

The Handbook of Environmental Chemistry

Volume 5 Part A

Water Pollution

With contributions by

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With 25 Figures and 29 Tables



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Preface

Environmental Chemistry is a relatively young science. Interest in this subject, however, is growing very rapidly and, although no agreement has been reached as yet about the exact content and limits of this interdisciplinary subject, there appears to be increasing interest in seeing environmental topics which are based on chemistry embodied in this subject. One of the first objectives of Environmental Chemistry must be the study of the environment and of natural chemical processes which occur in the environment. A major purpose of this series on Environmental Chemistry, therefore, is to present a reasonably uniform view of various aspects of the chemistry of the environment and chemical reactions occurring in the environment.

The industrial activities of man have given a new dimension to Environmental Chemistry. We have now synthesized and described over five million chemical compounds and chemical industry produces about one hundred and fifty million tons of synthetic chemicals annually. We ship billions of tons of oil per year and through mining operations and other geophysical modifications, large quantities of inorganic and organic materials are released from their natural deposits. Cities and metropolitan areas of up to 15 million inhabitants produce large quantities of waste in relatively small and confined areas. Much of the chemical products and waste products of modern society are released into the environment either during production, storage, transport, use or ultimate disposal. These released materials participate in natural cycles and reactions and frequently lead to interference and disturbance of natural systems.

Environmental Chemistry is concerned with *reactions in the environment*. It is about distribution and equilibria between environmental compartments. It is about reactions, pathways, thermodynamics and kinetics. An important purpose of this Handbook is to aid understanding of the basic distribution and chemical reaction processes which occur in the environment.

Laws regulating toxic substances in various countries are designed to assess and control risk of chemicals to man and his environment. Science can contribute in two areas to this assessment: firstly in the area of toxicology and secondly in the area of chemical exposure. The available concentration ("environmental exposure concentration") depends on the fate of chemical compounds in the environment and thus their distribution and reaction behaviour in the environment. One very important contribution of Environmental Chemistry to the above mentioned toxic substances laws is to develop laboratory test methods, or mathematical

correlations and models that predict the environmental fate of new chemical compounds. The third purpose of this Handbook is to help in the basic understanding and development of such test methods and models.

The last explicit purpose of the handbook is to present, in a concise form, the most important properties relating to environmental chemistry and hazard assessment for the most important series of chemical compounds.

At the moment three volumes of the Handbook are planned. Volume 1 deals with the natural environment and the biogeochemical cycles therein, including some background information such as energetics and ecology. Volume 2 is concerned with reactions and processes in the environment and deals with physical factors such as transport and adsorption, and chemical, photochemical and biochemical reactions in the environment, as well as some aspects of pharmacokinetics and metabolism within organisms. Volume 3 deals with anthropogenic compounds, their chemical backgrounds, production methods and information about their use, their environmental behaviour, analytical methodology and some important aspects of their toxic effects. The material for volumes 1, 2, and 3 was more than could easily be fitted into a single volume, and for this reason, as well as for the purpose of rapid publication of available manuscripts, all three volumes are published as a volume series (e.g. Vol. 1; A, B, C). Publisher and editor hope to keep the material of the volumes 1 to 3 up to date and to extend coverage in the subject areas by publishing further parts in the future. Readers are encouraged to offer suggestions and advice as to future editions of "The Handbook of Experimental Chemistry".

Most chapters in the Handbook are written to a fairly advanced level and should be of interest to the graduate student and practising scientist. I also hope that the subject matter treated will be of interest to people outside chemistry and to scientists in industry as well as government and regulatory bodies. It would be very satisfying for me to see the books used as a basis for developing graduate courses on Environmental Chemistry.

Due to the breadth of the subject matter, it was not easy to edit this Handbook. Specialists had to be found in quite different areas of science who were willing to contribute a chapter within the prescribed schedule. It is with great satisfaction that I thank all authors for their understanding and for devoting their time to this effort. Special thanks are due to the Springer publishing house and finally I would like to thank my family, students and colleagues for being so patient with me during several critical phases of preparation for the Handbook, and also to some colleagues and the secretaries for their technical help.

