Characterization and Determination of Halogenated Organic Compounds in River Water and Drinking Water

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Summary

Water samples collected from TE river and K drinking water supply system which takes water from the TE river were analyzed by means of GC/ECD, in order to characterize and determine halogenated organic compounds. Trihalomethanes, haloacetones, haloacetaldehydes, haloacetic acids, halopropionic acids were found to be present in both river and drinking water. Among these halogenated organics, the highest concentration was observed for haloacetic acids in the river water while haloacetic acids and trihalomethanes as disinfection by-products were detected at higher concentrations in the drinking water. Brominated compounds, such as bromodichloromethane and tribromoacetic acid, were also detected at high concentrations in the drinking water, although these compounds showed very low levels in the river water.

These results were also compared with those observed for TA river and S drinking water which takes water from the TA river.

Key words: halogenated disinfection by-product, river water, drinking water, organohalogens

INTRODUCTION

The occurrence of halogenated organic compounds in water systems has received much attention in recent years. While some of the halogenated compounds arise from contamination from industrial discharges, agricultural sources, and runoff in the water sources, the practice of chlorination in treatment of potable water, wastewater and cooling water has also been demonstrated to result in the formation of new organic compounds¹⁾. Of particular interest, because of their potential health significance, are the halogenated compounds in drinking water. Rook²⁾ and Beller et al³⁾ demonstrated that or-

ganic compounds in raw water are halogenated by reaction with chlorine, producing trihalomethanes in the finished water.

Chloroform, the most common trihalomethane, has been shown to be rapidly adsorbed on oral and intravenous administration and subsequently metabolized to carbon dioxide, chloride ion, phosgene and other unidentified metabolites⁴⁾. Mammalian responses to chloroform exposure include central nervous system depression, hepatotoxicity, nephrotoxicity, teratogenicity and carcinogenicity. These responses are described in mammals after oral and inhalation exposures to high levels of chloroform ranging from 30~350 mg/Kg, and the in-

tensity of response depends upon the dose. Although trihalomethanes are of concern because of their effects on health and significant levels in water supplies^{4,5)}, recent work⁶⁻⁹⁾ has shown that even higher levels of halogenated organic compounds, such as haloacetic acids, can be formed as the result of chlorination of natural water. It has also been shown that the mutagenic character of chlorinated drinking water is more closely associated with these halogenated organic compounds⁶⁾. In order to provide further insight into the possible role of organic compounds in the formation and elimination of halogen-incorporated compounds in water supply systems, we have continued the study of the aqueous chlorination chemistry and analytical chemistry of these compounds^{10,11)}. The purpose of this study is to characterize and quantify of trihalomethanes, haloacetones, haloacetaldehydes, haloacetic acids and other halogenated organics present in river waters as a source of potable water and drinking water. These findings provide background information that will be useful in assessing the health implications and trends of organic compound behavior in these rivers and drinking waters.

EXPERIMENTAL METHODS

Reagents

As previously reported¹⁰⁾, the following reagents were used as standards of halogenated compounds: haloacetonitriles, haloacetones, haloacetaldehydes, haloacetic acids and halopropionic acids (Hayashi Junyaku, Tokyo Kasei and Aldrich); trihalomethane standard solution and chloropicrin standard solution for water quality tests (Wako Pure Chemical Industries, Ltd.). The other reagents used were: hexane as extrac-

tion solvent for water quality test (Wako Pure Chemical Industries, Ltd.), *t*-butyl methyl ether for liquid chromatography (MTBE, Nacalai Tesque, Inc.), sodium sulfate anhydride as a dehydrator for residual agricultural chemical tests (Wako Pure Chemical Industries, Ltd.), ascorbic acid for elimination of residual chlorine, *N*-methyl-*N'*-nitro-*N*-nitrosoguanidine for preparation of diazomethane solution (Nacalai Tesque, Inc.), and sodium chloride as an analytical grade reagent (Wako Pure Chemical Industries, Ltd.). Sodium chloride was heated to about 450°C for about 6 hours before use.

