## CONTENTS

**CHAPTER 1: INTRODUCTION** ................................................................................................... 1  
  - Purpose .................................................................................................................................. 1  
  - Organization of Guide ....................................................................................................... 1  
  - Water Research Foundation Name Change .........................................................................1

**CHAPTER 2: FORMAT** ..................................................................................................................3  
  - Cover and Title of Report ....................................................................................................3  
  - Acceptable Software ............................................................................................................3  
  - Page Dimensions .................................................................................................... 3  
  - Typeface ............................................................................................................................................ 3  
  - Headings ........................................................................................................................................3  
  - Pagination ....................................................................................................................................4  
  - Sections of Report ......................................................................................... 4  
  - Front Matter .........................................................................................................................4  
    - Half Title Page ........................................................................................................  4  
    - Title Page .................................................................................................................5  
    - Disclaimer-Copyright Page ...................................................................................... 5  
    - Table of Contents .....................................................................................................5  
    - List of Tables ..........................................................................................................5  
    - List of Figures ..........................................................................................................5  
    - Foreword ..................................................................................................................5  
    - Acknowledgments ................................................................................................. 6  
    - Executive Summary ............................................................................................6  
  - Text ......................................................................................................................................6  
    - Chapter 1: Introduction ............................................................................................7  
    - Chapter 2: Methods and Materials ...........................................................................7  
    - Chapter 3: Results and Discussion .................................................................. 7  
    - Chapter 4: Summary and Conclusions ............................................................ 7  
    - Chapter 5: Recommendations to Utilities ........................................................7  
  - Back Matter............................................................................................................ 8  
    - Appendices .............................................................................................................8  
    - Glossary ..................................................................................................................8  
    - References .............................................................................................................8  
    - Abbreviations........................................................................................................ 8  
    - References in Text ........................................................................................ 9  
    - References in List ......................................................................................... 9

**CHAPTER 3: ART PREPARATION, SOURCE NOTES, AND PLACEMENT** 
  - Physical Appearance ..........................................................................................................15  
  - Black and White vs. Color Art ....................................................................................15  
  - Vertical or Portrait Orientation of Art When Possible .............................................. 15  
  - Legible Art ..................................................................................................................15  
  - Source Notes and Copyright: Two Separate Issues ..................................................15
CHAPTER 4: USE OF COPYRIGHTED MATERIALS

When to Request Permission, Copyright Guidelines
What is Copyrightable?
Fair Use
Citation of Source
How to Request Permission
Copyright Permission Form
Granting Permission
Guidelines on Publishing or Presenting Water Research Foundation Project Material

APPENDIX A: EXAMPLES
Half Title Page
Title Page
Title Page for Jointly Sponsored Project
Disclaimer/Copyright Page
Disclaimer/Copyright Page for Jointly Sponsored Project
Contents
List of Tables
List of Figures
Foreword
Acknowledgments
Executive Summary
References
Abbreviations
Table (With Source Note)
Figure (With Source Note)
Vertical (Portrait) Table That Runs Two Pages
Horizontal (Landscape) Table
Horizontal (Landscape) Figure
Equations
Lists

APPENDIX B: CHECKLISTS, FORMS, AND GUIDELINES (SEE MICROSOFT WORD FILE)
CHAPTER 1
INTRODUCTION

PURPOSE

The Water Research Foundation sponsors beneficial research to the water industry in North America and abroad. The final research report is one tool for communicating research results to the principal audience—water utilities. WRF 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 WRF Research Manager or Communications & Marketing (C&M) staff. Further, discuss with your Research Manager and C&M staff if you plan to prepare a research report as a final deliverable but wish to use a different format and style than the one presented in this guide.

ORGANIZATION OF GUIDE

This 8th edition of WRF’s Format Style Guide has three major sections. A template with WRF’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.

WATER RESEARCH 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 WRF. 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 the first reference, the acronym WRF may be used 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 Research 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 formatted on 8½” x 11” paper size. All margins should be set to 1”.

TYPEFACE

WRF 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.