I consider it a privilege to see my chosen subject grow. My interest in Environmental Chemistry dates back to my early college days in Vienna. I received significant impulses during my postdoctoral period at the University of California and my interest slowly developed during my time with the National Research Council of Canada, before I was able to devote my full time to Environmental Chemistry in Amsterdam. I hope this Handbook will help deepen the interest of other scientists in this subject.

Otto Hutzinger

This preface was written in 1980. Since then publisher and editor have agreed to expand the Handbook by two new open-ended volume series: Air Pollution and Water Pollution. These broad topics could not be fitted easily into the headings of the first three volumes.

All five volume series will be integrated through the choice of topics covered and by a system of cross referencing.

The outline of the Handbook is thus as follows:

1. The Natural Environment and the Biogeochemical Cycles
2. Reactions and Processes
3. Anthropogenic Compounds
4. Air Pollution
5. Water Pollution

Bayreuth, January 1991

Otto Hutzinger

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Epidemiologic Studies of Organic Micropollutants in Drinking Water

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Abstract

A large number of organic micropollutants have been identified in surface and groundwaters. These contaminants reach drinking water supplies from various sources, including municipal and industrial discharges and urban and rural runoff; however, the treatment of drinking water can contribute contaminants as well. Since its introduction in 1908, the chlorination of drinking water has been successful in preventing the transmission of infectious waterborne diseases, but the reaction of free chlorine with selected precursors in water has recently been found to produce organic micropollutants. These organic byproducts have likely been present in water supplies as long as chlorine has been used as a disinfectant because the important precursors are naturally occurring aquatic humic substances such as humic and fulvic acids. The widespread use of chlorine as a disinfectant and concerns about the public health problems of chlorine and its by-products have led to a number of epidemiologic studies in populations using chlorinated drinking water. Descriptive epidemiologic studies have consistently suggested increased risks of cancer of the bladder, stomach, large intestine, and rectum in areas where

This chapter was written by Gunther F. Craun in his private capacity. No official support or endorsement by the Environmental Protection Agency or any other agency of the Federal Government is intended or should be inferred.

chlorinated surface waters have been used. Analytical epidemiologic studies, which consider potential confounding and modifying factors, have shown a moderate increase in risk of bladder and colon cancer in populations with a long duration of exposure to chlorinated drinking water. Although much research has been conducted, it is not yet possible to determine whether there is a causal association between exposure to chlorinated drinking water and these cancers. This determination must await the results of several ongoing studies in this area. Results of an epidemiology study suggests an association between serum cholesterol and chlorinated drinking water, but this must be confirmed by additional research.

Occurrence of Organic Micropollutants in Drinking Water

The presence of trace concentrations of organic chemicals in drinking water and their potential adverse human health effects has been of concern for some time. Since the 1950s considerable knowledge has accumulated about organic chemicals and suspected carcinogens in river water and industrial wastes discharged to drinking water sources [1-9]. Chemical carcinogens have also been reported in treated municipal drinking waters [10-15]. In 1972 the U.S. Environmental Protection Agency (EPA) identified 46 potentially carcinogenic or toxic organic chemicals in the drinking water of three communities along the lower Mississippi River in Louisiana, and in 1974 EPA identified 66 organic chemicals in the New Orleans drinking water [16, 17]. Coleman et al. [18] found some 460 organic compounds in extracts of Cincinnati, Ohio, tap water sampled in 1974; these

Table 1. Occurrence of volatile organic contaminants in public surface water systems in the United States [20, 24]

