National Water Quality Monitoring and Assessment: Report on a Colloquium Sponsored by the Water Science and Technology Board, May 21-22, 1986 (1987)

Pages
119

Size
5 x 9

ISBN
0309320895

Water Science and Technology Board; Commission on Engineering and Technical Systems; Commission on Physical Sciences, Mathematics, and Resources; National Research Council

National Water Quality Monitoring and Assessment

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Colloquium 2 of a Series

Water Science and Technology Board
Commission on Engineering and Technical Systems
Commission on Physical Sciences, Mathematics, and Resources
National Research Council

NATIONAL ACADEMY PRESS
Washington, D.C. 1987

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This report represents work supported by agencies providing general support for activities of the Water Science and Technology Board, including the Bureau of Reclamation, U.S. Environmental Protection Agency, Federal Emergency Management Agency, National Science Foundation, U.S. Department of Energy, and U.S. Geological Survey.

Available from

Water Science and Technology Board
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

Printed in the United States of America

ID #
8-11-87

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PREFACE

The Water Science and Technology Board initiated a colloquium series in 1985 titled "Emerging Issues in Water Science and Technology," designed to focus attention and debate on important issues that need to be addressed by the scientific and engineering community. A report from the first colloquium, "Drought Management and Its Impact on Public Water Systems," was published in April 1985. It was the intent of the second colloquium to consider the need for a national water quality monitoring and assessment program and the major concerns should such a program be developed and implemented.

Seven individuals were selected to present their views on the subject at a meeting of approximately 50 participants in Reston, Virginia, on May 20, 1986. These individuals represented viewpoints not only from federal and state perspectives but from industry and academia as well. The colloquium began with a plenary session at which William C. Ackermann, University of Illinois at Urbana-Champaign, presented the keynote address. Presentations followed by Gerald T. Orlob, University of California-Davis, and Keros Cartwright, Illinois State Geological Survey, who discussed selected technical considerations in data collection and interpretation, involving respectively, surface water and ground water. In addition, several presentations covered the development of a national water quality monitoring and assessment program from the perspective of the USGS (Jacob Rubin), EPA (Lawrence J. Jensen), state government (Victoria J. Tschinkel), and industry (K. C. Bishop). Each of the colloquium attendees was then assigned to one of four separate workshop sessions, i.e., surface water, ground water, monitoring implications, and setting priorities under budget constraints, with

G. Richard Marzolf, Mary P. Anderson, Walter R. Lynn, and Gary Weatherford serving as rapporteurs, respectively. The rapporteurs summarized the discussions from their workshops at a final plenary session.

This report comprises two major sections--an overview and a more lengthy set of background papers by individual authors. A steering committee of Board members prepared the overview based on a review of the background papers and consideration of the presentations and workshop discussions that occurred during the colloquium. The entire report has been read by a group other than the authors, but only the overview has been subjected to the report review criteria established by the NRC's Report Review committee consisting of members of the NAS, NAE, and IOM. The background papers have also been reviewed, to a feasible extent, for factual correctness. However, in order to preserve the individual perspectives encouraged by the steering committee as a part of the colloquium process, the conclusions, recommendations, and findings arrived at in the background papers have not been exposed to the same type of intensive evaluation undergone by the overview.

The Water Science and Technology Board acknowledges the generous contributions of time and knowledge made by all participants in the colloquium; special thanks are due to those who made formal presentations. It is hoped that the discussions that took place and this report of the colloquium will be a useful contribution to the ongoing debate concerning water quality monitoring and assessment. Finally, the Steering Committee wishes to thank the staff of the Water Science and Technology Board, particularly Sheila D. David and Carole B. Carstater, for their valuable assistance in organizing the colloquium.

Steering Committee
Richard S. Engelbrecht, Chairman
James M. Davidson
Leo M. Eisel

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OVERVIEW

Does the nation need to know the quality of its natural waters? Of course it does, and for a variety of reasons. For example, the U.S. Congress has appropriated more than $40 billion over the past 15 years to build and upgrade wastewater treatment plants around the country. As a result of this expenditure it is likely that fewer pollutants (of certain types) are being discharged, but has the quality of our natural waters improved, worsened, or remained the same? Information from a number of specific, goal-oriented surveys and studies carried out by various federal, state, and local agencies, suggest that there has been a general improvement in certain aspects of the quality of surface water receiving treated wastewater effluent. The question remains, however, whether the comprehensiveness and reliability of the past surveys and studies have been adequate. If not, could a coordinated national effort toward water quality monitoring and assessment produce the needed results?

The terms "monitoring" and "assessment" are not synonymous in respect to water quality considerations. For purposes of this colloquium, monitoring refers to the repetitive collection of water quality data for some specific purpose, e.g., compliance and enforcement, or establishment of a management strategy. Assessment, on the other hand, uses monitoring data and other information to make an evaluation or interpretation of the data in terms of ambient conditions, identification of water quality problems, sources of pollutants and their impact, trends and effectiveness of control programs.

Although they were far from unanimous, the participants at the colloquium concluded that a national water quality monitoring and assessment program, in some form and at some level of effort, is warranted in order to improve comprehensiveness and reliability of information for decisionmaking. Among the reasons cited for having such a national program included the need to improve:

- characterization of the general quality of the nation's water resources;
- understanding of water quality trends, specifically changes showing improvement or worsening in conditions;
- understanding of the extent, nature, and causes of water pollution so as to suggest ways of protecting human health and the environment;
- setting of standards and assurance of compliance with regulations;
- development of water quality control technology;
- quality assurance/quality control efforts so as to ensure greater consistency, compatibility, and reliability of data collection;
- data base management and information exchange;
- understanding of aquatic phenomena; and
- predictive capability.

When the need for a national program was discussed, the term "network" was introduced. To some, this implied the establishment of fixed sampling stations around the country and the determination of the same water quality constituents at all sampling stations. Strong resistance was expressed to this approach on the basis that such a uniform national program would not be productive, given the diversity in landscape, land usage, and aquifer properties. Conversely, the thought was expressed that any new initiative in developing a national water quality monitoring and assessment program must take into account regional and even local conditions. For example, the protocol developed for collecting data in a given drainage basin should be designed to address specific ecosystem features and physical characteristics of that basin. Thus, the selection of sampling sites and analyses performed should be area-specific, i.e., should take into account the watershed or aquifer characteristics.

Strong sentiment was expressed by some that any new effort to develop a national water quality monitoring and assessment program should be built upon the current or projected programs designed by the states to fulfill their own needs. In this case, a national program would provide the necessary scientific leadership and coordination, and would aggregate and interpret on a national scale the data collected by the states. Others felt, however, that such a system is now impractical, given the diversity of interests and the current lack of uniformity in effort, capabilities, and commitment among the states. If these deficiencies could be corrected and proper direction or control exerted regarding sampling and analytical procedures (quality assurance/quality control) at the national level, such an approach would be feasible. This type of national effort might best be focused on developing and enhancing state activities in meeting the needs for a national water quality monitoring and assessment program. There was another point of view presented, one which saw the national and state programs as complementing each other and as differing from each other in well-defined ways, e.g. emphasis and scale.

Over the years, much more attention has been given to the quality of our nation's surface water than to that of its ground water. Yet, much remains to be done to improve the reliability of data collection and interpretation of the quality of surface water. Sampling design, sampling methods, analytical procedures (taking into account sensitivity or detection limits) are some of the issues crucial to collecting reliable water quality data. For example, as noted before on page 2, it is recognized that complex aquatic systems often have special sampling requirements. For proper evaluation and interpretation of data, it is important to know (1) where, when, how, and why a water sample was taken, (2) how the sample was handled prior to analysis, and (3) how and when the sample was analyzed. There was general agreement that the chemical and physical properties of surface water is important. The questions remain, however: What chemical and physical properties should be measured? Should the same measurements be made of all surface water? Some believed that measuring the same properties in all surface water was not a useful approach and that, instead, only those chemical and physical properties deemed to be important in characterizing a particular water body, as dictated by regional or local conditions, should be measured. In this sense, it was suggested that more attention should be given to biological variables, such as dissolved oxygen and organic carbon, which respond to biological processes such as photosynthesis and decomposition. These processes are mediated by the metabolic activities of living populations. Likewise, biomonitoring to determine the gross toxicity associated with a water often would be appropriate before attempting to identify and measure specific chemical properties.

The characterization of the sediments of surface water has been largely overlooked to date. The past stresses placed on a surface water can often be determined by examining the sediments of rivers and lakes. Additionally, sediments can serve as sinks for many substances with possible interchange with the water column. It is also essential to gather the usual hydrologic information characterizing the flow of the surface water in assessing its quality.

Concern for the quality of the nation's ground water has been heightened in recent years because of public health considerations. It was generally agreed that, ideally, any assessment of the quality of ground water must be approached in terms of an "aquifer system," which would include identifying its geologic, physical, chemical, and microbial characteristics. There was disagreement as to whether a new initiative to determine the quality of ground water at the national level was needed. Some felt that since human health is the major issue with ground water monitoring, long-term monitoring of trends in important aquifers will occur without a new initiative because of recently enacted regulations under the Safe Drinking Water Act. Moreover, characterization of aquifer systems continues to be a major activity of the U.S. Geological Survey. Also, in areas where ground water is an important resource, there are active state and local monitoring programs. Thus, the view was expressed that the current efforts are sufficient for national assessment purposes. However, some believed that the current efforts are insufficient to give adequate, national-scale information on the quality of ground water. This group believed that increasing drinking water monitoring cannot take the place of studying the quality of aquifer water itself and that there exists a real need for a larger and more organized approach to a national program for ground water quality assessment.

In the case of ground water, some felt that more attention should be given to collecting background water quality data in aquifers not currently experiencing contamination and to determining precursors of contamination. Others felt that a national program either should not or could not define the extent of contamination of aquifers. Thus, a national program should not attempt to target problem areas for study; small-scale, targeted studies might best be accomplished at the local level. There appeared to be a consensus among those present that the design and implementation of any monitoring program of ground water must be flexible and tailored to site-specific conditions.

The quality of surface water and ground water is usually linked. There are differences between ground water and surface water processes, and there are large methodological differences in the monitoring and assessment processes between ground water and surface water. Nevertheless, the physical linkages between ground water and surface water represent a poorly understood area that is very important in understanding how water quality is influenced by nature. Unfortunately, because of a time constraint, the colloquium did not provide an adequate opportunity for discussions on the interrelationship between the quality of ground water and surface water. Linkage between the quality of the two should serve as a focus for research by those involved in implementing monitoring and assessment activities.

It was generally accepted that the planned, repetitive collection of water quality information over a long period of time is usually more valuable than having a record over only a short interval of time. Unfortunately, data collections and interpretation are often vulnerable to any cutback in available funds. Crisis control, not long-term information collection, gets funded when a budget reduction is required. There has been a general lack of understanding among decisionmakers concerning the importance of water quality monitoring and assessment which have often been programmed as supporting elements for "action programs" within other budget categories and often at a reduced level of effort. There are, however, some hopeful signs of a gradual increase in the realization that a well planned, reliable water quality monitoring and assessment program needs to be an integral part of any acceptable water resource management strategy. Whatever the future directions and efforts made by various levels of government, there will be a need for a greater contribution from the private sectors--in funding, in in-kind effort, and in information exchange--if a more comprehensive and useful water quality monitoring and assessment effort is to evolve.

BACKGROUND PAPERS

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OBJECTIVES OF NATIONAL WATER QUALITY MONITORING AND ASSESSMENT
(Keynote Address)

William C. Ackermann
Emeritus Professor of Civil Engineering
University of Illinois

The Water Science and Technology Board has set a mighty task before us, and an important one. And we cannot be accused of undue reticence in accepting this assignment.

This is not the first attempt to specify a water quality monitoring program or make an assessment, nor will it be the last, but this effort may indeed be of critical importance. It comes at a time when this nation has been aroused to the subject for 15 years, has invested billions of dollars in remedial and preventive measures, yet is obviously locked in indecision as to which way to go or how fast.

The National Research Council with its long experience has brought together a manageably small group of experts and interests for optimum interaction. It has provided for considerations of both surface and ground water. It has nicely balanced the interests of the two principal federal agencies--the U.S. Geological Survey and the Environmental Protection Agency--along with the state and industry representatives. Each of us will have an opportunity to contribute to the process under competent rapporteurs before the deliberations are summarized by our chairman.

The role of the keynote speaker is a dirty job, but someone needs to do it. In a rambling and partially structured fashion I will attempt to initiate the process of our mutual discourse. How the NRC and the board plan to neutralize my prejudices, I do not know, but perhaps it is believed that my experiences in federal and state governments, some years in academia, and present private consulting will neutralize itself. With varying levels of confidence I will suggest some boundaries within which we should reach a consensus. Without intruding on the more specific territories of speakers to follow, I will offer certain straw-man beliefs that at best you can adopt and at worst may stimulate a useful discussion.

A planning session for this colloquium held in January was rather generous in its criticism of my outline, and I have tried to incorporate their suggestions. One of those suggestions leads me to believe that I should begin with an attempt to define the closely linked terms of monitoring and assessment. These are not synonymous terms, and we can perform a service by distinguishing between them.

In our context, I would suggest that monitoring consists of analytical measurements of water parameters whose purpose is to characterize water quality, and to ascertain whether these values fall within desired or specified limits. There are many and complex questions of what parameters to consider; how and when and how long to sample, analyze, and report; of priorities; and who will perform these steps.

Assessment follows from monitoring, and consists of making an appraisal, evaluation, or estimate of water quality problems, sources, trends, or program effectiveness from monitoring data and other information.

Monitoring must have a high degree of credibility and acceptance by all interested parties if it is to be useful. Assessment is a more applied and judgmental process. Monitoring and assessment are not necessarily carried out by the same agencies.

That our discussions have a goal and purpose is surely not open to question, but these might be subject to various definitions. I would suggest that we wish to ensure the public health and a healthy ecology and to maximize the sustained values that society derives from its water resources.

The recent EPA report, National Water Quality Inventory, 1984 Report to Congress, states that 73 percent of assessed river miles are supporting designated uses such as fishing, swimming, and the propagation of aquatic life. Some 78 percent of lake areas and 82 percent of estuaries and coastal areas are similarly in support. The most commonly reported pollutant of concern is fecal coliform bacteria. Nutrients, biochemical oxygen demand/dissolved oxygen depletion, and turbidity/total suspended solids are frequent concerns. Toxic pollutants are widely reported, of which metals are the most frequent, followed by pesticides and other organic chemicals. The most commonly reported problem affecting the nation's lakes is eutrophication. Ground water contamination is widely reported from landfills, waste lagoons, underground storage tanks, pesticide applications, septic tanks, and chemical, oil, and brine spills. The ground water assessment has not advanced much beyond having a protection strategy while we gather more facts.

Our perspective would be that of collective expertise and balanced interests that consider multiple users and the circumstances and timeliness of the present.

The elements of the hydrologic cycle with which we are concerned clearly encompass surface streams and lakes and ground water. I assume that this includes estuaries, but does it include brackish and saline ground water, and what about the near-shore ocean waters, and what about wet lands?

Hydrologists are fond of pointing out that our political laws treat surface and ground water as separate, and apply different doctrines, whereas these two kinds of water are at least partially connected. At this colloquium we all are aware of this, but there are separate presentations on surface and ground water. So we need to remind ourselves of the basic hydrology, and that under given circumstances flow can be in either direction. Whichever way the flow takes place, it carries along dissolved pollutants. Thus, a polluted stream can affect the local ground water, and polluted ground water can contaminate a stream.

To what extent does consideration of national water quality monitoring and assessment take into account sources? For many reasons our assessments will need to be able to distinguish between natural and man-made sources, and between point and nonpoint sources, because these affect whether and how some action program might be formulated. Are we concerned with measuring and characterizing acid rain and assessing the effect it has on water quality?

In considering the natural boundaries of our discussion we will need to identify the constituents or pollutants that we will consider. These will surely include organic and inorganic constituents and both dissolved and suspended materials, and in some cases bed-load transport. Other materials will constitute nutrients that can lead to secondary problems, as well as microorganisms and toxic substances. Other pollutants will include radioactive material and heat or elevated temperatures. The list can be very long, and judgments will be required to limit the number to those that tell us the most for the dollar, and therefore, are of highest priority. Some might feel that the measures should include fish and benthic organisms as valuable indicator organisms, but I think the possibility that a handful of broad surrogate indicators or indices will suffice is more an illusion than a possible approach to objective water quality monitoring and assessment.

With regard to current monitoring for possible future assessments, we might consider the desirability of banking some small percentage of samples for the future analysis of constituents that are not currently recognized but might be of future concern.

Before approaching judgments about national water quality monitoring and assessment, we need to remind ourselves of the principal classes of users, whose needs only partially coincide. Legislative bodies at the federal and state levels are concerned with establishing policy and programs and their funding and subsequent overview. They require neat summaries, generalizations, and options. The executive branches need to establish efficient organizations for implementation and must employ the most advanced technology. We must be sensitive to the needs of executive programs of remedial, preventive, or enforcement actions. Municipal and industrial users need to know ambient water quality in considering optional water supply and disposal sites, and their staffs must be able to comprehend the intricacies of water quality parameters. Planners and designers may wish to build upon monitoring information by applying various scenarios of the future and consider risk assessment. Environmental groups range across a broad technological spectrum as they strive to keep the whole system honest, and they are concerned with various concepts of ecosystem management. The research community is also diverse, but is generally concerned with cause and effect and will always want more data than can be produced by any system we can afford. The public is a terribly important user whose understanding and support are crucial. It wants to know whether water quality is getting better or worse, and if there are hazards, such as those from toxic materials. It would love to have a single index like the octane of gasoline, but we cannot devise such a convenience. Finally, a national water quality program of monitoring and assessment needs to consider other nations. These include our neighbors to the north and south with whom we share boundary waters, as well as more distant countries who look to us to lead the way in such matters.

PAST MONITORING AND ASSESSMENTS

Before considering some of the lessons we have learned from past success and failures at monitoring and assessment, we should consider where we stand as this moving train of water quality goes by. I cannot improve upon, and I hope that you can generally accept, a summary of the status quo as viewed by Alvin L. Alm in an address on "Meeting Water Quality Goals" at a Symposium on Options for Reaching Water Quality Goals in Washington, D.C., on August 15, 1984. The following paragraphs are taken from the published proceedings.

> We have succeeded in large part in arresting the degradation of our Nation's surface water, particularly from industrial discharges of conventional pollutants. Since 1972 we have cut industrial discharges of biochemical oxygen demand by 71 percent, of total suspended solids by 80 percent, of dissolved solids by 52 percent, and of heavy metals by 78 percent. This clean-up has been largely through the technology-provisions of the Clean Water Act Amendments of 1972.
>
> Our success in reducing pollution from municipal sewage treatment plants has been less dramatic, although substantial. Since the grants program to support the construction of municipal sewage treatment capacity went into effect, Congress has appropriated more than $40 billion to build and upgrade thousands of treatment plants around the country. The result has been a dramatic decrease in the biochemical oxygen demand, or organic matter, discharged into our streams. Despite a 12 percent increase in the organic load generated over the last decade, the amount discharged from sewage treatment plants has decreased nearly 50 percent. Without the improvements in treatment facilities, the discharge would have increased almost two-fold over this time.
>
> Recent studies confirm our impressions that we have succeeded in reversing the trend of water quality degradation. In 1983, a state survey was conducted by the Association of State and Interstate Water Pollution Control Administrators. The results

> of the Survey indicate that water quality remained the same or improved between 1972 and 1982 despite an increase in population, resource development, and recreational use. An overwhelming 84 percent of the stream miles surveyed maintained the same quality, while only 3 percent were degraded and 13 percent were improved. The results are corroborated by a national fisheries survey conducted by EPA and the U.S. Fish and Wildlife Service in 1982. This survey found that two-thirds of the Nation's waters can support sport fish, and that this capability has not changed measurably in the last 5 years. Overall 91 percent of the sample streams have remained "fishable," while 5 percent have been degraded and 4 percent have improved. In short, by controlling discharges of pollutants, we have made progress in achieving desired water quality.
>
> Despite a number of recent studies, we do not have a very good idea of the overall quality of ground water. There is, however, evidence of increasing contamination of ground water which we actually use. Nearly one-third of the large public drinking water supply systems are detecting man-made chemicals in their ground water supplies and more than 4,000 private or public wells have been closed or affected by contamination. Organic solvents, gasoline, pesticides, and nitrates are among the contaminants.

