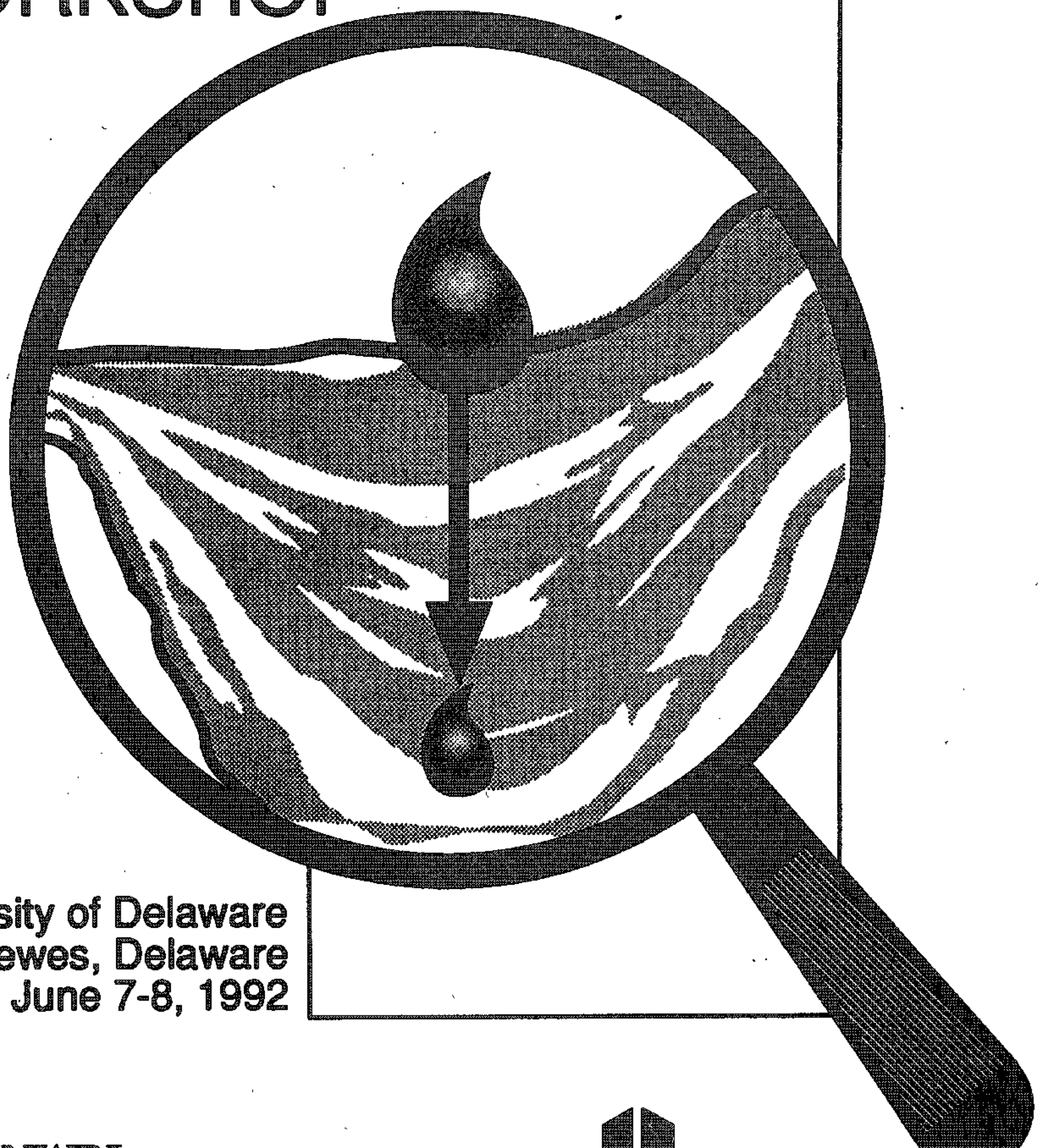
GROUNDWATER DISINFECTION RULE WORKSHOP



University of Delaware
Lewes, Delaware
June 7-8, 1992

NWRI
National Water Research Institute

WESTON INSTITUTE

Groundwater Disinfection Rule Workshop

Sponsored by

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Fountain Valley, California

in Collaboration with

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West Chester, Pennsylvania

Virden Conference Center
University of Delaware
Lewes, Delaware
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FOREWORD

This report describes the objective, organization, and results of a workshop which addressed the proposed federal Groundwater Disinfection Rule. The workshop was organized by the National Water Resources Institute (NWRI) of Fountain Valley, California, in collaboration with the Weston Institute (WI) of West Chester, Pennsylvania.

The Groundwater Disinfection Rule Workshop was a direct outgrowth of a cooperative joint-venture project between the NWRI and the U.S. Environmental Protection Agency (EPA). The project is intended to help promulgate a Groundwater Disinfection Rule called for by the 1986 Amendments to the Safe Drinking Water Act. Rule development requires minimizing some of the uncertainties associated with modeling the fate and transport of viruses in groundwater. The workshop was held to identify and support research needed to reduce costs of implementing the Groundwater Disinfection Rule by developing better estimates of virus sorption to aquifer media. This research may allow for less conservative assumptions and thereby provide savings and benefits to the regulated community.

Eighteen participants from the United States Government, water utilities, and the research community were invited to the University of Delaware's Virden Conference Center at Lewes, Delaware, arriving in the late afternoon of June 7, 1992. Of these participants, three were from the federal government, five were from water utilities, and ten were university-based researchers. The contents of this report was generated by the participants on Monday, June 8. The question placed before the participants was: ***What are the highest priority research problems needing to be solved in order to allow for the cost effective implementation of the 1995 Groundwater Disinfection Rule?***

The workshop results are presented in the order of importance attached to them by the participants. The top ten rankings in the three subgroups (i.e., federal, water utility, and research) are presented in the Preliminary Analysis Section and fully in the Appendix with added data analysis.

We want to acknowledge the important contributions made to the success of this workshop by the participants themselves, the EPA, the staff of the Virden Center, and Joe Pezeley, Carol Coren, Patricia Linsky, Tammi Wrice, Tasha Patrick, Bob Bowden, and Glen Ernst.

Co-chairs:
Ronald Linsky, *Executive Director, National Water Research Institute*
William S. Gaither, *President, Weston Institute*

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PARTICIPANTS

Top Row: (Left to Right) Rick Karlin, Chuck Noss, Tom Grubbs, Aaron Miles, Sam Farrah, and Phil Berger

Standing: Bill Gaither (Chairman), Joe Pezeley (Graphics), Rich Sakaji, Marylynn Yates, Bob Puls, Mark Sobsey, Marty Rigby, Dean Cliver, Bill Cairns, Carol Coren (Coordinator), and Ron Linsky (Secretary)

Seated: Jim Hunt, Chuck O'Melia, C.P. Huang, Yavuz Corapcioglu, and Mel Suffet

WORKSHOP ORGANIZATION

Preparations

On April 24, 1992, nationally-recognized experts were invited to attend the workshop and were briefed on the workshop's objective and the question to be addressed. Upon receipt of acceptances, materials were sent that described the process to be followed and included working papers for background reading and problem identification forms. A copy of the confirming workshop letter is included in Appendix F. Each participant was asked to arrive at the workshop with several problems identified and written on the forms provided.

Participants arrived at the Virden Center on Sunday afternoon in time for a social hour and dinner. Following dinner, the workshop objectives and procedures were reviewed. Questions were answered and participants were urged to return to their rooms to complete any write-up not yet written.

Agenda

The workshop was convened on June 8th at 8:00 a.m. The process utilized at the workshop was a modified form of the Nominal Group Technique (NGT) originated in the late 1960's by Professor Andre Delbecq of the University of Wisconsin (See References). Four principal steps were completed during the following eight hours.

- 8:00 - 8:15 a.m. Welcome and review of procedures
- 8:15 - 11:00 a.m. Problem Identification and Posting
- 11:00 - 3:30 p.m. Problem Consolidation (Including lunch break)
- 3:30 - 4:00 p.m. Problem Ranking by Individual Participants

Problem Identification and Posting

Participants were seated in alphabetical order at work tables. Name signs were provided. A maximum of three minutes was allotted to each individual to present his or her problem. At the conclusion of each presentation, the title proposed was reviewed for clarity and accuracy by Ronald B. Linsky, Executive Director

of the NWRI and Secretary of the workshop. If the title was deemed to not be adequately descriptive of the verbal presentation, the proposer was asked by the Secretary to consider a revised and improved title. In all cases, the originator retained the absolute right to accept or reject suggestions for change. Also, the workshop Chair was careful to ensure that only questions of clarification were asked of each presenter. Questioning of the validity of a presenter's problem was not allowed in order to prevent intimidation of any participant and to encourage the free flow of ideas in the workshop.

Experience shows that a group of 18 individuals will contribute, on the average, between 2.5 and 3.5 problems per participant. Typically, larger groups (e.g., 25 - 35) contribute fewer problems per person and smaller groups (e.g., 8 - 10) contribute a larger number of problems per person. Fifty-six problems were identified in the two hours and forty five minutes devoted to that step. Typically, half of the ideas put forth in the problem identification phase are generated by participants during the workshop process.

As each problem was presented, and the title agreed to by the originator and the secretary, the title was quickly lettered with large and highly visible printing, numbered sequentially, and posted neatly on the walls of the workroom for continuous reference by all participants. A sample problem identification form is included in Appendix G. Simultaneously, the text was taken to a nearby workroom to be compiled into a uniform format and type-style by word processors. Drafts of these write-ups were quickly returned to the authors for editing.

Consolidation

When all subjects had been introduced and posted, each was reexamined in numerical order to determine which, if any, should be combined or the ideas consolidated. This was to ensure that the later voting for priorities would not be distorted by individuals splitting their votes among similar subjects which were worded slightly differently. Each problem originator was asked to suggest other problems which were candidates for consolidation with theirs (or their problem to be consolidated under another, broader, problem). Whenever it was agreed, by consensus, that one or more problem statements should be consolidated, the author of the lead problem was asked to be the originator of an overarching problem description which would encompass the concepts of all problems being subsumed under it. He or she would then ask the originators of the problems


ROBERT
PULS
RICHARD
KARLIN


IRWIN
SUFFET
MARYLYNN
YATES
MARK
SOBSEY

subsumed under the new description to review and improve the write-up. A sample consolidation worksheet is included in Appendix H. The consolidation process reduced the number of problems from 56 to 28, a reduction of fifty percent. This is a typical percent reduction for a workshop addressing a question of the type confronted by these workshop participants. Participants then debated how issues might best be grouped, and the workshop chair and secretary ensured that these discussion came to focus as quickly as practical and the discussion moved on to the next problem.

As problems were consolidated, subsuming others, the new consolidated topic was posted with a letter "A" suffix added to the original number (e.g., Original problem 16, subsuming problems 4, 22, and 47, became 16A). The original problem 16 and othersubsumed problem titles were then removed from the wall. By the end of the consolidation process, half of the number of initial problems remained to be ranked.

Ranking

For the final step in the workshop process, each participant ranked the top ten problems in a descending order of importance. A sample ranking sheet is shown in Appendix I. Each ranking sheet was signed by the participant and turned in at departure. These were then compiled and analyzed by the project co-chairs.

Text Approval

Each participant reviewed and approved the final form of the text of each problem they originated and each consolidated problem description they wrote. This way there was approved text in the hands of the workshop coordinators (NWRI and WI) so that the final report could be published promptly.

PRELIMINARY ANALYSIS OF RESULTS

As noted in the previous section, each of the 18 workshop participants ranked in priority order, the 28 problems which remained following the consolidation step. Participant responses were entered as input data into a analysis program developed by the Weston Institute (see Appendix). The following four sets of results show the top ten priority problems selected by: (1) all 18 participants, (2) the three federal government participants, (3) the five water utility participants, and, (4) the ten research participants.

