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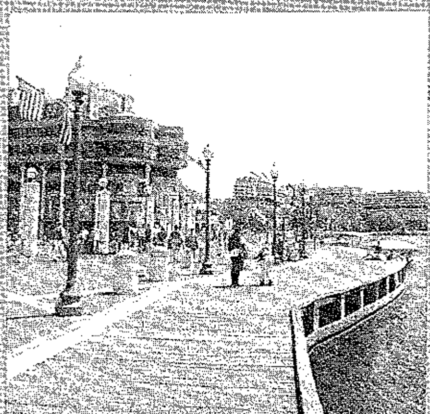
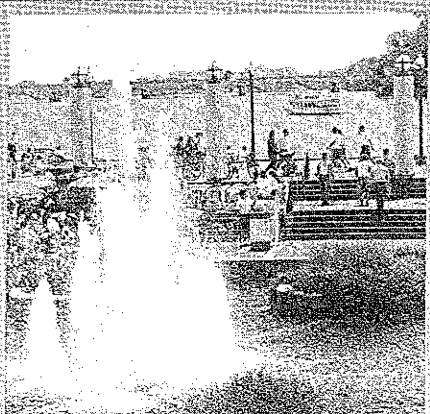
THE STRATEGY FOR IMPROVING WATER-QUALITY MONITORING IN THE UNITED STATES



TECHNICAL APPENDIXES

FINAL REPORT
OF THE
INTERGOVERNMENTAL
TASK FORCE
ON MONITORING
WATER QUALITY



Intergovernmental Task Force
on Monitoring Water Quality

February 1995

INTERGOVERNMENTAL TASK FORCE ON MONITORING WATER QUALITY

February 1995

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Technical Appendixes

TECHNICAL APPENDIX A

GLOSSARY OF WATER-QUALITY-MONITORING TERMS

The definitions in this appendix are solely related to the use of these terms in Technical Appendixes A through O. Other definitions for these terms may apply when the terms are used elsewhere.

Adverse effect An action that has an apparent direct or indirect negative effect on the conservation and recovery of an ecosystem component listed as threatened or endangered [U.S. Forest Service (USFS)] [1]

Ambient monitoring All forms of monitoring conducted beyond the immediate influence of a discharge pipe or injection well and may include sampling of sediments and living resources [U.S. Environmental Protection Agency (USEPA) Region 5].

Ancillary data

A. Other categories of data (see *Water-quality data*) critical to interpreting water-quality data and formulating courses of action. These ancillary categories of data will be considered only as they relate to information management and data sharing. Ancillary data critical to water-quality decisionmaking include, but are not limited to, land use/land cover; water use; population and demographics; soils, geology, and geochemistry; municipal and industrial waste disposal; agricultural and domestic chemical applications; climatological data; and human health and ecological effects [Intergovernmental Task Force on Monitoring Water Quality (ITFM)]

B. Those variables that might influence the indicators independent of what they are designed to denote [Environmental Monitoring and Assessment Program (EMAP)].

C. Data that are collected as a consequence of collecting target data, but that are not considered to be essential (Ohio EPA).

Aquatic community An association of interacting populations of aquatic organisms in a given water body or habitat (USEPA Region 5).

[1] Terms were provided by the agencies listed within the parentheses.

Aquatic ecosystem The stream channel, lake or estuary bed, water, and (or) biotic communities and the habitat features that occur therein (USFS).

Aquatic habitat Environments characterized by the presence of standing or flowing water (USFS).

Aquifer A body of rock that is sufficiently permeable to conduct ground water and to yield economically significant quantities of water to wells and springs [Bates, Robert L., and Jackson, Julia A., eds., 1987, *Glossary of Geology* (3d ed.): Alexandria, Va., American Geological Institute, p. 33].

Assessed waters Water bodies for which the State is able to make use-support decisions based on actual information. Such waters are not limited to those that have been directly monitored; it is appropriate in many cases to make judgments based on other information (USEPA Region 5, modified).

Beneficial uses Management objectives

Benthic fauna (or benthos) Organisms attached to or resting on the bottom or living in the bottom sediments of a water body (USEPA Region 5).

Bioaccumulate The net uptake of a material by an organism from food, water, and (or) respiration that results in elevated internal concentrations [U.S. Fish and Wildlife Service (USFWS)]

Biological assessment An evaluation of the biological condition of a water body by using biological surveys and other direct measurements of a resident biota in surface water (USEPA Region 5).

Biological criteria (or biocriteria) Numerical values or narrative expressions that describe the reference biological integrity of aquatic communities that inhabit water of a given designated aquatic life use (USEPA Region 5).

Biological integrity Functionally defined as the condition of the aquatic community that inhabits unimpaired water bodies of a specified habitat as measured by community structure and function (USEPA Region 5).

Biological monitoring (or biomonitoring) The use of a biological entity as a detector and its response as a measure to determine environmental conditions. Toxicity tests and biological surveys are common biomonitoring methods (USEPA Region 5)

Biological survey (or biosurvey) Consists of collecting, processing, and analyzing representative portions of a resident aquatic community to determine the community structure and function (USEPA Region 5).

Biomonitoring The measurement of biological parameters in repetition to assess the current status and changes in time of the parameters measured (USFWS).

Community component Any portion of a biological community. The community component may pertain to the taxonomic group (fish, invertebrates, algae), the taxonomic category (phylum, order, family, genus, species), the feeding strategy (herbivore, omnivore, carnivore), or organizational level (individual, population, community association) of a biological entity within the aquatic community (USEPA Region 5).

Compliance monitoring A type of monitoring done to ensure the meeting of immediate statutory requirements, the control of long-term water quality, the quality of receiving waters as determined by testing effluents, or the maintenance of standards during and after construction of a project (modified from Resh, D. M., and Rosenberg, V.H., eds., 1993, *Freshwater Biomonitoring and Benthic Macroinvertebrates*: New York, Chapman and Hall, 488 p).

Contaminant A material added by humans or natural activities that may, in sufficient concentrations, render the environment unacceptable for biota. The mere presence of these materials is not necessarily harmful (USFWS)

Critical habitat Those areas designated as critical for the survival and recovery of threatened or endangered species (USFS).

Data comparability The characteristics that allow information from many sources to be of definable or equivalent quality so that this information can be used to address program objectives not necessarily related to those for which the data were collected. These characteristics need to be defined but would likely include detection limit precision, accuracy, bias, and so forth (ITFM/Data Methods Collection Task Group)

Data quality objectives In the context of water-quality monitoring, the characteristics or goals that are determined by a monitoring or interpretive program to be essential to the usefulness of the data. They would include, but not be limited to, the specification of delineation of the limits of precision and bias of measurements, the completeness of sampling and measurements, the representativeness of sites relative to program objectives, the validity of data, and so forth (ITFM/Data Methods Collection Task Group).

Deep-water habitats Permanently flooded lands that lie below the deep-water boundary of wetlands (USFS).

Designated uses

A. A classification specified in water-quality standards for each water body or segment that relates to the level of protection from perturbation afforded by the regulatory agency (USEPA/OST).

B. Describes the chemical, physical, and (or) biological attributes covered by the use; this is, in essence, the narrative "criteria" (Ohio EPA).

C. Uses specified in water-quality standards for each water body or segment whether or not they are being attained (USEPA Region 5).

Diversity The distribution and abundance of different kinds of plant and animal species and communities in a specified area (USFS).

Ecological indicators Plant or animal species, communities, or special habitats with a narrow range of ecological tolerance. For example, in forest areas, such indicators may be selected for emphasis and monitored during forest plan implementation because their presence and abundance serve as a barometer of ecological conditions within a management unit (USFS)

Ecoregions (or regions of ecological similarity) A homogeneous area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variable. Regions of ecological similarity help define the potential designated use classifications of specific water bodies (USEPA Region 5).

Ecosystem A system that is made up of a community of animals, plants, and bacteria and its interrelated physical and chemical environment (USFWS).

Effectiveness monitoring Documents how well the management practices meet intended objectives for the riparian area. Monitoring evaluates the cause and effect relations between management activities and conditions of the riparian depend-ent resources Terrestrial and instream methods constitute monitoring that evaluates and documents the total effectiveness of site-specific actions (USFS).

Emerging environmental problems Problems that may be new and (or) are becoming known because of better monitoring and use of indicators (Ohio EPA)

Endangered species

A. Any species in danger of extinction throughout all or a significant portion of its range (USFS).

B. Animals, birds, fish, plants, or other living organisms that are threatened with extinction by manmade or natural changes in their environment. Requirements for declaring a species endangered are contained in Endangered Species Act.

Environmental indicators A measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality (ITFM)

Equivalency Any body of procedures and techniques of sample collection and (or) analysis for a parameter of interest that has been demonstrated in specific cases to produce results not statistically different to those obtained from a reference method (ITFM).

Estuarine habitat Tidal habitats and adjacent tidal wetlands that are usually semienclosed by land but have open, partly obstructed, or sporadic access to the open ocean and in which ocean water is at least occasionally diluted by freshwater runoff from the land (USFS).

Exposure indicators An environmental characteristic measured to provide evidence of the occurrence or magnitude of contact with a physical, chemical, or biological stressor (EMAP).

Featured (or species emphasis) A species of high public interest and demand. The management goal for these species usually is to maintain or improve habitat capability when economically and biologically feasible (USFS)

Fish and wildlife Any nondomesticated member of the animal kingdom that includes, without limitation, any mammal, fish, bird, amphibian, reptile, mollusk, crustacean, arthropod, or other invertebrate and that includes any part, product, egg, or offspring thereof or the dead body or parts thereof (USFS)

Fixed-station monitoring The repeated long-term sampling or measurement of parameters at representative points for the purpose of determining environmental quality characteristics and trends (USEPA Region 5).

Geographic information systems (GIS) A computerized system for combining, displaying, and analyzing geographic data. GIS produces maps for environmental planning and management by integrating physical and biological information (soils, vegetation, hydrology, living resources, and so forth) and cultural information (population, political boundaries, roads, bank and shoreline development, and so forth) (USEPA Region 5).

Habitat

A. A place where the physical and biological elements of ecosystems provide a suitable environment, and the food, cover, and space resources needed for plant and animal existence (USFS).

B. The physical/chemical theater in which the ecological play takes place; it is a template for the biota, their interactions, and their evolution (Hutchinson, 1965; Southwood, 1977).

Habitat capability The estimated carrying capacity of an area to support a wildlife, fish, or sensitive plant population. Habitat capability can be stated as being existing or future and normally is expressed in numbers of animals, pounds of fish, or acres of plants (USFS).

Habitat indicator A physical, chemical, or biological attribute measured to characterize the conditions necessary to support an organism, population, community, or ecosystem in the absence of stressors (EMAP)

Impact A change in the chemical, physical, or biological quality or condition of a water body caused by external sources (USEPA Region 5).

Impairment A detrimental effect on the biological integrity of a water body caused by impact that prevents attainment of the designated use (USEPA Region 5).

Implementation monitoring Documents whether or not management practices were applied as designed. Project and contract administration is a part of implementation monitoring (USFS).

Index period The sampling period during which selection is based on the temporal behavior of the indicator and the practical considerations for sampling (Ohio EPA, modified).

Indigenous species A species that originally inhabited a particular geographic area (USFS, modified).

Lacustrine habitat All wetland and deep-water habitats with the following characteristics: situated in a topographical depression or a dammed river channel; lacking trees, shrubs, persistent emergents, emergent mosses, or lichens with greater than 30 percent aerial coverage; and total area that exceeds 20 acres (USFS).

Listed species Any species of fish, wildlife, or plant officially designated by an agency as being endangered or threatened (USFS, modified).

Management indicators Plant and animal species, communities, or special habitats that are selected for emphasis in planning and that are monitored during forest-plan implementation to assess the effects of management activities on their populations and the populations of other species with similar habitat needs that they may represent (USFS).

Management indicator species Any species, group of species, or species habitat element selected to focus management attention for the purpose of resource production, population recovery, maintenance of population viability, or ecosystem diversity (USFS).

Metadata Information that describes the content, quality, condition, and other characteristics of data [Federal Geographic Data Committee (FGDC)]

Method comparability The characteristics that allow data produced by multiple methods to meet or exceed the data-quality objectives of primary or secondary data users. These characteristics need to be defined but would likely include data-quality objectives, bias, precision, information on data comparability, and so forth (ITFM/Data Methods Collection Task Group).

Method validation The process of substantiating a method to meet certain performance criteria for sampling and (or) analytical and (or) data handling operations (ITFM)

Metric A biological attribute, some feature or characteristic of the biotic assemblage, that reflects ambient conditions, especially the influence of human actions on these conditions (ITFM; Technical Appendix G).

Monitoring

A. The repeated measurement of some parameters to assess the current status and changes over time of the parameters measured (USFWS).

B. Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and (or) pollutant levels in various media or in humans, animals, and other living things (ITFM).

National Pollutant Discharge Elimination System A permit program under Section 402 of the Clean Water Act that imposes discharge limitations on point sources by basing them on the effluent limitation capabilities of a control technology or on local water-quality standards (USEPA Region 5).

Native species Any animal and plant species originally in the United States (USFS).

Nonpoint-source pollution A contributory factor to water pollution that cannot be traced to a specific spot; for example, pollution that results from water runoff from urban areas, construction sites, agricultural and silvicultural operations, and so forth (USEPA Region 5).

Palustrine habitat All nontidal wetlands that are dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and all such wetlands in tidal areas where salinity owing to ocean-derived salts is below 0.5 part per thousand. Also, all wetlands that lack such vegetation but with all the following characteristics: areas of less than 20 acres (for example, a pond); active waves form a bedrock shoreline, features lacking; water depth in the deepest part of a basin of less than 6.5 feet at low water; and salinity owing to ocean-derived salts that is less than 0.5 part per thousand (USFS)

Peer-reviewed literature A referable, obtainable, published document that is reviewed by a minimum of two technical reviewers who are located external to the author's organization (ITFM).

Perennial streams Permanently inundated surface stream courses. Surface water flows throughout the year except in years of infrequent drought (USFS)

Performance-based methods system A system that permits the use of any appropriate measurement methods that demonstrates the ability to meet established performance criteria and that complies with specified data-quality needs. Performance criteria, such as precision, bias, sensitivity, specificity, and detection limit, must be designated, and a method-validation process must be documented (ITFM).

Point-source pollution Pollution discharged through a pipe or some other discrete source from municipal water-treatment plants, factories, confined animal feedlots, or combined sewers (USEPA Region 5)

Population

A. For the purposes of natural-resource planning, the set of individuals of the same species that occurs within the natural resource of interest (USFS, modified).

B. An aggregate of interbreeding individuals of a biological species within a specified location (USEPA Region 5).

Potential habitat Habitat that is suitable for, but currently unoccupied by, the species or community in question (USFS).

Prelaboratory Methods that include all activities involved in collecting, preparing, and delivering a sample to the place of analysis For a traditional water sample, this would include activities and equipment for collecting, filtering, bottling, preserving, and shipping the sample. In the case of an in situ measurement, there would be no prelaboratory method. In the case of a field analysis of ground water for alkalinity, prelaboratory methods would include of pumping the sample and keeping it pressurized and out of contact with the atmosphere (ITFM/Data Methods Collection Task Group)

Reference value/conditions

A. A single measurement or set of selected measurements of unimpaired water bodies characteristic of an ecoregion and (or) habitat (USEPA/OST).

B. The chemical, physical, or biological quality or condition that is exhibited at either a single site or an aggregation of sites that represent the least impacted or reasonably attainable condition at the least impacted reference sites (Ohio EPA).

Response indicator An environmental indicator measured to provide evidence of the biological condition of a resource at the organism, population, community, or ecosystem level of organization (EMAP).

Riparian Of, pertaining to, or situated or dwelling on the bank of a river or other water body (Shuh-shiaw Lo, 1992, *Glossary of Hydrology*: Littleton, Colo., Water Resources Publications, p. 1250).

Riparian areas Geographically delineable areas with distinctive resource values and characteristics that compose the aquatic and riparian ecosystems (USFS, modified).

Riparian dependent resources Resources that owe their existence to a *riparian area* (USFS).

Riparian ecosystems A transition between the aquatic ecosystem and the adjacent terrestrial ecosystem; these are identified by soil characteristics or distinctive vegetation communities that require free or unbound water (USFS).

Riparian habitat The transition zone between aquatic and upland habitat. These habitats are related to and influenced by surface or subsurface waters, especially the margins of streams, lakes, ponds, wetlands, seeps, and ditches (USFS, modified).

River reach A river or stream segment of a specific length. Most reaches extend between the points of confluence with other streams (USEPA Region 5).

Riverine habitat All wetlands and deep-water habitats within a channel, with two exceptions—wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens and habitats with water that contains ocean-derived salt in excess of 0.5 part per thousand.

Selection criteria A set of statements that describe suitable indicators or a rationale for selecting indicators (ITFM).

Sensitive species Those plant and animal species for which population viability is a concern (USFS)

Standard As used in American Society for Testing and Materials (ASTM), a document that has been developed and established within the consensus principles of the ASTM and that meets the approval requirements of ASTM procedures and regulations. The term "standard" serves as an adjective in the title of documents, such as test methods, practices, and specifications, to connote specified consensus and approval. The various types of standard documents are based on the needs and usage as prescribed by the technical committees of the ASTM. "Consensus principles" include timely and adequate notice to all known interested parties; opportunity for all affected interests to participate in the deliberations, discussions, and decisions that affect the proposal; maintenance of records of discussions, decisions, and data accumulated in standards development; timely publication and distribution of minutes of meetings; distribution of ballots to all eligible voters and full reporting of results; and careful attention to minority opinions throughout.

Stressor indicator A characteristic measured to quantify a natural process, an environmental hazard, or a management action that results in changes in exposure and habitat (EMAP).

Threatened species Any species that is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range (USFS).

Threatened waters Waters that fully support their designated uses, but may not support uses in the future unless pollution-control action is taken because of anticipated sources or adverse pollution trends (USEPA Region 5).

Total maximum daily load The total allowable pollutant load to a receiving water such that any additional loading will produce a violation of water-quality standards (USEPA Region 5).

Toxic Relating to harmful effects to biota caused by a substance or contaminant (USFWS).

Toxicity test A procedure to determine the toxicity of a chemical or an effluent by using living organisms. A toxicity test measures the degree of effect on exposed test organisms of a specific chemical or effluent (USEPA Region 5).

Validation monitoring Determines if predictive model coefficients are adequately protecting the targeted resources. A long-term commitment to data collection is often required to establish an adequate data base. If the standard, which requires use of 50 percent or less of streamside herbaceous forage, for example, fails to achieve the desired instream habitat condition, then the standard would have to be modified for less forage consumption in the riparian complex(es) (USFS, modified).

Viable population A population that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its existing range in the planning area (USFS).

Water-quality criteria *Criteria* that comprise numerical and narrative *criteria*. Numerical criteria are scientifically derived ambient concentrations developed by the USEPA or the States for various pollutants of concern so that human health and aquatic life can be protected. Narrative criteria are statements that describe the desired water-quality goal (USEPA Region 5).

Water-quality data Chemical, biological, and physical measurements or observations of the characteristics of surface and ground waters, atmospheric deposition, potable water, treated effluents, and waste water and of the immediate environment in which the water exists.

Water-quality information Derived through analysis, interpretation, and presentation of water-quality and ancillary data (ITFM).

Water-quality limited segment A stretch or area of surface water where technology-based controls are not sufficient to prevent violations of water-quality standards. In such cases, new permit limitations are based on ambient-water-quality considerations (USEPA Region 5).

Water-quality monitoring An integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses (ITFM/Technical Appendix B).

Water-quality standard A law or regulation that consists of the beneficial designated use or uses of a water body, the numerical and narrative water-quality criteria that are necessary to protect the use or uses of that particular water body, and an antidegradation statement (USEPA Region 5).

Water-resource quality

A. The condition of water or some water-related resource as measured by biological surveys, habitat-quality assessments, chemical-specific analyses of pollutants in water bodies, and toxicity tests (USEPA/OST)

B. The condition of water or some water-related resource as measured by the following: habitat quality, energy dynamics, chemical quality, hydrological regime, and biotic factors (Ohio EPA).

Watershed The land area that drains into a stream, river, lake, estuary, or coastal zone (USEPA Region 5).

Wetlands Habitat that is transitional between terrestrial and aquatic where the water table is usually at or near the land surface or land that is covered by shallow water. Wetlands have one or more of the following characteristics: at least periodically, the land supports predominantly hydrophytic plants; the substrate is predominantly undrained hydric soil; and the substrate is nonsoil and is saturated with water or covered by shallow water at sometime during the yearly growing season (USFS).

TECHNICAL APPENDIX B

FRAMEWORK FOR A WATER-QUALITY-MONITORING PROGRAM

Water-quality monitoring is a critical support for any water-management program In this framework, water-quality monitoring is defined as "an integrated activity for evaluating the physical, chemical, and biological character of water in relation to human health, ecological conditions, and designated water uses." It includes the monitoring of rivers, lakes, reservoirs, estuaries, coastal water, atmospheric precipitation, wetlands, and ground water Without correct information, the state of the Nation's water resources cannot be assessed, effective preservation and remediation programs cannot be run, and program success cannot be evaluated To help water managers of programs of all levels from national to local collect data that will be shared and useful for meeting multiple objectives at all levels, the ITFM sets forth the following framework for monitoring programs

Water-quality monitoring can be grouped into the following general purposes:

- Describing status and trends.
- Describing and ranking existing and emerging problems.
- Designing management and regulatory programs
- Evaluating program effectiveness
- Responding to emergencies.

Although monitoring may vary in kind or intensity among the five purposes, they share a common design framework and the implementation steps outlined below.

In designing the implementing monitoring programs for surface and ground waters, it is vital to take into consideration the differences in the spatial and temporal characteristics, as well as the accessibility to monitoring of each of the resources. Equally important to the success of a program is the formulation and implementation of an effective data-management system and effective methods of communication and information exchange among collaborators, customers, and the general public.

I. Purpose
  - A. Purposes and expectations—Identify general purposes and expectations for the monitoring program
  - B. Specific program purposes—To the degree possible, identify the specific purposes of the monitoring program.
  - C. Share purposes—Determine if other data collectors and users have similar purposes that may influence other monitoring programs.
  - D. Customers—Who needs the data or information and for what reason? Determine if other agencies share the same purposes and if they can effectively combine resources.
  - E. Boundaries and timeframes—Identify general geographic boundaries and timeframes to the monitoring program.
  - F. Environmental indicators—Chose environmental indicators to measure the achievement of identified program purposes

II. Coordinate/collaborate.
  - A. Establish working Rrlations—Establish a working relation with Federal, State, Tribal, local, academic, and private agencies that collect and use water-quality information. If the agency has many programs, then integrate the individual monitoring programs into overall program goals.
  - B. Incorporate needs of others—If possible, incorporate needs of other agencies into the purposes of the program. Ensure the inclusion of data qualifiers with stored data so others know the accuracy and precision of the environmental data that was collected and analyzed

III. Design.
  - A. Existing environmental setting—Identify and describe the existing environmental setting, including its hydrology (surface and ground waters), biota, and resource use
  - B. Existing water-quality problems—Evaluate existing information to depict the known or suspected surface- and ground-water-quality conditions, problems, or information gaps; provide a current conceptual understanding; and identify management concerns and alternatives.
  - C. Environmental indicators and data parameters—Determine the environmental indicators and habitat and related chemical, physical, biological, and ancillary data parameters to be monitored.
  - D. Reference conditions—Establish reference conditions for environmental indicators that

can be monitored to provide a baseline water-quality assessment.

E. Data-quality objectives—Define the level of confidence needed, based on the data collected, to support testing management alternatives.

F. Data-set characteristics—Determine the basis for a monitoring design that will allow successful interpretation of the data at a resolution that meets project purposes. The basis for monitoring should include statistical reliability and geographic, geohydrologic, geochemical, biological, land use/land cover, and temporal variability.

G. Quality-assurance plan—Develop a quality-assurance plan (QA) plan that documents data accuracy and precision, representativeness of the data, completeness of the data set, and comparability of data relative to data collected by others.

H. Monitoring design—Develop a sampling design that could include fixed station, synoptic, event sampling, and intensive surveys; location of sites, such as a stratified random design; and physical, chemical, biological, and ancillary indicators.

I. Data-collection methods.—Develop sampling plans and identify standardized protocols and methods (performance based if possible) and document data to enable data comparison with other monitoring programs. Identify personnel and equipment needed.

J. Timing—Describe the duration of the sampling program and the frequency and seasonality of sampling.

K. Field and laboratory analytical support—Identify field and laboratory protocols or performance-based methods, which include detection level, accuracy, precision turnaround time, and sample preservation.

L. Data management—Describe the data-management protocol, which includes data archiving, data sharing, and data security that can be followed. Ensure that all data includes metadata, such as location (latitude and longitude), date, time, and a description of collection and analytical methods, and QA data.

M. Training—As necessary, train staff to collect, manage, interpret, or present water-quality data and information.

N. Interpretation—Identify interpretative methods that are compatible with data being collected and program purposes.

O. Communications—Determine how data and interpretive information can be communicated; for example, press releases, public meetings, agency meetings, conferences, popular publications, agency reports, journal articles, and so forth.

P. Costs—Determine the program costs and sources of funding.

Q. Iterative—Develop feedback mechanisms to fine-tune design.

IV. Implementation.

A. Establish and document sites—Construct wells, shelters, gage houses, staff gages, and other needed structures as needed in preparation for data collection; document ancillary data for sites.

B. Collect data—Collect data according to monitoring design and protocols; coordinate with other agencies where appropriate.

C. Review results—Review data-collection activities to ensure that protocols and QA plan are being followed and that data is complete and meets stated purposes.

D. Store and manage data—Archive data in such a manner that the accuracy and precision are maintained.

E. Share data—Provide data for other agencies upon request.

F. Summarize data—Provide data-summary information to managers when applicable.

V. Interpretation.

A. Data reliability—Define the accuracy and precision of environmental data by using quality-control data.

B. Interpret data tmeet stated purposes—Interpret the data, which include a description of the water-resources system, by using existing environmental and ancillary data to provide information useful to making water-quality-management decisions.

C. Statistical methods and model documentation—Use statistical packages and deterministic models that are well documented.

D. Management alternatives—Test management alternatives when they are known.

E. Coordinate interpretations—Consider management alternatives when interpreting data to meet the needs of collaborators and customers.

VI. Evaluate monitoring program

A. Meet goals and objectives—Determine if monitoring program goals and objectives were met.

B. Identify problems—Identify any monitoring problems associated with collecting and analyzing samples; storing, disseminating, and interpreting data; and reporting the information to managers and the public.

C. Evaluate costs—Evaluate the costs of the monitoring program relative to other costs, such as clean up, lost environment, and product produced.

D. Feedback—Use results of evaluation monitoring program to identify current and future needs and activities of agencies and data users.

VII. Communication.

A. Coordinate—Participate in the distribution of information to and with other agencies.

B. Write and distribute technical reports—Describe current water-quality conditions, spatial distribution, temporal variability, source, cause, transport, fate, and effects of contaminants to humans, aquifers, and ecosystems as appropriate.

C. Communicate with multiple audiences—Write lay reports or executive summaries for nontechnical audiences and peer review reports for technical audiences.

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

E. Make data available—Provide basic data for other data users as requested.

TECHNICAL APPENDIX C

TERMS OF REFERENCE— NATIONAL WATER-QUALITY MONITORING COUNCIL

I. Official designation

The National Water-Quality Monitoring Council (National Council) is the permanent successor to the Intergovernmental Task Force on Monitoring Water Quality (ITFM)

II. Purpose, scope, applicability, and functions

A. Purpose—The overall purpose of the National Council is to support water-quality-information aspects of natural-resources management and environmental protection. The National Council has a broad mandate that encompasses water-quality monitoring and assessment, which includes considerations of water quality in relation to water quantity. The purpose of the National Council is to coordinate and provide guidance and technical support for the voluntary implementation of the recommendations presented in the *Strategy for Improving Water-Quality Monitoring in the United States* (the strategy) by government agencies and the private sector. The intent of the strategy, presented in the final report of the ITFM, is to stimulate the monitoring improvements needed to achieve comparable and scientifically defensible information, interpretations, and evaluations of water-quality conditions. The information is required to support decisionmaking at local, State, Tribal, interstate, and national scales.

B. Scope—The scope of the National Council includes reviewing activities for monitoring the quality of fresh surface water, estuary and near-coastal water, ground water, and precipitation at local, regional, and national levels. The National Council will provide guidance for the collection, management, and use of water-quality information. This information is needed to assess status and trends, to identify and prioritize existing and emerging problems, to develop and implement management and regulatory programs and to evaluate compliance with environmental requirements and the effectiveness of programs and projects. Regarding marine environments, the National Council will assist the U.S. Environmental Protection Agency (USEPA), the National Oceanic and Atmospheric Administration (NOAA), the States, and the Tribes in their joint activities to gather water-quality-monitoring information.

The National Council will address and provide guidance for each of the following aspects of water-quality monitoring: institutional coordination and collaboration, identifying the objectives for monitoring, program design, environmental indicators and standard descriptors of aquatic and riparian conditions, reference conditions and sites, station selection, methods and data comparability, quality assurance and control, information management and data sharing, ancillary data needed to interpret basic water-quality data and information, data-interpretation and analysis techniques, reporting findings and information, training, incentives for participating in the strategy, benefits and costs of monitoring, evaluation of monitoring activities, and other issues necessary to the successful implementation of the strategy.

