Risk Reduction in Drinking Water Distribution Systems

Arnold and Mabel Beckman Center
National Academies of Sciences and Engineering
Irvine, California
February 27-28, 1994

NWRI National Water Research Institute

USEPA / ENVIRONMENTAL CRITERIA AND ASSESSMENT OFFICE

Risk Reduction in Distribution Systems Workshop

SPONSORED BY

National Water Research Institute

AND THE

United States Environmental Protection Agency
Environmental Criteria and Assessment Office

Arnold and Mabel Beckman Center
National Academies of Sciences and Engineering
100 Academy Drive
Irvine, California 92715
February 27-28, 1994

Published March 3, 1994
by

NATIONAL WATER RESEARCH INSTITUTE
10500 Ellis Avenue
P.O. Box 20865
Fountain Valley, California 92728-0865

National Water Research Institute Occasional Paper Number NWRI-94-1

FOREWORD

This report presents the results of a workshop which addressed the issue of risks to water quality while it is in a distribution system. The workshop was organized by the National Water Research Institute in collaboration with the U. S. Environmental Protection Agency's Environmental Criteria and Assessment Office in Cincinnati (ECAO-Cin).

Twenty-six participants from the federal government, water utilities, industry, the research community, and professional associations attended the workshop which was held in the Arnold and Mabel Beckman Center of the National Academies of Science and Engineering. The Beckman Center is located immediately adjacent to the campus of the University of California at Irvine.

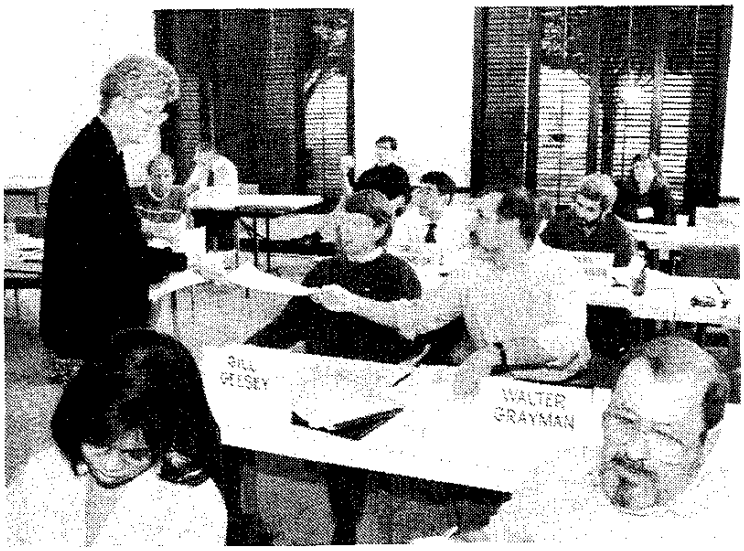
The priority problems presented in this report were generated by the participants. These are their words, written in response to the workshop question which was *What research is needed to reduce risks to water quality in drinking water distribution systems?*

The responses to that question are presented in this report in the order of importance attached to each by the participants. The report is organized into three sections. The first is an introductory section which describes how the workshop was conducted and provides a preliminary analysis of the results. The second part presents each of the ninety one responses to the workshop question grouped under 39 major headings which appear in the table of contents. The third part of this report comprises appendices which contain a more detailed analysis of the ranking of research problems by the participants, including an analysis of five sub-groups of participants.

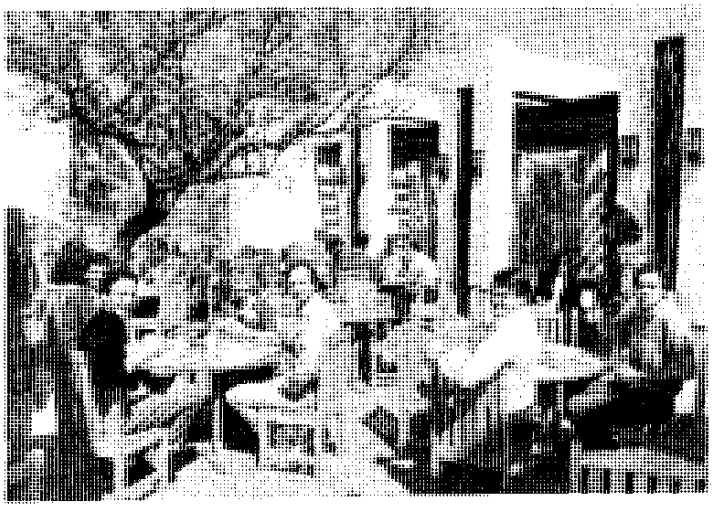
We want to acknowledge the insightful and substantial contributions made to this workshop by the participants themselves. The staff of the Beckman Center provided excellent accommodations and support. The workshop staff also deserves our thanks, including Lucy Bravo, Sunny Bathanti, Michael Abrams, word processors; Joseph Pezely, graphics; Greg Leslie, graphics assistant; Patricia Linsky, coordinator and editor; and Teresa Taylor, photographer.

Ronald B. Linsky
Executive Director
National Water Research Institute
Workshop Secretary

William S. Gaither
Gaither & Associates
Workshop Chair

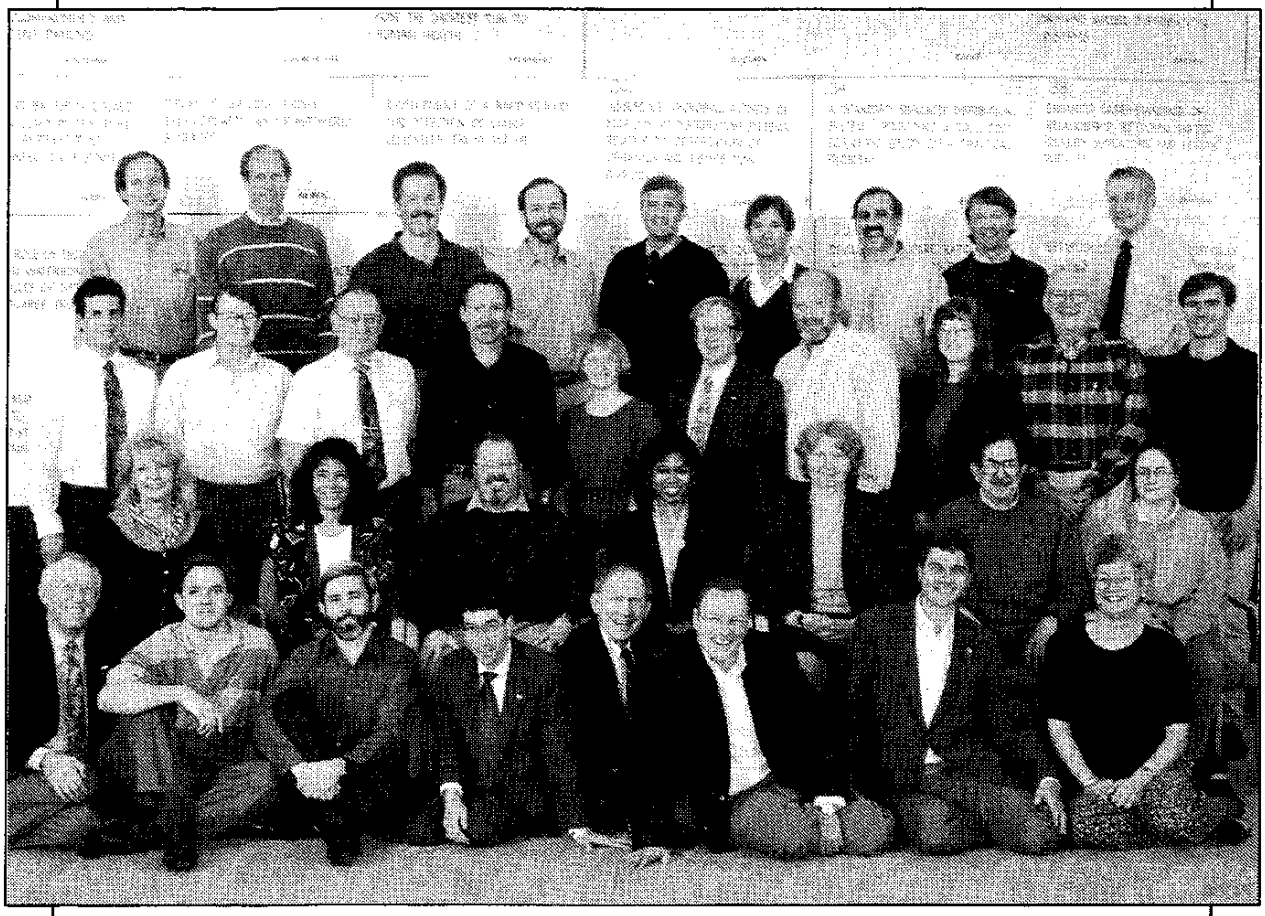

WALTER
GRAYSMAN


JOE
PEZELY



CONTENTS

PARTICIPANTS



TOP ROW: (LEFT TO RIGHT) Roy Wolfe, Rick Karlin, Steve Rieber, Steve Hubbs, Joe Falkinham III, Tim Ford, Walter Grayman, Gill Geesey, Joe Pezely *(Graphics)*

STANDING: Mike Abrams *(Word processor)*, Terry Harvey, Leonard Dueker, Harry Ridgway, Anne Camper, Slavomir Hermanowicz, Darrell Smith, Susan Velazquez, Bill Dresher, Greg Leslie *(Graphics Assistant)*

SEATED: Sunny Bathanti and Lucy Bravo *(Word processors)*, Jack DeMarco, Raynetta Curry-Grant, Anita Highsmith, Alan Holtzman, Karen Eager

FLOOR: Ron Linsky, Marc Edwards, Mark LeChevallier, Gregg Kirmeyer, Bill Gaither, Bob Clark, Stephen Clark, Patricia Linsky

WORKSHOP ORGANIZATION

Preparations

Planning for this workshop began in 1993 when the Executive Director of the National Water Research Institute (NWRI) began discussions with the Director of the Environmental Criteria and Assessment Office of the U.S. Environmental Protection Agency (EPA) concerning the possibility of developing a joint venture partnership to identify and support research addressing risk reduction in drinking water distribution systems.

Following the execution of a memorandum of agreement, the organizations began to plan a workshop that would address the issues of risk reduction in drinking water systems. In the winter of 1993, a group of nationally-recognized experts were identified and invited. When acceptances were received, materials describing workshop procedures and preparations needed were sent out with a confirming letter (See Appendix H). Also included in this mailing were copies of the working forms to be used at the workshop. Each participant was asked to arrive with some homework done and several problems written out which they would present.

Participants arrived on Saturday afternoon, February 26, and on Sunday the 27th toured *Water Factory 21* operated by the Orange County Water District and the supporting research laboratories. In the evening participants assembled at the Arnold and Mabel Beckman Conference Center, the west coast "home" of the National Academies of Sciences and Engineering, located adjacent to the campus of the University of California at Irvine. Following a social period, registration, and dinner, the participants took their designated places in the workroom. Dr. Terry Harvey, Director of the Office of Research of the USEPA, delivered an opening address, outlining his vision of the significance of the problems the group had gathered to address.

Next, the workshop chair explained the procedures to be followed during the workshop the following day and answered questions. Participants were encouraged to return to their quarters and complete any unfinished homework.

Agenda

Breakfast was served at the Beckman Center at 7:00 a.m. and the workshop began promptly at 8:00 a.m. The process followed was a modified version of the Nominal Group Technique developed by Professor Andre Delbecq and his colleagues at the University of Wisconsin in the decade of the 1960s (Ref. 1). The day was divided into three phases:

- **8:00-12:00 NOON** Identification and Posting of Research Problems
- **12:00 NOON** Lunch
- **12:45-4:15 P.M.** Consolidation of Problems into Coherent Groups
- **4:15-4:30 P.M.** Ranking of Top Ten Problems in Priority Order
- **4:30 P.M.** Adjournment

Beginning at approximately 9:30 a.m. and continuing throughout the day, authors were provided typewritten drafts of the problems they proposed and were asked to edit and approve the text.

Problem Identification and Ranking

The participants were seated in alphabetical order starting in the front row right facing the lectern. The participant whose sur name came latest in the alphabet was seated in the back row right facing the lectern.

Each participant, in turn, was invited to the lectern to present his or her highest priority response to the workshop problem which was posted on the front wall of the workroom. Three minutes were allowed for each presentation, timed by the chair with a digital display alarm clock located in front of the speaker. Some presenters used overhead graphics which are included in their text. Each speaker was responsible to provide camera-ready graphics when they required it in their text.

At the conclusion of each presentation, the speaker was asked by the secretary to repeat the title. If it represented clearly the ideas outlined in the oral presentation, the secretary accepted it without comment. If, in the secretary's opinion, the problem title did not represent what the presenters had just said, a modified title was proposed by the workshop secretary. This title could be accepted or rejected by the presenter. Questions of clarification were allowed from the other participants. Neither challenges nor suggestions to modify the thrust of the oral presentation were allowed by the chair. If a participant had in mind a variation on what was proposed, the chair encouraged her or him to write that up as a problem and present it as a discrete idea.

At the conclusion of each three minute (or less) presentation, the agreed upon title was lettered by the secretary on a 3" x 5" card, numbered, the originator's name noted, and the card was handed to the graphics person. The title was then quickly lettered on a 35" by 22" sheet of paper and posted neatly on the wall of the workroom. The lettering was of sufficient size that the most distant participant could read it with ease.

The Problem Identification Form (See Appendix I) on which the originator had prepared a detailed write-up, was assigned its number and delivered to the word processing room where it was typed in the format of this report. A draft was returned to the originator in the workroom for editing. All problems were edited at least once by the originators before they departed at the 4:30 p.m. adjournment time.

Consolidation

After all problems were posted on the workroom wall, the process of consolidation was started. The idea was to group the problems presented into larger ideas so that when the priority ranking phase was reached at the end of the session, participants would have no major ideas presented in duplicated or triplicate. Rather, all major ideas would be clearly separated with a cluster of related ideas grouped under one overarching title.

Obviously there are many ways in which a set of over 90 ideas can be grouped. The goal, as explained by the chair, was to strike a balance between subsuming too many titles under one heading and "burying" important ideas, and keeping each idea as a discrete title at the risk of confusing the rankers with too many similar options to vote for. Usually, the consolidation phase goal is to reduce the total number of ideas remaining on the workroom wall to 25 to 30 percent of the total number proposed. In the case of this workshop, 91 ideas were merged into 39 consolidated ideas, or approximately 43 percent of the original number.

This is the stage of the NGT process when considerable debate and discussion take place. To facilitate the process, each participant who originated a problem was asked to maintain a Consolidation Worksheet (See Appendix J) throughout the problem identification phase. When a similar problem was presented, the originator was responsible for noting its number on the worksheet. The workshop chair had alerted each originator at the start of the session that they would be called on in the consolidation phase to lead the discussion of how they would propose to group their problem with other problems.

Each problem originator was assured by the chair that they would retain the absolute right to either merge their problem into a group of similar problems, or to ask that their problem stand alone. Similarly, each originator was assured that they retained the absolute right to title their problem in the way they thought to be most accurate and to edit their text the same way.

Whenever problems were subsumed under a new group title, the texts of all problems included under that overarching title were included in their entirety in this final report.

Ranking

The final step in the process was to ask each participant to rank the top ten problems remaining on the workroom wall in descending order of priority as they saw them being responsive to the workshop question. A sample copy of the Ranking Sheet used is included as Appendix K. The results of these individual ranking sheets established an order of importance of the 39 problem titles left on the workroom wall following the consolidation step. That order is the order in which the body of this report is organized.

Text Approval

As noted earlier, as soon as prepared text was entered into the word processors, a draft was returned to the originator for further editing. Some originators made continued improvements and required several drafts before they were satisfied. With each participant's approval in hand at adjournment time, it was possible begin immediately to prepare this report.

PRELIMINARY ANALYSIS OF RESULTS

The results of this workshop were analyzed to determine what differences in priorities existed among five sub-groups of participants. This was done by taking the data from the Ranking Sheets (Appendix K) and compiling with members of the same group. The subgroups into which the participants were divided were (1) professional associations; (2) federal, (3) industry, (4) the research communities; and, (5) water utilities. No category could contain only one individual or the confidentiality of the ranking process would be compromised. Fortunately, the smallest group in this workshop contained four individuals and the largest group contained nine.

Listed below are tables which give abbreviated titles of the top ten priorities as established by the five subgroups listed above. The first table gives the ranking of all participants and is in the same order as the table of contents. Subsequent tables represent the priorities of a particular subgroup.

In Appendices B, C, D, E, F, and G, the complete rankings are given by each group. In those appendices three other items of information are given, including the number of times picked, the total points received, and the strength of feeling expressed as a percentage. A more complete explanation of these data, and how they are computed, is given in Appendix A of this report.

Top Ten Problems Ranked by All Participants (26)

1. Understand Importance of Biofilm Development and Microbial Interactions on Beneficial, etc.
2. Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical, etc.
3. Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth), etc.
4. Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance, etc.
5. Treatments to Control Bacterial Regrowth in Drinking Water
6. Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems, etc.
7. A Standard Simulated Distribution System: Providing a Tool for Scientific Study, etc.
8. Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality, etc.
9. Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence, etc.
10. Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria, etc.

Top Ten Problems Ranked by Professional Association Participants (4)

1. Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth), etc.
2. Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution, etc.
3. Understand Importance of Biofilm Development and Microbial Interactions on Beneficial, etc.
4. A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion, etc.
5. Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems, etc.
6. Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures,etc.
7. Permeability of Pipe and Gaskets to Various Chemicals in Soil
8. Identification of Biofilm Bacteria
9. Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence, etc.
10. Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance, etc.

Top Ten Problems Ranked by Federal Participants (4)

1. Understand Importance of Biofilm Development and Microbial Interactions on Beneficial, etc.
2. A Standard Simulated Distribution System: Providing a Tool for Scientific Study, etc.
3. Establish Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, etc.
4. Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence, etc.
5. Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance, etc.
6. A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion, etc.
7. Treatments to Control Bacterial Regrowth in Drinking Water
8. Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria, etc.
9. Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials
10. Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks

Top Ten Problems Ranked by Industry Participants (4)

1. Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance, etc.
2. Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical, etc.
3. Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials
4. Unified Distribution System Operating and Maintenance Guidance Document to Promote, etc.
5. Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria, etc.
6. Treatments to Control Bacterial Regrowth in Drinking Water
7. Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems, etc.
8. Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead, etc.
9 Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks
10. Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth), etc.

Top Ten Problems Ranked by Research Participants (9)

1. Understand Importance of Biofilm Development and Microbial Interactions on Beneficial, etc.
2. Treatments to Control Bacterial Regrowth in Drinking Water
3. Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, etc.
4. Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria, etc.
5. Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks
6. A Standard Simulated Distribution System: Providing a Tool for Scientific Study, etc.
7. Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution, etc.
8. Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials
9. Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence, etc.
10. Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth), etc.

Top Ten Problems Ranked by Utility Participants (5)

1. Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance, etc.
2. Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth), etc.
3. Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks
4. Unified Distribution System Operating and Maintenance Guidance Document to Promote, etc.
5. Understand Importance of Biofilm Development and Microbial Interactions on Beneficial, etc.
6. Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems, etc.
7. Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, etc.
8. Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu
9. Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials
10. Influence of Water Distribution Systems Conditions on Survival/Growth and Virulence, etc.

PRIORITY RANKING OF PROBLEMS

Notes:

1. The following 39 problems are presented in descending order of importance as ranked by all (26) participants.

2. In some cases, a priority problem will consist of a number of problems proposed by several participants. One lead participant was designated by the chair as the person responsible for composing a new title, the wording of which was acceptable to all originators of problems subsumed under the new title. In the case where the lead participant composed only a new and overarching title, the individual problems subsumed under that title are presented alphabetically by author name. If more than one problem title is included by one originator, the numerical order in which the originator presented his or her problems at the workshop determined the order in which the problems are listed.

3. In the case where the designated lead person composed not only a new title, but also a new statement of importance, objectives, and/or approach, this full text is presented immediately beneath the new title, followed by all of the problems, listed in alphabetical order as described in Note 2 above.


GREG
KIRMEYER

PRIORITY RANK 1

Understand the Importance of Biofilm Development and Microbial Interactions on the Beneficial and Detrimental Processes in Drinking Water Distribution Systems

ORIGINATORS:
Geesey on behalf of himself, R. Clark, Curry-Grant, DeMarco, Dresher, Falkinham, Hermanowicz, and Ridgway

The following research problems were subsumed under the above priority problem title:

PROBLEM: Understand the Beneficial and Detrimental Effects of Microbial Biofilms in Drinking Water Distribution Systems

ORIGINATOR: Geesey

Importance:

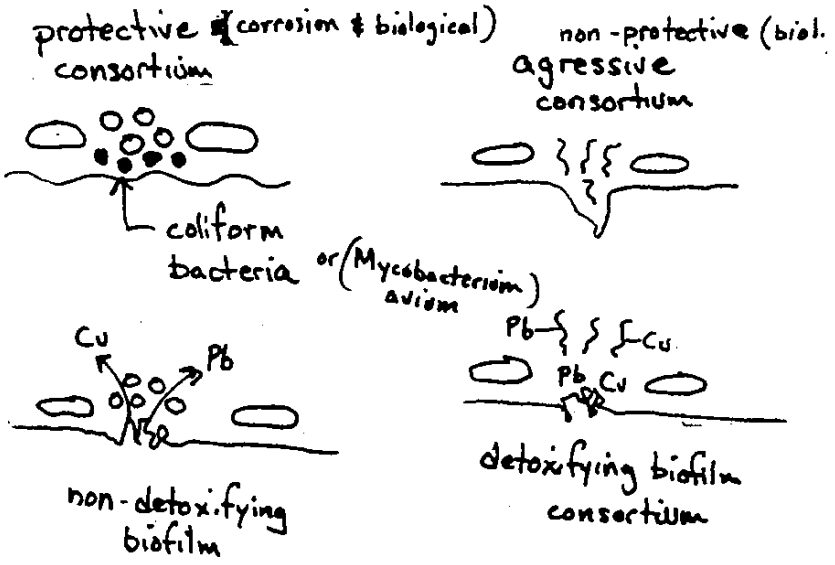
Biofilms can harbor and protect pathogens and indicator organisms from biocidal chemicals added to water. Biofilms can promote corrosion of pipe material under some circumstances and protect in others. Biofilms may remove toxins from water before they reach the consumer. They may also release toxic substances when conditions change.

Objective:

Determine how water chemistry and piping material and bacterial inoculum influence biofilm community structure and dynamics that have a significant impact on water quality at the consumer's tap.

Suggested Approach:

Define the important microbial populations which contribute to biofilms that form on distribution pipe surfaces. Determine the interactions that promote or deter pathogen/indicator organism maintenance, detoxification of water, and corrosion enhancement and protection of distribution piping materials.