Sample collection

Water samples were collected from the TE river at eight sampling stations and from the K drinking water supply system which takes water from this river in June and October 1995. Water samples were also collected from the TA river at six sampling sites and from the S drinking water supply system which takes water from this river in June and October 1996. S drinking water samples were also collected in June and October 1995. To avoid contamination, all utensils and containers were scrupulously cleaned and rinsed with deionized and distilled water before use. Each of these water samples was placed in an ice box and transported to the laboratory and then stored at 5°C for 1 day until subsequent organohalogen determination.

Organohalogen determination

As we previously reported¹⁰⁾, organic halogen compounds were determined using a GC/ECD (Hewlett Packard, 5890A) under the conditions shown in Table 1. The multi-component systematic analytical method for

Table 1 Apparatus and operational conditions of GC/ECD

Hexane fraction, MTBE fraction	
Gas chromatograph: HP5890 A (Hewlett Packard)	
Column: VOCOL™, 30m long × 0.25mm i.d., df=1.5μm	
Oven temperature: 45°C(5min)~5°C/min~180°C(6min)	
Carrier gas: He 14psi Total gas: He 57ml/min	
Make up gas: N ₂ 30ml/min	
Injection temperature: 200°C	
Injection system: Splitless 1μL, Purge-off time 0.5min	
Detector: ECD(⁶³ Ni), 270°C	
Methylated MTBE fraction	
Gas chromatograph: HP5890 A (Hewlett Packard)	
Column: SPB-20™, 30m long × 0.25mm i.d., df=0.25μm	
Oven temperature: 45°C(5min)~2°C/min~85°C(0min)~10°C/min~180°C(0min)~20°C/min~210°C(6min)	
Injection temperature: 225°C	
Carrier gas, Total gas, Make up gas, Injection system, Detector	
: the same as above	

organic halogens in drinking water established in our previous work¹⁰⁾ was also used in this study. Residual chlorine in drinking water (each 40 ml) was eliminated by addition of ascorbic acid. Before extraction with hexane (10 ml $\times$ 2 times), sodium chloride (15g) was added into the water sample. After dehydration, the combined extracts were infused into a capillary column GC/ECD for volatile organic halogen determinations.

The aqueous layer that extracted with hexane was mixed with sulfuric acid (1+1) to adjust the pH to 0.5 or less before extraction with an MTBE (2.5 ml $\times$ 2 times) for both volatile and non-volatile organic halogen analysis. Additional extraction with MTBE (10 ml) was also performed. The MTBE (2.5 ml $\times$ 2) fraction and

other MTBE (10 ml) fraction were dehydrated and infused into a capillary column GC/ECD for volatile organic halogen determinations. On the other hand, the dehydrated MTBE (2.5 ml $\times$ 2) fraction was methylated by diazomethane and infused into a capillary column GC/ECD for non-volatile organohalogen determinations.

RESULTS AND DISCUSSION

Halogenated organic compounds in TE river water and K drinking water

The minimum, maximum, and mean concentrations of each organohalogen and their detection frequencies in water samples collected from the TE river at eight sampling stations in June and October 1995 are sum-

Table 2 Minimum, maximum and mean concentrations of each organohalogen and their detection frequencies in water samples collected from the TE river at 8 sampling stations, and concentrations of each organohalogen in the K drinking water originating from the TE river (Unit: μ g/L)