| Contaminant | Occurrence Percent | Median Concentration* Range ($\mu\text{g/l}$) |
|---------------------------|-----------------------|--|
| Chloroform | 98.8 | 21.0 |
| Bromodichloromethane | 93.8 | 6.0 |
| Dibromochloromethane | 75.0 | 3.23 |
| Bromoform | 21.3 | 3.25 |
| <i>p</i> -Dichlorobenzene | 18.2 | 0.02-0.03 |
| Trichloroethylene | 13.6 | 0.2-0.3 |
| Carbon tetrachloride | 8.5 | 1.2-1.4 |
| Xylenes | 7.0 | 0.93 |
| Benzene | 4.8 | 0.1-1.0 |
| Toluene | 3.0 | 0.85 |
| Tetrachloroethylene | 2.5 | 0.50-0.92 |
| 1,1,1-Trichloroethane | 2.5 | 0.9-1.1 |
| 1,1-Dichloroethylene | 2.2 | 0.18 |
| <i>o</i> -Dichlorobenzene | 2.2 | 0.4 |
| <i>m</i> -Dichlorobenzene | 1.1 | 0.18 |
| Trichlorobenzene | 1.0 | 0.18 |
| 1,2-Dichloroethane | < 1.0 | 1.2-1.8 |

a Median is for detected values; if range is reported for median, contaminant was measured in more than one survey.

samples had been concentrated by the reverse osmosis process. The compounds which were identified included 41 polynuclear aromatics, 15 polychlorinated biphenyls, and a number of amines, amides, and other halogenated species. Currently more than 1100 organic compounds have been identified in drinking waters, most at or below the $\mu\text{g/l}$ level [19–21]. Many of these organic micropollutants are organic solvents and other synthetic organics that reach surface waters through industrial discharges, municipal sewerage effluents, improper storage and disposal of toxic wastes, spills and accidents, leaking storage facilities, and urban and agricultural runoff (Table 1). Groundwater supplies have also been found to be contaminated; volatile synthetic organics, such as tetrachloroethylene, trichloroethylene, and 1,1,1-trichloroethane, have been found in concentrations often higher than are found in the most contaminated surface waters [20, 21] (Table 2).

Chlorine, which has been widely used as a disinfectant to prevent the waterborne transmission of infectious disease, has also been implicated as contributing organic micropollutants to drinking water. In 1974, Rook [22] showed that the chlorination of water containing natural humic substances and inorganic bromide resulted in the formation of chloroform and other chloro-brominated methanes, and Bellar et al. [23] reported the formation of trihalogenated methanes following water chlorination. Additional studies [24, 25] have confirmed that the reaction of chlorine with humic substances in drinking water sources produces a group of

Table 2. Occurrence of volatile organic contaminants in public groundwater systems in the United States [20]

| Contaminant | Occurrence Percent | Median Concentration ^a Range ($\mu\text{g/l}$) |
|-----------------------|--------------------|---|
| Chloroform | 49.2 | 1.4–2.1 |
| Bromodichloromethane | 47.1 | 1.4–2.2 |
| Dibromochloromethane | 42.8 | 2.1–4.6 |
| Bromoform | 26.3 | 2.4–5.1 |
| Trichloroethylene | 9.6 | 0.88–1.20 |
| Tetrachloroethylene | 8.4 | 0.35–0.79 |
| 1,1,1-Trichloroethane | 8.3 | 0.32–1.20 |
| Dichloroethylenes | 5.7 | 0.23–2.70 |
| 1,1-Dichloroethane | 4.3 | 0.51–0.87 |
| Carbon tetrachloride | 3.2 | 0.32–1.20 |
| 1,1-Dichloroethylene | 2.5 | 0.28–1.20 |
| Dichloriodomethane | 1.9 | 1.2–2.8 |
| Xylenes | 1.9 | 0.32–0.59 |
| 1,2-Dichloropropane | 1.4 | 0.7–1.2 |
| Benzene | 1.2 | 0.6–9.0 |
| Toluene | 1.2 | 0.6–2.6 |
| p-Dichlorobenzene | 1.0 | 0.66–0.74 |
| 1,2-Dichloroethane | 1.0 | 0.57–2.90 |

^a Median is for detected values; contaminants were measured in more than one survey

halogen-substituted single carbon compounds referred to as trihalomethanes (THMs). Chlorination of drinking water is the largest source of THMs in tap water with the predominate THMs being chloroform and bromodichloromethane [26, 27].