PROBLEM: **Develop Information on the Capacity of Pipe Materials to Sustain Biofilm Growth**

ORIGINATOR: R. Clark

Importance:

Biofilm growth in drinking water distribution systems can pose operational problems, consume disinfectants and potentially harbor pathogens. It has been observed that some pipe materials support colonization more readily than others.

Objective:

To evaluate the capacity of various pipe materials to sustain biofilm growth and consume disinfectant. To suggest modifications in pipe materials and for coatings and linings that would minimize biofilm colonization.

Suggested Approach:

- Use pipe loops composed of various pipe material designed to simulate a range of residence times and hydraulic conditions, and to evaluate biofilm supporting potential of selected pipe materials.
- Evaluate the interaction of water quality, pipe material and disinfectant in supporting biofilm growth.
- Validate the results of these experiments using data from utility case studies.

PROBLEM: **Assessing Microbial Activity of Biofilms in Distribution Systems Relative to Degradation of Organics and Disinfection By-Products**

ORIGINATOR: Curry-Grant

Importance:

Water supplies, whether from surface or ground sources, receive some level of treatment, are disinfected, and are then pumped into distribution systems. These distribution systems offer large surface areas and appropriate conditions to establish biofilms. Since the different compounds used in water disinfection could impact the microbial activity within biofilms, it is important to determine how the biofilms which line these systems affect water quality within the distribution system.

Objective:

It is desirable to determine the extent to which biofilms in systems that are treated with different disinfectants can degrade or transform disinfection byproducts and other organics that pass through the distribution system.

Suggested Approach:

Harvest biofilms from various locations within distribution systems to demonstrate and quantify microbial activity. Assay microbial activity relative to degradation of organics, and disinfection byproducts. Changes in microbial activity should be correlated with physical aspects of the distribution systems and proximity to the treatment plant. Also, a measure of activity that may be used to evaluate the viability of the biofilm bacteria is their ability to convert ammonia to nitrate.

PROBLEM: **Defining When Water Quality and Pipe Changes Should Dictate Distribution System Pipeline Replacement/Renovation**

ORIGINATOR: DeMarco

Importance:

Most utilities do not incorporate water quality criteria in their pipe replacement programs. Only the most obvious problems are addressed and then only after customer complaints become numerous. Few systems consider tuberculation or biofilms in pipe upkeep programs. Such reactive procedures are obstacles in improving customer satisfaction and confidence with utility operations.

Many utilities have a number of lead service branches that may need to be removed. Since this is a costly endeavor, the replacement program will likely take place over a number of years. CDC has reduced its tolerable blood lead levels, and the existing lead branches may need to be replaced. However, which ones first, partial only, lead versus copper are questions needing more definitive answers.

Objective:

Determine what types of parameters can be associated with early deterioration in pipes and/or the quality of water conveyed and devise a prioritization method for lead service branch and copper service branch replacement.

Suggested Approach:

Instrumenting pipe sections of various age and types with continuous water quality monitoring devices such as chlorine monitors, velocity and pressure transducers, oxygen analyzer, TOC, TDS, etc. and observation of characteristics of inorganic pipe films, biofilm growth and resultant water quality may determine which parameters can be used by water utilities. A guidance document that points out factors of importance and how to use them effectively is a desired product.

PROBLEM: **Biolfilm Growth on Plumbing Materials:**
- **As a Host for Pathogenic Bacteria and Viruses**
- **As a Host for Microbiologically Influenced Corrosion (MIC)**

ORIGINATOR: Dresher

Importance:

The World Health Organization, in its recent "Guidelines for Drinking Water Quality," cautions on the build-up of biofilms on materials used in drinking water systems. No drinking waters are aseptic. Consequently, there is always a presence of an assortment of bacteria which, if allowed to multiply, can represent a hazard either to human health or to the integrity of the water supply system. Multiplication of bacteria occurs in biofilms associated with surfaces. These surfaces can be the sand used in filter media, piping in the distribution system or piping and fixtures in the consumer's building. Pathogenic bacteria have been found to propagate to differing degrees on various plumbing material surfaces. Likewise, MIC-causing bacteria have been found to be a cause of corrosion in plumbing materials. Reduction in chlorine residuals can be expected to increase biofilm build-up on materials in water distribution systems.

Objective:

To understand the conditions under which biofilms are formed in plumbing systems and, from this, to be able to:

- Recommend water treatment practices that minimize biofilm formation and bacteria propagation.
- Recommend sterilization procedures for decontaminating a system once it is infected.

Suggested Approach:

An extensive body of literature exists on this subject as a result of laboratory experimentation. These studies should now be coupled with field observation, measurement and analysis. Procedures should then be developed and field tested.

PROBLEM: **Sequence of Events Leading to Biofilm Development**

ORIGINATOR: Falkinham

Importance:

- Biofilms important in water quality.
- What's important? Bacteria, surface, or physiochemical parameters.

Objective:

- Identify primary colonizers and population membership.
- Identify physiochemical factors influencing biofilm development.

Suggested Approach:

- Follow biofilm development (in situ and in vitro).
- Describe physiochemical characteristics (in situ).
- Modify physiochemical parameters (in vitro) and follow biofilm development.

PROBLEM: **Effects of Transients on Microbial Colonization of Surfaces in Distribution Systems**

ORIGINATOR: Hermanowicz

Importance:

While colonization of surfaces by microorganisms have been extensively studied, most of the work has been done under steady flow and nutrient supply. There are indications that transient flow conditions (such as flow reversal) and variable nutritional supply affect metabolic status and may promote detachment.

Objective:

- Examine the effects of transient flow and nutrient supply on metabolic status of biofilm cells, its structure and detachment.

Suggested Approach:

- Develop biofilms in a hydrodynamically well-defined lab system and subject them to flow changes, including flow reversals and drastic changes in nutrient availability.
- Monitor metabolic status (e.g., using vital stains, uptake of radio labeled nutrients), biofilm structure and cell detachment.

PROBLEM: **Total Assessment of Microbial Regrowth in Full-Scale Distribution Systems**

ORIGINATOR: Hermanowicz

Importance:

Bacterial regrowth has been identified as a source of contamination yet little is known about the dynamics of distribution system colonization.

Objective:

- Investigate bacterial regrowth in a part of a full-scale distribution system.
- Develop mass and energy balance for substrates and microbial cells.
- Estimate growth and transformation kinetics.
- Examine the effects on water quality.

Suggested Approach:

- Identify and characterize a part of a distribution system with well-defined flow patterns.
- Monitor on four very frequent basis fluxes of nutrients and microorganisms.
- Attempt to balance the flow of nutrients and energy.
- Relate the fundamentals to water quality.

PROBLEM: **Interaction with Bacteria with Distribution System Materials**

ORIGINATOR: Ridgway

Importance:

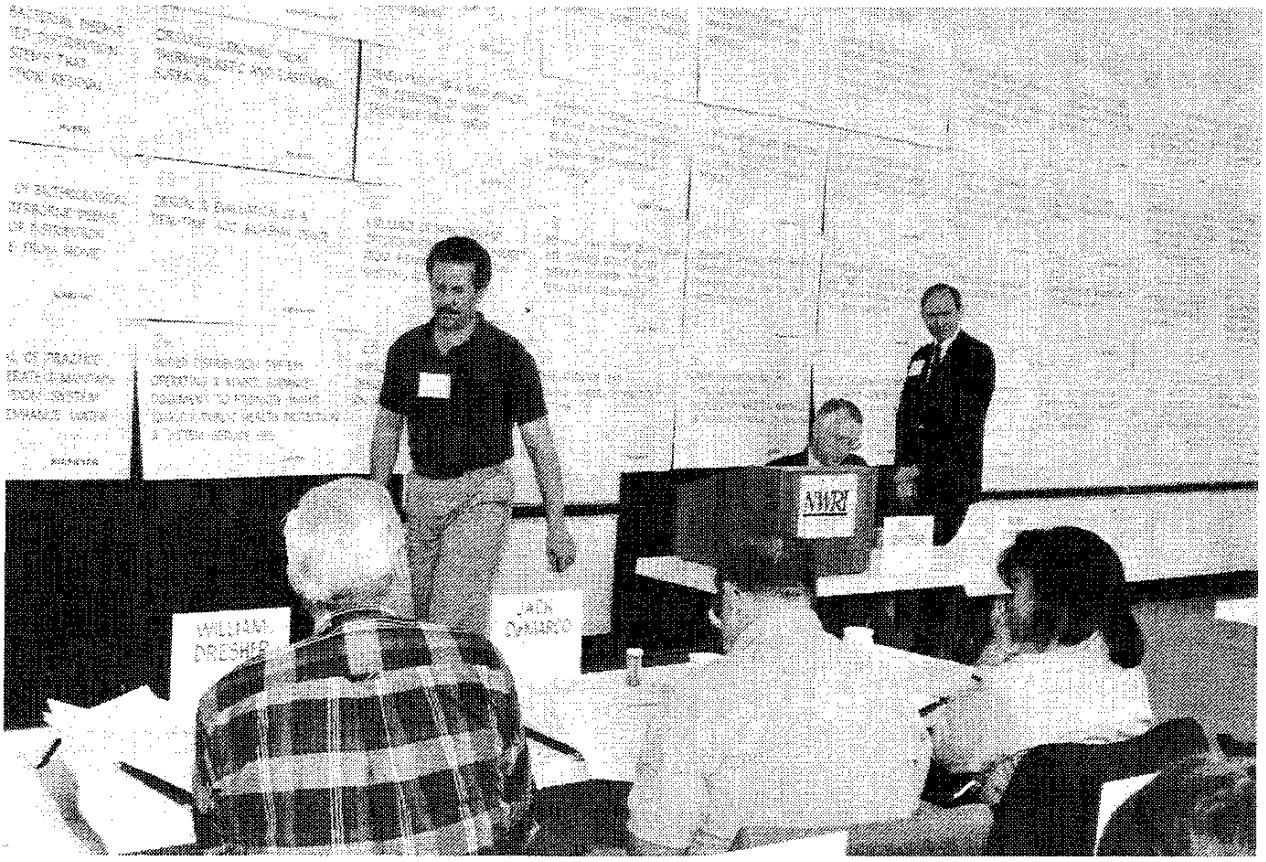
Microbial attachment to a surface is the first cellular event in biofilm formulation. Adhesion of bacteria to distribution system materials may enhance their survival and persistence.

Objective:

Determine affinity of specific bacterial isolates and native consortia to distribution system materials, including elastomers, polymers, and thermoplastics.

Suggested Approach:

Perform adhesion and colonization assays using distribution system materials. Employ both indicator and "heterotrophic plate count" bacteria and a wide variety of materials. Data could contribute to development of biofilm/colonization models for distribution systems.


WILLIAM
DRESHER
NIST

PRIORITY RANK 2

Assessment of Health Risks From Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication

ORIGINATORS:
Ford on behalf of himself, Highsmith, Holtzman, Smith and Velazquez

The following research problems were subsumed under the above priority problem title:

PROBLEM: **There is a Limited Understanding of Factors That Contribute to Emerging Diseases Associated with Water Use, Particularly in Institutional Settings**

ORIGINATOR: Ford

Importance:

Reducing health care costs and human suffering. Establishing risks of "new disease" or resurgent disease outbreaks. Establishing guidelines for institutional water use.

Objective:

Increasingly susceptible populations: HIV, elderly, other immunosupressed populations. We are seeing increasing rates in opportunistic infections, mycobacterial infections, Legionellosis and infections from antibiotic resistant strains. We need to further our understanding of routes of dissemination of infectious agents, their mechanisms of survival and proliferation, and the conditions that might increase virulence or result in antibiotic resistant strains.

Suggested Approach:

- Study environmental factors that result in proliferation and subsequent dissemination of these organisms: e.g. role of biofilms as protective environments, design of hot water systems (e.g., for control of Legionella sp. and Mycobacterium sp.), role of organics and inorganics (Zn and mycobacteria), role of distribution system components and disinfection regimes in creating more virulent or antibiotic resistant strains.
- Investigate modes of exposure (aerosols, drinking water, etc.).
- Establish effective doses and modes of infection (as biofilm aggregates, intracellularly, free living, etc).

PROBLEM: **Determine if Radon in Drinking Water Impacts on Reproductive Health**

ORIGINATOR: Highsmith

Importance:

Recently, an investigator suggested that pregnant women ingesting water with high levels of Radon may have daughters developing malignancies around age 20.

Objective:

Determine if a relationship exists between drinking water with elevated Radon levels and health effects.

Suggested Approach:

Examine current Radon data and cancer rates among 18-25 year-old females. Evaluate Radon levels in selected geographic areas by USGS mapping and with cancer rates.

PROBLEM: **Examine Waterborne Disease Outbreaks Reported to EPA/CDC Annual Surveillance with Unknown Etiology**

ORIGINATOR: Highsmith

Importance:

Each year 40-50% of outbreaks reported by State and Local health departments to the EPA/CDC annual surveillance are listed with unknown etiology. This may be due to incomplete or lack of information submitted at State and Local levels; inability to collect timely water samples; or to correlate illness epidemiologically.

Objective:

To seek to reduce number of outbreaks with unknown etiology.

Suggested Approach:

Recognize that test methodologies may be inadequate to isolate etiologic agent. Encourage illness reporting among local and State health officials.

PROBLEM: **Comparison of Nontuberculous Mycobactertia (NTM) Found in Potable Water with Isolates From Immunocompromised and Immunocompetent Patients**

ORIGINATOR: Holtzman

Importance:

One disseminated NTM (M. avium) infection is the second most common cause of death in AIDS patients. Studies in our laboratory suggest that water may be a source of this infection in these immunocompromised patients. Significant morbidity from NTM infections also occurs in immunocompetent patients (e.g., pulmonary disease in adults and pediatric facio-cervical lymphadenitis).

Objective:

To determine, more conclusively, the relatedness of potable water and clinical NTM in both immunocompromised and immunocompetent patients.

Suggested Approach:

Use of laboratory studies to include the following procedures: biochemicals, species-specific DNA probes, serotyping, multilocus enzyme electrophoresis, restriction analysis of ribosomal spacer DNA, pulsed field gel electrophoresis, restriction analysis of ribosomal spacer DNA by capillary electrophoresis, pulsed field gel electrophoresis of whole cell DNA restriction fragments and the attachment of these organisms to and their replication in host macrophages as a measure of virulence.

PROBLEM: **Identifying Populations Potentially at Risk From Drinking Water Contaminants (Microbes and Chemicals) and Developing a Strategy for Risk Communication and Management Within These Populations**

ORIGINATOR: Smith

Importance:

Certain subpopulations such as HIV and cancer patients, infants and the elderly may be at risk from drinking water contaminants. These subpopulations may be able to lower their risk for drinking water related illness by adopting certain practices such as boiling water or using alternative sources.

Objective:

- Identify specific populations at risk.
- Identify specific contaminants affecting these populations.
- Identify techniques and alternatives to provide these subpopulations with safe water for drinking, bathing and use in medical devices. Define role of PWS in protecting these subpopulations.

Suggested Approach:

Assemble a team to study the populations at risk, contaminants, and methods of control (i.e., treatment, POU, alternatives).

The team should include epidemiologists, physicians, health practitioners, water quality specialists, and subpopulation representatives.

PROBLEM: We Need to *Identify* Chemicals or Microbials in Drinking Water at the Tap Which Actually *Pose* the Greatest Risk to Human Health

ORIGINATOR: Velazquez

Importance:

Most of the discussions so far has focused on issues that affect our exposure to microbials/DBP's. In order to focus on reducing risks, first, we need to identify what qualities of drinking water actually pose the greatest risk. Ideally, this should relate to water at the tap, thereby taking into account changes that the water goes through during distribution. A good example of this is illustrated by lead. It wasn't until we started to gain a better understanding of the biological effects of lead, particularly in children, that this was identified as a significant risk and actions were taken to reduce our exposure to lead in drinking water.

Objective:

Determine more accurate dose-response relationships for microbials and DBP's for water at the tap.

Suggested Approach:

- Investigate changes in levels and/or types of microbials and DBP's (e.g., due to metabolism by microbials) that occur during the distribution process.
- More mechanistic research is needed to determine how DBP's are metabolized by humans and how they exert their toxicologic/carcinogenic effects.
- Need better understanding of how animal models relate to human risk, particularly the contentious B6C3F1 mouse liver tumors.
- Need better low-dose extrapolation models for determining carcinogenic risk from DBP's.
- Need more information on human variability in response to both microbials and DBP's.

PROBLEM: **Determine How Potential Health Effects From Mixtures (Both DBP's and microbials) to Which Humans are Exposed in Drinking Water Compare with Health Effects Risks From Single Components**

ORIGINATOR: Velazquez

Importance:

In setting standards (i.e., MCL/MCLG's) for contaminants in drinking water, we need to know whether interactions between different chemicals or microbials in a mixture can alter the effects that result from single exposures. For example, different disinfection regimens result in mixtures with varying components, or differing ratios between resulting by-products. Little is known about effects resulting from such mixtures.

Objective:

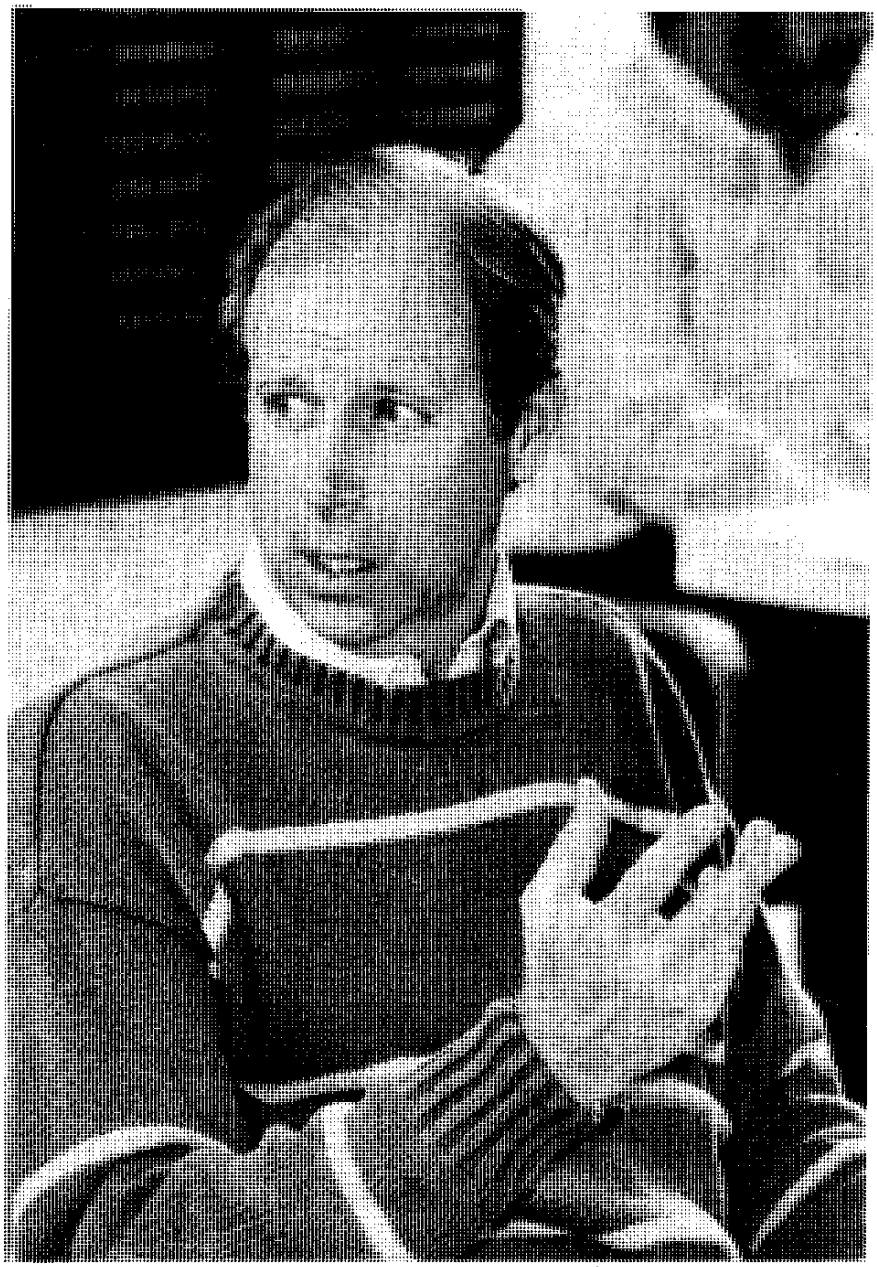
The objective of this research is to determine whether effects resulting from exposure to single chemicals or microbials in drinking water are independent from the effects due to other components present in drinking water.

Suggested Approach:

In vitro studies (e.g., mutagenicity) are of limited use. We need more mechanistic data on single chemicals (e.g., a lot of work is going on now with DCA and TCA) to determine whether the mechanisms of toxicity for two or more DBP's (or microbials) are similar.

Animal studies are then needed to test hypothesis generated from knowledge of mechanisms of toxicity/carcinogenicity.


NWRI



PRIORITY RANK 3

Epidemiological Studies to Determine the Role of the Distribution System (and Regrowth) in Waterborne Disease

ORIGINATORS:
Karlin on behalf of himself, DeMarco, Hubbs and LeChevallier

Importance:

Payment attributed 30 % of enteric disease to drinking water which met all applicable standards. The data showed a trend toward higher disease with distance in the distribution system. Given the concern over DBP's and attendant reduction in disinfectant levels, we need to know the current role of treatment versus regrowth.

Although Payment is repeating the study with an eye toward the role of regrowth, more definitive data is needed. For example, is the phenomena widespread or associated with some system peculiarity at the Payment site.

The outcome could shed light on whether resources could be better utilized by more stringent treatment or by better operation of the distribution system.

Objective:

To determine the relative roles of treated water distribution systems and home plumbing regarding waterborne disease risk.

Suggested Approach:

Several prospective epidemiological studies would examine the health status of test populations. Possible approaches could examine consumers of:

- Bottled water and tap water.
- Unchlorinated ground water versus chlorinated surface water.
- Point-of-Use devices (reverse osmosis) and tap water.
- The impact of location within the distribution system (e.g., near the treatment facility or in a dead-end area) on the health risk from drinking water.

Weekly, or bi-weekly health surveys could be conducted for test populations. End points of disease could include: gastroenteritis; bacterial, viral or parasitic infections; doctor visits; or work days missed. For populations using ground or surface waters, census date could be used to determine length of exposure. Hospital records could be compared to determine differences in illness rates.

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Determine the Role of Bacteriological Regrowth in Waterborne Disease. Separate Role Distribution System At-Large From Home Plumbing.**

ORIGINATOR: Karlin

Importance:

Payment attributed 30% of enteric disease to drinking water which met all applicable standards. The data showed a trend toward higher disease with distance in the distribution system. Given the concern over DBP's and attendant reduction in disinfectant levels, we need to know the current role of treatment versus regrowth.

