Going Against the Current: Expanding the Inland Aquatic Monitoring Culture of Federal and State Agencies

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ABSTRACT

My interest concerns the design of lake and stream monitoring programs implemented by federal and state agencies in response to the Clean Water Act. Past, and most current, monitoring designs select sites using judgement criteria. Such designs provide valuable data for assessing impacts of point source discharges. The Clean Water Act also requires a national assessment of all waters within the United States. The assessment is accomplished by compiling information obtained from state monitoring programs. Such data do not provide a defensible assessment. An impetus for change began in the late 1980s. The U.S. Geological Survey and the U.S. EPA initiated two independent programs: the National Water Quality Assessment program (NAWQA) and the Environmental Monitoring and Assessment Program (EMAP). These programs use two different scientific approaches for monitoring. In addition, States have competing monitoring requirements. When the academic community's scientific research perspective is added, the result is a natural adversity among the groups. The paper discusses the underlying cultural conflicts associated with monitoring and present mechanisms that have been used to expand the culture, especially with states.

Introduction

The United States interest in water quality began in the late nineteenth century with a now obscure law called the Rivers and Harbors Act of 1899. This law remained the principal basis for protection of water quality until the mid-twentieth century. The Water Pollution Control Act of 1948 (P.L. 80-845) provided the first federal funds for state water pollution control programs and started subsidies for the construction of sewage treatment plants. A key aspect was that all the details were left to the states. This process continued under the Federal Water Pollution Control Act of 1956 (P.L. 84-660) with increasing commitments in 1961 (P.L. 87-88), 1965 (P.L. 89-234), and 1966 (P.L. 89-753). For the most part no enforceable standards were imposed. In 1965 Congress created the Federal Water Pollution Control Administration and required the states to develop water quality standards for interstate waters. Adler et. al. (1993) state that "even then, enforcers had to prove that a particular polluter caused violations of these instream standards - no small task given the primitive state of water quality monitoring and science and the crowd of dischargers to most polluted waters."

An event on June 22, 1969, dramatized the state of water pollution at the time - the Cuyahoga River in Cleveland, Ohio, burst into flames, fueled by oil and other industrial wastes. In 1972, Congress passed the Clean Water Act, overriding President Nixon's veto. Significantly, the act begins with a statement of underlying visions and goals. Congress declared, "The objective of this Act is to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." For the first time, Congress framed the issue in terms of the entire aquatic ecosystem, not just chemical pollution. The Act also insisted that we restore and maintain aquatic ecosystems, and that we actively protect waters that were currently clean. The Clean Water Act was significantly modified in 1977 and 1987. Section 305(b) of the Clean Water Act mandated that the states monitor their waters and report their findings to EPA. EPA was required to submit the findings in a National Water Quality Inventory to Congress every two years. Hence a basis exists in the Clean Water Act for national statistics on the status of aquatic ecosystems.

Aquatic Monitoring 1960-1988

Monitoring of lakes and rivers during the period 1960-1988 can be characterized as follows. First, site selection was dominated by judgment selection of fixed sites. Since states were directly responsible for monitoring, their monitoring programs reflected their major priorities. Consequently, compliance monitoring of point source discharges constituted the primary objective of monitoring. Compliance monitoring initially focused on monitoring water quality in streams or lakes near point discharges. Subsequently, dischargers were required to monitor effluent directly, prior to its discharge. Regulatory monitoring related to drinking water was also a focus. Public and private drinking water facilities were required to monitor the chemical quality of their finished water.