TE River water and K drinking water	Jun.26 1995					Oct.19 1995				
	River water				Drinking water	River water				Drinking water
	Min.	Max.	Mean	Frequency		Min.	Max.	Mean	Frequency	
Total organic halogen	1.0	8.2	3.64	8/8	53.6	2.9	9.0	4.20	8/8	69.8
[Trihalomethanes]	nd	0.5	0.21	5/8	14.2	nd	1.4	0.24	5/8	20.8
Chloroform	nd	0.5	0.20	5/8	5.0	nd	1.2	0.20	4/8	4.7
Bromodichloromethane	nd	0.1	0.01	1/8	5.3	nd	0.1	0.01	1/8	7.7
Dibromochloromethane	nd	nd	nd	0/8	3.4	nd	0.1	0.03	2/8	7.0
Bromoform	nd	nd	nd	0/8	0.5	nd	nd	nd	0/8	1.4
[Haloacetonitriles]	nd	nd	nd	0/8	3.2	nd	nd	nd	0/8	5.2
Chloroacetonitrile	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
Dichloroacetonitrile	nd	nd	nd	0/8	2.0	nd	nd	nd	0/8	2.4
Bromochloroacetonitrile	nd	nd	nd	0/8	0.9	nd	nd	nd	0/8	1.7
Dibromoacetonitrile	nd	nd	nd	0/8	0.3	nd	nd	nd	0/8	1.1
Trichloroacetonitrile	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
[Haloacetones]	0.4	0.9	0.60	8/8	2.3	1.2	2.2	1.78	8/8	3.4
Chloroacetone	0.4	0.9	0.60	8/8	1.0	0.9	1.8	1.44	8/8	1.1
Bromoacetone	nd	nd	nd	0/8	0.3	nd	0.6	0.34	7/8	1.0
1,1-Dichloroacetone	nd	nd	nd	0/8	0.2	nd	nd	nd	0/8	0.4
1,3-Dichloroacetone	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
1,1,1-Trichloroacetone	nd	nd	nd	0/8	0.7	nd	nd	nd	0/8	0.9
1,1,3-Trichloroacetone	nd	nd	nd	0/8	0.1	nd	nd	nd	0/8	nd
[Halonitromethanes]	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
Chloropicrin	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
[Haloacetaldehydes]	nd	nd	nd	0/8	3.2	nd	0.2	0.06	3/8	6.1
Chloroacetaldehyde	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
Dichloroacetaldehyde	nd	nd	nd	0/8	0.5	nd	0.2	0.06	3/8	0.5
Trichloroacetaldehyde	nd	nd	nd	0/8	2.7	nd	nd	nd	0/8	5.3
Tribromoacetaldehyde	-	-	-	-	-	nd	nd	nd	-	0.3
[Haloacetic acids]	0.3	6.6	2.65	8/8	30.7	1	5.9	2.19	8/8	33.7
Chloroacetic acid	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
Bromoacetic acid	nd	nd	nd	0/8	0.2	nd	nd	nd	0/8	0.4
Dichloroacetic acid	0.3	1.9	0.90	8/8	9.1	0.2	1.2	0.50	8/8	8.1
Bromochloroacetic acid	nd	0.1	0.03	2/8	3.6	nd	0.1	0.01	1/8	4.2
Dibromoacetic acid	nd	nd	nd	0/8	2.3	nd	nd	nd	0/8	4.1
Trichloroacetic acid	nd	4.8	1.63	7/8	6.0	0.5	3.7	1.11	8/8	6.1
Dichlorobromoacetic acid	nd	0.4	0.10	3/8	1.3	nd	0.3	0.13	6/8	2.5
Dibromochloroacetic acid	nd	nd	nd	0/8	0.9	0.3	0.7	0.44	8/8	2.4
Tribromoacetic acid	nd	nd	nd	0/8	7.3	nd	nd	nd	0/8	5.9
[Halopropionic acids]	nd	0.7	0.18	3/8	0.5	nd	0.2	0.06	3/8	0.6
α -Chloropropionic acid	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
α -Bromopropionic acid	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	0.1
β -Bromopropionic acid	nd	nd	nd	0/8	nd	nd	nd	nd	0/8	nd
2,2-Dichloropropionic acid	nd	0.7	0.18	3/8	0.4	nd	0.2	0.03	1/8	0.4
2,3-Dichloropropionic acid	nd	nd	nd	0/8	0.1	nd	0.2	0.04	2/8	0.1

K drinking water is approximately half by half mixture of water from conventional water treatment plant, where water is treated with flocculation, sedimentation and sand filtration, and water from further advanced treatment plant, both waters are derived from the TE river.

marized in Table 2. The K drinking water is approximately half by half mixture of water from conventional water treatment plant, where water is treated with flocculation, sedimentation and sand filtration, and water from further advanced treatment plant. Both waters are derived from the TE river. The concentrations of organohalogens in the K drinking water are summarized in Table 2. In addition, the compositions of organohalogens quantified in the river and drinking waters are presented graphically in Fig. 1 as a circular diagram for each component.