Although Payment is repeating the study with an eye toward the role of regrowth, more definitive data is needed. For example, is the phenomena widespread or associated with some system peculiarity at the Payment site.

Objective:

To determine the relative roles of treated water distribution systems and home plumbing regarding waterborne disease risk.

Suggested Approach:

Better characterize the occurrence, numbers and species of bacteria, fungus, etc. in water distribution systems at a variety of drinking water systems.

Repeat the Payment study at utilities using a variety of treatment/distribution scenarios to determine the effects of these variables upon entire disease rates. Include a study of the effects of point-of-use devices on disease rates.

PROBLEM: **Lack of Association of Presence of Contaminants with Actual Versus Perceived Adverse Health in the Population**

ORIGINATOR: DeMarco

Importance:

The emphasis on resolving priorities for solving the myriad of problems perceived needs to be placed into perspective by looking at related data, i.e., Milwaukee situation.

Objective:

Provide perspective regarding whether health risks are overstated by using disease outbreak/reporting data collected by the health community.

Suggested Approach:

Use epidemiology, health reporting records, blood lead levels and like data from the health field to provide perspective of the real versus perceived problems. Also, make waterborne diseases a reportable item.

PROBLEM: **Assess the Impact of Point-of-Use (POU) Treatment Devices on Risk of Bacterial Disease**

ORIGINATOR: Hubbs

Importance:

Many consumers use POU devices to improve palatability of delivered water. Some devices degrade water quality and may pose a risk to public health.

Objective:

Formulate a health advisory for POU devices, based on potential health risk.

Suggested Approach:

Review existing data and conduct additional research as necessary.

PROBLEM: **Epidemiological Study of Health Risks Due to Drinking Water**

ORIGINATOR: LeChevallier

Importance:

Currently, the health risks due to consumption of drinking water are not well known or quantified. Therefore, there is no basis to evaluate the benefits of various intervention strategies. The results of this study would provide a foundation for formulating treatment strategies that would provide the maximum benefit to human health.

Objective:

The objectives of the study would be to define the greatest risks to health from drinking water. To determine the relative risks of chemical and microbial contaminants, and determine the health impact of water quality degradation in the distribution system.

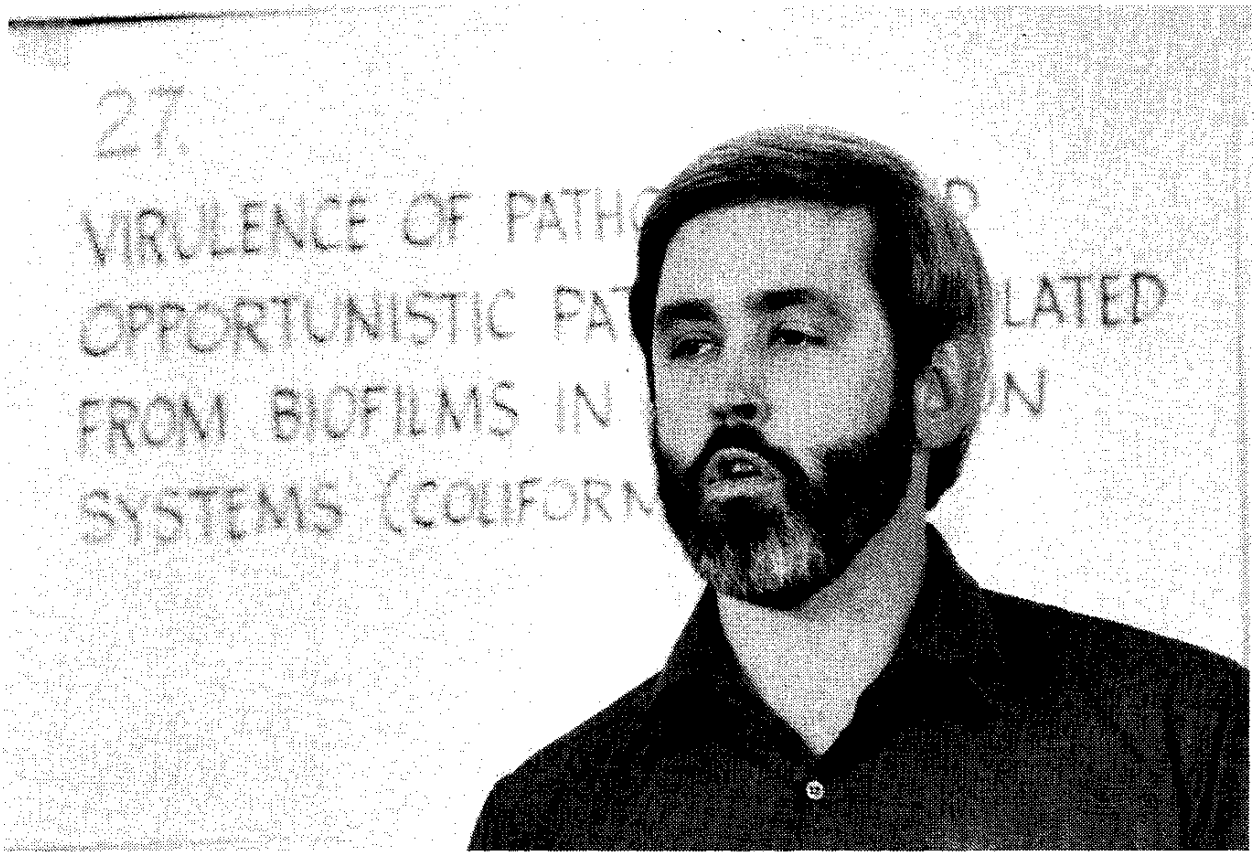
Suggested Approach:

A prospective epidemiological study would examine the health status of test populations. Possible approaches could examine consumers of:

- Bottled water and tap water.
- Unchlorinated ground water versus chlorinated surface water.

- Point-of-Use devices (reverse osmosis) and tap water.
- The impact of location within the distribution system (e.g., near the treatment facility or in a dead-end area) on the health risk from drinking water.

Weekly, or biweekly health surveys could be conducted for test populations. End points of disease could include: gastroenteritis, bacterial, viral or parasitic infections; doctor visits; or work days missed. For populations using ground or surface waters, census date could be used to determine length of exposure. Hospital records could be compared to determine differences in illness rates.



PRIORITY RANK 4

Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality

ORIGINATORS:
Grayman on behalf of himself and DeMarco

The following research problems were subsumed under the above priority problem title:

PROBLEM: Identification of Negative Impacts of Finished Water Storage Facilities on Water Quality and Mitigative Strategies to Minimize Impacts

ORIGINATOR: Grayman

Importance:

Historically, tanks and reservoirs have been considered as passive facilities in terms of their effects on water quality and have been designed and operated solely to provide hydraulic reliability. Recent studies have shown that storage facilities frequently negatively affect water quality in terms of lower chlorine residual, increased age and increased biological activity, etc. Identification of impacts of storage facilities on water quality and strategies to minimize these impacts are needed to insure that water quality does not degrade in the distribution system.

Objective:

For tanks and reservoirs, define:

- The extent of the water quality problem nationally.
- The relationship between design, operational and environmental conditions and the resulting water quality.
- Mitigative solutions for improving water quality.

Suggested Approach:

- Extensive national sampling program for tanks and reservoirs.
- Intensive sampling program for selected tanks and reservoirs.
- Large scale laboratory studies of the behavior of tanks.
- Development of mathematical model of the behavior (hydraulic and water quality) of tanks and reservoirs.
- Application of models to identify improved designs and operations.

RESULTS OF FIELD SAMPLING OF TANKS AND RESERVOIRS

STATE/ TANK NO.	FREE CL RESIDUAL IN INLET/OUTLET MINIMUM CONCENTRATION	MAXIMUM CONCENTRATION	ESTIMATES RESIDENCE TIME (DAYS)
California			
CA-1	0.01	1.61	—
CA-2	0.05	0.35	4.4
CA-3	0.01	0.08	2.3
Connecticut			
CT-1	0.01	1.20	—
Pennsylvania			
PA-1	0.15	0.65	—
PA-2	0.16	—	—
Washington			
WA-1	0.04	0.24	2.2
WA-2	—	—	4.3
WA-3	0.04	0.41	2.8
WA-4	—	—	0.7
WA-5	0.09	0.29	2.1
WA-6	0.02	0.26	2.2
WA-7	0.11	0.59	2.3
WA-8	—	—	2.3
WA-9	—	—	3.1
WA-10	0.02	0.20	13.2

PROBLEM: **Improving Current Distribution System Storage Tank Design and Operation for Effective Maintenance of Water Quality**

ORIGINATOR: DeMarco

Importance:

Most United States distribution system storage tanks are still being designed on a fire flow peak demand basis. However, frequent water turnover in distribution systems is more compatible with current water quality regulations. Customer satisfaction depends on maintaining high water quality throughout the distribution systems and their taps. The customers are defining a societal water quality need which engineering research must address.

Objective:

Determine storage tank configurations, inlet and outlet designs that maximize water turnover in distribution system storage tanks.

Suggested Approach:

Perform field scale investigations to understand the mixing and turnover in existing storage tank designs. Conduct a pilot scale storage tank system study to optimize design conditions. Preferably the optimized conditions of mixing and turnover can be scaled up through hydraulic similitude and installed at cooperative utilities. If optimization or improvements can be obtained by modifying existing tanks then utilities may cooperate willingly. Use mathematical models to estimate best operating modes and evaluate the use of these models to operate valves.

PRIORITY RANK 5

Treatments to Control Bacterial Regrowth in Drinking Water

ORIGINATORS:
LeChevallier on behalf of himself, R. Clark and Geesey

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Treatments to Control Bacterial Regrowth in Drinking Water**

ORIGINATOR: LeChevallier

Importance:

Water quality leaving the treatment plant is thought to be of high quality. However, bacterial regrowth in distribution system biofilms can degrade water quality and possibly increase the risk of gastroenteritis. Research needs to be performed to determine what treatment techniques are effective to prevent regrowth problems.

Objective:

The objective of the study would be to evaluate different treatment processes for reducing biodegradable organic carbon. Evaluations would include ozone/GAC, enhanced coagulation, membrane filtration, single and dual-stage filtration.

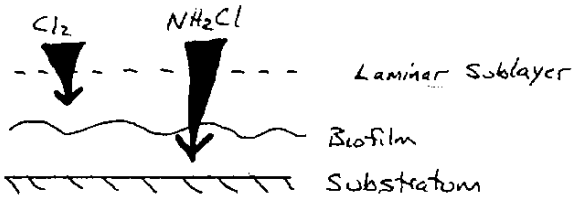
Suggested Approach:

Three parallel pilot units would test various source waters (ideally 3-5 types of water). The three units would be:

- Ozone with dual-stage (sand and GAC) filtration.
- Conventional treatment with enhanced coagulation and GAC filter-absorbers (no predisinfection).
- Nanofiltration.

The systems would be examined to determine the expected level of AOC and BDOC removal and the relative cost. Data analysis would be performed to determine which approach would be needed to achieve various levels of biological stability.

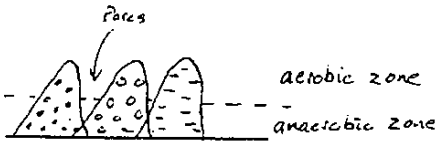
Transport Problems



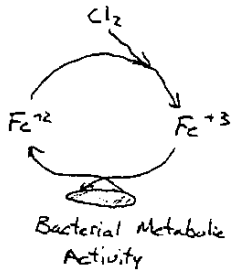
- Determine transport rates
- Determine reaction rates

Biofilm Structure

- Determine impact of aerobic and anaerobic zones
- Biofilm structure and pore size



Metabolic Activity



- Determine the impact of metabolic activity on cycling compounds that may react with biocides

Also may be relevant for
Nitrogen (NH_3)
Sulfur (H_2S)

PROBLEM: **Impact of Water Treatment Selection on Distribution System Water Quality to Achieve Microbial and Chemical Water Quality Goals**

ORIGINATOR: R. Clark

Importance:

Drinking water utilities in the U.S. will be making increased investments in treatment technology in order to achieve a wide range of stringent MCL's. The point of compliance will be in the distribution system at the point of consumption and yet most of the knowledge concerning the performance of these technologies is as at the discharge point of the process train.

Objective:

It is not clear what impact these treatment choices will have on distributed water quality. The objective of this project would be to develop a protocol and procedures to systematically study these choices under controlled conditions.

Suggested Approach:

- Design a series of experiments to explore the impact of water treatment choices on water quality using specifically-designed pipe loops.
- For example, one can study the use of membranes eliminating the formation of biofilms in distribution system. The cost should be balanced against the results.
- Another example would be the use of biological treatment which can be designed to minimize the formation of objectional by-products and biofilm simultaneously in the distribution system.
- Experiments should be conducted under controlled conditions, in pipe loops under rigorous experimental design procedures.

PROBLEM: Identify Novel Approaches to Enhance or Replace Current Biological Control Measures in Drinking Water Distribution Systems (in Order to Minimize Health Risks and Improve Longevity of Drinking Water Distribution System)

ORIGINATOR: Geesey

Importance:

We need to become more sophisticated in the way we control microbial growth and survival in drinking water before it gets to the consumers. Current approaches occasionally fail to protect the consumer from all types of hazards.

Objective:

Understand what limits growth and promotes irreversible inactivation of risk-related microbes in drinking water systems. Utilize this new understanding to develop cost-effective water management strategies in public and private water supplies.

Suggested Approach:

Set up pilot scale distribution systems in which water quality parameters can be manipulated and the growth and/or irreversible inactivation of "nuisance" microbes can be accurately monitored both in the water and on the walls of the system and serve as effective models for distribution systems which have a history of health and system maintenance problems.

PRIORITY RANK 6

Define the Risk of Bacterial Disease in Nondisinfected Distribution Systems Versus Systems That Carry a Disinfection Residual

PROBLEM: **Define the Risk of Bacterial Disease in Distribution Systems That Maintain a Disinfectant Residual Versus Those That Do Not**

ORIGINATOR: Hubbs

Importance:

The distribution system is subject to bacterial contamination from cross-connections, sanitary deficiencies in storage tanks, and from maintenance activities. A disinfectant residual is the last barrier of defense, after positive pressure.

Objective:

Review water borne disease outbreaks/occurrences in the past 5 to 10 years. Determine the possible reduction in disease/death by requiring that all systems maintain a disinfectant residual.

Suggested Approach:

Review CDC records/morbidity/mortality records. Determine percentage systems, population served by systems that do not feed disinfectant for distribution system residual. Predict impact of regulation requiring that all distribution systems maintain a disinfectant residual in distribution systems.

PRIORITY RANK 7

A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem

ORIGINATORS:
Edwards on behalf of himself, Camper, R. Clark, S. Clark, Grayman, Harvey and Smith

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Design of Pilot and Laboratory Scale Simulated Distribution Systems**

ORIGINATOR: Edwards

Importance:

Lack of standardized protocol and designs for physical (laboratory-scale/pilot-scale/full-scale) simulated distribution systems impedes research progress. Providing this tool is an important starting point for further study of distribution system behavior.

Objective:

To identify and discuss designs for simulated distribution systems that best represent the hydraulics, temporal variations, corrosion and biological behavior of real distribution systems.

Suggested Approach:

Compile (collect) designs of physical simulated distribution systems used to date. Fund a workshop for individuals who have used each design to discuss the relative merits/drawbacks of each. Make recommendations as to the "optimal" design and provide the rationale for each component. Make results available to distribution system researchers. Discuss limitations and possible need for a full-scale distribution system testing.

PROBLEM: **A Standardized Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem**

ORIGINATOR: Edwards

Importance:

Lack of standardized protocol in simulated distributions systems impedes research and prevents a rationale comparison of results between studies.

Objective:

Develop a standard "optimal" layout and operation protocol. Deviations from the standard individual research projects are likely and probably advisable under some circumstances, but a proper consideration of elements in previous design is still worthwhile.

PROBLEM: **Development and Evaluation of Monitoring Devices for Assessing Biofilm Development and Microbial Activity in Distribution System**

ORIGINATOR: Camper

Importance:

Increased interest in biofilms in distribution systems requires that proper monitoring tools be provided for the industry.

Objective:

Compare available technologies and develop new technologies to provide utilities with monitoring devices.

PROBLEM: **Impact of Distribution System Design and Operational Policies on Water Quality**

ORIGINATOR: R. Clark

Importance:

Distribution systems in the United States are designed and operated primarily for the maintenance of pressure, reliability and fire flow. These objectives result in excess capacity and generally long residence times which in turn may result in water quality degradation. Distribution systems represent the major investment for most drinking water systems.

Objective:

To find the optimal balance which would achieve both hydraulic and water quality objectives simultaneously.

Suggested Approach:

- Develop a system model that adequately describes the hydraulic behavior of a distribution system.
- Extend model to incorporate water quality measurements.
- Validate model with specific case study data.
- Modify operational policies or redesign systems to validate predictions from these models.

PROBLEM: **Relationship of Water Quality Changes to Hydraulic Conditions in the Distribution Center**

ORIGINATOR: S. Clark

Importance:

Aging, deteriorating water distribution systems in major U.S. cities will need replacement or rehabilitation in the near future. The historic design approach has emphasized hydraulics, especially fireflows, over concerns for water quality maintenance. Can these two design goals be cost effectively met?

Objective:

There is very little understanding of the water quality changes in a distribution system and a relatively good understanding of system hydraulics. We need to better understand the interrelationships.

Suggested Approach:

- Review of design and operating practices.
- Develop computer models to relate water quality to hydraulics.
- Collect monitoring data to verify computer models.

PROBLEM: **Development of a Full-Scale Test Distribution System**

ORIGINATOR: Grayman

Importance:

Laboratory and pilot level models of distribution systems are frequently insufficient for research studies. Use of actual systems may be limited due to negative impacts on water users. Studies using a full-scale system that is not in normal operation would avoid these problems.

Objective:

Build or find an abandoned full-scale distribution system (such as a closed military base) for testing risk reduction schemes.

Suggested Approach:

Determine the requirements for a full-scale system and then build or acquire such a system.

PROBLEM: **Assess the Fate and Transport Charateristics of Selected Chemicals After Final Treatments to Include Type, Concentrations, Temporal Aspects Within Distribution Pathways**

ORIGINATOR: Harvey

Importance:

Standard setting at treatment plants may not reflect actual exposure at consumption points; risk may increase, decrease, or change due to distribution transit.

Objective:

The point of consumption relates to actual human exposures and its appropriate translation to internal doses versus occurrences in the delivery and sourcing of pathways.

Suggested Approach:

- Select stressors of greatest significance.
- Develop "tracking mechanisms" for the transport/fate of the stressors.
- Adjust operational standards/guidance to accommodate true, user exposures to stressors.

PROBLEM: **Evaluating Changes in Disinfection By-Product (DBP) Concentration Levels and Diversity in Water Distribution Systems**

ORIGINATOR: Smith

Importance:

A number of physico-clinical factors in the distribution system may play a role in altering DBP concentration levels and diversity at the consumer tap.

Objective:

Define the mechanisms by which pH, time, temperature and changing disinfection levels impact DBP levels and diversity at the tap.

Suggested Approach:

Conduct a laboratory bench-top study with a field verification study.

PRIORITY RANK 8

Re-Evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks

REVISED TITLE:

Evaluate and Develop Methods to Compare Environmental Bacterial Indicators From Potable Waters and Those Associated with Health Effects in the Chemical Setting

ORIGINATORS:
Highsmith on behalf of herself, DeMarco, Eager, Grayman, Hermanowicz and Smith

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Re-Evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks**

ORIGINATOR: Highsmith

Importance:

Indicator organisms are assumed to have a correlation with the presence of microbial pathogens in water. Yet, the presence of a biofilm in a distribution system may create a microenvironment that could influence both the quantities and species of bacteria present in drinking water. The effect of this microenvironment on traditional indicator bacteria is unknown and should be evaluated. The use of additional indicator organism(s) may be warranted and should be investigated to ensure that the health risk is neither over nor under estimated.

Objective:

To determine the relationship between bacterial pathogens and their associated indicators in drinking water. To determine if the use of a single microbial indicator is adequate to assess drinking water quality and health risk.

Suggested Approach:

Conduct site surveys at distribution sites and perform laboratory studies to determine:

- The base level of pathogen and indicator contamination.
- The presence and level of those organisms in any associated biofilm.
- The suitability of secondary indicator organisms.

PROBLEM: **Lack of Association of Presence of Contaminants with Actual Versus Perceived Adverse Health in the Population**

ORIGINATOR: DeMarco

Importance:

The emphasis on resolving priorities for solving the myriad of problems perceived needs to be placed into perspective by looking at related data, i.e., Milwaukee situation.

Objective:

Provide perspective regarding whether health risks are overstated by using disease outbreak/reporting data collected by the health community.

Suggested Approach:

Use epidemiology, health reporting records, blood lead levels and like data from the health field to provide perspective of the real versus perceived problems. Also, make waterborne diseases a reportable item.

PROBLEM: **Use of Microscopic Particulate Analysis (MPA) as a Surrogate Parameter for *Assessment* and Optimization of Treatment Plant Performance**

ORIGINATOR: Eager

Importance:

The water industry needs surrogates beyond turbidity and coliform bacteria to evaluate water treatment plant performance and pilot study results.

Objective:

- Finalize MPA protocol based on the consensus method being used and approve as a standard method.
- Develop basis for use of MPA as a tool for assessing sanitary integrity of systems, and overall treatment process effectiveness.

Suggested Approach:

A variety of waters would be tested for MPA under various treatment scenarios to establish a database for the range of particulate reduction.

The same waters would also be classified according to measurements and risk assessment for Giardia and cryptosporidium.

Correlation of the MPA and actual risks would then be determined.

PROBLEM: **Enhanced Understanding of Relationship Between Water Quality Indicators and Health Impacts**

ORIGINATOR: Grayman

Importance:

Our ability to predict the effects of operational and design decisions on water quality indicators is improving. However, without an improved understanding of the relationship between the water quality indicators and resulting health effects, good decision-making is seriously impaired. See example below.

