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Water Chlorination. Part 2. Searching for Solutions in Troubled Waters— A Worldwide Perspective

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Last week we reviewed the history and current use of chlorination in the treatment of drinking water. Our discussion highlighted a number of potential risks associated with chlorine and some of its reaction products.[1] But what are the alternative methods currently under study for disinfecting public water supplies? Which organizations in the US and abroad are concerned with chlorination and water treatment? In this concluding essay, let's assess the state of public wasupplies around the world and end by discussing what ISI®'s research fronts reveal about the scientific literature related to chlorination.

Alternatives to Chlorine

As I noted in Part 1, although chlorination of water has been of tremendous value in eliminating waterborne disease, it may, nonetheless, present an environmental health hazard.[1] Chlorine can exert a toxic effect by direct action on organisms or by the formation of by-products through reaction with organic molecules present in the water. What can be done to reduce or eliminate this possible risk in water supplies? Four approaches are possible. First, the amount of chlorine added to the water can be reduced, or chlorination can be replaced with other methods. Second, the chemicals that react with chlorine to produce hazardous substances can be removed from the water before the chlorination process. Third, the hazardous chlorinated compounds can be removed from the water before the water is used. Fourth, chemicals that preclude the formation of chlorinated hydrocarbons can be used in combination with chlorine. Whatever method is chosen, it must be practical and cost-effective for large-scale use by public waterworks.

Chlorination of water can be reduced or discontinued only if a suitable alternative can be found for disinfecting it. Researchers are currently studying a number of possible alternative disinfectants, including chloramines, chlorine dioxide, bromine, iodine, ozone, ultraviolet light (UV), irradiation, and adsorption with granulated activated carbon (GAC) used in combination with other methods.

W. Kühn and H. Sontheimer, Engler-Bunte Institute of Water Chemistry, University of Karlsruhe, Federal Republic of Germany, have reviewed the principal alternatives to chlorine. They note that all water-disinfection processes have advantages and disadvantages. The disadvantages may include the formation of potentially harmful compounds that were not present in the untreated water. Such compounds may be toxic or may degrade water quality by promoting the growth of bacteria or algae.[2]

Chlorine, as we discussed last week, can react with organic matter in water to produce trihalomethanes (THMs) and other chlorinated organic compounds that may be toxic. These compounds are referred to as the Total Organic Chlorine (TOCl) of the water. Many water analyses include a measurement of chloroform, the most significant THM. In a particular sample of water, however, the TOCl may be much greater than the amount of chloroform. Chlorine can also react with bromide to produce bromine, which in turn may produce brominated compounds, another type of potentially hazardous chemical.

Chloramines, which are sometimes added to water as a substitute for chlorine disinfectant, are formed by the reaction of chlorine with ammonia or organic amines. Chloramines, reacting with organic compounds in water, produce about 70 percent less TOCl than chlorine and thus present less of a hazard in this regard. Unfortunately, chloramines also have less disinfecting power than chlorine. On the other hand, they persist longer in the distribution system.

Chlorine dioxide, another alternative disinfecting compound, has the advantage of producing much lower levels of THMs and TOCl than chlorine, and it produces no brominated compounds. One drawback is that chlorine dioxide can produce high concentrations of chlorates and chlorites, chemicals that can be toxic.[2]

Ozone is a very powerful oxidizing agent and disinfectant that has been used to treat water supplies. As with chlorine, ozone reacts with a great many compounds, but it does not produce chlorinated by-products. Ozone also kills virtually all microorganisms that are found in water. One factor that limits its effectiveness as a disinfectant is that it dissipates from water rapidly, leaving little residual disinfectant activity. Although this rapid dissipation makes ozone unsuitable for use as a sole disinfecting agent, ozonation can be successfully combined with chlorination to exploit the strengths of both methods. Another disadvantage of ozonation, however, is that, by converting nonbiodegradable compounds into biodegradable ones, it can promote the growth of bacteria and other microorganisms in water-distribution systems. The growth of certain species of microorganisms, in turn, can promote corrosion of pipes and other equipment.[2]

