United States
Environmental Protection
Agency

Office of Water
(WH-550)

EPA 811-R-92-005
August 1992

EPA

FRAMEWORK FOR DECISION MAKING: AN EPA PERSPECTIVE

Framework for Decision Making: EPA Perspective

Stig Regli[1], John E. Cromwell[2], Xin Zhang[2], Allen B. Gelderloos[3], William D. Grubbs[4], Frank Letkiewicz[5], Bruce A. Macler[1]

The United States Environmental Protection Agency (EPA) is developing national regulations to control for disinfectants and disinfection by-products (D/DBPs) in public drinking water supplies. EPA intends to propose regulations that will apply to all public water systems using disinfection and serving non-transient populations -- approximately 220 million people. This regulation would be unlike the current maximum contaminant level (MCL) for total trihalomethanes (TTHMs) which only pertains to systems serving more than 10,000 people.

A major issue is to ensure that the limits set for D/DBPs do not cause changes in treatment that result in significant increases in risk from waterborne pathogens or other DBPs not regulated at this time. A fundamental goal in setting any new regulation is to be able to conclude with confidence that the resultant changes in treatment would lead to a significant overall decrease in risk to public health. This paper will describe the analysis that EPA is undertaking in pursuit of meeting this goal.

Background

The Safe Drinking Water Act (SDWA) passed by the Congress of the United States requires the EPA to specify a maximum contaminant level goal (MCLG) for each regulated contaminant. MCLGs are set at levels at which no adverse health effects are expected to occur.

The SDWA also requires the EPA to set MCLs as close to the MCLG as is technically and economically feasible to achieve; the rule must specify such best available technology (BAT). If it is not technically or economically feasible to measure a contaminant

---

[1] - U.S. Environmental Protection Agency

[2] - Wade Miller Associates

[3] - Malcolm Pirnie, Inc.

[4] - Science Applications International Corporation

[5] - Abt Associates Inc.

at the level of concern, then the EPA must set a treatment technique requirement in lieu of an MCL.

Systems are not required to use BAT in order to comply with the MCL but can use other technologies as long as they meet all drinking water standards and are approved by the State. Systems unable to meet the MCL after application of the BAT can get a variance, extending the time for achieving compliance. Systems that obtain variances must meet a schedule approved by State health officials.

MCLGs are set at zero for contaminants that have carcinogenic potential from a drinking water exposure. In such cases the EPA attempts to set MCLs at levels which assure that lifetime risk from cancer through exposure in drinking water is between less than one in ten thousand to one in one million (10^{-4} to 10^{-6}), using conservative margins of safety in calculating such risk. Risk assessments usually entail: extrapolation from toxic effects in animal studies using high doses of exposure to predict the effects of low doses of exposure in humans; use of the linearized multistage model which is more conservative than most other models; and use of a 95% upper confidence interval for defining the risk factor.

Based on available occurrence, exposure, and health effects data, twelve chemicals have been identified for possible regulation (USEPA 1991a; USEPA 1992a; USEPA 1992b). Table I lists the candidate compounds for regulation, possible MCLGs, the health effect of concern, and the tentative cancer risk classification.

Table II indicates the concentration level for DBPs classified as B_2 compounds in drinking water at which excess lifetime cancer risk of 1 in 10,000 and 1 in 100,000 would occur as predicted by the upper 95% confidence interval, assuming 2 liters are consumed per individual per day. Table II also indicates the range at which the candidate compounds have been reported to occur in US drinking water supplies (for a more detailed characterization of D/DBP occurrence see USEPA, 1992a). The basis for the MCLGs, cancer risk classification, and the indicated cancer risks are described elsewhere (USEPA 1992b).

The EPA intends to set MCLs for each compound listed in Table I. However, three regulatory options are being considered for trihalomethanes (THMs) and haloacetic (HAAs) acids. For THMs the EPA is considering: 1) MCLs for each of the four THMs, 2) an MCL for total trihalomethanes (TTHMs), and 3) an MCL for each of the THMs and an MCL for TTHMs (which may be different from the sum of the individual THMs). Individual THMs are being considered as their health risks differ significantly; and the technical feasibility for limiting their formation can vary greatly,

depending upon source water quality. An MCL for TTHMs is being considered to act as a surrogate regulation to limit other DBPs and because of the precedent already established with the current TTHM standard.

For HAAs the EPA is considering: 1) MCLs for trichloroacetic acid (TCA) and dichloroacetic acid (DCA) as health effects data are available for each of these compounds; 2) an MCL for total HAAs (THAAs) including mono-, di-, and trichloroacetic acid; monobromo and dibromo acetic acid; and possibly bromochloroacetic acid; and 3) the combination of options 1 and 2. A limit for THAAs is being considered because all the compounds can be analyzed simultaneously using the same analytical method at no additional cost. A limit for THAAs would act as a surrogate to limit production of other HAAs and DBPs for which health risks are not yet determined. Future MCLs, when more data become available, may pertain to specific HAAs other than DCA and TCA, and/or an expanded list of HAAs including chloro-bromo acetic acids.

Issues With Defining BAT for DBPs

BAT must include disinfection but how much?

The easiest means for avoiding risk from D/DBPs is not to disinfect water. Obviously this is not a viable option, at least not for surface water supplies, since without disinfection waterborne disease would be rampant. Although not specified in the SDWA, the EPA must define BAT for controlling DBPs in conjunction with criteria to control pathogens.

The feasibility of complying with any D/DBP standard with a given BAT is directly affected by the need to also comply with microbial standards. Currently only two national standards have been promulgated in the U.S. to control for microbial concerns: the total coliform rule, and the surface water treatment rule (SWTR). Ground water disinfection requirements are under development.

The SWTR (USEPA, 1989a) requires that systems using surface water, or ground water under the direct influence of surface water, provide at least 99.9% (3 logs) and 99.99% (4 logs) removal or inactivation of *Giardia* cysts and viruses, respectively. These performance levels are not determined by measurement of *Giardia* or viruses but by assuming removal efficiencies by filtration and inactivation efficiencies by disinfection based upon design and operating conditions.

Well operated filter systems that meet recommended design and operating, and turbidity performance, criteria are assumed to

achieve 2 to 2.5 log removal of *Giardia* cysts, and a 1 to 2 log removal of viruses by filtration alone. Inactivation efficiencies for *Giardia* and viruses are determined based upon measurement of the product of "C" (disinfectant concentration in mg/l) and "T" (disinfectant contact time in minutes); the "CT" for a system equates to an inactivation efficiency indicated in tables in the SWTR.

The SWTR also requires systems to maintain a) a disinfectant residual of at least 0.2 mg/l at all times in the water entering the distribution system and, b) a detectable disinfectant residual or a heterotrophic plate count of less than 500/ml in at least 95% of the measurements throughout distribution system.

The total coliform rule (USEPA, 1989b) requires all public water systems (surface and ground water supplies) to measure for total coliforms in the distribution system and to ensure that no more than 5% of the measurements are total coliform positive. For any positive total coliform measurement, follow-up measurement of fecal coliforms or E. coli is required. No more than one positive fecal coliform or E. coli measurement is allowed in any given month.

The GWDR will establish minimal disinfection requirements for all ground water systems unless they are able to demonstrate they are not vulnerable to fecal viral and bacterial contamination. The vulnerability of wells for each system is to be determined based upon the location of fecal contamination sources, such as septic tanks and sewage lines, with respect to each well, and hydrogeological features.

Major issues are whether more microbial standards, and the disinfection required to meet these standards, are needed to limit microbial risk or to prevent significant increases in microbial risk under new D/DBP regulations. To what extent, if any, should the definition of BAT for the D/DBP regulations include additional microbial treatment requirements to address this concern?

Which technologies should be considered and how should treatment performance be defined?

How the EPA defines BAT will directly affect the level at which the MCLs are set and the potential for downside risks. Because health risks from by-products of alternate disinfectants are not as well characterized as they are for by-products of chlorination, it may be appropriate to define BAT as certain precursor removal technologies with chlorination for primary disinfection under this rulemaking (since MCLs do not have to be met using BAT this would not preclude the use of alternate disinfectants). Examples of precursor removal technologies include: a) conventional treatment optimized for DBP precursor

removal; b) granular activated carbon (GAC) as a filter media replacement; c) GAC following filtration; and d) membrane filtration.

Other technologies for BAT consideration, depending upon the source water quality, include conventional treatment or precursor removal technologies with use of alternate disinfectants, such as ozone for primary disinfection, and chloramines for residual disinfection.

The cost and performance of the above technologies will vary greatly depending upon design and operation. The technical and economic feasibility of using these technologies to achieve different MCLs can be greatly influenced by source water quality and system size. One approach to this dilemma is to define MCLs based on what some reasonable percentage (e.g., 90% or 95%) of systems could at least achieve if they were to apply BAT to their source water.

If the MCL were based on what all systems (or a very high percentage such as 99%) could achieve using the BAT, then the MCL would be higher and potentially much less protective for the population at large. On the other hand, if the MCL were set based on what a lower percentage of systems (e.g., 75%) could achieve, then treatment costs to comply, or the transactional costs to enforce compliance, might be unreasonable.

For logical decision making, a methodology is needed to predict performance of different BATs in the U.S. given the diversity of source waters and the effect that such diversity has on the treatability for DBPs and microbial concerns. Such a methodology should allow for prediction of BAT performance for controlling DBPs while also achieving different objectives for pathogen control.

Implications of Systems not Using BAT to achieve MCLs

Systems are not obligated to use BAT to achieve the MCL. If BAT were defined as one of the DBP precursor removal strategies as described above, systems could choose less expensive technologies such as adopting choramines or ozone and chloramines to achieve the MCL. In fact, use of such technologies might lead to lower levels of risk from chlorinated DBPs (e.g., levels well below the MCL) than if the BAT were used. However, depending upon the source water quality, such treatment changes may introduce new risks from other DBPs that are not yet well defined. Also, since chloramines are a much weaker disinfectant than chlorine, switching to chloramines may significantly increase microbial risk. Switching to ozone -- a stronger disinfectant than chlorine -- followed by chloramines to maintain a residual in the distribution system may lead to greater nutrient availability for bacteria to grow in the distribution

system. Such effects will largely depend upon the source water quality, and the treatment following ozonation.

If the MCLs are defined based on what conventional filtration followed by deep bed GAC and chlorine, or what membrane filtration and chlorine, could achieve, many systems would be expected to attempt meeting such MCLs using chloramines or ozone and chloramines due to cost. If chloramines, rather than chlorine, were included as a residual disinfectant in the definition of BAT, then the MCLs for chlorinated DBPs would be lower and even greater shifts to use of alternate disinfectants to achieve compliance could be expected. The potential health risk implications that might result from different shifts in technology needs to be considered when defining BAT.

Downside Risks with DBP Precursor Removal Technologies

Precursor removal technologies can remove substantial organic material and disinfectant demand. As more DBP precursors are removed, and the water is cleaner, the efficiency of disinfection is expected to increase per dose of disinfectant applied. A decrease in disinfectant demand allows for lower disinfectant doses to be applied and yet still maintain a residual in the distribution system. However, a significant decrease in the level of disinfection between the point of application and early points in the distribution system could increase microbial risk unless precautions are taken (e.g., increasing the disinfectant contact time prior to the first customer). The significance of such changes in risk depend on the pathogen concentrations in the source water, the change in effect that the water quality matrix has on interference with disinfection, the net change in the value of the CT product with respect to different populations receiving the finished water in the distribution system, and the net change in bacterial pathogens that might grow in the distribution system.

Precursor removal technologies can also change the ratio of disinfectant residual with respect to organic (e.g., humic and fulvic acids) and inorganic (e.g., bromide) precursors. This can lead to a change in the relative amounts of different types of DBPs that are formed. For example, depending upon the bromide concentration in the source water it becomes possible, with increased precursor removal, to decrease the amount of TTHMs or THAAs but to increase the concentration of specific brominated compounds (e.g., bromoform or brominated HAAs). Such changes in the relative amounts of the different DBPs could result in no net gain in risk reduction and possibly even an increase in risk. No health effects data are yet available on the brominated HAAs.

Strategy for Defining BAT and Appropriate MCLs

The EPA is taking the following steps to address the above issues and to determine appropriate MCLs for DBPs: 1) identification of candidate BATs for controlling both DBPs and pathogens; 2) definition of BAT in the context of also achieving microbial treatment objectives (the SWTR, coliform rule, or other criteria); 3) evaluation of candidate BAT performance with respect to pathogen and DBP control for different source water qualities; 4) consideration of candidate MCLs, based on what level is achievable by candidate BATs for a "reasonable" percentage of systems; and 5) consideration of potential net changes in risk from exposure to DBPs and pathogens (known and unknown), and the costs to implement such changes, to determine the optimum MCLs. The EPA is attempting to implement this strategy through use of a disinfection by-product risk assessment model (DBPRAM).

Overview of DBPRAM

Figure 1 illustrates the DBPRAM modeling framework. DBPRAM simulates raw water qualities for treatment plants throughout the U.S. and predicts: 1) the most likely treatment technologies that utilities would adopt to meet different regulatory targets (MCLs for DBPs and microbial treatment objectives); 2) the occurrence of trihalomethanes and haloacetic acids and the associated cancer risk (i.e., that which is currently quantifiable) after treatment changes are implemented; 3) the occurrence of pathogens -- using *Giardia* as the target organism -- in the finished water after treatment changes are implemented, and the associated risk from infection; and 4) the costs for meeting the treatment objectives. A detailed description of the model, assumptions, and results determined to date are described in a series of papers (USEPA, 1992c, Letkiewicz et al., 1992; Gelderloos et al., 1992; Grubbs et al., 1992; Cromwell et al., 1992).

Focus of Analysis

To date the modeling analysis has focused on systems which currently filter and disinfect surface water. Since these systems include those with the highest levels of DBP precursors and pathogens in the source water, they represent those with the highest possible changes in risk that could result from treatment changes to comply with D/DBP regulations. If regulatory scenarios can be described that assure a significant decrease in overall risk in these systems, then scenarios can also be described that ensure there is at least a positive net benefit in overall risk for systems with better source water quality (e.g., most ground water systems). Preferably, such regulatory scenarios

would also ensure there is no significant increase in risk for any particular system, no matter what its source water quality.

Due to limited data, the analysis has focused on a subset of filtered surface water supplies: those which do not use lime softening and which each serve more than 10,000 people. About 103 million people are currently served by systems meeting this description. Figure 2 illustrates key input and output parameters in the DBPRAM and the conceptual approach for estimating finished water quality from different treatment configurations. Probability distributions for raw water quality parameters affecting THM and HA formation were generated from different data sets (Letkiewicz et al 1992). Raw water *Giardia* data reflecting variation among cities (LeChevalier et al., 1991) and within cities (Hibler et al., 1987) were used to simulate national raw water occurrence (Grubbs et al 1992). A water treatment plant model was used to predict *Giardia* cyst concentrations and THMs and HAs in the distribution system as a function of different filtration and disinfection conditions (USEPAc, 1992, Gelderloos et al 1992).

THMs and HAAs have been targeted in the DBPRAM because they are among the DBPs identified to date that occur at highest concentrations in most drinking waters. They are also likely to be of the greatest health concern, and models are available for predicting their formation. *Giardia* cysts are targeted in the DBPRAM because more data are available on their occurrence in source waters than other pathogens; *Giardia* are much more resistant to disinfection than most other waterborne pathogens; and changes in treatment to control for DBPs, assuming that systems must still meet the minimal requirements of the SWTR, are likely to result in more significant changes in exposure from *Giardia* than from most other waterborne pathogens identified to date. Also, a dose response curve for *Giardia* is available for estimating risk from exposure (Rose et al 1991).

Treatment Constraints

The DBPRAM was run to predict the ability for systems to comply with different MCL targets for TTHMS and THAAs under two sets of treatment constraints. The first set of constraints, termed the "SWTR scenario", requires systems to:

- achieve at least a 3 log reduction in Giardia cysts by filtration and disinfection prior to the first customer;

- maintain a residual of at least 0.2 mg/l free chlorine (or 1 mg/l total chlorine if chloramines are used) at the end of the distribution system[1];

- maintain the free chlorine residual below 2 mg/l at the first customer because of concern from taste;

- maintain the chloramine residual below 3 mg/l at the first customer to remain below the possible MCLG (see Table II)[2] and;

- maintain a pH of at least 7.6 in the disinfected water entering the distribution system if the hardness is greater than 100 mg/l; maintain a pH of at least 8.0 if the hardness is less than 100 mg/l.[3]

The second set of constraints apply to an "Enhanced SWTR" (ESWTR) scenario. This scenario assures that systems with poorer source waters disinfect sufficiently to maintain a low pathogen risk (using *Giardia* as the target organism) while still complying with the D/DBP rule. The constraints in this scenario are identical to those of the "SWTR scenario" except that systems are required to achieve higher levels of treatment, depending upon the concentration of *Giardia* cyst in the source water, as follows:

---

[1] The disinfectant residual constraint in the distribution system is assumed necessary to meet the total coliform rule and the requirement to maintain a "detectable" residual in at least 95% of the samples taken in the distribution system under the SWTR.

[2] Since the above analysis was conducted, EPA has begun considering an MCLG for chloramines of 4 mg/l measured as total chlorine (USEPAb, 1992) to account for the health effects of monochloramine which cannot be practically measured by itself. In future model runs EPA will consider a constraint of 4 mg/l rather than 3 mg/l measured as total chlorine.

[3] These constraints are to simulate corrosion control and compliance with the lead rule.

Giardia cyst concentration/100 L (arithmetic mean)[4]	*Giardia* Removal/Inactivation
≤ 1	3-log
1-10	4-log
10-100	5-log
100-1,000	6-log
1,000-10,000	7-log

The modeling approach assumes that under both the SWTR and ESWTR treatment constraints, filtration plants are operating in accordance with the SWTR and are achieving 2.5 log removal of *Giardia* cysts. The model assumes that any additional treatment which is required is achieved through disinfection. The modeling approach assumes that plants will operate disinfection slightly beyond the minimum requirements to ensure continuous compliance during abnormal conditions. For disinfection through the treatment plant with chlorine, the chlorine dose is calculated to achieve at least 20% greater inactivation than required in the SWTR or ESWTR.

The only difference between the modeling approach for the ESWTR and the SWTR scenario is the amount of disinfection required in the plant depending on the raw water *Giardia* concentrations.

Initial Conditions and Compliance Sorting Routine

One hundred hypothetical treatment plants were individually evaluated through the treatment model to predict plant effluent and distributed water quality and to determine whether a system meets the treatment constraints and DBP MCLs.

Due to the large number of treatment configurations, and because systems are currently making changes in treatment to comply with the SWTR, total coliform, and lead rules, it was not possible to simulate a baseline of treatment practice. Rather, it was assumed that all treatment plants initially use chlorine as the only disinfectant, though plants use alternate disinfectants often because of source water quality with substantial THM precursors and the need to meet the current TTHM rule. The validity of the model for predicting treatment changes that

---

[4] EPA guidelines in the Guidance Manual to the SWTR (USEPA, 1991b) are based on a geometric mean but in this modeling analysis the arithmetic mean is used for purposes of conducting statistical analysis.

systems would make to comply with new DBPs standards was in part confirmed by comparing the percentage of systems predicted to modify their treatment to achieve a TTHM MCL of 100 µg/l with the percentage of plants that actually made such modifications to meet a target of 100 µg/l MCL (Gelderloos et al 1992, Cromwell et al 1992).

The predicted water quality of the 100 plants is evaluated through a "compliance sorting routine", sorting the treatment model output according to alternative DBP MCLs. If a system does not meet the constraints established by the SWTR (or the ESWTR) and the MCL of interest, the system implements the lowest cost modification necessary to meet the constraints. If the new treatment method is not sufficient to achieve compliance with either the treatment constraints or the DBP MCL of interest, the next lowest cost modification is added. This process is repeated for each system until it complies with the treatment constraints and the DBP MCL of interest.

The compliance sorting routine assumes that systems strive to comply with the MCL with a 20% margin of safety. In other words, for an MCL of 40 ug/l, it is assumed that systems would add sufficient treatment to consistently meet a level of 32 ug/l (40 - 0.2 x 40 = 32). Similarly, if a system needs 0.5 log of *Giardia* inactivation to minimally meet the SWTR treatment constraints (2.5 log removal is assumed by filtration) then a system would strive to attempt to achieve this level with a 20% margin of safety, i.e., 0.6 log inactivation (0.5 + 0.5 x 0.2 = 0.6). If higher levels of inactivation are needed to meet an ESWTR, then these levels are adjusted upward by 20% (e.g., achieving a 3 log level of inactivation would require 3.6 log of inactivation).

For coagulation/filtration plants using chlorine as the only disinfectant, the approach assumes the following order of alternatives, from the lowest cost alternative to the highest cost alternative:

- Elimination of pre-chlorination, if practiced;
- Installation of ammonia feed system to provide chloramines as secondary disinfectant;
- Increasing coagulant dose to improve DBP precursor removal;
- Switching to ozone/chloramines for disinfection; and
- Adding GAC (30 minute empty bed contact time with 6 month carbon regeneration frequency) or membranes.

The implementation of a chlorine/chloramine or an ozone/chloramine disinfection strategy may be effective for

complying with both the SWTR and ESWTR, and TTHM or THA limits. However, these alternative disinfection strategies may not be effective for other DBPs. For example, if a system has high bromide concentrations in the source water the use of ozone may lead to high bromate concentrations. Therefore, under some possible regulatory scenarios, the implementation of certain disinfection alternatives to chlorine may not be sufficient to comply with all MCLs. Therefore, the impacts of alternative DBP MCLs were evaluated under two different compliance approaches (see Figure 3). One compliance approach assumes that alternative disinfection strategies are available, with the other assuming that alternative disinfection strategies are not available, i.e., systems can only chlorinate.

The compliance approach assuming no availability of alternate disinfectants allows for prediction of the percentage of systems that would achieve different MCL targets through only use of precursor removal technologies. Estimation of the feasible performance of candidate BATs, such as optimized filtration for DBP precursor removal, or optimized filtration and GAC, if applied to source waters throughout the U.S., could form the basis for defining the MCL, e.g., the level of DBP(s) that at least 90 percent of the systems could achieve using the candidate BAT. The same approach can be applied for defining the performance of candidate BATs using alternate disinfectants.

Analysis of these two compliance approaches also makes possible national cost comparisons between allowed use of alternate disinfectants versus sole use of precursor removal strategies to achieve different regulatory targets. Such cost analysis is discussed elsewhere (Cromwell et al., 1992).

Risk Analysis

DBPs

The mean DBP concentrations predicted in the model described above were used to estimate cancer risk in each system. Figure 4 illustrates the methodology and the risk factors used to estimate the cancer cases per year from the predicted DBP drinking water concentrations. Risk factors for both the upper 95% confidence interval and the maximum likelihood (MLE) estimate were used in the analysis.

Though chlorodibromomethane has been tentatively classified as a group C carcinogen, a cancer risk factor equivalent to that for bromodichloromethane is assumed. A cancer risk factor for trichloroacetic acid was used based on animal data (USEPAb, 1992), even though it also is tentatively classified as a group C

carcinogen.[5] No risk numbers are available for the other HAAs (monochloroacetic, and mono and dibromoacetic acid) included in the predicted THAA occurrence levels and thus a zero risk factor is assumed for them.

Not included in the analysis are occurrence or risk estimates for chloral hydrate or bromate, or the chloro-bromo HAAs.

Giardia

Figure 5 illustrates the methodology for estimating *Giardia* occurrence and risk at the first customer. The analysis assumed a reduction in treatment performance of 1 log 5% of the time, all viable cysts as infective in humans, infections equivalent to illness for the purpose of identifying outbreaks, and outbreaks as identified if the illness rate at the first customer exceeded 1% within a 30 day period. Other assumptions are also used in different analyses (Grubbs et al 1992) but are not described here. A dose response curve (Rose et al., 1991) was used to estimate infections from the predicted occurrence levels.

Not indicated in Figure 5 is the assumption that the exposure predicted at the first customer represents 10% of the exposure for the total population:

number of infections per system = infection rate at first customer x total system population x 0.10.

This equations assumes die off of *Giardia* cysts from exposure to a disinfectant residual as they move through the distribution system. People receiving water in the middle of the distribution system, because of the large CT values achieved through such points, would be expected to be exposed to much lower *Giardia* cyst concentrations than people near the first customer. The 10% factor was assumed to account for an approximate weighted average for all systems for such effects.

Not included in this analysis are risks from other pathogens. This exclusion may be a significant limitation regarding pathogens more resistant to disinfection than are *Giardia* cysts (e.g., *Cryptosporidium*, possibly some viruses) and bacterial pathogens which might grow in the distribution system (e.g., *Legionella* and mycobacteria). Except for such concerns, it appears reasonable to assume that if risks from *Giardia* cysts

---

[5] Risk factors were used for these compounds because, conceivably, the cancer classification for these compounds could change to B_2 at a later date based on additional review of the existing data or new evidence from new data.

are shown to be negligible then the risks from most other pathogens would also be negligible. If the risks from *Giardia* cysts are shown to be significant, then the risks from exposure to pathogens less resistant to disinfection than *Giardia* may also be significant, but to a lesser degree.

Modeling Results

Aggregate Analysis

Figures 6 - 13 illustrate the predicted ability, based on the DBPRAM, for public drinking water supplies in the U.S. to meet different MCL targets for THAAs and TTHMs by different treatment technologies given treatment constraints to control for pathogenic organisms. The analyses in these Figures represent systems serving more than 10,000 people each and 103,000,000 collectively. These systems currently filter but do not soften. For the purpose of estimating exposure and associated risk, each of the 100 hypothetical water treatment plants was assumed to represent the same population (1,030,000 people). A detailed description of the information in Figure 6 is provided as an example of how to interpret the information in Figures 7-13 which are similarly structured.

Figure 6 - SWTR W/Alternative Disinfection. This Figure illustrates the analysis under which systems were allowed to use alternate disinfectants and DBP precursor technologies to meet MCL targets for THAAs ranging from 60 to 10 ug/l.

Column one indicates the MCL target level for THAAs (i.e., mono, di, and tri-chloroacetic acid, and mono and dibromo-acetic acid).

Column two indicates the degree of treatment applied (see treatment code description in upper left). Treatment code #1 indicates no treatment has been applied other than that necessary to meet the SWTR scenario treatment constraints.

Column three indicates the percentage of systems predicted to use different levels of treatment (from column two) to meet the target MCL based on lowest cost. For example, at an MCL of 30 the model predicts that 48% of the systems would meet this MCL without any treatment change; 12% would eliminate prechlorination; 22% would eliminate prechlorination and add chloramines; 14% would eliminate prechlorination, add chloramines, and increase alum dose to improve precursor removal; etc. The numbers in column three sum to 100% for each MCL alternative.