C. Applicability—As resources are available and consistent with applicable legal requirements, organizations that voluntarily choose to participate in implementing the strategy will implement ITFM recommendations and voluntarily use the guidelines and procedures developed by the National Council and accepted by the Advisory Committee on Water Information (ACWI)

D. Functions—The specific functions and tasks of the National Council include the following:

1. Maintain the institutional framework—To implement the strategy, establish and maintain collaborative partnerships that link monitoring organizations at

the national, regional, State, Tribal, and watershed levels

2. Evaluate progress—Evaluate and report the progress in implementing the strategy every 5 years beginning in 2000. The evaluation will include accomplishments, plans, recommendations, and a list of organizations that participate in implementing the strategy. The report will be distributed to Governors, the heads of executive agencies, the President, the Congress, and other interested parties.
3. Data quality and documentation—Develop and foster the implementation of monitoring activities for which the data quality is known and the documentation is adequate to support information sharing.
4. Indicators—Establish and maintain a process to identify and distribute comparable physical, chemical, and biological indicators to measure progress in meeting water-quality goals at the national and large regional levels. As part of the process to support comparable and policy-relevant indicators, produce guidance for implementing national indicators. Coordinate planning for implementing comparable indicators. (The plans will include agency-specific actions, data-quality guidelines, and schedules for reporting data intended for use in national assessment activities.) Encourage similar collaboration to achieve comparable and relevant indicators at the State and the watershed levels.
5. Information management and sharing—Provide easy access to and support of the sharing of information holdings by creating links among information systems that will constitute a nationwide distributed water-information network. The system links and the information-sharing networks will include Federal, State, Tribal, local, and private organizations among the primary and the secondary users of water-quality information.
6. Data elements, codes, and reference tables—Adopt and maintain an agreed-upon data-element glossary to provide common terminology and definitions for documenting water-quality data; that is, metadata. Continue to update and refine the data-elements glossary to meet additional requirements. Coordinate support for interagency efforts to maintain, update, and distribute common taxonomic and other codes and reference tables for use in automated data systems containing water-quality information. In particular, support the Interagency Taxonomy Information System.
7. Methods and data comparability—Provide technical guidance and coordinate other support necessary to achieve comparable measurements that have known quality. To carry out these functions, the permanent Methods and Data Comparability Board (MDCB) will be established. The MDCB will include a balanced membership of organizations that represent Federal, State, Tribal, interstate, and local government agencies and the private sector.
8. National assessment—Foster collaboration among organizations that participate in national, multistate, or State assessments of water-quality conditions and trends. Develop and distribute guidelines and procedures to improve the interpretation and integration of the physical, chemical, and biological/ecological data needed to describe water-quality conditions and trends and to understand the factors that cause water-quality conditions to change.
9. Reporting and public education—Foster a better understanding of water-quality conditions, trends, and issues among decisionmakers and the general public by developing and implementing common or linked

information-presentation and reporting methods, which would include suggested presentation formats.

10. Information dissemination—Establish a mechanism that uses modern information technology to make the activities, conventions, protocols, and guidelines that are part of the strategy widely accessible. The mechanism should be maintained over time as required to meet users needs and to document the evolving infrastructure that supports the strategy.

11. Training—Identify training requirements and recommend training activities to make the most effective use of monitoring resources and to facilitate data quality, comparability, and sharing.

12. International activities—Through existing mechanisms, foster communication, collaboration, and consensus to improve the availability and utility of water-quality information internationally. The National Council will learn from experts in other countries and evaluate technology and information for its applicability in the United States. Also, the National Council will share technology and information developed in the United States with other countries; in particular, the National Council will collaborate with appropriate entities under the North American Free Trade Agreement.

III. Membership

A. The National Council shall comprise a balanced membership of Federal, interstate, State, Tribal, local, and municipal government agencies and the private sector, which will include volunteer monitoring groups. The membership will include organizations that collect, analyze, interpret, disseminate, or use water-quality monitoring information, as well as those that develop monitoring technology, guidelines, and (or) standards.

B. State membership on the National Council will include one State agency representative from each of the 10 Federal regions. To allow full State participation over time, membership will rotate among the States in one-half of the regions every 2 years. To initiate the rotation on the National Council, States in Regions I, III, V, VII, and IX will rotate at the end of the first 2 years. States in Regions II, IV, VI, VIII, and X will rotate at the end of the first 4 years. Within each region, representatives of State water-quality-monitoring agencies will elect their representative to the National Council. State representatives will serve 4-year terms once the rotation noted above is established.

C. The Director of the U.S. Geological Survey (USGS) and the Assistant Administrator for Water of the USEPA will designate an additional 11 member organizations that have differing viewpoints and water-quality-monitoring and assessment functions. Other organizations that participate on the National Council will represent the following interests: Native Americans, agriculture, environmental interest groups, industry, local agencies and municipalities, river-basin commissions, and (or) in associations, universities, and volunteer monitoring groups. Nominations for this category of membership will be by members of the ACWI and other interested organizations. These other member organizations will serve 4-year terms and can be redesignated.

D. Each member organization will designate their representative and an alternate to the National Council.

E. The USGS and the USEPA will serve as cochairs of the National Council. The USGS will provide the Executive Secretariat for the National Council. Including the USGS and USEPA, Federal membership on the National Council will not exceed 10 representatives and will include the following organizations: the U.S. Department of Commerce/NOAA, the Tennessee Valley Authority, the U.S. Army Corps of Engineers, the U.S. Department of Agriculture, the U.S. Department of Energy, the USEPA/Offices of Water, the U.S. Department of the Interior/USGS, and either the National

Biological Service or the U.S. Fish and Wildlife Service. Additional Federal member organizations up to a total of 10 can participate as mutually agreed by the cochairs of the National Council. The Office of Management and Budget (OMB) will be invited to participate as a nonvoting member.

F. To ensure appropriate balance and expertise on the National Council, the cochairs may jointly designate additional member organizations not to exceed a total membership of 35.

G. Representatives or alternates are expected to attend all meetings of the National Council. If a member organization is not represented at three consecutive meetings, then the cochairs of the National Council may appoint a new member organization to replace the member that has failed to participate. The cochairs will consult with the member organization before removing it from the National Council.

IV. Meetings and procedures.

A. The National Council will meet a minimum of three times a year and at other times as designated by the cochairs. The cochairs will jointly determine the dates, times, and locations of the meetings in consultation with the members.

B. Representatives to the National Council will receive no pay, allowances, or benefits by reason of their service on the National Council. However, while away from their homes or regular places of business and in the performance of services for the National Council, non-Federal representatives to the National Council will be allowed travel expenses if needed. Travel expenses will include per diem in lieu of subsistence, in the same manner as persons employed intermittently in Government service are allowed such expenses under Section 5703 of Title 5 of the *United States Code*.

C. The presence of two-thirds of the representatives or designated alternates of the member organizations will constitute the quorum necessary to conduct business. The National Council will conduct business in an open fashion by attempting to discuss fully and resolve all issues through consensus and by recognizing the legitimate interests and diverse views of the National Council members. If complete agreement cannot be attained, then the following procedures will apply:

1. A consensus will exist unless one or more representatives request a vote.
2. If a vote is requested, then *Robert's Rules of Order* will apply, and the cochairs will poll the National Council. An affirmative vote of two-thirds of the members present will constitute approval. Each member organization may cast one vote.
3. Actions that constitute final reports or recommendations intended for nationwide implementation as part of the strategy will be signed by the cochairs. Representatives may prepare minority reports and provide them to the executive secretary within 1 week of a decision. Minority reports will be included in the final majority reports.
4. Agreements by the National Council may be reached in formal session or in writing on an individual basis after every delegate is advised in advance by the cochairs.

D. As resources are available and consistent with applicable legal requirements, organizations that chose to participate in the strategy will implement ITFM recommendations and will use the guidelines developed by the MDCB (or other subordinate groups) and approved by the National Council.

E. Before adopting guidelines or recommendations for voluntary implementation nationwide as part of the strategy, the National Council will announce proposed actions and products in the Federal Register for the purpose of obtaining public review and comments.

F. Summaries with action items of National Council meetings will be prepared by the executive secretary and distributed to all members and to the chair of the ACWI. In addition, meeting summaries and other documents will be available for public access and review.

G. Transcripts of each National Council meeting, recommendations adopted, and copies of all studies and reports received, issued, or approved in conjunction with the activities of the National Council will be available for public inspection on the Internet and for review and copying at the following location:

Office of Water Data Coordination
417 National Center
U.S. Geological Survey
12201 Sunrise Valley Drive
Reston, Virginia 22092

V. Period of time necessary for the activities of the National Council —The total period of time necessary for the National Council to carry out its activities is estimated to be for as long as the Federal Government has responsibilities and interests related to monitoring water quality.

VI. Official to whom the National Council reports—The National Council reports to the chair of the ACWI.

VII. Support services—Support services and executive secretariat for the activities of the National Council will be provided by the USGS. In addition, the USEPA and other organizations will provide services and other support to the Natioal Council as mutually agreed.

VIII. Duties of the National Council—The duties of the National Council are to provide information and develop advice as set forth in Section II.

IX. Termination date—The National Council will operate for as long as the strategy is implemented. The chair of the ACWI has the authority to terminate the National Council in consultation with the member organizations of the ACWI and the National Council.

X. Subordinate groups—For assistance in conducting its business, the National Council may establish subordinate groups. Such groups will gather information, conduct research, analyze relevant issues and facts, and draft proposed position papers and (or) recommendations for deliberation by the National Council. These groups, which will be established by the cochairs, will have the balanced perspectives and knowledge necessary to perform their assigned functions. Representatives that serve on subordinate groups may include organizations or experts that are not members of the National Council or the ACWI, but that provide the knowledgeable and interested individuals needed to carry out the assigned tasks. The "Terms of Reference" for permanent groups, such as the MDCB, will be reviewed and approved by the National Council and forwarded to the ACWI for concurrence. These groups will report directly to the National Council or, in some cases, through another subordinate group.

XI. Authority—The National Council is part of the Water Information Coordination Program mandated by OMB Memorandum No. 92–01, dated December 10, 1991. The National Council reports to the ACWI that operates under the Federal Advisory Committee Act.

TECHNICAL APPENDIX D

INDICATORS FOR MEETING MANAGEMENT OBJECTIVES—SUMMARY AND RATIONALE MATRICES

The U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey initiated discussions on water-monitoring activities in April 1991; the identification of pervasive problems associated with monitoring resulted in formation of the Intergovernmental Task Force on Monitoring Water Quality (ITFM). The ITFM, which was mandated by an Office of Management and Budget directive to strengthen coordination for water information nationwide, began work in January 1992. It comprises 20 representatives of Federal, State, and interstate governmental groups. In addition, nearly 150 Federal and State staff sit on the following task groups: Intergovernmental Framework, Data Management and Information Sharing, Data Collection Methods, Environmental Indicators, and Assessment and Reporting. This document represents one of the work products of the Indicators Task Group. The following paragraphs describe the structure of the matrix.

In the attached tables, categories of indicators for monitoring water-resource quality, as well as uses and management objectives, are listed and prioritized. The indicators are meant to describe the suitability of the water-resource use by management objective, not the effect of a usage on a water resource. Table 1 is a summary matrix of indicator groups versus categories of management objectives and presents an overview of appropriate usage. Table 2, which provides a brief rationale for the use of the indicator type, expands the information in table 1. All water-resource groups are addressed by the matrix—streams and rivers, lakes and reservoirs, wetlands, estuaries, coastal waters, and the Great Lakes. An indicator or indicator type, which has been identified as having priority, may not be applicable to the entire spectrum of water-body types. Specifically, different individual indicators are more important for evaluation of some water-body types than others.

Watershed-level indicators are treated differently from the other indicators. For these indicators, recommendations on priority are not given. Because much of this information changes slowly, data are collected once or infrequently during the course of a monitoring program. This background information is needed for interpretation of data from the other indicators.

Environmental indicators are a valuable tool for detecting problems and identifying causal relations. They allow management decisions to be made related to the protection of water-resource quality.

Three broad categories of environmental indicators—human health, ecological health, and economic concerns—are related to six water uses that represent specific management objectives. These management objectives are analogous to the "designated uses" that States set in their water-quality standards and report to the USEPA as part of the 305(b) program. The term "management objectives" is more broadly applicable to the interests of the numerous agencies and offices involved in the ITFM process. Within the broad areas of human health, ecological health, or economic concerns, the six categories of management objectives include three for human health—consumption of fish, shellfish, and wildlife; public water supply and food processing; and recreation (boating and swimming). Ecological health management objectives considered are in the context of aquatic and semiaquatic life, protected species, and aquaculture and recreation (fishing and catchability). For economic concerns, management objectives are industry (makeup and cooling water), transportation and hydropower, and agriculture and forestry.

Indicator categories are broad areas of environmental information that can encompass many specific measures related to those categories. For example, specific measures within the macroinvertebrate category can be derived from assemblage, community, population data, and lethal and sublethal toxicity data. Other biological indicator categories are fish, semiaquatic wildlife, pathogens and fecal indicator organisms, phytoplankton, periphyton, aquatic and semiaquatic plants, and zooplankton.

The category "chemical exposure/water chemistry" includes oxidative state, ionic strength, nutrients, potentially hazardous chemicals in water, sediment, and organismal tissue/bioaccumulation. Indicator categories related to physical habitat include water quantity, water temperature, suspended sediment/turbidity, bed sediment and substrate, geomorphology,

geomorphology, and riparian vegetation. Watershed-level stressors refer to factors that are often large scale and, in some cases, change at a different temporal scale than the other categories. Generally, these stressors are extrinsic to the aquatic system and include land-use patterns; vegetative cover; loading or application of chemical, sewage, or animal wastes; acid deposition; reaeration potential; channel or flow modification; sedimentary indicators; and location.

Table 1. Summary matrix of recommended environmental indicators for meeting management objectives for status and trends of surface waters (summary matrix)

[Shaded boxes with check marks are used to recommend a primary indicator (W S Davis, 4/15/92; revised 4/22/92, 6/23/92, 7/4/92, 7/13/92, 9/1/92 11/4/92, 11/17/92; J.B Stribling, 8/27/93)]

Indicator group	Categories of management objectives					
	Human health		Ecological health		Economic concerns	
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation (fishing, boating, and swimming, including catchability)[1]	Aquatic and semi-aquatic life (protected species and aquaculture)	Industry, energy, and transportation	Agriculture and forestry
Biological response and exposure (direct)						
Macroinvertebrates		X	**X**	**X**		X
Fish	**X**		**X**	**X**		X
Semiaquatic wildlife	X		**X**	**X**		X
Pathogens	**X**	**X**	**X**			**X**
Phytoplankton	**X**	X	X	**X**	**X**	
Periphyton				**X**		
Aquatic/semiaquatic plants		X	**X**	X	X	X
Zooplankton		X	X	X		X
Chemical exposure						
Water chemistry/odor/taste	X	**X**	**X**	**X**	X	**X**
Sediment chemistry	X	X	X	**X**	**X**	X
Animal/plant-tissue chemistry	**X**	X		**X**	X	
Physical habitat						
Hydrological characteristics	X	**X**	X	**X**	**X**	**X**
Water temperature	X	X	**X**	**X**	X	
Geomorphology and sediment physical characteristics	X	X	**X**	**X**	**X**	**X**
Riparian or shoreline zone	X	**X**	**X**	**X**	X	**X**
Watershed stressors						
Land use patterns		X	X	X	X	X
Location, setting, human alteration.		X	X	X	X	X

[1] This section also applies to "Human health."

NOTE: These indicators are intended to demonstrate the suitability of a water resource for a particular management objective or activity rather than to demonstrate the effect of the management objective on the water resources

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resources

[Selection of indicators to be used in specific programs will depend on selection criteria, water-body type, and management objective. **High-priority indicators are in boldface.** *Medium-priority indicators are italicized.* Low-priority indicators are in regular typeface. Numbers in brackets refer to reference at end of appendix. Literature citations included here offer some technical justification for indicator recommendations; the ITFM indicators task group does not mean to imply that these are the most appropriate. Also, some of the matrix cells with text do not yet have citations.]

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation: Boating, swimming, and fishing (including catchability)[1]	Aquatic and semi-aquatic life, protected species and aquaculture	Industry: Makeup and cooling water, and other types of water	Transportation and hydropower	Agriculture and forestry
			Part 1—Indicators of biological response and exposure				
Macroinvertebrates (including problem species): Assemblage, aqueous or sediment toxicity, harvesting, populations.		*Populations of problem species clog intakes (locally important).*	Populations and harvesting show availability. Toxicity tests may indicate toxic conditions. **Population of problem species show community alteration** [18, 33].	**Assemblage and harvesting show system status. Populations of problem species indicate invasion of species and alteration of community.** Toxicity tests may indicate toxic conditions [14, 23, 33].	Populations of problem species clog intakes.	Problem populations clog dam conduits and interfere with navigation.	Overabundance of noxious species may interfere with irrigation systems.
Fish (including problem species): Assemblage, biomarkers, abnormalities, aqueous or sediment toxicity, harvesting, communities, populations, biomass.	Abnormalities show possible carcinogen or parasite.		Growth, biomass, populations, and harvesting show availability. External abnormalities are repugnant to fishermen [16].	**Population or Assemblage show status of community. Biomarkers and abnormalities show parasites, toxicity or animal health. Toxicity tests may indicate toxic conditions. Harvesting shows system status** [16, 18].			Do.
Semiaquatic wildlife: Assemblage, populations, biomass, harvesting, biomarkers.			**Populations show number of harvestable organisms.** Biomarkers show exposure to chemicals [4, 21].	**Assemblage,** populations, biomass, and harvesting show system status. Biomarkers show chemical exposure [4, 5].			Do.
Pathogens and fecal indicator microorganisms: (E. coli, Giardia, avian botulism, fecal coliform.)	**Populations indicate presence of pathogens in shellfish** [35].	**Concentrations of indicator bacteria show pathogenicity** [1].	**Populations or assemblage indicate human** [29].	Concentrations of pathogens may indicate unhealthy conditions.			**Concentrations of fecal bacteria indicate livestock pathogens.**

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resource—Continued

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation: Boating, swimming, and fishing (including catchability)[1]	Aquatic and semi-aquatic life, protected species and aquaculture	Industry: Makeup and cooling water, and other types of water	Transportation and hydropower	Agriculture and forestry
Part 1—Indicators of biological response and exposure—Continued							
Phytoplankton: Assemblage, biovolume, chlorophyll *a*, primary productivity, trophic status, toxicity, toxic forms.	**Assemblage of toxic algae indicates possible presence in harvestable species.**	**Algal assemblage affects taste, odor, toxicity, and treatment.**	Assemblage shows food for herbivores. Primary productivity or trophic status shows eutrophication. Aesthetics affect use [13, 22].	**Assemblage, primary productivity and chlorophyll *a* show production to sustain ecosystem and aquaculture.** Biovolume shows health of community. Assemblage responds to and affects water chemistry. Trophic status shows eutrophication. Toxicity disrupts community [22].	**Chlorophyll *a* biomass can reduce utility of water for cleaning, textiles. Primary productivity enhances assimilative capacity.**		Some bluegreen algae are toxic to livestock under certain circumstances [34].
Periphyton: Assemblage, growth rate, chlorophyll *a*, colonization.				**Assemblage,** *chlorophyll a*, growth rate, colonization shows system status [2].			
Aquatic and semiaquatic plants (including introduced species): Biomass, percent cover, assemblage, trophic status.		Biomass clogs water intakes.	**Biomass or percent cover indicate habitat and flood availability.** Trophic status shows eutrophication. Biomass affects boating, swimming [22].	*Biomass or percent cover indicate habitat and food.* Assemblage and trophic status show food, habitat, and eutrophication [22].	Biomass clogs water intakes.	**Plant biomass impedes navigation.**	Overabundance of noxious species may interfere with irrigation systems.
Zooplankton: Assemblage, toxicity, biomass.		Biomass can log intakes.	Biomass shows food source for fish.	*Assemblage shows community status. Toxicity disrupts community.* Biomass sustains aquaculture.	.......do.......		

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resource—Continued

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation: Boating, swimming, and fishing (including catchability)[1]	Aquatic and semi-aquatic life, protected species and aquaculture	Industry: Makeup and cooling water, and other types of water	Transportation and hydropower	Agriculture and forestry
Part 2—Indicators of chemical response and exposure							
Oxygenation: Dissolved oxygen, BOD, benthic oxygen demand, redox potential of sediment, reaeration potential, assimilative capacity.		*Oxidation state affects processing techniques and palatability due to metallics and organics.*	**Respiration of fish. Anaerobic water is unaesthetic** [31].	**Respiration requires oxygen.** Sediment redox affects toxicity, benthic community [36].	Oxygen alters utility of water for waste discharge.		
Ionic strength: pH, hardness, alkalinity, acid neutralizing capacity, salinity, conductivity, total dissolved solids.	Ionic strength and pH affect availability of chemicals.	**Salinity and pH affect corrosiveness. Salinity alters potability and affects treatment.**	*Extreme pH irritates eyes. Ionic strength affects life and chemical processes including toxicity* [16].	**Ionic strength affects life, toxicity, and chemical processes. Hardness and pH alter habitat suitability** [16].	*Salinity and pH affect corrosiveness and utility for cleaning and textile industry. Solids accumulate on equipment.*	Density influences barge loading capacity. pH affects corrosion of turbines.	**Salinity and pH affect livestock, degradation of pesticides, crops and soil fertility. Hardness alters sensitivity to salt** [31].
Nutrients: Nitrogen phosphorus.		Influences algal growth thus potability and impingement on intake screens [31].	*Affects fish biomass, phytoplankton and macrophyte growth* [31].	**Affects productivity, toxicity and community structure** [31].			
Potentially hazardous chemicals in water.	*Affects bioaccumulation by food organisms* [33].	**Human toxicity** [1].	**Toxic to swimmers.**	**Toxic to aquatic life** [16, 36].	*Affects fitness for chemical industry.*		**Affects trees, soil, crops, and livestock.**
Odor and taste, unaesthetic chemicals.	*Odor in fish unattractive to consumer.*	**Affects palatability.**	Unattractive to user of water.	**Alters aquaculture product marketability.**			

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resource—Continued

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation: Boating, swimming, and fishing (including catchability)[1]	Aquatic and semi-aquatic life, protected species and aquaculture	Industry: Makeup and cooling water, and other types of water	Transportation and hydropower	Agriculture and forestry
Part 2—Indicators of chemical response and exposure—Continued							
Potentially hazardous chemicals in bottom or suspended sediment.	Gut contents of shellfish could be toxic [35].	Toxic to humans.	Toxic to swimmers.	**Toxic to aquatic life** [7, 34].	Affects pre- and post-treatment.	**Polluted sediment affects dredge permits** [24].	Chemicals on particulates alter fertility.
Poetentially hazardous chemicals in animal and plant tissue, bioaccumulation.	**Bioaccumulated chemicals toxic to consumer** [35].			**Show exposure, toxicity affects community** [30].			
Part 3—Indicators of physical habitat							
Quantity of water: Drainage area, water level, stream order, velocity, hydrologic regime, flow duration.	*Flow affects bacterial concentrations in shellfish.*	**Knowledge of quantity is required for use.**	*Maintenance of flow for rafting and fisheries* [25].	**Depth and flow needed for habitat, and aquaculture** [3].	**Required quantity.**	**Quantity required to maintain depth.**	**Required quantity for irrigation.**
Water temperature.	*Alters growth rate of harmful bacteria and algae.*	**Chemical treatment is temperature dependent.**	**Swimming and fisheries are temperature dependent** [25].	**Life processes and community structure are temperature dependent** [10].	Affects suitability as cooling water and type of chemical treatment.	Affects density and equipment longevity.	Can promote abundance of noxious species and suitability for irrigation.
Suspended sediment turbidity, color.		**Sedimentation affects longevity of dams and treatment.**	**Turbidity unaesthetic in some locales.**	**Sedimentation reduces habitat, clogs gills, and buries organisms. Turbidity affects primary productivity** [1, 36].	*Amount affects treatment, thus suitability and cost of process waters.*	Suspended sediment reduces equipment longevity. Sedimentation affects dams.	**Sedimentation clogs irrigation conveyances.**

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resource—Continued

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	**Public water supply and food processing**	**Recreation: Boating, swimming, and fishing (including catchability)[1]**	**Aquatic and semi-aquatic life, protected species and aquaculture**	**Industry: Makeup and cooling water, and other types of water**	**Transportation and hydropower**	**Agriculture and forestry**
Part 3—Indicators of physical habitat—Continued							
Bed sediment and substrate characteristics: Size distribution, embeddedness.	Affects chemical availability.	A source of suspended sediment.	*Mud bottoms are unaesthetic and reduce fish and habitat availability* [11].	**Affects habitat and chemical availability. Determines suitability for shellfish culture** [3, 12].	*Affects treatment, thus suitability and cost of process waters.*	Sediment affects equipment longevity, bank stability.	Sediments clog irrigation conveyances.
Geomorphology: Slope, bank stability, channel morphology.	Alters contact time with toxicants.		*Type of habitat (erosive and depositional) governs recreation potential* [11].	**Type of habitat (erosive and depositional) controls biotic community** [12, 15].	Erosion of banks threatens structures.	**Erosion and deposition affect depth, dam capacity, navigation and dam longevity** [32].	**Erosion of banks reduces cropland.**
Riparian or shoreline vegetation, canopy, cover.	Filters out toxics.	Reduces turbidity.	**Affects temperature, aesthetics and habitat, thus swimming and fisheries** [10].	**Affects habitat, temperature, productivity, oxygen, and inputs of organic matter** [10, 12].	.... do	Snags from fallen trees block access. *Plants alter flow of irrigation water.*	*Riparian strips alter erosion of banks thus cropland.*
Part 4—Indicators of watershed-level stressors							
Land use type and intensity: Human and livestock density.	Affects bioaccumulation [1].	Population determines quantity needed. Affects presence of chemicals. Source of pathogens.	Turbidity and sedimentation from urbanization and livestock reduces habitat quality and fish availability [9, 17, 19].	Land use affects turbidity, sedimentation, habitat quality, chemcial contamination or other disturbance [17, 20, 31].		Land use affects loading of sediments [32].	Urbanization reduces cropland.

Table 2. Rationale for use of indicators in water-resource-quality-monitoring programs for meeting water-management objectives relevant to selected surface-water uses. These are status and trends indicators meant to illustrate the suitability of a water resource for use by a management objective rather than demonstrate the effects of a particular management objective on that water resource—Continued

Categories of indicators	Human health and aesthetics		Ecological condition		Economic concerns		
	Consumption of fish, shellfish, and wildlife	Public water supply and food processing	Recreation: Boating, swimming, and fishing (including catchability)[1]	Aquatic and semi-aquatic life, protected species and aquaculture	Industry: Makeup and cooling water, and other types of water	Transportation and hydropower	Agriculture and forestry
Part 4—Indicators of watershed-level stressor—Continued							
Land cover, vegetation.		Alters hydrologic regime, thus availability.	Alters hydrology, thus severity and duration low and high water [20].	Alters hydrologic regime, thus habitat [17, 20].	Alters hydrologic regime, thus availability of water.	Alters hydrology, thus quantity of water and stability of hydrograph.	Alters hydrologic regime, thus availability.
Loading or application of chemical, sewage, or animal wastes.	Affects presence of chemicals in fish and birds [1].	Affects degree of treatment and usability[1].	Affects presence of hemicals in swimming water [1].	Affects DO, pathogenicity and chemical interactions [1].	Affects use for waste disposal and degree of treatment.		Affects soil.
Acid depostion and airborne pollutants.	Inputs affect chemical availability, thus consumption advisors.	Affects pH.	Acid deposition affects catchability in acid-sensitive areas [8, 27, 28].	Low pH and other chemical inputs affect aquatic life in acid-sensitive areas [8, 27, 28].			Affects pH which affects soil and crops.
Reaeration potential, assimilative capacity.		Affects food processing techniques.	May impart odor.	Affects recovery of system and community.	Affects ability to discharge waste.	Affects dam operations [26].	
Channel or flow modification, dams, channelization.		Dams alter availability of water.	Recreation potential depends on environment. Flow, channelization alter habitat [25].	Channelization and dams alter habitat suitability communities and migration [25].	Dams affect availability of water.	Depth and flow affect navigation, power.	Ditches alter availability of water.
Location: ecological or physiographic region, coordinates.		Affects water availability.	Affects amount of water and type of fishery [9, 20].	Affects amount of water and thermal regime.	Affects availability of water.	Affects water availability and evaporation.	Affects water availability.
Sedimentary indicators: Sedimentary diatoms, pollen.				Assemblage shows trophic history [6].			

[1] This section also applies to "Human Health and Aesthetics."

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TECHNICAL APPENDIX E

INDICATOR-SELECTION CRITERIA

The U.S. Environmental Protection Agency (USEPA) and the U.S. Geological Survey (USGS) initiated discussions on water-monitoring activities in April 1991; the identification of pervasive problems associated with monitoring resulted in formation of the Intergovernmental Task Force on Monitoring Water Quality (ITFM). The ITFM, which was mandated by an Office of Management and Budget directive to strengthen coordination for water information nationwide, began work in January 1992. It comprises 20 representatives of Federal, State, and interstate governmental groups. In addition, approximately 150 Federal and State staff sit on the following task groups: Intergovernmental Framework, Data Management and Information Sharing, Data Collection Methods, Environmental Indicators, and Assessment and Reporting. This document represents one of the work products of the Environmental Indicators Task Group (Task Group) and describes the selection criteria table (attached) and some of the supporting rationale.

Definition

The group developed the following definition of "environmental indicator ..... measurable feature or features that provide managerially and scientifically useful evidence of environmental and ecosystem quality or reliable evidence of trends in quality." Thus, environmental indicators must be measurable with available technology, scientifically valid for assessing or documenting ecosystem quality, and useful for providing information for management decisionmaking. Environmental indicators encompass a broad suite of measures that include tools for assessment of chemical, physical, and biological conditions and processes at several levels. These characteristics of environmental indicators have helped define the scope of the group activities.

This Task Group used guidelines gathered from the monitoring programs of eight Federal and State agencies or groups to establish a set of criteria that can be used to select biological, chemical, and physical indicators that will provide information appropriate for addressing objectives of particular programs. These criteria are organized into three broad categories—scientific validity (technical considerations), practical considerations, and programmatic considerations. The list of selection criteria includes those currently in use by the following offices or programs: USEPA, Office of Water; USEPA, Office of Policy, Planning, and Evaluation; USEPA, Environmetal Monitoring and Assessment Program; USEPA Region 2, Lake Ontario Stewardship; U.S. Department of Interior (USDOI), USGS; USDOI, U.S. Fish and Wildlife Service; U.S. Department of Agriculture, U.S. Forest Service; Ohio Environmental Protection Agency; and New York Bight Project.

We intend these criteria to be useful to any program in which indicators for describing environmental quality or measuring program success must be selected.

Selection of Appropriate Indicators

Standard Selection Criteria

Environmental indicators should be able to satisfy predetermined selection criteria to ensure their viability. These criteria provide a series of guidelines that shape the decisionmaking process, which results in an indicator that meets the needs of the program. It is important to put the selection criteria into a standardized format that can be useful for nationwide programs. Standardization of the selection criteria streamlines the indicator selection process, reduces costs, prevents duplication of effort, and provides a consistency, thereby increasing the potential for cross-program comparisons.

The task group decided that it should focus on indicators for which techniques, protocols, or equipment were either available or in advanced stages of development, rather than concentrate on potential measures; the group felt that concentrating on potential measures would be unrealistic considering the 1- to 3-year time limitation. It was decided to focus on attainable goals, and with the diverse experience and backgrounds represented on the group membership, there would be an abundance of information to compile to understand what is currently available.

Criteria Categories

Scientific validity is the foundation for determining whether data can be compared with reference conditions or other sites. Data collected from a sampling site become irrelevant if they cannot be easily compared with conditions found at a site determined to be minimally impaired. Factors must be balanced when considering the scientific validity of an indicator and its application in real-world situations. An indicator must not only be scientifically valid, but its application must be practical (that is, not too costly or too technically complex) when placed within the constraints of a monitoring program. Of primary importance is that the indicator must be able to address the questions that the program seeks to answer.