Beginning in 1972, the states also were required to provide reports to US EPA for its biennial report to Congress on the status of aquatic waters in the United States, informally termed the 305(b) report. The 305(b) report provides estimates of the number of stream miles, lake area, and estuarine area that meet specific designated beneficial uses. Designated uses include aquatic life support, fish consumption, shellfish harvesting, drinking water supply, primary contact recreation swimming, secondary contact recreation, agriculture, ground water recharge, and wildlife habitat. Section 305(b) of the Clean Water Act requires that the states biennially survey their water quality for attainment of designated beneficial uses. EPA's Office of Water provides guidelines to states on the information to be reported and also funds monitoring by the states (USEPA 1995). The process over the years can best be described as quasi-laissez-faire with EPA providing general guidelines to States. Consequently, the national report is a collection of information that can not be easily compared across states or from one report to the next. Adler et. al. (1993) report that "the percentage of waters assessed varies wildly among states", rarely is sampling done.

In 1987, the Clean Water Act increased its focus on the National Pollution Discharge Elimination System (NPDES) permitting process. These permits are supposed to be based on a detailed total maximum daily load (TMDL) and wasteload allocation, which take into account information about all sources of a pollutant into a given receiving waterbody. Section 303(l) institutes a listing of all state waters that fail to meet water quality standards or otherwise do not support designated uses. The TMDL process requires monitoring data to support its implementation and has been the cause of significant monitoring activity by the states.

During this period, state agencies and US EPA focused on monitoring the impacts of point sources to aquatic systems, i.e., compliance monitoring. This period can be characterized as a period of inadequate and inconsistent monitoring at all levels. Many individual point source discharges were adequately monitored for contaminants.

Impetus for Change

In the late 1980s several changes in our approach to monitoring began to take place in the United States. One major change was an increased interest in the biological or ecological condition of lakes and streams. Another was the realization that it was not feasible to monitor all lakes and rivers in the United States. This realization was partly the result of states being faced with declining funds with which to conduct monitoring.

Two major federal initiatives had their beginning in the late 1980s: the National Water Quality Assessment program (NAWQA) and the Environmental Monitoring and Assessment Program (EMAP).

In 1991, the U.S. Geological Survey began the NAWQA program. NAWQA provides consistent and comparable information on water resources in 60 of the largest and most important hydrologic systems in the United States. It covers about one-half of the conterminous United States and approximately 60-70% of national water use. The program focuses on 20 units at one time with each unit proceeding through three phases: initial planning and retrospective analysis of existing data (2 years), intensive data collection and analysis (3 years), and report preparation and low-level assessment activity (6 years). One third of the 60 units are in the intensive phase at any given time. The objectives of NAWQA are (Helsel 1995): "To describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers and aquifers. To describe for those areas how water quality is changing over time. To improve understanding of the primary natural and human factors that affect water-quality conditions." The stream sampling design focuses on selecting sites to represent the major land uses and physiographic regions. A combination of fixed sites and synoptic surveys are used to collect data appropriate to the building of relational models of water-quality and environmental factors. The models form the basis for generalizing the results to entire geographic regions. No attempt is made to estimate the stream length that meets specific designated uses or other criteria.

EPA's Environmental Monitoring and Assessment Program (EMAP) began in 1990 as an interagency, interdisciplinary program that would contribute to decisions on environmental protection and management by integrating research, monitoring, and assessment. EMAP's goal was to monitor and assess the condition of the ecological resources of the United States. To accomplish this goal EMAP proposed (1) to estimate the current status, trends, and change in the extent of selected indicators of the Nation's ecological resources on a regional basis with known confidence and (2) to seek associations among selected indicators of natural and anthropogenic stresses and indicators of condition of ecological resources. The intent was to provide annual reports on regional status. (Messer et. al. 1991). The program was designed to address the information needs for EPA's relative risk paradigm (Thornton et. al. 1993).

EMAP has evolved into a research program to develop the tools necessary to monitor and assess the status and trends of national ecological resources (USEPA 1997). EMAP's research goal is to develop the scientific understanding for translating environmental monitoring data from multiple spatial and temporal scales into assessments of ecological condition and forecasts of the future risks to the sustainability of our natural resources. A major part of the program is the conduct of large-scale regional geographic studies. These studies, lasting approximately five years enable researchers to investigate new monitoring methods at these scales and to provide monitoring data that are used in regional assessments of the status of the ecological systems. Major emphasis now is given almost exclusively to inland aquatic and estuarine ecosystems and to landscape analyses.