Bromine and iodine, both chemically related to chlorine, are strong oxidizing agents and disinfectants. However, they are more expensive than chlorine and have toxic properties that make them unsuitable for many water-treatment applications. S.A. Abbasi, Water Quality & Environment Division, Centre for Water Resources Development & Management, Kunnamangalam, India, notes that bromination is a practical alternative to chlorination in the treatment of swimming pools. This is in part because bromine loses less of its disinfecting power by reacting with ammonia than chlorine does.[3]

Of the other alternatives mentioned earlier, UV light and irradiation are impractical for treating large volumes of water. Adsorption of impurities with granulated activated carbon (GAC) has so far not been very effective in removing low-molecular-weight polar organics such as THMs from water, but it is effective in removing THM precursors, such as humic substances (material formed by the partial decomposition of organic matter).[2] A 1983 article by Sergio J. DeLuca, Water Research Department, Federal University of Rio Grande Do Sul, Porto Alegre, Brazil, and colleagues reviews the use of potassium ferrate. According to DeLuca, studies demonstrate the effectiveness of ferrate as a pretreatment prior to adsorption with GAC.[4]

Robert M. Clark, Office of Research and Development, US Environmental Protection Agency (EPA), Cincinnati, Ohio, compared chlorine, chlorine dioxide, ozone, and chloramines for cost-effectiveness. He found chlorine to be the cheapest water disinfectant. Clark noted, however, that operational costs of all the alternatives were only slightly higher than those for chlorination and that all were cost-effective when compared with the cost of not treating water.[5]

Are any of the alternatives safer than chlorination? Richard J. Bull, then of the Health Effects Research Laboratory, EPA, Cincinnati, and now at Washington State University, Pullman, maintains that it is too early to evaluate the relative hazards of alternative disinfectants. While acknowledging problems with chlorination, he says there is no basis for concluding that other compounds are any safer.[6]

A combination of methods may prove to be the best way to ensure wholesome water. Johannes J. Rook, Rotterdam Waterworks, the Netherlands, has experimented with moderate ozonation followed by moderate chlorination. In theory, the ozone breaks down the compounds that might react with chlorine. The chlorine is then added to provide residual disinfectant action. Similar treatment methods have been successfully used in Europe and a growing number of US cities.[7]

Another method explored by Rook is the application of ion-exchange resins to remove the organic compounds prior to chlorination. This method, while apparently quite effective, is also very expensive and, therefore, not yet practical for large-scale use. Rook also tested activated carbon for removing chlorinated organic compounds after chlorination. He found, however, that the carbon tended to become overloaded with contaminants, reducing its effectiveness.[7] In related research, Walter J. Weber and Abdullah M. Jodellah, Department of Environmental Engineering, University of Michigan, Ann Arbor, have found that the effectiveness of activated carbon in removing chlorinated compounds can be affected by the types of chemicals used in pretreatment of the water as well as by the types of organic matter in the water.[8]

Whether any change in current water-treatment practices is necessary depends on conditions in particular water supplies and treatment systems, such as the level of organic matter (whether naturally occurring or introduced by pollution). Whatever treatment system is used, though, Joseph A. Cotruvo, Office of Drinking Water, EPA, Washington, DC, believes that levels of THMs must be regulated. He argues that since the potentially hazardous THMs are produced as a result of human action (i.e., chlorination) and are indicative of a host of other, undefined by-products, their presence in our drinking water can and should be controlled.[9] In order to meet EPA standards, some US water systems will have to be modified.

Regarding chlorination of wastewater, Robert S. Ingols, Georgia Institute of Technology, Atlanta, urged in 1975 that the practice be stopped. He pointed to evidence that chlorinated wastewater harms many organisms in the environment, including some that are not intentional targets, and he noted that it may eventually threaten human health.[10]

At this point, we might ask whether the individual consumer of water can do anything to avoid potential problems associated with chlorination. Some "home remedies" have been proposed, and a number of these are available commercially.

