THE VALUE OF WATER QUALITY INFORMATION FOR NATIONAL ENVIRONMENTAL REGULATION

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INTRODUCTION

Environmental laws such as the Clean Water Act and the Safe Drinking Water Act in the United States have been implemented over the last 25 years in order to provide water to citizens that is safe for drinking, swimming, and fishing. Some of the protective measures which have been utilized for this purpose B such as nationally consistent regulatory limits for a suite of possible contaminants B are now being questioned. At issue is whether monitoring and regulation of contaminants is done in a cost-effective and Ascientifically sound@ manner.

Science can provide information to guide the regulatory process. From a scientist=s perspective, studies of how systems (air, water) respond to and transport natural and synthetic contaminants should be key to conducting monitoring that is effective from a standpoint of both protection and cost. Contaminants that pose the highest risk to human and ecosystem health, due either to toxicity or frequent occurrence, could receive highest priorities. Tailoring the suite of contaminants to those expected locally, due to regional patterns in sources and susceptibility, would avoid monitoring for contaminants with little chance of being found. Yet few scientific studies have as goals to answer the important questions of Where, When, and Why of regional and national water quality, and to communicate those results to policy makers in an understandable fashion.

SPECIFIC QUESTIONS SCIENCE CAN ANSWER

A first question is whether the suite of contaminants being investigated can be shortened without sacrificing protection of human health. Natural contaminants such as arsenic are present in large concentrations in some locations, but not in others. Synthetic contaminants also vary geographically, due to differing historic patterns of use. The suite of contaminants posing risk to health is not the same everywhere. Determining characteristic patterns of occurrence, such as pesticides that are regularly seen in urban streams but not in agricultural streams, will allow monitoring programs to emphasize those contaminants in some areas, rather than measuring "everything everywhere everytime.@ Decisions are currently made on what and what not to measure B using results of scientific determinations of what is likely to be present can only improve the process.

A second related question is whether different frequencies of measurement can be adopted based on the geographic variation in susceptibility to contamination. Some areas have soils, rock types, or other conditions that make them more susceptible to contamination than others. The challenge is in accurately understanding and then mapping how the risk of contamination changes, so that areas of greater risk receive greater protection.

In short, it is conceivable to tailor protection strategies so that goals for the protection of water quality are not sacrificed, by accounting for the geographic and temporal patterns in both contaminant sources and susceptibility of the environment. However, this requires a substantial amount of information in order for tailoring to occur. The understanding provided by properly-designed scientific programs such as the U.S. Geological Survey's National Water Quality Assessment (NAWQA) Program can form the basis for this tailoring. The goals of the NAWQA Program are to:

1. Describe current water-quality conditions for a large part of the freshwater streams, rivers, and ground water aquifers of the United States. ***Where?***
2. Describe how water quality is changing over time. ***When?***
3. Improve understanding of the primary natural and human factors that affect water-quality conditions. ***Why?***
4. Determine how these results can improve the management of water resources. ***How?***

Monitoring is generally not designed to address questions of spatial and temporal variation, but instead focuses on determining how frequently standards are violated, or on statistics of contaminant concentrations for a geographic region. A scientific assessment that addresses the above four questions provides much more. By addressing the "where, when, and why,@ an assessment provides guidelines for the "how" of tailored monitoring strategies. Understanding Awhy@ can provide insight into effective protection or cleanup strategies. Examples of proposed or State-implemented tailoring of monitoring, based on information gathered by USGS studies, illustrate the possibilities for moving monitoring beyond the Aeverything everywhere everytime@ scenario.

WHERE ARE PROBLEMS MOST LIKELY? MOST SEVERE?

Determining where water-quality problems are most likely to occur allow protection strategies to differ in different locations. Funds for protection, regulation, and further monitoring can be prioritized and spent on more critical areas and issues first. This can operate at a variety of scales. For example, in the two studies which follow, information can be used to allow less-frequent monitoring in locations less at risk to contamination.

Statewide Study: State of Washington

Ryker and Williamson (1996) studied the percentage of public supply wells with detectable levels of pesticides in the state of Washington. US law requires each public supply well with 15 or more connections to be monitored quarterly for pesticides, but allows the state to issue waivers based on evidence of low risk. Costs of monitoring in Washington were estimated to be $1100 per well per year, a considerable burden on households supplied by small systems. The state sought a way to implement more selective monitoring to best use its available monies to provide the greatest levels of protection. A joint USGS and State study determined that risks of ground water contamination by pesticides were not the same everywhere. More importantly, the risks could be predicted well enough that monitoring efforts could be scaled accordingly.

