

Format-Style Guide for Preparing Research Reports



About the Water Research Foundation

The Water Research Foundation (formerly Awwa Research Foundation or AwwaRF) is a member-supported, international, 501(c)3 nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers.

The Foundation's mission is to advance the science of water to improve the quality of life. To achieve this mission, the Foundation sponsors studies on all aspects of drinking water, including resources, treatment, distribution, and health effects. Funding for research is provided primarily by subscription payments from close to 1,000 water utilities, consulting firms, and manufacturers in North America and abroad. Additional funding comes from collaborative partnerships with other national and international organizations and the U.S. federal government, allowing for resources to be leveraged, expertise to be shared, and broad-based knowledge to be developed and disseminated.

From its headquarters in Denver, Colorado, the Foundation's staff directs and supports the efforts of more than 800 volunteers who serve on the board of trustees and various committees. These volunteers represent many facets of the water industry, and contribute their expertise to select and monitor research studies that benefit the entire drinking water community.

The results of research are disseminated through a number of channels, including reports, the Web site, Webcasts, conferences, and periodicals.

For its subscribers, the Foundation serves as a cooperative program in which water suppliers unite to pool their resources. By applying Foundation research findings, these water suppliers can save substantial costs and stay on the leading edge of drinking water science and technology. Since its inception, the Foundation has supplied the water community with more than \$460 million in applied research value.

More information about the Foundation and how to become a subscriber is available on the Web at www.WaterResearchFoundation.org.

Format-Style Guide for Preparing Research Reports

**Sixth Edition
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Prepared for:

Water Research Foundation

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CHAPTER 1

INTRODUCTION

PURPOSE

The Water Research Foundation sponsors beneficial research to the drinking water industry in North America and abroad. The final research report is one tool for communicating research results to the principal audience—drinking water utilities. The Foundation expects each contractor to write a clearly organized and understandable report. To bring consistency in the format, style, and content of its research reports, the Foundation has prepared this format-style guide. This guide assists contractors (i.e., authors) in preparing documents that utilities can readily use.

You should direct any questions concerning the contents of this guide to the project manager or Communications & Marketing (C&M) staff.

ORGANIZATION OF GUIDE

This sixth edition of the Foundation’s format-style guide has three major sections. A [template](#) with the Foundation’s style is also available. By carefully following the guidance throughout this publication, you can minimize delays in publishing the final report.

The first section—Chapters 1 through 4—provides a narrative covering publication procedure, format, table and figure preparation and placement, and use of copyrighted materials. The second section—[Appendix A: Examples](#)—supplements the narrative with numerous examples of how parts of a final report must look. Chapters 1 through 4 include electronic links to the individual examples in Appendix A. The third section—[Appendix B: Checklists, Forms, and Guidelines](#)—offers additional information related to report preparation or publication. Appendix B is a separate file in Microsoft Word® so the forms can be filled in electronically. For your convenience, the appendices also each include a table of contents so they can be printed out and used as separate documents.

FOUNDATION NAME CHANGE

The Water Research Foundation asks that all of its subscribers, researchers, partners, related organizations, and vendors use the proper name formats, as described below, when referring to the Foundation. Uniformity promotes the Water Research Foundation identity as an independent organization and assists readers in distinguishing it from other organizations with similar acronyms.

The full and complete name of the organization is—Water Research Foundation. In the first reference, the full name should be used in this format. After first reference, you may use the word Foundation with an uppercase “F” to refer to our organization. Never use an acronym (WRF) when referring to the Water Research Foundation.

CHAPTER 2 FORMAT

COVER AND TITLE OF REPORT

The Water Research Foundation provides the cover for the report. In cooperation with the project manager, select a descriptive but concise title for the cover. *The title should be no more than 75 characters.*

ACCEPTABLE SOFTWARE

Prepare the report with Microsoft Word® or Adobe InDesign® software.

PAGE DIMENSIONS

All reports should be printed on 8½” x 11” paper. For the final printing of the report, all margins should be 1”.

TYPEFACE

The Foundation prefers 12-point Times New Roman type with single spacing for the text throughout research reports. The chapter and section headings should be in 14-point type. Justify the right margin, hyphenating words when possible.

For an occasional table or figure, you may need to use a smaller type size. The Foundation prefers that type on art be no smaller than 8 point.

HEADINGS

For consistency in headings, use the format shown below and in the example. Pay special attention to the style of type, placement of heading, and spacing above and below the heading.

SECTION & CHAPTER HEADS	Bold uppercase letters, 14-point type, centered on line, and two line spaces below
A- OR FIRST-LEVEL	Bold uppercase letters, 12-point type, aligned at left margin, and a single line space above and below
B- or Second-level	Bold upper- and lowercase letters, aligned at left margin, and a single line space above and below
C- or Third-level	Bold, italic upper- and lowercase letters, aligned at left margin, and a single line space above and below
D- or Fourth-level	Bold, italic initial uppercase letter and lowercase letters, indented and run-in with text
E-or Fifth-level	Italic, initial uppercase and lowercase letters, indented and run-in with text

PAGINATION

Page numbers on the first page of each section and chapter will be centered ½” from the bottom of the page. Page numbers on subsequent pages will be on the top, outside corner of each page (left side for even pages and right side for odd pages), ½” from the top of the page. Headers should accompany these page numbers, with even pages displaying the title of the report (e.g., *Format-Style Guide*), and odd pages displaying the section or chapter number and title (e.g., *Chapter 1: Introduction*). See the template for style and location of the page numbers and headers. Page numbers should be in Times New Roman 10-point bold type and headings should also be italicized.

Page numbers should appear on all pages for the report with the following exceptions. Do not number the first four pages of the report. Number the rest of the front matter through the executive summary in lowercase roman numerals (i.e., v, vi, etc.). The contents must begin on page v.

Beginning with Chapter 1, number the remaining pages with consecutive arabic numerals (i.e., 1, 2, 3, etc.). Consider blank pages when numbering the pages, but do not type the page number on a blank page.

SECTIONS OF REPORT

Each major section of the report begins at the top of an odd-numbered page. To do this, you may need to insert a blank page if the text in the previous section ends on an odd-numbered page.

Foundation reports require sections to be in the following order when submitted:

1. Half-title page (required). Contains only the title of the report
2. Blank page for use by the Foundation (required)
3. Title page (required)
4. Disclaimer-Copyright (required boilerplate)
5. Table of Contents (required). Include A- and B-level headings under each chapter
6. List of Tables (if applicable)
7. List of Figures (if applicable)
8. Foreword (required boilerplate)
9. Acknowledgments (required)
10. Executive Summary (required)
11. Report Chapters (e.g., Chapter 1: Introduction, Chapter 2: Methods and Materials, etc.)
12. Appendices (optional)
13. Glossary (optional)
14. Reference list (required)
15. Bibliography (optional)
16. Abbreviation list (required)
17. Index (only included in selected reports)

FRONT MATTER

The front matter precedes the body of the report.

Half Title Page (page i)

The half title page contains only the title of the report.

Blank Page (page ii)

Include a blank page for page ii. The Foundation will add a standard statement to this page before sending the report to the printer.

Title Page (page iii)

The information on this page includes the title of the report, the name(s) and affiliation(s) of the contractor(s) who prepared the report, and information on the sponsoring organization and the publisher.

Disclaimer-Copyright Page (page iv)

Follow the example for the correct format and information for this page. If your project is funded as part of a cooperative agreement between the Water Research Foundation and another organization such as the U.S. Environmental Protection Agency, modify the information as shown in the example Disclaimer for a jointly sponsored project. The Foundation may add an ISBN (International Standard Book Number) to this page before sending the report to the printer.

Table of Contents (page v)

The contents page lists all major elements of the report, including sections in the front matter that *follow* the table of contents. Include chapter titles and A- and B-level (first- and second-level) subheadings in the table of contents. Please note that for the table of contents, *the A-level headings do not appear in capital letters*; only the initial letter of each word is capitalized.

