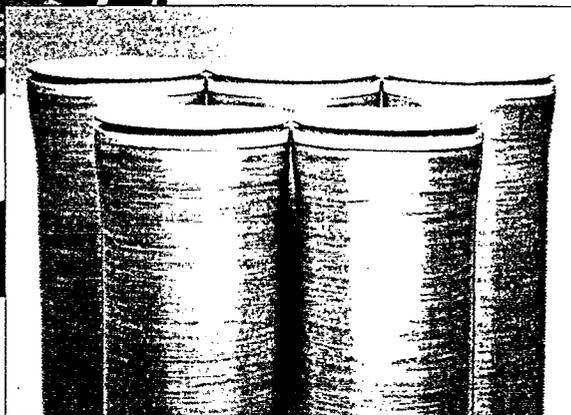


Enhanced coagulation (left) and membrane technologies (below) are two of the primary treatment processes considered for controlling organic carbon concentrations.



summary. Although the USEPA's regulatory impact analysis presents a comprehensive analysis of the costs of compliance, the estimation of benefits that would be gained by improving treatment is presented on a nationwide basis. In contrast, this article attempts to elucidate benefits with more detail on a case-specific basis, highlighting the influence of source water quality on risk reduction by organic carbon removal.

Background

Improving the removal of organic carbon prior to disinfection is one important strategy for reducing

DBP concentrations in water distribution systems. According to USEPA's regulatory impact analysis, more than 3,800 US surface water utilities (approximately 60 percent) would use this strategy to comply with the proposed Stage I regulations. The primary water treatment technologies considered for controlling organic carbon concentrations are enhanced coagulation,

granular activated carbon (GAC) adsorption, and membrane filtration. When chlorine is used as the disinfectant, these treatment technologies reduce the finished water concentrations of most DBPs by lowering the total organic carbon (TOC) concentration before the point of chlorination. Reducing the organic carbon concentration in water prior to the application of chlorine does not, however, guarantee risk reduction, particularly in waters containing bromide.

Halogenated by-products are formed during water disinfection by the reaction of aqueous chlorine and bromine with naturally occurring organic material in the source water. Bromine is produced by the oxidation of bromide ion by chlorine. Most drinking water sources contain low

FIGURE 1 Measured THM concentrations resulting from chlorination of synthesized waters containing 0.2 mg/L bromide

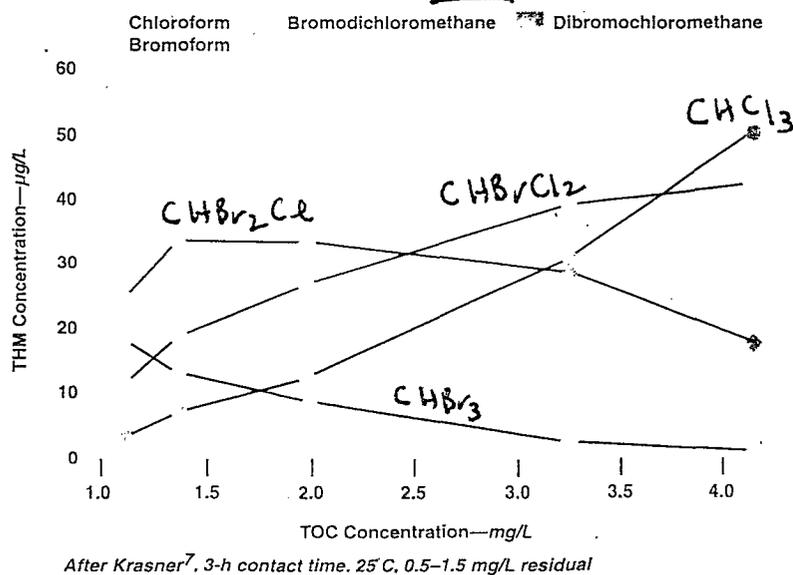
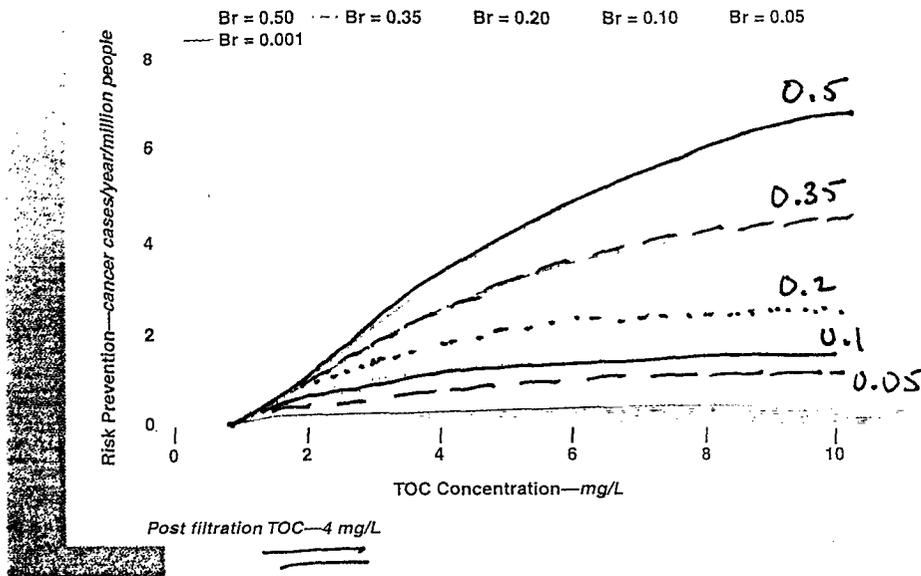