Of course, more detail is available in each of the several dimensions of time, place, and parameter. But on the other hand, there are numerous contradictions in the data which obscure more than the rather broad generalities.

Those of you who have studied the records of water quality monitoring are acquainted with the numerous frustrations in characterizing water quality and its trends. Generally, the record is too short for either a deterministic or a statistical basis for characterizing the variables. Interruptions of record keeping may be the result of project completion, or more often, the result of changing budget priorities. It seems that networks are particularly vulnerable to the budgetary ax because although they are used by all, they are the direct responsibility of none except the operating agency, which must bear the burden of budgetary defense for all of us. One of the important lessons from the past is to maintain continuity for an adequate time. This usually means a period of 5 or more years without change in the sampling or analytical process. We are dealing with variables that are highly variable in time and space.

During this most recent 15 or more years there has been a considerable sophistication of instrumentation and analytical methods, so that constituents that were once not detectable now can be measured in parts per billion. This too has the result of placing earlier records in question or of shortening the available record. Certainly, no one wishes to stop progress in the sampling or analytical processes, but we all need an arbiter agency whose judgment we trust, and who can decide which data are valid, because that agency has no regulatory program to defend and receives its satisfaction from being the accepted reference.

We recognize that monitoring and assessment involve more than characterizing a highly variable, but natural phenomena. Imposed on that system are accidental and unauthorized discharges that do not respond to any systematic occurrence. This adds a whole dimension of complication as we separate anomalous data that may be very important in tracing an illegal discharge, but are not part of a water quality characterization.

CONSIDERATIONS FOR THE FUTURE

There may be legitimate and lingering doubts on the part of some as to whether we can or should have a national water quality monitoring network. To them I would expose my conviction that we must have such a network, and I will attempt to describe my version of it, which this group will hopefully consider as a first approximation of what it will ultimately adopt.

To begin, one must recognize that a national network cannot be all things to all people. But that does not diminish its importance. Special-purpose measurements will always be made, and they need to be anchored to <u>the</u> national network. Thus, the national monitoring network must serve multiple, but not all special or passing needs. Hot spots that require immediate and intensive measurement will come and go, and they should. No national network can deal with the number and diversity of such problems.

Local and special-purpose monitoring networks on a state, local, or private/industrial scale are to be expected--in fact encouraged. Hopefully, this arrangement will permit greater detail and flexibility where warranted and desired, but we should make a strong case for uniform standards and procedures through the national network.

The national network must set the standards for field and analytical procedures, it must be promptly and widely available, its data must be of the highest quality and set the standards for any ancillary programs of measurement.

To contrive an analogy with the condition of our whole bodies, I think of the national monitoring as comparable to a physician taking our temperature and blood pressure. A local contamination is like a boil on the back of one's neck, and is dealt with by local treatment. It is only when such a local problem spreads that the broader indicators come into consideration.

The national network will contain the hydrologic elements of surface and ground water, and perhaps those less obvious elements such as estuaries, wetlands, and near-shore ocean waters as joint wisdom decides. The parameters to be included will be an elaboration of the general physical and chemical measures mentioned earlier. Again, there will need to be decisions regarding biological and other measures, which are important to some.

The national water quality monitoring network will report upon an important part of the environment, but it will not reflect the entire environment. Thought must be given to agreeing upon hydrologic and parametric measures, which can be necessary links with the atmosphere, the land, and the oceans for those studies that trace constituents from sources to ultimate sinks in the oceans or elsewhere.

Surface water measurements including lakes and estuaries should be built upon the framework of the stream system. Ground water should be organized to define and characterize aquifers, whether shallow or deep, local or extensive.

I am not sure that the organizers of this colloquium in asking me to speak of objectives had any desire that I talk about who will run the monitoring program, but I think it is as important a question as any; so I will speak briefly to the subject. A national network should be run by a single federal agency with the advice of the

NRC, major user agencies, and perhaps other advisory mechanisms. This does not foreclose limited partnerships and subcontracting or cost sharing. But I would not agree that the national monitoring network is a candidate for the currently popular shift to privatization.

Once the job has been defined by this meeting and others to follow, the job should not be turned over to a committee to run. I have had a lot of experience with committees.

I would particularly caution against attempting to build some regional dimension into the system--such as New England, or the Great Lakes region, or the Missouri River watershed. We have been notably unsuccessful on this scale, with the exception of the Tennessee Valley, and we do not have in place a national division of regional water areas. Let the states be the division of choice for any decentralization of the national effort. The technical and political entities are in place, and although they are highly variable, it has been demonstrated that the states can carry out national programs in a uniform manner when provided with clear guidelines.

Thus we would have national priorities, national standards, and a product of uniform quality and reliability. This would not prevent additional monitoring in limited areas or for special purposes when it is needed and can be supported.

Where does the process of creating a national water quality monitoring network begin? It can begin right here with an assessment of the needs of the many user types, and fortunately many of these needs are similar. It is also fortunate that water quality is already being monitored at many places and in acceptable fashion. From this ongoing effort must be fashioned an initial national network.

If anyone is still with me in body and in spirit, I would erect one more straw man for you to consider, embrace, or disown. The proposition is that once the national network is created out of existing stations and newly justified stations, that it not be altered for an agreed period on the order of 5 years. This will create the stability for internal analysis and for comparisons with subsequent periods.

There is a final postscript. No measurement of water quality should be made in the absence of quantity measurements, so that loads as well as concentrations can be computed.

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TECHNICAL CONSIDERATIONS IN DATA COLLECTION AND INTERPRETATION--SURFACE WATER QUALITY

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OBJECTIVES OF AN ASSESSMENT

Rapid advances in our technological society, steady growth in population, heightened awareness of the changing quality of our environment, and an appreciation that water is, in fact, a limited resource--all these factors contribute to a need to know where we are now in the quality of our nation's water supplies. We need this "state" of the system as a benchmark for determining how seriously we have been affected or have benefitted by changes in water pollution control priorities and for estimating where we expect to be in the future.

An assessment, a determination of the present state of the system, is needed to determine the degree of degradation or enhancement, which in turn must be referenced to a "background," the state at some prior time. Only with such information can we determine whether we have met targets set earlier in our quest for "clean water," or have failed to comply with standards and criteria for acceptable water quality. By comparison of today's state with that of yesterday, we can establish trends that if extrapolated into the future (with some reliable predictive tools) may tell us something of the risks we run for noncompliance with earlier targets. In turn, this may help us to identify areas of needed research and to establish reasonable funding priorities. At the very least, it will help those of us who are specifically concerned about increased stresses on the aquatic environment, to argue quantitatively, rather than with mere rhetoric, for the funding needed to protect and enhance water quality.

In this paper we will examine a few of the purely technical considerations in carrying out a national assessment, related primarily to the collection of water quality data and its interpretation. We will confine our examination to the quality of surface water.

QUALITY ASSURANCE/QUALITY CONTROL

By "quality" we mean here the reliability of a single observation in terms of the analytical technique used, the monitoring procedure, and the reproducibility of the result.

It is axiomatic that as the complexity of the quality dimension of surface water increases, so also must our analytical capabilities rise to meet the challenge. Unfortunately, it often appears that we may be losing ground in certain areas, notably in rapid and accurate detection of some of the more exotic toxicants that are known to be discharged into the surface water of our country. With increasing frequency we now find we are challenging the "lower detectable" limits for some species.

Examples of difficult-to-detect substances are the polychlorinated biphenyls (PCBs), biodegradable compounds that unfortunately are nearly ubiquitous in the large river systems serving as water supplies for the eastern and central United States, as well as many regions of the western United States. We find from recent experience that even though PCBs may be bioconcentrated to detectable levels in the living tissues of animals inhabiting aquatic environments, they may not be detected in the overlying water, except by the most heroic methods of physical-chemical extraction. Not only are laboratory concentration techniques for PCBs uncertain in validity and reproducibility, but they are costly and time consuming, attributes that do not commend such procedures for routine use. In the case of an accidental spill of PCBs in a Sierra Nevada reservoir in California it was necessary to use surrogate measures of water quality, e.g., turbidity, to signal potential transport of PCBs on suspended sediment, even though two alternative analytical methods showed no evidence of these substances in downstream flows (Orlob et al., 1986).

Occasionally we find that standards for toxic substances are below detectable limits, or at levels where the uncertainty in analytical technique is of the same order as the standard itself. In such cases we may question the reasonableness of a standard since a means of determining compliance, i.e., a reliable analytical method, is lacking. It seems that standards and detectability must go hand in hand.

The quality of an individual observation of surface water quality can only be assessed against a sampling set sufficient in size to include all information pertinent to the assessment objective. Are we interested in single values, means, trends, extreme values, or transient events? Each of these requires successively larger sample sets for results to be meaningful, at least in statistical terms. While a few random individual water quality samples may provide some useful information of the "yes-no" type, they are virtually without value in a comprehensive assessment unless they can be related to a natural background.

What exactly is natural "background"? For our purposes with substances completely foreign to the aquatic environment, e.g., many man-made toxics, the natural background is zero. In the case of naturally occurring substances like dissolved oxygen, background may be that which can be expected in the complete absence of a causative effect being monitored, e.g., a wastewater discharge. Background may be described in terms of mean values, trends, and extremal values, but may also have to be separated into deterministic (phenomenologically explainable) and stochastic (random) parts. The stochastic part may include both the uncertain responses of nature, the extreme occurrences that are expected at some frequency, and the "noise" of observation, which is identified with errors of observation, sampling, and analytical techniques.

Continuous monitoring systems, although limited in the number of parameters that can be observed, may provide the information needed for a complete statistical analysis. The most popular of these is the continuous EC recorder, which provides information directly relatable to agricultural water use, but also may serve as a surrogate for dissolved mineral species by correlation, usually in a simple linear relationship. Records derived in this manner serve also as baselines for assessment of intermittant monitoring programs for other water quality parameters, not susceptible to continuous observation or for which laboratory analysis is too costly.

An illustration of the use of the continuous EC record is found in the construction of a 55-year record of salinity (TDS) in the San Joaquin River near Vernalis, at the lower limit of San Joaquin Valley in California (Figure 2-1). The U.S. Bureau of Reclamation, in cooperation with the U.S. Geological Survey and the State of California, has maintained a water quality monitoring station at this location since about 1953. In the early years, through about 1973, complete chemical analyses of grab samples, collected as often as weekly, were performed. Subsequently a nearly continuous EC record has been obtained, reduced in the office to mean daily and maximum and minimum values. The record prior to 1953 is spotty, consisting of occasional grab sample observations of selected parameters, usually chlorides, TDS (by gravimetric methods), and EC. At a location about 18 miles downstream near Mossdale, within the influence of ocean-generated tides, the State of California monitored chloride concentrations at high slack water at intervals of 4 days, almost without interruption from 1929 to 1973. With these fragmentary records we may be able to develop a complete record of monthly water quality from 1930 to the present.

To construct the long-term record at Vernalis of monthly average TDS, partial records of EC, TDS, and chlorides at the two stations were utilized. First, a correlation was made between TDS at Vernalis and chlorides at Mossdale using the common period of record, 1953 to 1973. Then the missing TDS record at Vernalis for the period 1930 through 1952 was constructed from the 4-day chloride record at Mossdale. Finally, the TDS record was extended to 1982 at Vernalis using a TDS:EC correlation and the USBR's continuous EC record. The result is a continuous record of mean monthly water quality (TDS) at Vernalis for the period 1930 through 1984 as shown in Figure 2-2. It can be utilized as a baseline for evaluation of water quality changes that have occurred in the San Joaquin Valley during a period of intensive development for irrigated agriculture and for comparative evaluation of future strategies for water quality control.

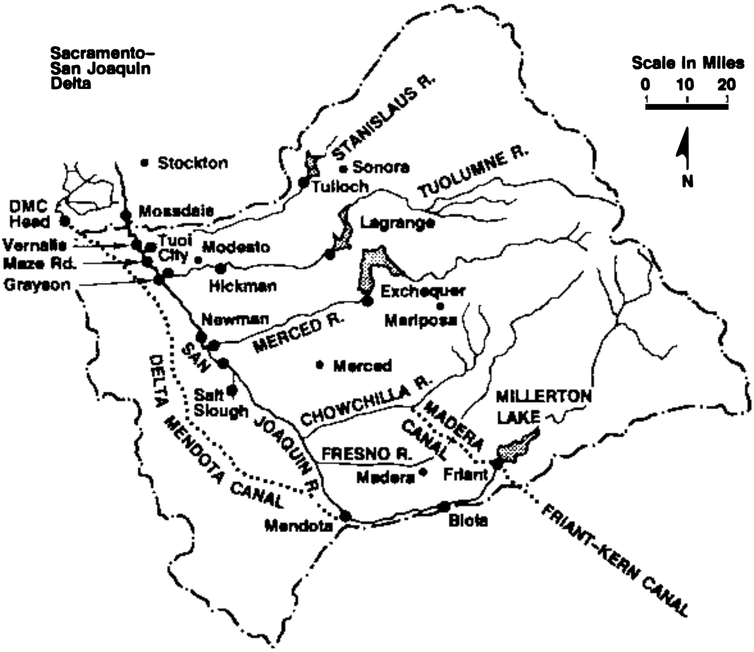

FIGURE 2.1 San Joaquin Basin in California with locations of water quality monitoring stations indicated.

SOURCE: Orlob and Ghorbanzadeh (1981).

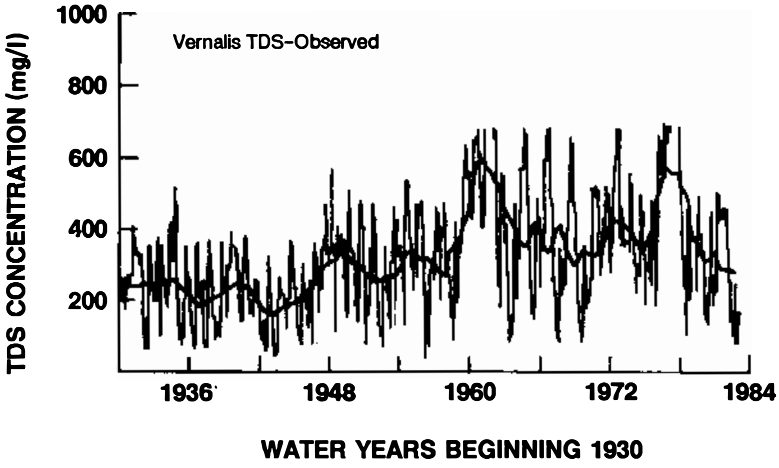

FIGURE 2.2 Total dissolved solids, San Joaquin River at Vernalis, 1930-1984.

SOURCE: Data from Department of Water Resources, California and U.S. Bureau of Reclamation, Mid-Pacific Region.

DESIGN OF SAMPLING NETWORKS

As illustrated by the previous example, monitoring locations are invariably relocated from time to time, as priorities and budgets change and as specific problems develop. Stations are dropped, relocated, and changed in sampling frequency and type of analysis, and/or new stations are added and techniques updated. The monitoring network of the past is seldom optimal for the present. While change is desirable in many instances, it is regrettable that continuity of record is often sacrificed. An intermittant record of long duration is usually more valuable than a short continuous record.

The "near-optimal" monitoring network is here defined as that which yields the longest continuous and consistent water quality record, while revealing the details of quality changes in time and space necessary for control decisions. Location of sampling (monitoring) stations should be predicated upon accessibility, proximity to locations where major water quality changes may be expected, e.g., stream confluences and wastewater outfalls, proximity to stage-discharge recorders, and distance to laboratory or data receivers (in the case of remote transmitters). The density of the network, a prime cost consideration, must be selected to reveal critical gradients, "sag" points, the potential passage of transients, and the possible violation of water quality standards. When grab sampling is the only available method, the network may have to be structured to conform with the mode of transportation and permissable delays between field and laboratory. A rough estimate is that a two-person crew operating from an automobile can cover a 150-mile circuit in one day, sampling 10 stations, with two field observations (pH and EC) each.

When the network is sparse and the records discontinuous, it is possible in certain cases to synthesize needed information by interstation and interconstituent correlations. This approach is illustrated for the case of a proposed diversion to California's North Bay Aqueduct, as shown in Figure 2-3. Here interstation correlations were made by a series of "synoptic" EC and chloride surveys, with sufficient spatial coverage to encompass existing stations with partial records (both continuous EC and periodic complete chemical analysis) and the proposed diversion location for which only minimal data were available. A water

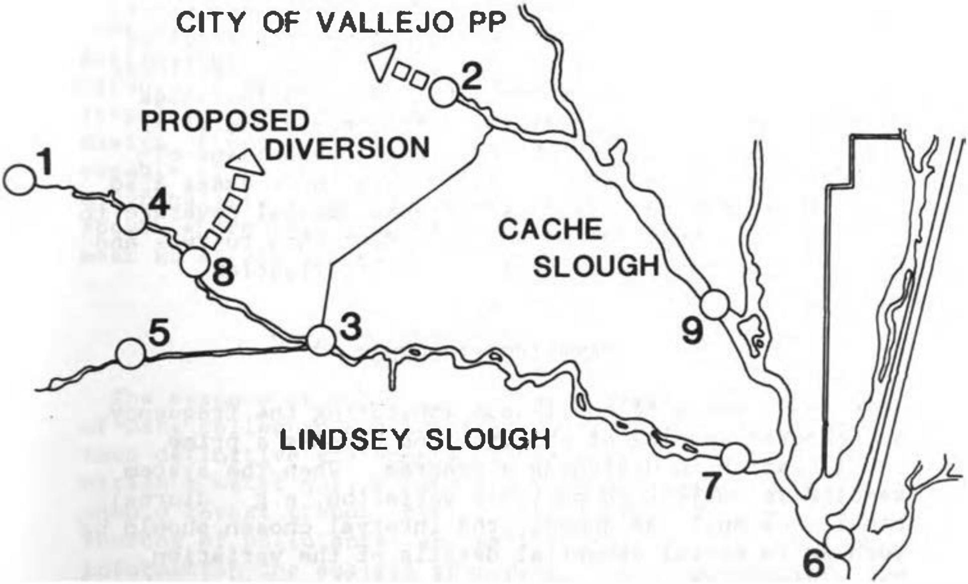

FIGURE 2.3 North Bay Aqueduct diversion location and water quality sampling locations.

SOURCE: Orlob and Marjanovic (1986).

quality "vector" for the diversion location was developed by correlating the principal mineral constituents with EC in power functions of the form

$$C = K(EC)^n,$$

where C is the constituent in question, and K and n are empirical constants. Finally, extremal values of quality constituents (EC, TDS, Cl^-, TH, Na^+, Ca^{++}, Mg^{++}, $SO_4^=$, and HCO_3^-) needed for water treatment plant design were developed from the statistics of the EC record at the present diversion location (Orlob and Marjanovic, 1986).

While the statistical approach described above proved satisfactory for the relatively small spatial scale of this problem, it may be unsuitable for highly nonlinear systems, e.g., estuarial networks. In such instances mathematical models describing hydrodynamic and water quality behavior may be the only reasonable means of extending the data base spatially. In these cases also it is necessary to provide additional spatial coverage in the monitoring network, i.e., extending them to two- and three-dimensional water quality characterization.

SAMPLING FREQUENCY

In the absence of continuous monitoring the frequency or temporal spacing of observations becomes a prime consideration in designing a program. When the system sampled is subject to periodic variation, e.g., diurnal, tidal, seasonal, or annual, the interval chosen should be such as to reveal essential details of the variation. For a sinusoidal curve no less than 6 observations should be made, preferably at least 10. Thus, a typical 12.5-hour tidal excursion in an estuary may require observations about every hour or so, while for a seasonally varying agricultural drain a semimonthly sampling may be sufficient. For transient events, sampling frequencies must be tailored to the event, minutes to hours for urban runoff, hours to days for natural watersheds, and days to weeks for snow and ice melt runoff. To provide adequate special detail in water bodies like estuaries and reservoirs, it is usually necessary to provide for observations at various depths at each monitoring location.