The Foundation prefers leaders (the series of dots) between the heading and the page number. When you use leaders, there must be a minimum of three dots between the heading and the page number. If a heading is too long to fit on one line, you will need to break it into two lines, indenting the second line.

List of Tables (begins on odd-numbered page)

This section should provide a list of all tables used throughout the report. All table captions should coincide with tables in the text.

List of Figures (begins on odd-numbered page)

This section should provide a list of all figures used throughout the report. All figure captions should coincide with figures in the text, excluding notes unless they distinguish one figure from another.

Foreword (odd-numbered page)

Use the standard text and format included in the example. Please note the spelling of *Foreword*.

Acknowledgments (odd-numbered page)

Use this section to thank utilities, project advisory committee members, research assistants, administrative assistants, laboratory technicians, employers, etc. The Foundation prefers that you use full first names rather than nicknames or shortened forms of first names. Also include the city and state or country for each person listed. Note correct spelling of *acknowledgments*.

Executive Summary (begins on odd-numbered page)

The executive summary is the most influential part of the report. Besides inclusion in the report, the executive summary will be posted as a separate document on the Foundation's Web site. It is crucial that this summary thoroughly covers the purpose, methods, and results of the project, emphasizing the practical applications of the research. Write the executive summary in a narrative style—leave the detailed data in the body of the report. Limit this summary's length to 2–4 pages of text and include the following sections.

1. **Objectives (required).** State the relevant objectives of the project.
2. **Background (required).** Provide a brief background summary on the issues relating to the project. Include a statement on what research gaps need to be filled concerning the issues.
3. **Approach (required).** Describe the research approach for this project including major tasks completed by the research team.
4. **Results/Conclusions (required).** In a few paragraphs, describe the results and conclusions of the research.
5. **Applications/Recommendations (required).** Describe how this research can be applied by water utilities and the drinking water industry. Applications could include economic implications, regulatory impacts, better communication with customers, technological advancements, management concerns, etc. Make recommendations on how the water industry can implement the research now. Use subheadings to focus on the specific applications and recommendations.
6. **Multimedia (optional).** If the report includes a CD-ROM, software, Web tool, or Web site, include this section with a description.
7. **Research Partners (optional).** Include co-funding organizations and/or Tailored Collaboration partners.

- 8. Participants (optional).** Most Water Research Foundation projects include assistance from utilities, companies, or other organizations. In a sentence or two, or short list, acknowledge these participants.

TEXT

It is encouraged to create the body of the report as the research is being conducted, so progress reports take on the general format of the final report. This makes compiling the draft final report less complicated.

Carefully review the periodic and draft final reports by proofreading for typographical errors, misspelled words, and grammatical errors. In addition, ensure that all references cited in the text appear in the reference list, and that figures and tables cited in the text are in chronological order and contain what the text says they do.

The chapters described below are a guide to help you develop the report. Your report may include additional chapters in between or before or after the ones listed here.

Chapter 1: Introduction (page 1)

The introduction is an overview of the situation—in essence, a statement as to the need for this research. Provide background information, review previous research on the topic, and outline the rationale for and the objectives of the current research.

Chapter 2: Methods and Materials (begins on odd-numbered page)

In this part of the report, technical information explains how you conducted the research. Another researcher ought to be able to use the information provided to duplicate the research. Describe statistical methods, materials used, modifications of standard procedures, and new methods. Simply reference standard methodology, saving details for descriptions of modifications or for new materials or methods.

Chapter 3: Results and Discussion (begins on odd-numbered page)

Describe in words, figures, or tables, actual results and statistical analyses of results. Report unusual results or difficulties with the experimental procedures. Provide interpretation of results as they relate to previous research and the objectives of the research being described.

Chapter 4: Summary and Conclusions (begins on odd-numbered page)

Briefly describe the research project, including purpose, approach, and significant results. Considering the results, describe conclusions drawn from this work. In addition, identify additional research needs related to the topic.

Chapter 5: Recommendations to Utilities (begins on odd-numbered page)

The recommendation section is a very important part of the final report. Most readers work for Foundation subscribers, principally public water utilities, that funded the research. These readers are drinking water professionals responsible for the operation of water treatment plans, maintenance of infrastructure, and water quality. Their interest is knowing how to apply your research.

This section should describe the significance of the results to utility practice, show how this information advances the science of water, and suggest how utilities can apply the project results. Additional steps and limitations or caveats should be identified so utilities can take them into consideration when using the information.

BACK MATTER

The back matter follows the text of the report.

Appendices (begins on odd-numbered page)

In this section, include supplementary material that may aid the reader. Appendices might include step-by-step analytical methods, raw data, or samples of questionnaire forms. If you include more than one appendix, use letters to designate the various appendices (Appendix A, Appendix B, etc.) and in numbers of equations, tables, and figures in the appendices (e.g., Table A.1, Figure B.5, etc.).

If the appendices are longer than the rest of the report, or if the report plus appendices totals over 400 pages, then the Appendices should be placed on a CD to be packaged with the final report.

Glossary (begins on odd-numbered page)

Consult the Foundation project manager to decide if your report needs a glossary. If you prepare a glossary, arrange the words in alphabetical order, placing each term on a separate line followed by its definition. End each definition with a period. Adopt a uniform style for definitions, i.e., using only phrases or only complete sentences, not both. If needed, use cross-references following a simple format: “Term. *See*. Preferred term.” For example,

Contactors. *See*. Post-filter adsorbers.

References (begins on odd-numbered page)

Use the guidance on the next page and the example when formatting the References.

Abbreviations List (begins on odd-numbered page)

Almost every research report contains a list of abbreviations. In the list for your report, define all abbreviations and acronyms used in the text. Include common abbreviations except for state names and chemical notation.

Alphabetize the list by abbreviations, ignoring punctuation, spaces, or symbols. Also ignore subscripts and superscripts unless they differentiate otherwise identical abbreviations. In those cases, list the abbreviations in order by their numerical and then letter subscripts and superscripts. List identical abbreviations in the alphabetical order of their definitions. List abbreviations beginning with a Greek letter at the end of the section representing the corresponding English letter. That is, an abbreviation beginning with a mu (μ) appears at the end of the abbreviations beginning with an em (*m*). Place individual symbols and Greek letters at the end of the list according to the alphabetical order of their definitions.

The abbreviations list in the example reflects abbreviations used throughout this guide and is for illustration only.

References in text

Cite literature references in the text according to the author-date method. In this method, the basic reference consists of the author's last name and the year of publication, with no punctuation in between, as in the following examples:

Concern about the initial portion of the filter run is due to the association of high turbidities with high particle counts (McCoy and Olson 1986).

McCoy and Olson (1986) found that the association of . . .

Note that when the entire citation (i.e., name and year) appears within parentheses, there is *no punctuation between the name and year*. Use commas to separate citations for two or more references within parentheses, but use semicolons if one or more of the citations contain commas.

(Bouwer and McCarty 1983a, Huyakorn et al. 1987, Bower and Wright 1987)

(Bouwer and McCarty 1983a; Bower and Wright 1987; Bae, Odencrantz, and Rittman 1990)

List the last name(s) of one to three authors, and designate four or more authors by using "et al." after the first author's last name.

References in list

For the reference list itself, include the names of all authors—even when there are three or more. Alphabetize entries according to the last name followed by the first name or initial(s) of the first author. For more than one author, alphabetize next by the last name of second author and then last name of third author. List entries for the same author(s) in chronological order by year.

For references published in the same year by the same author(s), use "a," "b," etc., designations (e.g., "1987a," "1987b") to differentiate them in the text and in the reference list.