Home Water Treatment

Obviously, everyone cannot have a privately owned waterworks. Various companies, however, market filters that can be attached to pipes or faucets in the home. In general, these filters use activated carbon. According to Steven Clark, Office of Drinking Water, EPA, Washington, DC, they can be quite effective in removing objectionable tastes and odors from water. Clark adds, however, that small units that mount above the sink are not very effective in removing relatively small molecules such as THMs.[11] *Consumer Reports*, on the other hand, has found that some of the filters that mount under the sink are effective against THMs. The magazine's staff found that the effectiveness of a specific filter depended on the form of carbon used and the rate of water flow. The staff noted two cautions about the filters. They become ineffective after a certain volume of water has been filtered. In addition, filters containing powdered carbon, as opposed to granular carbon, may eventually begin to release contaminants previously removed, so that the filtered water has higher levels of these substances than does unfiltered water.[12]

One way to avoid problems with tap water is to stop drinking it. A growing number of people in the US are turning to bottled water. Often obtained from springs, bottled water may have lower levels of hazardous chemicals than tap water. The fact that water comes in a bottle, however, does not necessarily mean that it is safe.

Robert H. Harris and Edward M. Brecher, editors, *Consumer Reports*, warn that bottled water may be contaminated both with harmful bacteria and any of the organic pollutants that may be found in tap water.[13] Nevertheless, wealthy persons can afford to buy bottled spring water free of chlorine and bacteria. Some health-conscious people would spend their income for this purpose as readily as others buy alcoholic beverages. Of perhaps greater importance, according to Leonard J. Greenfield, vice president, Rio Palenque Research Corporation, Miami, Florida, is the need to obtain information on whether any harmful substances are leached out of bottled-water containers. "Soluble organic substances resulting from breakdown of plastic containers and heavy metal contamination from the glass material of unknown origin may pose a far greater problem than THM contamination."[14]

Problems relating to chlorination and the broader issue of water treatment are not unique to the US. In fact, as we shall see, many countries have much greater problems in providing safe drinking water. Around the world, a large number of organizations deal with various aspects of water treatment. Their areas of interest range from basic scientific research to public health and practical applications of water-treatment technology.

Concerned Organizations

Table 1 shows the names and addresses of some of these organizations. There are far too many to permit a complete listing or discussion, but consideration of a representative sample will illustrate the range of their interests and activities.

The EPA bears responsibility for safeguarding the quality of water supplies in the US. In addition, it serves as a clearinghouse for information about water treatment from around the world. Interestingly, many other agencies and organizations refer inquiries about chlorination of drinking water to the EPA. Within the agency, activities related to drinking-water treatment center in the Office of Drinking Water, where Cotruvo is the director for Criteria and Standards.[15] According to Peter Christich, international activities specialist, the EPA Office of International Activities coordinates the exchange of information with other countries and cooperates on drinking-water issues with international organizations such as the World Health Organization (WHO).[16]

The American Water Works Association (AWWA) represents groups and individuals interested in public water supplies. It has 37,000 members in the US, Canada, and Mexico, including public and private utilities, manufacturers of water-treatment equipment, government officials, academicians, and consultants, according to Nancy Zeilig, editor, *Journal of the American Waterworks Association*.[17] AWWA develops standards, supports research relating to waterworks, and conducts training ses-

Table 1: A selected list of organizations concerned with disinfection of drinking water.