For discussion purposes, these criteria have been divided into three categories—scientific validity (technical considerations) practical considerations, and programmatic considerations. Although discussed separately, these categories are not entirely separate entities, but rather portions of characteristics that provide some guidance in the indicator-selection process.

Scientific Validity

As with any monitoring or bioassessment program, the data collected must be scientifically valid for it to be useful. Table 1 lists 11 guidelines that have been identified for assisting in this determination.

Measurements of environmental indicators should produce data that are valid and quantitative or qualitative and allow for comparisons on temporal and spatial levels. This is particularly important for comparisons with the reference condition. Interpretation of measurements must accurately discern between natural variability and the effects induced by anthropogenic stressors. This requires a level of sensitivity and resolution sufficient to detect ecological perturbations and to indicate not only the presence of a problem, but to provide early warning signs of an impending impact. The methodology should be reproducible and provide the same level of sensitivity regardless of geographic location. It also should have a wide geographic range of application and a set of reference-condition data that can be used for comparisons.

Practical Considerations

The success of a biomonitoring program is dependent on the ability to collect consistent data over the long term; consistency is directly related to the practical application of the prescribed methodologies. The practical considerations include monitoring costs, availability of experienced personnel, the practical application of the technology, and the environmental impacts caused as a result of monitoring.

A cost-effective procedure should supply a large amount of information in comparison to cost and effort. Of significant importance is the acknowledgment that not every quantitative characteristic needs to be measured unless it is required to answer the specific questions. It may be more important to have a range of qualitative and quantitative data from a large number of sites than it is to have a small number of quantitative parameter measurements from a small number of sites. Cost effectiveness may be dependent on the availability of experienced personnel and the ability to find or detect the indicating parameters at all locations. State-of-the-art technology is useless in a biomonitoring program if experienced personnel are in short supply or the data cannot be collected at all the stations. Equally important is the ability to collect the data with limited impact to the environment. Some collection procedures (for example, using rotenone to collect fish) are very effective, but minor miscalculations can cause significant environmental damage. These methodologies should be replaced with less destructive procedures.

Programmatic Considerations

Stated objectives of a program are an important factor in selecting indicators. Sampling and analysis programs should be structured around questions to be addressed. The term "programmatic considerations" simply means that the program should be evaluated to confirm that the original objectives will be met once the data have come together. If the design and the data being produced by a program do not meet the original objective(s) within the context of scientific validity and resource availability, then the selected indicators and uncertainty specifications should be reevaluated.

Another important consideration is the ease with which the information obtained can be communicated to the public. Although it is essential to present information for decisionmakers, scientists, or other specialized audiences, information for the general public needs to be responsive to public interests and summarized for clarity.

Table 1. Summary of some indicator selection criteria

[Sources: USEPA/Office of Policy, Planning, and Evaluation (OPPE), USEPA/Environmental Monitoring and Assessment Program (EMAP), USGS, U.S. Forest Service (USFS), U.S. Fish and Wildlife Service (USFWS), Ohio EPA, USEPA Region 2/Lake Ontario Stewardship Indicators, New York Bight Project]

Criteria/quality	Definition(s)
Scientific validity (technical considerations)	
Measurable/quantitative	Feature of environment measurable over time; has defined numerical scale and can be quantified simply
Sensitivity	Responds to broad range of conditions or perturbations within an appropriate time frame and geographic scale; sensitive to potential impacts being evaluated.
Resolution/discriminatory power	Ability to discriminate meaningful differences in environmental condition with a high degree of resolution (high signal to noise ratio).
Integrates effects/exposure	Integrates effects or exposure over time and space.
Validity/accuracy	Parameter is true measure of some environmental conditions within constraints of existing science. Related or linked unambiguously to an endpoint in an assessment process
Reproducible	Reproducible within defined and acceptable limits for data collection over time and space
Representative	Changes in parameter/species indicate trends in other parameters they are selected to represent
Scope/applicability	Responds to changes on a geographic and temporal scale appropriate to the goal or issue.
Reference value	Has reference condition or benchmark against which to measure progress
Data comparability	Can be compared to existing data sets/past conditions
Anticipatory	Provides an early warning of changes.
Practical considerations	
Cost/cost effective	Information is available or can be obtained with reasonable cost/effort High information return per cost
Level of difficulty	Ability to obtain expertise to monitor. Ability to find, identify, and interpret chemical parameters, biological species, or habitat parameter. Easily detected Generally accepted method available Sampling produces minimal environmental impact.
Programmatic considerations	
Relevance	Relevant to desired goal, issue, or agency mission; for example, fish fillets for consumption advisories; species of recreational or commercial value.
Program coverage	Program uses suite of indicators that encompass major components of the ecosystem over the range of environmental conditions that can be expected
Understandable	Indicator is or can be transformed into a format that target audience can understand; for example, nontechnical for public.

TECHNICAL APPENDIX F

ECOREGIONS, REFERENCE CONDITIONS, AND INDEX CALIBRATION

The Ecoregion Concept

Background and Purpose of Geographical and Ecological Classification

Over the past 20 years, various attempts have been made to address issues that concern our Nation's water quality These attempts usually involved using drainage basins, hydrologic units, or even political boundaries to delineate water-management units. Most methods used to research and assess water quality in these management units lacked the logical and useful spatial (geographical) framework with which to organize the results of environmental measurements into a meaningful perspective (Omernik and Griffithy, 1991). Implementation of a system to organize environmental information that is based on geographic patterns provides a mechanism for accomplishing the following tasks:

- Establishment of common environmental monitoring goals and objectives.
- Development of indicators that are meaningful on a site-specific basis and have broader scale significance
- Cooperative development of monitoring methods
- Organizing environmental data bases into applicable, accessible, multiuser units.
- Interstate usage of reference sites or reference data bases.
- Use of common reporting goals.

The ITFM has sought cooperation among monitoring groups at all levels of government (particularly among Federal and State agencies) in developing an ecoregional approach that will build many of the efficiencies into national monitoring activities (Intergovernmental Task Force on Monitoring Water Quality, 1992).

The choice of spatial frameworks for organizing environmental information influences the effectiveness of the research, assessment, and management of many aquatic-resource problems, particularly nonpoint-source pollution (Omernik and Griffith, 1991). It also can lead to the generation of large amounts of information and to large expenditures of money to produce statements about the biological integrity or use attainability of watersheds or large hydrologic units. Unless properly structured, the information collected within a framework may not be useful when compared with information from units in other regions of the country. The use of differences in land and water interactions, regional variations in attainable water quality, distinct biogeographical patterns (Wallace, 1869; MacArthur, 1972), and similarities and differences in ecosystems to delineate ecoregions makes the application of ecoregions in environmental analyses a powerful tool with which to organize environmental information.

Ecoregions can be distinguished by landscape-level characteristics that cause ecosystem components to reflect different patterns in different regions (Omernik, 1987). The delineation of ecoregions is based on patterns in geology, soils, geomorphology, dominant land uses, and natural vegetation. Omernik (1987) originally identified 76 ecoregions in the conterminous United States by using information from small-scale maps.

One of the values of the ecoregion concept in lake restoration and management is that it provides a rational basis for setting regional rather than national lake water-quality standards. The approach can take into account regional factors related to attainable water quality and thus can be used to designate lakes for protection and to establish lake-restoration goals that are appropriate for each ecoregion (National Research Council, 1992). The National Research Council of the National Academy of Science has similarly endorsed the use of the concept in the restoration and management of streams, rivers, and wetlands (National Research Council, 1992). Although the ecoregion concept has been applied and tested rather extensively in streams, rivers, and lakes, its application to wetlands, ground water, and estuaries has not been refined. Additional variables may be needed to determine the spatial distribution of ground-water, estuarine, and wetland ecoregions. For ground water, the additional variables may include redox potential, depth, and the geochemical environment. For wetlands, variables may include ground- and surface-water interactions. For estuaries, tidal influence, salinity profiles, depth, and substrate type may help define boundaries.

The U.S. Forest Service (USFS) developed a hierarchial framework on the basis of earlier work to provide a scientific basis for ecosystem management in the National Forests and Grasslands, as well as in other USFS programs (U.S. Forest Service, 1993).

Ecological units are defined on the basis of potential natural communities, soils, hydrologic function, landform and topography, lithology, climate, air quality, and natural processes for cycling plant biomass and nutrients.

At the ecoregion scale, units are recognized by differences in global continental and regional climatic regimes and physiography. The hierarchy defines three levels of ecoregions—domains, divisions, and provinces. Domains are based on broad climatic patterns; for example, polar, dry, humid, temperate, and so forth. Divisions are defined by isolating levels of vegetative associations that are defined by broad climatic regions. Provinces reflect broad vegetative regions that correspond to climatic subzones, which are based on continental climatic patterns; for example, length of dry season. Similar soil orders also characterize provinces.

Omernik and Gallant (1990) defined ecoregion aggregations in terms of 8 broad-level named regions generalized from the 76 ecoregions mentioned above. They are as follows:

- Northern Predominantly Glaciated Region.
- Central and Eastern Predominantly Forested Hills and Mountains Region.
- South-Central and Southern Humid Region
- Mixed Land-Use Region.
- Subhumid Agricultural Plains Region.
- Western Xeric Region
- Western Forested Mountains Region.
- Unique Alluvial and Coastal Plains Region

Because these eight regions do not provide the specificity needed for water-resource-quality-management activities, personnel in several States and U.S. Environmental Protection Agency (USEPA) regions are subdividing the ecoregions into subregions. Subregionalization is an effort to establish a more-detailed spatial framework that reduces the heterogeneity of the larger region; that is, in terms of biological communities and other ecosystem components, it provides a framework in which units exhibit greater relative interregional heterogeneity than they do intraregional heterogeneity (U.S. Environmental Protection Agency, 1991).

The use of ecoregions as the spatial framework for collecting and analyzing environmental information has the following advantages:

- An ecologically relevant system for classifying landscapes and drainage areas for monitoring bioassessment and biocriteria (U.S. Environmental Protection Agency, 1991).
- Independence from political boundaries, which allows for shared resources, data, and criteria, all of which translate into potentially substantial cost efficiencies.
- A logical classification of sites for the establishment of regionwide reference conditions.

Environmental Variables Used for Ecoregion Delineation

The concept of ecoregions has developed because of our need to study, describe, and communicate spatial information. Delineation translates the concept of regions into a tangible result or map. To

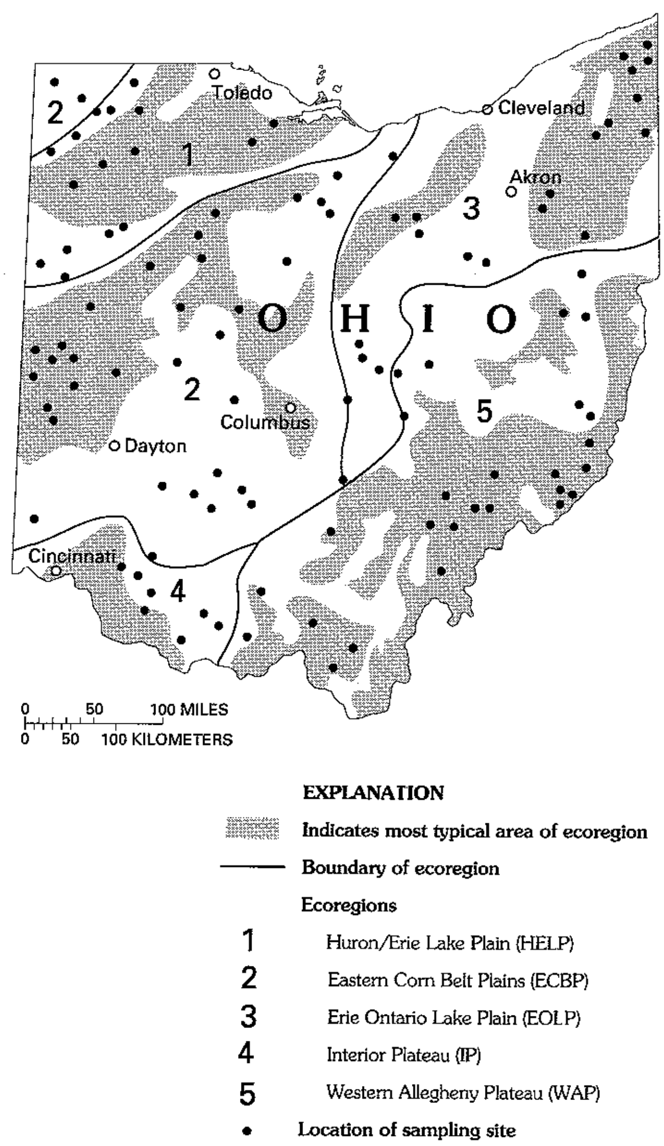

Figure 1. The five ecoregions of Ohio. Darker tones denote most typical areas. 1. Huron/Erie Lake Plain (HELP), 2. Eastern Corn Belt Plains (ECBP), 3. Erie Ontario Lake Plain (EOLP), 4. Interior Plateau (IP), and 5. Western Allegheny Plateau (WAP). Dots indicate location of sampling sites. (From Whittier and others, 1987.)

determine delineation of ecoregions, many environmental variables are examined. Some regions are delineated on the basis of existing maps that display climatological patterns, land-surface form/land use, natural vegetation, and species ranges or a combination of several environmental variables. These environmental characteristics taken individually may only produce inferences about regional characteristics, but combined, they help indicate the boundaries between areas of different ecological characteristics.

Because environmental characteristics are interrelated (for example, climate and surficial geology affect soil formation; soil formation and climate affect vegetation type, which further affects soil formation; and all these factors affect land use, which affects vegetative succession and soil formation), spatial distributions of many of the features coincide, reinforcing patterns that would not be entirely identifiable from any single variable (Gallant and others, 1989). Other factors that can be used to define ecoregions include bedrock geology, physiography, hydrologic drainage areas, lake phosphorous concentrations, and sensitivity of surface waters to acidic deposition.

Use of the Ecoregional Framework

By using the types of information described above, Omernik (1987) developed a map that divides the United States into the 76 ecoregions mentioned in "Background and Purpose of Geographical and Ecological Characteristics." As an illustration of the utility of an ecoregional framework, Ohio has, within its borders, five different ecoregions from the original delineations (fig. 1; Whittier and others, 1987). The Ohio Environmental Protection Agency (1987) developed biological criteria for these five ecoregions on the basis of two types of assemblage data—fish and benthic macroinvertebrates. The biological criteria are statements of ecological expectations for the regions. The numerical thresholds of the criteria are measures of use attainment for the water resources (Yoder, 1991). Information is categorized within each region by drainage area (headwater, wadable, boat-required reaches), and the interpretation of biological data is further enhanced through the assessment of site-specific physical habitat structure

Identification of Subregions (Subregionalization Activities)

Since the development of ecoregions, States have made efforts to divide ecoregions into subecoregions by using information with greater resolution concentrating on differences in patterns of environmental characteristics of particular ecoregions. The regional subdivision is based on the vegetative differences of an ecoregion; vegetation maps can indicate not only various types of plants, but can reflect erosion, drainage, recreational use, and grazing. Although changes in vegetation may not be reflected in all communities, it does provide a basis for examination of the possible subdivision of an ecoregion. Climate, physiography, land use, soils, and surface-water quality also are used for making subregional distinctions.

An example of an ongoing effort to subdivide ecoregions is the U.S. Geological Survey/USEPA Region 3 project in the Central Appalachian Ridge and Valley ecoregion of West Virginia, Virginia, Maryland, and Pennsylvania. This ecoregion consists of sharply folded sedimentary strata that have been eroded, which has resulted in a washboardlike relief of resistant ridges that alternate with valleys of less-resistant rock (Gerritsen and others, 1994). The region has been divided into the following subregions that correspond to ridges and valleys of different parent material (fig. 2; Omernik and others, 1992):

- Limestone valleys (fig. 2, 67a) are dominated by calcareous soils and have numerous springs. The subregion has fertile, well-buffered soils suitable for agriculture. Land use is predominantly agricultural, and small- to medium-sized cities are scattered throughout. Streams have low to moderate gradients and are high in alkalinity owing to the calcareous bedrock and soils and have high-nutrient concentrations owing to intensive agriculture.
- Shale valleys (fig. 2, 67b) are dominated by noncalcareous bedrock, primarily shale. Land use also is predominantly agricultural but is of lower intensity than in the limestone valleys. Streams have low to moderate gradient and are low in alkalinity. During dry years, streams in shale valleys may go dry in late summer or fall.
- Sandstone ridges (fig. 2, 67c) are dominated by highly resistant sandstones. Land use is predominantly forest, streams have steep to moderate gradients, and waters are low in alkalinity.

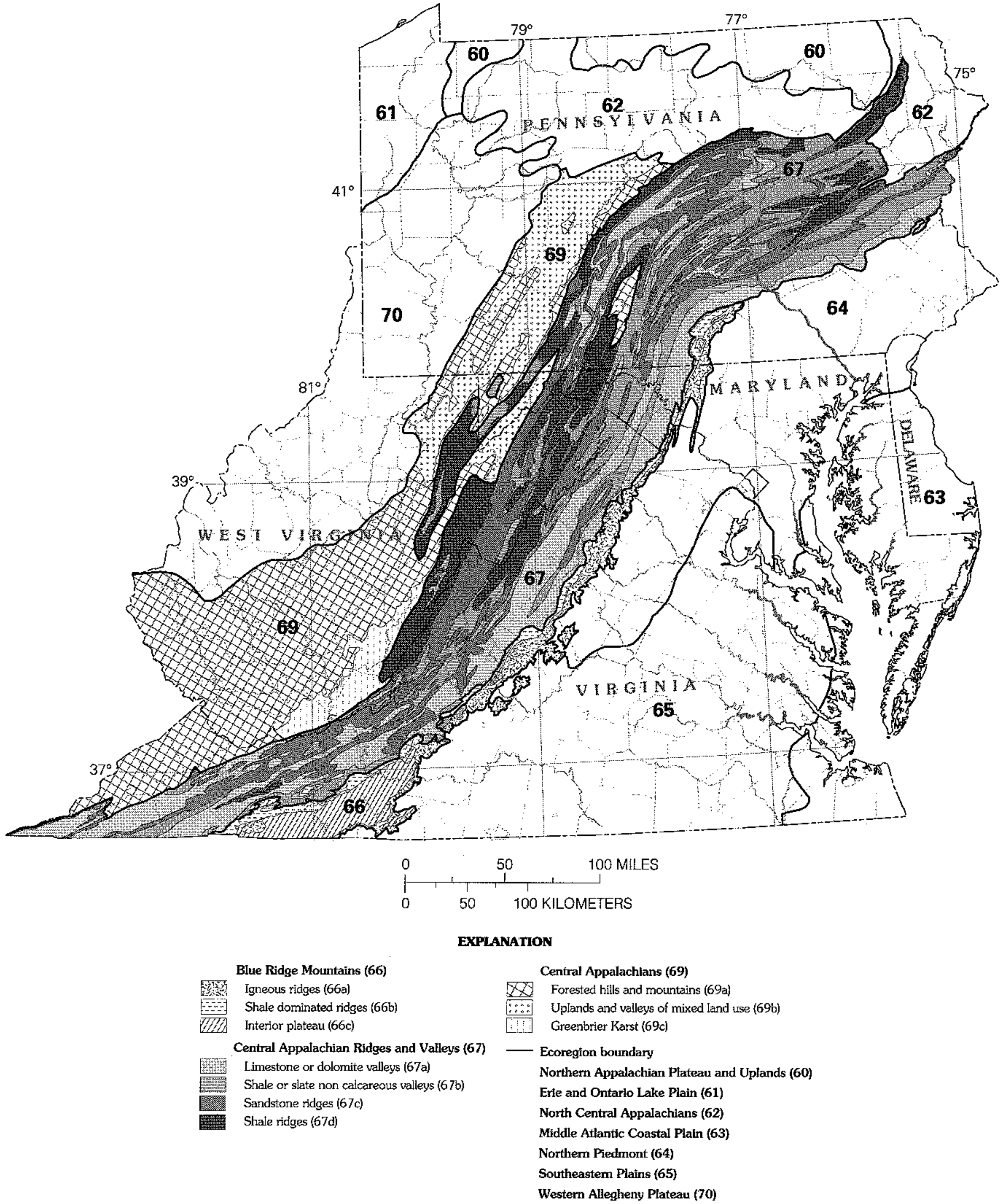

Figure 2. Ecoregions and subregions of the Blue Ridge Mountains, Central Appalachian Ridges and Valleys, and Central Appalachians.

- Shale ridges (fig. 2, 67d) are dominated by shale bedrock. Land use is predominantly forest, stream gradients have steep to moderate gradients, and waters are low in alkalinity. Streams on shale ridges frequently dry up during fall.

The subregions are not continuous and interdigitate throughout the Ridge and Valley. Each subregion occurs in each of the four States of USEPA Region 3.

Table 1 shows how selected criteria traditionally used to classify streams within the Ridge and Valley ecoregion (elevation, conductivity, temperature) relate to subecoregional classification, which incorporates these characteristics into their structure. Because these parameters (streamwater type, dominant fishery) are used to delineate subregion streams, they also can be used as criteria for reference conditions. Differences between subregions are accurately determined only if the best possible conditions are used for references and if accurate measurements of the same parameters are taken in all subregions.

Reference Conditions

Background and Purpose

The recognition and documentation of baseline expectations is important for any assessment program in which changes of chemical, physical, or biological attributes are being evaluated. Traditionally, site-specific reference sites have been used as "controls" or baselines for water-quality attributes from which deviations measured at test sites located elsewhere have been judged as an indication of the presence and, potentially, the degree of degradation of the test sites. Difficulties in the use of single reference sites for assessment of ecological degradation include the inability to meet many statistical assumptions required for various types of pairwise comparisons (that is, the problem of pseudoreplication) (Hurlbert, 1984; Stewart-Oaten and others, 1986), limitations in the ability to account for dynamic succession inherent in ecosystem processes (Loehle and others, 1990; Loehle and Smith, 1990), and the potential for underestimating impairment at a test site as a result of impacts that affect the reference site. However, there are some advantages in the use of the upstream/downstream study design for the evaluation of stream and river channels. Assuming that other factors are equal, such a design can provide guidance for the identification and location of point-source discharges. It also may enhance determination of the degree of impairment.

More recently, the development of an ecoregional framework (Omernik, 1987; Ohio Environmental Protection Agency, 1987; Whittier and others, 1987) has provided the basis for subregionalization (Gerritsen and others, 1994) in several parts of the country. Subecoregions provide a framework for establishing ecological expectations (reference conditions), which are based on the sampling of many minimally impaired reference sites within the subregion. These physical, chemical, and biological data are stratified (within a subregion) by the type and character of the water-body class to form a reference-condition data base for the subregion.

The establishment of ecological criteria is the central purpose of many water-quality-management activities. The concept of biocriteria implies a comparison of a test-site observation to the highest level of attainable ecological condition in a subregion. The USEPA is using "reference conditions" as the basis for making comparisons and detecting attainment of aquatic life use (U.S. Environmental Protection Agency, 1990, 1994). Such conditions should be applicable to an individual water body, such as a stream segment, and to water bodies generally on a regional scale. The reference condition is a critical element in the development of a biocriteria program.

Table 1. Preliminary stream classification and subregions of the Central Appalachians Ridge and Valley ecoregion

[From: Gerritsen and others. 1994]

Area	Streamwater type	Dominant fishery	Corresponding subregion
Highland	Low conductivity	Cold water	Shale ridge, sandstone ridge.
	High conductivity (owing to calcareous cement in rock formations or minor limestone strata).	do.	Sandstone ridge
Valley	Limestone spring (high conductivity)	do	Limestone valley
	Limestone influenced (high conductivity)	Cold or warm water	Do.
	Low conductivity	do	Shale valley.

Criteria for Reference-Site Selection

The two main criteria for the selection of reference sites are that they be minimally impaired and that they represent the natural biological community of the region. Sites that have been managed or altered by human intervention to increase fishability or to extend nonnative riparian vegetation are not improvements in the natural sense and, as such, should not be used as part of the reference-condition data base. Sites affected by locally unusual environmental factors also can result in unrealistic biological expectations. Reference sites should be representative of the water bodies under consideration and should exhibit conditions and biota similar to what is expected in water bodies in the ecoregion or subecoregion.

In areas where least-impaired or best-available sites have been significantly altered, the search for suitable sites must be extended over a wider area; multiState cooperation in the form of data- and reference-site sharing is the basis for such searches. If no suitable sites are found, then historical data, expert opinion,and (or)empirical models can be used to determine reference expectations for the region (Gibson and others, 1994). Historical data alone may not suffice owing to potentially questionable methods, lack of QA information, surveys made at impaired sites, and insufficiently documented methods and (or) objectives. Empirical water-quality models must be carefully evaluated before being used solely in the development of reference conditions. Because they generally are deficient in community-level evaluations, a consensus of expert opinion, as well as modeling and historical data, should be used in determining the reference condition. In any event, the goal of establishing reference conditions is to define the natural potential of the reference sites as being equivalent to that for natural lakes—best of ambient conditions or prediction regardless of the extent of human degradation that currently exists in the area. The development of reference-site-selection criteria for reservoirs [J. Gerritsen, and others, Tetra Tech, Inc., written commun. (draft report), 1994] showed that although natural conditions for reservoirs are nonexistent, operational criteria for establishment of reference models can be established.

Reference sites must be carefully selected because they will be used as a benchmark against which test sites will be compared. The ideal reference site will have extensive natural riparian vegetation, a diversity of substrate materials, natural physical structures, a natural hydrograph, and a minimum of known human-induced disturbances or discharges. There also should be a representative and diverse abundance of naturally occurring biological assemblages (Hughes and others, 1986).

However, it also is recognized that pristine conditions no longer exist, and, in practice, the level of the acceptable conditions for reference sites may be based on socioeconomic demands. Consider a county in which all the streams have been converted into canals or ditches; consequently, the habitat has been completely altered. Some of the canals receive point-source discharges, as well as nonpoint-source input, while others have clean water. On the basis of the framework described above, there would be two drastically different approaches for establishing reference conditions. The decision on the approach to be taken rests with the acceptance that the substantial habitat impairment of canals will not support naturally occurring biological assemblages, as defined by Hughes and others (1986). In the first approach, a composite of the best biological condition of the canals within the region is determined to represent the reference condition and, thus, the biological expectations. The alternative would be to take the best of the nonchannelized streams in an adjacent county within the same ecoregion or subregion and establish expectations more similar to a natural condition. The latter approach provides a more stringent basis for judgment of impairment. A decision to use this approach implies that there is acceptance of degraded physical habitat and may remove incentives toward efforts at improving overall ecological conditions. However, Gibson and others (1994) cautioned against the wholesale acceptance of significantly altered systems and stipulated that resultant criteria are interim goals subject to improvement. The result of the approach for establishing reference conditions in significantly altered systems, however, is nontechnical in nature and falls within the charge of policymakers.

Establishment of Reference Expectations by Indicator

Initially, regional expectations should be developed for each targeted indicator; these expectations may or may not vary across regional "boundaries." Whether this variation exists, and to what degree they differ, is critical.

Index Calibration

Background and Purpose

Data collected from regional reference sites must be evaluated to develop an understanding of the range of natural variability of those measurement parameters within and between ecoregions and subregions. For establishing numerical reference expectations, it is imperative that within-region variability of parameters be minimized and that among-region variability be maximized. One way this can be done is by stratification (or categorization) of ecological data within subregions by drainage area, habitat quality, local land use, or some other characteristic.

Different approaches for ecological assessments focus on different indicators, use of different sampling methods, sampling during different index periods, use of specialized data-evaluation procedures, and measurement of data at various scales. Regardless of the specific measurements or samples being taken, pilot studies or small-scale research may be needed to define, evaluate, and calibrate individual indicators. Past efforts that have been made to evaluate the use of metrics illustrate procedural approaches to this task (Angermeier and Karr, 1986; Karr and others, 1986; Davis and Lubin, 1989; Boyle and others, 1990; Barbour and others, 1992; Karr and Kerans, 1992; Kerans and others, 1992; Lyons, 1992; Resh and Jackson, 1993). Indicator metrics can be calibrated by evaluating the response to varying levels of stressors (Jongman and others, 1987). Sites must be carefully selected for controlled prospective studies to cover a wide range of suspected stressors. In general, impaired sites are selected to provide knowledge on the directional changes of indicators by using either single or aggregated metrics subjected to known stressors singly and in combination. The combination of selected impaired and reference sites is the basis for developing an empirical model of indicator response to stressors.

Dispersion and Aggregation of Data

Certain metrics may exhibit a continuum of expected values, which depend upon specific physical attributes of the sites that make up the reference data base. Fausch and others (1984) suggested that a line with a slope fit, which includes about 95 percent of the sites, is an appropriate approximation of a maximum line of expectations for the metric in question; for example, the number of fish species. The area on the graph beneath the maximum line can be trisected or quadrisected to assign scores to the range of indicator values. Alternatively, the median, 25th, and 75th percentiles of each metric may be plotted on a box and whisker graph for each ecoregion or subecoregion to display variability.

Comparison of the medians and ranges across environmental strata (ecoregions, subecoregions, stream or lake size, seasons) can help determine if it is necessary to segregate the data by the strata. For example, seasonal influences on an indicator can be examined by comparing the median and range between two samples obtained at the same site in different seasons and by using the same methods. If differences exist between the two seasons, then data from these two seasons should not be combined; that is, for this particular ecoregion, only spring data should be compared with spring data, and fall data with fall data. Separate criteria (or reference expectations) should be developed for spring samples and fall samples. Data that do not show such distinct seasonal differences may be combined. A similar approach can be applied to data that originate in different ecoregions, subregions, or sizes of water bodies.

For classification of reference conditions based on the best available (selected) sites, it is assumed that most of, if not all, the sites are minimally impaired. Therefore, the upper 50th percentile (values above the median) can be used as the delineation between what is considered to be impaired versus nonimpaired for each indicator or metric. When scoring each metric, the values in the upper range would receive the maximum score, and quartiles below the median would receive progressively lower scores. This approach is conducive to metrics that may have a modal response, rather than a monotonic one, because upper bounds on the expected condition can be established. Hypothetically, taxa richness may be best in a region when the number of taxa is between 25 and 35. However, in a water body with nutrient enrichment, the number of taxa may be 37. In this approach, the condition would be noted as indicating some degree of impairment owing to probable nutrient enrichment.

Unresolved Issues

In the 15 to 20 States where the ecoregion concept has been applied or implemented in natural-resource management, it has proven successful. The primary unresolved issue in using reference conditions as the basis for measuring water-quality impairment is the incompleteness of subregionalization work across the country. Delineation of small watershed boundaries being mapped by the Natural Resources Conservation Service, in collaboration with many other agencies, may help resolve this issue.

