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## Standard Guide for Planning and Implementing a Water Monitoring Program<sup>1</sup>

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### INTRODUCTION

Water resource monitoring has taken place in many forms for scores of years. This monitoring has been sponsored and performed by a variety of federal, state, and local public agencies; and perhaps by an even wider variety of private, quasi-public and industrial entities. Historically, much of the early data dealt with quantities of flow, and drinking water quality was judged by the standards of the period.

During the past several years the problems related to point and nonpoint sources of pollution of water resources have become increasingly apparent. Technology has improved dramatically, as the need for monitoring data has improved. There is a necessity for information on marine beaches and estuarine areas, fresh water swamps, ground water, wetlands, streams, and sediment deposits, and to better understand the entire hydrologic cycle.

The need for more and varied water quality information has expanded as rapidly as our technological ability to generate the information. Further, it has become increasingly difficult and sometimes impossible to understand and resolve conflicts among the different data sets available. Much of the data have been collected at different times, in different geographic areas, and for different purposes. The data have been collected by persons with varied training, using different methods, and with vastly different analytical capabilities. As a consequence, we presently are at the stage where we may know more about a given situation than we understand and workers in the field who receive the data are unable to integrate the data available into a useful solution. The need for standardization of monitoring programs is evident. Standardization does not herein mean everyone doing everything exactly the same way. It does mean the use of methods and procedures, where applicable, that follow recognized and documented protocols as well as the accurate recording and storage of the data in accessible formats.

Realizing the difficulties in water monitoring, the Office of Management and Budget (OMB) of the federal government charged the Water Information Program (WICP), a program of the U.S. Geological Survey's Office of Water Data Coordination, with studying water quality monitoring in the United States and recommending improvements. The Intergovernmental Task Force on Monitoring Water Quality (ITFM), a federal, state, and tribal partnership, was established under the WICP's Interagency Advisory Committee on Water Data to carry out this study. The results of three years of work by about 200 contributors have been captured in a series of three annual reports (1, 2, 3).<sup>2</sup>

The following summarizes the conclusions from those reports:

- (1) Monitoring programs shall keep pace with changing water-management programs.
- (2) A collaborative strategy is needed to link the many separate monitoring programs.
- (3) A genuine appreciation of the need for cooperation currently exists among monitoring agencies.
- (4) Recent advances in technology provide opportunities for interaction and cooperation that previously were impossible.

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<sup>2</sup> The boldface numbers in parentheses refer to a list of references at the end of this guide.

Based upon those conclusions, the following recommendations were made:

- (1) Implement an integrated, voluntary, nationwide strategy to improve water quality monitoring.
- (2) Charter a permanent national body to guide the implementation of ITFM recommendations.
- (3) Develop a framework for monitoring water quality that defines the components of a monitoring program.
- (4) Develop criteria with which to select parameters that measure progress in achieving water quality goals.
- (5) Recommend indicators to measure whether water quality uses designated by the state are being met.
- (6) Charter a Methods and Data Comparability Council to foster the development and use of performance-based methods of collection and analysis.
- (7) Use the ecoregions concept, reference conditions, and index calibration.

## 1. Scope

1.1 *Purpose*—This guide is generic in its application to surface or ground water, rivers, lakes, or estuaries (quantity and quality). It proposes a series of options that offer direction without recommending a definite course of action and discusses the major elements that are common to all purposes of water monitoring.

1.2 The elements described are applicable whether the monitoring is only for one location or integrates multiple measurement sites for the purpose of assessing a whole watershed, estuary, or aquifer system.

1.3 This guide is intended to outline for planners and administrators the components, process, and procedures which should be considered when proposing, planning, or implementing a monitoring program. The guide is not a substitute for obtaining specific technical advice. The reader is not assumed to be a technical practitioner in the water field; however, practitioners will find it a good summary of practice and a handy checklist. Other standard guides have or will be prepared that address the necessary detail.

