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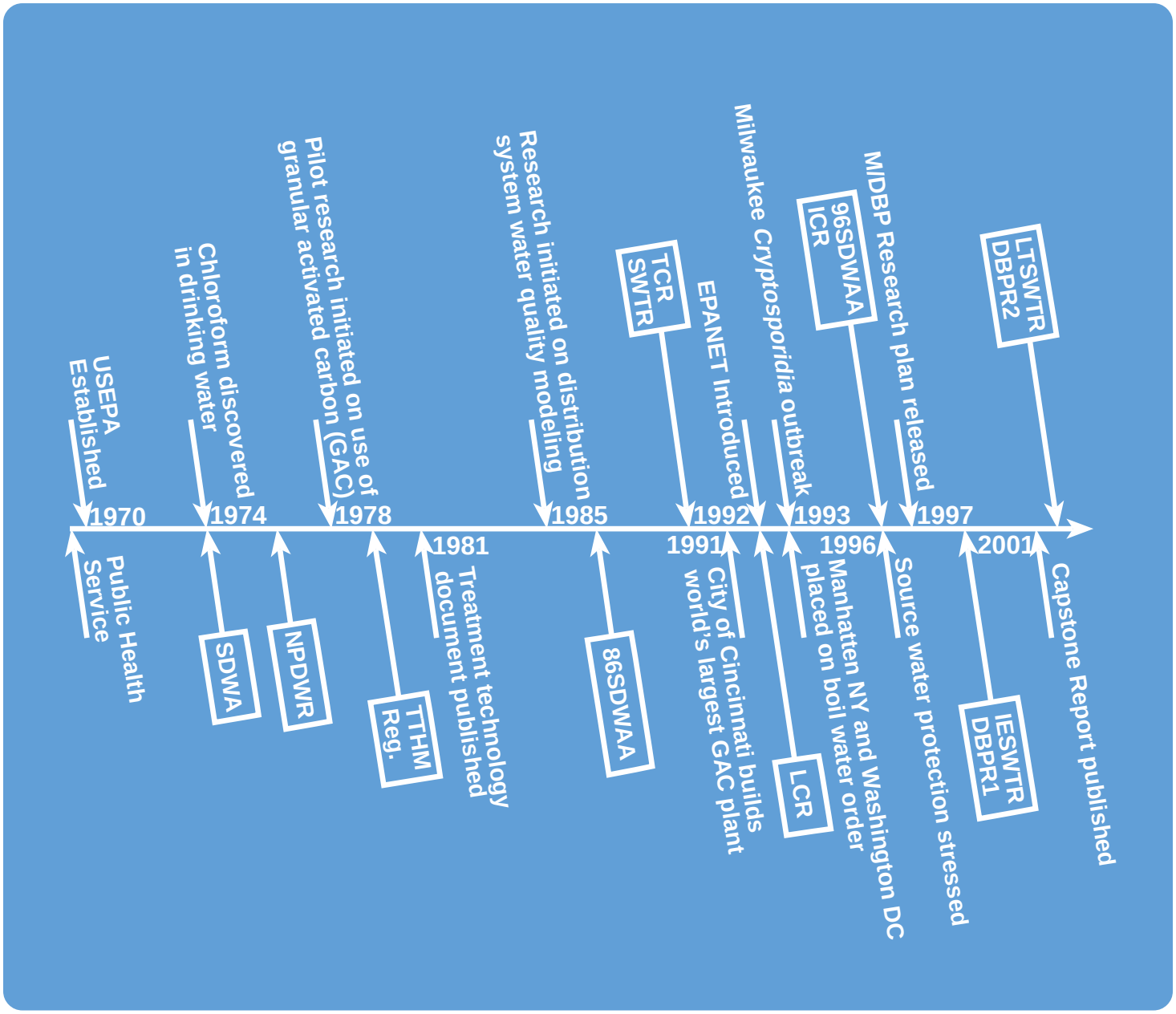
Controlling Disinfection By-Products and Microbial Contaminants in Drinking Water



