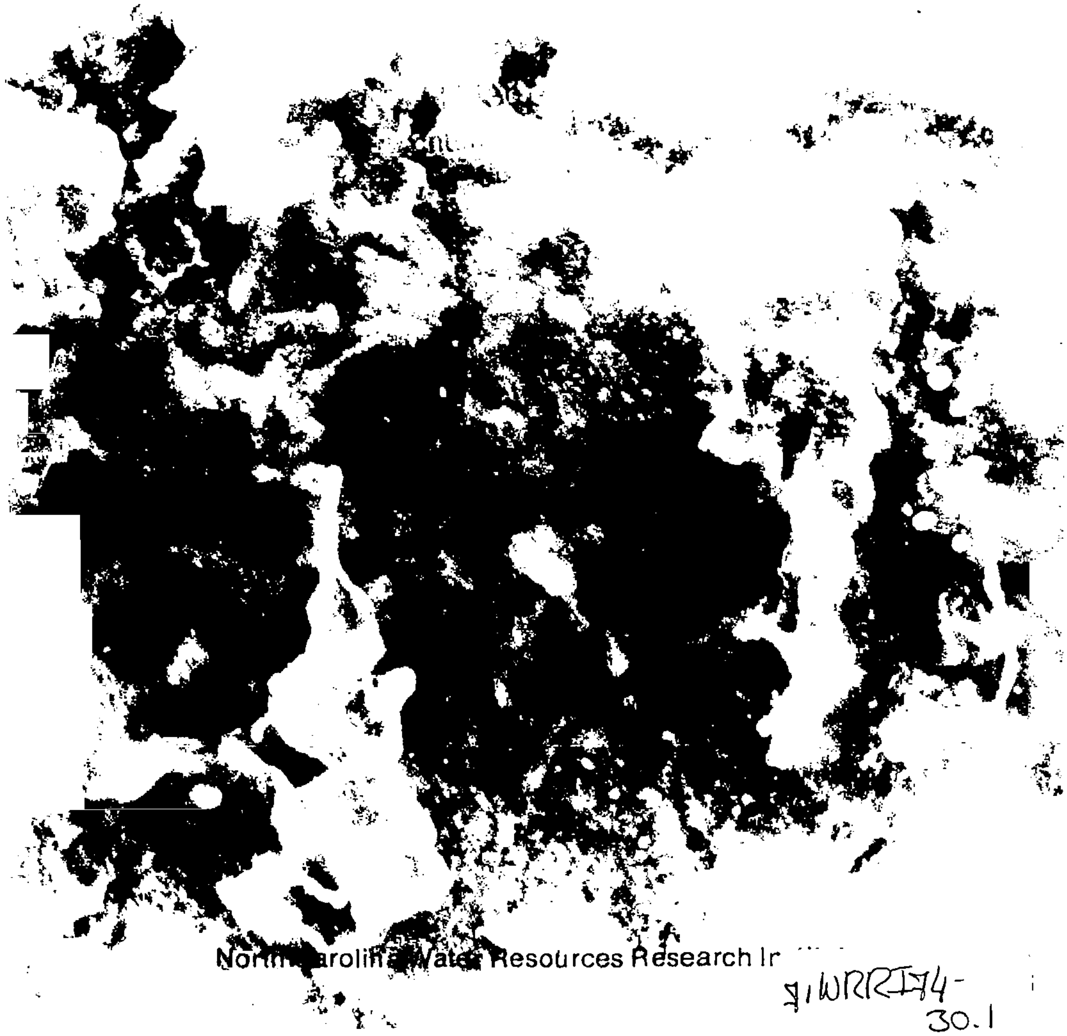
The proceedings of a national symposium on

The State of America's Drinking Water

North Carolina Research Triangle Universities
and the U.S. Environmental Protection Agency



North Carolina Water Resources Research Ir

Proceedings of National Symposia

1974 THE STATE OF AMERICA'S DRINKING WATER

1973 ULTIMATE DISPOSAL OF WASTEWATERS AND THEIR RESIDUALS

1972 COSTS OF WATER POLLUTION CONTROL

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These and subsequent Annual Symposia are successors to the Southern Water Resources and Pollution Control Conferences (1951-1971)

THE STATE OF AMERICA'S DRINKING WATER

National Symposium
September 26 and 27, 1974

Sponsored by the

RESEARCH TRIANGLE UNIVERSITIES
Duke University
North Carolina State University
University of North Carolina at Chapel Hill
U.S. ENVIRONMENTAL PROTECTION AGENCY

In cooperation with the

American Society of Civil Engineers
American Water Resources Association
American Water Works Association
Universities Council on Water Resources

Conference Secretariat

WATER RESOURCES RESEARCH INSTITUTE
OF THE UNIVERSITY OF NORTH CAROLINA
124 Riddick Building
North Carolina State University
Raleigh, North Carolina 27607

Edited by F. Eugene McJunkin

PREFACE

Many thoughtful observers of management, planning, design, operation, monitoring, and research in water supply and wastewater treatment have welcomed the increased public support and attention in recent years for their efforts. However this new interest has focused mainly on the discharge or wastewater end of our water systems with the intake or water supply end largely ignored - the outstanding success of America's water supply industry in reducing communicable diseases taken for granted - except perhaps for fluoridation.

Recognizing that the effluvia of an industrial society, especially its thousands of synthetic organic chemicals and its toxic metals, agricultural runoff carrying pesticides and agricultural chemicals, and even the storm runoff from urban streets, roofs, and yards may reach man through his drinking water, a dangerous fallacy has arisen: the best way to insure safe drinking water is through wastewater treatment. The reader of these *Proceedings* will find that approach woefully inadequate.

A second fallacy is that Americans have the world's best drinking water. Recent national and regional surveys show that water quality and its surveillance for too many systems fails to meet public standards. Further, many millions of space-age Americans, especially those living in rural America, have grossly inadequate drinking water.

While cholera and typhoid seem strange and remote to today's Americans, new concerns are rising over the possibility of health hazards to man from carcinogens and viruses in his drinking water. Evidence supporting these threats is sparse and inconclusive; however, the need for better knowledge and more research is fully apparent.

Although the Symposium was sponsored by the institutions shown on the title page, it is necessarily individuals who must plan, arrange, organize, and run such meetings and special acknowledgment must go to the Symposium Committee: Russell F. Christman, F. Eugene McJunkin, Daniel A. Okun, and Charles M. Weiss of The University of North Carolina at Chapel Hill; Charles Smallwood, Jr. of North Carolina State University; P. Aarne Vesilind of Duke University; and James H. McDermott of the Environmental Protection Agency. The Symposium enjoyed the cooperation of the American Society of Civil Engineers, represented by Ralph Stone; the American Water Resources Association, Harry E. LeGrand; the Universities Council on Water Resources, Ernest T. Smerdon; and the American Water Works Association, represented by Eric F. Johnson.

The Water Resources Research Institute of The University of North Carolina served as Secretariat for the Symposium. Its staff, David H. Howells, F. Eugene McJunkin, James M. Stewart, Linda Kiger, Eva McClung, Jennifer Jordan, and Rose Wilson, assisted by Mildred Weaver and JoAnn L. McJunkin, arranged and coordinated the program, registration, bookkeeping, printing, publication, physical arrangements, and all the other multitudinous details necessary to insure an orderly and successful Symposium.

With all due respect to the foregoing individuals, however, the success of the Symposium was largely due to the programmed speakers and to those who participated in the ensuing discussions, both within and outside the meeting rooms. Most of the discussions were tape recorded and are printed herein within the limitations of electronic transcription.

Selection of the Symposium theme and planning began in the spring of 1973. Its timeliness was accentuated by the passage of the Safe Drinking Water Act of 1974, signed into law by President Ford on December 17, 1974, ten weeks after the Symposium. Our hope is that these *Proceedings* will assist implementation and understanding of the objectives of the new Act.

F. Eugene McJunkin
Secretary for the Symposium

Chapel Hill, North Carolina
April 1975

TABLE OF CONTENTS

Opening Session

Luncheon

Health Relationships of Today's Water Supplies

Banquet

Water Supplies for Rural Areas and Small Communities

Luncheon

State of the Art of Water Supply

Symposium Summation

OPENING REMARKS

David H. Howells
Director
Water Resources Research Institute
of The University of North Carolina
Raleigh, North Carolina

Welcome to the National Symposium on Drinking Water. This symposium is jointly sponsored by the three Research Triangle Universities and the Environmental Protection Agency. The three universities are Duke University, North Carolina State University, and the University of North Carolina at Chapel Hill. A number of cooperating societies have also joined with us on a less formal basis. These include the American Society of Civil Engineers, the American Water Resources Association, the Universities Council on Water Resources, and the American Water Works Association.

Many of us here today, perhaps a considerable fraction, commenced our professional careers in one or another aspects of the environmental field back in the days when the principal concern with respect to water quality was health. Indeed, I think it's safe to say that the emphasis on health was so single-minded that the U. S. Public Health Service, which was the federal agency responsible for such things in those days, was severely criticized by the Congress for allegedly overlooking all other good uses of water such as fish and wildlife.

Then, in the process with which we are so painfully familiar, the pendulum began to swing to the other extreme where we find that health had been largely ignored. So we moved from a point where health was our dominant consideration to one today with which we are doing very little, particularly with respect to water.

Drinking water is undoubtedly the first ranking priority in water management; certainly, this is because of health considerations. Yet, drinking water has received too little attention on the national scene outside the realm of professional societies like the American Water Works Association.

Three recent actions created much of the interest behind this symposium. First, the proposed drinking water legislation which has been under consideration by the Congress for the past few years. The Safe Drinking Water Act suffered a major setback on September11 when the House Rules Committee unexpectedly deferred action until this next week. Mr. McDermott may tell us more about this. Of course, the Senate has already passed its version of the Act.

The second action is the proposed revision of the U. S. Public Health Service Drinking Water Standards. The last edition was

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**Note:* Professor Howells' remarks were transcribed from an electronic recording.

published in 1962 and has been under revision for many years. It is my understanding that the new standards are to be issued momentarily.

Third and last, the 1972 amendments to the Federal Water Pollution Control Act, particularly the sections dealing with planning, present new opportunities to deal more effectively with public water supplies in concert with water pollution control.

Professor McJunkin and his planning committee have put together a very fine program of high current interest. We hope that you will all find the symposium on this beautiful UNC campus and the charming community of Chapel Hill a most pleasant as well as a useful experience.

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Editor's Note: The Safe Drinking Water Act was signed by the President on December 17, 1974.

IMPACT OF THE SAFE DRINKING WATER ACT

James H. McDermott, P.E.
Director
Water Supply Division
Office of Water and Hazardous Materials
U. S. Environmental Protection Agency
Washington, D. C.

INTRODUCTION

*The Quest for Pure Water** began some 4000 years ago. Even the ancients recognized the acute effects of waterborne disease which the new sciences of epidemiology and bacteriology only began to catalogue during the last century.

Today, we recognize that the provision of safe drinking water involves more than a concern for just pathogenic bacteria and virus. There is growing concern about the more subtle, potentially toxic effects of inorganic as well as organic chemical agents. Public health workers, be they medical doctors, scientists or engineers, recognize the importance of constant vigilance in the application of the lessons taught by the history of our profession and concurrently analyzing and applying new information to control or otherwise mitigate the potential effects of waterborne chemicals upon this generation and future generations. The *quest* continues.

History gives ample evidence of the penalties paid by past civilizations which failed, through ignorance or neglect, to provide for the safety of their water systems. Modern history shows that such waterborne diseases as typhoid, dysentery, and cholera are controllable. In fact, they were all but eliminated in the United States by the 1930's by applying the principles identified in what are commonly referred to as the U. S. Public Health Service Drinking Water Standards.

Thus, it can be stated that the community water supply systems of this Nation serve more good safe drinking water to more people than any other nation of the world.

Why, then, is legislation currently pending before the Congress? What is the problem, and what are the major legislative provisions and impacts at the federal, state, and local levels?

While most American homes are blessed with an adequate supply of safe drinking water, many are not. Beginning with the National Community Water Supply Study of 1970, recent studies have suggested that we may have begun to backslide. Epidemiological evidence, as presented by Craun and McCabe, shows that the average annual number of waterborne outbreaks of biological etiology stopped falling around 1951 and may have even increased a little since that time. Indeed, studies have shown that an estimated 5,000 small systems,

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* Baker, M. N., American Water Works Association, 1949.

of an estimated total of 40,000 community systems, supply potentially dangerous water to 8 million people.

In addition to conventional community systems, it is worth noting that there are an estimated 200,000 self-supplied factories, shopping centers, restaurants, motels, parks, and resorts supplying drinking water on a regular basis to Americans both at work and at play. Further, it has been estimated that as many as 20 million Americans, inhabiting some 4 1/2 million dwellings do not have running water in the home.

During the last several years, deficiencies at the federal, state, and local level have been identified, catalogued, and analyzed by citizen groups, trade groups, professional organizations and government, including a recent report to the Congress by the General Accounting Office. Each of these groups has testified before the Congress during the last three years.

During this period, the legislative goals and objectives have remained the same, but the scope and mechanics of administration have increased.

During the current 93rd Congress, the Administration established a legislative priority for drinking water and introduced a proposed Safe Drinking Water Act.* The Senate passed its version of a drinking water act, S. 433, on June 25, 1973.

In the House of Representatives, the Subcommittee on Public Health and the Environment worked on water supply legislation throughout 1973 and then reported H. R. 13002 to the Full Committee earlier this year. Most recently, the House Full Committee on Interstate and Foreign Commerce gave major attention to the Subcommittee bill and then reported-out an amended version on June 20, 1974. Earlier this month, the House Rules Committee considered the bill and then deferred action until early October.

This series of events indicates that the legislative road is approaching a conclusion, if not in the current 93rd Congress, potentially in the 94th Congress next January. While many issues are still undergoing debate, it is appropriate that state regulators, utilities, and the Nation's universities convene meetings to consider the potential impact of this legislation and begin to assess and then implement their individual roles in the future.

Thus, meetings of this type jointly sponsored by the University of North Carolina, North Carolina State University, and Duke University are appropriate for at least two reasons:

> First, legislation is being considered because existing technology as codified in current Drinking Water Standards is not being uniformly applied. We must reassess our technology, with its proven capability in large cities and towns, with a view to its applicability to small systems.

**Editor's Note:* The Safe Drinking Water Act was signed by the President on December 17, 1974.

> Secondly, the professional community must establish research and development priorities with a view towards addressing immediate needs of the mid-70's, as well as future problem areas, including the health implications and safeguards required in the future era of reuse, renovation, and recycling.

GENERAL LEGISLATIVE CONSIDERATIONS

Let me start my discussion of the potential legislative impact on a reassuring note. EPA believes, and has testified on several occasions, that the identified drinking water quality problems of the Nation *do not* call for

> "changing the roles of Federal or State Government .... (but rather) by assuring the enforcement of National standards and by strengthening State and local programs."

Except for the scope of the standards and enforcement provisions, all bills under consideration by the Congress would reaffirm in law the well-established historical relationship between community water utilities, the universities, and government insofar as research, training, technical assistance, and standards setting and enforcement are concerned.

Further, EPA, as the advocates of the Administration bill, believes that the citizen has a role to play. The citizen pays either directly or indirectly for drinking water. He has a right to know what he is paying for. And, he has a responsibility to act and secure corrective action at the state and local level, and he will if someone would but inform him of current and/or potential problems and alternative solutions.

In this context, the Administration's bill is based in large measure on an evaluation of our federal experience with interstate carrier water supply programs involving definitive responsibilities at the local, state, and federal levels. Here, we can point to an institutional and technical model of accomplishment involving 650 interstate carrier watering points which, coincidentally (under current federal law), also serve a resident population of about 80 million people.

On the other hand, the Administration bill, and the Senate and House bills, have also drawn heavily on recent studies, the *Community Water Supply Study of 1970* involving numerous small systems and the series of State Program Evaluations that many of you are intimately aware of, including communities, semi-public and individual water systems.

Evaluation of the data collected in the last several years provides a simple profile describing underpar drinking water systems.

1. Inadequate collection and treatment facilities

2. Ill-trained and/or part-time employees
3. Poor operation and maintenance
4. Infrequent state or county inspections
5. Lower water rates (community systems)
6. Lack of public awareness

Why do these conditions exist in an environmentally conscious nation of the 1970's? To put it simply, in those instances where political, administrative, scientific, and engineering expertise have been brought to bear and augmented by public support, few problems are evident today. This is a general characteristic of large cities or mature communities, as typified by interstate carrier systems, which have confronted historic quality problems or growth problems.

But in all too many other instances, especially in smaller communities, the lack of a rallying point leads to apathy at the community leadership level in regard to the application of existing standards of good practice, and planning for the future.

DEFINITION OF PUBLIC WATER SUPPLIES

Against this perspective, the definition of the types of systems which may be covered by legislation is important. All bills cover

- not just large municipal systems
- not just the conventional community systems

but any system that regularly serves 10-15 service connections and/or 25-40 people. Thus, the proposed legislation potentially includes factories, condominiums, and resorts.

Further, a public water system would also be defined in S. 433 as one

> "which provides drinking water to carriers or *facilities or establishments* serving travelers in interstate commerce."

This means *not just* systems serving interstate carriers--airlines, trains, and buses--as in the past, but motels, restaurants, and parks.

As a consequence, except for individual household systems and those systems which qualify under an exclusion clause in H. R. 13002,* the vast majority of systems serving the traveling public

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*To qualify for an exemption, a system must qualify under all three of the following conditions:
(1) consist only of distribution and storage facilities; i.e., no collection and treatment facilities;
(2) obtain water from, but is not owned or operated by, a public system to which the regulations apply; and
(3) does not sell water to any person.

or residential communities would be covered by the regulatory provisions of the legislation.

DRINKING WATER STANDARDS

Federal Role

Now let's turn to the standards themselves, and the roles of federal, state, and local utilities, Table 1.

The legislation provides that the Administrator of EPA will establish *mandatory*, that is, primary drinking water standards. These would address all health-related limits for constituents of drinking water which:

> "may cause or transmit disease, chemical poisoning or other impairments to man."

As part of the primary health standards, the Administrator is also charged with specifying standards for the adequate monitoring and reporting of water quality. In addition to the primary recommended health standards, all bills call for the issuance of *recommended* secondary standards; i.e., aesthetic standards.

However, there are major differences between the Administration's bill and the Congressional bills. For instance, the current House and Senate bills would also require the issuance of regulations with respect to the operation and maintenance of public water supply systems. As noted above, the Administration limited the scope of its standards provisions to the establishment of constituent levels and the monitoring and reporting of quality. In addition, the House and Senate bills would require regulations covering site selection and construction of facilities with a view to mitigating the consequences of natural disasters. Moreover, the House and Senate bills provide for the establishment of a statutory advisory council to assist the Administrator in developing and implementing the standards.

State Impact

All bills make it quite clear that the states are intended to implement primary enforcement responsibility. The House and Senate bills, however, provide for direct federal enforcement of the primary standards as defined in these bills where states fail to provide adequate enforcement. On the other hand, the Administration bill specifically provides that EPA is to monitor activities "only to the extent necessary to determine if there is any adequate program to enforce the primary (Federal) standards." Federal enforcement in the Administration bill is limited only to monitoring, reporting, and public notification.

Encouraged by federal assistance and a legislative requirement that each state adopt standards that are no less stringent in scope and coverage than the federal standards, states are called upon to

Table 1

SAFE DRINKING WATER ACT OF 1974: DISTRIBUTION OF PRINCIPAL IMPLEMENTATION RESPONSIBILITIES

EPA	States	Utilities
- Define Program Dimensions	- Define State Programs	
- Establish Standards	- Prepare Required Plan	
- Evaluate State Programs and Plans*	- Adopt Standards	- Provide Water to Meet Standards
- Enforcement	- Specify Notification Regulations	- Provide Notification
- Technical Assistance	- Perform Monitoring and Surveillance & Report Quality	- Perform Required Monitoring and Report Quality
- Research and Special Studies	- Maintain Records and Report Files	- Make Improvements as Necessary
	- Provide Training and Technical Assistance	

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*Senate and House Bills

develop and implement well-rounded water supply programs. The organization designated by the Governor to implement the Act will be responsible for providing public water supply systems with technical assistance, training (Senate) enforcement where necessary, and planning assistance.

The states will find it necessary to conduct regular inspections of public water systems to establish conformance with state adopted drinking water standards. Further, under the Senate bill each state would be evaluated on a triennial basis, by EPA to establish the effectiveness of the state programs, just as the states are to evaluate the local water purveyor's program for conformance to the provisions of the state's standards.

Local Impact

The role of the local water utility will potentially involve not only compliance with the administrative and operational provisions of the states' standards, but also the regular collection and analysis of sufficient samples to evaluate drinking water quality relative to appropriate constituent limits. Further, depending upon which version of legislation passes and the regulations ultimately adopted at the federal and state levels, the utility or government agency will be responsible for advising the general public of standards violations.

PUBLIC NOTIFICATION

The Administration bill, and recently the House bill, call for federal issuance of regulations defining public notification with enforcement via state programs. The Senate bill provides that each state develop regulations governing public notification.

The numerous pressing community issues of our day, including schools, hospitals, energy, highways, the ever-present monetary problems, as well as the all too visible signs of air and water pollution, command attention. Pressed by these acknowledged issues, the community trusts that the stewards of our water supply systems, who are characterized nationally as the silent service, will alert them "when something goes wrong."

Public notification is a relatively new tool in water resource management. Fostered by both the environmentalists and the consumer advocates, it responds to the sentiment that just too much is happening in the use of the Nation's resources and in the preparation of consumer products that the consumer doesn't know about. A feeling of suspicion has developed with recent years regarding the true quality of many products, and the use of some of the Nation's resources in the production of these products. While the water supply industry has a relatively clean slate, should it expect a continued privileged status? Indeed, it is possible that a change in status is what is needed to overcome what Eric Johnson has referred to as the *Silent Service Syndrome*.

To put public notification within some context, let us look again at Table 1. The relationships between the EPA, the states and the utilities are depicted schematically here. An initial point to recognize is that EPA envisions little direct contact with individual utilities in the administration of this program. Under the Administration's bill, EPA's functions are restricted to establishment of national drinking water standards, for contaminant levels, and monitoring and reporting, to defining the program dimensions directed by the new legislation, to providing technical support in the development of the state programs needed to implement the new law, and to participating in enforcement actions, only with regard to public notification, monitoring and reporting if these are not adequately implemented by the state.

Once a state has begun to implement the standards promulgated consistent with the legislation, it will then proceed with independence to implement its own state program. This program will include state adoption of standards, including the specification of surveillance and monitoring requirements and procedures, the delineation of the mechanics of public notification procedures, and such other operational requirements or data and reporting needs as may be established.

The responsibility of the utility is straightforward. It must provide water which meets the standards. Its conformance with standards is established by a prescribed sampling and analytical system. Non-conformance, as specified within both the standards and the surveillance and monitoring procedures, triggers both corrective action and/or public notification. Failure in either of these latter two responsibilities may lead to selected public or individual legal actions.

If we focus now on public notification, Table 2 summarizes the key elements of this enforcement mechanism. Properly established in regulations, administered at the state level, and constructively implemented by the utility, it is a potentially viable substitute for both direct federal and state enforcement. Table 3 summarizes the division of responsibilities.

Full faith disclosure of problems that may occur, what the water supplier is doing or wants to do to achieve improvements, and what the customer (voter) may do to assist, are critical to any improvement program.

The public notification provision in its own right, or in conjunction with the citizen suit provision of the Administration bill and the Senate bill, should minimize the potential need for both state and federal enforcement action. From a technical standpoint all three bills, Administration, Senate, and House, can be interpreted to mean that it is in the supplier's self-interest to monitor quality changes which forewarn of developing conditions weeks or months in advance of the need to notify the public. When a spotty record occurs, the operator of a public water system will then seek state advice and assistance, enlist the support of consulting firms as necessary, and effect corrective action in advance of defined violation rather than wait to be told that he has a quality problem.

Table 2

PUBLIC NOTIFICATION - POTENTIAL ELEMENTS

1. What violations require notification?
   - a. Bad samples - Quality and frequency
   - b. Insufficient Sampling - repetitive and habitual

2. What types of notification are required?
   - a. Regular customer billings
   - b. Special customer mailings
   - c. Immediate public announcements
   - d. Could include corrective proposals

3. Consequences
   - a. Customer awareness and support
   - b. State/local participation
   - c. Plan for correction
   - d. Possible legal action

4. Who is involved?
   - a. Citizen
   - b. Utility
   - c. Locality
   - d. State
   - e. EPA

Table 3

PUBLIC NOTIFICATION - DIVISION OF RESPONSIBILITIES

1. EPA
   - General Notification Regulations
   - Coordination with Drinking Water Standards Provisions

2. STATE
   - Specific Operating Regulations
   - Dictates How & When to Notify
   - Follows up on Corrective Action
   - Gives Approval to Cease Reporting
   - Initiate Legal Action

3. UTILITY
   - Conduct Sampling & Analysis per Standards
   - Determines Deficiency as per Standards and Notifies per State Instructions
   - Takes Corrective Action per State Instructions

4. CUSTOMER
   - Fully Aware of Quality and Needs of the Utilities

SPECIAL STUDIES

In addition to the legislative proposals noted above, a most significant difference between the bills relates to the protection of underground sources of drinking water. A major section of the House bill would require EPA to promulgate underground injection control regulations to be enforced by the states with federal back-up. The Senate bill would only require EPA to conduct a study of the contamination of ground water resources which are utilized for the provision of drinking water.

The importance of ground water has definitely been established but the Administration does not recommend the comprehensive regulatory approach set out in the House bill. EPA had indicated that more experience is needed under the current authorities of the Federal Water Pollution Control Act. The realization that 50 percent of the Nation's population is dependent upon ground water has led both the Senate and the House to provide for a special study. A separate section in both the bill passed by the Senate and the bill pending in the House provide for a Rural Water Survey.

RESEARCH, TECHNICAL ASSISTANCE AND STUDIES

The bills also provide broad authority to provide technical assistance and to encourage and support drinking water research through grants and contracts. Acknowledging a federal responsibility in establishing standards, emphasis is placed on research and studies relating to the "cause, diagnosis, treatment, control, and prevention of physical and mental disease" of man and to the provision of a dependable supply of safe drinking water.

The three major bills include similar language. For instance, the Administration bill includes:

"1. New and improved methods to identify and measure the existence of contaminants in drinking water and to identify the source of such contaminants;

2. New and improved methods to identify and measure the health effects of contaminants in drinking water;

3. New methods of treating water to prepare it for drinking, to improve the efficiency of water treatment and to remove contaminants from the water;

4. Improved methods for providing a dependably safe supply of drinking water including improvements in water purification and distribution, and methods of assessing the health-related hazards to other characteristics of drinking water supplies; and studies of the health implications of the reclamation, reuse and recycling including both indirect and direct reuse wastewaters as sources of public water supplies."

TECHNOLOGY ASSESSMENT

There are two other provisions of the House bill that should be brought to your attention. First, the House bill provides by definition that for each contaminant which may have an adverse effect on human health, the Administrator must specify either

> a maximum contaminant level if it is economically and technologically feasible to measure the contaminant or
>
> each treatment technique which leads to a reduction of the contaminant, if measurement is not practical (on a routine basis).

Elsewhere in the bill, the Administrator would be required to publish in the *Federal Register* a list of contaminants for which recommended maximum limits cannot be established for lack of accurate measurement techniques, and his judgment of *required treatment* "to prevent known or anticipated adverse effects on the health of persons to the extent feasible."

In other words, The House bill would authorize treatment standards in those situations where lack of measurement techniques and/or firm health effects data would otherwise prevent the establishment and enforcement of a constituent standard.

In addition, the House bill would also require the Administrator to support a study by the National Academy of Sciences (or with another independent scientific organization). The study is to include an evaluation of primary constituent levels which are to be printed in the *Federal Register* within 90 days after the legislation becomes law. As part of this phase of the study, NAS would be directed to consider

a. the existence of groups or individuals in the population which are more susceptible to adverse effects than the normal healthy adult;

b. multi-media exposure;

c. synergistic effects from exposure or interaction by two or more contaminants; and

d. exposure and body burden which may alter physiological functions so as to increase the risk of illness.

Of particular importance is the fact that the proposed NAS study is also intended to recommend "studies and test protocols for future research on health effects . . . including a list of major research priorities and estimated costs necessary to conduct . . . priority research."

CONCLUSION

Collectively, the water supply profession has demonstrated the ability to supply most Americans with Safe drinking water. The future provides a new opportunity to expand the scope and level of service and performance based on current standards of good practice.

The immediate legislative challenge will be to extend and/or modify existing practice to apply to numerous small systems. The future also bodes well for bettering our knowledge of how to improve the quality and dependability of drinking water through research and development under the Safe Drinking Water Act.

So let us press on with implementation of existing technology today, while we concurrently begin to document research and development priorities so that we may assure future generations of Americans an adequate supply of safe drinking water.

QUESTIONS AND DISCUSSION

QUESTION: Can you summarize what the Safe Drinking Water Act is and what impact is expected on drinking water in the Nation?

MR. McDERMOTT: The current House bill is over sixty pages in length at the present time. You can make a career out of studying it.

But in a few words, it will be the first significant public health legislation passed in this country specific to drinking water. It will take us out of the current situation where many federal activities are hampered by a legislative provision that is explicit insofar as communicable disease is concerned to the neglect of the broad area of organic and inorganic chemicals. Further, it will establish requirements to assure that contemporary state drinking water standards are applied not only to large communities, but also to the small communities and many other semipublic small systems across the nation on a continuing basis.

QUESTION: (Mike Bell, Regional Engineer for the Division of Health Services in North Carolina) You mentioned something about the Senate version having information or wording pertaining to training of the utility people or the operators. Is this included in the House bill and to what extent will the federal legislation affect or assist in the training of our utility people?

MR. McDERMOTT: I singled out the Senate bill because in the report accompanying the Senate bill, specific recognition is given to the needs of the states to train their own state personnel as well as utility people as part of a well-rounded state program. Aside from that particular reference, the Senate and House bills include broad grant and contract provisions dealing with the training of personnel.

The legislation--it is quite broad and would accommodate both operator training and training of professionals including university training, thus recognizing the regulatory functions of state, federal and local agencies as well as the needs of consulting firms and the utilities.

QUESTION: Why has it taken the Congress so long to act?

MR. McDERMOTT: I think the Congress and the professionals who have testified before the Congress are to one extent or another analyzing their recent experiences with water pollution control and air pollution control legislation and asking themselves whether or not a similar legislative prescription is appropriate in establishing a legislative priority for drinking water.

As I see it, by definition or national consensus, there was a crisis in water pollution and a crisis in air pollution, and I believe many people are asking, "Do we have a crisis in water supply?"

I would say this--our studies have identified many violations of existing standards, but we have not said that there is a crisis.

As engineers and scientists, we all know that there's a safety factor built into the standards. So a violation doesn't mean imminent hazard. But what it tells us is that we're borrowing on equity, and you can't do that for very long and expect to avoid a crisis in the future.

We've got to do a better job today to prepare for the future, and I think what we're saying is we need a legislative base upon which to build. We are also saying, and few people seem to realize this, that we are trying to establish a new priority at the state level--a new priority recognizing the importance of the public health aspects of public water supply. You might think about that and establish in your own mind why it is that drinking water programs have gone downhill in the last few years and why it is that new priority is needed at the state and local levels.

QUESTION: Can you estimate the increased cost the utilities would bear as a result of this bill?

MR. McDERMOTT: We have answered this question at the request of the House Interstate and Foreign Commerce Committee for state programs and community systems.

We estimate that given a new priority at the state program level including technical assistance, training, and hopefully planning assistance with a view to regionalizing small systems into larger configurations, that the state program cost associated with community systems will rise from something like $10 million per year to upwards of $50 million per year. That would put more state people and county people out in the field to work with the local system both to identify problems and begin resolving them as quickly as possible. All too frequently the local utility man is not in a strong position to communicate with the local, political infrastructure for lack of technical experience or background. We see the state, or the county man, as the state's delegate, working with the utility man and with the local infrastructure to identify problems, the urgency for corrective action, and counseling all parties on effective means of accomplishing improvements.

At the local level we have estimated, and this is a rough estimate, that increased costs will be something in the order of $165 million per year, and most everybody gasps when they hear this number. Let's put that number in perspective.

The current annual receipts of the water works industry is estimated at $2.5 billion. Assuming there is little or no profit made on drinking water, these receipts are applied towards operation, maintenance, repairs, and expansions of existing systems. The depreciated value of existing systems is between $50 and $70 billion. If you look to the immediate future, it may well be necessary in the next 20 to 30 years to invest another $100 billion to repair and replace existing facilities which pump water if only to make sure that there's water in the fire hydrant if the fire bell should ring.

The issue is what is it worth to make sure that the bill-paying public receives the full benefits of past and future investment. What is it worth to make sure that the water is both safe and wet? Put all those numbers together, and you might draw the conclusion that the impact of the primary health constituent standards and monitoring to assure their implementation could mean perhaps an 8 to 10 percent increase on the average across the Nation in the community water bill. You may want to consider that as an insurance policy to make sure that the water is both safe and wet.

That's a long answer to what most people think of as a simple question. But while we are at it, let's go a step further and recognize the water bill as the cheapest utility bill we pay. If you read the House hearings, you will note a friendly conversation I had with Congressman Preyer of North Carolina where I noted that my water bill was substantially less per month than was my telephone bill, and I don't even have grown children. My children are still in grammar school. So think about that. What are the priorities of life, the life-support system? What are we investing in water supply to make sure the water is wet? What is an insurance policy worth to make sure that our drinking water is also safe?

QUESTION: (J. F. Green, Environmental Health Division in Charlotte) Is there a possibility which might result from this act of a decline or phasing out of small community water systems owned and operated by private utilities with increasing expansion and development of governmental systems in municipalities?

MR. McDERMOTT: Clearly, there has been a proliferation of small systems across this Nation in the last 15 years. I would fully expect that Dan Okun will discuss this issue this evening.

There were some 20,000 systems in 1963 when we last conducted a National community water supply inventory. Today, we are in the process of conducting another inventory and estimate there are 40,000 systems. Perhaps some systems were missed ten years ago, but most assuredly, a substantial number of small systems were added. These statistics are significant because our studies show that small systems are most likely to have deficiencies, probably because they cannot hire or retain competent operators.

To make a long story short, we would expect small systems to move into confederation, if not physically at least managementwise, with larger metropolitan systems.

I think this is going to be one of the major issues which state programs must confront. The states must work with the smaller communities to find out what is the best overall approach. In some instances, physical integration might be desirable. In other instances, separate community systems might be the best solution.

QUESTION: (Frank Reynolds, South Carolina Department of Health and Environmental Control) I want to know something about the funding provisions of the act. How much is put in it to go to states and how much for construction and solution of problems?

MR. McDERMOTT: Let me start with the question of construction funding. This is a public health bill, not a public works bill. There are no funds in this act to support construction grants. However, there is a small provision in the House bill which would guarantee loans not to exceed $10,000 where a small community is encountering difficulty in borrowing money.

Secondly, the administration's position has been opposed to state program grants to support or otherwise encourage the states to establish programs to implement the act. But the current Senate bill provides something like $5 million in the first year, and the House bill, which started with $5 million at the subcommittee, was raised to $15 million the first year and $25 million the second year by the full committee. This can be taken as their reaction to the needs of the states to implement a new program with a new program priority.

QUESTION: (Ken McElroy, Maryland Environmental Service) The State of Maryland has been encouraging EPA and the Congress to concentrate the federal efforts on the evaluation of the effectiveness of state programs and discourage the federal government from the specifying of regulations for operation, maintenance, planning, etc. It sounds from your remarks as if the Congress has moved somewhat further than the administration bill was originally proposed to include more specification and regulations for the various parts of the water supply management picture. Can you share with us what EPA has done to try to bring the Congress back to the original administration-proposed bill and perhaps share with us why you feel the Congress and its committees are so intent on specifying detailed regulations for the various aspects of the water supply program.

MR. McDERMOTT: I will not presume to tell you what the Congress does in its wisdom, or how they go about it or why they do what they do. They have held many hearings, and they have listened to many professional groups and individuals. EPA has testified in the Senate on at least three occasions and in the House on three or four occasions.

Perhaps all we can say is that the President has a responsibility to identify legislative needs. The House and Senate are largely a policy group. They translate need and testimony into legislative language.

I can assure you that EPA is taking advantage of every opportunity available to it to communicate with the House and Senate what its position is. I can only hope that others are doing the same thing. The important thing is that we can come up with a viable bill that we can all get behind and implement.

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THE DEVELOPMENT AND APPLICATION OF THE 1974 DRINKING WATER STANDARDS

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BACKGROUND

Water supply has a long and distinguished history in the United States. Beginning with the first piped water system for Boston in the 17th Century, the water supply industry has developed new sources of supply, built new systems, and planned successfully for the future growth of a vigorous, expanding country. Of considerably less age, drinking water standards have shared credit with the supplies for the past 60 years in the improvement of the quality of urban living and the defeat of the scourge of waterborne disease.

Drinking water standards in the United States are *Johnny-come-latelys* in the regulations authorized by the Quarantine Act of February 15, 1893. It was not until 19 years after the Act was passed that the first water supply related regulation was promulgated. It dealt with delivery rather than supply in that it prohibited the use of the common drinking cup on interstate conveyances. The first water quality standards were not promulgated until October 21, 1914, although a January 25, 1913, regulation had required that water used on conveyances be certified by state or local authorities to be incapable of conveying disease.

During FY 1914 approximately 9000 water sources for interstate carriers were registered, and it was estimated the list would contain 20,000 entries when it was completed. Apparently, train crews loaded water from any convenient source whenever it was needed, and these sources might be a well, spring, stream, etc. along the right-of-way which was favored by the conductor or other members of the crew. With enforcement of the Interstate Quarantine Regulations on water supply, the carriers consolidated their watering activities in a few watering points so that today approximately 700 water supplies serve the transportation industry. They concurrently serve almost 88 million residents or about one-half the population served by public supplies.

The water supply industry, whose performance country-wide is measured against the Drinking Water Standards, has achieved an enviable record. Craun and McCabe*(1) reported there were only 35 reported outbreaks of disease from community systems (an outbreak could involve as few as two persons) in the 10-year period 1961-70. These outbreaks resulted in almost 40,000 cases of disease. Considering that two outbreaks accounted for 32,000 cases and two more added another 4000 cases, the accomplishment of the industry is impressive.

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*Numbers in parentheses refer to correspondingly numbered items in the *References*.

Most waterborne disease outbreaks have biological etiologies, but a few are traceable to mineral constituents. The tremendous changes in our standard of living and the conveniences we accept as commonplace are the result of an explosion of applied technology. A by-product of these benefits has been an increasing deterioration of drinking water source quality due to the discharges of liquid wastes from increased population as well as from the industrial plants that produce the conveniences. With almost monotonous regularity, the scientific or popular press carries reports of the discovery of new insults to our bodies from these chemical by-products. They are often present only in microgram or even nanogram per liter quantities, and their effects are often reported to be discernible only after years of exposure. The disinfection of sewage with chlorine is under attack because of reported adverse effects on aquatic fauna and the possibility of the formation of organohalides (2) leading to questions about the safety of the practice for water supplies.

All this means that if the Drinking Water Standards are going to continue to protect human health, they must be continuously questioned, studied, and revised to cope with ambient conditions. The 1962 Standards were seven years old when the initial action was taken for their revision. A Technical Task Force was appointed in 1969 to review the Standards and prepare recommendation for their revision. Its job was completed in about two years, in time for the proposed revision to be submitted to a 14-member advisory committee appointed by the Administrator of EPA in September 1971. The Advisory Committee finished its review of the Task Force recommendations in September 1973 and submitted its report to the Administrator in December 1973. In the meantime, a Work Group had been appointed in EPA to review the Advisory Committee recommendations. The Work Group report has progressed to the point that it is being circulated to other government agencies for review as a last step prior to the publication in the *Federal Register* for formal public comment.

THE NEW "STANDARDS"

The Quarantine Act of 1893 restricts the regulations to those necessary to control the spread of communicable disease and, therefore, does not authorize the adoption of physical, chemical, or radiochemical standards. The drinking water legislation now before the Congress would authorize standards in three areas in addition to the biological standards. Several months ago the decision was made to proceed with the current Standards-setting process under the current authority. Thus, the package now approaching initial *Federal Register* publication has two parts. The Standards contain the bacteriological limits, the provision for the substitution of chlorine residual tests for coliform samples, and the turbidity limit. The guidelines contain the physical, chemical and radiochemical limits, appropriately identified as health or esthetic limits. If made necessary by enactment of new legislation prior to promulgation, the standards and guidelines can be repackaged as primary regulations (health standards) and secondary regulations (esthetic standards).

Users of the 1962 Drinking Water Standards will find relatively few changes in the proposed standards, although some of the changes will be important to some supplies. Differences between the 1962 Standards and the recommendations of the Task Forces, Advisory Committee, and Work Group are shown in Table 1. The proposed new standards that will have the greatest impact on the water supply utilities and the regulatory authorities are:

A. The reduction of the turbidity limit from 5 units to 1 unit and reclassification as a health-related constituent. The standard will allow turbidities up to 5 units if five conditions are met. The conditions are that the increased turbidity shall not

    (1) interfere with disinfection,

    (2) cause tastes and odors upon disinfection,

    (3) prevent the maintenance of an effective residual throughout the distribution system,

    (4) result in deposits in the distribution system, and

    (5) cause consumers to question the safety of the water.

B. The addition of a mercury standard of 2 micrograms per liter.

C. The addition of several pesticides for which monitoring will be required, and

D. The concept of radiation dose to replace the previous concentration of radioactivity in water.

Bacteriological Standards

The proposed Drinking Water Standards appear to be the result of natural evolution from the 1962 Standards. The changes are not great, and their effect on the utilities will be relatively small, except as the changed turbidity limit affects unfiltered surface supplies. In the microbiological area, the coliform limits are unchanged, and a table, derived from Figure 1 of the 1962 Drinking Water Standards, replaces Figure 1 to specify the minimum number of samples per month. The standard sample for the membrane filter technique will be doubled from 50 milliliters (ml) to 100 ml. This may, in effect, represent a slight tightening of that standard but the principal effect will be logistical. Some laboratories will have to purchase new sample bottles and shipping containers to have enough sample volume to meet the new standard.

A new bacterial count limit of 500 organisms per milliliter is introduced, but there is no fixed sampling schedule such as is

Table 1

CHANGES MADE TO 1962 PUBLIC HEALTH SERVICE DRINKING WATER STANDARDS

	1962	Task Force	Advisory Committee	Work Group
Bacterial Plate Count	--	500/ml		Include in Standards
Chlorine Residual Substitution	--	Allow in some cases		Standards
Turbidity	5 TU (rec.)	1 TU (Health)		Standards
Arsenic	0.05 mg/l (Mand.) 0.01 mg/l (Rec.)	0.1 mg/l (Health)		Guidelines (Health)
Fluoride	1.4 mg/l (79.3-90.5°)	1.1 mg/l (80-91°)		1.1 mg/l (79.3-90.5°)
	1.6 mg/l (70.7-79.2°)	1.2 mg/l (72-79°)	1.2 mg/l (>79°)	1.2 mg/l (70.7-79.2°)
	1.8 mg/l (63.9-70.6°)	1.4 mg/l (65-71°)	1.3 mg/l (66-79°)	1.4 mg/l (63.0-70.6°)
	2.0 mg/l (58.4-63.8°)	1.5 mg/l (59-64°)	1.5 mg/l (<66°)	1.5 mg/l (58.4-63.8°)
	2.2 mg/l (53.8-58.3°)	1.7 mg/l (55-58°)		1.7 mg/l (53.8-58.3°)
	2.4 mg/l (50.0-53.7°)	1.8 mg/l (50-54°)		1.8 mg/l (50.0-53.7°)
Mercury	--	0.005 mg/l (Health)	0.002 mg/l (Health)	Guidelines (Health)
Odor	T.O.N. 3 (Rec.)	T.O.N. 2 (Esthetics)	T.O.N. 3 (Esthetics)	Guidelines (Esthetics)
Organics				
Carbon Alcohol Extract	--	1.5 mg/l (Health)	3.0 mg/l* (Health)	Deleted
Carbon Chloroform Extract	0.2 mg/l (Rec.)	0.3 mg/l (Health)	0.7 mg/l* (Health)	Guidelines (Health)
Pesticides	--			
Chlorinated Hydrocarbon				
Insecticides				
Aldrin		0.01 mg/l	0.001 mg/l	
Aldrin + Dieldrin		0.01	--	--

(continued)

Table 1 (continued)

	1962	Task Force	Advisory Committee	Work Group
Chlordane		0.01	0.003	3 Guidelines (Health)
DDT		0.1	0.05	
Dieldrin		0.01 (Health)	0.001 (Health)	
Endrin		0.003 (Health)	0.0005 (Health)	0.2 Guidelines (Health)
Haptachlor		0.02 (Health)	--	--
Hept. Epox.		0.02 (Health)	0.0001 (Health)	0.1 Guidelines (Health)
Hept. + H.E.		0.02 (Health)	--	--
Lindane		0.1 (Health)	0.005 (Health)	5 Guidelines (Health)
Methoxychlor		0.5	0.1	100 " "
Toxaphene		0.1	0.005	5 " "
Organophosphate Insecticides	--	0.1 mg/l as Parathion (based on enz. inhib.)		0.1 mg/l as Marathion (based on organic P)
Chlorophenoxy Herbicides				
2,4-D		1 mg/l	0.02 mg/l	0.1 mg/l Guidelines(Hlth.)
2,4,5-T		0.005	deleted	
2,4,5-TP		0.2	0.03	Guidelines (Health)
Phenols	0.001 (Rec.)	Deleted		
Sodium	--	270 mg/l (Health)	Deleted	
Total Dissolved Solids	500 mg/l (Rec.)	Deleted		
Radioactivity				
Radium 226	3 μμc/l (Rec.)	1 μμc/l (Health)		5 μμc/l Guidelines(Hlth.)
Strontium 90	10 μμc/l (Rec.)	10 μμc/l (Health)		Aggregate alpha-
Gross beta	1000 μμc/l (Man.)	10 μμc/l (Health)		3000 organ-rem/yr.
Gross alpha		1 μμc/l (Health)		15 μμc/l
				Aggregate beta- 1500 man-rem/yr.

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*Represents improved extraction methodology rather than a raised limit.

specified for coliform. The Standards will provide only that the frequency of sampling and number and location of sampling points will be jointly agreed to by the utility and the regulatory agencies. The bacterial plate count can provide the operator valuable information on the efficiency of treatment and the degree of quality deterioration in the distribution system. Operators with their own laboratories should find the plate count a welcome additional quality control test.

Chlorine Residual

Data from various studies, including the Community Water Supply Study (3), were evaluated to determine the relationship between chlorine residual and bacteriological quality, as indicated by the coliform and the bacterial plate count examinations. It was concluded that residuals of 0.3 milligrams per liter (mg/l) of free chlorine in the system would result in samples that met both bacteriological parameters. This information, together with (1) an appreciation that bacteriological examinations are not free, (2) they take enough time that they provide only *post facto* information on bacterial quality, (3) are not useful as operating quality control tests, and (4) are generally not performed with sufficient frequency to provide a satisfactory historical record of accomplishment, has resulted in the inclusion of chlorine residual tests as a substitute for coliform examinations. There are conditions that must be met, but the Standards will allow the substitution for up to 75 percent of the coliform samples by supplies serving more than 5000 persons and substitution for 100 percent of the coliform samples by supplies serving 5000 persons or less. It is expected that the determination of chlorine residual from 2 to 6 times every day, together with turbidities of 1 unit or less, will provide more health protection than poorly controlled disinfection coupled with 2 to 6 bacteriological samples per month.

These are changes that will require utility personnel and regulatory agency personnel to change some of their practices; but, except for the effect of the turbidity limit on a few filtered supplies and probably most unfiltered surface supplies, their impact should be a favorable one.

Viruses

The new standards will not include a virus standard. It is well recognized that many raw water sources are polluted with enteric viruses and the water supplies derived from them depend entirely on treatment processes to remove them from drinking water. Even if the processes are completely effective when properly operated, breakdowns to occur and some plants' operations are marginal. This indicates a need for a virus standard because it might be expected that viruses are present in finished drinking water from time to time. With virological techniques rapidly being perfected to the point where they can be used to routinely monitor finished water quality, a standard may soon be forthcoming.

Except for the problem of viruses in water, the microbiological standards are fairly straightforward and based on standards and practices that have been demonstrated to be satisfactory and to provide a high degree of public health protection. The development of chemical and radiochemical standards has not always been so easy. The deliberations leading to the present recommendations have sometimes seemed to raise more questions than they answered.

Trace Substances

Refinement of techniques to measure small quantities of material has revealed constituents in water where we previously believed them to be absent. Parallel advances in observing health effects of traces of materials in test animals have complicated the standards development process.

Several years ago, there was intense public interest in the use of DDT with its subsequent appearance in water because DDT was believed to cause fragile shells in eggs of birds-of-prey with a resulting decline in their populations. Man was held to be intervening in the delicate balance of nature, and there was much debate over whether the benefits of artificial insect control outweighed the upset in the birds-of-prey balance. Many researchers reported the presence of DDT in the fat of animals, but there were no reports of adverse effects on humans. A DDT limit was developed and proposed based on chronic toxicity. The limit was calculated primarily on the basis of the extrapolated human intake that would be equivalent to that causing minimal toxic effects in rats and dogs. Data from human and animal investigations were used to develop the standards by adjusting for factors that influence toxicity such as inter- and intra-species variability, length of exposure, and extensiveness of studies. Safety factors were applied and an allowance was made for exposure from other media, such as food. This procedure was followed in setting all limits based on toxicity. But at the present time, no DDT limit is being proposed.

Based on experiments with rats and mice, there is evidence that DDT, aldrin, and dieldrin are potential human carcinogens. The development of a standard based on carcinogenisis is different from the development of one based on toxicity. In toxicity studies, the object is to establish the intake level that just has an effect on the human body. The standard is then set somewhat below that level to provide a margin of safety to protect the extra sensitive individual, to allow for experimental error and to allow for some failure to meet the standard by some water utilities.

On the other hand, chemicals that are carcinogenic do not have a *safe* or threshold level. Any quantity of the chemical must be considered to be harmful, and the process of standard setting thus becomes a process of balancing risk, occurrence of the chemical in water, and the economics of removing it from water.

What is an acceptable risk? Is it one in 10 thousand, one in 100 thousand, one in a million? If the cancer produced is relatively obvious and easy to cure, such as skin cancer, or invariably fatal, such as angiosarcoma of the liver, should this make a difference in the risk considered to be acceptable? Does the population exposed influence the acceptable risk? A risk of 1 per 100 thousand represents one cancer each century in a town of 1000, but it represents 80 per year in New York City. Should the standard be different for Crossroadsville and Mega City? After these questions have been answered how do you calculate back from experimental data to get the value for the standard? Several methods are available; but as if there were not complication enough, it is possible to get different answers from different people using the same data and method.

These are some of the questions that have been asked and debated during the development of the revised Standards. For aldrin, dieldrin, and DDT, the draft Standards now circulating have no proposed limits because they will be derived later by estimating the health risk associated with various concentrations and a comparison of the calculated concentrations with ambient levels to permit an assessment of the attainability of a limit using present day technology. This process is temporarily stopped by the non-availability of data on ambient levels. The pesticides data from the Community Water Supply Study are questionable, and the only other record is the 1969 Federal Water Pollution Control Administration Report on *Pesticides in Surface Waters of the United States--A Five-Year Summary (1964-1968)*. No definite conclusions can be reached on ambient levels in drinking water from these data. Therefore, EPA has planned and is ready to implement a survey of water supplies that will permit an estimate of current pesticide levels in drinking water to be made. It is planned that the survey be completed and the data be available within about 18 months.

Radioactive Substances

In setting the standards for radioactive constituents, the Work Group has accepted the recommendations of the EPA Office of Radiation Programs which introduce the concept of aggregate dose as a feature of the Standards. To apply such a standard, it is expressed in terms of dose. For Radium 226, other alpha particle emitters, and Radium 228, the standard is that the aggregate dose received by the customers of the supply shall not exceed 3000 organ-rem per year and that in no case shall the average Radium 226 and/or Radium 228 activity exceed 5 picocuries (pCi)/liter nor the gross alpha particle activity, including Radium 226, exceed 15 pCi/liter. The text states that the limiting concentrations of Radium 226 and Radium 228 should result in bone surface doses no

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Editor's Note: The curie (Ci) is the unit of radioactivity. It is the rate of decay in terms of disintegrations of the radium nuclei in one gram of radium per second; i.e., 3.70 x 10^{10} disintegrations per second. A picocurie (pCi) is one trillionth or 10^{-12} Ci. The rem (roentgen equivalent in man or mammal) is a quantitative measure of the biological effect of absorbed radiation.

larger than 60 organ-millirem per year. Thus, the standard could be read that the aggregate dose shall not exceed 3,000 organ-rem per year and in no case shall the individual dose exceed 60 organ-millirem per year. The standard then becomes one of an allowable individual dose of 60 millirem per year per person in populations up to 50,000. As population increases beyond 50,000, the allowable dose decreases until it reaches 6 millirem per year in populations of 500,000 or greater. A similar approach is used for Beta particle and photon activity from artificial radionuclides. The guidelines contain tables and numerical examples for calculating the aggregate dose from two or more radionuclides.

Impact on the industry

What will the effect of the new Standards and Guidelines be on the water utilities and on the regulatory agencies of the States? The numbers defining maximum allowable concentrations are not significantly changed from those in the 1962 Standards or those of guidelines that have been developed since 1962. It is possible to discuss the overall effects of the new Standards and Guidelines with some degree of certainty, but it is not possible to generalize on the effects on utilities vis-a-vis the effects on regulatory agencies because the states have different operating procedures defining who is responsible for what phase of surveillance and monitoring. Therefore, considering the utilities and the regulatory agencies as a whole to be the water supply industry, the effects can be generalized as follows.

The Standards re-emphasize the need to evaluate alternative sources and to select the one that presents the minimum risk of contamination by wastewaters with impurities that may be hazardous to health. Surveys of sources, treatment, and distribution facilities should be regularly made to identify health hazard and allow planning for their elimination or reduction. Water supply facilities should be designed, built, and operated in such a way that there is a high degree of capability and reliability to effect compliance with the quality standards. None of this is new. These concepts are contained in the 1962 Standards, and their effect on the industry will depend upon the existing degree of compliance compared to compliance in the future. The content and provisions of federal drinking water legislation when it is enacted will impact more on these provisions than will the new standards.

The familiar Figure 1 of the 1962 Standards will be replaced by tables based on the curve to eliminate the uncertainty over the number of bacteriological samples required to be examined. Depending on how the curve has been read, there may be some minor changes in the number of samples to be examined from any supply, but these should be minor and for the industry as a whole, there will be no effect. On the other hand, the possible substitution of chlorine residual for the coliform sample has the potential of reducing laboratory loads substantially. For example, it has been estimated the median size supply serves 5,000 persons. The number of samples required per month varies from 2 for those serving 2,500 or less to 6 for those serving 5,000. Assuming the average number of samples required is 3 per month and that half the supplies will utilize the substitution provisions, the bacteriological laboratory load would be reduced by 30,000 samples per month.

The turbidity standard will ultimately result in the construction and operation of filtration plants for all surface supplied systems. Since many of the larger systems do not now have filtration, the potential capital investment and operation costs are in the millions of dollars. These costs should be viewed in terms of their effect on the individual household monthly water bill. This has been estimated to be about 25 cents per month per capita. It has been pointed out that in communities where water supply revenues in excess of operating costs are paid into the general fund, that the use of revenue to finance new facilities represents an increase in taxes. Thus, the turbidity limit will impose additional costs on the users of some systems, either as an increased water bill or as increased local taxes.

At this time, the effects of the physical, chemical, and radiochemical limits will generally be small. Based on the limited national data available, few supplies will fail to meet the new guidelines; and when they do fail, they fail to meet esthetic limits. Enforcement of the guidelines by the states may not have an appreciable effect on the need for treatment facilities but will have a substantial effect on the laboratory work to be done. Data from the interstate carrier program (4) show that chemical analyses are not being uniformly performed across the country. The addition of mercury and nine pesticides plus the sometime need for analyses for specific radionuclides will increase the laboratory work load. The passage of the drinking water legislation will probably result in more, not less, chemical analyses.

The pending legislation will have far-reaching effects on the water supply industry. All water supplies covered by the legislation, perhaps as many as 240,000, will have to meet primary regulations. The regulations themselves will be updated regularly, the first time after a two-year National Academy of Sciences study of the interim regulations. The legislation provides for treatment standards in place of maximum allowable concentration limits under certain circumstances. The anticipated inclusion of standards for known carcinogens will require the industry to seek the development of new treatment methods. The conventional chemical precipitation/filtration/chlorination process will not be adequate to solve the anticipated problems.

In reviewing the impact of the legislation on 40,000 *conventional* water systems plus an additional 200,000 *other* systems that serve the traveling public, it was obviously not realistic to plan for the complete analysis of water from each surface supply annually from each ground water supply triennially, although it should be noted that such a schedule is substantially less than that required by the 1962 Standards which provide for semi-annual analyses with more frequent analyses if there is some presumption of unfitness due to the presence of undesirable constituents. Estimates of the impact of the primary regulations required by the legislation were based on, among other schemes, a sampling schedule that would require in the first year the complete analysis of samples from all surface supplies plus samples from the larger ground water supplies. During the second and third years, initial analyses of samples from the self-supplied *other* supplies obtained from the ground would be made. In total, an estimated 240,000 complete analyses would be performed over a seven-year period. Superimposed on this work load, beginning with the second year would be an annual *partial* analysis for surface water supplies and triennial *partial* analysis for ground water supplies where for any water supply the *partial* analysis would include only those constituents shown to be present in concentrations equal to or greater than 50 percent of the limit established in the regulations or which a sanitary survey had shown might be present in the water supply. This scheme, while requiring substantially less chemical analyses than a straight annual/triennial complete analysis, will still result in a substantial increase in the chemical laboratory work load of the industry. Every addition of a constituent to the drinking water standards will increase the effect.

CONCLUSION

Without being a treatise on any aspect of the Drinking Water Standards, this report has endeavored to present some of the history behind the present revision of the 1962 Drinking Water Standards, some of the questions that have been considered and how they have been resolved, and some observations of their potential effect on the water supply industry of the United States. It is obvious that some of the answers are interim in nature and that much additional research must be done on health effects and on treatment technology before standards can be developed that we can be reasonably certain protect human health adequately on a long-term basis.

REFERENCES CITED

1. Craun, Gunther F. and Leland J. McCabe (1973), "Review of the Causes of Waterborne Disease," *Jour. Amer. Water Works Assn.*, 65, 74-84.

2. Rook, J. J. (1974), "Formation of Haloforms During Chlorination of Natural Waters," *Water Treatment and Examination*, 23, Part 2, 234-243. (The Society for Water Treatment and Examination, Great Britain).

3. McCabe, Leland J., *et al.*, (1970), "Survey of Community Water Supply Systems," *Jour. Amer. Water Wks. Assn.*, 65, 670-687.

4. U. S. Environmental Protection Agency (1973), "Chemical Analyses of Interstate Carrier Water Systems," Washington, D. C.

QUESTIONS AND DISCUSSION

QUESTION: If pesticides or some of the pesticides are known to produce these bad effects and if the goal of the standards is to protect the water supplies, what is the reason for not setting the standards until further studies are made? That would seem to throw protection to the winds until we study it some more.

MR. LEE: Nine pesticides are scheduled to be included in the drinking water standards so there will be protection from at least nine more substances than were covered under the 1962 standards. In reference to the three that are omitted, aldrin, dieldrin, and DDT, the reason they are not included is that we don't know where to set the limits until we have more data. These three pesticides are possible carcinogens; and since there is a general feeling that no level of a carcinogen can be called *safe*, we have to find some basis for setting a limit. The basis we propose to use is to first find out how much of these pesticides are present in drinking water, then set the limit as low as we can without imposing undue economic hardship on water suppliers or communities. This way we can balance risk against cost. While it may seem that "protection is being thrown to the winds" until we establish limits, we are trying to get the necessary data as rapidly as possible; and since the standards will not be promulgated for some time yet, it is our hope that we will have the data and will establish limits by the time the standards go into effect.

QUESTION: (Mark Sobsey, UNC-CH) The whole question of toxic substances in water brings us to the problem of assay or detection methods for materials, not just three or perhaps a handful of pesticides, but a large variety of other chemical compounds that may be present in trace quantities in water and may also be toxic. Can you tell us what you know is being done in the way of the development of other kinds of assay methods for such substances, not specific ones but for the aggregate testing of materials that may be in water, any kind of biological assays that may be available?

MR. LEE: The development of new analytical methods is handled in another part of EPA, and my personal knowledge is only that these problems are being worked on. Specifically, what direction is being taken and how rapidly the work is progressing, I don't know, and I just can't comment.

QUESTION: (Frank Bell, EPA Water Supply Program) I wanted to ask something that Roger can confirm or not, but I think it will be useful for perhaps many of the people here. The question before us is not one that we have a proven cancer-producing potential in man. This is all extrapolated from animal experiments and so it's a suspected kind of a possibility. When we say we have a level of one in a million or something, that's strictly an extrapolated figure so we don't know that we're getting it. I think that's a fact of the case and also would clarify perhaps how they come out with the final figure on that. Is that right?

ANSWER FROM SOMEONE IN THE AUDIENCE: I think that's the point with the business of protection, whether there's some reason to be scared. This stuff bothers rats or dogs, and we don't have any hard line data on what concentration knocks people over; but there is some concern, and that's what the protection would seem to be all about. I think that's what the insurance value that was mentioned by both these speakers means. Just how much trouble do we want to go to to protect since we suspect there's a problem. The alternative is to wait until something bad happens and we have real data. Then, we have a very easy administrative way to handle the limits, but it's a heck of a price to pay.

QUESTION: (Jim Lamb, UNC-CH) You mentioned, as I recall, the number of samples or frequency of sampling would remain essentially the same for the country as a whole. Was this the rationale for this study actually or was it just something which carried over without change from the preceding standards?

MR. LEE: It carried over from the 1962 standards. It isn't something that we did without some consideration. The matter of bacteriological sampling frequency, and chemical sampling frequency received a great deal of discussion at all three levels of development of the standards by the technical task force beginning in 1969, by the advisory committee, and also by the working group that just recently finished its work on the standards. The consensus seemed to be that the basis for Figure 1 in the 1962 PHS standards is a pretty vague thing. We don't know what the rationale is or was. We do know, historically, that if water supplies are sampled at this frequency and if they meet the drinking water standards, then save for the experience in Riverside, California, ten years ago, public health appears to be adequately protected. We didn't feel there was any basis for making a change. We had no data to indicate what new sampling frequency should be adopted. To make a change just to make a change didn't seem to us to be an improvement. So we elected to stay with what we have.

QUESTION: (Herbert Swenson) Concurrent with the interest in revising 1962 standards, is there also interest to your knowledge in taking a fresh look and revision of the international standards on drinking water?

MR. LEE: I have no information on that at all. As far as I know, there is none. It has not been discussed to the best of my knowledge.