Top Ten Problems Ranked by All Participants (18)

RANK	ABBREVIATED TITLE
1	Chemical Aspects of Transport and Fate
2	Pathogen Indicators
3	Conservative Tracers
4	Virus Inactivation
5	Modeling Pathogen Transport
6	Spatial and Temporal Variability
7	Organic and Inorganic Compounds
8	Testing Transport Models
9	Indicator and Resistent Virus Data
10	Pathogen Transport in the Unsaturated Zone

Top Ten Problems Ranked by Federal Government Participants (3)

RANK	ABBREVIATED TITLE
1	Conservative Tracers
2	Chemical Aspects of Transport and Fate
3	Virus Inactivation
4	Pathogen Indicators
5	Testing Transport Models
6	Spatial and Temporal Variability
7	Expert System-Based Software
8	Pathogens in Unsaturated Zones
9	Indicator and Resistant Virus Data
10	Viral Capture Mechanisms

Top Ten Problems Ranked by Water Utility Participants (5)

RANK	ABBREVIATED TITLE
1	Pathogen Indicators
2	Organic and Inorganic Compounds
3	Chemical Aspects of Transport and Fate
4	Saturated vs Unsaturated Conditions
5	Spatial and Temporal Variability
6	Conservative Tracers
7	Definition of Natural Disinfection
8	Virus Inactivation
9	Role of Risk Analysis
10	Reclaimed Water for Recharge

Top Ten Problems Ranked by Research Participants (10)

RANK	ABBREVIATED TITLE
1	Chemical Aspects of Transport and Fate
2	Modeling Pathogen Transport
3	Pathogen Indicators
4	Conservative Tracers
5	Virus Inactivation
6	Viral Capture Mechanisms
7	Testing Transport Models
8	Organic and Inorganic Compounds
9	Indicator and Resistant Virus Data
10	Pathogens in Unsaturated Zones

PRIORITY RANKING

In Descending Order of Importance as Ranked by all Workshop Participants

Priority Rank 1: Chemical Aspects of Virus Transport and Fate

Problem: **Chemical Aspects of the Transport and Fate of Pathogens in Subsurface Environments and Water Treatment Technologies**

Originators: Berger, Huang, Mills, O'Melia, Puls

Importance:

The fate of pathogens in subsurface environment and in much of water treatment technology, depends in part on the attachment and possible reentrainment of pathogens to solid surfaces (aquifer materials, membranes, filter media). This, in turn, affects disinfection requirements. Stated another way, the colloid chemical aspects of aquifer systems affect natural disinfection and, similarly, solution and surface chemistry affect the performance of solid-liquid separation technologies. Both processes impact disinfection requirements.

Objective:

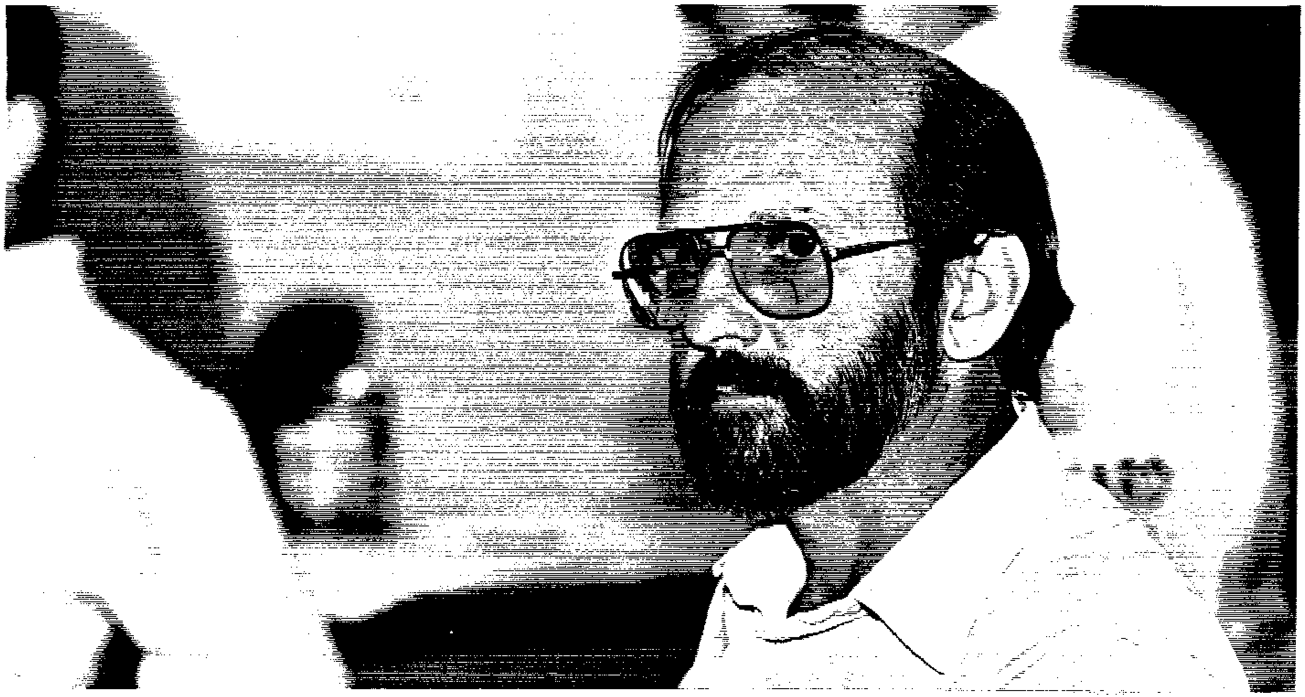
Determine the chemical conditions that promote or retard the attachment of viruses at solid surfaces in aquatic environments with emphasis on viruses. Consideration should be given to the surface properties of pathogens and "collector" solids, the role of natural organic matter and hardness, the effects of flushing (rapid changes in solution conditions), and electrostatic effects.

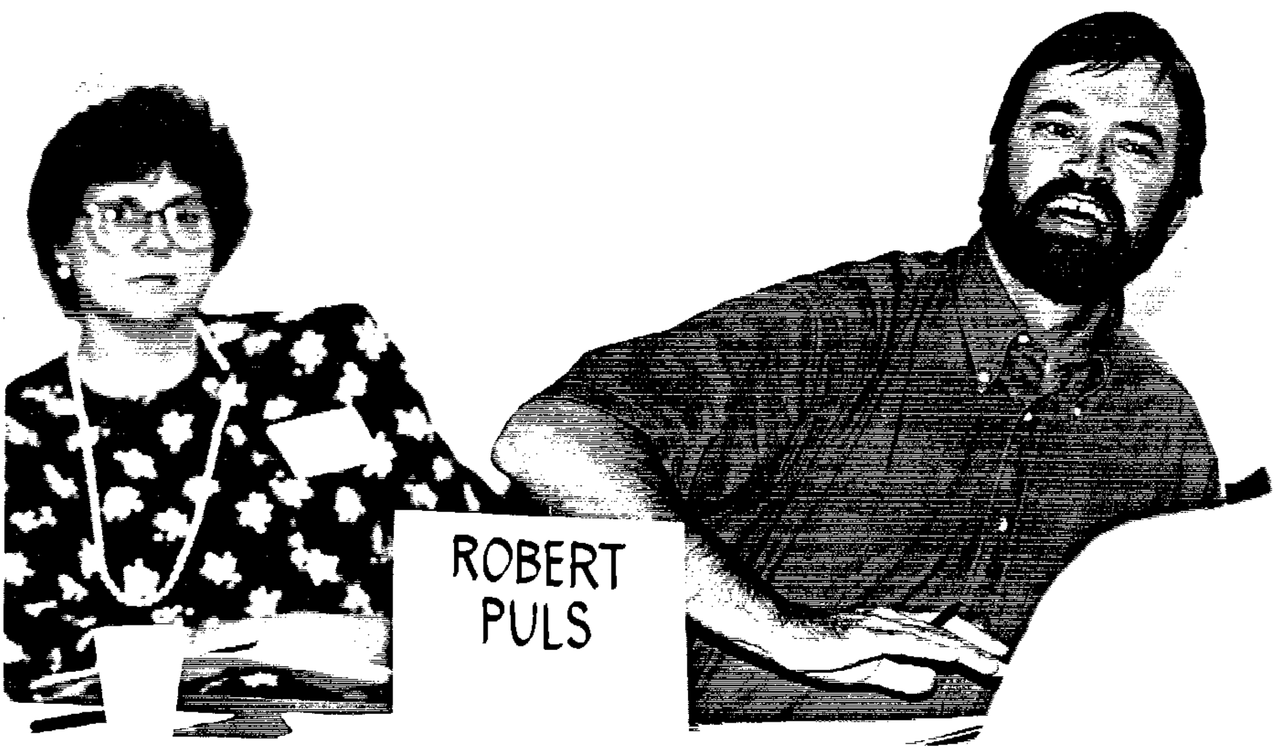
Suggested Approach:

- Modeling of attachment and detachment, in large part to design and interpret laboratory and field studies.

- Laboratory studies using several pathogens, with special focus on viruses, to determine chemical effects in pathogen retention, to consider the development of an "indicator virus" for attachment/removal, and to develop experimental attachment probabilities for use in the modeling of field situations.

- Field studies, including the use of laboratory estimates of pathogen attachment/retention. Work to include spectrum aquifer material, treatment technologies, and pathogens of interest. Field studies require interdisciplinary teams.





The following research problems were subsumed under the above problem:

Problem: **Effect of Solution and Surface Chemistry on Transport and Fate of Pathogens in Subsurface Environments**

Originator: O'Melia

Importance:

Fate of pathogens depends in part on attachment to and release from solid surfaces. These depend upon the solid surface (aquifer material), the specific pathogen, and the solution chemistry.

Objective:

Determine the chemical conditions that permit or retard pathogen retention in aquifers.

Suggested Approach:

- Theoretical, laboratory and field studies.
- What are good pathogens to model attachment/lack of attachment?

Problem: **Identification and Incorporation into Transport Models of Surface Chemical Factors Controlling Particle Stability and Transport in the Subsurface**

Originator: Puls

Importance:

Improved transport predictions would permit more accurate estimates for virus transport. This would probably allow more sites to qualify for "natural disinfection" while still being protective of human health.

Objective:

Determine surface chemical factors which most significantly affect particle stability and transport.

Suggested Approach:

The focus of this approach should be Focus-Desorption. This should include kinetic studies such as particle stability, surface chemistry, changes in aqueous chemistry, etc.

- Synthesis of existing data and analysis with respect to surface chemical factors.
- Additional laboratory and field research with representative aquifer materials and particles with detailed surface characterization.

Problem: **Should We Look at the Critical Density of Sources?**

Originator: Berger

Importance:

Water chemistry can have a major affect on colloid attachment efficiency. If we can define a critical water chemistry due to waste loading above which viruses are desorbed, would this be a better approach than deterministic modeling?

Objective:

Determine if this is a useful approach.

Suggested Approach:

- Field and laboratory investigations.

Problem: **Define Physical Chemical Behavior Submicron-to-Micron Range Particles in Aqueous Solutions**

Originator: Huang

Importance:

Predicting the movement of pathogens in soil water systems and the removal of pathogens from the aqueous phase are important to the decision making on the extent of disinfection requirements. Due to the submicron-to-micron nature of virus and bacteria, current solid-liquid separation processes are not able to effectively separate these microbial particulates from water. Moreover, the colloidal behavior of the submicron-to-micron range colloids in porous medium plays an important role on the transport and fate of pathogens in the groundwater. There is need to develop advanced technologies for the separation of submicron-to-micron particles from water and better prediction of transport and fate of pathogens in groundwater stems.

Objective:

- To develop unconventional solid-liquid separation technologies such as electro-filtration for the removal of pathogens from water.

- To study the chemical interactions between pathogens and soil particles in aqueous solutions.

Suggested Approach:

Approach to this problem lies on better understanding the modes and the kinetics of pathogens interactions with soil particles and other water born particulates. Developing and evaluating the advanced solid-liquid separation technologies.

Problem: **To Define the Effect of Electrostatic Forces on the Fate and Movement of Pathogens in Aquatic Systems.**

Originator: Huang

Importance:

Information will be useful in predicting the movement of pathogens in soil-water systems. It will also lead to the development of remediation and treatment technology for the removal of pathogens from water. It will provide a dissinfection alternative to chemical disinfection.

Objective:

To study the response and behavior of pathogens under electrostatic field.

Suggested Approach:

Laboratory and field experiments on the movement, die-off, and decomposition of pathogens under electrostatic field.

Problem: **What Quantitative Influence do Surface/Surface Interactions Have in Controlling the Retention of Pathogens in Porous Media?**

Originator: Mills

Importance:

A variety of factors are known to influence the "adhesion" of microorganisms to mineral grains. Quantitative relationships are not well established. Without such relationships, models can predict the transport of microbes in porous media only at the coarsest scale.

Objective:

The objective is to determine the pathogen surface properties and the mineral surface properties that interact to retard microbial transport, and to quantitate the cross-reactions of the various properties for purposes of model improvement.