Column four indicates the cumulative percent of systems meeting the target MCL through the specified level of treatment (graphically represented in the small figure on the right hand

side of the page). For example, at an MCL of 20 ug/l, 83% of the systems would be able to meet this standard (a level of 16 ug/l with the 20% margin of safety) without using GAC (treatment code #6). It is important to note that all of the treatment constraints would have to be met through each level of specified treatment. Thus, if chloramines are used, the system must still provide enough CT with either chlorine or ozone (if chlorine can not be feasibly used, i.e., treatment code #5) prior to the addition of ammonia, to achieve the 0.6 log inactivation of *Giardia* cysts necessary to minimally meet the SWTR.

If an MCL for THAAs were set at 10 ug/l, the model predicts that only 89% (last line in column) would be able to meet this MCL even with installation of GAC following filtration. As a result, 11% of systems would qualify for a variance if they installed GAC (see small figure in lower left).

Columns five and six indicate the predicted mean concentration of TTHMs and THAAs for the systems through the indicated level of treatment to meet the target THAA MCL. Note the effect of decreasing TTHMs as a function of lowering the MCL for HAAs without having any MCL for TTHMs. The fourth small figure from the bottom left side of the page graphically represents this relationship.

The first lines in each MCL target grouping indicate the predicted occurrence of TTHMs (55 ug/l) and THAAs (24 ug/l) with no treatment beyond the requirement to <u>minimally</u> meet the SWTR scenario treatment constraints using chlorine as the disinfectant and not having any MCL for either TTHMs or THAAs. However, this mean value <u>does not</u> include systems which are unable to meet the treatment constraints. Lines 2 through 6 under each MCL grouping indicate the cumulative mean concentration through each treatment tier, i.e., the average of those meeting and not meeting the MCL through the indicated level of treatment. Thus, the mean values in columns 5 and 6 through line 5 under-represent the expected mean value for all systems making no treatment changes to comply with an MCL.

The mean value in line 6 for each MCL grouping represents the mean value for all 100 hypothetical systems having made treatment changes to comply with the target MCL.

Column 7 shows the predicted cancer cases per year, at different MCLs for THAAs, caused by exposure from each of the THMs, assuming the risk factors at the 95% upper confidence interval. For example, a THAA standard of 20 ug/l (with no standard for TTHMs) is predicted to reduce the incidence of cancer attributed to THMs from at least 33.8 cases per year to 16.1 cases per year. A more precise way to interpret the data is to consider only line 6 under each MCL grouping. For example, a standard of 60 ug/l vs. a standard of 20 ug/l, assuming no TTHM standard were in

place, is predicted to reduce the incidence from 27.9 to 16.1 cases per year from exposure to THMs.

Column 8 indicates predicted cancer cases per year, at different THAA MCLs, attributed to THMs using the risk factors based on the maximum likelihood estimate. Note the much fewer predicted incidents of cancer versus those for the upper 95% confidence interval estimates.

Column 9 indicates the predicted cancer cases per year caused by exposure from THAAs assuming the risk factors are based on the 95% upper confidence interval.

Column 10 indicates the predicted cases of cancer attributed to THAAs (i.e., only di and trichloroacetic acid since no risk factors were available for the other HAAs), assuming the risk factors are based on the maximum likelihood estimate. The second small figure on the bottom left represents the combined annual cancer cases caused from exposure to both THAAs and TTHMs using the MLE risk factors.

Column 11 indicates the predicted incidence of infection per year. As the target MCL for THAAs decreases, the predicted incidence of infections increases (see also the small third figure from the bottom left). There are several factors contributing to this phenomena.

The first is the presence of more DBP precursors preceding disinfection resulting in higher disinfectant demand. As more precursors are removed at lower MCLs because of the adoption of precursor removal technologies, a lower disinfectant demand exists in the water and less disinfectant can be used to meet the constraint of providing a disinfectant residual at the end of the distribution system. In other words, in high oxidant demand waters the constraint of maintaining a residual in the distribution system is much more significant in affecting a higher level of inactivation than the constraint of minimally having to achieve the 0.5 log *Giardia* inactivation criterion.

A second is that many of the systems that switch to chloramines in lieu of chlorine as a residual disinfectant to lower THM or HAA formation have high disinfectant demand water. When using chlorine, such systems have to maintain a high dosage, and subsequently a high CT prior to the first customer, in order to maintain a free chlorine residual in the distribution system. When these systems switched to a chloramine residual in the distribution system, a much weaker disinfectant than chlorine, these systems no longer provided the high level of inactivation prior to the first customer. Rather, their level of inactivation was reduced to only meeting the 0.5 log inactivation criterion.

The difference in predicted *Giardia* incidence at high versus low THAAs may be understated because the SWTR scenario assumes that systems are designed and operated to minimally meet the disinfection constraints. In reality, many systems may provide higher levels of inactivation than would be minimally required and still meet the high THAA MCLs. However, recent water treatment plant data (LeChevalier et al 1991) appear to support the validity of the predicted *Giardia* infections in the high MCL range (Cromwell et al 1992).

Column 12 shows the predicted incidence of *Giardia* outbreaks at the 90th percentile for different THAA MCLs. For example, ten out of every one hundred systems, those with the highest *Giardia* cyst concentrations, are predicted to have an outbreak within every 3,089,000 years at an MCL of 60 ug/l, and within every 0.658 years at an MCL of 40 ug/l.

The large deviations in the predicted outbreak intervals for different target MCLs are explained by the large deviations around the mean among the systems with high concentrations of *Giardia* in their source water and the concurrent significant decreases in inactivation that theoretically could occur with treatment modifications. The model predictions suggest potentially very significant increases in the occurrence of waterborne outbreaks as the MCL for THAAs is lowered, i.e., without a parallel requirement for increased stringency of regulation to also control for *Giardia* (e.g., an ESWTR).

It is important to note that the assumptions in this analysis, such as the definition of what constitutes an outbreak or a symptomatic response (i.e., infection versus illness) have large uncertainties and will substantially affect the predicted output. The assumed criteria that define an outbreak, for the purpose of this analysis, appear to be overly conservative and the predicted outbreak intervals cannot be considered reliable estimates. Probably the most important indication of this analysis (rather than the specific predicted outbreak intervals) are the potentially large relative differences in likelihood for waterborne outbreaks to occur as a function of meeting increasingly stringent MCLs for DBPs.

Figure 7 - SWTR Without Alternative Disinfection. Under this modeling scenario systems can only use precursor removal technologies to meet the MCL target. The result of this constraint is that more systems would require use of GAC to achieve the target MCLs. If an MCL were set at 10 ug/l the model predicts that, even with use of GAC, 17% of the systems would not be able to meet this limit.

At an MCL of 60 ug/l, this scenario predicts a higher number of *Giardia* infections (246,531) than those predicted when alternate disinfectants could be used (213,045, Figure 6). This higher number is attributed to more systems reducing disinfectant demand than in Figure 6, because of greater use of precursor removal technologies, and subsequently lowering their disinfection dose while still being able to meet the minimal disinfection treatment requirements.

Figure 8 - Enhanced SWTR With Alternative Disinfection. This analysis differs from Figure 6 in that systems must achieve proportionally higher levels of *Giardia* inactivation as the source water concentration of *Giardia* cysts increases. Predicted *Giardia* infection incidence is reduced to below the 1/10,000 infection per person per year goal of the SWTR through implementation of the recommended guidance. The probability for outbreaks to occur is eliminated.

The predicted level of treatment necessary to meet the different MCL targets (columns 2, 3, and 4) is not much different than that predicted in Figure 6 without the ESWTR. The additional contact time within the plant required by the ESWTR (which is assumed can be added, if needed) to meet the inactivation target, does not significantly change the predicted concentration of THAAs at the average customer. As average residence time in the distribution system is about 1.6 days, the additional 1 to 3 hours in the plant, if chlorine is used, does not significantly increase THAA concentration to the average customer.

These results imply that requiring greater inactivation of *Giardia* for more highly contaminated source waters will not have a significant impact on the national costs of compliance. The cost for increased contact basin size following coagulation/filtration or GAC to meet the inactivation requirements of the ESWTR does not significantly influence the total cost. However, if systems do not have space to increase contact basin size, other options might then be required (e.g., a stronger disinfectant such as ozone which could significantly increase treatment costs).

Figure 9 - Enhanced SWTR Without Alternative Disinfection. This scenario is the same as Figure 8 except systems can only use precursor removal technologies to achieve the different THAA MCLs. The results in Figure 9 are similar to those in Figure 8 except higher levels of precursor removal technology are needed to achieve the MCLs. The technologies predicted to achieve the MCLs are almost identical to those in Figure 7 where no alternate disinfectants were allowed but less stringent disinfection requirements were required. This result is explained by the same logic as described under the description of Figure 8.

Figures 10 - 13 - These Figures are analogous to Figures 6 -9 except analysis targets for TTHMs in lieu of THAAs. Note how the concentrations of predicted THAAs are affected by systems targeting to achieve different TTHM MCLs, indicated in the fourth figures from the bottom left.

The results at the target MCL of 100 ug/l in Figures 10 are of particular interest. The constraints in the model that led to these results most closely represent the current situation today under the existing TTHM standard of 100 ug/l. The main difference is that some plants have not yet made treatment modifications to comply with the requirements of the SWTR, total coliform, and lead rules and that this may influence existing levels of TTHMs.

Figure 10 indicates that 61% of the systems using only chlorine as their disinfectant would be able to meet a TTHM MCL of 100 ug/l without making any treatment modifications. It also indicates that 21% would eliminate prechlorination, and another 18% would switch to chloramination in order to meet a TTHM MCL of 100. These results appear to approximate the changes that large filtered systems actually made to comply with the TTHM rule since it was promulgated in 1979 (Gelderloos 1992; Cromwell et al 1992).

Figure 10 also indicates predicted mean of 40 ug/l for TTHMs and 20 ug/l for THAAs in the distribution systems for all systems required to comply with a TTHM MCL of 100 ug/l. These results also appear to approximate the existing mean occurrence level for these groups of compounds in large filtered supplies today (Cromwell et al 1992).

Disaggregate Analysis (Changes in Risk to Individual Systems)

The modeling results discussed so far, which pertain to 103 million people, indicate that the risk from *Giardia* infections may increase by several hundred thousand per year under significantly more stringent DBP regulations than currently exist, unless revisions are made to the SWTR. What may be even more significant are the potential changes in microbial risk that might occur in populations of individual systems under new DBP regulations.

In order to understand the potential for changes in risk at the system level it becomes essential to examine the source water quality and level of treatment for individual systems. Figure 14 presents a plot of influent *Giardia* concentrations (Y" axis) versus estimated total log reductions achieved ("X" axis) at the plant effluent (first customer) based upon survey results from 46 different plants in the U.S. (LeChevalier et al 1991). A

critical underlying feature of these data, which can be considered a pre-SWTR baseline, made clear by the random scatter pattern in this plot, is that there appears to be no correlation between the influent *Giardia* concentration and the total log reduction achieved.

The vertical line at 3 log reduction indicates the minimal level of treatment required through the first customer by the SWTR, although higher levels of treatment may be needed to maintain the disinfectant residual in the distribution system. The diagonal line through the points represents the formula of providing the level of treatment, prescribed in the SWTR Guidance Manual, for systems to achieve a level of risk of less than one infection per 10,000 people per year (1/10,000). The points to the right of the diagonal line represent plants achieving more total log reduction than needed to meet the 1/10,000 risk target; points to the left represent plants achieving less total log reduction than needed to meet the 1/10,000 risk target.

The lack of correlation between the influent *Giardia* concentration and the total log reduction achieved could be attributable to numerous factors: 1) the lack of monitoring capability for *Giardia* and the knowledge of when to treat more or less; 2) attempts to comply with the current TTHM MCL (significantly, many of the plants to the left of the line are using chloramines.); 3) attempts to comply with current standards for coliforms and to maintain a chlorine residual in the distribution system (e.g., Ten State Standards); or 4) other treatment objectives served by pre-disinfection.

Figure 14 illustrates the relevance of considering changes in risk at the plant level rather than the average levels across all plants. The clear implication of the data in Figure 14 is that the minimum 3-log reduction requirement of the SWTR does not appear sufficient to achieve the target 1/10,000 risk level in most systems. The higher levels of total reduction specified in the SWTR Guidance Document appear to be necessary in order to assure meeting the target risk level. Another relevant issue is how the distribution of points indicated in Figure 14 might change as a function of different DBP regulatory targets.

The Monte Carlo simulation framework established in the DBPRAM is extremely well-suited to analyzing the relationship between influent *Giardia* levels and total log-reductions achieved at each individual plant. Since the influent *Giardia* distribution used to drive the simulation was developed from the above-described data, some direct similarities to the findings are to be expected in the model results. Unfortunately, a complete calibration check of the model against the survey findings (LeChevallier et al 1991) is not possible because the data were collected in a pre-SWTR compliance environment whereas

the model is constructed to include the SWTR requirements as initial constraints. Some similarities are nonetheless evident.

As discussed above, there are many possible reasons why the data in Figure 14 indicate a lack of correlation between the influent *Giardia* level and the total log reduction achieved. In the over-simplified reality of the DBPRAM, a few assumptions dominate this relationship. Figure 15 presents a plot similar to that of Figure 14 showing simulation results for a scenario that assumes implementation of the SWTR (with alternate disinfectants) and a TTHM standard of 100 ug/l. Of 100 simulated plants, 39 were determined by the DBPRAM algorithm to require treatment adjustments in order to meet a TTHM MCL of 100 ug/l. Only these 39 points are plotted in Figure 15. The plotted points reflect the relationship between influent *Giardia* and total log reduction after compliance with these modeling constraints.

Many of the 39 points in Figure 15 appear in a vertical line reflecting the SWTR requirement for a minimum of 3-logs of total reduction. By contrast to the pre-SWTR baseline reflected in the data in Figure 14, some of the points along the 3-log line in Figure 15 would represent a higher level of total reduction than in the pre-SWTR condition while others would represent a lower level. In the simplified model logic, those plants that were not previously achieving a 3-log level would have increased their level of total reduction to equal 3-logs, while some of those achieving more than a 3-log reduction would have dropped their level of total reduction to the 3-log minimum. Notably, all the points aligned vertically along the 3-log minimum are to the left of the diagonal line that defines the 1/10,000 risk threshold that the SWTR sought to achieve, indicating that they are incurring risks greater than this target level.

The remaining points plotted in Figure 15 show more than 3-logs of total reduction. Some of them are above the 1/10,000 risk threshold -- to the right of the diagonal -- while others are below it -- to the left of the diagonal. In tracing the source of these results through the model logic, it appears that they exhibit more than the 3-log minimum due to the additional SWTR constraint of maintaining a disinfectant residual in the distribution system. The simulated plants achieving more than a 3-log total reduction at the first customer (see Figure 15) represent conditions where enough total organic carbon (TOC) is present to require elevated chlorine dosages to overcome the chlorine demand of the TOC in the distribution system, but yet where the resulting contribution to TTHM formation is not significant enough to require additional TOC removal.

Figure 16 illustrates the effect of a tighter by-product MCL of 25 ug/l. Here 83 out of 103 plants would be required to change treatment in order to comply. As shown in the graph, the

result is that all the points are aligned along the 3-log minimum line. Those plants with more than 3-logs of total reduction in Figure 15 have been guided by the treatment algorithm into TOC removal strategies which in turn reduced the chlorine demands that had to be overcome in order to meet the SWTR residual requirement in the distribution system. As a result, the model predicts that all plants required to change treatment to meet a TTHM standard of 25 ug/l would reduce their total log reduction to the 3-log minimum.

As shown in Figure 16, the convergence to the 3-log minimum results in a risk level higher than the 1/10,000 target for all of the 83 plants compelled to modify treatment in meeting a TTHM MCL of 25 ug/l. The resulting change in endemic incidence of *Giardia* infections will be larger for some plants than for others. In particular, there may be some plants for which the co-occurrence of high influent TOC and high influent *Giardia* result in a very large increase in incidence due to significant drops in chlorine dosages for compliance with SWTR residual requirement after TOC removal has been triggered by the need to meet a TTHM MCL. The increase in incidence of *Giardia* infections has been computed based on the change in total log-reduction between one MCL and another, as computed by the DBPRAM. Results of this analysis are presented in Figures 17 and 18.

Figure 17 plots the cumulative distribution of the 100 simulated plants by their level of increase in annual *Giardia* infections per 1 million persons when moving from a TTHM MCL of 100 ug/l to an MCL of 75 ug/l. The plot confirms that some plants would face extreme conditions, resulting in significant increases in *Giardia* infections. Nearly 10 percent of the plants could experience increases of between 1,000 and 10,000 infections per 1 million population. The top end of this range approaches outbreak proportions. Figure 18 shows that the impact of a shift from a TTHM MCL of 100 ug/l to a TTHM MCL of 25 ug/l would produce increases in *Giardia* incidence on this same order of magnitude for over 30 percent of the plants. Figures 19 and 20 present the same results that are plotted in Figures 17 and 18 as bar charts, emphasizing the impacts at the extreme ends of the range.

The ultimate analysis that must be made is a comparison between the increase in incidence of *Giardia* infections and the corresponding decrease in cancer incidence that results from alternative MCLs. Combining the above analysis of *Giardia* infections with the by-product concentrations simultaneously projected by the DBPRAM produces such an analysis. Results are summarized graphically in the log-log plots presented in Figures 21 and 22. Figure 21 plots increased incidence of *Giardia* infections per 1 million persons versus decreased cancer incidence per 1 million persons for the plants having to change

treatment when the TTHM MCL is changed from 100 ug/l to 75 ug/l in a SWTR scenario (with alternate disinfectants).

Figure 22 presents the same picture for the plants that would have to change treatment if the TTHM MCL is changed from 100 ug/l to 25 ug/l. The pattern of the points plotted in these diagrams indicates that the degree of change in cancer incidence spans only one order of magnitude (less than one case per 1 million persons per year) while the degree of change in incidence of *Giardia* infections spans several orders of magnitude (from one to more than 10,000 infections per 1 million persons per year). This outcome indicates that the microbial risk is more sensitive to treatment changes needed to meet TTHM MCLs.

Figures 23 through 30 present the same series of graphs as Figures 15 through 22 except that the entire analysis is structured in terms of alternative MCLs for Total Haloacetic acids. The interpretation is identical to that described above.

One obvious direction indicated by these results would be to strengthen the SWTR before proceeding with requirements for additional by-product controls. In the ESWTR scenario, it is assumed that the portion of the SWTR Guidance Document which recommends an additional log of inactivation for each additional log of influent *Giardia* is converted to a mandatory requirement. In terms of the graphs presented in Figures 15 and 16, this requirement would mean that the model logic would result in the plants being lined up along or to the right of the diagonal line representing the 1/10,000 target risk level rather than along the vertical line representing the 3-log minimum required by the present SWTR. By definition of the 1/10,000 risk level as the target, there would therefore be no microbial risk trade-offs.

The evaluation of this option with the DBPRAM showed that adherence to the 1/10,000 risk level resulted in very little additional cancer incidence and in very little modification in treatment, and therefore very little additional cost. This outcome results from the model assumption that additional inactivation requirements at the first customer would be met with additional contact time at the plant effluent. This additional contact time allows inactivation requirements to be met without increased chlorine dosages. While the additional contact time contributes to inactivation, it does not contribute much in the way of additional by-product formation because the additional increment of contact time is trivial in proportion to the total residence time in the distribution system.

Model Shortcomings and Next Steps

This discussion will only pertain to model analysis or modifications anticipated to occur in support of the development of a proposed rule for D/DBPs. Much more research will be needed over a longer time frame to address the unknowns identified in the shaded areas of Figure 1.

Develop Predictive Capability for Bromate

Under the modeling scenarios with alternative disinfectants allowed, the DBPRAM currently selects ozone, with chloramines as a residual disinfectant, as an alternative disinfectant to chlorine to achieve lower levels of THMs and HAAs. This selection may lead to high levels of bromate formation in systems with high bromide concentration in the source water (AWWA, 1992).

Since exposure from bromate may result in greater risk than exposure from THMs or HAAs (Table II), depending upon the bromide concentration in the source water and the subsequent formation of bromate upon ozonation, the model may be inappropriately selecting ozone in the compliance sorting routine. The model may also be underestimating the total cancer risk from the selected distribution of technologies to meet a target MCL for THMs or HAAs. EPA is now developing formation equations for bromate and intends to include these equations in the modeling analysis in developing the proposed rule.

Extend Modeling Analysis to Smaller Systems

The current analysis only pertains to systems serving more than 10,000 people. Since EPA intends for the new DBP regulations to pertain to smaller systems, it becomes important to evaluate the potential risk and cost impacts in such systems. EPA is now expanding the application of DBPRAM to systems serving less than 10,000 people. This analysis will consider the following factors as being different from larger systems: a) possible smaller distribution system residence times, b) the potential for higher treatment failure rates, c) the effects of not having to already meet an existing TTHM MCL on net changes in total risk and d) economies of scale in installing and operating different technologies (e.g., using membrane filtration in lieu of GAC as a precursor removal technology).

Extend Modeling Analysis to Systems Using Lime Softening

Systems that use surface water and lime softening may represent those systems having the greatest difficulty in meeting microbial and DBP standards. Since these systems operate at high pH, it is more difficult to achieve effective inactivation with

most disinfectants. High pH conditions may also make it substantially more difficult to remove DBP precursors. Therefore, systems using lime softening may be the best indicator for characterizing potential changes in risk from exposure to DBPs and pathogens that might result under new regulations.

EPA is developing formation equations to predict THMs and HAAs for systems using lime softening. Also, new data are being developed to evaluate the inactivation efficiency of disinfection at high pHs (Logsdon et al, 1992). EPA anticipates using this new information to expand DBPRAM to predict potential changes in risk in lime softening systems under new DBP regulations.

Model Validation and Refinement

Some model validation analysis has already been conducted (Cromwell et al 1992, USEPAc, 1992) but much more is needed. DBP occurrence data being collected at water treatment plants will be compared with model predictions to evaluate the accuracy of model predictions. Sensitivity analyses are being conducted to determine which of the parameters and model assumptions have the greatest impact on affecting model predictions. EPA is also considering the use of different THM and HAA formation equations than are now being used in the DBPRAM (AWWA 1992).

The DBPRAM currently assumes that the data collected from one survey (LeChevalier et. al., 1991) is representative of the amplitude and variation among communities using filtered surface supplies in the US. The DBPRAM also assumes that the data collected from another source (Hibler et. al., 1987) is representative of the variation within a community. EPA will reevaluate and possibly modify these assumptions as more data become available. Also, several "what if" scenarios pertaining to the probabilities that infections may lead to illness, and the rate of illnesses that would likely cause an outbreak to be identified, will be considered in future model runs.

Conclusions

1. EPA has developed a model that predicts the occurrence of trihalomethanes (THMs), haloacetic acids (mono, di, and tri-chloroacetic acid; and mono, and di-bromoacetic acid, collectively cited as THAAs), and *Giardia* cysts in finished drinking waters in the U.S. as a function of source water quality and treatment practice. The model predicts risk of cancer from THMs, and di- and trichloroacetic acid, and risk of infection from *Giardia* cysts. The model is being used to predict the potential changes in treatment and risk that might result from different regulatory targets.

2. Model predictions currently only pertain to filtered systems that do not use lime softening, serve greater than 10,000 people, and collectively distribute water to 103 million people in the U.S. The model is currently being expanded to include analysis for systems serving less than 10,000 people and those which use lime softening.

3. More data are needed to evaluate the validity of the model predictions. Refinements in the model assumptions and predictive equations are anticipated and, therefore, the model predictions should be considered tentative. Two risk estimates for cancer are given: numbers without parenthesis indicate estimates based upon maximum likelihood risk factors, and numbers within parenthesis indicate estimates based upon the upper 95% confidence interval. Risk estimates for Giardia infections are based upon a maximum likelihood analysis.

4. Model predictions indicate that at the existing TTHM MCL of 100 ug/l, following compliance with the SWTR, total coliform rule, and lead rules, 45 (173) cases of cancer per year will occur based upon predicted exposure from THMs [1, (24) cases] and di- and tri-chloroacetic acid [44, (139) cases].

5. Model predictions indicate that if an MCL of 25 ug/l were set for TTHMs, and alternative disinfectants to chlorine were not allowed, 41% of the systems would be able to meet this standard without the use of GAC. 5% of the systems could not meet this standard with the use of deep bed GAC following optimized filtration for precursor removal. With allowed use of alternate disinfectants, 97% of the systems could meet a 25 ug/l standard without the use of GAC.

6. Model predictions indicate that if an MCL of 10 ug/l were set for THAAs, and alternative disinfectants to chlorine were not allowed, 43% of the systems would be able to meet this standard without the use of GAC. 17% of the systems would not be able to meet this standard with the use of deep bed GAC following optimized filtration for precursor removal. With allowed use of alternate disinfectants, 50% of the systems could meet the standard without the use of GAC. 11% of the systems could not meet the standard with the use of GAC.

7. Model predictions indicate that at a TTHM MCL of 25 ug/l, with no other DBP standard and allowed use of alternate disinfectants, 27 (102) cancer cases per year would occur based upon predicted exposure from THMs 0.4 (10 cases) and di- and tri- chloroacetic acid 26.2 (82 cases). At a THAA MCL of 10 ug/l (with no other DBP standard), 12 (45) cancer cases per year would occur based upon predicted exposure from THMs [0.4 (10.4) cases] and di and tri-chloroacetic acid [11.3 (35.3) cases].

8. Model predictions indicate that if systems were to only minimally comply with SWTR, i.e., not follow guidance of providing higher levels of inactivation for poorer source water quality, 340,000 *Giardia* infections per year would result under the TTHM MCL of 100 ug/l. A new standard of 25 ug/l for TTHMs alone would result in 170,000 additional *Giardia* infections per year. A new standard of 10 ug/l for THAAs alone would lead to 226,000 additional *Giardia* infections per year.

9. Under any new DBP MCL, e.g., 75 ug/l for TTHMs or 50 ug/l for THAAs, some systems would experience increases of 1000 to 10,000 Giardia infections per million people per year with decreases in cancer risk of 0.1 to 1 case per million people per year (based upon maximum likelihood estimates. If MCLs were set at, e.g., 25 ug/l for TTHMs or 10 ug/l for THAAs, more than 25% of the systems are predicted to experience this range of respective net changes in risk.

10. The modeling results indicate that it is not possible to conclude with certainty that the total risk will decrease as a result of any specific regulatory action.

11. If an enhanced SWTR could be implemented to achieve an infection rate of less than 1/10,000 at the first customer, where higher levels of treatment for *Giardia* were required depending upon the level of *Giardia* in the source water, the predicted number of *Giardia* infections per year would be less than 500.