In 1992 the Intergovernmental Task Force on Monitoring Water Quality (ITFM) was formed to review and evaluate water-quality monitoring activities nationwide and to recommend improvements. The ITFM issued a strategy for improving water-quality monitoring in 1995 (ITFM 1995). It concluded that "it has become clear that monitoring activities need to be improved and integrated better to meet the full range of needs more effectively and economically." The committee determined that a new approach to monitoring is required to target water-pollution-control resources to prioritize concerns and to evaluate the effectiveness of actions taken to prevent or remediate problems. In particular, a better balance of ambient and compliance monitoring was identified as a need. Their recommendations are organized around the topics of working together, sharing data, using comparable methods, designing monitoring programs, and reporting findings. They identified institutional and technical changes as necessary parts of a "strategy for nationwide, integrated, voluntary water-quality monitoring."

In July, 1995, the National Science and Technology Council through its Committee on Environment and Natural Resources created the Environmental Monitoring Team with the charge "to develop a national framework for integration and coordination of environmental monitoring and related research through collaboration and building upon existing networks and programs." The team proposed a conceptual framework described by CENR (1997). The framework proposed three levels of monitoring: intensive monitoring and research sites, national and regional resource surveys, and complete coverage programs (mainly remote sensing based). At each level existing programs were to be coordinated to meet the requirements. Neither ITFM nor CENR proposed the development of a new monitoring strategy to replace existing, diverse, overlapping, and incomplete programs.

A Preferred State for Aquatic Monitoring?

Aquatic monitoring encompasses many different measurement activities on multiple types of aquatic ecosystems. Ecosystems include lakes, reservoirs, streams, rivers, estuaries, coastal waters, wetlands as well as their associated riparian areas and upland watersheds. Monitoring may be intensive (e.g., daily at a single site), watershed (multiple sites with frequent measurements), or national (e.g., large number of sites measured annually). Aquatic monitoring involve only a single contaminant or may encompass a wide suite of ecological measurements.

The ITFM report gives a general set of recommendations for aquatic monitoring within the United States. It does not propose a specific vision nor specific organizational structure for monitoring. In that sense, it falls far short of outlining a federal/state environmental monitoring statistical framework. Although a number of changes have been made in the Clean Water Act, the basic requirements for monitoring have not changed much during the last 25 years. Ambient and compliance monitoring have always been part of the Act. However, the historical focus has been on compliance monitoring. Section 305(b) of the Clean Water Act requires EPA to complete "a description of the water quality of all navigable waters in such State during the preceding year" and " an analysis of the extent to which all navigable waters of such State provide for the protection and propagation of a balanced population of shellfish, fish, and wildlife and allows recreational activities in and on the water." Ambient monitoring that would enable quantitative, scientifically-defensible estimates as required by Section 305(b) has never been achieved. This difficult task requires either complete coverage of all navigable waters or a probability survey. Equally important is the requirement that monitoring must include more than water column chemistry, contaminants in fish tissue, and contaminants in sediment. Monitoring must include water column physical properties, biological measures, in-stream habitat, riparian habitat, and upland (or watershed) habitat to meet the requirements.

Prioritizing the monitoring effort is a daunting task. As in any statistical reporting effort, priorities must be set to meet the most important information needs of society within the budgets available. No organized effort to do this appears to be taking place. The National Water-Quality Monitoring Council (NWQMC) was established

as the successor to the ITFM in 1997. It is charged with enhancing the collaboration and coordination of water resource quality monitoring at the national, state, tribal, and local levels, as well as similar activities involving business and industry, academia, agriculture, and environmental groups. Its role is described on their web page: http://h2o.usgs.gov/public/wicp/nwqmc.html. No indication is given that a goal is to develop a federal/state environmental statistics framework, except as it may develop through voluntary cooperation. The terms of reference for the NWQMC do not include any reference to statistical survey design, or even the importance of site selection in monitoring.