To capture extreme quality episodes the problem is treated either as a transient case of predictable occurrence or as a random event of unknown frequency. The transient is treated in the usual way with a sampling interval small enough to describe the detail around the extreme value. The random event is identified explicitly with the sampling interval, as the average over the interval. If the instantaneous peak is desired, the interval must approach zero as a limit, i.e., a continuous record. Neither finite random sampling nor periodic sampling at finite intervals is capable of revealing absolute extremes of water quality.

As a practical matter, absolute extremes may not be as useful as statistical distributions of discrete observations that may provide most of the information desired for estimating risk and uncertainty. For example, frequency analysis of mean quality for various stipulated intervals provides a practical basis for design of water treatment facilities, which must be capable of surviving peak load events. Figure 2-4 shows a typical result for the North Bay Aqueduct case noted above, where the probability of exceedance is related to mean EC at various durations.

DATA ANALYSIS AND INTERPRETATION

The essence of water quality assessment is in analysis of data collected and translation of this information into definitive statements of where we are with the nation's water quality and where we are going. Analysis should reveal trends, cyclic variations, transients, sources of pollutants, and extreme values. From this information the analyst should be able to assess the adequacy of the data base, project the need for new data or for streamlining the monitoring program, and estimate the risk to the users of water.

To aid in analysis and interpretation of water quality data, we now enjoy the considerable advantages of the computer and the many new techniques it provides. For statistical analysis, estimation of means, variance, skewness and confidence limits, and regression, correlation, and hypothesis testing of masses of discrete data, there are a number of standard packages available, many of them built into the computer. For data storage and retrieval on a national scale we have access to EPA's STORET and USGS's WATSTOR, plus some analysis routines

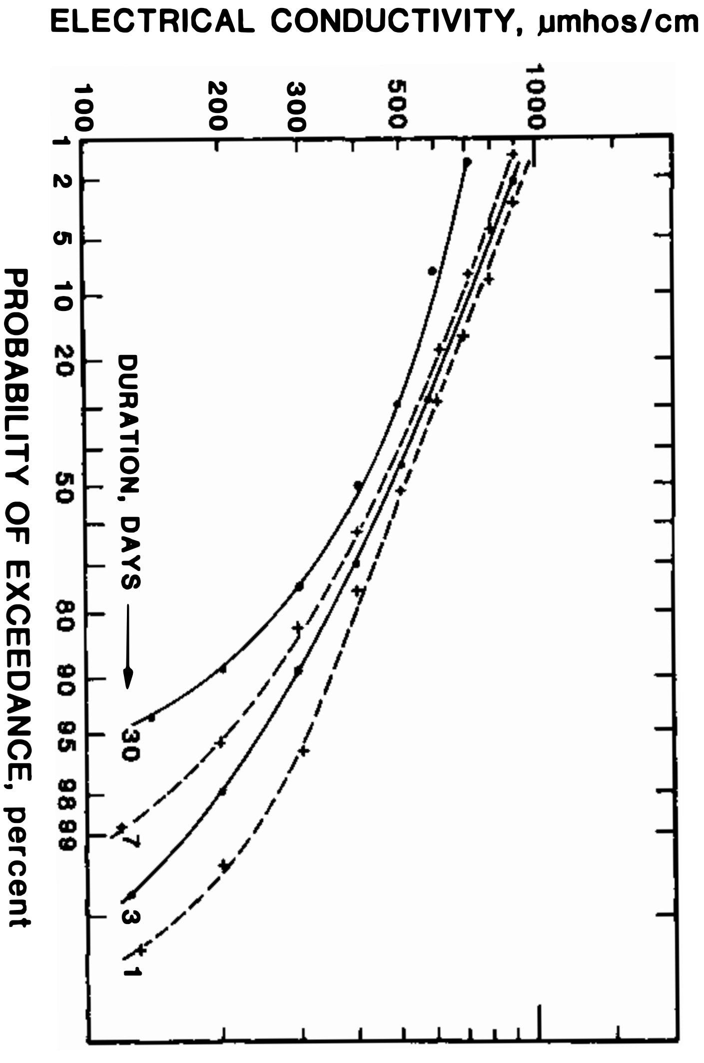

FIGURE 2.4 Probability of EC exceedance at various durations, North Bay Aqueduct Diversion.

SOURCE: Orlob and Marjanovic (1986).

that are inherent in these systems. While this will no doubt be of considerable value in the assessment process, since it already contains data useful for comparison purposes, it will have to be supplemented by some emerging techniques. Among these the most prominent are risk/reliability assessment, interactive use of the computer, and expert systems.

Risk/reliability assessment requires consideration of the variance in water quality induced by a combination of natural influences and man-made effects, with the primary focus on extreme values. Natural responses, as well as causative parameters, are characterized statistically as distribution functions, allowing statements concerning the frequency of exceedance of a target value. The approach is susceptible to mathematical modeling as a means of evaluating future scenarios, or for comparing alternative control strategies.

An example is presented in Figure 2-5, which shows the simulated distribution of coliform bacteria along a Southern California shoreline, resulting from a hypothetical discharge of untreated wastewater through an ocean outfall. The model "response" was developed by Monte Carlo simulation in which selected parameters in the model (density structure, current speed, direction, and so on) were treated as normally distributed variables as indicated from field observations. These distributions were then sampled randomly to form a representative set of explicit problems, say 100 or more, each of which was simulated with the model to give characteristic distributions of shoreline contamination. These were then combined arithmetically at the 80 percentile level to provide the composite distribution shown. This distribution can be compared with the California Water Contact Sports Standards, which stipulates a maximum 80 percentile MPN of 1000.

Interactive computer graphic methods draw heavily on data bases like STORET for information needed to run imbedded water quality models for simulation of alternative water pollution control strategies. These techniques, as developed by Loucks and French (1980) at Cornell University, for example, allow a resource manager/decisionmaker to examine alternatives visually, change boundary conditions at will, and see immediately the consequences of his actions. Loucks and his colleagues have successfully demonstrated the use of EPA's water quality model QUAL II in an interactive mode

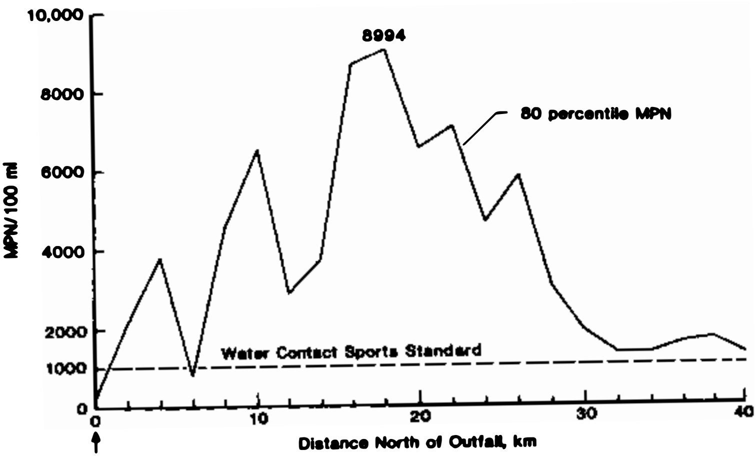

FIGURE 2.5 Distribution of coliforms along shoreline north of outfall, untreated wastewater discharge.

SOURCE: Unpublished simulation results by writer.

and are currently extending the technique for general use in water resource management.

An expert system is founded on a unique body of "hard" data stored in a computer and the logic to interrogate it for the solution of problems, usually with the aid of mathematical models. The data base presumably represents all current knowledge of the real world system--in our case, surface water quality for a particular river or estuary--and can be supplemented as new knowledge is acquired. The interrogation logic consists of software, e.g., models and statistical routines, that can be called for application by the problem solver. A potential exists for development of expert systems for water quality management, although, as yet, research effort in this area has been minimal.

FUTURE DIRECTIONS

Review of the present status of quality monitoring of the nation's surface water suggests the following tentative conclusions.

1. A national water quality assessment can serve to establish a background for determining accomplishments in water pollution control and for evaluating strategies for the future.
2. The current monitoring network provides valuable information for the assessment, but it needs critical examination to determine its adequacy to represent spatial and temporal variations in surface water quality.
3. Analytical methods have generally improved in recent years, but in some cases limits of detection may not be adequate to identify concentrations of toxic substances at levels known to be critical for bioaccumulation in the aquatic food chain.
4. Continuous monitoring of water quality is routinely practiced for only a few parameters, e.g., EC, pH, and temperature, but such records are valuable for the details they provide of extreme values and may serve as surrogates, by correlation analysis, for other constituents of interest.
5. Statistical analysis of water quality data, particularly of longer continuous records, can provide useful information on trends, cycles, transient events, and extreme values that is essential for establishing base lines for assessment of water quality control

alternatives. Standard statistical packages are generally available and can be easily applied with existing computer capabilities.

6. Water quality data management systems like STORET and WATSTOR provide essential foundations for water quality assessment, although it appears that they have not been as widely accepted as originally anticipated by their developers. To realize full potentials, such systems will need to be augmented with some new techniques like those of risk/reliability assessment and interactive use of computer in management decisionmaking. A potential exists for development of expert systems for water quality management.

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3

SELECTED TECHNICAL CONSIDERATIONS FOR DATA COLLECTION AND INTERPRETATION--GROUND WATER

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INTRODUCTION

The monitoring of ground water requires the extraction of a sample of fluid from the earth and the analysis of that sample for its chemical components. The method of sampling and type of chemical analysis will vary depending upon the physical characteristics of the aquifer, the chemical composition of the fluid sample, and the purpose for which the sample was extracted.

Within the last decade, methods of extracting samples from geologic media have come under increasing scrutiny, and the subject appears with increasing frequency in the scientific literature. The need for ever-increasing care in sample extraction is, in part, driven by the ever-increasing precision and accuracy of chemical analysis of fluid samples. In reviewing the potential for error in determining accurately what is in the ground, the potential error from the extraction procedure appears to far exceed that in the analytical procedures, while having far less (if any) quality control/quality assurance procedures.

The purposes for sampling ground water quality are little discussed in the scientific literature, and the regulatory and popular literature leave some confusion when seen from the scientific point of view. Not only does the purpose of sampling influence the sampling and analytical methodology, it also governs the sampling pattern or grid, depth, and number of wells required to obtain the needed data.

Finally, the data need to be stored in such a way that they will serve the intended purpose. Hopefully, the method of data storage and retrieval will also make the data usable for many other needs and for future studies. All too often, well-meaning persons accumulate large amounts of data only to find that data management was an afterthought limiting the usefulness of the data.

MONITORING WATER QUALITY

Ground water monitoring is a massive undertaking, and the goals must be clearly defined to meet any reasonable objective. We are convinced that a true, statistically valid, national ambient water quality network is beyond the financial resources that could reasonably be expended. There are a multitude of reasons for monitoring. The following is a partial list.

1. To assess the background or "ambient" water quality in the aquifers (i.e., what is the natural water quality?).
2. To assess the present status of water quality in the aquifers.
3. To determine, by detection monitoring, the suitability of the water for the present use (e.g., public drinking water, irrigation, and industrial processing).
4. To predict future ground water quality trends.
5. To establish, by special-purpose monitoring, the impacts of certain facilities, practices, or natural phenomena on local water quality.
6. To determine the origin, age, and evolution of ground water (i.e., research purposes).
7. To perform cosmetic monitoring (i.e., the appearance that something is being done).

Special-purpose monitoring can take on many forms and can be for a multitude of purposes. Much of the special-purpose monitoring is associated with determining the local impact on water quality of waste handling facilities, industrial sites, agricultural practices, and so on. The majority of ground water monitoring in the United States seems to be special purpose, and provides a very biased sample of national ground water quality and trends.

Research sampling of fluids in the earth is another form of special-purpose sampling. Frequently, research sampling also samples points of opportunity that provide insight into basic scientific principles and the evolution of the earth.

While most monitoring does not openly assert that it is simply cosmetic, all too frequently we find this to be the underlying purpose of some monitoring systems. Also, monitoring systems installed without sufficient geologic and hydrologic data may not serve the purpose intended and thus be cosmetic.

The discussion in this paper is not directed toward the latter three monitoring goals, but rather the first four.

TYPE OF MONITORING

The type of monitoring will obviously be dependent upon the purpose of monitoring. The first concern is with the scale of monitoring, which can range from very local (similar to special-purpose monitoring) to a national ambient water quality network. Regional and national networks probably are not possible in some localities. Detailed knowledge of both the regional geology and hydrology, and the monitoring site geology and hydrology are required.

It should be relatively easy to design an ambient or assessment water quality network for large, regionally extensive aquifers, provided the aquifer is not significantly perturbed by man's activities (e.g., overpumping or local contamination). These aquifers are characterized by relatively uniform physical properties, generally not complex geology, and long regional ground water flow systems. These aquifers are also relatively deep with limited local topographic control on the ground water flow system.

Near-surface aquifers, however, tend to have ground water flow systems controlled by local topographic relief. These aquifers will be broken into many segments distinguished by different ground water flow paths, each with potentially different water quality. However, certain distinguishing characteristics of water quality may result from the rock type of the aquifer.

In addition, in geologically complex aquifers such as alluvial or glacial systems permeable aquifer materials are often discontinuous, breaking the aquifer into many subaquifers, each with its own potentially different water quality. Add to this the fact that most such systems are relatively shallow, and, in turn, the ground water flow within each subaquifer may be broken into many segmented flow systems.

The monitoring of public water supply, industrial, and irrigation wells may be an expedient method of monitoring water quality. This will provide data on the quality of water in use with limited concern about the nature of the geologic and hydrologic discontinuities within the aquifer. However, this method will provide few data, if any, for the prediction of future water quality trends.

Likewise, it also presents a bias in the data to water in use. This bias may skew the data toward high-quality water if the water used is extracted from points within the aquifer with above-average water quality. The bias may also skew data toward lower quality water if the area where extraction occurs is contaminated by man's surface activities or altered by overpumping (the very reason water is needed at that point).

Finally, we can monitor regions that have been identified as "regions of concern." We do not propose that the region of concern should simply be the areas of major ground water extraction or areas of major concentration of man's activities, although this could be one approach. This will not provide the maximum efficiency of monitoring for the available fiscal resources. Our approach requires the integration of regional geologic and hydrologic studies to define the aquifers, their physical properties, their ground water flow regimes, and the regions where the aquifers may be susceptible to pollution from commercial, industrial, or agricultural activities. Based on this type of information we should be able to design a water quality network that will provide data on the existing water quality in the aquifer and changing water quality that may pose a threat to public health in the future.

The basic question that must be answered in designing a water quality network is: (1) do we want to determine the quality of water currently in use to assure public health (or whatever the use of the water); or (2) do we want to be able to predict future water quality changes prior to their affecting existing water users; or (3) do we want to assess the quality of available ground water; or (4) do we want to protect ground water from future contamination? These goals are by no means mutually exclusive, but the primary purpose must be established.

GROUND WATER MONITORING APPROACHES

Any consciously designed approach to ground water monitoring must be consistent and compatible with the objective(s) of the monitoring program. Clearly regional ambient ground water quality monitoring should be approached differently than, for example, monitoring ground water quality for site-specific RCRA compliance. Although, in either case, the design of a ground water monitoring network is an optimization problem in both space and time. Conceptually, the objective is to maximize the utility of the information provided by the monitoring program given a set of financial and manpower constraints. Consequently, the importance of an in-depth understanding of the goals of the monitoring program, in relation to network design, cannot be overstated. Care must be taken to ensure that the resulting data have meaning with regard to the monitoring program objectives.

Ground water quality monitoring requires that fluid from the geologic formation(s) of interest be analyzed by some technique. However, the analyses to be conducted will vary with the purpose of the monitoring program. Disregarding surface and near-surface geophysical techniques and emerging downhole instrumentation technologies, accepted practice is to remove fluid from the formation, via a well, with subsequent laboratory analysis of the sample. This approach results in a set of point data that (depending on the type of well construction, the sampling mechanism, laboratory procedure, and hydrodynamics of the ground water system) represent, to some degree, certain aspects of the in-situ water quality at a specific point in time. Much recent research (e.g., Gibb et al., 1981; Gillham et al., 1983; Keith et al., 1983; Nacht, 1983; Barcelona et al., 1984; Olea, 1984; Barcelona et al., 1985a) has focused on improving this process (i.e., providing greater quality control and quality assurance).

In general, the larger the data set (both temporally and spatially), the greater the confidence in any inference(s) made from the data. However, the size of the data set, especially for regional ground water quality monitoring, is limited by economic considerations and the availability of excess laboratory capacity. Therefore, two important considerations for the design of large-scale ground water quality monitoring programs are obviously the number and locations of sampling wells and the frequency of sampling.

Existing Wells Versus Specially Constructed Wells

Fundamentally, there are three approaches to the spatial location for ground water sampling:

1. Existing wells.
2. Newly constructed monitoring wells.
3. Some combination of existing and newly constructed monitoring wells.

Ambient ground water quality monitoring is often based on routine sampling from a network of existing wells. Using existing wells can reduce the overall cost of the ground water quality assessment program. However, there are liabilities associated with their use. In particular, sample collection procedures are often considerably different from those for specially constructed monitoring wells (Barcelona et al., 1983). Newly installed wells, optimally designed and constructed for a specific ground water quality assessment, offer much greater quality control and quality assurance than existing wells.

If existing wells are to be used, experience suggests that municipal and industrial wells are, in general, better suited for ground water quality determinations than are private domestic wells. Municipal and industrial wells are typically constructed and documented with greater adherence to quality control procedures than are private domestic wells. Municipal and industrial wells also tend to be better maintained than private wells. Certain criteria should be met, however, before a monitoring program can be reliably based on existing wells.

Details of construction of individual wells should be available and verifiable. The drilling log of each well should also be available and complete. The drilling log should contain information regarding the texture, color, size, and hardness of the geologic materials encountered during the drilling (Barcelona et al., 1985a). Any use of drilling fluids, grouts, and seals should also be noted in the record of well construction. Well casing materials should be documented. The type of well casing may have an effect on the quality of the collected water samples (Barcelona et al., 1983). The same considerations regarding well casing materials for newly constructed monitoring wells apply to the evaluation of the suitability of existing wells for ground water quality monitoring. Finally, if the monitoring program is to be based on existing wells, physical access to the wells for sample collection must be guaranteed.

Although a greater capital cost is involved, specially constructed ground water quality monitoring wells offer several advantages over reliance on existing wells. Strict adherence to quality control procedures for monitoring well design and construction can be assured for newly installed wells. Well construction materials can be selected for compatibility with the chemical constituents to be investigated. Barcelona et al. (1983) prepared a guide to the selection of materials for monitoring well construction as well as ground water sampling apparatus. Among other topics, this reference addresses such considerations as well location, well diameter, well depth, construction materials, drilling methods, and approaches to well development. Monitoring well design should be reflective of the objectives of the ground water monitoring program. Construction procedures should be thoroughly documented, including preparation of a drilling log and a well construction diagram (Barcelona et al., 1985a).

Monitoring Network Design

The assessment of ground water quality, at any spatial scale, involves the estimation of chemical variables distributed in three-dimensional space. A key consideration in establishing an effective, as well as efficient, ground water quality monitoring program is the spatial distribution of sampling locations. Care must be taken in designing monitoring well networks to avoid biasing any inferences made from the resulting data. For example, if the basic goal of the monitoring program is for a regional ambient ground water quality assessment, locating all sampling points immediately adjacent to waste disposal facilities may unnecessarily bias the results. Once again the importance of clear understanding of the objectives of the monitoring program cannot be overemphasized.