Each entry's components have a generic order. For the basic components of a book or report, the order is

Author or editor name(s) [Inverse order, last name first only for first author]. Year. *Title*. Place [Location of publisher]: Publisher's name.

The order for the basic components of a journal article is:

Author name(s) [Inverse order, last name first only for first author]. Year. Article title. *Journal name*, Volume number (Issue number): beginning page number–ending page number.

The most recent edition of *The Chicago Manual of Style* contains additional examples of reference styles for other types of documents. Some specific examples of complete references follow:

Acts, Public Laws, Statutes

National Environmental Policy Act, 1982. 42 *U.S. Code*. Sec. 4332.

Safe Drinking Water Act Amendments of 1986. 1991. Pub. L. 102-54, Sec. 3(q) (2), 105 Stat. 278.

AwwaRF report (use Water Research Foundation if report was published beginning in 2009)

Duranceau, S.J., D. Townley, and G. E.C. Bell 2004. *Optimizing Corrosion Control in Water Distribution Systems*. Denver, Colo.: AwwaRF.

Najm, I., N. Patania Brown, K. Gramith, and T. Hargy. 2009. *Validating Disinfection in Ozone Contactors*. Denver, Colo.: Water Research Foundation.

Book

Baes, C.F., Jr., and R.E. Mesmer. 1976. *The Hydrolysis of Cations*. New York: Wiley-Interscience.

Committee on Neurotoxicology and Models for Assessing Risk, National Research Council. 1992. *Environmental Neurotoxicology*. Washington, D.C.: National Academy Press.

CRC *Handbook of Physics and Chemistry*. 1970. 51st ed. Cleveland, Ohio: The Chemical Rubber Co.

Chapter in a Book

Gerba, C.P. 1987. Recovering Viruses From Sewage, Effluents and Water. In *Methods for Recovering Viruses From the Environment*. Boca Raton, Fla.: CRC Press.

Willett, W. 1990. Nutritional Epidemiology. In *Monographs in Epidemiology and Biostatistics*. New York: Oxford University Press.

Chapter in an Edited Book

Anholt, R.R.H. 1992. Molecular Aspects of Olfaction. In *Science of Olfaction*. Edited by M.J. Serby and K.L. Chobor. New York: Springer-Verlag.

Cotruvo, J.A., and M. Regelski. 1989. National Primary Drinking Water Regulations for Volatile Organic Chemicals. In *Safe Drinking Water Act: Amendments*,

Regulations and Standards. Edited by E.J. Calabrese, C.E. Gilbert, and H. Pastides. Chelsea, Mich.: Lewis Publishers.

Craun, G.F. 1986a. Recent Statistics of Waterborne Disease Outbreaks in the U.S. (1981-1982). In *Waterborne Diseases in the United States*. Edited by G.F. Graun. Boca Raton, Fla.: CRC Press.

Craun, G.F. 1986b. Recent Statistics of Waterborne Disease Outbreaks in the U.S. (1920-1980). In *Waterborne Diseases in the United States*. Edited by G.F. Graun. Boca Raton, Fla.: CRC Press.

Compact Discs

Becker, William C., and Charles R. O'Melia. 1996. Optimizing Ozonation for Turbidity and Organics (TOC) Removal by Coagulation and Filtration [CD-ROM]. In *AwwaRF 1998 Reference CD-ROM*. Available: AwwaRF, Denver, Colo. [cited September 15, 1998]

Sierra On-Line, Inc. 1998. Table 1. Major Causes of Death in the United States. In *Collier's Encyclopedia* [CD-ROM]. Available: <http://127.0.0.1:4500/col_table/DE006315T01.htm>. [cited October 20, 1998]

Dissertation or Thesis

Buffin, L.W. 1992. Treatment of Algae-Induced Tastes and Odors by Chlorine, Chlorine Dioxide, and Permanganate. Master's thesis. Virginia Polytechnic Institute and State University, Blacksburg.

Hundt, T.R. 1985. The Removal of Fulvic Acid Using Aluminum Coagulants: Mechanisms and applications. Ph.D. diss., The Johns Hopkins University, Baltimore, Md.

Edited Book

Budavari, S., M.J. O'Neil, A. Sith, and P.E. Heckelman, eds. 1989. *The Merck Index*. 11th ed. Rahway, N.J.: Merck.

Calabrese, E.J., C.H. Gilbert, and H. Pastides, eds. 1989. *Safe Drinking Water Act: Amendments, Regulations and Standards*. Chelsea, Mich.: Lewis Publishers.

Electronic Messages (email and discussion forum)

Colbourne, Jeni <101523.2603@compuserve.com>. 2007. Release of 2nd and 3rd progress reports. E-mail to rfreports <rreports@waterresearchfoundation.com>.

PACS-L (Public Access Computer Systems Forum) [Online]. Houston, Texas: University of Houston Libraries, June 1989-. Available from Internet: <listserv@uhupvm1.uh.edu>. [cited May 17, 1995]

Forthcoming ("In Press") Publication with Date

EMA Services, Inc. 1997. *The Utility Business Architecture: Designing for Change*. Denver, Colo.; AwwaRF and AWWA, forthcoming.

Forthcoming (“In Press”) Publication with No Date [N.d.]

Liu, J., J.C. Crittenden, D.W. Hand, and D.L. PeRam. [N.d] Destruction of Chlorinated Hydrocarbon in Water Using Heterogeneous Photocatalytic Oxidation. *Water Research*. Forthcoming.

Internet Sites

Borland International Inc. 1997. Oracle Licenses Borland’s Java Development Tools [Online]. Available: <<http://www.borland.com/about/press/1997/proracle.html>>. [cited December 11, 1997]

Katz & Associates Inc. 2009. Customer Relations Project Development (Project #563) [Online]. Available: <<http://www.waterresearchfoundation.org/newsprojects/custrel/custrel1.htm>>. [cited February 1, 2009]

Journal Article

Bennett, M.W., and W.J. Myers. 1992. Making Automated Systems Successful: How to Win the Hearts of Organizational Skeptics. *Jour. AWWA*, 84(1):52-54.

Entus, M. 1989. Running Lift Stations Via Telemetry. *Water Engineering and Management*, 137(111):41-43.

Karalekas, P.C., G.F. Graun, A.F. Hammonds, C.R. Ryan, and D.J. Worth. 1976. Lead and Other Trace Metals in Drinking Water in the Boston Metropolitan Area. *Jour. New England Water Works Assn.*, 90(2):150-172.

Online Databases

Morrison, R. Sean, Ellen Olson, Kristan R. Mertz, and Diane Meier. 1995. The inaccessibility of advance directives on transfer from ambulatory to acute care settings. In *JAMA, The Journal of the American Medical Association* [Online], August 9, 1995, 274 (6):478 (5p). Available: Infotrac Searchbank. Health Reference Center - Academic. <http://web7.searchbank.com/infotrac/session/795/933/27650303w3/19!fullart_>. [cited November 2, 1998]

U.S. Senate. 1998. Lethal Drug Abuse Prevention Act of 1998 [Online]. 105th Congress. 2nd sess. S. 2151. Version 2. Available: Lexis-Nexis. Congressional Universe. <http://web.lexis-nexis.com/congcomp/docu...a3&_md5=83c21c90531937284111478d24fb2bcd>. [cited November 2, 1998]

Paper in Published Proceedings

Horton, A.M. Corosion Effects of Electrical Grounding on Water Pipes. Paper No. 519 in *Corosion/91, March 11-15, 1991, Cincinnati, Ohio*. Houston, Texas: National Association of Corosion Engineers.

O’Connor, J.T., B.J. Brazos, W.C. Ford, L.L. Dusenber, and B. Summerford. 1984. Chemical and Microbiological Evaluations of Drinking Water Systems in Missouri. In *Proc. of the Twelfth Annual AWWA Water Quality Technology Conference*. Denver, Colo.: AWWA.