What would be a preferred state for inland aquatic monitoring in the United States? Should we expect to have a federal environmental statistical agency with data collection, analysis and reporting responsibility such as we have for national agricultural economic statistics, economic statistics, transportation statistics? Would it be cost-effective to centralize all inland aquatic monitoring through an integration of monitoring conducting by a single federal agency and a single agency within each State? Should an entirely new monitoring effort be planned, with the transition of existing programs into the new program? How closely linked should monitoring be to providing information for supplemental accounts to the National System of Accounts? At this time, I do not believe a preferred state for monitoring exists.

Changing the Culture

Since 1990, several efforts mentioned above have begun to change the culture of aquatic monitoring in the United States. How have these efforts fared? What resistance have they faced? Are they coordinated? Are they making a difference? What is the prospect that the United States will have a scientifically defensible national water quality report in the near-future? I consider these questions below under the topics of statistical methodology, statistical education, and sociology of organizations. My discussion focuses on statistical aspects, while ignoring equally important areas of ecological science, information management, and others.

Statistical Methodology

My discussion of statistical methodology will be limited to site selection issues. Other areas are important, such as response design (Stevens and Urquhart 1999) and determining cause-effect. However, much of the change in culture centers on site selection.

With rare exceptions, the entire history of lake and stream monitoring in the United States has been conducted through fixed station networks. Note that our use of the term lake will refer to both natural lakes and reservoirs and that our use of the term stream will refer to all streams and rivers from small headwater streams to the great rivers such as the Mississippi. Periodically, USEPA has conducted national or regional probability-based surveys of lakes and streams, but in most cases the surveys targeted a subset of lakes or streams. To the best of my knowledge, no state had integrated a probability-based survey as part of their basic monitoring program prior to 1990. The book used in a prominent monitoring design course, taught at least annually, includes no reference to probability-based survey design for site selection (Sanders et. al. 1983). The authors state that locating a site consists of selecting a river reach to sample, locating a specific site within the reach, and selecting representative locations on the cross-section at the site. They focus on the hydrology of the stream network and known locations of point sources as important factors in selecting the reach and site within the reach. Their network design approach does not appear to have an objective to provide quantitative estimates of the status of aquatic resources summarized for states or other geographic delineations.

EMAP proposed a radically different approach to sampling lakes and streams (Messer et. al. 1991). As stated previously, a primary objective was to produce quantitative status and trend information over large geographic regions. It was based on a two-stage probability-based survey design. The first stage consisted of a systematic area sample of 40 km^2 hexagons. The second stage constructed a list frame of all lakes or streams within each hexagon. A complex unequal probability weighting and spatial clustering algorithm was used to spatially disperse the sample and select an expected one site per hexagon (Overton et. al. 1990). The entire design used a newly created discrete global grid (White et al 1992). EMAP attempted to communicate the monitoring design to the monitoring and ecological community but with limited success. It was too much of a cultural change for the current way of doing business. Rather than recognizing the overall benefits of EMAP survey design, the details of the design became the focus. The statistical community also expressed concern about the design and how well it would meet the needs of EMAP. Some of their concerns were justified. The design required additional research on statistical methods before it could be supported theoretically. Since then, the necessary theoretical foundations for probability-based

survey designs of lakes and streams has been completed (Stevens 1997, Olsen and Stevens 1998, Stevens and Olsen 1999, Stevens and Urquhart 1999).

New theoretical developments were necessary to address the problems presented by large-scale probability-based survey designs for lakes and streams, as well as other ecological resources. The wealth of survey methodology and experience that exists for sampling human populations and institutions does not exist for ecological resources. Finding or extracting suitable sampling frames is only beginning to occur. Although EMAP relies heavily on design-based estimation methods, over time model-based methods will almost certainly become more important. Since spatial location is such an integral part of ecological resource monitoring, all statistical methods must incorporate the spatial dimension.