Knowledge of the hydrodynamics of the ground water system(s) being monitored is also of critical importance for the design of monitoring networks. For certain ground water monitoring program objectives an optimum monitoring network for a relatively homogeneous porous flow environment would look very different from an optimum network for a discretely fractured hydrogeologic medium. However, for other monitoring objectives (especially those involving a large regional scale) the fundamental differences between flow regimes may have very little impact on the design of an optimum sampling network.

Wood et al. (1984) discuss the basic data necessary for ground water monitoring design. The data requirements include information on surficial geology, bedrock geology, and the hydrodynamics of the ground water flow system(s) being monitored. Geologic and hydrologic information, coupled with a clear understanding of the objectives of the monitoring program, provides the basis for delimiting, in three dimensions, the ground water flow system to be monitored. The initial selection of the areal locations for monitoring wells (whether newly installed or existing) should be based on a screening of preexisting hydrogeologic data. However, in the case of newly constructed monitoring wells, additional hydrogeologic data will become available with the installation of each well. Therefore, the well site selection process should proceed in an evolutionary fashion, incorporating new data into the location selection process as the network is developed.

The selection of the areal locations of monitoring wells does not proceed independently from the determination of the depth of the wells and their screened interval. The depth of well screen placement and the screened interval are important considerations in the design of a ground water quality monitoring network. Once again, decisions regarding the vertical aspects of monitoring location selection must be based on the goals of the monitoring program and the best available hydrologic and geologic data. The larger the screened interval, the more vertically integrated will be the resultant water quality determinations. In some cases, such as regional, ambient ground water quality monitoring, a vertically integrated assessment may be the goal. However, for other monitoring purposes (e.g., contaminant plume delineation) nested monitoring wells with very short screened intervals may be required to meet the objectives of the program. These considerations apply equally to newly constructed monitoring wells and existing wells.

Monitoring networks should be designed so as to achieve the highest sampling efficiency practically possible. Sampling efficiency can be loosely defined as some measure of the ability of a particular network design to characterize a spatially continuous phenomenon from discrete point measurements. The two most important spatial factors related to sampling efficiency are sampling pattern and sampling density. Optimum sampling pattern and sampling density are largely a function of the intended scale of the monitoring program (which relates to the goals of the program) and the degree of spatial variability of the geologic formation(s) being sampled.

Sampling Pattern

Sampling pattern is the geometrical configuration of discrete sample locations in space (assuming reasonably uniform geology of the aquifers). The pattern of sampling can have a significant effect on the reliability of any inference(s) made from the analytical results of the monitoring program. Olea (1984) has investigated the impacts of sampling patterns on the efficiency of monitoring network designs. Fourteen patterns grouped into seven categories were the basis of comparison. The selected patterns were various types of regular and clustered patterns, and a random sampling pattern. Not surprisingly, the results of the study indicate that, for the same sample size, regular sampling is superior to random sampling and clustered patterns. Based on a comparison of standard errors, a hexagonal sampling pattern is slightly more efficient than a square pattern. However, for practical purposes they are equally efficient.

Sampling Density

Sampling density refers to the number of discrete sample points per space unit (e.g., number of wells per square mile). Sampling density is also a determining factor of the efficiency of a monitoring network. The density of a ground water monitoring network should be selected so as to provide sufficient detail of ground water quality compatible with the objectives of the monitoring program. As the network density increases so do initial capital costs and operational costs of the program. Therefore, the marginal value of the information gain from increasing network density must be traded against the marginal cost of increasing the density.

If the spatial pattern remains the same, any change in density changes the relative distance between points by a constant factor (Olea, 1984). The standard error can be reduced, theoretically to a limiting value of zero, by increasing the sampling density. According to Olea (1984), all other factors being equal with identical patterns that differ only in density, the sampling efficiency of the pattern with the higher density will differ from the efficiency of the pattern with the lower density by the ratio of the lower density over the higher density raised to the 0.25 power.

Geostatistical Approaches to Monitoring Network Design

During the past decade the application of geostatistical principles (i.e., structural analysis, kriging, and conditional simulation) to interpretation of ground water data greatly expanded. The use of geostatistical techniques is well-established for evaluation of the spatial variability of ground water flow parameters, particularly hydraulic head and transmissivity. However, less research has been conducted on the application of geostatistics to interpretation of hydrochemical data, and ground water quality monitoring network design. Samper and Neuman (1985) successfully performed a geostatistical analysis of selected chemical variables (i.e., concentration of major ions, electric conductivity, pH, and silica). Their results show that geostatistical approaches may be valid for evaluation of ground water chemical data, particularly on a regional scale.

In many situations, the principles of geostatistics may be appropriate for interpolation of point data in order to estimate the spatial distribution of certain aspects of ground water quality. Perhaps the greatest utility of geostatistics, specifically kriging, is for the design of optimized regional ground water quality monitoring networks. This assertion is particularly true for evolutionary monitoring networks where newly constructed monitoring wells are being added to a network composed of existing wells. Kriging provides a measure of the error of estimation, which can be mapped and used to guide the selection of locations for additional sampling points. The error maps show where the interpolated values deviated from the expected statistical structure, thus indicating the best locations to place additional wells

(Virdee and Kottegoda, 1984). However, this information can only serve as a guide because of other constraints on well location such as environmental concerns, political issues, and economic limitations. Nevertheless, a near-optimal monitoring network can be developed for a predetermined level of reliability.

The use of geostatistics in design of monitoring networks and interpolation of data is not without limitations, however. The major problem of applying kriging to ground water investigations is the lack of sufficient data to perform the structural analysis. Hughes' and Lettenmaier's (1981) suggestion that the minimum sample size should exceed 50 before kriging is superior to more traditional interpolation schemes (e.g., the least squares method). Even with sufficient data and suitable statistical support, structural analysis is highly subjective. Further, the theoretical basis for the application of geostatistics is the concept of regionalized variable, which is defined as a spatially correlated random variable. To date, there have been no definitive studies of the vaildity of assuming that hydrochemical properties of ground water behave as regionalized phenomena.

PROPOSED STATEWIDE GROUND WATER MONITORING NETWORK FOR ILLINOIS (CASE STUDY)

The Illinois Department of Energy and Natural Resources (ENR) determined in 1983 that a comprehensive monitoring network should be established to improve upon the collection of ground water quality data for the State of Illinois. One of the primary objectives for the monitoring program is to identify long-term regional trends in ground water quality. The proposed monitoring program (O'Hearn and Schock, 1984) is to provide systematic information on ground water quality for principal aquifers that serve public water supply wells in Illinois. By definition, a principal aquifer is an aquifer with a potential yield of at least 100,000 gallons per day per square mile and an areal extent of at least 50 square miles. Principal aquifers underlie approximately 60 percent of the state.

A detailed surficial geologic material mapping program was also begun in 1981. One of the goals of this mapping program was an interpretive map (Figure 3-1) of the potential for contamination of ground water by waste

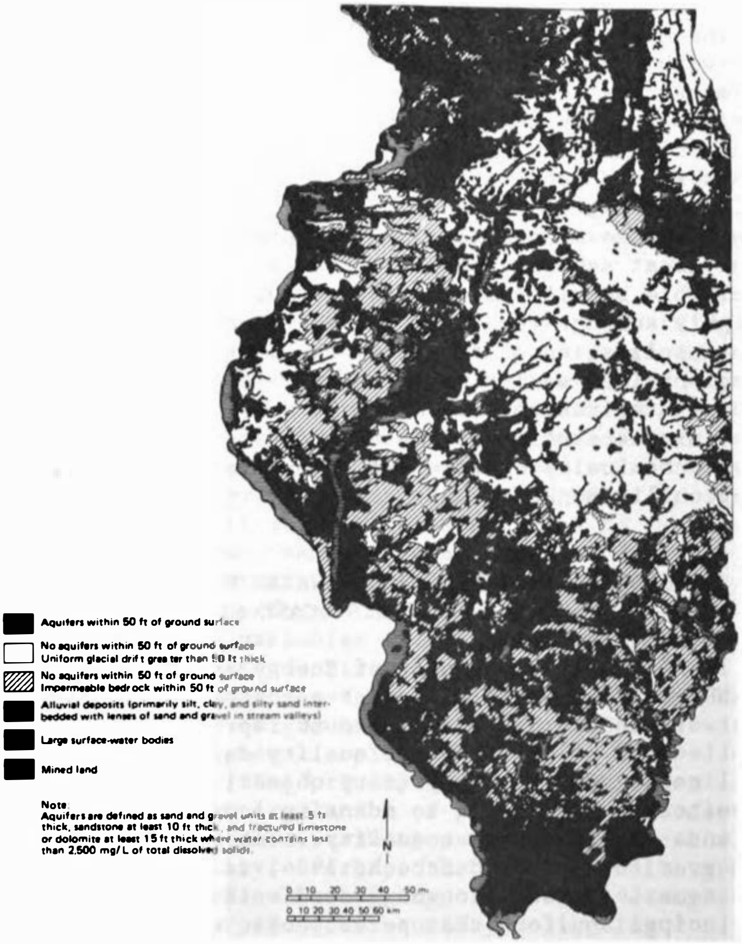

FIGURE 3.1 Aquifers within 50 ft of ground surface. (Modified from Berg and Krampton, 1984.)

SOURCE: Cartwright et al. (1986).

disposal and other activities on the land that could affect ground water quality (Berg et al., 1984a). More detailed mapping is now under way to provide the level of detail needed for decisionmakers. The detail available in the state map is adequate to design the framework of the proposed Illinois Ground Water Monitoring Network. However, the greater detail available in the local studies probably is required for design of a more comprehensive program to monitor and protect ground water.

The design of the monitoring network was based on an evaluation of existing water well and aquifer data for the State of Illinois. The proposed network design provides comprehensive statewide coverage of principal aquifers through the most effective and reliable means of data collection considered practically feasible. The proposed monitoring program is based on collection of data from existing public supply wells (PWS). Approximately 1300 PWS wells were chosen for the monitoring stations from a detailed review of nearly 5000 PWS wells. The selection was based on the reliability and completeness of historical information on each PWS well along with certain suitability criteria. The network includes 962 primary wells and 344 backup wells. The 962 wells are divided into 204 high-priority wells (i.e., tap principal aquifers designated as highly susceptible to contamination), 427 medium-priority wells (i.e., in principal aquifer areas considered less susceptible to contamination), and 331 low-priority wells located outside the boundaries of the principal aquifers (Illinois Department of Energy and Natural Resources, 1985).

The monitoring strategy that was recommended by O'Hearn and Schock (1984) will maximize the efficient use of fiscal and manpower resources by concentrating monitoring efforts where perceived needs are greatest. The plan calls for three independent levels of monitoring activity. The three levels are: (1) routine monitoring, (2) intensive surveys, and (3) special studies. The routine monitoring requires sampling of all wells to be completed every 3.5 years. Samples are to be analyzed for the primary and secondary standards required under the federal Safe Drinking Water Act. In addition, minor constituents, other trace metals, and volatile and nonvolatile organic compound determinations are to be made during level one monitoring. Intensive surveys are designed to provide more dense areal measurements of only the medium- or high-priority wells over a shorter time period. The potential need for special studies is also recognized by the program. Level three, based on the interpretation of the data collected from levels one and two, is also recognized by the monitoring program. The special studies focus on determining the magnitude, causes, and probable actions for significant contamination problems (Illinois Department of Energy and Natural Resources, 1985). Figure 3-2 shows the design criteria for the statewide regional ground water monitoring network for Illinois.

The Illinois Environmental Protection Agency (IEPA) is responsible for implementing the ground water monitoring network. Currently, the IEPA is in the second year of a 4-year program of sampling all public water supplies in the state. This assessment may act as a precursor to establishing the statewide ground water quality monitoring program recommended by O'Hearn and Schock (1984). The proposed network will provide much more detailed hydrologic and chemical data than the routine public supply monitoring. The State Geological and Water Surveys will assist the IEPA in establishing a sampling protocol for each well (the samples ultimately will be taken by local water plant operators) and laboratory practices, and review monitoring results. All data will be located in both the Survey's data base and IEPA files.

SAMPLING AND ANALYSIS

Of equal importance with efficiency of network design in assuring effective ground water monitoring is proper ground water sampling and analysis. A quality assurance program, which is composed of well-conceived and effectively implemented quality control procedures, should be followed. Quality assurance programs provide a means to minimize both systematic and random error. Strict adherence to a quality assurance program maximizes the likelihood that ground water sample collection will be conducted in a manner that ensures the reliability of analytical determinations. As with monitoring network design, detailed understanding of the overall objectives of the monitoring program is a key factor in determining sampling and analysis requirements.

The purpose of this section is to provide an overview of the technical considerations in sampling and analysis of saturated ground water systems for chemical

Aquifer Type	Aquifer Classification	Coverage of Primary Aquifers (Sq. Miles)	Number Wells 1000 Sq. Mile	Number Primary Network Wells *	Monitoring Priority Level	Monitoring Frequency **	Monitoring Parameters
SAND AND GRAVEL	Highly Susceptible Principal S & G	5,900	26	144	High	Level 1: 3.5 yr. Cycle Level 2: 2-5 yr. Cycle	SWDA Parameters, Organic Scan SWDA Parameters, Priority Pollutants
	Less Susceptible Principal S & G	5,900	17	102	Medium	Level 1: 3.5 yr. Cycle Level 2: 2-5 yr. Cycle	SWDA Parameters, Organic Scan SWDA Parameters, Priority Pollutants
	Non-Principal S & G	-----	-----	220	Low	Level 1: 3.5 yr. Cycle	SWDA Parameters, Organic Scan
SHALLOW BEDROCK	Highly Susceptible Principal S.B.	2,400	26	60	High	Level 1: 3.5 yr. Cycle Level 2: 2-5 yr. Cycle	SWDA Parameters, Organic Scan SWDA Parameters, Priority Pollutants
	Less Susceptible Principal S.B.	6,200	29	180	Medium	Level 1: 3.5 yr. Cycle Level 2: 2-5 yr. Cycle	SWDA Parameters, Organic Scan SWDA Parameters, Priority Pollutants
	Non-Principal S.B.	-----	-----	107	Low	Level 1: 3.5 yr. Cycle	SWDA Parameters, Organic Scan
DEEP BEDROCK	Principal D.B.	23,900	6	145	Medium	Level 1: 3.5 yr. Cycle Level 2: 2-5 yr. Cycle	SWDA Parameters, Organic Scan SWDA Parameters, Priority Pollutants
	Non-Principal D.B.	-----	1	4	Low	Level 1: 3.5 yr. Cycle	SWDA Parameters, Organic Scan

* Monitoring Network consists of 204 high priority and 427 medium priority wells in principal aquifers, 331 low priority wells in non-principal aquifers, and 344 alternate wells.

**Level 3, special studies may be warranted where analysis of level 1 or 2 data indicates an apparent problem. Level 3 special studies may involve wells from any level of monitoring priority and for any aquifer type.

FIGURE 3.2 Design criteria for the Illinois ground water monitoring network.

SOURCE: O'Hearn and Schock (1984).

parameters. Considerations in sampling the vadose zone are not included in this discussion. Nor are methods for hydrogeologic parameters (e.g., hydraulic conductivity) determination presented. The focus of this discussion is on routine ground water sampling and analysis. Emerging technologies for specific applications, such as in-situ techniques and downhole instrumentation, are not addressed.

Ground Water Sampling Procedures

The results of laboratory analyses can be expected only to be reliable assessments of the samples, field standards, and blanks as received. Therefore, careful thought and practice must be part of any sampling program in order to assure that representative samples are provided to the laboratory. A representative sample is one that accurately reflects in-situ conditions in close proximity to the sample point at the time the sample was collected. Assurance of representative samples requires that consideration be given to well purging, sample collection, and sample preservation.

Barcelona et al. (1985a) have prepared an extensive guide to the practical aspects of ground water sampling. They list potential sources of error in sample collection:

1. Proper calibration of all field measurement equipment and sampling equipment.
2. Assurance of representative sampling considering sampling frequency, well purging, and sample collection.
3. Use of proper sample handling precautions.

An in-depth error assessment is also provided by Barcelona et al. (1985a) and is as follows:

Ground Water Sampling Step	Sources of Error
Field measurement	Instrument malfunction; Operator error
Sample collection	Sampling mechanism bias; Operator error

Sample delivery/transfer	Sampling mechanism bias; Sample exposure, degassing, oxygenation; Field conditions
Field blanks, standards	Matrix interferences; Operator error
Field determinations	Instrument malfunction; Operator error; Field conditions
Preservation/storage	Matrix interferences; Handling/labeling errors
Transportation	Delay; Sample loss

Added to these potential errors are laboratory and analytical errors discussed later in this section.

Water that has remained in the well casing for more than approximately two hours has had the opportunity to exchange gases with the atmosphere and to interact with casing materials (Barcelona et al., 1985a). Consequently, it is recognized by virtually all hydrogeologists and geochemists that well purging must take place prior to sample collection. However, the number of well volumes to purge is still a somewhat controversial issue. According to Barcelona et al. (1985a), the factors involved in determining the proper number of well volumes to purge are: (1) hydrogeologic properties of the sampled formation, (2) well construction procedures, (3) pumping rate, and (4) sampling methodology. The yield potential of each well must also be factored into the determination of the number of volumes to purge. Consequently, well purging must be approached on a case-by-case basis. Stabilization of measurement of certain parameters such as pH, temperature, redox potential, and conductivity, as determined via flow-through devices, has been used as a guide indicating when representative samples can be obtained (Gibb, 1984). This approach eliminates the need to a priori determine the number of volumes to purge and offers consistency of methodology from one well to the next, even though different volumes may be purged.

Parameter Selection

Parameter selection is an important aspect of the design of a sampling program. The types of hydrochemical measurements to be made affect the choice of sampling equipment and the sampling methodology. Barcelona et al. (1985a) state that it is often wise to obtain slightly more chemical and hydrologic data than immediately required by the monitoring program. In practice, these additional data can generally be put to good use, especially later in time when the monitoring program becomes more established.

Ground water chemical parameters can be loosely divided into three categories: (1) general ground water quality parameters, (2) contamination indicator parameters, and (3) specific chemical constituents. General ground water quality parameters include various minerals and total dissolved solids content. General indicators of contamination (especially of a synthetic organic nature) are total organic carbon and total organic halogen. However, without a complete mineral analysis and prior to the detection of a change in ground water quality, the indicator parameter approach is of little utility (Barcelona et al., 1985a). The alternative is to monitor the presence (or absence) of specific chemical constituents. However, this approach requires either a great deal of financial resourcefulness or prior knowledge of chemical constituents likely to be present in the ground water system under investigation. For the case of large-scale regional ground water quality monitoring, little justification can be found for limiting analyses to a small set of specific chemical constituents. In any event, the selection of which parameters to initially include in the monitoring program should be based on both the short-term and the long-term goals (if different) of the program. The design of the monitoring program should be flexible enough to allow for a change in, or addition of, chemical parameters as the monitoring program is operated.

Sampling Frequency

How often samples are collected and analyzed is important in the design of an optimum ground water quality monitoring program. Sampling frequency affects the cost of the monitoring program and the appropriateness of any inference(s) made from the resulting data. The frequency of sample collection and analysis should be such that redundant information does not result, thereby increasing costs with no marginal gain in useful information. Conversely, sample collection should not be so infrequent as to negate the ability to accurately forecast trends in ground water quality. Ground water sampling frequency should be based on the objectives of the monitoring program and the hydrodynamics of the ground water system being monitored. Ground water movement is relatively slow, and there is little need to sample every few meters of flow path. Too frequent sampling could also perturb the ground water flow system and possibly bias the data.

Sampling Equipment

The type and material composition of the sampling apparatus can have a dramatic impact on the chemical composition of ground water samples. Therefore, the pumps, line feeds, and storage containers must be selected to minimize chemical alteration of the samples. Barcelona et al. (1985a) list the important characteristics of effective ground water sampling devices as:

1. Simple to operate to minimize operator error.
2. Rugged, portable, cleanable, and repairable in the field.
3. Good flow controllability.
4. Minimal physical and chemical disturbance of ground water solution composition.