Suggested Approach:

Large numbers of pathogens and indicators must be screened in controlled experiments using materials of known properties to determine the effect of varying the properties on retardation of the microbial particles. Response surfaces analysis can then assist in the development of modeling approaches to provide greater predictive accuracy.

Priority Rank 2: Pathogen Indicators

Problem: **Survey of Pathogen and Indicator Occurrence in Groundwater Supplies and the Circumstances of their Occurrence.**

Originators: Karlin, Sobsey, Yates

Importance:

Virtually nothing is known about the presence of viruses and other pathogens in groundwater and the circumstances of their occurrence. In order to properly design a regulation to disinfect groundwater, it is essential to know if, when, where, and especially why pathogens are present. Regulation (and exemption from regulation) will be based, at least in part, on the susceptibility of wells to pathogen contamination. We need better knowledge of the actual levels of microbial contaminants in real water supply wells.

Objective:

- Survey the presence and levels of pathogens (viruses, Legionella and other bacteria and protozoa) as well as indicator organisms in groundwater.
- Identify the types of microbial pathogens that are of most public health significance.
- Determine the aquifer characteristics related to susceptibility to microbial contamination.

Suggested Approach:

- Review the current data on pathogen occurrence in groundwater.
- Select a representative of drinking water supplies in the U.S.
- Develop various classification of wells for testing based upon aquifer characteristics (e.g., temperature, porosity, overburden characteristics, etc.).

- Develop representative groups (based upon classifications) of groundwater wells for sampling.
- Sample each well for target organisms and other analytes at least seasonally for one year.
- For the surveyed supplies, conduct a detailed sanitary survey, a geo-hydrological classification, and an analysis for other water quality constituents that might be related to pathogen and indicator occurrence and levels.
- Relate pathogen and indicator occurrence and levels to aquifer classification or type.

The following research problems were subsumed under the above problem:

Problem: **Survey of Virus Occurrence in Water Supply Wells**

Originator: Karlin

Importance:

Regulation or exemption from regulation will be based, at least in part, on the susceptibility of wells to viral contamination. We need a better knowledge of the actual level of virus in real water supply wells.

Objective:

- Determine the extent and level of contamination in water supply wells.
- Identify types of virus most likely to occur in water supply wells and their public health significance.
- Determine aquifer characteristics related to susceptibility to viral contamination.


Marylynn V. Yates
MARYLYNN

Suggested Approach:

- Review current data on virus occurrence in groundwater.
- Develop various classifications of wells for testing based upon aquifer characteristics (e.g., temperature, porosity, overburden characteristics, etc.).
- Develop representative groups (based upon classifications) of wells for sampling.
- Sample wells for virus.
- Relate virus occurrence to aquifer classification and type.

Problem: **Pathogen Occurrence in Groundwater and the Circumstances of their Occurrence**

Originator: Sobsey

Importance:

Virtually nothing is known about the presence of viruses and other pathogens in groundwater and the circumstances of their occurrence. In order to properly design a regulation to disinfect groundwater, it is essential to know if, when, where and especially why pathogens are present. This determines the need for disinfection and the type of disinfection practice.

Objective:

Survey the presence and levels of viruses, other microbial pathogens and indicators in groundwater and for those supplies, survey their sanitary and geo-hydrologic characteristics. Select groundwaters that are representative of drinking water supplies in the U.S.

Suggested Approach:

Conduct a national survey for enteric viruses, other microbial pathogens and indicators in a sufficient number and variety of groundwater to be representative

of drinking water supplies in the U.S. The survey should include sanitary and geo-hydrologic analyses of the supplies as well as quality analyses to determine if the presence of viruses can be related to other water quality constituents. The survey should be done seasonally for at least a year for each groundwater source.

Problem: **Groundwater Survey for Viruses and *Legionella***

Originator: Yates

Importance:

Adequate surveys have not been conducted to determine the occurrence of viruses or *Legionella* in groundwater.

Objective:

To determine the occurrence of viruses and *Legionella* in the groundwater in the United States.

Suggested Approach:

- Choose sites with a range of vulnerability to microbial contamination of the underlying groundwater. At least 100 sites should be identified.
- Collect groundwater samples periodically for at least one year.
- Analyze samples for viruses, *Legionella,* and indicator microorganisms.

Priority Rank 3: Conservative Tracers

Problem: **When Will Viruses be Transported Faster than Conservative Tracers?**

Originators: Corapcioglu, Berger, Hunt, Mills

Importance:

Data from field studies and laboratory experiments have shown that viruses and other colloids move more rapidly than conservative tracers. Models based on the conventional advective/dispersive transport equation could underpredict virus breakthrough.

Objective:

Identify mechanisms that operate in saturated porous media that would accelerate viruses compared to water. Pore-scale phenomena of concern are related to an anion and colloid size exclusion.

Suggested Approach:

Testable theories for viral transport need to be compared with laboratory experiments under conditions that isolate these mechanisms.

The following research problems were subsumed under the above problem:

Problem: **Facilitated Transport: Is it a Problem?**

Originator: Berger

Importance:

- Strict standard 1/10,000,000 PFU/liter.
- Facilitated transport will greatly shorten travel times.
- Anions can travel at twice velocity of tritium in low velocity (diffusion dominated) environments.
- Gerba and Yates recommend $R<1$ e.g. $R=0.7$.

Objective:

- Field, lab, and theoretical investigation of virus facilitated transport.

Suggested Approach:

- Field investigation of viruses injected directly into saturated zone.

Problem: **Incorporation of Pore Scale Considerations in a Viral Transport Model**

Originator: Corapcioglu

Importance:

It has been reported that viruses move faster than the average groundwater velocity. Thus, conventional advective/dispersive transport equation underestimates the distance viruses migrate.

Objective:

Develop a predictive viral transport model by incorporating pore scale velocity variations.

Suggested Approach:

Start formulation at pore scale, investigate velocity distribution in the pores, incorporate hydrodynamic principles at pore scale by representative elementary volume averaging in a macroscopic viral transport model.

Problem: **How does Hydrologic Heterogeneity Affect the Transport of Pathogens in Porous Media?**

Originator: Mills

Importance:

Much evidence suggests that particles in the viral and bacterial size range break through heterogeneous media before conservative tracers. The presence of preferred flow paths could allow pathogens in the source water to be transported to the well-head in cases where models based on the homogenous case predict complete removal, or transported to the well-head faster than those models predict.

Objective:

To determine the influence of micro- and macro- hydraulic heterogeneities on the transport of microbes in porous media. Additionally, questions of effective scale differences should be addressed.

Suggested Approach:

Laboratory-scale experiments should examine the transport of bacteria and viruses under controlled, heterogeneous conditions. Larger-scale experiments should also be undertaken. The results can then be used to develop theory-based models with appropriate phenomenological modifications.

Problem: **Can Conservative Tracers be Used to Predict Virus Transport?**

Originator: Hunt

Importance:

Under field conditions a conservative tracer, such as an anionic species or tritiated water, is useful in quantifying water transport. These tracers might be useful in determining flow paths and travel times that are critical in modeling maximum virus transport velocities. There is some empirical evidence that viruses move faster than the average water molecules or have greater dispersion resulting in more rapid transport and less opportunity for die-off and filtration.

Objective:

Determine under what conditions viruses will arrive sooner than conservative tracers during flow through porous media. A predictive model is needed for virus advection and dispersion through porous media compared to conservative tracers. The research should determine appropriate characterization of virus and porous media to make predictions.

Suggested Approach:

Formulate physically-based models for virus or colloid transport in porous media that quantify the importance of anion exclusion, hydrodynamic chromatography, Taylor dispersion, and dispersion caused by pore size distributions. The dominant processes should then be individually tested in the laboratory to determine their significance for porous media, and the level of characterization required for predictability.

Problem: **Visual Observation of Sub-Micron Particle Migration in the Pores.**

Originator: Corapcioglu

Importance:

To develop viral transport models, we have to understand individual mechanisms of particle transport and capture. Visual observations by electron microscope and NMR technique can help us to understand these mechanisms.

Objective:

Pore level observation of viral transport and capture by electron microscope and NMR.

Suggested Approach:

- Use of NMR and electron microscopes to look into viral migration in natural porous media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Priority Rank 4: Virus Inactivation

Problem: **Virus Inactivation in Groundwater**

Originators: Berger, Grubbs, Noss

Importance:

Virus survival time in groundwater will greatly impact set-back distances and other factors that affect natural disinfection variance decisions. Laboratory data on virus inactivation rates, however useful, must be demonstrated to be valid in field research. Of major concern is the effect of temperature on inactivation. However, work on groundwater chemistry and sorption onto solids, as related to survival, is also needed.

Objective:

Field studies should be conducted to verify virus inactivation rates in groundwater under a variety of environmental conditions normally encountered.

Suggested Approach:

Well with removable exposure cells should be constructed to allow ground water to diffuse into virus contact chambers.

The following research problems were subsumed under the above problem:

Problem: **Virus Inactivation in Groundwater**

Originator: Noss

Importance:

The use of the natural disinfection concept requires knowledge of viral inactivation rates in groundwater. This effort should focus on the temperature and groundwater chemistry impact on virus survivorship. The effect of virus sorption onto solids with regard to survival should also be evaluated.

Objective:

Some laboratory research is appropriate, but considerable field work should be used to assure that the most applicable data is available for use in modeling.

Suggested Approach:

Wells with removable exposure cells can be constructed to allow groundwater to diffuse into the virus contact chambers. In this design, virus inactivation rates in groundwater may be determined without concern for losses due to dilution or sorption. Samples of groundwater can be removed for analysis when virus test materials are recovered.

Problem: **Are Virus Inactivation Rates in the Field Reproducible.**

Originator: Berger

Importance:

- Controls breakthrough concentrations.
- Many factors control rate including temperature, antagonistic microbials, pH, organics.

Objective:

Measure inactivation rates in situ (in dialysis bags).

Suggested Approach:

Use approach of the Australians (Jansens et. al.)

Problem: **Use of Groundwater Temperature as a Natural Disinfection Criteria Discriminator**

Originator: Grubbs

Importance:

Easily measured criterion to determine qualification of sites for avoiding source water disinfection will facilitate rule implementation at lower resource cost.

Objective:

Defining series of temperatures for non-technical personnel to determine eligibility for natural disinfection.

Suggested Approach:

Use modeling and field data to set natural disinfection setback distances based on groundwater temperature.

Priority Rank 5: Modeling Pathogen Transport

Problem: **Indicators for Modeling Pathogen Transport and for Assessing Natural Disinfection.**

Originators: Cliver, Mills

Importance:

Surrogates (e.g., bacterial indicators for bacterial pathogens, bacteriophages for human enteric viruses) may offer important cost saving in carrying out transport studies and in determining the probable safety of groundwater sources. However, it must be shown that the indicator properly represents the pathogen.

Objective:

Find valid surrogates for pathogenic bacteria and viruses that may occur in groundwater.

Suggested Approach:

- Compare transport and die - off, in soil and groundwater, of bacterial indicators (e.g., *Legionella* sp. and bacteriophages with Hepatitis A virus).
- In testing field samples of groundwater, it is also important that the indicator suggest a human source of contamination.
- Surveys for pathogens in groundwater should include tests for candidate indicators.

The following research problems were subsumed under the above problem:

Problem: **Bacteriophage as an Indicator of Human Viral Contamination of Groundwater**

Originator: Cliver

Importance:

Some test that is more relevant than the total coliform test, as an index of human viral contamination, must provide the basis for assessing "Natural Disinfection."

Objective:

Devise a cheap, rapid bacteriophage test that, if positive for a raw groundwater sample, denotes a significant probability that the raw source water is contaminated with human enteric virus.

Suggested Approach:

- Devise reliable tests (concentration step plus biological detection step) for at least: total coliphage, F-RNA coliphage, phages of *Bacteroides* sp.
- Compare the incidence of these in human waste and sewage and in animal wastes, adding a "dipstick" serological or genetic test for human origin, if necessary.
- Compare transport and die-off properties of the preferred phage and of Hepatitis A virus, in water in selected soils, at representative temperatures.
- Apply the test at field sites where problems are known to exist, to determine validity.

Problem: **Does Transport of Indicators Adequately Indicate Transport of Pathogens?**

Originator: Mills

Importance:

Differences in surface properties are known to influence transport of colloidal particles. If indicator organisms are transported differently than pathogens, then decisions made on basis of indicator transport may be inappropriate.

Objective:

Examine differential transport of indicators and pathogens in heterogeneous porous media.

Suggested Approach:

Column and intermediate-scale experiments using defined and natural materials examining relative breakthrough behavior of indicators and pathogens under varying chemical and flow conditions.