Statistical Education

The inland aquatic monitoring community has a history of fixed-station, judgement-based site selection. Data from these sites are summarized routinely as if they were a simple random sample, i.e., sample means, proportions, variances are calculated. If scientifically defensible national estimates of the status of lakes and streams is to be attained (Paulsen et. al. 1998), this culture must be changed. What steps can be taken to change the culture?

Most members of the inland aquatic scientific community have an introduction to statistics as part of the undergraduate or graduate education. Typically, they have taken one or two courses for non-statistics majors and a number of years has elapsed since taking the courses. They understand the basic concepts of statistics, or at least know they should be concerned about particular issues. Most have been exposed to experimental designs and the need for randomization. It seems that all have heard that stratification is critical - so much so that stratification is used excessively even when it's not necessary. Seldom do they remember being introduced to probability-based survey design. If they have, they know simple random sampling, stratified random sampling, and systematic sampling. My conclusion is that the academic community (statistics, environmental science, ecology) must emphasize survey sampling more, so that the next generation of scientists has a broader base of statistical methods.

EMAP seriously misjudged the gap that existed between the design they proposed and the knowledge of the monitoring community. Based on our experience over the past ten years, we have found that the gap can be closed by acknowledging that statistical education is part of the process of designing a monitoring program. No textbook exists that focuses on survey designs for ecological resources, particularly aquatic ecosystems. Useful references are Gilbert (1987), Thompson (1992), and Schreuder et. al. (1993).

In 1994 EMAP began an effort, called Regional EMAP, that contributes to the statistical education of the monitoring community. Regional EMAP, or REMAP, is a program where every two years each of the ten EPA Regions is asked to participate in a monitoring study of an aquatic resource. EMAP provides (partial) funding for the study, but the Region selects the study area, resource, and objectives for the study. EMAP also contributes its research staff time to help the Region formulate the study, determine measurement protocols, and, most important, select a survey design. EMAP not only works with the study team to select the probability-based survey design, but actually selects the sample. An integral part of the process are discussions concerning the clarity of the study objectives, explicit definitions of the target populations, importance of the sampling frame, concepts of probability-based surveys, and importance of tying the statistical analysis to the survey design. Over 100 studies have begun under this program, involving hundreds of individual researchers and government agencies.

Sociology of Organizations

Changing culture always involves the sociology of organizations. What organizations are directly involved in the process? For inland aquatic resources, the principal organizational entities are EPA Office of Water, EPA Office of Research and Development, EPA Regional Offices, State monitoring agencies, U.S. Geological Survey, ecological academic community, statistical academic community. Other federal agencies and professional organizations are also part of the community, but the above illustrates the breadth of organizational entities.

Three organizations within EPA actively participate in pursuing the status of aquatic resources in the United States: Regional Offices, Office of Water, and Office of Research and Development. Regional Offices work directly with the states to implement the Clean Water Act monitoring requirements. Office of Water has responsibility for compiling the National Water Quality Inventory report to Congress and develops the federal regulations and guidelines for state monitoring. Office of Research and Development (ORD) conducts research in support of the Agency's mission to restore and maintain

the chemical, physical, and biological integrity of the Nation's waters. EMAP is an ORD initiative. A change in the culture of aquatic monitoring must have the agreement of the Office of Water. As in any organization, priorities differ among the three EPA offices. ORD's EMAP program was a radical initiative that could have been viewed as a direct threat to the current monitoring environment established by the Office of Water. Any radical change implies a measure of chaos during implementation. Keeping a firm handle on communications among the EPA offices would be critical to its success. Within ORD the budget for EMAP would likely have a significant negative budget impact on other research programs, given the likely constant budget of ORD. These and other considerations make changes in culture extremely difficult within an agency unless the change is mandated by Congress. This was not the case with EMAP.

EMAP and NAWQA, a program of USGS, began about the same time. Both stated that their objectives were to measure the status and trends of the inland aquatic resources. Confusion arose about the programs and a perception that they duplicated each other developed. Although EMAP was intended to be an interagency effort, the agencies found it difficult to collaborate.