Patent

Block, M., and T. Hirschfeld. 1986. Apparatus Including Optical Fiber for Fluorescence Immunoassay. U.S. Patent 4,582, 809.

Klainer, S., and M. butler. 1991. Specific Measurement of Organic Chlorides. Taiwan patent pending (notice of allowance received).

Presentation at a Meeting

Dabkowski, J. 1994. Safety While Working Near AC Powerlines. Presented at NACE International Western Region Conference, Seattle, Wash., October 31-November 4, 1994.

Hatfield, B. 1981. Melbourne Water Distribution System CoRosion and Its Mitigation. Presented at the Regional Conference of the Australian Water Works Association, Victorian Branch, October 1981, at Thomson Dam Construction Township.

Report, Bulletin, or Similar Document

Angel, S., K. Langry, T. Kulp, and P. Daley. 1988. The Feasibility of Using Fiber Optics for Monitoring Ground Water Contaminants. VII. Formation of Lumophores With Chloroform and Trichloroethylene. Topical Report, Contract No. W-7405-ENG-48. Las Vegas, Nev.: USEPA.

EPRI (Electric Power Research Institute). 1993. *Saving Operating Dollars*. Palo Alto, Calif.: EPRI.

Kodak laboratory Chemicals Catalog No. 54. 1990. 8-Hydroxy-1,3,5-pyrene-trisulfonic Acid Trisodium Slat, No. 119 1774. Rochester, N.Y.: Eastman Kodak.

Rules and Regulations

U.S. Environmental Protection Agency. 1989. 40 CFR Parts 141, 142 and 143. National Primary and Secondary Drinking Water Regulations; Proposed Rule. *Fed. Reg.* (Part II), 54(97): 22062-22160.

U.S. Environmental Protection Agency. 1991. 40 CFR Parts 141, 142 and 143. National Primary Drinking Water Regulations—Synthetic Organic Chemicals and Inorganic Chemicals; Monitoring for Unregulated contaminants; National Primary Drinking Water Regulations Implementation; National Secondary Drinking Water Regulations; Final Rule. *Fed. Reg.* (Part II), 54(20): 3526–3614.

Software

Schecker, W.D., and D.C. McAvoy. 1991. MINEQL⁺: A Chemical Equilibrium Program for Personal Computers. Hollowell, Md.: Environmental Research Software.

Standard Methods

APHA, AWWA, and WEF (American Public Health Association, American Water Works Association, and Water Environment Federation). 1992. *Standard Methods for the Examination of Water and Wastewater*. 18th ed. Washington, D.C.: APHA.

APHA, AWWA, and WEF (American Public Health Association, American Water Works Association, and Water Environment Federation). 1995. Part 6000 Individual Organic compounds: 6220 Volatile Aromatic Organic compounds. *Standard Methods for the Examination of Water and Wastewater*. 19th ed. Washington, D.C.: APHA.

Standards

- ASTM (American Society for Testing and Materials). 1988. *Annual book of Standards*, Part 31, D3370-76. Philadelphia, Pa.: American Society for Testing and Materials.
- AWWA (American Water Works Association). 1988. *American National Standard for Polyethylene Encasement for Ductile-Iron Piping for Water and Other Liquids*. ANSI/AWWA C105/A21.5-88. Denver, Colo.: AWWA.
- NACE (National Association of Corrosion Engineers). 1995. *NACE Standard RP-01-77 (1995 Revision), Recommended Practice: Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems*. Houston, Texas: NACE. Approved July 1977. Revised July 1983, July 1995.

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- Horton, A.M. 1991. Memorandum for Record: Indianapolis Water Company Corrosion Failures. United States Pipe and Foundry Company, Technical Services.
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CHAPTER 3

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This appendix contains numerous examples of points discussed in the narrative of Chapters 2 through 4. When you prepare your draft final report, please follow the format exactly as presented in this appendix. The examples provided include the following:

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CHAPTER 3

Chapter number and title (centered, bold, all caps)

LABORATORY SCALE OZONATION EXPERIMENTS

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2 line spaces

OZONATION OF TOXINS IN FOUR WATERS

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Introduction

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Several studies have shown that the destruction of m-LR by ozone is strongly dependent on the dose (Hart and Stott 1993, Carlile 1994, Fawell et al. 1993, Rositano and Nicholson 1996, Croll and Hart 1996, Hart et al. 1997). There is also evidence that the effectiveness of ozonation will depend on the water quality. Work by Hart and Stott (1993) and Carlile (1994) demonstrated that lower ozone doses were required for the destruction of microcystin in treated water compared with raw water, where the treated water had a significantly lower dissolved organic carbon concentration, and therefore lower ozone demand. Rositano (1996) found that ozonation of a culture of *Microcystis aeruginosa*, with cell counts equivalent to a heavy bloom, required high doses of ozone and extended contact times to destroy the microcystins present. Of these studies only Rositano et al. (1998) and Rositano (1996) related the required dose for destruction of microcystin LR to the appearance of a residual of ozone in solution. Carlson (1993), Bose et al. (1994) and Andrews and Huck (1994) have shown that the concentration of DOC, and the nature of the natural organic material (NOM), will affect the ozone demand of the water, as will the pH and alkalinity. As the ozone demand of the water will determine the ozone dose at which a residual can be detected, it is likely that this value is also very important in the ozonation of microcystin LR.

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Anatoxin-a is also destroyed by ozone, however the doses required for complete destruction appear to be higher than those required for microcystin (Carlile 1994, Pierronne, 1993). Carlile (1994) also found a strong effect of water quality – in particular DOC concentration - on the ozone doses required for destruction of the toxin.

Preliminary work of Rositano et al. (1998) on the ozonation of saxitoxins indicated that the toxicity determined by mouse bioassay decreased with increasing dose of ozone. At the time no analytical technique was available for saxitoxins.

In this Chapter the effect of ozonation on m-LR and m-LA, anatoxin-a and saxitoxins in four treated waters is described. The aim of the work was to clarify the effect of water quality on the destruction of the toxins, and to relate the results to practical application in a wider range of waters.

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Materials and Methods

C-level heading (flush left, bold, italics, title case)

Four Treated Waters

Treated water, before chlorination, was used in this study. The waters studied, the raw water source and the treatment processes are described below.

Hope Valley. Hope Valley Reservoir was sometimes supplemented by River Murray water. The treatment process was conventional treatment, alum coagulation, sedimentation, rapid sand/anthracite filtration.

D-level heading (indent, bold, italics, title case)

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Myponga. Myponga Reservoir was the water source. The treatment process was dissolved air flotation (DAF), rapid sand filtration.

Morgan. *Source water.* River Murray was the source water. The treatment process was conventional treatment, as for Hope Valley.

Groundwater. Lake Wallace and well water served as the Morgan groundwater, in an approximately 70:30 mixture. Treatment process: DAF, rapid sand/anthracite filtration.

NOM Analysis and Characterisation

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Samples were filtered through 0.45 µm membrane. True colour was determined by comparing the absorbance of the sample, at 456 nm (50 mm path length), with a platinum/cobalt standard (50 Hazen Units (HU)). Specific colour was determined by dividing true colour by dissolved organic carbon (DOC) concentration. DOC was measured using a Seivers 820 Total Organic Carbon Analyser. UV absorbance scans were obtained using a GBC UV/Vis 918 spectrophotometer. The specific UV absorbance (SUVA) was calculated using the equation: $SUVA=100*(abs_{254}/DOC)$. High performance size exclusion chromatography (HPSEC) analysis was based on the method used by Chin et al. (1994). The column (Shodex Protein KW-802.5, molecular weight range 0.1K-50K, Waters Australia) was calibrated using polystyrene sulphonates of molecular weight 35K, 18K, 8K, 4.6K and acetone. These compounds are considered to best represent the structure and conformation of NOM in solution. Ultraviolet absorbance at 260 nm was used for the detection of NOM during HPSEC analysis.