American Water Works Association
6666 West Quincy Avenue
Denver, CO 80235

Commission of the European Communities
Environment and Consumer Protection Service
200 rue de la Loi
B-1049 Brussels
Belgium

Environmental Defense Fund
444 Park Avenue, S
New York, NY 10016

Jadavpur University
Centre for Environmental Studies
Calcutta 700032
India

International Water Supply Association
1 Queen Anne's Gate
London SW1H 9BT
United Kingdom

Nagoya University
Water Research Institute
Furo-cho, Chikusa-ku
Nagoya 464
Japan

National Environment Engineering Institute, CSIR
Nagpur 440020
India

National Institute for Water Research
P.O. Box 395
Pretoria 0001
Republic of South Africa

Pan American Health Organization
525 23rd Street, NW
Washington, DC 20037

Swiss Federal Institute for Water Resources and Water Pollution Control
Ueberlandstrasse 133
8600 Duebendorf
Switzerland

US Environmental Protection Agency
Office of Drinking Water, WH-550
401 M Street, SW
Washington, DC 20460

Water Research Center
La Poveda
Arganda del Rey
Madrid, Spain

Water Research Centre
45 Station Road
Henley-on-Thames
Oxfordshire RG9 1BW
United Kingdom

Water Resources Research Unit
P.O. Box M. 32
Accra, Ghana

World Health Organization
Avenue Appia
1211 Geneva 27
Switzerland

sions for waterworks personnel. The association publishes a monthly journal.[18]

The Natural Resources Defense Council is a US public-interest group whose goals include protecting and improving environmental quality and public health. I have discussed the council in greater detail in a previous essay.[19]

The World Health Organization (WHO), an agency of the United Nations (UN), seeks to improve the health of the world's people by such means as preventing or controlling communicable diseases through technical projects and programs. In 1984 WHO published UN *Guidelines for Drinking-Water Quality*, a three-volume work that covers various aspects of water supplies.[20]

The Pan American Health Organization (PAHO) is concerned with health matters in the Western Hemisphere and is the WHO regional office for the Americas. PAHO assists nations in developing and promoting water-quality programs for the creation, extension, and improvement of water supplies. PAHO promotes disinfection of community water supplies and protection of water sources. The organization conducts seminars, courses, and workshops emphasizing simple methods of water treatment appropriate to developing countries. Chlorination, using easily maintained low-cost chlorinators, is one of the methods promoted by PAHO.[21]

The International Reference Centre for Community Water Supply and Sanitation (IRC) in The Hague, the Netherlands, was created in 1968 through an agreement between WHO and the government of the Netherlands. IRC serves as a clearinghouse for information and has the world's largest single collection of published and unpublished material on water and sanitation in and for the developing nations.[22]

Many of the organizations listed in Table 1, as well as many others not listed, fall into the category of national water authorities. In general, they share the goals of improving methods of water treatment and promoting public health by ensuring safe and high-quality water supplies.

Drinking Water around the World

The activities of the various national and international organizations concerned with water treatment reflect the wide range of conditions found around the world. While the basic technology of water treatment (coagulation and flocculation, filtration, disinfection, and so forth) is essentially the same in all countries, specific treatment measures and equipment depend on local conditions and the resources of local water authorities. For example, the widespread use of untreated water, the attendant problems of waterborne disease, and inadequate sewage systems in developing nations dictate a need to promote simple, reliable treatment systems that can be operated by personnel without a lot of technical training. In contrast, the industrial nations have sophisticated technological resources and highly trained persons, but they face problems such as industrial and agricultural pollution that stem from their technological development. Let's look at some of the problems faced in different areas.

Europeans share many of the US concerns that are associated with a high level of industrial development. They too are attempting to solve the problem of hazardous compounds in drinking water. According to Clark, Europeans have very high expectations for the quality of their water. While Americans have tended to stay with chlorination for disinfection, Europeans have for a long time experimented with other methods. For example, a number of European cities have established facilities for ozonation of their water supplies.[11]

While traveling to an international meeting in 1984, Maarten Schalekamp, then president, Swiss Gas and Water Industry Association, Zurich, had the opportunity to examine drinking-water conditions in the Soviet Union. He found a situation much like that in nations of the West. Major Soviet cities depend on surface water (lakes and rivers) for most of their water supply, while smaller towns and rural areas depend on groundwater (springs and wells). In most cases, the surface waters require extensive treatment before they can be piped to consumers. In contrast, most groundwater sources require only disinfection. Chlorination is apparently the most common method of disinfection used in the Soviet Union. Ozonation is also used, however. In fact, Moscow has the largest water-treatment plant in the world that combines ozonation with chlorination.[23]