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Controlling Disinfection By-Products and Microbial Contaminants in Drinking Water

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Notice

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Abstract

Historically drinking water utilities in the United States (U.S.) have played a major role in protecting public health through the reduction of waterborne disease. These reductions in waterborne disease outbreaks were brought about by the use of sand filtration, disinfection and the application of drinking water standards. Coincident with the passage of the SDWA of 1974, it was discovered that chloroform was a disinfection by-product (DBP) resulting from the interaction of chlorine with natural organic matter in water. Chloroform is one of a class of compounds called trihalomethanes. This finding posed a serious dilemma because it raised the possibility that chemical disinfection, which clearly reduced the risk of infectious disease, might also result in the formation of potentially harmful chemical by-products. Although disinfection of public drinking water had dramatically reduced outbreaks of diseases attributable to waterborne pathogens, the identification of chloroform in drinking water raised questions about possible health risks associated with these exposures. In the United States, since 1974, additional DBPs have been identified and concerns have intensified about health risks resulting from exposures to them. Although a causal relationship between DBP exposures and these health risks has not been conclusively established, risk managers have responded, in the interest of protecting public health, by developing alternative treatment systems and issuing rules and regulations designed to maintain protective levels of disinfection while reducing potentially harmful levels of DBPs. In 1981, the USEPA issued a report intended to summarize the "state-of-the-art" regarding the control of disinfection by-products in drinking water. However, EPA's current drinking water research program is more sophisticated than it was twenty years ago. For example, when the treatment technology manual was published in 1981, it reported primarily on treatment oriented research. Twenty years later, the technology research program includes source water protection, treatment technology and distribution system studies. The research also reflects a concern over balancing the risks of potential carcinogenic exposure against the risks from microbial infection. This document is intended to summarize the research that has been conducted in technology research by EPA since the publication of the 1981 treatment technology document.

Foreword

The U.S. Environmental Protection Agency is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threatens human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

E. Timothy Oppelt, Director
National Risk Management Research Laboratory

Preface

As part of his response to a letter from Robert Hooke, Sir Isaac Newton wrote, “If I have seen further . . . it is by standing on the shoulders of giants.” This statement, made in the 17th century, could easily describe the progress we have made over the last 25 years in identifying and controlling disinfection by-products (DBPs) and microbial contaminants in drinking water. In 1972, I was assigned to the staff of Dr. Andrew W. Breidenbach, director of EPA’s first National Environmental Research Center, and worked with Mr. Gordon Robeck to help bring the Water Supply Research Laboratory into existence. At the time, I had no idea of the impact that the program would have on drinking water in the United States and the world, nor did I have the slightest idea that I would eventually serve as the program’s director for 14 years.

I joined the staff of the Water Supply Research Laboratory shortly before the passage of the Safe Drinking Water Act in 1974. At that time, we were just beginning to recognize that chloroform was a by-product resulting from the interaction of chlorine with natural organic matter in drinking water. During my early years in the program, I had a chance to learn from not only Gordon Robeck, but from other such eminent scientists as Dr. James Symons, Mr. Leeland McCabe, and Mr. Edwin Geldreich. Although Robeck, Symons, McCabe, and Geldreich were “giants,” there were many other talented and highly productive individuals who contributed to the success of the program as well. In 1981, we published a document titled “Treatment Techniques for Controlling Trihalomethanes in Drinking Water,” which was an attempt to summarize contemporary knowledge in that important area. It was highly successful and, at the time, was considered a benchmark in the field. It was so successful that, after the USEPA’s supply of the report was exhausted, it was republished by the American Water Works Association and by the Japan Water Works Association. This document is intended to complement the 1981 volume by describing research completed by the National Risk Management Research Laboratory in the 20 years between 1981 and 2001.