12. The model predicts that the universe of systems that use surface water and which practice coagulation and filtration could use almost the same decision tree of treatment technologies (but with differences in the level of disinfection) to meet the existing SWTR and stringent DBP MCLs as they could to meet an enhanced SWTR and stringent DBP MCLs. If this conclusion is correct, the costs for complying with these two different regulatory scenarios would not be significantly different even though much greater microbial protection could be provided under an enhanced SWTR, if such a rule could be implemented.

13. If an enhanced SWTR could be implemented, any MCL for controlling THMs or HAAs would lead to greater use of alternate disinfectants, unless prevented through regulation, since these technologies are more cost effective for lowering THMs or HAAs than use of GAC or membrane filtration. Since the health risks from DBPs of alternate disinfectants to chlorine are largely unknown, it remains possible that greater use of alternate disinfectants could lead to greater health risks than those from chlorinated DBPs such as THMs and HAAs.

14. Precluding the use of alternate disinfectants to achieve lower levels of THMs and HAAs would lead to substantially greater treatment costs than if they were allowed. Also, use of alternate disinfectants allows for substantially lower THM and HAA concentrations to be achieved than if only precursor removal technologies were allowed.

References

Cromwell, J.E.; Zhang, X.; Letkiewicz, F. J.; Regli, S. and B. Macler. "Analysis of Potential Tradeoffs In Regulation of Disinfection By-Products." Office of Ground Water and Drinking Water Resource Center. Washington D.C. USEPA in press, 1992.

Gelderloos, A.B.; Harrington,G.W.; Owen, D.W.; Regli, S.: Schaefer, J.K.; Cromwell, J.E. and X. Zhang. "Simulation of Compliance Choices For Regulatory Impact Analysis". Office of Ground Water and Drinking Water Resource Center. Washington D.C. US EPA in press. 1992.

Grubbs, W. D., Macler, B. and S. Regli. "Modelling *Giardia* Occurrence and Risk." Office of Ground Water and Drinking Water Resource Center. Washington D.C. USEPA. EPA-811-B-92-005. 1992.

Hibler, C.P. Analysis of Municipal Water Samples for Cysts of *Giardia*. Report prepared for Office of Drinking Water, U.S. EPA, 1987.

LeChevallier, M. W., Norton, D.N. and R. G. Lee. Occurrence of *Giardia* and Cryptosporidium in Surface Water Supplies. Applied and Environmental Microbiology 57:2610-2616. 1991.

Letkiewicz, F.J.; Grubbs, W.G.; Lustiik, M.; Mosher, J.; Zhang, X. and S. Regli. "Simulation of Raw Water Quality and Water Treatment Characteristics in Public Water Supplies in Support of the Disinfection By-Products Regulatory Impact Analysis". Office of Ground Water and Drinking Water Resource Center. Washington D.C. USEPA. EPA-811-R-92-001. 1992.

Logsdon, G, et al. The Removal and Disinfection Efficiency of Lime Softening Process for *Giardia* and Viruses. Poster presentation, AWWA Annual Conference, Van Couver, Canada. 1992.

Rose, J.B., Haas, C.N., and Regli, S. Risk Assessment and Control of Waterborne Giardiasis. Amer. Jour. Public Health 81:709-713. 1991.

USEPA. National Primary Drinking Water Regulations: Filtration; Disinfection; Turbidity, Giardia lamblia, viruses, Legionella, and Heterotrophic Bacteria. Final Rule. Fed.Reg. 54:27486 (June 29,1989). 1989a.

USEPA. National Primary Drinking Water Regulations: Total Coliforms. Fed. Reg. 54:27544 (June 29, 1989). 1989b.

USEPA. Status Report on Development of D/DBP Regulations. Office of Ground Water and Drinking Water. USEPA. Wash. D.C. 1991a.

USEPA. Guidance Manual for Compliance with the Filtration and Disinfection Requirements for Public Water Systems Using Surface Water Supplies; USEPA, Wash., D.C. 1991b.

USEPA. Occurrence Assessment for Disinfectants and Disinfection By-Products (Phase 6a) in Public Drinking Water. Office of Ground Water and Drinking Water Resource Center. Washington D.C. USEPA. EPA-811-R-92-003. 1992a.

USEPA. Status Report on Development of MCLGs for Disinfectants and Disinfection By-products. Office of Science and Technology. 1992b.

USEPA . Water Treatment Plant User's Manual. Office of Ground Water and Drinking Water Resource Center. Washington D.C. USEPA. EPA-811-8-B-92-001. 1992c

Table I
Candidate Compounds For Regulation

trihalomethanes	possible MCLG *(RFD not yet approved)	health effect and cancer status *(tentative - not yet approved by CRAVE)
chloroform	0	cancer, B2
bromodichloromethane	0	cancer, B2
dibromochloromethane	60 μg/l	liver, C
bromoform	0	cancer, B2
total THMs	0	cancer, B2
haloacetic acids		
trichloroacetic acid	100 μg/l*	liver, C*
dichloroacetic acid	0	cancer, B2*
total HAs	0	cancer, B2*
(mono, di, and tri chloroacetic acid; mono and dibromoacetic acid)		
Other		
chloral hydrate	5 μg/l	liver, C*
bromate	0	cancer, B2*
chlorine	4 mg/l*	blood, D*
chloramines	3 mg/l**	blood, D*
chlorine dioxide	0.8 mg/l *	blood, neurological, D*
chlorite	0.3 mg/l *	blood, D*
chlorate	health advisory	

** 4 mg/l if measured as total chlorine

B_2 compounds include possible human carcinogens, C compounds include possible human carcinogens, and D compounds include those with inadequate or no human and animal evidence of carcinogenicity.

Table II
Drinking Water Concentrations (μg/l) for Lifetime Cancer Risks (upper 95% confidence interval)

DBP	10^{-4}	10^{-5}	known range of occurrence
Bromodichloromethane	60	6	0-100
Bromoform	400	40	0-50
Chloroform	600	60	0-340
Dichloroacetic acid**	10	1	0-80
Bromate**	5	0.5	?

** tentative risk estimate

Table I
Candidate Compounds For Regulation

trihalomethanes	possible MCLG	health effect and cancer status (tentative)**
chloroform	0	cancer, B2
bromodichloromethane	0	cancer, B2
dibromochloromethane	60 μg/l	liver, C
bromoform	0	cancer, B2
total THMs	0	cancer, B2
haloacetic acids		
trichloroacetic acid	100 μg/l	liver, C
dichloroacetic acid	0	cancer, B2
total HAs (mono, di, and tri chloroacetic acid; mono and dibromoacetic acid)	0	cancer, B2
Other		
chloral hydrate	5 μg/l	liver, C
bromate	0	cancer, B2
chlorine	4 mg/l	blood, D
chloramines	3 mg/l*	blood, D
chlorine dioxide	0.8 mg/l	blood, neurological, D
chlorite	0.3 mg/l	blood, D

* 4 mg/l if measured as total chlorine

** B_2 compounds include probable human carcinogens, C compounds include possible human carcinogens, and D compounds include those with inadequate or no human and animal evidence of carcinogenicity.

Table II
Drinking Water Concentrations (μg/l) for
Lifetime Cancer Risks (upper 95% confidence interval)

DBP	10^{-4}	10^{-5}	known range of occurrence
Bromodichloromethane	100	10	0-100
Bromoform	400	40	0-50
Chloroform	600	60	0-340
Dichloroacetic acid**	10	1	0-80
Bromate**	5	0.5	?

** tentative risk estimate

DBPRAM Modelling Framework

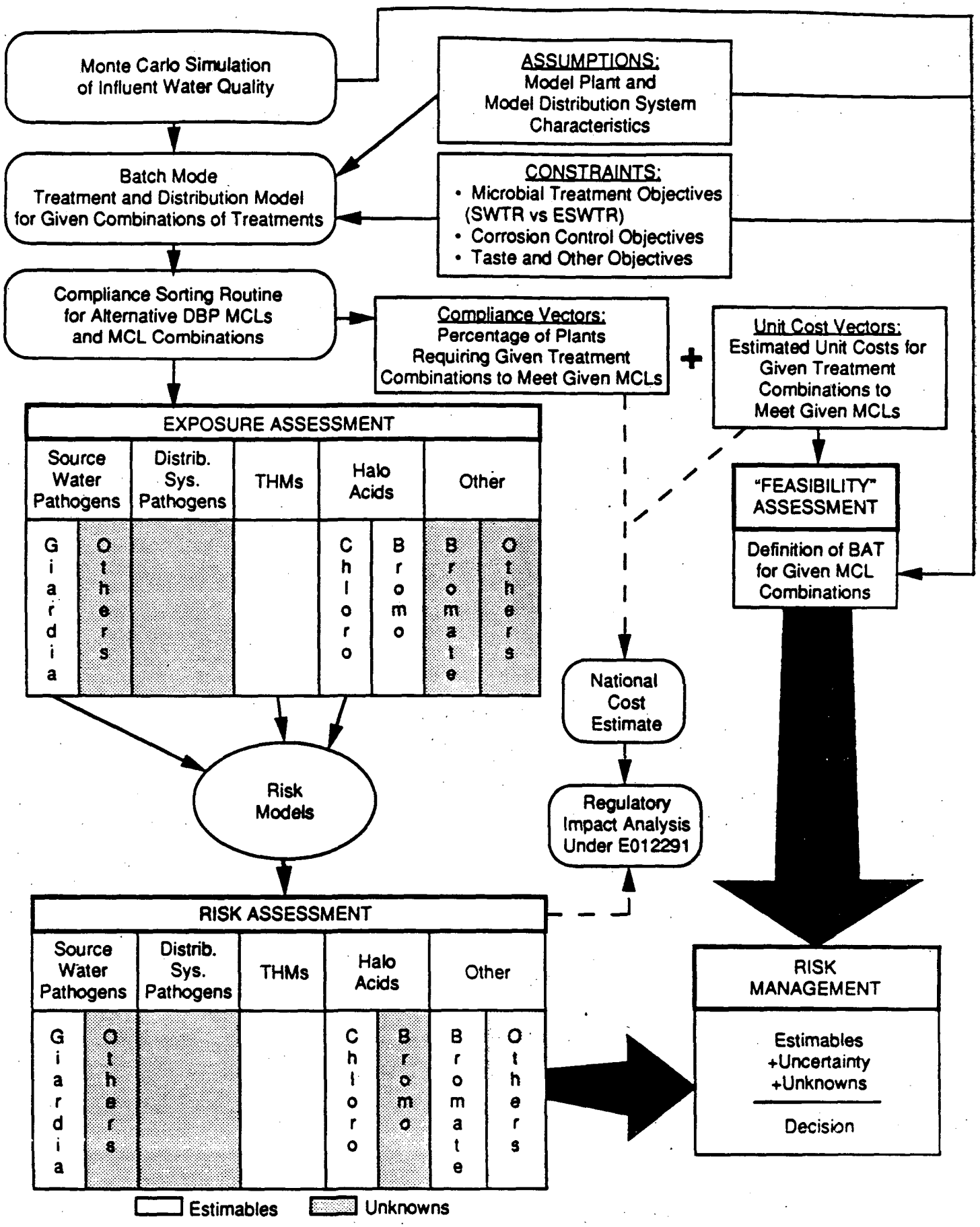
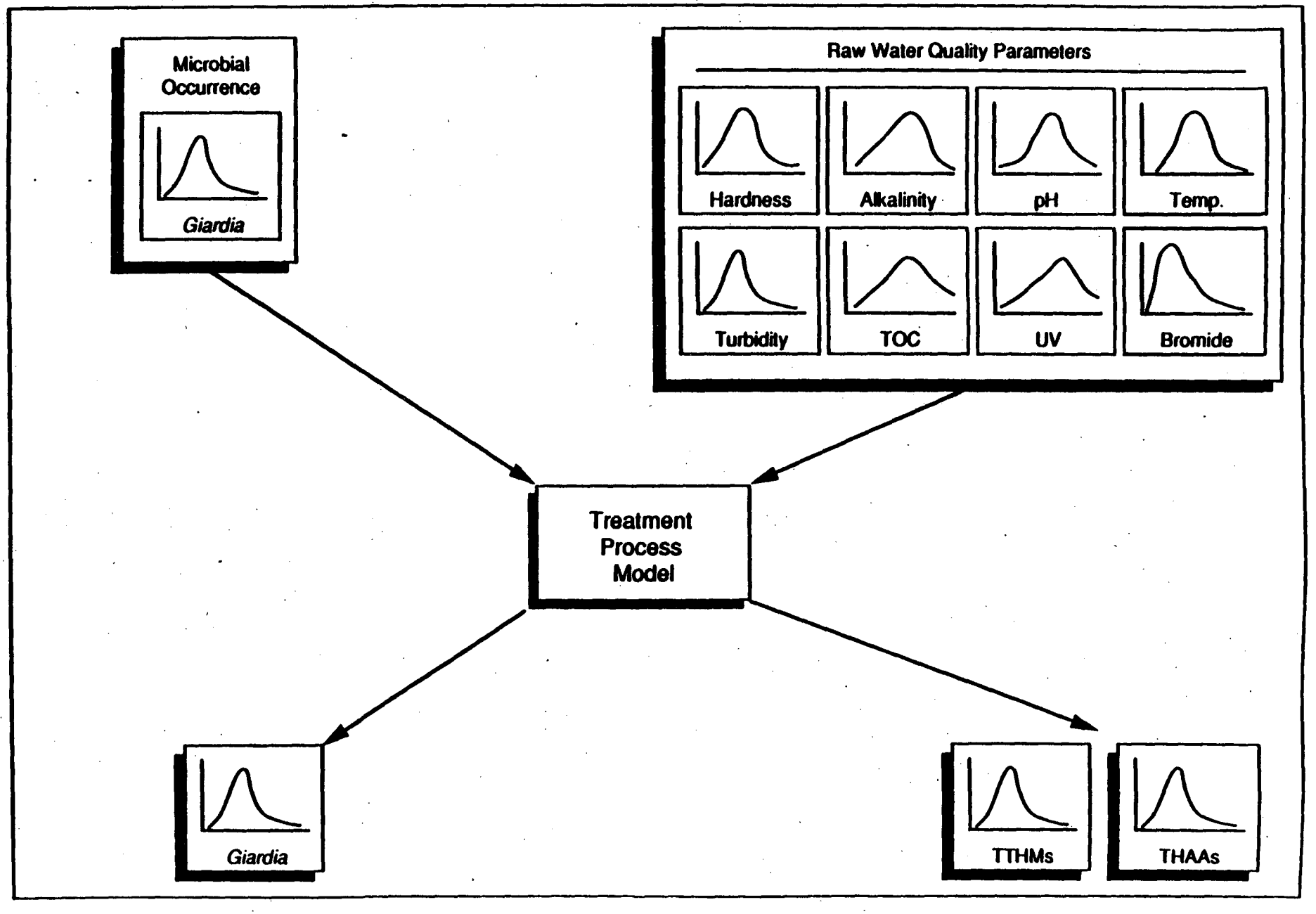


Figure 2

Major Parameters



Compliance Decision Tree

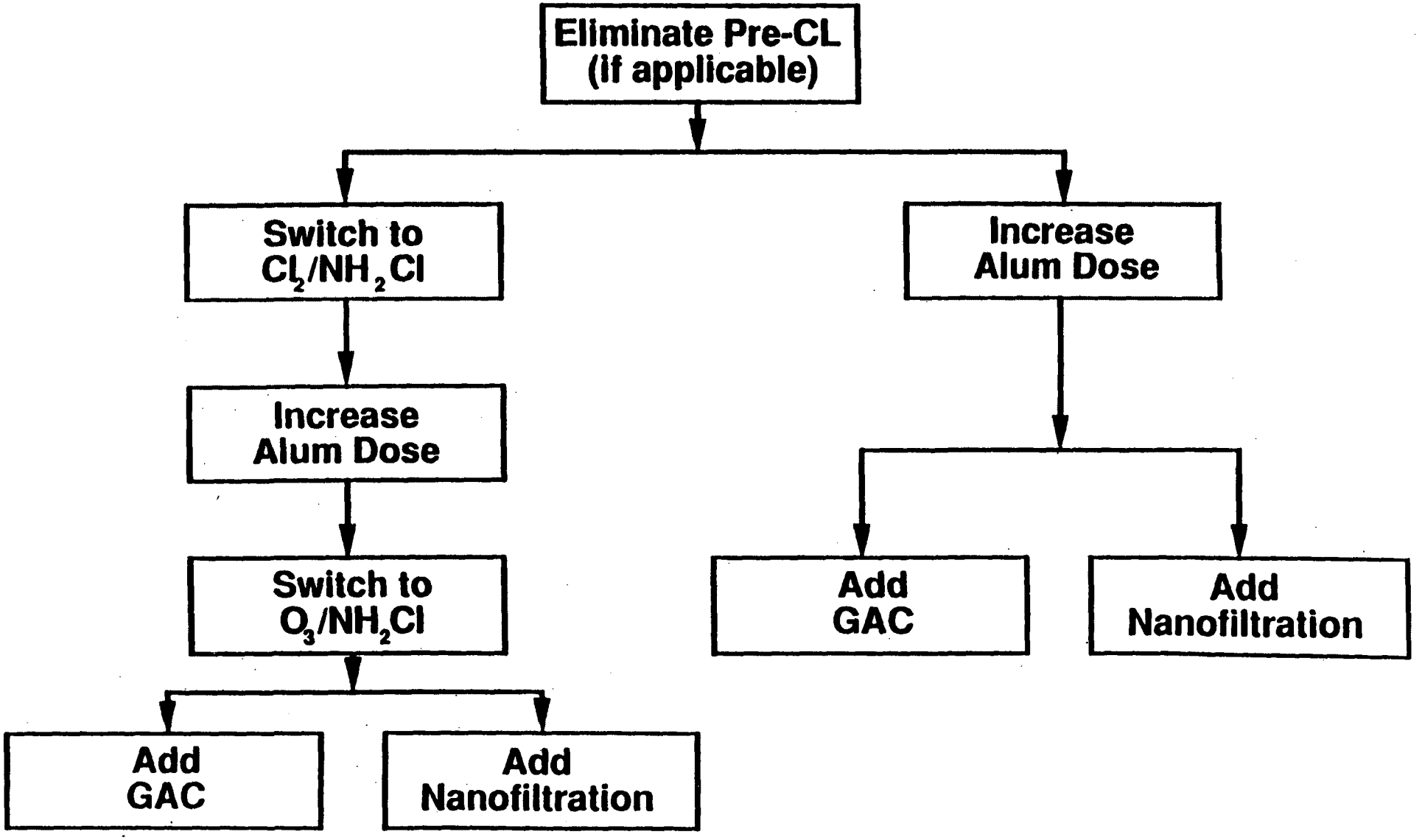


Figure 4

DBP Cancer Risk Calculation Data and Analysis

- **Model requires calculation of "cases per year:"**

$$\text{Population Exposed (persons)} \times \text{DBP Concentration } (\mu g/l) \times \text{Annual DW Risk Factor} \left(\frac{\text{cases/person/year}}{\mu g/l}\right) = \text{cases/year}$$

- **Derivation of Annual DW Risk Factor from MLE or Upper 95% CI Lifetime Risk Factor:**

$$\underset{\text{MLE or Upper 95\% CI Lifetime Risk Factor}}{\left(\frac{\text{cases/person/lifetime}}{\text{mg/kg/day}}\right)} \times \underset{\text{Conversion Factors:}}{\frac{1}{70\text{kg} \times \frac{1}{2\text{l/day}} \times 10^3\ \mu g/mg}} = \underset{\text{Lifetime DW Risk Factor}}{\left(\frac{\text{cases/person/lifetime}}{\mu g/l}\right)} \times \underset{\text{Conversion Factor}}{\frac{1}{70\text{ years/lifetime}}} = \underset{\text{Annual DW Risk Factor}}{\left(\frac{\text{cases/person/year}}{\mu g/l}\right)}$$

Divide Lifetime DW Risk Factor into 10^{-4}, 10^{-5}, 10^{-6} to obtain DW concentrations ($\mu g/l$) for these lifetime risk levels

DBP	MLE and Upper 95% CI Lifetime Risk Factors Used: MLE	Upper 95% Conf. Int.	DW Concentrations ($\mu g/l$) for Lifetime Risks (for Upper 95% CI) 10^{-4}	10^{-5}	10^{-6}	Comments
Chloroform	3.5×10^{-4}	6.1×10^{-3}	600	60	6	MLE from R. Bull, 95% CI from draft HA
Bromodichlormethane (BDCM)	8.2×10^{-4}	2.5×10^{-2}	140	14	1.4	MLE from R. Bull, 95% CI from draft HA
Dibromochloromethane (DBCM)	8.2×10^{-4}	2.5×10^{-2}	140	14	1.4	Assumed to be the same as BDCM
Bromoform	4.4×10^{-4}	7.9×10^{-3}	400	40	4	MLE from R. Bull, 95% CI from draft HA
Dichloroacetic acid	8.8×10^{-2}	2.8×10^{-1}	12.5	1.25	0.125	Provided by R. Cantilli (OST)
Tichloroacetic acid	2.1×10^{-2}	6.3×10^{-2}	55	5.5	0.55	Provided by R. Cantilli (OST)

Overview of *Giardia* Modelling

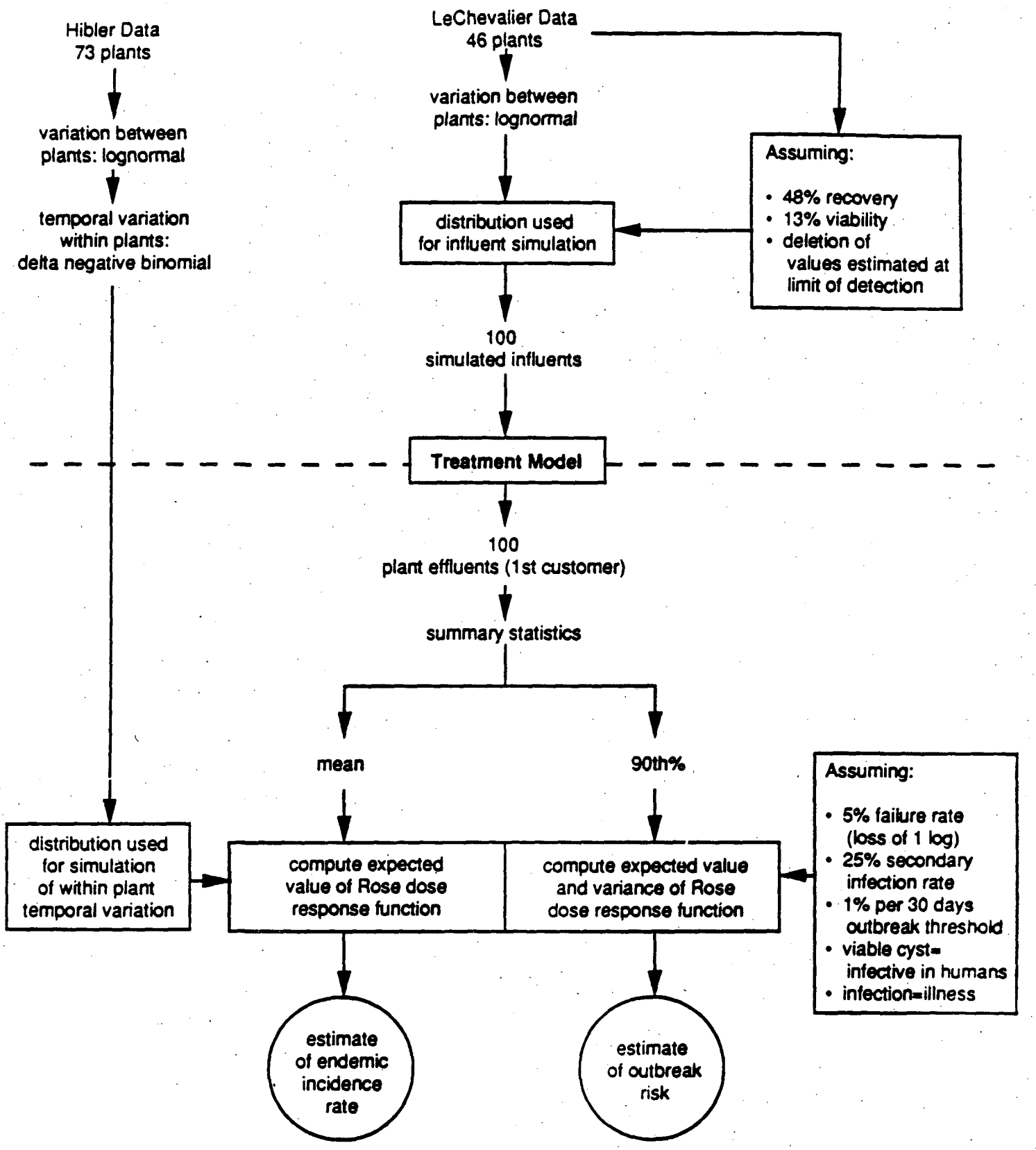


Figure 6

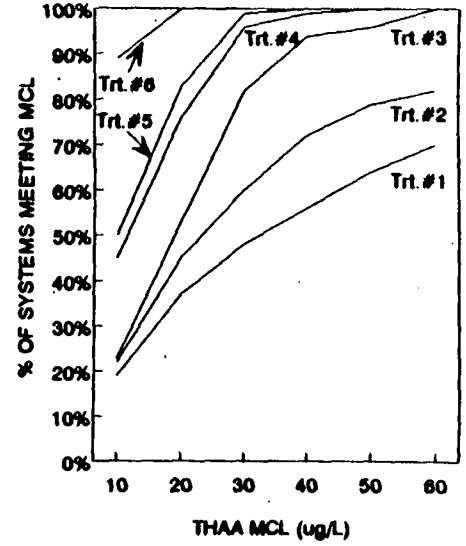
MODEL OUTPUT (surface w/o softening): SWTR W/ ALTERNATIVE DISINFECTION

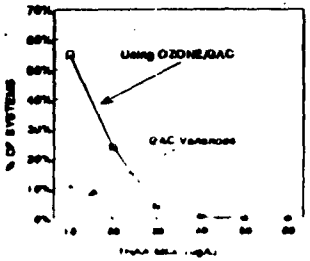
Treatment Code:

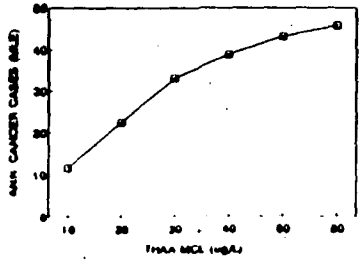
1 – not requiring further treatment modification	4 – pre-chlor + ammonia + alum dose
2 – eliminate pre-chlorination	5 – pre-chlor + ammonia + alum + ozone
3 – eliminate pre-chlor + add ammonia	6 – pre-chlor + ammonia + alum + ozone + GAC