For an occasional table or figure, you may need to use a smaller type size. WRF 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

<table>
<thead>
<tr>
<th>Level</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>A- OR FIRST-LEVEL</td>
<td>Bold uppercase letters, 12-point type, aligned at left margin, and a single line space above and below</td>
</tr>
<tr>
<td>B- or Second-level</td>
<td>Bold upper- and lowercase letters, aligned at left margin, and a single line space above and below</td>
</tr>
<tr>
<td>C- or Third-level</td>
<td>Bold, italic upper- and lowercase letters, aligned at left margin, and a single line space above and below</td>
</tr>
<tr>
<td>D- or Fourth-level</td>
<td>Bold, italic initial uppercase letter and lowercase letters, indented and run-in with text</td>
</tr>
<tr>
<td>E-or Fifth-level</td>
<td>Italic, initial uppercase and lowercase letters, indented and run-in with text</td>
</tr>
</tbody>
</table>
PAGINATION

Page numbers will be centered ½” from the bottom of the page. Page numbers should be in Times New Roman 10-point bold type.

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.

WRF 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.
“About the Water Research Foundation” Page (page ii)

WRF’s report template includes standard text on this page.

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.

Contents (page v)

The Contents page lists all major elements of the report, including sections in the front matter that follow the 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.

WRF 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 software, videos, a Website, etc., include this section with a description.
7. Research Partners (optional). Include co-funding organizations and/or Tailored Collaboration partners.
8. Participants (optional). Most WRF projects include assistance from utilities, companies, or other organizations. In a sentence or two, or short list, acknowledge these participants.

**Note: if you already mentioned participants in the Acknowledgments, there is no need to list them a second time in the Executive Summary.**

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. You may include some or all of these chapters, and additional ones not 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 submitted separate from 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 ($\mu$) 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; Odencrantz et al., forthcoming)

List the last name(s) of one to two authors, and designate three 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 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.

When in doubt about how to reference a particular type of source, follow the above format for books.
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**  

**AwwaRF Report published prior to 2009**  
*Note that there should be one space between multiple initials, as in the below example:*


**WRF Report published since 2009**  

**Forthcoming WRF reports**  

**Book With One Author**  

**Book With Multiple Authors**  

**Edited or Translated Book**  

**Book With an Author Plus Editor/Translator**  
Chapter in a Book

Chapter in an Edited Book

Chapter in Forthcoming Book

Compact Discs
Instructions from the Chicago Manual of Style are as follows:
Include the name of the author or other person primarily responsible for the content; the title, in italics or quotation marks, as applicable; the name of the recording company or publisher; any identifying number of the recording; indication of medium (compact disc, audiocassette, audiovisual file, etc.); and the copyright date or date of production or performance. Recordings consulted online should include a URL or DOI


Dissertation or Thesis

Journal Article
Journal names may be abbreviated, but please abbreviate consistently.


**Magazine Article**


**Newspaper Article**


**Online PDFs/Documents**

*When possible, include an access date.


**Organization as Author**


**Paper in Published Conference Proceedings**


**Patent**

**Presentation at a Meeting**

**Rules and Regulations**

**Standard Methods**

**Standards**

**Unpublished Documents, Reports, Memos**


**Unpublished Interviews and Personal Communications**

In a parenthetical citation, the terms personal communication (or pers. comm.), unpublished data, and the like may be used after the name(s) of the person(s) concerned, following a comma. Reference list entries are NOT necessary, though each person cited must be fully identified elsewhere in the text. Initials may be used for first names. The abbreviation et al. should be avoided in such citations.

(Julie Cantor, pers. comm.)

(A. P. Møller, unpublished data; C. R. Brown and M. B. Brown, unpublished data)

**Sources with an Unknown Publication Date**

When the publication date of a printed work cannot be ascertained, the abbreviation n.d. takes the place of the year in the reference list entry and text citations. Though it follows a period in the reference list, n.d. remains lowercased to avoid conflation with the author’s name; in text citations, it is preceded by a comma.

Smith, J. T. n.d. *Title of Work...*

(Smith, n.d.)

**Websites**


The below example is citing an individual entry from within an online EPA database. Note that the database title is not in quotations, while the specific entry is in quotations:


To cite an undated website in a reference list, use an access date rather than n.d. (no date):

CHAPTER 3
ART PREPARATION, SOURCE NOTES, AND PLACEMENT

The term art refers to all nontext, displayed material: tables, figures, graphs, charts, maps, and photographs. This chapter discusses both the physical appearance of art and the placement of art relative to text in the report.