1.4 *Monitoring Components*—A water monitoring program is composed of a set of activities, practices, and procedures designed to collect reliable information of known accuracy and precision concerning a particular water resource in order to achieve a specific goal or purpose. The purposes may range in scope from tracking status and trends on a regional or national basis to gathering data to determine the effects of a specific management practice or pollution incident such as a spill. This guide suggests and discusses the following process and components:

1.4.1 Establishment of program goals and objectives and recording of decisions in a written plan (see 6.1),

1.4.2 Developing background data and a conceptual model (see 6.1.12),

1.4.3 Establishment of data (quality, quantity, type) objectives (see 6.2),

1.4.4 Design of field measurement and sampling strategies and specification of laboratory analyses and data acceptance criteria (see 6.3),

1.4.5 Data storage and transfer (see 6.6),

1.4.6 Implementation of sampling and analysis strategies (see 6.4),

1.4.7 Data quality assessment (see 6.5),

1.4.8 Assessment of data (see 6.7),

1.4.9 Program evaluation (see 6.8), and

1.4.10 Reporting (see 6.9).

See also Fig. X1.1 in Appendix X1 and the condensed list of headings in Appendix X2.

1.5 *Monitoring Purposes*—Establishing goals defines the purpose for monitoring. Each purpose has some monitoring design needs specific to itself. There are six major purposes for water monitoring. They are as follows:

1.5.1 *Determining the Status and Trends of Water Conditions*—This can require long term, regular monitoring to determine how parameters change over time.

1.5.2 *Detecting Existing and Emerging Problems*—Determining if, how, or where a substance may move through an aquatic system, or if water quantities are changing.

1.5.3 *Developing and Implementing Management and Regulatory Programs*—Includes baseline and reconnaissance monitoring to characterize existing conditions such as to identify critical areas or hot spots; implementation monitoring to assess whether activities were carried out as planned; and compliance monitoring to determine if specific water quality or water use criteria were met.

1.5.4 *Responding to an Emergency*—Performed to provide information in the near term.

1.5.5 *Evaluating the Effectiveness of Water Monitoring Programs*—Is the monitoring able to achieve the stated goals? Also, monitoring to check on monitoring.

1.5.6 Supporting research objectives or validating of simulation models.

1.6 This guide is applicable to these purposes and provides guidance on some of the specific needs of each. After goals and objectives have been established, a specialist can define the type, frequency, and duration of sampling and measurements. The specialist also will be able to forecast the data analysis needed to meet the objectives.

1.7 There are related standards currently available or under development and several documents that prescribe protocols for water monitoring (4–5). See also Section 2.

1.8 This guide suggests that water monitoring programs use standardized documented protocols for all aspects of the program. Where they are not available or appropriate, the methods used should be documented.

1.9 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the*

responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>3</sup>

**D1129 Terminology Relating to Water**

### 2.2 Other Documents:

**Compilation of Scopes of ASTM Standards Relating to Environmental Monitoring, 1994, ASTM, Philadelphia, PA. PCN: 13-600003-16 (700 standards)<sup>4</sup>**

**ASTM Standards on Ground Water and Vadose Zone Investigations. PCN: 03-418094-38<sup>4</sup>**

### 2.3 EPA Documents:

**U.S. EPA 813/B-92-002 Definitions for the Minimum Set of Data Elements for Ground Water Quality<sup>5</sup>**

**U.S. EPA 910/9-91/001 Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska<sup>5</sup>**

## 3. Terminology

3.1 For definitions of terms used in this guide, refer to Terminology **D1129**.

### 3.2 Definitions of Terms Specific to This Standard:

3.2.1 *analyze*—to determine the relationship of parts or the value of a particular parameter.

3.2.2 *assess*—to determine importance of data.

3.2.3 *evaluate*—to determine significance or worth.

3.2.4 *measurement*—determining the values of a characteristic within a sample or in situ.

3.2.5 *metadata*—ancillary data that describe the natural conditions under which an environmental data value is measured, the purpose for collection, the methods and standards employed, and the organization responsible.

3.2.6 *sampling*—the removal of a portion of the water which may or may not be representative of the whole. This is not monitoring.

3.2.7 *water monitoring*—water monitoring consists of systematic activities conducted to characterize the quantity or quality, or both, of water.