Gibb (1984) divides sampling devices into five categories: (1) bailers, (2) suction lift pumps, (3) gas contact samplers, (4) positive displacement samplers, and (5) syringe samplers. Bailing is the simplest method for sample collection from small-diameter wells. Bailers require no power, are easy to transport, are easy to clean, and are economical. However, they also tend to be impractical when large volumes of water must be removed from the well casing. Further, the transfer of water from the bailer to the sample container may allow outgassing of volatile chemical constituents. Bottom-draw bailers reduce these sources of error.

Suction lift sampling devices, including peristaltic pumps, change the pressure in feed lines providing the possibility of degassing and loss of volatile organic compounds. Gas drive contact pumps may be appropriate for well purging. However, these devices may also affect the recovery of volatile organic compounds (Barcelona et al., 1985a). Positive displacement samplers (e.g., bladder pumps) are suitable for both well purging and collection of representative samples with minimum physical and chemical alteration. Syringe type samples cannot be used for well purging, but they are appropriate for sample collection for volatile organic compound analyses. However, the field performance of syringe-type samplers is open to debate.

The composition of sampling tubing is as important as the type of sampling device. In a study reported by Barcelona et al. (1985b) it was demonstrated that serious sample bias occurs quite rapidly due to sample contact with flexible tubing. All commonly used tubing materials were found to sorb organic compounds to some extent. However, sorbtion was greatest for polyvinyl chloride and silicone rubber tubing.

LABORATORY PROCEDURES/ANALYTICAL DETERMINATION

Laboratory quality control procedures should be followed to ensure that valid analytical results are obtained from laboratory analyses of ground water samples. Barcelona et al. (1985a) list the required components of an effective laboratory program. These are:

1. Proper calibration of instruments, verification of daily standardization and analytical performance parameters, daily analysis of sample replicates/standards/spiked samples/blanks by approved methodologies, and the use of quality control charts to document the validity of laboratory results.
2. Participation in round-robin or interlaboratory studies.
3. Prompt recording, storage, and retrieval of laboratory results with the corresponding analytical performance parameters.

Similar to sample collection, handling, and storage, there are specific steps in ground water sample analysis, each with associated errors (Barcelona et al., 1985a).

Ground Water Analysis Step	**Source of Error**
Samples, from storage **Field blanks and standards**	**"Aged" samples;** **Loss of analytes;** **Contamination**
Subsampling	**Sample aging/contamination in laboratory;** **Cross-contamination;** **Mishandling, mislabeling**
Procedural standards	**"Aged" standards;** **Analyst error**
Analytical separation	**Matrix interferences;** **Inappropriate/invalid methodology;** **Instrument malfunction;** **Analyst error**
Analysis	**Matrix interferences;** **Inappropriate/invalid methodology;** **Instrument malfunction;** **Analyst error**
Reference standards	**"Aged" standards**
Calculations	**Transcription/machine error;** **Sample loss in tracking system** **Improper extrapolation/ interpolation** **Overreporting/underreporting errors**

Assuming that the laboratory staff is well-informed concerning unusual attributes of samples, analytical quality control is straight- forward in comparison to quality control in sampling protocol. Quality assurance/quality control procedures should be capable of detecting and correcting problems associated with instrument malfunction, analyst error, and the use of

aged samples. The quality assurance program must also include procedures for the systematic, complete, and permanent documentation of information to support all claims made for all results (Helfrich, 1984).

CONCLUSIONS AND RECOMMENDATIONS

A national ground water quality monitoring program is a massive undertaking and must be thoroughly thought through to establish clear goals. The goals must be accompanied by a data management system to analyze the data in a timely manner and provide for future retrieval as other uses for the data are identified.

Some consideration should be given to the method of obtaining significant water samples much as is done for rock cores and cutting from wells. This could provide samples for future research efforts in understanding the evaluation of water within the earth and provide samples for future analysis as needs change.

We recommend that an optimum monitoring program be based on sound hydrogeologic data. To accomplish this, regional aquifer studies must be undertaken to understand the geology and hydrology of the major regional aquifers. The U.S. Geological Survey's Regional Aquifer Systems Assessment program is the beginning of such an effort. In addition to continuing the large Regional Aquifer System Assessment (which generally is multistate in scope), studies of major aquifers of more local importance must also be undertaken by appropriate state or federal agencies.

Second, a surficial geologic materials mapping program must be undertaken to establish the environmental relationship of the aquifers to man's activities on the land surface. Detailed geologic mapping, such as done in Illinois (Berg et al., 1984a), can identify areas that are potentially susceptible to contamination. However, further development of this mapping technique is desirable to establish the interconnection between the materials mapping and the ground water flow systems (Kempton and Cartwright, 1984; Berg et al., 1984b).

A coordinated approach of aquifer assessment and surficial geologic materials mapping can provide the basis for designing a ground water monitoring program that will identify the available high-quality ground water, determine the extent of ground water quality degradation that has already occurred, provide data to minimize future ground water quality degradation, and provide some predictive capability to identify potential public health problems.

Obviously, present public water supplies must continue to be monitored for public health purposes while national water quality monitoring is under development.

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4

DEVELOPMENT OF NATIONAL WATER QUALITY ASSESSMENT PROGRAM: A PERSPECTIVE OF THE U.S. GEOLOGICAL SURVEY

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INTRODUCTION

In a country as large and diverse as the United States of America, it is very difficult to develop an adequate National Water Quality Assessment (referred to below as the Assessment) even with generous budgetary support and relatively few personnel limits. Were it not for the difficulty of the task, most probably we would have by now a better National Assessment than we do, and today's colloquium would be devoting much more time to Assessment results. Possibly, the difficulty of developing the Assessment could be removed by some spectacular technological breakthroughs. Unfortunately, one cannot know when or whether such breakthroughs will occur. A more dependable, and more immediately applicable approach to Assessment planning seems to be one that utilizes the most advanced science and technology, but places the primary reliance on an innovative design and planning features. The aim of this presentation is to describe an Assessment program resulting from a design-innovation approach. At present such a program does not exist. The suggested program differs significantly from the traditional monitoring schemes. Though it is designed to satisfy a broad spectrum of national needs, preliminary estimates indicate that it has realistic budgetary and personnel requirements.

This paper is, in part, an outgrowth of USGS committee deliberations, which were summed up in the report, Principles of Perennial Acquisition and Analysis of National Data on Water Quality, by J. Rubin, J. P. Bennett, R. M. Hirsch, and S. N. Luoma, 90 pp., U.S. Geological Survey, 1985.

THE SUGGESTED ASSESSMENT'S CONCERNS AND OBJECTIVES

It is convenient to present the principal concerns and objectives of the suggested program by discussing briefly the meanings or implications of the words that make up the program's name.

First, it is assumed in this presentation that because the Assessment is "national," it must have a national scope, and, in addition, it must satisfy certain clearly defined national needs. An Assessment with a national scope must have a data base that involves either the whole country or so large a portion of the country that what happens in this portion is of utmost national significance. Furthermore, the program must meet the national need of an adequate, factual, and scientific information base for making national (i.e., federal, regional, or interstate) decisions about water quality and for supporting actions induced by such decisions. Such a base must be developed in hydrologically justifiable areal units that are unrestricted spatially by state or by local administrative boundaries.

The phrase "water quality" is taken as indicating the main concern of the Assessment: the suitability of the nation's water resources for a variety of uses. The water resources aspect means that the resource as a whole is involved and not merely some specific part (or parts) of it. Thus, for example, the Assessment must involve ground as well as surface water. Furthermore, the Assessment's data base must not be restricted to waters that create or are suspected of creating water use problems. A picture of the resource as a whole must also include adequate information on parts of the resource that currently are, or are thought to be, problem-free.

The determination of water quality must be based primarily on quantitative measurements, and these must be concerned with target variables, i.e., variables affecting directly the suitability of water as a resource (e.g., concentrations of certain widely present contaminants). Other, less direct ways of determining water quality occasionally will be useful. However, the propriety of their use ordinarily must be confirmed periodically by comparing their status with that of target variables.

In addition to determination of target variables, other measurements are essential. Certain measurements are needed in order to interpret the status of target variables. The variables involved (e.g., flow rates of surface or ground water) are called here support variables. In addition, determinations may include indirect measures (indicators) of selected variables or of the general suitability of water for a given use. Still another useful kind of variable to determine is one that integrates over time the status of a direct or indirect measure of water quality.

The program of collecting and interpreting water quality data must be continued over decades. This perenniality is required because of the need to discover unexpected changes in water quality as well as to reveal the presence of important trends, especially those that are slow (expected or unexpected). In order to be sufficiently sensitive to changes in water quality the program must pay special attention to target variables affected by human activities, like anthropogenic contaminants.

Lastly, consider the phrase "assessment program" in the program's name. As used here, this phrase denotes data collection as well as data interpretation. The word "assessment" is defined by means of the objectives that in our view the program should strive to fulfill. There are three such objectives.

First, an Assessment must produce, periodically, statements about the general (national, regional) water quality situation and about its changes with time. This can be accomplished by means of appropriate statistical measures, which refer to a single target variable or to certain sets of such variables. Second, an Assessment must attempt to determine the locations of the principal water quality problem areas and the nature of the problems encountered. Third, it must try to find the causes of these problems, mainly in terms of known processes and mechanisms.

The latter two objectives are essential, because without them the Assessment may fail to fulfill its role in serving as a factual and scientific base for many of the more specific national decisions and most of the relevant national actions. Determination of problem type and location requires investigations that may have to be considerably more detailed than those required by the statistical measure objective. The third objective, the determination of problem causes, is attained by means of even more intensive, explanatory studies. Such studies may be aided (but cannot be supplanted) by statistical interpretations, like those correlating target variables with a variety of water quality determining factors.

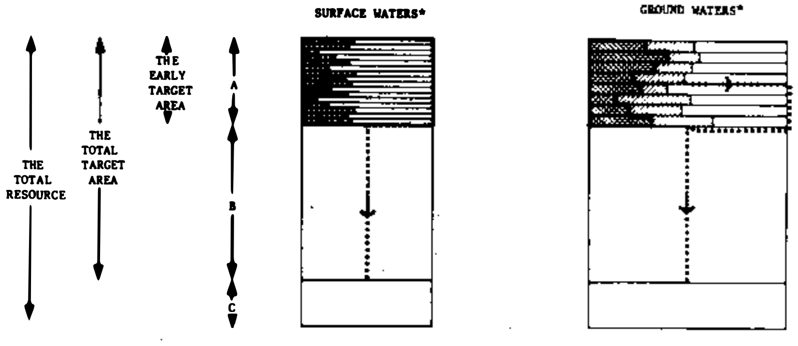
SEARCH FOR A REALISTIC PROGRAM DESIGN: DESIRABILITY VERSUS ATTAINABILITY

The Dilemma and Its Resolution

Trial computations based on the expected fiscal and personnel limitations show that it is not possible to pursue simultaneously and everywhere in the country all of the Assessment's objectives and concerns outlined above. Nevertheless it appears possible to attain the Assessment objectives in a reasonable manner using a number of design strategies. These include certain compromises, many (but not all) of which are slowly removed by a planned program evolution. In part, such an evolution is merely due to postponement of implemention of selected activities (i.e., it involves "stretching the program over time"). An additional, rather basic and often decisive aspect of this evolution is a gradual improvement in implementation efficiency due to the increase in understanding of the specific aquifers and watersheds (acquired to a large extent due to the program). It will be shown now how these strategies are employed in developing a realistic Assessment program.

Target Areas

A careful perusal of Figure 4-1 will show how the Assessment's current and future target areas are chosen. The Assessment's high-priority, surface and ground water early target areas (A in Figure 4-1), which are to be the main subject of investigation perhaps for as long as two to four decades, are considerably smaller than the corresponding total resources. This has been achieved partly by postponement (the B areas) and in part by a permanent compromise (the C areas). However, the high-priority A areas have been chosen to be so significant (see legend, Figure 4-1) that by themselves they are sufficient to qualify the Assessment as "National." Even within the high-priority areas, work must be accomplished in stages (Figure 4-1 shows how this is done for ground water; the rotational scheme suggested for surface water will be discussed presently). It may seem that such an additional postponement may excessively delay the Assessment's desired impact. However, supplementary sampling in the currently uninvestigated areas (as required by the statistical measures) and



LEGEND:

AREA'S DESIGNATION	AREA'S PRIORITY **	IS THE AREA A TARGET OF THE ASSESSMENT?	SOME OF THE CONDITIONS THE AREA MUST SATISFY
A	High	Yes. It is a primary target, to be investigated early in the program. (The horizontal lines divide it into subareas, which represent the initial Study Units***).	It accounts for 80 percent or more of fresh, surface- or ground-water diversion (pumping). It minimizes the target's spatial extent, maximizes the target's population and the diversity of its hydrologic conditions.
B	Medium	Yes. But much later than A.	Area remaining after A and C were delineated.
C	Lowest	No, not investigated by the Assessment.	Area either with very low probability of significant water use (e.g. ephemeral streams, very saline aquifers) or one which requires special investigation (e.g. estuaries).

▨ VISA -- Very Intensively Studied Area: part of a Study Unit found to have substantial water-quality problems.

(Ground Water only) -- Part of a Study Unit apparently with no substantial contamination, but with a high contamination-probability.

━━ Area enclosed by this border is the first to be investigated (after preliminary studies in the case of surface water or iterative search in the case of ground water).

···→··· These arrows indicate the direction of program's evolution. The evolution rate will vary from Study Unit to Study Unit and will depend on each Unit's conditions & prior knowledge.

* The area and subarea sizes depicted in this Figure do not represent any actually existing magnitudes. However, they are meant to suggest which areas are larger and which are smaller.

** Priorities A, B and C are based primarily on an area's water usage. There are also priorities within areas A (cf. shading). The primary criterion for choosing them is the severity of the water quality problems encountered.

*** Surface-water Study Units are large watersheds; most of them are U.S. Geological Survey's Hydrologic Subregions. Ground-water Study Units are large aquifers with known boundaries and known general flow patterns (mainly aquifers studied by U.S. Geological Survey's Regional Aquifer System Analysis, RASA, or major components of these aquifers). In the A areas there may be in all about ninety surface-water and about fifty ground-water Study Units.

FIGURE 4-1 Target areas of a National Water Quality Assessment, and their evolution.

timely reporting of all the current target area results should start making the Assessment relevant within a few years after it is fully operational.

Target Variables

Because the number of candidate variables is very large, selection of a manageable set of target variables requires drastic compromises. Clearly, the "postponement approach" is applicable. However, even when such an approach is used, the majority of the candidate variables cannot be reached within a reasonable period of time (primarily, due to the multiplicity of the trace organic contaminants). Hence, the difficult choice of the variables for the Assessment's first stage is of crucial importance. Some alleviation of the difficulty is provided by the fact that all target variables do not have to be studied everywhere. To utilize this fact, target variables are designated either as national targets (i.e., variables both measured and interpreted in the national context), or as national examples (i.e., variables measured only in the regions in which they tend to occur, but interpreted in the national context), or as regional targets (i.e., variables measured and interpreted only in specific regions). This approach does not eliminate the problem due to the multiplicity of variables in any or all of these categories. The first step in solving this problem is to restrict studies during the first stage to a limited set of national water quality issues. A reasonable set may include: suitability of water for broad use (as determined by major constituents and certain other features); chemical contaminants; and nutrient enrichment. Moreover, in the surface water Assessment, two additional issues, sediment- and atmosphere-transmitted contamination (especially acid rain) should be considered. For each issue, the selection of target variables must be made according to a set of predetermined criteria. Table 4-1 shows an example of such a set, evolved for the chemical contaminants issue.

The selection of the Assessment's biological variables is particularly difficult, because of the lack of large-scale experience with some of these variables and uncertainties about the readiness of certain especially attractive biological measures for national, freshwater monitoring. Table 4-2 shows our suggestion as to the

TABLE 4-1 Criteria for Selecting Target Chemical Contaminants by the National Water Quality Assessment

CRITERIA FOR INCLUDING A GIVEN CONTAMINANT IN THE ASSESSMENT											
"All or nothing" criterion*	The "weighted index" criteria**										
Consider aspects of chemical analysis:					Consider the effects:		Consider the behavior in the environment:				
can the contaminant be determined quantitatively? can this be done in a routine fashion?	expense of collection, extraction, analysis	detection limit in relation to expected ambient concentrations	reliability of analysis	analytical compatibility with other chemical species	human health effects	eco-system effects	is the contaminant a good representative of a class?	how extensive is the spatial distribution of the contaminant (and its class, if any)?	persistence (stability in environment)	mobility	expected trends in the contaminant's use & production.

* A variable is accepted if and only if this criterion allows it.

** For every "weighted index" criterion, each variable is assigned a score between zero and the criterion's maximum. The total score of a variable – its index count – determines the variable's priority level.

TABLE 4-2 Utilization of Biological Variables by a National Water Quality Assessment

BIOLOGICAL VARIABLES							
TARGET VARIABLES				INDICATOR VARIABLES			SUPPORT VARIABLES
primary producers	pathogenic micro-organisms	selected chemical results of biological activity (e.g. O_2 activity)	target species (e.g. a species of commercial interest)	eco-system: structural or functional aspects	indicator species (e.g. toxicity to a given species)	biological integrators	numerous species & activities
+	+	+	(+)	-	-	+	+

Legend: + = a current, national variable; (+) = possibly a current, national variable, but not under USGS leadership;
- = though not a current national variable, perhaps will become one in the future

choices to be made in connection with this problem during the Assessment's first stage.

Measurements: Their Placement and Timing

The Assessment program is carried out in Study Units (Figure 4-1) and it gathers its data at four types of sampling locations, which are listed and explained in Table 4-3.

TABLE 4-3 Principal Types of the Assessment's Sampling Activities

Total Duration Sampling Frequency	Ordinarily perennial, often continuing	Limited
Relatively high	FIXED STATIONS. Periodically sampled, fixed locations. Mainstay of the Assessment's sampling activities. However in certain cases, subject to planned, but intermittently periodic (e.g. 3 years on/ 6 years off) rather than regularly periodic sampling.	TEMPORARY STATIONS. Usually set up in connection with explanatory studies, modelling efforts, special problems. They last as long as does their purpose.
Limited	PERIODIC SURVEYS. Usually have higher sampling density than sampling stations. They check the representativeness of these stations.	"ONE-SAMPLING-ONLY" (INCLUDING SEARCHES). Usually, either searching for problems & problem areas, or concerned with finding the best locations for sampling stations.

In the case of surface water, sampling frequencies at such locations must be relatively high, because the riverine variables so often change rapidly and depend strongly on time of the year and weather. It is suggested that fixed stations (and most of the temporary stations) be sampled 12 to 20 times a year, with special attention being paid to the high-flow events, but with an adequate (though less frequent) sampling being carried out during the low-flow periods. Synoptic surveys, which periodically sample locations between the fixed stations, must be conducted at least once a year.

To ease the burden created by such a high frequency of sampling, it is suggested to impose on the surface water Study Units a rotational, "3 years on/6 years off" schedule. This schedule divides all the Study Units of the high-priority area A (Figure 4-1) into three groups, each group being fully operational only during 3 successive years out of each 9-year-long cycle. This arrangement makes most of the fixed stations (say, 75 to 80 percent of them) active only during 3 out of 9 years (the remaining stations are operated continuously). Such an intermittence results in some loss in the accuracy of time series analyses. However, it is believed that this loss is fully warranted by the budgetary and personnel savings realized. Clustering of sampling periods into 3 consecutive years (in contrast to more uniform, intermittent sampling schemes) is partly justified by managerial considerations. In addition, very likely it increases the probability that the sampling schedule will include a large variety of weather and streamflow conditions. Finally, concentration of efforts in a relatively small number of Study Units at a time makes it easier to conduct the more intensive, explanatory studies that attempt to identify and analyze the relevant processes and mechanisms.