COMMENT: (Russell Christman, UNC-CH) I don't know if any of you attended the Gordon Research Conference or how many of you were at the one in New Hampshire in July and talking about drinking water and things in it to be worried about. A man there was reporting on the use of gas chromatography-mass spectrometer, computer-linked systems as a very high-powered, very expensive way of detecting chemicals, and they've done this for drinking water. They've done it for the City of New Orleans' drinking water, and he showed what they found in it. There were several hundred people in the room gasping when he showed the slides of organic chemical compounds that the computer had identified in the drinking water. It leads you to suspect that there's probably some concentration in almost everything in the water, and as Roger said, the closer you look the more you're going to find. Setting standards for that list that was shown in the slide would be an enormous undertaking.

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NEW ENVIRONMENTAL HEALTH PROBLEMS IN WATER SUPPLY

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INTRODUCTION

I want to talk to you this afternoon about certain problems, as I see them, in environmental health, particularly the problems related to the water supply. I come to this meeting as a scientist particularly concerned about human health, and concerned about the toxic effects of chemicals. And it is on this subset of the many problems involved in water supply and its purity that I shall focus. I propose to suggest a series of problems, but then do not propose to bring forth a series of solutions like rabbits out of a hat. The concerns that I shall be talking about in the next few minutes, it seems to me, have no ready solutions, but must be concerns of all of us.

BACKGROUND

Let us first start out with some considerations of the chemical process industry. It has been estimated, and I think quite reliably, that between 500 and 1000 new chemicals are introduced into commerce every year; and these are added to approximately 10,000 chemicals that are presently produced, distributed, sold into commerce, and used in the United States. In addition to these end-product chemicals, there are many intermediates and by-products involved in the manufacture and disposal of such chemical entities. I think it is clear that it is inevitable that many of these chemicals are bound to find their way into the water supply and end up very possibly in the drinking water of the citizens of the United States.

Now this, as I indicated, is a result of the chemical process industry which has had a literally astronomical growth since the late 1930's and the early 1940's. This was signaled, I suspect we all remember--or most of us remember, by the slogen of "better things for a better life through chemistry." This, it seems to me, was really the second industrial revolution that occurred in the United States and the other developed countries; and in many ways it was significantly different from the first industrial revolution which probably caused the first serious pollution problems in the developed areas.

The first industrial revolution was primarily concerned with remaking, reshaping, and reworking existing materials in such a way that very little new was produced or added; and problems certainly were created--smoke, SO_x, etc.; but they were not problems of new

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**Editor's Note:* Dr. Rall was the luncheon speaker on Thursday, September 26.

and unique chemical compounds. By contrast, the second industrial revolution is based on the synthesis of totally new and novel chemicals--chemicals that man has never been exposed to before--and many of which have a potential for a vast array of toxic effects.

Now in light of this impressive number of new chemicals and existing chemicals in our commercial universe, let me suggest certain areas which we must be concerned about. First, we don't know what these compounds are, what the production volumes are, how they are produced, and where they are produced. There is no systematic mechanism for identifying newly produced compounds. The recent losses among the poultry and cattle industry in Michigan clearly illustrate this problem. Michigan farmers began to report that their poultry and livestock were ill and dying of a peculiar unrecognized disease. It was then appreciated that this appeared to be associated with brominated biphenyls which were present in the carcasses of these animals. The source of these brominated biphenyls was initially totally obscure. It was not known that such compounds were being made commercially. It was finally discovered that a small chemical manufacturing company had mistakenly shipped a new fire retardant (which they had just started producing) in bags which were labeled as some sort of food additive for the livestock and poultry. This fire retardant, which was to be added to plastics to make them less flammable, turned out to be a brominated biphenyl which accumulates very significantly in mammalian and avian systems and which is quite toxic. It had not been known that the brominated biphenyls were produced to be used as a fire retardant and were being used in commerce. The net result of this, fortunately, is that there has been no human health damage but the loss of many hundreds of heads of livestock and literally hundreds of thousands of chickens.

Secondly, there is no systematic mechanism to know the process by which these new chemicals are produced; and therefore, the intermediates and by-products which may appear in the environment. I think we are all reminded of the story of the halo ethers which have appeared in the Ohio River water, in the Rhine River water and a variety of other rivers which pass through major industrial areas. These halo ethers are a by-product of the manufacture of ethylene and appear in many instances to be discharged by the plant into the nearest available discharge system. The toxicity of some of the specific halo ethers that have been discovered in these river waters is not well understood. But what is clearly disturbing is that very close relatives are amongst the most carcinogenic substances known. Yet, these halo ethers are not commercial products, but they appear in the drinking water and can pose human health problems. Unfortunately, in this area there is no systematic mechanism to know of increases in production or new uses of commercially produced chemicals.

I think the two best examples of this are not new. The first certainly is the polychlorinated biphenyls of which peak production was about 80 million pounds a year in 1970, and the fact that polychlorinated biphenyls were a major environmental problem was not realized until they had been literally accidentally discovered in the carcasses of birds. Similarly, the phthalic acid esters of which production is about one billion pounds a year simply suddenly appeared in a whole variety of environmental areas. It is fortunate that neither of these compounds appears to be particularly toxic, at least at the levels that are environmentally observed.

MEETING THE PROBLEM

Thus, our first major problem: The need to develop systematic mechanisms to monitor the production of new and old chemicals. We need to know chemical identity, production volumes, processes, intended uses (how leaky?) and by-products. Unless and until we have this information, we will be playing a game of hide and go seek, forever doomed to be the loser.

I think the next major question is a very obvious one. How can we possibly test each of these chemicals to see if they have deleterious effects? It is a fair statement that most of these chemicals have not been tested to any significant extent. The recent wide publicity given to the problem of the vinyl chloride monomer which had been used in industry for 30 years before its rather striking carcinogenicity was demonstrated first in animals and subsequently in man indicates the real need to study in some detail these sorts of compounds. Similarly, the demonstration a few years ago that bischloromethylene ether was a particularly strong carcinogen was most important.

Bischloromethyl ether is used as an agent in polymerization processes to tie up the loose ends. Through a series of totally inadvertent scientific investigations unrelated to the fact that this was a widely used chemical in industry, it was discovered that this was highly carcinogenic. In fact, a tenth of a part per million in the inhaled air causes a significant increase in bronchogenic carcinoma. The fact that this compound is affected at a tenth of a part per million suggests that we cannot be complacent and simply say that most of these compounds are present at very low concentrations and, therefore, are likely to be non-toxic.

Another good example of the very high toxicity of such compounds are the tetrachlorodibenzodioxins of which between a tenth and one microgram per kilo will cause severe toxicity in certain laboratory animal species.

In the face of this very large number of compounds it seems to me absolutely necessary that we develop a battery of rapid, simple, presumptive toxicity tests--tests which would lead in progressively more detailed fashion to complete studies, by this I mean lifetime feeding studies--for those relatively few chemicals which appear to be most hazardous. This needs to be done again, I think, in a systematic fashion of reviewing each chemical in terms of its structure, what is known about the activity of that class of chemicals, the physical characteristics of the chemical which will tend to make it stable in the environment, which will tend to make it accumulate in biological systems, and some appreciation of the extent and use of the compound and those patterns of use of the compound which would bring it into close contact with man.

Research is moving in the direction of developing these simple presumptive tests. While there is some progress, it seems to me that we have just begun a very major and important task of developing a mechanism of surveying the vast number of chemical compounds to which we may well be exposed for human health effects.

We are then faced with a third and also very important question of what do these tests mean--what do these tests mean in terms of effects on man? In the test situation, even the lifetime feeding studies, we have a situation in which relatively high doses of the test compound are given to relatively few laboratory animals. What we want to estimate from this in the real-life situation is what do relatively low doses of the compound for very long periods of time mean for a very large number of people? And this is truly a very fascinating scientific problem involving molecular biology, pharmacology, physiology, genetics, mathematics, etc.

There are two primary aspects to this: One, the qualitative aspect, which is the nature of toxicity. Is the nature of toxicity in man the same as that seen in laboratory animals? The second is the quantitative aspect--the dosage aspect. What sort of a dose or concentration will be toxic in man? This is particularly complicated by the need for the very low-dose extrapolation.

Now the first, the qualitative answer, I think is reasonably well understood, and I think there is general agreement the chances are quite high, indeed, that if a compound causes a set of toxic reactions in a couple of laboratory animal species, it is likely to cause a similar set of toxic reactions in man. But the second problem, the one of low-dose extrapolations, is more difficult. I think the scientific community is not in a position to answer that today. This is a question of thresholds, of very low doses, and of very large numbers of people.

It is clear that there are some toxic effects for which thresholds do exist, but there are others for which thresholds may not exist or only exist at very low concentrations. And, as I indicated, I think this is a problem which will gain considerable scientific and public interest and attention in the ensuing year or two. A good example of this is the effort of the Environmental Protection Agency to delineate reasonable guidelines for the disposal of benzidine to public waters, and I would suggest you might read the EPA document on this. It is a good document and illustrates the sort of problems that we must face.

SUMMARY

I think these three problems that I have briefly touched on this afternoon are three of the major problems we shall be concerned with in the next decade--whether it be water quality, air quality, or simply environmental health research. We must develop methods to determine what chemicals are in our environment. We must develop mechanisms to rapidly and inexpensively estimate their toxicity, and we must understand the meaning for human health of the results of these toxicity tests.

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EPIDEMIOLOGY OF WATERBORNE DISEASE IN THE UNITED STATES, 1971-1973

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INTRODUCTION

The true incidence and clinical spectrum of human disease in the United States caused by the ingestion of impure drinking water is difficult to estimate. Outbreaks of various acute bacterial infections such as typhoid fever** (1), non-typhoid salmonellosis (2), shigellosis (3), and pathogenic *Escherichia coli* (4) have been caused by consumption of contaminated water. Of the viral infections, there are many well-documented reports of waterborne transmission of hepatitis A (5). In addition, many outbreaks of *sewage poisoning,* an acute gastrointestinal illness presumably caused by either coliform organisms or viruses, have also been recognized (6,7).

Since the establishment of the Food and Waterborne Disease Surveillance System in 1966, the Center for Disease Control (CDC) has tabulated reports of both food and waterborne disease outbreaks. Since 1971, CDC and Environmental Protection Agency (EPA) representatives have worked together to document and report waterborne outbreaks (8). Before interpreting these data, it is necessary to review the data reporting system and its limitations.

State health departments voluntarily submit reports of food and waterborne disease outbreaks to CDC. These reports include the number of people exposed to the incriminated food or water and the number who actually became ill, symptoms experienced, incubation period, duration of illness, etiologic agent, and results of laboratory studies. Before outbreaks can be reported, they must

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**Editor's Note:* Oral presentation by Dr. Hughes.

**Numbers in parentheses refer to correspondingly numbered items in the *References*.

Fig. 1 AVERAGE ANNUAL NUMBER, WATERBORNE DISEASE OUTBREAKS, 1938 - 1973

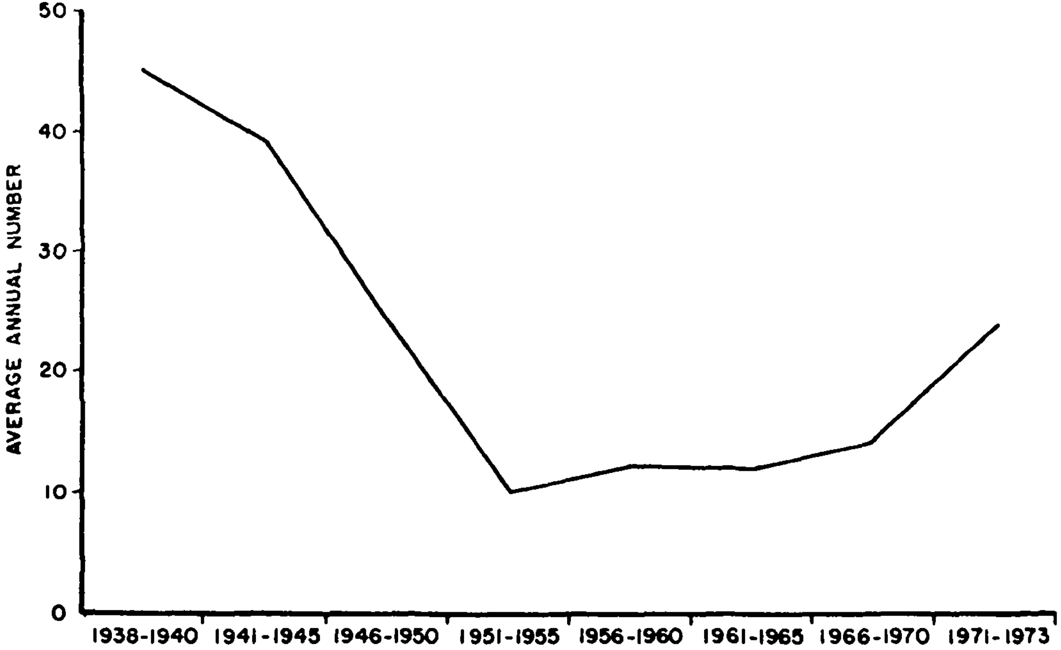
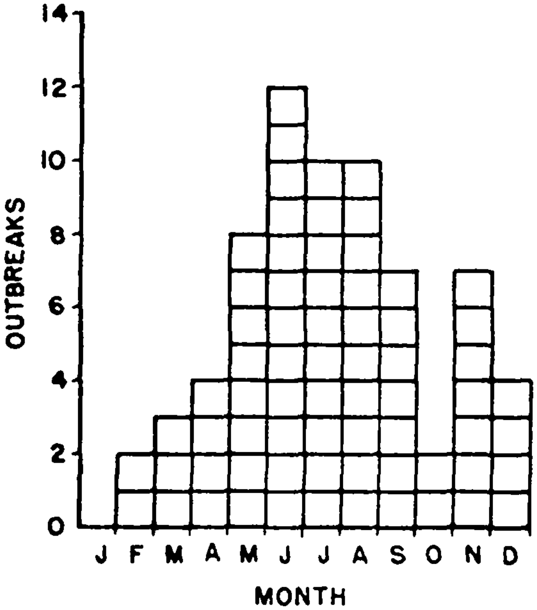


Fig. 2 WATERBORNE OUTBREAKS, 1971-1973

Fig. 3 69* WATERBORNE DISEASE OUTBREAKS BY MONTH OF OCCURRENCE, 1971-1973



* MONTH OF 2 OUTBREAKS UNKNOWN

first be recognized and then investigated. It is obvious, therefore, that because of the varying interest of practicing physicians to report illness and the limitations of budget and manpower in many state and local health departments, many outbreaks occur that are never reported to CDC or EPA. Furthermore, sporadic cases of illness following consumption of contaminated food or water will seldom be recognized or reported. Those outbreaks that are reported may be likened to the tip of an iceberg as they represent only a small percentage of the total number of cases. Despite these limitations, the data give an indication of the pathogens that cause waterborne disease and the types of water systems and deficiencies which are associated with outbreaks.

We define a waterborne outbreak as the occurrence of illness in two or more persons after drinking water which is implicated epidemiologically as the vehicle of transmission of the illness. In most reported outbreaks, the water source is found to be bacteriologically contaminated.

WATERBORNE DISEASE OUTBREAKS

National Picture

The mean number of waterborne disease outbreaks reported in the United States annually since 1938 (Figure 1) decreased from 45 between 1938 and 1940 to 11 between 1951 and 1955. Between 1956 and 1970, an average of 10 to 15 outbreaks were reported each year (9). However, in the past three years, an average of 24 outbreaks have been reported; this increase probably reflects a renewed interest in the problem of waterborne disease by health officials. The remainder of this discussion will concern those outbreaks reported between 1971 and 1973.

The number of outbreaks and cases reported each year between 1971 and 1973 are shown in Table 1. The large number of cases in 1971 may be explained by the occurrence of approximately 3500 cases of gastroenteritis in one outbreak following contamination of a municipal water supply in Pico Rivera, California (10).

The geographic distribution of reported outbreaks between 1971 and 1973 (Figure 2) probably reflects the level of interest in investigating and reporting them in different states rather than the true magnitude of the problem. Thirty states have reported at least one outbreak; Pennsylvania, Colorado, and New Jersey have reported the most outbreaks.

The seasonal occurrence of waterborne outbreaks (Figure 3) is apparent. The majority of reported outbreaks occurred between May and September; 32 of 69 (46 percent) reported outbreaks occurred in June, July, and August. An explanation for this clustering will be proposed later.

The diseases associated with the 71 outbreaks and 8537 cases are shown in Table 2. Sewage poisoning, a clinical entity characterized primarily by abdominal cramps and diarrhea 24 to 48 hours after consumption of contaminated water (6,7) accounted for 49

Table 1

WATERBORNE DISEASE OUTBREAKS AND CASES
1971-1973

	1971	1972	1973	Totals
Outbreaks	18	29	24	71
Cases	5,179	1,638	1,720	8,537

Table 2

ETIOLOGY OF WATERBORNE DISEASE OUTBREAKS AND CASES
1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Sewage poisoning	35	49	6,680	78.2
Hepatitis A	13	18	351	4.1
Shigellosis	10	14	941	11.0
Giardiasis	5	7	140	1.6
Chemical poisoning	4	6	205	2.4
Typhoid fever	3	4	217	2.5
Salmonellosis	1	1	3	0.1
TOTAL	71	99	8,537	99.9

percent of the outbreaks and 78 percent of the cases. Hepatitis A accounted for 18 percent of the outbreaks, while shigellosis accounted for 11 percent of the cases.

For analysis, water systems were classified as municipal, semi-public, or individual. Municipal systems are defined as public or investor-owned water supplies that serve communities. Semi-public systems are those used by several residences (for example, those in subdivisions) or by industries, camps, parks, resorts, institutions, or hotels. Individual water systems are those used only by individual residences.

The types of water systems implicated in the 71 waterborne outbreaks between 1971 and 1973 are shown in Table 3. Semi-public systems were implicated in 62 percent of the outbreaks and accounted for 45 percent of the cases, an average of 86 cases per outbreak. While municipal systems accounted for only 27 percent of the total outbreaks, they were responsible for 55 percent of the total cases, an average of 248 cases per outbreak. However, when the Pico Rivera outbreak was excluded, the average number of cases per outbreak involving a municipal system decreased to 67. Individual systems, on the other hand, accounted for 11 percent of the outbreaks but only 0.3 percent of the cases, an average of 3 cases per outbreak.

Table 3

WATERBORNE OUTBREAKS BY TYPE OF SYSTEM
1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Municipal	19	27	4,713	55.2
Semi-public	44	62	3,798	44.5
Individual	8	11	26	0.3
TOTAL	71	100	8,537	100.0

The system deficiency most often responsible for contamination of the water supply was untreated ground water which was implicated in 39 percent of the outbreaks (Table 4). Treatment deficiencies (for example, malfunction of a chlorinator) were involved in 35 percent. Although over 60 percent of the cases were associated with treatment deficiencies, over half these cases occurred in the Pico Rivera outbreak. When the system deficiencies implicated in outbreaks associated with semi-public systems were analyzed (Table 5), a similar trend was apparent. However, when system deficiencies in outbreaks involving municipal systems were examined (Table 6), deficiencies in the distribution system and treatment deficiencies were each implicated in 32 percent of the outbreaks, while untreated ground water was the most common deficiency of individual systems associated with outbreaks (Table 7).

Table 4

WATERBORNE OUTBREAKS BY TYPE OF DEFICIENCY
1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Untreated Surface Water	5	7	577	7
Untreated Ground Water	28	39	1,889	22
Treatment Deficiencies*	25	35	5,333	62
Def. in Distrib. System	6	8	449	5
Miscellaneous	7	10	289	3
TOTAL	71	99	8,537	99

*Includes outbreaks caused by systems using a known contaminated water source for which chlorination is required at all times to ensure potability.

Table 5

DEFICIENCIES OF SEMI-PUBLIC SYSTEMS ASSOCIATED WITH OUTBREAKS

1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Untreated Surface Water	2	5	100	3
Untreated Ground Water	18	41	1,795	47
Treatment Deficiencies	19	43	1,620	43
Def. in Distrib. System	0	0	0	0
Miscellaneous	5	11	283	7
TOTAL	44	100	3,798	100

Table 6

DEFICIENCIES OF MUNICIPAL SYSTEMS ASSOCIATED WITH OUTBREAKS

1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Untreated Surface Water	2	11	474	10.1
Untreated Ground Water	4	21	74	1.6
Treatment Deficiencies	6	32	3,713	78.8
Def. in Distrib. System	6	32	449	9.5
Miscellaneous	1	5	3	0.1
TOTAL	19	101	4,713	100.1

Table 7

DEFICIENCIES OF INDIVIDUAL SYSTEMS ASSOCIATED WITH OUTBREAKS

1971-1973

	Outbreaks		Cases	
	Number	Percent of total	Number	Percent of total
Untreated Surface Water	1	13	3	12
Untreated Ground Water	6	75	20	77
Treatment Deficiencies	0	0	0	0
Def. in Distrib. System	0	0	0	0
Miscellaneous	1	13	3	12
TOTAL	8	101	26	101

When waterborne outbreaks caused by semi-public and individual systems were examined by population affected and month of occurrence (Figure 4), it was apparent that 36 (69 percent) of the outbreaks involved a transient population (for example, travelers and campers) and that 32 of these 36 outbreaks (89 percent) occurred in the spring and summer months (that is, April through September). Many of these outbreaks involved systems in recreational areas that were not used during the winter.

Specific Examples

A brief review of five waterborne outbreaks that occurred in 1972 and 1973 and the results of a survey conducted in 1973 will provide examples of specific system deficiencies and measures employed to correct them.

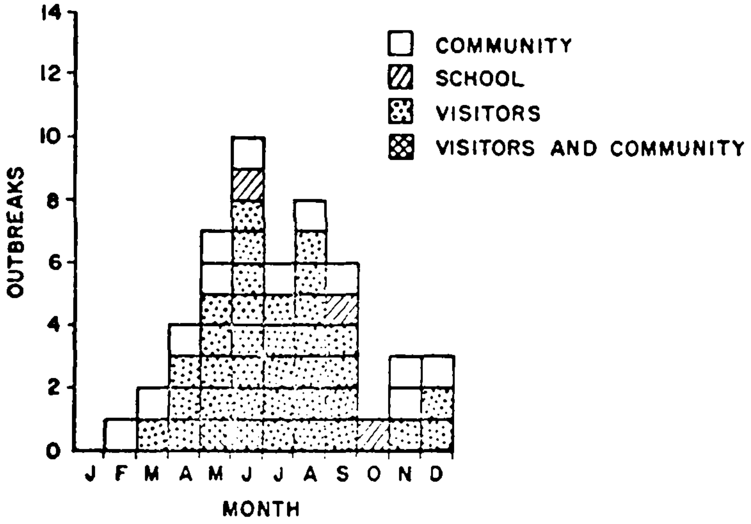
Typhoid in Dade County, Florida, Migrant Labor Camp

In February and March 1973, 210 cases of typhoid fever, 170 of which required hospitalization, occurred in a migrant labor camp in Dade County, Florida (11-13). Epidemiologic investigation clearly implicated water as the vehicle for transmission. Two wells, approximately 20 feet deep, supplied water for the camp. The ground water aquifer was composed of solution channels and both wells had a history of coliform contamination. The water was chlorinated prior to distribution, but the only contact time available was that provided in the distribution lines. This contact time was not optimal as evidenced by previous bacteriologic records showing coliform contamination in treated water collected at household taps near the wells. Gaseous chlorine was fed from a single 100-150 lb. cylinder through a manually operated rotameter; however, no scales were provided to determine when the cylinder was exhausted.

Samples collected on December 29 showed high coliform counts in both the raw water and treated water in the distribution system. Although only a limited number of samples were collected as part of routine surveillance, coliforms were found again in the raw water on January 3 and February 26. During the investigation numerous samples were collected and analyzed for both total and fecal coliforms. On March 2, samples of water from the wells showed high counts of both total and fecal coliforms. It was also discovered that sometime in early February chlorination was interrupted for approximately eight hours because of an exhausted gas cylinder. It was felt that the contamination of the water supply occurred at that time, although the source of contamination could not be identified.

Although no cross contamination between the camp sewerage and water systems could be demonstrated, fluorescien dye placed in a drain near the well house appeared in the well water within 3 1/2 minutes, and dye placed on the ground near the well house and wetted down appeared in the well water within 15 minutes. *Salmonella typhi* organisms were not isolated from the camp water or sewage despite the use of large-volume sampling techniques. The system deficiency in this outbreak was interruption of chlorination.

Fig. 4 51* WATERBORNE DISEASE OUTBREAKS ASSOCIATED WITH SEMIPUBLIC AND INDIVIDUAL WATER SUPPLIES, BY MONTH OF OCCURRENCE AND POPULATION AFFECTED, 1971-1973



*MONTH OF 1 OUTBREAK UNKNOWN

Control measures included a boil-water order and superchlorination of the well to 10 parts per million. Arrangements were made to pipe water from a private utility company into the camp, and bottled water was provided until this could be accomplished.

Shigellosis in Stockport, Iowa, School

In November 1972 a shigellosis outbreak affecting 208 students and staff occurred at a school in Stockport, Iowa (14). Nearly 150 additional secondary cases occurred in family contacts of these individuals. Epidemiologic investigation implicated the school's water supply. This supply was derived from two shallow-bored wells cased with ceramic pipe segments whose joints were not watertight. The wells were not chlorinated. The outflow pipes of the submersible pump of the well in use at the time of the outbreak had pierced the lining of the well below ground level permitting ground water to seep into the well. Numerous fluorescent dye studies were performed; dye flushed down the drain of the coach's shower, located a few feet from the wells, appeared in the well water three hours later. Water samples collected on two consecutive days yielded coliform organisms; in addition, *Shigella sonnei* was isolated from a 1600-milliliter sample of well water. The system deficiency associated with this outbreak was untreated ground water. Control measures consisted of superchlorinating the wells and promptly connecting the school to the municipal water supply.

Hepatitis at Alabama Rural School

In October and November 1972, 50 students and staff at an elementary school in a rural area of Alabama contracted hepatitis A, and the school's water was implicated as the vehicle of transmission (15). The school, located at the top of a hill, derived its water from two springs located 125 yards downhill. Inspection revealed that water in the springs came primarily from surface seepage. The spring water was stored in two concrete reservoirs, both of which were subject to contamination by surface water. Water was pumped uphill to a pressure tank where it was chlorinated before distribution. In early October, one incubation period before the onset of the epidemic, the bottle of hypochlorite solution was found empty having last been inspected three weeks previously; therefore, the water supply may have been unchlorinated for as long as three weeks. In addition, aerial photographs demonstrated lush vegetation overlying several lines in the drain fields of the school's two septic tanks and a prominent strip of vegetation extending downhill to within fifteen yards of the springs. Finally, rainfall during the month preceding the presumed date of exposure was unusually heavy.

Although water samples obtained at the school at the time of the outbreak were negative for fecal coliforms, samples of unchlorinated spring water were repeatedly positive. The system deficiency in this outbreak was a malfunctioning chlorinator.

Control measures consisted of transporting potable water from a nearby town and establishing an inspection log to ensure that the chlorinator would be checked daily. In addition, it was recommended that the septic tank drain fields be relocated and that either the municipal water be extended to the school or that wells be drilled.

Arsenic Toxicity in Minnesota Well

Beginning in May 1972, 11 cases of arsenic toxicity occurred in Perham, Minnesota (16). Epidemiologic investigation implicated well water, and two samples of the water were found to contain arsenic in concentrations of 21,000 and 11,800 parts per billion (maximum allowable in the U. S. is 50 ppb). The well began operating shortly before illness occurred. Investigation revealed an arsenic concentration of 12,600 parts per million in soil at a depth of two meters near the well. In the late 1930's, grasshopper bait containing arsenic had been stored on the property. Neighbors believed that the bait was later buried in the area although no documentation could be obtained. Thus, this outbreak was presumably caused by contamination of ground water by a chemical in the soil. Control measures consisted of disconnecting the well.

Shigellosis on Caribbean Cruise Ship

In June 1973, an explosive outbreak of shigellosis affecting 690 passengers and crew occurred aboard a cruise ship in the Caribbean Sea (17). Data from this outbreak have been excluded from the 1973 outbreak reports since it was not reported by a state. Epidemiologic investigation implicated water and ice aboard the ship as vehicles of transmission. In addition, two types of shrimp cocktail made from shrimp which had been in contact with water and ice on board were considered possible secondary vehicles. Six water samples obtained from the distribution system at the time of the outbreak contained elevated total and fecal coliform counts.

An investigation revealed that water was bunkered into four holding tanks and was pumped from these tanks into the distribution system by two fresh-water pumps. Chlorine was added as sodium hypochlorite by a non-automatic chlorinator to the suction manifold of the water pumps 20 feet proximal to charcoal filters. Since these filters removed the chlorine, the contact time of the chlorine in this system was calculated to be only four seconds. Inadequate chlorination was clearly an important factor in this outbreak. Additional investigation revealed that to wash the decks while in port, potable water from a pier source was connected to the fire-fighting system which normally contained circulating sea water. A hose connected to any fire hydrant could then be used to wash the decks. After completing this procedure, crew members extended a hose from a fire hydrant to an air relief vent of a water-holding tank to fill the tank, permitting contamination of the water in the tank with organisms originally present in the salt water in the fire system.

Control measures included recommending batch chlorination of water at the time of bunkering and installing an automatic hypochlorinator, a free-residual-chlorine feedback control analyzer in the distribution system, and a chart recorded to monitor free residual chlorine. In addition, the company was advised to cease the practice of bunkering water through the air relief vents. It was also recommended that color-coded hoses with caps be designated specifically for bunkering potable water only and that free residual chlorine be measured daily until an automatic chart recorder could be installed.

Giardia lamblia in Colorado

Between 1971 and 1973, *Giardia lamblia* was the fourth most common etiologic agent associated with waterborne outbreaks. In 1973, CDC and the Colorado State Health Department conducted a survey of 256 giardiasis cases that occurred in Colorado between July 1972 and June 1973 (18). Persons with giardiasis were significantly more likely to live in or near the mountains and to have ingested untreated mountain water obtained from streams or wells during the two months before the onset of their illness than were controls matched for age, sex, and place of residence. Untreated surface and ground water in the mountains, therefore, appeared to be important vehicles for transmission of giardiasis in Colorado.

Water-Contaminated Food

The outbreaks which were reported between 1971 and 1973 all directly followed consumption of contaminated drinking water. Contaminated water may also lead to human disease indirectly. For example, an outbreak caused by an invasive strain *E. coli* which affected at least 387 persons was traced to imported, commercially distributed French cheese in 1971 (19). The same serotype of *E. coli* was isolated from patients, samples of cheese, and a curdling tank in the plant in France. The source of *E. coli* was thought to be river water which was used to clean the plant. The filtration system used for filtering the river water was malfunctioning at the time the contaminated cheese was produced. In October and November 1973, approximately 285 cases of hepatitis A in Georgia and Texas were traced to the ingestion of raw oysters presumably contaminated in the ocean prior to harvesting (20,21). Thirteen outbreaks of foodborne disease traced to shellfish contaminated with *Vibrio parahaemolyticus* present in sea water have been reported in the United States since 1969 (22). Shellfish, both harvested from and freshened by water contaminated with human sewage, were implicated as vehicles in the transmission of cholera in Italy in 1973 (23). An outbreak of six cases of cholera in Guam in July 1974 was traced to the ingestion of a raw fish caught in a bay at a point near which *Vibrio cholerae* was isolated from bay water approximately six weeks later (24-26). These two cholera outbreaks illustrate how untreated human sewage disposed of near shore can cause disease. Ice used to chill syringes before collection of blood specimens for arterial blood gas determinations was implicated as the source of *Flavobacterium sp* sepsis in 14 patients in an intensive care unit in Prince George's County, Maryland. Arterial cannulae in patients had apparently been contaminated by ice water at the time the blood specimens were drawn (27).

Water Supply and Chronic Disease

Although the importance of contaminated water in the transmission of acute infectious gastrointestinal illness is generally well accepted, its influence on the development of certain chronic diseases remains controversial and unresolved. Reports have shown an inverse correlation between water hardness and the incidence of cerebrovascular accidents and cardiovascular disease (28). One report has even suggested that exposure to contaminated drinking water in a New England town was responsible for the development of multiple sclerosis, a degenerative disease of the nervous system, in eight patients a mean of 23 years after the exposure (29). Additional epidemiologic studies are clearly needed to assess the possible influence of drinking water of different compositions on the incidence and course of these chronic diseases (30).

SUMMARY

In summary, there is little doubt that disease caused by drinking contaminated water continues to occur in the United States. The true incidence of acute waterborne illness is difficult to estimate but is certainly greater than the number of outbreaks and cases reported annually to CDC and EPA. The possible contribution of components of drinking water to the etiology or progression of cardiovascular diseases remains undefined.

Reported outbreaks of waterborne disease most frequently involve semi-public systems which are frequently inadequately maintained and monitored. The most common system deficiencies associated with these outbreaks are lack of treatment of ground water and treatment deficiencies such as malfunctioning chlorinators. Although municipal systems account for fewer outbreaks than do semi-public systems, they account for more cases. The most common factors associated with these outbreaks are treatment deficiencies and deficiencies in the distribution system.

To decrease the incidence of waterborne disease, local, state, and federal agencies must work together to establish effective surveillance systems to permit prompt recognition and reporting of outbreaks and to coordinate effective maintenance and monitoring of municipal and semi-public water systems.

REFERENCES CITED

1. Neill, W. A., J. D. Martin, E. A. Belden, *et al.*, (1958), "A Widespread Epidemic of Typhoid Fever Traced to a Common Exposure," *New Engl. Jour. Med.*, 259, 667-672.

2. A Collaborative Report (1970), "A Waterborne Epidemic of Salmonellosis in Riverside, California, 1965: Epidemiologic Aspects," *Amer. Jour. Epidemiol.*, 93, 33-48.

3. Drachman, R. H., F. J. Payne, A. A. Jenkins, *et al.*, (1960), "An Outbreak of Waterborne Shigella Gastroenteritis," *Amer. Jour. Hyg.*, 72, 321-334.

4. Schroeder, S. A., J. R. Caldwell, T. M. Vernon, *et al.* (1968), "A Waterborne Outbreak of Gastroenteritis in Adults Associated with *Escherichia coli*," *Lancet*, 1, 737-740.

5. Moseley, J. W. (1957), "Waterborne Infectious Hepatitis," *New Engl. Jour. Med.*, 261, 703-708, 748-753.

6. Renteln, H. A., A. R. Hinman (1966), "A Waterborne Epidemic of Gastroenteritis in Madera, California," *Amer. Jour. Epidemiol.*, 86, 1-10.

7. Werner, S. B., P. H. Jones, W. M. McCormack, *et al.*, (1969), "Gastroenteritis Following Ingestion of Sewage-Polluted Water: An Outbreak at a Logging Camp on the Olympic Peninsula," *Amer. Jour. Epidemiol.*, 89, 277-285.

8. Merson, M.H., W. H. Barker, G. F. Craun, *et al.*, (1974), "Outbreaks of Waterborne Disease in the United States, 1971-1972," *Jour. Infect. Dis.*, 129, 614-615.

9. Craun, G.F., and L. J. McCabe (1973), "Review of the Causes of Waterborne-Disease Outbreaks," *Jour. Amer. Water Works Assoc.*, 65, 74-84.

10. Center for Disease Control (1971), *Morbidity and Mortality Weekly Rept.*, 20(37), 332-333.

11. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(9), 77-78.

12. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(10), 85.

13. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(13), 115.

14. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(3), 21-22.

15. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 21(51), 439-444.

16. Feinglass, E. J. (1973), "Arsenic Intoxication from Well Water in the United States," *New Engl. Jour. Med.*, 288, 828-830.

17. Merson, M. H., J. H. Tenney, J. D. Meyers, *et al.*, (in press), "Shigellosis at Sea: An Outbreak Aboard a Passenger Cruise Ship," *Amer. Jour. Epidemiol.*

18. Wright, R. A. (1974), "Giardiasis in Colorado: An Epidemiologic Study," presented at the Epidemic Intelligence Service Conference, April 15-19, 1974, Atlanta, Georgia.

19. Marier, R., J. G. Wells, and R. C. Swanson (1973), "An Outbreak of Enteropathogenic *Escherichia coli* Foodborne Disease Traced to Imported French Cheese," *Lancet*, 2, 1376-1378.

20. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(44), 372.

21. Center for Disease Control (1973), *Morbidity and Mortality Weekly Rept.*, 22(46), 388.

22. Barker, W. H. (1974), "*Vibrio parachaemolyticus* Outbreaks in the United States," *Lancet*, 1, 551-554.

23. Baine, W. B., A. Zampieri, M. Mazzotti, *et al.*, (in press), "The Epidemiology of Cholera in Italy in 1973," *Jour. Infect. Dis.*

24. Center for Disease Control, (1974), *Morbidity and Mortality Weekly Rept.*, 23(31), 269-270.

25. Center for Disease Control, (1974), *Morbidity and Mortality Weekly Rept.*, 23(32), 277-278.

26. Center for Disease Control, (1974), *Morbidity and Mortality Weekly Rept.*, 23(35), 302-307.

27. Stamm, W. E., R. E. Dixon, and J. E. Colella (1974), "Nosocomial Flavobacterium Bacteremia in Patients with Indwelling Arterial Cannulae," presented at the 14th Interscience Conference on Antimicrobial Agents and Chemotherapy, Sept. 11-13, 1974, San Francisco, California.

28. Schroeder, H. A. (1960), "Relation Between Mortality from Cardiovascular Disease and Treated Water Supplies," *Jour. Amer. Med. Assn.*, 172, 1902-1908.

29. Eastman, R., J. Sheridan, and D. C. Poskanzer (1973), "Multiple Schlerosis Clustering in a Small Massachusetts Community, With Possible Common Exposure 23 Years Before Onset," *New Engl. Jour. Med.*, 289, 793-794.

30. Neri, L. C., D. Hewitt, and G. B. Schreiber (1974), "Can Epidemiology Elucidate the Water Story?" *Amer. Jour. Epidemiol.*, 99, 75-88.

QUESTIONS AND DISCUSSION

QUESTION: Did you allude in your discussion to the single case of cholera that occurred in a resident of Port Lavaca, Texas, during 1973?

DR. HUGHES: No. I did not allude to that case. The source of the patient's cholera infection was sought for months by several of my colleagues at CDC, but it was never determined. The patient lived in a mobile home adjacent to a small motel. Both the motel and the mobile home were supplied with water from a 300-foot well. Although *V. cholerae* was not isolated from the well, the well was found to be contaminated with coliforms, and it is possible that water might have been the vehicle of transmission.

QUESTION: Does your department concern itself with cross connection control at all?

DR. HUGHES: We are responsible for surveillance of waterborne diseases, and we assist in investigations of waterborne disease outbreaks. If we discover a cross-connection during an epidemic investigation, we recommend it be corrected.

QUESTION: (Don Johnson, School of Public Health, UNC-CH) In view of the difficulty of identification of viral diseases, could you make any estimate as to how big the iceberg is underneath the tip that you alluded to in the beginning of your talk?

DR. HUGHES: I would hesitate to do that. No one knows the cause of sewage poisoning. *Escherichia coli,* other coliform bacteria, or viruses may be etiologic agent(s). Much experimental work is now being done to develop techniques for isolation and identification of viruses in stools of persons with gastroenteritis. Hopefully, within the next few years we may be able to answer that question.

QUESTION: (Hutchinson, EPA, Atlanta) I believe that the waterborne shigellosis outbreak that occurred in Richmond Heights, Florida, from January through March 1974 might shed some light on that. You probably have the correct figures, but there were eight or nine cases of shigellosis and then when you went in and made an indepth evaluation, 1200 gastroenteritis cases were estimated. Could you expand on that?

DR. HUGHES: Yes. Initially, only ten cases of shigellosis were recognized by health authorities. Our investigation revealed that approximately 1200 cases actually occurred. This finding is not uncommon. In common-source waterborne and foodborne outbreaks, it is not unusual to identify ten or sometimes as many as 100 times the cases that were initially recognized.

QUESTION: I think a couple of things are important about that. One is that they normally have 20 to 25 cases of shigellosis in that county a year so if they had not been really alert to the possibility of a common-source outbreak, it probably would have gone unnoticed. The other thing that's very interesting to us is that the seriousness of the disease changed. I don't know how that came about--maybe by the dosage or whatever, but you had only, say, 8 to 12 cases of clinical shigellosis, but subsequent investigation revealed that 100 times that many people were affected with a similar, possibly milder, illness that was not reported. In this example, the tip of the iceberg was quite small.

DR. HUGHES: That's right. It is significant that a waterborne outbreak as large as this one might not have been recognized at all; if local health authorities had not been conducting surveillance, the initial ten cases of shigellosis might not have been recognized as an unusual occurrence.

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ENTERIC VIRUSES AND DRINKING WATER SUPPLIES

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INTRODUCTION

Despite the fact that documented waterborne enteric virus disease has been recognized for nearly two decades (Viswanathan, 1957), the public health significance of enteric viruses in water has not been adequately evaluated and remains poorly understood. In this time of significant legislative activity concerning the quality of America's drinking water, the question of waterborne enteric virus transmission must be carefully considered. The purpose of this paper is to briefly review the status of our knowledge concerning the enteric virus problem with respect to drinking water, to assess its current public health significance, and to define the priorities for approaches to its further evaluation.

ENTERIC VIRUSES AND THEIR OCCURRENCE IN WATER AND WASTEWATER

So much information on waterborne enteric viruses has accumulated over the years that it is impossible to provide here a comprehensive review of all aspects of this subject. Instead, only those aspects of particular relevance to drinking water will be considered in detail. Comprehensive coverage of this subject is available in a number of recent reviews (Berg, 1967; Snoeyink and Griffin, 1971; University of Texas, 1974, American Public Health Association, 1974). (Full citations given at end of text.)

The viruses of major concern in water are those that infect the alimentary tract of man and are excreted in large quantities with the feces by infected persons. These are the so-called enteric viruses, and they are likely to be present in waters recently contaminated with sewage (Table 1). Because of the continuous use of oral polio vaccine, the most prevalent enteric viruses in sewage are often vaccine strain polioviruses. It should be kept in mind that enteric viruses are obligate intracellular parasites of man and, in the case of reoviruses, lower mammals as well. Therefore, they cannot multiply in sewage or water, and their numbers in aquatic environments will decrease due to removal and inactivation process. Enteric virus concentrations in domestic raw sewage cannot be precisely established because of limitations in virus detection methods and because of the variability in the amounts and types of viruses that may be present under different conditions. The socio-economic and hygienic level of the population and the time of the year influence the enteric virus concentration in sewage. In the U. S. the enteric virus concentration in raw sewage probably ranges from as little as a few to more than 100 infectious virus units per 100 ml, with peak levels occurring

Table 1

ENTERIC VIRUSES AND THEIR ASSOCIATED DISEASES

Virus Group	Number of Types	Common Disease Syndromes
Enteroviruses		
Polioviruses	3	Poliomyelitis, aseptic meningitis
Coxsackieviruses A	23	Herpangina, aseptic meningitis, exanthem
Coxsackieviruses B	6	Aseptic meningitis, epidemic myalgia, myocarditis, pericarditis
Echoviruses	31	Aseptic meningitis, exanthem, gastroenteritis
Adenoviruses	31	Upper respiratory illness, pharyngitis, conjunctivitis
Reoviruses	3	Upper respiratory illness, diarrhea, exanthem
Hepatitis Viruses		
Hepatitis A Virus (HAV)	1?	Viral hepatitis type A (HA) or "Infectious Hepatitis"
Hepatitis B Virus (HBV)	4	Viral hepatitis type B (HB) or "Serum Hepatitis"

in the late summer and early fall. If the coliform bacteria concentration of raw sewage is estimated at about 10^7 to 10^8 organisms per 100 ml, then the enteric virus concentration is perhaps 5 to 7 orders of magnitude lower (Clarke and Kabler, 1964, Geldreich and Clarke, 1971).

Little quantitative information is available on enteric virus levels in sewage-contaminated surface and ground waters, but there have been a number of reports of enteric virus isolations from such waters (Akin, *et al*, 1971). Most enteric virus isolations have been made from heavily polluted surface waters, but Berg and co-workers (1973) detected enteric viruses in Missouri River water having a fecal coliform concentration as low as 60 per 100 ml.

Virtually nothing is known about enteric virus levels in U.S. drinking water, a situation that I consider both unacceptable and, as I shall attempt to show, no longer justifiable or excusable. Initial reports of virus isolations from the drinking waters of two New England communities in 1972 are now considered questionable because of the likelihood of laboratory contamination of the water samples (Clark, *et al*, 1973; Clark, 1974). However, monitoring of the drinking water supply of Paris, France, during the 1960's revealed that about 18 percent of the 200 samples examined contained enteric viruses, and the average virus concentration was estimated at 1 infectious unit per 300 liters (Coin, *et al*, 1966). More recently, Nupen (1974) has reported finding enteric viruses in 10-liter samples of drinking water from communities in South Africa.

Although available evidence indicates that enteric virus concentrations in drinking water are likely to be very low, it is important to be mindful of the fact that as little as one virus infectious unit for laboratory host systems such as cell cultures is probably capable of also producing infection in man (Plotkin and Katz, 1967; Katz and Plotkin, 1967).

EPIDEMIOLOGY OF WATERBORNE ENTERIC VIRUS DISEASE

Documented evidence for waterborne transmission of enteric virus disease exists only for infectious hepatitis virus (hepatitis type A virus) and perhaps poliovirus. In recent years, more than 50,000 cases of type A hepatitis have been reported annually in the U. S., but of this total, only a fraction of a percent have been attributed to drinking water as a source. In the period 1961 to 1970 a total of 30 waterborne outbreaks of hepatitis type A involving 903 cases were reported (Craun and McCabe, 1973). It should be noted that the annual number of waterborne type A hepatitis cases is increasing, and that it is now the most prevalent waterborne disease attributable to a specific etiological agent. The majority of waterborne type A hepatitis outbreaks have been due to obvious sewage contamination of private and semi-public water supplies in which treatment was either inadequate or totally lacking. Outbreaks arising in public systems are usually caused by contamination through the distribution system.

With the possible exception of a few poliomyelitis outbreaks, there is no evidence of waterborne disease outbreaks in the U. S. due to other specific enteric viruses. The most prevalent waterborne disease in the U.S. is gastroenteritis of unknown etiology. In the period 1971-1972 there were 22 reported outbreaks involving 5615 cases (Merson, *et al*, 1974). Although the term gastroenteritis describes a recognizable clinical illness, this disease category for waterborne outbreaks is often used when laboratory studies either were not made or yielded completely negative results (Moseley, 1967, Goldfield, 1974). Although some waterborne outbreaks of gastroenteritis may represent the lack or inadequacy of laboratory work, it is also possible that some outbreaks in this category were caused by viral agents. In fact, evidence is now accumulating that the long-recognized clinical syndrome of acute infectious non-bacterial gastroenteritis (AING) has a viral etiology (Wyatt, *et al*, 1974). Virus-like particles have recently been detected in stool filtrates from an AING outbreak, and preliminary evidence suggests that they may be parvoviruses (Kapikian, *et al*, 1973). It is interesting to note that evidence is accumulating for the agent of hepatitis type A to also be a member of the parvovirus group (Feinstone, *et al*, 1973, Feinstone, *et al*, 1974).

Although documented waterborne virus disease is almost exclusively limited to a relatively small number of hepatitis type A outbreaks, it does not necessarily follow that waterborne transmission of other enteric viruses and resultant disease does not occur. One reason for this is the generally inadequate recognition and reporting of viral disease (Goldfield, 1974). Furthermore, Berg (1966a) has suggested that low-level enteric virus transmission via drinking water could occur in the absence of any recognizable waterborne disease. Individuals subclinically infected via water could serve as the initial or index sources of enteric virus infection in a community. Person-to-person transmission would then predominate, producing overt illness in the subsequent spread of the infection. Goldfield (1974) has suggested that the very nature of waterborne enteric virus transmission would make it difficult to recognize as a distinct disease entity when using the usual epidemiological surveillance procedures, and he cites several specific reasons for this position: (1) A substantial proportion of the population is likely to possess prior immunity to the virus and, hence, would have only inapparent infections. (2) The ratio of disease to inapparent infection is usually so low that only a small proportion of exposed susceptibles would develop clinical disease. (3) Most enteric viruses cause such a broad spectrum of enteric and respiratory disease syndromes that the scattered cases of illness would probably be too varied in symptomatology to be attributed to a single etiologic agent. (4) Secondary spread via person-to-person contact would quickly obscure the role of water in the initial dissemination of an enteric virus.

Thus, demonstration of enteric virus disease transmission via drinking water using conventional epidemiological procedures does not appear to be very likely unless there is an explosive disease outbreak due to extensive sewage contamination, such as the hepatitis type A outbreak that occurred in New Delhi, India, in 1955 (Viswanathan, 1957). Therefore, alternate investigative approaches are needed to recognize waterborne enteric disease transmission.

ENTERIC VIRUS REDUCTIONS BY WATER AND WASTEWATER TREATMENT PROCESSES

There is much experimental evidence to indicate that enteric viruses are considerably more resistant to various sewage and water treatment processes than either coliform or enteropathogenic bacteria. Thus, the initial high ratio of coliform bacteria to enteric viruses in raw sewage may be increasingly reduced as the water undergoes various treatment processes.

Sewage Treatment

The results of both laboratory and field studies have shown that sewage treatment will not remove or destroy all enteric viruses (Berg, 1966b). A conventional sewage treatment system consisting of both primary and secondary treatment plus effluent chlorination is not likely to reduce the enteric virus concentration by more than perhaps 99 percent (Sproul, 1974). Thus, if raw sewage contains, for example, 1000 infectious virus units per 100 ml, then the conventionally treated effluent can be expected to still contain at least 10 infectious virus units per 100 ml. From the limited experimental information currently available on virus removal by advanced wastewater treatment processes such as lime or alum coagulation and activated carbon adsorption, these processes could perhaps be expected to produce an additional 90 to 99 percent virus reduction (Sproul, 1974). In a field study on poliovirus removal from strong raw sewage by a packaged, physical-chemical, advanced wastewater treatment system, the overall virus reduction averaged about 99.95 percent (Sobsey, *et al*, 1973a).

Water Treatment

Chemical coagulation and flocculation with alum or iron is capable of achieving virus reductions of more than 99 percent if conducted with proper attention to such process variables as pH, coagulant concentration and flocculation speed (Sproul, 1974).

Water softening precipitation by the excess lime-soda ash process has been shown in laboratory experiments to be capable of reducing virus concentrations by more than 99 percent (Wentworth, *et al*, 1968). Virus reductions of even greater magnitude have been obtained at pH levels above 11.0 (Sproul, 1971).

Rapid sand filtration is not in itself effective for removing viruses from water unless the viruses are associated with larger particles that can be removed by entrapment or sedimentation in the filter bed. However, when preceded by chemical coagulation-flocculation and sedimentation, rapid sand filtration has achieved virus removals of about 99 percent (Robeck, *et al*, 1962; Berg, *et al*, 1968). Effective virus removal requires that floc breakthrough of the filter bed be prevented, because most of the viruses in a coagulated water will be present in the floc and will still be infectious.

Chlorination with hypochlorous acid is effective for virus disinfection and is capable of achieving substantial virus reductions if properly applied to water of adequate quality. However, it should be noted that many enteric viruses are considerably more resistant to chlorine than coliform bacteria (Berg, 1966c), and there is much variation in the relative chlorine sensitivity of different enteric viruses (liu, *et al*, 1971). Hypochlorite ion and combined forms of chlorine are relatively poor virucides, and the latter should not be relied on to produce any substantial enteric virus reductions. A free chlorine residual of 0.3 to 0.5 mg/l after 30 minutes is likely to produce a 99.99 percent reduction in enteric virus concentration if the water has a pH of less than about 8.5.

Ozone has received much recent attention as an alternative disinfectant to chlorine, but relatively little is known about its ability to inactivate enteric viruses. Available evidence indicates a threshold effect with virus ozonation, in that there is a certain critical ozone concentration below which virus inactivation is relatively poor and above which it is relatively good. This threshold ozone concentration has not been precisely established but appears to be within the range of 0.2 to 1.0 mg/l (Coin *et al*, 1964; Majumdar, *et al*, 1973; Katzenelson, *et al*, 1974). On the basis of limited laboratory experiments with only a few different enteric viruses, extensive virus inactivation has been achieved with relatively short contact times at ozone concentrations above the threshold level.

From the available experimental evidence, a properly managed water treatment system consisting of excess lime-soda ash softening, coagulation-flocculation, sedimentation, rapid sand filtration and chlorination is likely to produce a reduction in virus concentration of perhaps 8 orders of magnitude. In the absence of softening a 6 to 7 order of magnitude reduction could still be expected.

DETECTION METHODS FOR ENTERIC VIRUSES IN DRINKING WATER

Determining whether or not America's drinking waters contain enteric viruses and if they do, how much they contain, is obviously a key issue in evaluating the public health significance of enteric viruses in drinking water. Without such information, our knowledge concerning the waterborne virus question will remain indirect and largely speculative. Enteric virus concentrations in drinking water are likely to be so low that virus detection would be impossible unless the viruses are somehow concentrated from the water. It has been argued in the past that the lack of adequate methods for detecting small amounts of viruses in large volumes of water made it impossible to reliably and quantitatively determine if drinking water contained enteric viruses. I believe that this is no longer true and that adequate virus detection methodology is now available to quantitatively detect the presence of enteric viruses in drinking water.

Significant advances have recently been made in waterborne virus concentration methods which make it possible to detect small amounts of viruses in up to 100-gallon volumes of drinking water. Two types of methods appear to be promising: (a) flow-through filter adsorption-elution systems such as the Wallis-Melnick portable virus concentrator (Wallis, *et al*, 1972a; Wallis, *et al*, 1972b; Sobsey, *et al*, 1973b), and the apparatus developed by Hill and co-workers of the EPA (Hill, *et al*, 1974), and (b) ultrafiltration systems employing polymeric, anisotropic membranes in tangential fluid flow configurations (Nupen, 1973; Sweet, *et al*, 1974).

Filter adsorption-elution systems are based upon the fact that viruses present in water containing little or no organic matter will adsorb to the surfaces of submicron porosity cellulose ester or fiberglass filters under conditions of low pH and/or the presence of polyvalent cation salts. The adsorbed viruses that accumulate on the filter surfaces as the water is passed through the filter can then be eluted with a small volume of either protein, surfactant or high pH buffer solution. Using this approach the Wallis-Melnick portable virus concentrator concentrates enteric viruses in several hundred-gallon volumes of water to a volume of less than 10 ml by a two-stage process. In experimental trials with 100-gallon volumes of tapwater experimentally contaminated with small amounts of poliovirus, virus recovery efficiency averaged about 75 percent when concentrating the viruses nearly

40,000-fold (Sobsey, *et al*, 1973b). Comparable results have been obtained by Hill and co-workers at the EPA using a somewhat different apparatus which is based upon the same general principle (Hill, *et al*, 1974). In fact, the demonstrated capabilities of flow-through filter adsorption-elution systems for concentrating viruses from large volumes of water make it likely that such methodology will be included in the next edition of *Standard Methods* as a tentative procedure for finished waters.

The utility of ultrafiltration systems for concentrating small amounts of enteric viruses from large volumes of water has also been recently demonstrated. The basis for virus concentration by ultrafiltration methods is that water and microsolutes can be driven through a microporous membrane by pressure while macrosolutes such as viruses and other high molecular weight materials are retained and thereby concentrated because they are too large to penetrate the membrane pores. The application of anisotropic polymeric membranes has reduced virus losses due to adsorption and entrapment, and the use of equipment employing tangential fluid flow across the membrane surface has improved filtration fluxes by reducing membrane pore clogging due to concentration polarization effects. Experimental studies by a number of workers have shown that this methodology is effective in concentrating enteric viruses by factors of several thousand-fold from 100-liter volumes of tapwater (Sweet, *et al*, 1974; Nupen, 1974a). This type of methodology is now being used by Nupen and co-workers in a virological survey of South African drinking water supplies (Nupen, 1974b).

Another aspect of detection methodology for enteric viruses in water concerns the availability of suitable assay systems based upon virus infectivity for a laboratory host. No single type of cell culture or laboratory animal is capable of detecting all enteric viruses, and there is often considerable variability in host sensitivity to different virus types. Furthermore, some enteric viruses, notable hepatitis type A, cannot as yet be routinely assayed by infectivity in any laboratory host system. Although there have been a number of reports on the relative sensitivities of various cell culture systems for enteric virus detection, no systematic, comprehensive studies have been conducted on this problem. Despite the fact that there are limitations in our methods for assaying enteric viruses, the concurrent use of a number of the more sensitive cell culture systems available makes it possible to detect the majority of known enteric viruses that may be present in water.

Continued efforts should be made to increase the efficiency and reliability of existing waterborne virus detection methods, and the development of new and improved methods should be encouraged. However, it appears that reasonably reliable and sensitive methods are now available to conduct much needed virological surveys of drinking water. It should be recognized that this methodology is not recommended for routine use but rather for special or unusual situations. In addition, this methodology should be used only by highly trained workers having well-equipped facilities.

ENTERIC VIRUSES AND MICROBIAL DRINKING WATER STANDARDS

If reliable, sensitive virus detection methods are applied to America's drinking water and viruses are actually found, then the following question arises: How many viruses, if any, are to be allowed in drinking water? This, of course, brings us to the consideration of microbial standards for drinking water. Present microbial standards for drinking water utilize bacterial indicators of fecal pollution; namely, the coliforms. The use of the coliform group as indicator organisms is a well-established concept whose principles have been described in detail (Fair and Geyer, 1958) and whose adequacy is based largely upon experience (Geldreich and Clarke, 1971). It is important to recall that the coliform standard for drinking water *allows* a certain degree of fecal contamination. It embodies the concept of a small but acceptable or allowable risk of enteric infection and acknowledges the fact that all risk from enteric infection and disease cannot be eliminated from drinking water.

Although some have suggested that drinking water should contain no enteric viruses, the fact that we accept a small but measurable amount of fecal contamination in drinking water also implies that we are willing to accept small but possibly measurable amounts of enteric viruses in drinking water. Therefore, a critical question that must be answered is: What enteric virus concentrations are being allowed when drinking water is allowed to contain up to one coliform bacteria per 100 ml? In my opinion, this should be a major priority in evaluating the public health significance of enteric viruses in drinking water. Although surveillance studies on enteric viruses in the water supplies of several U. S. communities are now being conducted by the EPA (Akin, 1974; Clarke, 1974), these studies should be greatly expanded. It is only by knowing how many enteric viruses are present in drinking waters meeting current microbial standards that we can rationally and realistically begin to determine the risk of enteric virus infection and disease to those consuming the water. Only then will we be in a position to determine if current microbial standards are adequate with respect to enteric viruses.

SUMMARY

Enteric viruses are present in sewage and sewage-contaminated natural waters. Although information on enteric viruses in U. S. drinking waters is quite limited, viruses have been isolated from public water supplies in Paris, France, and in a number of South African communities.

Documented epidemiological evidence for waterborne transmission of enteric virus disease is largely limited to outbreaks of hepatitis type A which have resulted from the lack or inadequacy of treatment of private or semi-public supplies or from contamination of the distribution system of public supplies. The absence of documented waterborne disease outbreaks due to other enteric viruses does not necessarily mean that waterborne transmission of these viruses does not occur. The inadequacy of recognition and reporting of virus diseases and the characteristic epidemiological features of enteric virus transmission make it unlikely that enteric virus transmission via drinking water would be demonstrated by current epidemiological surveillance procedures, unless there was gross sewage contamination of the water supply.

Conventional primary-secondary sewage treatment systems are not likely to reduce the enteric virus concentration of sewage by more than 99 percent. A properly managed water treatment system consisting of coagulation-flocculation, sedimentation, rapid sand filtration and chlorination is likely to produce a reduction in virus concentration of perhaps 6 to 7 orders of magnitude.

Although waterborne virus detection methodology should be further developed and improved, reasonably sensitive and reliable methods are now available to quantitate small amounts of enteric viruses in up to 100-gallon volumes of drinking water. The two most promising methods for this type of water are flow-through, filter adsorption-elution systems and certain types of ultrafiltration systems.

Recognizing that it is impossible to eliminate *all* fecal contamination from drinking water supplies, surveillance studies to determine enteric virus levels in drinking waters meeting current microbial standards should be a major priority for research on viruses in water. It is only by knowing the extent of enteric virus contamination of currently acceptable drinking water supplies that we can begin to determine if current microbial drinking water standards are adequate with respect to enteric viruses.

REFERENCES CITED

1. Akin, E. W. (1974), in *Public Health Aspects of Viruses in Water*, page 1, Vol. 4, N. A. Clarke (ed.), National Environmental Research Center, Environmental Protection Agency, Cincinnati.

2. Akin, E. W., Benton, W. H., and W. F. Hill, Jr. (1971), "Enteric Viruses in Ground and Surface Waters: A review of Their Occurrence and Survival," in *Proceedings of the 13th Water Quality Conference, Virus and Water Quality: Occurrence and Control*, pp. 59-73, V. Snoeyink and V. Griffin (eds.), University of Illinois at Urbana-Champaign.

3. American Public Health Association, International Conference on Viruses in Water, June 9-12, 1974, Mexico City, *Proceedings* to be published.

4. Berg, G. (1966a), "Virus Transmission by the Water Vehicle. I. Viruses," *Health Laboratory Science*, 3: 86-89.

5. Berg, G. (1966c), "Virus Transmission by the Water Vehicle. II. Virus Removal by Sewage Treatment Procedures," *Health Laboratory Science*, 3: 90-100.

6. Berg, G. (1966c), "Virus Transmission by the Water Vehicle. III. Removal of Viruses by Water Treatment Procedures," *Health Laboratory Science*, 3: 170-181.

7. Berg, G. (ed.), (1967), *Transmission of Viruses by the Water Route*, 484 p., Interscience Publishers, New York.

8. Berg, G. (1973), "Reassessment of the Virus Problem in Sewage and in Surface and Renovated Waters," in *Progress in Water Technology*, Volume 3, pp. 87-94, Pergamon Press, New York.

9. Berg, G., Dean, R. B., and D. R. Dahling (1968), "Removal of Poliovirus 1 from Secondary Effluents by Lime Flocculation and Rapid Sand Filtration," *Jour. Am. Water Works Assn.*, 60: 193-198.

10. Clarke, N. A. (1974), in *Public Health Aspects of Viruses in Water*, page 5, Vol. 4, N. A. Clarke (ed.), National Environmental Research Center, Environmental Protection Agency, Cincinnati.

11. Clarke, N. A. and P. W. Kabler (1964), "Human Enteric Viruses in Sewage," *Health Laboratory Science*, 1: 44-50.

12. Clarke, N. A., Liu, O. C., Akin, E. W., and J. C. Hoff (1973), "Viruses in Drinking Water Study," *Progress Report*, 69 pp., August 29, 1973, National Environmental Research Center, Environmental Protection Agency, Cincinnati, Ohio.

13. Coin, L., Hannoun, M. C., and C. Gomella (1964), "Inactivation par l'ozone du virus de la poliomyelite présent dans les eaux," *La Presse Medicale*, 72: 2153-2156.

14. Coin, L., Menetrier, M. L., Labonde, J., and M. C. Hannoun (1966), "Modern Microbiological and Virological Aspects of Water Pollution," pp. 1-10, in *Advances in Water Pollution Research, Proceedings of the 2nd International Conference.* Pergamon Press, New York.

15. Craun, G. F. and L. J. McCabe (1973). "Review of the Causes of Waterborne-Disease Outbreaks," *Jour. American Water Works Association,* 65: 74-84.