Priority Rank 6: Spatial and Temporal Variability

Problem: **Spatial and Temporal Variability of Groundwater Quality**

Originator: Hunt, Karlin, Suffet

Importance:

Drinking water aquifers and the overlying unsaturated zone are not steady over time in terms of particles, chemicals and microorganisms at a well water source. The variability for each of these groups needs definition.

Objective:

Measure model microbe releases, humic colloids, and conservative chemicals surfaces in response to hydrodynamic forces as well as inorganic water quality perturbations (e.g., surface water infiltration). Hydrodynamic forces can be increased by increasing the flow rate through pumping, episodic rainfall events, and surface recharge, including reclaimed water. These variations can have severe effects on water quality and therefore treatment requirements.

Suggested Approach:

Field data indicates that variability exists. There is a need to develop tracer studies and to challenge studies on theories that should be tested in the laboratory. Physical models developed should be field tested.

The following research problems were subsumed under the above problem:

Problem: **How Can Virus Transport be Modeled Under Nonsteady Conditions?**

Originator: Hunt

Importance:

Drinking water aquifers and the overlying unsaturated zone are not steady over time in terms of water chemistry or water transport. Changes in chemistry and flow can erode off previously deposited particles in a manner that can not be predicted at this time.

Objective:

Need to measure and model virus release from fixed surfaces in response to hydrodynamic forcing as well as chemical perturbations. Hydrodynamic force can be increased by increasing the flow rate through pumping. Also, when other particles accumulate the formation permeability is reduced and constant flow conditions result in greater fluid shear. In partially saturated porus media, nonsteady flows and chemical perturbations are caused by episodic recharge events.

Suggested Approach:

Sufficient empirical evidence is available from the field to demonstrate the importance of this problem area. There needs to be more fundamental studies that propose theories and test these theories under controlled laboratory conditions.

Problem: **Rational Method for Defining the Gradation from Groundwater under the Influence of Surface Water to Naturally-Disinfected Groundwater**

Originator: Karlin

Importance:

Presence of certain organism types may be indicative of surface water influence. If "groundwater under influence" is the only type that is contaminated with viruses, bacteria and/or protozoans, disinfection alone will not be adequate. Where would the distinction be made; do we know enough?

Objective:

Determine whether the characteristics of wells contaminated with viruses or other organisms are an indication of surface water influence in relationship to variance criteria.

Suggested Approach:

Build on existing model(s) being used to identify groundwater under influence to see if presence of microorganisms is a determining factor in "surface water influence;" determine clear variance requirements for groundwater rule.

Problem: **Variability Testing of Groundwater Quality**

Originator: Suffet

Importance:

Scenarios of groundwater quality changing with time as functions of pumping rates at different locations in an aquifer, geological considerations and water quality, and infiltration of river of sea water into aquifers do occur. However, no sound principles of determining these conditions are available.

Objective:

To develop evaluation procedures for understanding variability of water quality at a well head or in a well field. Water quality includes chemical and biological paraments.

Suggested Approach:

- Develop monitoring test methods (physical testing) in the field to ascertain information on well water variability. Determine monitoring and time -- weekly, monthly, daily, hourly, etc. What is needed.

- Develop modeling, ideas to follow different scenarios and then test models in the field.

- Develop tracer studies and tools to evaluate variability.


ROBERT

Priority Rank 7: Organic and Inorganic Compounds

Problem: **Influence of Naturally Existing Organic and Inorganic Compounds on the Formation of Disinfection By-Products**

Originators: Karlin, Noss, Rigby, Suffet

Importance:

Coastal areas often have groundwater reserves with high color levels. Many communities are now exploring the use of these groundwater resources that may contain organic precursors and possibly bromide. When bromide is present in groundwater it can be oxidized, by a variety of disinfectant species, resulting in the production of brominated disinfection by-products. These brominated disinfection by-products are of concern to health. The formation of these compounds should be evaluated with regard to the presence of organic and inorganic (bromide) precursor materials in groundwater.

Objective:

To determine source water characteristics that will result in the formation of halogenated disinfection by-products.

Suggested Approach:

Selected source waters should be evaluated with respect to their potential for formation of halogenated disinfection by-products. Aspects of this research should include determinations of brominated disinfection by-product formation potential and the quantity of organic carbon in groundwater sources.

The following research problems were subsumed under the above problem:

Problem: **The Health Hazard Associated with Disinfection of Groundwater Containing Bromide**

Originator: Suffet

Importance:

- If disinfection is required by UV light (hydroxy radicals), ozonation, or any chlorine-type disinfectants, brominated inorganic (e.g., bromate) and/or organic by-products (e.g., brominated THMs) will form.

- The brominated disinfection by-products have been found to be more of a potential health hazard than chlorinated disinfection by-products.

- If bromide is present, the brominated disinfection products should form preferentially.

Objective:

To determine the extent of inorganic brominated byproducts (e.g., bromate) and organic brominated by-products from disinfection of groundwater.

Suggested Approach:

- Determine the extent of brominated DBP in a disinfected groundwater.

- Determine the bromate (bromate formation potential). Develop a test and survey.

- Determine the bromination organic DBP formation potential - Br-THMFP and TOBr.

- Determine the % of organic DBP of low and high MW.

OH^{1}

O_3 + H_2O_2

------> HOBr <=====> H^+ + OBr^-

Br^-

OBr^- NH_3

------> NH_xBr_y - Bromo Forms

Organics

------> Brominated DBPs

H_2O_2

------> Br^-

OH^0

------> BrO_3^-

Problem: **Examine the Occurrence of and Develop a Tool For Predicting the Presence of DBP Precursors in Water Supply Wells**

Originator: Karlin

Importance:

Wells which will require disinfection will also be most likely to be contaminated with organics including DBP precursors. The trade-off between DBP and disinfectants is critical to development of optimal rule mix.

Objective:

Identify aquifer characteristics likely to be associated with the presence of DBP precursors.

Suggested Approach:

- Review and summarize existing literature.

- Sample appropriate number of wells with a range of characteristics (porosity, temperature, character of vadose zone, etc.).
- Develop a model based upon sample data.
- Field check model.

Problem: **Influence of Naturally Existing Organic Materials on Disinfected Water Quality**

Originator: Noss

Importance:

Groundwater containing color, when disinfected with chlorine, may form THMs or other halogenated compounds. In the draft rule, UV irradiation is proposed for disinfection in the well field. This proposal addresses how UV irradiation as a pre-treatment process affects the formation of disinfection by-products following the use of a halogen-containing disinfectant.

Objective:

The goal of this project is to determine whether ultraviolet irradiation of source water alters the type and concentration of chlorine disinfection by-products.

Suggested Approach:

Selected source waters should be evaluated with respect to their potential for formation of chlorination by-products. The quality of chlorine disinfected water should be compared to UV-treated water and UV-treated/chlorinated water.

Problem: **When Disinfecting Groundwater with High Color, What are the Relative Risks Associated with Disinfection By-Products Formation Versus the Risks Posed by Pathogens?**

Originator: Rigby

Importance:

Many coastal communities have groundwater reserves with high color of organic origin. Communities are now actively exploring ways of developing this groundwater resource for potable use.

Objective:

To balance pathogen risks with risks associated with by-product formation when disinfecting groundwater with high color readings.

Suggested Approach:

Test a variety of high color waters for pathogens and simultaneously look for by-product formation as the result of various disinfection strategies.

Priority Rank 8: Testing Transport Model

Problem: **Testing of Pathogen Transport Models**

Originator: Yates

Importance:

Although several models of pathogen transport have been developed, none have been tested using data from a field site where pathogen contamination of groundwater has been documented. If EPA allows utilities to qualify for "natural" disinfection or to obtain a variance from disinfection using a pathogen transport model, the predictive ability of the models must be known.

Objective:

To determine the ability of models of pathogen transport to predict contamination at sites where contamination events have been documented.

Suggested Approach:

- Obtain data from several sites where pathogen contamination of groundwater has occurred (e.g., groundwater-borne disease outbreaks, field research sites).

- Input the data into several models (e.g., VIRALT, VIRTUS, VIROTRANS) and determine the accuracy of model predictions with documented field observations.

- Conduct sensitivity analysis to determine required accuracy level of input data.

- Assess ability of models to be used by water utility personnel.

Priority Rank 9: Indicator and Resistant Virus Data

Problem: **Disinfectability with Different Disinfectants Requires Data on Indicators, Resistant Viruses, Other Target Organisms, Pathogen Models, and Water Quality Parameters Influencing Disinfection**

Originators: Cairns, Cliver

Importance:

Risk-based disinfection requires knowledge of the most resistant pathogen or its surrogate to be monitored; or, knowledge of the relative resistance of the most resistant pathogen (usually virus) and the indicator which is to be monitored. Disinfectant comparisons for finding the most cost-effective technology should be risk-based.

Objective:

Identify preferred indicator organism of the disinfection process and develop dose-response curves for the most resistant virus (or its surrogate) and indicators for each disinfectant and the water quality parameters influencing disinfectant effectiveness and microbial aggregation.

Suggested Approach:

- Review and specify criteria for selecting an indicator and most resistant virus (or its surrogate), then select indicator and most resistant virus (or its surrogate).

- Validate selection (compare disinfectability relative to pathogens or organisms identified with most frequent disease in population).

- Establish indicator and most resistant virus dose response curves under standard water quality conditions and in different water qualities.

The following research problems were subsumed under the above problem:

Problem: **Need: Criteria and Data to Compare Disinfectants on Basis of Ability to Reduce Risk**

Originator: Cairns

Importance:

Criteria and data are needed when comparing the ability of different disinfectants to achieve the same level of risk reduction during the disinfection process. [Risk is a function of surviving numbers of the most resistant organism (typically viruses for groundwater), and therefore, the target level of indicator used when comparing disinfectants will vary for each disinfectant depending on relative sensitivity of indicator and most resistant viruses (MRV) under existing water quality conditions]. **(See Figure)**

Criteria and data are important for selection of:

- Best available disinfectant to cover broadest range of pathogens.
- Best disinfectant with acceptable levels of by-products and residuals.
- Most cost-effective disinfectant.

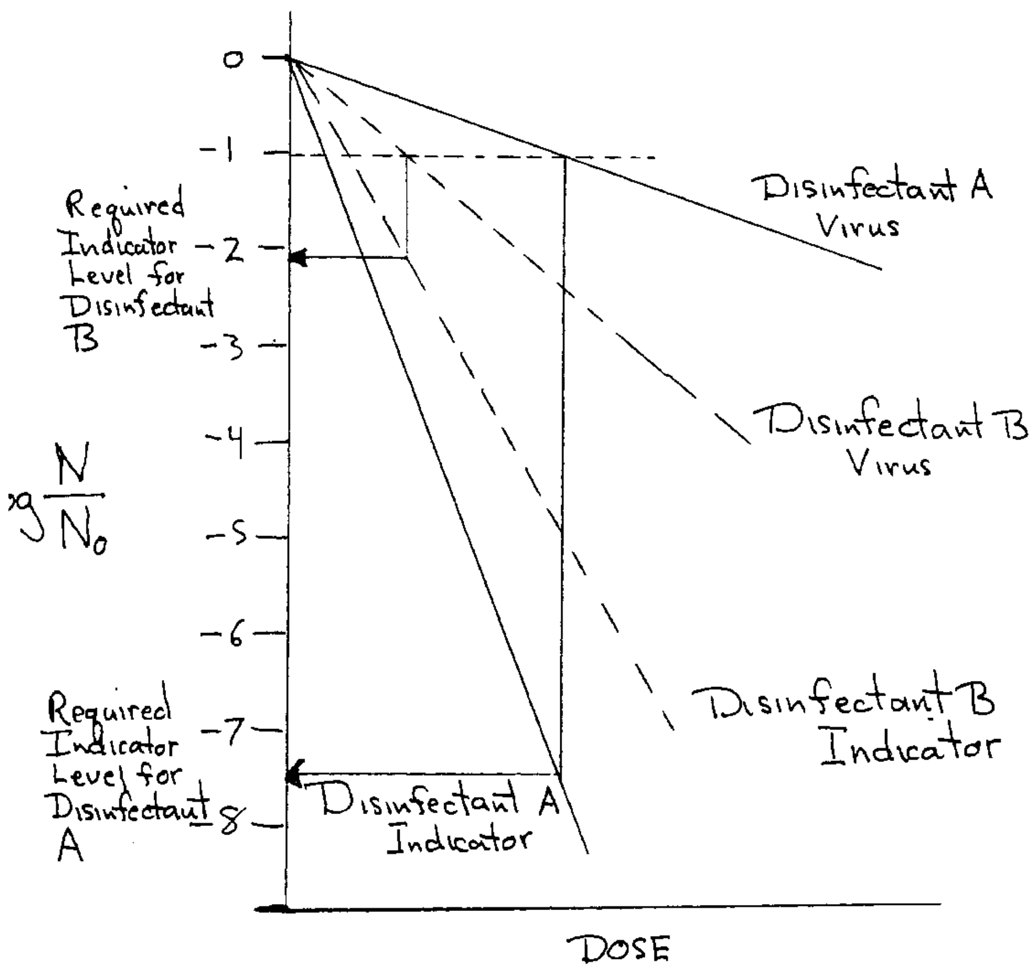
Objective:

Identify bacterial indicator organism and review or develop dose-response curves for indicator and for most resistant virus with each disinfectant at different water qualities.