Concentrations of ground water solutes ordinarily change relatively slowly and usually are not sensitive to fluctuating weather conditions. Hence, for a given sampling well, sampling frequencies of one sample per year or one sample per 3, 9, or even 18 years may be justified in most sites. Under such circumstances, the rotational, "x years on/y years off" plan described above for surface water usually is not feasible. The choice of sampling frequency in the case of ground water will depend upon the expected rates of change in concentrations of interest and upon the severity of the water quality problems encountered.

Determination of proper spatial density and distribution of sampling points gives rise to the most difficult and crucial design problem facing the Assessment program. The main reason for this difficulty is the very large discrepancy between the national scale of the program as a whole and the much smaller scale of individual, water quality problem areas. In connection with this problem, the concept of the program's resolution requirement is introduced. The primary purpose of the resolution requirement is to assure that in the course of the program's routine Study Area activities (i.e., activities in areas A of Figure 4-1), there will exist a high probability of detecting and delineating water quality problem areas that exceed certain predetermined, well-defined limits of size and of severity. An additional purpose of the resolution requirement is to serve notice that areas of smaller size or with less pronounced severity may escape detection by the Assessment and that they should be dealt with by approaches other than those of the National Assessment. The resolution limits must be fixed in such a way that a design based on them can attain the Assessment's objectives, i.e., that the extent of the recognized problem areas will be sufficient to characterize properly the Nation's water quality situation. On the other hand, the degree of resolution must not be so fine that the Assessment will require unrealistic levels of support. The resolution requirement will remove from the Assessment's consideration many relatively small, contaminated areas, most of them created by recent point sources. Even if not essential from the point of view of assessing the current national water quality situation, these areas may be important. However, they cannot be treated within a broad, nationwide resources assessment program. Instead, many such areas are within purview of and can be best treated by regulatory agencies (federal, state, or local) and by nonregulatory local entities. Continual exchange of information between all the water quality monitoring agencies will make it possible for many of the small contaminated areas to be taken into account by the Assessment.

The Assessment's suggested resolution limits call for the program's capability to identify substantially contaminated river segments that are 50 or more miles long and substantially contaminated aquifer segments of 100 square miles or more. It is suggested that to be considered as "substantially contaminated" a segment must show persistent and considerable water quality problems in at least one-third of its total extent. The areas confirmed to be substantially contaminated will be designed as VISAs (very intensively studied areas, see Figure 4-1) and will be subject to rather detailed investigations, using relatively high sampling densities and frequencies. These investigations will attempt to determine the nature and the causes of the problems encountered. In addition, such investigations may make it possible to improve the design of the sampling network and to supplement its data, e.g., by developing mathematical models. Obviously, the resolution limits within a VISA will be much finer than those that originally may have lead to this area's discovery or delineation (e.g., in aquifers the VISA resolution limit may be as fine as 3 to 4 square miles).

Preliminary calculations suggest the sampling strategies within Study Units that will be necessary to satisfy the above resolution requirements. In rivers, the fixed sampling stations will have to be no more than 150 miles apart, and their data must be regularly supplemented by periodic synoptic surveys.

Implementation of such a sampling density in area A (see Figure 4-1) and concurrent inclusion of the greater sampling densities needed in the VISA studies seem feasible, provided the "3 years on/6 years off" scheme is employed. To achieve the desired resolution limits in the ground water studies, a more extensive "stretching of the program over time" is needed. To start with, each aquifer Study Unit must be partitioned into hydrologically reasonable segments with areas that average, say, 100 square miles. With the aid of iterative search studies (perhaps lasting up to 3 years), these segments are divided (on the basis of the probability of having water quality problems) into three groups (see Figure 4-1). These groups are then studied in succession, the final study eventually leading to the Assessment's perennial, primarily monitoring stage.

In connection with the placement of individual sampling stations, a conflict arises between choices optimal for the statistical-measures aim of the Assessment and those best for the area-delineation and explanatory objectives. The suggested procedure is to let the two latter concerns have a primary influence and to depend on post-factum statistical analyses for obtaining the broad, statistical measures. However, in the cases in which a network based on problem-area-delineation and explanatory concerns is insufficient for a post-factum statistical analysis, supplementary stations must be established to meet the needs of such analysis.

Interpretations

Broad statistical measures and their trend indices, ordinarily computed for target variables, are essential to the Assessement. First, the levels of their magnitudes provide measures of the overall national significance of current or future water quality conditions and problems. Second, the inclusion of broad statistical measures is important because the need to produce them forces the Assessment design (at each stage of the program's evolution) to be sufficiently unbiased to be capable of producing them. This is very important, because of the anticipated, competing demands for information of immediate utilitarian or explanatory importance.

The explanatory interpretations are essential, first, because they indicate the causes of water quality problems encountered and possibly suggest means for their resolution. Second, they often help to improve the design and the operation efficiency of the data collection system. Third, because they are of limited duration, they provide the possibility of evolving the Assessment program, when, upon their completion in a given area, they free the Assessment's resources for new undertakings. Lastly, many of them will lead to a significant increase in understanding of water quality dynamics in different types of hydrologic settings. In the long run this may prove to be as important as the Assessment's more quickly felt contributions.

The interpretations leading to statistical measures may employ means of classical sampling analysis, modified somewhat to make post-factum analysis as efficient as possible. The explanatory interpretations will use a variety of approaches, which strongly depend on the current state of knowledge and on local conditions as well as on the scientific capabilities and ingenuity of the Assessment personnel. Approaches common to most of these interpretations will include: identification of sources of water (e.g., interaction between ground and surface water; ground water recharge; and overland flow); mass balance calculations; searches for sources and sinks of particular solutes; use of constituents adsorbed on sediments for defining water quality problems, past and present; and mathematical modeling.

ORGANIZATIONAL ASPECTS

The activities of the Assessment program are conducted at two levels--a national level and a local (Study Unit) level. The leadership provided at the national level must be sufficiently strong and the local personnel must be sufficiently cooperative to make possible a self-consistent, national program producing comparable information, which can be integrated and analyzed in the national context. The role of the local level activity is decisive not only because this activity constitutes a day-to-day implementation of the program, but also for two other reasons. First, in a program as large as the Assessment, direct supervision and direct quality control by the national leadership are subject to severe limitations. Second, the explanatory work, on which much of the program's success depends, while subject to general, national guidelines, cannot be directed by the national leadership. Hence, one must rely for much of the leadership and for much of the quality control on the local-level personnel. It is hoped that the blend of practical pursuits and creative scientific approaches, necessitated by the Assessment's design, will attract personnel of high scientific caliber to the local study teams, and that it will foster the development of local leadership as well as the greatly needed expertise in the water quality aspects of hydrologic-setting-based, regional hydrology. Finally, the proposed organizational framework gives rise to an effective, local, quality control, because it places the responsibility for data collection on the same scientists who carry out much of the Assessment's interpretations. The national leadership can at least roughly evaluate the reliability of this control by reviewing the Assessment's local interpretive reports.

POSTSCRIPT

No National Water Quality Assessment can satisfy all the relevant water quality information needs. The Assessment program suggested here may be able to respond to some of the untargeted needs (by adding or accelerating certain activities), provided either its budgets are increased or appropriate interagency cooperation is arranged. Many local needs (e.g., some of those involving known problem areas) as well as certain national needs (e.g., target species, see Table 4-2) can thus be accommodated. However, not all the water quality information needs can be satisfied by the Assessment. Certain cases may require large scale searches for problem areas that are too far below the resolution limit. In other cases, the approaches called for may be too different from those to which the program is geared. Information needed in connection with enforcement of the waste disposal laws is a good example of this kind of case. As previously explained, such needs must be satisfied by an effort that is very different from a National Assessment.

Because of the above reasons and other motives, even a most effective National Assessment program will not and should not eliminate the need for additional water quality monitoring activities. To make best use of the total means available, it is imperative to foster information exchange, planning coordination, and cooperation between the relevant agencies. A prerequisite to any pooling of resources is an agreement about methods employed and about means of quality control. A strong, high-quality National Assessment program can contribute most significantly to optimization of the total U.S. water quality monitoring effort, serving as a guide, a standard, and a national-scale unifier for the country's disparate, current or future water quality monitoring programs.

In spite of its compromises and inability to satisfy all the water quality information needs, we believe that the National Assessment described above will satisfy a decisive share of the attainable, national-scale, water quality information objectives. Futhermore, the design proposed here is flexible enough to allow adjustments (e.g., removal of some compromises), if appropriate means are provided. In fact, it is expected that once such an Assessment demonstrates its capabilities, a growing support from local and other sources will significantly increase its scope.

5

NATIONAL WATER QUALITY MONITORING AND ASSESSMENT FROM THE PERSPECTIVE OF THE U.S. ENVIRONMENTAL PROTECTION AGENCY

Lawrence J. Jensen
U.S. Environmental Protection Agency

The Environmental Protection Agency is responsible for protecting the nation's water quality under the Clean Water Act, the Safe Drinking Water Act, and other environmental laws. In implementing these laws, we and our counterparts in the states make regulatory, enforcement, and public policy decisions every day that are dependent on information from water quality monitoring and assessments. The better the information is, the better our decisions will be.

I would like to share with you our perspective on how those decisions can be improved with the right kind of monitoring and assessments. I am also eager to hear your views: they will be useful to us as an adjunct to two studies we are now sponsoring to recommend ways to improve the way we collect and manage water quality information.

The timing of this colloquium is particularly appropriate, since it enables us to share some of the important lessons both you and we have learned in the past 5 to 10 years about water quality monitoring. Some examples from our experience: We have learned the hard way that pollutants can be mobile in ways we had not anticipated; neither control programs nor environmental monitoring can be limited to just air or water, but must be integrated. We have learned that biological, ecological, and human health factors are at least as important as chemical and physical factors in assessing water quality. We have also learned the importance of risk assessment and risk management as disciplines for interpreting environmental information and making control decisions. And finally we have learned that the best way to perform sampling upon which to draw national conclusions is through careful statistical design.

I will describe how EPA makes regulatory and policy decisions using water quality monitoring and assessments, including the criteria we use to judge proposed data collection projects. I will then discuss four recent EPA projects that illustrate our approach. I will conclude by describing our plans for future water quality monitoring and assessments.

TARGETED MONITORING

To fulfill our mission, we and our state counterparts require very specific, targeted monitoring. This is because data from such monitoring must be legally defensible as support to enforcement, regulatory, risk assessment, and risk management actions. In other words, to be useful data collection efforts must be designed to meet specific needs.

Let me explain in more detail. From EPA's perspective a successful targeted monitoring project meets the following criteria:

- The project is designed to support a decision. The decision can be broad or narrow, short term or long term, local or national.
- The project has a clearly stated objective. The target population, the contaminants being studied, and other key design elements are specified as precisely as possible.
- The project has clearly articulated questions or hypotheses that the data are being collected to answer or test. Data are not collected blindly in the hope that we will decide later how to use them.
- The project has data quality objectives that specify the degree of precision, accuracy, representativeness, completeness, and comparability that agency management requires from the data.
- The project has quality assurance protocols and an approved project plan to assure that the data quality objectives are achieved.
- The project has received a proper scientific peer review before being implemented.

For several years we have been applying these criteria in reviewing data collection proposals within the agency. Not every approved project meets all of the criteria perfectly. Nevertheless we believe that the quality and usefulness of the water quality assessments resulting from this process are well worth the extra time and up-front planning it takes to ensure the criteria are met.

The targeted approach can be applied to both local and national decisions. I would like to describe four recent monitoring projects that illustrate the targeted approach when applied to national decisions. The projects are the National Dioxin Study, the National Surface Water Survey for the acid rain program, the Ground Water Supply Survey and the National Fisheries Survey.

NATIONAL DIOXIN STUDY

The first example is the National Dioxin Study. In 1983 Congress and the public began asking serious questions about the nature and extent of contamination in the United States from 2,3,7,8-tetrachlorodibenzo-p-dioxin (2378-TCDD), or dioxin for short. The 2378-TCDD isomer has caused lethal and chronic toxicological effects in test organisms at lower levels than any other synthetic chemical. Dioxin was found in high concentrations in Times Beach, Missouri, at Love Canal, and in other areas.

The question EPA faces with dioxin is, How widespread is dioxin contamination, and what should be our regulatory response?

If this question had arisen 5 or 10 years ago, we might have responded by what could be called the "heuristic approach" to monitoring. This approach consists of finding a laboratory capable of analyzing the pollutant, and sending laboratory staff out to collect as many samples as possible as quickly as possible to document the problem. If a problem is found, then sampling may be extended to additional areas.

There are obvious problems with the heuristic approach: results are not statistically representative and cannot be extrapolated; exposure pathways may not be fully analyzed; quality assurance may be forgotten; and the money may run out before meaningful results are obtained.

With dioxin the agency decided that a targeted approach was needed. Before we began to design a sampling program, we conducted an intensive effort to assess what was known about the multimedia exposures and risks from dioxin. This effort took about 6 months and resulted in a 43-page Dioxin Strategy. The strategy recommended evaluating dioxin contamination in each of seven tiers, ranging from manufacturing sites (Tier 1) to background sites (Tier 7). Sampling within each tier would be statistically designed to answer specific questions, such as, What proportion of Tier 3 sites are contaminated with 2378-TCDD at concentrations of 1 part per billion or more?

It is interesting to note that even though surface water are an important pathway for human exposure to dioxin, the strategy concluded that samples would generally not be taken from the water column. Instead sampling would focus on fish tissue, where because of bioconcentration the levels would be high enough to ensure detection at the levels of concern.

In 1984-1985 a study plan was developed and peer reviewed, samples were collected and analyzed from 900 sites, and results were submitted for management and peer review. We expect the final report to be issued later this year. So far the results indicate that dioxin contamination of soils is limited primarily to previously known pesticide manufacturing sites, although fish contamination is somewhat more prevalent than expected.

The study has succeeded in supporting EPA's regulatory decisions. Decisions have been made to pursue control actions at individual sites, and to investigate some previously unknown sources in pulp and paper manufacturing sites.

A SURVEY OF SURFACE WATER ACIDIFICATION

The second example comes from the acid rain program. One of the most important things we need to know in making statutory and regulatory decisions about acid rain is the degree to which surface water is becoming acidified: How bad is acidification today, and how bad is it likely to become if acid rain is or is not controlled?

In making these decisions, we found that there are no national estimates of the extent of acidic surface water. This is somewhat surprising, since pH and alkalinity are among the variables measured most frequently by states, EPA, and other federal agencies. Nearly 4 million observations of pH in U.S. surface water has been accumulated since 1960.

There are several reasons why these existing data could not answer our questions with the necessary degree of confidence. First, since the data were collected by scores of agencies using different sampling designs, the results could not be related to a statistical sampling frame. In other words there was no way to determine whether the results were representative of any waters other than those actually measured. Second, there was no consistent record of whether lake samples were taken during the fall turnover when mixing occurs. Without this information it was impossible to determine whether a given set of lake samples was in any way representative of the entire lake. Third, analytical methods for pH and alkalinity varied between agencies over time, and so it was difficult to assemble a consistent picture. Finally, there were not consistent quality assurance records to enable estimates of variability and bias to be generated.

To overcome these problems, EPA designed a three-phased National Surface Water Survey. When completed, the survey will help us decide what levels of acid rain control are needed. Sampling for Phase I of the study, to determine present chemical status of lakes and streams, began in 1984; sampling for Phase II to determine variability and key biological resources will continue through 1988; follow-on long-term monitoring will continue well into the 1990s.

The survey relies on a statistical design that enables unbiased inferences to be developed for national, regional, and subregional levels. For instance, Phase I involved 2,400 lakes selected through a probability sampling technique to be representative of U.S. lakes of a specified size range located in four regions of the country where surface water is expected to be potentially sensitive to acidic deposition.

The survey also includes carefully designed analytical methodologies and quality assurance protocols. Given the survey's objectives, the fall mixing period was chosen as the best time for sampling because within-lake chemical variability was expected to be minimal relative to other seasons. Where compromises were made to keep costs down, such as in collecting only one grab sample per lake, careful attention was paid to quantifying and verifying the effects on sampling error. The study design has been subject to extensive peer review from the beginning, including reviews by numerous scientists outside EPA and by the American Statistical Association.

The results so far have been very successful. Initial results from the eastern lakes portion of Phase I were released in August 1985. These preliminary data generally conform to what was expected: relatively few lakes in any region were below pH 5.0 and most were above pH 6.0. One unexpected result was a relatively high proportion of highly acidic lakes, that is, those at or below pH 5.0, in parts of Florida and Georgia. This possibly results from natural geological conditions and from marine aerosols.

The results also confirm the wisdom of the sampling and analytical design. For example, single grab samples for lakes compared favorably with results of more intensive sampling on selected lakes. The quality assurance protocols worked well in practice. The final reports on the results of Phase I are scheduled to be available later this year.

GROUND WATER SUPPLY SURVEY

The third example of a targeted monitoring program involves ground water. As public awareness of ground water increased in the last decade, anecdotal information began to indicate that volatile organic compounds (VOCs) were being found in a number of ground water sources of drinking water. EPA needed to decide which pollutants were serious enough problems to require specific regulation under the Safe Drinking Water Act.

To make this decision it would have been easy to follow the heuristic approach and start nonrandom sampling of water supply systems most likely to have problems. Instead we combined random sampling with nonrandom sampling to form a two-part survey.

For the random part of the survey, EPA used data on the occurrence of VOCs from a 1978 survey to estimate the necessary sampling sizes. Based upon the occurrence frequencies of 10 VOCs assessed in the 1978 survey we determine that random sampling of 500 water supply systems would yield acceptable confidence limits.

In the nonrandom part of the survey, EPA encouraged state agencies to try to identify problem supplies. We did this not only to expand state involvement but also to provide information on the frequency and extent of serious problems based on the state agency's knowledge of local conditions. The target number for these nonrandom sites was also 500.

The Ground Water Supply Survey was conducted in 1980-1981. A total of 5 trihalomethanes and 29 other VOCs were analyzed by purge-and-trap gas chromatographic methods. Duplicate analyses were conducted on 10 percent of samples, and confirmatory analyses were conducted on 100 percent of positive occurrences.

The results of the survey were published in May 1984. They showed that the percentage of supplies containing at least one VOC above the quantitation limits in the random survey was 16.8 percent for small systems (serving fewer than 10,000 persons) and 28.0 percent for larger systems. The figures for the nonrandom systems selected by the states were 22.4 percent and 37.3 percent for small and large systems, respectively. Resampling of contaminated supplies strengthened confidence in the quality of the analytical data, and also showed that VOCs in finished water can vary over time, especially in systems supplied by multiple wells.

The occurrence data from this study were used as part of the statutory decision process under the Safe Drinking Water Act to determine which specific VOCs require maximum contaminant level (MCL) regulations. These regulations were proposed last year.

NATIONAL FISHERIES SURVEY

The last example is the National Fisheries Survey. As we neared the end of the first decade of the 1972 Clean Water Act, we needed to make decisions about the adequacy of control programs. For instance, we encountered instances where water quality criteria to protect fish were being violated, but where apparently healthy fish communities existed. Conversely, there were instances where nominal chemical water quality standards were being met but where aquatic communities were severely affected.

Since the Clear Water Act requires us to protect aquatic communities, EPA needed to have some way of evaluating them. In 1980-1981 EPA convened a group of aquatic biologists to develop an approach. The National Fisheries Survey, conducted jointly in 1982 with the U.S. Fish and Wildlife Service, was the result. It is the first survey designed to relate the quality of the nation's surface water to the health and viability of the biotic communities dependent on those water resources.

One of the major problems in designing the survey was to define the population of U.S. waters to be sampled. To solve this problem we used information from EPA's River Reach File to help implement a two-stage probability sampling process. From the set of flowing waters appearing on 1:500,000 scale maps, 1300 stream reaches were selected for assessment.

The survey utilized a data collection questionnaire that was answered by the state fish and game experts most familiar with the 1300 reaches actually selected in the sample. There was a 98.5 percent response rate to the questionnaires. The respondents had an average of nine years' experience in the selected watersheds.

The results of the survey show that sport fish are found in 73 percent of the nation's flowing waters. Nevertheless, the survey also shows that the nation's waters are widely affected by pollution and problems with water quality. For instance, water quality is reported to affect adversely the fish communities in 56 percent of the waters, and water quantity factors affect fish communities in 68 percent of the waters.