As I indicated earlier, waterborne disease continues to present a tremendous problem for many developing nations. The International Reference Centre (IRC) estimates that more than 1.5 billion people in these nations do not have safe drinking water and that lack of safe water kills more than 30,000 people per day. Many people have to walk long distances to obtain water, and the water they get is often unsafe. It is interesting to note that since many societies regard water-carrying as a nonmasculine job, the burden of this task often rests with women and children.[22]

Arun Arunachalam, editor, *Indian Journal of Technology*, New Delhi, has described some of the problems encountered in India. He notes that the people of his hometown, about 300 miles south of Madras, drink untreated water. The water is brought in carts from wells outside the town and sold for a nominal price. According to Arunachalam, water from different wells can be easily identified by taste. Elsewhere in India, rivers provide a major water source for both municipal water systems and individuals who obtain their own water. The water is often contaminated by industrial effluents, sewage, wash water, and other pollutants, making the process of water treatment all the more difficult. Current government efforts focus on a cleanup of two of the principal rivers, the Ganges and the Yamuna.[24]

Abbasi notes that chlorination is virtually the only method for disinfection of water in India. However, only eight of the largest Indian cities and three of the smaller cities have full water-treatment facilities.[25]

In China, with the world's largest population and greatly varying conditions, providing safe water presents a tremendous challenge to the government. Responsibility for water supplies is decentralized. Local authorities design and operate their own systems, which are devised to suit local conditions. Designs for filtration units, chlorinators, and so forth emphasize simplicity and ease of operation by local people. According to Daniel A. Okun, professor emeritus, School of Public Health, University of North Carolina, Chapel Hill, the Chinese people take great civic pride in their water systems, and, in rural areas, having running water in one's house carries social status. Pride fosters public awareness of the importance of safe drinking water and promotes improvements in public health.[26]

PAHO is engaged in major efforts to improve water quality in Latin America. The agency's Environmental Health Program, coordinated by Guillermo H. Dâvila, has organized seminars, courses, and workshops on the improvement of drinking-water quality through better treatment and disinfection. PAHO has funded research into simple methods of disinfecting rural water supplies and provides assistance to nations seeking funds from sources such as the World Bank.

The examples we have discussed are not meant to be a comprehensive survey of water-treatment problems around the world. They do, however, suggest the variety of challenges faced by different nations.

The worldwide need for safe drinking water has led the UN General Assembly to declare the decade from 1981 to 1990 the International Drinking Water Supply and Sanitation Decade. The goal of the UN Decade, as it is known, is to provide safe water and adequate sanitation for all of the world's people by 1990. This goal is to be pursued through the agency of WHO.[27]

Many of the reports from around the world point out an important consideration for water-treatment planners: to be successful, any program must take local conditions into account. While the basic principles of water purification are the same everywhere, the technology varies with the resources that a given nation can commit to the problem. Officials of WHO and PAHO stress that a nation must be able to afford any equipment that is needed. If that equipment is to remain in operation, maintenance must be simple and local people must be trained to handle it.[27] Greenfield, who spent considerable time in South America, called to our attention the effectiveness of portable units used by the Armed Forces. One of them, which he obtained as WWII surplus equipment, made 34,000 gallons of potable water per day. When he was through with it he gave it to the local town. Such portable equipment is often more practical for small villages than centralized systems.[14] Further information on this kind of apparatus is provided by Frank DeVenuto and colleagues, Letterman Army Institute of Research, San Francisco, California, in their report on field production of safe water.[28]

Chlorination continues to play a major role in efforts to improve the world's water supplies. According to the IRC, 80 percent of all illness in developing countries stems from polluted water.[22] Diseases causing diarrhea, endemic in many countries, account for a large proportion of waterborne illness. These diseases have an overwhelming impact on the quality of life in developing nations.