16. Fair, G. M. and J. C. Geyer (1958), *Elements of Water Supply and Wastewater Disposal,* pp. 275-286, John Wiley and Sons, New York.

17. Feinstone, S. M., Kapikian, A. Z., and R. H. Purcell (1973), "Hepatitis A: Detection by Immune Electron Microscopy of a Virus-like Antigen Associated with Acute Illness," *Science,* 182: 1026-1028.

18. Feinstone, S. M., Kapikian, A. Z., Gerin, J. L., and R. H. Purcell (1974), "Boyant Density of Hepatitis A Virus Like Particle in Cesium Chloride." *J. Virology,* 13: 1412-1414.

19. Geldreich, E. E. and N. A. Clarke (1971), "The Coliform Test: A Criterion for the Viral Safety of Water," pp. 103-110, in *Proceedings of the 13th Water Quality Conference, Virus and Water Quality: Occurrence and Control,* V. Snoeyink and V. Griffin (eds.), University of Illinois at Urbana-Champaign.

20. Goldfield, N. (1974), "Epidemiologic Aspects of Waterborne Viral Disease," presented at the International Conference on Viruses in Water, June 9-12, 1974, Mexico City. *Proceedings* to be published by the American Public Health Association.

21. Hill, W. F., Jr., Akin, E. W., Benton, W. H., Mayhew, C. J. and W. Jakubowski (1974), "Apparatus for Conditioning Unlimited Quantities of Finished Waters for Enteric Virus Detection," *Appl. Microbiol.,* 27: 1177-1178.

22. Kapikian, A. Z., Gerin, J. L., Wyatt, R. G., Thornhill, T. S. and R. M. Chanock (1973). "Density in Cesium Chloride of the 27 nm '8FIIa' Particle Associated with Acute Infectious Nonbacterial Gastroenteritis: Determination by Ultracentrifugation and Immune Electron Microscopy," *Proc. Soc. Exp. Biol. Med.,* 142: 874-877.

23. Katz, M. and S. A. Plotkin (1967), "Minimal Infective Dose of Attenuated Poliovirus for Man," *Amer. Jour. Pub. Health,* 57: 1837-

24. Katzenelson, E., Kletter, B., Schechter, H., and H. I. Shuval (1974), "Inactivation of Viruses and Bacteria by Ozone," Chapter 17, pp. 409-421, in *Chemistry of Water Supply, Treatment and Distribution,* A. J. Rubin (ed.), Ann Arbor Science Publishers, Ann Arbor.

25. Liu, O. C., Seraichekas, H. R., Akin, E. W., Brashear, D. A., Katz, E. L., and W. F. Hill, Jr. (1971), "Relative Resistance

of Twenty Human Enteric Viruses to Free Chlorine in Potomac Water," pp. 171-194, in *Proceedings of the 13th Water Quality Conference, Virus and Water Quality: Occurrence and Control*, V. Snoeyink and V. Griffin (eds.), University of Illinois at Urbana-Champaign.

26. Majumdar, S. B., Ceckler, W. H. and O. J. Sproul (1973), "Inactivation of Poliovirus in Water by Ozonation," *Jour. Water Pollution Control Federation*, 45: 2433-2443.

27. Merson, M. H., Barker, W. H., Craun, G. F., and J. L. McCabe (1974), "Outbreaks of Waterborne Disease in the U. S., 1971-1972," *J. Infectious Diseases*, 129: 614-615.

28. Moseley, J. W. (1967), "Transmission of Viral Diseases by Drinking Water," pp. 5-23, in *Transmission of Viruses by the Water Route*, G. Berg (ed.), Interscience, New York.

29. Nupen, E. M. (1973), "Microbiological Quality of Water Supplies," presented at *Symposium on Water Utilization and Quality*, Institute of Water Pollution Control (South Africa) and the Division of Hydraulic and Water Engineering (S.A.I.C.E.), Johannesburg, Nov. 27.

30. Nupen, E. (1972a), "Virus Inactivation During Physical and Chemical Treatment," presented at University of Texas Conference on Virus Survival in Water and Wastewater Systems, April 1-3, 1974, Austin, *Proceedings* to be published.

31. Nupen, E. (1974b), Personal communication.

32. Plotkin, S. A. and M. Katz (1967), "Minimal Infective Dose of Viruses for Man by the Oral Route," pp. 151-166, in *Transmission of Viruses by the Water Route*, G. Berg (ed.), Interscience, New York.

33. Robeck, G. G., Clarke, N. A., and K. A. Dostal (1962), "Effectiveness of Water Treatment Processes in Virus Removal," *Jour. Am. Water Works Assn.*, 54: 1275-1292.

34. Snoeyink, V. and V. Griffin (1971), *Proceedings of the 13th Water Quality Conference, Virus and Water Quality: Occurrence and Control*, University of Illinois at Urbana-Champaign.

35. Sobsey, M. D., Wallis, C., Hobbs, M. F., Green, A. C., and J. L. Melnick (1973a), "Virus Removal and Inactivation by Physical Chemical Waste Treatment," *Jour. Env. Engng. Div., Proc. Amer. Soc. Civ. Engineers*, 99: 245-252.

36. Sobsey, M. D., Henderson, M., Wallis, C., and J. L. Melnick (1973b), "Concentration of Enteroviruses from Large Volumes of Water," *Appl. Microbiol.*, 26: 529-534.

37. Sproul, O. J. (1971), "Recent Research Results on Virus Inactivation by Water Treatment Processes," pp. 159-166, in *Proceedings of the 13th Water Quality Conference, Virus and Water Quality: Occurrence and Control*, V. Snoeyink and V. Griffin (eds.), University of Illinois at Urbana-Champaign.

38. Sproul, O. J. (1974), "Removal of Viruses by Treatment Processes," presented at *International Conference on Viruses in Water,* June 9-12, 1974, Mexico City. *Proceedings* to be published by the American Public Health Association.

39. Sweet, B. A., Ellender, R. D. and J. K. L. Leong (1974), "Recovery and Removal of Viruses from Water Utilizing Membrane Techniques," in *Developments in Industrial Microbiology,* Vol. 15, in press.

40. University of Texas at Austin, *Symposium on Virus Survival in Water and Wastewater Systems,* April 1-3, 1974, Austin, *Proceedings* to be published.

41. Viswanathan (1957), "Infectious Hepatitis in New Delhi (1955-56): A Critical Study," *Indian J. Med. Research,* Vol. 45, supplementary number.

42. Wallis, C., Homma, A., and J. L. Melnick (1972a), "A Portable Virus Concentrator for Testing Water in the Field," *Water Research,* 6: 1249-1256.

43. Wallis, C., Henderson, M. and J. L. Melnick (1972b), "Enterovirus Concentration on Cellulose Membranes," *Appl. Microbiol.,* 23: 476-480.

44. Wentworth, D. F., Thorup, R. T., and O. J. Sproul (1968), "Poliovirus Inactivation by Water-Softening Precipitation Processes," *J. Am. Water Works Assn.,* 60: 939-947.

45. Wyatt, R. G., Dolin, R., Blacklow, N. R., DuPont, H. L., Buscho, R. F., Thornhill, T. S., Kapikian, A. Z., and R. M. Chanock (1974), "Comparison of Three Agents of Acute Infectious Nonbacterial Gastroenteritis by Cross Challenge in Volunteers," *J. Infectious Diseases,* 129: 709-714.

QUESTIONS AND DISCUSSION

QUESTION: (Dr. Craun, EPA, Cincinnati) I have one comment that I'd like to make on your observation on waterborne infectious diseases that have been documented in regard to hepatitis A. It's true that in the private, which includes individual semi-public systems, the vast majority of infectious hepatitis outbreaks have been related to consumption of untreated contaminated water. Looking at municipal systems we do have a number of infectious hepatitis outbreaks that have also been related to this factor. However, when you look at infectious hepatitis outbreaks that have been documented in municipal systems employing some form of treatment, the vast majority of the outbreaks of infectious hepatitis seem to occur as a result of cross connections, not contamination getting through the treatment system. Do you have any comment on that?

DR. SOBSEY: It is important to recognize that the distribution systems of municipal water supplies must be protected from contamination by cross connections, back siphonage and other possible causes. Obviously, programs must be implemented to insure that adequately treated municipal drinking water is not degraded in quality after the water leaves the treatment plant and before it is consumed. The fact that outbreaks of infectious hepatitis in municipal water supplies occur largely as a result of cross connections suggests to me that chlorine residuals in such treated supplies are inadequate for controlling that type of contamination with respect to infectious hepatitis.

QUESTION: (Bob Stewart, Hazen and Sawyer, Raleigh) The business of viruses in public water supplies, especially large operated water supplies--are there any big systems like New York, Chicago or Los Angeles or foreign instances where the source waters are troublesome? Is there any kind of, say, virus analysis not necessarily as a routine thing, but as some kind of a research program associated with it or the Dallas water reuse or even in the space program where I suppose they've got to figure recycling people's water for days or months?

DR. SOBSEY: The question is what types of virus surveillance studies have been done on water supplies. So far as I know the only studies on large municipal supplies were those conducted in Paris, France, during the mid-1960's. They used an inefficient virus detection technique employing gauze swabs, but it was the only one that was readily available at the time. Viruses were very easily recovered from the raw water intake that the City of Paris was using, and viruses were recovered in the final finished water. I might add that the City of Paris uses ozonation and not chlorination. Ozone does not maintain a residual in the distribution system. It's my understanding that after the discovery of enteric viruses in Paris drinking water, the ozonation levels were increased, and in subsequent studies, the incidence of virus isolation from the drinking water was lower. The studies that I know about in terms of reclamation systems are those at the Windhock Wastewater Reclamation Plant in South Africa and the Santee project in Southern California. Extensive virus studies have been done on both systems, and those at Windhock are still in progress.

Virus surveillance studies on selected water supplies are now being conducted by the Environmental Protection Agency.

QUESTION: You made a statement to the effect that polioviruses are often the most prevalent enteric viruses in wastewater because of the widespread use of oral polio vaccine and that waterborne poliomyelitis is rare. Could you comment on the prospects of a vaccine for gastroenteritis?

DR. SOBSEY: The prospects of developing vaccines for waterborne gastroenteritis are dim and will remain so until more is known about the etiology of such outbreaks. The etiology of gastroenteritis, waterborne or otherwise, is not fully understood. The term gastroenteritis is used to describe a clinical syndrome which can be produced by reactions to such diverse things as foods, toxic chemicals, bacterial toxins and infections with enteropathogenic bacteria. In addition, there have been outbreaks of acute gastroenteritis of unknown etiology. Some of these outbreaks may have been due to viruses which have not yet been isolated and identified, such as the Norwalk outbreak in which parvovirus-like particles were found in bacteria-free filtrates of fecal samples collected from acute phase cases. As I mentioned before, the use of the term gastroenteritis for waterborne outbreaks also includes outbreaks in which laboratory work was either not performed or gave completely negative results.

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ORGANIC CHEMICALS IN DRINKING WATER

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INTRODUCTION

The reuse of wastewater is not innovative to this country. Unplanned, indirect reuse of wastewaters as a part of domestic water sources is a common practice; for example, where wastewater is discharged upstream into rivers used for domestic water supply. About 50 percent of the population in the United States uses water that in part is made up of wastewaters from industrial discharges, untreated sewage, urban runoff, and effluents from a variety of sewage treatment plants (1).** The Public Advisory Committee in their report on the proposed 1974 Federal Drinking Water Standards considered this situation and stated that it views with alarm the increase in the number of wastewater discharges, the decreasing dilution of these effluents with natural waters and the decreasing distances between these discharges and water supply intakes (2).

Planned reuse is also not new, particularly in California where almost every potential form of wastewater reclamation is practiced including crop irrigation, landscape-golf course irrigation, industrial water supply, recreational and ornamental impoundments and groundwater recharge. These activities range from the use of primary effluent on fodder, fiber and seed crops to two of the world's most highly publicized reuse projects, the recreational facility at Santee and the reclamation project at South Lake Tahoe. California has about 200 projects using renovated wastewater with an estimated 18 percent of all domestic wastewater being reclaimed for reuse or percolated to underground waters where it is available for reuse.

WASTEWATER REUSE

California policy is to encourage wastewater reuse where such uses do not present hazards to the public health. Wastewater, however, is an infectious, hazardous material which must always be

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* *Editor's Note:* Oral presentation by Dr. Spath.
**Numbers in parentheses refer to correspondingly numbered items in *References*.

treated with cautious respect. For each kind of reuse, there is a certain level of public health risk and hazard. Use of renovated wastewater for many purposes can be accomplished with safety when treatment and quality standards are appropriate to the degree of potential human contact.

With higher level risks, higher degrees of treatment are required, higher standards of performance are imposed, and the need for fool-proof reliability becomes compelling. Standards have been established by regulation for treatment facilities and product water quality for various uses. In California, regulations are in the process of being adopted to include reliability requirements for various types of reuse. These regulations, however, do not include standards for use of renovated wastewater for major groundwater recharge projects, nor for more direct use of renovated wastewater for domestic purposes.

Standards for the latter uses are not known to exist in any part of the world. Along with the problems of virus removal and performance reliability, a major obstacle to these uses lies in the uncertainty about the risks of chronic illness from long-term exposure to the residual organics that remain in the most highly treated wastewater.

HEALTH CONSIDERATIONS

Until recently, concern over ingestion of various, generally small, quantities of wastewater in drinking water has been focused on possible communicable disease transmission and, to a lesser degree, the possibility of acute toxic effects. The 1962 Public Health Service Drinking Water Standards do not address themselves to the existence of potentially toxic organic chemicals other than the gross standard for Carbon Chloroform Extract (CCE) which is not based on toxicological data. The proposed 1973 Federal Drinking Water Standards have been somewhat expanded to include limits for specific chlorinated hydrocarbon pesticides, the organophosphate insecticides and two chlorophenoxy herbicides with only those limits established for the chlorinated hydrocarbon pesticides being derived as tolerance for use levels over a lifetime. Moreover, the Advisory Committee takes the position that "the revised standards are not intended for the ultimate reuse of municipal wastewater as a direct source of public supply for human consumption with little or no intermediate dilution" (2).

Health agencies are not expressing concern over the matter of potential long-term effects from prolonged ingestion of organic residues originating in domestic sewage and other wastewaters reaching domestic water sources. Most important are those communities that have long been consuming water from supply sources receiving wastewater discharges. Information is needed on the identity of organic residues in these water sources and any resulting health effects from their use. With regard to the possible future use of renovated wastewater as a water source, research should be focused first on those organic constituents in domestic sewage from residential communities. The large number of new, potentially toxic, organic chemicals discharged by industries each year would make the use of industrial waste-laden sewage as a source highly unpracticable.

At present, available information on the nature and identity of organic chemicals in water supply sources burdened by upstream waste discharges and the raw and treated domestic sewage is limited. Techniques required to isolate and identify these materials are quite sophisticated and time-consuming. The most promising analytical tool for organic identification appears to be the gas chromatograph-mass spectrometer (GC/MS) computer couple system similar to that employed by EPA's Southeast Environmental Research Laboratory (3). As pointed out by Hrutfiord and Christman (4), these systems are expensive and are available at only a limited number of laboratories.

Little is known about the toxicity of residual organic chemicals, and assessment of adverse effects are relatively difficult. Although acute or chronic toxicity may be measured in animals using classical toxicological techniques, extrapolations from experimental animals to humans are often difficult and uncertain.

Screening tests to determine the carcinogenicity of a chemical is also an expensive and time-consuming operation. In the National Cancer Institute's (NCI) carcinogenesis program, each chemical tested for carcinogenicity requires, on the average, three years, 500 animals, and $70,000 (5).

Even less satisfactory is the evaluation of possible genetic effects; i.e., teratogenicity and mutagenicity. In addition to these difficulties, the possible synergistic effects of combinations of chemicals are almost totally unknown.

Regarding difficulties with respect to carcinogens, Stokinger and Woodward (6) wrote, "The question of the factor to be used to modify the limiting water concentration of a known or potentially carcinogenic agent poses an almost insoluble problem at present." The reasons for this pessimistic position relate to understanding lifetime dosage in water, the unknown relationship between carcinogenicity in animals and in man and the uncertain role of cocarcinogens. A study by Borneff (7) of the interrelationship of benzpyrene and detergents, both of which may be present in wastewater, showed that the simultaneous ingestion of both produced cancer, whereas ingestion of benzpyrene alone did not.

It is interesting to consider the position of the U.S. Food and Drug Administration (Food, Drug, and Cosmetic Act) (8) regarding food additives. The Delaney amendment states "that no additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal ...." This has been interpreted to mean that no substance can be added to food if it causes cancer in any animal at any dosage. Should this policy be applied to water, some present water supply sources would likely be rejected.

In similar fashion, from an industrial-hygiene point of view, hazardous carcinogenic substances have been identified for which no exposure by any route--respiratory, skin, or oral--should be permitted because of the high incidence of cancer in man (9). This list includes p-aminobiphenyl and benzidene and its salts (beta-naphthylamine, 4-nitrodiphenyl, dimethyl-sulfate, and bis-chloromethylether). At least two of them have been identified in river water (benzidine and napthylamine) (10).

DOMESTIC SOURCE AUGMENTATION

The pressures for reusing renovated wastewater as a means for augmenting existing domestic sources, especially in water-short areas, are steadily increasing. In California this trend has gained impetus from a legislative declaration of policy (11) (Porter-Cologne Water Quality Act of 1967) which states that "the people of the State have a primary interest in the development of facilities to reclaim water containing waste to supplement existing surface and underground water supplies ..." The Resources Agency of California in a preliminary statement of environmental goals and policy, not officially adopted, also proposes to commit the State to wastewater reuse "as a part of a comprehensive water supply and management program."

At present, there are three planned augmentation facilities in operation in California, all of which involve recharge of groundwater basins. These include the activities at Whittier Narrows, Hemet and Camp Pendleton (U. S. Marine Base). The largest operation, which began in 1962 at Whittier Narrows in Los Angeles County recharges between 50,000 to 60,000 acre-feet per year (44.8 to 53.7 MGD) of secondary effluent. Estimates have indicated that within ten to twenty years 100 percent of the water pumped from areas nearest the spreading grounds will be recharged water (12). Unfortunately, until recently the organic content of the basin water has not been adequately monitored.

A number of specific project proposals are also being developed for major groundwater replenishment with renovated wastewater. One such project, the Orange County Water District *Water Factory 21*, is near completion. This facility will inject a 50 percent blend of desalinated sea water and renovated wastewater into a groundwater basin for purposes of providing a sea water intrusion barrier. Approval of this project by the California State Board of Public Health is conditional and subject to strict controls including continuous monitoring of injected water and long-range studies of health effects of using renovated wastewater. An important condition applied to the project is "that an alternate source of domestic water supply shall be provided any user whose groundwater is found to be impaired by the injection program."

Other proposals, still in very preliminary form, would introduce reclaimed sewage into existing domestic water impoundments and even (in the extreme) utilize treated sewage directly as a portion of the raw water supply with or without dilution.

ALTERNATIVE USES

In many cases, proposals for the augmentation of domestic water sources have been made with little consideration given to non-engineering factors (e.g., environmental, public health, etc.) in evaluation of these projects. Since many of these projects, particularly those involving groundwater recharge, risk the potential degradation and possible loss of whole domestic water sources, a review of alternative uses would appear to be most appropriate. The substitution of renovated wastewater for high quality water for purposes requiring somewhat lesser quality water such as agricultural irrigation and industrial use for process and cooling could prevent the squandering of fresh water sources. Where this approach has been taken, the results have been most favorable.

As early as 1929, the City of Pomona initiated a project utilizing renovated wastewater for domestic irrigation of lawns and gardens. Kaiser Steel has reclaimed water for industrial purposes in their mill in Fontana, California, for 20 years. The City of Burbank supplies approximately 3.5 MGD of renovated wastewater for cooling purposes while Contra Costa County is about to embark upon a major reclamation activity by supplying 30 MGD to a number of oil companies for process and irrigation water.

A too-little noted reclamation operation exists at Colorado Springs where renovated wastewater is sold as irrigation water and with some additional treatment for industrial purposes. The cost of the renovated wastewater is $0.26/1000 gallons, while the price of potable water is $0.38/1000 gallons (13).

Reuse through regionalization of wastewater collection and renovation is being actively investigated in California, especially with regard to agricultural use. This approach has been considered in the San Francisco Bay Area where renovated bay area wastewater would be conveyed to the San Joaquin Valley for crop irrigation. Regionalization becomes attractive in such cases where available waste flows are sizable enough to make extensive renovated water transport practicable.

SUMMARY AND CONCLUSION

The unplanned introduction of a myriad of organic chemicals into domestic water sources occurs daily. Ingestion of these materials in various quantities exposes a large population group to potential health risks. Emphasis should be placed on determining these organic constituents and identifying their health effects. Intensive water quality surveillance programs must be instituted, and a protocol for examination must be developed employing the sophisticated tools required both for the concentration of these trace organics and their analysis.

Planned wastewater reuse for domestic purposes, both direct and indirect, carries a heavy burden of responsibility with it. The identity of organic residues in renovated domestic sewage has been only partly established and essentially nothing is known about potential health effects from long-term use of wastewater containing these substances. Such reuse projects must be approached with extreme caution and alternative, less restrictive uses considered especially in substitution for high-quality domestic water.

Without question, until more is known about this subject, efforts should be made to reduce quantities of stable organics now present in water supply sources and to prevent their introduction at places now receiving organics-free water. Since the proper position of a health agency must be conservative, no practice that increases the organics burden on a water supply should be encouraged or permitted until positive assurances of water safety are obtained (14).

REFERENCES CITED

1. U.S. Environmental Protection Agency Policy Statement on Water Reuse and Water Reuse Background Statement.

2. Public Advisory Committee Report (1973), "Federal Drinking Water Standards."

3. Webb, R. E., A. W. Garrison, H. K. Lawrence, and J. M. McGuire (1973), "Current Practice in GC-MS Analysis of Organics in Water," Environmental Protection Technology Series, EPA-R2-73-277, U. S. Environmental Protection Agency, Washington, D. C.

4. Christman, R. F., and B. F. Hrutfiord (1973), "Water Quality Standards for Organic Contaminants: Analytical Limitations and Possibilities," in *Proceedings Fifteenth Water Quality Conference, Organic Matter in Water Supplies: Occurrence, Significance, and Control*, University of Illinois, Urbana.

5. Anon. (1974), "Chemical Carcinogenesis: A Long-Neglected Field Blossoms," *Science*, 183, 940.

6. Stokinger, A. E., and R. L. Woodward (1958), "Toxicological Methods for Establishing Drinking Water Standards," *J. Amer. Water Works Assn.*, 50, 515.

7. Borneff, J. (1960), "Cancerogens Substanzen in Wassen und Boden IV Futterungoversuch, Unit 3, 4-Benzpyren und Detergentien," *Arch. f. Hyg. u. Bakt.*,

8. Food, Drug and Cosmetic Act, Title 21, Sec. 409 (348)(C)(3)(A) (January 1964).

9. Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment, American Conf. Gov't. Ind. Hyg. (1972).

10. *Water Quality Criteria Data Book: Organic Chemical Pollution of Freshwater*, (1970), Vol. 1, by A. D. Little Company, Inc., for Water Pollution Control Research Series, EPA 18010 DPU 12/70, U.S. Environmental Protection Agency, Washington, D. C.

11. California Water Code, Chapter 7, Article 2, Section 13511.

12. Central and West Basin Water Replenishment District (1970), "Management of Ground Water Quality in the Central and West Basin Water Replenishment District."

13. Okun, D. A. (1971), "New Directions for Wastewater Collection and Disposal," *Jour. Water Poll. Control Fed.*, 43, 2171.

14. Ongerth, H. J., D. P. Spath, J. Crook, and A. E. Greenberg (1973), "Public Health Aspects of Organics in Water Supply," *Jour. Amer. Water Works Assn.*, 7, 495.

QUESTIONS AND DISCUSSION

QUESTION: (Hutchinson) Just recently I had an opportunity to review that Orange County Water Factory No. 21 proposal. It's unusual in that California is a good distance away from Florida so what goes on in California sets a precedent which might be followed in Florida. There's a lot of interest in water reclamation, and this was described as being done. Then, when I checked into it, I found out that it was proposed, and there are a lot of safeguards which you mentioned. One thing I didn't notice in the documents I had was how close the drinking water supply was to this injection point. You mentioned specific requirements if any endangerment came about that there would have to be something done about it. Could you expand your remarks on that a little bit?

DR. SPATH: Ostensibly, the project was set up to be a sea water intrusion barrier. Recent information has indicated that it will have an influence on domestic water wells, although I'm really not sure as to how close they are and what the time of travel is through the underground. I think the California State Board of Public Health has put the proper restrictions on the operation; and secondly, they intend to convene a panel of medical experts who will take a look at this operation prior to its actual implementation and make a final judgment at that time as to whether to actually allow it to go in or add more safeguards. There is also the possibility that these domestic wells would be closed if a health hazard was found to exist after the project was in operation.

COMMENT: (from audience) I'd like to congratulate the author and the deliverer of the paper because it expresses sentiment with which I am in full agreement. I wanted to just add a little item on Colorado Springs. Our speaker mentioned that the reuse of wastewaters that are well treated has been extremely useful for cities because what it has done by substituting for fresh water is to put off, perhaps permanently, what would have been a very large new water resource project and would have required tunneling through the mountains and getting water from the west side of the Rockies. But I'd like to cite another example of this kind of reuse which I believe has far more potential and that's in the case of Singapore. Singapore is a highly industrialized island and has very limited fresh water resources. In trying to make these fresh water resources go farther, they established an industrial water supply made up entirely of activated sludge treatment plant effluent. They use this extensively for industrial cooling process water. They've done one other thing which I think is exceptional. They have these developments in the industrial area, and they connected this reused industrial water supply for the flushing of toilets. If fresh water is as short as it is in California and other areas, it seems to be rather strange to use it for the largest single household use which is toilet flushing.

QUESTION: (Dave Smith, School of Public Health, Graduate Student) Pursuing the thought that you presented today, there were three points made which seemed to me ought to warrant some discussion. First of all, since we assumed that the exact composition of the organic fractions in water is pretty well known and since the danger of the identified compounds is basically unknown and since the presence of these compounds which are known are basically ubiquitous, for example, BP is shown by Borneff in Germany to be found in ground water, surface runoff and river waters, doesn't this indicate better water treatment is more important than expending a great deal of money in wastewater treatment?

DR. SPATH: That certainly would be a good point, but I imagine economics has a great deal to do with that. Improved water treatment would also involve the expenditures of large sums of money; and since water treatment systems do not benefit from state and federal construction funding, municipalities must shoulder the full cost of these improvements. In many cases, this situation prohibits the construction of new systems even where they are badly needed.

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OVERVIEW OF PROBLEMS ASSOCIATED WITH INORGANIC CONTAMINANTS IN DRINKING WATER

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INTRODUCTION

On the federal level, the U. S. Public Health Service has for some 60 years had the responsibility for certifying the safety of drinking water supplied to and used on interstate carriers. Drinking water standards (1)** have been established and are applied to these particular water supplies. The current standards and proposed revisions include limits for some inorganic constituents. Each constituent limit was selected by an advisory group after consideration of various factors, such as occurrence, available scientific literature, legal precedence, and practical experience; and each has a different degree of scientific and field data to support its limit.

The U. S. Environmental Protection Agency inherited this responsibility from the Public Health Service and is currently updating the 1962 standards. The Water Supply Research Laboratory of the National Environmental Research Center in Cincinnati conducts health-effects studies and research for the agency to enable the setting of limits for various contaminants not in the *Drinking Water Standards* and for the revision of current limits not based on sound health effects data. In addition, the laboratory is responsible for development of the necessary engineering technology to ensure attainment of the limits established.

An overview of some of the problems associated with inorganic contaminants in drinking water and a discussion of some of the research being conducted in this area by our laboratory will be presented in this paper.

Almost always, whenever the chemical constituents of drinking water are discussed, a negative approach is taken and seldom is any consideration given to what elements should be present. Thus far, we have attempted to provide an optimum concentration of only fluoride in drinking water. The basis for this was derived primarily from epidemiological studies in areas where the naturally occurring concentration in water was either minimal, optimal, or

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* *Editor's Note:* Oral presentation by Dr. Craun.
**Numbers in parentheses refer to correspondingly numbered items in *References*.

excessive. Despite the numerous studies that confirm the beneficial aspects of maintaining an optimum concentration of fluoride in water, this issue is still controversial. The reason for mentioning the idea of optimal concentration is not to create additional controversy, but to emphasize that for many elements found in water, there is a beneficial effect, and we do not have to have a zero tolerance. The essential inorganic elements that man requires include calcium, magnesium, iron, sodium, potassium, and recent research (2) has suggested fluoride as essential. Animal studies have shown a need for zinc, copper, cobalt, and manganese. and man probably has the same essential needs. For many of the other heavy metals, there is no benefit known to date; but man seems to be used to exposure of some degree, and a zero tolerance is not always indicated.

WATERBORNE OUTBREAKS

Even though it is recognized that reporting is incomplete, it is helpful to review waterborne outbreaks to see which inorganic contaminants are most often involved in chemical poisonings. During the 27-year period 1946-1972, it was found that 405 waterborne outbreaks occurred in this country resulting in over 79,000 cases of illness (3,4). The vast majority of these outbreaks were associated with infectious agents, but 19 outbreaks and 279 cases of illness were related to chemical poisoning. There were 11 outbreaks because of inorganic contamination--about three percent of the total number of waterborne outbreaks documented during this period.

The chemical poisoning as a waterborne illness resulted in fewer cases per outbreak than the average, but there was an excessive number of deaths. For all waterborne illness, the mortality was only 0.05 percent, but the outbreaks from inorganic chemical poisonings had a mortality of 3.4 percent (208 cases of illness and 7 deaths).

The largest outbreak of this type caused 150 cases of illness in a Pennsylvania school--the fluoride feeder was run when the well was not pumped. The fluoride concentration was 67 milligrams per liter (mg/l), but a complicating feature was the detection of 4.5 mg/l of copper in the Kool Aid made with the water. A similar occurrence in North Carolina (5) was reported in April 1974 and is not included in the previous tabulations. Two hundred and one (201) students and 12 adults at a rural grammar school in Stanley County became ill within minutes after drinking orange juice at morning recess. There were 126 persons who did not drink the juice; none of these people became ill. The school's water is supplied by a private well. In the month prior to the outbreak, the water pump had operated intermittently, and in the week prior to the outbreak, while school was closed for the Easter holidays, the fluoride feeder malfunctioned causing fluoride solution to be fed into the water system continuously while the water pump was not operating. Laboratory analysis of the orange juice served at the school revealed a fluoride level of 270 mg/l. A water sample obtained at the school on the afternoon of April 16 had a fluoride concentration of 125 mg/l. Both of these outbreaks are consistent with the observation that as little as 16 mg of sodium fluoride can produce nausea while 65 mg can cause vomiting (5).

Arsenic was related to five, about half, of the outbreaks, and the reasons for the outbreaks are most varied. One outbreak of 10 cases and 3 deaths resulted when an arsenical weed killer was deliberately added to a well in West Virginia. These are the only murders that have been noted in the review of waterborne outbreaks. Two outbreaks concerned the backsiphonage of arsenic compounds into water supplies, and five cases of illness and four deaths resulted. Recently, a well was drilled at a new factory site in Minnesota, and people working there became ill (6). Arsenic was detected in the blood of those becoming ill, and investigation revealed arsenic in the well water--11.8 to 21 mg/l. The site had been used to mix grasshopper bait many years before, and it was reported that some unused pesticide had been buried where the well was drilled. Two girls in a Nevada family became ill, and after some difficulty of diagnosis, it was determined that they had arsenic poisoning. The well at the family ranch varied between 0.5 to 2.75 mg/l of arsenic from natural causes.

Two outbreaks of selenium poisoning occurred in families using private wells. A family in Colorado suffered from selenium poisoning because their well had 9 mg/l of the element. Another family in Alabama was reported ill because of drinking well water containing selenium.

Two outbreaks of copper poisonings and one of chromium were associated with water coolers or soft drink machines. When the valves of soft drink machines allow carbon dioxide to leak back into the water line, the copper tubing usually used for a feed line becomes excessively corroded. In many cases, the product tastes so bad it is not consumed; but sometimes the tastes are masked by the soft drink, and people drink it and become ill. The chromium outbreak was caused by the erroneous connection of the water feed tubing to a hot-water heating line that contained corrosion control chemicals.

It is useful to review these outbreaks so that the circumstances that allowed them to occur can be examined and future occurrence prevented by proper control. The water utilities and state control agencies should be interested in these statistics, but the research scientist is generally more concerned with chronic low-level exposures than acute poisonings.

The effect of drinking water quality on chronic disease mortality has been studied by a number of investigators since Kobayashi (7) showed a correlation between cerebrovascular mortality and the acidity of water supplies in Japan. Winton and McCabe (8) and Masironi (9) have summarized information presented by various investigators regarding the relationship of drinking water to disease and death. A number of investigators (10-24) have contributed evidence supporting hypotheses that areas with hard water tend to have lower death rates and less cardiovascular disease than soft water areas. The lower heart disease death rates could be caused by something beneficial in hard water or the higher heart disease death rates could be caused by something detrimental in soft water. Soft water is generally more corrosive and should contain more metal contaminants from water piping, whereas hard water contains larger amounts of calcium and magnesium. In addition to the hard versus soft water hypothesis, various trace substances have also been considered.

Lindeman and Assenzo (25) and Mulcahy (26) have presented evidence for Oklahoma and Ireland that is contrary to the findings of these investigators. Sauer (24) discussed one unpublished study of North Carolina data that showed an opposite relationship, with low death rates in the mountain counties having soft drinking water. Unfortunately, there are not enough data on water quality at the consumer's tap to enable studies to be very definitive, and there are many co-variables that must be considered.

McCabe (27) calculated the age-adjusted death rates for diseases of the cardiovascular system and the parts making up this inclusive category for the metropolitan areas of the country in 1950. These central city-county data were placed into three groups based on the mineralization of the drinking water supplied to at least half of the population of the area. In some cases, the water supply was so mixed that an area could not be included in the analysis. The limits used for dissolved solids content were 0-99, 100-199, and 200 or more milligrams per liter.

Table 1 displays these rates, and the people drinking the more mineralized water have lower heart disease mortality. Because cardiovascular disease is the leading cause of death, the total death rates reflect the same trends, and it cannot be said that the people are just dying of something else. These are sizable differences in death rates, and it is most important to understand the reasons for this occurrence.

Groundwater is more mineralized than surface water, and the smaller metropolitan areas are more likely to use groundwater because the yield will still meet their demands. Thus, there is an effect of the population size of the metropolitan area complexing these relationships. But both size and mineralization seem to have an effect that is additive.

Research on water hardness and human health has been most rigorously pursued in England, and there seems to be a general consensus there that municipal softening plants should not be built (16-18, 28).

Although we are still far from fully understanding the relation of trace elements in drinking water to cardiovascular diseases, it does appear likely that such a relation may exist. To better define the role of water quality in chronic disease mortality, particularly cardiovascular diseases, a cooperative study between our laboratory and the National Heart and Lung Institute, the National Center for Health Statistics and the Bureau of the Census is currently being conducted. A health and nutritional survey of some 4200 individuals in 35 geographically distributed areas is to

Table 1

CARDIOVASCULAR DISEASE
DEATH RATES AND WATER QUALITY
135 CENTRAL CITY-COUNTY AREAS

	Mineralization of Drinking Water Dissolved Solids - mg/l		
	0-99	100-199	200+
MALE-WHITE			
Diseases of Cardiovascular Sys.	643	616	583
Diseases of Heart	517	478	436
Vascular Lesions CNS	90	100	105
General Arteriosclerosis	21	23	24
Hypertension without Heart	7	8	9
Other Circulatory Diseases	6	6	7
FEMALE-WHITE			
Diseases of Cardiovascular Sys.	446	406	361
Diseases of Heart	330	282	237
Vascular Lesions CNS	87	94	93
General Arteriosclerosis	17	18	19
Hypertension without Heart	7	7	7
Other Circulatory Disease	4	4	4

(Age-adjusted death rates per 100,000)

Reprinted from the 16th Annual Sanitary Engineering Conference, *Trace Metals in Water Supplies: Occurrence, Significance, and Control*, Univ. of Illinois, Urbana-Champaign, Feb. 12-13, 1974.

be completed by December 1976 and will provide data on cardiovascular function for correlation with water quality data. The sample areas and sample persons have been selected by the Bureau of Census to be representative of the U. S. population. A comprehensive physical examination, which includes a medical history and cardiovascular questionnaire and the measurement of various health parameters such as blood pressure, EKG, cholesterol levels, will be conducted for each person. A major effort is being made to characterize the quality of drinking water for the study population and includes the collection and analysis of tap water samples and source water samples after treatment for some 28 trace elements and other water quality parameters that have been suggested or are felt to be related to cardiovascular disease (Na, K, Ca, Mg, As, Se, Si, F, NO_3, hardness, alkalinity, conductivity, pH, TDS, Li, V, Mn, Fe, Cu, Zn, Mo, Ag, I, Cr, Co, Ni, Cd, and Pb). For many of the elements, routine analytical methods cannot achieve the sensitivities required for detection of the element in the very low concentrations expected in drinking water and a combination of multi-elemental techniques such as proton-induced X-ray fluorescence and spark source mass spectrometry will most likely be utilized in addition to more routine analytical procedures such as atomic absorption, anodic stripping voltametry and wet chemical methods.

SOURCE OF METALS IN DRINKING WATER

Some of the problems come from geochemical pollutants. It is just part of the natural cycle of erosion and solution to have these contaminants in water. Arsenic, barium, and selenium are good examples of this problem. Supplies have been found that exceed the arsenic limit in the Southwest. Supplies exceeding the barium limit have been found in mid-Atlantic, Southern and Midwestern states. The State of Illinois EPA has identified 16 cities and 3 subdivisions as having drinking water sources with barium concentrations higher than the current limit (29). All of the supplies use well water and the highest concentration found was 10 mg/liter. Some supplies have been found to exceed the selenium limit in all but the Pacific northwest region, but the problem is greatest in the Denver region.

Other metals may result from industrial waste, and mercury would be the best example of this type of contamination. The EPA is establishing effluent standards for toxic pollutants to take care of this type of problem (30). Standards are proposed for nine toxic pollutants, and two of these are metals: cadmium and all cadmium compounds, and mercury and all mercury compounds.

There have been situations where industrial waste holding ponds have polluted groundwater with excessive metals, and several of these have involved chromium.

Municipal sewage can contribute metal to surface water and will continue to do so until more treatment is provided. The physical-chemical tertiary treatments proposed seem to be capable of removing most metal to required concentrations for water supply. The resulting sludges will be high in metals and must be suitably disposed.

A major source of metal contamination to drinking water is the water supply system. This starts out with the chemicals used in treatment. Copper might be added for algae control in reservoirs. Other treatment chemicals have trace metal content and may contribute to the metal levels in water. Aluminum is an example.

Corrosion of the distribution and household plumbing contribute to the metal content of drinking water. An industrial health survey was conducted in Chicago in 1968 (31). Water samples were collected as part of this survey and provide an opportunity to determine the metal content of a large number of samples from a single system. Composite samples were collected at the treatment plants, and these results can be compared with 550 grab samples collected from the distribution system to give an indication of metal pickup. Samples that had a higher concentration than the maximum found at the plant are used as evidence of metal pickup. The percent of samples with pickup were as follows: cadmium 15, chromium 17, cobalt 10, copper 28, iron 39, lead 20, manganese 32, nickel 34, silver 15, and zinc 67 percent.

The pickup of metal in the Chicago system did not result in samples exceeding the drinking water standards except for lead. For lead, 0.7 percent exceeded the limit. Some samples of drinking water exceeding the lead limit are common as it was found that 1.4 percent of the samples in the Community Water Supply Survey (32) exceeded the lead limit. When corrosive water is distributed, the problem can be more serious. Distribution studies conducted several years ago by EPA in Seattle (33) and Boston illustrate the effect of corrosive water on tap water quality. Both Boston and Seattle use impounded surface water and provide chlorination as the only treatment. Seattle also fluoridates adding $H_2Si\ F_6$. The hardness and alkalinity of these waters are low, and the pH is on the acidic side. The dissolved oxygen content of Seattle's water approaches saturation. The distributed waters are good solvents and exhibit aggressive corrosion tendencies. The following water quality parameters were measured on treated water at the source:

	Boston (MDC)	Seattle
1. pH	6.7	5.5
2. hardness ($CaCO_3$)	14 mg/l	-
3. TDS	50 mg/l	-
4. Alkalinity ($CaCO_3$)	8 mg/l	2 mg/l
5. Chlorides	12 mg/l	1.7 mg/l
6. Calcium	-	2.1 mg/l
7. Magnesium	-	0.3 mg/l
8. Conductivity	-	20 µmho*

In Seattle, that part of the distribution system served by the Tolt River was sampled. Samples were collected from 31 points in the distribution system, primarily from household taps, but some samples were collected from major transmission mains. Two types of samples were collected early in the morning for comparison, a *standing* and a *running* sample. *Standing* samples were the first water to run out of the faucet and represented water with a long residence time in the household plumbing and service line. *Running* samples were collected afterward, ensuring that the house lines were well flushed and represented water from the mains. This same procedure was followed in Boston, and *running* and *standing* samples were collected at 54 households in the Beacon Hill area. *Standing* samples that had a higher concentration than the *running* sample collected at the same point are used as evidence of metal pickup. The percent of samples with pickup were as follows: Boston - cadmium 13, chromium 39, copper 44, iron 52, lead 30, manganese 11, zinc 35; Seattle - cadmium 61, copper 73, iron 86, lead 95, manganese 82, zinc 95. The distribution samples collected in these two cities resulted in a number of the drinking water standards being exceeded.

In Boston, 19 percent of the distribution samples exceeded the limit for copper (1.0 mg/l), 9 percent exceeded the limit for iron (0.3 mg/l), and 65 percent exceeded the limit for lead (0.05 mg/l).

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*Micro-ohms.

In Seattle, some samples exceeded the drinking water standard for all six of the constituents measured: cadmium (0.01 mg/l) 7 percent, copper (1.0 mg/l) 24 percent, iron (0.3 mg/l) 76 percent, lead (0.05 mg/l) 24 percent, manganese (0.05 mg/l) 5 percent, zinc (5.0 mg/l) 10 percent. A summary of the Boston and Seattle data is presented in Table 2.

Table 2

DISTRIBUTION SAMPLING IN SEATTLE AND BOSTON

	Running Samples				*Standing* Samples			
	Max. Conc. (μg/l)	Mean Conc. (μg/l)	Standard Deviation	N	Max. Conc. (μg/l)	Mean Conc. (μg/l)	Standard Deviation	N
			Seattle					
Cd	0.8	0.3	0.1	28	25	2.5	5.2	28
Cu	1670	160	350	22	2050	450	610	22
Fe	1200	270	220	21	5400	1400	1300	21
Pb	17	5	4	22	170	39	49	22
Mn	23	11	4	22	79	24	17	22
Zn	1730	230	380	21	5460	1740	1520	21
			Boston					
Cd	8	1.0	1.4	54	5	0.7	1.0	54
Cr	8	3.1	1.9	54	8	3.4	1.8	54
Cu	1540	432	298	54	2410	494	504	54
Fe	560	141	116	54	442	142	83	54
Pb	241	58	49	54	321	80	78	54
Mn	34	24.6	4.8	54	42	25.4	2.9	54
Zn	1625	223	333	54	791	148	203	54

The difference in metal pickup between these systems is most likely related to the type of plumbing material and service lines in use. In Boston, a high percentage of homes sampled had lead service pipes; in Seattle, copper and galvanized iron were more commonly used. No lead pipes were reported in Seattle, and it is assumed that the source of lead in this case is from the solder used to join copper piping. Additional studies are currently being conducted in both cities. In Boston, a comparison of metal pickup in the MDC system with neighboring Cambridge will be available. A section of Cambridge is served by surface water from Hobbs Creek with characteristics similar to the Boston (MDC) source water, but the raw water is treated by coagulation, settling, filtration and pH adjustment to about pH 8.

To assist in gathering data on the water quality in distribution systems, a Mobile Water Quality Monitoring Laboratory, which was built under contract by the National Sanitation Foundation, was delivered to WSRL on October 1, 1973. Before delivery, it was field tested in Chicago for one month and in Philadelphia for one month. An on-board computer operates and collects data from each of the analyzer systems. The computer obtains data from each of the 17 different monitoring systems once or twice every 13 minutes and also can activate a sampler to collect samples with a preset frequency or whenever any of the 17 parameters shows an anomaly. The results are punched out on paper tape for later computer processing and analysis. Parameters measured by the mobile unit are: temperature, pH, alkalinity, dissolved oxygen, hardness, nitrate, fluoride, free and total chlorine, cadmium, lead, copper, index of corrosion, scale formation, sulfate, turbidity, and conductivity. Although no decision has been made regarding future surveys with the monitor, Boston, Seattle, and the Metropolitan Water District of Southern California have all expressed interest in cooperating in distribution system studies.

METAL INTAKE AND HUMAN BODY BURDEN

The Community Water Supply Survey (CWSS) collected water samples at the consumer's tap and covered 969 water systems located in nine geographic areas around the country (32). It was not a totally representative sample of the U. S., but its wide coverage should provide an estimate of the metal intake from water of consumers of community water supplies. Estimates of average intake of the metals are in Table 3 along with the percent of samples that had some of the elements present at 1 microgram per liter (μg/l) detection.

Table 3

ESTIMATED AVERAGE INTAKE OF METALS FROM WATER

COMMUNITY WATER SUPPLIES

	Average concentration μg per liter	Micrograms intake at 2 liters per day	Percent of samples with 1 μg per liter or more
Cadmium	1.3	3	63
Chromium	2.3	5	11
Cobalt	2.2	4	62
Copper	134.5	270	99
Iron	166.5	330	99
Lead	13.1	26	74
Manganese	22.2	44	78
Nickel	4.8	10	78
Silver	0.8	2	23
Zinc	193.8	390	100

Reprinted from the 16th Annual Sanitary Engineering Conference, *Trace Metals in Water Supplies: Occurrence, Significance, and Control*, Univ. of Illinois, Urbana-Champaign, Feb. 12-13, 1974.

The most widespread metal was zinc, being detected in 100 percent of the samples. With a 2-liter consumption of drinking water the average intake of zinc would be 390 μg. Iron was the next highest intake with 330 μg, but this would only supply 2 percent of the needed daily intake of the adult female. Copper, as well as iron, was present in virtually all of the samples, and the intake would be 270 μg per day.

Manganese intake would average 44 μg from drinking water and it is rather widespread, being present in 78 percent of the samples. Cobalt is another of the essential elements, and the intake from water is 4 μg.

Some investigators consider nickel and chromium to be essential. Water would make a contribution to the nickel intake of 10 μg per day. Chromium only occurred in 11 percent of the samples.

Lead and cadmium seem to be elements we do not need but receive with most of our drinking water. The maximum daily permissible intake of lead for children is set at 300 μg to prevent accumulation. The average intake from water may provide 5-10 percent of this allowed intake depending on the water consumption of the child. The average cadmium intake is 3 μg and is rather widespread, with 63 percent of the samples showing some cadmium.

Silver had the lowest average concentration of metals measured in the survey and was detected in only 23 percent of the samples. Mercury was not measured in the CWSS but was surveyed later (27). Of the 273 communities sampled, 96 percent had less than 1 μg of mercury per liter.

Most investigators feel that man's major source of trace metals is his food intake. A recent study of intake from food used institutional total diets for children 9 to 12 years of age (34). If a comparison is made between this study and the CWSS, it is found that the largest proportion of trace metal intake from water compared to food is for zinc, but this is only 4.3 percent of the total. Next is cadmium at 3.3 percent, and then manganese at 2.8 percent. The water cobalt intake was only 0.4 percent. The chromium intake figures out to be 0.8 percent, but it must be remembered that chromium does not occur in water very regularly.

If the average content of metals in water is to have any effect on man, there must be something different about the metal that occurs in water compared to metal that occurs in food. Metals often occur in food in a chelated form and may not be as available as the ionized form in water. To help answer this question, it is planned to study the physiological availability of various inorganic constituents, beginning with cadmium. The relative bioavailability of cadmium in drinking water will be compared with that of naturally occurring cadmium found in plants and grains, and with that of cadmium admixed with the diet. In each case, cadmium absorption is to be quantified in test animals. In addition, since cadmium has been suggested as a factor involved in cardiovascular disease, the effect of various concentrations of calcium and magnesium in drinking water on the absorption of cadmium will also be investigated.

The analysis of tissue, such as hair, nails, blood, and teeth, have proved to be an expedient method of measuring human body burdens in living populations (35). We are participating in epidemiological studies currently being conducted by EPA through the National Environmental Research Center (NERC) at Research Triangle Park to determine human body burdens of various trace elements and correlate these with environmental exposure. Studies have been completed in the New York City area, Charlotte, North Carolina, and

Birmingham, Alabama, and the data are being analyzed. Data from a pilot study show that even though man's intake of iron and manganese from water are relatively low when compared to food, gradients of iron and manganese have been observed in scalp hair in populations using different water supplies.

Because of the unusually high concentration of lead found in the Boston area, an epidemiological study was conducted to determine the relationship between lead body burden (as measured by blood lead levels) and the lead concentration in household tap water. The study is nearing completion, and results should be available within the next three months. Approximately 300 households in Brighton, Somerville, and Cambridge were sampled according to the type of service line, lead or non-lead. Blood samples were obtained from various residents according to age groupings and environmental samples collected at the home to determine other sources of lead exposure in addition to tap water. A questionnaire was administered to account for various co-variables.

TOXICOLOGICAL STUDIES

Research into the effects of chemicals in animal systems is an essential part of the effort to define possible health hazards. Animal experimentation has two basic advantages in this regard: (1) animals may be exposed under defined conditions with known amounts of a chemical to the point of maximum insult, and (2) measurements of effect may be made directly on the affected system.

Data from toxicological experiments also have definite limitations, but as long as the limitations of animal models are clearly recognized, they can be used to generate specific and useful information which is otherwise unobtainable. The range of qualitative data that can be provided from animal models is as follows:

1. Effect,
2. Bioavailability,
3. Long versus short-term toxicity,
4. Retention of effect,
5. Interaction with disease processes, and
6. Group-linked susceptibility.

Of all the types of drinking water contaminants, the trace metals have received more attention and research effort than any other in terms of their toxic effects. This has resulted in a huge volume of literature on certain of these elements. Unfortunately, many basic questions remain to be answered concerning the effects of this group of chemicals.

Consequently, we have projects that attempt to define the properties of toxic elements at the enzymic, subcellular, cellular, tissue, and whole animal levels of organization. These projects include: (1) studies of the effects of lead and manganese on the metabolic integrity of the central nervous system (since some water systems complex manganese by use of polyphosphates rather than by removing it, complexed manganese will also be investigated), (2) study of the effects of cadmium on hepatic detoxification enzymes,

(3) a study of the effects of cadmium on renovascular function, particularly its effect on the renin-angiotensin system and renal hypertension, and (4) studies to determine the absorption, distribution, and excretion and the toxic effects of subchronic ingestion of soluble barium. The barium study is in response to a need for additional health effects data to support the present limit of 1.0 mg per liter in drinking water.

Our approach to determining the effects of trace metals on the central nervous system combines elements of both neurophysiology and neurochemistry (36). By removing a slice of tissue from a specific area of the brain, we can examine certain aspects of brain metabolism directly and determine how it may be modified by trace metals. This test system is felt to be quite sensitive for documenting low-level effects and was initially employed to study methylmercury effects. Using this test system we found that cerebral cortex slices taken from rats exposed to methylmercury display altered metabolic responses to stimulation. The lowest dose at which change was observed occurred at exposures in the drinking water approximately 0.01 mg/kg/day for a six-month exposure. No effect was observed at an exposure approximating 0.002 mg/kg/day for the same time period. These doses would correspond to exposures of 0.7 and 0.14 mg/day for a 70 kg man, respectively. Considering all sources of exposure, these data support the 0.002 mg/liter limit proposed for mercury in drinking water.

MUTAGENIC/CARCINOGENIC EFFECTS

This area has received very little attention until recently in setting limits for water supplies, but it is becoming increasingly important. Because of the relatively large expense, time, and large numbers of test subjects required for animal studies, we have concentrated on rapid, sensitive screening techniques that can be applied to the assay of various chemicals or water samples directly. Our research is in the area of mammalian cell culture monitors or bacterial indicator systems.

We have completed control experiments, and the standardization of the BUdR-visible light technique for determining mutant mammalian cells in the CHO-K1 cell line is essentially complete. Application of the technique as a bioassay system was initiated late this year and will continue for the next several years. Inorganics to be screened for mutagenic activity will include arsenic, beryllium, cadmium, cobalt, nickel, selenium, barium, chromium, copper, lead, manganese, mercury, and zinc. All chemicals screened for forward mutation using the BUdR-visible light isolation technique will also be tested for their ability to induce reverse mutations at the proline marker. Thus, the assay system is useful for confirming the mutagenicity of chemicals by two independent methods. Several experiments have been carried out with respect to reverse mutation at the proline marker. Although all results obtained so far must be considered strictly preliminary, some interesting trends have been noted. Data obtained from experiments on cells not receiving treatment with chemicals show a low *spontaneous* mutation rate. Ethyl methane sulfonate (EMS), a mutagen known to be able to revert the proline lesion, was tested at two different concentrations and found to produce mutation rates significantly above the spontaneous rate. Arsenic (As_2O_3) has been tested, and data suggest a mutation frequency at least equal to that obtained with EMS, and possibly higher. On the other hand, all experiments with selenium (SeO_2) so far have yielded no revertants.

A grant was awarded last year to the Louisiana State University Medical Center to evaluate bacterial and/or mammalian cell monitors for use in screening municipal water supplies and sources for the presence of carcinogens. The first year of the grant was spent primarily in defining the test systems and evaluating the test systems with known carcinogens. The indicator systems were also employed on a limited number of finished and raw water samples from the lower Mississippi River. Indicator systems under investigation include histidine-dependent strains of *S. Typimurium*, mouse embryo cell R616U infected with the AKR mouse leukemia virus, the rat embryo cell S1193h, and the human diploid cell WI-38. Significant reversion rates were obtained from active carcinogens with histidine-dependent mutants alone but not with compounds requiring metabolic activation. The use of liver homogenates to activate such compounds resulted in significant reversion rates being obtained. A working bacterial indicator system was found, and the primary goal in the coming year will be the development of an efficiently functioning detection system and establishment of a standard technique applicable to all samples. For the mammalian cell monitors, further work on refining methodologies and techniques are required to ensure that a working system of high sensitivity is utilized. After the appropriate systems and methodologies are well-defined, a number of raw and finished water samples will be screened from the lower Mississippi River.

OCCURRENCE

Additional data on the occurrence of inorganics not included in the *Drinking Water Standards* are required to enable decisions to be made regarding needed health-effects studies. A survey of community water supply systems is to be conducted in the 35 areas currently included in the cardiovascular study since this will provide results based on a statistical sampling of the U. S. population.

The applicability of multi-elemental techniques, such as neutron activation, X-ray fluorescence, emission, and spark source mass spectrometry was reviewed for the analysis of these water samples. Spark source mass spectrometry was selected since this technique appears to have a broader range of elemental applicability and greater sensitivity at the present time and will be used to determine the occurrence of the following elements in the μg/l sensitivity range: B, Be, Al, Sc, Ti, Ga, Ge, Br, Rb, Sr, Y, Pd, In, Sn, Sb, Te, Cs, Ba, La, W, Pt, Tl, and Bi.

REMOVAL OF HEAVY METALS BY CONVENTIONAL TREATMENT

A program of research on the removal of trace inorganic substances by water treatment processes has been underway for several years at the Water Supply Research Laboratory. Constituents in the proposed EPA Drinking Water Standards that have been or are being studied are mercury, barium, arsenic, and selenium. Among those considered for possible future study are lead, cadmium and chromium. Treatment processes studied in the laboratory are iron coagulation, aluminum coagulation, lime softening, excess lime softening, and activated carbon adsorption. A water treatment pilot plant was recently installed and is capable of treating in parallel two 2 gpm streams of water. One treatment train of this plant has been operated in a conventional manner to study removal of metals.

Results of our research for the removal of inorganic contaminants have been summarized by Logsdon, *et al.* (37). Of the substances studied thus far (with the exception of selenium ^{VI}), if the limits in the *Drinking Water Standards* are not exceeded by a factor of more than 3 to 5, some conventional treatment method exists that should be adequate to reduce the concentrations below the limits set in the *Drinking Water Standards*.

Because of the limited amount of pilot-plant data available, it is not possible to make broad generalizations, but it can be stated that, so far, pilot-plant results agree with jar test results obtained earlier. Additional work involving treatment of raw river waters and groundwaters is needed because studies have used tap water that is dosed with bentonite to increase turbidity.

SUMMARY

There are health problems occurring because of chemical contamination of drinking water, but those that are recognized are small in number. Understanding the relation between drinking water quality and heart disease is very important. It is hard to imagine how drinking water could play a role because of the major intake of metals from food, but epidemiological evidence indicates an effect of water quality. The sources of water contamination and methods of treatment must be understood to protect the public's health and provide an acceptable quality drinking water. Standards are needed to judge the quality of water and should be applied to all water systems.

REFERENCES CITED

1. U. S. Public Health Service (1962), *Public Health Service Drinking Water Standards,* Publication No. 956.

2. Schwarz, K. (1972), "Trace Elements Newly Identified as Essential to Animals (Fluoride as an Essential Element)," 138th Meeting, Amer. Assoc. for the Advancement of Science, *Nat. Inst. of Health Fluoride Notes,* PPB-33.

3. Craun, G. F. and L. J. McCabe (1973), "Review of the Causes of Waterborne Disease Outbreaks," *Jour. Amer. Water Works Assn.,* 65, 74.

4. Merson, M. H., *et al.* (1974), "Outbreaks of Waterborne Disease in the United States, 1971-1972," *Jour. Infec. Dis.,* 129, 614.

5. *Morbidity and Mortality Weekly Report* (1974), Center for Disease Control, 23(22):199.

6. Feinglass, E. J. (1973), "Arsenic Intoxication from Well Water in the United States," *New England Jour. Med.,* 288:828.

7. Kobayashi, K. (1957), "Geographical Relationship Between the Chemical Nature of River Water and Death-Rate from Apoplexy," *Ber O'Hara Inst. Landwirtsch Biol.,* 11, 12.

8. Winton, E.F. and L. J. McCabe (1970), "Studies Relating to Water Mineralization and Health," *Jour. Amer. Water Works Assn.,* 62, 26.

9. Masironi, R. (1969), "Trace Elements and Cardiovascular Diseases," *Bull. WHO,* 40, 305.

10. Masironi, R. (1970), "Cardiovascular Mortality in Relation to Radioactivity and Hardness of Local Water Supplies," *Bull. WHO,* 43, 687.

11. Schroeder, H.A. (1960), "Relation Between Mortality from Cardiovascular Disease and Treated Water Supplies," *Jour. AMA,* 172, 1902.

12. Schroeder, H. A. (1960), "Relations Between Hardness of Water and Death Rates from Certain Chronic and Degenerative Diseases in the U. S.," *Jour. Chron. Dis.,* 12, 586.

13. Schroeder, H.A. (1974), "The Role of Trace Elements in Cardiovascular Diseases," *Med. Clin. North Am.,* 58, 381.

14. Schroeder, H. A. (1966), "Municipal Drinking Water and Cardiovascular Death Rates," *Jour. AMA,* 195, 81.

15. Schroeder, H.A. and L. A. Kraemer (1974), "Cardiovascular Mortality, Municipal Water, and Corrosion," *Arch. Environ. Health* 28, 303.

16. Morris, J. N., *et al.* (1961), "Hardness of Local Water Supplies and Mortality from Cardiovascular Disease in the County Boroughs of England and Wales," *Lancet*, 1, 860.

17. Crawford, M., *et al.* (1971), "Changes in Water Hardness and Local Death Rates," *Lancet*, 2, 327.

18. Crawford, M., *et al.* (1971), "Cardiovascular Disease and the Mineral Content of Drinking Water," *British Medical Bull.*, 27, (1), 21.

19. Biorck, G., *et al.* (1965), "On the Relationship Between Water Hardness and Death Rate in Cardiovascular Diseases," *Acta Med. Scand.*, 178, 239.

20. Bierstiker, K. (1957), "Hardnesses of Drinking Water and Mortality," *Tijdschr. Soc. Geneeck*, 45, 658.

21. Neri, L. C., *et al.* (1972), "Relation Between Mortality and Water Hardness in Canada," *Lancet*, 1, 931.

22. Perry, H. M. (1973), "Minerals in Cardiovascular Disease," *Jour. Amer. Dietetic Assn.*, 62, 631.

23. Fodor, J. C., *et al.* (1973), "Relationship of Drinking Water Quality to Cardiovascular Mortality in Newfoundland," *Can. Med. Assn. Jour.*, 108, 1365.

24. Sauer, H. I. (1974), "Relationship Between Trace Element Content of Drinking Water and Chronic Disease," in *Trace Metals in Water Supplies: Occurrence, Significance, and Control, Univ. of Ill. Bull.*, 71 (108), 39.

25. Lindeman, R. D. and J. R. Assenzo (1964), "Correlations Between Water Hardness and Cardiovascular Deaths in Oklahoma Counties," *Amer. Jour. Pub. Health*, 54, 1071.

26. Mulcahy, R. (1964), "The Influence of Water Hardness and Rainfall on the Incidence of Cardiovascular and Cerebrovascular Mortality in Ireland," *Jour. Ir. Med. Assn.*, 55, 17.

27. McCabe, L. J. (1974), "Problem of Trace Metals in Water Supplies - An Overview," in *Trace Metals in Water Supplies: Occurrence, Significance, and Control, Univ. of Ill. Bull.*, 71 (108):1.

28. Stitt, F. W., *et al.* (1973), "Clinical and Biochemical Indicators of Cardiovascular Disease Among Men Living in Hard and Soft Water Areas," *Lancet*, 1, 122.

29. Illinois Inst. for Environ. Quality (1974), "Advisory Report on Health Effects of Barium in Water," Envir. Health Resource Center Document 12.

30. Environmental Protection Agency (1974), "Proposed Toxic Pollutant Effluent Standards," *Fed. Regist.*, 38(247), 35388.

31. McCabe, L. J. and J. C. Vaughn (1969), "Trace Metals Content of Drinking Water from a Large System," National Meeting, Amer. Chemical Soc., Minneapolis.

32. McCabe, L. J., *et al.* (1970), "Survey of Community Water Supply Systems," *Jour. Amer. Water Works Assn.*, 62, 670.

33. Dangel, R. (1973), "EPA and City of Seattle Water Dept. Survey of Corrosion in the Tolt Distribution System," Unpublished Report.

34. Murthy, G. K., *et al.* (1971), "Levels of Antimony, Cadmium, Chromium, Cobalt, Manganese, and Zinc in Institutional Total Diets," *Environ. Sci. Technol.*, 5, 436.

35. Hammer, D. E., *et al.* (1971), "Hair Trace Metal Levels and Environmental Exposure," *Amer. Jour. Epidemiol.*, 93(2), 84.

36. Bull, R. J. (1974), "Toxicological Research: Its Application to the Setting of Drinking Water Standards," *Trace Metals in Water Supplies: Occurrence, Significance, and Control, University of Ill. Bull.*, 71(108), 49.