## 4. Significance and Use

4.1 The user of this guide is not assumed to be a technical practitioner in the water field. This guide is an assembly of the components common to all aspects of water monitoring and fulfills a need in the development of a common framework for a better coordinated and more unified approach to monitoring water.

<sup>3</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>4</sup> Available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959.

<sup>5</sup> Available from Superintendent of Documents, Government Printing Office, Washington, DC 20402.

4.2 *Limitations*—This guide does not establish a standard procedure to follow in all cases and it does not cover the details necessary to meet a particular monitoring objective.

## 5. A Primer on Water Monitoring Programs

### 5.1 *The Problem*—Why is water monitoring difficult?

5.1.1 The movement of water through the hydrologic cycle dwarfs other material cycles operating on the earth's surface, such as the carbon and oxygen cycles. Water's chemical and physical properties enable it to dissolve many substances and physically remove and suspend others. Consequently, as water encounters various substances in the atmosphere, on land surfaces, and below ground, the water's chemical composition changes, and the composition of materials suspended in the water changes. Physical and chemical processes further change its composition as water moves through the hydrologic cycle.

5.1.2 Human activities using land and water have greatly altered the kind and amount of substances that water encounters as it moves through the hydrological cycle. Often, some substances, including those biological communities living within water, are present at concentrations that impair various water uses. These substances are regarded as pollutants. Much of our effort to manage water resources is directed at reducing the addition of pollutants in water. Other management efforts are directed toward altering local pathways of water flow and maintaining or enhancing aquatic and marine habitats.

5.1.3 Across the globe or across a county there are large spatial and temporal variations in water flows and volumes, in the natural features, which impact water resources, and in the nature and extent of human land and water uses. Consequently, there can be large spatial and temporal variations in the composition of water. The problem that must be addressed in water monitoring is how to spatially and temporally characterize the composition of water and the source of this composition with sufficient accuracy and precision to support local and regional water uses and management efforts. Monitoring water as it flows through the hydrologic cycle is not easy.

5.1.4 Reading through the following list of procedures and considerations will provide the administrator or planner with insight into the details of needed expertise, complexity, and work tasks in the design, implementation, and evaluation of a monitoring project.

## 6. Procedure

### 6.1 *Establish Program Goals and Objectives:*

6.1.1 Define goals and objectives using a multidisciplinary team. This requires a variety of professionals with special insights in order to prepare a sensible plan.

6.1.1.1 Review existing data.

6.1.2 Prepare a plan of work from the goals, objectives, and decisions. This will be an iterating process as progress is made developing the components. The plan can use a pilot approach or phased-in approach.

6.1.2.1 Coordinate activities with other relevant agencies, groups, and persons.

6.1.3 Develop a project schedule and budget.

6.1.3.1 Establish budgetary and personnel requirements.

6.1.4 Set timelines.

6.1.5 Set interim goals, checkpoints, and review periods.

6.1.6 Identify adaptive management parameters in accordance with the project's objectives; these are project specific parameters, such as ground water flow direction and concentration, that are selected to be observed on a regular basis in order to determine the need for change of monitoring procedures.

6.1.7 Establish feedback loops related to review inputs. As data are collected they shall be reviewed in light of quality standards and in meeting program objectives.

6.1.8 Schedule flexibility for program adjustment.

6.1.9 Determine program costs and sources of funding.

6.1.10 Identify who will need or use the data and who will benefit from the project.

6.1.11 Identify and describe the existing environmental setting including its surface and ground water hydrology, physiography, climate, biology, and ancillary information such as population, land use, and water use.

6.1.12 Develop a conceptual model of the project area that relates the known water data and the surroundings that influence water conditions. The model will aid in predicting influences and selecting sampling sites.