Detection of pesticides varied with land use at the surface, the depth of the well, and the nitrate concentration in the well. The most frequent detections were found in shallow agricultural and urban wells having nitrate concentrations over 2.7 mg/L as nitrogen. Using these criteria as predictive factors, drinking water wells were classified into three risk groups. Low risk wells were granted a full waiver, monitoring for pesticides only once every three years. High risk wells maintained quarterly monitoring, while medium risk wells obtained a partial waiver. Costs of the sampling and assessment were recovered by the savings resulting from the reduced monitoring schedule within three months of the first year.

National Study: Nitrate in Ground Water of the United States

Natural and anthropogenic conditions associated with high nitrate levels in ground water were assessed in

20 large areas across the United States (Nolan *et al.*, 1997). High nitrate levels were found to occur in areas with high inputs of nitrogen to the land surface, high population densities, cropland with few interspersed woodlands, and areas with well-drained soils. Maps of these factors were overlain so that their combinations determined four risk categories for high nitrate levels in U.S. ground water. Areas with at least 2100 kg of nitrogen applied per square kilometer or population densities greater than 386 persons per square kilometer, and with well-drained soils as defined by the U.S. Census of Agriculture, exhibited the highest risk. Waters from deeper wells (greater than 100 ft.) exhibited less pronounced effects. Risk of contamination was portrayed in a national map.

Twenty-five percent of shallow wells in the high-risk group exceeded the drinking-water standard of 10 mg/L nitrate. Only three percent of shallow wells in the lowest risk group exceeded the standard. Areas where nitrate concentrations are expected to be most severe are clearly identified. These results can be useful in prioritizing areas where remediation and prevention programs are to be established. Monitoring programs for nitrate could focus more intensive efforts in states or counties in proportion to their risk of contamination. Contrasts between the populations of low and high risk areas can be studied by epidemiologists. Though smaller-scale studies are necessary to provide the detail needed for most local purposes, a consistent national perspective allows state and national monitoring to allocate more resources to areas with the highest risks of contamination and greatest variation.

WHEN ARE PROBLEMS MOST LIKELY? MOST SEVERE?

While ground water quality can change rapidly over distances, stream quality changes most quickly with time. An old (hydrologic) adage goes that A90% of the sediment is moved by a stream during 10% or less of the time.@ The highest streamflow, which occurs only during a few days of each year, carries markedly higher sediment concentrations than average or low streamflows. Trace metals, phosphates, and some organic compounds such as PCBs and some pesticides, also move in the same pattern. This has important implications for monitoring strategies. Random or infrequent sampling schemes may completely miss any chemicals or sediment particles moving in this fashion.

How can this complexity be taken advantage of in order to tailor monitoring programs? One example was given by the seasonal sampling strategies of Battaglin and Hay (1996). Herbicides such as atrazine and alachlor are applied in great quantities in the spring on land of the Midwestern United States. They are found in streams in sufficient amounts and frequencies to exceed drinking water criteria. Their maximum contaminant levels (MCLs), above which some enforcement actions may be taken, have been defined as annual mean concentrations. Rules for monitoring (U.S. EPA, 1991) state that a minimum of four quarterly samples are to be taken in order to compute the annual mean. Stream concentrations of herbicides are not evenly distributed throughout the year, but are accentuated greatly in the spring. Battaglin and Hay show that over 40% of annual means based on quarterly samples underestimate annual mean herbicide concentrations. Instead, three samples taken in the spring averaged with 9 zero concentrations for the remainder of the year, provides a much more accurate estimate of the annual mean. Indeed, this three-sample method provides estimates almost as accurate as 12 monthly samples, for considerably less expense. This is a simple example of the statistical principle of sampling more frequently during periods of greater variability, combined with knowledge of how a stream system works. The result is a more efficient sampling design than a monthly or quarterly program which presumes no prior knowledge of the system.

WHY DOES WATER QUALITY DIFFER BETWEEN AREAS AND TIMES?