37. Logsdon, G. S., *et al.* (1974), "Removal of Heavy Metals by Conventional Treatment," in *Trace Metals in Water Supplies: Occurrence, Significance, and Control, Univ. of Ill. Bull.*, 71 (108):111.

QUESTIONS AND DISCUSSION

QUESTION: Do you care to say anything about the correlation between the blood levels of the metals in Boston that you said you were studying? I'm not sure I heard you clearly on that.

DR. CRAUN: We have collected and analyzed blood samples and various environmental samples, such as tap water, house dust, house paint, for most of the study participants. The results of these analyses and data obtained from the questionnaire are currently being compiled so I can't make a statement on that now. However, our data analysis should be completed within the next three months or so.

QUESTION: The goal of this, though, is to correlate metal intake in water with levels accumulating in the blood?

DR. CRAUN: For lead, yes.

QUESTION: Just out of curiosity, how did you get the blood samples? Were these volunteers?

DR. CRAUN: Blood samples were obtained by the micro or finger prick technique. With this technique, approximately 0.1 ml of blood is collected from the finger tip by capillary tube. This technique is frequently used in many of the lead screening programs with good success. The advantage, of course, is that participants are much more agreeable to having blood collected than if venous sampling were used. However, with the micro technique considerable care is required to avoid contamination problems in both collection and analysis. We employed a field worker experienced in this technique and found, through control studies, that contamination was not a problem in our case.

In our study, we sampled all age groups, children through elderly adults, and the field team visited homes to collect the samples. One of the interesting things we noticed during the study, and I hope you regard this as preliminary because all the data have not been analyzed, was that in some homes adults as well as children were showing up with high lead levels indicating a possible common source of exposure. We are following up on this by doing a case-control study of a smaller number of families that have been referred to us by community lead screening programs in the Boston area. We are selecting our cases from homes where at least 2 family members have been found to have a higher than the normal background level of blood lead. The control population is being selected on the basis of having low blood leads and each control is to be matched with the appropriate case and a detailed study conducted to see if there are differences in environmental sources of lead exposure.

QUESTION: I was curious as to how these people were selected. Taking blood from people is a little different than taking a water sample.

DR. CRAUN: There was a large amount of publicity through both the newspapers and TV in the area, and people have been quite cooperative.

QUESTION: But they volunteered?

DR. CRAUN: Yes. We originally made a selection of study participants and sampled volunteers from this group. We selected about 200 homes in each of the three communities in the study expecting a response rate of about 50 percent.

QUESTION: Oh, I see, you chose these people first for some reason?

DR. CRAUN: Yes. We chose our study population on the basis of lead service lines. We felt that tap water from homes with lead service lines would most likely contain some lead. Since we also wanted a control group not exposed to lead in tap water, we selected homes having service lines of other materials.

QUESTION: (Jim Lamb, UNC-CH) I wasn't clear in looking at your data on metals pickup, how you separated pickup from analytical error. In some instances, for example, in one of them you showed a 13 percent pickup. I wondered whether you determined statistically if that really was a significant pickup.

DR. CRAUN: For the Boston and Seattle data, analytical error was taken into account in determining if the concentration of a *running* sample was, indeed, lower than a *standing* sample. In this respect, the percentages reflect pickup and not laboratory error. A statistical analysis has not yet been done to determine if the pickup is significant. I would think that for those metals showing a low percentage of pickup, such as cadmium, that the pickup will not be statistically significant. (*Note:* The following comments are added to clarify this point. A statistical analysis of these data was done after the paper was presented. The t-test was used to determine if the observed increase in concentration of the various metals from a *running* sample to a *standing* sample was due to random error or if the differences were real. Realizing that variances are not the same for the two sets of data, the Satterswait formula was used to calculate the appropriate degrees of freedom for testing the significance of the differences. For *all metals* analyzed in the *Seattle* study, this test revealed that there is less than a 95 percent chance that the observed increases are due to random error; and hence, it appears that the *standing* samples definitely have a higher level of metals than do the *running* samples. This significance, however, was not found in the Boston data.)

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EVALUATING STATE DRINKING WATER QUALITY SURVEILLANCE PROGRAMS

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BACKGROUND

During the past several years, the Water Supply Branch of the Environmental Protection Agency and its predecessor, Public Health Service agency, has completed, or underway, twelve State Water Supply Program Evaluations. One of the first was completed in January 1971 by the Region IV staff in Atlanta for the State of Tennessee. The Region IV Water Supply Branch subsequently conducted evaluations for the States of Kentucky, Georgia, and a fourth state soon to be released. In view of the large quantity of information and data gathered during these evaluations, it seemed appropriate to compile the results for the southeastern states. This paper summarizes important water supply conditions found in the four states and characterizes the State Water Supply Programs which provide public health and engineering surveillance.

These State Water Supply Program Evaluations followed the long established Public Health Service tradition of providing technical assistance and special studies to states. Other more direct means of federal assistance have not recently been available to State Water Supply Programs.

During discussions with Tennessee Water Supply Program officials in spring of 1970, the idea developed that a comprehensive program evaluation by an outside, authoritative agency (then the Public Health Service) would serve two essential purposes:

1. It would provide an independent, unbiased appraisal of the current Tennessee program perhaps more objectively than could be done by program administrators involved on a day-by-day basis.
2. Hopefully, it would attract a wider, more attentive audience to the problems and needs of the water supply industry and public agencies charged with health and engineering surveillance responsibilities.

**Editor's Note:* Oral presentation by Mr. Hutchinson

Pursuant to these discussions, Dr. Eugene W. Fowinkle, Commissioner, Tennessee Department of Public Health, requested that the Public Health Service evaluate the Department's Water Supply Program.

SCOPE OF EVALUATION

The scope of the evaluation and the procedures developed for the Tennessee study guided subsequent state program evaluations in the Southeast and elsewhere in the country.

The principal objectives of the evaluation were to determine the effectiveness of the current program and, if necessary, recommend modifications and additions needed for a fully satisfactory program. The effectiveness of the current program was determined by studying water utility compliance with state requirements and general standards of good water supply practice. The regulatory program could not be judged adequate if many deficiencies were found. Similarly, if few deficiencies were found, large-scale changes or increases in the state program would be difficult to justify.

The basic water supply statutes, regulations, and program policies were reviewed. The program activities, responsiveness to problems, staffing, and leadership were critically examined. State-sponsored waterworks operators training courses and their influence on water utilities were observed. Reported waterborne disease outbreaks were studied. Additionally, many state and local health department employees, municipal officials, waterworks personnel, and citizens were interviewed, and state and other bacteriology and chemistry laboratories were surveyed and evaluated.

Three general classes of water supply systems were identified. These were: (1) public water supplies - systems generally serving a resident population larger than a specified minimum, plus possibly other types of systems specified as public by state regulations; (2) small public water systems (sometimes called semi-public Class III, or other designation) - systems generally serving fewer than the specified minimum resident population for public water supplies or serving the non-resident public at installations such as child care centers, service stations, roadside restaurants, campgrounds, parks, and motels; and (3) private, individual systems serving a single family. The dividing line between public and small (or semi) public supplies differed somewhat from state to state, but in all cases such a distinction had been made for the administration of the state program.

A cross-section of the water supply industry in each state was selected for study. The sample was selected to represent supplies of varying size, geographic location, types of source, and types of treatment. It included municipally owned systems, investor-owned systems, and utility districts. Unfortunately, the total number of supplies which could be examined with available resources was limited. Thirty-nine (39) public supplies were examined in Tennessee, 36 in Kentucky, 20 in Georgia, and 30 in the fourth state (See Table 1). These supplies serve in excess of 5.4 million people.

Table 1

NUMBER OF WATER SUPPLIES STUDIED AND
POPULATION SERVED BY STATE

State	Number of supplies studied	People served (millions)	Percentage of those who use public supplies
Tennessee	39	1.7	58
Kentucky	36	1.2	61
Georgia	20	1.0	31
4th State	30	1.5	24

It was also necessary to obtain a representative sample of the small (or semi) public systems. Since state inventories of these systems were generally incomplete, it was decided to select several counties and evaluate all the small public supplies located within them. Selection of the counties was based upon geographic location, geological conditions affecting groundwater, land use and economic patterns in the county, and local health department resources. Generally, three counties were selected in each state. The small public supplies were located and surveyed with the assistance of county health department sanitarians.

Private, individual systems were included in the Tennessee and Kentucky evaluations. Many persons are dependent on this type system for daily use and little data existed as to the number, type, or condition of these systems. Nearly 600 systems were surveyed in each state through contract with the Southern Regional Education Board, who employed college students to perform the work and prepare reports. A similar study had been conducted previously in Georgia. The results and conclusions of these studies are the subject of another paper and will not be further discussed here.

FINDINGS

Principal findings assembled from the 125 public water supply systems and the 282 small or semi-public water systems studied in the Southeast are shown in Tables 2 through 5.

With only a few exceptions, the data shows great similarity between the status of the water supply industry in the four states. In those instances where marked differences exist, they usually can be accounted for by priority or resource differences in the state programs or by geological differences between the states.

It is not the purpose of these data to promote comparison of one system against another or one state against another. Taken as a group, the water systems showed significant deficiencies, and this is the finding that the State Program Evaluations attempted to document. Those water system deficiencies and deficiencies in health agency surveillance provided the basis of recommendations for improvements in the state water supply surveillance programs.

Table 2

DRINKING WATER QUALITY

	Percent of Supplies Studied				
	Tenn.	Ky.	Ga.	4th State	Overall
PUBLIC WATER SUPPLIES					
Failed Bacterial Standards - 12-month period	31	31*	35**	33***	31
Failed Mandatory Chemical Standards	5	3	0	0	2
Failed Recommended Chemical Standards	33	22	5	20	22
Failed to Fluoridate at Correct Level****	50	64	17	43	47
SMALL PUBLIC WATER SUPPLIES					
Failed Bacterial Standards - Single sample	19	36	12	5	17
Failed Mandatory Chemical Standards	-	5	7	0	4
Failed Recommended Chemical Standards	13	34	33	36	30

*17% had no data.
**25% had insufficient data to judge.
***37% had insufficient data to judge.
****Based on state requirements for acceptable range. Thus, some states had narrower range of acceptable fluoride levels.

Table 3

WATER SYSTEM SURVEILLANCE

	Percent of Supplies Studied				
	Tenn.	Ky.	Ga.	4th State	Overall
PUBLIC WATER SUPPLIES					
Failed Bacterial Sampling Requirement	54	64	55	70	61
Failed Chemical Sampling Requirement	80	6	15	43	39
No annual State Agency Inspection	41	67	50	47	51
Inadequate Cross-Connection Program	72	92	90	90	85
SMALL PUBLIC WATER SUPPLIES					
No Health Agency Visit	17	37	27	51	33

Table 4

WATER SYSTEM FACILITIES

	Percent of Supplies Studied				
	Tenn.	Ky.	Ga.	4th State	Overall
PUBLIC WATER SUPPLIES					
Need Additional Treatment Facilities	67	58	70	70	65
Need Additional Storage	28	19	50	47	34
Inadequate Source Protection	33	28	45	10	27
SMALL PUBLIC WATER SUPPLIES					
No equipment for Disinfection	59	36	89	83	69
Visible Sanitary Defect	9	34	17	1	14

Table 5

WATER SYSTEM OPERATION

	Percent of Supplies Studied				
	Tenn.	Ky.	Ga.	4th State	Overall
PUBLIC WATER SUPPLIES					
Part-time operator	36	39	45	27	36
Operator not certified	33	56	50	29	41
No chlorine residual	30	28	47	30	32
Important operation changes needed	62	73	55	37	57
SMALL PUBLIC WATER SUPPLIES					
No chlorine residual	46	68	56	77	62

In general, the State Water Supply Programs were plagued by common problems. In historical perspective, water supply surveillance was among the first environmental programs established in the state health agencies. During the decades of the 1950's and 1960's, other environmental programs were initiated and/or gained momentum at the state and federal levels. At best, water supply programs remain virtually unchanged, although effectiveness decreased as key personnel abandoned water supply activities for better funded, more rapidly expanding programs. The net effect was a de-emphasis of water supply activities.

As shown in the data, public health surveillance in the four states evaluated was not adequate to assure continuous, safe drinking water. This is probably best supported by the almost uniformly high rate of failure to meet bacteriological quality and surveillance requirements (Tables 2 and 3). In addition, an equally crucial deficiency not immediately apparent was the lack of careful review and analysis of the bacteriological data which was available. In one state, data was simply not reviewed at all. In other states, review was neither timely nor consistent; and when it was reviewed, it was often not interpreted in accordance with existing state regulations. In many instances, it was impossible to document any response whatsoever to unsatisfactory quality.

A related deficiency common to all four state programs was in engineering inspections of system facilities (Table 3). Overall, less than one-half of the public systems had been inspected by a representative of the state surveillance agency during the 12-month period selected for evaluation. Although not apparent from the data, the lack of system inspection is even more serious for the small public supplies, where the health agency visit generally consisted of collecting a bacterial sample by a county health department employee. The deficiencies in facility inspection generally were attributed to shortages of personnel assigned to the field surveillance activity. Several of the state programs had essentially abandoned routine field surveillance so as to redirect available resources to those supplies with known problems.

The frequency and extent of chemical surveillance was dependent in large measure upon available laboratory resources. In several instances, state governmental reorganizations had separated the water supply programs from available chemistry laboratories. Capability was not available in any of the states to perform analyses for many constituents of health significance (such as trace metals or pesticides) in sufficient numbers to support a routine surveillance program. Most of the analyses reported in the data included few constituents of health significance. Chemical analyses of samples collected as part of the state evaluations and analyzed in EPA laboratories showed a significant percentage of public and small public supplies failed to meet recommended (esthetic) chemical standards. A few supplies failed to meet mandatory (health) chemical standards.

Water system operation was shown to be deficient in all states evaluated, with the level of operation generally decreasing with system size (Table 5). Training and certification of operators has impacted many in the waterworks industry, and the studies indicate that those trained and certified operate better (although not necessarily faultless) water systems. Much remains to be done, however, to upgrade the training and reach the remaining approximately 40 percent who are not trained or certified. Also, many systems with trained and certified operators had important deficiencies.

Failure to maintain a chlorine residual throughout the distribution system was a common operational failure in all states. Less than a third of the small public supplies were equipped with a chlorinator and well over one-half of those were not operating it.

Three of the four water supply programs evaluated were operating under legislation which provided significantly less legal authority than was provided for other state environmental programs. There was also much reluctance on the part of the state programs to utilize the limited legal avenues available. Further, legal staff was not generally available to mount an effective water supply enforcement program.

RECOMMENDATIONS

Program needs were detailed for each state as evidenced by the data summarized above and more fully developed in the complete State Evaluation Reports. All four programs were judged to be without sufficient staff and laboratory resources to conduct a satisfactory program to protect public health. Recommendations were submitted for staff and budget increases which enable the state programs to provide needed services. Recommended staffing levels ranged from approximately three to four times existing levels, with similar ranges of budgetary increases. The establishment and staffing of additional regional offices was recommended in order to put more engineering personnel in the field. Substantial increases were also recommended in budget and staff of bacteriological and chemical laboratories.

Additions and changes to water supply program legislative authority were recommended, generally to provide a more comprehensive program and to provide more responsive enforcement measures. While cooperation and encouragement should continue to be emphasized, expanded use of legal techniques were recommended when voluntary measures fail to achieve necessary or timely compliance.

Recommendations were directed toward State Rules and Regulations for inclusion of additional and more stringent standards and guidelines on raw and finished water quality, surveillance requirements, and numerous other details.

Recommendations were also submitted regarding program priorities and administration. All state programs were judged weak in the review of bacteriological surveillance data and response when data indicated water did not meet established standards. More consistent review of this data and more timely response to potential problems were recommended. Engineering inspections on at least an annual frequency were recommended. Basic management tools, such as accurate and complete inventories of all public water systems regulated under legislative authority, standardized engineering inspection forms, and program-wide distribution of policy documents were also suggested.

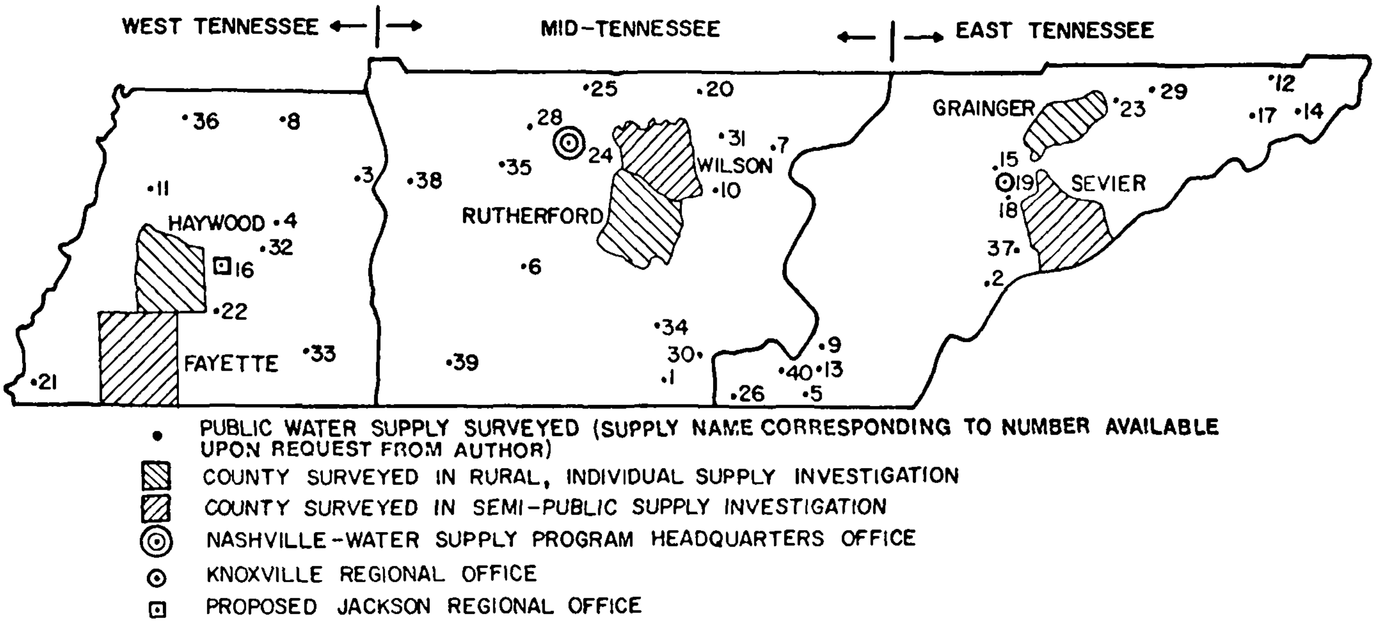
SUMMARY

In summary, water supply practice was found deficient in all four states, as were the state programs designed to assure adequate quantities of safe drinking water to the public. This conclusion is not reassuring with regard to the future.

State legislatures, the administrative levels of state government, and the water supply industry need to make more vigorous commitment to restore and broaden the margins of safety that our water supplies provide against transmission of disease, toxic substances, and shortages of water in the Southeast. Today and in the future, provision of safe, adequate water supplies will depend on universal application of high waterworks industry standards and vigorous regulations, surveillance, and enforcement by public environmental control agencies.

FIGURE IA

Location of Water Supplies Surveyed



● PUBLIC WATER SUPPLY SURVEYED (SUPPLY NAME CORRESPONDING TO NUMBER AVAILABLE UPON REQUEST FROM AUTHOR)

▧ COUNTY SURVEYED IN RURAL, INDIVIDUAL SUPPLY INVESTIGATION

▨ COUNTY SURVEYED IN SEMI-PUBLIC SUPPLY INVESTIGATION

◎ NASHVILLE-WATER SUPPLY PROGRAM HEADQUARTERS OFFICE

⊙ KNOXVILLE REGIONAL OFFICE

⊡ PROPOSED JACKSON REGIONAL OFFICE

FIGURE 1B
Location of Water Supplies Surveyed
KENTUCKY

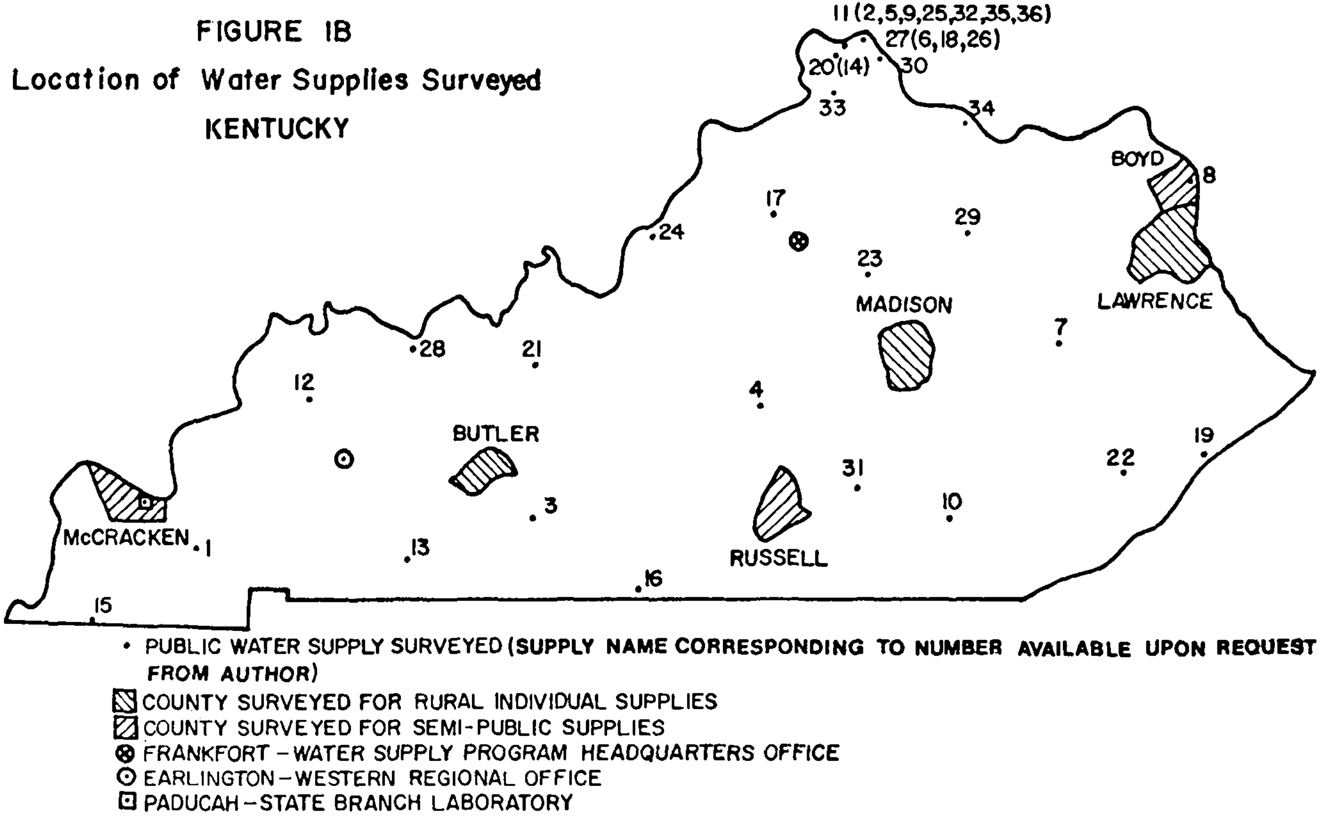
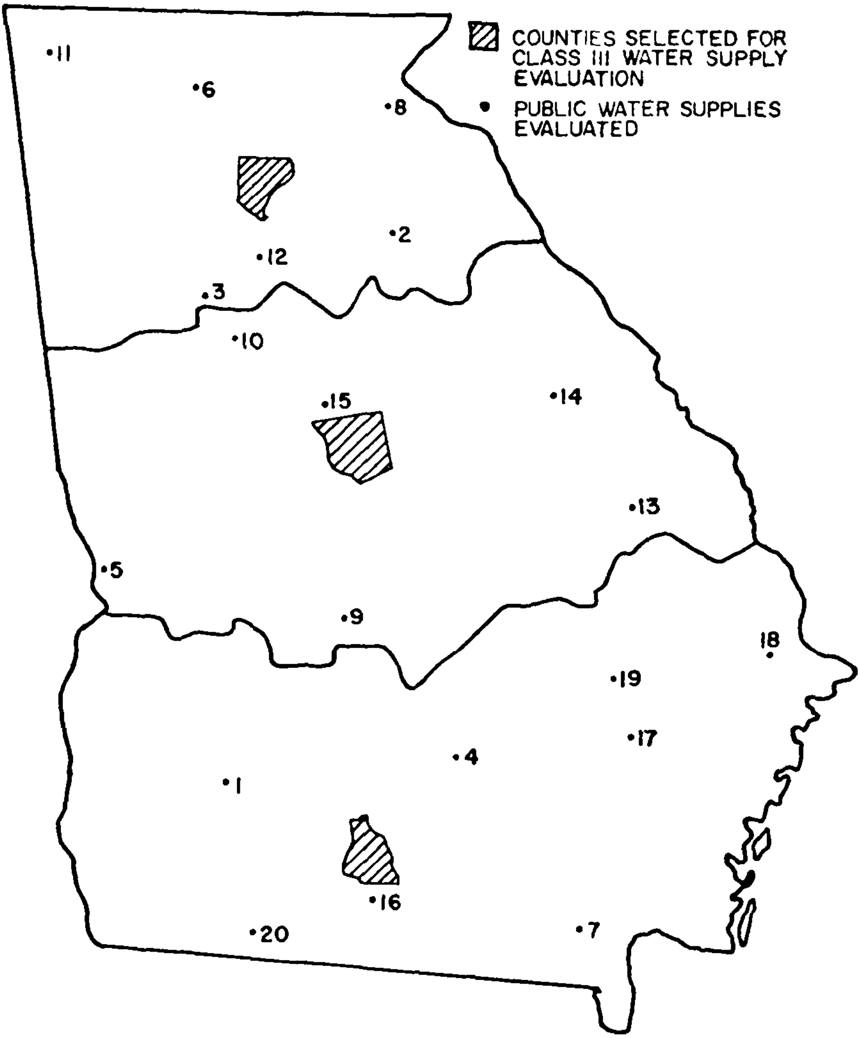


FIGURE 1C

Water Supply Systems Selected For Study : GEORGIA



NORTH GA.

11-KENNSINGTON WATER AUTHORITY
6-ELLIJAY
8-HABERSHAM MILLS
12-LAWRENCEVILLE
3-ATLANTA
2-ATHENS

MIDDLE GA.

10-HENRY CO.
15-MONTICELLO
14-MITCHELL
13-MIDVILLE
9-HAWKINSVILLE
5-COLUMBUS

SOUTH GA.

1-ALBANY
4-BROXTON
19-REIDSVILLE
18-AZALEA PARK ANNEX
17-ODUM
16-OAK ST. SUBDIVISION
20-THOMASVILLE
7-FOLKSTON

APPENDIX A

Evaluation Criteria

The effectiveness of the State's Water Supply Program was gauged to a large degree on the basis of drinking water quality, adequacy and condition of water system facilities, and water supply surveillance.

WATER QUALITY

Bacteriological quality of public water systems was judged by comparing the bacteriological sampling record compiled during the previous 12 months against the Public Health Service Drinking Water Standards. Any system failing to meet the bacteriological limits one or more of these months was considered to have failed the bacteriological standard. Since the Water Supply Programs do not routinely sample all small public water systems, they were judged on the basis of a single bacteriological sample collected during the field visit and examined by the department laboratory. Any sample showing organisms of the coliform group in three or more of five 10 ml portions (MPN of 9.2 or greater), a membrane filter count of greater than 4 coliform colonies per 100 ml, and/or having fecal coliform bacteria was considered to have failed the bacteriological standard.

Chemical quality of public water supplies was judged on the basis of a trace metals sample collected from the water treatment plant during the field inspection. Carbon filter, radiological and pesticide samples were also collected at selected treatment plants utilizing surface waters. These samples were analyzed by Environmental Protection Agency laboratories. Each sample was compared individually to the Public Health Service Drinking Water Standards and determined as either:

1. meeting the standards for all constituents, or
2. meeting all *mandatory* constituent limits, but failing to meet one or more *recommended* constituent limits (some are aesthetic parameters), or
3. failing to meet one or more *mandatory* constituent limits, or
4. failing to meet both recommended and mandatory limits.

FACILITIES

Public water supply source, treatment, operation and quality control were judged on the basis of the *Manual for Evaluating Public Drinking Water Supplies* and the Drinking Water Standards, employing the same interpretations as were used in the U. S. Public Health Service Community Water Supply Study.

Source

Quality of the source was judged where possible by chemical analyses and also by past experience of the treatment plant operator. Quantity was judged by historical experience and current water demands. Source protection was judged by the type of source, potential and/or actual problems, and adequacy of monitoring conducted.

Treatment

Treatment was judged on the basis of the facilities and their operation (as observed on the day of the field visit), bacteriological records and chemical analyses. Effective of disinfection was judged by the presence of a detectable free chlorine residual in all parts of the distribution system.

Distribution System

Finished water storage was judged adequate if elevated or non-pumped storage equaled or exceeded the system's average daily demand. Pumped storage was included only where on-site internal combustion or steam auxiliary powered pumping equipment was available. Raw water storage was also included if auxiliary power was available to provide treatment and pumping. Storage for *distribution only* systems included consideration of storage in the parent system. A distribution system pressure of at least 20 psi in all parts of the system was considered adequate.

Quality Control

Water quality testing was judged by the bacteriological and chemical tests being performed by the water purveyor on finished water. Record-keeping practices were judged by records maintained at the water treatment plant or water treatment plant operator's office and available for inspection at the time of the field visit. The cross-connection control program was judged by the existence of an ordinance, program implementation, and progress toward eliminating hazards.

Small public water systems were judged on the basis of the *Manual of Individual Water Supply Systems* in addition to the references already cited. The adequacy of these facilities was judged on the basis of a sanitary survey accomplished at the time of the field visit.

SURVEILLANCE

Water supply surveillance was judged on the basis of the Drinking Water Standards and the *Manual for Evaluating Public Drinking Water Supplies*. Bacteriological surveillance was considered satisfactory if the number of bacteriological samples examined per month during previous 12 months met the minimum number specified by the Drinking Water Standards. Chemical surveillance was considered satisfactory if a chemical analysis (as distinguished from normal in-plant operational checks) was performed by the state or an independent laboratory within the past three years, and there was no record of significant problems. (The supplies were not rated unsatisfactory even though a state's routine analysis might have only included few constituents of health significance.) Engineering surveillance was considered satisfactory if an inspection by Water Supply Section personnel had been made sometime during the previous year. More frequent than annual inspections, however, are considered necessary for optimum surveillance.

OTHER CRITERIA

Bacteriological laboratories were judged on the basis of the Public Health Service Manual entitled, *Evaluation of Water Laboratories,* and *Standard Methods for the Examination of Water and Wastewater*. Chemical laboratory procedure was also judged by *Standard Methods*.

The adequacy of operator training was judged by the absence or presence of operational and quality control deficiencies, the operator's certification status, and the operator's awareness of the relationship between drinking water quality and public health.

REFERENCES CITED

1. U. S. Environmental Protection Agency (1970), *Community Water Supply Study - Analysis of National Survey Findings,* Bureau of Water Hygiene, Washington, D. C., 111 pp.

2. U.S. Environmental Protection Agency (1973), *Evaluation of the Georgia Water Supply Program,* Region IV, Atlanta, Georgia, 192 pp.

3. U.S. Environmental Protection Agency (1972), *Evaluation of the Kentucky Water Supply Program,* Region IV, Atlanta, Ga., 228 pp.

4. U.S. Environmental Protection Agency (1971), *Evaluation of the Tennessee Water Supply Program,* Region IV, Atlanta, Ga., 208 pp.

5. U.S. Public Health Service (1966), *Evaluation of Water Laboratories,* PHS Publication No. 999-EE01, Supt. of Documents, Gov. Printing Office, Washington, D. C. 20402, 54 pp.

6. U.S. Environmental Protection Agency (1972), *Manual of Evaluating Public Drinking Water Supplies,* Supt. of Documents, Gov. Printing Office, Washington, D. C. 20402, 62 pp.

7. U.S. Environmental Protection Agency (1973), *Manual of Individual Water Supply Systems,* Supt. of Doc., Gov. Printing Off., Washington, D. C. 20402, 155 pp.

8. U.S. Public Health Service (1962), *1962 Public Health Service Drinking Water Standards,* PHS Publication No. 956, Supt. of Doc., Gov. Printing Office, Washington, D. C. 20402, 61 pp.

9. *Recommended Standards for Water Works,* (1968), Great Lakes - Upper Mississippi River Board of Sanitary Engineers, Health Education Service, P.O. Box 7283, Albany, N. Y. 12224, 87 pp.

10. *Standard Methods for Examination of Water and Wastewater,* (1971), 13th Edition, APHA, AWWA, and WPCF, Amer. Pub. Health Assn., New York, N. Y., 874 pp.

QUESTIONS AND DISCUSSION

QUESTION: (Jim Stewart, WRRI-UNC) What consideration has been given to recommending to some of these states where they have viable regional organizations the possibility of regional layout for the training, surveillance, handling of water samples, etc. on a regional basis, particularly in areas where there are a lot of these small rural systems?

MR. HUTCHINSON: I really don't want to get too deeply into the subject of rural individual water supply systems, but assuming that you meant rural public systems, in the interest of time I didn't cover all our recommendations. One of our main recommendations was for the establishment of regional offices to bring the state program people in closer contact with field problems so that they might be more responsive to these problems. I believe three of the states we evaluated did have some resemblance of a regional activity already with regional labs, etc. Almost universally, though, we didn't find chemical analytical capabilities at that level, but we did find bacterial analytical capabilities. It's probably questionable whether sophisticated analytical work should be done at the regional level. That may depend upon whether a region had a particular problem or something of that nature. In that case perhaps that region ought to be equipped to respond immediately with sophisticated chemical analysis. Certainly, regional bacterial laboratory capability is needed since we're dealing with time-dependent samples here, and there's just no way that you can adequately handle them without going to regional labs. Those states which depend upon mail service have run into very difficult problems recently. I know in the Atlanta area mail from just north of Atlanta goes to Chattanooga and then is bulked up and sent back to Atlanta. If you've mailed bacterial samples from there, you aren't going to get them to the laboratory in the thirty hours that's required.

QUESTION: Earlier today we heard some of the speakers express concern over situations in which there might be a potential percentage risk, maybe one in a million or one in 100,000, from some trace organic compounds. Here, we see you mentioning the possibility of cross connections in Tampa, and I know of a U. S. Public Health Service funded recycling project in which they had a two-inch pipeline of fresh sewage sludge connected to the city's water supply even though it was built under constant supervision of the U. S. Public Health Service, and so I wonder if you'd care to comment. At the same time, we've heard a suggestion that perhaps we need to have some separate systems for flushing toilets with non-treated water. Would you care to comment on the risks that you foresee in the acceptability of such programs?

MR. HUTCHINSON: Well, I've already made some side comments on that paper about the risk of cross connections. We think it's very great. In St. Petersburg, Florida, there is a water reuse project planned which will use treated wastewaters for irrigation purposes. The immediate program is for the water utility to have full control over the tapping and distribution of renovated water which is good, I think. I am a little bit apprehensive, though, when you look into the future of that system. The planning people are faced with the problem of population growth and increasing sewage flow, and there are just so many golf courses to irrigate so they had to come up with some scheme to get rid of all of the future waste that they were going to be reclaiming. So they proposed the idea of distribution to households for flushing purposes and fountains, etc. Once the renovated water is piped to industry or into individual households control is weakened, and there is a great potential for cross-connection control problems, problems that we haven't been able to solve when we only have two systems, that being generally water supply and waste disposal.

Let me respond to the first part of your question. I wouldn't want to leave the impression that we think that the interest in pesticides and other more sophisticated organic pollutants is not necessary. The only thing that we'd like to point out with these data is that some very well-known surveillance techniques and quality control techniques are not being followed in accordance with best acceptable practice. I think you really need both. What our data show is that state programs have not been funded properly. Generally, we find that there are very good people in the state programs but that they've had to compromise their activities to do what they could, and this is where the real problem lies--in the surveillance and follow-up on water supply management.

QUESTION: I think Dr. Hughes is still here and maybe this is related to him. One time a number of years ago working for the Florida State Board of Health, we had a problem in which we were trying to determine one of these tip of the iceberg situations in which we knew that oystermen were defecating overboard on the beds that they were harvesting shellfish from, and we tried to ascertain how frequently that happened. We never published our results, but we did estimate the size of the iceberg by using an indicator product; that is to say, we surveyed the boats, and those which had mounted inside their little windbreaker cabin a roll of toilet paper were considered presumptive positive for at least occasional use of the water. In that respect, I wonder if anyone in the CDC has looked at possibly correlating sales of registered specifics for diarrhea and anti-diarrhea compounds like paregoric in areas where they've had--I'm not really being facetious--outbreaks of intestinal or gastroenteritic disease and then try to correlate that. I wonder if that's been done?

DR. HUGHES: Well, I can't comment on the shellfish problem. We wouldn't recommend that, obviously. As far as looking at sales of anti-diarrheal medication, that is a technique we frequently use when we go into an area where we think there has been an outbreak. We'll review hospital records and local pharmacy records. These are useful techniques and will give you some idea of what is really occurring in a community.

QUESTION: Have you and Dr. Hughes got together--I was looking at your table, and it came to my mind--have you done any kind of epidemiological studies of these places that are not doing what they're supposed to be doing? In other words, 40 percent are not doing what they're supposed to be doing, and you're going in there taking a sample of those towns, say, or systems and those systems that are not doing so and so, do they have a high incidence of certain types of diseases? Are you doing any kind of correlation in this area?

MR. HUTCHINSON: As far as I know, there's no routine follow-up, and I don't know that we would want to be in the position of saying just because these people fail to carry on the required surveillance or fail to operate their chlorinator properly that people were dying in the streets. What we are saying is that the factor of safety has certainly been reduced, and what we can say is that disease has been caused in similar instances when conditions were just right. I'll just give you two examples--Homestead and Richmond Heights, both in Dade County, Florida, where there was a combination of improperly disposed wastes, contaminated ground water and inadequate water treatment.

DR. HUGHES: That's a good question, and we really haven't tried to do these kinds of prospective studies. I'm not sure, really, how good an idea that would be from an epidemiological standpoint. We know a lot from experience. We tried to make an analysis of foodborne disease. Food handling in many places is atrocious. But a number of things have to go on simultaneously. You could theoretically go into an area that has an inadequate water supply and monitor that area for a year or two or three without finding anything.

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STRATEGIES FOR ASSURING HIGH QUALITY DRINKING WATER IN THE FUTURE

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BACKGROUND

During this symposium, a wide range of proposals is being made to help the United States have adequate quantities of wholesome drinking water. Increasing population, with increasing per capita requirements, moving towards a fixed level of resources from which to meet these demands, suggests to some that we may need to accept a deterioration in drinking water quality because of the far more extensive water reuse that will need to be employed. This need not be the case.

However, even where water resources have been adequate in the United States, as has been well documented by the several recent large-scale studies, a substantial number of those now being served by public supplies are not being assured an adequate supply of high quality drinking water continuously. A problem, equally challenging but which has received little attention up to now, is the situation of the approximately fifty million people in the United States who are not served by public water supply systems at all and who are, therefore, dependent upon their own private resources.

Accordingly, a strategy for providing wholesome water supply in adequate quantities for the future must consider not only all those now being served from public water supply systems and the upgrading of these supplies but also bringing those not now served into the system, assuring them the surveillance that should accompany the provision of public water supply service. The strategy is one that should facilitate the implementation of the many other recommendations made at this symposium.

PROPOSAL

The strategy here proposed flows from one of the principal findings of the surveys, that the smaller systems do not have the resources in facilities, manpower, or funds to provide high quality service. Without significant institutional changes, they are not likely to have these resources, even after the Safe Drinking Water Act is passed and even if its provisions are implemented. Furthermore, as the reuse of wastewater, either planned or unplanned

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**Editor's Note:* Dr. Okun was the banquet speaker on Thursday, September 26.

becomes more widely practiced, the separate planning of water supply projects without full integration with wastewater management is not likely to lead to the most effective and economical solutions for best use of the total water resource.

To quote Lincoln Steffen: "I have seen the future, and it works." The future is the past and present in the United Kingdom. It lies in the regionalization of water enterprises. Beginning during the throes of World War II, the British inaugurated a program of *regrouping* of water supplies which, in less than thirty years, has seen some 1300 separate water supply systems serving 40 million people reduced to fewer than 200 systems serving 50 million people. Where each water supply system in the United States serves an average of about 5,000 people, the average in England and Wales at the beginning of 1974 was something well over 250,000 people. Not only did this assure a well-organized water service for the urban population, it provided the institutions which were able to reach out into the rural areas to the extent that today well over 99 percent of the total population of England and Wales, much of it quite rural, is served from public water supply systems.

This regrouping of water supplies and the success story accompanying it are well known. This regrouping did not directly address the problems of reuse that flow from increasing demands approaching limited resources. Accordingly, the British have just undertaken another major reorganization, this one to take place not over a span of almost thirty years but overnight. It has been my privilege to be in England during the process of this reorganization. I have no illusions that anything on this scale can be adopted in the United States. However, the reorganization and the process of reorganization may have valuable lessons for us as we agonize with drinking water bills, amendments to water pollution control amendments, state versus federal responsibilities, federal grants and the like.

WATER REORGANIZATION IN ENGLAND AND WALES

On April 1, 1974, ten Regional Water Authorities (RWA's) took over virtually every responsibility for the management of water and its uses, including ownership of facilities, from 1609 separate agencies that had served some 50,000,000 people in England and Wales. Included among the agencies taken over were:

29 river authorities
187 water supply undertakings, and
1393 sewerage and wastewater treatment agencies.

Created by the Water Act 1973, each RWA is responsible for the planning, design, construction, operation and financing of facilities in the area for:

a. the conservation, augmentation, distribution and proper use of water resources and the provision of water supplies;

b. sewerage and the treatment of wastewaters and other effluents;

c. the restoration and maintenance of the wholesomeness of rivers and other inland and coastal waters;

d. the use of inland water for recreation;

e. land drainage and prevention of flooding; and

f. fisheries in inland and coastal waters.

Formation of national water policy is the joint responsibility of the Secretary of State (for the Environment and for Wales) and the Minister of Agriculture, Fisheries and Food, with the Secretary being responsible for the execution of policy in all matters except land drainage and fisheries, which reside with the Minister.

The original intention of the Government was that the RWA's be small with members selected by the Secretary of State and the Minister for the individual's capacity to assist with water management. Many objected to a change in responsibility for water from representative bodies to bodies appointed by Government. In the face of this opposition and in hopes of easing passage of the legislation, the bill as submitted to Parliament called for larger authorities with local authority representation to be a majority on each Regional Water Authority, the remainder to be appointed by the Government.

The bill also called for the creation of a National Water Council (NWC) to be comprised of the ten appointed chairmen of the RWA's and ten others appointed by the Secretary of State and the Minister for their knowledge of the field. The only statutory responsibilities of the NWC are rather trivial: training and testing of water works fittings. Planning, which had been the responsibility of the Water Resources Board, created by the Water Resources Act 1963, and terminating its existence with the Water Act 1973, becomes a responsibility of a new Central Water Planning Unit in the Department of Environment. Whether NWC continues to be weak, characterized by an M. P.* as a "toothless, bloodless, zombie-like body" depends upon the actors. Already RWA chairmen and officers are working in concert and the NWC may evolve into a stronger body than originally anticipated.

The RWA's and their officers were appointed soon after the Act was passed in August 1973, operating in *shadow* form until April 1, so that they were off and running when the ownership and responsibility became theirs.

THE BACKGROUND TO REORGANIZATION

In the light of an impending reorganization of local government,**a Central Advisory Water Committee (CAWA) was charged in September

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*Member of Parliament.

**The Local Government Act 1972 reduced the number of local authorities in England and Wales from 1424 to 456, also on 1 April 1974.

1969, with examining the existing organization of water management. The committee found that responsibility for water was fragmented amongst many separate bodies with conflicts between them and inadequate machinery for resolving the conflicts. The problems were: inflexibility in the use of resources; division of responsibility between river authorities and water supply undertakings for development of new sources; promotion of large schemes; and inadequate levels of wastewater treatment. In their report of April 1971, CAWC concluded that reductions in the number of operating units and changes in relationships amongst authorities were necessary to permit the formation and implementation of comprehensive water management plans.

The Government, in December 1971, agreed that the existing system was not adequate to meet the water management problems of future, with serious water shortages expected in the mid-1980's. According to J. E. Beddoe, then Undersecretary of the Department of Environment and *architect* of the reorganization, inasmuch as any major reorganization is bound to be accompanied by initial disorganization, it would be better to undergo this trauma before crisis was at hand. Also, it seemed propitious to combine the water reorganization with local government reorganization which would involve many of the same local authorities.

So complete a reorganization at one fell swoop was possible, in part, because of two previous reorganizations that exposed the need for and the benefits to accrue from a more comprehensive reorganization: the Water Act 1945 and the Water Resources Act 1963.

The Water Act 1945 was an important precursor to the reorganization because it led to the regrouping of water supply undertakings already mentioned. Nothing similar had been initiated in the sewerage field with the result that the average population served by sewerage and sewage disposal authorities was still about 30,000. It was recognized that inadequate levels of wastewater treatment stem from the poor facilities and poor operations that generally result when a local authority is too small to afford competent management, engineering, and scientific supervision. Hence, the reorganization was to accomplish for the water pollution control field what already had in large measure been accomplished in the water supply field.

Another important precursor to the reorganization was the Water Resources Act 1963 which created the River Authorities and the Water Resources Board. The decade-long life of the River Authorities provided valuable data, experience in river management, and personnel that were already attuned to the types of responsibilities expected of the RWA's.

The Water Resources Act 1963 did not go far enough. The Government believed that all aspects of the hydrologic cycle should be under the purview of a single authority. The philosophy behind the creation of the Water Resources Board and the River Authorities needed to be extended to include management of all water operations and in particular greater consideration of water quality in water management than had been possible under the limited mandate held by the Water Resources Board.

Not explicitly stated, but clear from the types of studies initiated in the U. K. over the last few years, was the belief that the reorganization would permit more efficient investment for both water supply and water pollution control. For example, direct water reuse for non-potable purposes is far easier to initiate when both water and wastewater facilities are owned and managed by the same authority. In selecting points of abstraction for water supply and points of disposal for effluents, many more options are available when all the facilities and resources in a river basin are owned by a single authority than where each municipality must fend for itself. The potential exists for optimizing investments in pollution control to yield the greatest benefit for the least cost, a difficult goal to reach when each local authority and industry is required to invest separately in pollution control to meet some uniform and often arbitrary standard, as is now the case in the United States.

The rational approach to financing made possible by the reorganization is one of its most attractive features. Water supply financing has never been a problem either in the United Kingdom or in the United States, and national exchequer subsidies have not been necessary in the United Kingdom or United States except for extension of water supply service into rural areas. On the other hand, the financing of pollution control measures has been difficult in both countries.

The financing policy for the RWA's is to include a single residential charge for water resource development, water supply transmission, treatment and distribution, sewerage, wastewater treatment and disposal, and water quality monitoring and regulation. Studies are underway looking into metering of the residential services and charges for metering, charges to industries for trade waste discharges into sewerage systems and into water courses, charges for abstractions for water for industrial and agricultural purposes and charges for the recreational uses of water. The RWA's are to be entirely self-financing, going to central government only for loans for capital construction.

THE COMPARABLE U. S. SITUATION

In the United States, water supply undertakings have been proliferating with some 30,000 now serving about 150,000,000 people. Each supply system has to fend for itself with often meager resources.

The situation with regard to wastewater collection and disposal had been much the same in the two countries, but the Water Act 1973 will remedy the situation in England and Wales by bringing all the works into the RWA's, assuring far better quality operation than can possibly be afforded by small communities. It is conceded that in the United States the quality of wastewater treatment plant operation, particularly in smaller communities, has not matched the investment in facilities.

In the United States the response to the public demand for water pollution control has resulted in more and more dependence on federal grants to the extent today of legislating that 75 percent of the construction costs of municipal interceptors and treatment works, amounting to 5,000 million dollars annually, shall be provided. With state governments adding another 10 to 15 percent, a local authority in the United States can expect 85 to 90 percent of its capital cost to be met from grants; and hence, few local authorities are likely to initiate projects until they are assured of grant support. Accordingly, the federal bureaucracy has a stranglehold on pollution control progress, and the rate of progress is a function of the level of funding the federal government is prepared to commit to this sector of the economy in competition with all other demands on treasury resources.

As pollution originates locally, the financing of its alleviation should be financed as a charge for service rather than as a drain on the federal exchequer, which needs to fund many other functions of government which cannot be financed locally.

The construction grant program in the United States has spawned other diseconomics. Because only capital funds are provided, the tendency is to provide facilities that maximize construction cost and minimize operating cost, rather than optimizing the design.

Another major problem in the U. S. today is the requirement for uniform treatment across the country regardless of the local needs. Secondary treatment and nutrient removal are required in places where this costly treatment will have no discernible effect, or where nutrient removal is contraindicated such as when the effluent is used for irrigation. Industries of the same type are required to provide the same degree of treatment with no regard to whether they are on a small stream where the plant should not have been sited in the first place or on a large body of water where that degree of treatment is superfluous.

The new RWA's own their water resources, and they will be responsible for supplying water to municipalities and industries and for promoting the recreational use of their waters. They will not need to nor are they likely to adopt uniform standards of treatment. They will be in a position to optimize all their investments: construction and operation, water supply and wastewater treatment plant size and location, degree of treatment to be provided, etc.

In particular, they should be able to preserve their limited resources of naturally pure waters, whether in upland streams or underground, for potable purposes by optimizing reuse of wastewaters or polluted river waters for non-potable purposes such as for industry and irrigation. In the United States today, downstream communities are at the mercy of their upstream neighbors. With the highly complex organic chemicals present in most urban wastewaters that are not readily removed in either water or wastewater treatment, the uncertain effects of long-term exposure to these chemicals ingested in our drinking water hangs as an unknown threat over all consumers of reused water. Regional integrated management offers a mechanism for eliminating this problem.

The RWA's structure and size offer opportunity for selection from a wide range of options in managing water, and it is in exploring such options that the reorganization offers the greatest promise.

CONCLUSION

Engineers throughout the world and we in the United States particularly should be observing developments in Britain closely because the reorganization may well help stimulate the adoption of rational water management programs elsewhere.

Acknowledgment

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PROBLEMS IN SMALL WATER SYSTEMS

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INTRODUCTION

Although all public water supply systems have problems and will continue to have problems, the type and severity of these problems generally will vary with the size of the water system. This discussion will be primarily concerned with problems in small water systems located in North Carolina; however, it is believed that these problems are ones which are common to small water systems in other states.

In order to discuss small water system problems, we need a frame of reference relative to the size of the systems. Since we will be discussing problems in North Carolina, let us use the definition of a public water supply system in North Carolina as the basis for discussion. The North Carolina General Statutes state "any water supply furnishing potable water to ten or more residences or businesses or combination of residences or businesses shall be deemed a public water supply." Based on this definition we have more than 2,649 public water supply systems in the State of North Carolina which serve over 3,400,000 people.

GROWTH IN SYSTEM NUMBERS

The growth of public water supply systems from 1962 to 1974 is shown in Figure 1. You will note that the systems have been separated into two major categories: municipal systems and community systems. The municipal category includes (1) incorporated cities and towns, (2) sanitary districts, and (3) Farmers Home Administration financed non-profit water associations. The community category includes (1) subdivision, (2) mobile home park, and (3) industries which serve small contiguous villages. You will note on the graph the increase in community water systems between 1966 and 1968. During this period, a statewide survey of public water supply systems was conducted, and a number of public water systems privately owned were discovered which had not been approved by the Division of Health Services, formerly the State Board of Health. Also, you will note on the municipal line an increase of systems between 1970 and 1972. This was the result of the transfer of FmHA water associations from the community category to the municipal category. Based on the design criteria, the size and the total number of water associations, it was felt that they should be considered more as a municipal supply rather than a community supply. The overall growth of public water supply systems since 1964 has been at the rate of approximately 200 new systems per year with no appreciable decrease anticipated in the next two to five years.

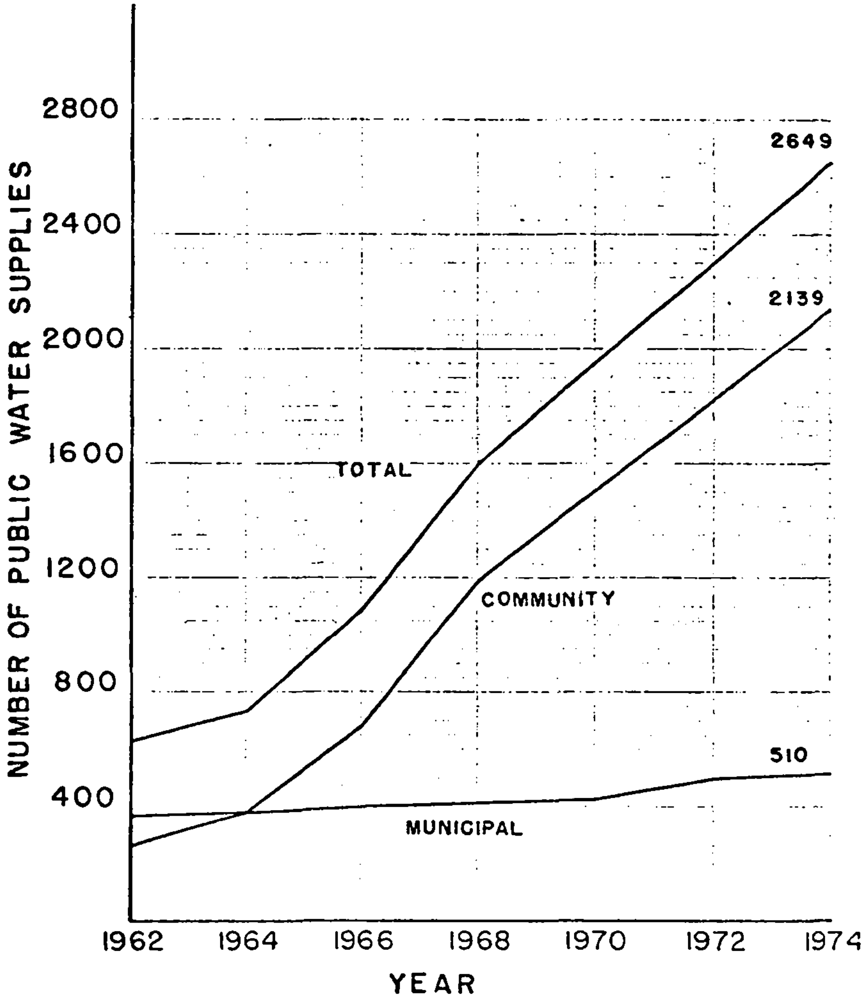

FIGURE 1. Growth of Public Water Supply Systems 1962-1974

Figure No. 2 shows the distribution of water systems according to population. You will note that almost 2,200 public water supply systems serve a population of less than 1,000 people, 260 systems serve a population of from 1,000 to 5,000 and the remaining systems, 119 in number, serve the rest of the population. Also shown on this figure is the estimated population served by municipal and community water systems. My purpose in showing these graphs is to indicate the scope of the problem in North Carolina and that it is the size of the water supply system, not the type that has more problems. Whether it is a municipal or a community public water supply system is relatively immaterial; the problems are basically the same for each type of system. Of course, the larger water supply systems are not free from problems; however, theirs are primarily ones of a technical nature.

PROBLEMS OF SMALL SYSTEMS

While one may consider any number of specific problems or problem areas concerning small water systems, basically the problems resolve themselves into three general categories: first is financing the system; second is system planning; and third is system operation, maintenance, and management. Although they are almost impossible to separate, let us look at each one of these problems individually.

Financing

First, system financing. The term system financing would include initial planning, construction of the system, operation and maintenance, and provision for future expansion and improvement. A satisfactory water rate structure would be a part of system financing. In many cases a water system owner is a real estate developer who is primarily interested in selling pieces of property or renting a space on which to locate a mobile home. He is not at all concerned with a public water supply system except that by having such a system in his development he can obtain more lots per acre than if he had individual wells serving each particular lot. Because he is not interested in a water system, he will not provide the necessary financial resources for proper professional planning for the entire system or for locating and properly protecting adequate sources of water supply. Most of the money goes into land development rather than water system development. In many instances the entire system has been planned and constructed by a plumber or a local well driller whose knowledge of water distribution systems may be extremely limited but whose inventory of small size water pipe is more than adequate for the distribution system. With insufficient funds allocated to the water system, the supply is inadequate even before it is constructed.

Generally, small municipal water systems do not have a problem with financing initial planning and construction. Their financial problems center around operation and maintenance and funding expansion and improvements.

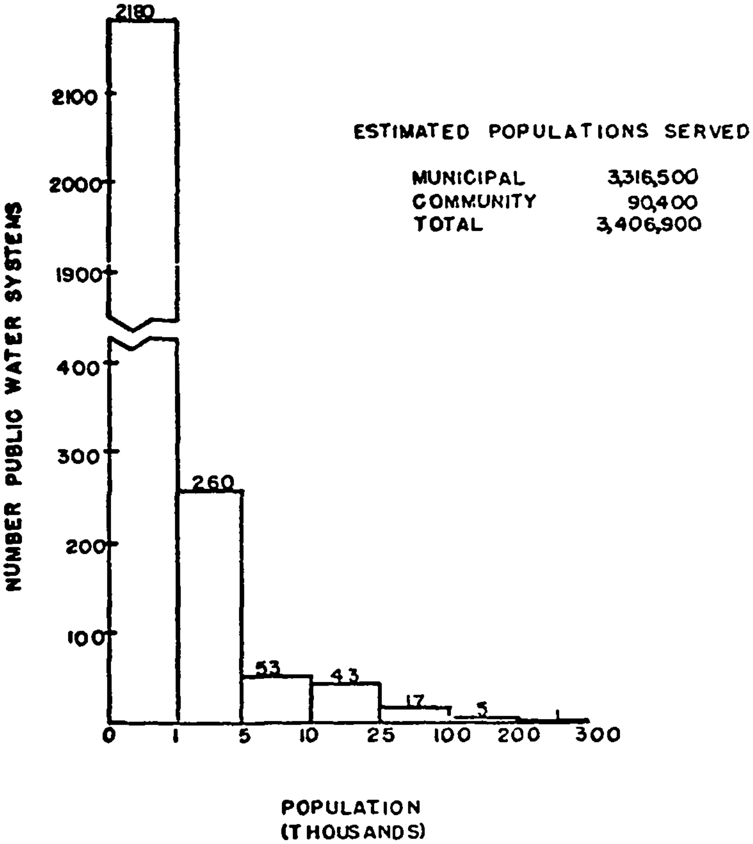

FIGURE 2. Distribution of Systems According to Populations

Planning

System planning, the second problem, is concerned with the planning of the water system itself and the relationship of this system to the surrounding area and other water systems which may be nearby. The design of the water system may have been accomplished with little or no professional engineering advice. As state regulatory agencies have an engineering capability, this would mean that a water system could or would be constructed without the knowledge or approval of the regulatory agency.

Within the water system itself, many problems would be evident through inadequate planning, such as:

1. well sites inadequately protected from sources of pollution,
2. improper well site location,
3. source of supply capacity inadequate to meet demand,
4. inadequate storage capacity,
5. distribution pipeline too small, and
6. no provision for water quality control.

The water system may be designed without consideration for future expansion. In this instance, a concurrent problem may be the adding of more connections to the system when it is already at design capacity. Reserving well sites as future sources of supply in many instances is not considered. Therefore, the demand for water exceeds the available supply.

The relationship of several different water systems in a small geographic area is frequently not considered. In many cases two or more water systems are located adjacent to each other with each system utilizing its own source of supply. In many instances, it would appear that having fewer sources of supply would be much more feasible and definitely more economical; but because the water system owners are competitive relative to land development, there is little or no cooperation regarding the consolidation of several small systems into one larger system. However, there are examples of a land developer consolidating his separate subdivision water systems into one larger, more efficient system. A few small municipalities have been guilty of this *separatism* if you could call it that.

Operation, Maintenance, and Management

The third problem area is system operation, maintenance, and management. Some specific problems in this area are as follows:

1. no operator or manager for the system,
2. untrained and inexperienced operators and/or managers,

3. lack of standby equipment and/or parts in case of breakdown,
4. no knowledge of water quality and treatment,
5. no funding for depreciation or expansion,
6. no laboratory for water quality control, and
7. absentee or out-of-state ownership.

One may add many more specific problems under one or more of the above categories, particularly in the categories of operator and manager. In some instances, maintenance of the water system occurs when there is a breakdown and no water is available to the customers. Small municipal water systems may be a little bit better prepared for problems than the privately owned water systems. However, even though municipalities may have partially trained personnel and limited laboratory facilities for water quality analysis they are not much better off than the small water system with no qualified operator or laboratory facilities. Nevertheless, city and town *fathers* will state that their water system is operating very satisfactorily, and there are no problems with operation, maintenance, or management.

SOME SUGGESTED SOLUTIONS

Financing

Given these three problems in small public water supply systems, is there anything that can be done to reduce these problems to a more workable level? Since small water system owners do not have the financial resources to operate and maintain the system in accordance with accepted practice and regulatory requirements, a solution must be found outside of these systems. The most obvious answer is to reduce the number of small water systems in some manner. To this end, several approaches are being used in North Carolina.

One approach which has proved beneficial in this regard has been the Farmers Home Administration program of financing non-profit water associations within the state. Although the program was viewed with some skepticism with regard to the adequacy of design of some of the systems, it has proven to be quite satisfactory in many areas of the state. Although rural water associations are formed and constructed to supply a safe, potable water in areas where only individual water supplies were previously available, in several instances association water lines closely paralleled or were adjacent to small water supply systems. A number of these water system owners found it more advantageous to either purchase water from the water association or to give or sell the distribution system to the water association thereby getting out of the water business entirely. It should be mentioned, however, that the water associations did not accept all of these small water systems unconditionally; in some situations they refused to accept the system at all because it was totally unsatisfactory to be included in the association's system. In general, the subdivision developer sold or donated his system, and the mobile home park owner connected his system to the water association lines.

The expansion of existing municipal distribution systems and the construction of county water systems provide two other alternatives available to the small water system owner. In some situations the owner may be able to sell his water system to the governmental system, but in most instances the system is absorbed by the larger governmental one.

The sale of the small water system by the owner to another water system owner or to a privately owned public utility is an additional alternative. The consolidation of many small inefficient water supplies in this manner has proved to be advantageous in some areas of the state. The major advantage is a more dependable water supply source for the consolidated systems.

With regard to the first problem, that of water system planning, there is no readily discernible solution for the small water system owner. Since he does not have the financial resources for the initial construction of his system, he cannot be expected to properly operate and maintain his system once it is in operation. Small municipal water systems have the same type of problem primarily due to poor fiscal policy in the past. However, there is a solution for these systems which will be discussed in greated detail in another portion of this paper.

Planning

With regard to water system planning, the 1971 North Carolina General Assembly enacted additional legislation relative to public water supply system requirements which has had an impact on public water supplies in the state. This statute provides supplemental authority to the existing statutes relative to public water supply systems and authorized the Department of Human Resources:

1. To adopt standards and criteria for the design and construction of public water supply systems constructed or modified on or after January 1, 1972.

