WATER-QUALITY MONITORING OF RIVERS

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Contents

Summary

The large number of physical, chemical, and biological attributes of water that can be monitored coupled with the high cost of sample collection and laboratory analysis present a fundamental challenge for the design of water-quality monitoring networks. Effective design requires a precise statement of objectives and a clear understanding of the approaches that will be used to analyze the data collected by the network. Cost constraints generally require difficult compromises to be made among sampling frequency, number of sampling locations, precision of results, and breadth of objectives. This chapter focuses on monitoring networks for rivers and contrasts two basic approaches to network design, a fixed-station network and a probabilistically based network. Examples from water-quality networks in the United States of America are presented to illustrate advantages and disadvantages of these approaches.

1. Introduction

Water-quality monitoring provides information on the physical, chemical and/or biological status of water resources. Monitoring programs exist at all spatial and temporal scales, from long-term programs at the national scale to short-term programs at the scale of a single sampling site. Data from monitoring programs are needed to answer questions such as

- Does a river support recreational, water supply, and aquatic life uses?
- Is water quality improving or degrading?

- What are the effects of point sources, such as sewage treatment facilities, factories or feedlots, on rivers?
- What are the aquatic effects of acid deposition?
- What is the relation between fertilizer use and eutrophication of surface waters?

These, and many other scientific and management questions, are the impetus for water-quality monitoring.

Many national water-quality networks began in the 1970s, in response to increased public concerns about the integrity of aquatic ecosystems, as well as the traditional concerns for public health. In the United States, the National Stream Quality Accounting Network (NASQAN) was established by the U.S. Geological Survey (USGS) in 1973 to provide nationally consistent information on the quality of water moving within and across national borders, to determine spatial variability, to detect temporal changes in water quality, and to lay the groundwork for future assessments of changes in stream quality. Many state governments in the U.S. also established water-quality monitoring programs of various kinds at approximately the same time.

Many early monitoring networks had the generic objectives of “status and trend”: What is the status of water quality and is it improving or degrading? For example, the intent of the USGS NASQAN program was to provide a “base-level” of water-quality information for broad national planning. The program measured sanitary indicators, nutrients, major ions, and trace elements at a network of nearly 500 sites sampled monthly in 1978. However, the information gleaned from analysis of NASQAN data was not as complete as hoped. Although a picture of the broad spatial pattern of water quality was achieved, data frequently were not available where there was greatest interest in water quality, because stations were not chosen to assess the response to specific pollution control measures. For example, no change in dissolved oxygen concentrations was detected at NASQAN stations despite improved sewage treatment, but this non-result is not surprising because stations were not located near enough to sewage outfalls to observe the difference. Conversely, trends in water quality also were observed frequently, yet could not be readily attributed to any cause because ancillary data were lacking.

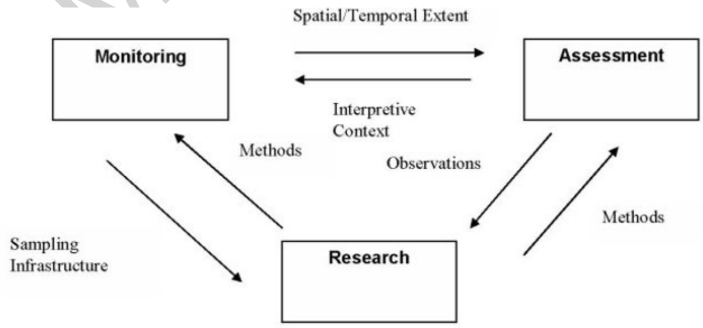

Figure 1. Relations and feedback among monitoring, assessment, and research.

The conclusion from the NASQAN program was that a generic “status and trend” objective could not be achieved given the sparseness of the data in space and time. Rather, only much more specific—and much narrower—objectives could be achieved.