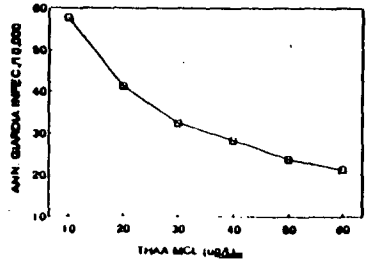
Population = *103,000,000* *(persons)*

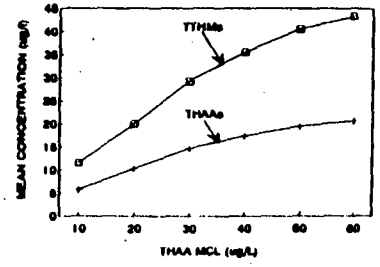
MCL (THAAs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By-Products (Avg Qua.)[3] TTHMs	Mean Concentrations of By-Products (Avg Qua.)[3] THAAs	Cancer Incidence THMs 95%	Cancer Incidence THMs MLE	Cancer Incidence HAAs 95%	Cancer Incidence HAAs MLE	Giardia Infections Endemic[4] Infections	Giardia Infections Epidemic[5] (90%) #.Yrs. to Outbreak
60	1	70	70	56	24	33.6	1.3	153.3	49.4		
60	2	12	82	46	21	30.2	1.1	139.9	45.0		
60	3	18	100	43	21	27.9	1.1	139.3	44.6		
60	4	0	100	43	21	27.9	1.1	139.3	44.6		
60	5	0	100	43	21	27.9	1.1	139.3	44.6		
60	6	0	100	43	21	27.9	1.1	139.3	44.6	218,045	3,089,000
50	1	64	64	55	24	33.6	1.3	153.3	49.4		
50	2	15	79	45	20	29.9	1.1	137.3	44.1		
50	3	17	96	42	20	27.3	1.0	134.6	43.3		
50	4	4	100	41	20	26.9	1.0	131.4	42.3		
50	5	0	100	41	20	26.9	1.0	131.4	42.3		
50	6	0	100	41	20	26.9	1.0	131.4	42.3	297,000	2.488
40	1	56	56	55	24	33.6	1.3	153.3	49.4		
40	2	16	72	42	19	28.0	1.1	131.5	42.3		
40	3	22	94	36	18	25.1	0.9	123.9	39.6		
40	4	5	99	36	18	24.5	0.9	118.7	38.1		
40	5	1	100	36	17	24.4	0.9	118.2	38.0		
40	6	0	100	36	17	24.4	0.9	118.2	38.0	289,000	0.058
30	1	48	48	55	24	33.6	1.3	153.3	49.4		
30	2	12	60	40	19	27.0	1.0	126.9	41.4		
30	3	22	82	34	17	22.7	0.8	115.2	37.0		
30	4	14	96	30	15	21.6	0.8	103.4	33.2		
30	5	3	99	30	15	21.5	0.8	101.8	32.7		
30	6	1	100	29	15	21.4	0.8	100.8	32.4	294,621	0.174
20	1	37	37	55	24	33.6	1.3	153.3	49.4		
20	2	8	45	39	16	25.9	1.0	126.1	40.5		
20	3	8	53	29	16	19.5	0.7	108.9	35.0		
20	4	23	76	23	13	17.4	0.6	88.0	28.2		
20	5	7	83	22	12	16.6	0.6	82.5	26.5		
20	6	17	100	20	10	16.1	0.6	69.9	22.1	412,000	0.016
10	1	19	19	55	24	33.6	1.3	153.3	49.4		
10	2	3	22	36	16	25.2	0.9	124.2	39.9		
10	3	1	23	26	16	17.1	0.6	108.6	34.9		
10	4	22	45	16	12	13.6	0.5	78.4	25.1		
10	5	5	50	15	10	12.1	0.4	67.6	21.7		
10	6	50	99	12	6	10.4	0.4	35.3	11.8	576,460	0.008











[1] percent of systems [illegible] each treatment tier (includes 20% over - design factor)
[2] cumulative percent [illegible] able to meet MCL at each treatment tier (includes 20% over - design factor)
[3] mean concentration [illegible] treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] [illegible]

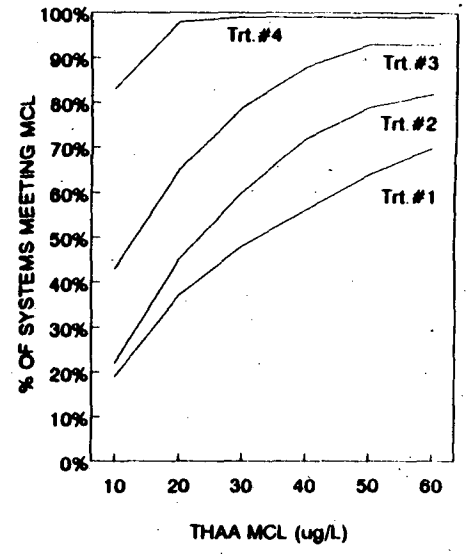
Figure 7

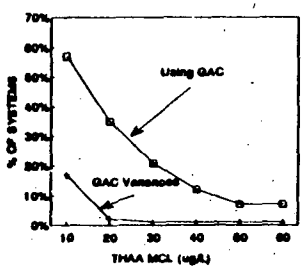
MODEL OUTPUT (surface w/o softening): SWTR W/O ALTERNATIVE DISINFECTION

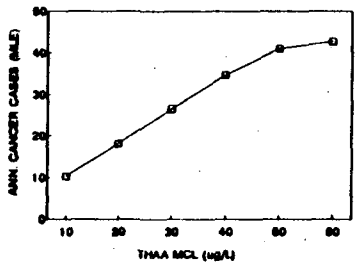
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre–chlorination
3 – eliminate pre–chlor + modify alum dose
4 – pre–chlor + alum dose + GAC

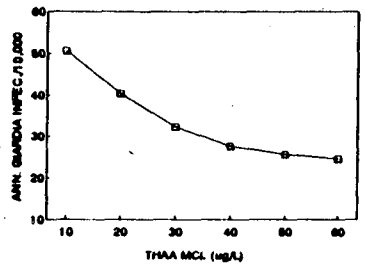
Population = *103,000,000* *(persons)*

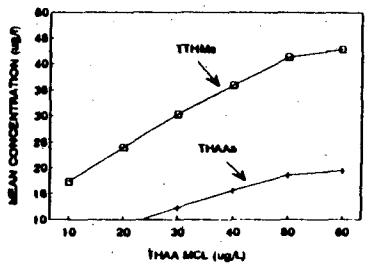
MCL (THAAs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By–Products (Ave. Qua.)[3] TTHMs	THAAs	Cancer Incidence THMs 95%	THMs MLE	HAAs 95%	HAAs MLE	Giardia Infections Endemic[4] Infections	Epidemic[5] (90%) #.Yrs. to Outbreak
60	1	70	70	56	24	33.8	1.3	153.3	49.4		
60	2	12	82	46	21	30.2	1.1	139.9	45.0		
60	3	11	93	44	20	29.2	1.1	134.0	43.1		
60	4	7	99	43	19	28.2	1.1	129.7	41.7	240,531	212.089
50	1	64	64	55	24	33.8	1.3	153.3	49.4		
50	2	15	79	45	20	29.9	1.1	137.3	44.1		
50	3	14	93	43	19	28.6	1.1	128.4	41.3		
50	4	7	99	41	19	27.7	1.0	124.5	40.0	257,280	1.091
40	1	56	56	55	24	33.8	1.3	153.3	49.4		
40	2	16	72	42	19	28.0	1.1	131.5	42.3		
40	3	16	88	39	17	26.6	1.0	116.8	37.5		
40	4	12	99	38	16	25.3	0.9	105.0	33.7	277,142	0.658
30	1	48	48	55	24	33.8	1.3	153.3	49.4		
30	2	12	60	40	19	27.0	1.0	128.9	41.4		
30	3	19	79	35	16	24.6	0.9	105.1	33.8		
30	4	21	99	30	12	22.7	0.8	89.9	25.8	324,059	0.174
20	1	37	37	55	24	33.8	1.3	153.3	49.4		
20	2	8	45	39	16	25.9	1.0	126.1	40.5		
20	3	20	65	31	14	22.2	0.8	93.9	30.1		
20	4	35	99	24	9	19.1	0.7	54.6	17.5	408,045	0.034
10	1	19	19	55	24	33.8	1.3	153.3	49.4		
10	2	3	22	38	16	25.2	0.9	124.2	39.9		
10	3	21	43	26	13	20.3	0.7	84.2	27.1		
10	4	57	99	17	8	14.6	0.5	39.6	9.8	508,430	0.008











[1] percent of systems installing each treatment tier (includes 20% over–design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over–design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

Figure 8

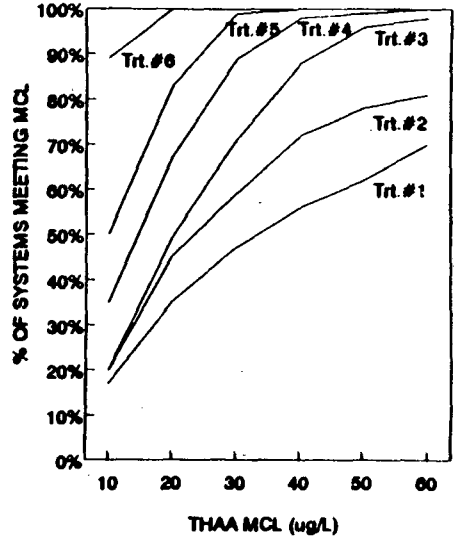
MODEL OUTPUT (surface w/o softening): ENHANCED SWTR W/ ALTERNATIVE DISINFECTION

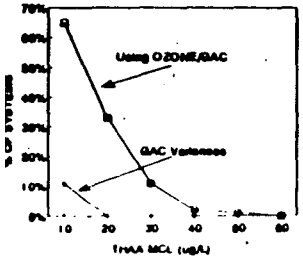
Treatment Code:

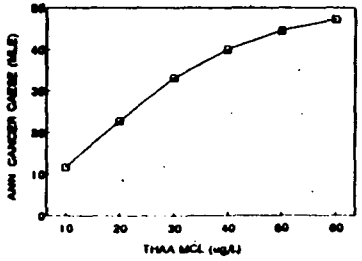
1 – not requiring further treatment modification	4 – pre-chlor + ammonia + alum dose
2 – eliminate pre-chlorination	5 – pre-chlor + ammonia + alum + ozone
3 – eliminate pre-chlor + add ammonia	6 – pre-chlor + ammonia + alum + ozone + GAC

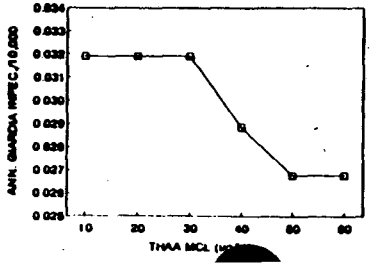
Population = *103,000,000* *(persons)*

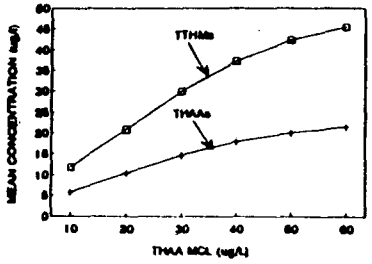
MCL (THAAs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[1]	Mean Concentrations of By-Products (Ann.Ave.)[2] TTHMs	THAAs	Cancer Incidence THMs 95%	THMs MLE	HAAs 95%	HAAs MLE	Giardia Infections Endemic[3] Infections	Epidemic[3] (90%) #.Yrs. to Outbreak
60	1	70	70	57	25	34.6	1.3	156.3	50.3		
60	2	11	81	48	21	31.2	1.2	143.2	46.1		
60	3	17	98	46	22	29.4	1.1	144.9	46.6		
60	4	2	100	45	22	29.1	1.1	143.4	46.1		
60	5	0	100	45	22	29.1	1.1	143.4	46.1		
60	6	0	100	45	22	29.1	1.1	143.4	46.1	[illegible]	Infinity
50	1	62	62	57	25	34.6	1.3	156.3	50.3		
50	2	16	78	46	21	30.7	1.2	139.5	44.8		
50	3	16	98	44	21	28.7	1.1	139.3	44.6		
50	4	3	99	43	20	28.2	1.1	138.1	43.8		
50	5	1	100	42	20	28.1	1.1	135.3	43.5		
50	6	0	100	42	20	28.1	1.1	135.3	43.5	[illegible]	Infinity
40	1	56	56	57	25	34.6	1.3	156.3	50.3		
40	2	16	72	44	20	29.0	1.1	135.1	43.4		
40	3	16	88	41	20	26.8	1.0	131.8	42.4		
40	4	10	98	38	18	25.9	1.0	123.2	39.6		
40	5	2	100	37	18	25.7	1.0	121.7	39.1		
40	6	0	100	37	18	25.7	1.0	121.7	39.1	[illegible]	Infinity
30	1	47	47	57	25	34.6	1.3	156.3	50.3		
30	2	12	59	42	19	26.0	1.0	132.5	42.6		
30	3	12	71	37	19	24.6	0.9	124.9	40.2		
30	4	18	89	32	16	22.9	0.8	107.2	34.4		
30	5	10	99	30	15	22.2	0.8	101.6	32.6		
30	6	1	100	30	15	22.2	0.8	100.6	32.6	319	Infinity
20	1	35	35	57	25	34.6	1.3	156.3	50.3		
20	2	10	45	40	19	28.8	1.0	129.0	41.4		
20	3	4	49	33	18	22.1	0.8	120.0	38.6		
20	4	18	67	28	14	19.2	0.7	95.9	30.8		
20	5	16	83	23	12	17.5	0.6	82.9	26.6		
20	6	17	100	21	10	16.9	0.6	69.3	22.2	319	Infinity
10	1	17	17	57	25	34.6	1.3	156.3	50.3		
10	2	3	20	39	19	26.1	1.0	127.6	41.0		
10	3	0	20	31	18	20.0	0.8	122.9	39.5		
10	4	15	35	21	13	15.5	0.6	86.5	28.4		
10	5	15	50	16	10	12.4	0.4	67.6	21.7		
10	6	50	100	12	6	10.6	0.4	36.4	11.9	319	Infinity











ercent of systems [illegible] each treatment tier (includes 20% over-design factor)
umulative percent [illegible] able to meet MCL at each treatment tier (includes 20% over-design factor)
ean concentration [illegible] treatment tier of all systems; those meeting MCL and those not meeting MCL

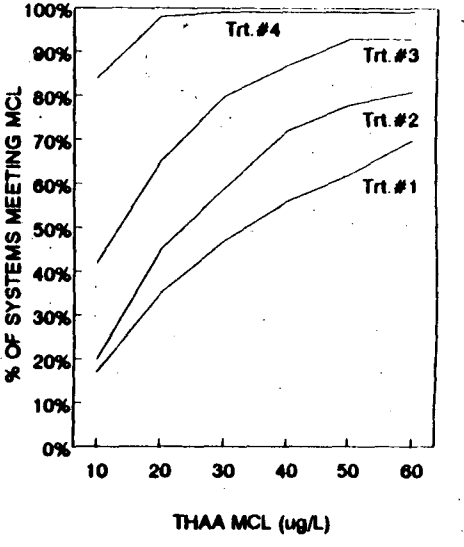
Figure 9

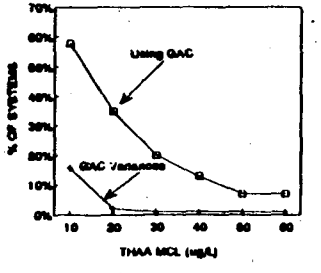
MODEL OUTPUT (surface w/o softening): ENHANCED SWTR W/O ALTERNATIVE DISINFECTION

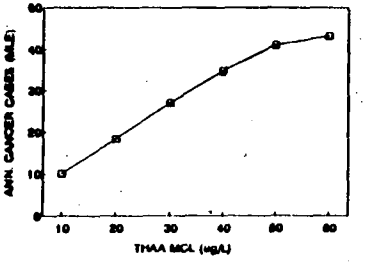
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre–chlorination
3 – eliminate pre–chlor + modify alum dose
4 – pre–chlor + alum dose + GAC

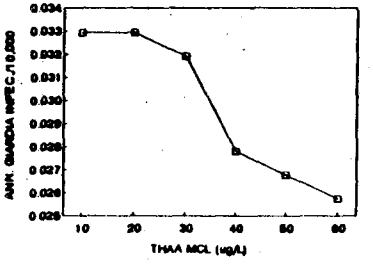
Population = 103,000,000 *(persons)*

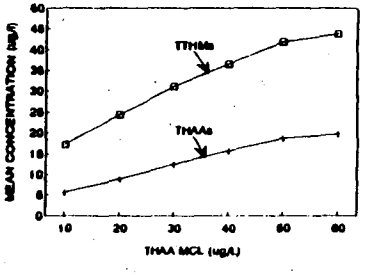
MCL (THAAs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By–Products (Ave.Qua.)[3] TTHMs	THAAs	Cancer Incidence THMs 95%	THMs MLE	HAAs 95%	HAAs MLE	Giardia Infections Endemic[4] Infections	Epidemic[5] (90%) #.Yrs. to Outbreak
60	1	70	70	57	25	34.8	1.3	156.3	50.3		
60	2	11	81	46	21	31.2	1.2	143.2	46.1		
60	3	12	93	45	20	29.9	1.1	135.3	43.5		
60	4	7	99	44	20	28.8	1.1	131.0	42.1	250	Infinity
50	1	62	62	57	25	34.8	1.3	156.3	50.3		
50	2	16	78	46	21	30.7	1.2	139.5	44.8		
50	3	15	93	43	19	29.2	1.1	128.4	41.3		
50	4	7	99	42	19	28.2	1.1	124.5	40.0	260	Infinity
40	1	56	56	57	25	34.8	1.3	156.3	50.3		
40	2	16	72	44	20	29.0	1.1	135.1	43.4		
40	3	15	87	40	18	27.3	1.0	119.2	38.3		
40	4	12	99	37	16	25.6	0.9	105.4	33.9	270	Infinity
30	1	47	47	57	25	34.8	1.3	156.3	50.3		
30	2	12	59	42	19	28.0	1.0	132.5	42.6		
30	3	21	80	36	16	25.3	0.9	106.2	34.1		
30	4	20	99	31	13	23.9	0.8	92.0	29.4	310	Infinity
20	1	35	35	57	25	34.8	1.3	156.3	50.3		
20	2	10	45	40	19	26.6	1.0	129.0	41.4		
20	3	20	65	32	14	22.7	0.8	95.1	30.5		
20	4	35	99	24	9	18.5	0.7	65.4	17.8	360	Infinity
10	1	17	17	57	25	34.8	1.3	156.3	50.3		
10	2	3	20	39	19	26.1	1.0	127.6	41.0		
10	3	22	42	26	13	20.6	0.8	84.8	27.2		
10	4	58	84	17	8	14.6	0.5	39.0	8.6	380	Infinity











[1] percent of systems installing each treatment tier (includes 20% over–design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over–design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

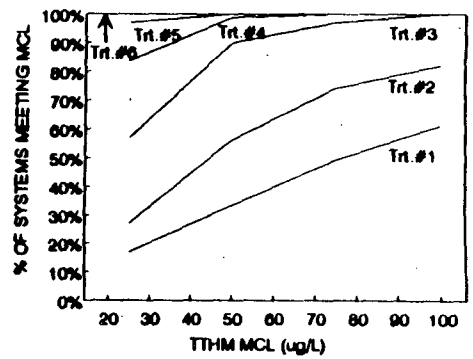
Figure 10

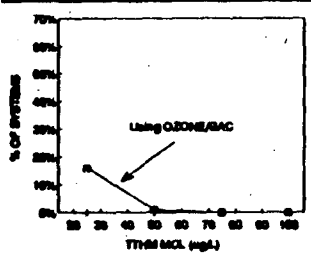
MODEL OUTPUT (surface w/o softening): SWTR W/ ALTERNATIVE DISINFECTION

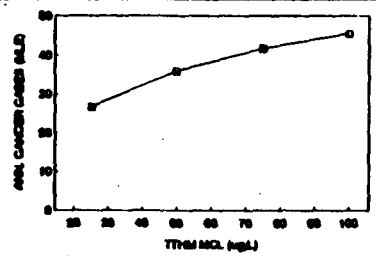
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre-chlorination
3 – eliminate pre-chlor + add ammonia
4 – pre-chlor + ammonia + alum dose
5 – pre-chlor + ammonia + alum + ozone
6 – pre-chlor + ammonia + alum + ozone + GAC

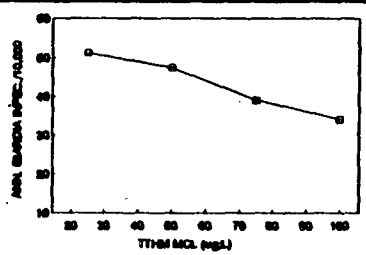
Population = 103,000,000 *(persons)*

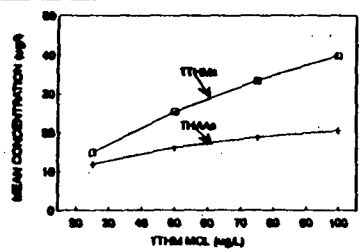
MCL (TTHMs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By-Products (ug/L)[3] TTHMs	Mean Concentrations of By-Products (ug/L)[3] HAAs	Cancer Incidence THMs 95%	Cancer Incidence THMs MLE	Cancer Incidence HAAs 95%	Cancer Incidence HAAs MLE	Giardia Infections Endemic[4] Infections	Giardia Infections Epidemic[5] (90%) #.Yrs. to Outbreak
100	1	61	61	55	24	33.8	1.3	153.3	49.4		
100	2	21	82	42	20	27.0	1.0	136.1	43.7		
100	3	18	100	40	20	24.6	0.9	136.7	44.6		
100	4	0	100	40	20	24.6	0.9	136.7	44.6		
100	5	0	100	40	20	24.6	0.9	136.7	44.6		
100	6	0	100	40	20	24.6	0.9	136.7	44.6	340,082	2.60
75	1	49	49	55	24	33.8	1.3	153.3	49.4		
75	2	25	74	39	19	25.0	1.0	132.1	42.5		
75	3	23	97	34	19	21.0	0.8	129.6	41.7		
75	4	3	100	33	19	20.7	0.8	127.5	41.0		
75	5	0	100	33	19	20.7	0.8	127.5	41.0		
75	6	0	100	33	19	20.7	0.8	127.5	41.0	390,216	0.16
50	1	33	33	55	24	33.8	1.3	153.3	49.4		
50	2	23	56	37	18	23.9	0.9	126.6	40.7		
50	3	34	90	26	17	17.4	0.7	116.6	37.5		
50	4	9	99	26	16	16.0	0.6	110.4	35.4		
50	5	1	100	25	16	15.9	0.6	109.9	35.3		
50	6	0	100	25	16	15.9	0.6	109.9	35.3	474,085	0.04
25	1	17	17	55	24	33.8	1.3	153.3	49.4		
25	2	10	27	36	18	23.2	0.9	124.9	40.1		
25	3	30	57	23	16	14.1	0.5	107.7	34.6		
25	4	27	84	17	13	10.6	0.4	88.5	28.4		
25	5	13	97	15	12	9.9	0.4	84.6	27.2		
25	6	3	100	15	12	9.6	0.4	81.7	26.2	518,148	0.008











[1] percent of systems installing each treatment tier (includes 20% over-design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over-design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

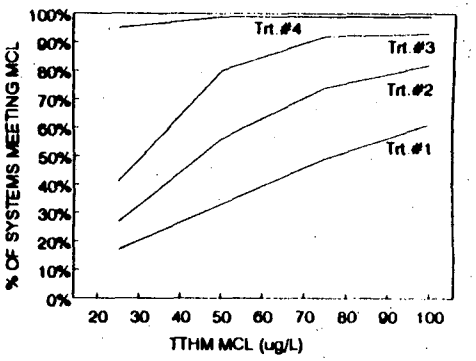
Figure 11

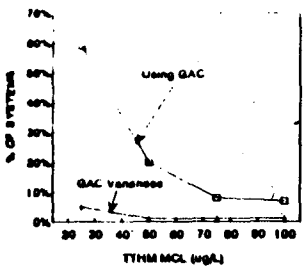
MODEL OUTPUT (surface w/o softening): SWTR W/O ALTERNATIVE DISINFECTION

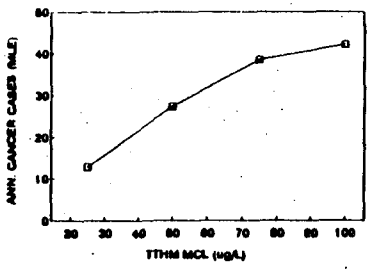
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre-chlorination
3 – eliminate pre-chlor + modify alum dose
4 – pre-chlor + alum dose + GAC

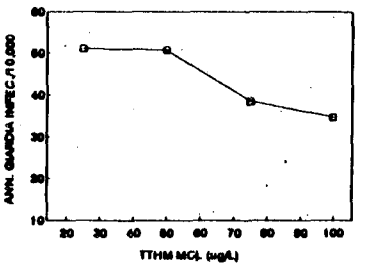
Population = 103,000,000 (persons)

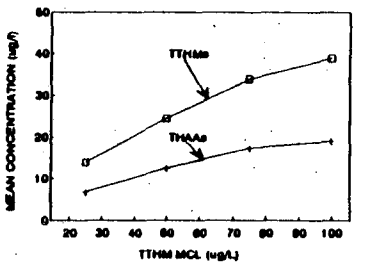
MCL (TTHMs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By-Products (Avg Qua.)[3]		Cancer Incidence				Giardia Infections	
						THMs		HAAs		Endemic[4]	Epidemic[5]
				TTHMs	THAAs	95%	MLE	95%	MLE	Infections	(90%) #.Yrs. to Outbreak
100	1	61	61	55	24	33.8	1.3	153.3	49.4		
100	2	21	82	42	20	27.0	1.0	136.1	43.7		
100	3	11	93	40	20	25.4	1.0	132.6	42.6		
100	4	7	99	39	19	24.7	0.9	128.4	41.3	347,110	1.091
75	1	49	49	55	24	33.8	1.3	153.3	49.4		
75	2	25	74	39	19	25.0	1.0	132.1	42.5		
75	3	18	92	35	18	22.5	0.9	122.1	39.2		
75	4	8	99	34	17	21.5	0.8	117.3	37.7	395,220	0.182
50	1	33	33	55	24	33.8	1.3	153.3	49.4		
50	2	23	56	37	18	23.9	0.9	126.6	40.7		
50	3	24	80	29	15	19.1	0.7	102.6	33.0		
50	4	20	99	24	13	16.4	0.6	88.3	28.8	507,790	0.035
25	1	17	17	55	24	33.8	1.3	153.3	49.4		
25	2	10	27	36	18	23.2	0.9	124.9	40.1		
25	3	14	41	26	13	17.3	0.6	88.5	28.4		
25	4	59	95	14	7	10.1	0.4	39.0	12.5	510,880	0.009