2. To require disinfection by a method approved by the Commission for Health Services of all public water supplies introduced on or after January 1, 1972, and of all existing public water supplies whenever the number of water samples from a public water supply system is found to exceed the limits for coliform bacteria established in the drinking water standards of the U.S. Public Health Service, or when conditions are found to exist which make the continued use of the water potentially hazardous to health.

3. To require that all proposed public water supply systems be designed in such a manner as will permit the provision of an adequate, reliable and safe supply of water to all service areas anticipated

pated or projected by the owner, owners or developer of the system, and as will further permit interconnection of the system, at an appropriate time, with an expanding municipal, county or regional system.

4. To require that detailed plans and specifications for all public water supply systems be prepared by an engineer licensed to practice in the State of North Carolina, and approved by the Commission for Health Services prior to construction of any part of the proposed system, or prior to the award of a contract (if any) for construction.

5. To require developers or owners of proposed privately owned public water supplies to submit with their plans such evidence as may be required by the Commission for Health Services concerning arrangements made for continued operation, service and maintenance of the proposed water supply system.

The above requirements, particularly the requirement calling for detailed plans and specifications to be prepared by a licensed professional engineer, have drastically reduced the number of new small public water supply systems. A developer now will plan his subdivision with greater care than before knowing that he must have an investment in the water system for the services of a professional engineer in addition to disinfection facilities once the system has been constructed and placed in operation. If he is planning a small development, he will tend to think of providing a distribution system only and consider connecting this system to some nearby existing public water supply. In some instances developers have contacted a water utility company and turned over the entire proposed water system project to that company for design, installation, operation, and maintenance.

This legislation has not greatly affected small municipal water supplies as they normally have had their plans and specifications prepared by a consulting engineer. The financing requirements have dictated this policy rather than any legislation.

Operation, Maintenance, and Management

This brings us to the third problem area regarding small water systems; the operation, maintenance, and management of a small public water supply system. Our previous discussion has centered primarily on small systems serving subdivisions and mobile home parks. The small municipal water system also has operational and maintenance problems. Small municipalities generally have a water superintendent who is also sewerage superintendent, street superintendent, chief of police, fire chief, building inspector, and garbage truck driver on Wednesdays. In addition, the same individual may be the town treasurer and tax collector in his spare time. Because the existing rate structure may be incapable of providing sufficient revenue, the small municipality is unable to provide operating and maintenance personnel for its water system and to make such necessary improvements as may be required to operate the system efficiently.

As previously mentioned, the small privately owned water system suffers even more from a lack of adequate revenue for operational and maintenance costs as well as any renovations or improvements which may be needed. Although there is little or no help available to the privately owned water system for improving operation, maintenance, and management, there is an inducement for the municipal water systems--the North Carolina Clean Water Bond Act of 1971.

NORTH CAROLINA CLEAN WATER BOND ACT OF 1971

As approved by the voters of the State, the Clean Water Bond Act provides $70,000,000 for water systems and water system improvements. Briefly, this Act provides for an allocation of up to 25 percent of the total eligible costs of a water system project as a grant to a local unit of government within the State. The *local unit of government* phrase eliminates any privately owned public water supply system including FmHA water associations from obtaining these funds. The local unit of government category encompasses cities and towns, sanitary districts, water and sewer authorities, metropolitan water districts, and, of course, county governments. One consequence of this Act is that county officials are taking a close look at water and sewer facilities within the county and are proposing additions, changes, and alterations to these facilities to provide better coverage either throughout the entire county or in a major portion of the county.

Since the Clean Water Bond Act took effect on July 1, 1972, 233 grant applications have been received as of September 18, 1974. Of these, 208 have been given grant commitments; of these, 10 grants have been paid in full, in essence meaning the project is complete; an additional 100 to 130 are presently under construction; the remainder are in various stages in the grant processing sequence.

The Grant Program has had a tremendous impact on all public water facilities within the State. Although privately owned water systems are not eligible for these funds since they are not units of government, upon completion of the governmental system they can request permission to connect to the distribution line in order to obtain an adequate and safe water supply. As previously mentioned, one of the problems with small water systems whether they be publicly or privately owned is an inadequate, unreliable or unsatisfactory source of supply. Several municipalities without a public water supply system have submitted grant applications to finance a new water system. Also, some municipal governments have submitted grant applications relative to the purchase of an existing privately owned water system presently serving their area.

To qualify for a grant an applicant must meet a number of criteria. One requirement is the relationship of the work proposed to a regional water supply concept in a particular area which may be adjacent to the governmental unit or consists of an area encompassing one or more counties. Another requirement is the fiscal responsibility of the applicant. This has greatly affected small municipal water systems in that now they are required to either have or develop a sound fiscal policy for the future operation, maintenance and management of the water facility. The financial requirement includes not only repayment of the debt which may be owed in conjunction with the bond grant, but is also concerned that the estimated revenues will provide funds for the proper future operation, maintenance, and administration, reasonable expansion of the project, and the estimated annual principal and interest requirements for this debt as well as for any outstanding debt incurred for the existing facility. Additionally, a capital reserve fund must be established for the project. To date, the Clean Water Bond Act has been instrumental in improving and upgrading existing water treatment facilities and distribution systems, and in providing needed water systems in areas where there were none previously. The Grants Program has provided an incentive to municipal water systems for fiscal responsibility that laws or rules and regulations could not provide.

Additional legislation which has been of limited benefit in the reduction of small water systems is the Regional Water Supply Planning Act of 1971. This act creates a revolving fund of $200,000 for lending to units of government who desire or wish to pursue a study relative to a regional water supply system in a particular locality. This is a planning loan for the purpose of determining the feasibility of a regional water supply system. It has had limited success because of the limited amount of funds available for lending purposes and because the Clean Water Bond Act was passed at approximately the same time and had a greater impact.

To date, 23 study plans or requests for a Regional Water Supply Study have been submitted, and 22 of these studies have been financed. One study is pending because the funds have run out in the revolving fund. Several of these studies have been completed, and it is anticipated that very shortly the concerned units of government will submit formal requests for a Clean Water Bond grant to implement the recommended regional water supply system plan.

The increase in privately owned water utilities in the past few years has affected the operation and maintenance of many small water systems. As mentioned previously, these water utilities are becoming increasingly important as they are taking over the smaller inefficient water systems and providing better service to their customers. These utility companies can provide the necessary spare parts and other equipment for the proper operation of a water system. Additionally, should any specific problems arise in a particular system, they are more readily available and have the expertise to attempt to solve the particular problem. Although it is not the complete answer nor does it solve all of the problems, the utility company has reduced the number of separate public water systems and has certainly reduced the number of specific water problems normally encountered by each separate water system.

PROGNOSIS

Although there are still many small public water systems which are experiencing the previously mentioned problems, progress is being made toward the reduction in numbers of these systems and, hopefully, in the future the total elimination of these problem systems. It is expected that the growth of public water systems will continue for the foreseeable future; however, these new water systems are expected to be adequately financed, planned, constructed, operated, and maintained to insure that the water delivered to the consumer is adequate and safe for drinking and domestic purposes. Additionally, through proper design these systems will have the capability of being interconnected with larger municipal or county-type water systems as the occasions occur, thereby reducing the numbers of smaller public water systems. While relatively few projects have been completed under the Clean Water Bond Act of 1971, side benefits are accruing to these partially completed projects. A number of small inefficient water systems have connected or will connect to the partially completed projects and subsequently will go out of business as a separate water system or by mutual agreement will purchase water from a larger system for resale to its consumers. The result will be better coordination and management of public water supply systems in North Carolina which will insure that citizens supplied water by these systems will have an adequate supply of high-quality water for drinking and domestic purposes.

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Editor's Note: Discussion of this paper follows Mr. Rose's paper.

FINANCIAL CONSIDERATIONS FOR RURAL WATER SYSTEMS

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BACKGROUND

It is with a great deal of pleasure that I accept the opportunity to discuss the design and financing of rural water systems with you here in Chapel Hill. It is appropriate that the leaders in the private sector, educators, and state and federal government officials maintain a dialogue. We believe that most of you share with us a common goal of helping to make rural America a better place in which to live.

The Farmers Home Administration, now officially referred to as FmHA, has been actively involved with the design and financing of rural water systems for a number of years. Originally, the Pope-Jones Act of 1937 authorized the making of loans for rural water systems. This program, although modest in the beginning, has grown by geometric proportion. This year it will exceed $600 million for the financing of water and waste disposal facilities. Although the Farmers Home Administration is seldom in the limelight, this program has not grown to be the largest program for the financing of water systems in the United States without controversy and agony.

DESIGN OF RURAL SYSTEMS

It is estimated that about 75 percent of the nation's population are currently served by municipal-type, urban water systems. These folks live on about 3 percent of the geography of the nation. At the inception of the program for financing rural water systems, we found that most educators, consultants, and state regulatory officials insisted designs to serve small or isolated rural communities follow virtually the same standards as required for large urban areas. Engineers in FmHA knew that it was a virtual impossibility for these small isolated communities to meet the same rigid standards for fire protection, storage capacity or reserve flows as those maintained for urban areas.

In North Dakota, FmHA has been instrumental in the design and financing of rural water systems to serve farmers in the Red River Valley where the total length of pipe needed to serve the community totaled more than 500 miles. Imagine the financial complications with 7-foot burial depth, imported treated water and 1/2-mile between users. Similarly, in Iowa we are now working on a project that will serve a large percent of four rural counties through a distribution system almost 2,000 miles long. It should come as no surprise to you engineers that a system may be designed on the basis of providing for the expected peak domestic demands or it may be designed on the basis of providing for full fire flows.

Fire flows are ordinarily assumed to be 500 gallons per minute at each fire plug. A recent research program conducted by an engineering professor at Oklahoma State University shows that the peak instantaneous demands on a small lateral line serving 18 customers is less than 18 gallons per minute and 10 gallons per minute would meet peak demands for all but about one percent of the time. In FmHA, engineers suggested a design flow of two gallons per minute with a residual dead end flow of five gallons per minute to serve a lateral line of 20 customers would require 45 gallons per minute. This design concept has proven through countless experiments to be very, very conservative. We have actually experienced 400 percent growth without dire results. The dynamic and hydrostatic pressure has always been much greater than those anticipated as a result of careful hydraulic calculations. The engineers in FmHA basically ushered in new eras of rural water system design. This basic revision in design has now made it possible to serve a very large part of the remaining 97 percent of the geography of the United States with feasible water systems. This program bears some semblance to REA co-ops which have miraculously lit up rural America. It is not possible to run water lines in Nevada where distances are five miles or more between homes; but we are working on a countywide ranch water system in South Dakota where the average spread runs 400 cows on 4,000 acres of land. Admittedly, this system will be costly, but when you compare it to the only alternative available consisting of frozen stock ponds in the winter or drought-stricken ponds in the summer, it may be a bargain. These ranchers feel that they can pay for it.

The question may be asked: Why has the FmHA program for the financing of rural water systems continued to expand while some of the comparable programs of the other federal agencies have been less fortunate? I believe the answer rests in the fact that we have recognized new materials such as plastic pipe, new concepts such as multimedia filters or hydropnuematic pressure systems, and we have insisted that the meager grant funds allotted by Congress be utilized only on those projects where they were absolutely essential to bring the project into financial feasibility.

Usually, at meetings such as this, the question inevitably arises, sometimes facitiously, why the FmHA engineer feels compelled to so carefully review designs and financial plans prepared by professional consulting engineers. We have found through experience that with a few consulting engineers we must protect their constituents from massive overdesign and unrealistic feasibility analysis. There are only a very few engineering firms who are not responsible, but it takes only a few to weaken the structure so extensively that programs come tumbling down. The very structure for payment of private consulting engineering fees based upon a percentage of construction costs comes under scrutiny. The promoter-type consulting engineer makes more money trying not to improve his design or the financial feasibility of the project than does the responsible engineer. Furthermore, his projects require greater amounts of federal grants to bring them into financial feasibility. Couple this with the lack of initiative caused by the difficulty of swaying or changing regulatory agencies and you commence to sense the debts of our frustration. One of the greatest needs in state regulatory agencies is to have trained personnel in the design and review categories that fully understand the interrelationship between the latest scientific methods and the technology used by the consulting engineer on a day-to-day basis. Ultraconservatism is probably the most important reason by which state regulatory agencies have been unable or unwilling, in some cases, to accept changes which have been used successfully in other states for years. FmHA has financed the installation of thousands of rural water systems where hundreds of thousands of miles of plastic pipe has been used; yet, some state regulatory agencies will not permit its use. Regulatory officials tend to be the world's greatest pessimists. This is understandable.

COSTS

Costs of building a water system have nearly doubled in the past year. It becomes clearly obvious, then, why we find it necessary to explore every avenue to keep costs in balance. We are on a collision course. We are also hamstringing small communities with rules, regulations, and design criteria that are not acceptable. We force them to design for population growth increases that are totally unrealistic when their problem is maintaining the customers on the system. We forced the use of a mechanical treatment plant that will be obsolete in 1985.

This problem of increased construction costs and the increasingly heavy burden being placed on some of these rural communities is certainly going to require us to do a lot of soul-searching in the years ahead. If we do not, we will surely find that our present methods will force construction costs so high that more and more projects will be unfeasible.

Today is an excellent time for shared responsible action. Now, the general public is up in arms and demanding that something be done to alleviate long contaminated water supplies. The public will not support a water and waste program unless we provide the necessary leadership.

If we fail to take the initiative and grasp leadership now, then the vacuum will be filled by those with selfish motives and the public support will vanish along with the millions of dollars wasted.

Some technocrats feel that the solution rests in massive government grants. To be totally realistic, we must admit that this approach is not long workable. First, the cost of meeting the staggering needs for water systems in America would require tremendous sums. Long before this task is complete, Congress will have grown weary of an ineffective program.

Then how can we prevent the problems mentioned from recurring? We can improve on the evaluation of water flows. Our designs ought to be predicted on the use of 20th century materials rather than 18th century materials.

We must critically review some of our consumption use figures as they relate to rural areas. The accepted methods of flow calculations of 100 gallons per capita per day yield totally unrealistic quantities of water.

Ultraconservatism is probably the most important reason why we have not been able to sell new methods in the design of water treatment and distribution systems. Regulatory officials often tend to be the world's greatest pessimists. When told that a design less than the maximum allowable may not perform satisfactorily, 40 years hence they increase all of the sizes of all components. Elected public officials such as the mayor and town council often are the world's greatest optimists. When the engineer tells the city officials that the installation of the water system will reverse 30 years' population decline, they accept this without question. After a few years, they recognize that they have been sold a monster. By then, the Farmers Home Administration is the only one still around.

So when we concern ourselves about high cost systems, unworkable design guides, and overdesign, it is not without good and justifiable reasons. We are firmly convinced that there are more design bloopers in overdesign than in all others combined.

NEEDED APPROACHES

It should not be interpreted that the purpose of these remarks is to encourage greater reliance on basic research. There is already adequate knowledge available at our fingertips. What we need is the full utilization and implementation of the useful ideas already discovered and proven by research.

One of the greatest needs in regulatory agencies is to have trained personnel in the design and review categories that fully understand the interrelationship between the latest scientific methods and the technology which is used on the day-to-day basis. Unfortunately, this type of individual does not exist today. The need is now, but our educational system has not yet either recognized the need or risen to the challenge. You should offer your assistance.

We frequently read about a major fire. Less dramatic, though, is the thousands of rural communities that are presently using water supplies contaminated by pollution which affects the health of a very large minority in our country. There is no drama when the water must be hauled in trucks, of inferior quality, or be trapped from a rooftop. Similarly, the thousands of polluted wells that are used every day by an unsuspecting public are undramatic.

Consulting engineers, likewise, are content to use outmoded water designs--partially because the profits are greater with the use of the old antiquated concepts but mostly because federal and state regulatory agencies refuse to allow new ideas to be developed as it would upset their status quo and force them to revise arbitrary engineering manuals.

Complacency and the lack of foresight are the culprits to blame for the huge backlog of unfunded applications that presently confront us. There are an awful lot of people to convince--engineers, federal and state regulatory agencies, educators, and others.

The very structure for private consulting engineers fees is based on a percentage of construction costs and must come under scrutiny. The promoter-type consulting engineer makes more money trying not to improve his design than the responsible engineer. Couple this with the lack of initiative caused by unchanged regulations and you begin to sense the depths of our frustration.

Our failure to come to grips with the problems resulting from these problems mentioned, will ultimately yield damaging results. I believe that if we can use the services of responsible, capable engineering firms that make progressive changes, the program of rural development will continue to advance. It may not double and redouble in size like it has for so many years during the last 12 years, but it will, nevertheless, continue to grow. So long as we can assure Congress that the limited grant funds provided are being utilized wisely and only in those few communities where it is absolutely essential and where engineers continue to accept new ideas, we should move ahead.

In the development of our nation, water has always been considered a relatively minor factor for consideration. There has been a rather laissez-faire approach taken by the public. If we are to be truly successful in solving the gigantic task of water and sewer for the thousands of communities in America, then we must enlist the full support and cooperation of all our people.

SUMMARY

Finally, we must continue to use progressive new approaches. In the face of all of the established opposition, we must continue to find and train people who are committed to self-confident teams of water experts that are the new breed of the future. They must furnish the leadership.

The challenge that lies before us is awesome. We can exercise the option to meet it or run; and hopefully, history will indicate that we made the right choice.

QUESTIONS AND DISCUSSION

QUESTION: I was interested in the statement about the percent of the wells that were contaminated. These were individual wells. I wonder if you could tell us about the public water supplies contaminated or polluted?

MR. RUNDGREN: We don't maintain records as to the percentage that may be contaminated or polluted. We do have several systems that the laboratory analysis shows positive for coliform bacteria, but the biggest fault in that is the obtaining of the samples. We've got, I'd say by making a guess, 20 to 40 systems that have a history of positive bacterial results; but whenever our field personnel go out and take samples, those samples come up negative. So it's a matter of the individual obtaining the sample. Sometimes it's almost impossible to train a person to take a sample properly. We do not maintain a specific record on the percentages that are positive on these systems.

QUESTION: (Bob Stewart, Hazen and Sawyer) I have a question for Mr. Rose. I'd like to say, first, that I'm now on the AWWA Plastic Pipe Committee with Mr. Rose, and we do have some differences in philosophy which I guess will be resolved. I'm also a consulting engineer. Mr. Rose has raised some questions about our activities that I think would take longer than the time we have to adequately resolve. I do think that the FmHA-type water system as an intermediate level of design between the community-type system and the municipal type system has a role and a place and needs adequate specifications and methods for the construction. Really, what I'd like to ask Mr. Rose is the extent to which the FmHA has developed such specifications and procedures as has the Department of Agriculture's Soil Conservation Service done for the design of dams where they have very excellent procedures.

MR. ROSE: We do not distribute plans and specifications which may be used by the general engineering fraternity. We have 58 engineers to ride herd over a $650 million water and waste disposal program. I think it's a matter of philosophy. I have, through the years, given reams of material to our engineers to read and digest; but when it comes down to the final analysis, I want them to make individual judgments about what is the best design for each particular system. I don't want them to dictate that in a particular state, consulting engineers will use, as an absolute minimum, a design that must provide 5 gallons a minute at the dead end and 3/4 of a gallon a minute for each customer because we'd be making the same mistakes that have been made by other agencies or other organizations. Each community project has special features that must be analyzed differently. Arbitrary rules are not the way to go. We leave a great deal of latitude to engineers. We hope that adequate training will enable each engineer to weigh all features in a reasonable and systematic manner so that they can come up with the best judgments available. I challenge the educational institutions to help us in this matter. They ought to be teaching people who can bridge the gap in realistically analyzing costs as well as technical designs.

QUESTION: (Dale Swisher, AID, Washington) The last question was one that I had down also as to availability of guidelines, standards or whatever you wish to call it; but I found this to be an extremely interesting session this morning. I've still got 20 or 25 questions here. I'll confine these to two and both happen to be directed to Mr. Rose. If you are permitting the use of standards for construction which are somewhat less than normal, what has been the net results in terms of money? Do you have any per capita costs as a result of using these less-strenuous standards? How do they compare with costs of construction in the urban communities? Also, this question of how do you get around State Department of Health standards which are based upon the normal standards? I hope that is clear.

MR. ROSE: To begin with, I refuse to admit that we have used less than acceptable standards on any of our water systems. We have systems designed in Kansas and Oklahoma and other places called *constant flow* systems, a system in which you build individual storage tanks on the farm. They are nothing more than a replacement for the tank truck and cistern. Then, we design for various stages in between. Take this example: The water supply line to the tank is the *transmission line* and that part of the pipeline network that provides for instantaneous peaks is the *distribution system*. We know from past experience that you can design a transmission line quite satisfactorily for a rural community on the basis of half-a-gallon a minute per customer. Think about it for a minute. The average user in North Carolina uses roughly 4,400 gallons per month. If you divide 4,400 gpm by the number of minutes in a month, this comes to approximately a tenth of a gallon per minute per customer. So you see, when we design a transmission line on the basis of 0.5 gallons per minute, we essentially have a factor of safety of five. When you design a system to serve large geographical areas, you may actually design a system in which 70 percent are *transmission lines* designed to meet the average need of an entire service area and 30 percent *distribution lines* that must carry the peak flows. To do this, we strategically locate *peak only* tanks. All I'm saying is that there are a great number of different ways of approaching the same problem.

Today, I'm delighted that many of the engineering firms that we're dealing with are making extensive use of computers. In the past, they'd come up with one or two schemes. If they could sell it to FmHA and the owner, then that was about as far as they'd go. Today, many have computer programs. They may evaluate 15 or more different systems. Ultimately, they find the best balanced system to serve the specific needs of a community. That's the program for cost comparisons. Let's get down to basics. Take plastic pipe versus cast iron pipe. I don't know whether plastic pipe is inferior. They both have individual characteristics and have to be treated as such. Plastic pipes cost considerably less than cast iron. The basic design concept of evaluating each proposal individually has opened up fantastic areas of rural America that can now be developed. We're working today on systems in North Dakota that have 600 miles of pipeline that will serve 300 ranches or farmers. The pipe is laid 7 1/2 feet deep, and they have to bring the water in from 15 to 20 miles away. We're doing this with an indebtedness of $4,000 per tap. So obviously, the acceptance of new ideas and new concepts has opened up a vast area that can be served.

Right now, we're technically capable of feasibly serving any part of North Carolina that's now endowed with solid rock. The Health Department or regulatory agencies are as varied as the people that are there. We find some are ten times more progressive than others. If a new idea comes up and they accept it and if they push it, consequently, their states really benefit. Also, some regulatory agencies are ultra, ultra-conservative. There's not enough lateral movement of information from one state to another to alleviate the fears of failure.

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PROBLEMS OF INDIVIDUAL SUPPLIES

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INTRODUCTION

Healthful, comfortable living requires the availability of an adequate quantity of good quality water for drinking and household use.

The consumer would be well advised to obtain his water from a public water supply system, if possible, in order to free himself of the responsibility of quality, operation, and maintenance. This is frequently impossible, however, or not economically feasible. The Environmental Protection Agency estimates that 50 million people obtain water for drinking and domestic use from systems serving a single household. These systems will be discussed in this paper.

The relationship between overall acceptability of water supply systems and their size seems to be that the smaller the system - the more likely it is to have problems. This conclusion followed from data compiled in the Community Water Supply Study (McCabe, *et al.*, 1970) conducted in 1969 by a Bureau of the U. S. Public Health Service which became a part of the Environmental Protection Agency shortly thereafter. This study's findings have been well publicized and discussed. There seems to be general agreement that the smaller systems have more prevalent and more acute problems.

**Editor's Note:* Oral presentation by Mr. Taylor.

This conclusion quite naturally raises additional questions about the safety and adequacy of the even smaller systems, the rural individual systems.

HOW SERIOUS IS THE PROBLEM?

It has been recognized for a century that disease can be caused by consuming water containing pathogenic microorganisms. Diseases most frequently associated with contaminated water are amebiasis, cholera, dysentery, gastroenteritis, infectious hepatitis, salmonellosis, shigellosis, and typhoid fever.

Consuming water containing toxic materials can also cause illness and death. These materials can be naturally occurring, but more and more industrial and agricultural chemicals are finding their way into natural waters. This paper, however, principally will discuss matters related to infectious diseases.

Weibel, *et al.* (1964), and McCabe and Craun (1971) studied the occurrence of waterborne disease in the United States during the period 1946 to 1970. Of the 360 known outbreaks or poisonings attributed to drinking water during this 25-year period, over 70 percent involved private* water supplies. The 254 reported disease outbreaks associated with private water systems involved over 12,600 people with 25 deaths. Most of the waterborne disease outbreaks (40 percent involving approximately 8,970 people) were reported as gastroenteritis, a non-specific enteric disturbance. Typhoid fever accounted for 47 (18 1/2 percent) of the outbreaks, infectious hepatitis 36 (14 percent), and shigellosis 23 (8 percent). The greatest number of deaths were related to chemical poisoning (36 percent), followed by enteropathogenic *E. coli* (16 percent) and shigellosis (16 percent). Amebiasis and typhoid each accounted for 12 percent of the waterborne deaths.

In absolute numbers, deaths resulting from private water supply outbreaks are relatively small. The inconvenience, human suffering, and economic loss associated with these outbreaks, however, is significant. The total impact of low-grade illness and subclinical chronic disease remains unknown. This type of waterborne illness, characterized by lethargy and reduced vigor, may aggravate problems associated with the economically depressed rural areas. D. J. Schliessmann, *et al.* (1958), showed that intestinal disorders gradually vanish when populations such as these are provided abundant quantities of safe, palatable water.

LITERATURE

It has long been accepted by health agency personnel and water supply engineers that many problems can be avoided if initial well

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*Private supplies as referred to in these studies included a number of systems serving camps, recreational facilities, trailer courts, and similar establishments in addition to individual water systems.

site selection and construction incorporates certain protective measures. Recognition of the important role which these factors play in the safety of the supply is reflected by the early and widespread appearance of manuals and guides prepared by federal and state agencies and by national organizations. A few of the better known of these were *Ground Water Supplies* (USPHS, 1937), *Farmstead Water Supply Manual* (USDA, 1943), and *Rural Water Supply Sanitation* (USPHS, 1945). These original publications have been superceded by revisions prepared by successor agencies. In addition, essentially every state and many local health agencies have prepared guides and pamphlets on the subject.

Two of the more recent federal government publications which have received wide distribution are *Water Supply Sources for the Farmstead and Rural Home* (USDA, 1971) and EPA's *Manual of Individual Water Supply Systems.*

GEORGIA, TENNESSEE, AND KENTUCKY STUDIES

About 50 million persons in the United States depend on individual water supply systems. Federal and state studies to date indicate that it can be conservatively assumed that an average of 40 percent of these supplies are contaminated. Thus, it is possible that as many as 20 million citizens could be drinking water which does not meet safety standards. Several millions may be drinking water from sources that are grossly polluted.

Discussions between the Public Health Service's Atlanta Regional Office and the Southern Regional Education Board (SREB)* in 1969 led to agreement that an individual water supply study would provide useful information to a number of groups. As a result, a contract was awarded to SREB to study individual systems in four counties of Georgia having different geological and climatological conditions. The principal objectives of the study were to determine: (a) how well these systems satisfied requirements set forth in the U.S. Public Health Service Drinking Water Standards; (b) how well they were able to supply the quantities of water needed; (c) how construction and geology affect the safety and adequacy of the systems; and (d) to what extent state and local agencies had been able to provide advice and services to the owners of these systems. This paper deals primarily with the findings from the first three.

Similar studies were carried out in Tennessee in 1970 and in Kentucky in 1971. Since a variety of geological formations, ground water potentials, and socio-economic conditions were encountered in the three states, the data combine to form a reasonably complete picture of individual water supply practice. The total numbers of supplies investigated, by kind of source, are: 339 dug wells; 118 hand-augered (bored) wells; 1001 drilled wells; 14 jetted wells; 81 driven wells; 68 springs; and 149 cisterns. Detailed information

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*Southern Regional Education Board is a public agency of 15 southern states created by interstate compact to assist in the development of higher education and the fostering of social and economic growth in the South.

on the studies has been presented in individual county reports published by the Southern Regional Education Board. See *References*.

College students were employed by the Southern Regional Education Board to perform the field inspections and sampling. Laboratory work was done in local, state, and federal laboratories. Special questionnaires were prepared for use by the interns and training sessions were conducted. Considerable effort was made to gather all of the information possible on construction details and geology, since there was a growing conviction among water supply engineers that in most areas these two elements are the most important ones in determining the safety of a groundwater source.

BACTERIAL INDICATORS OF CONTAMINATION

Tests run throughout these studies used both total coliform and fecal coliform bacteria as indicators of pollution. According to some bacteriologists, the fecal coliform bacteria are more reliable indicators of recent contamination by warm-blooded animals.

A concentration of four organisms or more of the total coliforms in 100 milliliters (ml) of the sample was taken as evidence of significant contamination (membrane filter technique). The presence of one or more of the fecal coliform organisms per 100 ml of the sample was taken as evidence of significant contamination.

It should be noted that even with the membrane filter technique, in which the entire 100 ml are processed, it is possible to get *negative* results (i.e., no evidence of contamination) from a contaminated source. This means that among those wells showing *no contamination*, an unknown percentage might show contamination if they were repeatedly sampled through a period of months. Thus, it is possible that the percentages of sources contaminated are higher than those reported.

FINDINGS

Contamination

As high as 70 percent of the supplies showed evidence of contamination. Degrees of contamination varied according to the geology, the construction features, and the kind of water source (spring, well, or cistern).

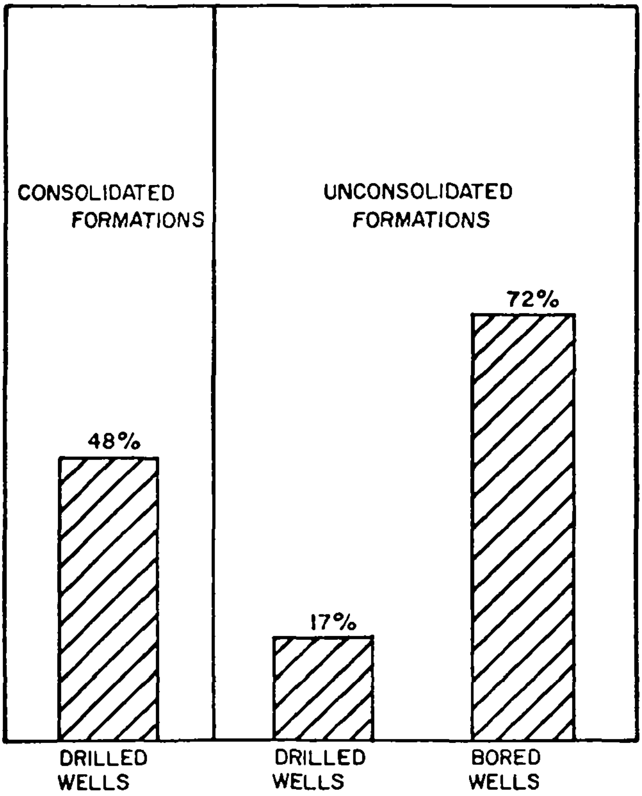
Geology

The data confirm what had earlier been supposed: that drilled wells tapping water sources in consolidated formations (limestone, sandstone, etc.) were more likely to be contaminated than drilled wells in unconsolidated (sand, clay, gravel) formations. Figure 1 portrays this difference.

Construction Methods

The method used to construct wells, and the construction details themselves, affect the safety of the supply. Deficiencies in

FIGURE I
Percent of wells constructed in different formations showing total coliform bacteria (Georgia 1969; Tennessee 1970)*



*EVIDENCE OF CONTAMINATION TAKEN AS 4 OR MORE PER 100 ml.

well construction among these supplies were so numerous that much of the data have defied interpretation. It has not been possible to correlate specific deficiencies with degrees of contamination. Nevertheless, some interesting general conclusions have been drawn.

It is apparent from Figure 2 that the dug wells were the worst with 79 percent of them showing evidence of contamination with coliform organisms. Bored wells, while noticeably better, still showed contamination in 46 percent of the cases. Drilled and driven wells appeared much better, with 18 percent of these contaminated, and jetted wells even better with only 7 percent showing presence of these organisms.

The data reported in Figure 2 were collected from Georgia where both consolidated and unconsolidated geological formations were represented and where there were enough examples to make the data more meaningful.

Turning again to Figure 1, it can be seen that the supposedly favorable characteristics of unconsolidated formations were not enough to offset the undesirable features of bored well construction; these hand-constructed, bored wells with their open-jointed construction and lack of adequate sanitary covers produced water of poor bacteriological quality.

Figure 3 (data from Tennessee) reinforces the conclusion that drilled wells are more likely to be safe. The bored wells were almost entirely in unconsolidated formations; the drilled wells were constructed in both kinds of formations. The fact that the bored wells were completed in formations generally conceded to favor good sanitation, did not by itself assure safety.

Formation Seals

Practically any method of well drillings is likely to leave at least some open space between the well casing and the face of the bore hole. If left open, contaminants from the surface can easily find their way into the well.

Most good well construction codes call for sealing this annular space with a slurry of pure cement. A few codes permit the use of clay. While sealing the annular space is common in the construction of wells for community supplies, it is not generally done in individual systems.

Only in Kentucky was it possible to establish an apparent correlation between the presence of a formation seal and the probability that the well would be free of contamination (see Figure 4). There was little difference between those wells reported to have no cement seal and those said to have only 5 to 10 feet of it. For those reported having 10 to 20 feet of seal, however, the probability of contamination was significantly lower.

Springs and Cisterns

Figure 5 describes the situation faced by families which depend on these sources. Data from Georgia and Kentucky show that 90

FIGURE 2
Percent of individual wells of different construction showing presence of total coliform bacteria - all kinds of formations (Georgia 1969)

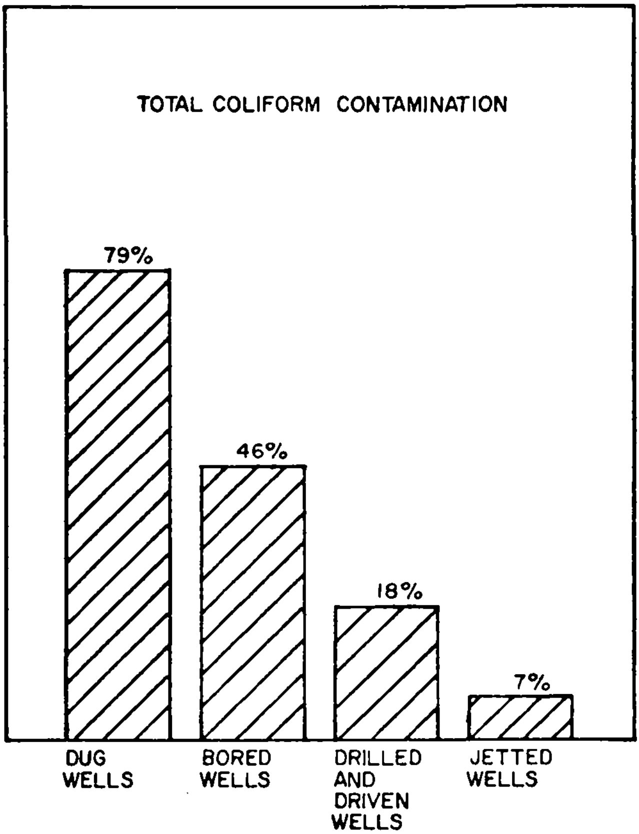
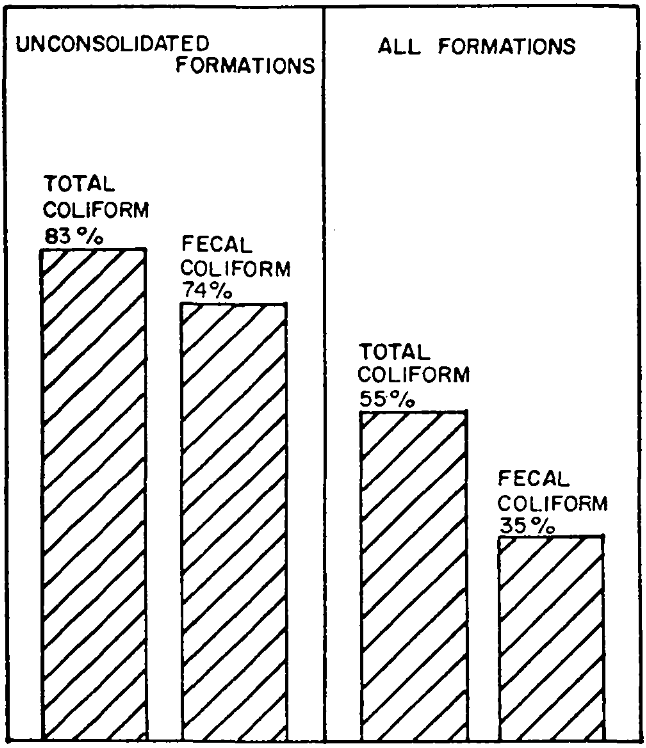


FIGURE 3

Percent of wells showing presence of total coliform* and fecal coliform bacteria** (Tenn. 1970)

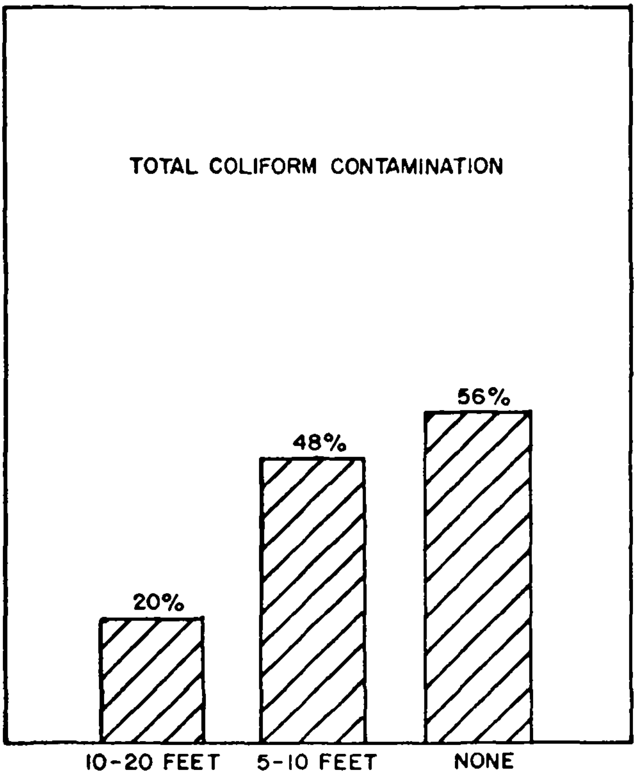


* EVIDENCE OF CONTAMINATION TAKEN AS 4 OR MORE PER 100 ml.

** EVIDENCE OF CONTAMINATION TAKEN AS 1 OR MORE PER 100 ml.

FIGURE 4

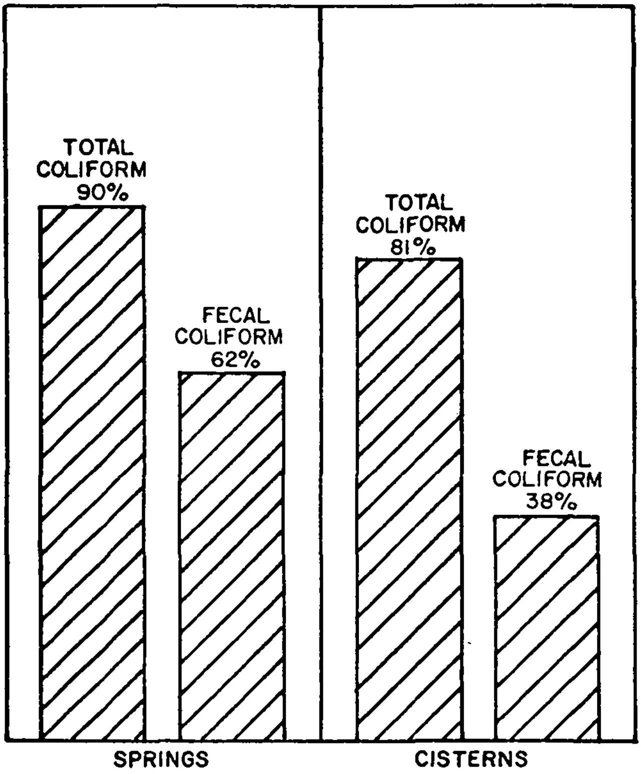
Percent of wells showing presence of total coliform bacteria* with different amounts of cement grout formation seal (Kentucky 1971)



*EVIDENCE OF CONTAMINATION TAKEN AS 4 OR MORE PER 100 ml.

FIGURE 5

Percent of sources showing presence of total coliform* and fecal coliform bacteria** (Georgia 1969 and Kentucky 1971)



*EVIDENCE OF CONTAMINATION TAKEN AS 4 OR MORE PER 100 ml.

**EVIDENCE OF CONTAMINATION TAKEN AS 1 OR MORE PER 100 ml.

percent and 81 percent of these sources, respectively, had coliform organisms. A majority of the springs were located in regions where consolidated formations predominate. Springs in consolidated formations benefit very little from natural filtration, and their flows are promptly and pronouncedly affected by rainstorms. Many are little more than downstream termini for surface water drainage systems in channeled or fractured formations.

The cistern systems encountered in these studies typically consisted of rooftop rain catchment areas with gutters and downspouts carrying the water directly to a storage basin or tank. A majority of the systems depending on cisterns were located in Madison County, Kentucky. Cisterns are generally poorly constructed and maintained without any means either for filtering the incoming water or for disinfecting it prior to use. The cisterns encountered in these studies seldom had any provision for draining and cleaning. Indeed, many lacked even minimal protection to exclude insects, birds, and rodents.

Typically, cistern users were well pleased with the *quality* of the water. (One such pleased consumer had been relying on a cistern supply which inspection revealed contained a small animal floating on the surface.) Primary reasons for satisfaction with the cistern water, of course, are taste and softness.

Well Casing

Sufficient casing must be in place, of course, before any effective formation seal can be installed. It was not possible to establish a correlation between amount of casing installed and degree of contamination. However, inspections in the field and rereview of the data indicate that in some cases, very little casing was installed. This was especially true for the consolidated geology, where as little as 8 or 10 feet were sometimes used, barely enough to prevent caving of the top-soil and to provide support for pumping equipment.

Experience in the actual construction of wells has shown that welding proficiency varies greatly, and good, sound welding techniques are needed to assure strong, water-tight joints.

Indiscriminate use of perforated casing, in the hope of catching any and all sources of water, has led to contamination problems in many areas of the country. Polluted surface water can easily gain access to a well through poorly welded joints and perforations located above the water zone, especially in the absence of an effective formation seal.

There was little opportunity in these studies to examine water well casing and joints. However, other evidence, such as short lengths of casing, and casing loose in the hole, leads an observer to question its integrity.

Covers

An adequate well cover, for the purpose of these studies, was taken to be any cover which would provide good protection against entry of contaminants. To qualify as an adequate cover, it had to protect against direct fall-in, flooding, and splash. Nearly all wells equipped with electric motor-driven pumps were provided protection from the elements. This generally consisted of a weatherproofed box large enough to cover the well and the pumping equipment. Exposure to flooding was rare, either from natural bodies of water or from leaks at the pump house.

The shift away from hand-dug and hand-augered (bored) wells in recent years has made it easier to provide suitable covers for the sources.

Consumer Knowledge

Few homeowners were well enough informed on the basic construction features of their water wells to answer intelligently questions put to them by the investigators. This may in part explain the consumer's general indifference to the condition of his water supply. As reported in *The Forgotten Water Consumer* (Whitsell and Hutchinson, 1971), the individual water supply user in these studies seems to be concerned only with the possibility that he might not have enough water. Water quality and safety were seldom considerations in his preference for one source over another.

Common Deficiencies

The data from these three studies supplemented by other field observations, lead to the conclusion that the outstanding deficiencies in individual system wells are:

1. insufficient and substandard (thin-wall) well casing,
2. inadequate *formation seal* between the well casing and the bore hole,
3. poor welding of casing joints and indiscriminate perforation of casing,
4. lack of sanitary well covers,
5. use of unsealed, jointed casing in certain types of well construction; e.g., hand-augered (bored) wells and dug wells,
6. reliance on the difficult-to-protect dug well, and
7. use of well pits to protect from freezing.

CONSTRUCTION RECOMMENDATIONS

The safety of individual home water supplies can be increased by assuring that the following construction features are included in the wells:

1. Construct wells by drilling (cable tool or rotary equipment), driving or jetting.

2. Use schedule 40 or heavier steel casing with watertight welded or threaded - and - coupled joints.

3. Install solid (unperforated) casing to extend at least 5 feet below the lowest anticipated static water level, and, when practicable, 5 feet below the pumping water level.

4. Fill the annular space between the casing and the bore hole with a suitable sealant (preferably cement grout).

5. Grout the annular space beginning at a point just deeper than the deepest frost penetration and extend to the depth necessary to seal out surface and other undesirable water. Minimum grout thickness should be 1 1/2 inches, placed always from the bottom upward

6. Take special care to locate consolidated rock formation wells so that the relative orientation of the well and sources of pollution afford maximum natural protection.

7. Place no pit at or near the well. Any pitless unit should be carefully selected and installed to seal out pollution.

8. Extend steel well casing at least 8 inches above the ground or floor surface.

9. Equip every well with a cover which will exclude polluted water, vermin, etc.

10. Vent the well to the atmosphere with the vent opening at least two feet above the highest known flood level.

REFERENCES CITED

1. Davis, Barry (1969), "Water Quality Survey, Bartow County, Georgia," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

2. Gilliard, R. M. (1969), "Water Quality Survey, Mitchell County, Georgia," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

3. Hinkle, Randy (1971), "A Water Quality Survey of Lawrence County, Kentucky," Southern Regional Education Board and Environmental Protection Agency, Atlanta, Georgia.

4. Johnson, C. F. (1970), "Water Quality Survey, Rutherford County, Tennessee," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

5. LaCavera, A. J., Sr., (1969), "Water Quality Survey, Coweta County, Georgia," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

6. Long, L. W. (1971), "An Individual Water Supply Survey," Southern Regional Education Board and Environmental Protection Agency, Atlanta, Georgia.

7. McCabe, L. J., J. M. Symons, R. D. Lee and G.G. Robeck (1970), "Survey of Community Water Supply Systems," *Jour. Amer. Water Works Assn.*, 62(11), 670-687.

8. McCabe, L. J. and G. Craun (1971), "Waterborne Disease Outbreaks 1961-1970," American Water Works Assn., Annual Meeting, Denver Colorado.

9. Peppers, Larry (1970), "Water Quality Survey, Haywood County, Tennessee," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

10. U. S. Public Health Service (1937), "Ground-water Supplies," Prog. Rpt. Comm. on Ground-water Supplies, Conference State Sanitary Engineers (1936), *Public Health Reports*, Sup. No. 124, U. S. Government Printing Office, Washington, D. C.

11. U. S. Public Health Service (1962), "Public Health Service Drinking Water Standards," *USPHS Pub. No. 956*, U.S. Gov. Printing Office, Washington, D. C.

12. Purdom, Steve (1969), "Water Quality Survey, Wayne County, Georgia," Southern Regional Education Board and U. S. Public Health Service, Atlanta, Georgia.

13. Roach, E. Steve (1970), "Water Quality Survey, Grainger County, Tennessee," Southern Regional Educational Board and U. S. Public Health Service, Atlanta, Georgia.

14. Schliessmann, D. J., F. O. Atchley, M. J. Wilcomb, Jr., and S. F. Welch (1958), "Relationship of Environmental Factors to the Occurrence of Enteric Disease in Areas of Eastern Kentucky," *U. S. Public Health Service Publication No. 591.*

15. Stephens, Robert (1971), "Water Quality in Rural Madison County Kentucky," Southern Regional Education Board and Environmental Protection Agency, Atlanta, Georgia.

16. U. S. Department of Agriculture (1963), *Farmstead Water-Supply Manual*, Farm Security Administration, USDA, Washington, D. C.

17. U. S. Department of Agriculture (1971), *Water Supply Sources for the Farmstead and Rural Home,* Agriculture Engineering Research Division, USDA, Washington, D. C.

18. Weibel, S. R., F. R. Dixon, R. B. Weidner, and L. J. McCabe (1964), "Waterborne Disease Outbreaks - the 15-Year Period 1944-1960," *Jour. Amer. Water Works Assn.,* 56(8), 947-958.

19. Whitsell, W. J. and G. D. Hutchinson (1971), "The Forgotten Water Consumer," ASAE Paper No. 71-701, Amer. Society of Aggricultural Engineers, St. Joseph, Michigan.

20. Whitsell, W. J. and G. D. Hutchinson (1971), "Seven Danger Signals for Individual Water Supply," ASAE Paper No. 71-701, Amer. Society of Agricultural Engineers, St. Joseph, Mich.

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LEGAL CONTROLS FOR PROTECTING UNDERGROUND SOURCES OF DRINKING WATER*

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INTRODUCTION

Protection of the quality of America's drinking water has recently become a prominent consideration of the nation's lawmakers as a result of increasing attention to quality-related problems. It appears that this concern will culminate in the passage of federal legislation designed to protect our drinking water.

One of the notable characteristics of some of the proposed legislation such as the bill currently before the House of Representatives-- H.R. 13002** (1)--is the emphasis which is placed on groundwater as a source of water supply. One major section is devoted to the protection of underground sources of drinking water. Reference to some basic water use statistics indicates that this emphasis is fully justified. United States Geological Survey estimates of water use in 1970 (2) indicates that nearly one-fourth of total water withdrawals in the United States consisted of groundwater. When public water supplies alone are considered, ground water constituted more than one-third of the total.

The importance of ground water as a source of drinking water comes more clearly into focus when rural water supplies are considered. Of all the water used by the estimated 41 million people served by private domestic systems in 1970, approximately 95 percent was derived from underground sources--a quantity of two and one-half billion gallons per day. When it is recognized that much of the water privately withdrawn for domestic supply is used in an untreated condition, the potential magnitude of the ground water quality problem and the need for its control become obvious.

PROPOSED DRINKING WATER LEGISLATION

The primary ground water quality control measure currently proposed is the provision in H.R. 13002 for federal regulations for state underground injection control programs. The Administrator of

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**Numbers in parentheses refer to correspondingly numbered items in *References*.

the Environmental Protection Agency (EPA) is directed to prepare regulations containing minimum requirements for effective programs to prevent underground injection endangering drinking water sources. The committee voting in support of the bill strongly suggested that the existing EPA policy on deep well injection be ratified and serve as a basis for establishing the minimum requirements mandated in the bill (3). The existing policy, published as Administrator's Decision Statement No. 5 (4), was adopted by the Federal Water Quality Administration, EPA's predecessor, in 1970 (5) and revised by EPA in 1973. Ratification by passage of the House bill would provide a direct legislative basis for implementation which does not presently exist.

The scope of the regulatory controls of H.R. 13002 with regard to subsurface waste disposal is limited to those activities encompassed by the term *underground injection* which is defined as "...the subsurface emplacement of fluids by well injection" (6). Use of the term *injection* to define the same word provides little insight into the scope of activities encompassed, but use of the word *well* appears to establish general limits. The committee report accompanying the bill states that the definition "...is intended to be broad enough to cover any contaminant which may be put below ground level and which flows or moves, whether the contaminant is in semisolid, liquid, sludge, or any other form of state" (7). This provision appears to be only an explanation of the type of substances to which the bill applies. The reference to "...any contaminant which may be put below ground level..." does not explicitly recognize any restriction on the means of subsurface emplacement, but the specific inclusion of the word *well* in the language of the bill appears to override any broader interpretation of scope that may be suggested by this provision.

The bill does contain a restriction on controls applicable to certain types of injection. It states that the regulations are not to impose requirements which interfere with or impede the injection of waste fluids extracted from the earth during oil or natural gas production and the injection of fluids to facilitate recovery of oil and natural gas *unless* such requirements are essential to assure that underground sources of drinking water will not be endangered (8). This provision is designed to minimize constraints on energy production activities (9).

A more general and perhaps more significant limitation on the applicability of the proposed act results from its provisions being limited to injection well operations. Since injection is usually associated with subsurface emplacement of fluids by means of pressure, the question arises as to whether waste disposal operations utilizing gravity flow into a well would be encompassed. An example of this restriction on the use of the word injection is contained in a subsurface waste disposal policy statement (10) adopted by the Florida Department of Pollution Control. Relatively shallow wells which utilize gravity flow are identified as *drainage* wells and are distinguished from *injection* wells. Separate policy provisions are provided for each of the two types of wells.

Even though it is assumed that all disposal wells are encompassed by the bill, many sources of ground water pollution do not involve the use of wells. Waste materials can be placed underground by other types of excavation, and a variety of surface or near-surface activities can result in contamination. In fact, reference to legal records concerning ground water pollution problems to date indicates that the source of contamination in a large majority of the cases has consisted of surface waste disposal operations, leaking pipelines and storage facilities, agricultural practices, septic tanks, mining, industrial operations, and other activities not covered by the proposed law.

If H. R. 13002 is approved by the House, differences between this bill and the drinking water bill approved last year by the Senate (11) will have to be resolved. Although certain provisions of the two bills are similar, the Senate bill does not provide for regulation of underground injection. Thus, it is conceivable that compromise between the two legislative bodies will result in deletion or substantial modification of the controls for protection of ground water quality.

FWPCA AMENDMENTS OF 1972

Since the control measures in H. R. 13002 have not been officially adopted, it is of interest to consider the nature of the legal controls currently in effect. The Federal Water Pollution Control Act Amendments of 1972 constitute the principal legislative basis for existing control over ground water quality. This act gives more consideration to ground water quality than did any of the previous water quality legislation. Many of the general responsibilities vested in the Administrator of EPA by the Act apply to both surface and ground waters. These responsibilities specifically encompassing ground water include development of comprehensive programs for preventing, reducing or eliminating pollution; water quality monitoring; publication of information concerning the health effects of pollutants in water; and the issuance of information concerning processes, procedures, and methods to control pollution (12).

In contrast to the applicability of these general provisions, the direct regulatory provisions of the legislation do not explicitly apply to ground water. The national goal of eliminating the discharge of pollutants by 1985 (13) encompasses navigable waters only. The National Pollutant Discharge Elimination System (NPDES) permit program applies to "... the discharge of any pollutant ...," (14) a term which appears to be limited to discharges into navigable waters on the basis of definitions contained in the Act (15) and its legislative history (16). It is possible to argue that the legal definition of navigable waters encompasses ground water since it is often a part of or tributary to surface bodies of water. The definition of navigability has previously been extended to include non-navigable streams that are tributary to and affect the navigable capacity of a navigable stream (17). However, to argue that the inclusion of ground water is within the definition of navigable streams is weakened by the provisions of the Act itself which often refer to navigable and ground water as if the two constitute distinct legal classifications.

In the absence of specific regulatory authority with respect to the pollution of ground water, the approach taken by EPA is to use regulatory powers incidental to the control of surface discharges (18). A good example of this approach is given by current EPA controls over injection wells. Where such wells are used as part of a total waste disposal program having other elements requiring an NPDES permit, EPA regulations provide that the injection well will also be subjected to permit conditions (19). These conditions can then be made to reflect EPA injection well policy which has no independent legislative basis.

The 1972 Amendments also extend federal control with respect to ground water pollution through requirements for state pollution control programs. The Act makes provisions for the administration of the NPDES permit program to be transferred to the states when certain conditions are met, one of which is the existence of adequate authority to issue permits which control the disposal of pollutants into wells (20). Another mechanism for federal influence over ground water quality consists of the requirement for areawide waste treatment management plans for area identified as having substantial water quality control problems (21). Such planning is required to encompass both surface and ground water. Since these plans are subject to the approval of the Administrator, they provide a basis for federal control over certain aspects of ground water quality.

Thus, it is obvious that existing water quality legislation suggests federal concern for ground water quality and provides mechanisms for EPA involvement. However, this authority is limited as is reflected by current legislative activity such as the attempt to enact H. R. 13002 with its legal controls over ground water quality.

STATE CONTROLS OVER GROUND WATER QUALITY

Since federal controls over ground water quality are still in a developmental phase to some extent, it is of interest to consider the status of such controls at the state level of government. Unlike federal legislation, state pollution control law generally applies to both surface and ground waters. A cursory review of state legislation indicates all states have the authority to control waste disposal into ground water. Maine, in 1973, was the last state to amend its pollution laws to include all discharges rather than surface waste discharges (22).

In addition to these general controls over ground water quality, specific controls with regard to certain types of subsurface disposal methods have been enacted in some cases. A significant example consists of state controls applicable to injection wells. Some of the states have prohibited waste injection and certain others probably do not have suitable geologic conditions; but a substantial number allows injection under some form of legal control. Considerable variation exists among these states with regard to the nature of the controls imposed. Since geologic formations seldom stop at political boundaries, a case can be made for federal guidelines to insure compatible regulations.

Although legal controls exist with regard to specific subsurface waste disposal practices and ground water quality in general, underground sources of drinking water have not always been given adequate protection. Pollution control law has generally emphasized point discharges while many ground water quality problems result from activities not falling into this category with the result that implementation of legal controls in this area has often been incomplete.

PRIVATE GROUND WATER RIGHTS

Federal and state legislative controls over ground water quality are supplemented by a second system of legal controls consisting of the private ground water rights of individuals. The extent to which the right to uncontaminated ground water has been recognized has varied over time and among jurisdictions.

The right to an uncontaminated ground water supply has not been recognized as a basic property right in a number of cases. The courts in such instances have held that landowners have the right to develop and use property for lawful purposes without accountability for the effects of such activities on the ground water supply of others, provided that negligence is not involved. The stipulation that the activities must be conducted in a non-negligent manner suggests that the party who pollutes ground water may be liable for resulting injury under some circumstances, but the courts have often refused to sustain allegations of negligence where the activity responsible for contamination has been conducted in the usual, customary manner. Activities that have been given protection in this manner include the burial of animal carcasses, mining operations, use of septic tanks, and various industrial and commercial processes (23).

The denial of liability in such cases is based on the premise that liability should be dependent on the ability of the perpetrator of injury to have reasonably anticipated the harmful consequences of his actions. Due to deficiencies of information concerning ground water movement, it has been held that the party engaged in lawful uses of property cannot reasonably be required to anticipate ground water contamination. Thus, the imposition of liability for such occurrences has been viewed as an unnecessary restriction on developmental activities. This developmental bias may have diminished to some extent in recent years but is still an important factor with regard to ground water rights.

In opposition to the holdings of these cases that give little protection from ground water pollution, another group of decisions has established a basic right to uncontaminated ground water. Recognition of this right has been accomplished in different ways. One approach involves the liberalization of the negligence doctrine such that ground water contamination is viewed as a foreseeable result of developmental activities under certain conditions. For example, the court in an 1890 Pennsylvania decision (24) refused to accept the defense that injury to wells could not be foreseen or avoided and imposed liability for ground water contamination because the existing state of knowledge was viewed as adequate for the injury to have been avoided. The court noted that failure to recognize advancements in geological knowledge "...would be in violation of the living spirit of the law..." (25).

Another means of giving recognition to the right of uncontaminated ground water is to treat its pollution as the creation of a nuisance. The courts have often taken this approach in cases involving ground water pollution. For example, the escape of oil which percolates through the soil and results in the destruction of the springs of an adjacent landowner has been held to be a nuisance for which liability will be imposed (26). Acceptance of the nuisance doctrine is in effect recognition of a property right in an unpolluted water supply since the concept of nuisance is generally based on unreasonable interference with the use and enjoyment of property. Although the reasonableness of the pollution-causing activity is a basic consideration in the determination of liability in a nuisance case, the fact that the activity is lawful and in accordance with standard practices does not necessarily preclude a finding of liability.

A third approach consists of adopting the view that the landowner has an absolute right to uncontaminated ground water with strict liability imposed for activities which pollute underground water supplies. In some cases the courts specifically adopt a common law doctrine of strict liability originating in an 1868 English court decision (27). For example, the doctrine was accepted in the United States as early as 1895 in a Minnesota court decision (28) involving contamination of ground water by a petroleum product that had escaped from storage tanks. Another origin for the strict liability concept consists of statutes that control certain specific activities such as disposal of salt water extracted during production of oil and gas (29). Still another group of cases has involved the application of a strict liability concept without explicit acknowledgment of the doctrine (30). It is interesting to note that some form of a strict liability concept has been accepted in more than half of the states, and the number is gradually expanding (31).

Aside from the fundamental question of whether the right to uncontaminated ground water is legally recognized, there are other issues which are significant with regard to the evaluation of water rights as a ground water quality control mechanism. One of the most important concerns the question of causation--can the party injured by the pollution establish proof as to the source of the contaminant? It is obvious that the party who initiates a legal proceeding must be able to sustain his charges against the party alleged to be responsible for a particular injury-causing activity, but the burden of proof in cases of ground water contamination can be especially difficult for the injured party. Although the fact of his injury may be very certain, a general lack of knowledge concerning ground water movement in the area in question may limit his right to recover from the specific individuals responsible.

Direct proof of causation can sometimes be obtained by depositing dye or some other easily detectable substances into the suspected source of pollution and determining whether it appears at the site of pollution damage. For example, causation was established in a 1963 Pennsylvania case (32) involving pollution of a well by a sanitary landfill operation when the well water turned red and sudsy after a truckload of red paint and a large quantity of soap-like material were deposited in the landfill.

However, direct evidence is not always obtainable, and the courts in recognition of the resulting hardship placed on the injured party have in many ground water pollution cases accepted indirect proof consisting largely of circumstantial evidence. The specific factors which are adequate to establish such proof depend on the details of the particular case, but those which are generally relevant include the proximity of the alleged source, the existence of other possible sources, the time relationship between the alleged pollution-causing activity and the injury, the capability of the suspected source to pollute, and the existence of a physical connection between the suspected source and the polluted water (33). No one factor is usually sufficient in itself for an inference of causation. Nor is it necessary in each case that all the factors be included. However, the more positive inferences that can be made, the greater the chance of showing causation to the satisfaction of the court.

Another significant consideration with regard to the effectiveness of judicially enforced water rights as a legal control over ground water quality is the responsive nature of the courts. Because of the nature of ground water flow, a contaminated condition often cannot be corrected on a short-term basis. Thus, a system of rights which are usually enforced by litigation after a problem has developed is not a very efficient control mechanism.

The concept of injunctive relief is designed to provide a remedy in situations likely to involve irreparable harm or where suits for damages otherwise provide inadequate relief, but the use of injunctions in cases of potential ground water pollution has been limited by the fact that considerable uncertainty is usually associated with potential pollution. The courts generally require that the pollution in question be relatively certain and will not issue injunctions where the injury is highly speculative (34).

CONCLUSION

This review of existing legal controls over the quality of underground sources of drinking water indicates the absence of a single comprehensive program. Existing federal controls are relatively undeveloped and lack a direct legislative mandate. Basic authority for control is better established at the state level, but legal provisions in many cases have not been thoroughly implemented or translated into actual control procedures. Private rights concerning ground water quality supplements governmental controls to some extent, but the basic nature of the judicial process and the problems encountered in the enforcement of the individual's rights limit the effectiveness of this mechanism.