PHYSICAL APPEARANCE

Black and White vs. Color Art

Color may be used in research reports. However, if you prepare the report in color, keep in mind that many users will print the PDF version of the report in black and white, so faint colors such as yellow will appear white, while darker colors such as red will appear black when printed.

Vertical or Portrait Orientation of Art When Possible

WRF prefers that art be designed and positioned vertically on the page, in portrait layout, because vertical art is easier to read. However, horizontal or landscape-oriented tables and figures are acceptable if the art would not be legible vertically. For example, tables with six or more columns are usually presented most clearly in a horizontal format that allows 9” for the table “width” (see horizontal [landscape] table).

Legible Art

Always look over all art carefully to see that it is legible and looks professional and proofread art for typographical errors. If type is not legible or graphics look blotchy in your original art, that art will look even worse on the printed page. Handwritten labels are not acceptable. The Foundation prefers that type on art be no smaller than 8 point.

SOURCE NOTES AND COPYRIGHT: TWO SEPARATE ISSUES

If either the data or the physical art itself is not yours, you must include a source note with the art. The scholarly responsibility of acknowledging sources is separate from the legal responsibility of requesting permission for material under copyright. Art without a source note will be assumed both to be your data and to be your creation. For example, if you have created a table or graph to display significant data from another source, you should cite the source of the data (using the author-date system).

All source notes should include a minimum of the author’s last name and year of publication (“Source: Smith 1987”). Some source notes may require wording to clarify the extent of duplication.

Source: author year. (Art itself taken from source)
Source: Data from author year. (Data only from source)
Source: Adapted from author year. (You modified art from source)
For one or two authors, give both last names; for three or more, use the first author’s last name and “et al.” List complete bibliographic information for all source notes in the reference list (see “References”).

The source note for a table should be positioned at the foot of the table before other notes (see example table). The source note for a figure precedes its caption on a separate line (see example figure).

If you use art taken from a copyrighted publication or you closely reproduce art from a copyrighted source, you must also request permission to use the art from the copyright holder. See the sample letter requesting permission. Not requesting permission can delay publication of your report, so you should request permission early. Chapter 4 discusses use of copyrighted materials. Please consult your project manager or C&M staff with questions about copyright.

**PLACEMENT OF ART RELATIVE TO TEXT**

The Foundation assumes that you create tables for your report using your word processing or desktop publishing software and therefore can position each table close to the first mention of it in the text.

Because you most likely create figures with another type of software, you have a choice in placing the figures. You may either group figures at the end of the chapter in which they appear, or you may position each figure within the text close to the first mention of it in the text. Choose one approach to figure placement and use it throughout your report.

All the following guidelines apply when placing art within the text:

- When placing art on a page with text or other art, insert at least one line return of space to separate the art from text or other art.
- Art should follow its first mention in the text closely, unless it is grouped at the back of a chapter or appendix.
- For tables and figures that run two or more pages, follow these rules:
  - First page of art carries art number plus caption and the phrase “(continued)” should appear at the foot of the art.
  - On all following pages, table headings or figure captions should be the number and the phrase “(continued)” with no title.
- For tables, please remember to repeat column heads on each page of table.
- Place all footnotes at foot of last page.

**TABLES**

Table numbers should be double-digit, keyed to the number of the chapter in which the table appears (Table 2.1, Table 3.1, etc.). Center table captions (number and title) above the table (see example table). The table caption should be in bold type. Use sentence style capitalization for table title, column headings, and entries within the table. Units of measure in captions should appear in parentheses. Use an extended single rule (a line) above and below column heads and at the end of the table.

Use footnotes to explain or supplement material presented in a table, and use source notes to credit data taken from another source. Place a table’s source note before all other notes at the foot of the table (see example table).
FIGURES

Number figures (including drawings, charts, photographs, etc.) with double-digit numbers keyed to the chapter number in which the art appears (Figure 2.1, Figure 2.2, Figure 3.1). A figure’s caption (number and title) should be flush left beneath the figure (see example figure). The figure caption should be in bold type. Use sentence style capitalization for figure titles, notes, and legends. However, use headline style capitalization for labels within a figure or along axes of a graph. Units of measure in axes labels should appear in parentheses.