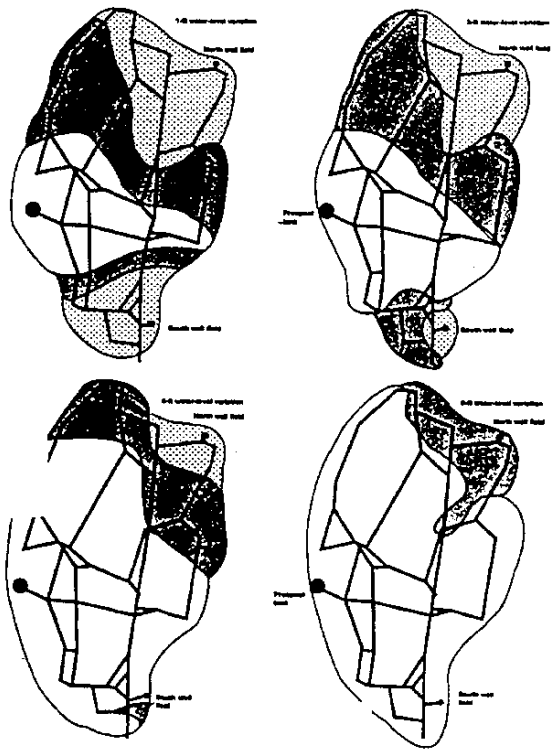
Objective:

Develop statistical relationships between water quality indicators (such as chlorine residual) and resulting health effects. This would replace the single "standard" which says that values above that concentration are bad and values below that concentration are okay.

Suggested Approach:

Example:

Is it better to have a small area with *very* low chlorine residuals or a larger area with chlorine residuals that are slightly low? Without a clear understanding of the relationship between the water quality indicator (e.g., Chlorine) and health effects, that question cannot be answered.



Minimum chlorine residual in distribution system as a function of water level variations in Prospect tanks.

LEGEND

- Chlorine residual <20 percent
- Chlorine residual 20-50 percent
- Chlorine residual >50 percent

Chlorine residual as a percentage of residual leaving the treatment plant

PROBLEM: **Total Assessment of Microbial Regrowth in Full-Scale Distribution Systems**

ORIGINATOR: Hermanowicz

Importance:

Bacterial regrowth has been identified as a source of contamination yet little is known about the dynamics of distribution system colonization.

Objective:

- Investigate bacterial regrowth in a part of a full-scale distribution system.
- Develop mass and energy balance for substrates and microbial cells.
- Estimate growth and transformation kinetics.
- Examine the effects on water quality.

Suggested Approach:

- Identify and characterize a part of a distribution system with well-defined flow patterns.
- Monitor on four very frequent basis fluxes of nutrients and microorganisms.
- Attempt to balance the flow of nutrients and energy.
- Relate the fundamentals to water quality.

PROBLEM: **Development of Molecular-Based Methodologies to Compare/ Assess Environmental and Clinical Strains of Indicator Bacteria**

ORIGINATOR: Smith

Importance:

Utilities and regulators need a decision-making tool for public health protection during periods of elevated indicator-organism recovery (e.g., biofilms) that occur without evidence of fecal contamination or waterborne disease.

Objective:

Develop a tool for investigating waterborne disease outbreaks and evaluating the risk potential for distribution systems with active biofilms.

Suggested Approach:

Evaluate/develop molecular methods to compare/assess environmental versus clinical strains of indicator bacteria. Specifically, compare genetic properties of i.e. klebsiella pneumoniae, clinical and environmental isolates when klebsiella pneumoniae are being recovered from the distribution system.

PRIORITY RANK 9

Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence of Pathogenic Microorganisms

ORIGINATORS:
Falkinham on behalf of himself, Dresher, Harvey and Ridgway

The following research problems were subsumed under the above priority problem title:

PROBLEM: Influence of Water Distribution Systems' Conditions on Survival/Growth and Virulence of Pathogenic Microorganisms

ORIGINATOR: Falkinham

Importance:

- Conditions in water distribution systems may promote growth and pathogenicity of microorganisms
- Water treatment and distribution systems may concentrate pathogenic microorganisms.

Objective:

- Model water distribution system.
- Measure physiochemical parameters within system.
- Does model predict observed parameters?
- Measure influence of conditions on microbial pathogenicity, survival or growth.

Suggested Approach:

- Select water distribution system with known source of pathogens (e.g., Mycobacterium avium, Legionella pneumophila, Giardia lambia).
- Model and measure conditions within system.
- Compare model predictions with observed.
- Measure influence of range of conditions on survival/growth and virulence.
- Vary conditions, predict response of microorganisms, observe response.

PROBLEM: **Influence of Stagnation on Water Distribution Systems**

ORIGINATOR: Dresher

Importance:

The World Health Organization, in its recent "Guidelines for Drinking Water Quality", cautions on stagnation in water distribution systems and the development of microbial induced corrosion (MIC). With EPA-mandated reduced chlorine residuals, there appears to be developing serious corrosion (MIC), with implied health aspects, in systems that are stagnant for extended periods of time. Stagnation may occur in both the municipal distribution system and within buildings. It occurs in new construction, where the water system is filled for testing several months before occupancy, or it may be designed into a building in an extension of the plumbing system that is used infrequently. MIC is known to occur with most metals including nickel, titanium, steel and copper.

Objective:

To reduce corrosion, and potential health effects, in installations where drinking water may be stagnated for extended periods of time.

Suggested Approach:

Develop water system sterilization procedures for the effective sterilization of the water distribution and plumbing systems. Such procedures should be in keeping with environmental mandates for drinking water and waste water discharge.

Develop plumbing system designs that eliminate stagnation points within the system.

PROBLEM: **Role of Dissolved Metals in the Water Purification Process**

ORIGINATOR: Dresher

Importance:

- With mandated reduction of chlorine residuals, the question of assuring a sanitary water supply becomes important. It has been found that certain metals, such as silver and copper, in trace amounts, stress coliform and other bacteria in drinking water. This stressed state may be utilized to increase the effectiveness of chlorination. This effect has been used in swimming pool water treatment but not in municipal systems. (Note: metal concentrations are below the range of EPA established limits.)
- The presence of metal-injured coliforms can present difficulties in accurately analyzing the sanitary quality of drinking water.

Objective:

To make use of metallic ions normally found in drinking water to enhance the sanitation process.

Suggested Approach:

Additional laboratory studies are needed to understand the effect. These should be followed by in-field studies to determine the degree to which this effect is effective in a practical system and to learn how to optimize the effect in practice.

PROBLEM: **Determine the Effectiveness of Residual Disinfection Injected at Treatment Against (Viruses, Bacteria, and Protozoan) Microbes at Pipe Dead Ends (Particularly *E.Coli, Mycobacteria Avium, Cryptosporidium,* and Enteroviruses).**

ORIGINATOR: Harvey

Importance:

As disinfection levels are challenged in direct proportion to distance from treatment, microbial risks (including regrowth) seems highest for long distance users.

Objective:

An assessment of risk based upon biodynamics of the distribution system of distances and residual protectants to quantify risk factors - first customer versus last.

Suggested Approach:

- Develop reliable viability assays test for each microbial type – sentinels approach.
- Dose responses in animal – human models for pathogenicity.
- Test at pilot scales the distance/disinfection levels versus risk levels.
- Leads to focusing solutions at greatest risk locations and a measure of risk reduction(s) achieved.

PROBLEM: **Identification of Genotypic and Phenotypic Changes of Bacteria Introduced to Distribution System Environments**

ORIGINATOR: Ridgway

Importance:

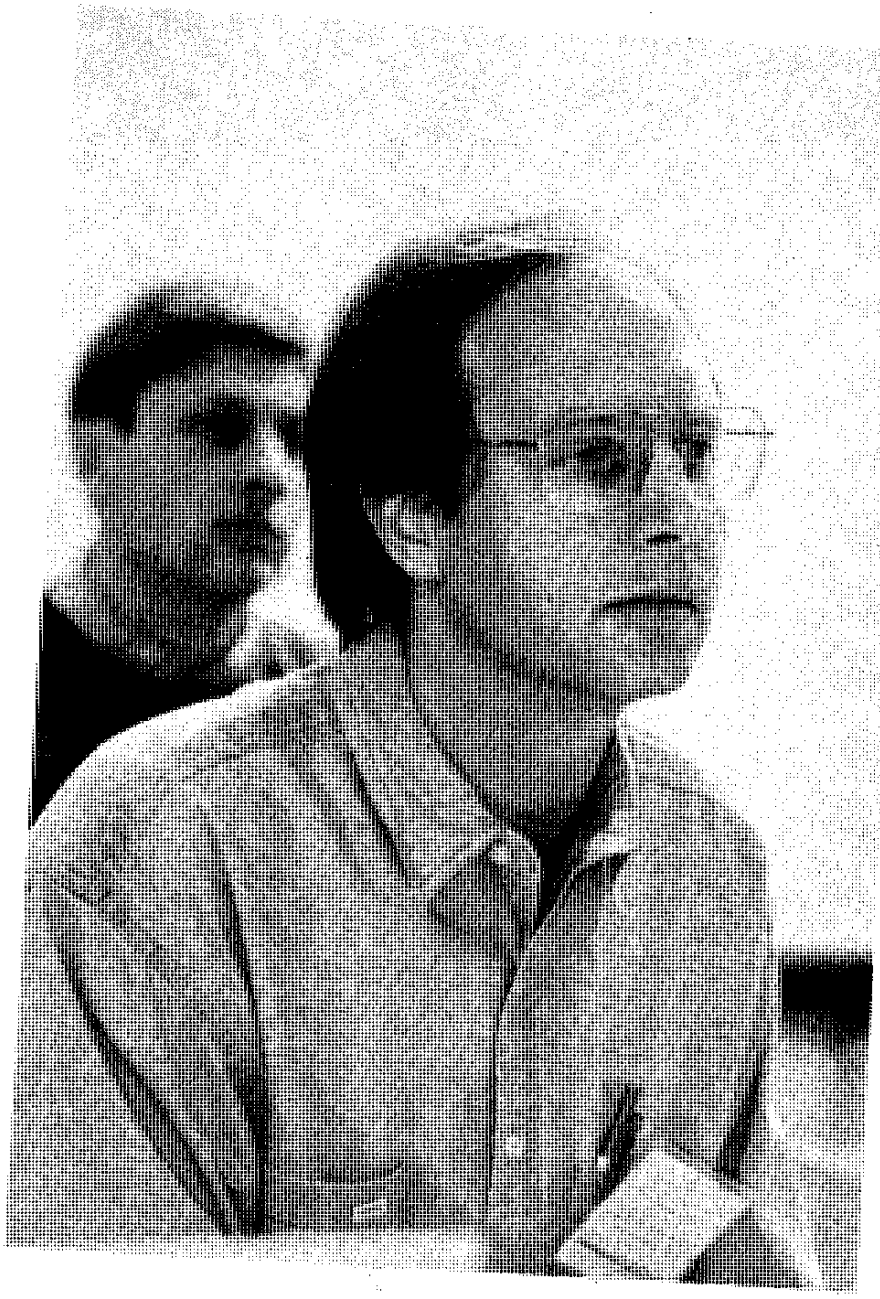
We do not understand genotypic/phenotypic changes that bacteria undergo when they are introduced into distribution systems or water treatment processes. Some of these changes may result in their enhanced survival and persistence.

Objective:

Characterize genotypic/phenotypic changes of indicator and other bacteria when placed under distribution system conditions.

Suggested Approach:

Employ a battery of genetic, biochemical, and physiological techniques to monitor and track dynamic changes that cells undergo when they are introduced to distribution system environments.



PRIORITY RANK 10

Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern

ORIGINATORS:
Wolfe on behalf of himself and Falkinham

The following research problems were subsumed under the above priority problem title:

PROBLEM: Development of a Rapid Method for Detection of Viable Legionella From Water

ORIGINATOR: Wolfe

Importance:

A significant number of cases of legionellosis occurs each year. Although viable Legionella can be recovered in hot water tanks and home plumbing systems, few viable Legionella are recovered from distribution system even though Legionella cells can be detected.

Objective:

- Develop a rapid method for measuring viable Legionella from water.

Suggested Approach:

- PCR approach (polymerase chain reaction, RNA).
- Use of vital stains w/fluorescent antibodies.

Then study ecology in distribution system.

PROBLEM: Develop and Compare Rapid, Simple and Inexpensive Methods for Enumeration of Viruses and Microorganisms

ORIGINATOR: Falkinham

Importance:

Lack of tests or expense of existing tests = lack of knowledge.

Objective:

- Develop tests/collect tests of different methodologies.
- Compare methodologies.
  - Sensitivity
  - Specificity
  - Utility

Suggested Approach:

- Test Development.
  - DNA-based
  - Amplification-based
  - Classical
- Comparison.
- Commercial Development.

PRIORITY RANK 11

Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials

ORIGINATORS:
Camper on behalf of herself, R. Clark, Dresher and LeChevallier

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Interaction of Disinfectants, Corrosion Control Regimes and Bacteria in Distribution Systems**

ORIGINATOR: Camper

Importance:

Improved water quality by effectively integrating corrosion control appropriate for distribution system materials with disinfectants for control of microbial growth.

- Reduced main deterioration.
- Increased water stability and quality.
- Reduced microbial contamination.
- Economical chemical addition.
- Compliance with lead and copper rule.

Objective:

Observe and monitor interactions of commonly used disinfectants and corrosion control strategies on:

- Corrosion rates.
- Disinfection efficacy on planktonic bacteria and biofilm organisms on reactive distribution system materials.

Suggested Approach:

Conduct laboratory and pilot scale research utilizing flowing systems with:

- Chlorine.
- Monochloramine.
- Phosphate based inhibitors on ferrous metal pipes.
- Ph control/alkalinity.

- Relevant hydrodynamic and nutrient regimes.

Measure:

- Corrosion rates.
- Disinfectant residuals.
- Biofilm/density.
- Planktonic cells.

PROBLEM: **An Assessment of the Microbial-Chemical Interactions That Occur in Distributed Drinking Water**

ORIGINATOR: R. Clark

Importance:

It is becoming increasingly apparent that water quality can experience significant degradation in drinking water distribution systems. Distribution systems may consist of thousands of miles of pipe of many types of materials. Variable residence time, chemical reactions, growth of microorganisms, and loss of chlorine residuals in the bulk phase, and formation of biofilm and chemical reactions at the pipe wall can change water quality as it moves through distribution system pipes.

As MCLs become more stringent and increase in number, compliance at the tap will become increasingly difficult. An increased understanding of the factors that contribute to water quality degradation will be required if utilities are to meet the requirements of the SDWA.

Objective:

Evaluate:

- The effect of different types of treatment on distributed water quality.
- The interaction of chemicals and microorganisms and their effect on distributed water quality.
- The effect of various flow regimes on water quality.
- The effect of various types of pipe materials on the growth of biofilm on pipe walls.

Suggested Approach:

- Evaluate the interactions listed under controlled experimental conditions.
- Develop predictive models.
- Calibrate models in full scale systems.
- Apply models to improve distributed water quality.

PROBLEM: **Develop Information on the Capacity of Pipe Materials to Sustain Biofilm Growth**

ORIGINATOR: R. Clark

Importance:

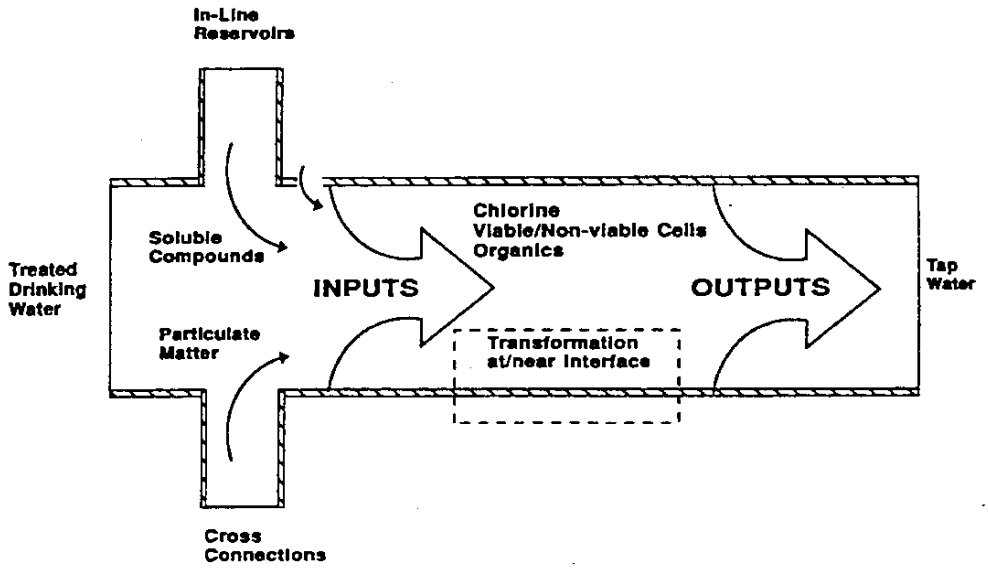
Biofilm growth in drinking water distribution systems can pose operational problems, consume disinfectants and potentially harbor pathogens. It has been observed that some pipe materials support colonization more readily than others.

Objective:

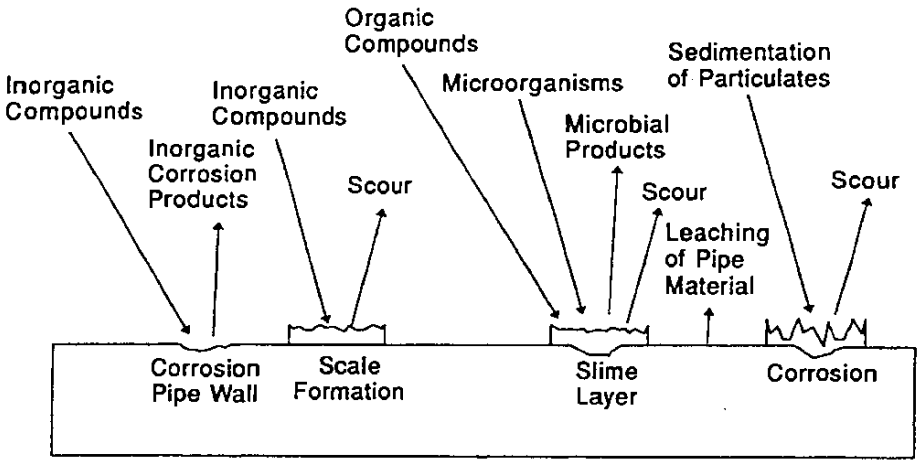
To evaluate the capacity of various pipe materials to sustain biofilm growth and consume disinfectant. To suggest modifications in pipe materials and for coatings and linings that would minimize biofilm colonization.

Suggested Approach:

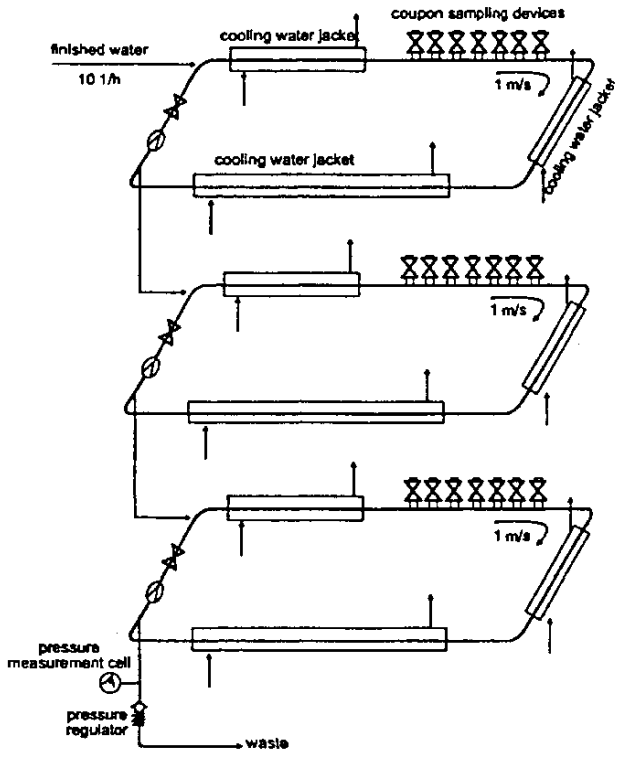
- Use pipe loops composed of various pipe material designed to simulate a range of residence times and hydraulic conditions, and to evaluate biofilm supporting potential of selected pipe materials.
- Evaluate the interaction of water quality, pipe material and disinfectant in supporting biofilm growth.
- Validate the results of these experiments using data from utility case studies.