Passage of proposed drinking water legislation in the form of H. R. 13002 would constitute a substantial improvement over the existing situation, but the controls established by the law will not resolve all ground water quality management problems. Adequate controls over injection wells are essential, but ground water contamination has a variety of other sources. Since so many of man's activities have the potential to pollute underground water, the scope of necessary controls must be quite broad and in many instances may have to consist of land use controls rather than restrictions on waste disposal alone. The development and implementation of controls in many of these areas is complicated by the lack of physical control technology and procedures. The development of this technology and its incorporation into the necessary legal controls must be an integrated process and is one that is not likely to be quickly nor easily accomplished.

REFERENCES CITED

1. H. R. 13002, 93d Congress, 2d Sess. (hereinafter cited as H.R. 13002).

2. U. S. Geological Survey (1972), "Estimated Use of Water in the United States in 1970," *Geological Survey Circular 676.*

3. House of Representatives Report No. 93-1185, 93d Congress, 2d Sess., p. 29 (hereinafter cited as Report No. 93-1185).

4. U.S. Environmental Protection Agency (Feb. 6, 1973), "Administrator's Decision Statement No. 5."

5. Federal Water Quality Administration (Oct. 15, 1970), "Policy on Disposal of Wastes by Subsurface Injection," (Com. 5040.10).

6. H. R. 13002, Sec. 1421 (d)(1).

7. Report No. 93-1185, p. 31.

8. H. R. 13002, Sec. 1421 (b)(2).

9. Report No. 93-1185, p. 31.

10. Florida Department of Pollution Control (June 1, 1972), "Revised Policy on Drainage and Injection Wells," Technical Memorandum No. 8-12.

11. S. 433, 93d Congress, 1st Sess.

12. P. L. 92-500, approved October 18, 1972, Sec. 102(a), 104(s), 304.

13. Id., Sec. 101(1).

14. Id., Sec. 402(a)(1).

15. Id., Sec 502(12).

16. *1972 U. S. Code Cong. & Adm. News*, p. 5356.

17. See *United States* v. *Grant River Dam Authority*, 363 U. S. 229, 232 (1960); *Oklahoma* v. *Atkinson Co.,* 313 U. S. 508, 525, (1940); *United States* v. *Rio Grande Dam and Irrigation Co.,* 174 U. S. 690, 608 (1898).

18. *U. S. Environmental Protection Agency* (1974), "Water Quality Strategy Paper," 2nd ed., p. 69.

19. 40 *C.F.R.* 125.26A.

20. P. L. 92-500, approved October 18, 1972, Sec. 402(b)(D).

21. Id., Sec. 208.

22. *Main Stat.*, Title 38, Sec. 413.

23. See *Long* v. *Louisville and Nashville R. R. Co.*, 107 S. W. 203 (Ky. 1908); *North-East Coal Co.* v. *Hayes*, 51 S. W. 2d 960 (1932); *Gagnon* v. *Landry*, 234 A. 2d 674 (R.I. 1967); *United Fuel Gas Co.* v. *Sawyers*, 259 S. W. 2d 466 (Ky. 1953).

24. *Collins* v. *Chartiers Vol. Gas Co.*, 18 Atl. 1012 (Pa. 1890).

25. Id., at 1014.

26. *Hauck* v. *Tide Water Pipeline Co.*, 26 Atl. 644 (Pa. 1893).

27. *Rylands* v. *Fletcher*, L. R. 3 H. L. 330 (1868).

28. *Berger* v. *Minneapolis Gaslight Co.*, 62 N. W. 336 (Minn. 1895).

29. See *Gulf Oil Corp.* v. *Alexander*, 291 S. W. 2d 792 (Tex. 1956).

30. See *Augustine* v. *Hinnen*, 433 P. 2d 354 (Kan. 1968).

31. William L. Prosser (1971), *Handbook of the Law of Torts*, 4th ed., St. Paul, Minn., West Publishing Co., p. 509.

32. *Reinhart* v. *Lancaster Area Refuse Authority*, 193 A. 2d 670 (Pa. Super. Ct. 1963).

33. See *Bumbarger* v. *Walker*, 164 A. 2d 144 (Pa. Super. Ct. 1960); *Harper-Turner Oil Co.* v. *Bridge*, 311 P. 2d 947 (Okla. 1957); *Jackson* v. *U. S. Pipeline Co.*, 141 A. 165 (N.J. 1937); *Masten* v. *Texas Co.*, 140 S.E. 89 (N.C. 1927); *Enders* v. *Sinclair Refining Co.*, 263 N.W. 568 (Wis. 1935).

34. See *Reid* v. *Memphis Memorial Park*, Tenn. App. 105 (1927); *Davis* v. *Atkins*, 35 S.W. 271 (Ky. 1896).

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EMERGENCY SUPPLIES

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INTRODUCTION

When disaster strikes, the immediate concern is *survival* and survival calls for a minimal supply of safe water. Not enough attention has been paid to this subject.

Considerable attention has in the past been directed to the subject of broad planning for emergency water supply preparedness, and the American Water Works Association has produced an excellent handbook (1).* Planning emphasis is usually put on preservation, protection, and rehabilitation of the existing utility facilities with little attention to the plight of the people who are deprived of water service completely.

However, an adequate supply of safe water is, next to air, the most urgent necessity for human survival. Where a community water system is destroyed or disabled for any extended period, there arises an urgent need to provide water for the affected people. Such an event could arise from an act of war, some other man-made event or from a natural disaster such as an earthquake or a major flood. This paper will examine the subject in general for U. S. cities and will consider two actual and one hypothetical example of water supply emergencies resulting from earthquake disasters striking metropolitan areas.

THE PROBLEM OF EMERGENCY SUPPLY

When one considers emergency supply, the tendency is to ask first where can the source water be found and how can it be purified. One thinks of miscellaneous ponds and streams and of emergency purification units.

For some countries or areas of the world this may be an appropriate first approach. There may be locations where public water supply sources or purification facilities are in short supply, and a major disaster may knock out virtually all of the existing facilities. However, this is generally not the case in the United States.

Development is such in the United States that water and water treatment facilities are generally available. Destruction of any given set of water systems in the core of a metropolitan area will usually leave surviving systems in outlying areas. Even if electricity is also knocked out in the outlying areas, there will usu-

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*Numbers in parentheses refer to correspondingly numbered items in the *References*.

ally be enough emergency power to operate the treatment works and to pump into tanker trucks.

The per capita quantities of water required under emergency circumstances will be much less than normal requirements. The Army/Air Force (2) estimates a requirement of five gallons per man per day for drinking and cooking purposes; and the old U. S. civil defense organization (7) estimates a temporary requirement of four-five gallons per person per day for drinking, cooking and personal hygiene needs. However, the emergency response effort in the Managua earthquake (3) aimed at getting one gallon to each person each day and during the peak of the problem had to be satisfied with much less. Obviously, the amount of water required to sustain life will be much less than that required to enjoy it.

For the U. S., it can be assumed that an adequate supply of safe water will usually be available somewhere in the vicinity of a disaster. Surviving treatment works will be able to serve over thirty times as many people on emergency rations as on the average U. S. metropolitan use which is about 160 gallons per capita per day (6). The very significant problem, then, remains--how to transport it and distribute it to the needy population on a timely basis.

CASE PRESENTATIONS

The case discussions will illustrate three different types of situations and can be used to highlight some of the problems with regard to which preparations and thinking can be done in advance.

1. *San Fernando, California* (4,5)

   At 6:01 a.m. Tuesday, February 9, 1971, an earthquake with a 6.6 magnitude on the Richter scale struck the City of San Fernando and surrounding areas in the City of Los Angeles. It was particularly devastating to the 2.42 square-mile area of the City of San Fernando.

   The severity of damage to the water distribution system was immediately apparent due to an approximately 1500 major leaks; the distribution reservoirs were emptied almost immediately. Electrical power was cut off from all of the pumps on its wells; no water was available anywhere in the city. Severe damage was done to the Van Norman water supply dam, and a major flood threatened, but this had no direct relationship to the problem of water supply for San Fernando.

   The City obtained temporary connections with the City of Los Angeles and the Metropolitan Water District water systems to replace its disabled well sources; the City did not return to its well sources until November 12, 1971. Restoration of water service connections did not begin until four days after the earthquake and was only 80 percent completed twelve days afterward. The U. S. Army Corps of Engineers was instrumental in rehabilitating the remaining 20 percent of the system in the more severely damaged areas of the city.

Therefore, for a period of from 4 to 12 days, a city of 18,000 people was out of water to some degree. An estimated 20 percent of the residents left the area to stay with friends or relatives elsewhere in the metropolitan area. This left about 14,000 people requiring service during the period of maximum need.

Voluntary and official help was promptly obtained. The Schlitz Brewing Company donated the use of 18 tanker trucks serviced with water from its brewery. Other water tank trucks were rented. All told, 33 tank trucks and trailers were obtained for San Fernando, but seven were loaned to a nearby community. With an estimated average size of 4,000 gallons, the 26 water trucks furnished 104,000 gallons of mobile-stored water for serving 14,000 people. The trucks were equipped with manifolds and multiple spigots and were positioned at strategic points in the city for direct use by citizens. The trucked water was chlorinated. According to reports, the emergency water service was accomplished with a minimum of hardship, no significant complaints about a lack of water, and no health problems to the residents.

2. *Managua, Nicaragua*

At 12:30 a.m. on December 23, 1972, a major earthquake struck Managua causing widespread devastation, deaths, and distress. This was a much greater disaster than the San Fernando earthquake. The distribution system sustained thousands of breaks and pressure dropped to zero in all parts of the city except in the near vicinity to the water treatment plant.

The source of water was a volcanic crater lake; the treatment plant was located on the rim of the crater. While electrical service was maintained to the plant and the pumps, landslides during the earthquake and the possibility of further landslides afterwards threatened continued operation of the plant. Contingency planning was done for possible loss of the plant; but fortunately, the plant held up through the crisis period.

In response to a request from the Nicaraguan Government, the U. S. military responded with broad-scale medical, logistical, sanitary engineering, and the like assistance. My discussion is based on the after-action report (3) prepared by Major Fred V. Huff, the Sanitary Engineer responsible for U. S. water supply assistance. The assistance rendered fell into three phases as follows:

a. An initial survey and estimates of the situation, so necessary to the devising of remedial measures. This was performed by a preselected and pre-trained Disaster Assistance and Survey Team which was maintained by the U. S. Southern Command located in the Panama Canal Zone.

b. The actual rendering of assistance. In an emergency situation of this magnitude, confusion reigns, resources are floating hither and yon and problems tend to be of a demanding nature. It was essential to keep a cool head, cut red-tape wherever possible, use what resources you can and to keep in as close communications as possible.

   People poured into the area from all over offering assistance, but they could not all be used; in fact, many just added to the problem by bringing extra bodies to feed and shelter. The key to voluntary assistance in a disaster is to offer some skill or equipment which can be readily factored into the disaster response. In fact, a group of Boy Scouts from Costa Rica, who brought their own food and shelter, were put to useful work; a water tank truck and two jeep-type vehicles with drivers were volunteered by a private contractor and were put to good use. To assist with communications, nightly coordination meetings were held with a Nicaraguan official.

c. Turnover of activities to Nicaraguans. Once the crisis period is past, the principal objective of outside help should be to return all activities to local agencies in a smooth fashion. This was accomplished approximately 14 days after the earthquake, but the U.S. tank trucks were left for an additional period because many people still did not have piped water service.

   Of the 405,000 people in Managua, approximately 300,000 were without water immediately after the earthquake. Approximately 200,000 left or were evacuated to other towns in Nicaragua. Approximately 100,000 people required some type of trucked water service. Prior to the trucked water program getting effectively underway, the people were in dire straits, and reports were received of the use of insanitary ponds and other available surface water.

Resources for conducting the trucked water program were roughly as follows:

-- Forty-three tank trucks and trailers from the Government of Nicaragua, the U. S. Forces and a private contractor for a total volume of 37,000 gallons.

-- Nine U. S. Erdlator water purification units. Two were used for chlorination purposes, but none for complete water treatment purposes; portable rubber tanks, hoses and fittings were put to good use.

-- Some 5,000 filled water cans were flown in from the Panama Canal Zone. However, some petroleum product cans were accidentally filled, and the water was non-potable; fortunately, this was discovered before many had been distributed.

-- Some additional rubber storage tanks of an airborne type were brought in but didn't prove too useful.

The general plan was to set up the military collapsible and portable storage tanks at selected points in the city; then, to keep them filled by the available tank trucks. This was partially accomplished, but the people were also served directly from the tank trucks.

Three significant problems were encountered in making the trucked water program effective:

(1) The rubble and disarray of the city imposed a long delivery time for the trucks; drivers became confused and lost. In response to this, Major Huff set a priority to develop additional watering points located close to problem areas. Three deep-well watering points were established including the use of portable electrical generating equipment; these wells not only helped the trucked-water effort but also provided water for the people in the immediate vicinity to the wells.

(2) The facilities at the Managua water plant were not suitable for the rapid filling of the tanker trucks so that lengthy delays occurred in the filling process. This problem was relieved by using working hydrants in the vicinity of the plant and by establishment of three auxiliary watering points.

(3) Many tank trucks never reached their destination with a water load. Caught in traffic or slowed by rubble, the trucks would be drawn down by the water-hungry people. This problem was also relieved by establishment of the additional watering points and by the improved operating of the system.

In the initial stages, relatively little attention was given to assuring water quality beyond the increasing of the chlorine residual at the treatment plant from 1.0 to 5.0 milligrams per liter. However, later in the operation, booster chlorination was given to the trucked water. Chlorine residual tests by the military at various points in the distribution system always revealed some degree of residual. No health problems were detected from water.

While the water supply recovery program for Managua did not prevent hardship or distress, it was *life-saving* and represented a commendable effort with limited resources. We in the U. S. can be pleased and proud of the key positive role played by our forces in this effort.

Summarizing, I would like to quote Major Huff: "The fact that not a single case of typhoid occurred, nor any dysentery beyond that normally experienced in the area, is probably attributable primarily to the actions to move persons out of the downtown area and the superhuman efforts on water supply taken by personnel of U. S. military,

> volunteers from third countries, and most of all to the Nicaraguans themselves."

3. *Hypothetical Earthquake in the San Francisco Bay Area*

   Several years ago in connection with state and federal efforts to do advance planning, the National Oceanic and Atmospheric Administration prepared an analysis of a series of simulated earthquakes striking on the San Andreas Fault and on the Hayward Fault.

   For water supply, an earthquake on the Hayward Fault would be the far more devastating of the two. The fault runs west of the various water supply reservoirs of the East Bay Municipal Utilities District but east of large concentrations of population in Oakland, Berkeley, etc. Ground shifting would undoubtedly rupture the joining conduits and distribution lines. NOAA states that a great earthquake (8.3 on the Richter Scale) will severely cripple the water supply system and will require up to six months to restore permanently.

   It is expected that a large portion of the water systems located out of the damage zone will survive and be able to furnish adequate, safe water. The problem will be distribution, not availability or treatment of potable water.

   My own estimates indicate that about 1,200,000 people would be discommoded by an 8.3-force earthquake and would require some type of temporary water service. If 20 percent were to leave the area to stay with friends and relatives, this would leave about 1,000,000 people to be taken care of. Trying to furnish five gallons per day for each person would require a trucking capacity of five million gallons per day. If this were accomplished solely by trucks operating on a once-per-day basis, it would require 1200 tank trucks with an average volume of 4000 gallons each.

DISCUSSION AND POSSIBLE GOVERNMENTAL ROLES

Comparison of the three earthquake cases will reveal three different levels of magnitude and types of problems; the utilized or proposed resources are summarized in Table 1.

Examination of these figures shows that Managua clearly had less resources to cope with its water supply problem than San Fernando but still did an adequate life-saving job. The greater availability of resources to San Fernando is not surprising since it is located within a vast metropolitan area, most of which remained undamaged. There was no great strain in responding to its problem.

Table 1

EMERGENCY SUPPORT

Name	Persons served	Number of tank trucks	Volume of tank trucks (gals)	Persons served per tank truck	Tankage volume per person (gals/cap)
San Fernando, California (2/71)	14,000	26	104,000	540	7.4
Managua, Nicaragua (12/72)	100,000	43	37,000	2,340	0.4
Hayward Fault, California (Hypothetical)	1,000,000	1,200	5,000,000	800	5.0

The hypothetical case of an 8.3-force earthquake along the Hayward Fault presents a scene of greater dimensions. However, it is located in a large metropolitan area, most of which will remain intact if badly shaken and the bulk water supply will be available. Comparing the Hayward case with the Managua case will show that a life-saving response mission can be handled with less resources than those proposed if necessary. The problem will be to get the water from the potable sources to the people in their neighborhoods in an effective manner.

Water for survival presents a planning problem often overlooked at the various governmental levels. Local utilities, civil defense or other responsible agencies can address this problem by:

-- Locating and assessing alternate water supplies which could be made available when the basic water system is knocked out. Factors to be assessed would be accessibility for tank trucks; the capacity of filling facilities; travel distances involved, and the like.

-- Communicating or establishing mutual aid agreements with nearby utilities.

-- Making a rough inventory of trucks and establishing communications with breweries, milk plants or other possible sources of trucks for carrying water.

At the state level, the water supply agencies can provide a valuable service by:

-- Encouraging the water utilities or other local agencies to do the above.

-- Providing state leadership in accomplishing the above on a statewide basis, complementing and supplementing the local efforts, as necessary.

The federal role should be:

-- To encourage and stimulate state and local activity.

-- To furnish technical assistance and background information which should be helpful in the work.

-- To be always ready, particularly via the military, civil defense, and related resources, to give emergency help to a stricken community, during the crisis period.

An attractive feature of the roles laid out on the previous page is that they are intensely practical and can be accomplished with relatively little resources. This kind of readiness planning will require attention annually to keep it renewed and current.

CONCLUSIONS

1. The main problem of emergency water supply for life-saving purposes in the United States will be the effective distribution of water to the needy people, rather than the provision of bulk water sources and portable treatment units.

2. Simple and practical steps are outlined for the various governmental levels in readiness planning for emergency water supply for life-saving purposes.

3. In particular, attention is pointed to the capability of the military, civil defense and related agencies for assisting in the response to water supply crisis situations.

REFERENCES CITED

1. *Emergency Planning for Water Utility Management* (1973), American Water Works Association, *AWWA No. M 19.*

2. *Field Hygiene and Sanitation* (1970), Departments of the Army and the Air Force, Army FM 21-10 and Air Force AFM 161-10.

3. Huff, Fred V., "Nicaragua Disaster Relief After Action Report on Water Supply Activities," (Jan. 1973) (Unpublished).

4. *Report on Damage to the Water Wells, Reservoirs, and Water Distribution System of the City of San Fernando Caused by the San Fernando Earthquake of February 9, 1971,* (June 1972), Office of City Engineer, San Fernando, Cal.

5. *San Fernando Earthquake-February 9, 1971,* (November 1971), Report of the Los Angeles County Earthquake Commission.

6. *The Nation's Water Resources,* (1968), U. S. Water Resources Council, Washington, D. C.

7. *Waterworks Engineering in Disaster* (1943), Office of Civil Defense, OCD Pub. #2022.

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AN APPROACH TO PROVISION OF RURAL WATER SUPPLIES

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INTRODUCTION

A good deal has been said here in the last two days about the state of America's drinking water in 1974. I am here to talk to you about a particular aspect of this problem: America's rural drinking water problem.

To a large extent, America's drinking water problem is a rural drinking water problem. Although most of you are familiar with it, let me re-state some of the conclusions of the famous 1970 United States Public Health Service Community Water Supply Study. Of the 969 communities studied, fully 41 percent of those investigated did not meet minimum federal drinking water standards. And the smaller the system, the higher the probability that it was substandard. Only 50 percent of the systems serving fewer than 500 people met the minimum standards--and 24 percent exceeded the mandatory limits for contaminants. As a matter of fact, most of the systems that exceeded the coliform bacteria limit served a population of 5,000 or less. A convincing demonstration, I believe, of the sad state of water supply in rural America.

No wonder, then, that we have been much concerned with the passage of the Safe Drinking Water Act of 1974. We were, of course, just as concerned with the passage of the Safe Drinking Water Acts of 1972 and 1973, and it now appears quite possible that we will be forced to deal with a Safe Drinking Water Act of 1975. I am here to talk about what it is that one group, National Demonstration Water Project, is trying to do to help alleviate some of these problems.

NATIONAL DEMONSTRATION WATER PROJECT

But before we get into a discussion about just what it is that the NDWP does, I think it might be appropriate to tell you just exactly what NDWP is. Quite simply, our project was funded by the Office of Economic Opportunity with a mandate to improve the delivery of needed sanitary services to rural residents nationwide, particularly those with low incomes and those who live in isolated and remote rural locations.

As initially funded, NDWP sought to bring adequate water facilities to a particular and limited geographic area: The five counties immediately surrounding Roanoke, Virginia. OEO's intention was that if the project were successful, its experience could

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Editor's Note: Mr. Zimmerman was the luncheon speaker on September 27, 1974.

be duplicated in other areas of the country that face similar serious problems.

The success of Demonstration Water Project, as it was originally known, led to the establishment of the national program late in 1971. In April, 1973, a greater degree of institutionalization was achieved with the incorporation of NDWP in the District of Columbia. Using the Virginia project as a base, NDWP steadily grew until it now consists of six affiliate projects, which are spread from Florida to New Mexico.

Our basic objective is to precipitate basic changes in the way that water and waste disposal services are delivered to rural Americans. To do this, we have set forth four primary goals:

1. Through our six affiliate projects, to build upwards of 30 million dollars worth of facilities by the end of this decade, using our own limited funds to leverage funds from other sources.
2. To design and test models for the organization, development and operation of rural water and sewer projects.
3. To gather and disseminate, by publication and personal contact, both a technical and non-technical expertise necessary for such development.
4. To forge a national alliance which can complete the job of bringing better water and sewer facilities to rural areas after the NDWP program has ended.

Why, then, do we have these ambitious goals? Simply because between 20 and 30 million Americans in rural areas have inadequate facilities for providing drinking water and wastewater disposal. Many, in fact, have no facilities at all and must carry water to their homes from other sites; others have facilities, such as shallow wells and privies, commonly found to be inadequate in terms of health and convenience; and still others have facilities which can be adequate but which may not be functioning properly because they have been poorly constructed.

The consequences of all of this are tragic. Health problems that are directly caused by contaminated water are the most visible. I'm sure most of you remember the typhoid outbreak that occurred in a Florida migrant labor camp early in 1973. It was not an isolated case. As a matter of fact, in the last decade, there were 130 known or reported outbreaks of disease or poisoning caused by contaminated drinking water. EPA experts believe that perhaps 10 times as many such outbreaks actually occur, but go unreported for a variety of reasons. The more subtle effects of inadequate facilities--in school attendance, work habits, personal cleanliness, community economic development--are considerably more difficult to measure scientifically. For its part, NDWP is planning to conduct an impact study that will attempt to find ways of measuring these subtler effects, but at the moment, we must rely on observation, case histories, and a few scattered studies as evidence of the impact of water and sewer development on a community.

The data which are available convincingly support the conclusion that the nation pays an excessive price for inadequate facilities. Rural residents suffer from chronic health problems, and their communities suffer from a retardation of social and economic development. One of the results of this has been a steady population out-migration which creates problems of overcrowded urban areas at the same time that it denudes the rural community. If we face these realities, it is hard for us to deny that obtaining better water and sewer service for rural areas should be a matter for general public concern.

Pollution and geography are two key elements which underlie the rural water and sewer problem. It is by now a familiar fact that most of the nation's streams are polluted by human and industrial wastes and that the once pure underground aquifers, which are the major source of water for rural areas, have been as adversely affected in many cases. The result is that an ample and convenient supply of pure water, as well as adequate wastewater disposal, can only be obtained by extensive drilling, pumping, piping, storing, and disinfecting.

In general, our urban areas have been able to solve their water and sewer problems. Their very density has been an advantage in this regard. And, of course, they are very well developed in a political and organizational sense. However, the more scattered rural population, especially those living outside any incorporated municipality, cannot usually be reached by traditional water and sanitation systems. They must rely instead on individual supplies or water systems of a different sort.

When we add low incomes to the equation, we find that many rural residents cannot pay the cost of constructing and maintaining an adequate water and wastewater system. They are thus faced with a dilemma: either move to the city or endure poor water and sewer service.

One would expect, given the seriousness of the problem, that government would be anxious to do something about it. Unfortunately, this has not always been the case. Local authorities, usually pleading lack of funds, have allowed the problem to go unattended; only a few states have effective programs for water and sewer development; and federal programs have been limited and uncoordinated. New legislation has also been ineffective. The Rural Development Act of 1972, which could make some contribution to a solution, has yet to be fully implemented.

Rural water and sewer development is a complicated and costly process involving the financing, developing, and sustaining of facilities. There are problems peculiar to rural communities in all of these areas which were apparent at the inception of the NDWP program and, indeed, were among the reasons for its inception.

I would like to discuss each of these briefly by way of background, before going on to a discussion of the current NDWP program. As far as financing is concerned, there seems to be a widespread, if erroneous, belief that local communities can finance their own facilities, and if they cannot, the states will, and that federal participation can be limited to loans, at least for water systems. It is our experience, however, that loans alone simply cannot do the job.

FINANCING

A rural water and sewer system can be an expensive proposition--at the very least $3,000 per connection--and as you know, the cost of everything from plastic pipe to plant operators is rising almost on a daily basis. A community which attempts to finance a system purely through loans, even 5 percent 40-year loans from the Farmers Home Administration, soon finds itself in a quandary. Its first obligation, of course, is to meet the debt service requirement and additionally a reserve obligation as well. If it then adds enough to the water bill to cover adequate operation and maintenance and a reasonable equipment replacement reserve, the water bill is likely to go higher than most rural residents--and, indeed, most urban residents--can afford to pay, 15 to 20 dollars, or even higher depending upon the initial cost of this system. The classic pattern has been for the community to skimp on everything but debt service; thus, the system soon deteriorates. If grant funds were available to help finance system construction costs, debt service could be held down and the system could be well operated while still charging a reasonable monthly rate. The comment we very often get is that grant funds, after all, are available. Our reply to this would be that: yes, grant funds have been available, but they have not always been continuously available and have not always gone to the people most in need. The Farmers Home Administration is a case in point. Since about 1965, Farmers Home has operated a modest grant program. In 1972, as I have mentioned before the Congress raised grant authorization for this agency to 300 million dollars a year, thus giving promise of increased activity in this regard. Unfortunately, early in 1973, grant funds for this program were withheld by the Administration, and state and local governments were encouraged to fill this gap with federal funds from general and special revenue-sharing programs or with their own appropriations. Following the Congressional pressure, the grant program was restored in fiscal 1974 and 150 million dollars in funds were released. This is a good sign, but past performance makes us worry that this momentum will carry forward in the following years.

On the waste disposal side, the Water Pollution Control Act of 1972 would seem to offer a replacement for the sewer portion of the Farmers Home program. This has not been the case because the Act was passed primarily as a means to clean up the nation's waterways; thus, the most serious municipal polluters are being given funding precedence. Rural communities will be far down on the statutorially required priority list and will likely stay there for the foreseeable future.

While these are the main funding sources, there are several others who are able to provide at least minimal funds. The various regional commissions--Appalachian, Four Corners, Coastal Plains, etc.--also have a limited amount of grant funds available, but they are tightly controlled by the governors of the states involved. The Economic Development Administration of the Department of Commerce has a grant program tied closely to industrial development in designated target areas, but funding beyond the end of this year would seem to be questionable. It should also be mentioned that several states--Missouri, New Mexico, Georgia, North Carolina, Alabama, Washington, Florida--have grant programs for water facilities construction. Many states, of course, have grants available for sewer construction, but these are used primarily to match EPA grant funds.

Adding to the problem that is caused by the lack of grant funds is the fact that many rural communities lack the necessary expertise to find out what funds are available and how to go about getting them. Local private groups, such as community action agencies, are a help but may themselves lack the funds, leadership, or inclination to move into water and sewer projects when there are many other problems to be dealt with in the community. Federal and state agencies, however, often have the resources and experience in facilities development which local communities lack, possibly including a network of regional and local offices.

Present policy, unfortunately, is commonly to use the *application* approach, waiting like bankers for someone to come in and apply for a loan or grant. Far too often, no application comes in, or, if it does, it is incorrect and must be redone with resulting frustration and delays.

We believe that funding agencies could identify communities which seem to be in need of assistance and help them to design water and sewer systems and the financial packages to construct them. Individuals in some federal and state agencies have done this for years, but the exercise of the outreach function has in general been very dismal. In fact, many of the people we talked to in rural areas complain that they must submit large amounts of complicated paperwork before these agencies will even begin to process the application.

DESIGN

Both state and federal agencies also tend to be unimaginative when it comes to the design of rural water and sewer systems. For example, a cluster well system--that is, multiple water sources or sewage treatment facilities under central management--may be more economically feasible in an area with a scattered rural population than a traditional central system. Yet, such a system may have difficulty obtaining health department approval so prevalent is the belief that city water--in the sense of good quality water--can only be obtained through a city system.

OPERATION AND MAINTENANCE

Although financing and development are obviously crucial, possibly the most crucial area of rural water and sewer development is the sustaining, or support, of the facilities themselves. Poor operation and maintenance, rather than a lack of facilities to begin with, is the chief reason why rural facilities are inadequate today. This is more than a problem of poorly trained operators. Instead, operation and maintenance is affected by all the things which relate to the water and sewer system from the original financing to the regulation of the system by the state.

The original financial arrangements for rural projects have often been based on unrealistic appraisals of likely operation and maintenance costs in the past, and these costs are rising everywhere. A water-sewer system cannot be operated on a shoestring; and if this fact is not faced at the outset, no amount of patching and improvising later on can save the situation. Unfortunately, not enough hard information about true support costs has been available to rural projects in the past, a need which NDWP is trying to meet with systematic study of these costs in several states. When information is available, funding agencies must provide enough assistance at the construction stage to allow a water system to finance its own support needs in the future.

In order to keep costs down as much as possible, arrangements for operation and maintenance should be as innovative as possible, an approach which immediately suggests the need for cooperation by funding and approving agencies. Training users to operate the facilities is one approach which may work in some cases and which NDWP is testing. However, they will have difficulty performing all the technical tasks that are required, even with the best designed training program. On the other hand, small water-sewer companies find it hard to afford truly professional operation and maintenance. An alternative is to establish non-profit support companies to provide support services for a large number of small community associations, thus giving each of them better service than it could afford on its own. Here again, the biggest roadblock may be funding agencies which prefer more traditional support arrangements.

REGULATION

A major factor affecting the successful sustaining of facilities is federal and state regulation. What rural systems face here is the familiar problem of quality versus costs. As concern with water pollution has increased in recent years, there has been a steady trend toward upgrading water-sewer facilities--better state design standards, mandatory operator certification, toughened federal drinking water and treatment plant effluent standards, and so on.

All these changes represent improvements in the quality of water-sewer service and no one opposes that. At the same time, there may be trouble ahead for rural systems if the higher standards being imposed are not examined carefully on the basis of necessity and cost. Although all federal and state agencies should be alert to the problem, many are not. States often use urban design criteria to force rural communities to build elaborate systems which they do not need and cannot afford.

As noted earlier, the problems which have been described here are current problems, but they have been in existence for quite some time. The inadequacy of rural water-sewer facilities cannot be remedied unless these problems are attacked, and it was this challenge which NDWP was designed to meet.

NATIONAL DEMONSTRATION WATER PLAN (NDWP) METHODOLOGY

At the present time, NDWP uses two basic methods to achieve its goals: affiliate projects operated in six states in partnership with NDWP and national program components, which are planned and executed by NDWP contractors.

The affiliate projects--in Virginia, West Virginia, South Carolina, Arkansas, New Mexico, and Florida--were all chosen because of unique features that would contribute to a thorough testing of NDWP methodology. All are centered in low-income, rural areas and have in common strong organizations with the capability of sponsoring complex projects under joint venture arrangements.

As they have evolved, the field activities of the affiliate projects concern three basic model approaches:

1. *The Non-profit Model.* A private, non-profit company performs the development function, including the establishing of separate non-profit water companies. Through these companies, the users own and manage the facilities which are constructed. Support capability, in some cases, is built into each company through an extensive training program. However, the long-run success of such ventures is yet to be demonstrated. An alternative support arrangement which seems increasingly attractive is to have a separate support company, possibly the development company itself (a *D and S* company) provide operation and maintenance for several community water associations.

   The non-profit approach helps to keep costs down and may be especially well-suited to the *cluster-well* technique which NDWP has supported.

2. *The Public Agency Model.* In some instances, a public agency is the best vehicle for water-sewer system operation, especially if the project includes sewer as well as water facilities because non-public bodies, at the present time, are not eligible for EPA financing. A public service district seems the most suitable public agency. (Such districts are allowed to operate water-sewer facilities in most states but are not always called by this exact name. They may be *utility districts* or *sewer improvement districts.*) There is some user control because the districts are

governed by elections. Both development and support can be provided by a non-profit company or companies.

In some cases, a non-profit may develop facilities which are then owned and supported by a traditional entity, such as a municipality.

3. *The Electric Co-op Model.* Another type of organization which can serve as a suitable entity for water-sewer development is the rural electric cooperative. The belief in NDWP is that REC's can be induced to apply the vast expertise they have gained in bringing electricity to rural America to water-sewer facilities, assuming they can receive the same financial help from federal or state sources and technical assistance from NDWP. One of NDWP's most promising state affiliates is built around a group of rural electric cooperatives.

   Co-ops which enter the water-sewer business will usually spearhead the development process, support the facilities constructed, *and* own and operate the facilities. However, co-ops will probably (as in the Florida affiliate) do their work through a separate non-profit corporation in the development stage, and it is possible that *separate*, user-owned water companies would be used in some cases.

(The table on the following page summarizes the three NDWP models and lists examples of projects which are applications of them.)

It seems likely that as rural water-sewer development goes forward, all these models could appropriately be applied within the boundaries of a single area. Thus, a non-profit, cluster-well approach might be used in an isolated rural area; a rural *bedroom* community near a municipality may best be served by subsidized extension of municipal service; larger communities may be served by a rural electric cooperative or a public service district.

Our affiliate projects also have been concerned with involving state governments in programs that will show new approaches for state government in this field. Joint activities in one or more states where affiliates exist are planned to include:

1. studying the operation and maintenance costs and activities of rural utilities;

2. formulating criteria for selecting target communities and areas to receive assistance with inclusion of all residents, including those in areas too isolated to be served by central systems;

3. establishing procedures for evaluating the cost impact on rural utilities of proposed state health regulations;

Table 1

NATIONAL DEMONSTRATION WATER PROJECT MODELS

Model		Development Function	Ownership and Mgt. Function	Support Function	Example
NONPROFIT	I	Non-profit development company	Non-profit user-owned water-sewer company	Non-profit user-owned water-sewer company	Virginia project
	II	Non-profit development company	Non-profit user-owned water-sewer company	Non-profit support company	New Mexico project
PUBLIC AGENCY	I	Non-profit development company	Public service district	Non-profit support company	West Virginia project Arkansas project (Poplar Grove)
	II	Non-profit development company	Public (City) water company	Public (City) water company	South Carolina project (Possum Hill)
COOP	I	Cooperative-controlled non-profit	Cooperative-controlled non-profit or REC	Rural Electric Cooperative	Florida project
	II	Cooperative-controlled non-profit	Non-profit user-owned water-sewer company	Rural Electric Cooperative	Florida project

4. testing the feasibility of *front-money* programs administered by states to assist communities in reaching funds for financing facilities under major federal programs; and

5. developing training programs concerning management of utilities for local boards responsible for operation of public and private utilities.

We are very much committed to making our affiliate projects successful in concrete terms. This means a significant number of both water and sewer connections. But we also don't want these projects and their accomplishments to exist in a vacuum. All of them, we feel, have implications far beyond their local areas. Thus, the reason for our other major program component: The *national* component of NDWP.

The major components being used at the present time in our national program include:

1. affiliate coordination and assistance,
2. research and publications,
3. the National Information Clearinghouse,
4. the Management and Technical Assistance Program, and
5. the National Alliance Program.

In a sense, all of these components interrelate and support each other. For example, the research program provides input to the local projects and the publication effort, the MTA program uses the lessons learned in the local affiliates to help communities with similar problems, and the publication program provides books and reports useful to both the local projects and the MTA program.

A discussion of all these components would take much more time than I have here today. Let me concentrate on our publication program, as I believe it would be of most interest to you.

NATIONAL DEMONSTRATION WATER PROJECT PUBLICATIONS

It is our thought, in the publications program, to eventually produce a *Rural Water-Sewer Bookshelf* which can serve as the most authoritative statement on both the theoretical and practical aspects of rural water-sewer development. Our two most recent publications include this rather hefty volume called *The Guide to State and Federal Policies and Practices in Rural Water-Sewer Development.* The guide brings together, we believe for the first time, all currently available information on both federal and state rural water and sewer programs. It was written primarily to meet the need of local, state, and national planners--and others interested in rural development--for a single reference work in this important field.

The result of exhaustive new research, the contents include a summary and analysis of current policies and practices; and an agency-by-agency and state-by-state survey of research, regulatory and funding programs. As you can see, numerous tables are included to summarize both the similarities and differences between the states' programs in several important categories.

Our second new publication is entitled *O&M - Guide for the Support of Rural Water-Wastewater Systems.* This is not a technical work. Instead, it was written especially to meet the needs of managers of rural water and wastewater facilities for a comprehensive treatment of system financial management, personnel and equipment control, and technical oversight. Comprehensive coverage is given to the following topics among others: Support company management; operating and maintaining water systems; operating and maintaining wastewater systems; training and utilization of plant operators; and estimating operation and maintenance costs. As you can see, the guide is very expensively illustrated and contains 44 tables and many figures, as well as an appendix which contains sample reporting forms, selected ordinances for the control of wastewater inflow, standard wastewater tests and examples of current water-wastewater system costs.

Of our prior publications, let me mention *Wastewater Treatment Systems for Rural Communities,* a manual for the construction of small wastewater systems. It includes information on traditional systems, such as septic tanks, and on innovation approaches. A particularly valuable part of the book is a very lengthy appendix which contains a survey of available equipment and equipment data sheets. We have a companion volume to Mr. Goldstein's, entitled *Rural Water Systems Planning and Engineering Guide.* We have also published a guide to the organization and development of projects at the local level.

As you can imagine, we are forced to sell these books, although I should hasten to add that the revenues derived do not nearly cover the cost of their preparation.

We do manage to give quite a few things away, and I have brought along a variety of this material. I hope you will take advantage of this and take some of them along with you today. I have also brought along order forms for the publications we sell should you find any of them of interest.

Even though we're proud of both our local affiliate projects and our national program, NDWP fully realizes that its resources alone are not adequate to bring about the changes in national priority that are needed if rural water-sewer deficiencies are to be made good. In an effort to broaden the impact of its programs and policies, it has organized the National Alliance program component as a means of bringing together individuals and groups who are committed to rural development.

The Commission on Rural Water forms the basis for this program. Let me tell you a little bit about it.

COMMISSION ON RURAL WATER

When OEO* originally funded this demonstration effort, it was their hope that it would form the basis for a new national commitment. At their suggestion, therefore, NDWP has fostered the formation of the national Commission on Rural Water. Although it receives staff services from NDWP, the Commission stands independent of NDWP responsibilities for implementing the overall demonstration program. Membership currently includes such organizations as the American Public Health Association, the Ground Water Council, the National Water Well Association, federal agencies such as EPA and OEO--and the State of New Mexico environmental improvement agency.

Working through the Commission, the National Alliance will attempt to bring to the attention of the widest possible public the problems that rural residents face in acquiring adequate facilities. They will also press for appropriate policy changes to deal with those problems. While our short-range goals change depending upon the current funding and political situation, we do have several long-range goals that we feel are vitally important. We begin with the assumption that there is a public responsibility for supporting the construction of needed facilities. We feel further that this responsibility must be turned into a firm public commitment that includes, for obvious reasons, the provision of adequate grant funding. We have found through bitter experience that loan funds alone cannot do the job. We also feel that federal and state agencies should be more willing to provide funds for other than central systems. After many months of discussion, the Farmers Home Administration has agreed to test this concept in NDWP affiliate projects. By other than central, we simply mean that if it takes 45 wells to serve 100 families, then let's put in those 45 wells, but also put in the administrative entity necessary to operate and maintain them.

Funds for other than public bodies are also very necessary. For example, EPA will not provide grant funding for any but public bodies. Greater flexibility needs to be built into this program.

We also need to eliminate burdensome and unnecessary design requirements. Not shoddy standards. But design requirements that are realistic for rural areas, not simply urban standards applied to rural areas.

I have talked a long time, and I feel that I have only scratched the surface, both in describing the problems and in articulating NDWP's response to them. But I am pleased to have been able to be here today to share my thoughts with you. I urge you to likewise share your thoughts and ideas with me. We are, after all, in the same boat; but without more and better water the boat will continue to be mired in public apathy.

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*Office of Economic Opportunity, a U. S. government agency.

DESIGN OF WATER TREATMENT FACILITIES

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INTRODUCTION

In this discussion of water treatment plant design, I will touch briefly on the following subjects: pilot scale investigation; flexibility in design; flocculation and chemical coagulants; sedimentation; filtration; instrumentation and control of the processes; and sludge and wastewater treatment and disposal.

PILOT SCALE INVESTIGATIONS

It is often wise to conduct pilot scale treatment investigations of a water supply even if the raw water is of comparatively good quality. The investigations themselves do not represent a large investment in time or money, and the results can lead to a savings in capital and operating expenditures.

For example, in Springfield, Massachusetts, the quality of the water supply historically has been high; however, the water does require treatment for reduction of color and at times iron and manganese. An expansion of the existing facilities, which consisted of slow-sand filters, was required to keep pace with increasing water demand. It was found, however, that additional slow-sand filters would not be feasible because of land and labor requirements, and that a rapid filtration plant would probably be more economical. A simple pilot plant was operated at the site of the filtration works to see if rapid filtration preceded by coagulation and flocculation would adequately reduce the color, iron, and manganese. A few weeks of operation indicated that this mode of treatment was satisfactory, and the need to construct sedimentation basins was thereby eliminated. It was estimated that over two million dollars in construction funds were saved because sedimentation basins did not have to be built.

Pilot scale investigations of water supplies have also shown that different waters of apparently similar quality react very differently under the same treatment conditions. In some cases, relatively good quality waters have not reacted favorably to the direct filtration approach. On the other hand, it has been possible to maintain reasonable filter runs using the direct filtration process on certain highly turbid waters.

Other references will be made in this text to pilot operations that can be conducted to determine criteria for design and operation of a full-scale plant.

DESIGNING IN FLEXIBILITY

Numerous process, chemical and hydraulic calculations are made in the course of designing a water filtration plant. If you were to wade through these calculations for any particular facility, one thing becomes evident: before any calculation can be started, basic assumptions have to be made. For example, a number of assumptions have to be made to determine the capacity of a facility, the population to be served in the design year, the average daily water consumption of this population, the average daily industrial water consumption, and the ratio of the consumption on the days of maximum demand to the average daily consumption. We have seen many communities grow faster than had been projected. It is somewhat like predicting the economy of the nation; and yet, design criteria have to be set and plans made.

Because of these assumptions, flexibility must be built into the design. Administrative and chemical facilities, for example, can be designed to accommodate long-range needs, while initial process units can be designed for a shorter period, and the site can be planned for orderly expansion.

There are a number of additional ways to design flexibility into a facility. A few examples are:

1. Conduits that transport the water to and from process units can be designed for higher rates than the process units. This allows for higher loadings on the process units in the future. If the conduits in some of the older plants have been designed with additional hydraulic capacity, upgrading of these plants to high-rate filtration would be a much simpler matter.

2. Chemical conduits can be run to a number of points in the process. Ever-changing chemicals and their application make this mandatory.

3. Allowance can be made for separating the flow through one line of process units from the main stream. This enables the plant operators to conduct full-scale experimental chemical and process tests while maintaining the plant in operation.

FLOCCULATION AND CHEMICAL COAGULANTS

The choice of chemical coagulant and its rapid dispersion into the water is critical to efficient settling and filtration of the impurities. The choice of chemical is dependent on laboratory, pilot and full-scale plant testing. However, even though a particular chemical appears to give the best treatment during one period, variations in raw water quality, and the development of new chemicals can lead to another chemical or a combination of chemicals that may be desirable in the future.

Here again, flexibility in design is called for. The structures housing chemical storage and feeding facilities, for example, should be designed to accommodate bulk liquid storage of aluminum or iron salts as well as providing space for storing small liquid or dry chemical containers. And the feeding equipment should be designed accordingly. Also, where an alkali is required for pretreatment and/or pH control, facilities for storing and feeding both lime and caustic soda can be designed into the plant.

The equipment selected to provide rapid dispersion of the chemicals into the water, as well as that for slower flocculation, can be equipped with variable speed drives to give a wide band of mixing speeds.

The amount of flocculation required varies with the water, its temperature and with the chemical used. Pilot plant tests of the water in Springfield, Massachusetts, showed that when the temperature of the water was low, a period of about 15 minutes of tapered flocculation provided the most efficient filtration. This appears somewhat at variance with the commonly held theory that where direct filtration is practiced, a short rapid flocculation period to build a pinpoint floc is desirable. It may be that during full-scale plant operation a short flocculation period will be desirable under certain conditions. The flocculation basins and the mixing equipment, in this case, were designed to allow for a variable speed and period of flocculation.

Interestingly, recent pilot tests conducted at the Springfield facility indicate that a polymer rather than aluminum salts may be used as the prime coagulant. The fact that the full-scale plant will be in operation this fall points out the validity of a flexible chemical design.

Results of pilot scale tests recently conducted in Sydney, Australia, for a large water treatment facility indicate that the Sydney water supply, which contains 25 units of artificial turbidity, can be treated by direct filtration. The pilot tests have not yet shown definitively whether alum salts or a polymer will be the best chemical, nor exactly what period of flocculation will be desirable. The period of flocculation or conditioning could be dependent on the chemical. Again, the intention is to design the mixing equipment and flocculation structures with flexibility in mind. In this case, a large channel will be used to provide up to 15 minutes of conditioning. Provisions will be made for flocculating at various points in the channel.

Certain polymers have recently been used as the prime coagulant for the reduction of turbidity and/or color in some waters. The polymers have been used to date with varying degrees of success in different supplies. Where the polymers are effective, they can sometimes be more economical than aluminum or iron salts, and their use results in a smaller amount of waste sludge.

SEDIMENTATION

Regardless of the fact that direct filtration may grow in popularity for the treatment of relatively good waters, sedimentation will continue to be a workhorse in many applications. The design of the basins is dependent on the treatment plant site, the climate, and on the experience and opinions of the designer. There are a number of options open to the designer, however, including horizontal removal flow-thru basins, upflow basins, horizontal trays, and inclined tubes.

Horizontal flow-thru basins--with or without mechanical sludge removal equipment--have been used in numerous plants. T. R. Camp addressed the area of sedimentation at length and proposed that trays be installed in new and existing plants to increase the flow-thru capacity of the basins. His firm, Camp Dresser & McKee, designed trays into existing basins in Cambridge, Andover, and New Bedford, Massachusetts; Troy, New York; and Concord, New Hampshire.

The use of inclined settling tubes was introduced by Microfloc, Inc., and the use of settling tubes in certain installations, especially in the upgrading of existing plants, has become attractive. Tubes are being installed in the existing sedimentation basins in the Willimantic, Connecticut, water treatment plant to upgrade the capacity. This step, along with the placement of dual-media in the existing filter boxes, will allow for increasing the flow-thru capacity of these two processes at a minimum expenditure.

Upflow type basins have been used with success in the United States and extensively in other parts of the world. The sludge blanket concept allows for a higher unit area loading than with horizontal flow-thru basins. Thus, similar to the horizontal tray and inclined tube installations, the upflow basins should be more economical and should take up less space than conventional horizontal flow-thru basins.

FILTRATION

As the most important process in the treatment flow stream, filters must be designed as the safety valve ahead of the consumer in addition to removing a substantial amount of the impurities in the water. Whether or not the plant is designed with sedimentation basins, the filters should be designed to effectively remove impurities through the full depth of media at a relatively high rate of filtration.

Dual-media anthracite coal and sand filters are currently being designed at rates of 5-10 U. S. gallons per minute per square foot of surface (gpm/sf). A third media of garnet has been used in some installations. Whether the filter be designed using two or three media, the size and consistency of the floc penetrating the media, and the relative gradation of the media are of prime importance. Enough emphasis cannot be given to the choice of coagulating chemical, the control used in feeding the chemical into the water, and the rapid dispersion of the chemical into the water. The effectiveness of the sedimentation and filtration processes are dependent on the coagulation step.

The selection of a reasonable filter rate also depends upon a number of factors, including the quality of the raw water, the pretreatment provided (e.g., sedimentation or not), and the number of filters that could probably be out of service at any one time. Pilot filter tests can be of considerable value and should be conducted for each water supply as noted earlier. However, most waters are amenable to being filtered at a rate of at least 5-6 U.S. gpm/sf with proper pretreatment. Higher rates may be employed where sedimentation is practiced and the raw water is of relatively good quality. The rate must be chosen in concert with the design of the backwash pumps and the choice of a minimum reasonable backwashing cycle. As a treatment facility gets larger, the higher rates should be considered more seriously, since the economic savings become substantial and because there is usually more flexibility in backwashing due to the larger number of filters.

One notable exception of this rule-of-thumb is the filter design rate chosen for the large Sydney, Australia, treatment facility. With sedimentation, the rate would probably have been 7-8 U. S. gpm/sf. When it was decided to treat without sedimentation, the rate was dropped back to 5-6 U. S. gpm/sf.

There are a number of other choices required when designing a rapid dual or multi-media filter. For example:

> Should an ancillary wash be included; and if so, should it be air or surface? A number of plants have experienced a layer of mudballs on the surface of the filters, requiring air or surface wash to break up this layer.
>
> What type of filter bottom is needed, since this choice is somewhat dependent on whether or not air is provided? It should also be considered that some bottoms require a layer of gravel underneath the sand; others are designed to directly hold the sand.
>
> How will filtration rate be controlled? For example, there are many plants being designed in the U.S. today using automatic constant filter rate control devices. A number of designers, however, advocate minimization of control devices, especially in geographical areas where it is assumed that operation and maintenance will not be given full attention.

INSTRUMENTATION AND CONTROL OF THE PROCESSES

High quality, reliable instrumentation is available today to the extent that a water treatment facility can be fully automated if desired. Small plant or large, the decision to automate and to what degree should be made by the engineer only after sufficient discussions with the client. It was mentioned above that a choice has to be made on the mode of filter control. In an area where sophisticated operating personnel are available, the filtration and backwashing processes can be completely automated. This can result in a minimum of operating staff and a highly reliable process. Where conditions are different, the better choice could be a minimum of automation, resulting in additional operating staff, but less equipment to maintain.

Conditions are not always this black and white; however, it may be a wise decision to automate certain processes even though a sophisticated operating staff may not be available. After all, the use of instruments could make certain pre-set limits of operation automatic, thus cutting down on the chances of operational errors. Such a decision demands that the equipment will be maintained properly.

In addition to automation of the filtration process, instrumentation and control technology is advanced enough to automate the chemical processes and hydraulic flow-thru. In larger plants, consideration can be given to computerizing the logging of data, control loops and maintenance programs.

SLUDGE AND WASTEWATER TREATMENT AND DESIGN

The sludge removed from the sedimentation basins and the wastewater resulting from backwashing the filters often creates as much more of a challenge to the engineer than does the design of the treatment processes themselves.

Primarily, the method of treatment and disposal of the wastewater and solids is dependent on the chemicals used in the treatment process. Lime sludge resulting from the softening process is voluminous, and a decision has to be made between dewatering and disposing of the sludgecake or recalcifying. Alum sludge can be dewatered and disposed of to land or it can be dried in lagoons or drying beds. Recently, more attention has focused on settling of the wastewater and holding of the sludge and bleeding the solids to the wastewater treatment plant. The supernatant can be either reclaimed and treated or disposed of to a local watercourse under controlled conditions.

The use of polymers as the prime coagulant results in a smaller volume of sludge. Where the right conditions prevail, consideration can be given to applying wastewater directly to the land.

SUMMARY

In this discussion, I have attempted to highlight some of the more important developments in the design of the major water treatment processes. Many major design elements including intakes and screens, pumping facilities, and filtered water storage basins have not been discussed. I have, however, tried to show the importance that lies in the choice and application of chemicals and the design of the flocculation, sedimentation and filtration processes. I have mentioned the use of the direct filtration process and the economic advantages of that process for treating certain water supplies.

The importance, based on my experience, of piloting treatment processes should not be underestimated. To this end I have stressed certain applications of pilot plants including those for direct filtration, choice and application of chemicals, filtration rates and degree of flocculation required. I have also tried to illustrate the importance of designing flexibility into the treatment works to allow for expansion, as well as for future improvements in chemicals and processes.

There are many important design decisions that have only been alluded to. For example, the choice of filter bottoms; the mode of control of the filters; and the degree to which a water treatment facility should be automated. The Filtration Problems Committee of the American Water Works Association (AWWA), chaired by Professor John L. Cleasby, is currently attempting to address some of these design options. I am pleased to be a member of this Committee and trust that the on-going exchange of ideas and test results will continue to improve design and operation practices.

QUESTIONS AND DISCUSSION

QUESTION: (Robert Stuart, Hazen & Sawyer) I noted that you have indicated that the disposal of solids from a waste treatment plant creates a major design problem for which there is no one good solution. Could you comment on this.

MR. PRENDIVILLE: I agree. There is no one good solution. In many cases where a waste treatment facility is available and where the quantities of solids from the water treatment process are not that much compared to those from the wastewater, it has been feasible to discharge the solids to the waste treatment facility through the wastewater collection system. This has turned out economical in many large cities and regions, and in smaller cities and towns it would be more questionable. Many plants have been designed with lagoons or drying beds. Disposal of the solids in either a liquid or solid state to the land certainly has possibilities, especially where polyelectrolytes are used as the prime coagulant.

QUESTION: (Jim Lamb, UNC-CH) Most of your comments, I think, were directed toward basically the processes which we are now using or have used for some years. I wonder what you see as the present thrust, if any, toward the use of some of the new techniques which have been proposed for waste treatment in the water supply field.

MR. PRENDIVILLE: I have mainly addressed the processes used for many years. What I have tried to stress are the current improvements being designed into existing processes such as coagulation and filtration. In regard to techniques recently used in the wastewater field that might be common to the filter treatment field, one of these would be the use of activated carbon either in a powdered or granular form for removing organics in existing water or a water supply. Activated carbon can be used in place of anthracite coal in a filter bed and serves both a filtering and adsorption purpose.

QUESTION: (Professor Howells, WRRI) I would like to ask you when you're dealing with a public water supply treatment problem on a source stream that is relatively polluted where there are chemical plants upstream and you do certainly have some refractory organics, how do you approach this? How much do you attempt to determine just what the nature is and treatability, etc.?

MR. PRENDIVILLE: There is a water treatment facility in Lowell, Massachusetts, which treats water from the Merrimack River. Raw wastewaters are now being discharged into the river upstream of the water treatment facility. Wastewater treatment facilities are now being constructed on the river. The treatment facility as it exists has limited capabilities for handling taste and odors due to organics in the supply. We had recommended that new activated carbon and sand filters be installed at the treatment facility. In addition, we had looked at the possibilities of ozone, but since the existing plant has a rather large chlorine installation, we did not recommend at this time that new ozone facilities be installed. Studies have been conducted to determine organics in the river. There is a question on the life of the carbon filters depending on the level of organic material required to be removed. It appears that the carbon filters could have a life prior to regeneration of up to two years where the removal of organics causing with taste and odors is the only criteria. Studies done to date seem to indicate that the carbon would have a much shorter life prior to breakthrough of some of the other organics in the supply.

QUESTION: (Professor Howells) I think you should mention something about disinfection and what comes to my mind is every so often we sort of go through this cycle again of what are the alternatives to chlorine and somehow or other we throw them up and examine them and we always come back to chlorine. You might comment on that a little. Would you seriously consider ozone in new plant design?

MR. PRENDIVILLE: Ozone has been considered for disinfection of water supplies in the U. S. At the present time, most states require a chlorine residual in the water; and therefore, even if ozonation was to be used, a small amount of chlorine would still have to be added to the water to provide the residual in the system. Because of the latest crisis in chlorine supply, the production of hypochlorite on site has been considered in many instances. This becomes simply a matter of capital and operational economics and the availability of chlorine gas.

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WATER RATES: AN ASSESSMENT OF CURRENT ISSUES

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INTRODUCTION

An assessment of rate-making policies in the urban sector of the water utility industry within the United States is timely. This derives from two sources. First, the scientific as well as philosophical bases for determining rate-making policies have increasingly been questioned. These questions have been raised at an increasing rate by a wider cross-section of professional and public interest groups than in the past, particularly within the past five years. Secondly, the water utility industry has begun to respond to criticisms of their rate policies. This has resulted in several fundamental changes; changes that are more significant than any that have been made since the turn of the century. Acknowledging the significance of these trends, this paper focuses on these questions currently being raised and the resulting responses.

A useful distinction in explaining the evolution of rate-making policies is that between the views on this subject taken by economists and by the industry. Although this dichotomy has generally characterized the two ends of the rate-making spectrum, there have been certain points of agreement, a phenomenon that is becoming much more prevalent. The most important distinction between economists and the industry concerns the fact that economists focus their attention on *rate structures*. That is, they are concerned with the incentive effects of various types of pricing systems; e.g., flat versus metered rates, uniform versus seasonal metered rates, decreasing block versus increasing block rates, etc. The emphasis is placed on determining what effect various rate structures will have on water use and investment in new facilities. Alternatively, the industry has been concerned with *rate levels;* i.e., generating enough revenue to meet costs (revenue requirements). As a result, *rate structures* have rarely been reviewed and changed even less frequently. *Rate levels*, however, have frequently been altered, particularly in the recent past. Rate revisions have typically been an upward adjustment in the rate level to meet increased costs, leaving rate structures unchanged.

Since changes in rate levels involve no modifications in rate-making philosophy, the historical overview of rate making in the United States is limited to a chronology of the few changes that have occurred in rate philosophies or structures. From the Civil War to roughly the turn of the century, urban water, with the exception of that supplied by individual wells and cisterns, was supplied by private and public water companies on a flat rate basis. Meters were generally not used to measure water consumption; and hence, rate structures did not contain a commodity charge or price per unit of water consumed. Rather, the flat rate was based on the number of residents, type of fixtures, number of rooms, or other physical features associated with the customer's property; e.g., lot size. In the case of the public companies, taxes were also used to generate revenue. While dominant in the early years of the industry, flat rates still exist in numerous small water systems and in some larger ones, such as Sacramento, California. Moreover, there are several large systems--e.g., Baltimore, Denver, and New York--in which some of their residential customers continue to be charged on a flat-rate basis.

It should be emphasized that this discussion is exclusively limited in coverage to the United States. For measurement, although not by meters, and allocation on the basis of use, were practiced in Roman times [Frontinus, 97 A.D. (Trans., Herschel, 1913)]. Roman water rights were not riparian and reverted to the government to be reallocated to other applicants upon the death of an original owner. The amount of water that was allocated to an applicant, many of whom were residential users, was measured by the size of the orifice that he was allowed to insert into an aqueduct. As long as the heads were roughly the same, this was a reasonable way to measure and allocate water. The only exception to this practice was the ancient grants for public baths, where no measurement was required. Certainly, this method was more sophisticated than flat rate systems in which the use by an individual customer is not in any way measured, and his water bill only roughtly correlates with water use.

The conversion from flat to metered rates was the first major change in rate structure that occurred in the United States water utility industry. With the introduction of meters to facilitate measurement, utilities began to assess rates, in part, on the basis of the amount of water consumed. The conversion to metering was rather swift in the industrial segment of the market with the major switch taking place between 1900 and 1910. This is not to say that there were not commodity charges based on measured use prior to 1900. For example, in Baltimore, large industrial users were not assessed a flat rate charge, but were charged on the basis of the number of wine barrels of water that they consumed. The bulk of the metering of individual residences took place in the period between 1920 and 1935.

Associated with the switch to metering was the declining block rate structure. The first units (block) of water consumed in any billing period are purchased at a certain rate. Successively larger units (blocks) are purchased at lower prices. Although this structure has dominated since the inception of metering, there have been changes in it in the past ten years. Thus, another fundamental change in rate structures has been made by some utilities. It has usually been in the form of eliminating the declining block and switching to uniform commodity charges in which every unit is sold at the same price.

It can, then, be said that metering, the first major change in rate structure, has generally been completed. The second change, the elimination of declining block rates has begun. More importantly, some utilities are seriously considering yet a third major change in rate structures, a switch to a system of seasonal rates in which rates would be higher in seasons of high cost, high use than in seasons of low cost, low use.

ECONOMIC PRINCIPLES

Before embarking on an assessment of the evolution of ratemaking policies, the scientific and logical basis for criticism must be given. This basis is briefly presented here.

An increase in the consumption of a commodity produces a benefit to the consumer. Expansion of output requires, however, withdrawal of resources from the production of some other item and, therefore, entails a cost to the would-be consumers of foregone alternative products and services. The general role of prices is to balance benefits and costs at the margin; i.e., to assert proper checks which will ensure that an incremental increase in the production of a commodity is balanced by a corresponding increase in consumption of that commodity. Prices, therefore, have two functions: to discourage excessive consumption of a commodity and to induce the desired supply of that commodity.

In a perfectly competitive economy, prices are determined by an automatic, impersonal market mechanism where they are adjusted so that the quantity of goods demanded equals that of goods supplied. When prices are determined in this setting, all economic choices are efficient; i.e., real income is maximized. Therefore, under conditions of perfect competition, a pricing policy is not required. The need arises where industries, such as the water industry, are not perfectly competitive. The fundamental question concerns the determination of the optimum pricing policy to be adopted.

The optimum pricing policy depends on the analyst's objective function. With economic efficiency as the standard, social welfare is maximized when the difference between social benefits (total revenue plus consumer surplus) and social costs (measured as an opportunity cost) is the greatest. The pricing criterion achieving maximization of this social welfare function is that the price of any service or commodity should be equated to the costs of producing another unit of the same service or commodity; i.e., price equals marginal cost (see Williamson [1966] for a straight-forward proof).