In any monitoring program, only a small number of samples can actually be collected and analyzed. Some method must be employed to relate these data to the entire population of interest. One method is to assume that the statistics generated are applicable to the entire area. Without a knowledge of Awhere@ and Awhy,@ however, averages computed may be far from the truth for any specific location.

Bricker and Rice (1989) provide an example of the benefits of incorporating the "where" and "why" of water quality into a sampling design for determining the ability of streamwaters to neutralize acid precipitation. Their objective was to compute the mean and standard deviation for the acid-neutralizing capacity (ANC) of streams in western Maryland. As this characteristic is known to be caused by the carbonate content of rocks through which the streams flow, they based their sampling design on the geology of the region. Locations with more carbonate were expected to have high ANC, and lower variability, and so were sampled less frequently than their proportion of surface area on a map would dictate.

Two benefits resulted from their approach. First, their estimates of mean ANC were less biased, and had lower variance, than one which used the regular grid pattern common to monitoring programs. This gives more accurate and precise estimates of the potential impact of acid precipitation for the same area using the same number of samples. Second, by relating ANC values to rock type, they could produce an estimate for ANC tailored to any location in their study area, rather than being limited to a single average value for the entire area as their best prediction of ANC.

Understanding why problems are more severe in certain areas, or at certain times, has a second important advantage B it leads to possible solutions. Without hard scientific information, monitoring is little better than a physician tracking a patient's decline, without understanding how to treat the disease. An assessment of cause is like a diagnosis which leads to improved and (often) less-expensive methods of monitoring the patient's progress. Expensive bone-marrow samples are not warranted for routine infections.

To tailor monitoring programs, a baseline of assessment activities is needed to evaluate and diagnose. For example, the assessment of pesticides in Washington State's ground water cost 1.4 million dollars, a considerable investment. However, the monitoring savings realized were estimated by the state agency at 18.0 million dollars over a three-year period. The key to tailoring their monitoring was an answer to "why,@ why some wells were vulnerable and others not. The answer to those who appropriately ask "what additional value is there in more water quality measurements after all these years of effort@ is in the "why" applied to maximize protection from contamination through better understanding of, and more efficient monitoring of, the "where" and "when.@

HOW CAN PROGRAMS BE TAILORED TO BE MORE EFFICIENT?

Scientific assessments must provide a base of regular sampling over space, time, and constituent coverage in order to understand how contaminants behave in hydrologic systems. These assessments should have the explicit goal to understand the "why" of contamination, and to communicate this scientific information to policy and regulatory officials. With this effectively communicated, efficiency is gained by sampling more frequently when and where the greatest uncertainty exists and the costs of making an error in judgment are the highest.

THE FINAL LINK B COMMUNICATING WITH POLICYMAKERS

Scientists measure and interpret complex systems. In particular, the natural sciences must deal with uncontrolled variations in driving factors such as weather, temperature, soils, and geology. Environmental studies add to this the effects caused by human behavior, which is if anything less predictable. As a result, the important patterns present in data are difficult to tease out. Scientists, always cognizant of the complexity of their results, often have a difficult time planning for and summarizing the implications of their work - it is not part of their training.

Policy makers also deal with complex systems, but are required to turn information into informed decisions. They are rarely trained in the disciplines of science and so require Atranslations@ B concise results in non-technical language. Scientists are not trained to communicate in this way. The result is a gulf in culture and communication between science and policy. Important water quality and economic issues of our day provide an opportunity to bridge this gulf.

CONCLUSIONS

Scientific assessment programs can provide information on where water-quality problems are likely to occur, when they are most likely, and the factors that control them. Knowing which factors control differences in occurrence is the key to understanding how to tailor future monitoring, and to addressing policy-relevant issues. As with other societal activities, funding for scientific studies of water quality is increasingly difficult to obtain. Yet the understanding they provide is critical to developing cost-effective and minimally intrusive strategies to manage and protect water resources. Scientists do not often "speak the same language" as the people who would use their information for making policy decisions. In order for the transfer of information from science to policy to occur, scientists must make policy-relevance an explicit objective of the work they do.

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BIOGRAPHY

Dennis Helsel currently heads a team of scientists interpreting trace element (trace metal and radionuclide) concentrations across the United States for the USGS National Water Quality Assessment Program. He is co-author of the textbook *Statistical Methods in Water Resources* (Elsevier, 1992).