In 1972, all of the drinking water research activities conducted by the USEPA were concentrated in the Water Supply Research Laboratory. When the Safe Drinking Water Act was passed in 1974, the Laboratory was blessed with a generous allotment of funds and staff. However, through reorganizations and redirections over the past 20 years, various aspects of the program have been transferred to other organizational units in EPA. In the early 1990s, there was serious consideration of its elimination because it represented “mature technology.” Support from the American Water Works Association (AWWA), the American Water Works Association Research Foundation (AWWARF), and the Association of State Drinking Water Administrators (ASDWA) helped it survive that difficult period.

Drinking water research has now become an integral part of the USEPA’s base research program. Each of the laboratories and centers in EPA’s Office of Research and Development (ORD) has a core research program devoted to various aspects of drinking water research. It is effectively coordinated by Dr. Fred Hauchman, who serves as National Drinking Water Research Program Manager, and by Mr. E. Timothy Oppelt who, as Director of the National Risk Management Research Laboratory (NRMRL), is the Executive Lead. The EPA works collaboratively with other organizations and research programs including the AWWA, AWWARF, ASDWA, the National Association of Water Companies, and the Association of Metropolitan Water Authorities.

Just as the state of drinking water research in EPA has changed, the nature of the science and engineering support for the program has also changed. During the past 20 years, research in the areas of disinfection by-products and microbial contaminant control has become complex and scientifically challenging. NRMRL’s Water Supply and Water Resources Division (WSWRD), the direct successor of the Water Supply Research Laboratory that initially focused on treatment technology, has evolved into a program that is fundamental and science-based. It researches small systems technologies, distribution systems, and source water protection, and has sponsored projects throughout the world.

The ORD drinking water program has a long and productive history in EPA and has evolved into a broadly based, complex, and scientifically challenging program. I believe that the material contained in this document reflects the progress that we have made in research related to the control of DBPs and microbial control in drinking water during the past 20 years. The underlying principle that continues to govern all of our research in WSWRD is protecting the public health of the American drinking water consumer.

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Abbreviations

AOC ..... assimilable organic carbon
AOP ..... Advanced Oxidation Process
APO ..... antibiotic-preserved oocysts
ARC/INFO® ..... ESRI's® (Environmental Systems Research Institute, Inc.) commercial
..... GIS (Geographic Information System) software
ARM-II ..... Agricultural Runoff Management Model
ASTM ..... American Society for Testing and Materials
AWBERC ..... Andrew W. Breidenbach Environmental Research Center
AWWA ..... American Water Works Association
AWWARF ..... American Water Works Association Research Foundation
BAA ..... bromoacetic acid
BAC ..... biological activated carbon
BAT ..... best available technology
BCAA ..... bromochloroacetic acid
BCAN ..... bromochloroacetonitrile
BDOC ..... biodegradable dissolved organic carbon
BMP ..... best management practice
BOM ..... biodegradable organic matter
BWC ..... backwash chlorinated
CAA ..... chloroacetic acid
CCC ..... Chlorine Chemistry Council
CCL ..... contaminant candidate list
CFU ..... colony forming unit
CGR ..... coliform growth response
CH ..... chloral hydrate
Ci ..... curie
CLR ..... chlorine residual
CLSA ..... closed loop stripping apparatus
CP ..... chloropicrin
CSO ..... combined storm water-sewage overflows
CSTR ..... continuous-flow stirred-tank reactor
CSU ..... Colorado State University
CT ..... contact time
CT-ORW ..... conventionally treated Ohio River water
CTA ..... cellulose triacetate
CWA ..... Clean Water Act
DBAA ..... dibromoacetic acid
DBAN ..... dibromoacetonitrile
DBMS ..... data base management system
DBP ..... disinfection by-product
DBPFP ..... disinfection by-product formation potential
DBPR ..... Disinfection By-products Rule
DCAA ..... dichloroacetic acid
DCAN ..... dichloroacetonitrile
D/DBP ..... disinfectants/disinfection by-products
DE ..... diatomaceous earth (filtration)

Abbreviations, Cont'd.