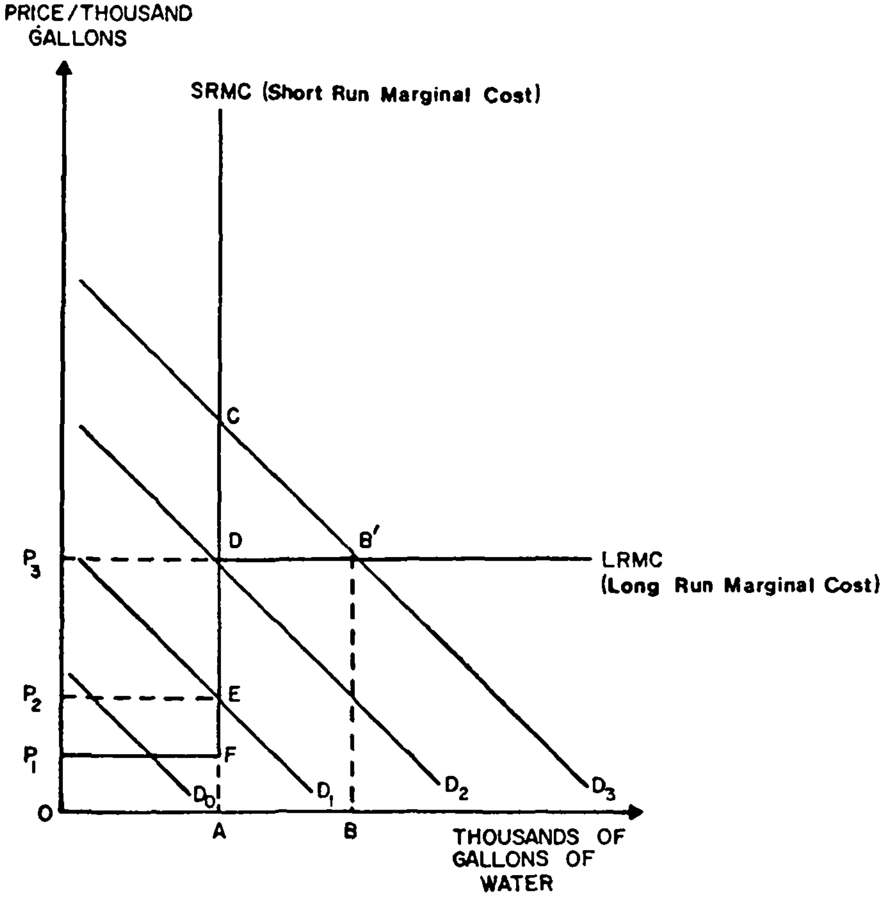
Let us begin our discussion of the rationale for marginal cost pricing by assuming that we have an existing facility requiring that a price be determined for its output. Generally, prices measure a consumer's marginal gains. Therefore, if price is equated to marginal cost, no gain can be derived from either expanding or contracting output (incremental gains equal increment costs). Alternatively, if price exceeds marginal cost, a facility will be underused; the incremental consumer gains from increased output, measured by price, will exceed incremental costs of providing an increment to output. In the third instance, if price is less than marginal cost, there will be an excess demand for the service or commodity; incremental benefits, measured by price, will be less than incremental costs. Therefore, faced with the problem of setting a price for the output of an existing facility, one should set price equal to marginal cost.

When demands grow and existing capacity becomes fully used, price should be raised to ration capacity. As time passes, the point will be reached when the price that rations capacity exceeds operating costs plus properly discounted capital costs of a new increment to capacity. At this point, investment in the new capacity should be made; benefits, measured by price, will exceed the relevant marginal costs (operating plus discounted capital costs). The appropriate level of investment in capacity will be reached at the point when the value of the new capacity is balanced against the value of its opportunity cost. Therefore, the rule price equals marginal cost aids not only in pricing to achieve optimum output from an existing facility but also in determining when to invest in additional capacity.

These pricing and investment rules can be more clearly seen by viewing Figure 1. As shown here, demand is growing from D_0 to D_3, and prices are equated to short-run marginal costs (SRMC). The SRMC function is assumed to be constant (OP_1) until capacity is reached at OA, when it becomes vertical. The long-run marginal cost function (LRMC) is also displayed. It includes the capacity costs, expressed as a discounted flow, plus operating costs. Let us assume that the initial demand is D_0; then, the optimum price would be P_1 which would only cover running costs and no capacity costs. It is optimal to raise price to P_2 as the demand grows to D_1. At this price, operating costs are being covered, and a contribution toward covering capacity costs (the rectangle P_2EFP_1) is being made. It continues to be optimal to raise price along the vertical segment of the SRMC function as the demand grows until price (P_3) equals the long-run marginal costs; i.e., until consumers are willing to pay an amount equal to running costs plus the full capacity costs. As demand grows beyond this point (D_2) additional investments in capacity should be made. For example, if the demand shifts to D_3, it will become efficient to make an investment in new capacity of AB. In this case, the value (benefits) of the additional capacity is represented by ABB'C while the costs (running plus capacity) are represented by ABB'D. The net benefit is represented by the triangle CDB'. This example is highly simplified. If strictly followed, it would be similar to trying to navigate a ship on the basis of rules derived from an analysis of calm sea conditions. However, it displays the basic fundamentals of pricing and investment criteria.

Although the theory of marginal cost pricing is clear to most economists, they often become confused when applying the principles. The major source of this confusion arises over what the correct concept of marginal cost actually is. The problem usually revolves around the fact that the economic model contains concepts that are only remotely related to the actual decision under consideration. For example, the extreme short-run marginal and long-run marginal

FIGURE 1
Application of Marginal Cost Pricing



cost concepts are usually not relevant for the decision at hand, which is to set water rates for the next one to three years. The relevant marginal cost is the one covering the same period of time as the rate decision. If rates are being designed today for 1975-1976, one is interested in evaluating the incentive effects of rate changes upon consumers and their water consumption in future years (1975-1976). Hence, the relevant marginal costs and rates should reflect the savings to the utility, if consumers reduced their consumption, and they should also reflect the additional costs the utility will incur, if consumers increased their consumption during these years. So that in practice, a *medium run* concept of marginal cost is probably more appropriate than either the short or long-run concept presented in Figure 1 (Vickrey, 1971). However, this does not invalidate the basic principles of marginal cost pricing which are used as a basis for critiqueing industry practices.

AN ASSESSMENT OF RATE-MAKING POLICIES

The pricing policies of most water enterprises in the United States are largely based upon financial and not economic criteria (see Hanke and Davis, 1973, for a comprehensive review). These financial criteria are applied *ex post* and are not an integrated part of a pricing-investment planning process (Anderson and Turvey, 1974). The financial criteria are concerned with price levels, rather than price structures. By designing pricing policies that are not based upon economic criteria, water enterprises cannot effectively determine how fast expansion should be, how output should be divided among various competing users, and how existing capacity can be more fully utilized. These are the questions to which the economic approach to pricing, outlined earlier, is addressed.

There are numerous methods that are actually used in designing pricing policies. This paper is limited to a discussion of the general and most salient features of the financial or accounting approach used by the industry. The accounting approach begins with an inventory of all of the undertaking's assets. Depreciation rules are applied to the value of these assets to yield an average annual capacity cost. Variable costs are then evaluated. Usually, these are broken down on the basis of customer-related costs; e.g., costs that are not correlated with either the demand for capacity or water; these include metering and billing costs and those that vary with the quantity of water demanded; e.g., chemical costs, etc. used to treat water. These accounting costs are then allocated to consumers so as to reflect the accounting cost that consumers are imposing on the water enterprise. Oftentimes these costs are, in effect, lowered to the local project beneficiaries because the federal government is a project partner and shares a portion of the costs (usually, a portion of the capacity or capital cost).

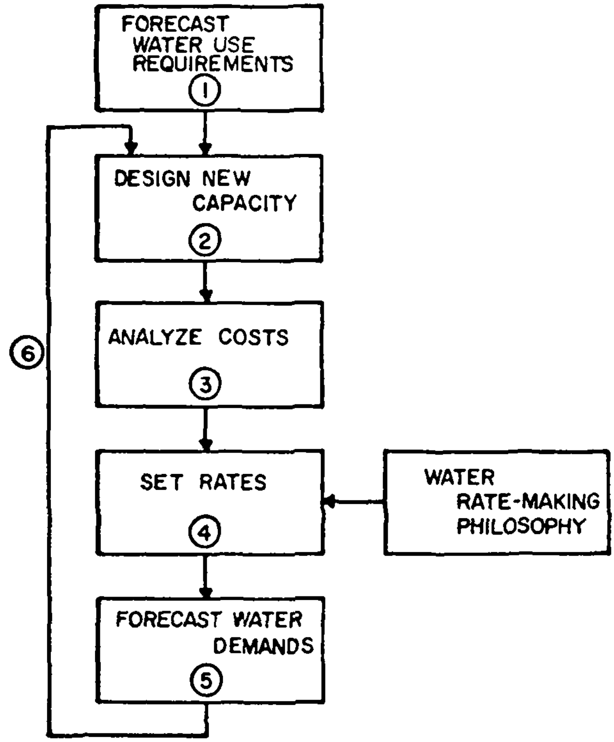
As noted earlier, the rate structures that are used to allocate these costs or revenue requirements are numerous. However, the most prevalent are multi-part tariffs that consist of a fixed charge per unit of time, related to customer costs and a portion of capacity costs, and a declining block commodity charge, related to variable costs (excluding customer costs) and a portion of capacity costs.

There are several significant defects associated with the traditional approach used to design pricing policies. The first of these concerns the process and assumptions that are used to set rates. Figure 2 will assist in evaluating the rate determination process. Traditionally, the industry forecasts water requirements (Step 1). These forecasts assume that urban water use will increase proportionately, or in some other simple relation, to the increase in population and economic activity (Hanke and Boland, 1971). If existing capacity is not adequate to meet the requirements, new capacity is designed (Step 2). Then, an analysis of system costs is conducted to determine the utility's revenue requirements (Step 3), and the level of rates is set (Step 4) so that the appropriate amount of revenue can be generated. This process is one in which the engineering and physical planning takes place in Steps 1-3. It is in these steps that revenue requirements are calculated. In Step 4, the financial or accounting staff determines the rate level based on a rate-making philosophy that is rarely changed. Thus, the areas of physical and financial planning are largely separate. Moreover, the assumptions used in the water use requirements forecast are extremely important as they determine the new capacity design and costs, and it is these revenue requirements which then dictate rate levels to the finance staff.

The process used in the economic approach can be sharply contrasted to this. The first four steps are essentially the same, with the exception that the economic rate philosophy will be one in which price is set equal to marginal cost. However, the similarities in process disappear at this point. For the economist goes on to forecast water demands (Step 5), after tentative rates have been determined. These demands are a function, among other things, of the price per unit of water. Although this fact has long been denied by some in the industry, evidence supporting the fact that use is affected by changes in prices (other variables held constant and controlled for) is overwhelming (Hanke and Bower, 1974; and Russell, 1973). The process continues by using the demand forecasts and returning (Step 6) to the second step, initiating an iterative process which is terminated when the incremental system costs are balanced against the incremental benefits. Unlike the conventional process, the economic approach ties together financial and physical planning. In this way, the demand side of the demand-supply relationship is explicitly considered whereas the traditional approach involves only the supply side.

The second defect, and one that economists have most often pointed out, concerns the fact that the accounting approach is based upon historical average costs and not marginal or incremental costs. By using average and not marginal costs, the price level is not correct and resources are not allocated efficiently. To attain efficient resource allocation, prices must be related to the opportunity costs of changes in consumption. The addition of a new consumer or an increase in the consumption of an existing consumer will impose additional (incremental) costs upon the undertaking, while reductions in consumption will save costs; it is these alterations in incremental, not historical, costs that should be reflected in pricing policies. If prices reflect these incremental costs,

FIGURE 2
The Rate-Making Process



they will reflect the value of resources used or saved by changes in consumption. The valuation of these resources requires a forward-looking estimate. After all, it is future behavior that we are interested in modifying. The backward-looking estimate (toward sunk costs) used by accountants creates the illusion that resources which can be used or saved are as cheap or as expensive as in the past. This will either lead to overinvestment or overuse, or underinvestment or underuse, depending on whether incremental costs are higher or lower than the average.

A third defect of the accounting approach stems from its neglect of incentive effects. This is basically a problem concerning water rate structure rather than rate level. Even if prorated accounting costs were equal to marginal costs (the cost levels were equated), neglecting incentives would remain a serious problem. Rate structures should reflect the incremental cost structures of the utility, so that the change in the price to the consumer of altering consumption is a reflection of the change in the cost to the enterprise. It is extremely important to note that some increases in consumption are much more costly than others. These costs, which vary depending on when and where water is consumed, should be reflected in the rate structure. This is what gives the consumers incentives to which they can respond and should be the way in which the utility communicates with customers.

Currently, water enterprises do not vary rate structures as cost vary. Again, averages are used which create uniform prices over important cost dimensions. These uniform prices mask changes in costs and result in resource misallocation. It is important to realize that the economic approach to pricing does not suggest that every change in cost dimensions be reflected in a rate structure. This is because the administrative costs associated with metering and billing on a basis that would perfectly reflect incremental cost changes would outweigh the efficiency gains associated with such a practice (Peters, 1966). Also, extremely complex rate structures might so bewilder customers that they would be counterproductive.

Thus, one must consider reflecting only those changes in cost structure that yield efficiency gains through incentive effects which outweigh the administrative and billing costs associated with imposing them. Two prime candidates for change then become the uniform pricing systems in which prices are uniform over time and space although the cost of supplying customers varies from one time period within the production cycle to another and from one part of the system to another (Davis and Hanke, 1973).

As mentioned above, the demand for municipal water is characterized by large variability over time. The fact has important implications for design, operation, and financing of water systems. Since each individual user of water has a specific use pattern--which may or may not be the same from day to day--and the water system represents users of many different types, the observed aggregate demand displays considerable randomness. Still, certain patterns of behavior are discernible. The effect of diversity* is, in general, a dampening of demand peaks. Such dampening is more pronounced as the absolute size of the water system increases, reflecting greater consumer diversity.

A study reported by Orndorff (1966) analyzed the peak demand behavior of individual residences in a suburban area near Baltimore, Maryland. In this study, the peak demand sustained for as long as one minute was, in general, more than fifty times that sustained during a maximum day. The peak demand sustained for one hour was about five times the maximum day rate. The effect of diversity within entire communities can be illustrated by comparing this ratio to that reported by Fair, Geyer, and Okun (1966) for typical water systems--peak hour rate averaging 2.5 times the daily rate. No data are available for peaks of shorter duration in large water systems.

The major design problem associated with demand peaks is proper sizing of various components in the water system. The distribution system in the immediate vicinity of the water users has been customarily sized to accommodate the maximum instantaneous flows expected. In many cases, these are determined by possible fire flows, a special type of demand not responsive to pricing policy or other unilateral action by the water utility. The allowance to be made for fire flows is normally determined by certain widely used criteria, eliminating instantaneous peak demands as a design factor in much of the system.

Major transmission lines--those transporting water to whole sectors of the service area--are not usually designed to meet short-term peak flows. Instead, elevated storage is provided at various locations in the distribution system so that the highest instantaneous demands can be supplied both by storage and transmission, the storage tanks refilling during periods of lower demand. Again, the actual size and location of these storage tanks is frequently determined by fire flow considerations rather than expected peak demands. The transmission lines supplying these storage tanks, as well as the pumping, treatment, and many types of supply works, are customarily designed to meet maximum day demands. This convention shifts attention from short-term peaks to longer cycles.

An examination of daily demands on a water utility over a long period of time will disclose two types of cyclical behavior--weekly and annual patterns. In the winter, the weekends usually record a slight drop in daily use--a result of commercial and institutional, and to some extent industrial inactivity. In the summer, however, the weekends may include the very highest daily demands, directly

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*Consumer diversity and its effect on system design is usually analyzed by a diversity factor which is defined as the ratio of the sum of the non-coincident maximum demands of the various subdivisions of a system, or part of a system, to the maximum demand of the whole system, or part under consideration.

related to intensive lawn sprinkling. A more predictable usage pattern is the annual cycle. In virtually every part of the United States, water use rises dramatically in the summer months as lawn irrigation is practiced by residential users. An analysis of past experience in the Washington, D. C., area has shown that water use in the period from May through October, inclusive, has averaged approximately 24 percent higher than use during the remaining six months of the year. The actual distribution of demand during the peak period is a function of local weather conditions; therefore, it is not consistent from year to year.

It can be seen that two types of strong temporal variations occur in municipal water demand--daily use and seasonal cycles. The daily use cycle is accommodated by locating elevated storage in the distribution areas, the design criteria for much of the required storage and associated distribution piping being determined by fire flow requirements--a factor unrelated to demand fluctuations. For this reason, it is asserted that the little variation in marginal cost can be attributed to daily cycles of demand experienced by typical municipal water agencies.*

The second variation in demand, that of seasonal demand, has important implications for cost. Most major works--transmission lines; treatment, pumping, and certain types of supply works; and major storage facilities--must be designed to accommodate the maximum day, determined almost completely by seasonal use. The capacity costs associated with these facilities reflect the demands solely during the summer season. If prices are uniform and averaged over seasons, while demands vary over seasons, significant inefficiencies result. By setting prices in this manner, the peak period rates understate the peak-load opportunity costs, inefficiently encouraging peak-load consumption. This will encourage additional investments in the water supply system since it is the peak demands that systems are designed to meet. On the other hand, the off-peak rates overstate the appropriate opportunity costs, and off-peak demands are inefficiently constrained. In addition to creating an inefficient use of resources, a uniform pricing system can be inequitable because the off-peak users subsidize the peak users (Rees, 1974; and Sewell and Roueche, 1974).

Before making comments regarding uniform rates over space, several important, but often overlooked points regarding water supply costs should be made. There are two types of system expensions that have markedly different effects on water system costs ((Gaffney, 1969). The first type involves expanding the system by enlarging the enterprise's service area and lengthening the lines. Particularly if population density falls, as it usually does, this type of expansion will result in increasing costs. Conversely, the second type of expansion is one in which costs decrease as a result of increasing the number of consumers within a given area.

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*In some parts of the world daily peaks are handled in part through storage by individual users, as in some residential areas in Caracas, Venezuela. More explicit consideration of such possibilities might have important efficiency effects.

Therefore, when economies of scale are realized by system (volume) expansion, it is a result of the economies of density being greater than the diseconomies of distance.

Uniform pricing over space leads to a social loss in efficiency when marginal opportunity costs vary over space. Moreover, those customers who reside in low density areas farthest from the water system's load center are being subsidized by those who reside in high density areas closest to load centers.

The effects of the dual system of uniform prices over space and time may combine to markedly affect the areal growth patterns of urban areas. By charging uniform rates, the enterprise imposes a *tax* on consumers who are located in high density areas that are near the load center of the enterprise. In addition, these rates provide a subsidy for consumers who are in low density areas that are located farther away from load centers. This process not only leads to an overinvestment of resources in the supply of water services, but it also results in a premature development of land at the rural-urban fringe. Uniform prices subsidize population diffusion and urban sprawl. This means that potential economies of density are not realized while diseconomies of distance are.

Uniform prices over time act to complement those over space, and, therefore, further aggravate the problems of overextension of service and urban sprawl. The users who live farthest from the water system's load center are usually those who contribute most to the system's peak load problem. Users who live in low density neighborhoods have the largest sprinkling demands. As noted earlier, these demands create most of the system's peaking. The uniform rates offer no special incentive for the lawn irrigator to alter his peak demands; therefore, current pricing practices tend to encourage the consumer to move away from load centers and to develop in low density areas.

For many water undertakings, rate structures that reflect temporal and spatial cost variations should be adapted. This can be done by implementing seasonal and zone prices. These inno ations, in addition to the use of an economic planning process, and incremental rather than historical costs, would greatly increase the efficiency with which resources in the water resource sector are used.

NEW TRENDS

The most important trend in rate-making policies is the narrowing of the gap between economic and industry thinking on the subject. In fact, this gap is virtually non-existent in some of the most recent studies and proposals by utilities. For example, the Washington Suburban Sanitary Commission, which serves Prince George's and Montgomery Counties in Maryland, has been sponsoring studies that have examined the effect that various rate structures would have on the utility's operations. A computer simulation model of the W.S.S.C. has been used in these studies to evaluate rate structures and their impact on water use, sewer flows, costs, revenues and required investment. (Boland, Hanke, and Church, 1972). These studies focused on rate structures involving various forms of seasonal prices and increasing block rates. The studies have also examined the possibilities for switching to a zonal pricing structure in which rates would vary with the cost of serving different zones within the two-county service area. Unlike conventional rate studies that examine rate levels required to meet a given revenue requirement, the W.S.S.C. studies have only dealt with the problem of rate structure. That is, they have reviewed various rate-making philosophies. If it is determined that one of the new rate structures should be adopted, then a more conventional rate study would have to be conducted to set the new rate structure at a level that generated the appropriate amount of revenue.

The Denver Water Board, another large utility, has also begun to examine the issues surrounding the design of rate structures. Although not as fully developed as the W.S.S.C. studies, the Denver Water Board research has the same general objective: to determine the impact of rate structures on the Water Board's operations. It is being directed by Professor J. Ernest Flack and myself through a grant to the University of Colorado.

The most ambitious piece of research of rate structures yet to be proposed is a study on the drawing boards of the East Bay Municipal Utility Districts in Oakland, California (East Bay Municipal Utility District, 1974). The East Bay proposal is of particular interest for two reasons. First, their service area is one of the most diversified and complex in the country. Customers range from heavy industry to small residences and micro climates and elevations vary greatly within the service area. This complexity will not only pose difficulties to the researchers who study alternative rate structures, but it could provide a situation in which rate structures that are much more complex than in the past generate significant gains for the utility and their customers.

The East Bay proposal, unlike the other rate structure studies, calls for a detailed study of consumption patterns, costs, rate structures, and the socio-economic impact of the alternative structures. It is essentially three studies, rather than one. As the staff committee who drafted the proposal wisely recognized, the past studies of rate structures have not been based on a detailed analysis of demand and cost conditions. Rather, existing data on consumption patterns and costs, as well as numerous assumptions, have been utilized. In a utility as complex as the East Bay Municipal Utility District, this approach could easily lead to spurious results. Therefore, the East Bay proposal has correctly recommended that detailed background studies of demands and costs be conducted so that the analysis of rate-making alternatives would be based on as few assumptions as possible.

Some might discount the above-mentioned new developments as only being studies of alternatives and not actual changes in policy. This would be a rather narrow point of view. Not only should these utilities be commended for analyzing alternative rate structures to improve their operations but also one should not disregard these as being insignificant developments. They have not been conducted in the past so that the fact that these rate structure issues are being examined by the industry gives sign of a significant new trend. For if the economists' ideas concerning rate structures have current practical merit, utilities, armed with these new studies, will adopt new approaches. In fact, one utility, the Fairfax County Water Authority, has proposed a rate structure change that can only be equalled in its significance by the introduction of metering. Their Board, which is chaired by Fred C. Morin, has approved a seasonal pricing structure (Fairfax County Water Authority, 1974). The Water Authority serves Fairfax County, Virginia. It is not particularly complex, serving 83,473 retail customers, of which 79,313 are individually metered, single family and townhouse dwelling units. The current rate structure is the conventional declining block variety: the first 10,000 gallons is billed at a rate of 72 cents per thousand, and 58 cents per thousand for the next 490,000 gallons, with a minimum charge per quarter of $7.20.

The proposed rate structure, after a transition period, would ultimately (June 1, 1976) evolve into one in which a base rate of 60 cents per thousand gallons would be charged. In addition, a surcharge or excess rate of $2 per thousand gallons would be charged on all water used in excess of 1.3 times each customer's winter quarter use with the winter quarter defined as any quarterly billing period based on meter readings obtained between February 1 and April 30. The revised rates would also eliminate the minimum charge substituting a $3 service charge per quarterly billing.

While foregoing judgment on the precise validity of this rate structure, it can be said that it is the most dramatic and innovative change in water-utility rate structures in this century. Also, the change was made for all the right reasons, at least from the point of view of the logic that is involved in designing rates. The Board stated that "the concept of the excess use rate is to increase equity by assessing excessive peak users with the extra cost of maintaining capability to meet their peak requirements and to effect water conservation by reducing peak demands. Under the present system, with no excess use rate, this extra cost is shared by all the consumers." (Fairfax County Water Authority, 1974, p. 2.)

REASONS FOR CHANGE AND SOME WORDS OF CAUTION

There are two reasons for the dramatic increase in rate structures and convergence of the economists' and the industry's views. First, in the late 1960's a characteristic, which Charles Luce, former chairman of the National Water Commission, has called the *benign cycle*, ceased to exist. To this point natural endowments, technological change, and improved operating efficiencies generated economies of scale and worked together to reduce the costs of delivering urban water. As a result, utilities requested changes in rate levels only infrequently, and almost never altered their rate structures. In the late 1960's a combination of factors generated a rapid increase of costs. General price inflation began to have a significant influence. For example, the price of chlorine purchased by the Fairfax County Water Authority increased by 164 percent from 1968 to 1974, while plant operator's wages increased by 58 percent during the same period. This is not to overlook the sharp jump in debt service charges. Also, extra costs were added as more marginal reservoir sites were developed and economies of scale exhausted. Environmental regulations, particularly on the sewerage side, imposed heavy costs and yielded as yet uncalculated benefits on the utilities and their customers. So what was once a relatively inactive function within a water utility's operations has become very active. With rising costs, utilities are, for the first time, having to regularly revise rates to obtain increased revenue. As a result of these increasing costs, the *benign cycle* has come to an end because of internal financial pressures. This simple fact has done more than anything else to bring economic and industry thinking closer together.

The second reason for the utilities' interest in price structures is also rooted in cost increases but comes from external pressures of consumer and environmental groups, rather than from internal pressures of finance. Although economists have been critical of water utility rate structures for some time, it has been the general public that has ultimately both provided the greatest pressure and received the greatest response to their efforts. Consumers want to assure that those who purchase water are charged prices that reflect the costs they impose. What were once small subsidies from some low-cost consumers to high-cost consumers, when rates were uniform over time and space, have become large subsidies under increasing costs, and they are no longer acceptable. Environmentalists have entered the public participation process under the banner of conservation. They argue that much demand could be reduced by properly designed rate structures and that this will reduce the amount of investment--e.g., reservoir sites--which threaten the integrity of the environment. For example, the threat of a lawsuit by the Environmental Defense Fund quickly moved the East Bay Municipal District into action.

Even with the internal motivations of finance and the external pressures from consumer and environmental groups, the new trends in rate-making philosophies face obstacles. One of these is internal to the utilities and is essentially that old shoes are more comfortable than new ones. The economic approach to rate making and design calls for much more integration and coordination between physical (the engineers) and financial (the accountants) planning. This is bound to require reorganization which will threaten certain vested interests within utility staffs. Tradition within public and quasi-public bureaucracies is difficult to change and imposes high risks on *top management*, who do not know exactly how far they can move toward breaking tradition before they might stir up the previously inert mass of staff bureaucrats (Tullock, 1965).

The second obstacle is external to the utility. Most rate studies are conducted by private consulting firms. These firms build great fixed investments mainly in the form of training and experience of human capital in the conventional approach to rate design. They do not have as great an incentive to look at new rate philosophies as one might initially think. For they would rather spread the overhead that they have invested in their rate philosophy than invest in evaluating other options. This, of course, is the same game that is played by many of the same firms when they resell essentially the same plans to different bureaus. Once the investment by the consultant in the basic plans has been made, he can drastically reduce his costs by making a few modifications and reselling the same basic plans. This incentive effect will, no doubt, strongly dampen the trends that have recently begun to appear.

However, even though bureaucracies are slow to adopt change and consulting firms have strong incentives to resist new approaches, the industry's view of water rates will continue to converge on that of the economists. This will occur largely because of the increased costs that water utilities will face in the future.

ACKNOWLEDGMENT

Many of the ideas expressed in this paper are the result of research and collaboration with my colleagues at The Johns Hopkins University, John J. Boland, Robert K. Davis, and Abel Wolman. I would also like to thank those in the industry who have given me many hours of counsel concerning the practical aspects of rate design: Robert McLeod, Alfred Machis, and Arthur Brigham of the Washington Suburban Sanitary Commission, Bob McWhinnie, and Joe Spaulding of the Denver Water Board, Vincent Byrne of the Fairfax County Water Authority, and Jim Lattie of the East Bay Municipal Utility District.

REFERENCES CITED

1. Anderson, D. and R. Turvey (1974), *Economic Analysis of Electricity Pricing Policies: An Introduction*, International Bank for Reconstruction and Development, Washington, D. C.

2. Boland, J. J., S. H. Hanke and R. L. Church (1972), *An Assessment of Rate-Making Policy Alternatives for the Washington Suburban Sanitary Commission*, The WSSC, Baltimore.

3. Davis, R. K., and S. H. Hanke (1972), "Municipal Water," in *1971 Annual on Benefit-Cost Analysis*, eds. A. Hardberger, *et al.*, Aldine-Atherton, Chicago.

4. East Bay Municipal District (January 23, 1974), "Progress Report on Purposes and Scope Water Consumption and Pricing Study," Unpublished.

5. Fair, G.M., J.C. Geyer and D. A. Okun (1966), *Water and Wastewater Engineering*, Vol. 1 of *Water Supply and Wastewater Removal*, John Wiley and Sons, New York.

6. Fairfax County Water Authority (August 15, 1974), "Statement of Necessity for, and Description of Proposed Revision of Rates, Fees and Charges for Water Services," Unpublished.

7. Frontinus (97 A.D.), *The Water Supply of the City of Rome*, Translated by Clemens Herschel (2nd ed.), Longmans, Green, and Company, London.

8. Gaffney, M. (1969), "Replacement of Individual by Mass Systems in Urban Growth," *Proceedings of the American Real Estate and Urban Economics Association*, 4.

9. Hanke, S. H., and J. J. Boland (1971), "Water Requirements or Water Demands?" *Jour. Amer. Water Works Assn.*, 63, 5.

10. Hanke, S. H., and R. K. Davis (1973), "Potential for Marginal Cost Pricing in Water Resource Management," *Water Resources Research*, 9, 4.

11. Hanke, S. H., and B. T. Bower (1974), "Economic Aspects of Attaining Efficiency in the Use and Reuse of Water," a paper presented to the United Nations Panel on Water Reuse, Tel Aviv, Israel.

12. Orndorff, J. R. (1966), *Domestic Water Use Differences in Individual Well and Public Water Supplies*, Department of Environmental Engineering Science, The Johns Hopkins University, Baltimore.

13. Peters, W. (1966), "Notes on the Timing of the Introduction of Meters," *Manchester School of Economic and Social Studies*, 18, 5.

14. Rees, J. A. (1974), "Water Management and Pricing Policies in England and Wales," in Leversedge, editor, *Priorities in Water Management,* Western Geographical Series, Vol. 8, Department of Geography, University of Victoria, British Columbia, Canada.

15. Russell, C. A. (1973), "Restraining Demand by Pricing Water Withdrawals and Wastewater Disposal," a paper presented at a Seminar on the Management of Water Supplies, The University of East Anglia, Norwich, England.

16. Sewell, W. R. D., and L. Roueche (1974), "The Potential Impact of Peak Load Pricing on Urban Water Demands: Victoria, B. C., a Case Study," in Leversedge, editor, *Priorities in Water Management,* Western Geographical Series, Vol. 8, Department of Geography, University of Victoria, British Columbia, Canada.

17. Tullock, G. (1965), *The Politics of Bureaucracy,* Public Affairs Press, Washington.

18. Vickrey, W. S. (1971), "Maximum Outputs or Maximum Welfare? More on the Off-Peak Pricing Problem," *Kyklos,* 24.

QUESTIONS AND DISCUSSION

QUESTION: (Dan Okun, UNC-CH) I think this is a very important subject and a very interesting presentation, and I want to thank Dr. Hanke for being here. I have one comment to make, and then I have a question. The comment is that this increasing block rate has been introduced several places. The one that I know best is in Israel where this has already been used now for some years. This leads to a question. This matter of observing people and how they are likely to be affected by the price of water--would there be any reaction to increasing price in anything other than lawn sprinkling or irrigation because this is where the big bulk comes in, whether people would change their habits in the bath and other things; for the apartment dweller, that's one question. The second question, and I'm glad you brought up the\electrical industry, is how do the utility commissions look at this marginal cost being a basis for rate systems? The third is a more, perhaps, practical question. In the water industry as contrasted with some of the others and, as you pointed out, somehow we have developed all of the lower cost water sources, in many cases the next projected investment in capacity will mean that the marginal cost will be based on a very substantial new high-cost investment which makes for a very large marginal cost jump; and if we get people to pay this, I'm wondering about fairness because consumers might be paying for something that may go on for a very long time, and these people are paying for something which they're not getting. What are your comments on that?

DR. HANKE: I'm glad you brought up Israel because that's a perfect example of what happens when you run out of all the, shall we say, conventional potential supplies and costs are at an extremely high level. You become rational like the economic models in the economic textbooks, and you start charging a marginal cost for water. The rates, as far as I have been able to determine, are more rational than anywhere in the world simply because their water resources are scarce. They have few options left in Israel. They have to be rational and can't afford to play some of the games that we have been playing in the United States. Also related to the issue of water rates in Israel is your second question. Some studies in Israel have looked at your question regarding consumption--let me set the problem up. You ask whether price affects sprinkling and irrigation use, but not inside-the-house, domestic use. You can answer this, I think, in the clearest way by looking at apartments. In Israel, they have two kinds of apartment metering systems. One is where you meter the whole building and everybody pays part of the water bill in the form of some increment in the rent, and they usually don't even know what it is. The other system is where each individual apartment is metered. There are two significant differences that result from these two systems. First, where the individual consumer pays directly for the water that he uses, he consumes significantly less than when he does not, roughly 15 to 35 percent less. The second aspect of this, that has important implications for system design, is the fact that the standard deviations and standard errors that exist in the data on the individual apartment users are much smaller than where you meter the whole building. So you don't have to build as big a safety margin into your system if you are metering individual apartment units because you don't have as big a spread in the data. Therefore, you can do a lot better job forecasting demands and designing systems. In summary, inside-the-house use is also affected by rates. There's no doubt about that. I can report to you that another study that I conducted, looking at the switchover from flat rates to meters, the inside-the-house consumption was reduced by 36 percent. This was in Boulder, Colorado. Not only was use reduced by 36 percent, but it stayed down and continued to fall off as people continued to adjust to the fact that they were paying an incremental price.

On the question of utility commissions' response to these new rate structure proposals, I must confess that each commission varies greatly in its approach. Let me give you some examples: In Maryland, the Baltimore Gas and Electric Company is currently involved in a rate case in which some of the leading people in the world have been involved in putting forth the idea of marginal cost pricing. The utility commission there is so political, however, that I really don't think the testimony is going to have much effect. On the other hand, in Wisconsin the Wisconsin Commission has been responsive to the economists' proposals. They have taken out their declined block rate; and they are going to do some experimentation in Wisconsin just to see what kind of response is induced by various kinds of price structures. Michigan is also about ready to change and do some experimentation. But it depends on the local situation, and there is a lot of variation from commission to commission. However, I think the cost factors are just so great that commissions are going to get pressed up against the wall, and they will have to look at some alternatives.

On the last question, the fairness issue regarding why some consumers who have been in the system for twenty years should have to pay a new increment to capacity: Briefly, my response is that we are interested in influencing future behavior and future water use because that's where the increment to cost is going to take place. We are not interested in influencing past behavior.

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TRAINING OPPORTUNITIES AND THE SAFE DRINKING WATER ACT

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INTRODUCTION

A chain is as strong as its weakest link, and America's drinking water will be no better than the industry personnel. So in the era of the Safe Drinking Water Act, we find ourselves faced with both a qualified manpower shortage situation as well as perhaps a *knowledge gap* between our personnel and their job. Training of these personnel is vital. Please notice that I said personnel and not operators. Here, we must include, in addition to operators, the chemists, the clerical personnel, the maintenance personnel, utility engineers and the executive managers regardless of what his title might be.

Many of the remarks which I shall make today are not my own. In referencing material for preparation of this paper, I found that the most important things I might say to this group have already been said. Accordingly, I shall devote my time to summarizing items which are already documented.

For six years the American Water Works Association (AWWA) Education Program demonstrated a continued and remarkable growth pattern. More than 5,700 persons in water supply have attended 152 management and technical training courses since the formation of the Education Department in 1968. In 1973, more than 1,550 attended 33 AWWA-conducted training courses, establishing a new record year. More important is the fact that the quality of training has been in the highest traditions of the association. Student and section evaluators rated the courses from 4.5 to 4.8 from a scale of 5. These evaluations indicate a quality level in the superior range.

The new three-day Management Seminar designed for the middle-managers and top supervisors of both water and wastewater utilities met with instant success and has practically supplanted the 5 1/2 day version. The Diamond Shamrock Corporation measured the effectiveness of the training and calculated a return on investment of $1,270 based on actual savings from applying techniques learned in the seminars against the tuition fee.

An AWWA course yielding an incalculable return on a small investment is the Emergency Planning Seminar for water utility management. The seminar discusses disaster effects, vulnerability

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**Editor's Note:* Mr. Shaw's paper was read for him by Mr. Frank L. Ward, Superintendent of Plants, City of High Point, N. C.

**Mr. Shaw is Chairman, Training Publications Committee, American Water Works Association.

assessment, protection measures, emergency operations planning, personnel and training requirements and provides a model contingency plan. Both the seminar and accompanying manual were developed under the AWWA Emergency Planning Committee's supervision and funded by the federal government. Over 400 water supply people have attended the nine seminars conducted during the past two years.

ACCIDENT PREVENTION

Accident prevention is everyone's business, and 302 water utility men made it their business to attend the seven AWWA seminars conducted during 1973. The Occupational Safety and Health Act became effective in 1971, and many utility managers have requested AWWA to develop and conduct a training program designed to enable them to comply with the law. Beginning in 1974, AWWA's safety seminar will incorporate the OSHA requirements as well as methods to set up and motivate an effective accident prevention program in the utility.

OPERATOR TRAINING

Launched in 1972, the AWWA Chlorination Workshop became an immediate success. So great was the demand that two additional workshops had to be added to those already scheduled in 1973, and the 1974 schedule was also filled. Other interested sections were referred to available dates in 1975. Expert reviewers and evaluators claim that the course and manual provide all that an operator needs to know to perform his job well and prepare him for the certification examination. The manual, published as Water Chlorination Principles and Practices, has become a runaway bestseller.

The Cross Connection Control Seminar first conducted in 1971 showed a declining interest among AWWA sections in 1973. Only 3 seminars were held with a total attendance of 198. Several sections having an interest in the course cancelled their interest when they learned that the program is managed, administered, and conducted by the section with AWWA staff assistance.

ONE-DAY CONFERENCE SEMINARS

Three particularly relevant one-day seminars were developed in 1973, and a record-breaking 311 persons registered which was almost double that of the previous year. Developing Water Rates had 138 registrants; Minimizing and Recycling Water Plant Sludge, 112, and Occupational Safety and Health Act (OSHA), 61. Five one-day seminars were developed for the 1974 Boston Conference of AWWA.

1. Developing Water Rates (Management)
2. OSHA Compliance and Accident Prevention (Management)
3. Upgrading Existing Water Treatment Plants (Water Quality Division)
4. Enhancement and Control of Reservoir Water (Resources Division)
5. Public Information/Public Relations (Management)

OKLAHOMA PROJECT

An AWWA manpower and training research proposal was submitted to the Environmental Protection Agency four years ago and found merit, but EPA had no legislation to fund water supply programs. Early in 1973, EPA's manpower director and AWWA's education director requested the funds from the Office of Education, HEW, which provided the necessary $200,000. The contract was awarded to the Oklahoma Vocational-Education Department with the work to be performed by the Oklahoma Research Foundation and under the guidance of an Advisory Committee composed of mainly AWWA members. Work began in July 1973 and is expected to be completed by the end of 1974. The project, in addition to providing information of who needs training, where, when, and how many is expected to produce model job descriptions, performance standards, work-load indicators, staffing guides and a host of valuable data. In addition to obtaining valuable data by questionnaires, trained researchers from the Foundation will conduct on-site surveys at 80-90 selected water utilities. Utilizing the data obtained, a training task analysis will be performed to produce a nationwide training plan. This project, I think, will be the real meat of AWWA's training program.

AIR FORCE WATER TRAINING PROGRAM

Under study by the Education Training and Publications Committee is the Air Force Training Course conducted at the Training Command's Sheppard Air Force Base in Texas. This 330-hour course which claims 84 percent or 277 hours is civilian related and utilizes the most advanced and most efficient mix of all instructional methods known today. Costing the Air Force well over $1,000,000, it is available to AWWA for a *retrieval* or mastering cost of less than $12,000. Adding the cost of editing and printing, the Association could provide the industry with an exceptional training program for less than $30,000. The package would include: lesson plans, training standards, student study guides, student workbooks, manuals (text material numbering 3,464 pages), 8 black and white and 4 color 16 mm motion picture film, 250 slides 35 mm, 975 film strips and 17 accompanying phonograph records, and other visual training aids. Preliminary information is most promising. Assuming the committee's review is favorable, the course as adapted to AWWA requirements would reflect favorably on AWWA's new Denver image and provide a most valuable service to the water supply industry.

ACCREDITATION

Guidelines were developed by the AWWA Accreditation Committee and submitted to the Technical and Professional Council for their approval. Objectives of the accreditation program are to recognize the water supply educational programs meeting AWWA standards of excellence and provide guidance to improve substandard programs. The guidelines, when finalized, will be distributed to all sections and the program will be publicized in all media available including *Willing Water*.

NEW TRAINING COURSE DEVELOPMENT

Work on a new AWWA training course, Taste and Odor Control, was started in May, and a second new workshop for distribution system operators will be developed probably in 1974. Visual training aids and manuals are planned for both courses.

TRAINING AIDS

Revision of the *Water Supply Visual Aids Index* was accomplished by the staff and published in the 1973-74 AWWA Yearbook. Reprints in pamphlet form are available. An updated version will be a regular feature of future yearbooks.

TRAINING DIRECTORY

The *Water Utility Training Directory* is an AWWA staff compilation of training courses being conducted by all agencies throughout the United States and Canada. The directory should assist all managers in planning training programs and is valuable to section education committees and state health or EPA agencies.

SALARY AND FRINGE BENEFIT SURVEY

Over 4,800 water utilities have been requested to participate in a new 1974 Compensation and Fringe Benefit Survey. Questionnaires were mailed in January.

The project work is being performed by the AWWA staff under supervision of the Compensation Committee and is being funded by the Oklahoma Research Foundation whose computers will be used to collate the data. Analysis and publication of the report is expected in October of 1974.

PREVENTIVE MAINTENANCE MANUAL

A new AWWA committee has been activated to "review the currently published and available documents on preventive maintenance in water utility systems and determine if there is a need for additional documents for AWWA use." The committee has also been charged with a task of cataloging existing material and to establish a recommended preventive maintenance program.

AWWA TRAINING MANUALS AND MATERIALS

In a recent survey by the Training Publications Committee, 15 of 22 sections responding reported that the *Basic Water Treatment Operator's Manual* was in widespread use in their sections. Publication sales have averaged over 600 per month and over 7,500 have been sold since publication. Also on the best-seller list are the *Emergency Planning Manual* (5,000 sold) and the *Chlorination Manual* with 6,500 sales.

BRAZIL

AWWA is also working outside of the United States on a program which will benefit both domestic and foreign interests. A recently negotiated contract will permit the National Housing Bank of Brazil to translate and print in Portuguese a selection of AWWA training publications. Brazil has also made provisions to help fund the development of new AWWA training courses and manuals for the benefit of both parties.

The programs which I have described are for the most part attributable to the untiming efforts of one man, Walter Peters, the Director of Education for AWWA.

Up to now I have only talked about what AWWA is doing. There are a number of catalogues from several sources which outline materials and systems for training. One of the most comprehensive is a four-volume report which was prepared by John Austin and Harry Durham of Clemson University. The project was funded by the Environmental Protection Agency and awarded to Charles County Community College of La Plata, Maryland.

Volume I contains information on audio-visual equipment currently in use in the water quality field.

Volume II deals with instructional materials in use by training organizations in the water quality field. The materials have been tabulated under the headings of titles, authors, type of material, intended audience, designed usage, source and costs. As an example, Identity Number 835 is *Fundamentals of Water Supply Operation* by the Environmental Protection Agency. It is printed material intended for basic operations (entry level) by an individual. The source is EPA, and the cost is $10.

Volume III which is *Selecting Audio-Visual Equipment* provides guidelines which can be used to assist in the selection of such equipment to meet particular needs. These guidelines suggest factors which should be considered in selecting a video tape recorder such as compatability (interchangeability), ease of operation, availability of service, ease of maintenance, picture quality, portability and reliability.

Volume IV is titled *Selecting Instructional Media and Instructional Systems.* This volume proposed a system which includes a worksheet which will standardize the production of lesson plans. A procedure for selecting appropriate instructional media is described.

Of the documents, Volume II is the most useful.

I think it is apparent that the technology for proper personnel training is readily available. The materials and equipment are available and catalogued. It may be from a national organization like AWWA or from a state or federal agency or perhaps from the local community college. It is available to us, and we need only to avail ourselves of it.

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MATHEMATICAL OPTIMIZATION OF WATER SUPPLY SYSTEMS STATE OF THE ART

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INTRODUCTION

Mathematical Optimization and Systems Analysis Techniques have been used extensively in many parts of the overall water supply system ranging from the actual abstraction of water from ground and surface water sources to the primary collection and conveyance system, the water treatment plant, and the final distribution system.

Optimization methods have been used to design well fields, i.e., to determine the number, type and capacity of wells required to maximize the yield from the field, or, given a well field, to decide how it should be operated to produce a certain yield at minimum cost.

For surface water sources, the questions arise of the level to which the reservoir should be developed and the guaranteed supply that can be expected.

Given, then, a number of ground and/or surface water sources, how should they be inter-connected, and what kind of pipeline network is necessary to deliver the water to the points of demand? The answer to this question leads to a general network model, and the general methods of network analysis become applicable.

At the treatment plant level, the questions arise as to what type of treatment is necessary, what combination of units is required, and how a minimum cost treatment plant can be designed.

Finally, the question of an optimal water distribution system arises. How can the distribution network be designed in such a way that the required amounts of water are delivered at the required pressures? This latter problem is probably the most studied one, and numerous algorithms and solution techniques exist.

For all the above-mentioned areas of modeling, the dynamic and time aspects must be taken into consideration, which means a study of the capacity necessary at a given time, looking over a finite planning period. This gives rise to the typical capacity expansion problems and the sequencing of the construction of individual parts of the system.

The use of mathematical models and optimization techniques such a linear programming, dynamic programming, etc. aids in the analysis of water supply systems in four major ways:

1. it allows the analysis of more alternatives at every level of decision-making;
2. it allows a better testing of the assumptions and an estimation of the influence of economic, political, and environmental uncertainties;
3. it provides a mechanism whereby all assumptions and judgments are made explicit and are clearly laid out, and
4. it serves as a communications tool for all the professionals involved in water supply systems planning.

The extensive literature on the subject is reviewed and several examples of the application of these techniques is presented. Several areas which require further study and development are discussed.

BACKGROUND

The use of systems analysis and optimization techniques for formulating and solving problems of water supply systems is only of very recent origin and has been used for only a little more than ten years. To define exactly what systems analysis means or involves is somewhat difficult, and there is no general agreement on a definition, except to say that it is an approach to problem solving that focuses on the entire problem or system, rather than on each of its separate components. It is an approach that tries to quantitatively define alternate courses of action and provides a means of evaluating them in an orderly fashion with the aim of selecting those which are better than others. This idea of a comprehensive analysis is not new, but it is only in recent years that the mathematical and computational tools have become available which permit the analysis of many more alternatives than have heretofore been possible. And, it is hoped, by being able to compare many alternative choices of action, the decision makers would be able to define those combinations of system components that best meet the management objectives.

In carrying out a systems analysis study there are a number of more or less standard steps which are outlined below:

1. Formulation of the problem.
2. Construction of a mathematical model which describes the most important variables of the system.
3. Definition of a criterion function, or measure of merit.
4. Collection of data to allow an estimation of the various parameters of the model.
5. Derivation of optimal solutions through formal algorithms.
6. Testing of the model, the solutions, and the sensitivity of the parameters.
7. Implementation of the best solution.

The first step involves the formulation of the problem and a definition of the objectives of the study. Alternate courses of action and the major variables of the problem under study must be delineated. This leads to Step 2; namely, the construction of a mathematical model. The quantitative relationships between the variables of the problem must be established. The third step is the definition of a criterion function or measure of merit. Since the system under investigation may be in many different states, or the system to be constructed may consist of many alternate solutions, it is necessary to have a criterion which compares one system against another. Such criteria might be a minimum cost system, or one which has the greatest cost-benefit ratio, or a system which maximizes the total net benefits.

The fourth step is the collection of data to allow an estimate of the parameters of the model. This may be the most time-consuming step, and depending on its outcome the entire model may have to be modified due to a lack of data. Thus, Step 4 should be carried out simultaneously with Steps 1 to 3.

Step five, then, seeks to determine an optimal solution to the problem, if it is at all possible, through the application of a number of formal algorithms which will be described later on.

One of the most important steps is a testing of the model, the solutions, and the sensitivity of the parameters. To make the model mathematically tractable, usually some simplifications are introduced. Their validity and the influence certain parameters have on the optimal solution must be studied carefully.

Among the many techniques and tools available to the system analyst, the following are the major ones:

Linear Programming
Nonlinear Programming
Dynamic Programming
Integer Programming
Stochastic Programming
Geometric Programming
Network Techniques PERT/CPM
Simulation Techniques
Classical Optimization Techniques

The techniques of linear and non-linear programming deal with optimization problems where the maximum or minimum of linear or nonlinear functions is to be found subject to equality or inequality constraints. Several examples of its use will be given below. Dynamic programming deals with the optimization of multi-stage decision processes, whereas interprogramming attempts to find solutions to problems where the variables may take on only integer values. Stochastic programming is concerned with problems in which some of the variables and parameters are random variables. Geometric programming deals with optimization problems where stems of products of variables must be optimized. The network techniques--PERT--which stands for *program evaluation and review technique*--and CPM--which stands for critical path method--are management techniques for the control of large-scale research and development projects or for large construction jobs. Simulation techniques are used for the simulation of large systems not with the explicit attempt of finding the optimum but rather just to observe what happens when certain basic parameters are changed.

All of these techniques would be mostly of academic interest were it not for the concurrent development of high-speed digital computers. It is well to remember that the first commercially available computer came on the market only in 1951 with UNIVAC I. Now, only 20 years later the digital computer is having an unbelievable impact on our societies. Computing speeds have increased more than 100-fold and storage capacities, a thousand-fold, and costs decreased to about 1/1000 of the early models. But most of all, they have become so widespread that today no engineering firm or university is without such a system or at least without easy access to one.

All of these mathematical modeling and computational techniques cannot by themselves solve water supply systems problems. They merely increase the capability of generating information that can be used in the decision-making process, especially those requiring public policy decisions.

One should also note that optimal solutions to *models* of water supply systems are often not the optimal solutions to the actual *problems* themselves. *One should, therefore, not expect the results from any quantitative systems analysis study to be implemented without modifications, no matter how impressive the results may appear on the computer printout.*

In reviewing the literature on the subject matter, it can be classified into several major categories as follows:

Population projections and forecasts of demand
Development of ground and surface water sources
Regional system considerations
Design of the water treatment plant and capacity expansion
Design of the Distribution System.

Since the forecasting of demand will be treated by another speaker at the Symposium, no attention will be given to this very important aspect. An example of the design of a well field will be given as well as an example of a regional supply system. And finally, some problems in the design of the distribution system are shown.

Editor's Note: The examples cited above were presented orally and with visual aids not available for reproduction herein.

REFERENCES CITED

General Water Supply Network

1. Aron, G. (1969), "Optimization of Conjunctively Managed Surface and Groundwater Resource by Dynamic Programming," Water Resources Center, Contrib. 129, Univ. of Calif., Berkeley, Calif.

2. Becker, L. and W. Yeh (1974), "Optimal Timing, Sequencing, and Sizing of Multiple Reservoir Surface Water Supply Facilities," *Water Resources Research,* 10, No. 1, 57.

3. Bugliarello, G., W. D. McNally, J. T. Gormley, and J. T. Onstott (1966), "Hydro, A. Computer Language for Water Resources Engineering," *Civil Eng.,* 36(11), 69.

4. Buras, N., and Z. Schweig (1969), "Aqueduct Route Optimization by Dynamic Programming," *Jour. Hydraul. Div., Proc. Amer. Soc. Civil Engr.,* 95(HY5), 1615.

5. Burt, O. R. (1970), "On Optimization Methods for Branching Multistage Water Resource Systems," *Water Resources Res.,* 6(1).

6. Butcher, W. S., *et al.* (1969), "Dynamic Programming for the Optimal Sequencing of Water Supply Projects," *Water Resources Res.,* 5, 1196.

7. Carey, G. W., and L. Zobler (1968), "Linear Programming of Water Transfers in the New York Metropolitan Region," *Proc. 4th Amer. Water Resources Conf.,* New York, N. Y., 658.

8. Clyde, C. G., and R. N. DeVries (1971), "Optimization in Municipal Water Supply System Design," *Water Resources Bulletin,* 7(5), 1049-48.

9. Clyde, C. G., B. C. Jensen, and J. H. Milligan (1967), "Optimizing Conjunctive Use of Surface Water and Groundwater," *Proc. Symposium Groundwater Development in Arid Regions,* Utah State Univ., Logan, Utah, p. 59.

10. Cochran, G. F., and W. S. Butcher (1970), "Dynamic Programming for Optimum Conjunctive Use," *Water Resources Bulletin,* 6(3), 311-322.

11. Deininger, R. A. (1969), "Systems Analysis for Water Supply and Pollution Control," in "Natural Resource Systems Models in Decision Making," *Proc. 1969 Water Resources Seminar,* Water Resources Res. Center, Purdue Univ., Lafayette, Ind.

12. Deininger, R. A. (1970), "Systems Analysis of Water Supply Systems," *Water Resources Bulletin,* 6(4), 573-79.

13. Delucia, R. J., and P. Rogers (1972), "North Atlantic Regional Supply Model," *Water Resources Research,* 8(3), 760-765.

14. deNeufville, R. (1970), "Cost Effectiveness Analysis of Civil Engineering Systems: New York City's Primary Water Supply as an Example," M.I.T. Dept. of Civil Engineering, Cambridge, Mass.

15. deNeufville, R., *et al.*, (1971), "Systems Analysis of Water Distribution Networks," *Proc. Am. Soc. of Civil Engineers,* 97 (SA6), 825.

16. DeVries, R. N., and C. G. Clyde (1971), "Optimization in Municipal Water Supply System Design," *Water Resources Bull.,* 7, 1048.

17. Doody, J. J. (1969), "Conjunctive Use of Ground and Surface Waters," *Jour. Amer. Water Works Assn.,* 61, 345.

18. Dracup, J. A., and Y. Y. Haimes (1968), "On Multilevel Optimization in Ground Water Systems," *Proc. Nat'l. Symp. on Anal. Water Res. Systems, Amer. Water Resources Assn.,* Denver, Colo., p. 122.

19. Gupta, I. (1969), "Linear Programming Analysis of a Water Supply System," *AIIE Trans.,* 1(1).

20. Heaney, J. P. (1968), "Mathematical Programming Analysis of Regional Water Resource Systems," *Proc. Nat'l. Symp. on Anal. Water Resources Systems, Amer. Water Resources Assn.,* Denver, Colo., p. 231.

21. Hoppel, S. K., and W. Viessman, Jr., (1972), "A Linear Analysis of an Urban Water Supply System," *Water Resources Bulletin,* 8(2), 304-11.

22. Howson, L. R. (1957), "Factors Affecting Long Distance Transmission of Water," *Jour. Amer. Water Works Assn.,* 49(10), 1359-68.

23. Hufschmidt, M. M. (1966), "Water Resources Systems Analysis," *Proc. Amer. Water Resources Assn.,* p. 460.

24. Hufschmidt, M. M., and M. B. Fiering (1966), *Simulation Techniques for Design of Water Resource Systems,* Harvard University Press, Cambridge, Mass.

25. Hughes, Trevor C., and Calvin G. Clyde (1969), "Municipal Water Planning - Mixed Integer Approach," *Journal of the Hydraulics Division, ASCE.*

26. Kally, E. (1969), "Pipeline Planning by Dynamic Computer Programming," *Jour. Amer. Water Works Assn.,* 61(3), 114.

27. Lauria, D. T. (19), "Water Supply Planning by Mixed Integer Programming," *E.S.E. Publication No. 298,* Dept. of Environmental Sciences and Engineering, University of N. C., Chapel Hill, N. C.

28. Linaweaver, F. P., Jr., and C. Scott Clark (1964), "Costs of Water Transmission," *Jour. Amer. Water Works Assn.*, 56(12), 1549-60.

29. Loucks, D. P. (1968), "Comment on Optimization Methods for Branching Multistage Water Resource Systems," *Water Resources Res.*, 4, 447.

30. Meier, W. L., Jr., and C. S. Beightler (1967), "An Optimization Method for Branching Multistage Water Resource Systems," *Water Resources Res.*, 3, 645.

31. Meier, W. L., Jr., and C. S. Beightler, (1968), "Optimization of Branching Multistage Systems: A Reply to a Comment by D. P. Loucks," *Water Resources Res.*, 4, 1385.

32. Meier, W. L., R. W. Lawless, and C. S. Beightler (1968), "Geometric Programming: New Optimization Technique for Water Resource Analysis," *Proc. 4th Amer. Water Resource Conf.*, New York, N. Y., p. 524.

33. Meier, W. L., A. O. Weiss, C. D. Puentes, and J. C. Moseley (June 1971), "Sensitivity Analysis: A Necessity in Water Planning," *Water Resources Bulletin*, 7(3), 529-41.

34. Mobacheri, F., V. S. Budhraja, and F. E. Mack (Aug. 1971), "Conjunctive Use of Sea and Fresh Water Resources: An Integer Programming Approach," *Water Res. Bull.*, 7(4), 823-30.

35. Morin, T. L., and A. M. Esogbue (1971), "Some Efficient Dynamic Programming Algorithms for the Optimal Sequencing and Scheduling of Water Supply Projects," *Water Resources Res.*, 7 (3).

36. Russell, C. S. (July 1-3, 1968), "An Application of Non-Linear Programming to the Planning of Municipal Water Supply Systems: Some Results," *Proc. of the National Symposium on the Analysis of Water Resource Systems*, Denver, Colo.

37. Singh, K. P. (1971), "Economic Design of Central Water Supply Systems for Medium Sized Towns," *Water Resources Bull.*, 7, 79.

38. Shipman, H. R. (1967), "Water Supply Problems in Developing Countries," *Jour. American Water Works Assn.*, 59(7), 767.

39. Sturman, G. M. (1971), "Systems Analysis for Urban Water Supply and Distribution," *Jour. Environ. Systems*, 1, 67.

40. Weddle, C. L., S. K. Mukherjee, J. W. Porter, and H. P. Skarhein (1970), "Mathematical Model for Water-Wastewater Systems," *Jour. Amer. Water Works Assn.*

41. Young, G. K., and M. A. Pisano (1970), "Nonlinear Programming Applied to Regional Water Resource Planning," *Water Resources Research*, 6(1), 32-42.

Design of Well Fields

42. Aguado, E., and I. Remson (1974), "Ground-Water Hydraulics in Aquifer Management, *Proc. Am. Soc. of Civil Engrs.,* 100(HY1), 103.

43. Aguado, E., *et al.,* (1974), "Optional Pumping for Aquifer Dewatering," *Proc. Am. Soc. of Civil Engrs.,* 100(HY7), 869.

44. Bear, J., and O. Levin (1966), "An Approach to Management and Optimal Utilization of Aquifers," *Proc. Amer. Water Resources Conference,* Chicago, p. 200.

45. Brown, G., and R. Deacon (1972), "Economic Optimization of a Single-Cell Aquifer," *Water Resources Research,* 8(3), 557-64.

46. Deininger, R. A. (1970), "Systems Analysis of Water Supply Systems," *Water Resources Bulletin,* 6(4), 573-79.

47. Young, R. A., and J. D. Bredehoeft (1972), "Digital Computer Simulations for Solving Management Problems of Conjunctive Ground Water and Surface Water Systems," *Water Resources Research,* 8(3), 533-56.

Water Distribution Systems

48. Adams, R. W. (1961), "Distribution Analysis by Electronic Computer," *Jour. of the Inst. of Water Eng.,* London, 15, p. 415.

49. Camp, T. R. (1939), "Economic Pipe Sizes for Water Distribution Systems," *Trans. ASCE,* 104, 190-213.

50. Camp, T. R., and H. L. Hazen (1934), "Hydraulic Analysis of Water Distribution by Means of an Electric Network Analyzer," *Jour. of NEWWA,* 48, 383.

51. Cembrowicz, R. G. (1971), "Mathematical Model of a Water Supply System Under Fluctuating Demand," dissertation Harvard University.

52. Cembrowicz, R. G., and T. T. Harrington (1973), "Capital Cost Minimization of Hydraulic Network," *Proc. Am. Soc. of Civil Engrs.,* 99(HY3), 431.

53. Chenoweth, H. and C. Crawford (1974), "Pipe Network Analysis," *Jour. Am. Water Works Assn.,* p. 55.

54. Cross, Hardy (1936), "Analysis of Flow in Networks or Conduits or Conductors," *Bulletin #286,* Univ. of Ill. Engineering Expt. Station, Urbana, Ill.

55. Deb, A. K., and A. K. Sarkar (1971), "Optimization in Design of Hydraulic Networks," *Proc. Am. Soc. of Civil Engrs.,* 97(SA2) p. 141.

56. Deb, A. K. (1974), "Least Cost Design of Branched Pipe Network System," *Proc. Am. Soc. of Civil Engrs.,* 100(EE4), 821.

57. deNeufville, R., and J. Hester (1969), "Discussion of 'Water Distribution System Analysis,'" by Shamir, U., and Howard, C. D. D., *ASCE, Hydraulics Div. J.,* 95(HYL).

58. deNeufville, R., *et al.,* (1971), "Systems Analysis of Water Distribution Networks," *Jour. San. Engr. Div., Proc. Amer. Soc. Civil Engr.,* 97(SA6), 825.

59. Dillingham, J. H. (1967), "Computer Analysis of Water Distribution Systems, Part II," *Water and Sewage Works,* pp. 43-54.

60. Dillingham, J. H., "Computer Methods for Water Distribution Systems Design," *16th Annual ASCE Conf., Hydraulics Div.*

61. Donachie, R.P. (1974), "Digital Program for Water Network Analysis," *Proc. Am. Soc. of Civil Engineers,* 100(HY3), 393.

62. Duffin, R. J. (1947), "Non-Linear Networks," *Bulletin of Amer. Math. Soc.,* 53, pp. 963-971.

63. Epp, R., and A. G. Fowler (1970), "Efficient Code for Steady-State Flows in Networks," *Jour. Hyd. Div., Proc. ASCE.*

64. Graves, Q. G., and D. Branscome (1958), "Digital Computers for Pipeline Network Analysis," *Jour. San. Eng. Div., Proc. ASCE,* Paper #1608, and Discussion by Hamblen, J., in *Jour. San. Eng. Div., Proc. ASCE.*

65. Gupta, Ishwas (1969), "Linear Programming Analysis of a Water Supply System," *AIIE Transactions,* 1(1).

66. Hoag, L. N., and G. Weinberg (1957), "Pipeline Network Analysis by Electronic Digital Computer," *Jour. Amer. Water Works Assn.,* 49, 5, p. 517-24.

67. Howson, L. R. (1957), "Factors Affecting Long Distance Transmission of Water," *Jour. Amer. Water Works Assn.,* 49, 10, 1359-68.

68. Hughes, T. C., and C. G. Clyde (1973), "Municipal Water Planning - Mixed Integer Approach," *Proc. Am. Soc. of Civil Engineers,* 99(HY11), 2079.

69. Jacoby, S. (1968), "Design of Optimal Hydraulic Networks," *Jour. Hyd. Div., ASCE,* 94(HY3), 641-660.

70. Jacoby, S. L. S., and L. W. Twigg (1968), "Computer Solutions to Distribution Network Problems," *Proc. Natl. Symp. on Anal. Water Resources Systems, Amer. Water Resources Assn.,* Denver, Colo., p. 167.

71. Karmeli, D., Y. Gadish, and S. Meyers (1968), "Design of Optimal Water Distribution Networks," *ASCE J. of Pipeline Div.,* 94 (PL1).