The concentration of THMs is dependent on the presence and concentration of the precursors, chlorine species, dosage, and contact time, and the water pH and temperature [26]. In most instances, higher levels of THMs are found in water supplies using surface water, but groundwaters in some areas contain sufficient precursor material to result in high levels [26, 28]. Significant levels of THMs [29] are generally not found in waters which are chloraminated, but this depends upon the specific treatment process used (e.g. how chlorine and ammonia are reacted to produce chloramines for water disinfection).

Halogenated compounds in addition to THMs can also be formed when humic substances are chlorinated in the laboratory [24, 30–33] and during the chlorination of drinking waters [23, 24, 34, 35] (Table 3). Substantial evidence indicates that humic substances, which constitute about 30–50% of the dissolved organic carbon in water, are the principal precursors of THMs and other chlorinated organic species present in drinking water as the by-products of disinfection with chlorine [36]. Studies of chlorination of model compounds and isolated humic and fulvic acid precursors have improved the understanding of the reaction mechanisms and by-products formed. Specific by-products depend on the molecular

Table 3. Partial list of by-products of chlorination of drinking water

| | |
|--|------------------------------|
| Chlorinated hydroxyfuranones | Haloaldehydes |
| 3-chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone | Chloroacetaldehyde |
| E-2-chloro-3-(dichloromethyl)-4-oxobutenoic acid | Dichloroacetaldehyde |
| | Trichloroacetaldehyde |
| Chloropicrin | Haloketones |
| | 1,1,1-Trichloropropanone |
| Chlorophenols | 1,1,3,3-Tetrachloropropanone |
| 2,4-Dichlorophenol | Hexachloropropanone |
| 2,4,6-Trichlorophenol | 1,1-Dichloropropanone |
| 2-Hydroxychlorophenol | Trihalomethanes |
| Cyanogen chloride | Chloroform |
| | Bromoform |
| Haloacetonitriles | Dibromochloromethane |
| Dichloroacetonitrile | Bromodichloromethane |
| Dibromoacetonitrile | Chlorodibromomethane |
| Bromochloroacetonitrile | |
| Trichloroacetonitrile | |
| Haloacids | |
| Monochloroacetic acid | |
| Dichloroacetic acid | |
| Trichloroacetic acid | |
| Monobromoacetic acid | |
| Dibromoacetic acid | |

structures of the humic and fulvic acids undergoing chlorination, the chlorine-to-carbon ratio, water pH, time of reaction, and several other factors [37, 38]. The by-products fall into two general categories: volatile, hydrophobic and nonvolatile, hydrophilic compounds. The principal by-products, especially at high chlorine-to-carbon ratios are volatile, hydrophobic (primarily chloroform), but a large number of nonvolatile, hydrophilic products are also formed, including both chlorinated and unchlorinated aromatic and aliphatic compounds [37]. The production of hydrophilic compounds appears to increase at low chlorine-to-carbon ratios while higher ratios favor the formation of the volatile by-products [37]. The lower ratios more closely represent typical drinking water disinfection conditions, and at these ratios the humic acid precursors tend to support the formation of unchlorinated by-products to a greater extent than do the fulvic acid precursors [37]. Increasing the chlorine-to-carbon ratio favors the formation of chloroform and a larger fraction of identifiable products. However, the yield of identifiable by-products from the chlorination of humic and fulvic acids isolated from natural surface waters is but a small fraction of the starting organic material. For example, the 28% of the total organic halogen identified by Coleman et al. [34] in the Ohio River humic fraction represents less than 10% of the starting organic material and even less of the total organic carbon in the river water.

It has been difficult to identify many of the individual organic micropollutants in drinking waters. They are present as complex mixtures of very small concentrations of individual chemicals, and the bulk of this organic material is relatively non-volatile. These nonvolatile by-products of chlorination may be more important than previously believed, especially when water sources contain high levels of organic material. Improved methods are needed for characterizing the nonvolatile products, as simple, accurate analytical methods are not yet readily available for the identification and quantification of even the major individual compounds [37]. The principal analytical method has been solvent extraction, followed by derivation and gas chromatography/mass spectrometry (GC/MS) and isotope dilution, GC/MS, and GC microwave-plasma emission [37]. Chlorination also produces incompletely oxidized compounds of potential concern [37]. Research has focused on the halogenated organics partly because they are conveniently measured; the oxidized products are not so easily detected [37].