As IRC's program officer, T.K. Tjiook, says, the potential benefits of controlling these diseases override the problems attributed to chlorination. Tjiook therefore recommends chlorination as part of water-treatment programs in developing countries.[29]

Improvements in water treatment, whether in developing nations or the industrialized world, hinge upon scientific and technological advances. To see what directions current research is taking, let's look at some of the scientific literature in this area.

ISI Research Fronts

A search of ISI's files revealed several hundred papers and books related to chlorination of water, including 81 published in 1983 and 226 in 1984. Table 2 shows some of the journals in which papers appeared, together with an impact factor that measures the citation frequency for the average article published during the preceding two years. The focus of these journals ranges from basic research to the technology of water treatment and environmental concerns.

Table 2: Selected list of journals reporting on chlorination research. A = journal title. B = 1983 impact factor.

A	B
Applied and Environmental Microbiology	2.084
Atmospheric Environment	1.968
Environmental Health Perspectives	1.029
Environmental Pollution Series A—Ecological and Biological	0.852
Environmental Science & Technology	2.393
Journal of Environmental Engineering—ASCE	1.052
Journal of the American Water Works Association	0.763
Journal of the Water Pollution Control Federation	1.031
Water Research	1.454
Water Science and Technology	0.257

Table 3 shows five 1983 research fronts and four 1984 research fronts related to chlorination. These fronts identify areas of significant research during those years and point out the core papers seminal to that research. The first of these research fronts is #83-0040, "Toxicity and other effects of chlorine dioxide, chlorite, chlorate and other drinking-water disinfectants." Nine citing papers in 1983 are linked by two core papers published in 1980 and 1979. One paper, by Mohammed S. Abdel-Rahman and colleagues, Department of Pharmacology, Ohio State University College of Medicine, Columbus, appeared in 1980.[30] The other is by W. Paul Heffernan and colleagues, Health Effects Research Laboratory, EPA, Cincinnati.[31] Both papers were published in the *Jour-*

Table 3: The 1983 and 1984 *SCI®/SSCI®* research fronts on chlorination. A = number. B = name. C = number of core papers. D = number of citing papers.

A	B	C	D
83-0040	Toxicity and other effects of chlorine dioxide, chlorite, chlorate and other drinking-water disinfectants	2	9
83-2481	Chlorine disinfection and hepatitis-A virus inactivation in the monitoring of virological quality in potable and waste water	2	12
83-2982	Kinetics of the formation of bromate and hypobromous acid during the ozonation of bromide-containing drinking waters	2	8
83-3674	Methods of chlorine analysis and removal in aquatic systems with emphasis on the responses of fish	3	23
83-4876	Comparison of chlorine and chlorine dioxide in treatment of drinking water; studies of *Giardia* and other intestinal parasites	6	29
84-1568	Sorption and uptake of organic pesticides, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and other environmental pollutants by soils, water and fish	26	215
84-4741	Mass spectrometry studies of the biodegradation of chlorinated S-triazines and polychlorinated biphenyls	2	9
84-5275	Kinetics of chlorination of triethanolamine and other amines and organics in aqueous solution	7	31
84-8925	Detection of chlorine dioxide in water	2	11

nal of Environmental Pathology and Toxicology.

The most active research front related to water chlorination is #84-1568, "Sorption and uptake of organic pesticides, chlorinated hydrocarbons, polycyclic aromatic hydrocarbons and other environmental pollutants by soils, water and fish." Twenty-six core papers in this front were cited by a total of 215 citing papers. Many of these papers deal with the area of toxic effects produced by reaction products of chlorine.