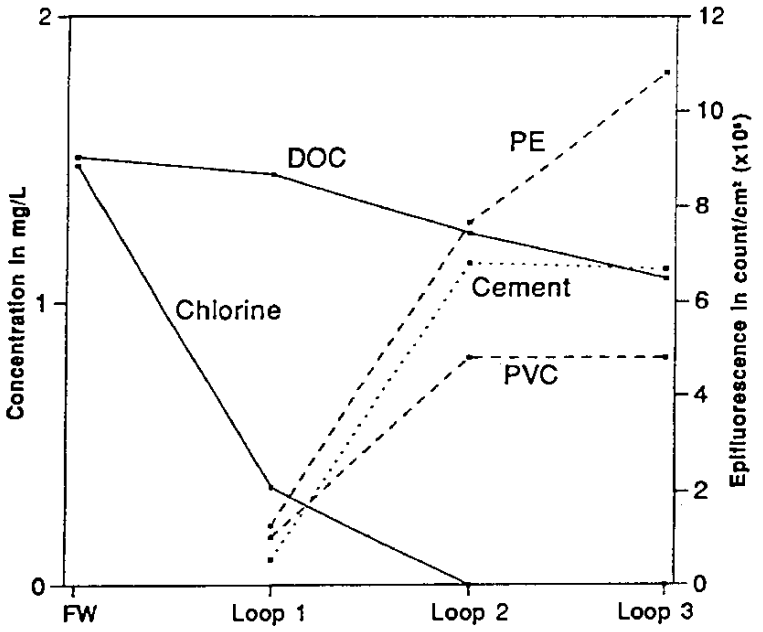
Water Distribution Pipe



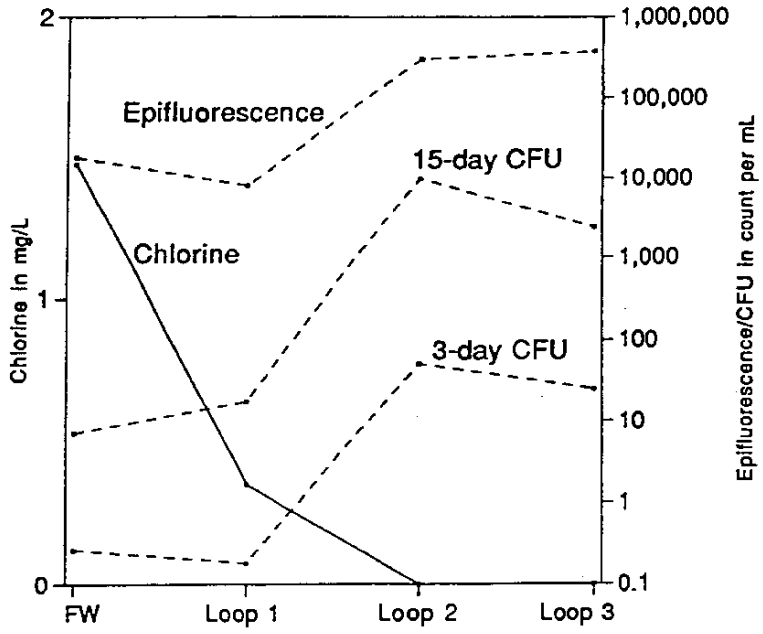
Water Distribution Pipe



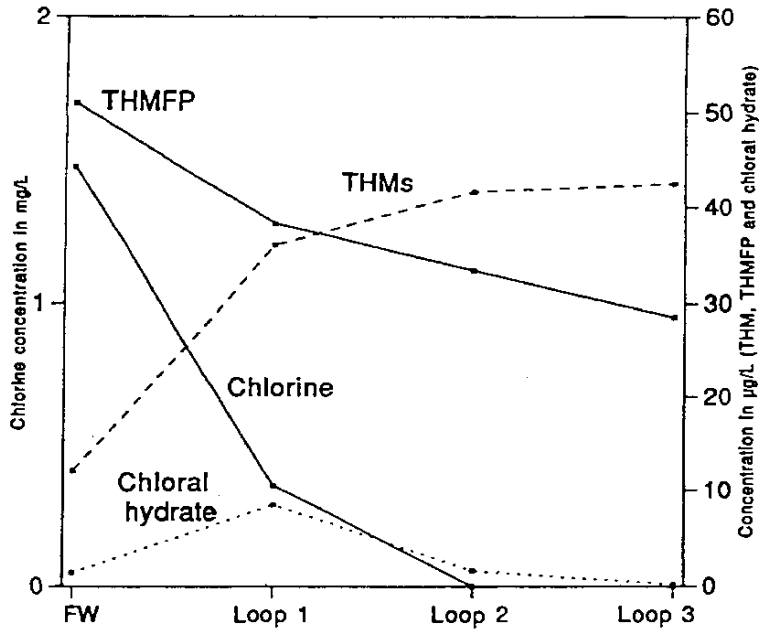
Experimental Distribution Network



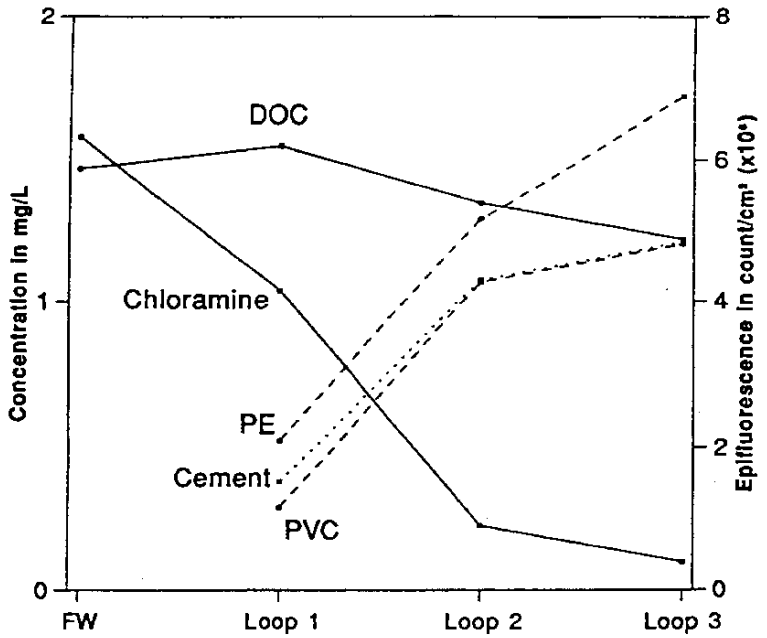
Chlorine, DOC and Epifluorescence by loop and pipe material



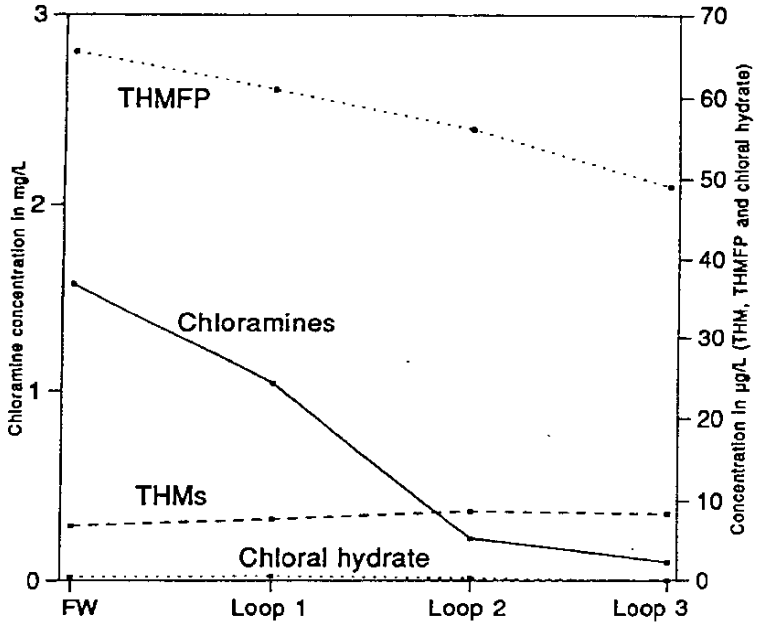
Chlorine, Epifluorescence & CFU by loop



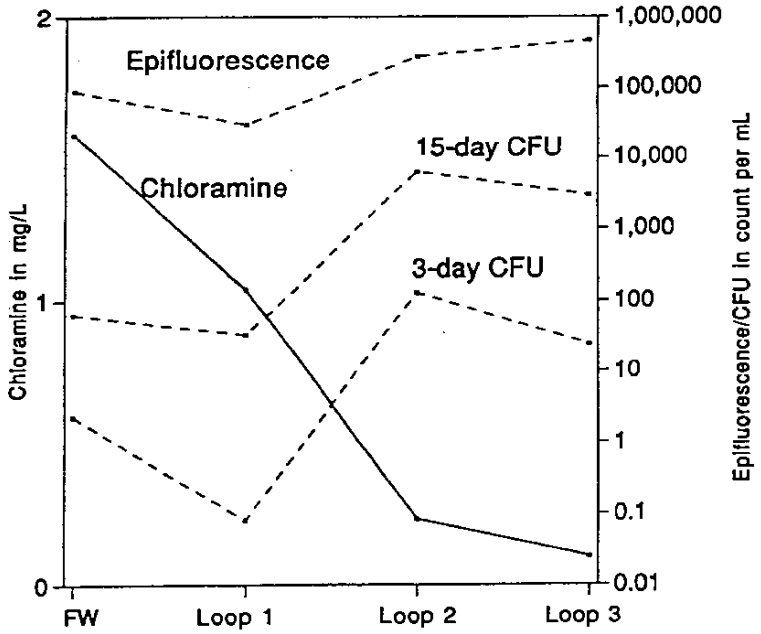
Change in Trihalomethane Formation in the Experimental System (Chlorinated)



Chloramine, DOC and Epifluorescence by loop and pipe material



Change in Trihalomethane Formation in the Experimental System (Chloraminated)



Chloramine, Epifluorescence & CFU by loop

PROBLEM: **Effects of New Water Treatments on Old Water Distribution Systems**

ORIGINATOR: Dresher

Importance:

EPA mandates under the "Lead and Copper Rule" require that water be treated to reduce its corrosiveness to metals in the distribution system. In some cases it has been found that the introduction of treated water to existing mains has caused unusual problems with cast iron and steel piping which has led to iron contamination of the water delivered to the customer, leakage of mains and possible iron-induced accelerated corrosion of copper hot water systems.

Objective:

To develop a method of treating water in a manner that the newly treated water does not interfere with the materials in the existing water distribution system.

Suggested Approach:

Laboratory studies are needed to develop an understanding of the mechanism of corrosion products protecting the existing system when a change is made in the supply water.

Having done this, water treatment procedures should be elevated both in terms of their ability to fulfill the requirements of the Lead and Copper Rule and to avoid undo change in the installed system.

While not strictly within the context of treatment under the Lead and Copper Rule, the recent experience of the City of Tucson in attempting to mix treated Central Arizona Project water with their existing ground-water source is a strong case in point. (Cast iron water mains lost their protective coating of iron oxide and major failure of the pipe resulted! This, in spite of the fact that the CAP water was adjusted to be the same Ph as the existing water.)

PROBLEM: **Modeling Disinfection Mechanisms for Biofilm**

ORIGINATOR: LeChevallier

Importance:

Control of biofilm bacteria by disinfection requires a biocide that will be effective for attached organisms. Currently there is no model to base the selection of an appropriate secondary disinfectant.

Objective:

The project would develop a model to describe the transport and interaction of commonly used disinfectants (free chlorine, monochloramine, chorine dioxide) with biofilm microorganisms and reactive compounds.

Suggested Approach:

- Experiments would determine transport of biocides within a biofilm matrix.
- Examine the reaction rate of biocide with non-target compounds.
- Determine the impact of biofilm structure of biocide effectiveness.
- Determine the role of microbial activity on disinfection resistance.

PRIORITY RANK 12

Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water From Varying Sources

ORIGINATORS:
Curry-Grant on behalf of herself and Camper

The following research problems were subsumed under the above priority problem title:

PROBLEM: Enumeration and Identification of Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Waters From Varying Sources with Differing Treatments and Disinfectants

ORIGINATOR: Curry-Grant

Importance:

The disinfection process refers to a reduction of microbial content in the water supply and is not intended to provide sterilization. Therefore, the distribution system is constantly being seeded with low levels of microorganisms that may or may not be opportunistic pathogens. As municipalities have become more concerned with controlling the formation of chlorinated disinfection by-products in distribution systems, there has been less reliance on maintaining a free chlorine residual. As a result, many have favored a less potent combined chlorine residual for protection of the distribution system. Therefore, the question that must be addressed is: Are distribution systems that receive water from sources of varying quality, and differing treatments and disinfectants, more likely to become reservoirs for microorganisms of public health concern?

Objective:

Study distribution systems that receive treated surface versus ground water. Other variables to be researched should include the disinfectant type, concentration, and contact times.

Suggested Approach:

Initial efforts should be directed toward identifying specific genera of microorganisms. This can be accomplished using specific antibodies and fluorescent staining procedures. Confirmation and enumeration of microorganisms can be achieved with either probe or conventional microbiological techniques.

PROBLEM: **Virulence of Pathogens and Opportunistic Pathogens Isolated From Biofilms in Distribution Systems (Specifically Coliforms)**

ORIGINATOR: Camper

Importance:

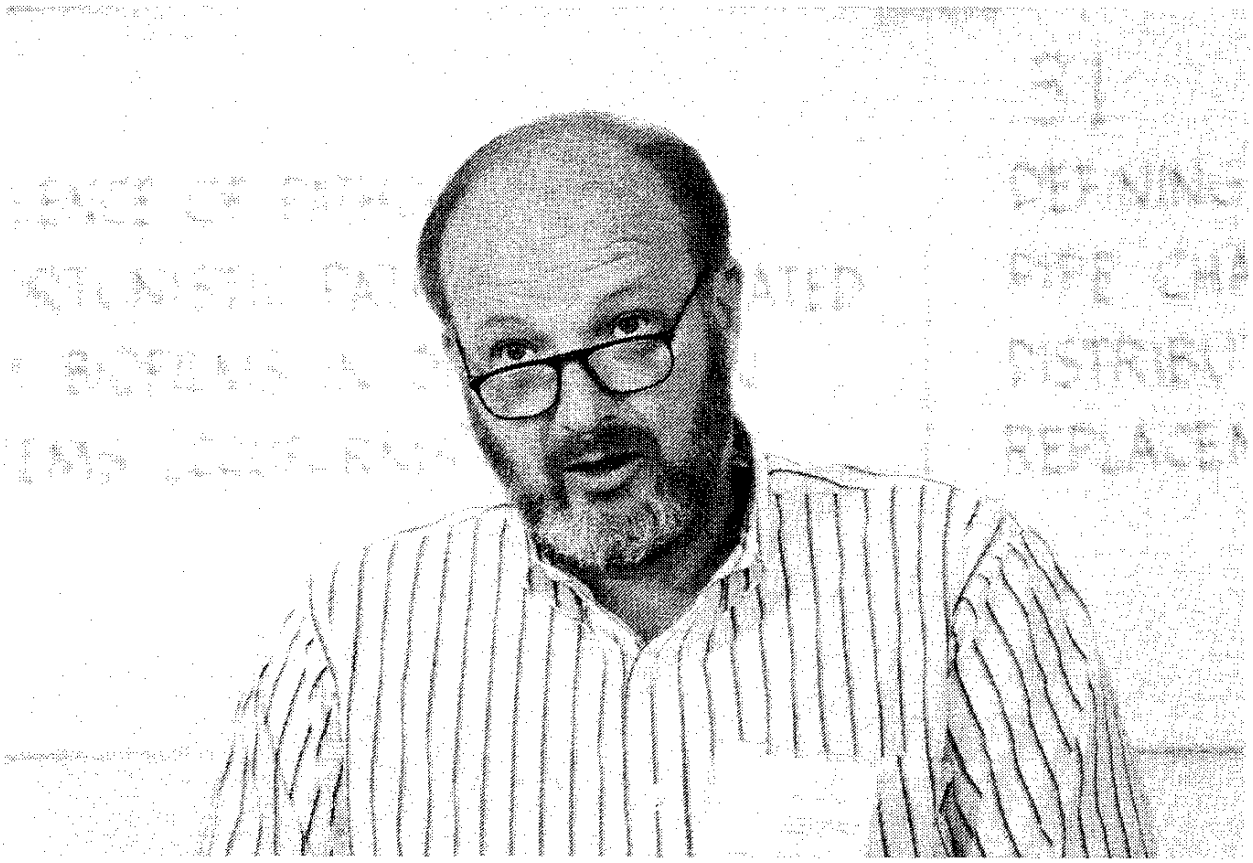
Decide if public health is at risk from regrowth events.

Objective:

Answer question of whether indicator or organisms "attenuated" through biofilms growth are capable of producing disease.

Suggested Approach:

- Test virulence of organisms isolated during regrowth events.
- Conduct laboratory studies to do same with organisms from "developed" biofilms.



PRIORITY RANK 13

Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality, Public Health Protection and System Service Life

ORIGINATORS:
Smith on behalf of himself and Kirmeyer

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Unified Distribution System Operating and Maintenance Manual of Practice to Promote Water Quality, Public Health Protection and System Service Life**

ORIGINATOR: Smith

Importance:

The water distribution system is a complex entity that contains a variety of elements such as pipes, storage reservoirs, pumps, valves, pressure regulating devices and fire hydrants. Each element in the system has its own unique requirement for proper operation and maintenance. Moreover, the siting and installation of these elements can impact water quality and system performance and serviceability. Improper design, operation, or maintenance of water distribution systems can result in water quality deterioration. Poorly maintained systems may become subject to undesirable microbial growth, excessive main failures and cross-connections all of which can cause waterborne disease. Other factors impacting these systems include internal and external corrosion, reduced carrying capacity and excessive water losses. Improved and standardized distribution system operation and maintenance procedures will help minimize the potential for water quality deterioration and waterborne disease and extend system service life.

Objective:

Identify, evaluate and compile effective distribution system operating and maintenance practices into a guidance document applicable to all public water supply systems, regardless of system size. This document will clarify and expand on the EPA's "best technology" concept for distribution system maintenance and could become the standard for conducting distribution system sanitary surveys. Major topics to be included in the guidance document are:

- Monitoring programs.
- Cross-connection control.
- Security and safety.

- Emergency response, trouble shooting procedures.
- Record keeping systems.
- Maintenance and rehabilitation procedures.
  - Flushing programs.
  - Disinfection of water mains and distribution facilities.
  - Water main rehabilitation.
  - The repair of mains, valves and hydrants.
  - Tank and standpipe maintenance.
  - Corrosion control.
- Training programs for operators and maintenance personnel.

Suggested Approach:

Review literature, Ten-State Standards, AWWA standards and manuals and perform an industry-wide survey of distribution system operation and maintenance practices. The survey should encompass a sufficient cross-section of small, medium and large public water supply systems.

PROBLEM: **Manual of Practice — How to Operate and Maintain a Water Distribution System to Maintain/Enhance Drinking Water Quality**

ORIGINATOR: Kirmeyer

Importance:

Distribution system operators have the desire to provide a high quality water to their consumers; however, historically many do not have the technical know-how or have not had the responsibility. Now, they have the responsibility because of USEPA regulations for system water quality, but they have no "manual" or "how-to book" to refer to as a standard of practice. The existing documentation is fragmented and often out of date.

Objective:

Develop a state-of-the-art Manual of Practice to maintain water quality based on our current knowledge of distribution system operation and factors that degrade or enhance water quality.

Suggested Approach:

- Designate a lead author to organize the manual.
- Select pertinent topics including water quality monitoring, management structure, new main installation, repairs, dechlorination and disposal of water, reservoir operation, blending of sources within the system, flushing, cross connections control etc.
- Retain authors/co-authors to address each of the subjects (should be practical utility operations/engineering staff).
- Prepare manual in 18 months as a basis for improved operation.

PRIORITY RANK 14

A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls

ORIGINATORS:
S. Clark on behalf of himself and DeMarco

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls**

ORIGINATOR: S. Clark

Importance:

Material used on pipe interiors have potential to degrade water quality by dissolution of chemicals or support of microbial growth. The two major problems are bacterial regrowth leading to total coliform violations and possibly human exposure to opportunistic pathogens. In iron water mains the aesthetic quality of the water can be adversely impacted.

Objective:

- Correlate changes in water quality with various treatment practices designed to minimize pipe corrosion.
- Characterize the physical and microbiological components of the surface materials (films) on the inside of various pipe materials.

Suggested Approach:

- Examine water quality parameters and correlate with changes in interior pipe films using various physical, chemical and microbial techniques.
- Examine in-situ means of pipe rehabilitation where pipe is in poor condition or water quality modifications will not correct the situation.

PROBLEM: **Water Distribution System Materials Causing Water Quality Degradation by Chemical Leaching and Support of Microbial Growth**

ORIGINATOR: S. Clark

Importance:

Existing materials in use are related to water quality degradation which in some cases is causing increased risk to human health.

Objective:

Develop and demonstrate materials/coatings that minimize water quality degradation and risks to human health.

Suggested Approach:

- Examine pipe/tank coatings that minimize metals corrosion, chemical leaching and microbial growth.
- Develop/demonstrate new construction and in-situ rehabilitation techniques for distribution system components.
- Verify in field properties.

PROBLEM: **Water Quality Degradation by Distribution Pipe Material**

ORIGINATOR: DeMarco

Importance:

Assuring the maintenance of a disinfectant residual, minimal bacterial population, and minimal turbidity/rust, etc. throughout the entire distribution system is critical.

Objective:

To determine the impact of age, type of material, and condition of pipe, e.g., tuberculation on water quality, chlorine demand, and biofilm formation.

Suggested Approach:

A geographic distribution of water treatment facilities, which have a variety of pipe materials and known distribution system problems, should be sampled over several seasonal changes to determine associations between pipe material and condition with water quality.

PRIORITY RANK 15

Establish a Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, Including New Sampling Devices

ORIGINATORS:
Harvey on behalf of himself and Grayman

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Establish a Standardized, Statistically Valid Set of Sampling Plan(s) for Distribution Systems (Small and Large) Including New In-Process Sampling Devices for Both Chemicals, Materials, and Microbes**

ORIGINATOR: Harvey

Importance:

Reducing and automating the number of sampling points yet still having acceptable confidence bands around analytes are both cost effective and provides assurances for risk management decisions.

Objective:

The objective is to create a set of "common sampling plans" driven by high risk stressors that serve for both standards setting and operating and monitoring parameters encompassing appropriate confidence bounds.

Suggested Approach:

- Select prototype distribution systems (2-3)
- Sample using surrogate stressor(s) where possible.
- Determine statistically based/confidence intervals determined via sampling plans with distribution size and types as variables.
- Pilot Level - Full systems verification, set up National data base for success measurements.

PROBLEM: **Development of Distribution System Sampling Regulations and Procedures to Minimize Exposure Risk**

ORIGINATOR: Grayman

Importance:

Water quality can vary both spatially and temporarily in a distribution system. In order to insure that water quality meets required levels, procedures for defining a robust sampling program are needed.

Objective:

Develop a set of procedures and resulting regulations for defining a sampling program that will minimize exposure risk.

Suggested Approach:

Use statistical analysis of sampling data and water quality models of a wide range of distribution systems to evaluate the ability of alternative sampling schemes to minimize risk of exposure to unacceptable levels of harmful constituents.

PRIORITY RANK 16

Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu

ORIGINATORS:
Edwards on behalf of himself, Dresher, Karlin and Reiber

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Effect of Inhibitors on Corrosion of Pb, Cu and Brass**

ORIGINATOR: Edwards

Importance:

The high cost of proprietary inhibitors, the still unresolved primary and secondary effect of inhibitors on plumbing materials in distribution systems, and the severe public health impacts (i.e., increased concentrations of heavy metal corrosion by-products in drinking water) make this item of high societal priority.

Objective:

To define the specific water quality regimes in which inhibitors have beneficial effects and those for which inhibitors have adverse effects.

Suggested Approach:

Expose lead, copper and brass plumbing materials to waters with a wide range of pHs and alkalinities to establish baseline data on corrosivity. Parallel experiments, in which the same waters will be tested but with inhibitor addition, will clearly establish the relative benefits or disadvantages of each inhibitor type (i.e., ortho-, poly-, and higher chain phosphates) on copper and lead corrosion by-product release. A combination of conventional and electrochemical corrosion monitoring techniques should be used to maximize the research obtained for the effect expended. This should be a rational scientific laboratory-based study as compared to the collection of anecdotal utility experiences.

PROBLEM: **Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu**

ORIGINATOR: Edwards

Importance:

The high cost of proprietary phosphate-based inhibitors, the still unresolved primary and secondary effect of inhibitors on plumbing materials in distribution systems, and the severe public health impacts (i.e., increased concentrations of heavy metal corrosion by-products in drinking water) make this item of high societal priority.

Objective:

To define the specific water quality regimes in which inhibitors have beneficial effects and those for which inhibitors have adverse effects.

Suggested Approach:

Expose lead, copper, and brass plumbing materials to waters with a wide range of pHs and alkalinities to establish baseline data on corrosivity. Parallel experiments, in which the same waters will be tested but with inhibitor addition, will clearly establish the relative benefits or disadvantages of each inhibitor type (i.e., ortho-, poly-, and higher chain phosphates) on copper and lead corrosion by-product release. A combination of conventional and electrochemical corrosion monitoring techniques should be used to maximize the research obtained for the effect expended.

PROBLEM: **Passivation of Lead in Drinking Water Distribution Systems**

ORIGINATOR: Dresher

Importance:

It has been found that ppb quantities of lead in drinking water may be harmful to health, particularly that of small children. The EPA has mandated the application of water treatment practices that reduce the amount of lead in drinking water as well as the removal of lead pipe in water distribution systems.