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TECHNICAL APPENDIX G

MULTIMETRIC APPROACH FOR DESCRIBING ECOLOGICAL CONDITIONS

The Intergovernmental Task Force on Monitoring Water Quality (ITFM) supports the national goal of using multimetric approaches for biological data in combination with information on physical and chemical indicators to assess water quality. Multimetric approaches to water-quality assessment, where locally modified, applied, and nationally compared, are a recommended component of a national assessment of the ecological condition of natural resources. The following steps are necessary to accomplish this goal nationally: establishment of reference conditions in the context of ecoregions/subecoregions; further development of information about the interrelations among biological, chemical, and physical characteristics of ecosystems; recognition of when local or regional modifications to the approach are needed; recognition that reference conditions are necessary to assess community-level responses at sites of interest; and establishment of a mechanism that allows data to be aggregated at appropriate regional or national levels.

The Multimetric Approach

The accurate assessment of biological integrity requires a method that integrates biotic responses by examining patterns and processes from individual to ecosystem levels. Classical approaches select some biological attribute that refers to a narrow range of perturbations or conditions. Many ecological studies focus on a limited number of parameters that may include one or more of the following: species distributions, abundance trends, standing crop, and production estimates. Usually, parameters are interpreted separately with a summary statement about the overall health of the system. This approach is limited in its usefulness because the attributes emphasized may not reflect overall ecological health (Karr and others, 1986). This is analogous to the removal of single-species toxicity testing from "environmental realism" and the low applicability for assessments of system-level responses (Buikema and Voshell, 1993).

An alternative approach is to define an array of metrics, each of which provides information on a biological attribute and, when integrated, functions as an overall indicator of biological conditions. The strength of a multimetric approach is its ability to integrate information from individual, population, community, and ecosystem levels and to evaluate, with reference to biogeography, a single ecologically based index of water quality (Karr and others, 1986; Plafkin and others, 1989; Karr, 1991; Barbour and others, 1995). Multimetric assessments provide detection capability over a broader range and nature of stressors and give a more complete picture of biological condition than single biological indicators. The Ohio Environmental Protection Agency (1987) suggested that combined strengths of metrics minimize any individual weaknesses

Metrics

The validity of an integrated assessment that uses multiple metrics is supported by the use of metrics firmly rooted in sound ecological principles (Karr and others, 1986; Fausch and others, 1990; Lyons, 1992). A metric or biological attribute is some feature or characteristic of the biotic assemblage that reflects ambient conditions, especially the influence of human actions. A composite of appropriate metrics provides an accurate reflection of the biological condition at a study site. A large number of metrics have been used (for example, see Karr and others, 1986; Fausch and others, 1990; Kay, 1990; Noss, 1990; Karr, 1991), and each is essentially a hypothesis about the relations between an instream condition and human influences (Fausch and others, 1990). Gray (1989) stated that the three best-documented responses to environmental stressors are reduction in species richness, change in species composition to dominance by opportunistic species, and reduction in mean size of organisms. However, because each feature responds to different stressors, the best approach to assessment is to incorporate many attributes into the assessment process. These metrics can be surrogate measures of more complicated elements and processes as long as they have a strong ecological foundation and enable the biologist to ascertain the attainment or nonattainment of biological criteria, designated uses, or some other statement on ecological condition.

A number of metrics have been developed and subsequently tested in field surveys of benthic macroinvertebrate and fish assemblages (Karr, 1991). Because metrics have been recommended for fish assemblages (Karr, 1981; Karr and others, 1986) and benthic macroinvertebrates (Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989; Barbour and others, 1992; Karr and Kerans, 1992), they will not be reviewed extensively here. A list of fish

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Much of the text and several figures in this issue paper were taken from Barbour and others (1995) and U.S. Environmental Agency (1994).

assemblage metrics used in the Index of Biotic Integrity (IBI) is presented in table 1, which includes local variations used in regional IBI applications.

Benthic metrics have undergone similar evolutionary developments and are documented in the Invertebrate Community Index (ICI) (Ohio Environmental Protection Agency, 1987), the Rapid Bioassessment Protocols (RBP's) (Shackleford, 1988; Plafkin and others, 1989; Barbour and others, 1992; Hayslip, 1993) and the benthic IBI (Kerans and others, 1992). Metrics used in these indices are surrogate measures of elements and processes of the macroinvertebrate assemblage. Although several of these indices are regionally developed, some are more broadly based and may be appropriate for use in various regions of the country. Selected metrics are listed by specific approach in table 2. Winget and Mangum (1979) and Mangum (1986) developed and tested the Biotic Condition Index (BCI), which is a metric similar to the Hilsenhoff Biotic Index (Hilsenhoff, 1987). The BCI incorporates characteristics of aquatic insect taxonomic diversity with tolerance characteristics on the basis of stream gradient, substrate composition, total alkalinity, and sulfate (U.S. Forest Service, 1989).

Figure 1 illustrates a conceptual structure for attributes of a biotic assemblage in an integrated assess

Table 1. Index of Biotic Integrity metrics used in various regions of North America

[IBI, Index of Biotic Integrity, X = metric used in region. Taken from Karr and others (1986), Hughes and Gammon (1987), Ohio Environmental Protection Agency (1987), Miller and others (1988), Steedman (1988), Lyons (1992). Many of these variations are applicable elsewhere]

Alternative IBI metrics	Midwest	New England	Ontario	Central Appalachia	Colorado Front Range	Western Oregon	Sacramento/ San Joaquin	Wisconsin
1. Total number of species	X	X		X	X		X	
Number of native fish species	X		X			X		X
Number of salmonid age classes[1]						X	X	
2. Number of darter species	X			X	X			X
Number of sculpin species						X		
Number of benthic insectivore species		X						
Number of darter and sculpin species	X	X						
Number of salmonid yearlings (individuals)[1]						X	X	
Percentage of round-bodied sucker	X							
Number of sculpins (individuals)							X	
3. Number of sunfish species	X				X			X
Number of cyprinid species						X		
Number of water-column species		X						
Number of sunfish and trout species			X					
Number of salmonid species							X	
Number of headwater species	X							
4. Number of sucker species	X	X				X		X
Number of adult trout species[1]						X	X	
Number of minnow species	X				X			
Number of sucker and catfish species			X					
5. Number of intolerant species	X	X			X	X		X
Number of sensitive species	X							
Number of amphibian species							X	

Table 1. Index of Biotic Integrity metrics used in various regions of North America—Continued

Alternative IBI metrics	Mid-west	New England	Ontario	Central Appa-lachia	Colorado Front Range	Western Oregon	Sacra-mento/ San Joaquin	Wis-consin
Presence of brook trout			X					
6. Percenage of green sunfish	X							
Percentage of common carp						X		
Percentage of white sucker		X			X			
Percentsge of tolerant species	X							X
Percentage of creek chub				X				
Percentage of dace species			X					
7. Percentage of omnivores	X	X	X	X	X			X
Percentage of yearling salmonids[1]					X	X		
8. Percentage of insectivorous cyprinids	X							
Percentage of insectivores		X				X		X
Percentage of specialized insectivores				X	X			
Number of juvenile trout							X	
Percentage of insectivorous species	X							
9. Percentage of carnivores	X	X	X					X
Percentage of catchable salmonids						X		
Percentage of catchable trout							X	
Density catchable wild trout							X	
10. Number of individuals	X		X	X	X	X	X	X[2]
Density of individuals		X						
11. Percentage of hybrids	X	X						
Percentage of introduced species					X	X		
Percentage of simple lithophills	X							X
Number simple lithophills species	X							
Percentage of native species							X	
Percentage of native wild individuals							X	
12. Percentage of diseased individuals	X	X	X	X	X	X		X

[1]Metric suggested by Moyle and others (1986) and Hughes and Gammon (1987) as a provisional replacement metric in small western salmonid streams

[2]Excluding individuals of tolerant species

Table 2. Examples of metric suites used for analysis of macroinvertebrate assemblages

[EPT Ephemeroptera/Plecoptera/Trichoptera. Metrics in Idaho, Oregon and Washington are currently under evaluation]

Alternative benthic metrics	Invertebrate community index[1]	Rapid bioassessment protocols[2]	Rapid bioassessment protocols[3]	Rapid bioassessment protocols[4]			Benthic index of biotic integrity[5]
				Idaho	Oregon	Washington	
1 Total number of taxa	X	X	X	X	X	X	X
Percentage of change in total taxa richness				X	X	X	
2 Number of EPT taxa	X	X		X	X	X	
Number of mayfly taxa	X						X
Number of caddisfly taxa	X						X
Number of stonefly taxa							X
Missing taxa (EPT)			X				
3 Number of Diptera taxa	X						
Number of Chironomidae taxa				X		X	
4 Number of intolerant snail and mussel species							X
5 Ratio of EPT/Chironomidae abundance				X	X	X	
Indicator assemblage index			X	X	X		
Percentage of EPT taxa				X			
Percentage of mayfly composition	X						
Percentage of caddisfly composition	X						
6 Percentage of tribe Tanytarsini	X						
7 Percentage of other Diptera and noninsect composition	X						
8 Percentage of tolerant organisms	X						
Percentage of *Corbicula* composition							X
Percentage of Oligochaete composition							X
Ratio of Hydropsychidae/Trichoptera		X			X		
9 Percentage of individuals–dominant taxon		X		X	X	X	
Percentage of individuals/two dominant taxa							X
Five dominant taxa in common		X	X		X		
Common taxa index			X			X	
10 Indicator groups				X		X	
11 Percentage of individuals omnivores and scavengers							X
12 Percentage of individuals collector gatherers and filterers							X
Percentage of individuals filterers				X		X	
13 Percentage of individuals grazers and scrapers				X			X
Ratio of scrapers/filterer collectors				X	X	X	
Ratio of scrapers/scrapers plus filterer collectors		X					

Table 2. Examples of metric suites used for analysis of macroinvertebrate assemblages—Continued

Alternative benthic metrics	Invertebrate community index[1]	Rapid bioassessment protocols[2]	Rapid bioassessment protocols[3]	Rapid bioassessment protocols[4]			Benthic index of biotic integrity[5]
				Idaho	Oregon	Washington	
14. Percentage of individuals strict predators							X
15. Ratio shredders/total individuals (eauals Percent shredders)		X		X		X	
16 Percentage of similarity functional feeding groups quantitative similarity index		X	X	X			
17. Total abundance							X
18. Pinkham-Pearson community similarity index.		X					
Community loss index					X	X	
Jaccard similarity index				X			
19. Quantitative similarity index (taxa)		X	X				
20 Hilsenhoff biotic index		X		X	X	X	
Chandler biotic score				X			
21. Shannon-Weiner diversity index					X		
Equitability				X			
Index of community integrity				X			

[1]Ohio Environmental Protection Agency (1987) [2]Barbour and others (1992), revised from Plafkin and others (1989)
[3]Shackelford (1988) [4]Hayslip (1993). [5]Kerans and others (1992)

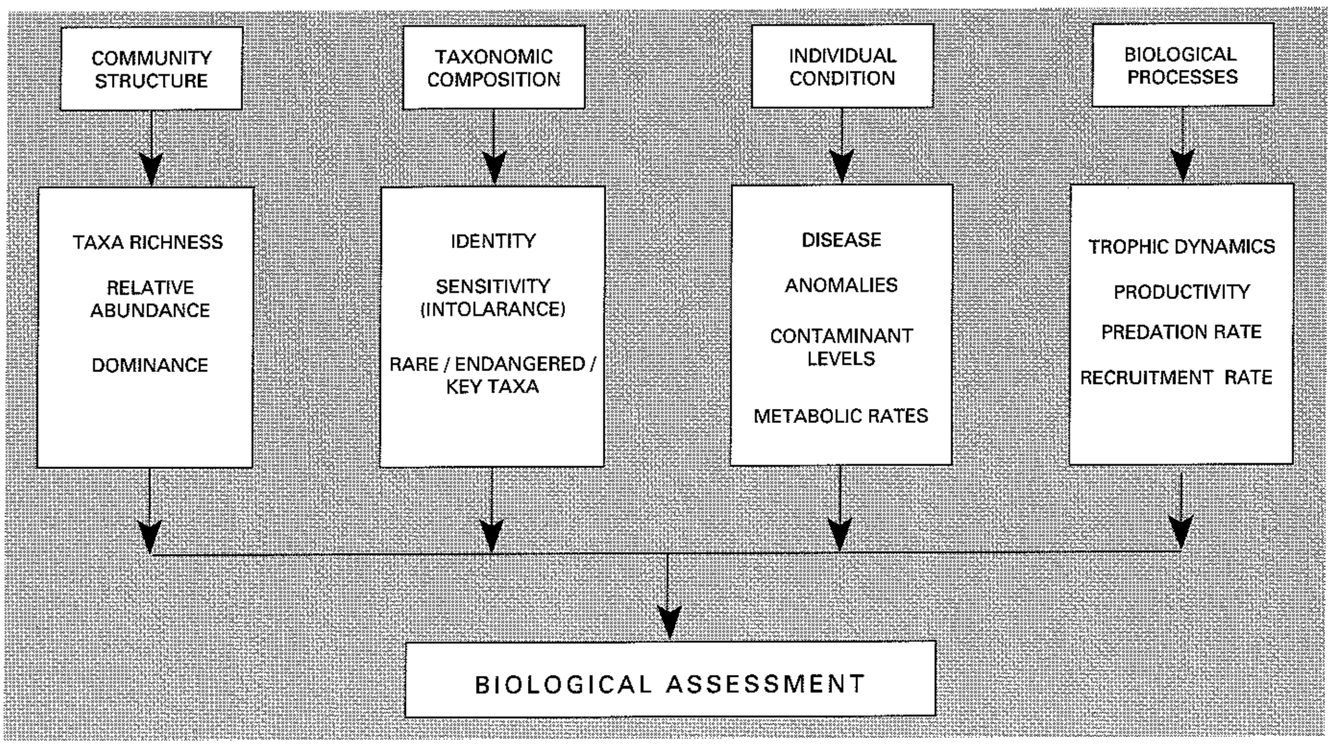

Figure 1. Organizational structue of the attributes that should be incorporated into biological assessments.

ment that reflects overall biological condition A number of these attributes can be characterized by metrics within four general classes—community structure, taxonomic composition, individual condition, and biological processes.

Community structure can be measured by the variety and distribution of individuals among taxa Taxa richness, or the number of distinct taxa, reflects the diversity within a sample of an assemblage. Multimetric uses of taxa richness as a key metric include the ICI (Ohio Environmental Protection Agency, 1987), the Fish IBI (Karr and others, 1986), the Invertebrate IBI (Kerans and others, 1992), and the RBP's (Plafkin and others, 1989). Taxonomic richness also is recommended as critical information in assays of natural phytoplankton assemblages (Schelske, 1984). Taxa richness usually is species level but also can be evaluated at designated groupings of taxa, often at higher taxonomic levels (that is, genus, family, order) in assessments of invertebrate assemblages.

Relative abundance of taxa refers to the number of individuals of one taxon compared with that within the entire sample. Dominance, which is easured as percent composition of the dominant taxon (Barbour and others, 1992), is an indicator of community balance or lack thereof. Dominance is an important indicator when the most significant taxa are eliminated from the assemblage or if the food source is altered. Dominants-in-common (Shackleford, 1988) is a comparison with reference conditions to evaluate the extent to which dominance may reflect human influence

Taxonomic composition can be characterized by several classes of information, such as identity and sensitivity. Identity is the knowledge of individual taxa and associated ecological principles and environmental requirements Key taxa, which are those of special interest or are ecologically important, provide information that is important to the identity of the targeted assemblages. The presence of exotics or nuisance species may be an important aspect of biotic interactions that relates to identity and sensitivity. Sensitivity refers to the numbers of pollutant-tolerant and pollutant-intolerant species in the sample The ICI (Ohio Environmental Protection Agency, 1987) and the RBP's (Plafkin and others, 1989) use a metric based on species tolerance values A similar metric for fish assemblages is included in the IBI (table 1).

Recognition of rare, endangered, or important taxa provides additional legal support for remediation activities or recommendations. Species status for response guilds of bird assemblages (for example, whether they are threatened or endangered, native or introduced, or of some commercial or recreational value) also relates to the composition class of metrics (Brooks and others, 1991)

Individual condition metrics are those that refer to the degradation of physical or physiological health of individual organisms. This type of metric is not commonly used for benthic macroinvertebrates; examples of fish metrics for individual condition are "percent individuals diseased" and "precent individuals with fin rot."

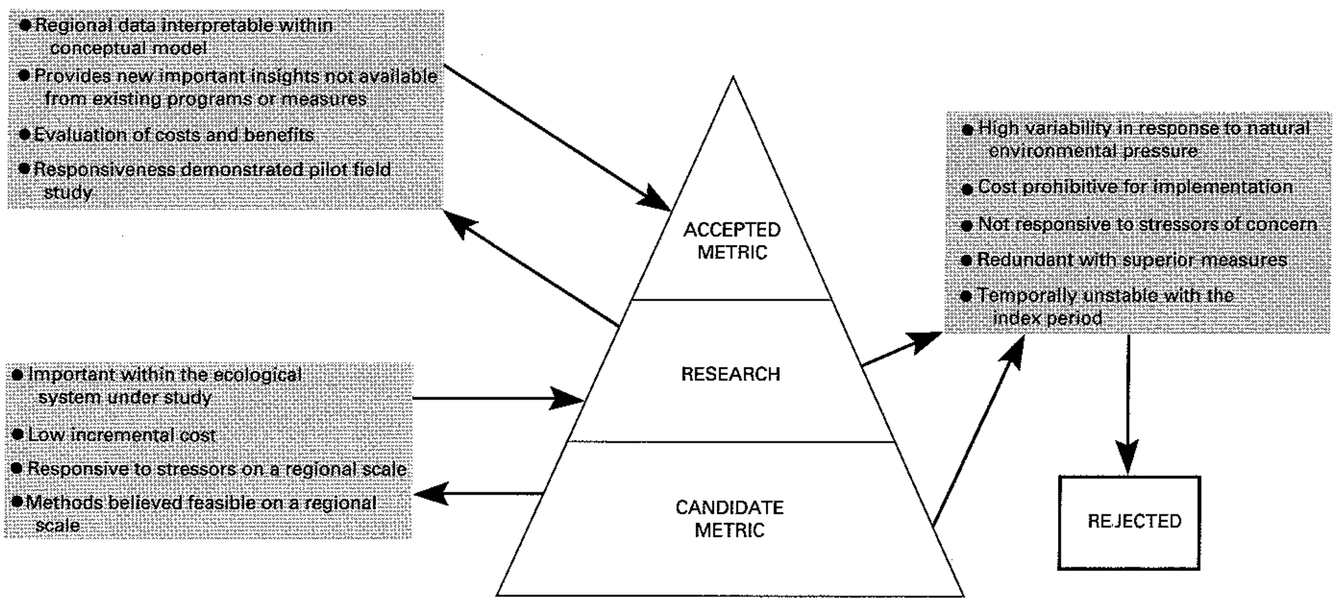

Figure 2. Tiered metric development process (Adopted from Holland, 1990).

The functional aspects of *biological processes* can be divided into several categories as potential metrics. Trophic dynamics encompass functional feeding groups and relate to the energy source for the system, the identity of the herbivores and carnivores, the presence of detritivores in the system, and the relative representation of the functional groups. Abundance estimates are surrogate measures of standing crop and density that can relate to contaminant and enrichment problems.

Inferences on the biological condition can often be drawn from a knowledge of the capacity of the system to support the survival and propagation of the top carnivore. This attribute can be a surrogate measure for predation rate. Without stable food dynamics, populations of the top carnivore reflect stressed conditions. Likewise, if production at a site is considered to be high on the basis of organism abundance or biomass and if high production is natural for the habitat type under study (as per reference conditions), then biological conditions would be considered to be good. Fitness is the capacity of an individual or population to maximize reproductive success by the production of viable offspring (Price, 1975) and figures significantly in recruitment rate. Life cycle success, therefore, should include age-specific birth and death rates.

Process metrics have been developed for a number of different assemblages. For example, table 1 indicates at least seven IBI metrics that deal with trophic status or feeding behavior in fish, which focuses on insectivores, omnivores, or herbivores. Also, the number or density of individuals of fish in a sample (or an estimate of standing crop) is a measure of production and, thus, in the function class of metrics. Additional information is gained from density measures when they are considered to be relative to size or age distribution. Three RBP metrics for benthic macroinvertebrates focus on functional feeding groups (table 2; Plafkin and others, 1989; Barbour and others, 1992). Brooks and others (1991) used trophic level as one category for rating avian assemblages. It may not be necessary to establish metrics for every attribute of the targeted assemblage. However, the integration of information from several attributes, especially a grouping of metrics representative of the four major classes of attributes (fig. 1), would improve and strengthen the overall bioassessment.

Development of Metrics

The development of appropriate metrics follows definition of the taxa to be sampled, the biological characteristics at reference conditions, and, to a certain extent, the anthropogenic influences being assessed. In many situations, because multiple stressors impact ecological resources, a specific cause-and-effect assessment may be difficult. However, change over sets of metrics in response to perturbation by certain stressors (or sets thereof) may be used as response signatures (Yoder, 1991). A broad approach for program-directed development of metrics may be modeled after Fausch and others (1990), Holland (1990), Barbour and others (1992), or Karr and Kerans (1992). Candidate metrics (fig. 2) are selected on the basis of knowledge of aquatic systems, flora and fauna, literature reviews, and historical data. Candidate metrics are then evaluated for efficacy and validity for implementation into the bioassessment program. Less-robust metrics or those not well founded in ecological principles are eliminated in this research process. Metrics with little or no relation to stressors are rejected. Core metrics are those remaining that provide information useful in differentiating among sites that have good- and poor-quality biotic characteristics. Core metrics should be selected to represent diverse aspects of structure, composition, individual health, or processes of the aquatic biota. Together, they should form the foundation for a sound integrated analysis of the biotic condition to judge the attainment of biological integrity. Thus, metrics that reflect community characteristics are appropriate in biocriteria programs if their relevance can be demonstrated, if the response range can be verified and documented, and if the potential for program application exists. Regional variation in metric details are expected, but the general principles used to define metrics need to be consistent over wide geographic areas (Miller and others, 1988).

Calibration of Metrics

Pilot studies or small-scale research may be needed to define, evaluate, and calibrate metrics. Metrics can be calibrated by using controlled prospective studies (Jongman and others, 1987); that is, by evaluating the response of metric values to varying levels of stressors. Sites must be carefully selected for controlled prospective studies so that a wide range of suspected stressors on the stream ecosystems can be included. In general, impaired sites are selected because single and combined stressors have impacted them. The selected impaired sites and the reference sites are the basis for the development of an empirical model of metric response to stressors.

Metrics can be evaluated following model development. Candidate metrics that do not respond to any of the stressors expected in a region may be eliminated. Metrics also are evaluated for variability with respect to responsiveness; those with high variability compared with the range of response should be used with caution. A more-detailed discussion of metric calibration is provided in Technical Appendix F.

Rating the Metrics

Once the reference condition is established from a compiled set of reference sites, the expectations for each metric can be delineated. Certain metrics may exhibit a continuum of expectations that are dependent on specific physical attributes of the reference streams. For example, the total number of fish species changes as a function of stream size estimated by stream order or watershed area for a number of undisturbed reference sites (Fausch, and others 1984). When reference site data are plotted, the points produce a distinct right triangle, the hypotenuse of which approximates the upper limit of species richness. Fausch and others (1984) suggested that a line with a slope fit to include about 95 percent of the sites is an appropriate approximation of a maximum line of expectations for the metric in question. When different stream classes have different expectations in metric values and a covariat, such as drainage area, exists that produces a monotonic response in a metric, a plot of survey data for each stream class versus the covariante may be useful (fig. 3).

As shown in figure 3, the area on the graph beneath the maximum line can then be trisected or quadrisected to assign scores to a range of metric values. It should be noted that as drainage area increases, there is a leveling or diminishing rate of increase in the number of species, which accounts for the bending of the lines. Even so, the upper line represents the maximum-species richness across the range of drainage area (Yoder and Rankin, 1995). The scores provide the transformation of values to a consistent measurement scale to group information from several metrics for analysis. An alternative is to calculate the median, 25th, and 75th percentiles and display the results in a box and whisker graph (fig. 4). For each metric, the sites are sorted by stream class (for example, ecoregion, stream type, and so forth) and plotted to ascertain the spread in data and the ability to discriminate among classes. If such a representation of the data does not allow discrimination of the classes, then it will not be necessary to develop a separate biocriterion for each class; that is, a single criterion will be applicable to a set of sites that represent different physical classes. Conversely, if differences in the biological attribute are apparent and appear to correspond to the classification, then separate criteria are necessary.

For each metric, which is based on the distribution of metric values in the reference data base, scoring categories are developed on the basis of different percentiles of the observed range of individual metrics. For example, a reference data base has a maximum taxa richness value of 28 and a median value of 21. The scoring categories, which use the 50th percentile as the most appropriate threshold, would appear as follows:

Metric value ranges	Bioassessment points	Condition category, by percentiles
≥21	6	≥50th
14 – 20	4	25th – 49th
7 – 13	2	13th – 24th
0 – 6	0	≤12th

With these types of categories established for all metrics, calculated values from test-site samples can be compared with the reference-based criteria for assignment of bioassessment scores. An alternative to assigning scores is to calculate the percent deviation from the maximum species richness line for each value obtained in calculating the metric from bio-logical data collected at a site. In this approach, assessment of acceptability would be based on the percentage of reference value.

Aggregation

After defining the lower limit of the highest nonimpaired category and dividing the remainder of the value range into one or more impaired categories (fig. 3), actual metric values are substituted for the percentile limits of those category ranges. The ranges of metric values are put into scoring tables that provide the ability to associate bioassessment scores to individual metrics (for example, tables 3, 4), thus "normalizing" the values. The Ohio Environmental Protection Agency (1987) established tables that are based on some decided-upon percentiles as discussed above. As shown in table 3, they recognize three

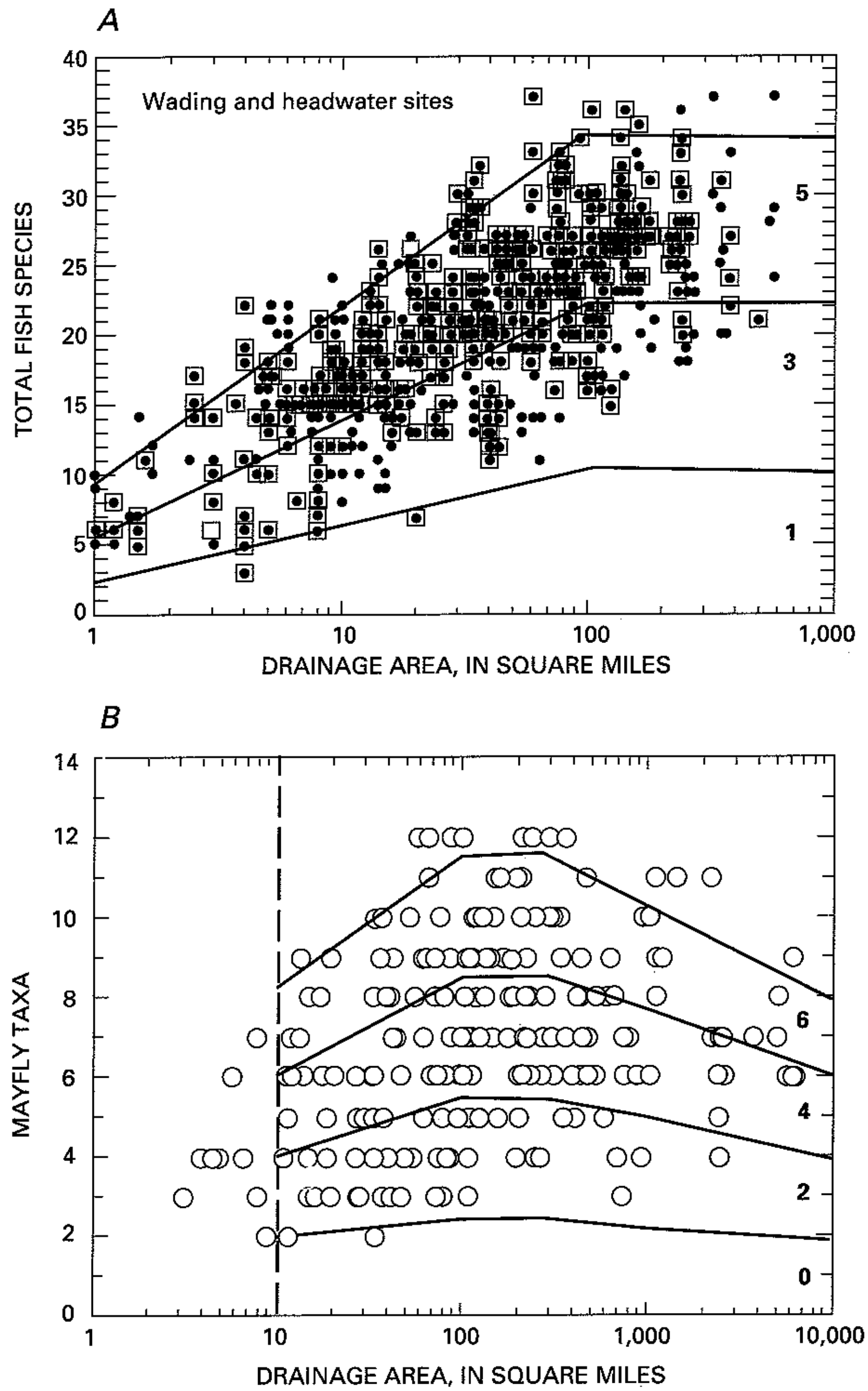

Figure 3. Examples of the technique used to calibrate the Index of Biotic Integrity (IBI) and the Invertetrate Community Index (ICI) for the drainage area dependent metrics of each index. The number of fish species (*A*) and number of mayfly taxa (*B*) vs. drainage area demonstrate the use of the 95 percent maximum-species richness line and the trisection and quadrisection methods used to establish the IBI and the ICI scoring criteria (Yoder and Rankin 1995).

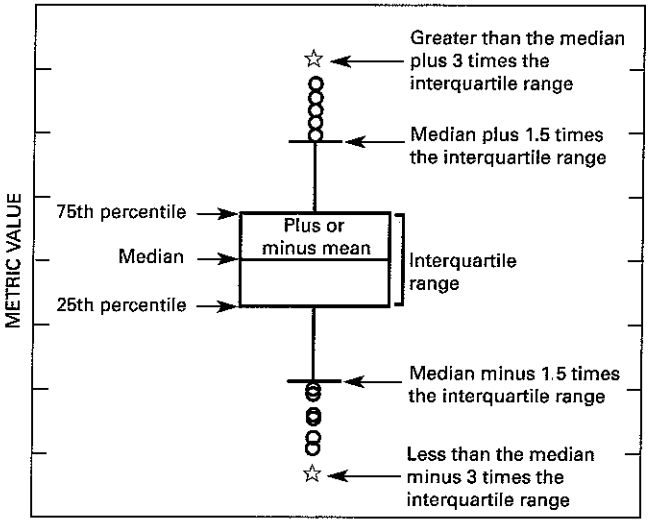

Figure 4. Metric value and stream class to ascertain the spread in data and the ability to discriminate among classes.

categories of metric scoring ranges for fish-assemblage data collected at nonwadeable (boat) sites.