[1] percent of systems installing each treatment tier (includes 20% over-design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over-design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

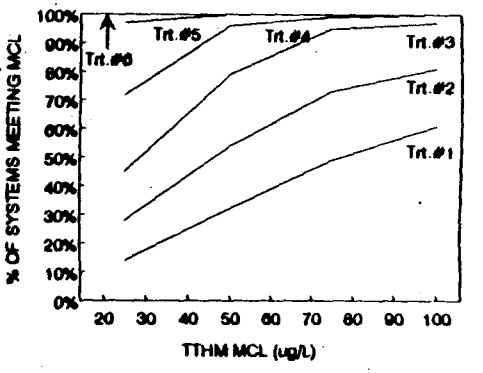
Figure 12

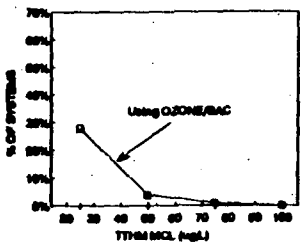
MODEL OUTPUT (surface w/o softening): ENHANCED SWTR W/ ALTERNATIVE DISINFECTION

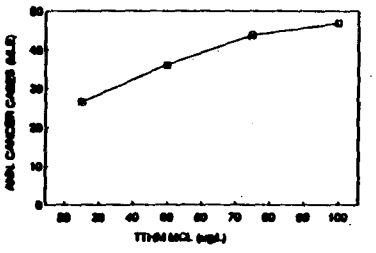
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre-chlorination
3 – eliminate pre-chlor + add ammonia
4 – pre-chlor + ammonia + alum dose
5 – pre-chlor + ammonia + alum + ozone
6 – pre-chlor + ammonia + alum + ozone + GAC

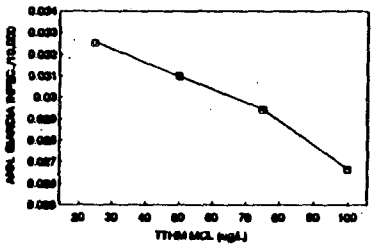
Population = 103,000,000 *(persons)*

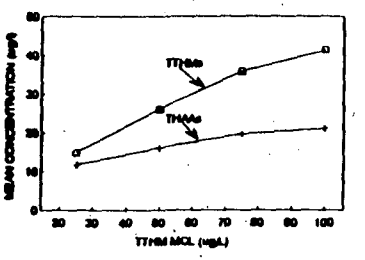
MCL (TTHMs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By-Products (Ave. Ops.)[3] TTHMs	HAAs	Cancer Incidence THMs 95%	THMs MLE	HAAs 95%	HAAs MLE	Giardia Infections Endemic[4] Infections	Epidemic[5] (90%) # Yrs. to Outbreak
100	1	61	61	57	25	34.8	1.3	156.3	50.3		
100	2	20	81	44	21	26.0	1.1	139.6	44.9		
100	3	16	97	43	22	26.2	1.0	145.3	46.7		
100	4	3	100	41	21	25.8	1.0	142.6	45.8		
100	5	0	100	41	21	25.8	1.0	142.6	45.8		
100	6	0	100	41	21	25.8	1.0	142.6	45.8	267	infinity
75	1	49	49	57	25	34.8	1.3	156.3	50.3		
75	2	24	73	41	20	26.0	1.0	135.9	43.7		
75	3	22	95	36	20	23.2	0.9	137.6	44.2		
75	4	4	99	36	20	22.2	0.9	134.3	43.2		
75	5	1	100	36	20	22.1	0.9	133.5	42.9		
75	6	0	100	36	20	22.1	0.9	133.5	42.9	295	infinity
50	1	32	32	57	25	34.8	1.3	156.3	50.3		
50	2	22	54	39	19	24.9	0.9	130.4	41.9		
50	3	25	79	33	19	20.0	0.8	126.1	40.5		
50	4	17	96	27	17	16.9	0.6	112.6	36.2		
50	5	4	100	26	16	16.4	0.6	110.4	35.5		
50	6	0	100	26	16	16.4	0.6	110.4	35.5	310	infinity
25	1	14	14	57	25	34.8	1.3	156.3	50.3		
25	2	14	28	37	19	24.0	0.9	128.0	41.1		
25	3	17	45	29	18	17.4	0.7	119.9	38.5		
25	4	27	72	19	14	12.4	0.5	93.9	30.2		
25	5	25	97	15	12	10.0	0.4	84.4	27.1		
25	6	3	100	15	12	9.8	0.4	81.5	26.2	325	infinity











[1] percent of systems installing each treatment tier (includes 20% over-design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over-design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

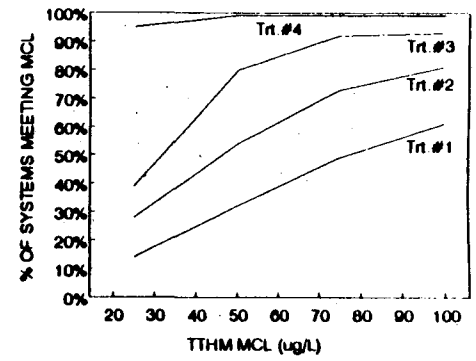
Figure 13

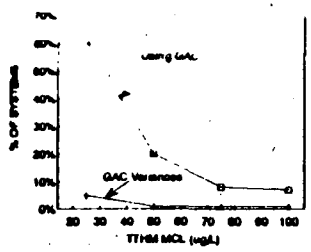
MODEL OUTPUT (surface w/o softening): ENHANCED SWTR W/O ALTERNATIVE DISINFECTION

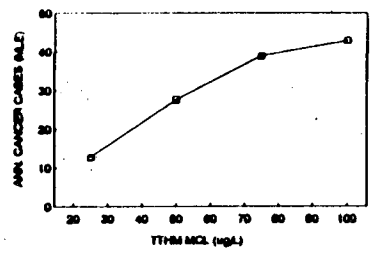
Treatment Code:
1 – not requiring further treatment modification
2 – eliminate pre-chlorination
3 – eliminate pre-chlor + modify alum dose
4 – pre-chlor + alum dose + GAC

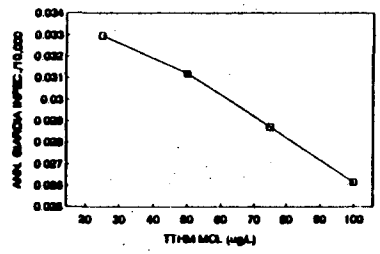
Population = *103,000,000* *(persons)*

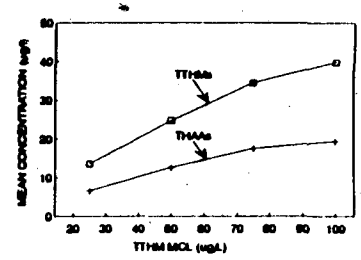
MCL (TTHMs)	Trt. Code	% of Sys. Ending[1]	Cumulative % of Sys. < MCL[2]	Mean Concentrations of By-Products (ug/L)[3] TTHMs	Mean Concentrations of By-Products (ug/L)[3] THAAs	Cancer Incidence TTHMs 95%	Cancer Incidence TTHMs MLE	Cancer Incidence THAAs 95%	Cancer Incidence THAAs MLE	Giardia Infections Endemic[4] Infections	Giardia Infections Epidemic[5] (90%) #.Yrs. to Outbreak
100	1	61	61	57	25	34.8	1.3	156.3	50.3		
100	2	20	81	44	21	26.0	1.1	139.6	44.9		
100	3	12	93	41	20	26.0	1.0	134.8	43.3		
100	4	7	99	40	19	25.2	1.0	130.5	41.9	282	Infinity
75	1	49	49	57	25	34.8	1.3	156.3	50.3		
75	2	24	73	41	20	26.0	1.0	135.9	43.7		
75	3	19	92	36	18	22.8	0.9	123.6	39.7		
75	4	8	99	34	18	21.8	0.8	118.8	38.1	287	Infinity
50	1	32	32	57	25	34.8	1.3	156.3	50.3		
50	2	22	54	39	19	24.9	0.9	130.4	41.9		
50	3	26	80	30	15	19.3	0.7	104.2	33.5		
50	4	20	99	25	13	16.5	0.6	84.5	27.1	312	Infinity
25	1	14	14	57	25	34.8	1.3	156.3	50.3		
25	2	14	28	37	19	24.0	0.9	126.0	41.1		
25	3	11	39	26	13	17.5	0.7	89.6	28.8		
25	4	61	95	14	7	9.9	0.4	38.8	12.5	330	Infinity





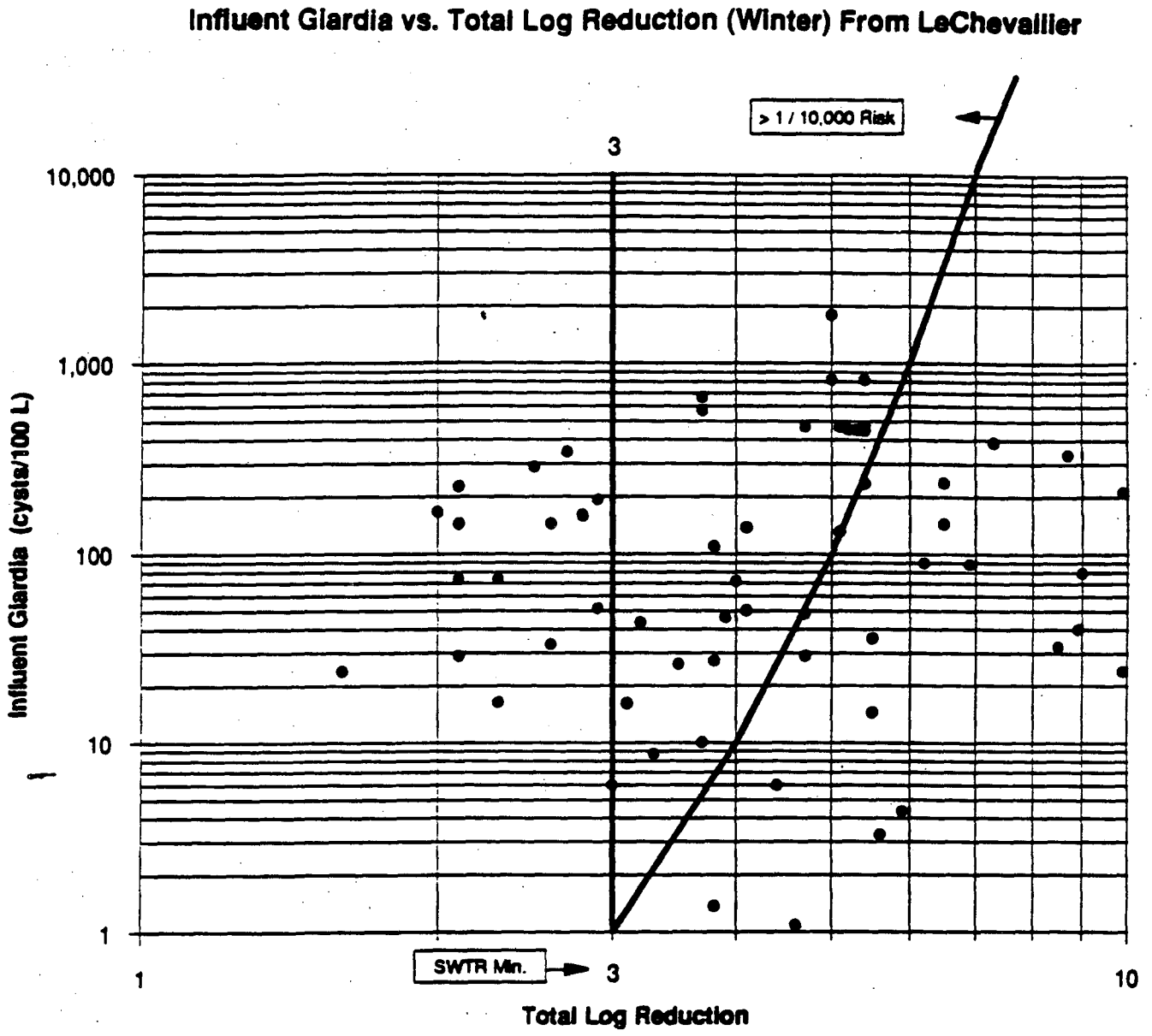






[1] percent of systems installing each treatment tier (includes 20% over-design factor)
[2] cumulative percent of systems able to meet MCL at each treatment tier (includes 20% over-design factor)
[3] mean concentration at each treatment tier of all systems; those meeting MCL and those not meeting MCL
[4] assumes 10% of population exposed at first customer
[5] estimate for 90th percentile

Figure 14


Influent Giardia vs. Total Log Reduction (Winter) From LeChevallier
> 1 / 10,000 Risk
3
10,000
1,000
100
10
1
Influent Giardia (cysts/100 L)
SWTR Min.
3
1
10
Total Log Reduction

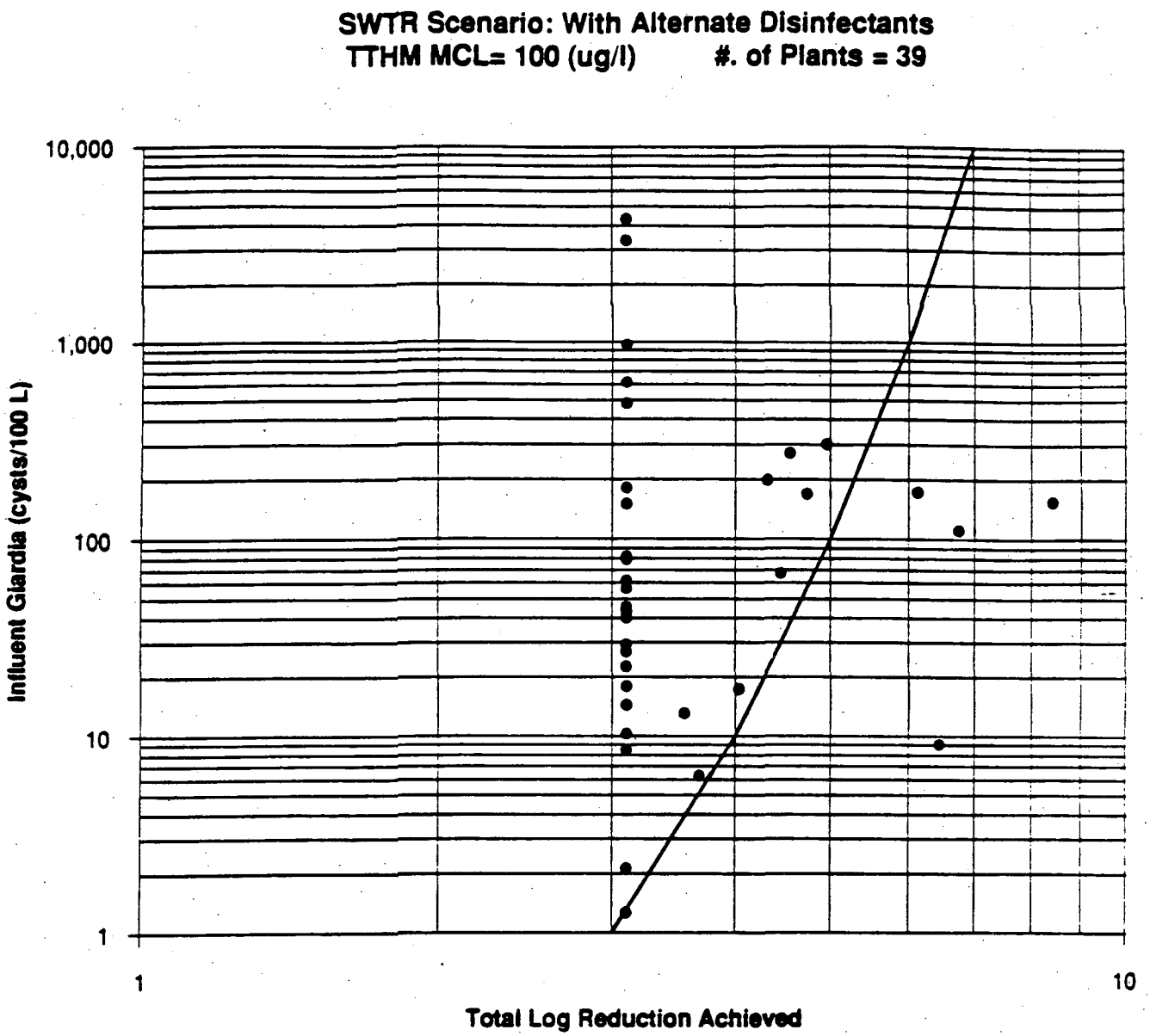
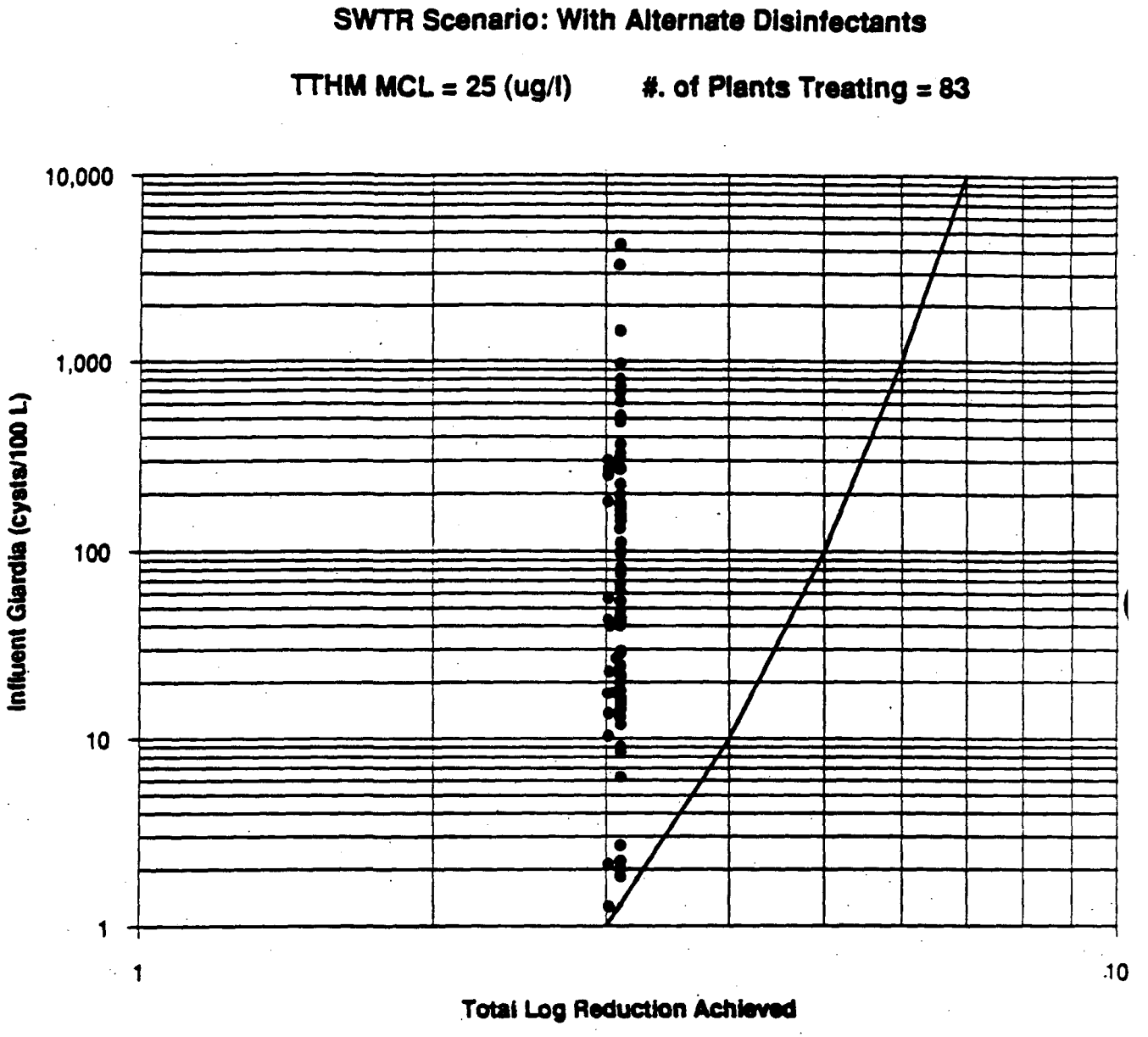

SWTR Scenario: With Alternate Disinfectants
TTHM MCL= 100 (ug/l)
#. of Plants = 39
10,000
1,000
100
10
1
Influent Giardia (cysts/100 L)
1
10
Total Log Reduction Achieved

Figure 16


SWTR Scenario: With Alternate Disinfectants
TTHM MCL = 25 (ug/l)
#. of Plants Treating = 83
10,000
1,000
100
10
1
Influent Giardia (cysts/100 L)
1
10
Total Log Reduction Achieved

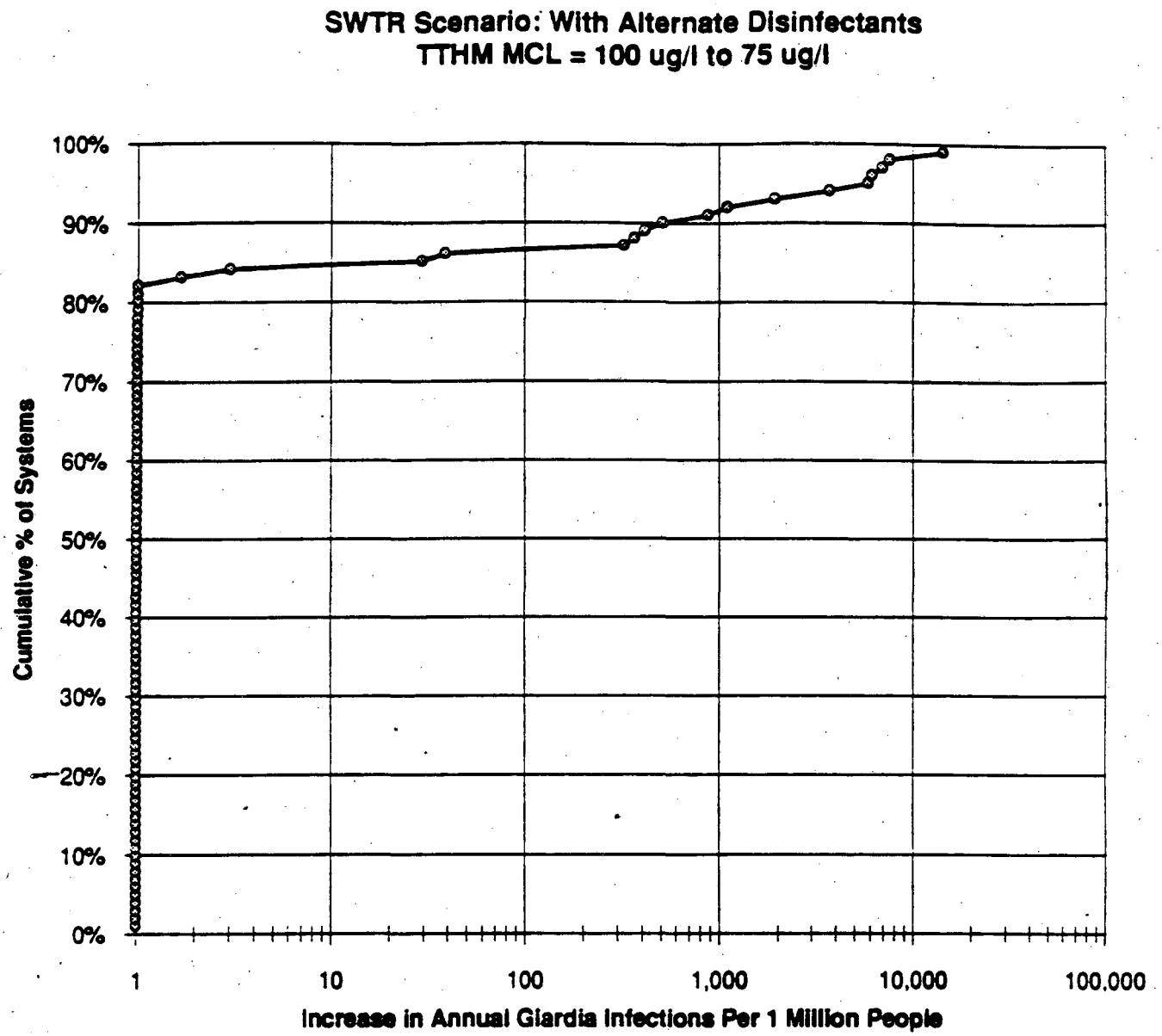
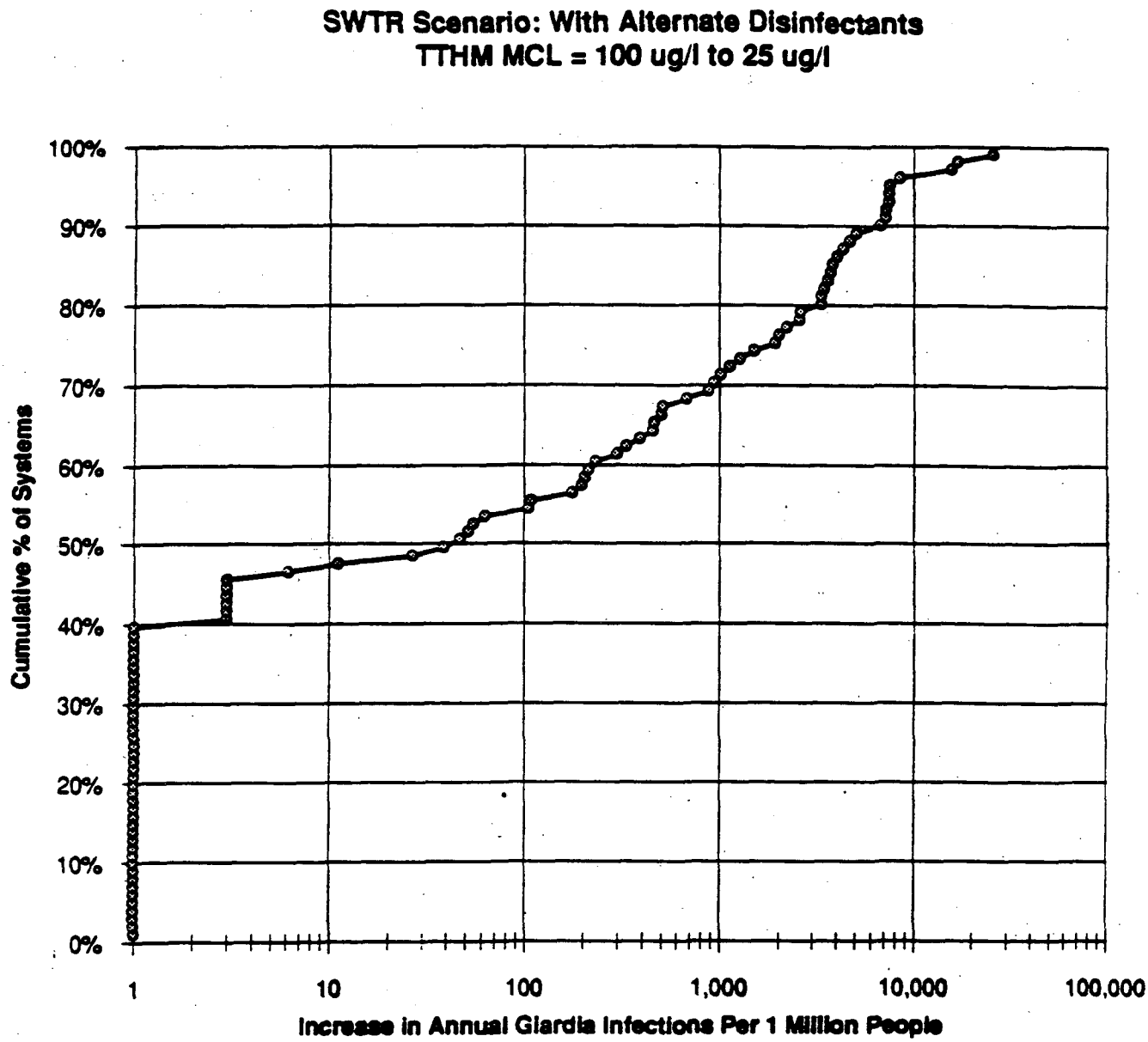