A fundamental concept in water-quality monitoring is that data always will be a limiting factor for any analysis. The high cost of sample collection and laboratory analyses precludes operating a sufficient number of stations with a sufficiently high sampling frequency to answer a broad range of questions. Thus, monitoring networks must be carefully designed to answer specific questions, which generally are limited in number, rather than to provide data for unspecified purposes. Moreover, network designs must explicitly address how data will be extrapolated in space and time from the limited measurements to characterize water-quality conditions. Assumptions often must be made to interpret monitoring data and to convert the data from monitoring networks into information that is technically defensible and relevant to policy or water-resource management questions. Water-quality networks must be designed such that these extrapolations and assumptions, when needed, are scientifically valid and support sound water-resource management.

Water-quality monitoring is best viewed as one part of an integrated, three-part process (Figure 1) of *research*, *assessment*, and *monitoring*.

- *Research* discovers the processes controlling water quality, identifies new problems, and develops the field and laboratory methods to address them. Research is conducted at only a few locations and does not attempt to determine the extent of the problem. Monitoring depends on research to determine what to measure and how to measure it.

- *Assessment* refers to the collection and analysis of water-quality and ancillary data, to place water quality into context and to understand why the water quality is as it is. Research provides the process understanding, but assessments attempt to apply this understanding over larger areas. Often, a large proportion (as much as one-half) of program resources are devoted to data interpretation, with a smaller portion devoted to data generation costs, such as sample collection and laboratory analyses. Sufficient resources exist to develop interpretive approaches (and to design data collection) to assure that the data are relevant to water-quality problems. Assessment programs provide information on what, how, and when to measure water quality so that the monitoring data will be meaningful; that is, these programs have the flexibility to develop an *interpretive* context for water-quality data. Within the USGS, the National Water-Quality Assessment (NAWQA) program performs detailed assessments of approximately 40 basins around the country. (For more information on NAWQA, see http://water.usgs.gov/nawqa.)

- *Monitoring* refers to the collection of data to describe some aspect of a resource (status) and changes in that resource over time (trend). Monitoring programs provide data on a broad spatial and/or temporal context. Data collection is the primary effort of the program; data analysis is limited to reducing the data by means of a pre-defined interpretive context into useful information. Within the USGS, the NASQAN program was redesigned in 1995 to monitor rivers larger than those studied in NAWQA. A narrow objective—estimating the annual loading of contaminants at fixed stations—was defined for the program that was achievable within the limited resources. Approximately 70 percent of NASQAN's resources are used for data collection. (For further information on NASQAN, see http://water.usgs.gov/nasqan.)

There is extensive feedback among the activities shown in Figure 1. Monitoring derives its methods and interpretive context from research and assessment, respectively, but it also provides both a cost-effective sampling infrastructure for researchers to use and data that are spatially and temporally more extensive that those collected by assessment programs. Effective characterization of riverine water quality requires all three components. Historically, it often has been difficult to integrate these three components because responsibilities for these activities have been divided among various government agencies, universities, and, in federal systems, different levels of government.

2. Design Considerations for Water-Quality Monitoring Networks

2.1 Monitoring Objectives

The first step in the design of any water-quality monitoring program is to define the objectives of the monitoring activity. Monitoring objectives also may be represented as information needs, the fulfillment of which allows water-quality managers and others to make informed decisions about regulations, actions, or programs. Objectives of water-quality monitoring programs commonly are stated to include determining current water-quality conditions, detecting trends, and collecting data for model studies. Because of the large inherent variability, both spatial and temporal, in water-quality conditions and because of the wide variety of parameters that can be measured as indicators of quality, specific monitoring objectives that are achievable within program resources are essential for effective water-quality monitoring programs.

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Worldwide Web Resources

http://water.usgs.gov/nawqa/ [Information on the USGS's National Water Quality Assessment]

http://water.usgs.gov/nasqan/ [Information on the USGS's National Stream Quality Accounting Network]

http://water.usgs.gov/owq/Fieldprocedures.html [USGS's National Field Manual]

http://www.epa.gov/emap/ [Information on the US EPA's Environmental Monitoring and Assessment Program]

http://www.epa.gov/ost/ [Information from the Office of Science and Technology of the US EPA's Office of Water including laboratory analytical methods, water quality standards, and ambient water quality criteria]