The type and graphics in the figures must be legible. If your art is blotchy or hard to read, it will become worse when printed.

The Foundation prefers that type on figures be 12-point size. On occasion, however, a figure may need smaller type but not smaller than 8 point. Use real sub- and superscript characters (“ft^2” not “ft2” or “ft^2”) and real Greek letters (“µm” not “um”). To avoid ambiguity, spell out words unless you abbreviate a term in the text (“concentration” not “concn.” but “GAC” is okay).
CHAPTER 4
USE OF COPYRIGHTED MATERIALS

WHEN TO REQUEST PERMISSION, COPYRIGHT GUIDELINES

You are responsible for obtaining written permission to use any material copyrighted by others. You must request permission before submitting your final report.

What is Copyrightable?

A U.S. copyright may exist for a work of authorship reduced to a tangible medium of expression. It can be a literary work, musical work, dramatic work, pantomime or choreographic work, pictorial, graphic, or sculptural work, motion picture or other audiovisual work, sound recording, or architectural work. Copyright law may apply to a work even though:

- the author has not filed for copyright officially
- there is no legend indicating copyright ownership on a work
- a work is unpublished

As a result, if you use a work or a portion of a work, you should request permission from the publisher (for a published work) or from the author (for an unpublished work) before using it in any Water Research Foundation materials.

Most government publications are in the public domain because public funds supported their development (this is usually true for U.S. federal, state, country, and city government publications and for government publications of other countries). “Public domain” means that material is not protected by copyright and may be used without requesting permission. However, it is best to check with the government entity that created the work to ensure that there is no ownership of the work, for example, by a private contractor who may have jointly created the work with the government. Any work published before 1906 is in the public domain and is not copyrighted.

For a helpful introduction to copyright basics, watch the following video: [http://www.copyright.com/learn/media-download/copyright-basics/](http://www.copyright.com/learn/media-download/copyright-basics/).

Fair Use

Portions of some copyrighted materials may be used without permission. If you are using an “insubstantial” portion of a copyrighted work for scholarly and noncommercial purposes, permission is not required under interpretation of fair use. However, the definition of fair use varies depending on the facts of each case. To avoid difficulties, you need to request permission for all uses of previously copyrighted works of authorship.

In the case of artwork, for example, you must obtain permission to use in your report any tables, charts, amps, photographs, etc., taken from a previously published, copyrighted source. If you take data from several sources and create your own table or figure from that data, you do not need to request permission, but you must list your sources beneath the new piece of art.
Citation of Source

You should always give a proper source for material that is not yours, regardless of whether or not you need to request permission for a quote, figure, or table. (See Source Notes and Copyright: Two Separate Issues on page 15) The scholarly responsibility of providing accurate citations is a separate issue from the legal responsibility of requesting permission for reuse of copyrighted material. For example, if you take raw data from several sources or use materials that are not copyrighted, you should properly cite the source of such data or materials.

HOW TO REQUEST PERMISSION

When requesting permission, clearly identify the material and state how and where you intend to use it. Be specific, stating author, title, edition number, year of publication, and page number for materials from books.

Identify figures and tables by numbering the copyrighted source, and text materials by beginning and ending wording. If the material is from a journal, include the journal title, volume and page numbers, article title, and author’s name. Make sure to request permission from the original publisher, not from one that reproduced the material. Send two original letters requesting permission; the publisher will retain one and sign the other and return it to you. See the sample letter requesting permission. Send the written permissions or copies of your requests for permission (if permission has not yet been granted) to the project manager, along with the final report. The Foundation will file them with other contract materials. If the publisher requests any fees, talk to the project manager.

You may request permission to use Foundation materials directly from the Foundation Web site by completing the form at http://www.waterrf.org/Pages/request-material-use.aspx.