SWTR Scenario: With Alternate Disinfectants
TTHM MCL = 100 ug/l to 75 ug/l
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative % of Systems
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections Per 1 Million People

Figure 18


SWTR Scenario: With Alternate Disinfectants
TTHM MCL = 100 ug/l to 25 ug/l
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative % of Systems
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections Per 1 Million People

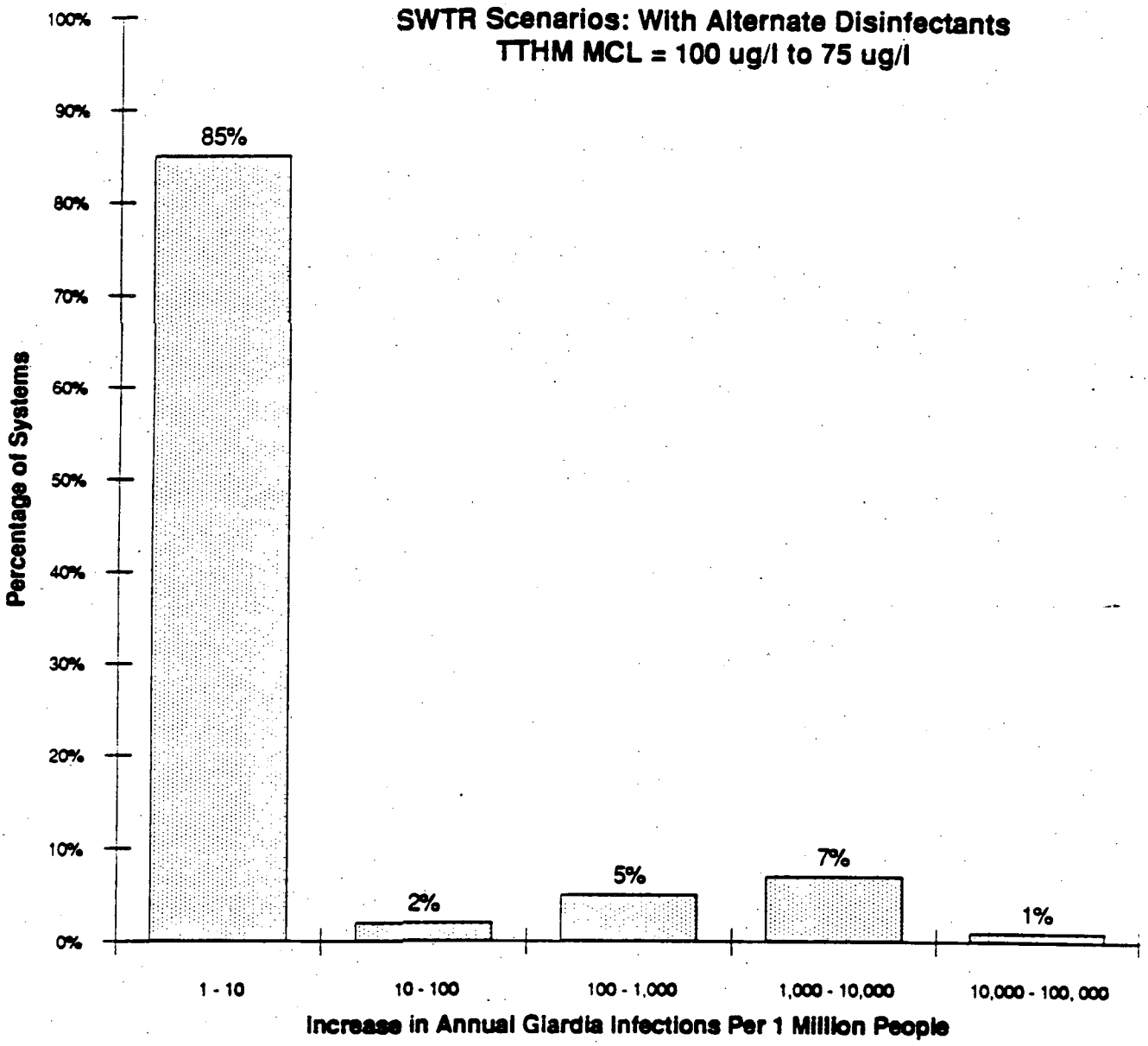
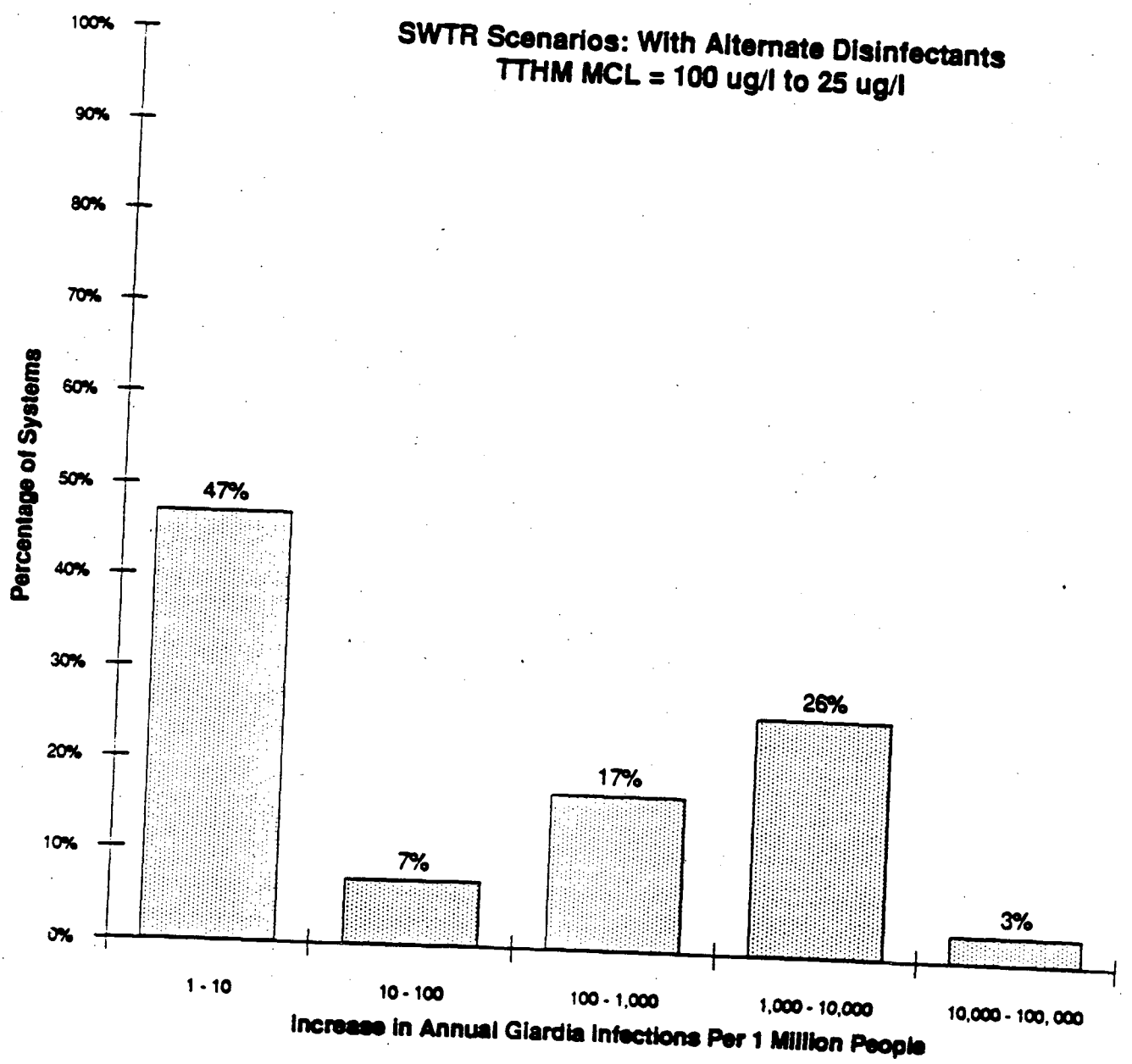

SWTR Scenarios: With Alternate Disinfectants
TTHM MCL = 100 ug/l to 75 ug/l
Percentage of Systems
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
85%
2%
5%
7%
1%
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
Increase in Annual Giardia Infections Per 1 Million People

Figure 20


SWTR Scenarios: With Alternate Disinfectants
TTHM MCL = 100 ug/l to 25 ug/l
Percentage of Systems
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
47%
7%
17%
26%
3%
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
Increase in Annual Giardia Infections Per 1 Million People

SWTR Scenario: With Alternate Disinfectants

From TTHM MCL = 100 ug/l to 75 ug/l
Change in Risks Per 1 Million People

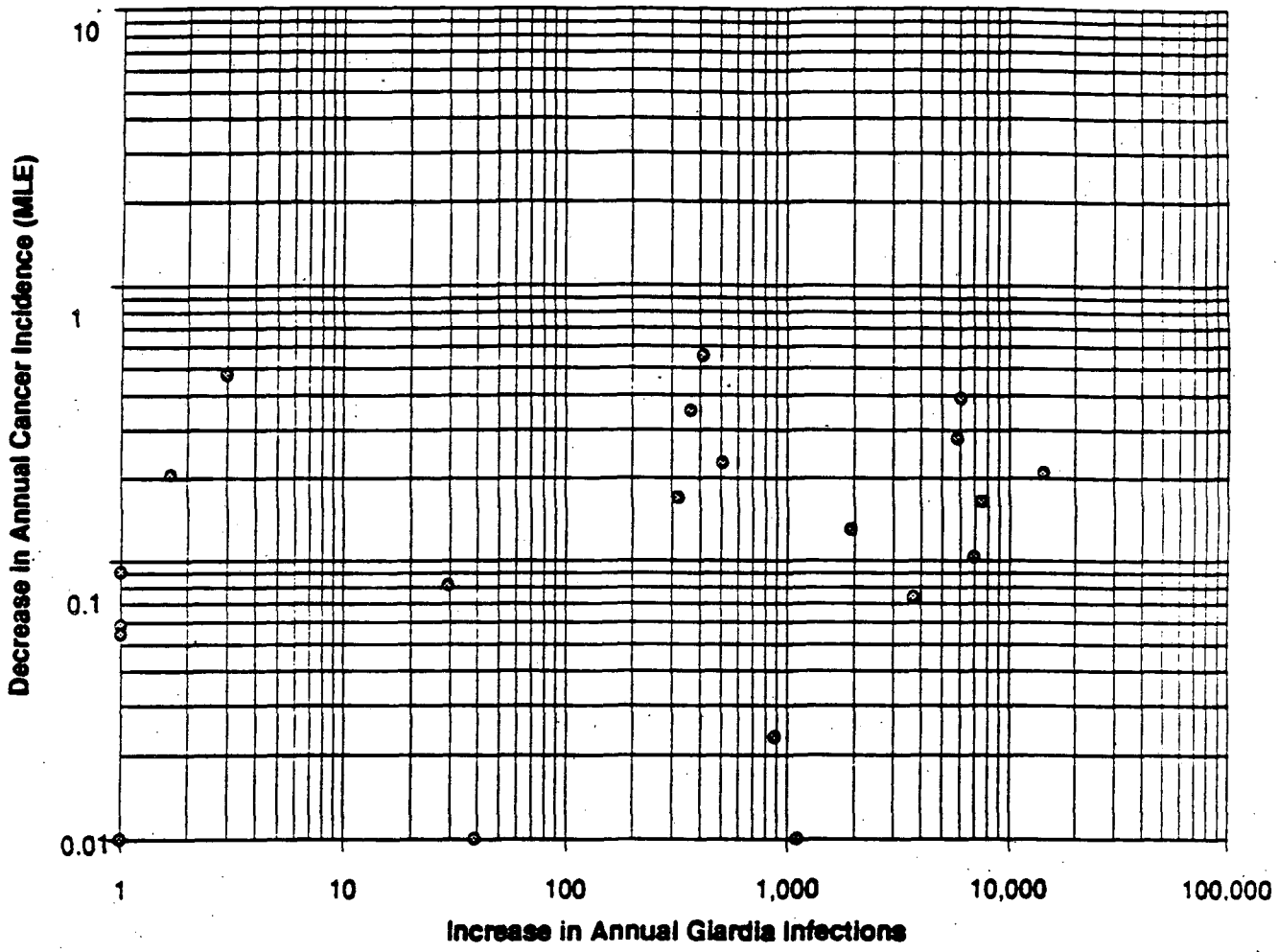
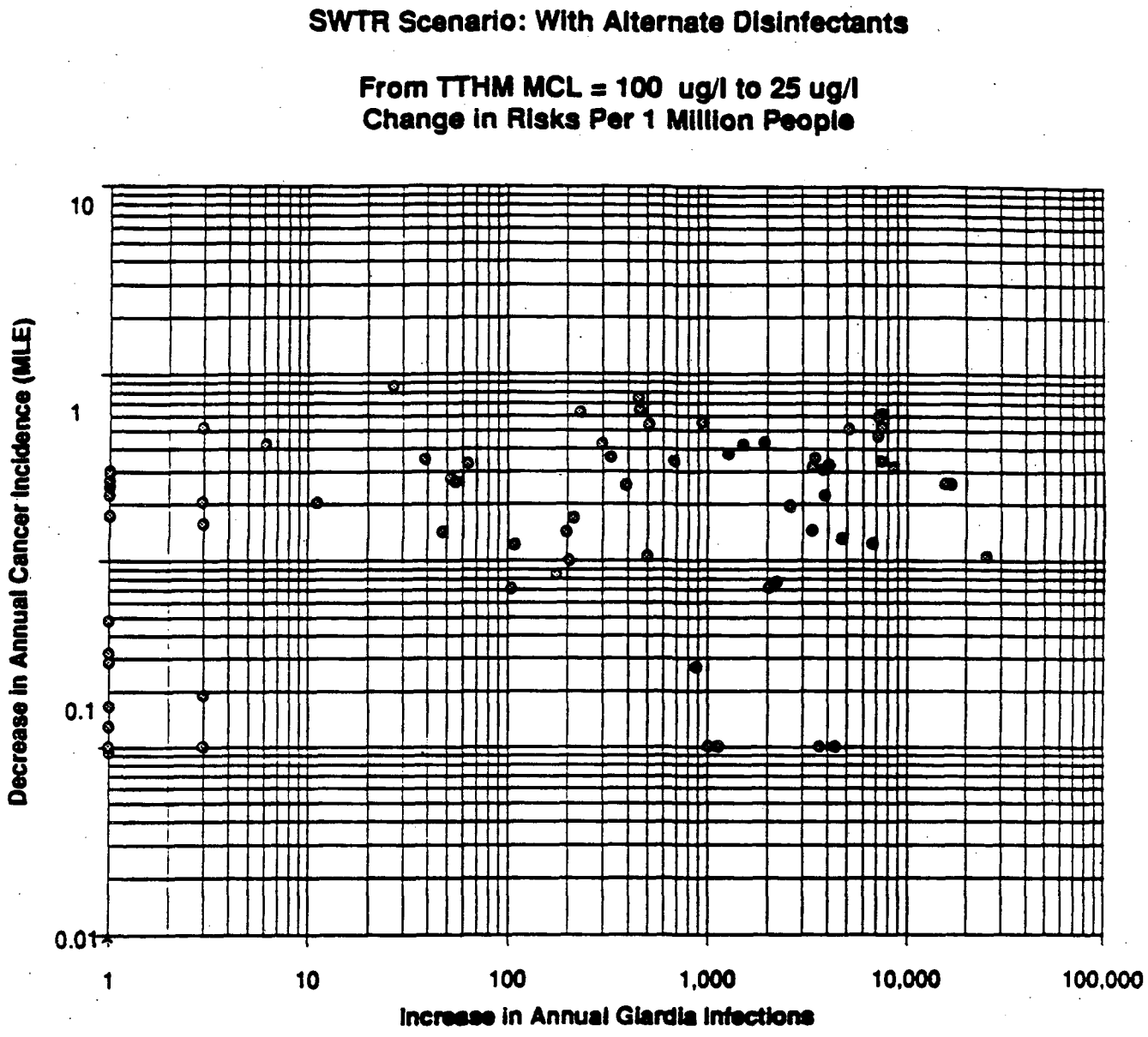


Figure 22


SWTR Scenario: With Alternate Disinfectants
From TTHM MCL = 100 ug/l to 25 ug/l
Change in Risks Per 1 Million People
Decrease in Annual Cancer Incidence (MLE)
10
1
0.1
0.01
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections

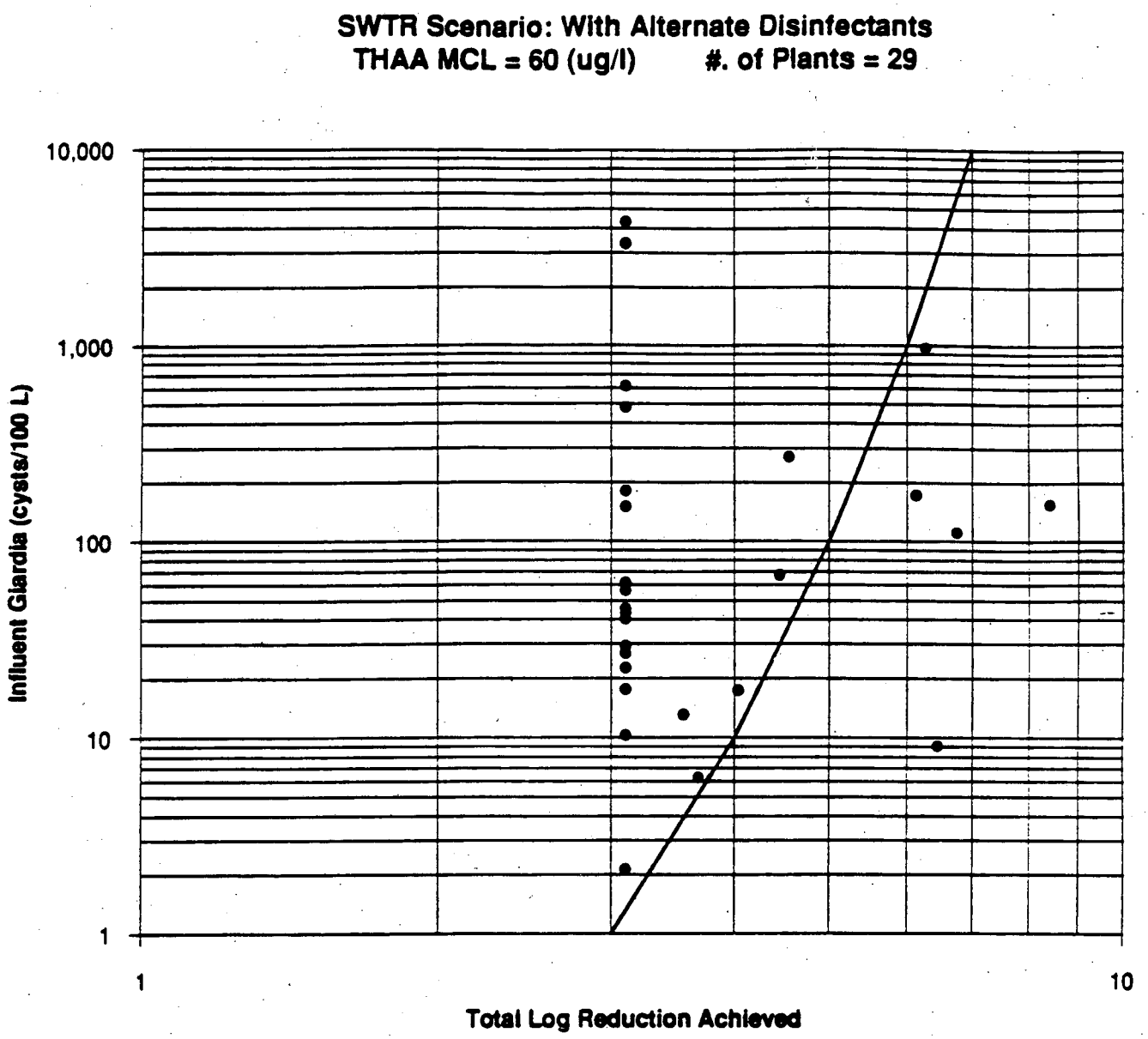
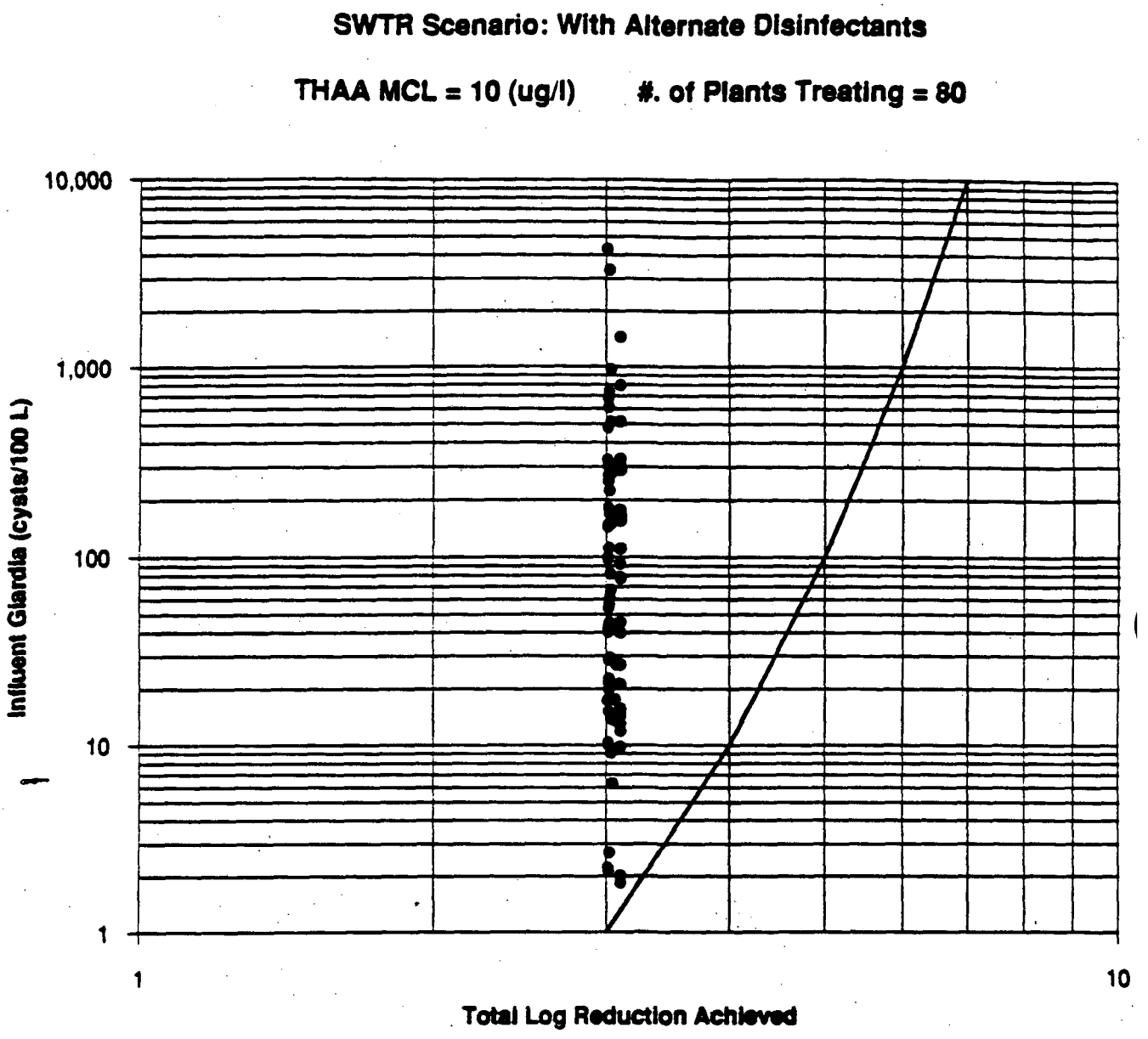

SWTR Scenario: With Alternate Disinfectants
THAA MCL = 60 (ug/l)
#. of Plants = 29
10,000
1,000
100
10
1
Influent Giardia (cysts/100 L)
1
10
Total Log Reduction Achieved

Figure 24


SWTR Scenario: With Alternate Disinfectants
THAA MCL = 10 (ug/l)
#. of Plants Treating = 80
10,000
1,000
100
10
1
Influent Giardia (cysts/100 L)
1
10
Total Log Reduction Achieved