Trihalomethanes, haloacetones, haloacetaldehydes, haloacetic acids and halopropionic acids were detected in these water samples collected from the TE river, although no haloacetaldehydes were quantified in the June-river water. Also no haloacetonitriles and halonitromethanes were detected in the river water samples collected in June and October 1995. The total concentration of organohalogens in these river waters was approximately $4 \mu\text{g}/\ell$. Among these halogenated organics quantified, the highest concentration was found to be haloacetic acids in river waters as sampled in June and October 1995. About 89 and 94% of the total amount of organic halogens detected in the June-river and Oc-

tober-river waters can be accounted for by the presence of haloacetones and haloacetic acids, respectively (Fig. 1). In addition, the TE river water as sampled in October 1995 was characterized by a higher concentration of haloacetones, compared with those observed for other halogenated organics.

High concentrations of chlorinated organics such as chloroform, chloroacetone, dichloroacetaldehyde, trichloroacetic acid were generally observed in the river water, as compared with those detected for brominated compounds. Chloroacetone has been shown to be present at high concentrations in pool water¹²⁾ and drinking water derived from a certain source¹³⁾. In the present work, higher concentrations of trihalomethanes and haloacetic acids were also observed for the river water collected from a certain site, near wastewater discharge from densely populated areas. Therefore, some of these organohalogens detected in the TE river seem to arise from contamination from industrial discharge, agricultural sources, and domestic and medical wastewaters.

As expected from the previous works^{7,9)} and the literature⁸⁾, trihalomethanes, haloacetonitriles, haloacetones, haloacetaldehydes, haloacetic acids and halopropionic acids were detected at comparatively high concentra-

Fig. 1 Circular diagrams for concentration(%) of each organohalogen group in the TE river water and the K drinking water originating from the TE river

tions in the K drinking water as sampled in June and October 1995. No chloropicrin as the halonitromethane was quantified in these K drinking waters. Brominated compounds, such as bromodichloromethane and tribromoacetic acid, were also detected at high concentration in the K drinking water, although these compounds were very low in the TE river waters. The total concentrations of halogenated organics in the K drinking water samples were found to be approximately 15-times higher than those detected in the TE river waters. Among these compounds detected, trihalomethanes and haloacetic acids were found to be main disinfection by-products, while other halogenated organics were minor ones (Table 2 and Fig. 1).

Halogenated organic compounds in TA river water and S drinking water

Minimum, maximum, and mean concentration of each halogenated organic compound and their detection frequencies in water samples collected from TE river at six sampling sites in June and October 1996 are summarized in Table 3. The concentrations of each halogenated organic compound in S drinking water which originated from the TA river are also summarized in Table 3. In addition, the compositions of organohalogens quantified in the river waters and drinking waters are presented graphically in Fig. 2 as a circular diagram for each group together with those observed in the TA river water samples.

As Table 3 shows, trihalomethanes, haloacetones,

Table 3 Minimum, maximum and mean concentrations of each halogenated organic compound and their detection frequencies in water samples collected from the TA river at 6 sampling stations, and concentrations of each halogenated organic compound in the S drinking water originating from the TA river

(Unit: $\mu\text{g/L}$)