Limited information (Table 4) is now available on the occurrence of disinfection by-products other than the THMs from a 1988–89 survey of 35 water treatment facilities selected to provide a broad range of source water quality and treatment processes in the United States [39]. THMs were the largest class of by-product detected on a weight basis [39]; 39 $\mu\text{g/L}$ was the median value for total THMs (Table 5). The THMs distribution and overall median were similar to that found in an earlier survey of 727 water facilities in the United States [40]. The haloacetic acids were the next most significant by-product fraction with a median value of 19 $\mu\text{g/L}$. Cyanogen chloride was found to be preferentially produced in chloraminated water supplies. Formaldehyde and acetaldehyde, which have been identified as by-products of ozonation [39, 41], were also detected in chlorinated water supplies.

Pilot plants studies of various chlorinated by-products indicate that pH is the water quality parameter which has the most significant effect on the formation of

Table 4. Occurrence of disinfection by-products in 35 water facilities in the United States [39]

| Disinfection By-product | Median Concentration ^a Range ($\mu\text{g/l}$) |
|--------------------------|--|
| Chloroform | 9.6-15 |
| Bromodichloromethane | 4.1-10 |
| Dichloroacetic acid | 5.0-7.3 |
| Trichloroacetic acid | 4.0-6.0 |
| Dibromochloromethane | 2.6-4.5 |
| Formaldehyde | 2.0-5.1 |
| Acetaldehyde | 1.8-2.7 |
| Trichloroacetaldehyde | 1.7-3.0 |
| Dichloroacetonitrile | 1.1-1.2 |
| Dibromoacetic acid | 0.9-1.5 |
| Bromochloroacetonitrile | 0.50-0.70 |
| Dibromoacetonitrile | 0.46-0.54 |
| 1,1-Dichloropropanone | 0.47-0.55 |
| Cyanogen chloride | 0.45-0.80 |
| 1,1,1-Trichloropropanone | 0.35-0.80 |
| Bromoform | 0.33-0.88 |
| Chloropicrin | 0.10-0.16 |
| Monochloroacetic acid | < 1.0-1.2 |
| 2,4,6-Trichlorophenol | < 0.4 |
| Trichloroacetonitrile | < 0.29 |

a Quarterly median values spring 1988 to winter 1989

Table 5. Major classes of disinfection by-products [39]

| Disinfection By-product | Median Concentration ^a Range ($\mu\text{g/l}$) | Percent of Total Measured Halogenated By-products |
|---|--|--|
| Trihalomethanes | 40-34 | 37-58% |
| Haloacids | 13-21 | 22-36% |
| Aldehydes | 4-7 | 5-12% |
| Haloacetonitriles | 3-4 | 3-7% |
| Trichloroacetaldehyde | 2-3 | 2-4% |
| Haloketones | 1-2 | 1-3% |
| Total measured halogenated by-products | 58-82 | — |

a Quarterly medians of the sums of compounds in that class rounded to nearest $\mu\text{g/l}$

b Quarterly medians of the sum of the measured halogenated by-products for all 35 facilities; The quarterly medians for total organic halide was 150-180 $\mu\text{g/l}$

THMs, trichloroacetic acid, dichloroacetic acid, trichloroacetaldehyde, dichloroacetonitrile, and 1,1,1-trichloropropanone; trends were not discernible for monochloroacetic acid, dibromoacetic acid, chloropicrin, dibromoacetonitrile, trichloroacetonitrile, and bromochloroacetonitrile [42]. The maximum and minimum yields of nearly all the halogenated organics, with the possible exception of

dichloroacetic acid, could be controlled by changing the pH at which the various reactions occur. During water treatment at low water pH, the formation of THMs would be minimized, but the formation of most of the other by-products would be maximized. These studies also indicated that the precursors for all of the chlorination by-products could be controlled in a similar manner through physical removal mechanisms.

