EXECUTIVE SUMMARY

OBJECTIVES

The objective of this study was to investigate the formation and degradation (both chemical and biological) of key non-regulated disinfection by-products of human health concern in drinking water distribution systems.

BACKGROUND

Disinfection by-products (DBPs) are a broad group of compounds produced as an unwanted by-product of drinking water disinfection. Many of these compounds have been assessed as potentially hazardous to human health, especially when ingested at high concentrations over a lifetime. The U.S. Environmental Protection Agency (EPA) has regulated two groups of organic DBPs, the trihalomethanes (THMs) and the haloacetic acids (HAAs). It is generally understood and widely acknowledged that these two groups only represent a fraction of the DBPs formed in municipal drinking water systems. Accordingly, there is intense interest in identifying and controlling exposure to the other non-regulated DBPs that are deemed to be hazardous.

To assess and control emerging DBPs, it is key to understand their formation and degradation in municipal drinking water systems. Most of the non-regulated DBPs are acknowledged to be unstable or reactive intermediates. Thus, it is extremely important to know if they persist for periods too short to survive distribution to the consumers' tap, or if they persist longer, and become ingested by the public. In addition, it is important to understand how they form, and the impact of various treatment conditions on their formation and control. Armed with this knowledge, water treatment engineers will be much better able to protect the public from hazardous DBPs.

APPROACH

This work was conducted through both laboratory studies and field sampling events. The first project task was to establish a list of target non-regulated DBPs. The second task pertained to laboratory-scale studies of chemical or abiotic degradation, and formation of some key target DBPs. These tests were conducted in a manner that supports the subsequent development of chemical kinetic models. The third and major phase of this project involved collection of field samples from 11 utilities. These were analyzed for the target DBPs to reveal spatial variability across these systems. Additional samples were collected to harvest solids (e.g., biomass, corrosion products) from these utilities. These solids were tested in the laboratory to assess their impacts on degradation of the target DBPs. Use of abiotic controls assisted in separating chemical degradation from biodegradation. The final task was to summarize and integrate existing and new knowledge acquired from this project. Recommendations were proposed for the minimization of non-regulated DBPs represented by the target group of compounds.

RESULTS AND CONCLUSIONS

Thirteen intensive sampling campaigns were conducted at the 11 participating utilities between January 2011 and June 2012. Each utility was sampled at least once. Two separate sampling events (June and August 2011) were conducted at Utility #2, so that both normal operations and a period of temporal disinfection switch ("chlorine burn") could be evaluated. At Utility #5, there were substantial changes in source and treatment that led to a second sampling event in April 2012. Samples were collected from about a dozen sites representing finished water; water with low, medium, and high water ages; and water from sites typically associated with nitrification or low chlorine residuals. These samples were quenched, sealed headspace-free, and rushed to UMass and Yale for analysis of a suite of DBPs, both regulated and non-regulated. The utilities made field measurements and provided some additional laboratory analysis on the samples. They also provided water ages for each location, whether determined by calibrated hydraulic models or by expert judgment.

Hydrant flush samples were collected from each utility at the time of the main distribution system sampling event. These were used in the UMass laboratory for testing for the presence of bacteria capable of biodegrading various halogenated DBPs. This laboratory work included incubating suspensions of the sediment in the presence of DBPs and monitoring the loss over time. In addition, samples were analyzed for the presence of dehalogenase genes. Other laboratory tests were conducted to assess abiotic degradation of some key disinfection by-products. Conditions of interest included pH, chlorine residual, temperature, and presence of reducing agents.

Results indicated that concentrations of most unregulated DBPs were highly variable between different utilities and even across some service areas within a single system. There were no reliable or universal relationships between the regulated DBPs (THMs and HAAs) and the non-regulated compounds. However, there were patterns that could be identified based on residual disinfectant type, pH, and treatment, especially the use of strong oxidants and long free chlorine contact times for systems using chloramines. Most water systems have bacteria with dehalogenase genes that are capable of biodegrading a wide range of DBPs. Proliferation of these organisms to the point that they actually depress DBP levels in the system is less common and seems to be related to areas prone to nitrification. Many non-regulated DBPs are subject to alkaline hydrolysis and abiotic degradation. Stability of these compounds in actual distribution systems is often greater than expected from simple laboratory experiments, suggesting protective mechanisms may be at play.

APPLICATIONS AND RECOMMENDATIONS

There is no single set of recommendations for distribution system operation and management that will minimize all DBPs. This leads utilities wishing to be proactive on non-regulated DBPs to make their own choices about which compounds are most important to minimize and to balance their treatment objectives to meet their operational needs. Without reliable human carcinogenicity data or epidemiological data resolved down to the compound level, the best guide might be the growing body of literature on compound-specific genotoxicity. With this as a guide, utilities should try to avoid the use of chloramines, especially when used with short free chlorine contact times. This will help minimize the concentration of DBPs containing one or two halogens on a single carbon atom, as well as compounds with high levels of bromine incorporation, and especially iodine incorporation (e.g., TOBr, TOI). Of course, we recognize that this may not be possible for many utilities, given the current regulatory constraints. General

recommendations for treatment and supply are to reduce the amount and reactivity of DBP precursors through better TOC removal, strong oxidation or selection of supplies with lower TOC and total nitrogen.

Control of NDMA and nitrosamines in general is a concern to many utilities, especially those using chloramines. The best options for utilities wishing to reduce NDMA concentrations are to (1) avoid the use of chloramines, or if not possible, minimize nitrification, (2) avoid the use of cationic polymers with quaternary amine groups, (3) increase contact time with free chlorine if possible, and (4) avoid raw water sources impaired by wastewater discharges. As with many of the unregulated DBPs, use of strong oxidants like ozone or chlorine dioxide is likely to help in controlling nitrosamine precursors.

RESEARCH PARTNERS

We wish to thank the participating utilities for their support and assistance:

- Charleston SC
- Knoxville TN
- San Francisco CA
- East Bay Municipal Utilities District
- Contra Costa Water District
- Pinellas County FL
- Monroe MI
- Ann Arbor MI
- Wyoming MI
- Cincinnati OH
- Minneapolis MN