Objective:

To develop a treatment that passivates lead as it appears in materials used in drinking water systems in order to reduce its rate of leaching and thus avoid replacement of materials now installed. Such treatment could be by additive to the water or by an isolated chemical modification of the lead-contaminating surface.

Suggested Approach:

Lead-containing materials are successfully used in drinking waters that are hard and high in sulfate due to the development of an insoluble film of lead sulfate on the surface. Explore for other possible ways of passivating lead that are compatible with good drinking water practice.

PROBLEM: **Effect of Corrosion Control Practices on Mobility of Lead From Brass Faucets**

ORIGINATOR: Karlin

Importance:

There is increasing concern over the role of lead in brass faucets. Recent changes in treatment practices to protect the public from lead exposure from lead pipe/ solder may or may not have reduced brass lead solubility.

Objective:

Determine whether lead/copper control practices are effective in reducing lead from brass faucets.

Suggested Approach:

Conducted a bench study using a "pipe loop" approach.

PROBLEM: **Effectiveness of Caustic Silicates as Corrosion Inhibitors**

ORIGINATOR: Reiber

Importance:

Silicates are being widely marketed for controlling corrosion on Pb and Cu surfaces — their efficacy is, as yet, unproven.

Objective:

Distinguish between pH effects and corrosion inhibition related solely to SiO2.

Suggested Approach:

Pipe loop program — metal leaching studies.

PRIORITY RANK 17

Development and Evaluation of Rapid Methods for Measuring Assimilable Organic Carbon (AOC)

ORIGINATORS:
Ridgway on behalf of himself and Wolfe

The following research problems were subsumed under the above priority problem title:

PROBLEM: Design and Evaluation of a Real-Time AOC Bioassay Device

ORIGINATOR: Ridgway

Importance:

AOC may be an important parameter affecting the survival, persistence, and regrowth of distribution system microorganisms. A more rapid, sensitive, and automated AOC measurement technique is needed.

Objective:

The objective is to design, build, and test a real-time AOC detection/measurement technique.

Suggested Approach:

Using molecular-genetic techniques, place the lux operon under control of a growth/division related promoter of Pseudomonas p17. Then place recombinant organisms in a gel matrix on end of an optical fiber element which is connected to a photo multiplier device and computer. The recombinant organisms would be pre-starved for nutrients, either before or after gel embedding. Light emission would indicate presence of AOC.

PROBLEM: Development of a Rapid Method for Measuring Assimilable Organic Carbon (AOC)

ORIGINATOR: Wolfe

Importance:

Measurement of the AOC content of drinking water provides information on the survival, persistence and potential for bacterial regrowth in the distribution system. Measurement of AOC is becoming increasingly important as new

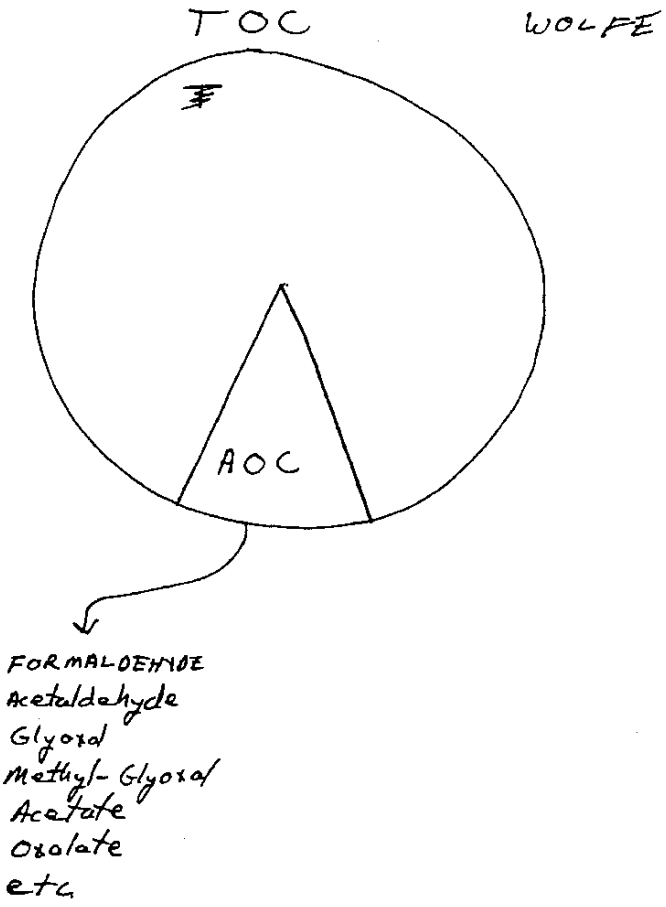
regulations promote the use of ozone disinfection as an alternative to chlorination. Ozonation is well recognized to dramatically increase the level of AOC in water. Unfortunately, the current methods for measuring AOC require several days to weeks before results are obtained. Having a rapid, direct method for AOC measurement would enable utilities to more efficiently study the potential for bacterial regrowth.

Objective:

The objective of this project is to chemically analyze AOC to determine correlations with chemical components. Chemical analysis of the major AOC constituents would provide a more rapid measure of regrowth potential in the distribution system.

Suggested Approach:

Samples of unozonated and ozonated water would be analyzed for AOC and a host of oxygenated organic compounds, such acetaldehyde, formaldehyde, glyoxal, methylglyoxal, and oxalic acid, and correlated with the change in AOC. Samples of the ozonated water could be subjected to biofiltration to compare removal of AOC, and the specific organic chemical compounds. Relationships may exist between AOC and the individual and combined organic chemicals such that direct chemical measurement could replace the time-consuming analysis for AOC. Different source waters need to be evaluated.



PRIORITY RANK 18

Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality

ORIGINATORS:
Edwards on behalf of himself and Wolfe

The following research problems were subsumed under the above priority problem title:

PROBLEM: **Secondary Effects of Distribution By-Product Control on Distribution System Water Quality, or Effects of New Water Treatments on Old Water Distribution Systems (The Sequel)**

ORIGINATOR: Edwards

Importance:

Unprecedented changes in water treatment practice are currently under consideration for the new DBP rule. Lower residuals, alternate disinfectants and new/enhanced treatment process may have profound effects on biofilm growth and corrosion control.

Objective:

To address and explore secondary impacts of DBP control on water quality degradation in distribution systems.

Suggested Approach:

Select about four of the most promising means of addressing the DBP rule and examine their relative effects on distribution system water quality. The study should include an examination of biofilm growth and corrosion control, bacterial levels, AOC and corrosion by-product release. One of the alternatives must be enhanced coagulation.

PROBLEM: **Impacts of Enhanced Coagulation on Microbial Quality of Water in the Distribution System**

ORIGINATOR: Wolfe

Importance:

The upcoming Disinfection/Disinfectant By-Products (DBP's) Rule is designed to reduce the levels of DBP's in the distribution system. This rule will require

utilities treating with surface waters with Total Organic Carbon levels of > 2.0 mg/L to implement enhanced coagulation (EC). In the EC process, elevated levels of a coagulation are added to remove DBP precursors and primary disinfection is delayed until after the sedimentation process to limit DBP formation. However, shifting the point of disinfection to the end of the treatment process results in a reduced margin of safety from waterborne disease and increase the potential for microbial regrowth in the distribution system.

Objective:

The objective of the project would be to determine if there are microbial risks associated with moving the point of primary disinfection to the end of the treatment train. This will provide information on loading of bacteria in the distributions system and whether microbial problems will occur.

Suggested Approach:

Experiments would be conducted at full-scale level. Samples would be collected throughout the treatment train (before and after implementation of EC) and analyzed for coliforms, heterotrophic plate count bacteria, and assimilable organic carbon. Biofilm samples would be collected from the undisinfected flocculation and sedimentation basins.

PRIORITY RANK 19

Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses

PROBLEM: **We Have a Limited Understanding of A) Viral Abundance and B) Modes of Disinfection Resistance/Treatment Survival of Viruses**

ORIGINATOR: Ford

Importance:

The majority of gastrointestinal (GI) infections are unreported or undiagnosed. Viruses may be implicated in many outbreaks of GI disease of unknown etiology, and their abundance may be much greater than previously suspected.

Objective:

To understand and reduce risks from viruses in drinking water. To provide more effective monitoring and development of specific indicators of viral contamination (using molecular approaches). In addition, we need to understand the role of viruses in gene transfer in drinking distribution system water biofilms. Gene transfer in biofilms is an important concern for dissemination of virulence and/or antibiotic resistant factors.

Suggested Approach:

Emphasis is required on development of detection techniques and standardized procedures for water treatment personnel. Conduct investigations on efficacy of virus removal procedures (e.g., point of use filtration to reduce GI disease).

PRIORITY RANK 20

Organics Leaching from Thermoplastic and Elastomeric Surfaces

PROBLEM: **Identification of Organics Leaching from Thermoplastic and Elastomeric Surfaces**

ORIGINATOR: Reiber

Importance:

- Plastics and rubber components leach:
  - Plasticizers.
  - Antioxidants.
  - Waxes.
  - Solvents.
- Under stagnation conditions, the concentration of leachates may be significant.
- The NSF 60 guidelines for distribution system materials lack rigor and are incomplete.
- Degradation of elastomers, as is common in chloraminated systems, accelerates leaching.
- We have little understanding of the effects of disinfectant oxidants on leachates or the influence of microbial metabolism on these substances.

Objective:

- Identify common constituents of proprietary elastomer formulations.
- Rigorous analytic evaluation of elastomeric degradation products.
- Determine leachate stagnation concentrations in residential tap samples.

Suggested Approach:

- Field study.
- Cooperative agreement with manufacturers.

PRIORITY RANK 21

Identification of Biofilm Bacteria

ORIGINATOR:
LeChevallier

Importance:

Although water is something that every person requires each day, the microbial composition of drinking water is not well characterized. Comparison of different waters based on plate count valves is not necessarily an indicator of the microbial quality of water.

Objective:

- To evaluate procedures for bacterial identifications in water.
- Compare Rapid procedures (such as API, NFT), substrate-based methods (Biology), and molecular component techniques (fatty acid, phosphorylate lipids, RNA typing, etc.).

Suggested Approach:

- Determine the proportion of total bacteria that are capable of being isolated and identified.
- Determine approaches that can enhance the portion of identifiable bacteria.
- Compare identifications obtained by different systems.

PRIORITY RANK 22

Research Needed on the Importance of the Nitrogen Cycle in Water Distribution Biofilms and its Control

ORIGINATORS:
Ford on behalf of himself and Hubbs

Importance:

Important in breakdown of chloramine disinfectants; responsible for formation of nitrites and nitrates.

Objective:

Provide guidelines for risk reduction from e.g. nitrites. For example, enhance denitrification rates.

Suggested Approach:

Study conditions that enhance nitrification and/or denitrification in distribution system biofilms (temperature, organics, anaerobic conditions).

PROBLEM: **Control of Nitrification in Distribution Systems Using Chloramine**

ORIGINATOR: Hubbs

Importance:

Nitrification can quickly deplete chloramine residuals in distribution systems, leaving the system with no residual disinfectant.

Objective:

Evaluate both chemical factors and management practices that will be effective in controlling nitrification in distribution systems.

Suggested Approach:

- Review existing practice.
- Evaluate susceptibility of nitrifying bacteria to parameters feasibly controlled in the distribution system (pH, disinfectant residual, others).

PRIORITY RANK 23

Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead by the Water in Excess of Standards

PROBLEM: **To Locate Lead Service Lines and Develop Non-Treatment Methods that will Prevent the Uptake of Lead by the Water in Excess of Standards**

ORIGINATOR: Kirmeyer

Importance:

Concerning lead service lines, there is serious concern by several utilities that they may need to remove their portion of lead service lines if they cannot meet lead action levels per the new federal Lead and Copper Rule. There is an estimated range of 2.3 to 5.1 million lead service lines in the United States. Total estimated cost nationwide to remove only the utility portion of the lead service lines is $3.4 to $5.1 billion. To replace the entire line would cost utilities $10.0 to $14.1 billion. This could be a very significant cost for the relatively few utilities faced with removal of thousands of lines. Less expensive methods to address this problem must be found.

Objective:

Identify methods to help utilities to locate lead service lines and develop methods, either by removal of the line, or coating of the line in place to prevent release of lead.

Suggested Approach:

- Develop better methods for location of lead service lines.
- Field test coating methods for lead service lines that remain in place.
- Field test methods for removal of lead service lines to develop less disturbing methods.
- Make recommendations to utilities to help locate lead service lines and reduce to potential for lead uptake either through removal of lines and/or coating in place.


DARRELL
SMITH

PRIORITY RANK 24

Development of Technology for Reducing Risk in Distribution Systems in Less-Developed Countries and Inner-Cities

ORIGINATORS:
Grayman on behalf of himself, Ford and Holtzman

The following research problems were subsumed under the above priority problem title:

PROBLEM: Development of Cost-Effective Methods for Transferring Risk Reduction Technology in Distribution Systems to Poorer Countries

ORIGINATOR: Grayman

Importance:

Poorer countries experience many of the same water quality problems in distribution systems that are found in the United States at a level that may be significantly more serious. However, they cannot generally afford the highly sophisticated (and expensive) technology available to us.

Objective:

Develop variations on available technology that can be made available at lower costs to poorer countries (and even to poorer water utilities in the United States).

Suggested Approach:

Fund research (subsidize commercial ventures) to develop such technology.

PROBLEM: Development of Strategies for Drinking Water Treatment in Less-Developed Countries

ORIGINATOR: Ford

Importance:

Other countries look to the United States for advanced technologies. Many of these technologies are completely unsuitable for application in those countries, both for economical and geographical/climatological reasons.

Objective:

Provide a consensus on alternative water treatments suitable for a wide variety of geographical and economic regions. NWRI should be careful not to operate in the vacuum of North America alone.

Suggested Approach:

The first step may be to provide a forum for discussion — an international symposia between NWRI, AID, World Bank, UNIDO, etc., and government representatives from less-developed countries.

PROBLEM: **Evaluate Water Quality in Inner-City Areas**

ORIGINATOR: Holtzman

Importance:

Could lead to better health conditions related to water in these areas.

Objective:

To be sure that water quality is up to standards elsewhere in the city.

Suggested Approach:

Usual monitoring methods.

PRIORITY RANK 25

Interactions Between Disinfection of Suspended Microbial Cells and Surface Colonization

ORIGINATOR:
Hermanowicz

Importance:

Disinfection of suspended cells is one of the treatment processes. The disinfected cells (dead, injured, viable) are then introduced to a distribution system where they may attach to walls, colonize the surfaces, recover from injuries or provide substrate for growth.

Objective:

The objective is not to study disinfection of attached cells/biofilms, but rather to investigate the fate of disinfected cells as they interact with surfaces.

Questions to be answered:

- How well do they attach?
- If injured, do they recover?
- If dead, do they provide nutrients and promote growth?

Suggested Approach:

Disinfect bacteria with various agents and monitor their deposition under defined hydrodynamics. Use microscopic observations combined with vital staining and traditional microbiological techniques to assess their growth, recovery, etc.

PRIORITY RANK 26

Inadequate Source Water Quality

ORIGINATOR:
Ford

Importance:
Improvements in source water quality will inevitably lead to improved drinking water quality.

Objective:
To obtain definitive guidelines for watershed management.

Suggested Approach:
Identify major risks to the watershed and develop a close interaction, including incentives, with industry, agriculture and other development interests.

PRIORITY RANK 27

Lack of Understanding of the Existing Condition of U.S. Distribution Systems Related to Maintaining Water Quality

ORIGINATORS:
DeMarco on behalf of himself, Dresher, Eager, and Kirmeyer

The following research problems were subsumed under the above priority problem title:

Importance:
A host of activities are being proposed to determine what risks exist in Distribution Systems and what new work can be done to minimize these risks. The industry practitioners need to know what is now being done by leading utilities and how well these activities are thought of as interim solutions.

Objective:
We need to define what real risks now exist, what causes these risks, and how we can cope with them now. We also need to raise the level of awareness of utility managers and regulators regarding potential problems in the future.

Suggested Approach:
Conduct seminars/workshops at Annual AWWA, WQTC, DSS, NAWC, AMWA and also local water meetings related to maintaining water quality that the customer receives.

PROBLEM: **Effects of New Water Treatments on Old Water Distribution Systems**

ORIGINATOR: Dresher

Importance:
EPA mandates under the "Lead and Copper Rule" require that water be treated to reduce its corrosiveness to metals in the distribution system. In some cases it has been found that the introduction of treated water to existing mains has caused unusual problems with cast iron and steel piping which has led to iron contamination of the water delivered to the customer, leakage of mains and possible iron-induced accelerated corrosion of copper hot water systems.

Objective:

To develop a method of treating water in a manner that the newly treated water does not interfere with the materials in the existing water distribution system.

Suggested Approach:

Laboratory studies are needed to develop an understanding of the mechanism of corrosion products protecting the existing system when a change is made in the supply water.

Having done this, water treatment procedures should be elevated both in terms of their ability to fulfill the requirements of the Lead and Copper Rule and to avoid undo change in the installed system.

While not strictly within the context of treatment under the Lead and Copper Rule, the recent experience of the City of Tucson in attempting to mix treated Central Arizona Project water with their existing ground-water source is a strong case in point. (Cast iron water mains lost their protective coating of iron oxide and major failure of the pipe resulted! This, in spite of the fact that the CAP water was adjusted to be the same Ph as the existing water.)

PROBLEM: **Field Study of Water Quality, Distribution System Pipe Materials, and Pipe Biofilms Under Various Corrosion Control Scenarios**

ORIGINATOR: Eager

Importance:

Water suppliers do not have enough data from empirical observations of the condition of pipe materials which have been in service for a period of time to understand all of the implications of changing water quality for corrosion control. The available information on the role of biofilms and water quality changes in iron corrosion is also insufficient.

Objective:

- To characterize corrosion films on different material specimens collected to represent a range of water treatment conditions.
- Determine effects of using several different corrosion inhibitors versus PH/alkalinity adjustment on cast iron tuberculation and lead/copper passivation films.
- Characterize and compare the microbiology of the specimens.

Suggested Approach:

First, a literature review of all recent related research would be conducted and used to plan the materials and microbiological tests. This approach would require cooperation from a dozen or more water utilities. A review of treatment and water quality history would accompany distribution system monitoring survey to characterize the water quality and degree of variability. Spectroscopic, microscopic,

and elemental analysis of pipe films on samples, and visual observations of a number of material samples from different parts of each system would be made. Also, pipe film samples would be analyzed for presence of microorganisms, and various microscopic/culture/staining and other more sophisticated methods used to describe the biological community. The implications of the presence of organisms would be discussed: metabolism, environmental conditions for growth, impact on material corrosion. The condition of the pipe specimens and the composition and structure of corrosion films would be compared, and where possible related to the water quality (treatment) and the presence and nature of biofilms.

PROBLEM: **To Assess the Conditions of North American Water Distribution Systems and Develop a 10-Year Research Agenda**

ORIGINATOR: Kirmeyer

Importance:

There is an estimated 880,000 miles of distribution system piping, with a replacement value of $185 billion. Some 26% of this piping is in fair to poor condition. Better methods are needed to assess conditions of and construct repairs of piping than are presently available. Further, the effects of this deteriorated piping on water quality need to be further defined.

Objective:

Refer to the following table where research needs are presented. This was an AWWA RF project that will be published in 1994.

Suggested Approach:

Refer to the following table.

TABLE ES-4 (SEE REFERENCE 2)

Water distribution system infrastructure	Water quality maintenance and regulatory issues	Corrosion, permeation, and materials deterioration	Distribution system design and operations
1 - ☐ Develop more accurate, user friendly, nondestructive test methods to determine condition of existing piping.	1 - ■ Document causes and control measures for nitrification.	1 - ■ Develop a general framework for corrosion control to meet the Lead and Copper Rule.	1 - ■ Develop distribution system performance standards.
1 - ● Develop less expensive, quicker and less disturbing methods for pipeline rehabilitation.	1 - ■ Develop and test methods for control of bacterial regrowth.	1 - ■ Characterize and recommend effective uses of phosphates and ortho-polyphosphate blends to reduce lead and copper.	1 - ☐ Develop guidelines for calibrating and using hydraulic models in system design and operation.
1 - ☐ Develop better testing procedures for new pipe to prevent future problems and predict life under various environmental conditions.	1 - ● Document methods and effectiveness of various approaches for disinfectant residual maintenance.	1 - ● Develop corrosion evaluation techniques, including pipe loops and electrochemical instrumentation, for use in optimization studies.	1 - ☐ Develop, calibrate, and use water quality models including use of the model to plan distribution system flushing programs.
2 - ● Expand understanding of and causes for pipe material deterioration, leaks, and breaks.	2 - ● Document causes of and control measures for DBPs and develop simulated distribution tests for DBPs.	1 - ☐ Investigate and recommend methods for manufacturing low lead brass for use in plumbing fixtures.	2 - ☐ Develop guidance for selecting and implementing SCADA systems.
3 - ☐ Develop innovative methods for pipe replacement in existing corridors.	2 - ● Identify and develop kinetics for biological, chemical, and physical factors that influence water quality changes in support of water quality models.	1 - ☐ Determine relationship between corrosion, corrosion control and biofilm development.	3 - ☐ Develop guidance for implementing mapping and GIS systems.
3 - ● Document causes of and preventative measures for external corrosion.	3 - ◆ Develop, test, and evaluate innovative methods for locating, removing and replacing lead service lines.	2 - ☐ Develop standards of performance for corrosion control.	3 - ☐ Develop guidance for water system energy audits and recommend energy efficiency programs.
3 - ● Improve leak detection equipment to reduce noise interference.	3 - ◆ Develop, test, and evaluate methods for lining or coating lead plumbing and lead service lines to prevent lead leaching.	3 - ● Document causes of and solutions for deterioration and leaching of pipe linings and coatings.	
	3 - ☐ Evaluate water quality deterioration in storage tanks.	3 - ● Determine cause of permeation of pipe and joint materials by solvents, and recommended solutions and standards for use.	

Notes: Priority 1: 0 to 2 years Priority 2: 3 to 5 years Priority 3: 5 to 10 years ☐ No study underway ■ Ongoing projects or projects funded in 1993
● Some work completed, but more research needed ◆ Develop arrangements with selected utilities who have lead service lines that may need to be removed.

PRIORITY RANK 28

Determine Bacteriological Impact of Depressurization During Pipeline Repairs/Replacements Using Existing Practices

ORIGINATOR:
DeMarco

Importance:

Every utility makes numerous repairs and replacements each year in their distribution system. The adverse sanitary, hygiene, health and economic impacts of lengthy interruptions of water service needs to be brought into perspective with the actual health threats posed by existing pipeline repair practices.

Objective:

Determine what bacterial growths exist during existing pipe repair practices.