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LIST OF TABLES ........................................................................................................................ vii

LIST OF FIGURES ....................................................................................................................... ix

FOREWORD .................................................................................................................................. xi

ACKNOWLEDGMENTS ............................................................................................................. xiii

EXECUTIVE SUMMARY ........................................................................................................... xv

CHAPTER 1: INTRODUCTION AND BACKGROUND ...............................................................1

Overview ......................................................................................................................................1

Objectives ....................................................................................................................................1

Significance of the Project ...........................................................................................................2

Review of Previous Studies .......................................................................................................2

CHAPTER 2: IDENTIFICATION AND EVALUATION OF POTENTIAL

METHODOLOGIES AND TECHNOLOGIES ...........................................................................5

Determining Potential Direct Identification Techniques .......................................................6

Literature Search .......................................................................................................................7

Patent Search ...........................................................................................................................7

Interviews With Vendors ..........................................................................................................8

Potential Direct Identification Technologies ...........................................................................8

Overview of Indirect Method ....................................................................................................17

Conclusions ...............................................................................................................................18

APPENDIX A: TECHNOLOGY SEARCH ..................................................................................67

APPENDIX B: DIRECT METHOD FIELD TESTS ......................................................................71

APPENDIX C: DEFECTOSCOPE AF 2.833 SETUP PROCEDURE ...........................................79

REFERENCES .............................................................................................................................85

ABBREVIATIONS .......................................................................................................................87
<table>
<thead>
<tr>
<th>Table Number</th>
<th>Table Title</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Cases of injury in various industries</td>
<td>7</td>
</tr>
<tr>
<td>3.1</td>
<td>Relationships between raw water quality and treatment processes</td>
<td>35</td>
</tr>
<tr>
<td>3.2</td>
<td>Treatment process and water quality parameters in relation to automation level and staffing</td>
<td>37</td>
</tr>
<tr>
<td>3.3</td>
<td>Plant size and complexity in relation to automation level and staffing (sorted by plant size)</td>
<td>38</td>
</tr>
<tr>
<td>3.4</td>
<td>Plant size and complexity in relation to automation level and staffing (sorted by number of treatment processes)</td>
<td>39</td>
</tr>
<tr>
<td>3.5</td>
<td>Plant size and complexity in relation to automation level and staffing (sorted by complexity index)</td>
<td>40</td>
</tr>
<tr>
<td>3.6</td>
<td>Plant size and flow variation in relation to automation level and staffing</td>
<td>41</td>
</tr>
<tr>
<td>3.7</td>
<td>Plant criticality in relation to automation level and staffing</td>
<td>42</td>
</tr>
<tr>
<td>3.8</td>
<td>Control system design or installation date in relation to automation level and staffing</td>
<td>43</td>
</tr>
<tr>
<td>3.9</td>
<td>Control system remoteness in relation to automation level and staffing</td>
<td>44</td>
</tr>
<tr>
<td>5.1</td>
<td>Common analytical sensors used in water treatment</td>
<td>70</td>
</tr>
<tr>
<td>5.2</td>
<td>Common sensor operating principles</td>
<td>71</td>
</tr>
<tr>
<td>6.1</td>
<td>Maintenance labor time estimation for turbidity analyzer</td>
<td>84</td>
</tr>
<tr>
<td>6.2</td>
<td>Estimates of maintenance time for some common water treatment plant instruments</td>
<td>84</td>
</tr>
<tr>
<td>6.3</td>
<td>Instrumentation maintenance labor time estimate</td>
<td>88</td>
</tr>
<tr>
<td>6.4</td>
<td>Software maintenance labor time estimate</td>
<td>88</td>
</tr>
<tr>
<td>6.5</td>
<td>Control system hardware maintenance labor time estimate</td>
<td>89</td>
</tr>
<tr>
<td>6.6</td>
<td>Total maintenance labor time estimate</td>
<td>89</td>
</tr>
</tbody>
</table>
FIGURES

1.1 Participating utility field-testing location map ..........................................................5

2.1 Typical connections to domestic electrical configurations and potable water services ..........................................................9

2.2 Alternating current return paths .............................................................................11

2.3 Corrosion rates of steel in soil exposed to various levels of AC ..............................17

2.4 Comparison of virtual DC and AC waveforms created by hand-held hair dryer .......21

4.1 Participating utilities reporting shock incidents related to removing water meters during the period 1989-1994 ........................................................................36