6.1.13 Collaborate with others who can contribute information and support.

## 6.2 *Establish Data Objectives:*

6.2.1 The what, how, how many, and how good of measurements depends on many factors, especially why the monitoring is being done. The needs of the end users have to be clearly identified. Data shall be collected and measured in accordance with established norms and standards. Measurements of physical parameters and environmental indicators are made to determine the following:

6.2.1.1 Concentrations of both natural and synthetic constituents dissolved or suspended in water,

6.2.1.2 Physical characteristics of water (temperature, turbidity, color, density, and conductivity),

6.2.1.3 The volumes of water present in various compartments of the hydrologic cycle,

6.2.1.4 The flow rates of water between various compartments of the hydrological cycle,

6.2.1.5 The loading of dissolved and suspended constituents between compartments of the hydrologic cycle,

6.2.1.6 The rates of chemical and physical processes,

6.2.1.7 The status of biological communities living within or adjacent to surface and ground waters,

6.2.1.8 The quality of aquatic habitats,

6.2.1.9 The factors that influence any of the above, and

6.2.1.10 The suitability of water for a particular use.

6.2.2 Define requirements for data analyses. For example, what is the supporting information, such as land use, that is needed to analyze the data?

6.2.3 Define interaction of various professional skills, for example, field worker taking samples, chemist, hydrologist, data manager, data analyst, and the person who interprets the data, to ensure that all work to be done and who is to do it are identified.

6.2.4 Based upon the stated program objectives, determine the scope of the monitoring program by doing the following:

6.2.4.1 Determining the areal extent needed to meet objectives,

6.2.4.2 Determining the analysis or parameters needed to meet objectives,

6.2.4.3 Determining what is known,

6.2.4.4 Investigating related prior work,

6.2.4.5 Correlating objectives and scope with objectives attained by prior work,

6.2.4.6 Evaluating existing information to depict the known or suspected surface and ground-water quality conditions, problems, or information gaps,

6.2.4.7 Providing a current conceptual understanding,

6.2.4.8 Identifying management concerns and alternatives,

6.2.4.9 Analyzing prior data for integration with new data,

6.2.4.10 Determining whether the work can be used,

6.2.4.11 Determining impact of locations of monitoring sites on data from prior work and upon proposed work,

6.2.4.12 Determining impact of access to prior and future sites upon prior data and data to be collected, and

6.2.4.13 Evaluating impact of past and present sampling methodology upon past and proposed data, including equipment variations, for example, manual, automatic, remote, and experience of personnel, with respect to environmental requirements and data needs.

6.2.5 Identify null hypothesis option, that is, what happens if monitoring is not performed.

6.2.6 Establish reference conditions for environmental indicators that can be monitored to provide a baseline water-quality assessment.

6.2.7 Define data management needs.

6.2.8 Evaluate monitoring program, that is, can goals be achieved?

6.3 *Design of Field Measurements*—All measurements should conform to standard methods, documented protocols, or at least documented to provide a clear description of the methods used. The use of nonstandard methods is appropriate where the use of standard methods would not be suitable for the successful implementation of the work.

6.3.1 Evaluate spatial aspects of monitoring activities, for example, where to sample or measure. Will locations be acceptable and accessible? Are the samples representative? What will be the exact location for the measurement point in reference to location in a stream, depth in a well, location in a lake, or depth in a bay in order to get representative samples within the scope of the project.

6.3.2 Evaluate temporal aspects of monitoring activities, for example, how frequently and how long to sample. Factors to be considered include tidal effects, climatic effects, seasonal effects, scale effects, daily effects, and annual effects.

6.3.3 Select monitoring sites. Consider access, long term use, physical hardships, and special equipment.

6.3.4 Select environmental indicators and data parameters. Evaluate the environmental indicators and habitat and related chemical, physical, biological, and ancillary data parameters to be monitored. Select monitoring mechanisms and methods.

6.3.5 Identify specific factors that impact sampling sites. Consider the following:



6.3.5.1 Relationship between site monitored and point sources,

6.3.5.2 Relationship between site monitored and non-point sources,

6.3.5.3 Relationship between site-monitored and environmental variations (influencing conditions), for example, the edge of a swamp, thalweg of river, intertidal position, depth of well screen, thickness of strata, riffle, rapid, pool, aquatic zone in a lake, or depth in ocean, that is, any and all significant variations,

6.3.6 Define probable water level, stage and frequency variations, and relationship to monitoring methodology,

6.3.7 Select sampling approach to achieve objectives. Consider the following:

- (1) Fixed station,
- (2) Synoptic,
- (3) Intensive,
- (4) Event sampling,
- (5) Sample type (grab/composite point/spatially integrated/continuous),
- (6) Frequency and duration, and
- (7) Scale.