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Preparation of Stock Ozone Solution

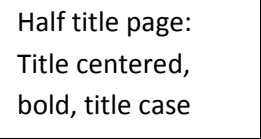
A stock solution of ozonated water was prepared by constantly bubbling ozone gas through high purity water either at room temperature ($20\text{o C} \pm 1\text{o C}$) or on ice (4o C) (Figure 3.1). Ozone gas was generated by an Ozonia CFS-1A ozone generator fed with high purity oxygen. The ozone concentration in the gas phase was varied by varying the current to the ozonating unit, typical concentrations for ozone in the gas phase ranged between 50 and 60 mg L⁻¹. The Indigo Colorimetric Method (APHA et al. 1998) was used for determination of the ozone concentration. The concentration of ozone was determined at regular intervals during each experiment to minimise errors in the applied doses. The room temperature during ozonation experiments remained constant at 20o C.

Determination of Ozone Requirement for Four Waters at T=5 Minutes

Volumetric flasks (100 mL) containing 75 mL of test water were prepared. Flasks were dosed in triplicate with increasing volumes of ozonated water up to 15 mL. High purity water was added to each flask such that after the addition of ozone the final volume was 90 mL. The flasks were shaken vigorously for 5 minutes, 10 mL of indigo solution was then added to the flask and again shaken for another 15 seconds. The residual was then determined. For the Myponga and Hope Valley waters, the ozone stock solution was generated at room temperature and the concentration of ozone was between 10.7 mg L⁻¹ and 13.6 mg L⁻¹.

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Optimization of Filtration for Cyst Removal



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Optimization of Filtration for Cyst Removal

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This publication is a result of one of these sponsored studies, and it is hoped that its findings will be applied in communities throughout the world. The following report serves not only as a means of communicating the results of the water industry's centralized research program but also as a tool to enlist the further support of the nonmember utilities and individuals.

Projects are managed closely from their inception to the final report by the Foundation's staff and large cadre of volunteers who willingly contribute their time and expertise. The Foundation serves a planning and management function and awards contracts to other institutions such as water utilities, universities, and engineering firms. The funding for this research effort comes primarily from the Subscription Program, through which water utilities subscribe to the research program and make an annual payment proportionate to the volume of water they deliver and consultants and manufacturers subscribe based on their annual billings. The program offers a cost-effective and fair method for funding research in the public interest.

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EXECUTIVE SUMMARY

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OBJECTIVES

The purpose of this project was to assess the extent and implications of copper pitting and pinhole leaks for residential potable water plumbing systems. Additionally, the project team planned to investigate known and suspected causes of copper pitting and pinhole leaks through case studies at participating communities.

BACKGROUND

Copper pitting that manifests into a pinhole leak greatly shortens the usable lifespan of potable plumbing pipes. The resulting leak can damage housing infrastructure and other valuables or potentially lead to mold growth. Homeowners, in turn, are adversely impacted by pinhole leaks and bear the financial burden associated with premature pipe failure. Unfortunately, factors that cause pinhole leaks and corresponding mitigation strategies are not well understood.

APPROACH

Multiple data sources were used to assess the extent of pinhole leaks. National surveys were conducted targeting plumbers, homeowners, businesses, and corrosion experts. The team also reviewed a database of copper failures spanning 30 years. The mechanistic causes of pinhole leaks were investigated via intensive case studies at participating communities, where hydrological, biological, and aqueous chemical factors were considered.

RESULTS/CONCLUSIONS

Pinhole leaks have been confirmed in all states and most major urban areas. Approximately 8.1 percent of homeowners nationally have experienced at least one pinhole leak and between 21–60 percent of homes in certain communities have observed pinhole leaks. The total cost of pinhole leaks and pinhole leak prevention in the United States is estimated at \$967 million annually, with the largest proportion of cost (\$564 million) in single family homes particularly devoted to repairs (44 percent). About 58 percent of responding water utilities reported using corrosion inhibitors, and annual costs of dosing corrosion inhibitors per customer (connection) ranged from \$0.10 to \$5.72 with an average of \$1.16.

Case studies at communities experiencing pinhole leaks were designed to confirm suspected pinhole leaks and identify new mechanisms causing pinhole leaks. In terms of internal copper corrosion problems caused by unfavorable water chemistry and microbiology, three factors emerged with strong links to pinhole leaks: (1) high pH and high levels of disinfectant, exacerbated by aluminum and other particles, (2) local production of H₂S in and around pits by sulfate reducing bacteria (SRB), and (3) erosion corrosion in hot water recirculation systems. Other factors are believed to influence pitting corrosion and pinhole leaks.

APPLICATIONS/RECOMMENDATIONS

The results of the various surveys demonstrate that copper pitting is a nationwide concern, particularly where certain unfavorable water chemistry and microbiological factors are present in the distribution system.

Economic Implications

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The total cost of pinhole leaks and pinhole leak prevention in the United States is estimated at \$967 million annually, with the largest proportion of cost (\$564 million) in single family homes. Repair costs comprise the largest proportion of overall costs (44 percent) followed by time costs (31 percent) and property damage costs (25 percent). Costs of pinhole leaks relative to the number of single family homes are proportionately higher in hot spot areas than in the rest of the United States due to two factors: (1) higher incidence of pinhole leaks, and (2) higher costs per pinhole leak. Total costs in hot spot regions varied from \$580 to \$1,716 compared to \$459 in the rest of the United States. Approximately half of respondents were willing to pay more for a guarantee that their plumbing would remain leak free for 50 years. Mean willingness to pay was higher for respondents who have had a pinhole leak (\$1,258) compared to respondents that had no leaks (\$1,021).

In general, pinhole leaks have received little attention from water utilities, as the annual amount spent by U.S. utilities is \$350,000 a year to monitor pinhole leak complaints. About 58 percent of responding water utilities reported using corrosion inhibitors, and most utilities on average have been using inhibitors for 15 years. The results of this research demonstrated that the relatively low cost of a utility using corrosion inhibitors to reduce copper pitting (annual average cost of \$1.16 per customer account) can save customers hundreds to thousands of dollars in plumbing and repair costs.

Customer Relations Benefits

The results of this study provide utilities with a better understanding of the occurrence, costs, and factors that contribute to pinhole leaks in customer plumbing. By being proactive about addressing pinhole leaks in the community, utilities can improve customer satisfaction and reduce negative complaints for the utility's customer service department.

Water Quality and Hydraulic Impacts

Three water quality and hydraulic factors were shown to have a strong correlation to pinhole leaks: (1) high pH and high levels of disinfectant, exacerbated by aluminum and other particles, (2) local production of H₂S in and around pits by sulfate reducing bacteria (SRB), and (3) erosion corrosion in hot water recirculation systems. Significant effort was expended in this project to refine techniques capable of detecting sulfides and SRB bacteria involved in copper pitting corrosion under conditions found in potable water systems.

Operational Impacts

This project developed a protocol to help utilities assess the extent of pinhole leaks in their community. The protocol involves surveys of local plumbers, cultivating relationships with customers, and a proactive effort to take when leaks are encountered.

MULTIMEDIA

The printed report is accompanied by a searchable CD-ROM that contains detailed case studies from the participating communities. The case studies include detailed information on the hydrological, biological, and aqueous chemical factors that led to copper pitting failures.

RESEARCH PARTNER

USEPA

PARTICIPANTS

Utilities from Florida, New Mexico, Tennessee, Ohio, Connecticut, and Iowa participated in this project.