Suggested Approach:

Implement a testing program during pipe repair, and pull together data from existing locations to determine the actual versus perceived problems with existing practices. Devise database, preferred method, and then test. Evaluate impact of the practice used.

PRIORITY RANK 29

Permeability of Pipe and Gaskets to Various Chemical in Soil

ORIGINATOR:
Karlin

Importance:

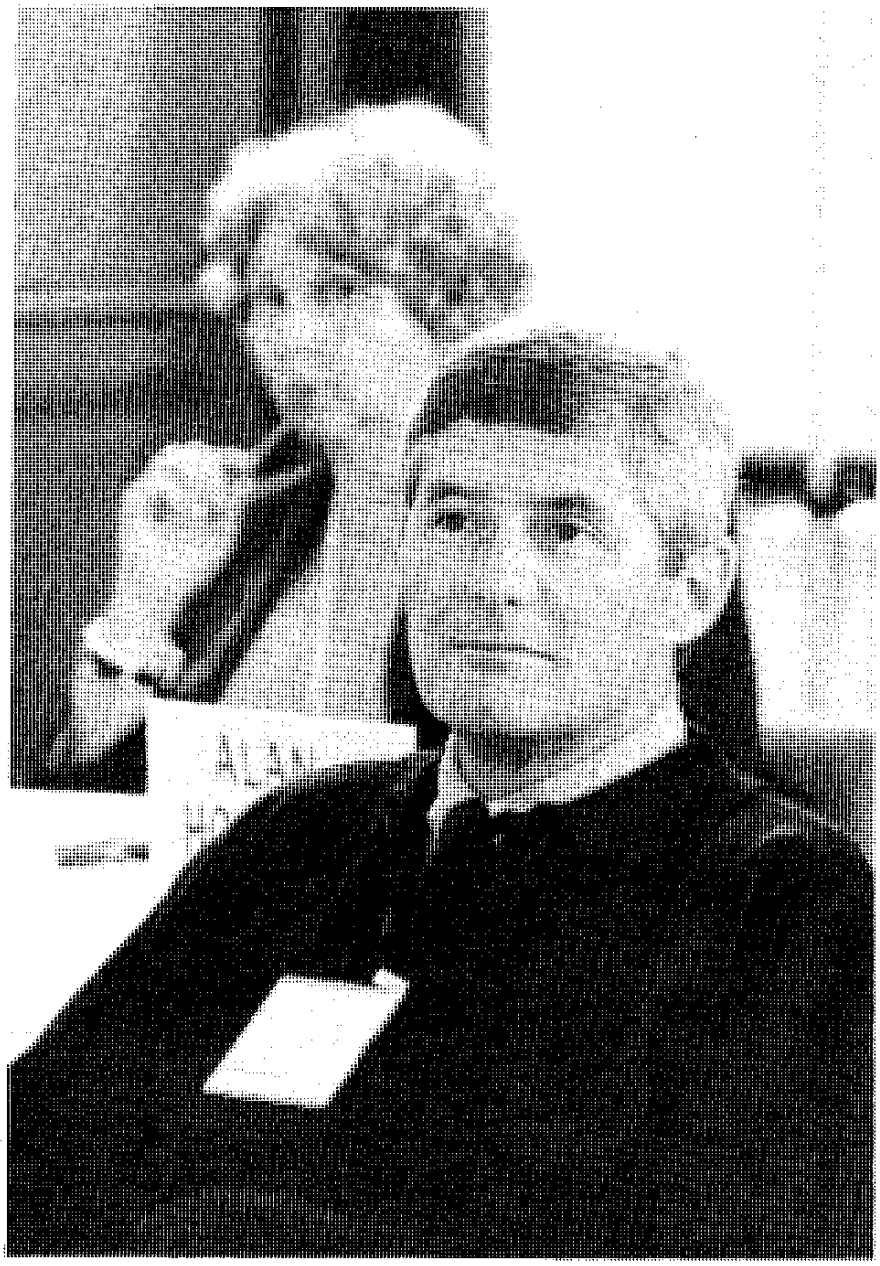
Spills and leaks of chemicals into soils could allow contaminants to enter drinking water if piping materials are not impervious to these chemicals. In order to assure protection of water quality from such threats, knowledge of piping material capabilities is needed.

Objective:

Consolidate existing knowledge and develop new data as necessary to assist utilities with dealing with existing/potential chemical contaminants in soil.

Suggested Approach:

- Literature review.
- Lab testing in simulated soil condition versus immersion in pure chemical.



PRIORITY RANK 30

Exposure to Radon and Progeny From Shower Aerosols

ORIGINATOR:
Eager

Importance:

Would provide quantitative data to compare inhalation exposure from volatilization of radon in water with exposure from background air. Importance relates to risk assessment as a basis for standard setting.

Objective:

- Develop understanding of radon levels in household air resulting from volatilization in the shower.
- Assess the range of the percentage of exposure from this source and routes of exposure.

Suggested Approach:

Field measurements of exposure levels in a statistically significant sample of homes with waterborne radon levels in the 1000 pLi/h range. The methods of measurement must distinguish radon from progeny exposure.

PRIORITY RANK 31

Determine Impact of Consumer Flushing of Residential Plumbing in Reducing Bacterial and Chemical Risks in Drinking Water

ORIGINATOR:
Hubbs

Importance:

Many water quality problems that originate in the home plumbing system could effectively be reduced by early-morning flushing of the home plumbing systems.

Objective:

Determine the value of advancing consumer awareness of altering personal behavior (shower/flush in morning prior to drawing water for consumption).

Suggested Approach:

In a variety of distribution systems, perform automated sampling in the home with-and-without early morning flushing. Look at corrosion by-products and microbials.

PRIORITY RANK 32

Comparison of Nontuberculous Mycobacteria (NTM) Found in Reclaimed Water and in Immunocompromised and Immunocompetent Patients

ORIGINATOR:
Holtzman

Importance:

NTM produce significant disease in humans, and water may be a potential source. With the increased interest in and use of reclaimed water, it would seem advisable to evaluate this water for NTM.

Objective:

To determine the relatedness of reclaimed water NTM to clinical isolates found in both immunocompromised and immunocompetent individuals.

Suggested Approach:

Water samples collected from surface or ground water and reclaimed water prior to and after mixing would be shipped to our laboratory for processing. NTM found in these samples would be profiled by a panel of laboratory procedures for comparison with clinical isolates.

PRIORITY RANK 33

Research into the Nature of Aggressive Waters

ORIGINATOR:
Dresher

Importance:

Some sources of water have developed a reputation to being "aggressive" to materials used in the water distribution system. Such waters may come from a single source, or two "non-aggressive" waters when mixed may become aggressive.

Objective:

To be able to establish, in advance, to what degree a water is aggressive to materials in a water distribution system and to be able to prescribe treatment to reduce its aggressiveness.

Suggested Approach:

This is a subject that has been studied and debated for many years. A new approach to the subject should be sought out and applied.

PRIORITY RANK 34

Internal Cathodic Protection for Residential Plumbing Systems

ORIGINATOR:
Reiber

Importance:

A simple inexpensive alternative for controlling internal corrosion and metal release in plumbing system. The approach offers a cheap technical fix that can be installed in new homes as well as retrofitted to existing homes. It would take the place of the rather ineffective point-of-use devices now being used for on-site corrosion control.

Objective:

The technology is already well-developed. However, application to the protection of internal plumbing surfaces will require:

- Development of a solid-state electronic control system.
- Evaluation of new types of aluminum and magnesium anodes for insertion into the plumbing system.
- Determination of the most effective polarization regimes.

PRIORITY RANK 35

Water Treatment Versus Distribution System Maintenance for Water Quality

ORIGINATOR:
Hermanowicz

Importance:

Current practice emphasizes water treatment and compliance with water quality standards as water leaves the plant. It can be, however, expected that distribution system maintenance has a large effect on water quality.

Objective:

- Review in a systematic way programs of distribution system maintenance and their effects on water quality.
- Compare the effectiveness and costs of these programs with water treatment costs and efficiency.

Suggested Approach:

- Identify maintenance practices in United States and the world.
- Review the experience of utilities which have developed programs for distribution system maintenance with an active water quality component and evaluate their effectiveness.

PRIORITY RANK 36

Reduction of Nontuberculous Mycobacteria (NTM) in Drinking Water by Point-of-Use Decontamination Systems

ORIGINATOR:
Holtzman

Importance:

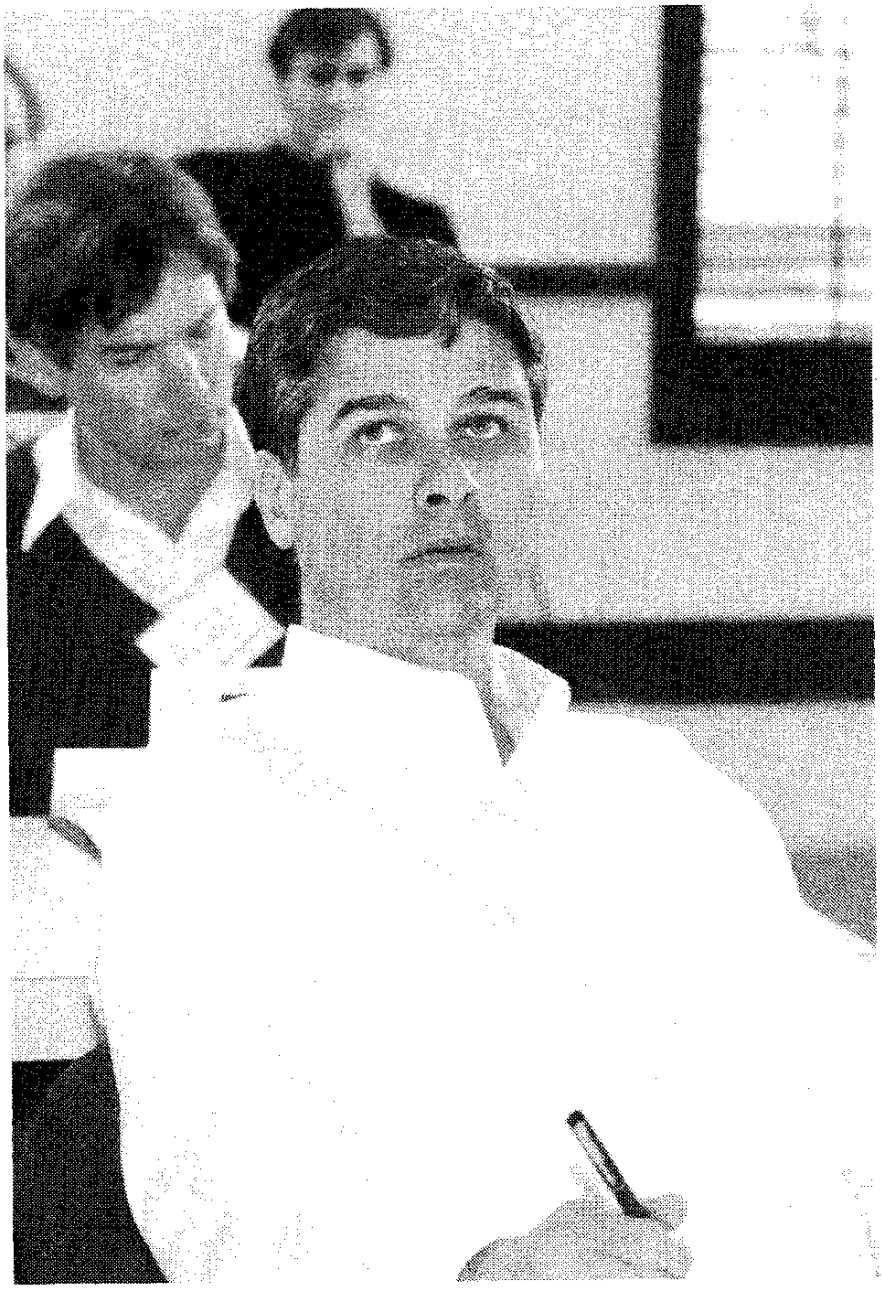
These organisms, particularly Mycobacterium avium, can cause disease in immunocompromised patients (in AIDS it is the second leading cause of death). NTM can also cause disease in immunocompetent individuals (e.g., facio-cervical lymphadenitis in children and pulmonary infection in adults).

Objective:

To determine the efficacy of several point-of-use water treatment systems to reduce water NTM, principally bacteriostatic filters and UV irradiation.

Suggested Approach:

Sterile tap water seeded with NTM would be pumped through the point of use systems to determine the change in NTM counts before and after treatment. If the study demonstrated the efficacy of a system in NTM reduction, a similar evaluation of the system would be done on homes, buildings and hospitals previously shown to harbor these organisms.



PRIORITY RANK 37

Identifying, Prioritizing and Correcting Outdated and Failing Distribution System Components

ORIGINATOR:
S. Clark

Importance:

Many large cities have aging distribution systems which receive little maintenance and are usually "patched up" after a failure. The cost of complete replacement is beyond the capability of most cities. Little is known about prediction of failure, prioritization and in-situ repairs.

Objective:

- Methodologies for identifying area of distribution systems needing maintenance and repair.
- A way to prioritize the need for repairs.
- Methods of rehabilitation/repair (e.g., in-situ) that are affordable but yet increase reliability and improve water quality.

Suggested Approach:

- Application of remote-sensing techniques and non-destructive testing to identify and prioritize areas of distribution systems needing repair/rehabilitation.
- In-situ repair/rehabilitation of pipes and valves — improving reliability, flow and quality at a reasonable price.

PRIORITY RANK 38

Determine the Risks from Unprotected Fire Sprinkler Systems on Non-Manufacturing Structures

PROBLEM: **Determine the Risks from Unprotected (Without Backflow Prevention Devices) Fire Sprinkler Systems in Non-Manufacturing Structures**

ORIGINATOR: Dueker

Importance:

Concern exists whether the cost of protection is of value.

Objective:

Determine if risks exist.

Suggested Approach:

Sample and analyze systems; tabulate data.

PRIORITY RANK 39

Copper Corrosion at Low-Level Disinfectant Residuals

ORIGINATOR:
Hermanowicz

Importance:

Copper corrosion has been associated (at least in one case) with the absence of disinfection residual while at low-levels of the residual, corrosion was inhibited.

Objective:

- Evaluate conditions under which low levels of disinfectants promote or inhibit copper corrosion.
- Elucidate mechanisms of this phenomenon.

LIST OF WORKSHOP PARTICIPANTS

Ms. Anne Camper
Montana State University
Center for Biofilm Engineering
409 Cobleigh Hall
Bozeman, MT 59717-0398
406/994-4906
406-9946098 Fax

Dr. Robert Clark
U.S. Environmental Protection Agency
Risk Reduction Engineering Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268
513/569-7201
513/569-7185 Fax

Ms. Raynetta Curry-Grant
Water Environment Research Foundation
601 Wythe Street
Alexandria, VA 22314
703/684-2474
703/684-2492 Fax

Mr. Jack DeMarco
Cincinnati Water Works
5651 Kellogg Avenue
Cincinnati, OH 45228
513/624-3333
513/624-3351 Fax

Mr. Leonard Dueker
City of Scottsdale
Water Resources Department
9388 E. San Salvador Drive
Scottsdale, AZ 85258
602/391-5681
602/391-5616 Fax

Dr. Marc A. Edwards
University of Colorado at Boulder
Department of Civil Engineering
Box 428
Boulder, CO 80309-0428
303/492-5736
303/492-7317 Fax

Mr. Timothy Ford
Harvard University
School of Public Health
40 Oxford Street
Cambridge, MA 02138
617/495-8351
617/495-5672 Fax

Mr. Stephen W. Clark
USEPA
401 M Street, SW-Mail Code 4603
1219 East Tower
Washington, DC 20460
202/260-7575

Dr. William H. Dresher
International Copper Association
260 Madison Avenue, 16th Floor
New York, NY 10016
212/251-7241
212/251-7245 Fax

Ms. Karen Eager
New England Water Works
42-A Dilla Street
Milford, MA 01757
508/478-6996
508/634-8643 Fax

Dr. Joseph O. Falkinham, III
Virginia Tech
Department of Biology
Blacksburg, VA 24061-0406
703/231-5931
703/231-9307 Fax

Dr. Gill Geesey
Montana State University
409 Cobleigh Hall
Bozeman, MT 59717-0398
406/994-4770
406/994-6098 Fax

Dr. Terry Harvey
U.S. Environmental Protection Agency
Environmental Criteria & Assessment Office
26 W. Martin Luther King Drive
Cincinnati, OH 35268
513/569-7531
513/569-7475 Fax

Dr. Slavomir Hermanowicz
University of California-Berkeley
Department of Civil Engineering
631 Davis Hall
Berkeley, CA 92721
510/642-0151
510/642-7483 Fax

Dr. Alan Holtzman
Olive View-UCLA Medical Center
14445 Olive View Drive
218 Laboratory Building
Sylmar, CA 91342-1495
818/364-3449
818/364-3465 Fax

Mr. Richard J. Karlin
AWWA Research Foundation
6666 W. Quincy Avenue
Denver, CO 80235
303/347-6104
303/730-0851 Fax

Mr. Mark W. LeChevallier
American Water Works Service Co., Inc.
1025 Laurel Oak Road
Voorhees, NY 08043
609/346-8261
609/346-8360 Fax

Mr. Harry Ridgway
Orange County Water District
P. O. Box 8300
Fountain Valley, CA 92728-8300
714/378-3200
714/378-3373 Fax

Ms. Susan Velazquez
U.S. Environmental Criteria &
Assessment Office
26 W. Martin Luther King Drive
Cincinnati, OH 45268
513/569-7571
513/569-7579 Fax

Dr. Walter M. Grayman
730 Avon Fields Lane
Cincinnati, OH 45229
513/281-6139
415/281-6139 Fax

Ms. Anita K. Highsmith
Centers for Disease Control
and Prevention
1600 Clifton Road-MS-A44
Atlanta, GA 36329
404/639-2317
404/639-3296 Fax

Mr. Stephen A. Hubbs
Louisville Water Company
435 So. Third St.
Louisville, KY 40202
502/569-3600

Mr. Gregg Kirmeyer
Economic & Engineering Services
P.O. Box 1989
Bellevue, WA 98009
206/451-8015
206/451-8096 Fax

Mr. Steven Reiber
HDR, Inc.
500 108th Avenue, NE
Bellevue, WA 98004
206/453-1523
206/453-7107 Fax

Mr. Darrell Smith
So. Central Connecticut Regional
Water Authority
90 Sargent Drive
New Haven, CT 06511-5966
203/624-6671
203/624-1498 Fax

Mr. Roy L. Wolfe
Metropolitan Water District of
Southern California
350 South Grand Avenue
Room 1108
Los Angeles, CA 90071
213/217-6241
213/217-6951 Fax

REFERENCES

1. Delbecq, Andre L., A. H. Van deVen, and D. H. Gustafson, *Group Techniques for Program Planning — a guide to nominal group and delphi processes,* Green Briar Press, 6612 Green Briar Road, Middleton, Wisconsin 53562, 1975: 174p.

2. Kirmeyer, Gregory J., *An Assessment of the Condition of North American Water Distribution Systems and Associated Research Needs,* Economic and Engineering Services, Inc., Bellevue, Washington 98005: 13p.

3. Clark, Robert M, B. W. Lykins, Jr., *Modeling Distribution System Water Quality,* Presented at the International Seminar on Ecological Effective Technologies for Water and Wastewater Treatment, Vologda, Russia, September 1993: 23p.

4. Clark, R. M., J. A. Goodrich and L. J. Wymer, *Effect of the Distribution System on Drinking-Water Quality,* J. Water SRT-*Aqua* Vol. 42, No. 1., 1993: pp. 30-38.

5. Clark, R. M. and J. A. Goodrich, *Modelling Human Exposure to Contaminants From Drinking Water,* J. Water SRT-*Aqua* Vol. 41, No. 4,1992: pp. 224-230.

6. Clark, Robert M., L. A. Rossman, and J. A. Goodrich, *Modeling the Variation in Human Exposure to Contaminants From Drinking Water,* J. of *Exposure Analysis and Environmental Epidemiology,* Suppl. l., 1992: pp 159-175.

7. Clark, Robert M., W. M. Grayman, R. M. Males, and J. A. Coyle, *Modeling Contaminant Propagation in Drinking Water Distribution Systems, Aqua* No. 3, 1988: pp. 137-151.

8. Geldreich, Edwin. E., K. R. Fox, J. A. Goodrich, E. W. Rice, R. M. Clark, and D. L. Swerdlow, *Searching for Water Supply Connection in the Cabool, Missouri Disease Outbreak of* Escherichia Coli 0157:H7, *Water Research,* Vol. 26, No. 8, 1992: pp. 1127-1137.

9. Grayman, Walter M. and R. M. Clark, *Using Computer Models to Determine the Effect of Storage on Water Quality,* EPA/600/J-93/380, July 1993: pp. 67-77.

10. Ridgway, H. F. and B. H. Olson, *Scanning Electron Microscope Evidence for Bacterial Colonization of a Drinking-Water Distribution System,* J. *Applied and Environmental Microbiology,* 0099-2240/81/010274-14$02.00/0, Jan. 1981: pp 274-287.

APPENDICES

APPENDIX A

Explanation of Priority Ranking System and Data Analysis

The following appendices contain more detailed analyses of priority ranking data derived from the ranking sheets (Appendix K) completed by each participant as the final phase of the workshop process. These appendices contain three types of information, in addition to the title of the problem.

The numerator of the fraction in the first column is the number of times which that problem was picked by the participants from the group, or subgroup, identified at the top of the page.

The second bit of information, the denominator of the fraction, is the total number of points the project received based on a number one (highest) rank being given ten points, a number two rank being given nine points, and so on down to the tenth ranked project being given one point. All other projects not selected received zero points.

The third item of information in the appendices is given in the column titled Strength of Feeling. This is simply the percentage obtained by dividing the total number of points received by the total number of points which could have been given if everyone had selected that particular problem as their first priority. Since there were 26 participants, the denominator would be 260. If every participant awarded a particular problem their highest rank, (i.e., a one), then the Strength of Feeling would be 100% (i.e. 260/260 x 100 = 100%) If all rankers selected a particular problem as their second highest priority, its Strength of Feeling would be 90%. If no one selected a particular problem, its Strength of Feeling would be 0%.

As an example, the highest ranking problem selected by all participants and shown in Appendix B received 134 points. Thus, the Strength of Feeling is computed as 134/260 x 100 = 51.5%.