6.3.8 Define monitoring and sampling program; develop sampling plans and identify standardized protocols and methods (performance based if possible); and document data to enable comparison with other monitoring programs. Considerations are as follows:

6.3.8.1 Published consensus standards,

6.3.8.2 Methodology,

6.3.8.3 Equipment,

6.3.8.4 Procedures,

6.3.8.5 Frequency,

6.3.8.6 Ancillary events (temperature, rain, relationship to stage, releases, current),

6.3.8.7 Seasonal and other temporal variations,

6.3.8.8 Constituents,

6.3.8.9 Environmental Indicators (chemical, physical, biological, surrogate indicators),

6.3.8.10 In situ analysis,

6.3.8.11 Sample transport, and

6.3.8.12 Qualifications of personnel.

6.3.9 Define analytical methodology.

6.3.9.1 Define data-quality objectives, including the level of confidence needed to meet the management objectives.

6.3.9.2 Determine basis for monitoring design that will allow successful interpretation of the data at a resolution that meets project purposes.

6.3.9.3 Identify field and laboratory protocols, or performance-based methods including sample collection, preservation, and transportation and including detection level accuracy, precision, and turnaround time. (See *Compilation of Scopes of ASTM Standards Relating to Environmental Monitoring and ASTM Standards on Ground Water and Vadose Zone Investigations.* )

6.3.10 Establish a Quality Assurance/Quality Control (QA/QC) Program (Quality Assurance Program Plan (QAPP)).

6.3.10.1 Identify and designate requirements for QA/QC procedures for field sampling methodology. Evaluate the following:

- (1) Replicability of field measurements,
- (2) Representativeness of field measurements,
- (3) Natural variation of data,
- (4) Limitations of data collected as a consequence of unavoidable variations, and
- (5) Impact of field methods upon project objectives, that is, if field sampling has a probable variability of two orders of magnitude, the project objectives cannot be reported with less.

6.3.10.2 Identify and designate requirements for QA/QC for laboratory procedures.

6.3.10.3 Develop a Quality Assurance Project Plan documenting accuracy and precision, representativeness of the data set, and comparability of data to prior data or data collected by others, or both.

6.3.10.4 Define laboratory analytical requirements, quality assurance protocols, chain of custody procedures, and quality assurance procedures for all testing, for example, suspended solids, particulate gradation.

6.3.10.5 Select confidence limits that shall be obtained for the data to be meaningful.

6.3.11 Define qualifications of personnel.

6.3.11.1 Prepare safety plan for project.

6.3.11.2 Define skill levels that are required for various portions of the work, including training requirements, and certification and registration.

6.3.11.3 Define training program necessary to obtain needed skill levels.

6.3.11.4 Define test for personnel as a function of the field QA/QC. Can personnel make reliable measurements for the specified precision?

6.3.12 Evaluate field measurement program.

6.4 *Implementation of Sampling and Analysis Strategies:*

6.4.1 Collect data according to monitoring design and protocols.

6.4.2 Review data collection activities relative to protocols and monitoring design.

6.4.3 Follow QAPP plan and document deviations from plan.

6.4.4 Regularly review data for completeness and for accuracy and precision from QC data.

6.4.5 Regularly review data relative to changing monitoring design to accomplish objectives.

6.5 *Data Quality Assessment*—Base data QA on results of QAPP.

6.5.1 Review custody records.

6.5.2 Compare laboratory spikes.

6.5.3 Consider collection conditions.

6.5.4 Meet statistical protocol.

6.5.5 Meet confidence criteria.

6.5.6 Determine statistical reliability of data using QA information.

6.5.7 Evaluate data, that is, does it meet goals?

6.6 *Data Management:*

6.6.1 Identify and use standard protocols, if appropriate, for reporting and storing of data (see EPA 813).

6.6.2 Identify storage methods for ancillary data.

6.6.3 Define metadata storage needs. This is information that can be used to support the measured data (for example, date, time, location, collection methodology, QA data).