Indent
turnover lines

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Centered,
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ABBREVIATIONSCentered,
bold, all caps

A_a	effective cross-sectional area of the advecting volume
A_s	effective cross-sectional area of the volume of storage zones in the bioreactor
AC	alternating current
A-C	asbestos cement
AC-ma*h	product of the average milliamperes of AC and the contact time
AHA	Aldrich humic acid
amp	ampere
ANSI	American National Standards Institute
AOC	assimilable organic carbon
APHA	American Public Health Association
Assn.	Association
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BDOC	biodegradable dissolved organic carbon
BOM	biodegradable organic matter
$Bq\ m^{-3}$	Becquerel per cubic meter
$^{\circ}C$	degrees Celsius
C_a	concentration of tritiated water in the advecting fluid within the bioreactor
CBE	Council of Biology Editors
CFR	Code of Federal Regulations
Cl.	Club
cm	centimeter
cm^2	square centimeter
Co.	company
DC	direct current
diss.	dissertation
DO	dissolved oxygen
DOC	dissolved organic carbon
dpm/mL	disintegrations per minute per milliliter
DU	dielectric union
EBMUD	East Bay Municipal Utility District
ed.	edition
eds.	Editors
ES	effective size
EPRI	Electric Power Research Institute
$^{\circ}F$	degrees Fahrenheit
Fed. Reg.	Federal Register

Note space between
alphabetical groupsIgnore punctuation or
symbols when
alphabetizing

Model calculations were performed using two available computer programs which calculate equilibrium chemical speciation and include surface complexation modeling of ion adsorption at the oxide-water interface, HYDRAQL (Papelis et al. 1988) and MINEQL⁺, v.3.0 (Schecher and McAvoy 1994). For consistency between programs, the diffuse double layer was chosen to describe electrostatic effects at the charged oxide surface. The two programs are very similar. The principal differences are: (1) MINEQL⁺ has interactive input and output interfaces, (2) HYDRAQL has more flexibility in modeling surface electrostatics, (3) MINEQL⁺ includes in its thermodynamic data base the adsorption constants compiled by Dzombak and Morel for hydrous ferric oxide, (4) ionic strength corrections for adsorption constants (i.e., activity coefficients for solution species) are made automatically by MINEQL⁺ but not by HYDRAQL. To obtain identical results with both programs, adsorption constants must be individually adjusted in the HYDRAQL input file.

The surface complexation model can be applied to model the removal of dissolved constituents during coagulation by assuming that (1) the added coagulant is stoichiometrically converted to the hydroxide solid, (2) removal of the dissolved constituents can be attributed to adsorption, which occurs to the same extent as would adsorption on an equivalent concentration of preformed sorbent, and (3) the adsorbed contaminant is entirely removed by settling and filtration such that the concentration of the contaminant in the product water corresponds to its calculated dissolved concentration. For ferric chloride, stoichiometric conversion to the hydroxide solid (HFO) yields 0.55 mg HFO/L per mg FeCl₃ added.

Characteristics of HFO recommended by Dzombak and Morel, including stoichiometry, specific surface area, surface site concentrations and adsorption constants, were used. The HFO surface parameters and equilibrium constants used in the modeling are summarized in Table 2.8 and Table 2.9.

PROCEDURES FOR MEMBRANE STUDIES

Membrane Test Unit

A laboratory RO/NF test unit was constructed for the membrane studies. This unit offers a wide range of applied pressures, crossflow velocities, and feedwater temperatures. Ultimate temperature control is of paramount importance to obtaining reproducible data of membrane selectivity.

Table callout
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Table 2.8

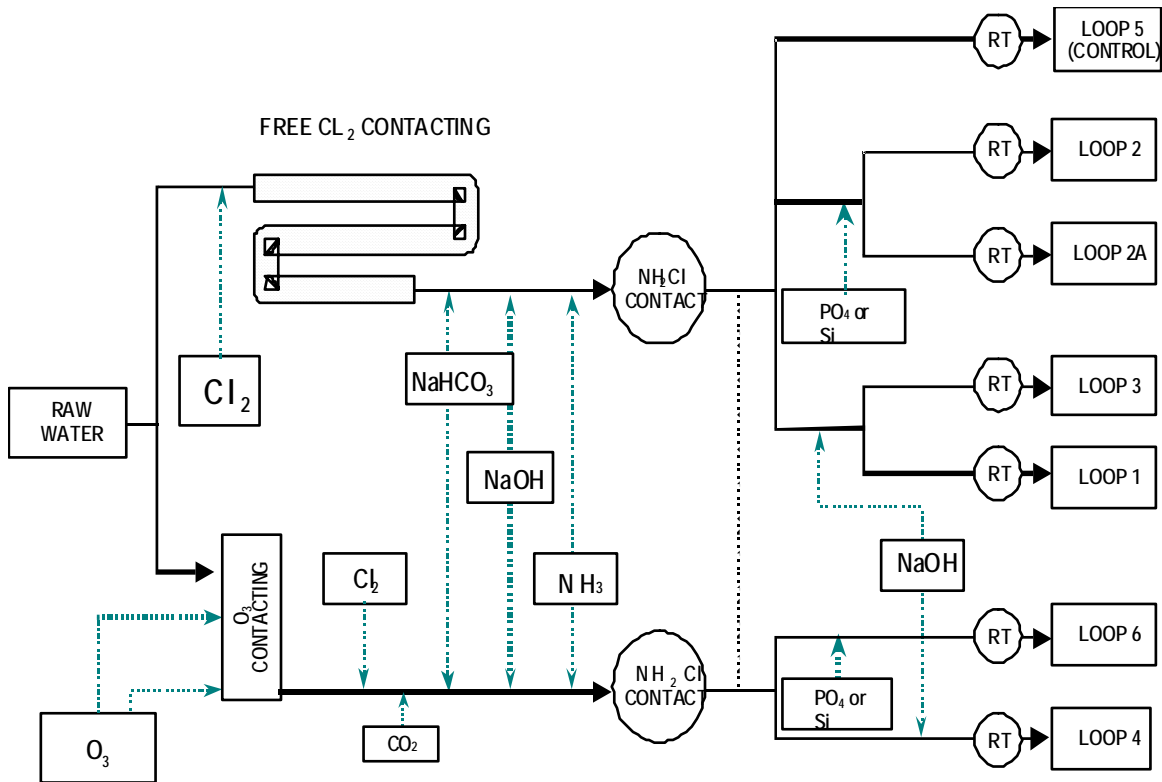
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HFO surface parameters used in the computer modeling

Parameter	Formula	Value
Stoichiometry	Fe ₂ O ₃ ·H ₂ O	89 g HFO/mol Fe
Surface area		600 m ² /g
Surface site density		
Weak adsorption sites	(≡Fe ^w OH)	0.2 mol sites/mol Fe
Strong adsorption sites	(≡Fe ^s OH)	0.005 mol sites/mol Fe

Source: Dzombak and Morel 1990.

Source note at the foot of table



Source: AWWA 1997.