EPA regional offices and state monitoring agencies have enormous investments in compliance and TMDL monitoring. Although the states are required to contribute to EPA's national report, most do not view that reporting as critical to meeting their primary monitoring objectives. EMAP focused on obtaining data to meet the requirements for the national report. Even more critical, the monitoring was designed to provide national and regional estimates, not state-level estimates. Many states did not see what benefit EMAP would bring to them. EMAP envisioned a future where the sample size and survey design would address state-level concerns about status and trends. However, the cost to do so prohibited proposing a state-level program. The consequence was that states found it difficult, if not impossible, to support the change in culture.

Some in the academic ecological community are involved directly or indirectly; some are not. A typical view is that monitoring is not research and consequently does little to further our understanding of the aquatic ecosystems. Most ecological research occurs in small watersheds and in limited geographic extent. The studies appropriately use concepts associated with experimental design. The measurements focus more on ecological processes and can be labor and time intensive; variability is a major factor. Consequently, when a large-scale monitoring program, such as EMAP, states that it will make biological measurements over large geographic areas and generally restrict the measurements to be obtainable within a single day, the community is naturally apprehensive. Their concerns are legitimate and must be addressed as part of the research necessary to implement a monitoring program. EPA, like most federal agencies, actively solicits external peer review. EMAP was no exception and initiated a review by the National Research Council (NRC) during the development and planning phase of the program. Their final report (NRC 1995) concluded "that EMAP's goals are laudable. However, because achieving the goals of this ambitious program will require that EMAP successfully meet many difficult scientific, practical, and management challenges, the committee continues to question whether and how well all these goals can be achieved." They were concerned that the design was at too coarse a scale in time and space to detect meaningful changes, that further development of biological indicators of ecological health was required, and that the retrospective monitoring approach may not match needs of assessment. From a statistical perspective, they recommended stratified random sampling by ecoregion, linking with site-specific intensive research study sites, and undertaking more power analyses of ability to detect change. These concerns can not be dismissed and were not dismissed by management within EPA. The social culture of EPA responded to the reviews, in some cases as providing guidance on how to improve the program and in others as justification for reducing or eliminating it. Peer review panels must understand the social culture of an agency in terms of how it interprets external reviews.

The academic statistics community raised many of the same scientific concerns as their ecological counterparts. Although the ecological community questioned the basic use of probability-based survey designs, the statistical community accepted that basic concept. Their concerns focused on the particular survey design choice. What was the basis for EMAP's decision to use a systematic grid area sample for the first stage? Would the design provide the required precision? Why rely on design-based estimation, rather than incorporate model-based estimation? A committee from the American Statistical Association reviewed the statistical aspects of EMAP during the same time period as the NRC review. Although the reviews were supportive of EMAP's use of survey sampling and the statistical underpinnings of the program, they also expressed concerns, as mentioned above. These reviews were valuable inputs to the statistical team designing EMAP. They provided

ammunition to organizations and individuals who were not in favor of EMAP.

Understanding the social culture of all organizations that are involved in or can influence decisions on the development and implementation of a monitoring program is critical. At times, it may take more effort to manage the social culture and its expectations than to address the myriad of scientific issues. This is particularly true when the monitoring program is a radical change from the status quo.

Conclusions

Some of the issues involved in changing the culture of monitoring aquatic ecosystems have been given. After ten years working within EPA as part of the Environmental Monitoring and Assessment Program statistical design team, I believe that the monitoring culture is changing - but more slowly than I expected. Although having a solid scientific foundation is important, understanding the social culture that affects the monitoring program may be more important. Significant advances in aquatic monitoring have occurred as the result of EMAP. In 1990, no state used survey designs as an integral part of their monitoring program. In 1996, two states used survey designs; by 1999 the number increased to 11 states . Other states continue to express interest and most states have been involved in one or more survey designs developed by EMAP. By working with individual states on problems of direct interest to them, EMAP has the opportunity to introduce probability-based surveys. The states have the opportunity to see how such surveys can help them answer some of their questions. Gradually, support is building for a cultural change in the use of survey designs nationally.