6.6.4 Define georeferencing standards.

6.6.5 Describe the data management protocol.

6.6.6 Transmit data to other users.

6.6.7 Archive data.

6.6.8 Secure data.

6.7 *Data Interpretation and Assessment (Evaluate, Analyze, and Assess Data):*

6.7.1 Evaluate data to determine if objectives can be achieved.

6.7.1.1 Test and quantify hypotheses.

6.7.2 Analyze data to determine statistical significance.

6.7.2.1 Determine temporal variability and spatial distribution.

6.7.2.2 Identify statistical and deterministic significance of data.

NOTE 1—Nonparametric and other statistical packages fit here.

6.7.2.3 Quantify source, cause, transport, and fate of constituents.

6.7.3 Assess data to measure impact of results.

6.7.3.1 Interpret data to meet objectives.

6.7.3.2 Show relationship between ancillary and water quality data.

6.7.4 Coordinate interpretation with collaborators and customers.

6.7.4.1 Review interpretation with collaborators and customers and provide feedback.

6.7.4.2 Address management alternatives.

6.7.5 Use deterministic models for testing management scenarios.

6.8 *Program Evaluation:*

6.8.1 Identify problems.

6.8.1.1 Identify problems associated with collecting and analyzing the data and with storing and disseminating the data to intended users.

6.8.1.2 Identify problems associated with interpreting the data and with reporting the information to water resource managers and the public.

6.8.2 Evaluate costs.

6.8.2.1 Evaluate costs as compared to program objectives to determine need to modify program.

6.8.2.2 Make recommendations for changes in program design, if needed.

6.8.3 Evaluate water monitoring program.

6.8.3.1 Determine if objectives were met.

6.8.3.2 Identify new purposes or revised objectives for a second phase of sampling.

6.8.3.3 Identify changes in the monitoring design.

6.8.4 Determine if information satisfies the stated objectives.

6.8.4.1 Determine if land and water use activity laws, standards, or guidelines or any combination thereof, need to change.

6.8.5 Identify current and future needs not addressed in the current program.

6.9 *Communication and Report:*

6.9.1 Prepare information for identified audiences. Consider the following items:

6.9.1.1 Write the report with regard to stated objectives.

6.9.1.2 Write concise and timely reports.

6.9.1.3 Use graphical and visual techniques to assist reader and listener.

6.9.1.4 Describe current water related conditions, spatial distribution, temporal variability, source, cause, transport, fate, and effects to human, and wildlife as appropriate.

6.9.1.5 Write lay reports or executive summaries for non-technical audiences.

6.9.1.6 Write reports subject to peer review.

6.9.1.7 Place large data sets and statistical tables in appendices or in separate data reports.

6.9.1.8 Distribute reports to identified users.

6.9.1.9 Make presentations to assist management and the public in understanding the significance of results.

6.9.1.10 Use electronic word processing formats of accepted and widespread use.

6.9.1.11 Make reports available in electronic format.

6.9.2 Prepare data for data users.

6.9.2.1 Make data readily available in standardized computer format.

6.9.2.2 Make data, reports, and presentations in a timely manner (real time data may require special arrangements).

6.9.3 Determine how, whether, and when (by schedule) data and its interpretation will be communicated, for example, through press releases, public meetings, agency meetings, conferences, agency reports, journal articles, etc.

6.9.4 Report the following information:

6.9.4.1 Data citation and explanation,

6.9.4.2 Limitations, variability for other problems with data specifically including limitations with field and laboratory methodology and procedures,

6.9.4.3 Specific discussion of the data and the conclusions indicated by the data, and the precise way these relate to the defined objectives of the project,

6.9.4.4 Determine and discuss how the data, the conclusions, and the project in its entirety relates to other work, and how better coordination and assimilation can be attained, and

6.9.4.5 A summarization of conclusions and recommendations.

6.10 *Cooperation and Coordination*—A water monitoring program seldom can be implemented without coordination of several individual entities. Planning, field work, transport, laboratory work, data management, and data analysis are seldom handled by one group. Formal procedures shall be written to ensure that all understand their role in the process. All levels should understand the program objectives.