DIC ..... differential interference contrast
DO ..... dissolved oxygen
DOC ..... dissolved organic carbon
DOM ..... dissolved organic matter
DPO ..... dichromate-preserved oocyst
DSS ..... Distribution System Simulator
DVM ..... Discrete-Volume Method
DWF ..... dry-weather flow
DWQM ..... Dynamic Water Quality Model
DWSRF ..... Drinking Water State Revolving Fund
EBCT ..... empty bed contact time
ECD ..... electron-capture detection
EDM ..... Event-Driven Method
EFL ..... East Fork Lake
EPA ..... Environmental Protection Agency (US)
EPANET ..... An EPA-developed computer program that performs simulation of hydraulic
..... and water quality behavior within drinking water distribution systems
EPS ..... extracellular polysaccharide
ESCA ..... Electron Spectroscopy for Chemical Analysis
ESWTR ..... Enhanced Surface Water Treatment Rule
ETV ..... Environmental Technology Verification (Program)
FAC ..... filtration avoidance criteria (Chapter 4)
FAC ..... free available chlorine (Chapter 11)
FBDOC ..... fast biodegradable dissolved organic carbon
FC ..... fecal coliform
FDM ..... Finite-Difference Method
FID ..... flame-ionization detection
FISH ..... fluorescent in situ hybridization
FLOWSED ..... A one-dimensional mathematical model that computes FLOW conditions
..... and SEDiment movement
FP ..... formation potential
FRT ..... filter run time
FS ..... fecal streptococci
FY ..... fiscal year
GAC ..... granular activated carbon
GC ..... gas chromatography
GC/MS ..... gas chromatography/mass spectroscopy
GIS ..... Geographic Information System
GM ..... geometric mean
GMR ..... Great Miami River
GS ..... Green Swamp
GT ..... coagulant mixing intensities
GWR ..... Ground Water Rule
GWUDI ..... ground water under the direct influence of surface water
HAA ..... haloacetic acid
HAAFP ..... haloacetic acid formation potential
HAN ..... haloacetonitrile

Abbreviations, Cont'd.

HFTF ..... high-flow thin film
HL ..... head loss
HPC ..... heterotrophic plate count
http ..... hyper text transfer protocol
HX ..... hydrohalic acid
IC ..... ion chromatography
IC-ICP-MS ..... ion chromatography inductively coupled plasma mass spectrometry
ICP-MS ..... inductively coupled plasma mass spectrometry
ICR ..... Information Collection Rule
IESWTR ..... Interim Enhanced Surface Water Treatment Rule
IFA ..... indirect fluorescent monoclonal antibody
IMS ..... integrated membrane system
IR ..... infrared (spectroscopy)
JWWA ..... Japan Water Works Association
L ..... liter
LCR ..... Lead and Copper Rule
LTD ..... long-term demand
LTESWTR ..... Long Term Enhanced Surface Water Treatment Rule
MCLG ..... maximum contaminant level goal
MCL ..... maximum contaminant level
M/DBP ..... microbial pathogens/disinfection by-products
MF ..... microfiltration
mg/L ..... milligrams per liter
MIOX ..... mixed oxidants
MR ..... Mississippi River
M/R ..... monitoring and reporting
MRDL ..... maximum residual disinfectant level
MRDLG ..... maximum residual disinfectant level goal
MS ..... mass spectroscopy
MS ..... molecular size
MSL ..... mean sea level
MWCO ..... molecular-weight cutoff
MWL ..... Miami Whitewater Lake
MX ..... Mutagen X
NAS ..... National Academy of Sciences
NBDOC ..... non-biodegradable dissolved organic carbon
NC ..... non-chlorinated
NCER ..... National Center for Environmental Research
ND ..... not detected
NF ..... nanofiltration
NIEHS ..... National Institute of Environmental and Health Sciences
NIPDWR ..... National Interim Primary Drinking Water Regulations
NMR ..... nuclear magnetic resonance
NMWD ..... North Marin Water District
NOM ..... natural organic matter