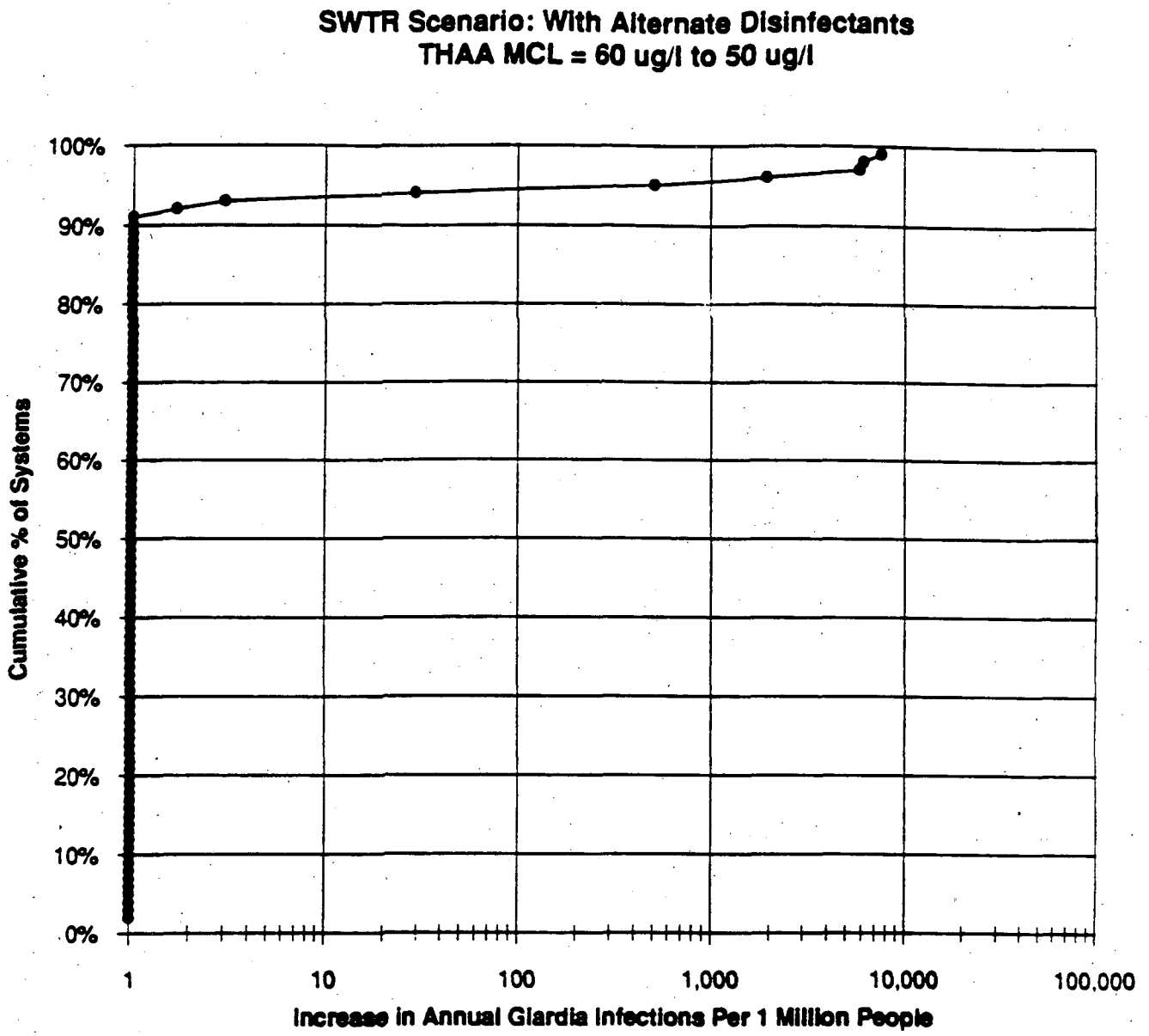
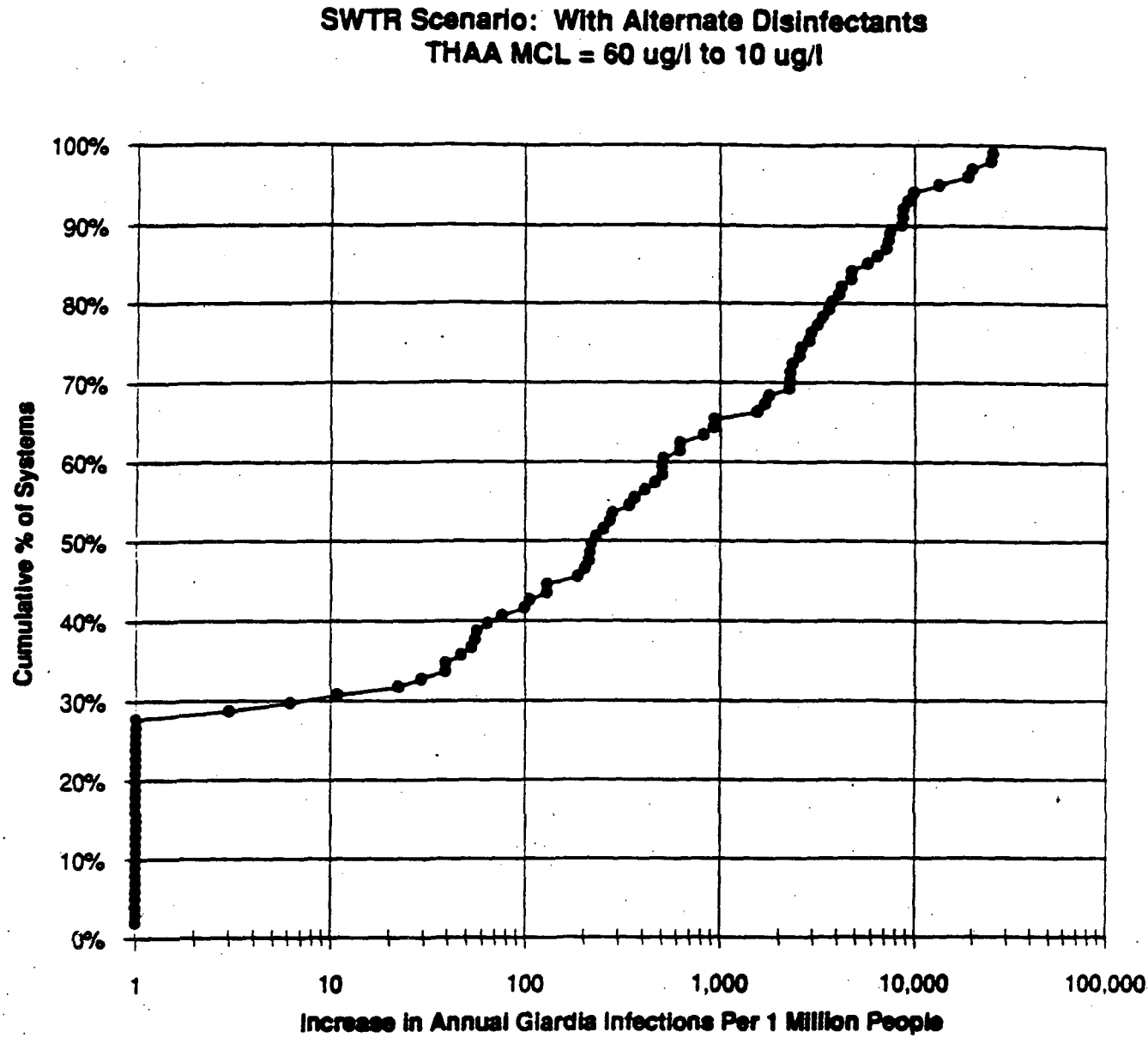

SWTR Scenario: With Alternate Disinfectants
THAA MCL = 60 ug/l to 50 ug/l
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Cumulative % of Systems
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections Per 1 Million People

Figure 26


SWTR Scenario: With Alternate Disinfectants
THAA MCL = 60 ug/l to 10 ug/l
Cumulative % of Systems
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections Per 1 Million People

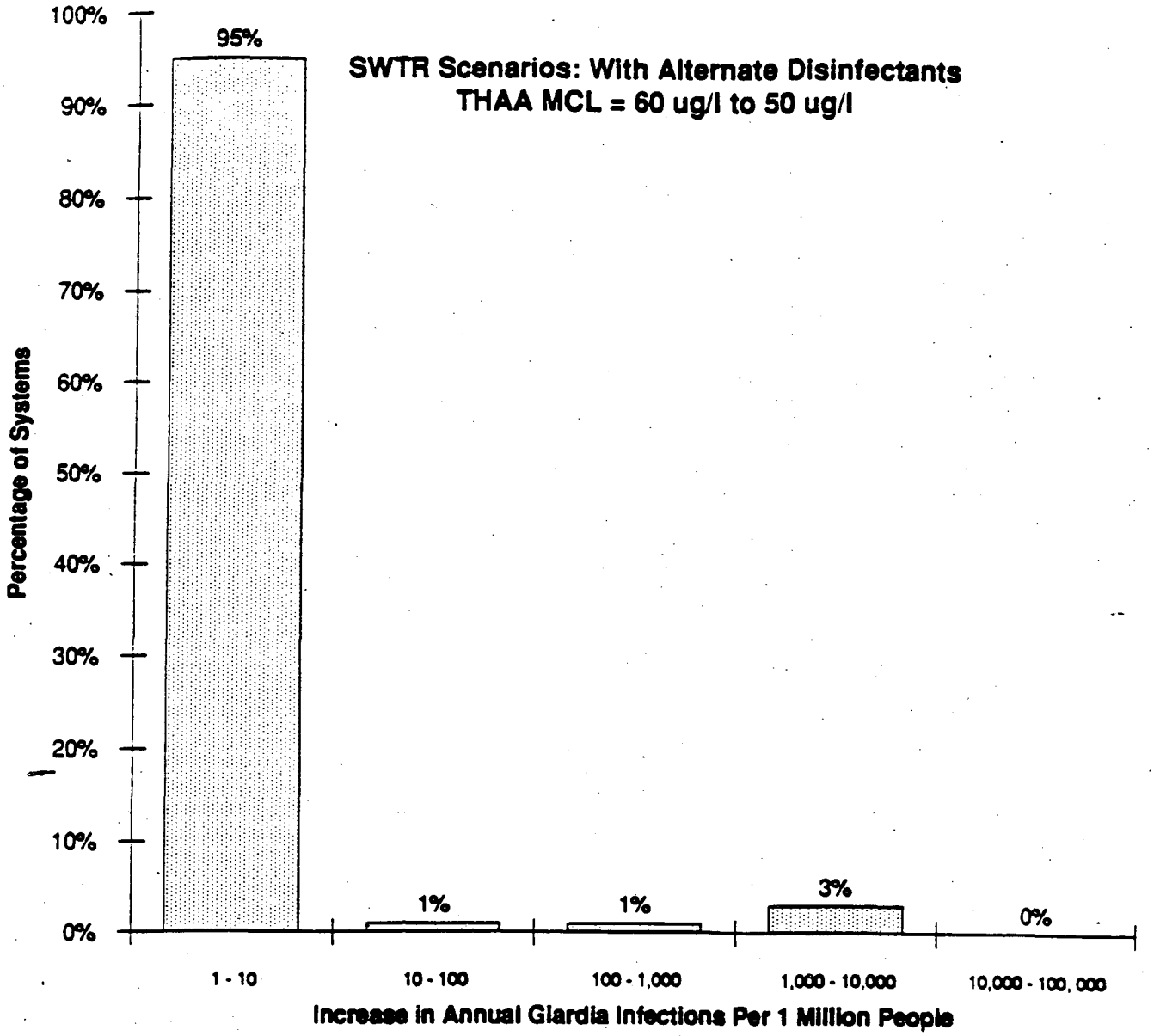
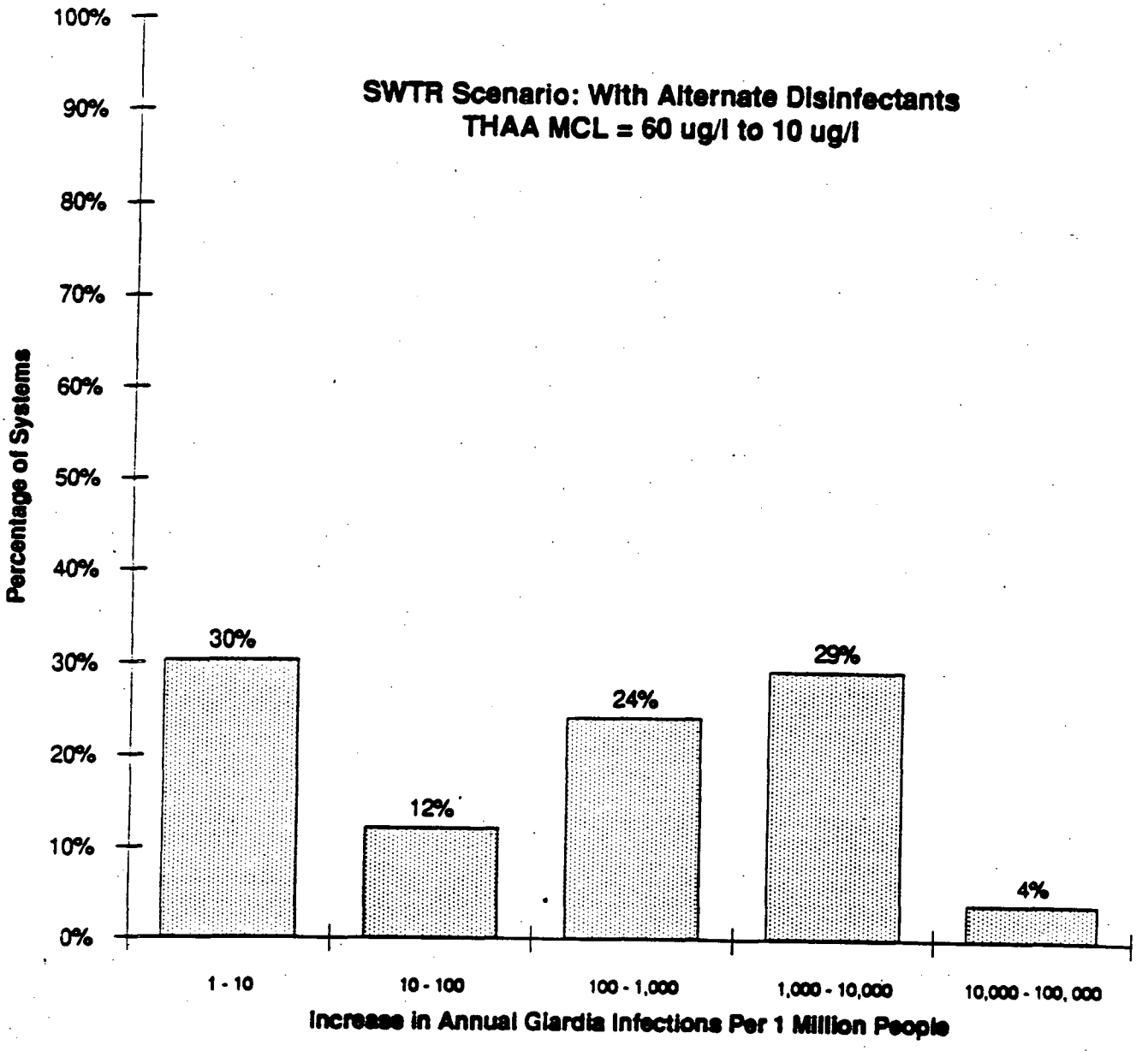

SWTR Scenarios: With Alternate Disinfectants
THAA MCL = 60 ug/l to 50 ug/l
Percentage of Systems
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
95%
1%
1%
3%
0%
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
Increase in Annual Giardia Infections Per 1 Million People

Figure 28


SWTR Scenario: With Alternate Disinfectants
THAA MCL = 60 ug/l to 10 ug/l
Percentage of Systems
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
30%
12%
24%
29%
4%
1 - 10
10 - 100
100 - 1,000
1,000 - 10,000
10,000 - 100,000
Increase in Annual Giardia Infections Per 1 Million People

SWTR Scenario: With Alternate Disinfectants

From THAA MCL = 60 ug/l to 50 ug/l
Change in Risks Per 1 Million People

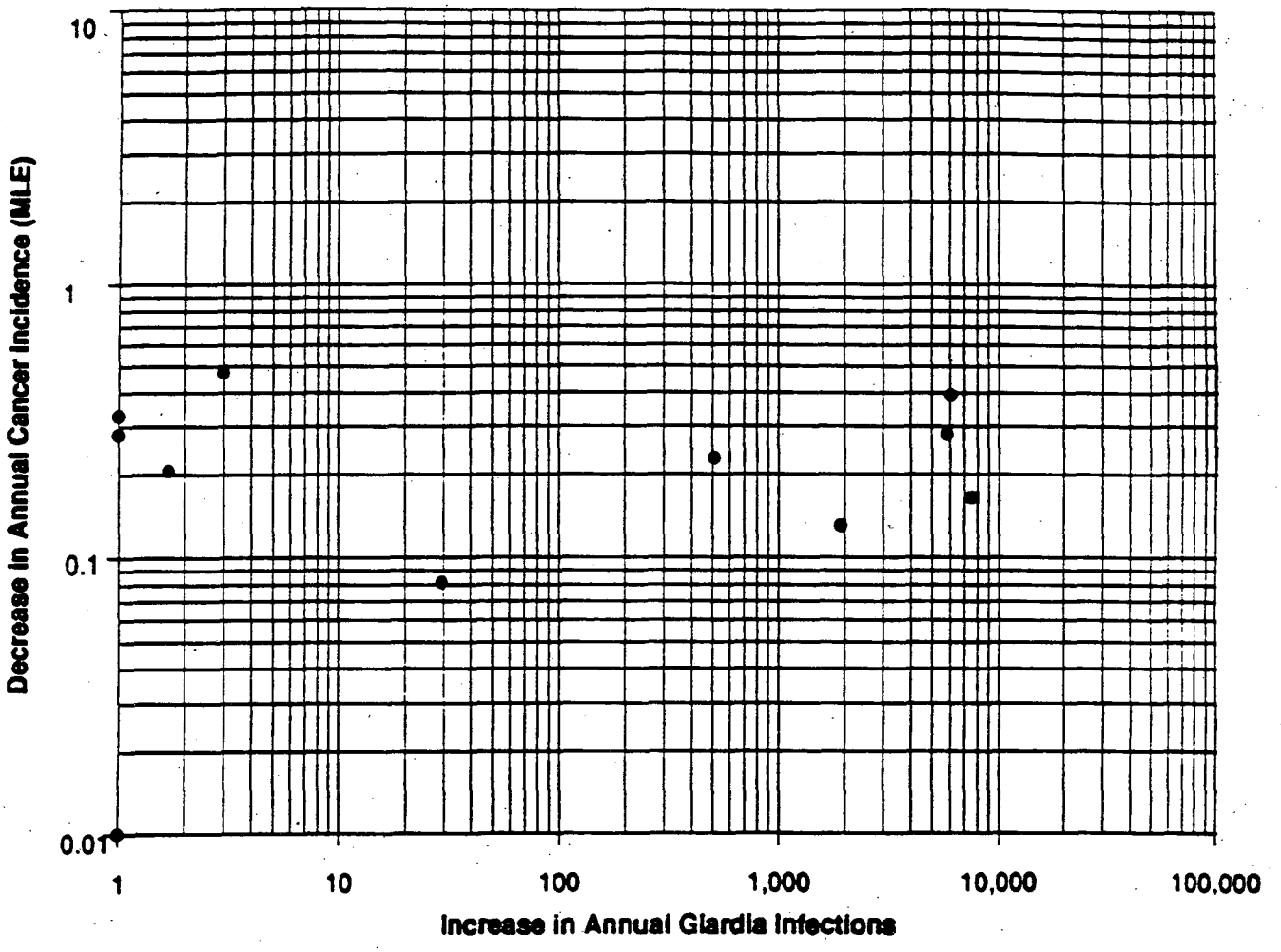
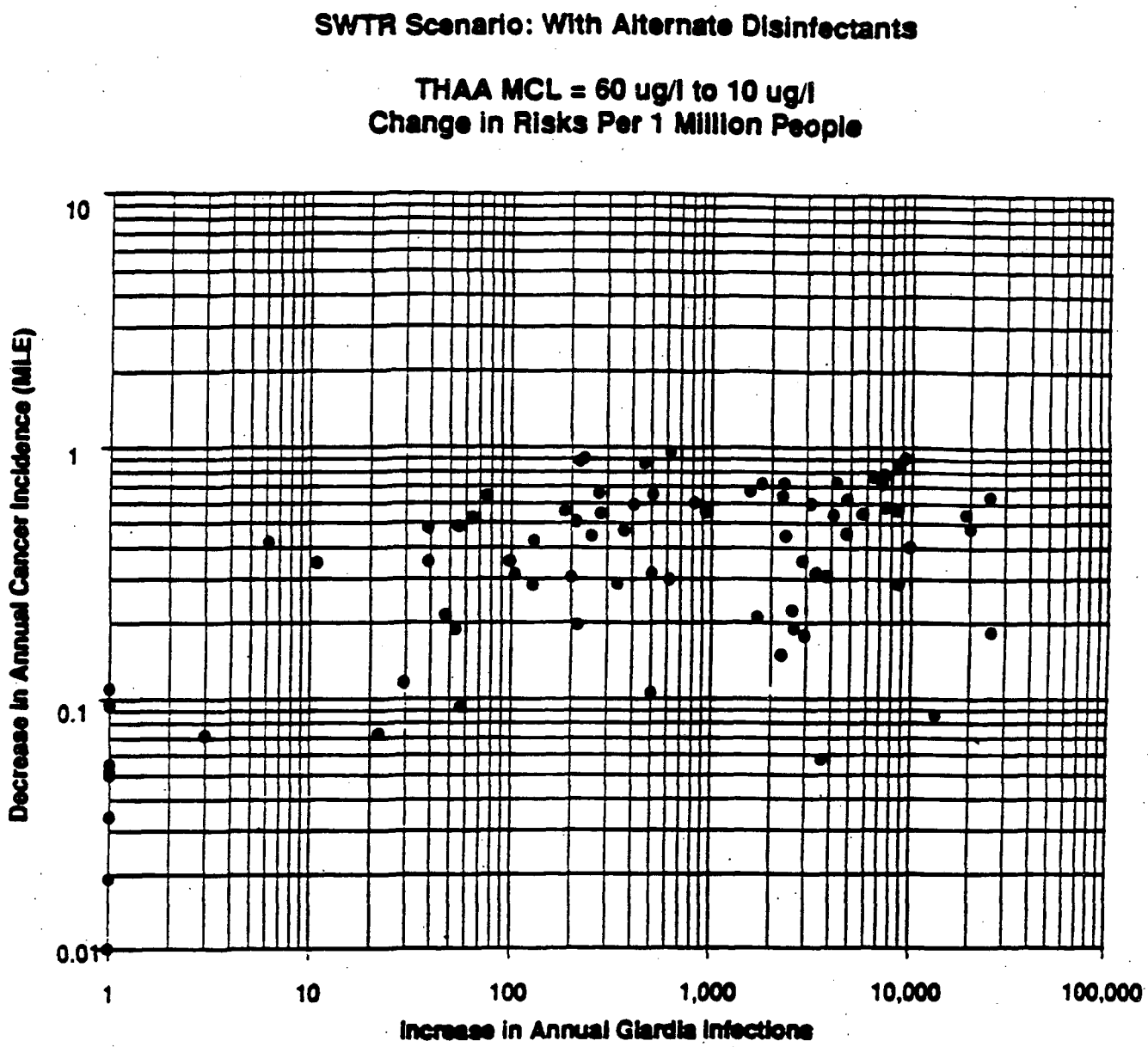


Figure 30


SWTR Scenario: With Alternate Disinfectants
THAA MCL = 60 ug/l to 10 ug/l
Change in Risks Per 1 Million People
Decrease in Annual Cancer Incidence (MILE)
10
1
0.1
0.01
1
10
100
1,000
10,000
100,000
Increase in Annual Giardia Infections

STATUS REPORT ON ANALYTICAL METHODS TO SUPPORT THE DISINFECTANT/DISINFECTION BY-PRODUCTS REGULATION

August 1992

Background

The United States Environmental Protection Agency (EPA) is developing national regulations to control disinfectants and disinfection by-products (D/DBPs) in public drinking water supplies. Twelve D/DBPs have been identified for possible regulation under this rule[1,2,3], based on available occurrence, exposure, and health effects data. EPA intends to set maximum contaminant levels (MCLs) for these D/DBPs, and analytical methods will be specified for use in demonstrating compliance with each MCL. This document provides a summary of the analytical methods that EPA intends to propose as compliance monitoring methods. A discussion of surrogate measurements that are being considered for inclusion in the regulation is also provided.

There are several technical issues that EPA is trying to resolve before the methods discussed in this document are proposed/promulgated. The public is encouraged to contact EPA, if they have information that will help EPA in this process. Information should be addressed to:

Patricia Snyder Fair, Chair
D/DBP Analytical Methods Task Force
U.S. Environmental Protection Agency
Office of Ground Water & Drinking Water
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Disinfectants:

Chlorine and Chloramines. The measurement of chlorine residuals will be required as part of the D/DBP Rule in order to demonstrate compliance with MCLs for chlorine and monochloramine. The utility will have the option of either measuring free or total chlorine residuals for the chlorine MCL. Compliance with the monochloramine MCL will be based on a total chlorine residual measurement, because monochloramine cannot be practically measured by itself.

There are many analytical methods available for measuring chlorine residuals, and each has certain limitations. All methods are subject to interferences, so the accuracy and

precision of the analysis will vary with matrix. Low level free chlorine measurements are subject to interference errors from chloramines and other oxidants.

Several methods for measuring chlorine residuals were promulgated with the Surface Water Treatment Rule (SWTR)[4]: 1) amperometric titration; 2) DPD ferrous titrimetric method; 3) DPD colorimetric method; and 4) the leuco crystal violet (LCV) method. These were referenced to the 16th Edition of *Standard Methods for the Examination of Water and Wastewater*[5]. EPA used these methods as the starting point for determining methods that are applicable to the D/DBP Rule. Methods listed in the 17th Edition of *Standard Methods*[6] were also considered. Table 1 summarizes the methods most likely to be proposed with the D/DBP Rule. The methods required to demonstrate compliance with the SWTR will also be updated to be consistent with the D/DBP Rule.

EPA intends to propose three of the four chlorine residual methods from the SWTR, when the D/DBP Rule is proposed. The LCV method will not be proposed. It was not included in the 17th Edition of *Standard Methods*, due to its relative difficulty and lack of comparative advantages. EPA thinks it is unlikely that this method is being used, so dropping it should have little effect on the regulated community.

EPA is considering approval of two additional methods for compliance monitoring: 1) the syringaldazine (FACTS) method for free chlorine and 2) the iodometric electrode method for total chlorine. Both methods are included in the 17th Edition of *Standard Methods*.