Suggested Approach:

- Review and specify criteria for selecting viral or bacterial indicator and MRV (workshop and peer review). The concept of a workshop (or forum) is described in "proposal" sent to NWRI by Trojan Technologies Inc. as a result of discussions with Drs. Asano and Tchobanoglous in California.

Same virus risk for both disinfectants
BUT different indicator levels



- For each disinfectant, identify indicator and MRV (use creativity - e.g., HPC + seeded bacteriophage which may be both process indicator and amplifier of E. coli in distribution lines).

- Review and/or develop dose response curves for indicator and MRV with each disinfectant:

  - in a standard water quality.

  - in different water qualities having parameters (e.g., pH, alkalinity, temperature, TOC, particles, etc.) which could influence the disinfectant and/or microbe aggregation.

Problem: **Bacteriophage as an Indicator of Successful Disinfection of Groundwater**

Originator: Cliver

Importance:

If disinfection of raw groundwater is required in a given system, the principal goal is inactivation of human enteric viruses. A safe bacteriophage surrogate is needed to demonstrate that the system achieves antiviral disinfection.

Objective:

Identify a bacteriophage that does not occur spontaneously in raw groundwater, is as resistant as Hepatitis A virus to disinfection, and can safely be added to raw water in disinfection procedure.

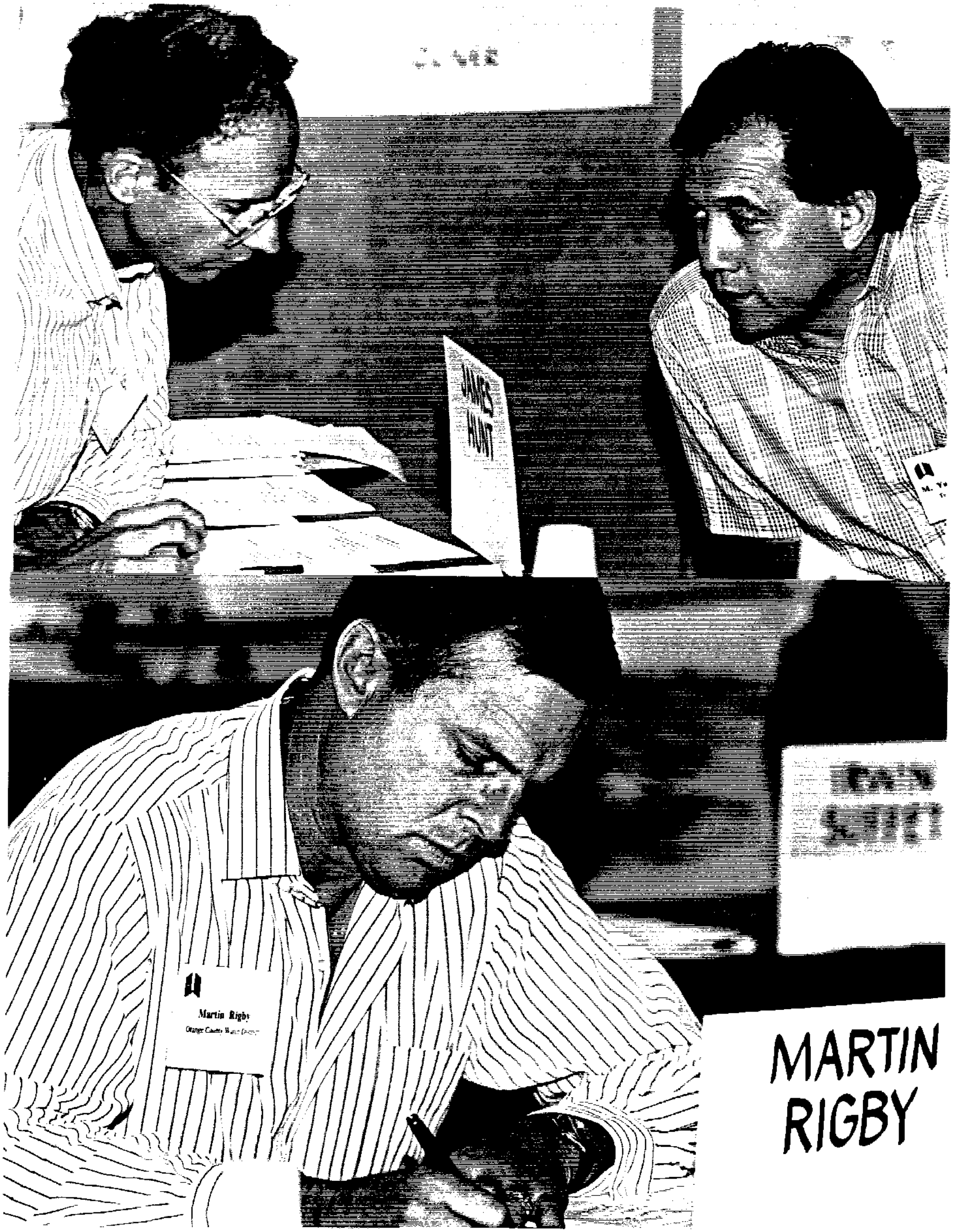
Suggested Approach:

- Select a phage (based on its bacterial host) that does not occur spontaneously in waste water or raw water.

- Compare the selected phage with Hepatitis A virus for inactivation in raw groundwater by various disinfection methods (bench scale).

- Evaluate the phage in pilot-scale disinfection tests of various raw groundwater with various disinfectants.

- If raw groundwater sources with consistently significant levels of coliphage can be identified, compare inactivation of the exogenous phage and the indigenous coliphage, with a view to monitoring post-disinfection coliphage in that system on a regular basis.



MARTIN RIGBY

Priority Rank 10: Pathogens in Unsaturated Conditions

Problem: **Can Virus Transport in the Unsaturated Zone be Predicted?**

Originator: Hunt

Importance:

Pathogens are present in near-surface soils, and their transport in the west to groundwater must pass through extensive unsaturated alluvial material. Water and solute movements are poorly defined in the unsaturated zone, and there is no predictive capability for colloid transport.

Objective:

Develop theories and experimental procedures to address colloid transport in unsaturated porous media that offer predictive capability.

Suggested Approach:

Fundamental studies combined with laboratory investigations of colloid removal during steady infiltration. Since deep bed filtration theory does not apply, considerable theoretical development is required. (Nonsteady studies would follow on later.)

Priority Rank 11: Saturated vs. Unsaturated Conditions

Problem: **How do Saturated/Unsaturated Groundwater Conditions Affect Pathogens Transport.**

Originator: Rigby

Importance:

With increased interest in injection as a method of groundwater recharge, it is important to determine how natural disinfection mechanisms operate under saturated and unsaturated conditions.

Objective:

To develop methods of determining the natural disinfection capabilities of groundwater basins under saturated and unsaturated conditions.

Suggested Approach:

Monitor pathogens transport under a variety of saturated/unsaturated conditions.


JAMES
HUNT

Priority Problem 12: Viral Capture Mechanisms

Problem: **Viral Capture Mechanisms**

Originators: Corapcioglu, Hunt

Importance:

Most available viral transport models make use of linear adsorption isotherms which lead to the use of a retardation coefficient. However, viral capture might be described by other approaches such as filtration theory or non-linear equilibrium partitioning.

Objective:

Consideration of various capture mechanisms for inclusion in a viral transport model. Possible mechanisms to be considered include filtration, coagulation, aggregate breakup, and sorption.

Suggested Approach:

Development of various types of viral transport models based on above mentioned mechanisms and comparison with laboratory experiments.

The following research problems were subsumed under the above problem:

Problem: **Are Viruses Colloids or Solutes?**

Originator: Hunt

Importance:

Models available in the literature adopt these two competing and conflicting approaches to represent virus transport in the subsurface. Since models like these will be used to determine field-scale virus transport, it is essential to understand the fundamental mechanisms of virus transport.

Objective:

Research must determine if viruses are colloidal or dissolved. If viruses are colloids, then transport will be predictable from theories based on colloid science for processes such as coagulation, aggregate breakup, filtration, and erosion. If viruses are solutes, then phase partitioning through adsorption and desorption determines transport.

Suggested Approach:

Carefully controlled laboratory experiments should be designed to test these two approaches. Testing of theoretical approaches must be based on comparison with data not used for model calibration.

Problem: **Quantification of Viral Capture Mechanisms**

Originator: Corapcioglu

Importance:

Most available viral transport models make use of linear adsorption isotherms which lead to a definition of a retardation coefficient. Consideration of other types of formulations can lead to better predictive techniques.

Objective:

Look into possibility of incorporating particle/collector approaches and their formulation in viral transport models.

Suggested Approach:

Development of capture formulation by using particle/collector approach and incorporating resulting formulations in viral transport model and comparison of different types of capture formulations with experimental data.

Priority Rank 13: Role of Risk Analysis

Problem: **Investigation into the Role of Risk Analysis for the Validation of Groundwater Disinfection Rule Variance Criteria and Natural Disinfection Criteria**

Originator: Sakaji

Importance:

The USEPA will find it difficult, but not impossible, to implement a groundwater disinfection rule, in a cost-effective manner without conducting a risk analysis. Without a risk analysis, there will be no quantitative information on which the USEPA could base a balanced approach in the implementation of the rule. Of equal importance will be the need to show that natural disinfection and variance criteria provide trade-offs that provide an equal degree of protection (i.e., equivalent levels of risk). A risk analysis will provide numerical evidence that the variance criteria do not depend on a *qualitative* assessment of risk.

Objective:

A risk analysis combines hazard assessment, exposure assessment, and risk assessment into a cost-benefit analysis which considers costs of treatment and other societal costs (e.g., loss of worker productivity and impact on state programs) based on a proposal regulation and several options. The cost-benefit analysis can then be used by risk managers to set regulations after exploring regulatory options and alternatives.

Suggested Approach:

- Collect and summarize water quality data on pathogens, disinfection by-products, and disinfection by-product precursors (hazard assessment).

- Identify hazards of concern; specific pathogens or disinfection by-products.

- Evaluate the spatial and temporal distribution of the water quality data.

- Identify specific instances of waterborne disease outbreaks associated with the use of groundwater. Determine whether these outbreaks are biological or chemical in origin.

- Exposure Assessment.
- Summarize pathogen dose-response information (risk assessment).
- Evaluate fate and transport models for pathogens and organics (risk assessment).
- Cost/benefit analysis (e.g., cost of treatment and cost to society).
- Sensitivity analysis.

The following research problems were subsumed under the above problem:

Problem: **Groundwater Disinfection - Hazard Assessment**

Originator: Sakaji

Importance:

Hazard identification is needed to provide a clear definition of the problem that is to be resolved and the problems that may arise as a result of any proposed solution. As a first step in risk analysis, hazard assessment provides a clear definition of the problem. Such an assessment should clearly identify the hazards associated with the disinfection of groundwater and the hazards associated with *not* disinfecting groundwater.

Objective:

In order to complete a hazard assessment, it will be necessary to identify and characterize potential biological and chemical hazards associated with the disinfection of groundwater. Such an examination should not only look at problems associated with raw water but should include hazards produced during treatment (disinfection by-products). Meeting such objectives should include an answer to the question of whether or not water systems serving groundwater are adequately protected under the coliform rule. If not, a hazard assessment should also identify whether equal protection can be achieved in both surface

water and groundwater systems. Completing a hazard assessment should also aid in the identification of criteria for a sanitary survey.