4.2 Participating utilities reporting corrosion failures of distribution and service piping due to grounding effects from 1989 to 1994 ..................................................36

6.1 Schematic diagram of current paths for buried electrically continuous water services ..................................................................................126

6.2 Schematic diagram of current paths for buried electrically discontinuous water services ..................................................................................127

6.3 Schematic diagram of current paths for electrically discontinuous water services in air ..................................................................................128

6.4 Copper and zinc concentrations as a function of AC-ma*h for initial scoping tests at EBMUD with 123 VAC applied ......................................................................133

6.5 Lead concentration as a function of AC-ma*h for initial scoping tests of EBMUD with 123 VAC applied ..................................................................................133

6.6 Copper and zinc concentrations as a function of AC-ma*h for initial scoping tests at EBMUD with ~53 VAC applied ......................................................................134

6.7 Lead concentration as a function of AC-ma*h for initial scoping tests at EBMUD with ~53 VAC applied ..................................................................................134

6.8 Follow-on testing test article Type “A”; Cu/DU/Cu .....................................................................137

6.9 Follow-on testing test article Type “B”; Cu/PVC/Cu ................................................................138

6.10 Follow-on testing test article Type “C”; Cu + Pb/DU/Cu + Pb ..............................................139

Note that section begins on odd-numbered page
The Water Research Foundation (Foundation) is a nonprofit corporation that is dedicated to the implementation of a research effort to help utilities respond to regulatory requirements and traditional high-priority concerns of the industry. The research agenda is developed through a process of consultation with subscribers and drinking water professionals. Under the umbrella of a Strategic Research Plan, the Research Advisory Council prioritizes the suggested projects based upon current and future needs, applicability, and past work; the recommendations are forwarded to the Board of Trustees for final selection. The Foundation also sponsors research projects through the unsolicited proposal process; the Collaborative Research, Research Applications, and Tailored Collaboration programs; and various joint research efforts with organizations such as the U.S. Environmental Protection Agency, the U.S. Bureau of Reclamation, and the Association of California Water Agencies.

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

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

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

EPA

PARTICIPANTS

Utilities from Florida, New Mexico, Tennessee, Ohio, Connecticut, and Iowa participated in this project.
CHAPTER 1
LABORATORY SCALE OZONATION EXPERIMENTS

OZONATION OF TOXINS IN FOUR WATERS

Introduction

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.

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.

Materials and Methods

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.
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**

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*(abs254/ 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.

**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 (20o C ± 1o 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.


ABBREVIATIONS

Aa effective cross-sectional area of the advecting volume
Ae 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

°C degrees Celsius
Ca 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
cm² 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

°F degrees Fahrenheit

Note space between alphabetical groups
Ignore punctuation or symbols when alphabetizing

Just like the first page of a chapter, the Abbreviations list will always begin on an odd-numbered page
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 by 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 2.8**

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<tr>
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*Source: Dzombak and Morel 1990.*

Figure 4.1 Pipe rack schematic
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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
### Table 9.3
Electrochemical fundamentals—bronze

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<th>Combined Cl₂‡ (mg/L)</th>
<th>Exposure Duration (days)</th>
<th>Corrosion current density§ (μA/cm²)</th>
<th>Surface potential** (mV)</th>
<th>Anodic Tafel slope†† (mV/decade of current)</th>
<th>Cathodic Tafel slope†† (mV/decade of current)</th>
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</table>

*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 1μA/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.
Figure 3.5 Bacteria identification by season for the free-chlorine system

Note use of black, white, and patterns, no gray shading

Center landscape figure on the page

Flavobacterium spp.

Methylobacterium spp.
Pseudomonas spp.

Staphylococcus spp.

Sphingomonas spp.

Kurthia spp.

Fall
Winter
Spring
Summer

Bacillus spp.

Mycobacterium spp.

Flavobacterium sp.

Fall
Winter
Spring
Summer

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

Percent of Total
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.

\[ A = \frac{Q}{HLR} \] (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.

\[ Y = \frac{D_i - D_f}{R * F} \] (6.2)

where

- \( Y \) = number of years of operation before sand bend 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

**Electronics and Scope**

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.