Two research fronts relate to the sensitivity of waterborne pathogens to chlorine. One of these is #83-2481, "Chlorine disinfection and hepatitis-A virus inactivation in the monitoring of virological quality in potable and waste water." Here again there are two core papers, one by Pasquale V. Scarpino, Department of Civil and Environmental Engineering, University of Cincinnati, Ohio,[32] and one by Gerald Berg and colleagues, Environmental Monitoring and Support Laboratory, EPA, Cincinnati.[33] By comparison with fields in biotechnology, the research effort here is minuscule. Only 12 papers were published on this topic in 1983. On the other hand, #83-4876, "Comparison of chlorine and chlorine dioxide in treatment of drinking-water; studies of *Giardia* and other intestinal parasites," was somewhat more active. We found six core papers associated with 29 citing papers. The most frequently cited core paper was written by Lawrence S. Ritchie, 406th Medical General Laboratory, US Army, in 1948. It concerns another sedimentation technique for routine stool examinations. Some procedures change only slowly in the public-health field.[34]

Chemical reaction kinetics are addressed by research front #83-2982, "Kinetics of the formation of bromate and hypobromous acid during the ozonation of bromide-containing drinking waters," and by research front #84-5275, "Kinetics of chlorination of triethanolamine and other amines and organics in aqueous solution." Front #83-2982 consists of two core papers and eight citing papers. The core studies were reported by W.J. Blogoslawski, Middle Atlantic Coastal Fisheries Center, National Marine Fisheries Service, Milford, Connecticut,[35] and colleagues and W.J. Masschelein and M. Denis, Laboratories of the Brussels' Intercommunal Waterboard, Belgium.[36]

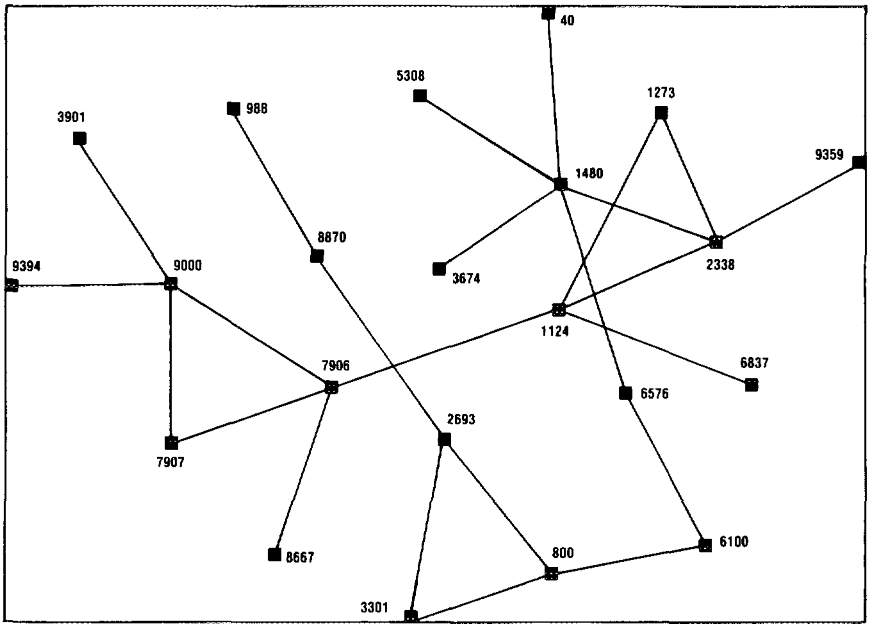
Research fronts #83-3674, #84-8925, and #84-4741, shown in Table 3, deal with experimental methods relating to analysis of water disinfectants. The most-cited paper from these fronts is a 1981 review article by William A. Brungs, National Water Quality Laboratory, EPA, Duluth, Minnesota. Cited 12 times in 1983, it discusses the effects of residual chlorine on marine life.[37]

Figure 1 is a multidimensional scaling map, which we call a second-level (C-2) cluster map, showing research fronts relating to "Toxic effects and analysis of trace metals and organic compounds in aquatic systems." This map demonstrates how core papers in each of 22 research fronts provide us with the links for their identification. The names of the research fronts are given in Figure 1. Nine of them concern the use of high-performance liquid chromatography (HPLC).