Suggested Approach:

- Water quality survey, with a statistical validation of the sampling program.
- Identify hazards of concern; specific pathogens or disinfection by-products.
- Evaluate TTHMFP in groundwater.
- Look at spatial and temporal distribution of the water quality data.
- Look at and identify specific instances of waterborne disease outbreaks associated with the use of groundwater. Determine whether these outbreaks are biological or chemical in origin.
- Chlorate production during hypochlorite storage.
- DBP's from UV


TOM
GRUBBS

<u>Priority Rank 14</u>: <u>Definition of Natural Disinfection</u>

Problem: **Defining an Implementable, Scientifically Defensible Set of Natural Disinfection Criteria Applying to Public Water System Sources**

Originator: Grubbs

<u>Importance</u>:

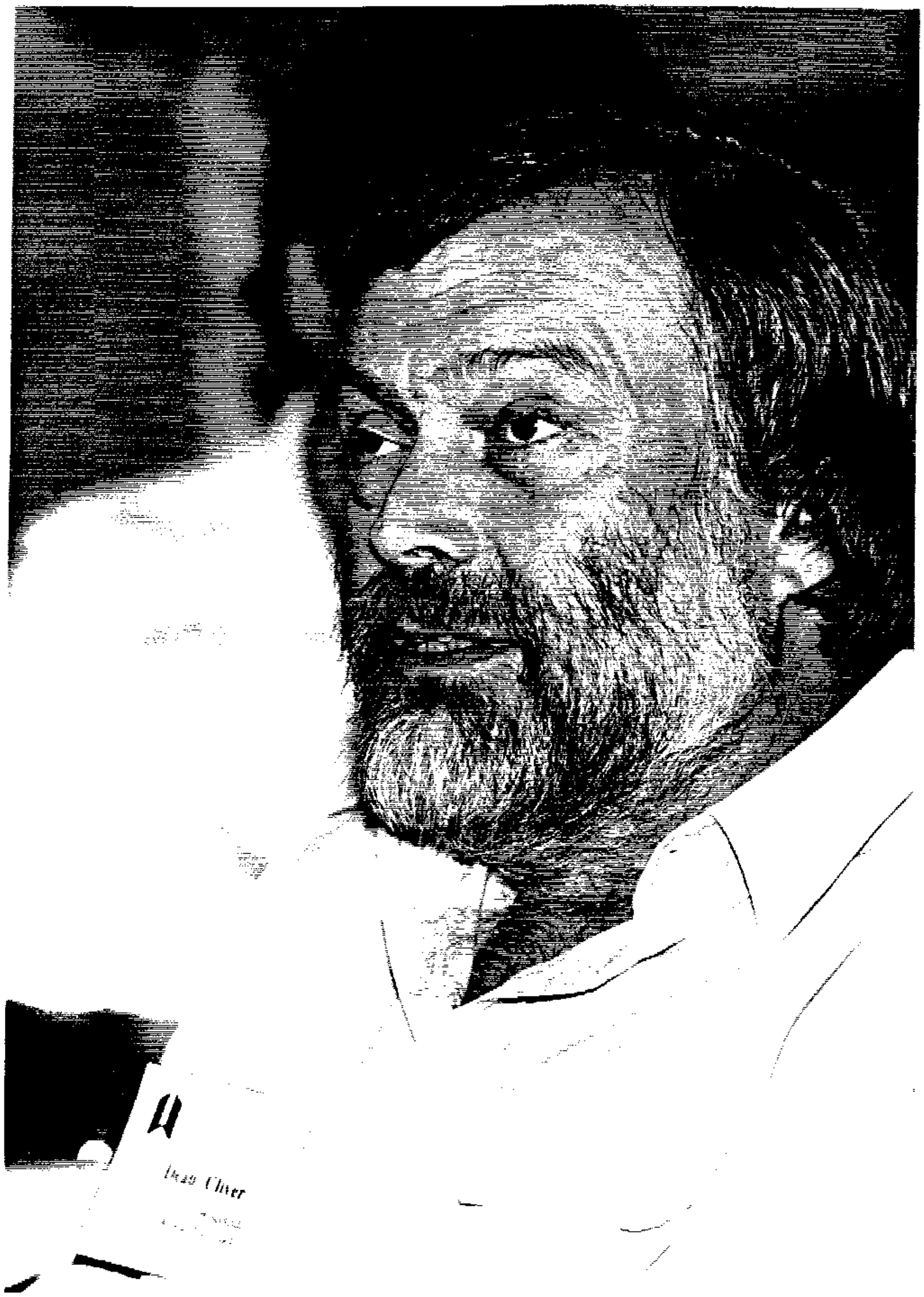
By allowing nonvulnerable systems to avoid source water disinfection treatment by chemicals, there will be a monetary savings (no need to install/operate equipment) with no loss of health protection from microbial contaminants (and a net health protection gain from avoiding DBPs).

<u>Objective</u>:

A set of easily calculated criteria that non-technical personnel can apply to show that the risk of waterborne disease is below an EPA-defined acceptable level. Ideally, the result would be set back distances based on one or several variables (e.g., temperature, saturated/unsaturated flow, soil type).

<u>Suggested Approach</u>:

Review/consolidate literature data and data generated by this workshop to define.



Priority Rank 15: Migration of Viruses

Problem: **Migration of Viruses Through Preferential Pathways**

Originators: Cliver, Corapcioglu, Puls

Importance:

Conventional viral transport models consider a single medium excluding migration through geologic heterogeneities and preferential pathways, such as fractures, cracks, fissures, root channels, etc. Incorporation of a second medium which is more conductive to viral transport can improve the existing predictive techniques.

Objective:

To develop a predictive viral transport model for dual media subsurface environments and perform experiments designed to evaluate the effect of geologic heterogeneities and dual media.

Suggested Approach:

Combination of large-scale laboratory and possibly field-scale experiments with viral transport models incorporating heterogeneities and dual media representation of subsurface environments.

The following research problems were subsumed under the above problem:

Problem: **Migration of Viruses Through Preferential Pathways**

Originator: Corapcioglu

Importance:

Conventional viral transport models consider a single medium excluding migration through preferential pathways, such as fractures, cracks, fissures, root channels, etc. Incorporation of a second medium which is more conductive to viral transport can improve the existing predictive techniques.

Objective:

To develop a predictive viral transport model for dual media subsurface environments.

Suggested Approach:

Develop viral transport formulation for a non-porous medium and couple with a porous medium model. Obtain a simultaneous numerical solution and compare with experimental data obtained under controlled conditions.

Problem: **Meso & Macro Scale Laboratory and Field Experiments to Evaluate the Transport of Virus and Bacteria.**

Originator: Puls

Importance:

Information needed to determine the significance of preferential flow from a from human health standpoint and for assessment of "natural disinfection" criteria.

Objective:

Evaluate hydrologic and geologic conditions which permit early breakthrough of colloids in advance of average water flow velocity.

Suggested Approach:

Combination of field and large-scale laboratory experiments which are designed to clearly evaluate effects of hydrologic and geologic heterogeneities.

Problem: **Applying "Preferential Flow" Principles to Models of Pathogen Transport in Groundwater.**

Originator: Cliver

Importance:

Improved methods of hydrogeological analysis are needed in characterizing groundwater recharge and the risk of viral contamination of raw water.

Objective:

Determine how differences in hydraulic conductivity within a "real," complex soil system affect the virus transport predicted by current models.

Suggested Approach:
?? Not my field.

Priority Rank 16: Deterministic Models

Problem: **Alternatives to Deterministic Models for Predicting Pathogen Fate and Transport in the Subsurface**

Originator: Yates

Importance:

Deterministic models cannot be used in an absolute sense - they can only be used in a relative sense (i.e., comparing the fate and transport of one microorganism to another). In addition to any threshold level of contamination set by regulation, a probability level of that contamination should also be specified. In other words, the regulation should specify that there must be a certain (e.g., 99%) probability that the level of contamination is no greater than 2 viruses per 10 million liters.

Objective:

Find alternatives to deterministic models that have meaning in a regulatory framework.

Suggested Approach:

- Establish distributions of factors affecting microbial fate in the subsurface (e.g., the distribution of values for virus adsorption to a given soil).

- Determine how to incorporate conditional probability into management decision-making.

Priority Rank 17: Humic Material Colloids

Problem: **Understanding Humic Material Colloids that Transport Chemicals in Subsurface Environments**

Originator: Suffet

Importance:

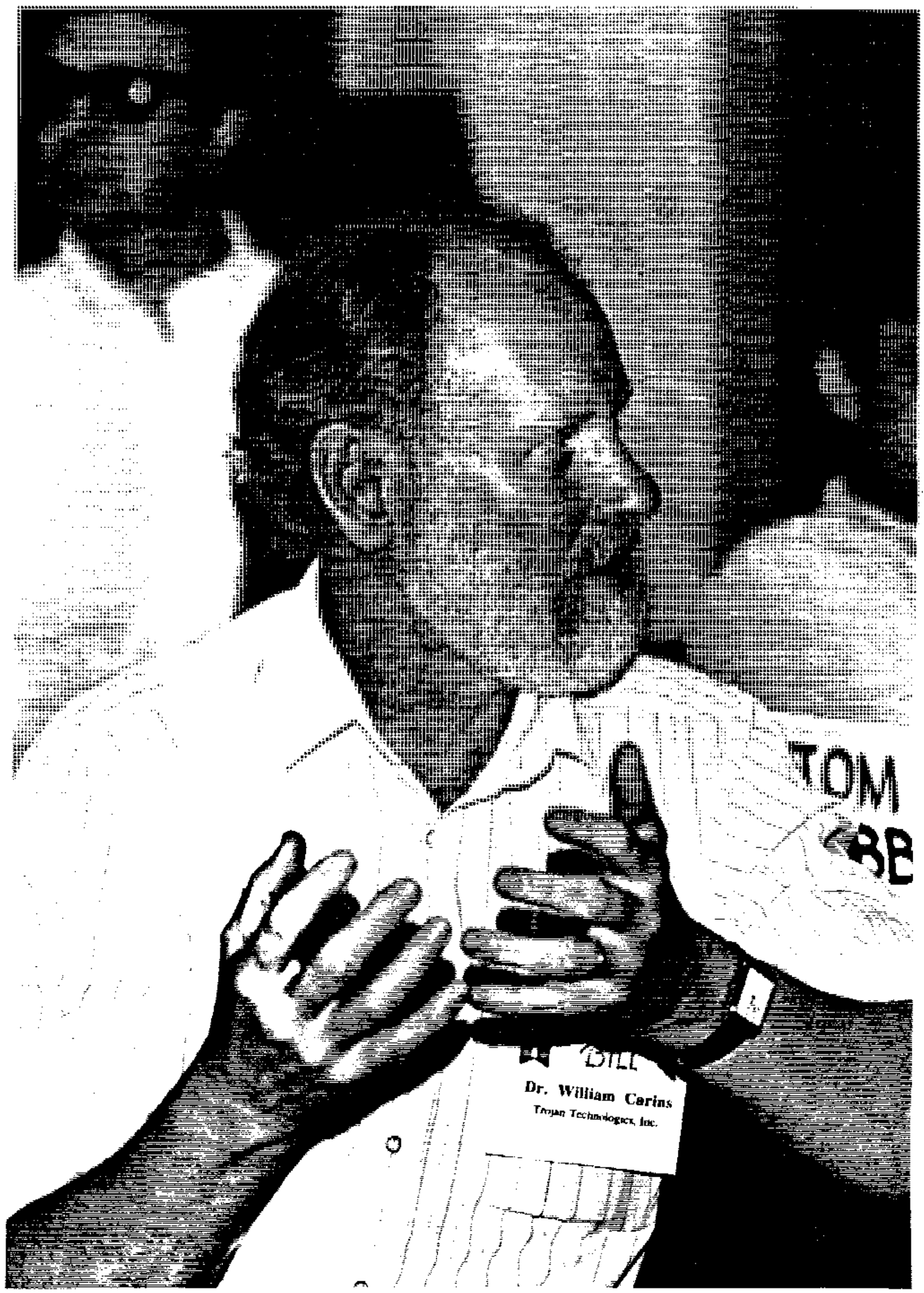
- Humic materials are present and are not sufficiently defined.
- Humic materials are colloidal in nature and are mixtures of many different molecular weight compounds of 500-10,000 molecular weight.
- Humic materials can facilitate transport of hydrophobic pollutants by so-called humic-organic associations where the apparent solubility (<45u size) occur.

Objective:

Develop an ability to define humic material colloids on a molecular level.