FIGURE 7 Theoretical cancer risks induced by THMs as a fraction of bromide concentration



the chlorination of waters with 0.05 mg/L bromide and baseline characteristics (Table 1). Figure 3 clearly shows that total THM concentration decreases as TOC concentration decreases. In this low-bromide water, chloroform dominates the species distribution at elevated TOC concentrations. The distribution of THMs shifts to more brominated forms as raw water TOC concentration decreases and the ratio of bromide to chlorine increases; (the chlorine dose tends to be proportional to the TOC concentration based on the chlorine demand model).

The theoretical risk induced by each THM species was calculated from its respective concentration by applying the cancer potency factors on page 44. The resulting risk profiles (Figure 4) are concentration profiles weighted by the relative risk of each species. Figure 4 indicates the relative contribution to total risk by each species and displays important trends not readily apparent from the concentration profiles.

As illustrated in Figure 4, model calculations indicate that bromodichloromethane is the largest contributor to the theoretical cancer risk for a chlorinated water with 0.05 mg/L bromide and baseline characteristics. This occurs despite the larger concentration of chloroform because the cancer potency factor for bromodichloromethane is one order of magnitude greater than that for chloroform. As TOC concen-

tration decreases and the corresponding bromide-to-chlorine ratio increases, the more-brominated species dominate the risk profile.

The risks attributable to each THM species exhibit peaking behavior in the sequence: TOC corresponding to peak chloroform risk > TOC corresponding to peak bromodichloromethane risk > TOC corresponding to peak dibromochloromethane risk > TOC corresponding to peak bromoform risk. Using Figure 4 as an example, the risk associated with dibromochloromethane peaks at a TOC concentration of about 2 mg/L. For TOC concentrations above 2 mg/L, the risk associated with dibromochloromethane increases as

raw water TOC concentration decreases. For TOC concentrations below 2 mg/L, the risk associated with dibromochloromethane decreases as TOC concentration decreases.

Above 6 mg/L TOC, increasing risks posed by bromodichloromethane and dibromochloromethane with decreasing TOC concentration offset the decreasing risk associated with chloroform. Below 2 mg/L TOC, the risks associated with bromodichloromethane and dibromochloromethane decrease with decreasing TOC concentration. Thus, in this low-bromide water, total risk appears to be more sensitive to organic carbon concentration at lower organic carbon concentrations.

As the bromide concentration is increased to 0.4 mg/L for water with identical baseline characteristics, the ratio of bromide to chlorine increases correspondingly. Figure 5 shows that the more-brominated species predominate in the concentration profile; espe-

Performance Simulation Models

Coagulation-filtration performance simulation models¹⁵

$$\ln(\text{TOC}_f) = -0.16 + 1.16 \times \ln(\text{TOC}_{\text{raw}}) - 0.45 \times \ln(\text{alum dose}) - 0.07 \times \ln(\text{TOC}_{\text{raw}}) \times \ln(\text{alum dose}) + 0.057 \times \text{pH}_c \times \ln(\text{alum dose})$$

$$\ln(\text{UV}_f) = -4.64 + 0.879 \times \ln(\text{UV}_{\text{raw}}) - 0.185 \times \ln(\text{alum dosage}) + 0.564 \times \text{pH}_c$$

in which TOC_{raw} —initial (raw water) TOC concentration (mg/L), TOC_f —final TOC concentration at the point of chlorine addition (after filtration), UV_{raw} —initial (raw water) UV absorbance (mg/L), UV_f —final UV absorbance at the point of chlorine addition (after filtration), pH_c —pH of coagulation (assumed—6.3 for this analysis), alum dose—mg/L as $\text{Al}_2(\text{SO}_4)_3 \times 14 \text{H}_2\text{O}$