After scoring all metrics for each of the sites, aggregation of these normalized metric scores is possible. By assuming equal weighting among metrics, a simple summation can accomplish aggregation. If the contribution of one or more metrics needs to be emphasized or increased over the remainder owing to, perhaps, specific recognition of known problems (habitat degradation or point-source discharges) and expected responses, then individual metrics can have a weighting factor incorporated. The weighting factor can be applied to either the calculated metric value or the normalized metric score.

Unresolved Issues

The multimetric approach to biological assessment has been criticized because the reduction of taxonomic composition and abundance data to a handful of indices loses the rich information in the original data. Often, these criticisms do not consider how the indices are to be employed. Management acts on a small handful of societal actions; for example, regulation of point sources, controlling urban runoff, and fisheries management. Biological assessment must reduce the complexity of the ecosystem in such a way that management can act. For example, it is unrealistic to expect that the species composition of harpacticoid copepodes will be "managed" in streams. Final decisions on impact/no impact or management actions are not made on the single aggregated value alone; rather if comparisons to established reference values indicate an impairment in biological condition, then component parameters (or metrics) are examined for their individual effects on the aggregated value.

A larger issue is the statistical distribution, behavior, and uncertainty of indices and metrics generated in the multimetric approach. This issue will be

Table 3. Index of Biotic Integrity metrics and scoring criteria based on fish-community data from more than 300 reference sites throughout Ohio applicable only to boat (nonwadeable) sites

[IBI, Index of Biotic Integrity, <, less than; >, greater than; ≤, less than or equal to. Table modified from Ohio Environmental Protection Agency (1987). For further informtion on metrics, see Ohio Environmental Protection Agency (1987)]

IBI metrics	Scoring criteria		
	5	3	1
Total number of species	>20	10 – 20	<10
Percentage of round-bodied suckers	>38	19 – 38	<19
Number of sunfish species	>3	2 – 3	<2
Number of sucker species	>5	3 – 5	<3
Number of intolerant species	>3	2 – 3	<2
Percentage of tolerant species	<15	15 – 27	>27
Percentage of omnivores	<16	16 – 28	>28
Percentage of insectivores	>54	27 – 54	<27
Percentage of top carnivores	>10	5 – 10	<5
Percentage of simple lithophils[1]	>50	25 – 50	<25
Percentage of deformities, eroded fins, lesions, and tumors anomalies	<0.5	0.5 – 3.0	>3.0
Fish numbers	<200	200 – 450	>450

[1]For sites in a drainage area of less than or equal to 600 square miles; for sites in a drainage area greater than 600 square miles scoring categories vary with drainage area

Table 4. Bioassessment scoring criteria developed for Rapid Bioassessment Protocols benthic macroinvertebrate metrics based on 300-organism subsamples of double-composite square-meter kicknet samples from the Sandusky River in Ohio

[≥, greater than or equal to; ≤, less than or equal to U.S. Environmental Protection Agency, written commun. (draft report), 1994. For more information on individual metrics, see Barbour and others (1992)]

Metric	Scoring criteria			
	0	2	4	6
Taxa richness	0– 6	7 –13	14 –20	≥ 21
Hilsenhoff biotic index	≥ 5.1	5.0– 3.7	3.6– 2.3	≤ 2.2
Scrapers/(scrapers plus filter collectors) x 100	0–19.3	19.4–38.7	38.8–58.1	≥ 58.2
Ephemeroptera/Plecoptera/Trichoptera (EPT)/ (EPT plus chironomidae) x 100	0–25	26 –50	51 –75	76–100
Percentage of contribution of dominant taxon	100–76	75 –51	50 –26	≤25
EPT Index	0– 3	4 – 6	7 – 9	≥10
Shredders/total x 100	0–25	26 –50	51 –75	76–100
Number of Hydropsychidae/total Trichoptera x 100	100–76	75 –51	50 –26	≤25
Pinkam-Pearson Community similarity index	0– 1.6	1.7– 3.3	3.4– 5	≥5.1
Quantitative similarity index (QSI)-taxa	0–25	26 –50	51 –75	76–100
Dominants-in-common-5	≤1	2	3	≥4
QSI-functional feeding group	0–25	26 –50	51 –75	76–100

resolved as the approach is increasingly adopted and data are generated and analyzed. Currently, the most pressing need is for side-by-side comparison of different analytical approaches; for example, multimetric assessment, multivariate community ordination, and multiple regression.

It is important to understand the effects of various stressors on the behavior of specific metrics. An often-stated concern is that IBI values will be misleading unless the sensitivity of the monitored populations to specific pollutants are well characterized. These concerns are often directed at the use of tolerance values inferred from incomplete field observations. Nonetheless, field fisheries biologists who have extensive local experience do, in fact, know the distribution and ecological requirements of the resident fish species. The general concept of integrating tolerance information with distributional data has been used successfully in a variety of situations (Karr and others, 1986; Mangum, 1986; Hilsenhoff, 1987; Ohio Environmental Protection Agency, 1987; Plafkin and others, 1989; F.A. Mangum and D.A. Duff, U.S. Forest Service, written commun., 1992).

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TECHNICAL APPENDIX H

TERMS OF REFERENCE— INTERAGENCY METHODS AND DATA COMPARABILITY BOARD

I. Mission, authority, scope, and applicability

A. Mission—The mission of the Methods and Data Comparability Board (MDCB) is to promote and coordinate the collection of comparable water-quality data. The MDCB is part of the implementation of the recommendations and strategy of the Intergovernmental Task Force on Monitoring Water Quality (ITFM), as documented in the Final Report entitled the *Strategy for Improving Water-Quality Monitoring in the United States* (the strategy), dated August 1995.

B. Authority—The authority for the MDCB, the National Water-Quality Monitoring Council (National Council), and the Advisory Committee on Water Information (ACWI) is the Office of Management and Budget Memorandum No. M–92–01. This memorandum requires Federal executive agencies to collaborate with all levels of government and the private sector in conducting water-information activities.

C. Scope—The MDCB, in collaboration with Federal, State, Tribal governments, and private sector organizations, will provide a framework and a forum for comparing, evaluating, and promoting approaches that yield comparable data in all appropriate water-quality-monitoring programs. Action will be taken to improve the scientific validity of water-quality data, to establish comparable approaches to collecting water-quality-monitoring information, to provide a forum for advancing the state of technology of water-quality methods and practices, to assist all levels of government and the private sector in collecting monitoring information in a comparable and coordinated manner, and to recommend initiatives that lead to data comparability among agencies.

D. Applicability—As resources are available and consistent with applicable legal requirements, organizations that voluntarily choose to participate in the nationwide strategy will implement ITFM recommendations and will use future guidelines and procedures developed by the MDCB and other subordinate groups, adopted by the National Council, and accepted by the ACWI. Before adopting guidelines or recommendations for voluntary implementation as part of the strategy, the National Council will announce proposed actions and recommendations for the purpose of obtaining public review and comments.

II. Objectives—To assure the successful implementation of the nationwide strategy on a priority basis, the MDCB will be responsible for achieving the following objectives in collaboration with appropriate Federal, State, and Tribal orgnizations:

A. Group and prioritize methods, which include those applicable to indicators where interagency comparability is important.

B. Develop and promote guidelines to ensure methods and data comparability for priority methods.

C. Develop and promote a performance-based methods system.

D. To meet current and future needs, coordinate the establishment of reference methods for use as baselines with which to compare the performance of alternate methods.

E. Develop guidelines for validating alternative methods against a reference method or specified performance criteria.

F. Support and promote a national laboratory-accreditation program and investigate the need for a prelaboratory-certification program.

G. Establish a set of minimum data-qualifiers for use in describing water-quality measurements.

H. Identify and support program needs for reference methods, standardized performance validation samples, and methods-comparison exercises.

I. Collaborate with other groups to establish and maintain a glossary of water-quality-related terms and data elements required to implement the strategy and to facilitate communication, to establish reference sites for the purpose of comparing field methods, and to conduct other tasks as needed.

J. Provide advice and consultation about methods and data comparability to assist organizations that participate in implementing the strategy.

K. Encourage organizations that are not voting members of the MDCB to participate in methods validation and other activities of the MDCB. The meetings will be open to representatives of any organization that participates in the strategy.

III. Membership.

A. The MDCB membership shall include organizations that represent all levels of government and the private sector. Member organizations may include Federal, State, Tribal, and local government agencies, academia and the research community, private sector nonprofit groups that develop and distribute consensus methods and guidelines, volunteer monitoring groups, the regulated community, and other organizations that collect or use water-quality information. The membership shall represent a balance of interests, expertise, and geographical distribution.

B. The MDCB shall consist of 15 delegates whose terms shall last 3 years. Terms shall be staggered so that normally no more than five members will be replaced in any single year. To achieve the staggered terms, the initial members shall serve as follows: five will be designated for 3-year terms, five will be designated for 2-year terms, and five will be designated for 1-year terms.

C. The cochairs of the National Council shall designate the member organizations of the MDCB in consultation with the members of the National Council. The member organizations shall designate their delegates to the MDCB.

D. The member organizations shall include the U.S. Environmental Protection Agency (USEPA), the U.S. Geological Survey (USGS), other Federal Government agencies, five State or Tribal government agencies, and five organizations that represent other monitoring sectors. The USEPA delegate shall serve as chair, and the USGS delegate shall serve as vice chair.

E. Each delegate to the MDCB will be expected to attend all meetings of the MDCB or designate a permanent knowledgeable alternate who can attend for the member organization in the absence of the delegate. In the event an organization has no delegate or alternate at more than three consecutive meetings, the chair of the MDCB may inform the cochairs of the National Council and request that they appoint a new member organization.

F. In addition to the voting members of the MDCB, organizations that are implementing the strategy may send nonvoting representatives to participate in the meetings. If a nonvoting representative wishes to make a presentation to the MDCB, then a request must be made to the chair in advance of the meeting to schedule the presentation on the agenda. Also, the chair may request and recognize nonvoting representatives to participate in discussions of the MDCB.

IV. Support staff—An executive secretariat and other support for the MDCB shall be provided by the USGS, through the Office of Water Data Coordination, or other Federal organizations as mutually agreed upon by the supporting agencies.

V. Procedures

A. The MDCB will meet every 3 months with additional meetings called at the request of the chair in consultation with the members.

B. The MDCB will have the authority to create temporary subordinate groups (operating for less than 1 year) to deal with issues that require specialized expertise. Permanent subordinate groups must be approved by the National Council.

C. Actions that constitute final reports or recommendations intended for nationwide implementation as part of the strategy will be signed by the chair of the MDCB and transmitted to the executive secretary of the National Council for approval and public review.

D. Members who maintain a view contrary to that adopted by the MDCB may submit a minority report or recommendation to the chair for transmittal to the National Council.

E. The MDCB will work in collaboration with the National Council to develop and execute the budget for the MDCB.

VI. Quorum/voting—It is the intent of the MDCB to discuss and attempt to resolve all issues through consensus and by recognizing the legitimate interests and diverse points of view of the members of the MDCB. However, acknowledging that complete agreement may not be possible for every deliberation, the MDCB must be able to decide certain difficult issues. To this end, the following rules will apply:

A. Two-thirds of the delegates or alternates will constitute a quorum. Each member organization shall have one vote.

B. The members will strive to operate by consensus. A consensus will exist unless one or more delegates request a vote.

C. If a vote is requested, then the chair will request a motion, and *Robert's Rules of Order* will apply. An affirmative vote of two-thirds of all the delegates or alternates present will approve the motion.

D. The MDCB may reach consensus in formal session at meetings, in teleconferences, or in writing on an individual basis after every delegate is advised in advance by the chair. The rule for a quorum applies regardless of the method for conducting business.

VII. Documentation

A. Agendas and records of actions by the MDCB will be prepared and disseminated to members and participants by the secretary. Records of actions will be submitted to all delegates for concurrence. Complete records of all MDCB activities, which will include those of its subordinate groups, shall be maintained by the secretary and the Office of Water Data Coordination.

B. The MDCB will prepare an annual report for the National Council. The report will contain the following information: the activities of the MDCB during the past year and plans for future years, a budget request, a list of delegates and alternates, accomplishments, products, recommendations, and an evaluation of the progress in implementing the methods and data-comparability aspects of the strategy. The budget request will identify support and resources that participating organizations plan to provide. Also, the budget request will estimate travel and other support needed for 2 fiscal years beginning on October 1. The report will be submitted to the executive secretary of the National Council by March 1.

TECHNICAL APPENDIX I

DATA COMPARABILITY AND PERFORMANCE-BASED METHODS POLICY PAPER—COMPARABILITY OF DATA-COLLECTION METHODS

Each year Federal and State government agencies spend in excess of $1 billion to monitor the quality of water. The programs are conducted to assess status and trends in water quality, to identify and rank existing and emerging problems, to design and implement resource-management programs, and to determine compliance with regulatory programs. Although the data that are collected by government agencies are useful to the individual organizations that sponsor the program, future data users within the same organization and data users outside the collecting agency typically find it difficult to use existing data with confidence. The reasons for this situation are many:

- The objectives for the original data-collection program were less rigorous than the current data needs demand or, more likely, are not known.
- Information about the data, such as detection level, precision, bias, and water sampling and sample/handling methods, are unavailable or not readily available.
- Information about the analytical methods and laboratory quality assurance (QA) are not easily accessible or are unavailable.
- The quality control of data entry, storage, transfer, and retrieval processes are unknown.

A related problem for those providing data is that many regulatory and nonregulatory programs specify the methodology to be used in analyzing water samples. Although this provides each monitoring program with a measure of comparability, there has been virtually no methodologic consistency between programs. Therefore, data providers must respond to requests for different methods for determining the same constituent, often within the same measurement range. This program-specific approach to water-quality monitoring inappropriately and inefficiently increases the demands on limited resources while reducing the utility of water-quality information available.

Intergovernmental Task Force on Monitoring Water Quality (ITFM) has as its principal objective the development of an integrated, voluntary nationwide strategy for water-quality monitoring. Implicit is the collection of comparable data of known quality. This appendix presents the approach of the ITFM Data Collection Methods Task Group (Task Group) to the collection of samples and analysis of environmental data in a manner that produces comparable data and permits the merger of data from many sources into definable data sets to address the needs of the user community. In this appendix, sampling, sample handling, field and laboratory methods, and data qualifiers that are used to describe these activities are considered, and an institutional framework to encourage evaluation and implementation of the component principles of data comparability is proposed. Data comparability is defined by the ITFM as the characteristics that allow information from many sources to be of definable or equivalent quality so that it can be used to address program objectives not necessarily related to those for which the data were collected.

Achieving data comparability and communicating the characteristics of the data that permit assessment of comparability (utility) by a secondary user are the key technical issues to be addressed. The issues involved in achieving data comparability to maximize data utilization are consistent with operating in a well-defined quality system. Methods and procedures need to be fully described, validated, and performed by competent practitioners, and performance needs to be evaluated against a reference. These requirements are equally applicable to field and laboratory data and physical, chemical, and biological measures. However, the extent to which they can be applied varies significantly and is discussed in the following sections.

Prelaboratory Practices

Samples must represent, as closely as possible, the water-quality characteristic or biological community that is being evaluated. In the last few years, there has been a renewed recognition that prelaboratory sample-collection methods can result in dramatically different concentrations of analytes and other water components being delivered to the analyst. Although this is not new or contrary to most people's intuition, the problems associated with prelaboratory techniques, such as sampling, sample process, preservation, containers, and shipping conditions, can be expected to increase. Laboratory equipment and techniques continue to be developed that push the detection limits of target analytes well below concentrations that can result from contamination introduced in prelaboratory processes. For example, particulates from the sampling environment can result in elevated concentrations of dissolved trace metals. Different filtration pressures and volumes can result in dramatically different constituent concentrations measured from the same sample by using the same pore-size filter. Thus, more skill will be required to perform the prelaboratory work as demands increase to measure lower and lower parameter concentrations more precisely.

For many analytes, the equivalency of prelaboratory techniques must be demonstrated if the results reported by different groups are to be compared. There is no longer any question that the individual sample collector must continually demonstrate competence in prelaboratory techniques if the resulting analyses are to be internally reliable or comparable with the results of other groups. For chemical measurements, analytes of this nature generally include constituents measured in concentrations of less than 10 micrograms per liter. Demonstrating comparability of prelaboratory techniques when collecting biological and other samples for analyses requires most of the same considerations as laboratory methods. Integral components of the sample-collection process include written procedures, training, documentation that defines conditions under which the techniques are equivalent, and validation data from field tests of the techniques involved. Because of the vast number of different conditions under which samples must be collected and the comparably large number of natural and contaminated water, sediment, and habitat matrices, it is probable that many prelaboratory techniques will need to be used side by side in the matrix to be measured to establish comparability. Side-by-side comparisons are costly, especially in the field. To limit duplication of on-site comparisons, it is recommended by the ITFM that Federal and cooperating agencies consider maintaining a common on-line computerized listing of comparable prelaboratory methods and associated validation data. One approach to developing a list of comparable field methods is to start with documented side-by-side comparisons of comparable techniques. The initial list can be supplemented by any agency that acquires comparison data on additional procedures.

The documentation of a prelaboratory technique would include the same elements that are typically included in the description of a laboratory method; results of sample analysis would demonstrate that in the matrix of interest and for the type of sample (for example, flow-weighted surface water, ground water, and so forth), the sample is not contaminated or reduced in analyte concentration within a specified limit or is representative of the biological community being evaluated. There also would be a qualitative estimate of the skill level required to perform the technique. For those techniques that require greater skill, more-frequent quality-control samples would be recommended.

In summary, prelaboratory methods become more important as the number of secondary-data users increases, data from varying habitats are compared, and method detection levels decrease. The construction of an index of equivalent prelaboratory methods into a national electronic data base, which would include access to QA information that demonstrates applicability of the method, is recommended. The maintenance of a list of accessible sites is proposed for prelaboratory methods verification, such as springs, wells, and large lakes at which constant, known concentrations of analytes or aquatic and semiaquatic communities exist. Such sites would be utilized by two or more water-quality-data-collecting entities for the purpose of evaluating comparability of prelaboratory data-collection techniques.

Laboratory Practices

There are two general ways of approaching the acquisition of comparable chemical, biological, and physical data. One way is for everyone to use identical analytical procedures. This is the current practice within many of the national water-quality-monitoring programs. By using this rigidly prescriptive approach, laboratories and data-collecting entities must maintain competence in a large number of prescribed methods (one for each of the monitoring programs); this produces, in some cases (more frequently for chemical analyses), almost identical data. Unfortunately, when these data are stored in a multiuser data base, the original data-quality objectives and data characteristics usually are lost. This is neither practical nor cost effective.

The alternative approach is to specify the data-quality requirements for a program and to permit the data-collecting entity or laboratory to select the method that best meets its specifications. This is called a performance-based methods system (PBMS). A PBMS is defined as a system that permits the use of any appropriate sampling and analytical measurement method that demonstrates the ability to meet established performance criteria and complies with specified data-quality objectives. The Task Group has recommended the use of PBMS as a mechanism to assure data comparability. Performance criteria, such as precision, bias, sensitivity, specificity, and detection limit, must be designated, and a sample collection or sample-analysis method-validation process, documented. The implementation of a PBMS with corresponding required data qualifiers entered into a multiuser data base will allow divergent data from numerous environmental programs to be used for many purposes. Eventually, a PBMS should apply to all measurement systems. However, initial application is proposed only for chemical and physical laboratory methods. Implementing a PBMS will be a principal activity of the Methods and Data Comparability Board.

For a PBMS to work, the following basic concepts must be defined and targeted:

- Data-quality objectives must be set that realistically define and measure the quality of data needed.
- Reference (validated) methods must be made available that meet these objectives.
- The selected methods must be as good as or better than the reference method.
- There must be proof of method adequacy.
- Method ruggedness must be demonstrated

If a laboratory chooses to use a nonreference method, then the following information and performance criteria should be supplied to assure validity:

- Specific reference method.
- Deviations from the method (with explanation).
- Method blank results.
- Reference sample results
- Spike, duplicate spike, and duplicate sample results.
- Surrogate results (if applicable).
- Tuning results to meet method specifications (if applicable).
- Calibration checks to meet specifications.
- Sample data results (with qualifiers).
- Method detection limits.
- Sampling and preservation

Similar checklists (or procedures) need to be developed to address the unique features of prelaboratory methods and eventually biological and other systems, which are equally important.

Defining the performance criteria of a method to meet data-quality objectives is the first step in initiating a PBMS. Statistically based quality-control criteria for replicate measurements and calibrations should be established as a measure of required precision. Bias limits are determined by analyzing spiked samples, standard reference materials, and performance-evaluation samples. Method detection limits over a significant period of time are required to determine the application of a method to monitoring needs or regulatory requirements. The performance range of a method also should be determined. The method must not generate background or interferences that will give false qualitative or quantitative information. If a method is considered to be applicable for multimedia, then documented evidence should be available to support this use. The Task Group strongly recommends using methods that have been published in peer-reviewed or equivalent literature and that meet or exceed the performance criteria of reference methods for the analytes of interest. (Many of these principles, approaches, and needs are equally applicable regardless of their use in generating chemical, physical, or biological data.)

Achieving these goals in all media requires training, the availability of matrix-specific performance-evaluation materials, the implementation of a laboratory-accreditation process, and the systematic audit of activities. The current stock of standard chemical and biological reference materials and performance evaluation samples is limited or, in some cases, nonexistent and needs to be developed or expanded to cover a wider range of constituents and media.

The training requirements to execute a PBMS and to reach some level of national comparability are extensive because of the diversity of water-quality-monitoring programs and data requirements. A "National Curriculum" needs to be established and should include formal and informal components.

The Task Group recognizes the need for laboratory accreditation with periodic review of activities as an important element in the PBMS. The concept of a national accreditation program was recently approved by a Federal interagency committee, the Committee on National Accreditation of Environmental Laboratories, and discussed at the National Environmental Laboratory Accreditation Conference in February 1995. Factors to be included in such a program should be based on International Standards Organization (ISO) Guide 25 and address organization and management; quality-system audit and review; personnel; physical accommodations and work environment; equipment, reference materials, and reference collections; measurement traceability and calibration; calibration and test methods; handling of calibration and test samples; records; certificates and reports; subcontracting of calibration and testing; outside support and supplies; and complaints.

The programmatic elements and resources required to achieve data comparability by using a PBMS are presented in table 1. In this presentation, sampling and laboratory-related processes are included, as are physical, chemical, and biological disciplines

In summary, implementation of a PBMS will be consistent with the production of data of known quality based on scientific procedures and judgments rather than on methods and procedures that have been mandated by regulatory programs. A PBMS will provide the incentive to develop innovative and better methods that are cost effective. This will allow greater flexibility by the water-quality-monitoring community that is consistent with total quality management

Data Qualifiers

The Task Group has recommended a minimum set of water-quality-data qualifiers that must reside with the sampling and analytical information. These data qualifiers should be evaluated and updated subsequently as standardization of information continues. They are as follows:

- Parameter, constituent, or identifier determined (including chemical abstract number, if available).
- Sample matrix—Characterization and condition.
- Method (technique)—How collected, handled, analyzed, evaluated.
- Value measured—Concentration, population, ratio.
- Location—Latitude and longitude of site.
- Time—Date and time of day.
- Who measured—Collecting and analyzing agency.
- Data source—Whose monitoring program.
- Indications of data quality (including quality descriptors, such as precision, bias, detection limits, defined quality system).

Methods and Data Comparability Board

Objectives

The Data Collection Methods Task Group has recommended that the Interagency Advisory Committee on Water Data (IACWD), under which the ITFM functions, establish a Methods and Data Comparability Board (MDCB). With the concurrence of participating agencies, the MDCB will coordinate those water-quality-monitoring protocols, methods, and practices being carried out by government agencies to improve the efficiency and effectiveness of these efforts and to improve the comparability of the resulting data. It also will reconcile inconsistencies among agencies in current practices and encourage governmentwide coordination to conduct the most economical and scientifically defensible approach to water-quality monitoring.

The MDCB will provide a framework and a forum for common approaches to data collection in all appropriate water-quality-monitoring programs.

Table 1. Resources needed to support a plan for achieving data comparability

Principal function	Field site (sampling related)			Laboratory site (measurement process)		
	Physical	Chemical	Biological	Physical	Chemical	Biological
Reference methods	X	X	X	X	X	X
Reference materials				X	X	X
Reference collections						X
Reference sites	X	X	X			
Performance evaluation/calibration materials	X	X	X	X	X	X
Laboratory accreditation				X	X	X
Formal training programs (classroom, on the job training)	X	X	X	X	X	X
Computer resources to access reference methods and method-comparability data	X	X	X	X	X	X
Method-comparability data	X	X	X	X	X	X

Action will be taken to improve the scientific validity of water-quality data; to establish common approaches to collecting water-quality-monitoring information; to provide a forum for advancing state-of-the-art technology in water-quality methods and practices; to assist all levels of government in carrying out monitoring in a coordinated, mutually enforceable manner; and to recommend initiatives that lead to data comparability between agencies.

To accomplish its objectives, the Board will establish priorities and function in the following areas.

- **Organizational Framework**

From an organizational perspective, the following principles will be operative:

- The MDCB will be an intergovernmental, proactive, decisionmaking body with membership from public and private organizations.
- Financial resources will be identified and secured for the MDCB to accomplish its mission. The MDCB should be able to achieve governmentwide cost savings in the long term through the cooperation of its members.
- The MDCB will utilize a PBMS for establishing data comparability of analytical methods, which include prelaboratory procedures.
- All agencies will be encouraged to work together to reach agreement in a consensus-building manner.

- **Quality Assurance and Methods Comparability**

The MDCB will actively develop interagency approaches to ensure data comparability. Important specific activities will include establishing minimum data-quality criteria, conducting intercomparison exercises (testing comparability of methods), using performance and reference samples, validating methods, characterizing reference sites, and problem solving among agencies.

- **Accreditation**

To assure data quality and comparability, the MDCB will investigate accreditation of laboratories and certification of employees.

- **Guides and Training**

A critical aspect of assuring data quality and comparability is the availability of suitable training materials and guides. The MDCB will investigate publishing criteria for validating a method; publishing guides, materials, and standards; issuing specifications for operating under a PBMS; and issuing training curricula to meet the needs of users.

Acknowledgments

The authors wish to thank the members of the Task Group for their efforts in developing the recommendations set forth in this paper. In particular, Wayne Webb of the U.S. Geological Survey (USGS) evaluated the significance of prelaboratory practices on measurement data, Ann Strong of the U.S. Army Corps of Engineers, developed the position of performance-based methods, Orterio Villa of the U.S. Environmental Protection Agency (USEPA) suggested that an interagency board be formed to assure data comparability in water-quality-monitoring programs, Tom Bainbridge of Wisconsin drafted the Terms of Reference (Appendix H) for the MDCB, and Bernard Malo of the USGS was instrumental in assembling the positions presented in this paper. Herb Brass of the USEPA and Russell Sherer of the South Carolina Department of Health and Environmental Control cochaired the Task Group. This technical appendix is based on a paper presented at the Water Environment Federation Analytical Specialty Conference in Santa Clara, California, August 8–11, 1993.

TECHNICAL APPENDIX J

TARGET AUDIENCES, MONITORING OBJECTIVES, AND FORMAT CONSIDERATIONS FOR REPORTING WATER-QUALITY INFORMATION

The Intergovernmental Task Force on Water Quality Monitoring (ITFM) was established to develop and initiate implementation of a strategic plan to achieve effective collection, interpretation, and presentation of water-quality data and to improve the availability of information for decisionmaking at all levels of government.[1] To this end, the Assessment and Reporting Task Group (Task Force) is reviewing available water-quality reports to identify features and information-presentation techniques that should be used in summary reports to produce understandable interpretations of water-quality conditions. This exercise will ultimately result in guidelines for agencies or individuals who prepare water-quality reports.

Tables 1 and 2 were developed as a framework for anyone who prepares water-quality reports. Table 1 presents a framework for comparing target audiences to the monitoring objectives of the ITFM, as presented in its first-year report. This table is intended to help identify the most relevant issues and concerns for the target audiences. For each audience, authors should establish a priority ranking for each of the ITFM monitoring purposes to help determine report content and presentation sequence. For example, people who use (drink from, recreate on, live near) a particular water body probably will be most interested in the water-quality status and trends, as well as in existing or emerging problems, while policymakers will be more interested in how well water pollution-control programs have addressed these issues.

Table 2 presents a framework for format considerations in presenting water-quality information to target audiences. Authors should complete each block in the matrix for their target audiences to help determine the most effective style and format for communicating their information. For example, resource managers and scientists usually want more technical information than the general public, and the style of the document should reflect this. Audience categories, monitoring objectives, and format definitions are presented below.

The Task Group also has reviewed several documents as examples of publications that address the various monitoring objectives, use specific formatting styles, and (or) are directed to specific audiences. Excerpts from these documents are being incorporated into a compendium to provide authors with examples of particularly effective techniques for reporting water-quality information. This compendium and these tables will be reviewed by additional focus groups to obtain target audiences input into the reporting guidelines.

[1]Intergovernmental Task Force on Monitoring Water Quality, 1992, *Ambient Water-Quality Monitoring in the United States—First Year Review Evaluation and Recommendations.* 51 p.

Audience Categories

The audience is the group to whom the information product is targeted. The Task Group has identified the following audience categories:

- *Interested public/concerned citizens.*—People who have a general interest in the quality of water resources and a vested interest in the quality of specific water bodies. Their vested interest usually is related to the locations of their homes, their uses of water bodies for various purposes (for example, fishing, boating, swimming, water supply), or their livelihoods. Examples include lakefront property owners, anglers, commercial fishermen, marina owners/operators, recreational boaters and skiers, and local environmental advocacy groups.

Table 1. Framework for water-quality documents/materials—Audience vs. monitoring objective

Audience	Monitoring objectives: Defining status and trends	Identifying problems	Providing information for policies and programs	Evaluating program effectiveness	Responding to emergencies
Interested public/ concerned citizens					
Media/ general public					
Policy-makers					
Resource managers					
Scientists . . .					