Figure 4.1 Pipe rack schematic

Source note between figure and caption

Figure caption flush left below figure, bold, sentence style capitalization

Center table number and title
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Table 5.3
Number of community water systems sampled and planned for the random survey,
by source-size category and state

State or other entity	Number of CWSs sampled / number of CWSs planned										Per- centage of planned	
	Source-size category											
	GW- VSM	GW- SM	GW- MED	GW- LRG	GW- VLRG	SW- VSM	SW- SM	SW- MED	SW- LRG	SW- VLRG	Total	
AK	4/4	1/1	0	0	0	1/1	0	0	0	1/1	7/7	100
AL	0/0	2/2	2/2	1/1	0	0	0	1/1	3/3	5/5	14/14	100
AR	2/2	2/2	1/1	0	0	0	0/1	1/1	1/1	1/1	8/9	89
AZ	5/5	2/2	1/1	2/2	1/1	0	0	0	0	6/6	17/17	100
CA	19/20	5/5	4/3	7/7	11/11	2/2	2/2	2/2	5/5	30/30	87/87	100
CO	4/5	1/1	0	0	0	1/1	1/1	0/1	2/2	6/6	15/17	88
CT	5/5	1/1	0	0	0	0	0	0	2/2	5/5	13/13	100
DE	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
FL	13/13	5/6	3/3	7/7	17/17	0	0	0	1/1	3/3	49/50	98
GA	11/12	2/3	1/1	1/1	1/1	0	1/1	1/1	3/3	8/8	29/31	94
HI	0	1/1	0	0	1/1	0	0	0	0	0	2/2	100
IA	7/7	4/4	1/1	1/1	1/1	0	0	0	0	2/2	16/16	100
ID	5/5	1/1	1/1	1/1	0	1/1	0	0	0	1/1	10/10	100
IL	7/7	4/5	2/2	2/2	1/1	0	1/1	1/1	3/3	8/8	29/30	97
IN	4/4	4/4	2/2	2/2	1/1	0	0	1/1	1/1	4/4	19/19	100
KS	4/4	3/3	0	1/1	0	0	1/1	1/1	1/1	3/3	14/14	100
KY	1/1	0	0	0	0	0	1/1	2/2	4/5	2/2	10/11	91
LA	8/8	5/5	1/3	2/2	½	0	0	1/1	1/1	5/5	24/27	89
MA	2/2	0/1	2/2	3/3	1/1	0	0	1/1	4/4	8/8	21/22	95
MD	3/4	1/1	1/1	1/1	0	0	0	0	1/1	5/5	12/13	92
ME	2/2	1/1	0	0	0	0	1/1	0	1/1	0	5/5	100
MI	8/9	4/4	1/1	1/1	1/1	0	0	1/1	2/2	4/4	22/23	96
MN	5/6	4/4	1/1	3/3	0	0	0	0	1/1	2/2	16/17	94
MO	8/8	4/4	2/2	1/1	1/1	0	1/1	1/1	1/1	4/4	23/23	100
MS	5/5	8/9	3/3	2/2	0	0	0	0	0	0	18/19	95
MT	4/5	1/1	0	0	0	0	0	0	0	1/1	6/7	86
NC	15/16	3/3	1/1	1/1	0	0	1/1	2/2	4/4	7/7	34/35	97
ND	1/1	1/1	0	0	0	0	0	0	1/1	0	3/3	100
NE	5/5	2/2	1/1	1/1	0	0	0	0	0	1/1	10/10	100
NH	5/5	1/1	0	0	0	0	0	0	1/1	1/1	8/8	100
NJ	3/3	2/2	2/2	4/4	1/1	0	0	0	1/1	8/8	21/21	100
NM	5/5	1/1	1/1	1/1	1/1	0	0	0	0	0	9/9	100
NV	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
NY	12/15	3/4	1/1	3/3	4/4	1/1	2/2	2/2	4/4	16/16	48/52	92
OH	7/7	4/4	2/2	3/3	2/2	0	1/1	1/1	4/4	10/10	34/34	100
OK	3/3	1/2	1/1	1/1	0	1/1	2/2	2/2	2/2	4/4	17/18	94

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Table 5.3 (Continued)

State or other entity	Number of CWSs sampled / number of CWSs planned											Per- centage of planned
	Source-size category											
	GW- VSM	GW- SM	GW- MED	GW- LRG	GW- VLRG	SW- VSM	SW- SM	SW- MED	SW- LRG	SW- VLRG	Total	
OR	5/6	1/1	0	1/1	0	1/1	1/1	1/1	2/2	2/2	14/15	93
PA	11/14	4/5	2/2	1/1	0	1/1	1/1	2/2	6/6	15/15	43/47	92
RI	0	0	0	0	0	0	0	0	0	1/1	1/1	100
SC	3/4	1/1	1/1	0	0	0	0	0	2/2	3/3	10/11	91
SD	2/2	1/1	0	0	0	0	0	0	0	1/1	4/4	100
TN	1/1	1/1	1/1	1/1	1/1	0	1/1	2/2	4/4	4/4	16/16	100
TX	25/24	12/14	3/6	3/3	3/3	0/1	1/2	2/2	5/5	17/17	71/77	92
UT	3/3	1/1	1/1	1/1	0	0	0	0	0	4/4	10/10	100
VA	11/11	2/2	0	0	0	0	1/1	1/1	2/2	6/6	23/23	100
VT	2/3	1/1	0	0	0	0	1/1	0	0	0	4/5	80
WA	15/17	4/4	1/1	2/2	1/1	1/1	1/1	0	1/1	2/2	28/30	93
WI	7/7	4/4	2/2	1/1	1/1	0	0	0	1/1	3/3	19/19	100
WV	2/2	0/1	0	0	0	0	2/2	1/1	1/1	1/1	7/8	88
WY	2/2	0	0	0	0	0	0	0	0	0	2/2	100
NA	6/6	2/2	0	0	0	1/1	0	0	0	0	9/9	100
PR	1/2	1/1	1/1	1/1	0	½	2/2	0/1	1/4	6/8	14/22	64
	292/	121/	50/	63/	53/	12/	26/	30/	79/	228/	954/	
Total	311	132	54	63	53	14	28	32	83	230	1,000	95
Percent- tage of planned	94	92	93	100	100	86	93	94	95	99	95	

GW - ground water; SW - surface water; VSM - very small; SM - small; MED - medium; LRG - large; VLRG - very large; NA - Native American Lands; PR - Puerto Rico

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Table 9.3
Electrochemical fundamentals—bronze

Metal type	Exposure conditions				Exposure Duration (days)	Electrochemical data*			
	Class	pH	Free Cl ₂ † (mg/L)	Combined Cl ₂ ‡ (mg/L)		Corrosion current density§ (μA/cm ²)	Surface potential** (mV)	Anodic Tafel slope†† (mV/decade of current)	Cathodic Tafel slope†† (mV/decade of current)
Bronze	1	8.8	0	0	1	0.55	30	40	90
					7	0.17	60	80	150
					20	0.16	60	85	160
	2	7.5	0	0	1	0.7	20	40	80
					7	0.18	60	70	120
					20	0.17	80	80	120
	3	6.0	0	0	1	2.35	10	35	60
					7	1.0	60	80	100
					20	0.5	65	90	120
	4	7.5	0.5	0	1	2.8	170	60	160
					7	1.2	70	60	170
					20	0.5	60	60	170
	5	7.5	0	0.50	1	2.5	130	75	170
					7	0.8	80	70	170
					20	0.4	70	60	160

Source: Reiber 1993

*Some polarization data points are interpolated from measurements preceding or following the stated duration.

†Free chlorine presented as mg/L total Cl₂.

‡Combined chlorine presented as mg/L total Cl₂.

§Corrosion current density is convertible (Faraday's Law) to a corrosion penetration rate. The approximate conversion constant for copper-based metals is 1 μA/cm² = 1.2 mpy.

**Surface potentials are measured relative to the Ag-AgCl reference electrode (3 M).

††Tafel slopes are expressed as the polarization offset (mV) corresponding to a decade increase in current density.