72. Lemieux, P. F. (1972), "Efficient Algonithm for Distribution Networks," *Jour., Hyd. Div., Proc. Am. Soc. of Civil Engrs.,* (HY11), 1911.

73. Liang, T. (1971), "Design Conduit System by Dynamic Programming," *Proc. Am. Soc. of Civil Engrs.,* 97(HY3), 383.

74. Linaweaver, F. P., Jr., and C. Scott Clark, (1964), "Costs of Water Transmission," *Jour. Amer. Water Works Assn.,* 12, 1549-60.

75. Lischer, V. C. .(1948), "Determination of Economical Pipe Diameters in Distribution Systems," *Jour. Amer. Water Wks. Assn.,* 40(8), 849-67.

76. Manne, A. S. (1961), "Capacity Expension and Probabilistic Growth," *Econometrica,* 29(4), 632-49.

77. Martin, D. W., and G. Peters (1963), "The Application of Newton's Method to Network Analysis by Digital Computer, *Jour. of Inst. of Water Engr.,* 17(2), 115.

78. McIlroy, M. S. (1950), "Direct Reading Electrical Analyzer for Pipeline Networks," *Jour. Amer. Water Works Assn.,* 42, p. 347.

79. McPherson, M. B. (1962), "Application of System Analyzer," *Water and Sewage Works,* Ref. and Data Number, pp. R-53.

80. McPherson, M. R., and M. Heidari (1966), "Power Consumption with Elevated Storage Compared to Direct and Booster Pumping," *Jour. Amer. Water Works Assn.,* 58(12), 1585.

81. Neigut, E. G. (1964), "Distribution Designed by New Method," *Waterworks and Wastes Engineering,* pp. 46-49.

82. Pitchai, R. (1966), "A Model for Designing Water Distribution Pipe Networks," Ph.D. Thesis, Harvard University.

83. Schaake, C., and D. Lai (1969), "Linear Programming and Dynamic Programming Application to Water Distribution Network Design," Mass. Inst. of Technology, Hydrodynamics Laboratory, Report No. 116.

84. Shamir, U., and C. D. Howard (1968), "Water Distribution Systems Analysis," *Jour. Hyd. Div., ASCE,* 94(HY1), 219-33.

85. Shamir, U., (1947), "Optimal Design and Operation of Water Distribution Systems," *Water Resources Research,* 10(1), p. 27.

86. Smith, D. V. (1966), "Minimum Cost Design of Linearly Restrained Water Distribution Networks," Master Thesis, Dept. of Civil Engineering, M.I.T.

87. Sturman, G. M. (1971), "Systems Analysis for Urban Water Supply and Distribution," *Jour. Environ. Systems,* 1, 67.

88. Tong, A. L., F. T. O'Connor, D. E. Stearns, and W. O. Lynch (1961), "Analysis of Distribution Networks by Balancing Equivalent Pipe Lengths," *Jour. Amer. Water Works Assn.*, 2, 192.

89. *Urban Water Resources Research* (1968), A Study for OWRR, ASCE, New York, N. Y.

90. Warga, J. (1954), "Determination of Steady-State Flows and Currents in a Network," *Paper #54=43=4*, Proc. of the Inst. Soc. of Amer. 9, Part 5.

91. Watanatada, T. (1973), "Least Cost Design of Water Distribution Systems," *Proc. Am. Soc. of Civil Engr.*, 99(HY9), 1497.

92. Whittington, R. B. (1960), "Pipe Lines with Constant Draw-off by Side Branches," *Jour. Inst. of Water Engineers*, London, Vol. 146, p. 459.

93. Wood, D. J. (1971), "Analog Analysis of Water Distribution Networks," *Proc. Am. Soc. of Civil Engrs.*, *Transport Eng. Jour.*, TE2, p. 281.

94. Zarghamee, M. S. (1971), "Mathematical Model for Water Distribution Systems," *Jour. Hyd. Div.*, *ASCE*, pp. 1-14.

Models of Treatment Plants (Staging)

95. Dostal, K. A., et al. (1966), "Development of Optimization Models for Carbon Bed Design," *Jour.*, *American Water Works Assn.*, 58(9), 1170.

96. Harrington, J. J. (1967), "The Role of Computers in Planning and Managing Water Utilities," *Jour.*, *New England Water Works Assn.*, 81(3), 231.

97. Lauria, D. T. (1973), "Water Supply Planning in Developing Countries," *Jour. Amer. Water Works Assn.*, 46(9), 583.

98. Muhich, A. J. (1966), "Capacity Expansion of Water Treatment Facilities," unpublished Ph.D. dissertation, Harvard University, Cambridge, Mass.

99. Riordan, C. (1969), "Toward the Optimization of Investment-Pricing Decisions: A Model for Urban Water Supply Treatment Facilities," Ph.D. Thesis, Cornell Univ., Ithaca, N. Y.

100. Singh, Krishan P. and C. G. Lonnquist (1972), "Water Treatment Plant Staging Policy," *Water Resources Bulletin*, 8(2), 239-49.

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WATER DEMAND FORECASTING—SOME CONCEPTS AND TECHNIQUES

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INTRODUCTION

To forecast the future, whether in connection with water usage or one's fortune, is to play God. Divination, it's called, and those who do it are seers, soothsayers, wizards, prophets and clairvoyants. What engineer would not leap at the chance to join such company? Hence, this paper.

Through history, society has accorded its forecasters special honors and privileges. In ancient times, successful prophets were treated as messengers of the gods, if not gods themselves. The unsuccessful, of course, were handled a bit differently. These days, engineers who inaccurately predict the future are not boiled in oil nor are the accurate housed in temples; but then, neither are the risks of forecasting as great now as formerly.

Not because of lesser interest in the future are risks reduced. Indeed, modern man appears to be as concerned with what lies ahead as his ancient forebears. Rather, the tools of present-day forecasters seem to be improved which makes the profession somewhat less risky. No longer is the prophet constrained to rely on cards, dice, entrails, and tea leaves. Instead, he has the most modern and sophisticated of all tools . . . the mathematical model!

Of course, not everyone is convinced that its use will result in forecasts better than those by crystal balls, palmistry and the like. Gardner Brown (1968) writes:

> "If (a) water-use projection is required, except for very special circumstances, the most efficient way to go about it is as follows: Bring together two economists, two engineers, perhaps one lawyer, maybe a few representatives from industry, one or two perspicacious politicians, and one secretary. Pay them well and give them two days, at the end of which a final report is due. If these men reach an impasse at any point, the conflict is to be resolved by coin flippings--as many times as necessary to reduce the choices to one. This procedure, it is submitted, will provide water-use projections as accurate as any other method for a fraction of the cost . . ."

The warnings of skeptics notwithstanding, I must get on with the business of describing mathematical models.* First, however, it is necessary to offer some definitions and economic concepts regarding demand.

DEFINITIONS AND CLASSIFICATIONS

The word *demand* is a technical term in economics; it represents the amount of a commodity that would be purchased at a given price.** A demand schedule (or curve or function) represents the various quantities of a good that consumers will take off the market at alternative prices. Requirements or needs, on the other hand, represent unexplained and unqualified desires for a commodity: I need a new car; this town needs six million gallons of water daily.

A forecast or prediction is an estimate of the future state of a variable based on a number of explicit assumptions. If the quantity of water used in a community is assumed to be a function of such things as population, per capita income, price and rainfall, then a prediction of future usage would be the estimate associated with specific levels of these casual variables. Such variables their interrelationships, and the values they take constitute the assumptions upon which the forecast is based. A projection, on the other hand, is an estimate of the future state of a variable based on an extrapolation of past trends. With projections, there is assumed to be only one casual variable--time.

Sewell and Bower (1968) describe the following three classifications of water demand: (1) where the water is demanded (a locational classification), (2) whether the water is consumed (a dichotomous classification), and (3) the purposes for which the water is demanded (a usage classification).

The locational classification recognizes withdrawal uses, flow uses, and on-site uses. Withdrawal refers to uses that require removal from the watercourse including such things as municipal, industrial and agricultural supply. Where data on water use are available, they generally refer to withdrawal use. Flow use includes usage in the channel for navigation, waste dilution, hydro power, and the like. On-site use refers to use of water where it occurs; recreation, aesthetic enjoyment and propogation of wildlife are included in this category.

Consumptive use refers to situations where less water is directly returned to the source than is withdrawn. In irrigation,

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*The art of forecasting by means of cards, ax heads, and crystal balls is respectively called chartomancy, axinomancy, and crystallomancy--mancy meaning *to prophesy*. It seems that this paper might be appropriately subtitled, *The Art of Modelomancy*.

**Cf. Chapter II of *Forecasting Water Demands* by Thompson, et al. (1966) for useful definitions.

two-thirds of the water is *lost* through evapotranspiration; five percent of industrial water is not returned. If *consumption* is expanded to include quality as well as quantity, then quality is *consumed* by such things as reservoir storage, cooling, and washing.

The purposes for which water is demanded are varied and constitute the most commonly used basis for forecasting. Such purposes include residential supply, irrigation, cooling, industrial process, commercial supply, street washing, and fire protection.

ECONOMIC THEORY OF DEMAND

Classical economic theory of demand assumes that individuals gain utility or satisfaction from the consumption of goods and services.* The individual's appetite for such goods is insatiable; marginal utility, however, diminishes with increasing consumption. Once the individual has many goods, addition of another increases utility only slightly. Actually (the theory goes), the satisfaction derived from each unit is less than that obtained from the previous. In a two-commodity world that includes water (W) and everything else (E), an individual's utility function might be denoted

$$U = u\ (W,\ E), \qquad (1)$$

which is shown graphically in Figure 1. The curved isoutility lines (U^0, U^1, ...) are infinite in number, each one indicating all the combinations of W and E which produce a constant level of utility. Note that if amounts of both W and E are increased, a higher level of utility is obtained; that is, $U^0 < U^1 < U^2 < \dots$ While an absolute or cardinal measure of utility is not available (which makes Figure 1 suspect), an ordering of preferences is all that is really required.

Suppose the price of water is P_w and the price of everything else is P_e; assume further that the consumer's disposal income is I. The problem of allocating income between water and everything else is expressed mathematically as follows:

$$\begin{aligned} &\text{Maximize} && U = u(W,\ E) \\ &\text{Subject to} && P_w W + P_e E = I. \end{aligned} \qquad (2)$$

Clearly, the budget constraint of (2) is linear which plots as a straight line in Figure 2; the ordinate and abscissa intercepts are I/P_e and I/P_w, respectively. The consumer's problem, then, is to find that combination of W and E on this line which coincides with the highest isoutility curve. Clearly, the optimal quantities are W* and E*, as shown.

Now assume everything remains constant except the price of water. As P_w decreases, the abscissa intercept of the budget line increases causing the line to shift right as shown in Figure 3. The

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*A description of the economic theiry of demand can be found in books like those of Baumol (1972) and Leftwich (1960).

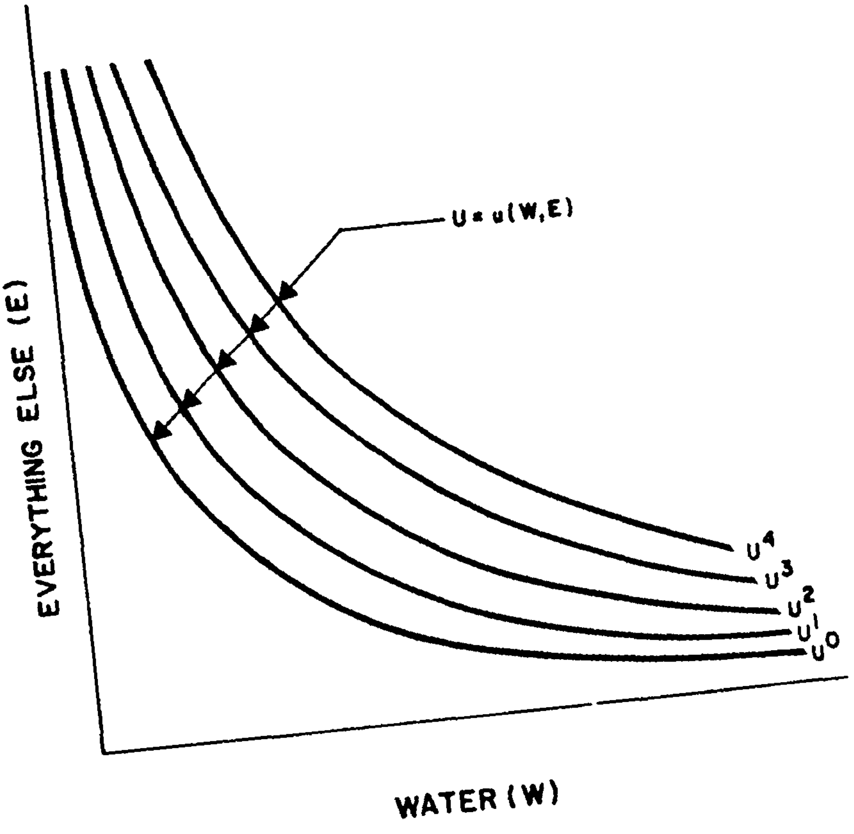

FIGURE 1— CONSUMER UTILITY FUNCTION

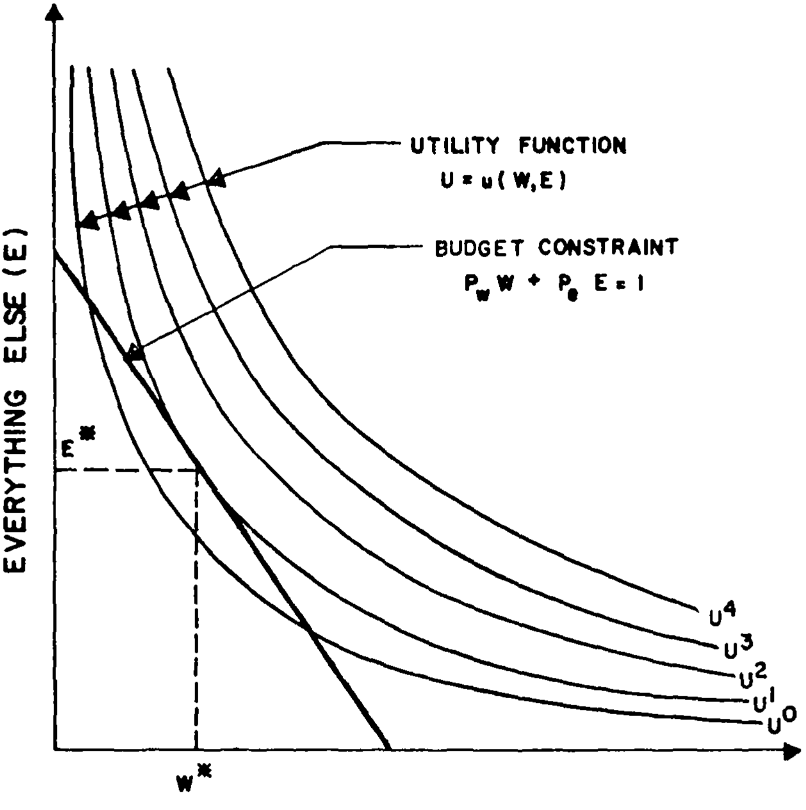

FIGURE 2 — OPTIMAL BUDGET ALLOCATION

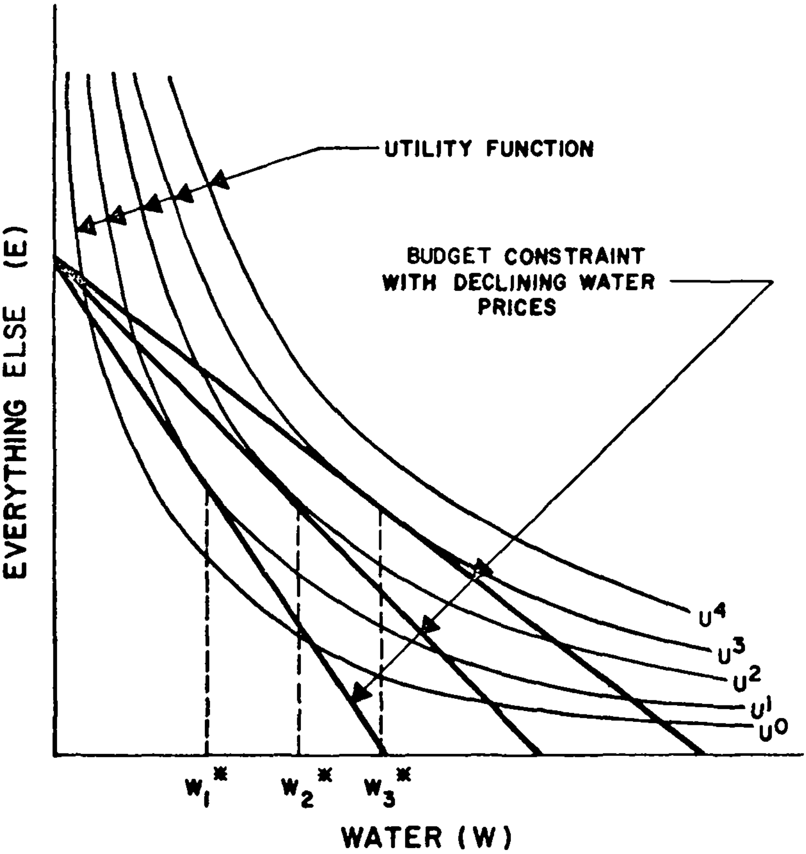

FIGURE 3— OPTIMAL WATER PURCHASES AT ALTERNATIVE PRICES

optimal quantities of water which the consumer should purchase (i.e., those that maximize utility) are denoted W_1^*, W_2^*,... A plot of these quantities versus the water prices upon which they depend results in the familiar demand curve shown in Figure 4.

Every individual in the water market (which is usually a city or town) presumably has a demand function of the general type in Figure 4. Adding the quantities of water demanded by all consumers at alternative prices results in the market demand function which, for domestic use, probably has the characteristic shape shown in Figure 5. Note that the quantity of water demanded is relatively constant over a wide price range when prices are high. Such price inelasticity of demand results from the fact that the small quantities of water (for which there are no substitutes) are going to satisfy the basic necessities of life. Most communities in developing countries operate in this region of the demand curve. As water is used for less essential purposes, the curve flattens and the sensitivity of quantity demanded to price increases. Eventually, a price is reached below which quantity remains constant; at this level consumers have all the water they can use.

The demand function by itself does not identify the quantity of water demanded by the market. For this, we need to know the market price which, at equilibrium, comes about from the interaction of market supply and demand. Given that the supplier seeks to be compensated for the costs of providing each additional unit of water, the market supply function is simply the producer's marginal cost curve which rises (eventually) for increasing quantities produced. Market price at equilibrium, then, is $\hat{P}$ as shown in Figure 6, and the quantity of water demanded by the market is $\hat{W}$.

VARIABLES AFFECTING WATER DEMAND FORECASTS

The preceding economic theory identifies the basic variables underlying demand which ought to be considered in making water forecasts. At the root of demand are social tastes and preferences; the desires upon which the consumer's utility function (U) is based. Included are desires for green lawns, swimming pools, and daily showers. Desires which less obviously affect demand include preferences for goods which directly or indirectly require large amounts of water for production, such as high octane fuels and brightly colored clothing.

Certainly, per capita income (I) and the prices of other goods (P_e) affect water demands. The price of water itself (P_w) is a key determinant. Population defines the size of the domestic market and thus must be considered; similarly, the industrial and commercial complexion of a community is basic to demand.

New technology may affect water usage from both the demand and supply sides. New water-using appliances for the home, colored paper products and nuclear power generation account for increasing demands. Technological advances in water development are designed to shift the water supply curve to the right thereby reducing the cost per unit provided. The use of monomolecular films on reservoirs, new membranes for desalting and cloud seeding are all intended for this purpose.

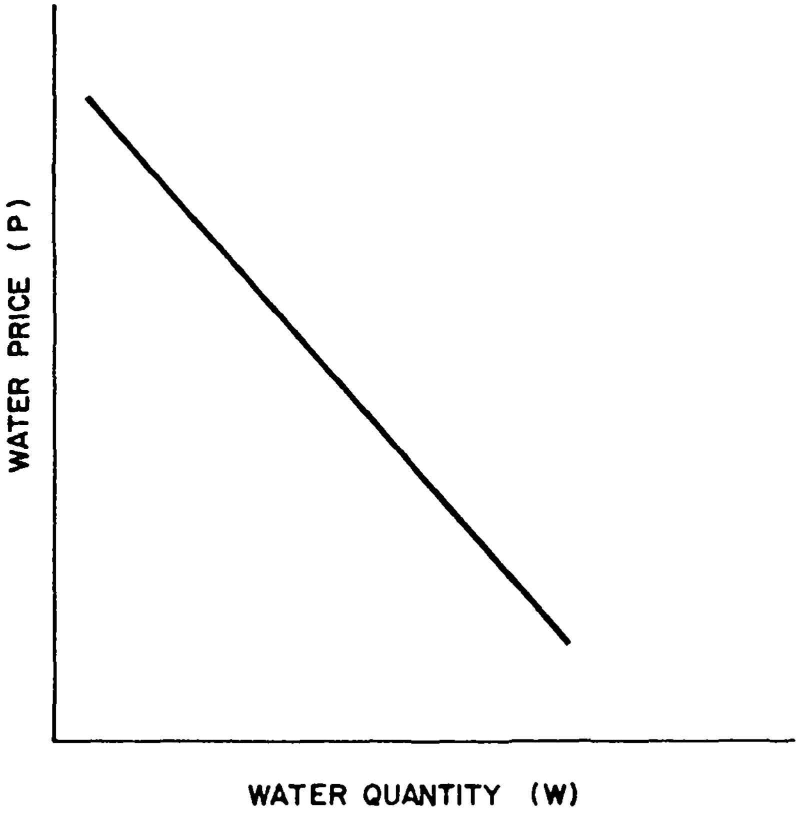

FIGURE 4 — WATER DEMAND FUNCTION

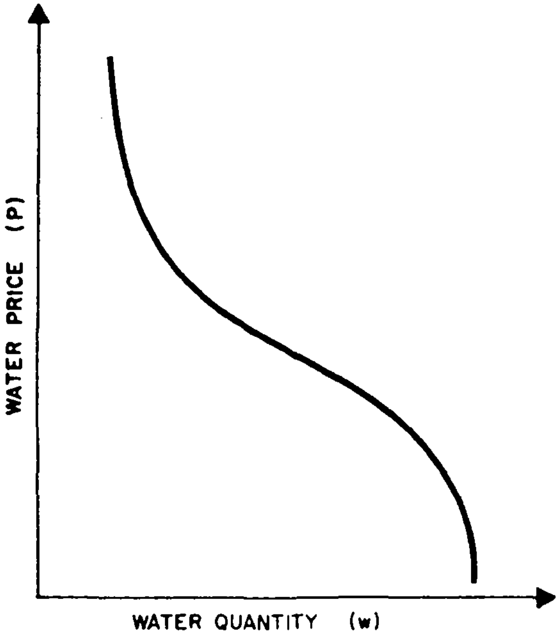

FIGURE 5— MUNICIPAL WATER DEMAND FUNCTION

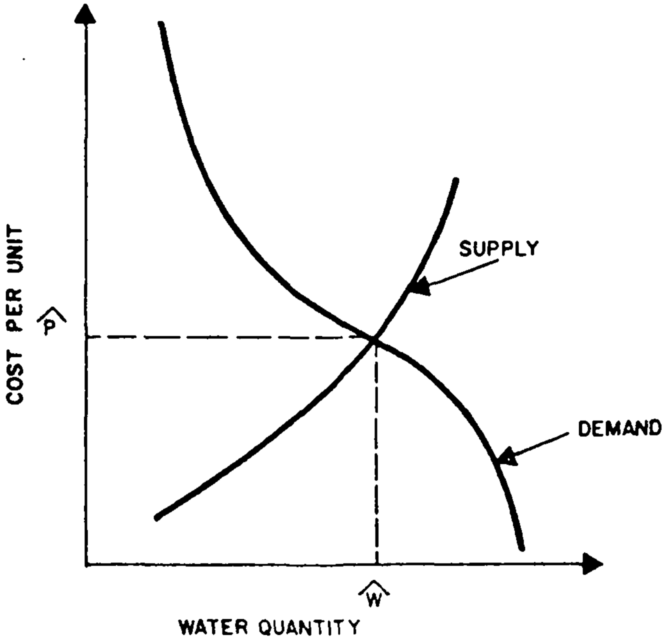

FIGURE 6— MARKET DEMAND FOR WATER

Like technology, policy decisions affect demands from both the supply and demand sides. Lawn sprinkling restrictions, water metering, *and wastewater effluent standards and charges* all *tend to suppress* the quantities of water demanded. Subsidies for construction of wastewater treatment plants and declining block prices, on the other hand, encourage water use.

If water demand forecasts are to be accurate, the future state of all such variables must be considered.

STRATEGY FOR WATER DEMAND FORECASTING

For all the rhetoric regarding demands, seldom are they the subject of forecasting. Rather, the overwhelming majority of predictions is for future requirements or needs; indeed, the mathematical models presented herein are intended for this purpose. In demand forecasting, it is necessary to take explicit account of the increasing scarcity of water and the difficulty of making it available. In the absence of such accounting, it is implicitly assumed that the costs of supply will be relatively the same in the future as they are today. While this might not be an unreasonable assumption for many water-rich regions of the United States and abroad, it is clearly erroneous where supplies will be hard pressed to meet the demands placed upon them. And, of course, as population increases, the number of such water-rich regions declines thereby invalidating forecasts which focus primarily on needs and requirements.

Since the remainder of this paper is concerned with water requirements, it is appropriate to at least outline a strategy for forecasting demands. Howe (1968) has presented such a strategy which is summarized as follows. Let us assume the availability of a market demand function of the type in Figure 5 which indicates the various quantities of water that will be taken off the market at alternate prices. Howe and Linaweaver (1967) report functions of this type for residential water demands.

For the market under consideration, the first step is to forecast future water requirements as accurately as possible using projection or other techniques. Having done this, preliminary engineering plans must be prepared to determine how such requirements can be met at least cost. Assuming a cost allocation policy, the next step is to calculate the prices that would most likely be charged for the proposed system. This is followed by a determination of the quantity demanded at these prices using the demand function assumed to be in hand at the outset. If this amount differs substantially from the requirements previously forecasted, it is necessary to (1) prepare revised plans, (2) recalculate costs, and (3) estimate a new quantity demanded based on adjusted prices using the demand function. Repeated use of this procedure should ultimately cause convergence between forecasted requirements and demands.

While this strategy is conceptually straight-forward, application presents significant problems, including the need for (1) commercial, industrial, and updated residential water demand functions,

(2) an economic base study that includes consistent forecasts of population, employment, income and other economic indicators, and (3) accurate cost estimates of proposed facilities and a realistic pricing plan.

MODELS FOR FORECASTING WATER REQUIREMENTS

A number of quantitative techniques have been developed for water requirements forecasting, some of which are described in this section. By no means is this intended to be an exhaustive survey; the most commonly used methods, however, are included. While several classifications might be proposed, forecasting techniques are divided herein into (1) time series models, (2) regression models, and (3) input-output models.

Time Series Models

Time series models are used for the projection of historical data into the future.* Such projections can be made of water usage data if they are available or of a surrogate variable such as population, households, or telephones. (If population or another surrogate is used, it is necessary to multiply projected values by a water use factor such as gallons per day per person to obtain future estimates of community water requirements.) Although historical data are generally available in the United States enabling use of time series models, their use is precluded in new towns, some rural areas, and in developing countries where such data are lacking.

The most basic time series models assume either arithmetic or geometric increase in the dependent variable (water usage, population, etc.) over time. If $y(t)$ is the dependent variable (say, rate of water usage) in year t, then arithmetic growth assumes the rate of change of y is a constant. Mathematically, $dy/dt = B$, which integrates to the following

$$y(t) = B_0 + B\ t. \qquad (3)$$

With historical data for $y(t)$ and t, the parameters of (3), B_0 and B, can be evaluated by least squares analysis. Principal interest is in B, the water usage growth rate, which has typical units, mgd per year. Equation (3) is used for projection by setting B_0 equal to the most recent usage rate for which data are available and letting t measure time from that year.

More common than this analytical procedure is the graphical technique wherein historical $y(t)$ values are plotted on arithmetic paper versus t. A straight line is fitted to the plot by eye and another line parallel to it is projected into the future from the last y value; Figure 7A illustrates.

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*Cf. Chapter 5 of Fair, *et al.* (1966) for a description of the most basic time series models.

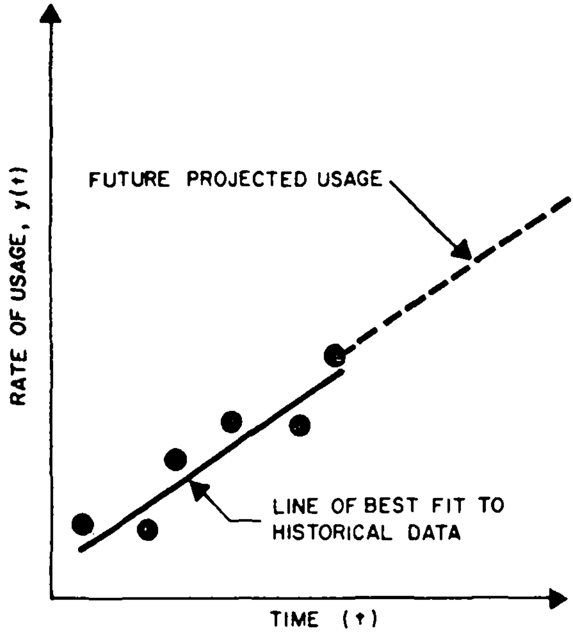

FIGURE 7A— LINEAR PROJECTED USAGE

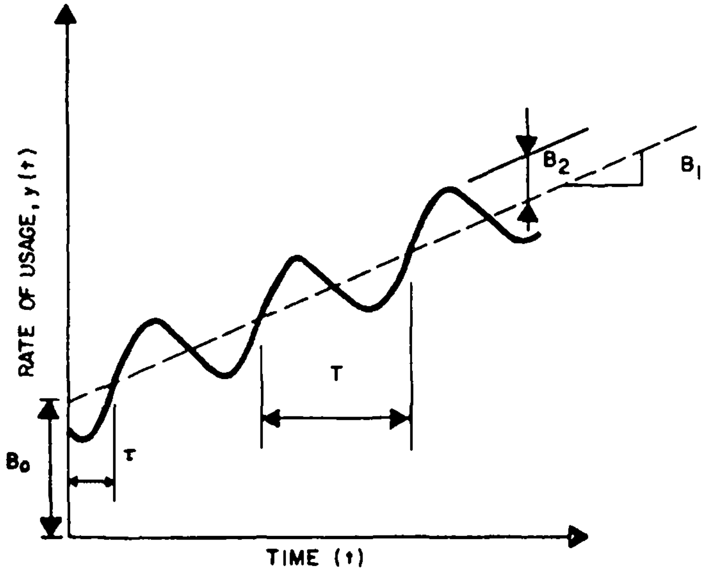

FIGURE 7B— PERIODIC PROJECTED USAGE

If the rate of change (dy/dt) of water usage is proportional to use (y), geometric instead of arithmetic growth is implicitly assumed. Mathematically, $dy/dt \sim y$ which implies $dy/dt = By$; integration yields

$$y(t) = B_0 \, e^{Bt}. \tag{4}$$

As in the arithmetic model, y(t) and t are the dependent and independent variables, respectively. Parameters B_0 and B can be evaluated by least squares after linearizing (4) by taking the (natural) log transform. Thus, in regression analysis, it is necessary to use ln[y(t)] values for the dependent and t values for the independent variables. As before, interest is in B (with units, per year) which is obtained directly from least squares calculations. Equation (4) can then be used for projection by setting B_0 equal to the most recent usage data point and measuring future time from that year. Graphical techniques are also used for geometric models; the procedure is identical to that for arithmetic growth except semilog paper is used, y(t) being plotted on the log scale.

Less commonly used but still of interest are auto-correlation models wherein time does not enter explicitly as the independent variable. Rather, the rate of usage (or other dependent variable) in year i+1 is assumed to depend only on the rate of usage in year i. Mathematically, $y_{i+1} = f(y_i)$.

Auto-correlation models frequently relate the percentage change in the variable of interest during the next year or decade with its value at the beginning of the time period. If y_i is, say, the rate of water usage in year i and z_i is the percentage change in y_i in the succeeding time period, then typical linear, exponential and power models relating these variables are shown in (5A), (5B), and (5C), respectively

$$z_i = B_0 + B \, y_i \tag{5A}$$

$$z_i = B_0 e^{B \, y_i} \tag{5B}$$

$$z_i = B_0 \, y_i^{B}. \tag{5C}$$

These equations can be readily transformed to autocorrelation functions by recognizing that $z_i = (y_{i+1} - y_i)/y_i$. Making this substitution in (5A), for example, and solving for y_{i+1} yields

$$y_{i+1} = B_1 \, y_i + B \, y_i^{2}; \tag{6}$$

similar substitutions can be made in (5B) and (5C). In (6), B_1 is a constant with value $1 + B_0$. The parameters of (5) or (6) can be evaluated by least squares analysis or more approximately by plotting z_i versus y_i on arithmetic, semilog or log-log paper and fitting a line by eye. Once the parameters (B_0 and B) are evaluated, the equations can be used recursively to calculate succeeding y_{i+1} values starting with the most recent y_i for which a numerical value is available. An example is included in Chapter 5 of Fair, *et al.* (1966).

More general auto-correlation models postulate y_{i+1} instead of z_i as the dependent variable. The simplest of such models is the linear equation

$$y_{i+1} = B_0 + B\,y_i; \qquad (7)$$

exponential and power functions of the type in (5) relating y_{i+1} and y_i are also possible. While the parameters B_0 and B can be estimated from curve fitting or by regression analysis, Draper and Smith (1966) show that in the case of (7), $B_0 = \bar{y}\,(1-r_1)$ and $B = r_1$, where $\bar{y}$ is the mean of the data sample and r_1 is the lag-1 serial correlation coefficient.

Where monthly or daily estimates of future water usage are desired, the rather gross projections obtained by the above time series models may be inadequate. In this case, cyclical variations from one period to the next are required which necessitates use of Fourier analysis. Descriptions of such analysis may be found in a number of texts including Tintner (1965); Gracie (1966) presents the analysis of water usage data using Fourier techniques.

In the basic model of equation (3), usage is projected into the future as a linear function of time as shown in Figure 7A. To superimpose a cyclical variation as shown in Figure 7B, it is merely necessary to add a sine wave to the function which results in the following model:

$$y(t) = B_0 + B_1 t + B_2 \sin(\omega t - \theta). \qquad (8A)$$

In this expression, ω is the angular frequency with units, degrees (or radians) per unit time ($\omega = 360°/T$), and T is the period of the wave; the time for a complete cycle. It is necessary to specify T in advance; for water usage data, values of 1, 7, 30, 120, and 365 days are common. The phase shift of the wave is denoted θ with units, degrees or radius ($\theta = 360°\tau/T$), where τ is the time lag to the start of the first wave, as shown in Figure 7B. The parameters of (8A) to be evaluated by regression analysis using the historical data trace include B_0, B_1, B_2 and θ; y and t are the dependent and independent variables, respectively, and ω is a parameter for which numerical value is available once the modeler selects T.

Unfortunately, (8A) is not linear in the parameters and, hence, is not an appropriate model for regression analysis. It can be suitably transformed, however, via a trigonometric identity and changes of variables to yield the following:*

$$y(t) = B_0 + B_1 t + A \sin \omega t + B \cos \omega t, \qquad (8B)$$

in which t, $\sin \omega t$ and $\cos \omega t$ are the independent variables for which numerical values are available or can be calculated.

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*$\sin(\omega\tau - \theta) = \cos\theta \sin\omega\tau - \sin\theta \cos\omega\tau$, $A = B_2 \cos\theta$, and $B = -B_2 \sin\theta$.

Equations (8) include the single wave (or harmonic) shown in Figure 7B. It is possible, however, that the data reflect several harmonics (e.g., daily, weekly, monthly, seasonal, and annual cycles). Such harmonics imply the superposition of wave upon wave. While it is unusual to include more than one or two harmonics in a predictive model, several (approximately n/2, where n is sample size) can be included merely by adding additional terms to (8), each with its own unique ω. The resulting model is

$$y(t) = B_o + B\ t + \sum_i (A_i \sin \omega_i\ t + B_i \cos \omega_i\ t). \qquad (9)$$

Regression Models

Unlike time series models which include a single independent variable, regression models generally include several; between two and six is common, although an extraordinary model by Wong, *et al.* (1963) included twenty. While the independent variables cannot unequivocally be viewed as the causitive factors underlying demand, such is usually implied. In the case of community demand, the independent variables are most often indicators of social, economic, and weather conditions in the water market. Selection of variables to be included in models for which published data are already available or can be easily obtained frequently poses serious problems.

A sound theoretical basis for postulating regression models for water demand is seldom available. As a result, modelers often propose quite general additive or multiplicative expressions like those of (10A) and (10B) and rely on statistical tests for deleting superfluous terms.

$$Y = B_o + B_1X_1 + B_2X_2 + \ . \ . \ . + B_iX_1^{\ 2} + B_jX_2^{\ 2} + \ . \ . \ .$$

$$+ B_kX_1X_2 + B_eX_1X_2X_3 + \ . \ . \ . + B_zX_1X_2\ . \ . \ . \ X_n \qquad (10A)$$

$$Y = B_oX_1^{\ B_1}\ X_2^{\ B_2}\ . \ . \ . \ X_n^{\ B_n} \qquad (10B)$$

Such tests identify those parameters (B's) not significantly different from zero.

The additive model of (10A) can be very cumbersome if more than just a few independent variables (X's) are included. In practice, such models are often initially formulated with only first-order terms, ignoring all interactions such as X_1X_2, $X_1X_2X_3$, etc. and powers of X greater than one. Simplistic models of this type which are linear in both parameters and variables are almost always inadequate. To make them more realistic, quadratic models like that of (10C) are sometimes postulated; interactions are often ignored due, among other things, to the difficulty of interpreting their meaning.

$$Y = B_0 + B_1X_1 + \ldots + B_nX_n + B_{11}X_1^2 + B_{nn}X_n^2$$

$$+ B_{12}X_1X_2 + \ldots + B_{n,n-1}\, X_nX_{n-1} \tag{10C}$$

Square-root models are also used which are similar to (10C) except that $\sqrt{X}$ terms replace X^2.

A clear advantage of the multiplicative model of (10B) is its simplicity. It can be readily linearized by logarithmic transformation making it necessary to use logs of data on Y and X's in regression analysis. With n independent variables, the model includes only n+1 parameters for evaluation; messy interactions do not exist. The major disadvantage, however, has to do with exponents. Consider X_2 in (10B), for example. Taking the partial derivative with respect to it results in the following:

$$B_2 = \frac{\partial Y/Y}{\partial X_2/X_2} \tag{11}$$

the numerator of which is the percentage change (as a decimal) in the dependent variable; similarly, the denominator is the percentage change in X_2. Hence, B_2 represents the percentage change in the rate of water usage per percent change is X_2. This, it may be recognized, is a measure of elasticity; if X_2 were price, B_2 would be the price elasticity of demand. The problem here is that the multiplicative model implicitly assumes that all such elasticities are constant, which is generally untenable except with a narrow range of values for each X.*

Fundamentally, regression models define the interrelationships between water usage and the variables upon which it depends. If used for forecasting, it is necessary to estimate future values of the X's for the year in question. Almost always, this is a difficult task. Equally or more difficult, however, is the need to estimate future values of model parameters (the B's). It does not necessarily follow that the values such parameters assume in a base year for which data are available will remain constant into the future. Thus, it is desirable to postulate and solve models of the type in (10) for several base years followed by time series analysis of parameters or else include time explicitly in the model as an independent variable. While this approach is recommended, it is seldom followed.

A number of regression models for water usage are reported in the technical literature; only a few are mentioned herein. Howe and Linaweaver (1967) present the results of an extensive study of residential water demand in the U. S. Separate models are reported for (1) houses with water meters and public sewers, (2) houses and apartments charged a flat rate for water but served with public

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*If, for example, the price elasticity were constant, the demand function would be as shown in Figure 8 which is significantly different from Figure 5.

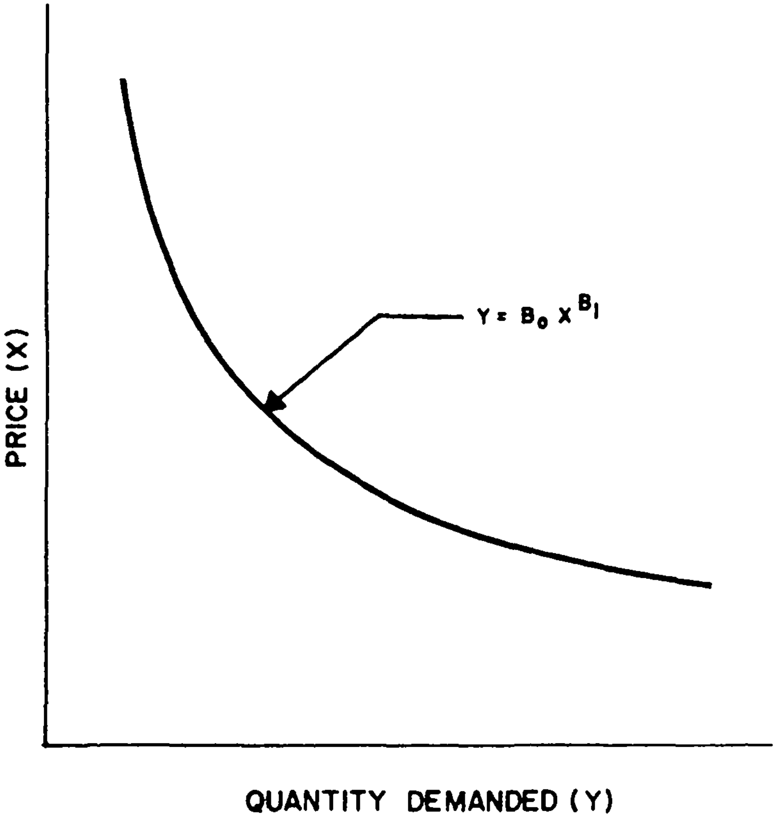

FIGURE 8 — DEMAND FUNCTION WITH CONSTANT PRICE ELASTICITY

sewers, and (3) houses with water meters and septic tanks. The dependent variable is the rate of usage per dwelling, and the principal independent variables include the market value of the home, its age, the number of persons in the dwelling, average water pressure, and the sum of water and sewer charges. Separate models for summer sprinkling demand include the irrigable area and net effective rainfall as independent variables. Both additive and multiplicative models are postulated, although the former are simple expressions, linear in variables as well as parameters. A typical result is the following which indicates the average annual quantity demanded per dwelling for domestic purposes (in gallons per day) for residences with water meters and public sewers:

$$q = 206 + 3.47 V - 1.30 P; \tag{12}$$

in (12) V is market value of the home in thousands of dollars and P is the average charge for water and sewer services in cents per thousand gallons.

An early regression model of residential demand was developed by Fourt (1958) who included price, the number of days of summer rainfall, average number of persons per meter and total population served as independent variables. A highly disaggregated regression model for community water usage is that of Wong, *et al.* (1963), previously mentioned. Among the twenty independent variables were the following: industrial employment, maximum and minimum water prices, percent of housing in one-, two-, three-unit and larger structures, average household size, percent of owner-occupied units, median income and average home value. A number of special purpose univariate regression models are reported in the literature. Commonly used independent variables include water price, personal income, and various indicators of economic activity.

Main I is a fairly recent model for community water usage developed by Hittman Associates (1969) which appears to be well verified. The model divides water requirements into residential, commercial, industrial, and public categories. Residential requirements are estimated using the models of Howe and Linaweaver, while commercial, industrial and public uses are estimated from water coefficients. It is necessary for the user to obtain community data on such variables as the number of barber chairs in town, the square feet of car washes, the number of car stalls in drive-in movies, and up to fifty additional categories in order to predict commercial requirements. Industrial estimates are based on some 200 coefficients for which employee data by industrial sector are required. Public usage covers thirty categories such as system losses, bus and airport terminals, and free service. While agreement between observed and estimated water usage based on Main I is good, the model is highly disaggregated and requires vast amounts of data for use.

Main I is the predecessor of Main II which is the Hittman model for forecasting future requirements. While Main I enables prediction of water usage at any point in time, Main II is concerned with forecasting values of the independent variables upon which future usage depends. Three techniques are included in Main II for such forecasting: projection by interval growth models, time series analysis of local data, and use of external forecasts. Projection by growth models makes use of national rates of increase in variables based on data from a number of Standard Metropolitan Statistical Areas throughout the United States. This option is most appropriate for variables of lesser importance or where local information on trends is lacking. Time series analysis of data can be selected for variables whose future growth is expected to differ significantly from national averages, and external forecasts merely provide for using future estimates developed apart from the Main model. To date, extensive use has not been made of the Main models apparently due to their highly disaggregated nature.

Input-Output Models

The modern development of input-output modeling began in the 1930's due in large part to the work of Leontief (1966). Such modeling fundamentally accounts for the industrial production of a region required to satisfy society's demands for goods and services taking interindustry transfers of goods into consideration. Because input-output analysis focuses on industries, its use for water requirements forecasting is limited to that sector of the economy.

The produced goods and services (i.e., outputs) of each industrial sector in a region is the sum of the output which goes to satisfy the requirements of other industries (i.e., interindustry demand) plus that which goes to satisfy the final demand of consumers.

$$\begin{bmatrix}\text{Total}\\ \text{Sector i}\\ \text{Output}\end{bmatrix} = \begin{bmatrix}\text{Sector i}\\ \text{Output for}\\ \text{Interindustry}\\ \text{Demand}\end{bmatrix} + \begin{bmatrix}\text{Sector i}\\ \text{Output for}\\ \text{Final}\\ \text{Demand}\end{bmatrix} \qquad (13)$$

If X_i is the output of industrial sector i in a particular year, Y_i is the final demand for goods or services of industry i, and A_{ij} is the amount of type-i goods or services required by industry j to project a single unit of type-j goods, then the fundamental relationship in (13) can be written in symbols as follows:

$$X_i = A_{i1}X_1 + A_{i2}X_2 + \ldots + A_{ij}X_j + \ldots + A_{in}X_n + Y_i. \qquad (14)$$

Equation (14) is an expression for a single industrial sector such as textile manufacturing. The economy of a nation, state or other large region, however, consists of several sectors, each requiring a separate equation like (14).* Such a set of linear equations constitutes the basic input-output model of the region. If [X] is a column vector of outputs from each industrial sector, [Y] is a column vector of final demands for products from each sector, and [A] is a square matrix of *input coefficients* representing the

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*North Carolina's input-output model, for example, consists of 58 sectors.

amounts of goods required to produce a unit of output by each industry, then the set of linear equations can be written in matrix notation as follows:

$$[X] = [A][X] + [Y] \qquad (15A)$$

The heart of input-output modeling consists of developing numerical values in [A] for a base year. This work requires examination of the regional economy to determine the amounts of goods purchased by (or sold to) each industry of the region from every sector. Additionally, an accounting of regional imports and exports together with the goods and services going to satisfy final consumer demands must be made. Analysis of the data from such study results in a matrix of values for [A].* With numbers in hand, (15A) can be rearranged as follows:

$$[X] - [I - A]^{-1} [Y], \qquad (15B)$$

where I is the identity matrix, and $[I-A]^{-1}$ is a square matrix called the Leontief inverse of same dimension as [A]. The numerical values of the inverse matrix define the amounts of goods and services required from each industry per unit of final demand. Specifically, the element in the i-th row and j-th column indicates the amount of good i required per unit of final demand for good j. The elements of this matrix, then, define required amounts of goods and services to satisfy both consumer demand (i.e., direct demand) and interindustry demand (i.e., indirect demands).

Expression (15B) is the form input-output models take when used as tools for forecasting. If national, state or other regional agencies are able to estimate future levels of final consumer demands [Y], the associated amounts of output [X] from each industrial sector of the region required to meet then can be estimated from (15B). This assumes, of course, that the values of [A] remain constant over time. Such forecasts of industrial output are entirely consistent with the structure of the regional economy which is, perhaps, the principal strength of input-output forecasting.

Once planners are able to forecast industrial outputs required to meet final demands, a number of other predictions become possible, the most important of which for our purposes are industrial water requirements. Assuming that industrial water usage is primarily a function of industrial output, requirements are estimated by multiplying each output in [X] by an appropriate water use coefficient. If [W] is a row vector of such coefficients, total industrial water requirements in the region needed to satisfy final consumer demands [Y] is obtained from the following:

$$[W][X] = [W][I-A]^{-1} [Y]. \qquad (16)$$

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*Such analysis is described by Miernyk (1965).

Expression (16) denotes the use of input-output models for industrial water requirements forecasting in a region. Given numerical values for the inverse matrix and with a vector of industrial water use coefficients, water requirements can be forecasted for any future schedule of final demands [Y]. Assuming [W] and $[I-A]^{-1}$ remain relatively constant over time (at least for short periods), the principal work of forecasting reduces to estimation of future values for [Y].

A number of problems and difficulties surround development and use of input-output models for water requirements forecasting. One of the most serious is that industrial production functions represented by [A] are linear. Another is that [A] is assumed to remain constant over time. Development of values for [W] is difficult. Almost always, the industrial sectors of input-output models are comprised of similar but nonetheless different industries. Hence, the usage coefficients of [W] must be aggregate values uniquely determined for the input-output model under consideration. A final problem is that resulting forecasts are regional values, to be useful except for the broadest kind of water resources planning, they must be disaggregated to subareas such as river basins or counties.

The problems of input-output forecasting notwithstanding, the technique has been applied in a number of instances. Lofting, *et al.* (1968) reports its use in California; Hite, *et al.* (1971) in South Carolina, and the United States Army Corps of Engineers (1972) in northeastern United States. A number of studies involving input-output models for statewide water requirements forecasting are currently in progress under the aegis of the Office of Water Resources Research (1973); included is work by Lauria in North Carolina, Moncur in Hawaii, and Rohdy in Colorado.

CONCLUSIONS

Economic theory provides valuable insights into the phenomenon of water demand. To large extent, the theory helps identify the principal determinants of usage including such things as consumer preferences and income, the prices of water and other goods, the role of technology and policy, and the size and type of the water market. Although the interrelationships among these variables are complex, attempts can be made to quantify them using mathematical techniques like those discussed herein. Thus, the combination of economic theory and mathematical modeling enables investigators to understand and quantify with reasonable accuracy the water demand phenomenon.

While this observation on the state of our knowledge is encouraging, it does not necessarily imply that we are well equipped to make good forecasts of future water demands. The reason is that our theory deals fundamentally with static situations. For the present point in time, we can often estimate demands with fair precision. The dynamic theory that is necessary, however, to anticipate the conditions that will account for future demands is generally lacking. To large extent, then, we must continue to rely on time series analysis and projection of trends for future estimates, which, of course, does not really explain demand growth over time.

Future use of time series analysis, especially of the simplest kind, will continue to focus on water requirements rather than demands. It is doubtful that much attention will be given to the supply side of the phenomenon. This approach may result in reasonable estimates as long as water is not a particularly scarce commodity. But there is general agreement that the day is fast approaching for many regions of the United States and abroad when scarcity will be of serious concern. More and more communities are having to go far afield to obtain water to satisfy their needs. The increased costs, of course, will be passed on to the consumer which may, indeed, lead to reduced usage thus invalidating requirement forecasts based on simplistic approaches.

While the state of the forecasting art is perhaps not as bright as we might like, it is probably not inconsistent with the state of the art for planning public water supply facilities. It is necessary to keep in mind that forecasting is not an end in itself. Rather, forecasts provide the basis for planning expansions and new facilities. At a very fundamental level, then, erroneous forecasts result in the loss of excess capacity sooner or later than desired; that is, in under or overdesign. Of course, more serious problems due to erroneous forecasts might also result, but even if water demand forecasts could be made with perfect certainty, questions of optimal planning would remain since our knowledge in this area is incomplete. As a result, work on improving demand forecasting must proceed simultaneously with efforts to improve our decision making. One without the other will not necessarily result in improvement; both are necessary.

REFERENCES CITED

1. Baumol, William J. (1972), *Economic Theory and Operations Analysis*, 3rd edition, Prentice-Hall, Englewood Cliffs.

2. Brown, Gardner M., Jr. (1968), "Industrial Water Demands: A Critique," in *Forecasting the Demands for Water*, ed. by W. R. Derrick Sewell and Blair T. Bower, Policy and Planning Branch, Department of Energy Mines and Resources, Ottawa, Canada.

3. Draper, N.R. and H. Smith (1966), *Applied Regression Analysis*, John Wiley, New York.

4. Fair, G. M., J. C. Geyer, and D. A. Okun (1966), *Water and Wastewater Engineering, Vol. 1, Water Supply and Wastewater Removal*, John Wiley, New York.

5. Fourt, L. (1958), "Forecasting the Urban Residential Demand for Water," Agricultural Economics Seminar, Department of Agricultural Economics, University of Chicago, unpublished.

6. Gracie, G. (1966), "Analysis of Distribution Demand Variations," *J. Am. Water Works Assn.*, 58, 51-67.

7. Hite, J.C. and E. Laurent (1971), "Empirical Study of Economic-Ecologic Linkages in a Coastal Area," *Water Resources Research*, 7, 1070-1078.

8. Hittman Associates (1969), "Forecasting Municipal Water Requirements: The Main II System," a Report to the Office of Water Resources Research, U. S. Dept. of the Interior, on work performed under Contract No. 14-01-0001-1977.

9. Howe, Charles W. (1968), "Municipal Water Demands," in *Forecasting the Demands for Water*, ed. by W. R. Derrick Sewell and Blair T. Bower, Policy and Planning Branch, Dept. of Energy Mines and Resources, Ottawa, Canada.

10. Howe, C. W. and F. P. Linaweaver, Jr., (1967), "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," *Water Resources Research, III*, 13-32.

11. Leftwich, Richard H. (1960), *The Price System and Resource Allocation*, Holt, Rinehart and Winston, New York.

12. Leontief, W., (1966), *Input-Output Economics*, Oxford University Press, New York.

13. Lofting, E. M. and P. H. McGauhey (1968), "Economic Evaluation of Water: Part IV, An Input-output Linear Programming Analysis of California Water Requirements," Water Resources Center, Univ. of California, Berkeley.

14. Miernyk, W. H. (1965), *The Elements of Input-Output Analysis*, Random House, New York.

15. Office of Water Resources Research (1973), *Water Resources Research Catalog,* Water Resources Scientific Information Center, Washington, D. C.

16. Sewell, W. R. Derrick, and B. T. Bower (1968), "Introduction," in *Forecasting the Demands for Water,* ed. by W. R. Derrick Sewell and Blair T. Bower, Policy and Planning Branch, Department of Energy Mines and Resources, Ottawa, Canada.

17. Thompson, R. G., M. L. Hyatt, J. W. McFarland, and H. P. Young (1971), *Forecasting Water Demands,* National Water Commission, Arlington, Virginia.

18. Tintner, G. (1965), *Econometrics,* John Wiley, New York.

19. U. S. Army Corps of Engineers (1972), "North Atlantic Regional Water Resources Study," a Report by the Corps of Engineers, North Atlantic Division, New York.

20. Wong, S. T., J. R. Sheaffer, and H. B. Gotaas (1963), "Multivariate Statistical Analysis of Metropolitan Area Water Supplies," Northeastern Illinois Metropolitan Area Planning Commission, Chicago, Illinois.

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SUMMATION

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Denver, Colorado

The basic question asked when we started this symposium was: What is the state of America's drinking water? I would say, having heard the speeches of the past two days, that the state of America's drinking water is not nearly as bad as any newspaper reporter would report to the public from having heard what was said here--unless, that is, our vital statistics are lying to us. On the other hand, it's not nearly as good as we would think--we who are in the field--or as good as we would want it to be. The federal drinking water standards that are coming up are going to demand that it be better, and our AWWA water quality goals certainly urge that it be better than that.

One point that has been made very clear is that the state of America's drinking water is not nearly as good as our present technology permits. This is true not only for the small utilities that have been blamed for much of the bad press we have received, but also the large utilities. For instance, New York City is not going to meet the turbidity requirement of the new drinking water standards, and we have been told that Seattle and Boston are causing problems in health through the quality of their drinking water. Furthermore, our water is perhaps worse than we all think it is. This has become obvious certainly from the considerable discussion about what we don't know about water. One approach to solving this problem, of course, is research. I know that you people here are most interested in seeing research promoted. The only alternative I can suggest is to get rid of our sophisticated instrumentation and not measure any more of these things that we could not measure in the past. After all, what we didn't know then has obviously not hurt us. I think, however, that you will join me in choosing to promote research as AWWA has been trying to do of late.

By the way, I was delighted to hear Gunther Craun report that research is now being done on trace metals and on this matter of soft water and heart disease. The soft water-heart disease problem has been a particularly difficult one for AWWA to answer--particularly when AWWA's water quality goals call for softening water. We want those answers, and we have been urging EPA and its predecessor agencies to do something about them for many years.

I did want to mention that we should not forget, in all these cries of desperation concerning the quality of our water, that we have been reasonably successful in the last sixty years in working as a federal-state-local team to produce water of a quality that's pretty good. We used to say, until people like Dan Okun got after us, that we're producing the best water quality in the world. Now, having listened to the talks of the last couple of days, I have decided that we are perhaps providing the best water in North America, south of Canada, that is. The team that produced this reasonable state of performance was pretty much broken up in meeting the crisis of water pollution control. Gary Hutchinson discussed this at the state level. The same thing or perhaps worse happened at the federal level. It happened, too, in the fields of education and research, where people wanted to follow the challenge and, of course, the dollars that were afforded water pollution control. Now it seems that the water supply team is to be brought together again through legislation--through the Safe Drinking Water Act, if Congress ever gets to vote on it.

Basically, the job of the Safe Drinking Water Act will be to reorder the priorities of EPA so that it recognizes the importance of solving the problems of the drinking water field. As far as we're concerned and as far as most of the people here who have discussed the problem are concerned, it seems that the basic objective of the Act is something that we can all agree on; that is, better water for people. As your vice chancellor mentioned yesterday noon, water for people has long needed a boost. But there are some worries in this new legislation for state and local members of the team. In the first place, there seems to be a threat of federal dictation rather than cooperation. I know that the states are always concerned about this, and the utilities are worried, too. Some of those provisions that worry us have to do with the establishment of standards for the design, construction, maintenance, and operation of water utilities. Not only do we feel that such standards can freeze the technology but, as was pointed out this morning by Cecil Rose, we need flexibility; we need to be judged by our performance, by our results, not by how we do things. The required notification procedures have been particularly disturbing to the water supply field. The water suppliers want consumer understanding, but they are afraid that the notification procedures now specified may mislead rather than inform the public in the same way that the cranberry and cyclamate notifications aroused panic rather than understanding.

We think, too, that the fines that are built into the new legislation are not going to build very many water utility facilities and that the extensive reports that apparently gather dust on the shelves are not going to help to get the job done. But the basic worries that both states and utilities have are financial ones concerning the tremendous burden that the requirements of the Act will be putting on both the state for its surveillance program and the utilities for their improvement programs. I think that this worry is perhaps overblown. If we approach this with a positive idea, both the states and the utilities can use these requirements to get what they should have wanted all along; that is, better programs--better programs both in surveillance and in providing water service to people. I feel very strongly, with Dan Okun, that we should not wait for the *free* money from Washington to do these jobs. These accomplishments are what we should be aiming to do ourselves, and I believe that we will find that we can do them at less net cost than waiting for the recycled dollars to come back from Washington. Actually, we not only lose time, the time of getting good service in the interim, but we are also losing in the inflationary rise in cost at the same time.

Some interesting ideas have developed in this discussion, and I would like to mention a few of them. Regionalization was one mentioned by a number of speakers during the two days, and I trust that they were talking not necessarily about physical consolidation of utilities because now that I'm a Denverite, I've seen the 100-mile-apart communities up in the Rockies, and I know that we have no hope of physical connectives out there. But there are opportunities for regionalization of management and engineering, and I hope that we will have an opportunity to overcome some of the political problems that are hampering this movement. In Great Britain, as Dan Okun pointed out, some 1,300 water utilities and even more wastewater operations have now been consolidated into ten water authorities. Such drastic action here would probably set off a second American Revolution. I know I've talked to mayors on a good many occasions, and the minute I mentioned consolidation or regionalization, they turned off their hearing aids.

Quite apart from consolidation, the amalgamation of water and wastewater operations was another point discussed in the symposium. This is a trend that is now going on. At least 50 percent of all water utilities are involved in some kind of consolidation with wastewater operations. One form of such amalgamation was suggested in a recent Oregon bill. This bill would have required that the discharge of a community's sewage treatment plant effluent be upstream of the water supply intake. One of our legislators apparently felt this would solve the problem of treating the upstream neighbor's sewage. Of course, the representatives from Portland, Oregon, which gets its water up at Bull Run Watershed high up in the mountains, were a little dismayed with this and managed to get the bill defeated. This kind of thinking, though, provides a good example of what can go on if we do not keep our eye on some of our legislators.

One good reason why I hope we do not follow the British example too soon, by the way, is that a result of their consolidation that Dan Okun didn't mention last night was the demise of the British Water Works Association, and I'm not quite ready for retirement, yet.

Another idea that was brought up was that of dual water systems and the need to explore the economic feasibility of separate systems for making reused water available for non-potable uses. We, too, would be worried about the cross connections that could follow and create problems, but I would point out that we already have a dual water system. I've been reading the literature about bottled water supply, and I understand from the Deer Park Spring Water ads that tap water is merely for washing whereas Deer Park water is for drinking. Actually, Deer Park is offering *virgin water,* which must mean water used before only by virgins, for all water, we understand has been used before.

Still another new idea expressed was that of providing public water supplies for everyone. I think we have to be a little careful because I am not at all sure that everybody wants public water supply. As a matter of fact, if they had heard our symposium, I'm sure they wouldn't want them. But there are many people who have no option but individual wells, and I think we have to lean toward providing public water supply at least to everyone who wants it. Of course, this can come head-to-head with our idea of keeping water systems self-sufficient. We're going to have to find ways to make these two desires compatible.

A point that I think everyone mentioned is the importance of reuse. Of course, it isn't a new idea, but the fact that we are closing a cycle is something that we have to prepare people for not only physically, but psychologically. It's a point that I know we asked questions about in the Gallup poll that AWWA conducted a year ago, and we were surprised to find out that in the Denver area, where the environmentalists are quite strong, people apparently thought there was some magic to reused water that made it better than fresh water. Perhaps this is a start to getting the psychological acceptance, but I think we in the water industry are still much more interested in feeding our people potable water that comes from a fresh source as long as we can.

Let me very briefly summarize this whole thing by saying, not only do we need to know more--that is, to do more research--but we also need to communicate our knowledge better. We must see that the knowledge gets to the utility people who have to use it to do a better job of supplying water and water service to the public; but also, just as important, that the knowledge gets to the public itself, because it is the public that has to buy these new improvements that has to buy this monitoring that we are going to use when the Safe Drinking Water Act passes. This is the basic message that we have been trying to get through to our congressmen. It is the message that we must get through to our own utility people, too, because they are not doing the job of selling their service to the public. Research first and then, through communication, its application to the job of providing "Better Water for People."

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