The survey has been useful in helping EPA to implement statutory responsibilities to evaluate the biological integrity of the nation's waters. It has also been used to support decisions to place emphasis on nonpoint source controls, and to use biomonitoring in developing point source controls.

FUTURE DIRECTIONS FOR WATER QUALITY MONITORING

I will conclude by discussing future directions for water quality monitoring. Targeted monitoring programs of the type I have discussed will continue to play a vital role in developing regulations and implementing environmental statutes. We will also be working to improve reporting of water quality through the Section 305(b) reports we receive from the states every 2 years. These reports summarize what we and the states know from a variety of sources including targeted monitoring, site-specific studies, and routine state monitoring programs.

We are currently addressing the issue of what information we as managers need to have about water quality and how our monitoring programs can help provide that information. In short, we cannot target future monitoring activities very well unless we know the specific regulatory and policy decisions we need to make 3 to 5 years from now.

Our approach for addressing this issue is to conduct two independent information management reviews for surface water and ground water. Both studies were initiated early this year and will produce results before the end of the year. I will describe briefly what we expect to accomplish with these two studies.

Ground Water

For ground water, the agency recently completed its Ground Water Monitoring Strategy. Ground water monitoring in the United States is in the early stages of development and is hampered by many problems, as has been pointed out by the Office of Technology Assessment. The strategy contains a cross-agency analysis of the need for and use of ground water data over 5 years and provides a blueprint or framework for guiding ground water monitoring to support decisions under hazardous waste, Superfund, drinking water, and other legislation. The agency is now implementing the strategy, including a specific list of both short-term and long-term actions.

The strategy establishes seven objectives for ground water monitoring activities:

1. Characterize the nation's ground water resources.
2. Identify new contamination problems.
3. Assess known problems to support regulatory development and standard setting and respond to site-specific problems.
4. Assure compliance with regulations.
5. Evaluate program effectiveness.
6. Improve data quality.
7. Develop a ground water data management system.

While actions are under way to implement all seven objectives, EPA is undertaking a special study to ensure that the objective of improving data management is achieved. This study will establish a baseline by asking questions such as: What regulatory, enforcement, and policy decisions require monitoring data? What are the uses of the data? Who needs the data? Using this baseline, the study will evaluate current data availability and accessibility against the target, or ideal situation. The goal of the study is to recommend how to reduce the gap between the current situation and the target where it is realistic and cost-effective to do so. The study is scheduled to provide recommendations by the end of this year.

Surface Water

Since 1977 when the Clean Water Act was amended to place emphasis on toxic pollutants, a major focus of surface water monitoring programs has been to provide data for the regulation and control of 129 priority pollutants in point source discharges. For example, the largest single national monitoring effort since 1977 has been to sample industrial effluents to help develop best-available technology (BAT) regulations for industries.

Now that much of this work has been completed, we are looking ahead to the decisions EPA and the states will be making under the Clean Water Act in the next 3 to 5 years. States will be deciding on water-quality-based controls in waterways where BAT controls are not adequate to meet in-stream water quality standards. EPA will be deciding whether standards and controls are needed for pollutants beyond the 129 priority pollutants. Both states and EPA will be enforcing compliance with existing discharge permits, and evaluating water quality results from control programs.

The Surface Water Monitoring Study currently under way is examining what kind of information we will need to make these decisions, and will recommend how monitoring programs can be improved to provide adequate support for the most important decisions. The study team is conducting extensive interviews with senior officials from EPA, three states, and several external organizations. The interviews review the actual use of monitoring data in today's decisions and focus on needs for future decisions.

When completed later this year, the surface water study will recommend an agenda for coordinated action within the agency to improve surface water monitoring support for decisionmaking.

CONCLUSION

We are looking forward to the analysis and recommendations from both surface and ground water studies, and fully expect that EPA's water quality monitoring programs will benefit substantially from these reviews.

In conclusion, EPA's goals for its water quality monitoring and assessments have changed substantially in recent years, from programs that often seemed only to be interested in getting as many data as quickly as possible, to programs that are targeted on specific issues, designed to meet data quality objectives, and committed to making data accessible. We recognize that these goals are not always fully attainable, but we believe they are very important to achieve. We have found that water quality monitoring programs need to be developed in the context of current or future environmental decisions that need to be made, and we are now in the process of reviewing current programs to ensure that this happens.

I look forward to obtaining as many ideas from you as I can about how monitoring and assessment programs can be improved, since I believe everyone benefits when we have better information available for environmental decisions.

6

A NATIONAL WATER QUALITY ASSESSMENT: FLORIDA'S PERSPECTIVE

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A National Water Quality Assessment should only be pursued if it will be truly useful to those who receive the information it provides. If it identifies water quality trends and helps environmental managers anticipate water quality problems, it will be useful; if it merely tells them what already has happened, it won't.

In this discussion of the need for and operation of a National Water Quality Assessment, I will describe Florida's experience with ground and surface water pollution, and how these problems were detected.

I also will describe steps Florida has taken, based on its experiences, to establish its own ground water monitoring network.

And finally, I will offer my view on establishment of a nationwide network for ground water and surface water monitoring.

GROUND WATER IN FLORIDA

Several years ago, we discovered serious problems with ground water contamination. Several examples of these problems--none of which were discovered by routine monitoring--clearly show the need for systematic monitoring programs.

- Aldicarb--The discovery of the highly toxic pesticide aldicarb in Florida's ground water in 1982 was our first indication that we had been taking our ground water for granted. News that Long Island's ground water was contaminated by the application of aldicarb to potato fields prompted Florida officials to investigate the ground water in Florida because of the extensive use of aldicarb on citrus groves, and the similarities between the hydrogeology of Florida and of Long Island.

Because of its toxicity, aldicarb is applied in diluted granular form to the soil. In the late 1970s, studies on the decomposition of the pesticide in the soil did not predict its persistence in ground water, but monitoring in Florida revealed a monitor well with 315 parts per billion of the chemical. The contamination seemed to have persisted for at least 2 years. Fortunately, only two contaminated drinking water wells were found, and levels were below 10 parts per billion, the recommended safe level for drinking water.

More recently, traces of aldicarb were detected in the Biscayne aquifer--the sole source of drinking water for Dade and Broward Counties (Miami and Ft. Lauderdale)--although none of the findings was above two-tenths of a part per billion. New samples will be taken as part of a 2-year study to determine how agricultural activity in a 147-square-mile area of southwest Dade County affects water quality.

- EDB--As a follow-up to aldicarb, the state began to test ground water for EDB (ethylene dibromide) in 1983. The pesticide was used extensively in Florida as a fumigant to control nematodes in citrus and other crops. Until it was first discovered in drinking water wells, EDB was not thought to be a threat to drinking water. It was supposed to evaporate readily, and to dissolve only slightly in water.

After the discovery of EDB in ground water, Florida immediately began a program to test wells in the high-risk areas--areas where EDB had been extensively applied and where we might expect to find it in the ground water. And we did. About 1,100 of the more than 10,000 drinking water wells we sampled were found to be contaminated.

- Gasoline--Gasoline is the number one polluter of ground water in Florida. We estimate that about 10 percent of the 60,000 underground storage tanks in the state are leaking, and the Department of Environmental Regulation is investigating 415 cases of gasoline contamination in ground water.

In 1982 the entire public water supply for the City of Belleview (near Ocala in North Central Florida), which served a population of 3,000, was shut down when gasoline was discovered in its water. The source was traced to a nearby service station that had lost approximately 10,000 gallons of gasoline several years earlier. Bellview was forced to abandon its wellfield and drill a new one at an estimated cost of $700,000. The contaminated ground water has yet to be cleaned up.

- Other Chemicals--Contamination of ground water by various other chemicals is second to gasoline. The department has compiled a list of 413 suspected and known sites with chemical contamination of the ground water. A site where ground water was contaminated by the actions of a state agency is a classic example of these kinds of problems. The site is near Fairbanks, north of Gainesville in North Central Florida, where the Florida Department of Transportation had used a sinkhole as a dumpsite. A DER-DOT investigation recovered and removed 1,046 drums, some of which had leaked and had contaminated some 50 private drinking water wells in the area. At a cost of several hundred thousand dollars, the DOT installed 34 monitor wells, and connected some 225 homes to alternative water supplies. Pumping of the aquifer and removing the volatile organics continues today.

FLORIDA'S GROUND WATER MONITORING NETWORK

Each of these contamination problems points out the need for systematic monitoring, geared toward discovery of problems that are specific to certain areas. Of course, a monitoring system is only as good as what it is designed to find. We are now developing a monitoring network in Florida that not only will establish background water quality for each of the three major aquifers in the state, but will detect or predict changes in ground water quality from point and nonpoint sources of pollution.

A major consideration in the establishment of a monitoring network for pollution sources is that it provide data that are specific to the aquifers and to the characteristics of an area. Site-specific data will be used to analyze trends in water quality as they relate to variables in hydrogeology, land use, and the location of pollution sources. The analyses ultimately will be planning tools to help local governments develop land and water use plans--traditionally done by local governments without the benefit of site-specific water quality data.

The other part of the state's overall monitoring network watches the background quality of ground water. The state has defined major aquifer systems and their recharge areas, the cones of depression around major wellfields, areas of saltwater intrusion, and the location of wetlands, springs, sinkholes, and free-flowing wells. This information will be put to good use in fine-tuning the monitoring network and the adoption of regulations to protect unique and sensitive aquifers.

THE NATIONAL WATER QUALITY ASSESSMENT FOR GROUND WATER: FLORIDA'S VIEW

Florida's monitoring program produces both background water quality data and pollution source data that are specific to certain areas, and that take into consideration the differences between the areas. Florida probably has little practical use for a National Water Quality Assessment for ground water. I am quite skeptical that such an assessment could provide the site-specific data Florida produces and needs. But I do have some specific suggestions for current national programs and on what the federal role should be for data collection and analysis.

- EPA's STORET system--This computerized data base has been of little regulatory use to the state as far as ground water is concerned, although our surface water program does use it. It is cumbersome and does not lend itself to data manipulation or analysis. It is designed primarily as a surface water data system, but the USGS periodically feeds ground water data into it.
- WATSTOR--On the other hand, WATSTOR has potential for ground water if the USGS could modify it to make it more pollution oriented. As it stands now, it is designed to store basinwide, largely geophysical, data about the nation's aquifers, with such parameters as the water level, temperature, and salinity. Though useful, these are not very helpful for evaluating the effects of pollution sources on water quality. The USGS recognizes this deficiency and plans to redesign WATSTOR.

As one suggestion, it might be helpful to reorient the U.S. Geological Survey slightly by changing its charter to make it a more involved and environmentally oriented agency that can provide states and the Environmental Protection Agency with more useful data about the nation's resources.

I question whether a federal water quality assessment will be useful to Florida--or to any other states--unless it is carefully designed to be flexible. By flexible, I mean that it must be changeable to meet the changing needs of the states in the various regions of this tremendously variable nation. Here, I am not referring to the artificially created regions of the federal government, but to regions of the country in the geographic, economic, and geologic sense.

It will do Florida little good if a rigid and inflexible system is designed that does not let us sample for contaminants that are used in the southeastern United States, at the depths most commonly used by public and private drinking water wells, at the concentrations needed for our specific regulatory programs, and taking into account specific regional and local differences in geology.

I repeat: a national water quality assessment will be useful only if it can identify trends and predict problems--trends and problems that are of interest to those who use the system.

Florida feels that the Geological Survey and Environmental Protection Agency roles in data collection and analysis might be to help states develop state-specific, and aquifer-specific, ground water monitoring networks similar to the Florida monitoring network. They also might help us with sampling and analysis procedures, and with special projects. We all can use technical support in the form of personnel, laboratory and computer services, mapping, and coring and drilling capabilities--or the funding to allow us to acquire these capabilities. The states should then be allowed to operate water quality programs that meet their individual needs, with assistance from the federal agencies.

Local programs may be involved in a subcontractor capacity to the states. A state-controlled program is necessary, however, if uniformity, quality control, and adequate basinwide analysis of data are to be provided.

SURFACE WATER IN FLORIDA

Two surface water pollution-related problems also were not discovered by routine monitoring, which, traditionally, is effective for detecting conventional problems, but falls short in detecting or explaining the more unconventional problems. Again, if you do not know to look for something, you would not find it.

- Ulcerative Fish Syndrome--Commercial and sport fisherman in the Jacksonville area last year began to report catches that included numerous fish with unusual lesions on their bodies. Specimens of fish with the disease also have been found in waters near Tampa Bay, and elsewhere on the Atlantic seaboard. The cause is unknown. A fungus appears to cause the degeneration of the fish's flesh, but we do not know whether the fungus causes the disease. The department has prepared a contract with the University of South Florida to perform a 1-year, $50,000 study that we hope will help us find the cause.
- Loss of Seagrass--In the last few years, we have noticed a decline in the extent of seagrass beds throughout Florida--not counting areas we can easily explain, such as those lost to dredge and fill operations and to other point sources. We have not been able to determine the exact cause for the decline through routine monitoring, although we suspect it is related to water quality.

Both of these examples indicate the need for a more regional approach to surface water quality monitoring, with an increase in the number of parameters studied. They also suggest an entirely different level of monitoring, such as ecosystem monitoring, which would include analysis of sediments for heavy metals and hydrocarbons. The monitoring should be for both chemical and biological parameters. Of course, we all realize the expense and complexity of this proposition.

NATIONAL WATER QUALITY ASSESSMENT FOR SURFACE WATER: FLORIDA'S PERSPECTIVE

I now will turn to Florida's view of the need for and limits of a national assessment for surface waters.

- Information needs and uses--If the assessment were conducted through a regional approach, as I think it should be, states could use the experience of others to anticipate their needs, and to evaluate various control and clean-up strategies. But, of course, the value of the data would depend, in part, on the degree of similarity between the resources in each state, or in the region.

The assessment also would help coordinate efforts on issues that affect interstate waters. When it was applicable, Florida would use the information for regulatory purposes, and the data could be integrated with other water quality information for planning and decisionmaking.

- Limits--Current programs are inadequate in coverage--both spatially and in the number of parameters treated for. For instance, programs that deal with nonpoint source control (stormwater) frequently address only sedimentation problems, and ignore nutrients, metals, and oils that are discharged with the sediments. In Florida, we also find more and more often that we need information on toxic materials in the environment.
- Biological monitoring--particularly for the larger organisms, the fish and the shellfish--is needed to add to our picture of the health of an area. We need to be able to assess population balance as well as know the kinds and amounts of materials that are stored in tissues.

And the fact that marine waters are proposed to be excluded from the assessment, would limit its use for Florida, where we have a sizeable need for hydrographic information. Also, for the assessment to be useful to Florida--and this is of special importance--it must have consistent quality assurance and quality control.

There also are problems with the speed of processing data and in ready access to information. States have had to devise their own methods to obtain and evaluate information. This results in disparities in decisionmaking and in perceptions of success or failure of control strategies. Finally, we must schedule the sampling rotation to provide us with information to track conditions in Florida--a fast-growing state where those conditions can change rapidly. Changes over even a brief period could make even the best information useless in a very short time.

SUMMARY

I certainly commend the Geological Survey for its interest in a national assessment for ground and surface water. There is no doubt the nation needs a wealth of good data for local, state, and federal decisionmaking. But as I have indicated, a regional approach seems more practical for both ground and surface water.

Also, the set of parameters tested for needs to be broader than it is presently, as shown by my examples on the diseased fish, and the state's experience with exotic chemicals in its ground water. In surface water, there should be added emphasis on biological sampling, and I believe we should concentrate more heavily on sampling for toxics in both surface and ground water.

For ground water, I believe the assessment would draw more on the state's data than the other way around. The Geological Survey plans to take immediate measures to expand its information base on ground water. Data for this can be taken from Florida's ambient network, its central repository system--which is to contain all historic data that various local, state, and federal agencies have acquired--and from the state's pollution source subnetwork.

An ambient network will help Florida only if it anticipates, explains, or helps prevent such problems. We will welcome help with our water quality monitoring programs from the federal government--but only if it meets those requirements.

7

WATER QUALITY ASSESSMENTS: A PRIVATE SECTOR PERSPECTIVE

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This paper focuses on the need for high-quality environmental data in water quality surveys. This is needed for private industry's planning uses and as a guide for effective rules and regulations. Without high-quality data, poor or controversial decisions often result. Recent ground water data-gathering efforts illustrate this point very well. The value or impact of environmental data for the private sector depends upon the quality of the science that is brought to this very difficult problem. Even when data have a large standard deviation, when the data have been gathered in an open, cooperative, scientific atmosphere, the data have been accepted as the baseline from which to make decisions.

Private industry's needs for water quality assessment are coincidental with good public policy. Industries in the United States, as a fact of life, consider the impact of their activities on the environment. Certainly, the passage of the Comprehensive Environmental Response and Compensation Act (Superfund) has dispelled any notion that mere compliance with existing law will shield one from future responsibility. Beyond the liability questions, individuals in the private sector in this country are part of the society. Like the rest of society they want to protect our environment. Many major companies have policies that protect the

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The author would like to thank the EPA's Technical Support Division in Cincinnati and the Department of Rural Sociology of Cornell University for their help in understanding the planning that went into the surveys. Particular thanks go to Frank Westrick (EPA) and Joe D. Francis (Cornell).

environment--regardless of the existing laws. In this vein voluntary actions such as cooperative oil spill clean-up coops by the oil industry, chemical awareness and emergency response efforts of the chemical industry, and erosion control efforts in the forest products industry are becoming more and more frequent.

Most good decisions are based on good information. Conversely, bad or poor information can lead to bad decisions. Because assessing the meaning of environmental information is often difficult, laws and regulations are too often controversial. Similarly, the siting or planning decisions made internally by private industry are not as obvious as we would like. The better the data, the easier all of these actions become. Data gathered for expediency are actually of negative value.

A good example of solid environmental data is the nation's ambient air quality monitoring network for priority pollutants (Air Pollution Control Association, 1985). This objective has been clearly defined. A rigorous quality assurance and quality control program is in place. The entire program is a cooperative, scientific endeavor. All results are published and open to the scrutiny of peer review. In short, we know: what we are measuring, how we are measuring it, and how confident we are of the answer. Even though we all admit it is not perfect, and we may not even like the results, we all agree on what the facts are. For the air, cooperative government-industry studies are becoming the starting point for problem solving. For instance, major joint efforts are now under way in Southern California, the Gulf Coast, and California's San Joaquin Valley to assess the critical factors in providing clean air. Experience with the air issues has shown that the best studies are open to scrutiny by everyone concerned. From our experience with air studies and ground water studies, the following elements stand out as the foundation of quality information:

- The objective(s) should be clearly defined.
- The population that is to be measured should be clearly described.
- The quality of the data should be measured and reported.

The following example provides specific insight into how companies may use good data. In 1981-1982 Chevron, U.S.A. conducted a survey of its underground gasoline storage tanks. The results of the survey provided a statistical basis for predicting which tanks had a high probability of failure. Using this information, Chevron proceeded on a voluntary $125 million nationwide tank integrity program. The program was justified and the priorities set by the results of that survey. It allowed a reasoned timely response to an emerging environmental problem.

Similarly, a major pesticide manufacturer has made plans to prove its new product will not become a major ground water contaminant. While no such requirement exists under law, the experience from nationwide monitoring for pesticides has highlighted those chemical properties that seem to make a chemical a potential contaminant. Comparing these properties to those of a new chemical allows a developer to predict the likelihood of contamination.

How do we obtain these good data? The first step is to examine the lessons of the past. Let us examine some recent nationwide and state assessments of ground water quality and how the results have been applied to industry. From the experience of these surveys some general rules arise on how to better do these assessments from industry's perspective. As these surveys have taken place, there has been a sequential learning process, and each has been better than its predecessor.