APPENDIX B

All Problems (39) Ranked by All Participants (26)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	20/134	51.5%
2.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	14/95	36.5%
3.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	14/86	33.1%
4.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	14/82	31.5%
5.	Treatments to Control Bacterial Regrowth in Drinking Water	13/74	28.5%
6.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	12/70	26.9%
7.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	11/69	26.5%
8.	Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks	11/67	25.8%
9.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence of Pathogenic Microorganisms	13/66	25.4%
10.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	11/65	25.0%
11.	Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials	11/64	24.6%
12.	Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water from Varying Sources	10/61	23.5%
13.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	8/60	23.1%
14.	A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls	8/43	16.5%
15.	Establish Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, Including New Sampling Devices	8/40	15.4%
16.	Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu	8/40	15.4%
17.	Develop and Evaluate Rapid Methods for Measuring Assimilable Organic Carbon (AOC)	8/33	12.7%
18.	Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality	7/33	12.7%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
19.	Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses	6/29	11.1%
20.	Identification of Organics Leaching from Thermoplastic and Elastomeric Surfaces	4/24	9.2%
21.	Identification of Biofilm Bacteria	6/22	8.5%
22.	Research Needed on the Importance of the Nitrogen Cycle in Water Distribution Biofilms and its Control	4/19	7.3%
23.	Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead by the Water in Excess of Standards	6/16	6.2%
24.	Development of Technology for Reducing Risk in Distribution Systems in Less Developed Countries and Inner-Cities	2/16	6.2%
25.	Interactions Between Disinfection of Suspended Microbial Cells and Surface Colonization	2/15	5.8%
26.	Inadequate Source Water Quality	3/15	5.8%
27.	Lack of Understanding of the Existing Condition of U.S. Distribution Systems Related to Maintaining Water Quality	3/14	5.4%
28.	Determine Bacteriological Impact of Depressurization During Pipeline Repairs/Replacements Using Existing Practices	3/13	5.0%
29.	Permeability of Pipe and Gaskets to Various Chemicals in Soil	3/13	5.0%
30.	Exposure to Radon and Progeny from Shower Aerosols	1/10	3.8%
31.	Determine Impact of Consumer Flushing of Residential Plumbing in Reducing Bacterial and Chemical Risk in Drinking Water	5/9	3.5%
32.	Comparison of Nontuberculous Mycobacteria (NTM) Found in Reclaimed Water and in Immunocompromized and Immunocompetent Patients	2/8	3.1%
33.	Research into the Nature of Aggressive Waters	2/8	3.1%
34.	Internal Cathodic Protection for Residential Plumbing Systems	3/7	2.7%
35.	Water Treatment vs Distribution System Maintenance for Water Quality	2/7	2.7%
36.	Reduction of Nontuberculous Mycobacteria (NTM) in Drinking Water by Point-of-Use Decontamination Systems	2/6	2.3%
37.	Identifying, Prioritizing and Correcting Outdated and Failing Distribution System Components	2/4	1.5%
38.	Determine the Risks from Unprotected Fire Sprinkler Systems on Non-Manufacturing Structures	0/0	0.0%
39.	Copper Corrosion at Low-Level Disinfectant Residuals	0/0	0.0%

APPENDIX C

All Problems (39) Ranked by Professional Association Participants (4)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	3/27	67.5%
2.	Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water from Varying Sources	3/25	62.5%
3.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	3/19	47.5%
4.	A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls	3/18	45.0%
5.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	3/17	42.5%
6.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	2/12	30.0%
7.	Permeability of Pipe and Gaskets to Various Chemicals in Soil	2/11	27.5%
8.	Identification of Biofilm Bacteria	2/10	25.0%
9.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence of Pathogenic Microorganisms	2/8	20.0%
10.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	1/8	20.0%
11.	Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality	1/8	20.0%
12.	Research Needed on the Importance of the Nitrogen Cycle in Water Distribution Biofilms and its Control	1/7	17.5%
13.	Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses	1/6	15.0%
14.	Treatments to Control Bacterial Regrowth in Drinking Water	1/6	15.0%
15.	Lack of Understanding of the Existing Condition of U.S. Distribution Systems Related to Maintaining Water Quality	1/6	15.0%
16.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	1/5	12.5%
17.	Inadequate Source Water Quality	1/5	12.5%
18.	Comparison of Nontuberculous Mycobacteria (NTM) Found in Reclaimed Water and in Immunocompromized and Immunocompetent Patients	1/4	10.0%
19.	Research into the Nature of Aggressive Waters	1/4	10.0%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
20.	Identification of Organics Leaching From Thermoplastic and Elastomeric Surfaces	1/3	7.5 %
21.	Develop and Evaluate Rapid Methods for Measuring Assimilable Organic Carbon (AOC)	1/3	7.5 %
22.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	1/3	7.5 %
23.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	1/2	5.0 %
24.	Reduction of Nontuberculous Mycobacteria (NTM) in Drinking Water by Point-of-Use Decontamination Systems	1/1	2.5 %
25.	Impact of Consumer Flushing of Residential Plumbing in Reducing Bacterial and Chemical Risk in Drinking Water	1/1	2.5 %
26.	Internal Cathodic Protection for Residential Plumbing Systems	1/1	2.5 %

APPENDIX D

All Problems (39) Ranked by Federal Participants (4)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	4/35	88.0%
2.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	3/27	67.5%
3.	Establish Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, Including New Sampling Devices	4/21	52.5%
4.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence of Pathogenic Microorganisms	3/20	50.0%
5.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	3/14	35.0%
6.	A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls	2/12	30.0%
7.	Treatments to Control Bacterial Regrowth in Drinking Water	2/10	25.0%
8.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	1/9	22.5%
9.	Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials	2/8	20.0%
10.	Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks	1/8	25.8%
11.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	1/7	17.5%
12.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	1/7	17.5%
13.	Interactions Between Disinfection of Suspended Microbial Cells and Surface Colonization	1/7	17.5%
14.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	1/6	15.0%
15.	Develop and Evaluate Rapid Methods for Measuring Assimilable Organic Carbon (AOC)	1/5	12.5%
16.	Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water from Varying Sources	1/4	10.0%
17.	Water Treatment vs Distribution System Maintenance for Water Quality	1/3	7.5%
18.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	1/3	7.5%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
19.	Identifying, Prioritizing and Correcting Outdated and Failing Distribution System Components	1/3	7.5%
20.	Determine Bacteriological Impact of Depressurization During Pipeline Repairs/Replacements Using Existing Practices	1/3	7.5%
21.	Inadequate Source Water Quality	1/2	5.0%
22.	Determine Impact of Consumer Flushing of Residential Plumbing in Reducing Bacterial and Chemical Risk in Drinking Water	1/2	3.0%
23.	Lack of Understanding of the Existing Condition of U.S. Distribution Systems Related to Maintaining Water Quality	1/2	3.0%
24.	Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses	1/1	2.5%
25.	Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead by the Water in Excess of Standards	1/1	2.5%

APPENDIX E

All Problems (39) Ranked by Industry Participants (4)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	3/23	57.5%
2.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	3/21	52.5%
3.	Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials	3/20	50.0%
4.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	2/18	45.0%
5.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	3/15	37.5%
6.	Treatments to Control Bacterial Regrowth in Drinking Water	2/15	37.5%
7.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	2/12	30.0%
8.	Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead by the Water in Excess of Standards	3/11	27.5%
9	Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks	2/10	25.0%
10.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	1/10	25.0%
11.	Establish Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, Including New Sampling Devices	2/9	22.5%
12.	Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu	1/9	22.5%
13.	Identification of Organics Leaching From Thermoplastic and Elastomeric Surfaces	1/8	20.0%
14.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	2/7	17.5%
15.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	1/6	15.0%
16.	Develop and Evaluate Rapid Methods for Measuring Assimilable Organic Carbon (AOC)	2/5	12.5%
17.	Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water from Varying Source	1/5	12.5%
18.	Internal Cathodic Protection for Residential Plumbing Systems	1/4	10.0%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
19.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence of Pathogenic Microorganisms	1/3	7.5 %
20.	Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses	1/3	7.5 %
21.	Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality	1/3	7.5 %
22.	Identification of Biofilm Bacteria	1/3	7.5 %

APPENDIX F

All Problems (39) Ranked by Research Participants (9)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	7/54	60.0%
2.	Treatments to Control Bacterial Regrowth in Drinking Water	7/37	41.1%
3.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	5/36	40.0%
4.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	5/32	35.6%
5.	Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks	5/28	31.1%
6.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	5/28	31.1%
7.	Virulence of Pathogens and Opportunistic Pathogens Found in Biofilms of Distribution Systems Receiving Water from Varying Sources	5/27	30.0%
8.	Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials	4/25	27.7%
9.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence o Pathogenic Microorganisms	4/25	27.7%
10.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	5/22	24.4%
11.	Develop and Evaluate Rapid Methods for Measuring Assimilable Organic Carbon (AOC)	4/20	22.2%
12.	Increase Understanding of Viral Abundance, Modes of Disinfection Resistance, and Treatment Survival of Viruses	3/19	21.1%
13.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	2/16	17.8%
14.	Development of Technology for Reducing Risk in Distribution Systems in Less Developed Countries and Inner-Cities	2/16	17.8%
15.	Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality	4/13	14.4%
16.	Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu	3/13	14.4%
17.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	2/13	14.4%
18.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	2/11	12.2%
19.	Research Needed on the Importance of the Nitrogen Cycle in Water Distribution Biofilms and its Control	2/9	10.0%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
20.	Interactions Between Disinfection of Suspended Microbial Cells and Surface Colonization	1/8	8.9%
21.	Inadequate Source Water Quality	1/8	8.9%
22.	Identification of Organics Leaching From Thermoplastic and Elastomeric Surfaces	1/7	7.8%
23.	Reduction of Nontuberculous Mycobacteria (NTM) in Drinking Water by Point-of-Use Decontamination Systems	1/5	5.6%
24.	Research into the Nature of Aggressive Waters	2/4	4.4%
25.	Water Treatment vs Distribution System Maintenance for Water Quality	1/4	4.4%
26.	Research into the Nature of Aggressive Waters	1/4	4.4%
27.	A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls	2/3	3.3%
28.	Determine Bacteriological Impact of Depressurization During Pipeline Repairs/Replacements Using Existing Practices	1/2	2.2%
29.	Permeability of Pipe and Gaskets to Various Chemicals in Soil	1/2	2.2%
30.	Internal Cathodic Protection for Residential Plumbing Systems	1/2	2.2%
31.	Identifying, Prioritizing and Correcting Outdated and Failing Distribution System Components	1/1	1.1%
32.	Establish Standardized Statistically Valid set of Sampling Plans for Distribution Systems, Including New Sampling Devices	1/1	1.1%

APPENDIX G

All Problems (39) Ranked by Utility Participants (5)

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
1.	Improving Storage Tank and Reservoir Design and Operations for Effective Maintenance of Water Quality	5/26	52.0%
2.	Epidemiological Studies to Determine the Role of the Distribution System (& Regrowth) in Waterborne Diseases	4/24	48.0%
3.	Re-evaluation of Microbial Indicators Used to Determine Potable Water Quality and Health Risks	3/21	42.0%
4.	Unified Distribution System Operating and Maintenance Guidance Document to Promote Water Quality Public Health Protection and System Service Life	2/20	40.0%
5.	Understand Importance of Biofilm Development and Microbial Interactions on Beneficial and Detrimental Processes in Drinking Water Distribution Systems	4/19	38.0%
6.	Define Risk of Bacterial Disease in Non-disinfected Distribution Systems vs. Systems that Carry a Disinfection Residual	4/18	36.0%
7.	Assessment of Health Risks from Drinking Water: Emergent Disease, Chemical Exposures, and Risk Communication	3/18	36.0%
8.	Effect of Phosphate-Based Inhibitors on Corrosion of Pb and Cu	3/12	24.0%
9.	Impact of Corrosion Control on Disinfection of Biofilms on Reactive Pipe Materials	2/11	22.0%
10.	Influence of Water Distribution Systems' Conditions on Survival/ Growth and Virulence of Pathogenic Microorganisms	2/10	20.0%
11.	Exposure to Radon and Progeny from Shower Aerosols	1/10	20.0%
12.	A Field Study on Degradation of Water Quality Due to Chemical Leaching, Corrosion and Microbial Growth on Pipe Walls	1/10	20.0%
13.	Establish Standardized Statistically Valid Set of Sampling Plans for Distribution Systems, Including New Sampling Devices	1/9	18.0%
14.	Secondary Effects of Disinfection By-Products Control on Distribution System Water Quality	1/9	18.0%
15.	Determine Bacteriological Impact of Depressurization During Pipeline Repairs/Replacements Using Existing Practices	1/8	16.0%
16.	Develop and Evaluate Rapid, Simple, and Specific Methods for Enumerating Viable Bacteria in the Distribution System of Public Health Concern	1/7	14.0%
17.	Determine Impact of Consumer Flushing of Residential Plumbing in Reducing Bacterial and Chemical Risk in Drinking Water	3/6	12.0%
18.	Organic Leaching From Thermoplastic and Elastomeric Surfaces	1/6	12.0%
19.	Treatments to Control Bacterial Regrowth in Drinking Water	1/6	12.0%
20.	Lack of Understanding of the Existing Condition of U.S. Distribution Systems Related to Maintaining Water Quality	1/6	12.0%

RANK	ABBREVIATED TITLE	TIMES PICKED/ PTS.	STRENGTH OF FEELING
21.	Identification of Biofilm Bacteria	1/5	10.0%
22.	Identify and Locate Lead Service Lines and Develop Methods to Prevent the Uptake of Lead by the Water in Excess of Standards	2/4	8.0%
23.	Comparison of Nontuberculous Mycobacteria (NTM) Found in Reclaimed Water and in Immunocompromized and Immunocompetent Patients	1/48	8.0%
24.	A Standard Simulated Distribution System: Providing a Tool for Scientific Study of a Practical Problem	1/3	6.0%
25.	Research Needed on the Importance of the Nitrogen Cycle in Water Distribution Biofilms and its Control	1/3	6.0%

NWRI National Water Research Instit

10500 Ellis Avenue, P.O. Box 20865, Fountain Valley, CA 92728-0865 (714) 378-3278 Fax (714) 378-

February 3, 1994

Participant
Address
City, State

Dear Participant:

Thank you for accepting our invitation to participate in the NWRI/EPA Nominal Group Technique workshop on "Risk Reduction in Drinking Water Distribution Systems". The workshop will be held on February 27 and 28, 1994, at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering which is adjacent to the University of California-Irvine campus.

The NWRI will underwrite all travel costs and expenses associated with this workshop. Travel reimbursement forms will be provided upon your arrival. The following information will assist you in arranging your travel plans:

- Out-of-town participants should fly into the John Wayne Airport in Orange County. We suggest that you make your own arrangements and plan to arrive on Saturday, February 26, to take advantage of the lower Saturday layover airfares.

- Hotel reservations have been made at the Holiday Inn-Irvine/Orange County Airport, 17941 Von Karman, Irvine, California. Telephone 714/863-1999. The hotel does provide a shuttle service to and from the airport.

- Arrangements have been made for daily transport between the Holiday Inn and the Beckman Center which is located at 100 Academy Drive in Irvine, California. Telephone: 714/721-2200; FAX: 714/721-2288.

The NWRI is arranging tours to points of interest, and we will keep you informed as these plans are solidified.

This folder contains information which will help you to be a more effective workshop participant. Please allow yourself at least two hours to review this material and to prepare for the workshop before arriving. It is important that you attend the entire workshop (Sunday and Monday) and do not depart before we are finished.

Please read the description of the guidelines and procedures we will follow at the workshop. We need to adhere to these so that we can complete our work before adjournment time. Of particular importance is the Problem Identification Form. Please prepare a full write-up on each topic which you plan to propose. You may propose as many topics as you wish.

Should you have any questions prior to the workshop, please call me at 714/378-3278.

I am looking forward to seeing you at the workshop and producing a useful report on the results of our efforts. Thank you again for agreeing to participate in this workshop.

Sincerely,

NATIONAL WATER RESEARCH INSTITUTE

Ronald B. Linsky
Executive Director

RBL:lb
Enclosures

cc: Ms. Susan F. Velazquez
Dr. William S. Gaither

Nominal Group Technique Workshop on
Risk Reduction in Drinking Water Distribution Systems

February 27-28, 1994

The workshop will be conducted employing the Nominal Group Technique to ensure that (1) each participant's time and talents are used effectively, and (2) a useful report will result. Please observe the following guidelines:

1. Participants will register on Sunday, February 27, between 5:30 p.m.- 6:00 p.m. in the lobby of the Beckman Center. Dinner will be served at 6:30 p.m. in the Executive Dining Room followed by a discussion of workshop procedures.

2. The workshop will begin at 8:00 a.m. on Monday, February 28, and will conclude no later than 4:30 p.m.

3. If you **cannot** stay for the entire workshop, please **do not** come.

4. Come prepared with each of your proposals written up on a Problem Identification Form. You will be free to modify, improve or add to your write-ups as the workshop progresses.

5. The workshop will consist of four distinct parts:

   - **Problem Identification.** Each individual will be asked in turn to identify for the group his or her highest priority problem. Three to five minutes of uninterrupted time will be allotted to describe its importance, the objective of the research or development project, and the hypothesis or suggested approach. Discussion will be limited to questions of clarification. The title will be written in large letters on paper, numbered, originator noted, and posted on the wall. This process will continue until all topics are identified.

   - **Consolidation.** All proposed problems will be reviewed. When agreed upon by consensus, those with similar themes will be consolidated. An ad hoc working group will be formed to generate a substitute statement which incorporates the concepts embodied in those being subsumed.

   - **Priority Ranking.** Each individual will be asked to rank in priority order his or her top 10 problems. Each ranking sheet must be signed.

   - **Text Approval**. As the last step in the workshop, each participant will be asked to proofread and approve his or her final text. The workshop results will be published and distributed to the participants.

APPENDIX I

Please duplicate this form as required *Please Print or Type*

Problem Identification Form
RISK REDUCTION IN DRINKING WATER DISTRIBUTION SYSTEMS

Name:_____

Organization:_____

Workshop question: *What facts and information are needed to reduce risks to water quality in drinking water distribution systems?*

Limit to space provided below and to a three minute presentation at the workshop.

Problem Title: (20 word maximum)

Importance: (What is your rationale? Why is solving this problem important to Society?)

Objective:(Define project clearly so that a useful result can be obtained.)

Suggested Approach: (How would you attack this problem?)

APPENDIX J

CONSOLIDATION WORKSHEET

RISK REDUCTION IN DRINKING WATER DISTRIBUTION SYSTEMS

YOUR PROBLEM #_____

OTHER PROBLEMS WHICH COULD BE

CONSOLIDATED WITH THIS ONE:

#_____ Originator_____

#_____ Originator_____

APPENDIX K

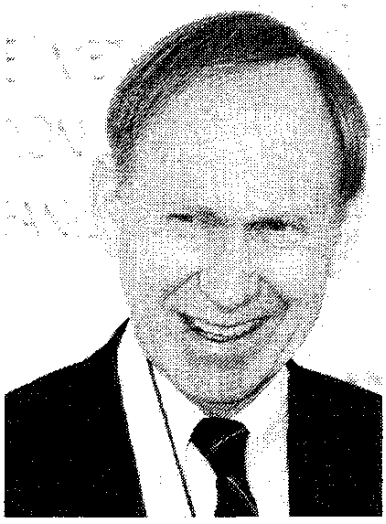
PROBLEM RANKING SHEET

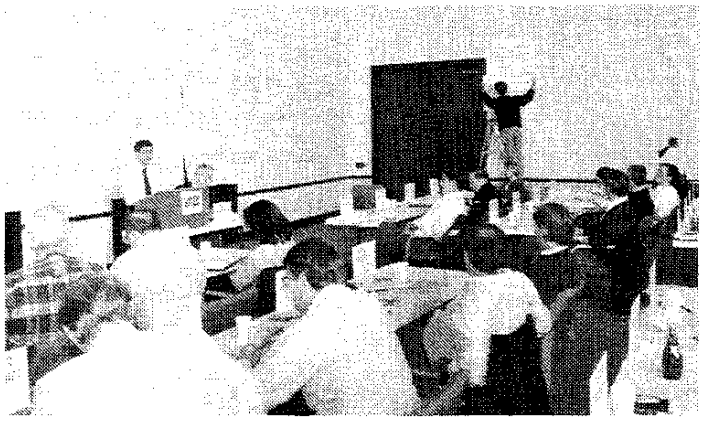
RISK REDUCTION IN DRINKING WATER DISTRIBUTION SYSTEMS

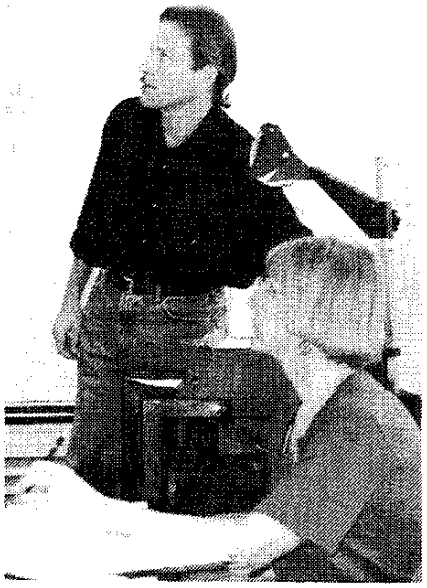
(1 = Highest to 10 = Lowest)

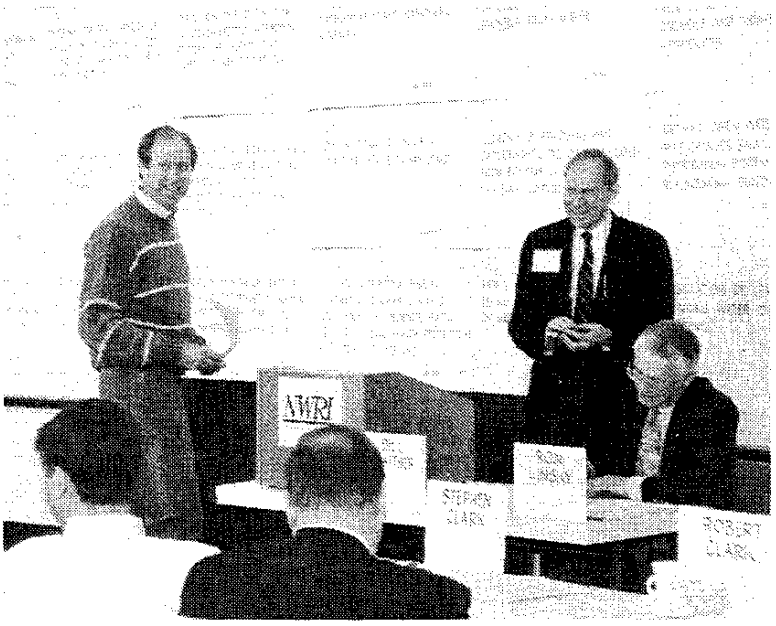
Your Problem Rank	Problem Number
1	_____
2	_____
3	_____
4	_____
5	_____
6	_____
7	_____
8	_____
9	_____
10	_____

Signed: _____ and _____
(Please Print) (Signature)








AWRI