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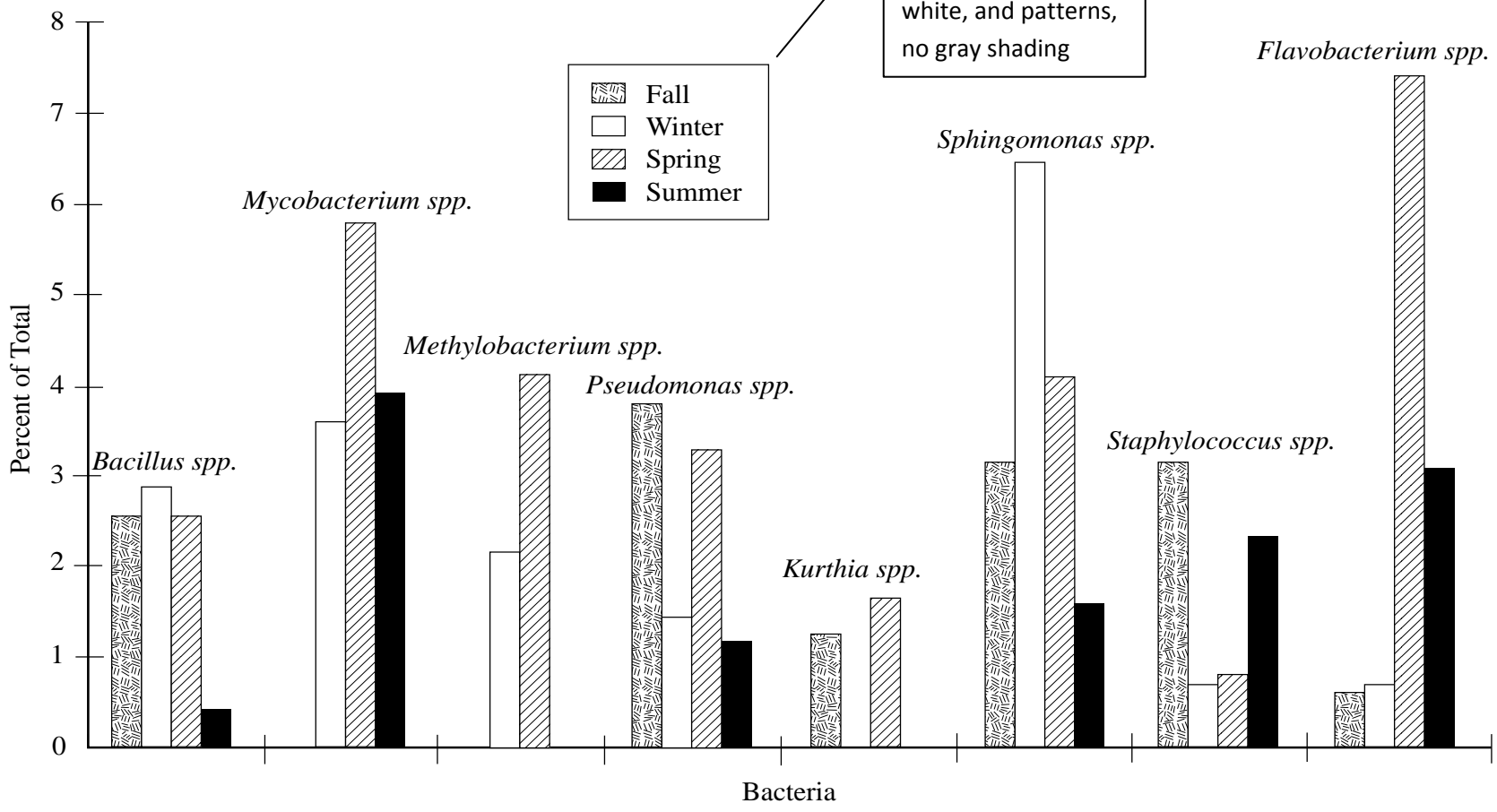


Figure 3.5 Bacteria identification by season for the free-chlorine system

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Hydraulic Loading Rate

Acceptable hydraulic loading rate range for SSF is 0.016 – 0.16 gallons per minute per square foot (gpm/ft²) (0.04 – 0.4 meters per hour [m/h]) (Huisman and Wood, 1974). A hydraulic loading rate of 0.08 gpm/ft² was selected for the SSF plant based on the information obtained through pilot study. This hydraulic loading rate meets the Arizona Department of Environmental Quality (ADEQ) design requirements, 0.032 – 0.16 gpm/ft² (ADEQ, 1987).

Filter Area

The total filter area is calculated by using Equation 6.1.

Callout in text

Indent or center equations

$$A = \frac{Q}{HLR}$$

Equation number in parenthesis

(6.1)

where A = filter bed area, square feet (ft²)
 Q = SSF plant peak flow, gallons per minute (gpm)
 HLR = hydraulic loading rate, gallons per minute per square foot (gpm/ft²)

Two acres of filtration area would be needed to treat 10 MGD of water through SSF at a hydraulic loading rate of 0.08 gpm/ft² (0.2 m/h). For the SSF plant to produce 175.6 MGD, eighteen filters of two acres each would be needed. For plant redundancy and reliability, an additional two filters of two acres each was considered, resulting in a total of twenty parcels with a total of 40 acres of filtration area.

Initial Height of Filter Sand Bed

Visscher recommended a bed depth between 2.65 and 2.95 ft (0.8–0.9 m) (Visscher, 1987). Depth of 3.0 ft is selected for SSF plant to mirror pilot test sand depth.

Indent and define variables

$$Y = \frac{D_i - D_f}{R * F} \quad (6.2)$$

where Y = number of years of operation before sand bed is rebuilt
 D_i = initial height of filter sand bed, ft
 D_f = minimum height of filter sand bed, ft
 R = sand depth removal per scraping, ft per scraping
 F = frequency of scraping, number of scrapings per year

Operators of the slow sand facility at West Hartford, Conn., do not remove the schmutzdecke from their filters, they disrupt the layer by harrowing, and a portion of the debris is removed by headwater drainage (AWWA, 1991; Collins et al., 1991). For SSF cost development, it was assumed that the filters would be cleaned using “harrowing” method as opposed to scraping, which was done for pilot testing.

configuration provided the most definitive results for the sorting of Pb from the other materials. Surface probe measurements are not significantly affected by changes in pipe diameter. Surface probes are typically inserted into the test object to obtain measurements from an inside surface but can also be used on the outside of a test object.

Proper probe selection is essential for the successful outcome of a test. The following criteria were used in the selection of the eddy current probe:

- Electrical considerations:
 - Enhancing the phase separation of the Pb signal from the signals of the other metals found in water service lines. In general, phase separation due to conductivity changes in the test subject for the alloys of interest increases with decreasing frequency.
 - Decreasing the sensitivity to lift-off. The sensitivity to lift-off decreases with lower frequency.
 - Being a side sensing probe to enhance contact with surface
 - Being compatible with the eddy current instrumentation
- Mechanical considerations:
 - Size relative to the diameter of the service line
 - Length of cable relative to the length of the service line
 - Waterproof

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Electronics and Scope

Bullet for main point and
dash for subpoint

The electronic circuitry of test instruments varies, depending on the manufacturer and the mode of operation. The electronics typically operate on a bridge circuit principle. Test objects are placed in each of the two coils. The secondary coil and its test object are represented by a fixed load of 16 μH . The bridge circuit is then electrically balanced. The result of this balance is described as a point on an impedance plane. With the primary coil (test coil) in air, a zero point is determined. Then, using samples taken from water service lines as known materials, the instrument's (such as Defectoscope 2.833 [manufactured by Foerster Instruments, Inc., Pittsburgh, Pa.]) response to Pb, Cu, Fe, galvanized iron, brass, and plastic is evaluated (Figure 3.5). Note that plastic shows no response on the scope. Although galvanized iron is now shown on the figure, its response is similar to that of Fe and appears slightly to the left of Fe. The response to these materials is displayed as a varying amplitude and phase signal on the instrument's screen. An unknown service line's response can then be compared to the response of known samples. This comparison was the basis for the determination of Pb.

Several methods of eddy current data presentation can be employed. Phase and amplitude are the basic bits of information coming from the probe as it interacts with the materials around it. Other important information about the test relates to probe position.

The signals can be interpreted by a local observer (as done in this study) or by some form of automatic control device (such as a threshold alarm and sorting gate for product inspection on an assembly line). The display method employed during this project was the "flying dot" on a CRT, which is a real-time display of phase and amplitude. In this method, the CRT graphically represents an impedance plane. The test coil's impedance appears as a point on the screen. The position of the point has both amplitude and phase values. This method of presentation is common.