The chlorination of both humic and fulvic acids results in the formation of direct acting mutagenic chemicals in the *Salmonella*/microsome assay, and there is evidence to indicate that water chlorination is responsible for the majority of the mutagenic activity present [43]. Mutagenic compounds which have been identified in chlorinated drinking waters are similar to those identified when solutions of humic substances are chlorinated in the laboratory, suggesting that the reaction of chlorine with natural humic substances is the likely source of mutagen formation in drinking water [35]. Humic acid chlorination products were studied to identify the chemicals responsible for the mutagenicity formed during water chlorination. Nineteen chlorinated organic compounds were identified and quantified in ether extracts of chlorinated humic acid solutions; ten of these compounds, including a number of chlorinated propanones and chlorinated propenals, were found to be direct acting mutagens in the *Salmonella*/microsome mutagenicity assay [44]. Studies have also demonstrated the widespread occurrence of mutagenic activity in uncharacterized organic concentrates of treated drinking water; these concentrates consist primarily of the nonvolatile organics which are difficult to identify [45, 46].

Numerous studies have shown that increased levels of mutagenic activity are present in chlorinated drinking water compared with the corresponding untreated water [47]. Studies have also been conducted to assess the mutagenicity of several alternative disinfectants, and results have been fairly consistent for the comparison of chlorine, chloramine and chlorine dioxide. Chlorination was found to produce the largest amount of mutagenicity with chloramine and chlorine dioxide usually producing less [47]. Ozone treatment of water was found to both eliminate activity and raise activity to intermediate levels or levels as high as obtained with chlorination [47]. Results with ozone are less consistent, however, and may be complicated by some studies which have included the addition of chlorine to ozonated waters and others in which the untreated water was mutagenic. Once mutagenic compounds have been generated, they can be at least partly removed by coagulation-flocculation and filtration; granular activated carbon treatment is especially effective with the total removal of mutagenic activity reported for several months [47].

3-Chloro-4-(dichloromethyl)-5-hydroxy-2(5H)-furanone (MX) has been detected by GC/MS in drinking water samples from three chlorinated drinking water systems in the United States and in a chlorinated humic acid solution; MX appeared to account for a significant proportion of the mutagenicity of these samples [48]. MX and its geometric isomer *E*-2-chloro-3-(dichloromethyl)-4-oxobutenoic acid (*E*-MX) have also been detected in 23 chlorinated drinking waters in Finland and extracts of chlorine treated humic acid; preliminary reports indicate MX and *E*-MX have been detected in tap water samples from the United Kingdom too [49]. The concentration of MX found in chlorinated humic water solutions has ranged from 190 to 380 ng/l, and in chlorinated drinking water the

range was 5-67 ng/l [47]. *E-MX* was found in the range of 390 to 700 ng/l in chlorinated humic water solutions and 8 to 41 ng/l in chlorinated drinking water [47]. The compound *MX* is an extremely potent, acid fraction mutagen with levels of 2 ng/l able to produce a response in the *Salmonella*/microsome mutagenicity assay [47]. *E-MX* is approximately 10 times less mutagenic than *MX* but is, nevertheless, important because under certain conditions it can be converted back to *MX* [47]. With the exception of *MX* and *E-MX*, the total mutagenicity contributed by all identified mutagenic compounds in drinking water has been found to account for less than 10% of the total observed mutagenic activity [47]. As measured by strain TA100, *MX* may be responsible for 20% or more of the mutagenicity observed in chlorinated humic solutions and up to 57% of mutagenicity in chlorinated drinking water acid fraction concentrates; *E-MX* may be responsible for 6 to 12% of the mutagenicity in humic water solutions and 1 to 2% of observed mutagenicity in chlorinated drinking water [47].