TA River water and S drinking water	Jun.10 1996					Oct.25 1996				
	River water				Drinking water	River water				Drinking water
	Min.	Max.	Mean	Frequency		Min.	Max.	Mean	Frequency	
Total organic halogen	2.2	13.2	4.83	6/6	126.8	2.9	4.2	3.45	6/6	95.8
[Trihalomethanes]	nd	0.1	0.02	1/6	25.8	nd	0.3	0.13	4/6	32.4
Chloroform	nd	0.1	0.02	1/6	15.0	nd	0.2	0.07	3/6	10.7
Bromodichloromethane	nd	nd	nd	0/6	8.0	nd	0.1	0.02	1/6	12.7
Dibromochloromethane	nd	nd	nd	0/6	2.6	nd	0.1	0.03	2/6	8.0
Bromoform	nd	nd	nd	0/6	0.2	nd	0.1	0.02	1/6	1.0
[Haloacetonitriles]	0.1	0.3	0.18	6/6	7.6	nd	0.7	0.30	5/6	8.2
Chloroacetonitrile	nd	nd	nd	0/6	0.1	nd	0.2	0.03	1/6	0.1
Dichloroacetonitrile	nd	nd	nd	0/6	5.4	nd	0.1	0.03	2/6	4.2
Bromochloroacetonitrile	nd	nd	nd	0/6	1.5	nd	0.1	0.02	1/6	2.6
Dibromoacetonitrile	0.1	0.3	0.18	6/6	0.6	nd	0.2	0.08	3/6	1.3
Trichloroacetonitrile	nd	nd	nd	0/6	nd	nd	0.6	0.10	1/6	nd
[Haloacetones]	0.5	1.5	0.72	6/6	3.8	0.6	1	0.88	6/6	2.4
Chloroacetone	0.4	0.7	0.53	6/6	0.5	0.4	0.8	0.68	6/6	0.5
Bromoacetone	nd	0.1	0.05	3/6	nd	0.1	0.1	0.10	6/6	nd
1,1-Dichloroacetone	nd	nd	nd	0/6	0.2	nd	nd	nd	0/6	0.1
1,3-Dichloroacetone	nd	0.2	0.03	1/6	nd	nd	nd	nd	0/6	nd
1,1,1-Trichloroacetone	nd	nd	nd	0/6	2.9	nd	nd	nd	0/6	1.7
1,1,3-Trichloroacetone	nd	0.5	0.10	2/6	0.2	0.1	0.1	0.10	6/6	0.1
[Halonitromethanes]	nd	nd	nd	0/6	0.3	nd	nd	nd	0/6	0.2
Chloropicrin	nd	nd	nd	0/6	0.3	nd	nd	nd	0/6	0.2
[Haloacetaldehydes]	0.4	4.6	1.31	6/6	16.9	0.8	1.5	1.22	6/6	12.3
Chloroacetaldehyde	nd	nd	nd	0/6	0.1	0.1	0.2	0.13	6/6	0.1
Dichloroacetaldehyde	0.3	4.5	1.28	6/6	2.2	0.6	1.0	0.75	6/6	1.5
Trichloroacetaldehyde	nd	0.1	0.03	2/6	14.6	nd	0.1	0.08	5/6	10.5
Tribromoacetaldehyde	-	-	-	-	-	nd	0.6	0.25	3/6	0.2
[Haloacetic acids]	0.6	7.2	2.22	6/6	66.9	0.7	1.4	0.92	6/6	39.5
Chloroacetic acid	nd	nd	nd	0/6	2.7	nd	nd	nd	0/6	0.6
Bromoacetic acid	nd	nd	nd	0/6	nd	nd	nd	nd	0/6	0.2
Dichloroacetic acid	nd	nd	nd	0/6	29.1	0.2	0.4	0.28	6/6	12.3
Bromochloroacetic acid	nd	nd	nd	0/6	6.5	nd	nd	nd	0/6	5.1
Dibromoacetic acid	nd	nd	nd	0/6	1.3	nd	nd	nd	0/6	3.9
Trichloroacetic acid	0.4	5.0	1.23	6/6	22.2	0.4	0.8	0.53	6/6	9.2
Dichlorobromoacetic acid	nd	1.6	0.57	3/6	4.8	nd	nd	nd	0/6	4.5
Dibromochloroacetic acid	nd	nd	nd	0/6	0.3	nd	nd	nd	0/6	2.7
Tribromoacetic acid	nd	nd	nd	0/6	nd	nd	0.6	0.10	1/6	1.0
[Halopropionic acids]	0.2	0.5	0.28	6/6	2.5	nd	nd	nd	0/6	0.8
α -Chloropropionic acid	nd	nd	nd	0/6	nd	nd	nd	nd	0/6	nd
α -Bromopropionic acid	nd	nd	nd	0/6	nd	nd	nd	nd	0/6	nd
β -Bromopropionic acid	nd	nd	nd	0/6	nd	nd	nd	nd	0/6	nd
2,2-Dichloropropionic acid	nd	nd	nd	0/6	1.1	nd	nd	nd	0/6	0.8
2,3-Dichloropropionic acid	0.2	0.5	0.28	6/6	1.4	nd	nd	nd	0/6	nd

haloacetaldehydes, haloacetic acids and halopropionic acids, which were detected in the TE river waters, were also quantified in these water samples collected from the TA river. No chloropicrin was detected in the TA river waters, as with the TE river samples. Haloacetonitriles, which were not detected in the river waters, were newly quantified in the TA river samples. However, their concentrations were very low, as were the trihalomethane levels. In addition, 2,3-dichloropropionic acid was detected in the TA river waters collected in June 1996, but no halopropionic acids were quantified in the October samples. Furthermore, a number of brominated organic compounds were detected in the TA river waters collected in October 1996, as compared with those quantified in the June-water samples.