The Nationwide Statistical Assessment of Rural Water Conditions (Cornell University and EPA Office of Drinking Water, 1984a) was mandated by the Safe Drinking Water Act of 1974. The stated goal of this survey was to assess the "quality of the nation's rural water supplies." EPA and members of the Department of Rural Sociology at Cornell University participated in the planning process. The population of wells to be sampled was determined through a random statistical selection process. The actual water sampling and description of the location were carefully designed and tested. The planning began with Cornell's reviewing the available information and existing methodology for undertaking such a study. From this review emerged a plan. The plan was reviewed, pretested, and finally approved.

The methodology for selecting the locations was an excellent model for future work. The survey statistically chose the sample population to be measured. A rigorous definition of rural water supplies was developed and documented. The sample was then representative of these populations in four regions, in standard metropolitan statistical areas, and the population of the area. The results were representative of an estimated 21 million households. Each separate breakdown category was weighed by standard statistical methods to be representative of its fraction of the total sample. The planning was flawless. However, the quality of the analytical data is unknown. The results of the quality assurance/quality control (QA/QC) program were not available (Cornell University and EPA Office of Drinking Water, 1984b).

The plan itself required personal interviews with the occupants of the dwellings served by the water supply. A visual inspection was conducted of the system prior to sampling. Professional survey takers were employed and underwent an intensive 2-week training course prior to the start of the survey.

The results of this study are important. Table 7-1 shows the percent of wells that exceeded the drinking water standards (MCLs). Over 60 percent of the wells sampled exceeded one and 30 percent exceeded at least two of these standards. This information could have had profound influences on public policy. Instead, publication was delayed, and the data have been of limited use--either to industry or government. Where did it go wrong? The quality of the data was not established. One can only assume the cost of QA/QC was sacrificed in favor of more samples. Consequently, though the data lead to a major conclusion, they have had little impact on governmental decisions or industrial planning. No one knows if the analytical results are correct. The quality of the data <u>must</u> be measured and reported. Given the large costs of conducting major surveys today ($5-10 million), they should all be done as well as possible--or not at all. Dollars saved on QA/QC can invalidate an entire survey. Time saved by shortcutting the planning process can lead to information of only limited value.

The Ground Water Supply Survey (GWSS) was the second of the nationwide water supply surveys (Westrick et al., 1984). The objective of the survey was to measure the extent of contamination by VOCs of the nation's ground water. Because the survey attempted to measure extremely low levels of substances, this survey did have a rigorous QA/QC program. The selection of the population of water

TABLE 7-1 National Rural Water Quality Survey Results

Category	Constituent	Has Primary (P), Secondary (S), or No (N) MCL	Percent of Rural Households Exceeding Standard
Microbial	Total coliform	P	29
	Fecal coliform	N	12
	Standard plate count	N	19
Physical and chemical	Turbidity	P	17
	Color	S	2
	Total dissolved solids (as determined from conductance)	S	15
Inorganic	Calcium	N	
	Magnesium	N	0
	Nitrate-N	P	3
	Sulfates	S	4
	Iron	S	19
	Manganese	S	14
	Sodium	N	14
	Lead	P	17
	Arsenic	P	1
	Selenium	P	14
	Fluoride	P	3
	Cadmium	P	17
	Mercury	P	24
	Chromium	P	0
	Barium	P	0
	Silver	P	5
Organic	Endrin	P	0
	Lindane	P	0
	Methoxychlor	P	0
	Toxaphene	P	0
	2,4-D	P	0
	2,4,5-TP	P	0
Radioactive	Gross alpha	P	1
	Gross beta	P	0

SOURCE: Cornell University and EPA Office of Drinking Water (1984a).

wells to be sampled originally was intended to be a representative sample of the nation's ground water used for drinking water. Selection was based on random selection from EPA's municipal water system data base. However, to enlist the aid of the states to help with the actual sampling, half of the systems were selected by the states. There was no guarantee state selection was random--rather, the expectation was that the states' selection process was directed to those systems most likely to be contaminated. This decision limited the statistical power of the survey.

As mentioned, this survey did include an extensive QA/QC program. This program called for the employment of reference, duplicate, and blank samples. However, the details of this part of the program have never been published or open to critical scientific review. Unfortunately, most of the levels of detection in this survey were very low (0.1 to 0.5 ppb). At this level random error becomes important. The significance of this error was not described in the report of the results. The survey report has avoided the key question of data reporting--the quality of the data.

The American Chemical Society's Committee on Environmental Improvement's "Principles of Environmental Analysis" defines the limit of detection as a method of detection that can be statistically differentiated from (blank) sampling noise 99 percent of the time (Keith et al., 1983). Examination of the sheer number of samples in the GWSS puts this into perspective. The survey population was made up of 945 samples, each analyzed for 29 volatile synthetic organic chemicals for a total of over 27,405 individual results. Even a small percentage of false positives leads to a large number of apparent detections.

Figure 7-1 shows the expected results of the GWSS if a random false positive result is one percent for each of the 29 VOCs. This is contrasted in the figure to the reported results from the random portion of the GWSS. Given that these are "real world" samples and not reference samples, one percent is not an unreasonable number of false positives. For example, samples of Lake Tahoe water were found to yield false detections about 20 percent of the time when analyzed for VOCs (Armstrong and Carlton, 1984). A closer reading of the GWSS shows when "37 supplies were resampled from the original point, 25 occurrences in the original sample did not recur in the resample." Nevertheless, these results have been used to

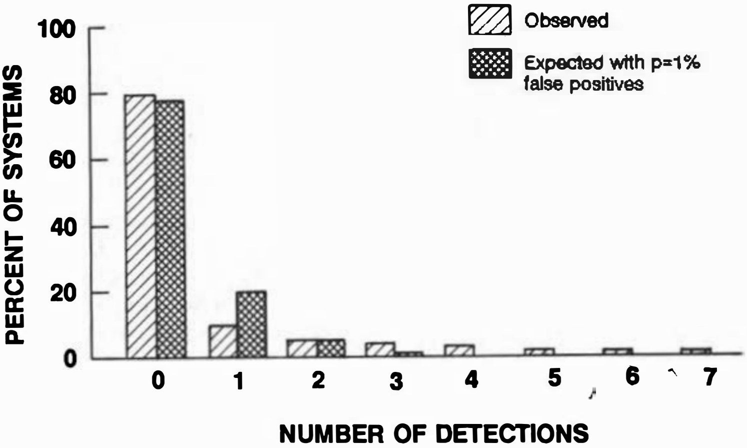

FIGURE 7.1 Results of EPA nationwide survey for volatile chemicals in ground water.

justify broad public policy decisions (Fed. Reg., June 12, 1984, volume 49, number 114, pages 24330-24354). Recommended maximum contaminant levels (RMCLs) or drinking water standards under the Safe Drinking Water Act have been set for nine VOCs in part based on the need demonstrated by this survey. Whether correct or not, this survey provided impetus for a major rule making. This rule making led to much debate and a large sink for the resources of both industry and government (Fed. Reg., November 13, 1985, volume 50, number 219, pages 46880-46901).

Another type of survey was the interpretation of ground water monitoring reports undertaken under the Resource Conservation and Recovery Act (RCRA). These data have been used to justify further enforcement of "recalcitrant industry," attack EPA for improper attention to a national problem, and force devotion of incalculable resources to the problem.

However, the data are in at least one aspect flawed. The statistical test designed for RCRA monitoring was based on a year of quarterly sampling (Code of Federal Regulations, Part 264, Appendix IV, and Part 265, Appendix V; Robert P. Bedel, Office of Management and Budget, to Milton Russell, Office of Policy, Planning and Evaluation, EPA, personal communication, December 16, 1985). Results from four quarters were to be averaged and compared to the wells' downgradient from the facility. However, the test did not consider the variations in water quality with time, i.e., seasonal fluctuations. Because of the unanticipated degrees of statistical freedoms, many, if not most, of the reporting facilities failed the Student's t-test. It is general knowledge that the test is flawed, but it is too late for industry. Its use has triggered resampling, negotiations, and consultation as a minimum. This waste could have been avoided if the test had been tested <u>before</u> it was applied nationally.

An example of a survey that has benefitted from this learning process and is useful to both government and industry is the monitoring program conducted by the California Department of Health Services (DHS) under Section 4026.2 of the California Health and Safety Code. This is the so-called A.B. 1803 survey (California Department of Health Services, 1985; Khalifa et al., 1983). The planning process for this program took almost 2 years. The sampling, quality control, and data analysis have been exemplary.

The goal of the survey was to determine the frequency of contamination of California's large municipal water systems by organic chemicals. Large water systems were defined as those greater than 200 users. Each system was classified as to the type of contaminants most likely to be found. Each system then submitted a sampling plan, which was reviewed and approved by the DHS. A representative sample of the water system was required--no less than 25 percent of the wells. The owner of the system was then required to carry out the plan. The DHS established criteria for certifying laboratories and monitoring QA/QC throughout the program. Any detection was resampled and reanalyzed. This eliminated the question of false positives.

Table 7-2 provides a summary of the data. The results of the survey have not been major new problems or programs--rather, the result has been a much clearer picture of where industry and government should focus to prevent contamination. Certain chemical classes are more likely to be in ground water (Bishop, 1985). And of these classes, only those chemicals with certain properties are likely to represent a general threat to the nation's ground water. A program such as this can lead to a better allocation of resources by all concerned parties. Indeed, such a monitoring scheme is now proposed nationwide for reauthorization of the Safe Drinking Water Act (Safe Drinking Water Act Amendments, 1986).

Table 7-3 provides the frequency with which individual chemicals were detected. Surprisingly, very few currently registered pesticides were found in the California Large Water System Survey. Nevertheless,

TABLE 7-2 Summary Data from California Large Water System Survey

Systems sampled	819
Wells sampled	2900
Wells with confirmed positives	18%
Systems exceeding DHS action level	6%

SOURCE: California Department of Health Services (1986).

TABLE 7-3 Results from California A.B. 1803 Survey (15 most frequently found contaminants)

Chemical	Number of Detections
Perchloroethylene	138
TCE	118
Chloroform	86
1,1,1-Trichloroethane	38
DBCP	36
1,1-Dichloroethylene	35
Carbon tetrachloride	29
1,2-Dichloroethane	16
Bromodichloromethane	15
1,2-Dicholoroethylene	12
Bromoform	8
Dibromochloromethane	8
Atrazine	7
Simazine	7
Freon-13	6

SOURCE: California Department of Health Services (1986).

DBCP, EDB, Aldicarb, and other pesticides have been found in California ground water. Understanding the magnitude of pesticide contamination is a very difficult problem. Many states have extensive ongoing programs to sample their ground water (Holden, 1986).

Surveys for pesticide contamination have typically focused not on random sampling of ground water, but on directed sampling of wells suspected of contamination. The results of these surveys have been presented as representative of the underlying aquifers as a whole. This has misled much of the public to believe pesticides threatened much of the nation's water supplies (Center for Communication Dynamics, 1985). Indeed, more careful examination is leading to a logical way to predict the location of pesticide problems (Kerr, 1985).

The California Department of Food and Agriculture has conducted a survey that was intended to determine quality of the major basins (Weaver et al., 1983). The CDFA survey was designed to determine the frequency of contamination of California ground water in the four major ground water basins shown in Figure 7-2. Four

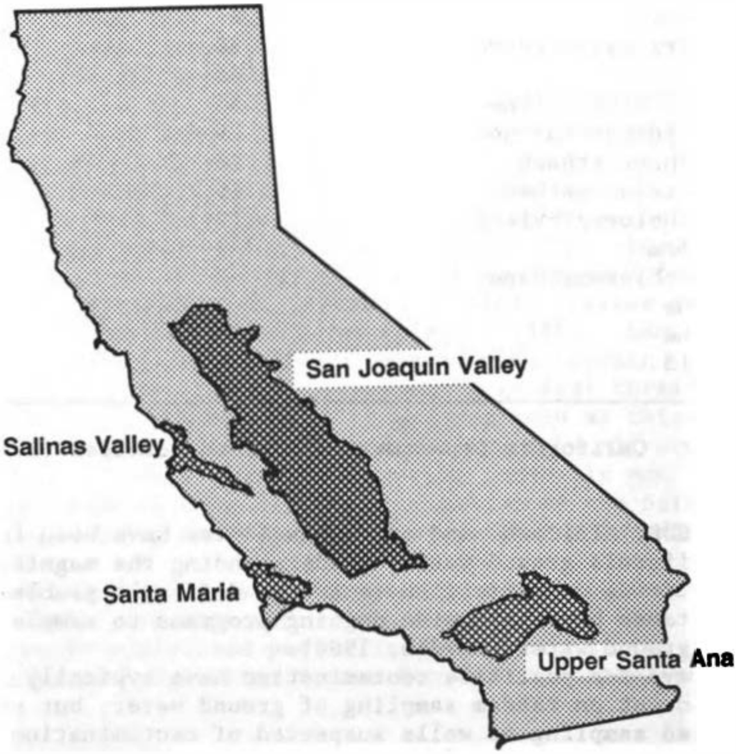

FIGURE 7.2 **Ground water basins.**

SOURCE: **Weaver et al. (1983).**

representative pesticides were selected: DBCP, EDB, Atrazine, and Carbofuran. The survey divides each basin into 36 square-mile sections and locates a well in a representative location for that section. Strict quality control was maintained on the sampling and analytical program. The results show that limited contamination has occurred; primarily by DBCP and EDB, which were injected into the ground.

Indeed, experience in nationwide monitoring is beginning to emerge into a pattern. Agricultural chemicals with certain physical properties are found in certain hydrogeologic conditions (Council for Agricultural Science and Technology, 1985; Cohen et al., 1984).

There has been a steep learning curve in conducting surveys (U.S. EPA, 1985). The goal is to determine how widespread pesticide contamination is across the country. Using the surveys discussed here as a guide, the following outline would provide quality information for industry and the nation. Many of these points are discussed in more detail in the <u>Guidelines for Determining the Presence of Agricultural Chemicals in Groundwater</u> (National Agricultural Chemicals Association, 1985).

Objective: First, the objective should be clearly defined: "With what frequency are pesticides found in representative ground water?" or "How many drinking water wells in rural communities have detectable levels of pesticides?"

Planning: The planning should take advantage of data already gathered. The plan should be tested and then finalized. The Rural Water Supply Survey was an excellent model.

Sample Population: Counties should be selected to be representative of different agricultural areas. The counties should be weighed in proportion to their population. The specific location should be selected as representative of the county. Finally, the distribution versus depth should be determined. EPA is currently working with the USGS and others to design such a system.

QA/QC: Following the GWSS the survey should use blank, duplicate, and spike samples. As in the California Survey, detections should be resampled and reanalyzed. Failing this, there will be a number of detections simply from the sheer number of samples--as apparently was the case in the EPA's GWSS survey.

Data Analysis: The statistical representations and error analysis should be presented.

Peer Review: The entire process should be open to peer review. The survey will be the basis for far-reaching decisions and deserves the best science that can be applied to the problem. The ongoing cooperative efforts in the air programs serve as an appropriate model.

The results would then be useful to all developers and regulators of agricultural chemicals. By looking at which chemicals were found in what locations, simple rules may result. Planners could avoid marketing certain chemicals in vulnerable areas. Management practices could be applied to minimize the expectation of residues reaching the ground water.

In conclusion, industry can and will use scientific data on water quality in a host of planning functions. The key to this effort is working together and learning from the mistakes of the past. Water quality surveys are very difficult. But when done together as rigorously as possible, they serve as an excellent base for decision making. The results will allow industry and government to focus their attention on true problems--existing and potential. This benefits us all. Industry can make better decisions. Regulators can protect the environment at less cost to industry, and the public is ultimately the better served.

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APPENDIXES

APPENDIX A

BIOGRAPHICAL SKETCHES OF PRINCIPAL CONTRIBUTORS

William C. Ackermann is a civil engineering graduate of the University of Wisconsin. He holds D.Sc. degrees from Northwestern and Southern Illinois Universities. He has been employed by the Tennessee Valley Authority, the Agricultural Research Service, and the Office of the President, and was Chief of the Illinois State Water Survey from 1956 to 1979. From 1979 to 1985 he was adjunct professor of civil engineering at the University of Illinois and is currently professor emeritus. He is active as a consulting engineer and is a member of the National Academy of Engineering, the Lincoln Academy, and numerous societies.

K. C. Bishop III received his B.S. degree in chemistry from the University of California at Santa Barbara and his Ph.D. from Yale University in 1973 for his work on the metal catalyzed rearrangements of small ringed hydrocarbons. After postdoctoral work at Stanford, he joined Chevron Research Company in 1974. His research projects were primarily in the area of catalysts and sulfur control. In 1981 he joined the Environment and Health Protection Staff of Chevron Chemical Company. In this position he organized Chevron's program for hazardous waste site cleanup, instituted RCRA's ground water requirements, and coordinated pesticide ground water issues. He has recently joined the Government Affairs Staff as policy coordinator for environment and health issues including ground water, pesticides, community right to know, and emergency response.

Keros Cartwright is geologist and head, General and Environmental Geology, Illinois State Geological Survey, and adjunct professor of geology, Northern Illinois University. He received a Ph.D. in geology from the University of Illinois at Urbana-Champaign. He was a geologist on the Humboldt River Project for the State of Nevada, the U.S. Geological Survey, and the U.S. Agriculture Research Service from 1959-1961. He was visiting professor of geology at the University of Waterloo in 1976. He has been a consultant in hydrogeology on problems associated with waste disposal to both government agencies and private corporations in the United States and in Canada.

Richard S. Engelbrecht received his A.B. from Indiana University and his M.S. and Sc.D. from Massachusetts Institute of Technology. He has been on the faculty of the University of Illinois at Urbana-Champaign since 1954. He is a professor of environmental engineering and has distinguished himself in the field of water pollution research and water quality control. He is a member of the National Academy of Engineering and was a member of the National Research Council's Water Science and Technology Board.

Lawrence J. Jensen was nominated by President Reagan to be the assistant administrator for water at the Environmental Protection Agency in September 1985. At the time of his nomination, he had been serving as an associate solicitor at the Department of the Interior, where he dealt with water rights, public land management, mineral leasing, and Indiana law issues. He received his law degree from Brigham Young University in 1976 and came to Interior from a private law practice in Salt Lake City, Utah.

Gerald T. Orlob has professional experience equally divided between civil engineering education, research, and consulting practice. He holds a Ph.D. from Stanford University in hydraulic engineering; he has been concerned with the development and application of mathematical models and systems analysis in environmental management, primarily related to the hydrodynamics and water quality of natural systems; he founded and developed a consulting engineering firm, Water Resources Engineer, Inc. At present, he is professor and chairman of the department of civil engineering of the University of California, Davis.

Jacob Rubin received a Ph.D. in soil physics from the University of California, Berkeley. From 1962 to present he has been research soil scientist, National Research Program, U.S. Geological Survey, Water Resources Division. He conducts and supervises research on water flow in unsaturated porous media and on transport of reacting solutes in sediments and soils. Since 1974 he has been a consulting professor at Stanford University, where he has taught and also supervised Ph.D. students. He has been consultant to the Ministry of Agriculture of the governments of Israel and Italy.

Victoria J. Tschinkel was appointed secretary of the Florida Department of Environmental Regulation in 1981. Prior to that, she served as assistant secretary in various other management positions with the agency, starting with its creation in 1975. She is a zoology graduate of the University of California, Berkeley. Her entire career has been spent in environmental work, including positions in teaching and research before joining Florida's state government in 1974. She has served on numerous state and national advisory boards and committees, including appointments to the U.S. Department of Energy Advisory Board, the National Research Council's Space Applications Board, the EPA's Toxic Substances Advisory Committee, and the Florida House Speaker's Water Task Force.

APPENDIX B

ATTENDEES AT COLLOQUIUM

WILLIAM C. ACKERMANN, University of Illinois, Urbana
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PAUL BUSCH, Malcolm Pirnie
PAUL CAMPANELLA, U.S. Environmental Protection Agency, Washington, D.C.
CAROLE B. CARSTATER, National Research Council
KEROS CARTWRIGHT, Illinois State Geological Survey
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SHEILA D. DAVID, National Research Council
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