Table 2. Framework for water-quality documents/materials—Audience vs. format

Audience	Format						
	Printed materials				Electronic media		
	Reading level	Level of detail	Layout	Graphics	Audio presentation	Video presentation	Personal computer data base and presentation of geographic information system
Interested public/ concerned citizens							
Media/general public							
Policymakers							
Resource managers							
Scientists							

- *Media/general public.*—Representatives of organizations whose main function is mass communication, such as newspapers, general interest magazines, radio stations, and television stations, as well as the audiences to which their reports are directed. Members of this audience have a general interest in water-resource quality, but less of a vested interest than the interested public/concerned citizens categories.
- *Policymakers.*—Persons who set national, State, or agency environmental goals and establish programs for attaining them. Examples include lawmakers and other elected officials who are directly accountable to the public, top-level managers in State and Federal agencies who are directly accountable to elected officials, and oversight agencies, such as the Office of Management and Budget and the General Accounting Office.
- *Resource managers.*—Persons who are responsible for implementing programs to protect or improve water-resource quality or for operating systems, such as reservoirs, that are designed to modify or control natural variables. Examples include line staff and managers of State and Federal water-resource, land-management, and fisheries agencies, as well as environmental staffs of municipalities and regional planning agencies. Organizations represented in this audience category include national programs and regional offices of the U.S. Environmental Protection Agency (USEPA), the U.S. Geological Survey (USGS), the Natural Resources Conservation Service (NRCS), the U.S. Fish and Wildlife Service, the National Park Service, the U.S. Forest Service, and the U.S. Army Corps of Engineers (USACE); the natural resources divisions of the Tennessee Valley Authority, the Bureau of Reclamation, and the Bonneville Power Administration; and the hydropower divisions of private utilities, such as the Duke Power Company and the Southern Company.
- *Scientists.*—Individuals engaged in technical observation, identification, description, experimental investigation, and theoretical explanation of natural phenomena. Examples include individuals who are involved in university research programs; research divisions of agencies, such as the USGS, the Agricultural Research Service, the NRCS, the National Biological Service, the National Marine Fisheries Service, the USACE, and the USEPA; and industry-supported research organizations, such as the Electric Power Research Institute and the Pulp and Paper Institute.

Monitoring Objectives

The monitoring objectives defined by the ITFM, and the questions they address are as follows:

- Defining status and trends. (How healthy is this body of water? Is its quality improving or deteriorating?)
- Identifying existing and emerging problems. (Where are the problem areas?)

- Providing information to support development and implementation of policies and programs for water-resource management. (What is needed to correct problems or protect good quality waters?)
- Evaluating program effectiveness. (Are we doing the right thing? Are we accomplishing what we want to accomplish and at a reasonable cost?)
- Responding to emergencies.

Format Definitions

Formatting decisions should be based on the type of audience the document is trying to reach. The format should enable the audience to understand and use the information in the document. *Box 1* summarizes the types of information usually presented in water-quality reports, and *Box 2* suggests some special considerations for formatting. The format criteria suggested by the Task Group are as follows:

- *Reading level.*—Reading level or level of education of targeted audience
- *Level of detail.*—Integration of information from different disciplines; importance of the "whole picture" as opposed to a piece of the picture. Different audiences have varying needs in the amount and type of information that needs to be presented.
- *Layout.*—Integration of text and graphics; color, use of fonts, headers, white space, columns, bullets, sidebars, footnotes, and other features to improve clarity and readability.
- *Graphics.*—Choice and placement of photographs, drawings, charts, graphs, tables, study area maps, schematic maps, and other graphic devices to illustrate points covered in text, or to supplement textual information.

Box 1. Types of Information Usually Presented in Water-Quality Reports

- Status of aquatic flora and fauna.
- Status of water-quality indicators.
- Monitoring activities.
- Trend assessment.
- Management activities.

Box 2. Special Considerations for Presentation of Information

- For most audiences, reports should be short; documents that consist of an executive summary and supporting appendices could accomplish this.
- In large reports, particularly those with several authors, the same types of information should be presented consistently throughout the report to help readers easily recognize similarities and differences among sites.
- The font must be large enough to be read comfortably and should be modern, readable and attractive as opposed to a typewriter style. For most persons, reading speed is faster for serif style fonts, as compared to similar blocked fonts.
- Margins should be large enough to prevent a page of information from overwhelming the readers.
- Running heads and feet that include such information as chapter number, chapter name, document name, and page number are helpful.
- Summary information can be included at the beginning of sections or in sidebars.
- Section headings should provide organization for the reader and be in large, bold, and (or) distinctive type to distinguish them from regular text.
- A two-column format is easier to read.
- Monotony of text can be broken up with graphics, tables, and (or) summary information.
- Graphics may be displayed in boxes to attract attention.
- Some gloss is good, although it can be overdone.

These criteria may apply to either printed materials or electronic information. Printed materials may range from fact sheets to technical reports; electronic-information presentations may range from audio and video presentations, such as radio public service announcements, television informationals, packaged educational presentations, and video news releases, to electronic release of reports on the Internet.

TECHNICAL APPENDIX K

ANNOTATED BIBLIOGRAPHY OF SELECTED OUTSTANDING WATER-QUALITY REPORTS

The documents included in this bibliography were selected by members of the Assessment and Reporting Task Group (Task Group) for review by a focus group that comprised individuals who represent each target audience (interested public/concerned citizens, media/general public, policymakers, resource managers, scientists) The focus group was asked to complete a questionnaire designed to determine each participant's appraisal of the documents with respect to the following questions:

- How well does the document achieve its objectives; that is, considering the intended audience, does it clearly and concisely convey appropriate water-quality information?
- How well is the information presented; that is, does the document have distinctive formatting or graphical presentation elements that make it particularly effective in relating information to the reader?

Each document listed in the following bibliography is annotated to summarize this information, as contributed by Task Group members and focus group participants.

Dahl, T.E., 1990, *Wetlands losses in the United States—1780's to 1980's*: U.S. Fish and Wildlife Service, 15 p.

This is the first of two reports to Congress on the status of wetland resources in the United States. This report focuses on documenting historical wetland losses from colonial times through the 1980's. The document is a good example of how to target information for policymakers. Because of the succinctness of the text and the efficacy of the graphics, the report also is a good source of information for the general public. Distinctive features that enhance the report's effectiveness are its use of maps and tables, a large font, large headings, running heads, the active voice, and an attractive page layout with wide margins. By using varying shades of orange and black (not very good choices), the report achieves a colorful and cost-effective presentation.

Hamilton, P.A., and Shedlock, R.J., 1992, *Are fertilizers and pesticides in the ground water? A case study of the Delmarva Peninsula—Delaware, Maryland, and Virginia*: U.S. Geological Survey Circular 1080, 16 p.

This report addresses the issue of degradation of water quality from the use of fertilizers and pesticides on the Delmarva Peninsula. The report was prepared as part of the National Water-Quality Assessment (NAWQA) Program of the U.S. Geological Survey (USGS); NAWQA includes investigations in 60 study areas that represent a variety of geologic, hydrologic, climatic, and cultural conditions. This report is primarily targeted toward interested public/concerned citizens because it discusses a specific region and water-quality issue; the report also is effective in providing information to the general public and policymakers. Distinctive features that enhance the report's effectiveness are its use of color, maps, tables, charts, photographs, question-and-answer format, a large font, large headings, the active voice, information contained in sidebars and insert boxes, directions on how to obtain additional information, and an attractive page layout.

Kentucky Environmental Quality Commission, 1992, *State of Kentucky's environment—A report of progress and problems*: Kentucky Environmental Quality Commission, 340 p.

This report was mandated by the State Legislature to assess environmental trends and conditions in Kentucky. Trends are assessed to determine whether programs for water, air, waste management, natural resources, toxics, coal mining, and energy are achieving their intended results. The report is intended to provide State policymakers and concerned citizens with a better understanding of the environmental conditions of Kentucky, but it also is appropriate for resource managers and scientists. Distinctive features that enhance the report's effectiveness are its use of maps, tables, charts, graphs, photographs, large headings, the active voice, summary statements contained in sidebars, running heads, an index, an acronym list, and an attractive page layout. By using varying shades of blue, the report achieves a colorful and cost-effective presentation.

Rinella, J.F., Hamilton, P.A., and McKenzie, S.W., 1993, *Persistence of the DDT pesticide in the Yakima River Basin, Washington*: U.S. Geological Survey Circular 1090, 24 p.

This report addresses the issue of degradation of water quality from the use of the pesticide DDT in the Yakima River Basin. The report was prepared as part of the NAWQA Program of the USGS, which consists of investigations in 60 study areas that represent a variety of geologic, hydrologic, climatic, and cultural conditions. This report is primarily targeted toward interested public/concerned citizens because it discusses a specific region and water-quality issues; the report also is effective in providing information to the general public and policymakers. Distinctive features that enhance the report's effectiveness are its use of color, maps, tables, charts, photographs, question-and-answer format, a large font, large headings, the active voice, information contained in sidebars and insert boxes, directions on how to obtain additional information, and an attractive page layout

South Florida Water Management District, 1993, *Florida Water*: Communications Departments of the South and Southwest Florida Water Management Districts, v. 2, no. 1., 35 p.

Florida Water, the quarterly magazine of Florida's five water-management districts, is published to generate awareness of the need to conserve and protect State water resources and aquatic ecosystems. Although this magazine is primarily targeted toward interested public/concerned citizens because it discusses a specific region, it could be useful to policymakers. Distinctive features that enhance the magazine's effectiveness are its use of maps, photographs, feature stories to discuss particular issues or water resources, large headings, question-and-answer format, the active voice, summary statements contained as inserts, footer text, directions on how to obtain additional information, and an attractive page layout.

Tennessee Valley Authority, Water Management Division, 1993, *River pulse*: Tennessee Valley Authority, 20 p.

This annual series of 20- to 30-page reports on the condition of the Tennessee River and its tributaries provide status and trend information on how well these water bodies support recreation, fish consumption, aquatic-life, navigation, water-power, and water-supply uses. *River Pulse* is primarily targeted toward interested public/concerned citizens because it discusses a specific region and water-quality issue; the report also is effective in providing information to the general public and media. One of its special features is lake-by-lake assessment of ecological health and of the suitability of recreation areas for swimming. Distinctive features that enhance the report's effectiveness are its use of schematic maps, photographs, charts, graphs, feature stories on particular issues or water resources, large headings, question-and-answer format, large font, the active voice, summary statements contained as inserts, foot text, directions on how to obtain additional information, directions on what individuals can do to help, and an attractive page layout. Its use of color is especially effective.

U.S. Environmental Protection Agency, Office of Water, 1992, *The quality of our Nation's water—1990*: U.S. Environmental Protection Agency, EPA–841/K–92–001, 45 p.

This document is designed to help the general reader understand the problem of water pollution in the United States. Its focus is on the sources, types, impacts, and extent of water pollution and the actions government and citizens are taking to control such pollution. The information is condensed from the U.S. Environmental Protection Agency's (USEPA) *1990 Report to Congress*. Because of the succinctness of the text and the efficacy of the graphics, the report is a good source of information for the general public. Some distinctive features that enhance the report's effectiveness are its use of maps, graphs, photographs, question-and-answer format, bullets, a large font, summary information contained in box inserts, feature stories on particular issues or water resources, large headings, the active voice, directions on how to obtain additional information, directions on what individuals can do to help, and an attractive page layout. By using varying shades of blue, the report achieves a colorful and cost-effective presentation.

Wisconsin Department of Natural Resources, 1992, *Wisconsin water quality assessment report to Congress*: Wisconsin Department of Natural Resources, WR254–92–REV, 250 p.

This report details the findings of water-quality assessments in Wisconsin and provides descriptions of the specific State programs that control, manage, and prevent water-quality degradation. It was prepared to satisfy the reporting requirements under section 305(b) of the Clean Water Act and to assist the USEPA in reporting the Nation's progress in meeting and maintaining goals for fishable and swimmable waters. This report is useful to the general public, media, policymakers, resource managers, and scientists. Distinctive features that enhance the report's effectiveness are its use of maps, tables, charts, graphs, photographs, bullets, large headings, the active voice, summary statements contained in sidebars, running heads, a glossary, an acronym list, and an attractive page layout with wide margins

TECHNICAL APPENDIX L

GROUND-WATER-QUALITY-MONITORING FRAMEWORK

This appendix outlines issues that relate to the design and implementation of ground-water-quality-monitoring programs. These issues address the unique characteristics of ground water and are consistent with the overall water-quality-monitoring objectives outlined by the Intergovernmental Task Force on Monitoring Water Quality (ITFM).

Developing a General Understanding of the Resource and Monitoring Program Objectives

Ground-water monitoring is a critical component of water-resource-management programs. The hydrologic connections between ground and surface waters mandate that monitoring programs for all water resources be closely linked. By acknowledging this close hydrologic connection, ground-water monitoring can provide critical support to surface- and ground-water-management programs.

Ground-water-quality monitoring is defined as an integrated activity for obtaining and evaluating information on the physical, chemical, and biological characteristics of ground water in relation to human health, aquifer conditions, and designated ground- and surface-water uses. With accurate information, the current state of the Nation's ground-water resources can be better assessed; water-resource protection, preservation, and abatement programs can be run more effectively; and long-term trends in ground-water quality and the success of management programs can be evaluated.

While acknowledging that ground-water monitoring provides critical information to support ground- and surface-water-management programs, it is vital to consider the differences in the spatial and temporal characteristics of ground and surface waters when designing and implementing monitoring programs. Ground water has a three-dimensional distribution within a geologic framework and is characterized by contrasting aquifer and geologic features, limited accessibility (that is, ground water must be sampled through an existing or newly drilled well or a spring), and differences in rates of movement (that is, in general, ground water moves much more slowly than rivers). Therefore, the design and implementation of a ground-water-quality-monitoring program must be based on a thorough understanding of the unique hydrogeological characteristics of the ground-water-flow system under investigation and the locations of particular land uses and other contaminant sources likely to affect ground-water quality. As a result, no one national design and implementation of a ground-water-monitoring program can be recommended. Instead, each State, Tribal, and local jurisdiction must design a monitoring program that takes into account the hydrogeological setting, existing water quality, contaminant source locations, and beneficial uses of the water resource.

An important aspect of any ground-water-qualty-monitoring program is the effective sharing and using of data from various sources. One such area of exchange is among programs designed to gather background- or ambient-monitoring data and those designed to gather regulatory compliance-monitoring data. Although the statutory and regulatory requirements for implementing a background- and a compliance-monitoring program may be different, most of the requirements for obtaining data on specific chemical parameters are applicable for both purposes. In cases where appropriate data-quality objectives are met for either background or compliance monitoring, the data will be mutually beneficial for both purposes.

The Ground-Water Focus Group of the ITFM has identified the following general objectives for monitoring programs:

- Assess background or ambient-ground-water quality conditions.
- Comply with statutory and regulatory mandates.
- Determine changes (or lack of change) in ground-water-quality conditions over time to define existing and emerging problems; to guide monitoring and management priorities; and to evaluate effectiveness of land- and water-management practices and programs.
- Improve understanding of the natural and human-induced factors (for example, land use activities) affecting ground-water quality.

The Ground-Water Focus Group identified three general types of ground-water monitoring currently (1994) conducted by Federal, State, local, and private organizations to accomplish one or more of the objectives stated above.

Background Monitoring

A wide variety of chemical, physical, and biological contaminants may affect ground-water resources. As a result, background and ambient-ground-water-monitoring programs are designed to establish baseline water-quality characteristics and to investigate long-term trends in resource conditions. The parameters measured in baseline-monitoring programs provide a set of descriptive data on general ground-water conditions.

Monitoring for Specific Land-Use Impacts on Ground-Water Quality

Monitoring programs also typically focus on assessing the impact from contaminant sources that are related to specific land uses. For these regional or localized monitoring efforts, monitoring parameters are identified on the basis of a thorough understanding of the resource to be evaluated and the sources of contamination.

Facility-Based or Compliance Ground-Water Monitoring

Compliance monitoring is conducted in response to specific regulatory requirements or permit conditions [for example, the Resource Conservation and Recovery Act (RCRA), hazardous-waste-unit monitoring or in support of remedial activities [for example, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) site monitoring].

The next section elaborates on one key component of ground-water-monitoring-program design—the selection of parameters to be monitored to serve as indicators of ground-water quality. The "Ground-Water-Quality-Monitoring Framework" section outlines a detailed framework for designing and implementing a ground-water-monitoring program. This framework is provided as guidance to water-quality-program managers and technical staff to assist in identifying the key components of new or expanded ground-water-monitoring efforts.

Selection of Ground-Water-Quality Indicators

One of the key elements in the design of a water-quality-monitoring program, whether the program is focused on background conditions, land use impacts, or compliance monitoring, is the selection of the properties, elements, and compounds (indicators) to be measured. Ground- and surface-water quality may be characterized by literally thousands of indicators. Selection of indicators for monitoring programs should be based on their relevance to important water-quality issues, such as human health protection, the monitoring objectives outlined above, and the existence of appropriate analytical methodologies. For some water-quality issues, the choice of indicators to be monitored is a simple task; for example, the substances relevant to the issues of nutrient enrichment and salinity are of limited number, and their chemical analysis is inexpensive. In contrast, for the issue of toxic contamination, the selection of indicators is much more difficult because of the large number of potentially toxic trace elements, pesticides, and other synthetic/organic contaminants to consider, and their analysis is expensive.

Because of differences in the importance of water-quality issues in various regions of the country and because of the potential for significant differences in the objectives of monitoring programs, no one set of indicators is suitable or appropriate for all monitoring programs. Further, changes in the indicators of interest will occur through time as analytical capabilities improve and become less costly and as knowledge increases about the production of chemicals, geographic usage patterns, and other factors that affect the likelihood of water-quality problems associated with particular constituents.

Criteria for Indicator Selection

Indicators appropriate for ground-water-quality monitoring should meet two general criteria. First, a parameter should be a candidate for monitoring because it fulfills any of or all the following:

- Is potentially toxic to human health and the environment, livestock, and beneficial plants; for example, pesticides, volatile-organic contaminants, trace elements, sodium, nitrogen species including nitrite, and nitrate.
- Impairs the suitability of the water for general use; for example, hardness, iron, manganese, taste, odor, and color.
- Is of interest in surface water and may be transported from ground- to surface-water systems; for example, nitrogen species ammonia, nitrite, and nitrate.

- Is an important "support variable" for interpreting the results of physical and chemical measurements; for example, temperature, specific conductance, major ion balance, depth to the water table, and selected isotopes

Second, analysis of the candidate indicator should be affordable by using well-established analytical methods at appropriate minimum-detection and reporting levels necessary to achieve the objectives of study.

Based on these criteria, the following general groups of indicators should be considered for ground-water-monitoring programs.

- Field measurements (temperature, specific conductance, pH, dissolved oxygen, alkalinity, depth to water).
- Major inorganic ions and dissolved.
- Nutrients.
- Dissolved organic carbon.
- Pesticides.
- Volatile organic chemicals.
- Metals and trace elements.
- Bacteria.
- Radionuclides.

Continuing research is needed on techniques for identifying microbiological indicators for ground-water monitoring. Nonetheless, monitoring programs should take into account the many State and local requirements for the assessment of *Escherichia coli* as a measure of fecal contamination.

Process for Selecting Specific Indicators for Ground-Water-Quality Monitoring

The proposed process for selecting specific indicators for ground-water monitoring is illustrated in Figure 1 and is discussed below.

Step 1. Analyze Existing Information

The first step in the process is to determine whether there is a recently documented occurrence of the indicator(s) by using existing information. Over the years, a large amount of ambient water-quality data has been collected by many organizations to address a wide range of objectives. Much of these data can be obtained from the U.S. Environmental Protection Agency's (USEPA) STOrage and RETrieval (STORET) and the U.S. Geological Survey's (USGS) National WATer Data STOrage and REtrieval (WATSTORE) system computerized data bases. Many of these data should be

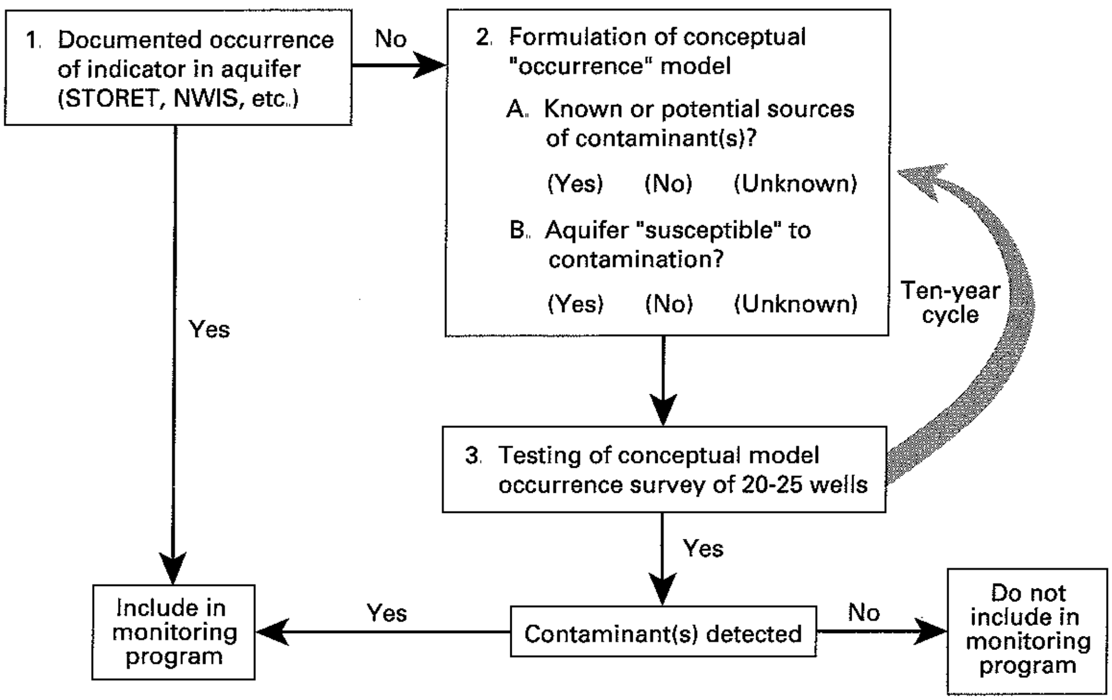

Figure 1. Process for selecting specific indicaters for ground-water-quality monitoring.

useful for selecting indicators, provided that appropriate care is taken to ascertain the manner in which they were collected and analyzed and the individual settings they represent. For example, for pesticides and other trace organic contaminants, it is important that information used to establish the occurrence of these contaminants in the environment be based on appropriately sensitive analytical procedures.

Additional data, some of which may not be in computer files, may be obtained through contacts with other agencies and organizations or through literature reviews. Municipalities, other utilities, and the private sector collect a large amount of water-quality data, often at considerable expense, to comply with statutory and regulatory mandates. For example, under the Safe Drinking Water Act, public water-supply systems routinely collect ambient-water-quality data for use in the operation of their systems or for compliance purposes. These data are not routinely included in national computerized data bases, but may be available from State agencies or individual water utilities and facilities. Similarly, under the RCRA, hazardous waste facilities are required to monitor ground water upgradient and downgradient of waste-disposal units for contaminants likely to be found in the waste stream(s) managed by the facility. If a contaminant is detected, then the facility may be required to monitor for a broader list of constituents (*Federal Register,* App. 9, v. 40, pt. 264), whether those constituents are likely to be found at the facility or not. Many of these data should be useful for providing information on locally important indicators and the occurrence of different indicators in relation to different types of facilities and sources.

Step 2. Determine Whether the Contaminant Is Likely to Occur in the Ground-Water System

This step assesses the likelihood that specific indicators, which have no documented occurrence and have not been determined in samples collected from the aquifer system, will be present. This assessment addresses the question: Is it likely that this contaminant is present in this ground-water system? Formulation of a response to this question should take into account what is known about the potential sources of the contaminant(s) of interest, the physical and chemical properties of the contaminants that govern their transport to ground-water systems and knowledge of the local hydrogeology and susceptibility of the aquifer to contamination. Tables 1 and 2 provide examples of indicators that could be considered for monitoring in areas with different types of land use and sources of contaminants. The tables provide a starting point for evaluating the relation between land-use patterns and likely contaminant loading to ground water. For example, ground-water-monitoring programs in regions of agricultural land use should consider pesticides that are or were readily applied to crops in the region, are persistent, and are readily transported to the ground-water system.

Table 2 provides a suggested set of ground-water-quality-monitoring parameters to be included in facility-based monitoring programs. This list is not intended to substitute for parameters monitored under existing regulatory programs. These parameters, which were identified on the basis of a review of historical facility-based monitoring records, are intended to be used as guidance for new or expanded facility-based monitoring activities. Parameters chosen for a particular facility also should be based on an understanding of the materials handled at the facility, if that information is available.

Step 3. Test and Validate Contaminant Occurrence

The hypothesis that a contaminant is likely or unlikely to occur in an aquifer system should be tested as part of an "occurrence survey." This step is especially important because of our limited knowledge and understanding of the occurrence of different contaminants in ground water. An occurrence survey would consist of monitoring selected wells in the aquifer system to be sampled. The number of wells to be assessed would be determined on the basis of the size of the study region and the complexity of the hydrogeologic setting. On the basis of the results of this survey, the investigator would determine whether or not the contaminant should be included for subsequent sampling of the system. As knowledge of the occurrence of different contaminants in different environmental settings improves, the uncertainty associated with understanding of indicator occurrence, as well as the need for extensive verification, should decrease.

The above process should be repeated at an appropriate interval (for example, 10 years for background or land-use-impact monitoring) or as deemed necessary, given changes in land and water-management activities, chemical use patterns, or analytical methods. For compliance monitoring, verification of the presence of likely contaminants may be conducted more frequently or as specified under regulation or the conditions of a permit.

This approach to selecting water-quality parameters is being implemented by several of the States.

Table 1. Indicators likely to be associated with different land uses

Parameters	Municipal/domestic/commerical/agricultural land use[1]											
	Municipal			Domestic				Commercial		Agriculture		
	Landfill	Sewer/ pipeline	Other uses[2]	Sanitation	Storage[3]	General use[4]	Irrigation	Sanitation	Commercial property[5]	Irrigation	Animal feedlots	Cultivation
Physical:												
Color	X	X	X	X	X	X	X	X	X	X	X	X
Odor	X	X	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X	X	X
Specific conductance	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X
Total dissolved solids	X	X	X	X	X	X	X	X	X	X	X	X
Common ions	X	X	X	X	X	X	X	X	X	X	X	X
Volatile organic carbon	X		X[6]		X[6]		X					
Perchloroethylene	X											
Trichloroethylene	X						X					
Trichloroacetic acid	X						X					
1,1 Dichloroethylene	X						X					
Methylene chloride	X						X					
Vinyl chloride	X						X					
Semivolatiles[2]	X		X[7]		X[7]							
Pentachlorophenol	X											
Polycyclic aromatic hydrocarbons.[3]	X											
Dioxins	X											
Polychloinated biphenyls	X											
Petroleum hydrocarbons	X		X		X	X			X			
Benzene, toluene, ethylene, xylene	X	X	X		X				X			
Pesticides			X			X	X		X	X	X	X
Metals	X	X										
Arsenic	X	X										
Cadmium	X	X										
Chromium		X										
Lead	X	X										
Nickel		X										
Zinc		X										
Nitrate		X	X	X		X	X	X	X	X	X	X
Biological		X	X	X		X		X				
Pathogens		X	X	X		X		X			X	

[1]This is a subset of possible land use and source terms. They are intended as examples for indicator use.
[2]Municipal activities might include vehicle maintenance areas, and salt storage piles.
[3]Domestic storage includes such things as underground oil and gas storage tanks.
[4]General domestic activities include domestic lawn fertilization and home and garden pesticide use.
[5]Commercial property includes retail stores and office buildings.
[6]As appropriate to suspected contaminants; for example, TCE might be useful indicator around maintenance areas where degreasing operations are untertaken.
[7]As appropriate to suspected contaminants; for example, PCP might be a useful indicator around lumber storage areas.

Table 2. Indicators associated with manufacturing or industrial land use

[This is a subset of possible land use and source terms. They are intended as examples for indicator use.]

Parameters	Chemical			Electrical	Landfills/waste sites					Mining		Lumber	Pesticides	Petroleum	
	Battery recycling	Solvents	Munitions	Plating	Poly-chlorin-ated biphenyls sites	Dioxins and furans sites	Landfills	Organics sites	Metals/ organics sites	Mining waste	Asbestos	Wood treatment	Manufacture/ storage/load-ing	Refining storage	Gas stations
Physical															
Color	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Odor	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Specific conductance	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Temperature	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Common ions[1]	X	X	X	X	X	X	X	X	X	X	X	X	X	X	
pH	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Total dissolved solids	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Vc Perchloroethylene		X	X	X	X		X	X	X					X	
Tetrachloroethylene		X	X	X	X			X	X				X		
Trichloroethylene		X	X	X	X		X	X	X		X	X	X	X	
Trichloroaceticacid		X		X	X		X	X	X						
1,1 Dichloroethylene		X		X	X		X	X	X				X		
Methylene chloride		X	X	X	X		X	X	X						
Vinyl chloride		X			X		X	X	X				X	X	
Semivolatiles[2]		X		X	X	X			X			X	X		
Pentachlorophenol												X		X	
Polycyclic aromatic hydrocarbons.[3]		X								X		X	X		
Dioxins and furans						X									
Polychlorinated biphenyls				X	X				X			X		X	X
Petroleum hydrocarbons			X										X	X	X
Benzene, toluene, ethylene, xylene.		X	X	X	X		X	X	X		X	X	X X		
Pesticides[4]														X	
Trace elements	X	X	X	X	X		X	X	X		X	X	X		
Arsenic	X	X	X	X	X		X	X	X	X		X	X		
Cadmium	X	X	X	X	X		X	X	X	X	X		X		
Chromium		X	X	X	X		X	X	X	X		X	X	X	
Lead	X	X	X	X			X	X	X	X		X	X		
Nickel		X	X	X	X		X	X	X	X	X	X	X		
Zinc		X	X	X	X			X	X	X		X	X		
Radionuclides			X							X					

[1]Chloride and sodium ions may serve as indicators of salinity. An ionic balance may provide a fingerprint for comparison of ground-water quality in different areas.
[2]Semivolatile organic compounds are the second most frequently detected class of orgnnic priority pollutants and also may be suitable for some types of leak detection.
[3]Polycyclic aromatic hydrocarbons are prevalent in petroleum, coal, and wood-treatment products and are pervasive in commercial and industrial processes and wastes.
[4]Pesticides that are appropriate for use as ground-water indicators will vary regionally according to crops and agricultural practices.

For example, Florida has focused the set of parameters monitored under their ambient program on the basis of their understanding of local water-quality patterns and contaminant sources. In regions of high agricultural land use, Florida focuses on nitrate and chloride levels in ground water to assess trends in water quality. Similarly, Florida focuses on certain trace metals (for example, arsenic, barium, cadmium, chromium, copper, mercury, nickel, silver, zinc) in regions of industrial land use.