Suggested Approach:

- Define the molecular structure of humic materials that can interact with microorganisms and hazardous chemicals.
- Define the fractions of humic materials that are critical for transport, i.e., M.W., charge, charge/MW ratio, chemical functionality.
- Define the effect of water quality conditions for transport, e.g., pH, ionic strength.
- Utilize equilibrium and column studies to define parameters.
- What structural or chemical properties of humic material facilitate transport of chemicals and microorganisms?
- Develop methods to characterize the humic materials that interact with chemical and microorganisms in subsurface environments.


TOM
Dr. William Carins
Trojan Technologies, Inc.

Priority Rank 18: Risk-based Disinfection Strategies

Problem: **Criteria to be Used in a Risk-Based Disinfection Strategy Needs to be Defined and Illustrated by Example**

Originators: Cairns, Cliver

Importance:

Some effort is needed to identify whether risk reduction refers to infection possibility or to disease occurrence; what organisms are the basis of risk (most resistant virus or surrogate?), and what the reference point is for determining risk reduction (site average virus concentration, site maximum, national maximum?). Cost savings possible by not over disinfecting.

Objective:

- Develop a rationale for risk-based disinfection.
- Develop supportive data base for rationale.

Suggested Approach:

Use combination of workshop, field research, and peer review.

The following research problems were subsumed under the above problem:

Problem: **Objectives, Methods of Implementing, and Examples of Risk-Based Disinfection Strategy Needed**

Originator: Cairns

Importance:

- The rationale behind a risk-based disinfection strategy must be defined before it can be implemented and before criteria can be identified for site-specific exemption from a disinfection requirement.

- Cost-effectiveness for different disinfectants should be compared on an equal-risk and not an equal-indicator basis when comparing technologies.

- Risk is global and how to handle by-product risk, residual risk, and safety of operator/community as well as infection risk needs to be assessed.

Objective:

The objectives and methods of implementing a risk-based disinfection strategy need to be defined, and then a set of examples in which the strategy, field data on most resistant viruses, and dose-response curves are used to determine the target bacterial indicator when using different disinfectants and water qualities.

- Define disinfection strategy in terms of risk level (10^{-4} infections/yr), target pathogens (most resistant viruses) and presumed predisinfection levels (site average, site max, national max), etc. **(See Figure)**

- Collect and summarize existing field data on virus concentrations in predisinfection waters.

- Translate to risk.

- Determine log reductions for acceptable risk.

- Use disinfection strategy, field data, and dose-response curves to determine indicator log reductions to achieve target risk level with representative or actual water qualities.

- Determine risk associated with produced by-products, residuals, safety, etc.

Suggested Approach:

- Use workshop and peer review. The concept of a workshop (or forum) is described in "proposal" sent to NWRI by Trojan Technologies Inc. as a result of discussions with Drs. Asano and Tchobanoglous in California.

- Use research team to respond to RFP and workshop participants on Project Advisory Committee (PAC).
- Utilize a team plus project advisory committee plus peer review.

Problem: **Risk Assessment Based on Disease Rather than Infection**

Originator: Cliver

Importance:

Order-of-magnitude uncertainties that are left in risk modeling will create order-of-magnitude confusion in implementing disinfection of groundwater.

Objective:

Base risk estimates on health effects (viral illnesses), rather than probability of infection.

Suggested Approach:

Human subjects - maybe study communities (Indian reservations and some other rural communities in U.S., nearby developing countries) for incidence of infection and disease with upgrade water supply quality.

Priority Rank 19: Prequalifying Conditions

Problem: **Identification of Appropriate Natural Disinfection Prequalifying Conditions.**

Originator: Grubbs

Importance:

Noncompliance with prequalifying conditions will eliminate the need for further evaluation of groundwater sources for compliance with natural disinfection criteria.

Objective:

List and define what conditions must be met before a system can be evaluated for compliance with natural disinfection criteria.

Suggested Approach:

Evaluate the importance of certain site-specific characteristics, such as well construction practices (and compliance with code), compliance with other regulations (e.g., Total Coliform Rule), and sanitary surveys in ensuring that source water is not contaminated as it is withdrawn.

Priority Rank 20: Reclaimed Water for Recharge

Problem: **How Does the Use of Reclaimed Water for Recharge Affect Natural Disinfection Mechanisms.**

Originator: Rigby

Importance:

Municipalities in many states are using, or are planning to use, ever-increasing quantities of reclaimed water for recharge of potable aquifers. The impact of such practices on natural disinfection needs to be understood.

Objective:

To determine treatment levels and recharge procedures/characteristics necessary for safe recharge of potable aquifers with reclaimed water, with particular attention to natural disinfection mechanisms.

Suggested Approach:

At several different recharge sites, first define the biological/chemical/physical characteristics of the recharge water and then establish a monitoring/research program to determine the short and long-term impacts of spreading/direct injection recharge operations on natural disinfection mechanisms.

<u>Priority Rank 21</u>: <u>Cryptosporidium</u>

Problem: **Do We Know Enough About *Cryptosporidium* Oocytes and Viable but not Culturable Pathogens Travel in Soil and Survival in Groundwater**

Originator: Farrah

<u>Importance</u>:

Previous laboratory and field studies and models might not be applicable to *Cryptosporidium* oocyte and visible but not culturable pathogens.

<u>Objective</u>:

- Determine the ability of *Cryptosporidium* oocytes to migrate through soil.
- Determine the survival of *Cryptosporidium* oocytes in groundwater.

<u>Suggested Approach</u>:

Study transport through soil columns and survival in groundwater under different conditions.

Priority Rank 22: Equality of Pathogen Sources

Problem: **Are all Pathogen Sources Equal?**

Originator: Grubbs

Importance:

Natural disinfection criteria may be able to use source type as a discriminator.

Objective:

Determine whether different sources have sufficiently different characteristics to differentiate natural disinfection criteria by nearest source/sources? (Characteristics include pathogen density, type, concentration variation over time).

Suggested Approach:

Review literature and field studies of various sources (septic tanks, sewer lines, landfills, surface water) to determine characteristics/discriminators for natural disinfection criteria.

Priority Rank 23: Expert System-Based Software

Problem: **Development of Expert-System-Based Software for Disinfection Criteria Evaluation**

Originator: Puls

Importance:

This would provide a useful tool (and framework) for states and EPA to assess "natural disinfection" potential. Importance for protection of human health and judicious use of financial resources.

Objective:

Produce user-friendly software to assist in decision-making on qualification for "natural disinfection".

Suggested Approach:

- Assemble expert team.
- Synthesis of data - factors controlling pathogen transport.
- Poll other interdisciplinary 'experts' for opinions.
- Prioritize factors.
- Quantify?
- Build expert system software as initial framework- flexible enough to incorporate new data.

Priority Rank 24: Filters for Pathogen Removal

Problem: **Can Filters be Developed to Provide Long-term Removal of (Bacterial, Viral, and Protozoan) Pathogens from Water without Greatly Increasing the Heterotrophic Plate Count?**

Originator: Farrah

Importance:

In-line filters that can remove pathogens could: (1) reduce or eliminate the need for disinfection and, (2) provide an additional safety barrier against transmission of pathogens in case of failure of disinfection systems.

Objective:

Filters that can absorb viruses in water over a wide pH range have been described:

- The ability of these filters to remove bacterial, viral, and protozoan pathogens from water over long periods of times should be determined.
- Some of these filters are commercially available; some have been described in the literature, and some are being investigated. Some use inexpensive materials such as sand, diatomaceous earth, and fiber glass.

Suggested Approach:

Filters will have groundwater passed through them for periods of time ranging from weeks to months. The filters will then be tested for their ability to remove pathogens from water. The heterotrophic bacteria released by the filters will be monitored through the time of use.

Priority Rank 25: Control of DBP's

Problem: **Advanced Treatment Technologies for DBP's and Minimization of DBP Production**

Originator: Huang

Importance:

Disinfection is the ultimate and integral part of drinking water treatment. While many disinfectants have been suggested, it appears that the chlorine will continue to dominant the practice. The presence of humic substance in groundwater poses a danger to water quality in that chlorination of humic substances will lead to the formation of halogenated hydrocarbon, e.g., trihalomethanes (THMs). The toxic nature of halolenented hydrocarbons has been clearly documented for rat and mice. Although THMs are suspected carcinogens for man, their toxic potential has not been questioned. While many physical chemical treatment methods and measures have been suggested, effective control technology is not yet available.

Objective:

- To develop disinfection alternative technologies with a special emphasis on non-chlorine base methods, e.g., acoustic, optical, and electromagnetic processes.

- To study advanced chemical oxidation processes for the removal of humic substances and DBPs. Method such as catalytic oxidation with hydrogen peroxide can be promising in removing DBPs and precursors from water.

Suggested Approach:

The problem of DBP control can be approached from two ends: minimization of DBP generation and removal of DBPs once they are generated during disinfection operations. The development of disinfection alternatives can contribute to the minimization of DBP production. The development of advanced chemical oxidation processes will provide effective options for DBP removal.

Priority Rank 26: Institutional Barriers

Problem: **Institutional Barriers to the Implementation of the Groundwater Disinfection Rule Natural Disinfection criteria**

Originator: Sakaji

Importance:

State water law regarding water rights may vary significantly among primary states. It is important to identify those cases in which variance criteria or natural disinfection criteria may not be applicable. If natural disinfection criteria are used, how will the enforcement agencies ensure that the criteria will be maintained over time. This will effect the frequency at which sanitary surveys are conducted to maintain protection of the groundwater basins. Institutional barriers may include USEPA policies or regulations that do not provide consistent guidance or uniform regulations between USEPA divisions. These inconsistencies should be identified prior to developing regulatory proposals.

Objective:

- To ensure uniformity of policy and regulation within EPA divisions.
- To ensure that the natural disinfection criteria can be used in all states.

Suggested Approach:

Summarize, review, and evaluate state water law with respect to the application of natural disinfection criteria.

Priority Rank 27: Composite Models

Problem: **Identification of Appropriate Pathogen for GW Modeling/Testing**

Originator: Grubbs

Importance:

Modeling to determine natural disinfection criteria is necessary to develop implementable provisions.

Objective:

A single or "composite" pathogen to complete rule making - characteristics to be considered include dose-response, severity of reaction, occurrence, resistance to disinfection/removal, mobility.

Suggested Approach:

Should we use a composite pathogen? If so, should we use the worst individual pathogen for each characteristic to result in reasonable worst case (given that we have no data or limited data on many pathogens)?

Priority Rank 28: Biofilm Growth

Problem: **Need Criteria to Quantify AOC Impact on Biofilm Growth and on Prophylactic or Reactive Strategies**

Originator: Cairns

Importance:

- By making water quality an integral component of risk (along with the pre-disinfection most resistant virus [MRV] level), emphasis is drawn to water quality (especially AOC) as an issue in drinking water treatment to improve drinking water quality with less cost.
- By addressing biofilms, the myths of chlorination and needed residuals will be diminished, and we will be able to develop better processes for AOC reduction sooner.

Objective:

- Criteria are needed to assess how water quality impact on biofilm growth in a distribution system should be incorporated into a risk-based disinfection strategy.
- Guidelines are needed for when to increase indicators, at what concentrations, and how to address increased risks resulting from poor water quality entering distribution lines.
- Redefine distribution line maintenance, POE disinfection and residual requirements (specifying biofilm-effective disinfectants) in terms of water quality parameters (e.g., AOC) and changes in microbial growth along the distribution line (or sudden appearance of pathogen indicators such as FC or seeded bacteriophage increases). **SEE FIGURE**

Suggested Approach:

- Using field sites with no FC in lines, establish HPC changes along lines as a function of AOC and/or other water quality parameters.

- Review data correlating HPC and FC changes with AOC in distribution system and quantitate implications for risk based on nutrient-limited growth rates.

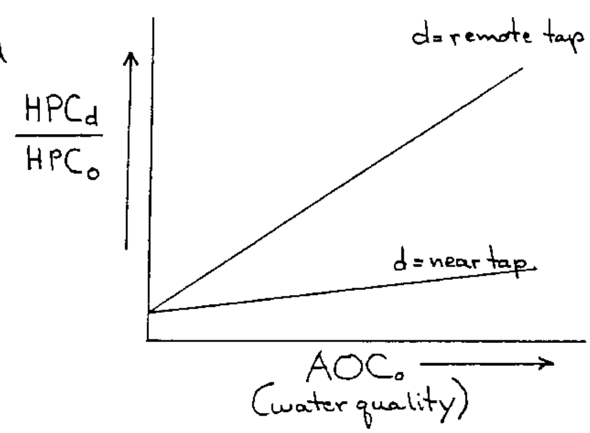
- Determine dose of biofilm-effective disinfectants (chloramine, etc.) to control HPC and FC changes at different AOC levels.