Conclusion

As the foregoing discussion shows, chlorination and the larger subject of drinking-water treatment represent a multifaceted subject of genuine importance to the general public. The discussion of chlorination and its alternatives indicates that the industrialized nations are currently facing the problem of improving a water-treatment process that has had tremendous benefits for the public health. A review of the scientific literature has shown that researchers continue to explore the effects of this

Figure 1: The C-2 level map for cluster 30, "Toxic effects and analysis of trace metals and organic compounds in aquatic systems," showing links between research fronts. A = 1983 research front number. B = research front title.



A	B
83-0040	Toxicity and other effects of chlorine dioxide, chlorite, chlorate and other drinking-water disinfectants
83-0800	Complexation and toxic effects to plankton of copper, cadmium and other metals in aquatic systems
83-0988	Lead, radionuclide and synthetic elemental uptake in terrestrial ecosystems
83-1124	Analysis of chlorophenol and other phenol derivatives by high-performance liquid chromatography (HPLC) using electrochemical detectors
83-1273	Gas-chromatographic analysis of chlorinated phenyl esters and related compounds formed in pulp bleaching
83-1480	Trihalomethane photoinduced decomposition in drinking water; production of dihaloacetonitriles by algae
83-2338	Analysis of trace organic compounds in water using HPLC after preconcentration
83-2693	Determination of the distribution of copper, cadmium and heavy metals in seawater using atomic absorption spectrometry and other techniques
83-3301	Geochemistry and mixing behavior of colloidal iron aggregates and dissolved substances in estuaries
83-3674	Methods of chlorine analysis and removal in aquatic systems with emphasis on the responses of fish
83-3901	Methods for the estimation of free and conjugated catecholamines in human plasma
83-5308	Biodegradation and adsorption by activated carbon in treatment of landfills and other wastes
83-6100	Use of physical separation techniques in trace metal and heavy metal speciation from natural waters
83-6576	Structure, characterization of copper and other metal uptake by aquatic humic substances
83-6837	Application of dual electrochemical detectors for HPLC of pterins and related compounds
83-7906	Electrochemical detection in HPLC
83-7907	Electrochemical detection of catecholamines in HPLC
83-8667	HPLC and other aspects of catecholamine analysis and detection
83-8870	Determination of atmospheric inputs of heavy metals including lead and cadmium
83-9000	Electrochemical detection in determination of catecholamines by HPLC
83-9359	Presence, introduction and removal of mutagenic activity associated with the by-products of drinking-water disinfection in the Netherlands and other places
83-9394	Dopamine receptor binding studies with agonists dipropyl-5, 6-ADTN and 3,4-dihydroxyphenylimino-2-imidazolidine

process, as well as the mechanisms by which those effects occur, in order to find ways to improve effectiveness and safety.

In contrast to the industrialized world, the developing nations face the more immediate problem of simply establishing safe drinking-water supplies. Surveys of the world's drinking-water supplies amply demonstrate the magnitude of this problem. At the same time, these reports show what serious efforts by national and international agencies can accomplish to relieve the problem, given adequate resources and support.

Our review suggests that water treatment will be an interesting subject to watch in the future. We will be particularly interested to see how water treatment will be improved and how the nations of the world will progress in pursuing the goals of the UN Decade. While water treatment will not attract the attention devoted to the problem of starvation, it is of course no less relevant. Further, the problems of water treatment are related to the larger issue of whether we will have enough usable water in the future. Groundwater in many areas is becoming contaminated with chloride from seawater because of coastal drainage practices, and underground aquifers are being polluted by toxic wastes.[14] The public is tantalized by the short-term and real plight of starvation in Africa, but death from cholera or other waterborne diseases has been commonplace for so long it is difficult to maintain the public's interest. Politicians thrive on short-term problems that are soluble immediately. Serious persons, whether scientists or public officials, need to take the long-range view.

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