Ground-Water-Quality-Monitoring Framework

The attachment to this appendix outlines a framework of the activities to be included within a ground-water-quality-monitoring program. This framework is intended for program managers and technical staff. The outline highlights the following:

- Defining the purpose of the monitoring program.
- Coordinating and collaborating with other governmental and nongovernmental organizations.
- Designing the monitoring program.
- Implementing the monitoring program.
- Interpreting data generated by the monitoring program.
- Evaluating the effectiveness of the monitoring program.
- Communicating the results of the monitoring effort with governmental and nongovernmental organizations, and the public.

For monitoring efforts to be successful, systematic approaches need to be adopted for identifying the chemical, physical, and biological parameters to be measured in ground water. The attachment provides a format for developing and implementing such a systematic approach.

Conclusions

The Ground Water Focus Group concluded that no one national approach to the design and implementation of ground-water-monitoring programs can be recommended. Instead, each State, Tribal, and local jurisdiction must design a monitoring program that takes into account the hydrogeological setting, existing water quality, contaminant-source locations, and beneficial uses of the water resource. By applying the Ground-Water-Quality Indicator selection process described in the section and the Ground-Water-Quality-Monitoring Framework in this Technical Appendix, agencies can develop and implement consistent and defensible approaches for conducting background- and land-use-impact- and compliance-monitoring programs.

The Ground Water Focus Group recognizes that many agencies do not have the capability or sufficient resources to undertake or complete the effort described above in a short timeframe for all aquifers within their jurisdictions. Therefore, it is recommended that agencies work together, to the extent possible, by combining their resources and talents to begin a systematic process of sampling those aquifers that are the highest priority (for example, those that have the largest population and water use) for the full set of indicators identified for each aquifer. Depending on the availability of resources, this approach may extend the amount of time needed to assess all aquifers within an agency's jurisdiction. Nonetheless, the slow traveltimes typically observed in ground water relative to surface water make this tradeoff a reasonable assessment strategy. Contaminants move slowly in ground water, and, as a result, the quality of ground water observed at a well tends to change slowly. Therefore, monitoring ground water in a systematic manner will gradually result in the development of high-quality, comparable data sets that, in the aggregate, will increase knowledge of the occurrence and distribution of indicators in ground water, and environmental settings where different indicators should be included in monitoring programs and, conversely, where it is less necessary to monitor for them.

Ground-Water-Quality-Monitoring Framework

I. Purpose.
  A. Purposes and expectations of participating agencies and customers.
    1. What data are being collected and why?
    2. How will the data be stored and displayed?
    3. How will the results be evaluated?
    4. What does each agency contribute and receive from the monitoring program?
  B. Some objectives of the monitoring program.
    1. Need for a general overview (background and ambient monitoring) of ground-water quality in specific aquifers.
    2. Need to identify trends in ground-water quality that are related to regional land-use and nonpoint sources of contamination. Need to identify localized trends

in ground-water quality that are related to specific contaminant sources (facility-based/compliance monitoring).

- C. Purposes and expectations of monitoring agency.
  1. Near- and long-term requirements and needs that include coordination and collaboration with other agencies and customers, data management, periodic evaluation of monitoring effor, QA/AC considerations, laboratory and field analytical support and service, and training.
  2. Prioritize objectives for monitoring strategies. Prioritization may be based on principle hydrogeologic units, well type, analytes of concern, relation of water quality to land use, surficial aquifers/artesian aquifers, and timeframe for monitoring activity.
- D. Environmental Indicators—Selection of environmental indicators to measure achievement of monitoring agency objectives and purposes.
  1. Select indicators on the basis of the type of monitoring activity—ambient (baseline), evaluation or detection, and compliance (response and remediation).
  2. Select indicators on the basis of other objectives of the monitoring program from coordinators and collaborators.

II. Coordinate/collaborate.

- A. Identify potential participants.
  1. Establish a working relation with Federal, State, tribal, local, academic, and private agencies.
  2. Communicate project objectives and goals.
- B. Define roles of participants.
  1. Participants may provide financial or technical information, interpretation of data, and or resource, technical, or regulatory management expertise.
- C. Define needs of users and establish data-quality objectives.
  1. If possible, incorporate needs of other agencies/groups who use the information into the purposes of the program.
  2. Ensure the inclusion of data qualifiers with stored data so others know the accuracy and precision of the environmental data that are being collected and analyzed.

III. Design.

- A. Define objectives and scope of project.
  1. Hydrogeologic units to be monitored.
  2. Analytes of concern.
  3. Well types.
  4. Land use.
  5. Timeframe.
  6. Financial considerations.
  7. Personnel considerations.
  8. Analytical considerations.
  9. Data-management considerations.
  10. Other resources and constraints.
- B. Existing environmental setting—Identify and describe the existing environmental setting, which includes its hydrology (surface and ground waters), biota, and resource use.
  1. Geohydrology.
     - a. Delineate aquifers and confining units of the geohydrologic framework. Identify their vertical and lateral extent and degree of confinement and the lithostratigraphic and hydraulic characteristics of each unit.
     - b. Conceptualize and describe the ground-water-flow regime, which includes flow paths, sources of recharge and discharge, water budget, ground-water/surface-water interactions, flow rates and age of water at different points in the regime. Design a model as necessary.
  2. Biota.
     - a. Identify biological communities that can be affected by ground-water quality in aquifers and confining units.
     - b. Identify biological communities that can be affected by the quality of ground water that discharges to surface waters and wetlands.
  3. Resource use.
     - a. Identify past, current, and potential users of the ground water and how quality may affect ground-water use.
     - b. Identify past, current, and potential ground-water users and how use may affect ground-water quality.
     - c. For the ground-water-supply system, determine the past, current, and potential withdrawals or recharge in

terms of volume, location, and aquifer name. Identify changes in ground-water-flow paths and aquifer hydraulic characteristics that result from ground water use.

C. Existing water-quality problem—Evaluate available information to provide a current conceptual understanding of existing ground-water-quality problems; depict the known or suspected ground-water-quality conditions, problems, or information gaps; and identify management concerns and alternatives.
   1. Provide a current conceptual understanding of factors that affect spatial and vertical distribution in water quality.
      a. Identify historical, present, and possible future land use/land cover and expected water-quality effects of the land use/land cover.
      b. Identify geochemical conditions in aquifers and confining units that affect water quality, which include mineral content of sediments as it affects ion exchange and other water/mineral reactions and organic and mineral content of sediment as it affects oxidizing and reducing conditions.
      c. Hydrologic system.
      d. Effects of flow paths on contaminant transport, which include effects of age of water on likely presence of contaminants.
   2. Evaluate past and present water quality on the basis of existing information. Evaluate existing information in terms of quality, representativeness, and usefulness; for example well construction impacts on water quality or heterogeneities in the natural system.
   3. Identify management concerns and alternatives. Identify and prioritize problems, needs, and information gaps.

D. Environmental indicators and data parameters—Determine the appropriate or applicable environmental indicators and related chemical, physical, biological, and ancillary data parameters to be monitored. Indicator selection is related to the following criteria:
   1. Program objectives (ambient, detection/evaluation, and response/compliance).
   2. Existing hydrogeology.
   3. Natural setting (physiography, climate, land cover).
   4. Condition/character of the sampling site (well, spring, lysimeter).
   5. Past/present land-use activities.
   6. Designated uses of ground water (drinking water, recharge to surface water to support recreation).

E. Reference conditions—Establish reference conditions for environmental indicators that can be monitored to provide a baseline ground-water-quality assessment.

F. Confidence level—Define the level of confidence needed for the data to support testing management alternatives.

G. Data-set characteristics.
   1. Determine basis for monitoring design that will allow successful interpretation of the data at a resolution (scale) that meets project purposes.
   2. The basis for monitoring should include statistical reliability and geographic, geohydrologic, geochemical, biological, land use/cover, and temporal variability.

H. Quality assurance plan—Develop a quality-assurance plan that documents data accuracy and precision, representativeness of the data, completeness of the data set, and comparability of data relative to data collected by others.

I. Monitoring design—Design a sampling plan for existing or proposed sites. Design may include sampling-site distribution and location (wells and springs) and environmental indicators (physical, chemical, biological, ancillary).
   1. Design the general-ground-water monitoring network on the basis of the conceptual study design and the study and characterization of the area.
   2. Select and characterize the specific sites. Document the basis for the selection of each existing or proposed site as it fits the conceptualization, network design, and data quality objectives.

a. Historical and present adjacent land use/land cover.
b. Availability of existing data and collection points.
c. Hydrogeologic setting—Aquifers, point in the flow path and so forth.
d. Accessibility.

3. Design the collection points at the site(s).
   a. Sampling sites include wells, lysimeters, spring boxes, or other sample collection points.
   b. Locations.
   c. Construction specifications.
4. Identify personnel and equipment needs.
5. Estimate costs of network.
6. Ground-water indicators selected may be constituent based, administrative, or part of a tiered or screening monitoring approach. For further information, refer to the ITFM discussion and matrices for ground-water indicators.

J. Data collection methods—Develop sampling plans and identify applicable protocols and methods, and document data to enable data comparison with other monitoring programs in accordance with QA/QC requirements. Refer to program-specific guidelines. Identify personnel and equipment needs.
   1. Develop a plan for sample collection.
      a. Frequency and timing.
      b. Collection.
      c. Sample handling.
      d. Preservation.
      e. Shipping (chain of custody).
   2. Develop data documentation plan/chain of custody/labeling.
   3. Identify personnel, equipment, and training needs.
   4. Develop health and safety documents.
   5. Estimate cost of data collection.

K. Timing—Describe duration of sampling program and frequency and seasonality of sampling.

L. Field and laboratory analytical support—Identify applicable field and laboratory protocols or performance-based criteria, which include detection level, accuracy, precision, turnaround time, and sample preservation.
   1. Identify personnel, equipment, and other support needs for field and laboratory.
   2. Identify field and laboratory QA/QC requirements.
   3. Select performance-based criteria for evaluation of analytical capabilities and results.
      a. Criteria include detection levels, accuracy, precision, sample-holding times, sample preservation, performance-evaluation samples (replicates, blanks, spikes), data turnaround time, and mechanisms and format for reporting data.
      b. Personnel needs, which include training and turnover.
      c. Facility and equipment needs.
   4. Estimate cost of field and laboratory analytical support.

M. Data management—Describe data-management protocols, which include archiving, sharing, and security. Ensure the inclusion of metadata, such as location (latitude and longitude), date, time, a description of collection and analytical methods, and quality-assurance data.
   1. Define user requirements.
      a. Data format—Hard copy and digital (geographic and spatial data).
      b. Interface—How the user sees the system.
      c. Data types—Primary and ancillary data.
      d. Input, storage, and verification mechanisms.
      e. Applications.
      f. Output format.
      g. Security—Who needs access to what?
   2. Considerations for the conceptual design of the digital system.
      a. Requirements, which include such types of data as ancillary, metadata, and water-quality-data parameters.
      b. Minimum data set or recommended ground-water-data elements (refer to "Definitions for the Minimum Set of Data Elements for Ground Water (USEPA 813/B–92–002) and the "ITFM Recommended Data Elements for Water Quality Monitoring").

c. Uses—Storage, retrieval, graphic and tabular presentation, complex analysis, desired procedures access, and data dissemination.
d. Inventory available hardware and software.
e. Estimate costs for acquisition of hardware and software, training, implementation, operation, and maintenance.
f. Benefits.

3. Test plan and standards—Basis for hardware and software selection or development of a digital system.
4. Functional analysis of a digital system.
5. Physical design of a digital system—System selection and (or) development.
   a. Hardware.
   b. Data-base structure (ASCII, spreadsheet, relational).
   c. Software.
   d. User training and support.
   e. System administration—Backup, recovery, maintenance, security, documentation.

N. Training.
1. Activities related to monitoring that require training, these include designing, collecting, managing, interpreting, and reporting and communicating water-quality data.
2. Support activities that require training, these include data-management activities and laboratory analysis.

O. Interpretation—Identify statistical/analytical methods that are relevant to the data within specified confidence levels for program purposes.
1. Understand the sample size.
2. Understand the parameters.
3. Identify statistical/analytical methods (refer to Section V.).

P. Communications.
1. Identify technical and lay audiences.
2. Identify mechanisms and formats for presenting/distributing information; for example press releases, public meetings, agency meetings, conferences, popular publications, agency reports, and journal articles.

Q. Costs.
1. Determine the program costs and sources of funding.
2. Include in the cost estimates implementation, interpretation, and communication activities of the monitoring program.

R. Program modification—Develop feedback mechanisms to fine-tune/improve design.

IV. Implementation.

A. Establish and document sites (selected during design and planning stages).
1. Construct wells, shelters, gage houses, staff gages, and other structures as needed in preparation for data collection.
2. Document ancillary data for sites.

B. Collect data.
1. Collect data according to specified monitoring design and protocols.
2. Coordinate with other agencies as appropriate.

C. Review results.
1. Review data-collection activities to ensure that protocols and the QA plan are being followed.
2. Review data-collection activities to ensure that data are complete and meet stated purposes.

D. Store and manage data.
1. Archive data so that the accuracy and precision are maintained.
2. Review data in accordance with data management plan.

E. Share data—Provide lists of data for other agencies upon requests.

F. Prepare data summaries.
1. Provide information to managers periodically.
2. Provide information to collaborators and cooperators according to schedules.

V. Interpretation.

A. Data reliability—Define the accuracy and precision of the hydrogeologic and ancillary environmental data.

B. Interpret data to meet stated program purposes—Interpret the data, which include a description of the ground-water-resources system, by using existing environmental and ancillary data to provide information necessary to making management decisions related to water quality.
1. Geohydrologic systems analysis.
   a. Temporal and spatial analysis.
   b. Climatic impacts on ground-water systems.

c. Ground-water/surface-water interaction; for example, discharge and recharge effects.
2. Hydrogeochemical analysis.
a. Water/rock interactions.
b. Land use.
3. Comparison of data to monitoring objectives.

C. Statistical methods and model documentation—Use statistical packages and deterministic models that are well documented.

D. Assess management impacts—Evaluate management alternatives and assess their impacts on the resource.

E. Coordinate interpretations—Coordinate the interpretations of data with collaborators and the user community.

VI. Evaluate monitoring program.

A. Meet goals and objectives—Determine if monitoring program goals and objectives are being met.
1. Assess usefulness of project data/information for local, regional, and national assessments.
2. Evaluate the need for program modifications and develop appropriate recommendations for ground-water monitoring.
3. Evaluate organizational concerns and coordination for private sector interface and local, State, and Federal interface.

B. Identify problems—Identify any monitoring problems associated with collecting and analyzing samples; storing, disseminating, and interpreting data; and reporting the information to managers and the public.
1. Evaluate the strengths and weaknesses of the monitoring-program design.
2. Evaluate the data-collection and the interpretation methods.
3. Evaluate the information-transfer methodologies used to report the data and information to resource managers, the public, and the scientific community.

C. Evaluate costs—Evaluate the costs of the monitoring program.

D. Feedback—Use results of evaluating monitoring program to identify current and future needs.

VII. Communication.

A. Coordinate—Participate in the distribution of information to and with other agencies and interested groups, such as environmental, industrial, and agricultural constituents.

B. Prepare and distribute technical reports—Describe current water-quality conditions; spatial distribution; temporal variability; and sources, causes, transport, fate, and effects of contaminants based on monitoring results to humans, aquifers, and ecosystems as appropriate.

C. Communicate with multiple audiences—Prepare lay reports or executive summaries for nontechnical audiences and peer review reports for technical audiences.

D. Presentations—Make presentations to assist management and the public in understanding the significance of results. Presentations could involve the use of public information networks, which include newspapers, radio, and television.

E. Provide available data—Provide available data for other data users as needed.

TECHNICAL APPENDIX M
DATA-ELEMENTS GLOSSARY

Introduction

The Data Management and Information Sharing Task Group (DMIS) of the Intergovernmental Task Force on Monitoring Water Quality (ITFM) has prepared the Data-Elements Glossary to support effective collection, interpretation, and sharing of data related to water-quality monitoring. The intent of this glossary is to provide common terminology and definitions for documenting water-quality data; that is, metadata. Standardization and adoption of these elements will improve the availability of information for decisionmaking at all levels of government. The full glossary of recommended data elements represents most of the base data requirements for agencies that are developing new water-quality-data systems. The DMIS considers "agencies" to mean any group that collects water-quality data, including Tribe, State, Federal, and nongovernmental organizations, or the regulated community. The set of minimum data elements, which is a subset of the glossary, are those elements the DMIS believes are necessary to facilitate the exchange of data among existing data-management systems.

The DMIS recommends that the ITFM adopt the following recommendations related to the Data-Elements Glossary:

- Agencies, the regulated community, and others that collect water-quality data are encouraged to adopt the recommended data elements for water-quality-data systems and the minimum elements for facilitating information sharing.
- Provide a self-documenting data-export capability from each data base and promote the development of standardized report formats.
- Promote the development of a standard interface to individual water-data systems based on the minimum data elements and provide electronic access to data systems and the means to easily transfer data from one system to another. Additional data considered to be appropriate for sharing should be included in the system.
- Identify potential sources of reference tables, such as aquifer names, taxonomic codes, and methods, and recommend that agencies be designated to maintain individual reference lists. For example, the U.S. Geological Survey (USGS) may be the authority to maintain the hydrogeologic units reference table, and the National Oceanic and Atmospheric Administration (NOAA) may maintain the taxonomic code. Reference tables for sampling and analytical methods could be assigned to an intergovernmental methods council. The authorities agree to accept update requests from all groups that are participating in water-quality monitoring.

Glossary Components

According to the DMIS, agencies involved in water-quality monitoring should identify and describe the following high-level functions:

- Projects and surveys that involve monitoring of the aquatic environment.
- Those physical sites at which the monitoring is conducted.
- The events and samples that occur at those sites.
- Analytical results that relate to these events and samples

Within each of these high-level functions, the DMIS identified a series of data elements. The format for each element is as follows:

Name The data element name.

Definition The meaning of the data element. Existing definitions were used where possible; definitions from several sources were combined if necessary to prepare a sufficiently broad definition and were attributed to the DMIS rather than to the original source documents. In some cases, several alternative definitions are provided, with the preferred definition listed first. In these cases, several sources also are provided. Source materials that were searched for data-element definitions included the following:

- Chesapeake Bay Program
- *Definitions for the Minimum Set of Data Elements for Ground-Water Quality* (U.S. Environmental Protection Agency, 1992)
- *DQO-IDS Data Dictionary* (U.S. Environmental Protection Agency, 1993)

- Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
- *McGraw-Hill Dictionary of Scientific and Technical Terms* (Parker, 1994)
- NWIS–II Lexicon (U.S. Geological Survey, written commun., 1994)
- STORET modernization (American Management System, Inc., writen commun 1992)
- *USEPA QA Glossary* (U.S. Environmental Protection Agency, 1988)

Format An indication of whether the data-element field is a character or a numeral.

Source The document source for the data-element definition. "DMIS" is given as the source for those definitions developed by the DMIS or for definitions that resulted from combining existing definitions from many source documents

Authority The agency or program responsible for maintaining the reference table of terms. Authorities were indicated where individuals knew that an agency had a reference list; however, no authorities have been formally identified.

Related terms Synonyms for the data-element name that may appear in existing data systems, such as STORET or NWIS –I. The field is blank in many cases, but terms will be added as appropriate.

Recommended Data Elements

Most of the data elements in the Data-Elements Glossary are considered to be recommended data elements. These are elements that should be included in the design of new data systems to document adequately the environmental data stored in the systems. Elements include those that characterize the location of measurements or samples, such as station number and name; the sample, such as date and time; and the results, such as constituent, reporting form, value, and units. The elements listed above are common to most of the current data systems. The other recommended data elements include the quality-control (QC) data that are needed for secondary users to assess the utility of the data. At the project level, these include the project data-quality objectives and project quality-assurance (QA) methods. At the sample and result levels, they include the data collector and analyst, field and analytical methods, type of equipment used, and the results of QC samples and measurements.

The organization and format of the data elements are intended to promote consistent terminology among water-quality-data systems to facilitate the exchange of data. It is not required that agencies have identical data systems or similar data structures. However, the grouping of the elements in the glossary does imply some relations. For example, the projects and survey elements probably would be in one table or a series of closely related tables in each agency's data system. Similarly, the elements grouped as location-reference information, site characteristics, events and samples, and results probably would be in separate tables in a relational data-base-management system. Other relations, such as a link between the project information and samples or results, probably would be appropriate; however, these relations are less intuitive and will depend on how the data are to be queried and reported. Thus, it is equally important to adopt standard reports so that each agency can provide the appropriate keys or links in their respective data systems.

Minimum Data Elements

To facilitate the exchange of existing data, 23 data elements have been designated as minimum data elements. These elements are not considered to be more important than the recommended elements. They are those that would most likely be used to qualify a query for water-quality data from any agency's data system. The ITFM participating agencies would be expected to modify the existing user interface or to develop new interfaces to their data systems to incorporate data retrievals based on these elements. The designation "(GW)" indicates that an element is intended only for ground water; an "(SW)" indicates a surface-water-only element. The elements are as follows:

- Site name.
- Site number.
- Site type.
- Federal Information Processing Standard (FIPS) county code.
- FIPS state code.
- Latitude.
- Longitude.
- Aquifer name (GW).
- Ecoregion code.
- U.S. Environmental Protection Agency (USEPA) river reach code (SW).
- Hydrologic unit code (HUC).

- Water-body name
- Water-body type.
- Habitat type.
- Well depth (GW)
- Collection start date.
- Collection end date.
- Collecting organization.
- Sample depth.
- Sample medium code.
- Constituent.
- Reporting form.
- Taxonomic key.

The intent of the minimum elements is to standardize the querying capabilities of existing data systems and thus facilitate the sharing of data. Agencies should provide a querying capability that is based on the minimum elements, but additional, or less, capability may be appropriate in some cases. For example, if a particular data system has results keyed to individual projects, then it would be appropriate to provide an ability to query based on project number or name. Conversely, there would be no utility in providing a taxonomic key query if the data base did not contain taxonomic information or an aquifer name query if the data base contained only stream data

Glossary of Data Elements

The elements are listed alphabetically within each of four high-level functions—projects and surveys; physical sites/station; events, samples, and (or) observations; and results. N/A means not applicable.

Projects and Surveys

Name Ancillary data
Definition Narrative summary of the types and sources of supporting information used for the completion of the project
Format Character
Source DMIS
Authority N/A

Name Cooperating organizations
Definition Organizations supplying resources to the project
Format Character
Source DMIS
Authority N/A
Related Terms Resource group

Name Data administrator
Definition Person responsible for ensuring that the data standards for the collected information including media, standard codes, input formats, output formats, system to be used, and data integration concerns are met.
Format Character
Source DMIS
Authority N/A
Related Terms Data manager

Name Funding organization(s)
Definition Name of the organization(s) providing funding and other resources for the project.
Format Character
Source DMIS
Authority N/A

Name Location of data
Definition Place and (or) system where the results from the project reside along with the location where other data used by the project reside and methods to access this information.
Format Character
Source DMIS
Authority N/A
Related Terms Data repository

Name Sponsoring organization(s)
Definition (1) Officially empowered group responsible for the project and the data resulting from the monitoring effort. (2) Lead agency or group taking responsibility for the monitoring project development and implementation and the resulting data management
Format Character
Source (1) DMIS, (2) Ground Water Focus Group of the ITFM
Authority N/A

Name Principal investigator
Definition Person primarily responsible for the execution of the project.
Format Character
Source DMIS
Authority N/A
Related Terms Project Chief, Project Leader, Project Manager

Name Project data-quality objectives
Definition Narrative describing the proposed quality level for data that is desired or required and the methods employed to obtain the planned quality level. The QA plan is management's tool for achieving this level of quality for data.
Format Character
Source DMIS
Authority N/A

Name Project description
Definition Narrative explaining the purpose, scope, and objectives and geographical area of the project.
Format Character
Source DMIS
Authority N/A
Related Terms Project abstract

Name Project duration
Definition Scheduled time frame for performing the collection, analysis, assessment, and publication of the results from the project in years.
Format yyyy
Source DMIS
Authority N/A

Name Project funding
Definition The amount of money spent on the project.
Format Character
Source DMIS
Authority N/A

Name Project methods
Definition Narrative summary describing procedures used throughout the project consisting of sampling, analysis, and (or) assessment.
Format Character
Source DMIS
Authority N/A
Related Terms Method type

Name Project name
Definition Name of a monitoring effort where biological, sediment, water quality, or bioassay data are collected for a specific purpose (for example, benthic study, water-quality study) at one or more sampling stations
Format Character
Source STORET modernization (American Management System, Inc., written commun., 1992)
Authority N/A
Related Terms Program name, Project label, Project title, Survey name

Name Project number
Definition Alphanumeric designation assigned by the responsible agency.
Format Alphanumeric
Source DMIS
Authority N/A

Name Project products
Definition Reports, data sets, and publications produced by the project.
Format Character
Source DMIS
Authority N/A
Related Terms Data set id

Name Project QA procedures employed
Definition (1) Description of the quality assurance and quality control activities to be followed for a project. (2) Series of planned or systematic actions required to provide adequate confidence that a product or service will satisfy given needs.
Format Character
Source (1) *USEPA QA Glossary* (U.S. Environmental Protection Agency, 1988). (2) *McGraw-Hill Dictionary of Scientific and Technical Terms* (Parker, 1994)
Authority N/A
Related Terms QA project plan

Name Project references
Definition Bibliographic references to other relevant studies.
Format Character
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A

Physical Sites/Station

Site-Identification Information

Name Site alias
Definition Alternate designation for a station that may be assigned by any organization.
Format Char30
Source STORET modernization

Authority N/A
Related Terms Station alias, Secondary station number

Name Site establishment date
Definition (1) Date the site was established by the sponsoring organization. (2) Date that construction of a sampling or measuring location was completed. (3) Starting date of the daily values that are a result of either a feature measurement or a data analysis activity.
Format yyyymmdd
Source (1) DMIS, (2) Tri-Service CADD–GIS, 1993 (3) NWIS II Lexicon (U.S. Geological Survey, written commun., 1994)
Authority N/A

Name Site description
Definition (1) Narrative description of the site, facility, section, area, or volume represented by the "Site name." (2) Description of site where sample was collected.
Format Char300
Source (1) DMIS, (2) Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Station description, Location description

Name Site name
Definition Official agency name given to a data collection station.
Format Char30
Source NWIS II
Authority N/A
Related Terms Station name, Site label

Name Site network
Definition Network(s) in which the station participates.
Format Char30
Source DMIS
Authority ITFM or its designated representative

Name Site number
Definition Unique alphanumeric designation assigned by the responsible organization.
Format Char15
Source DMIS
Authority N/A
Related Terms Station number, Site code

Name Site organization
Definition Organization that establishes a sampling or measuring location.
Format Char30
Source Tri-Service CADD–GIS (1993)
Authority N/A
Related Terms Site owner

Name Site purpose
Definition Intended purpose of the site and the rationale for choosing the location.
Format Char300
Source DMIS
Authority N/A
Related Terms Site selection criteria

Name Site type
Definition Codes assigned to represent the type of station from which samples were taken or measurements made; for example:
- **rxsc** River cross section with several vertical sections.
- **biox** Biological measurement/sampling transect.
- **sngl** Single point for measurement or sampling.
- **mltp** Multiple, random measurement and sampling points represented by one or more offsets.
- **area** User-defined area with the centroid defined by a latitude, longitude, and altitude.
- **volm** User-defined volume with the centroid defined by a latitude, longitude, and altitude.
- **well** Well with several sampling points.
- **lysm** Lysimeter with several sample points.

Format Char4
Source DMIS
Authority ITFM or its designated representative

Location-Reference Information

Name Altitude
Definition Vertical distance from the National Reference Datum to the land surface, reference mark, or measuring point at the site (feet or meters).
Format Num 5.2 (feet or meters)
Source Ground Water Minimum Data Elements
Authority N/A
Related Terms Elevation

Name Altitude method
Definition Method used to determine the altitude value, including the National Reference Datum on which the altitude is based
Format Char4
Source Ground Water Minimum Data Elements
Authority USEPA Office of Ground Water and Drinking Water
Related Terms Method type

Name Bottom depth
Definition Depth of water column at station, measured from the surface of the water to the sediment/water interface.
Format Num 6.2 (feet or meters)
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Depth

Name FIPS county code
Definition FIPS numeric code to indicate the county (or county equivalent) in which a site is located.
Format nnn
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority FIPS

Name FIPS state code
Definition FIPS alphabetic or numeric code to indicate the state in which the site is located.
Format aa or nn
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority FIPS

Name Land net
Definition Location of a site described by the U.S. township and range-grid survey system.
Format SnnTnnaRnna (S31T06NR66W)
Source DMIS
Authority N/A

Name Land net code
Definition Code that represents the appropriate 0.5 or 0.25 section description of the site (North, South, East, West, Northeast, Southeast, Northwest, Southwest).
Format Char2, Char2, Char2
Source DMIS
Authority N/A

Name Latitude
Definition Coordinate representation that indicates a location on the surface of the Earth by using the equator as the latitude origin, reported in degrees, minutes, and seconds.
Format +/-ddmmss.ssss (N = +; S = -)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Lat/long accuracy
Definition Quantitative measurement of the amount of deviation from true value present in a measurement that describes the correctness of a measurement.
Format Num 4.2 (+/-)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Lat/long method
Definition Procedure used to determine the latitude and longitude, includes the reference datum.
Format Char4
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority Standard methods adopted by ITFM or its designated representative
Related Terms Method type

Name Longitude
Definition Coordinate representation that indicates a location on the surface of the Earth by using the prime meridian as the origin, reported in degrees, minutes and seconds
Format +/-dddmmss.ssss (W = -; E = +)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Section node distance
Definition Distance from initial point of river cross section or biological transect to the point of sampling or measurement (feet or meters).