Abbreviations, Cont'd

NPDES ..... National Pollutant Discharge Elimination System
NPDWR ..... National Primary Drinking Water Regulations
NPOX ..... nonpurgeable organic halide
NSDWR ..... National Secondary Drinking Water Regulations
NPWA ..... North Penn Water Authority
NRCS ..... Natural Resources Conservation Service
NRMRL ..... National Risk Management Research Laboratory
NTM ..... non-tuberculosis mycobacteria
NTU ..... nephelometric turbidity unit
O&M ..... operation and maintenance
OBP ..... ozone by-products
OR ..... Ohio River
ORD ..... Office of Research and Development
ORP ..... oxidation reduction potential
ORSANCO ..... Ohio River Valley Water Sanitation Commission
ORW ..... Ohio River water
PAC ..... powdered activated carbon
PBS ..... phosphate buffered saline
PC ..... prechlorinated
PCA ..... plate count agar
PCB ..... polychlorinated biphenyl
PCR ..... polymerase chain reaction
PFU/L ..... plaque forming unit/liter
PHS ..... Public Health Service
PM ..... precursor material
POE ..... point-of-entry
POU ..... point-of-use
POX ..... purgeable organic halide
POXFP ..... purgeable organic halide formation potential
PVC ..... polyvinyl chloride
PWS ..... public water system
QUALNET ..... A temporal and spatial prediction model of chlorine distribution in a pipe
..... network under unsteady-flow conditions
R2A ..... A low-nutrient-content growth medium for performing heterotrophic plate
..... counts
Reg-Neg ..... Regulatory-Negotiation Committee
RO ..... reverse osmosis
RF1 ..... A topological and geographic (GIS) coverage of the primary rivers and
..... streams in the coterminous United States
RSSCT ..... Rapid Small Scale Column Test
RTS ..... Remote Telemetry System
RTU ..... remote telemetry unit
SAC ..... spectral absorption coefficient
SAR ..... structure-activity relationship
SBDOC ..... slowly biodegradable dissolved organic carbon
SCADA ..... Supervisory Control and Data Acquisition
SCCRWA ..... South Central Connecticut Regional Water Authority

Abbreviations, Cont'd.

SDS ..... simulated distribution system
SDWA ..... Safe Drinking Water Act
SDWAA ..... Safe Drinking Water Act Amendments
SL ..... Stonelick Lake
SMCL ..... secondary maximum contaminant level
SOC ..... synthetic organic chemical
SSF ..... slow sand filtration
SSO ..... sanitary sewer overflow
STP ..... sewage treatment plant
SUVA ..... specific ultraviolet absorbance
SWP ..... source water protection
SWTR ..... Surface Water Treatment Rule
TC ..... total coliform
TCAA ..... trichloroacetic acid
TCAN ..... trichloroacetonitrile
TCR ..... Total Coliform Rule
TDM ..... Time-Driven Method
TDS ..... total dissolved solids
T&E ..... test and evaluation
THM ..... trihalomethane
THMFP ..... trihalomethane formation potential
TOC ..... total organic carbon
TOX ..... total organic halide
TOXFP ..... total organic halide formation potential
TPC ..... total particle count
TSA-SB ..... tryptic soy agar-sheep's blood
TSS ..... Ten-State Standards
TT ..... treatment technique
TTHM ..... total trihalomethane
TTHMFP ..... total trihalomethane formation potential
UF ..... ultrafiltration
UFC ..... uniform formation condition
UK ..... United Kingdom
USDHEW ..... United States Department of Health, Education and Welfare
USEPA ..... United States Environmental Protection Agency
USGS ..... United States Geological Survey
UV ..... ultraviolet
UVA ..... ultraviolet absorbance
WASP4 ..... Water Quality Analysis Simulation Program (release number four)
WSWRD ..... Water Supply and Water Resources Division
www ..... World Wide Web
XAD® ..... A functionalized poly (styrene-di-vinylbenzene) resin

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