The total concentration of halogenated organic compounds in the TA river waters was approximately $4 \mu\text{g}/\ell$. Among these halogenated organics, the highest concentration was observed for haloacetic acids in the June-river waters, and for haloacetaldehydes in the October-water samples (Table 3 and Fig. 2), respectively. About 88% of the total amount of organic halogens detected in the TA river water samples can be accounted for by the presence of haloacetones, haloacetal-

dehydes and haloacetic acids (Fig. 2). In addition, the TA river water as sampled in June 1996 was characterized by the higher concentrations of dichloroacetaldehyde and trichloroacetic acid, as compared with those observed for other halogenated organics in the TA river samples.

Trihalomethane, haloacetones, haloacetaldehydes and haloacetic acids were detected at higher concentrations in the S drinking waters as sampled in June and October 1996 (Table 3). The total concentration of organic halogen compounds was $127 \mu\text{g}/\ell$ in the June-water sample and $96 \mu\text{g}/\ell$ in the October-sample, respectively, and these levels were found to be over 26-times higher than those detected in the TA river waters. Marked increases in the concentrations of organic halogens were found for trihalomethanes, haloacetonitriles and haloacetic acids in the S drinking waters. Similar concentration levels and compositions of halogenated organics to the data presented in Table 3 and Fig. 2 were also observed in the S drinking water sampled in June and October 1995 (data not shown). Comparison of the total concentration of halogenated organic compounds between the K and S drinking waters indicates that advanced water treatment reduces the con-

Fig. 2 Circular diagrams for concentration(%) of each halogenated organic compound group in the TA river water and the S drinking water originating from the TA river

centrations of halogenated disinfection by-products, especially those in the groups of haloacetic acids and trihalomethanes.

Usually, chlorine-treated water contains a relatively high concentration of chlorinated organic compounds as compared with other halogenated organics¹⁴⁾. In the present work, considerably higher concentrations of brominated compounds were found in the K and S drinking waters, although these compounds were at low concentration in the TE and TA river water samples. Over 40% of total halogenated organics quantified were brominated compounds in these drinking water samples, except for the June-S drinking water. Even higher ratios of brominated organics to total halogenated compounds were found for trihalomethanes, haloacetonitriles and haloacetic acids in these drinking waters. Several workers have demonstrated that chlorination or ozonation of surface and ground water containing bromide ions produces high concentrations of brominated trihalomethanes¹⁵⁻¹⁷⁾. However, the origin of the bromide ions in the water samples could not be clarified because of the limited samples in this survey. It has been reported that brominated organics are more mutagenic than chlorinated compounds¹⁸⁾, so it is particularly significant that brominated organics were found during this study of chlorine-treated water.

CONCLUSIONS

Aqueous chlorine is used to disinfect raw water destined for human consumption. The concentrations and compositions of halogenated organic compounds in the TE and TA river water samples and in the K and S drinking waters which originated from each river were determined by means of GC/ECD and then characterized in the present work.

A number of halogenated organic compounds were detected in the river water and drinking water samples. The total concentrations of halogenated organics were ranged from 3.45 $\mu\text{g}/\ell$ to 4.83 $\mu\text{g}/\ell$ with a mean concentration value of 4 $\mu\text{g}/\ell$ in the TE and TA river waters. Among these compounds, the highest concentration was observed for haloacetic acids in both the TE and TA river water samples. The K drinking water showed a total concentration of organic halogens ranging from 54.1 $\mu\text{g}/\ell$ to 69.8 $\mu\text{g}/\ell$, while the range of these compounds levels in the S drinking waters was from 96 $\mu\text{g}/\ell$ to 127 $\mu\text{g}/\ell$. Comparison of the total concentrations of halogenated organics between the K and S drinking

waters indicated that advanced water treatment reduces the concentrations of halogenated disinfection by-products, especially those in the groups of trihalomethanes and haloacetic acids. Among these organohalogens, higher concentrations and higher ratios of brominated compounds to total organic halogens in both drinking waters were observed for trihalomethanes and haloacetic acids.

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