Many questions remain on what a federal/state national environmental statistical program might look like. However, it appears certain that progress toward such a goal is being made.

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References

Adler, R. W., J. C. Landman, et al. (1993). The Clean Water Act 20 Years Later. Washington, DC, Island Press.

CENR (1997). Integrating the Nation's environmental monitoring and research networks and programs: A proposed framework. National Science and Technology Council, Committee on Environmental and Natural Resources, The Environmental Monitoring Team. Washington, DC, 100pp. http://www.whitehouse.gov/WH/EOP/OSTP/html/OSTP_Home.html.

Gilbert, R. O. (1987). Statistical Methods for Environmental Pollution. New York, Van Nostrand Reinhold.

Helsel, D. R. (1995). Design of a relational water-quality assessment program. 1995 Proceedings of the Biometrics Section. Washington, DC, American Statistical Association: 60-67.

ITFM (Intergovernmental Task Force on Monitoring Water Quality) (1995). The strategy for improving water-quality monitoring in the United States: Final report of the Intergovernmental Task Force on Monitoring Water Quality. Washington, DC, U.S. Geological Survey: 25.

Messer, J. J., R. A. Linthurst, et al. (1991). "An EPA program for monitoring ecological status and trends." Environmental Monitoring and Assessment 17: 67-78.

NRC (1995). Review of EPA's Environmental Monitoring and Assessment Program: Overall Evaluation. Washington, D.C., National Research Council, National Academy Press.

Olsen, A. R., D. L. Stevens, Jr., et al. (1998). "Application of global grids in environmental sampling." Computing Science and Statistics 30: 279-284.

Overton, W. S., D. L. Stevens, et al. (1990). Design Report for EMAP, Environmental Monitoring and Assessment Program. Washington, D.C., U.S. Environmental Protection Agency, Office of Research and Development.

Paulsen, S. G., R. M. Hughes, and D. P. Larsen. (1998) "Critical elements in describing and understanding our nation's aquatic resources." J American Water Resources Association 34: 995-1005.

Sanders, T. G., R. C. Ward, et al. (1983). Design of Networks for Monitoring Water Quality. Littleton, Colorado, Water Resource Publication.

Schreuder, H. T., T. G. Gregoire, et al. (1993). Sampling methods for multiresource forest inventory. New York, John Wiley & Sons.

Stevens, D. L., Jr. (1997). "Variable density grid-based sampling designs for continuous spatial populations." Environmetrics 8: 167-195.

Stevens, D. L., Jr. and A. R. Olsen (1999). "Spatially restricted surveys over time for aquatic resources." Journal of Agricultural, Biological, and Environmental Statistics: (in press).

Stevens, D. L., Jr. and N. S. Urquhart (1999). "Response designs and support regions in sampling continuous domains." Environmetrics (in press)

Thompson, S. (1992). Sampling. New York, John Wiley & Sons.

Thornton, K. W., D. E. Hyatt, et al. (1993). Environmental Monitoring and Assessment Program Guide. Research Triangle Park, NC, U.S. Environmental Protection Agency, Office of Research and Development, Environmental Monitoring and Assessment Program, EMAP Research and Assessment Center: 35.

USEPA (1995). Guidelines for preparation of the 1996 State Water Quality Assessments (305(b) Reports). Washington, DC, U.S. Environmental Protection Agency, Office of Water.

USEPA (1997). Environmental Monitoring and Assessment Program (EMAP) Research Strategy. Washington, DC, U.S. Environmental Protection Agency, Office of Research and Development: 16.

White, D., A. J. Kimerling, et al. (1992). "Cartographic and geometric components of a global sampling design for environmental monitoring." Cartography and Geographic Information Systems 19(1): 5-22.