Chloroform, the other THMs, and other chlorinated by-products have likely been present in drinking waters as long as chlorine has been used as a water disinfectant because the important precursors which react with chlorine to produce these by-products are naturally occurring aquatic substances. The first continuous application of chlorine for disinfection of a municipal water supply in the United States was in 1908 in New Jersey [50]. By 1940 some 31% of the community water systems provided disinfection and 67% of the U.S. population received disinfected or filtered water [38]. The use of chlorine as a water disinfectant is now widespread. In the United States chlorine is being used to disinfect about 95% of the drinking water [37], and over 170 million people regularly consume water which has been chlorinated [50]. Because of the identification of the various by-products associated with chlorination, water suppliers in the U.S. are considering use of other disinfectants, such as ozone, chlorine dioxide, chloramine, or a combination of disinfectants, such as ozone followed by chlorine or chloramine.

Drinking Water Regulations for Organic Micropollutants

The United States Congress enacted the Safe Drinking Water Act (SDWA), P.L. 93-523, in 1974. The SDWA established drinking water regulations for public water supplies to prevent adverse effects on human health. National Interim Primary Drinking Water Regulations [51] for bacteria, turbidity, 10 inorganic chemicals, 6 pesticides, and radionuclides became effective on June 24, 1977. Amendments [52, 53] to the SDWA in 1977 reflected growing concern over the issue of disinfection by-products, as additional regulations were included for a maximum contaminant level (MCL), monitoring, and reporting for THMs in community water systems of more than 10,000 people. The EPA was also required to study the reaction of chlorine with humic substances to better understand the contaminants that result from such reactions and their public health effects. The SDWA was again amended in 1986 to require the EPA to regulate 83 contaminants by June 1989, and EPA has undertaken a comprehensive reassessment of the interim

regulations and evaluation of additional contaminants which should be regulated in order to establish National Primary Drinking Water Regulations (NPDWR) [54, 55]. In promulgating the NPDWRs, maximum contaminant level goals (MCLG), which are nonenforceable health goals, are recommended in addition to the MCL which is the enforceable standard. MCLGs are based solely on health considerations and for human and suspected human carcinogens must be established at zero levels. MCLs are established on health and other considerations, such as economics, analytical detection levels, and feasibility of treatment for removal. A treatment technique rather than an MCL can be specified if it is not economically or technologically feasible to ascertain the level of a contaminant in drinking water. The NPDWRs are to be reviewed periodically and amended whenever changes in technology, treatment techniques, or other factors permit greater health protection. The EPA has published MCLGs and promulgated NPDWRs for 8 volatile organic chemicals [56] and fluoride [57] and has proposed MCLGs for a group of 43 inorganic chemicals, synthetic organic chemicals including pesticides and microbiological contaminants [58]; MCLGs, MCLs, and monitoring requirements for a number of additional contaminants are currently being considered (Tables 6-8).

The EPA has also prepared criteria for use by state regulatory agencies to determine when filtration will be required for public water systems using surface water sources and disinfection requirements for all public surface water systems [59]. The revised regulations for total coliform bacteria have recently been published, and requirements for the disinfection of groundwater are under consideration [60]. These regulations are to prevent the transmission of waterborne infectious diseases. The surface water treatment requirements [61] will regulate certain protozoa, viruses, and bacteria by prescribing treatment techniques; all surface water systems must achieve at least 99.9% removal/inactivation of *Giardia lamblia* cysts and 99.99% removal/inactivation of viruses. Chlorine has been a very effective water disinfectant, but the new disinfection requirements may necessitate the use of high concentrations of chlorine and/or longer contact times for certain water supplies to inactivate these waterborne pathogens. This could result in increased levels of THMs and other chlorinated by-products, and regulations for

Table 6. U.S. Environmental Protection Agency regulations for volatile organic chemicals in drinking water [56]

| Contaminant | MCLG mg/l | MCL mg/l |
|------------------------------|--------------|-------------|
| Vinyl chloride | zero | 0.002 |
| Trichloroethylene | zero | 0.005 |
| Carbon tetrachloride | zero | 0.005 |
| 1,2-Dichloroethane | zero | 0.005 |
| Benzene | zero | 0.005 |
| 1,1-Dichloroethylene | 0.007 | 0.007 |
| <i>para</i> -Dichlorobenzene | 0.075 | 0.075 |
| 1,1,1-Trichloroethane | 0.20 | 0.20 |