Method 4500-Cl E for measuring low levels of total chlorine residual is also available in the 17th Edition of *Standard Methods*. Although it is not useful for measuring total chlorine residuals at concentrations near the MCL, it is useful for determining compliance with the SWTR requirements for a detectable residual in the distribution system. Therefore, EPA is considering approval of this method when it updates methods for the SWTR. Data obtained using this method can also be used to demonstrate compliance with the total chlorine residual MCL in the D/DBP Rule.

The 18th Edition of *Standard Methods*[7] will be available for purchase in August, 1992, so the D/DBP Rule will cite it for descriptions of the chlorine residuals methods. The method numbers did not change from the 17th to the 18th edition, so the numbers given in Table 1 can be used with either edition. Since EPA is required to review its regulations every 3 years, EPA anticipates incorporating the latest versions of the methods into the D/DBP Rule each time it is reviewed.

Historically, EPA has required all analyses that are done to demonstrate compliance with an MCL, be performed by a certified laboratory. Because chlorine residuals are not stable, these samples must be analyzed immediately and cannot be transported to an off-site laboratory. Utility personnel have been performing chlorine residual analyses either in the field or in the treatment plant. EPA feels these measurements should continue to be made at the water system by any person acceptable to the State. It is not EPA's intent to require the certification of each water system for chlorine residual measurements.

EPA will continue to allow the use of DPD colorimetric test kits for field measurements of chlorine residuals, if they are approved by the State.

Chlorine Dioxide. The SWTR promulgated two methods for measuring chlorine dioxide residuals: 1) amperometric titration and 2) the DPD method. The 16th Edition of *Standard Methods* was cited as the reference. As discussed above for chlorine residual measurements, the latest versions of methods for measuring chlorine dioxide residuals (see Table 1) will be cited in the D/DBP Rule.

The 17th Edition of *Standard Methods* proposes a second amperometric titration method (4500-ClO_2 E) for measuring chlorine dioxide residuals. EPA is considering adding it as an acceptable compliance monitoring method.

The methods for chlorine dioxide residuals are indirect methods, because the concentrations are determined by difference. Amperometric titration methods are preferred over the DPD method, if they are used by highly trained personnel.

It is EPA's intent to continue to allow the measurement of chlorine dioxide residuals at the water system by any person acceptable to the State.

Due to the limitations of the current methodology, EPA is seeking information on new methodology that may be applicable for compliance monitoring. New methods must provide demonstrated advantages over the current methods and have the potential for being distributed in a standard format to interested public in the timeframe of the D/DBP regulation. New methods must be useable in the field or by utility personnel.

Disinfection By-Products:

Trihalomethanes. There are two methods currently approved for THM compliance monitoring: EPA Methods 501.1 and 501.2. These packed column, gas chromatography (GC) methods were

promulgated with the 1979 THM Rule[4]. EPA intends to propose two capillary column GC methods by the end of 1992: EPA Methods 502.2[7] and 524.2[10]. After a 45 day comment period, the methods will be promulgated, and they can be used for THM compliance monitoring effective 30 days after promulgation. EPA Methods 502.2 and 524.2 are in general use in many laboratories, because they are used to measure the concentrations of volatile organic compounds (VOCs) in drinking water.

EPA Methods 502.1 and 524.1[9] are not being proposed in 1992 and they are not being considered for the D/DBP Rule, because they use packed column chromatography. The GC technology has progressed to the point that packed columns are becoming obsolete. EPA is considering eliminating packed column GC methods (EPA Methods 501.1 and 501.2) from the list of approved THM compliance monitoring methods when the D/DBP Rule is proposed. This would not be implemented until the monitoring requirements of the D/DBP Rule become effective.

EPA Method 551[11] is the only new method that is likely to be added for THM compliance monitoring when the D/DBP Rule is promulgated. It involves adjusting the ionic strength of the sample, extracting the analytes into methyl-tertiary-butyl ether (MTBE), and analyzing the extract by capillary column GC with electron capture detection (ECD). This method can also be used to measure the concentrations of haloacetonitriles, chloropicrin, 1,1-dichloropropanone, 1,1,1-trichloropropanone, and chloral hydrate, if the appropriate dechlorinating agents are used.

Several laboratories around the country have modified EPA Method 551 by using pentane, instead of MTBE, as the extraction solvent. When this is done, chloral hydrate (CH) is not included in the analysis, because CH is too polar to be extracted by pentane. EPA Method 551 permits the analyst to modify GC columns, GC conditions, detectors, extraction techniques, concentration techniques, internal standard or surrogate compounds, as long as the analyst demonstrates the modified method still meets the performance criteria established in the method. Therefore, if Method 551 is approved for THM compliance monitoring, approval to use pentane will not be considered necessary as long as the method performance criteria are met. This will eliminate some of the need for approval of alternative test procedures (ATPs).

Many commercial sources of MTBE are contaminated with chloroform, necessitating cleanup prior to use in THM analyses. MTBE can be purified by distillation using appropriate safety precautions, but it should not be stored for long periods of time, in order to prevent the formation of peroxides. At least some lots of OmniSolv (EMScience) MTBE labeled "Suitable for Spectrophotometry, Liquid Chromatography, Gas Chromatography,

Residue Analysis, Assay by GC: 99.9% pure" have not contained measurable levels of chloroform or chlorinated solvents, indicating suitable purity MTBE can be produced commercially. This should encourage laboratories to make the need for high purity MTBE known to their local solvent suppliers. Manufacturers may be willing to prepare and market special lots, when they are aware of a market for their product.

The EPA methods that are likely to be approved for compliance monitoring of THMs are summarized in Table 2. All of these methods include the option to use ascorbic acid as a dechlorinating agent. This practice is under review, because ascorbic acid may cause the loss of brominated THMs under some conditions. If laboratories are aware of alternatives to the HCl and ascorbic acid required by EPA Method 524, they are encouraged to share that information with EPA. (Sodium thiosulfate and HCl were originally included in 524, but they cause interference problems with some of the early eluting analytes included in the method. Thiosulfate and HCl can still be used, if the sample does not have to be analyzed for the early eluting compounds.)

Chloral Hydrate. EPA Method 551[11] will be proposed as the compliance monitoring method for chloral hydrate (CH), but additional work must be done before the method is ready for general use. Chloral hydrate is subject to base-catalyzed hydrolysis, and the current version of the method does not provide a mechanism for preventing hydrolysis. This method will require the addition of a preservative, probably in the form of acidification. Work is underway to evaluate preservatives for CH. EPA solicits data demonstrating the stability of CH in drinking water samples. The data must indicate the dechlorinating agent used, preservation procedure, sample pH, storage conditions and holding time.

The regular dechlorinating agent (NH_4Cl) recommended in Method 551 cannot be used in some drinking water matrices, because it interferes with the CH analysis. Either ascorbic acid or sodium sulfite can be used under those circumstances. Since ascorbic acid causes problems with THM analyses in some matrices, EPA prefers the use of sodium sulfite. As part of the effort to evaluate preservation techniques for CH, EPA will look at how THMs are affected. It is anticipated that a technique can be developed in which THMs and CH could be measured in the same sample using EPA Method 551. If successful, this would reduce the monitoring costs associated with these analytes.

Some laboratories have expressed concern about the safety of using MTBE. EPA recommends that ether extracts should be stored in an explosion-proof refrigerator/freezer.

The availability of standards for CH has been a problem for laboratories. However, dilute solutions of CH in acetone are now available from NSI Environmental Solutions, Inc. (Research Triangle Park, NC) [Catalogue # 001179-01-01, $32.00] This is an EPA certified standard. A neat standard is available from Supelco (Bellefonte, PA) [Catalogue # 4-8048]. Other commercial sources may become available during the next year.

Very few laboratories are doing CH analyses. EPA is not aware of any commercial laboratories, but this should change over the next few years as utilities include it as a by-product of interest in their bench and pilot scale treatment studies.

Chloral hydrate will be included in the EPA Performance Evaluation (PE) Studies by the end of 1992. This will provide laboratories an opportunity to evaluate how well the method is performing for them. It will also provide EPA with an estimate of how many laboratories are doing CH analyses and how well they are doing.

Haloacetic Acids. The EPA method that will be proposed for haloacetic acid (HAA) compliance monitoring will give the analyst several options. The initial (standard) version of Method 552[11] specified the following steps in the procedure: 1) extraction with MTBE after sample pH adjustment to >11.5; 2) discard MTBE fraction and adjust pH of sample to <0.5; 3) extraction with MTBE; 4) concentration and drying of the extract; 5) conversion of the HAAs to their methyl esters using diazomethane; and 6) analysis by capillary column GC/ECD.

A microextraction option was later added to EPA Method 552[12]. This option eliminated the cleanup extraction, extract concentration, and extract drying steps. The 18th Edition of *Standard Methods* will include a microextraction method for measuring HAAs. EPA is considering it as a compliance monitoring method, because it is equivalent to the option described in Method 552.

EPA is also developing a liquid/solid extraction technique using ion exchange resins and an acidic methanol derivatization procedure[13]. A written procedure should be available for public distribution by the end of 1992, and it will be designated EPA Method 552.1[10].

All of the above procedures will be proposed as compliance monitoring techniques; all will be covered under EPA Method 552. Giving the analyst the flexibility to choose extraction technique and derivatization method should make it easier to begin this analysis in the laboratory. The acidic methanol derivatization procedure will also eliminate the concern expressed by some states and other entities over the use of diazomethane due to

safety issues.

The quantitation procedures specifed in the current version of EPA Method 552[11] must be clarified prior to proposal of the D/DBP Rule. The initial procedure (described above in the first paragraph under HAAs) does not require that standards be extracted, and no correction is made for analytes which are not fully extracted from the aqueous sample (e.g., dibromoacetic acid [DBAA]). The microextraction option recommends the preparation of aqueous standards that are carried through the same procedure as the samples. Using this option, the analytical results are automatically corrected for less than 100% extraction efficiencies. Either calibration method will be acceptable for compliance monitoring, if EPA only sets MCLs for dichloroacetic acid (DCAA) and trichloroacetic acid (TCAA), because both acids are extracted from water at > 90% efficiency. However, EPA is also considering a total HAA (THAA) MCL. Samples from utilities with high levels of bromide ion in their source water may contain high levels of the brominated and mixed bromochloro-acetic acids. Since these acids are not extracted from water as efficiently as the chlorinated acids, use of the initial HAA analytical procedure (described above in the first paragraph under HAAs) would give a lower THAA result than the microextraction procedure. For this reason, future versions of Method 552 will specify that aqueous standards be used for calibration purposes. Analyses performed to meet compliance monitoring requirements for a THAA MCL must use aqueous standards for calibration purposes.

Five of the HAAs (monochloroacetic acid [MCAA], DCAA, TCAA, monobromoacetic acid [MBAA], and DBAA) have been included in EPA PE studies, since study WS026 (spring, 1990). A calibration procedure for the HAAs was not specified with the PE studies, so laboratories reported data from both procedures. Since the two procedures are not equivalent for several of the HAAs, EPA will specify that HAA PE samples be analyzed using aqueous standards in future PE studies.

EPA Method 552 specifies the HAA standards be prepared in MTBE, but many laboratories are using methanol instead of MTBE. Recent work by Yuefeng Xie[14] at the University of Massachusetts, indicates that over time the acids will undergo conversion to their methyl ester analogs when stored in methanol. The conversion rate varies with analyte and storage conditions. Unless the analyst specifically checks for this conversion by analyzing a non-derivatized standard, it is unlikely the problem would be detected. The use of ester or mixed free acid and ester standards will provide inaccurate results, due to differences in extraction efficiencies between acids and esters. EPA has not studied this problem, but recommends that if laboratories must continue to use methanol, they monitor their methanol standards for this conversion, and prepare fresh standards when esters are

detected. As an alternative, laboratories should prepare HAA standards in MTBE.

There are 9 haloacetic acids (HAAs) that could potentially be included in a THAA MCL. However the EPA Method 552 only includes 6 of the HAAs (MCAA, DCAA, TCAA, MBAA, DBAA, and bromochloroacetic acid [BCAA]). Tribromoacetic acid (TBAA) is not included, because it is not reliably measured using the current techniques. The remaining 2 HAAs (bromodichloroacetic acid [BDCAA] and dibromochloroacetic acid [DBCAA]) have not been tested with Method 552, because standards are not commercially available. It is unlikely that TBAA, BDCAA, or DBCAA will be included in Method 552 in the timeframe of this regulation.

EPA is aware of three suppliers that are selling or plan to sell HAA standards:

1) Supelco, Inc. (Bellefonte, PA) is distributing a calibration standard that contains MCAA, DCAA, TCAA, MBAA, DBAA, and BCAA (catalogue # 4-8047). They will also market a BCAA standard in solution form as a custom chemical.
2) Absolute Standards, Inc. (New Haven, CT) is selling a HAA QC sample, containing MCAA, DCAA, TCAA, MBAA, DBAA, 2,4-dichlorophenol (24DCPh), and 2,4,6-trichlorophenol (246TCPh). A standard containing the methyl derivatives of the same compounds is also available, thus, providing laboratories a mechanism for checking the derivatization efficiency of their method. BCAA will soon be added to the free acid standard mixture, and should be available for release in August, 1992 (catalogue # 30054).
3) ULTRA Scientific (North Kingstown, RI) plans to release a standard containing MCAA, DCAA, TCAA, MBAA, DBAA, BCAA, 24DCPh, and 246TCPh (catalogue # PHM-552A). The standard is tentatively scheduled for release in early August, 1992, assuming successful results from a 60 day time storage study.

EPA believes there will be adequate laboratory capability available by the time compliance monitoring for HAAs is required. Sixteen laboratories participated in the WS029 PE study by analyzing the HAA sample. This number is expected to increase significantly over the next few years, as laboratories expand their analyses to address the new regulations.

Chlorite, (Chlorate) and Bromate. An ion chromatography method will be proposed as the compliance monitoring method for these anions. EPA does not intend to propose an MCL for the chlorate ion (ClO_3^-), but a description of the analytical method is presented here since it can be determined with the chlorite ion (ClO_2^-). The current version of EPA Method 300.0 Part B[15] can be used for measuring ClO_2^- and ClO_3^- in drinking waters. In some cases, a weaker carbonate eluent may be required[16], because ClO_3^-

elutes in the void volume in high ionic strength samples. A change in the eluent strength is permitted as part of Method 300.0 Part B, as long as the analyst demonstrates that the quality control requirements outlined in the method are met (see Sections 10.1.1 and 11.1 of the method).

Chlorite ion is unstable in many waters[1], so a preservation technique will be required if the samples cannot be analyzed within 15 minutes of collection. Recent studies[16,18] indicate ethylenediamine (EDA) is a suitable preservative for ClO_2^-, and it does not adversely affect analysis of the other anions at the concentrations typically found in drinking water. Therefore, EPA is considering requiring the addition of EDA to samples analyzed for ClO_2^- compliance monitoring.

Measurement of ClO_3^- in samples containing a free chlorine residual will also require the use of EDA. Free chlorine reacts with ClO_2^- to form ClO_3^- and chloride.

Samples containing a chlorine dioxide residual must be sparged with an inert gas (e.g., He or Ar) at the time of collection to eliminate the chlorine dioxide. Otherwise, ClO_2 will continue to form ClO_2^- and ClO_3^- in the samples. Prior to sparging, the samples must be protected from light to prevent photodecomposition of the chlorine dioxide to form ClO_2^- and ClO_3^- [19].

EPA is aware of other techniques (e.g., flow injection analysis [FIA]) that are being used to measure chlorite and chlorate. FIA and/or any other applicable procedure will be considered as a potential compliance monitoring method, if it is demonstrated to be as accurate and precise as ion chromatography. The technique would have to be available in a standard format for public distribution.

Analyses for bromate ion in drinking water samples will require a modification to the EPA ion chromatography method, due to the interference from chloride present in these matrices. One approach is to pretreat the sample with a silver media in order to remove the chloride[20]. When this technique is used, traces of silver are deposited on the IC analytical column, necessitating the removal of silver before using the column for bromide analyses. Another alternative is to change the eluent. Recent studies[16,18] demonstrate that substituting a borate eluent for the carbonate eluent specified in the method not only provides the resolution required to quantitate bromate ion in drinking water, but also gives a more stable baseline. All the DBP anions can be measured using the same chromatographic conditions with the borate eluent. Sections 10.1.1 and 11.1 of EPA Method 300.0 Part B permit the use of the borate eluent as long as the analyst demonstrates that the quality control requirements outlined in

the method are met.

EPA is concerned about the ability to reliably measure bromate at the levels necessary for this regulation. Studies are underway in several laboratories, including EPA, to examine ways to lower the detection limit for this anion. Concentration techniques are the most promising avenues of research. EPA requests information on any techniques that are demonstrated to be effective in drinking water matrices.

Chlorite, chlorate and bromate ions are now included in EPA PE studies. Thirteen laboratories participated in study WS029.

Surrogate Measurements:

Simulated Distribution System (SDS) Test. EPA may consider the use of a Simulated Distribution System (SDS) test as a surrogate measurement of DBP concentrations in the distribution system. EPA will recommend a modified version of the procedure described in Method 5710 E in the 17th edition of *Standard Methods* (reference will be updated to the 18th edition when proposed). The method is written for use in determining THM concentrations, but it can be extended to other DBPs as long as appropriate dechlorinating agents are used after the storage period. Results of the test are not valid, if there is no detectable chlorine residual at the end of the storage period. If the test is used to determine a "worst case" for consumer exposure, then the sample storage period should be representative of the maximum distribution system temperature, pH, chlorine concentration and the longest detention time in the distribution system. EPA will accept data comparing results from the SDS test to actual distribution system samples. The data must include a full description of the SDS test conditions, including dechlorination procedures and analytical methods used to quantitate the DBPs. Information concerning the data from distribution system samples should include temperature, chlorine residuals, pH, and approximate detention time of the water in the system.

Total Organic Carbon. There are 3 methods for measuring organic carbon listed in the 17th Edition (18th Edition) of *Standard Methods*, and 2 of them are applicable to requirements of the D/DBP rule. The persulfate-ultraviolet oxidation method (5310 C) and the wet-oxidation method (5310 D) provide the sensitivity necessary for low level organic carbon measurements, so they will be recommended if organic carbon is proposed in the D/DBP rule as a surrogate measurement for DBP precursors. Depending upon the sample pretreatment, several different organic carbon fractions are measured by these methods. If the sample is filtered through a 0.45μm pore size filter before analysis, Dissolved Organic Carbon (DOC) is measured. Purging the sample

prior to analysis results in the measurement of Nonpurgeable Organic Carbon (NPOC). Both of these parameters have been used as indicators of raw water quality. EPA will accept information concerning the use of DOC or NPOC as a surrogate for DBP precursors in source water.

Total Organic Halide. Method 5320 B in the 17th Edition (18th Edition) of *Standard Methods* will be recommended for determining Total Organic Halide (TOX). The sample must be dechlorinated and acidified at the time of collection. Sodium sulfite crystals or a FRESHLY prepared sulfite solution should be used for dechlorination. Following dechlorination, the sample is acidified to a pH < 2 using nitric acid in order to preserve the sample. If the bottles must be shipped to the sampling site with the reagents already present in the bottles, then sulfuric acid should be substituted for nitric acid. Department of Transportation (DOT) regulations must be followed when shipping bottles containing sulfite and sulfuric acid.

UV Absorbance. There is not a standardized method for this parameter. The technique originally used to establish a relationship between raw water UV absorbance and THM formation involved filtering the sample through a 0.45μm pore size filter and then measuring UV absorbance at 254 nm. The filter must be prewashed to remove water-soluble organics. EPA will accept information concerning the applicability of alternative procedures for defining this measurement.

EPA is evaluating its data to determine the relationship between TOC and UV absorbance. It may be necessary to measure both parameters in order to better characterize raw water quality.

EPA will accept data demonstrating interferences to the UV measurement at 254 nm that would prevent its use in specific raw waters.

General Comments:

EPA knows the laboratory capacity for doing DBP compliance monitoring samples is not yet in place. However, EPA believes the capacity can be developed by the time monitoring requirements take effect. PE samples will be available for all the DBPs during 1992, so laboratories can take advantage of those opportunities to demonstrate competency. Part of the laboratory certification process will involve successful performance in PE studies. Laboratories can request PE samples through their State Certification Officer and participation is free.

EPA does not have interlaboratory method performance data for the non-THM DBP methods. EPA anticipates that good

laboratories will be able to achieve quantitative results on analyses of PE samples that are within at least ± 40 % of the sample's true value for the non-THM DBPs. However, this has yet to be demonstrated. Some performance data will be generated using the results from PE studies. EPA will also examine alternatives ways to obtain the data, such as round robin studies among several laboratories currently analyzing drinking water samples for DBPs.

The most recent PE studies that included the THMs indicated that the majority of the laboratories participating in the studies were able to achieve results within ± 20 % of the THM sample's true value. Therefore, EPA will continue to require that level of performance for certification for THM analyses.

References:

1. USEPA. Status Report on Development of D/DBP Regulations. Office of Ground Water and Drinking Water. Washington, D.C. 1991.

2. USEPA. Occurrence Document in Support of the Development of the D/DBP Regulations. USEPA Publications. Washington, D.C. in press. 1992.

3. USEPA. Status Report on Development of MCLGs for Disinfectants and Disinfection By-products. Office of Science and Technology. Washington, D.C., 1992.

4. USEPA. Drinking Water; National Primary Drinking Water Regulations; Filtration, Disinfection; Turbidity, *Giardia lamblia*, Viruses, *Legionella*, and Heterotrophic Bacteria; Final Rule. Fed. Reg., 54:124:27486 (June 29, 1989).

5. *Standard Methods for the Examination of Water and Wastewater*, 16th Edition, American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1985.

6. *Standard Methods for the Examination of Water and Wastewater*, 17th Edition, American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1989.

7. *Standard Methods for the Examination of Water and Wastewater*, 18th Edition, American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 1992.

8. 40 CFR 141, Subpart C, Appendix C.

9. USEPA. *Methods for the Determination of Organic Compounds in Drinking Water*, EPA/600/4-88/039, PB91-231480, National Technical Information Service (NTIS), December 1988 (revised July 1991).

10. USEPA. *Methods for the Determination of Organic Compounds in Drinking Water - Supplement II*, Environmental Monitoring Systems Laboratory, Cincinnati, OH, August 1992.

11. USEPA. *Methods for the Determination of Organic Compounds in Drinking Water - Supplement I*, EPA/600/4-90-020, PB91-146027, NTIS, July 1990.

12. Barth, R.C. & Fair, P.S. "Disinfection By-Prodcuts: Analysis of Haloacetic Acids and Chlorophenols; Microextraction Procedure vs. USEPA Method 552." AWWA Water Quality Technology Conference (WQTC) Proceedings, November 1990.

13. Hodgeson, J.W., Collins, J., & Becker, D. "Advanced Techniques for the Measurement of Acidic Herbicides and Disinfection Byproducts in Aqueous Samples." Proceedings of the 14th Annual EPA Conference on Analysis of Pollutants in the Environment. May 1991.

14. Xie, Yuefeng, University of Massachusetts, Amherst, MA, personal communication, May, 1992.

15. USEPA. The Determination of Inorganic Anions in Water by Ion Chromatography Method 300.0. Environmental Monitoring Systems Laboratory, Cincinnati, OH, August 1991.

16. Hautman, D.P. & Bolyard, M. "Analysis of Oxyhalide Disinfection By-Products and Other Anions of Interest in Drinking Water by Ion Chromatography," International Ion Chromatography Symposium Proceedings. October 1991.

17. Pfaff, J.D. & Brockhoff, C.A. "Determination of Inorganic Disinfection By-Products by Ion Chromatography," *Jour. AWWA*, 82:4:195 (April 1990).

18. Hautman, D.P. & Bolyard, M. "Analysis of Inorganic Disinfection By-Products Using Ion Chromatography," AWWA WQTC Proceedings. November 1991.

19. Zika, R.G. ET AL. "Sunlight-Induced Photodecomposition of Chlorine Dioxide," *Water Chlorination Chemistry: Environmental Impact and Health Effects*. Vol. 5, Lewis Publ., Inc., Chelsea, Mich. (1985).

20. Kuo, C. and Weinberg, H.S. "Analysis of Inorganic Disinfection By-Products Using Ion Chromatography," AWWA WQTC Proceedings. November 1990.

Table 1. Methods Being Considered for Use in Compliance Monitoring of Disinfectant Residuals Under the D/DBP Rule

Residual	Methodology	Std Meth*	Working Range (mg/L)
Free Chlorine	Amperometric Titration	4500-Cl D	$\geq$ 0.1
	DPD Ferrous Titrimetric	4500-Cl F	$\geq$ 0.1
	DPD Colorimetric	4500-Cl G	$\geq$ 0.1
	Syringaldazine (FACTS)	4500-Cl H	$\geq$ 0.1
Total Chlorine	Amperometric Titration	4500-Cl D	$\geq$ 0.1
	Amperometric Titration	4500-Cl E	$\leq$ 0.2
	DPD Ferrous Titrimetric	4500-Cl F	$\geq$ 0.1
	DPD Colorimetric	4500-Cl G	$\geq$ 0.1
	Iodometric Electrode	4500-Cl I	$\geq$ 0.1
Chlorine Dioxide	Amperometric Titration	4500-ClO_2 C	$\geq$ 0.1
	DPD Method	4500-ClO_2 D	$\geq$ 0.1
	Amperometric Titration (proposed)	4500-ClO_2 E	$\geq$ 0.1

* Method Number Used in the 17th and 18th Editions of *Standard Methods*.

Table 2. Methods Being Considered for Use in Compliance Monitoring of Disinfection By-Products Under the DBP Rule

Residual	Methodology*	EPA Method (Ref)**	Working Range† (μg/L)
Trihalomethanes	P&T/GC/ElCD & PID	502.2 (9)	≥ 2.0
	P&T/GC/MS	524.2 (10)	≥ 0.5
	LLE/GC/ECD	551 (11)	≥ 0.5
Chloral Hydrate	LLE/GC/ECD	551 (11)	≥ 0.5
Haloacetic Acids	LLE or SPE /GC/ECD	552 (10&11)	≥ 5.0
Chlorite & Chlorate	IC	300.0 Part B (15)	≥10††
Bromate	IC	300.0 Part B (15)	≥10††

* P&T = purge and trap; GC = gas chromatography; ElCD = electrolytic conductivity detector; PID = photoionization detector; MS = mass spectrometer; LLE = liquid/liquid extraction; ECD = electron capture detector; SPE = solid phase extraction; IC = ion chromatography

** Reference for method is given in ().

† The concentrations listed in this table are estimates of the lowest levels laboratories can routinely measure with confidence. For methods involving multianalytes (e.g., THM methods), the range is given for the analyte with the highest detection/quantitation level.

†† Based on experience in EPA's laboratory using a borate eluent. These levels may be optimistic for many drinking water laboratories.