- Recommend preferred prophylactic and emergency disinfection strategies and when to use them to cope with increased risk due to high AOC (with or without line contamination by pathogens):
  - increase plant disinfection dose (minimize colonizing rate only)
  - use biofilm disinfectant (or pegging, if gross contamination)
  - POE disinfection
  - change process to remove AOC

Water Quality correlations with risk and the need to respond or develop prophylactic approaches

Increased Need to Respond
- increase plant disinfection level
- use biofilm disinfectant (what dose for what AOC to balance k_{growth} and $k_{inactivation}$)
- POE disinfection
- change treatment process to reduce AOC

Increased Risk if line contamination occurs (quantitate based on microbial growth rates, virus adhesion to biofilms, etc.)



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on
1995 Groundwater Disinfection Rule

June 7-8, 1992

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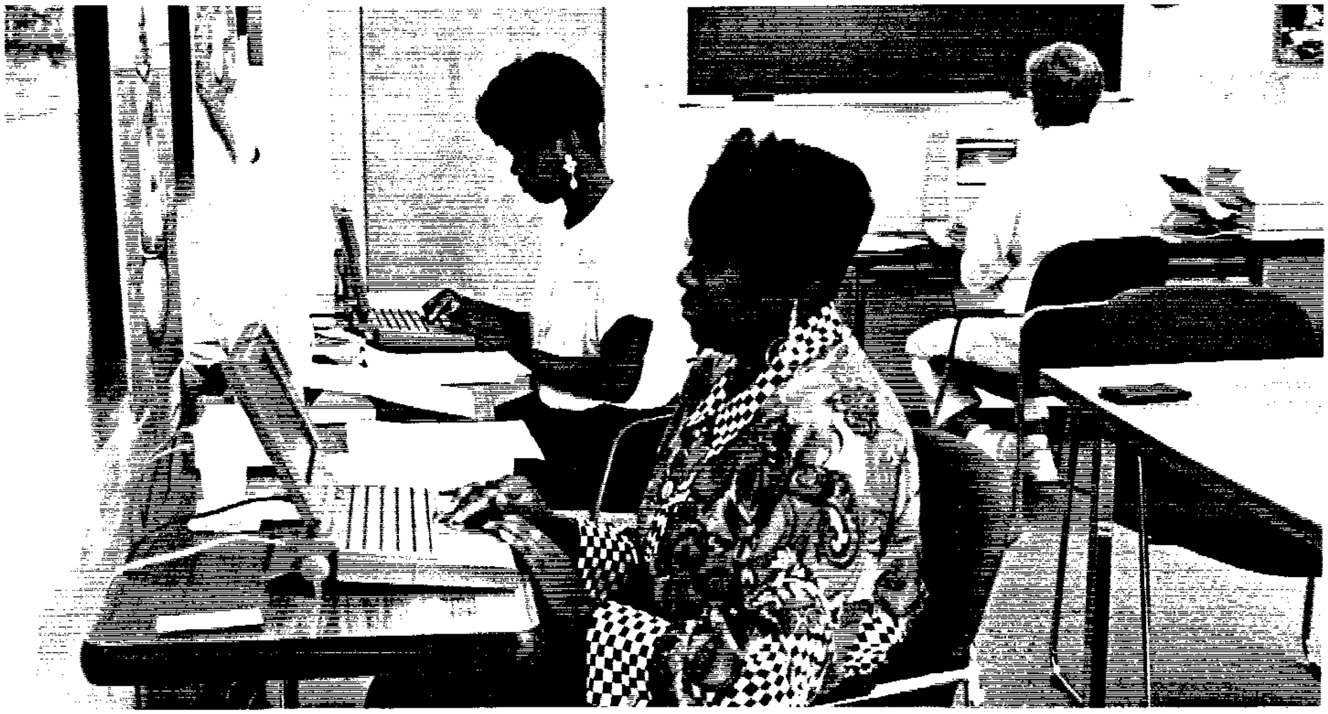

APPENDIX A

Description of Priority Ranking System

Participant decisions derived from the Nominal Group Technique used at Weston Institute Workshops are analyzed by a program designed to rank priorities in descending orders of importance. In addition to a numerical order of priority problem rankings, three other analyses are made from the information:

- The first is the total number of points assigned by the rankers. The maximum credit which can be given to a problem by an individual is ten. This continues in descending order to a one for the 10th problem ranked. All other problems are assigned by the software, a uniform penalty of zero. Thus the maximum number of points which could be assigned to a problem in this workshop with 18 participants is 180 (i.e, 10 x 18 = 180). The actual points assigned to a problem are listed in the following tables.

- The second category of analysis is the number of times a problem is picked.

- The third category of analysis is "Strength of Feeling" attached to a problem by participants. This is computed by dividing the actual points assigned, divided by the total number of possible points which could have been assigned if all participants had ranked the problem as their highest priority.

APPENDIX B

All Problems (28) Ranked by All Workshop Participants (18)

RANK	ABBREVIATED TITLE	TIMES PICKED/POINTS	STRENGT OF FEELI
1	Chemical Aspects of Transport and Fate	15/117	65.0%
2	Pathogen Indicators	15/105	58.3%
3	Conservative Tracers	14/81	45.0%
4	Virus Inactivation	11/70	38.9%
5	Modeling Pathogen Transpor	11/69	38.3%
6	Spatial and Temporal Variability	8/50	27.8%
7	Organic and Inorganic Compounds	8/49	27.2%
8	Testing Transport Models	8/47	26.1%
9	Indicator and Resistent Virus Data	7/41	22.8%
10	Pathogen Transport in Unsaturated Zone	9/40	22.2%
11	Saturated and Unsaturated Conditions	9/39	21.7%
12	Viral Capture Mechanisms	9/38	21.1%
13	Role of Risk Analysis	6/30	16.7%
14	Definition of Natural Disinfection	5/28	15.6%
15	Migration of Viruses	6/23	12.8%
16	Deterministic Models	4/22	12.2%
17	Humic Material Colloids	3/19	10.6%
18	Risk-Based Disinfection Strategies	4/17	9.4%
19	Pre-Qualifying Conditions	5/17	9.4%
20	Reclaimed Water for Recharge	4/15	8.3%
21	Cryptosporidium	4/14	7.8%
22	Equality of Pathogen Sources	4/13	7.2%
23	Expert System-Based Software	2/12	6.7%
24	Filters for Pathogen Removal	1/10	5.6%
25	Control of DBP's	1/9	5.0%
26	Institutional Barriers	5/9	5.0%
27	Composite Models	1/4	2.2%
28	Biofilm Growth	1/2	1.1%

APPENDIX C

All Problems (17) Ranked by Federal Government Participants (3)

RANK	ABBREVIATED TITLE	TIMES PICKED/POINTS	STRENGTH OF FEELING
1	Conservative Tracers	3/22	73.3%
2	Chemical Aspects of Transport and Fate	2/19	63.3%
3	Virus Inactivation	2/17	56.7%
4	Pathogen Indicators	2/14	46.7%
5	Testing Transport Models	3/13	43.3%
6	Spatial and Temporal Variability	2/13	43.3%
7	Expert System-Based Software	2/12	40.0%
8	Pathogens in Unsaturated Zones	2/11	36.7%
9	Indicator and Resistant Virus Data	1/9	30.0%
10	Viral Capture Mechanisms	2/9	30.0%
11	Migration of Viruses	2/8	26.7%
12	Deterministic Models	2/6	20.0%
13	Composite Models	1/4	13.3%
14	Prequalifying Conditions	1/3	10.0%
15	Role of Risk Analysis	1/2	6.7%
16	Equality of Pathogen Sources	1/2	6.7%
17	Modeling Pathogen Transport	1/1	3.3%

APPENDIX D

All Problems (21) Ranked by Water Utility Participants (5)

RANK	ABBREVIATED TITLE	TIMES PICKED/POINTS	STRENGT OF FEELI
1	Pathogen Indicators	5/43	86.0%
2	Organic and Inorganic Compounds	4/26	52.0%
3	Chemical Aspects of Transport and Fate	3/22	44.0%
4	Saturated vs Unsaturated Conditions	3/22	44.0%
5	Spatial and Temporal Variability	4/21	42.0%
6	Conservative Tracers	4/18	36.0%
7	Definition of Natural Disinfection	3/15	30.0%
8	Virus Inactivation	2/13	26.0%
9	Role of Risk Analysis	2/13	26.0%
10	Reclaimed Water for Recharge	2/12	24.0%
11	Testing Transport Models	2/11	22.0%
12	Indicator and Resistant Virus Data	1/10	20.0%
13	Risk-Based Disinfection Strategies	2/10	20.0%
14	Pathogens in Unsaturated Zones	2/9	18.0%
15	Modeling Pathogen Transport	2/8	16.0%
16	Pre-Qualifying Conditions	2/8	16.0%
17	Institutional Barriers	3/5	10.0%
18	Equality of Pathogen Sources	1/3	6.0%
19	Humic Material Colloids	1/2	4.0%
20	Biofilm Growth	1/2	4.0%
21	Viral Capture Mechanisms	1/2	4.0%

APPENDIX E

All Problems (25) Ranked by Research Participants (10)

RANK	ABBREVIATED TITLE	TIMES PICKED/POINTS	STRENGTH OF FEELING
1	Chemical Aspects of Transport and Fate	9/76	76.0%
2	Modeling Pathogen Transport	8/60	60.0%
3	Pathogen Indicators	8/48	48.0%
4	Conservative Tracers	7/41	41.0%
5	Virus Inactivation	7/40	40.0%
6	Viral Capture Mechanisms	6/27	27.0%
7	Testing Transport Models	3/23	23.0%
8	Organic and Inorganic Compounds	4/23	23.0%
9	Indicator and Resistant Virus Data	4/20	20.0%
10	Pathogens in Unsaturated Zones	5/20	20.0%
11	Humic Material Colloids	3/19	19.0%
12	Saturated vs Unsaturated Conditions	6/17	17.0%
13	Deterministic Models	2/16	16.0%
14	Spatial and Temporal Variability	2/16	16.0%
15	Role of Risk Analysis	3/15	15.0%
16	Migration of Viruses	4/15	15.0%
17	Cryptosporidium	4/14	14.0%
18	Definition of Natural Disinfection	2/13	13.0%
19	Filters for Pathogen Removal	1/10	10.0%
20	Control of DBP's	1/9	9.0%
21	Equality of Pathogen Sources	2/8	8.0%
22	Risk-Based Disinfection Strategies	2/7	7.05
23	Pre-Qualifying Conditions	2/6	6.0%
24	Institutional Barriers	2/4	4.0%
25	Reclaimed Water for Recharge	2/3	3.0%

NWRI National Water Research Insti
10500 Ellis Avenue, P.O. Box 20865, Fountain Valley, CA 92728-0865 (714) 378-3278 Fax (714) 37

May 20, 1992

Dear Participant:

Thank you for taking time from your busy schedule to participating in the Groundwater Disinfection Rule Workshop. The workshop will be held June 7-8 at the Virden Retreat Center at the University of Delaware located in the seaport town of Lewes, Delaware. The workshop will be facilitated by the National Water Research Institute and the Weston Institute.

This folder contains information which will help you 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 8:00 a.m. to 4:30 p.m. workshop 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. Reproduce the form so that you can use a separate sheet for each topic. You may propose as many topics as you wish.

If you have any questions prior to the meeting, please call me at (714) 378-3278.

I am looking forward to seeing you on June 7-8 and producing a useful report on the results of our workshop efforts. Thank you again for your interest and help.

Sincerely,

NATIONAL WATER RESEARCH INSTITUTE

Ronald B. Linsky
Executive Director

cc: Dr. Wm. Gaither, Weston Institute

APPENDIX G

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

Problem Identification Form
GROUNDWATER DISINFECTION WORKSHOP

Name:____

Organization:____

Workshop question: *What are the highest priority research problems needing to be solved in order to allow for the cost effective implementation of the 1995 Groundwater Disinfection Rule?*

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 H

<u>CONSOLIDATION WORKSHEET</u>

GROUNDWATER DISINFECTION RULE WORKSHOP

YOUR PROBLEM # ______________________________

OTHER PROBLEMS WHICH COULD

BE CONSOLIDATED WITH THIS ONE:

#__________ Originator ____________________

#__________ Originator ____________________

APPENDIX I

PROBLEM RANKING SHEET

GROUNDWATER DISINFECTION RULE WORKSHOP

(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)