Format Num 4.2 (feet or meters)
Source DMIS
Authority N/A
Related Terms Site offset

Environmental Reference Information

Name Aquifer name (GW)
Definition Soil or rock unit that by virtue of its hydraulic properties has a distinct influence on the storage or movement of ground water. The zones include aquifers and confining units.
Format Char50
Source NWIS–II
Authority U.S. Geological Survey (USGS)
Related Terms Hydrogeologic unit

Name Aquifer type (GW)
Definition Description of the physical condition of the aquifer, which includes confined/unconfined, fractured, karst, and consolidate/unconsolidated/semiconsolidated.
Format Char50
Source Ground Water Focus Group of the ITFM
Authority N/A
Related Terms Hydrogeologic setting, Aquifer matrix

Name Ecoregion code
Definition USEPA code of ecoregions, which are homogeneous areas defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables.
Format Char7
Source Lake Michigan Mass Balance; Study (Tetra Tech, Inc., 1993), U.S. Environmental Protection Agency, written commun., 1994)
Authority USEPA

Name USEPA river reach code (SW)
Definition Code representing a section of a river or stream defined by the components of the River Reach File 3 (RF3) file.
Format Char12
Source DMIS
Authority USEPA

Name HUC
Definition Code that represents the region, subregion, accounting unit, and cataloging units of hydrologic units (watersheds), as defined by the U.S. Water Resources Council. The current code is 8 characters but is being expanded to 16 characters to provide for greater subdivision of watersheds.
Format Char16
Source NWIS–II
Authority FIPS
Related Terms HUC

Name Water-body alias (SW)
Definition User-defined name of a water body that differs from the official name approved by the Board of Geographic Names (Geographic Names Information System).
Format Char50
Source DMIS
Authority N/A

Name Water-body name
Definition Name of the lake, stream, river, estuary, or other water feature related to the physical site.
Format Char50
Source DMIS
Authority USGS, Geographic Names Information System

Name Water-body type
Definition Code that represents the type of water body, such as stream/river, lake, canal, aquifer, or spring
Format Char4
Source DMIS
Authority USEPA
Related Terms Station type, Site type

Site Characteristics

Name Geomorphology code (SW)
Definition Code used to define the secondary topographic features which are carved by erosion in the primary elements and built up of the erosional debris at the indicated site.
Format Char4
Source *McGraw-Hill Dictionary of Scientific and Technical Terms* (Parker, 1994)
Authority ITFM or designated representative

Name Habitat
Definition Narrative description of morphology, substrate, aquatic and riparian cover of the site, offset point, or cross section.

Format Char300
Source DMIS
Authority N/A

Name Habitat type code
Definition Code for a finite list of habitat characteristics.
Format Character
Source DMIS
Authority N/A

Name Land use/cover code
Definition Code that represents the land-use types, as defined by the Anderson classification system.
Format Char4
Source DMIS
Authority USGS

Name Microhabitat name
Definition Name that designates a specific, small isolated patch of homogeneous habitat.
Format Character
Source DMIS
Authority N/A

Name Site use code
Definition Code that represents the primary use and water use, status, and water quality.
Format Char2
Source DMIS
Authority USGS

Name Substrate code
Definition Code that represents the material to which sessile organisms are attached.
Format Char4
Source DMIS
Authority N/A
Related Terms Bottom type

Name Well casing diameter (GW)
Definition Inside diameter of the well casing at land surface (inches).
Format Num 5.2
Source NWIS–II Lexicon (U.S. Geological Survey, written commun., 1994)
Authority N/A
Related Terms Casing nominal diameter

Name Well casing material code (GW)
Definition Code that represents the type of casing material used.
Format Char4
Source NWIS–II Lexicon (U.S. Geological Survey, written commun., 1994)
Authority USGS

Name Well depth (GW)
Definition Depth of the completed well below the land surface, in feet or meters.
Format Num 7.2 (feet or meters)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Well open interval, bottom (GW)
Definition Bottom of the open or screened interval of the well (feet or meters below land surface).
Format Num 6.2 (feet or meters)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Well open interval, top (GW)
Definition Top of the open or screened interval of the well (feet or meters below land surface).
Format Num 6.2 (feet or meters)
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A
Related Terms Well screen top depth

Name Well screen type code (GW)
Definition Code that represents the type of screen and material used in the production interval of the well.
Format Char4
Source DMIS
Authority USGS
Related Terms Slot sizes, Screen mesh size

Name Well seal code (GW)
Definition Code that represents the type of seal or fill used in the well.
Format Char2

Source DQO–IDS Data Dictionary (U.S. Environmental Protection Agency, written commun., 1993)
Authority USGS

Events, Samples, Observations

Events

Name Analysis end date
Definition Date that analysis was completed.
Format yyyymmdd
Source DMIS
Authority N/A
Related Terms Report date

Name Analysis end time
Definition Time that analysis was completed.
Format hhmm
Source DMIS
Authority N/A

Name Analysis Organization
Definition Textual information used to identify the name of the group that is performing the analysis associated with a result.
Format Character
Source DMIS
Authority N/A
Related Terms Agency, Organization name

Name Analysis start date
Definition Date that analysis began.
Format yyyymmdd
Source DMIS
Authority N/A

Name Analysis start time
Definition Time that analysis began.
Format hhmm
Source DMIS
Authority N/A

Name Analyst
Definition Name or identification of the person performing the analysis.
Format Character
Source DMIS
Authority N/A
Related Terms Event contact name

Name Analytical method
Definition Method of analysis applied to determine the analytical concentration/value for a particular parameter. Reference to the specific analytical method should include information on the minimum detection limit of that method and the units of measurement used.
Format Character
Source Ground Water Minimum Data Elements (U.S. Environmental Protection Agency, 1992)
Authority N/A

Name Analyzing lab
Definition Name of the facility from which the analytical result was obtained.
Format Character
Source DMIS
Authority N/A
Related Terms Organization name

Name Batch number
Definition Alphanumeric designation assigned to samples treated as an analytical grouping (with the same controls) for preparation and (or) analysis.
Format Character
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Batch name

Name Biological part code
Definition Alphanumeric code that designates the identification of the specific anatomical part of an organism that is being measured; for example, liver, heart, cell wall, or whole organism.
Format Character
Source DMIS
Authority N/A

Name Collecting organization
Definition Name of a group that is in charge of collecting a sample or making a measurement.
Format Character
Source STORET modernization (American Management Systems, Inc., written commun., 1992)
Authority N/A
Related Terms Agency, Organization name

Name Collection end date
Definition Date that measurement or sampling was completed.
Format yyyymmdd
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Sample end date

Name Collection end time
Definition Time that measurement or sampling was completed.
Format hhmm
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A

Name Collection start date
Definition Date that measurement or sampling began.
Format yyyymmdd
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Sample start date
Name Collection start time
Definition Time that measurement or sampling began
Format hhmm
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A

Name Data collector
Definition Individual who collects a sample or makes a measurement.
Format Character
Source DMIS
Authority N/A
Related Terms Event contact name

Name Data analysis method
Definition Process of transforming raw data by arithmetic or statistical calculations, standard curves, concentration factors, and so forth, and collation into a more useful form.
Format Character
Source STORET modernization (American Management Systems, Inc, written commun, 1992)
Authority N/A
Related Terms Data reduction

Name Field lot number
Definition Alphanumeric designation used to group together all field samples associated with or judged against a particular set of QC samples
Format Character
Source Tri-Service CADD–GIS (1993)
Authority N/A
Related Terms Shipment bundle id

Name Field preparation methods
Definition Name of method(s) that involves the addition to a sample, such as a solution, or procedures, such as the filtering or drying of a sample before shipment to laboratory.
Format Character
Source DMIS
Authority N/A

Name Instrument component number
Definition Instrument component identification number; for example, one column of a gas chromatograph.
Format Character
Source DMIS
Authority N/A

Name Instrument log
Definition Narrative that concerns the use and maintenance of equipment for past projects and events to aid in the identification of any suspected anomalies.
Format Character
Source DMIS
Authority N/A

Name Instrument number
Definition Instrument identification number or characters used by the organization doing the analysis.
Format Character
Source DMIS
Authority N/A
Related Terms Serial number, Lab equipment id

Name Laboratory preparation methods
Definition Name of method(s) that involves the addition to a sample, such as a solution, or procedures, such as the filtering or extraction or digestion of a sample before analysis.
Format Character
Source DMIS
Authority N/A

Name Method references
Definition Identification or textual information that identifies a published source describing the method used to analyze the sample and produce the result.
Format Character
Source DMIS
Authority N/A
Related Terms Method type description

Name Offset point
Definition Point whose location is defined by using azimuth (degrees) and distance (feet or meters) relative to a predefined site (locational point).
Format Degrees (Num 5.2) and distance (Num 6 2 feet or meters)
Source STORET modernization (American Management System, Inc., written commun , 1992)
Authority N/A

Name Preparation or extraction end date
Definition Date that preparation or extraction was completed
Format yyyymmdd
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A

Name Preparation or extraction end time
Definition Time that preparation or extraction was completed.
Format hhmm
Source DMIS
Authority N/A

Name Preparation or extraction start date
Definition Date that preparation or extraction began
Format yyyymmdd
Source DMIS
Authority N/A

Name Preparation or extraction start time
Definition Time that preparation or extraction began
Format hhmm
Source DMIS
Authority N/A

Name QC sample type
Definition Blank, spike, split, or replicate sample whose results are compared to a sample or control to ensure that the sample test results are within expected parameters.
Format Character
Source Modernized STORET
Authority N/A
Related Terms Field blank, Trip blank, Equipment blank

Name Replicate number
Definition Alphanumeric designation used to identify the replicate sample taken or observation made.
Format Character
Source DMIS
Authority N/A

Name Sample alias
Definition Alphanumeric designation used for internal tracking to remove bias
Format Character
Source DMIS
Authority N/A

Name Sample collection method
Definition Name that identifies the process or procedure used to collect a sample or make a measurement.
Format Character
Source DMIS
Authority N/A

Name Sample comments
Definition Notes or comments about sample.
Format Character
Source Lake Michigan Mass Balance Study (Tetra Tech, Inc., 1993)
Authority N/A
Related Terms Sample note

Name Sample depth
Definition Depth (feet or meters) at which a sample is collected for analysis relative to the land surface or surface of a water body or a ground-water table.
Format Num 7.2 (feet or meters)
Source DMIS
Authority N/A
Related Terms Depth

Name Sample medium code
Definition Alphanumeric code that designates the environmental material about which results are reported from either direct observation or collected samples; for example, water, tissue, and (or) sediment.
Format Character
Source DMIS
Authority N/A
Related Terms Sample matrix

Name Sample number
Definition Alphanumeric designation of a unit, substance, specimen, or observation taken at a specific date, time, and geographic location for the purpose of determining the identity and characterization of chemicals, bacteria, plants, animals, or other substances and (or) materials of concern.
Format Character
Source STORET modernization (American Management Systems, Inc., written commun., 1992).
Authority N/A
Related Terms Sample name, Sample Id

Name Sample size
Definition Weight, volume, dimensions, or count of elements or individuals in the sample or sample aliquot.
Format Num 7.2 (units)
Source DMIS
Authority N/A

Name Secondary sample number
Definition Unique number used to identify a portion of the original sample. Sufficient information is provided to trace the sample within the organization's laboratory-management system.
Format Character
Source DMIS'
Authority N/A
Related Terms Subsample number, Laboratory number, Sample Id

Name Voucher collection location
Definition Information required to identify the location where the analyzing organization maintains the voucher collection.
Format Character
Source DMIS
Authority N/A
Related Terms Reference collection, Standard reference material

Results

Name Bias of value
Definition Systematic error that is manifested as one or more consistent positive or negative deviations from the known or true value. It differs from random error, which shows no such deviation, in that it is inherent in a method or is caused by some artifact or idiosyncrasy of the measurement system.
Format Numeric
Source USGS National Water Quality Laboratory (written commun., 1994)
Authority N/A

Name Constituent
Definition Physical, chemical, or biological variable (component, element, compound) that may be assigned a value as the result of a measurement or observation.
Format Character
Source NWIS–II Lexicon (U.S. Geological Survey, writen commun., 1994)
Authority N/A
Related Terms Analyte, Characteristic

Name Detection level method
Definition Method for determining the detectable quantity of a constituent on the basis of laboratory conditions, analytical method, and (or) field conditions.
Format Character
Source DMIS
Authority N/A
Related Terms Method detection limit, Practical quantitation limit

Name Detection level value
Definition Numeric quantity of an analyte that can be assessed and reported to a level of confidence that the analyte concentration is greater than zero and is determined from an analysis of a sample in a given matrix that contains the analyte.
Format Numeric
Source DMIS
Authority N/A

Name Error value
Definition Numerical value of the error assigned to a result on the basis of the appropriate error model.
Format Numeric

Source DMIS
Authority N/A
Name Precision of value
Definition Degree of similarity or mutual agreement among independent measurements of the same quantity as a result of repeated application of the process under specified conditions, without reference to the known or true value.
Format Numeric
Source USGS National Water Quality Laboratory (written commun., 1994)
Authority N/A
Related Terms Precision units

Name QA/QC results
Definition Narrative description of the collective quantitative and qualitative results of analyses of supplementary samples (replicates, blanks, standards, and so forth) that serves to evaluate the acceptability of the result.
Format Character
Source DMIS
Authority N/A

Name Reporting form
Definition Form of a value reported for a constituent; for example, nitrate as nitrogen, alkalinity as calcium carbonate.
Format Character
Source NWIS–II
Authority N/A

Name Reporting unit
Definition (1) Designation by which a determined or specified amount of a measured or estimated quantity can be compared with any other quantity of the same kind; for example, micrograms per liter, feet per second and so forth. (2) Measurement scale that accompanies the value supplied in the sample result. (3) Dimensional unit of the value of a constituent.
Format Character
Source (1) DMIS, (2) STORET modernization (American Management Systems, Inc., written commun., 1992), (3) NWIS–II Lexicon (U.S. Geological Survey, written commun., 1994)
Authority N/A
Related Terms Unit Id, Unit description

Name Result comment
Definition User or analyst supplied textual information that concerns the result obtained from a measurement or an analysis.
Format Character
Source DMIS
Authority N/A
Related Terms Proc result description

Name Result type
Definition Statistic or statistical element used as a basis for reporting the results of an analysis; for example, discrete, continuous, mean, median, max, and so forth.
Format Char4
Source DMIS
Authority N/A
Related Terms Statistical qualifier, Result code

Name Review and validation code
Definition Code that indicates that the result has been reviewed and has passed validation checks according to the program or protocol indicated and that the result as reported is the result that was determined
Format Char4
Source DMIS
Authority N/A

Name Taxonomic key
Definition Alphanumeric designation for the unique, official scientific name of a biological organism and its position in the taxonomic nomenclature hierarchy.
Format Character
Source DMIS
Authority NOAA
Related Terms Taxa category, Taxonomic code

Name Value
Definition Numerical quantity-determined, computed, or estimated or descriptive text assigned to a constituent as the result of a measurement or observation, includes values for analyses of QA/QC samples.
Format Numeric
Source DMIS
Authority N/A
Related Terms Result, Quantitative value

Name Value qualifier(s)
Definition Code(s) that specify a qualification of the result; for example, less than, greater than, estimated, and so forth
Format Character
Source DMIS
Authority N/A
Related Terms Remark code, Flag, Tag

Name Voucher number
Definition Identification used to specify which reference sample was used by the organization doing the analysis to classify a biological sample.
Format Character
Source DMIS
Authority N/A

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TECHNICAL APPENDIX N

EVALUATION OF A PERFORMANCE-BASED METHODS SYSTEM APPROACH TO FIELD AND PRELABORATORY METHODS

Introduction

Regardless of the type of data being collected, field methods share one important feature in common—they cannot tell you whether the information collected is an accurate portrayal of the system of interest We may know, with some accuracy, properties of a given sample taken from the field, but typically, we are interested in answering questions on much larger spatial and temporal scales. To grapple with this problem, environmental scientists and statisticians have long recognized that field methods must strive to obtain samples and (or) data that are representative of the site conditions at the time of sampling.

In environmental monitoring studies, certain desired data-quality objectives (DQO's) can be identified at the outset; that is, the degree of sample representativeness, data precision, and the site conditions over which the information data are collected are established at the inception of a study so that appropriate sampling methods can be designed (Technical Appendix I). Those DQO's define not only how a given study or monitoring program is carried out, but also how or when such information could be appropriately utilized by other users. This is a significant issue because without such explicit communication of DQO's and method characteristics, it is difficult to separate errors associated with field-method error from natural variation.

The DQO's will dictate, among other things, two critical components of any field method—the geographic extent of the site and field-method timing. Both of these components must be defined for any field method because they bear directly on the representativeness of the samples or data collected. The same field method executed either at a different type of site or at a different time (season, for example) may not perform with similar efficiency, precision, or bias. The DQO's are critical in defining the types of sites and sampling times over which a given field method is likely to yield data representative of the actual conditions of interest.

Figure 1 shows the steps involved in many types of field methods In situ field methods in which no samples are actually collected for laboratory analysis are distinguished from those in which samples are collected because the two types of methods require somewhat different treatment in defining performance criteria In situ methods follow an abbreviated sequence of steps as shown in figure 1. Performance criteria are associated with each step of a given method. Table 1 illustrates examples of performance criteria and ways in which these criteria would be addressed for a generic field method in which samples are collected and analyzed by using laboratory procedures. In this type of scenario, performance criteria for a given procedure or protocol, which consists of several procedures, can be characterized by subjecting the field method to a specific range of tests, each one followed by the same laboratory analysis. Differences among laboratory results are assumed to be due to performance characteristics of the method and not to either the laboratory analysis or differences in the analyte among samples. The degree to which these assumptions are true will depend on the precision of the laboratory method used and the type of site.

Aquatic systems have certain factors or considerations that bear directly on appropriate sample timing and location within the context of developing performance criteria Table 2 summarizes some of the factors for several different types of aquatic systems, which include streams, lakes, estuaries, and ground water. Depth, for example, may be a factor for examining certain analytes in large streams, lakes, and estuaries where a vertical profile component could be important. Therefore, whether particular samples are depth integrated or surface grabs can result in very different results and perhaps different method-performance characteristics; this depends on the system. Similarly, for systems where there is a flow, such as in streams and some shallow aquifers, flow-proportional samples may yield a much different measurement than grab samples or time-composite samples Again, these different forms of sampling may have different associated performance characteristics even for the same analyte and accompanying laboratory procedure Knowledge of important site factors can be used to minimize differences among replicate samples, thereby ensuring a more precise determination of field-method-performance criteria. The information presented in table 2 suggests another important effect of the type of site on performance-criteria characterization For some systems, such as shallow ground water and small streams, season or precipitation can have a significant effect on the analyte

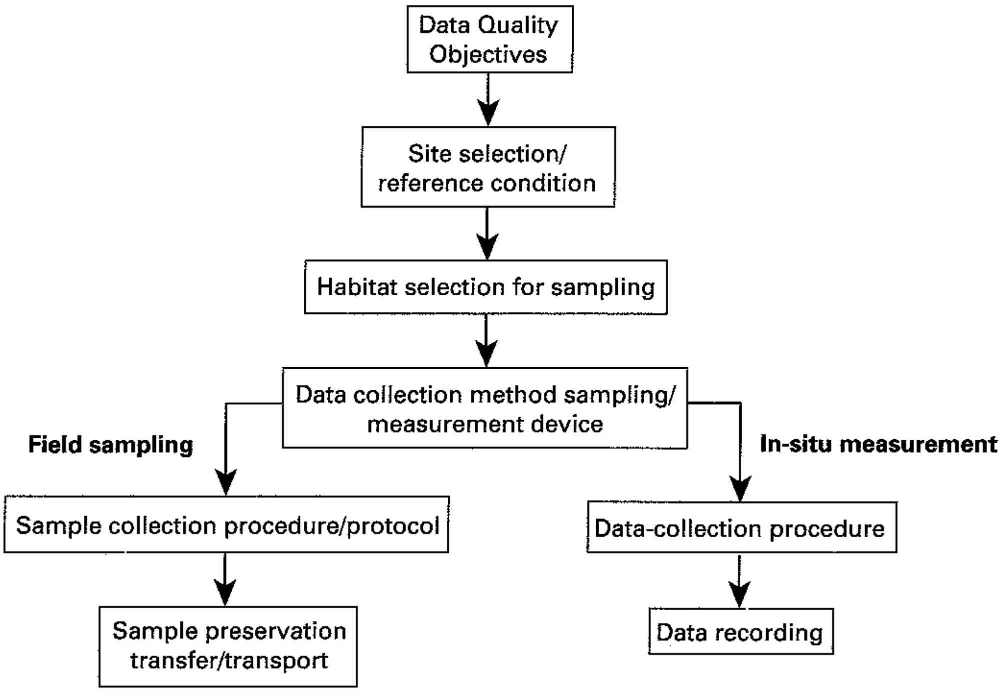

Figure 1. Procedural steps required in field methods.

being measured. Therefore, in some type of sites, a given field method may be used to examine a broad range of environmental conditions to characterize criteria, such as performance range or interferences, adequately. Note that for such sites as deep ground-water systems, seasonality or precipitation may play a very minor role in terms of certain analyte concentrations or other characteristics of the water. In this case, sample timing may not be a major factor that affects performance characteristics for some deep ground-water field methods and analytes.

Field methods, whether they yield in situ measurements or laboratory-based measurements, rely on adequate training to carry out the method with the most accuracy and precision (Technical Appendix I). It is desirable to have training evaluations or proficiency testing of results available for the corresponding field data so that a secondary user could independently judge the quality of the information. Part of characterizing performance criteria for a given field method will include aspects of training and the level of expertise necessary to perform specific steps. Unlike laboratory methods, where operator training can be directly evaluated (through the use of performance-evaluation samples and fortified spike samples, for example), adequate field-method training is evaluated by means of more indirect means. One way in which field-method training and performance characteristics may be evaluated is through the use of "standard" sites. Standard sites are locations in which the variability in the analyte or measurement of interest is low over a specific time period or habitat condition. Furthermore, the variability

Table 1. Translation of some performance criteria derived for laboratory analytical testing to field methods

[DQO. data-quality objective]

Performance criteria	Procedural steps or methods
Precision	Duplicate samples/split samples for later analysis, replicate samples and measurements from the same site.
Bias	Field-spiked samples, equipment blanks, sampling reference sites from different regions.
Performance range	Sampling in a range of habitat environments consistent with DQO's, examination of range of related analytes or measurements
Interferences	Habitat effects on measurement quality, sampling device performance over different environmental conditions, spiked samples
Method detection limit	Equipment blanks, sampling in sites known to have absence of analyte, spiked samples.

Table 2. Examples of factors that could affect performance criteria for different types of aquatic sites

Example factors	Stream		Lake	Estuary	Ground water	
	Small	Large			Shallow	Deep
Site factors	Reach Land use Flow	Reach Depth Transect Land use Flow	Wind Depth Transect Inflow/outflow Littoral/pelagic Bottom type	Depth Salinity zone Bottom type Wind	Terrain Land use Irrigation Pumping	Regional Context Land use? Pumping
Sample timing	Time of day Season Precipitation Flow Shading	Time of day Season Precipitation Flow	Time of day Season Precipitation	Time of day Season Tides Precipitation	Precipitation Season Tides Pumping	Not an issue?
Sample type	Flow weighted Grab Benthic	Flow weighted Grab Depth integrated. Benthic	Depth integrated. Horizontal tow Grab Benthic	Depth integrated. Horizontal tow Grab Benthic	Grab Time/flow Composite	Not an issue?

around the mean value is well defined. As a result, samples can be repeatedly taken in such a location over that time period, and similar measurements can be obtained. In this way, the standard site is analogous to a performance standard in laboratory analytical work. Adequate training can be evaluated by having a particular field crew sample at least one, and preferably more, standard site. Significant deviations between the new crew results and those obtained historically for the site and similar environmental conditions (with a mean and some measure of variance) could indicate inadequate training or proficiency.

Also, selected "regional" training centers under interagency(s) direction ("Methods and Data Comparability Committee," see below) could review "crew" or "individual" training survey methods or protocols so that some standardization of training or methods could be achieved on a geographical basis.

Characteristics that define a reference site will be specific to what is being measured. For biological collection methods (Technical Appendixes F, O) geomorphic and cultural factors, such as ecological region, watershed or basin, land use, habitat type, and lack of anthropogenic disturbances, are critical in defining a reference condition that is analagous to a standard site in the present context. When controlled or defined, these attributes yield consistent results over a given time period for biological data. Similar attributes may be useful in defining reference sites for some chemical and physical field methods. Certain types of measurements, however, may require different reference-site attributes. For example, a field method designed to collect water temperature or major ion data may choose certain freshwater springs as one type of condition because a fairly consistent level of water temperature or major ion is observed during a certain time period. Similarly, some deep ground-water aquifers may provide appropriate reference sites for certain analytes because the concentration is stable over time.

In addition to using carefully selected reference sites, another way to evaluate proficiency of training and to characterize various performance criteria for analytical, biological, and some physical methods is through the use of field blanks. For analytical and biological measurements, results of field blanks will indicate the degree of cross-contamination among samples and overall carefulness in carrying out the field procedures. Clearly, use of field blanks is limited to those methods in which samples are collected for later laboratory analysis. Field methods that yield in situ measurements may not be amenable to this procedure. Instead, such methods must rely on several field teams and several measurements at the same locations to characterize method proficiency and other performance criteria.

The flow chart presented in figure 2 summarizes the major steps in defining performance criteria for a given field method involving sampling. As noted previously, the DQO's will define what is measured, the site, and the timing of interest. For those methods in which samples are collected for later analysis, several types of tests are available to characterize performance criteria. Several samples should be collected from the same location (a reference site) at the same time to quantify sampling precision or reproducibility. Ideally, this should be repeated at different times (seasons) and different sites to ensure that realistic precision estimates are obtained. Also, this sampling will help quantify the performance range and potential interferences of the method. In addition, field blanks should be performed with sufficient frequency to quantify contamination and method sensitivity. For biological methods, field blanks could be samples that consist of water without the organisms of interest into which the sampling device is placed. Assuming that laboratory methods have been satisfactorily validated, field blanks that contain significant quantities of the analyte of interest suggest that the field method may introduce a certain bias or lack proficiency. Recovery may also be addressed for some chemical analytes by utilizing field-spiked samples at the point of sample collection or before a particular prelaboratory procedure (sample preservation, filtering) if that is the method of interest. Finally, the field method should be performed over a range of site conditions applicable to the DQO's to characterize the performance range and method robustness. Site conditions would include conditions other than those represented at standard sites. In many ways, the process just described may be iterative by defining new sites and new sampling index periods and repeating the sampling and laboratory analyses.

The flow chart presented in figure 2 can pertain to a field protocol as a whole, which would consist of several steps or methods, or could pertain to an individual step. For example, the USGS study on nutrient-preservation methods for ambient samples, dealt with one step within a larger field-sampling protocol, namely how samples are preserved. If individual steps are to be examined, then it is critical that other steps in the process be held constant; that is, field and laboratory methods for steps outside the one of particular interest need to be performed in a similar manner by using the same equipment and standard operating procedures.

The discussion thus far has focused on field methods in which samples are collected and analyzed. Several types of field methods, however, do not result in samples being collected. Data are collected directly instead. Examples would include in situ measurement of pH or dissolved oxygen by using a field meter and probes, in situ enumeration and identification of fish species collected, and physical habitat measurements,

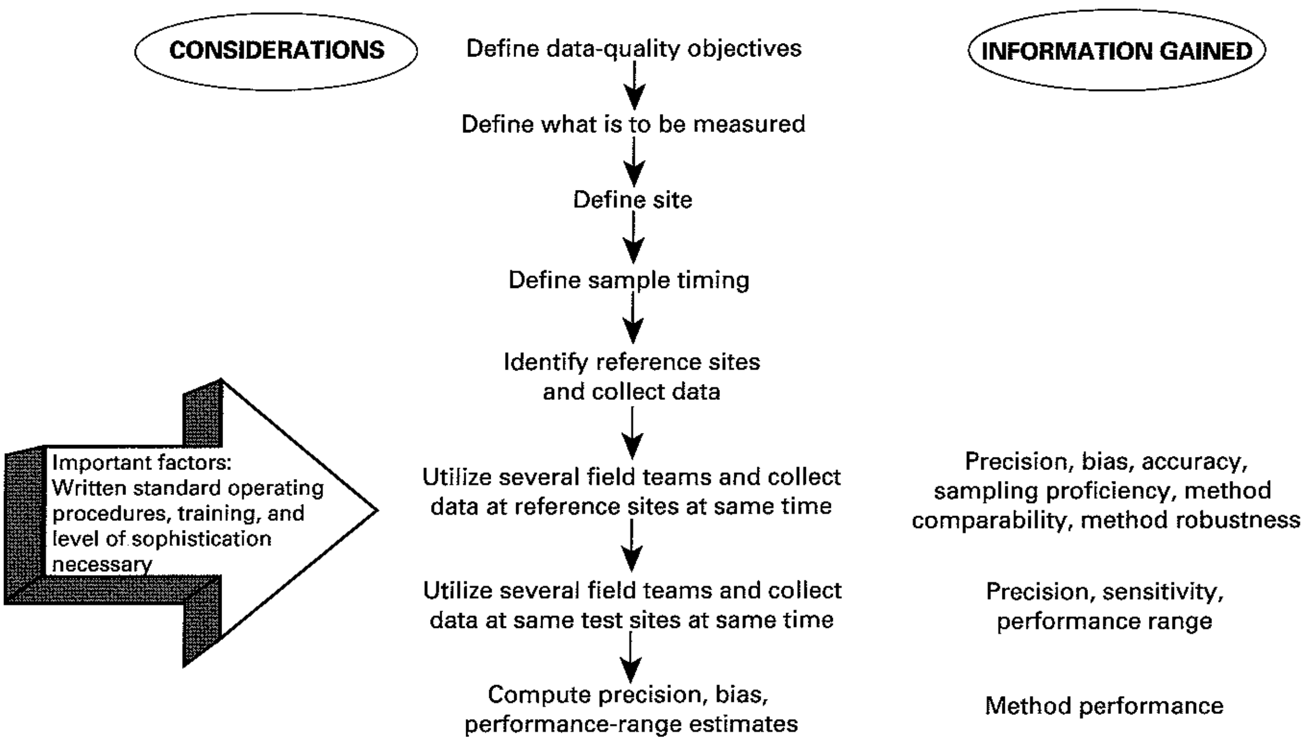

Figure 2. Procedural steps in relation to developing performance criteria for metods that involve sampling.

such as percent shading, stream velocity, and stream gradient. In these instances, the framework just discussed cannot be utilized to characterize performance criteria. In situ field methods must be subjected to a framework that relies heavily on interfield crew evaluations and several measurements in the same locations (fig. 3).

Reference sites are important for in situ measurements as they are with true sampling methods because the value of the reference site becomes a "standard" by which to judge measurement precision and relative bias. However, test sites or nonreference sites are just as important in defining the degree of measurement consistency among different field crews and certain performance characteristics of the method. Where a sampling instrument is involved, such as for stream velocity or pH, these should be calibrated before data are recorded. Furthermore, for some parameters, such as dissolved oxygen, samples can be preserved and analyzed by using appropriate laboratory procedures. The laboratory results are then used to verify the results of the on-site method.

Field-Method Comparability

Once performance characteristics, such as precision, performance range, and bias, are quantified for given field methods, comparability of methods can be examined. Field methods that include the collection of samples for which a laboratory analysis is obtained will require a different evaluation framework than methods in which no actual samples are collected. After samples are collected and analyzed, either in the laboratory or onsite, comparability of the field methods can be judged by examining performance characteristics of each method, as well as the measurements of the samples collected. The framework for evaluation is similar to the flow chart shown in figure 2. Several samples were collected by using two methods at the same reference sites and at the same time (fig. 4). Both sets of samples were subject to the same on-site or laboratory procedures. Several measurements were computed for each method. If a method that produces more variability in the measurements (less precision) than another, then this would be a basis for defining the degree of

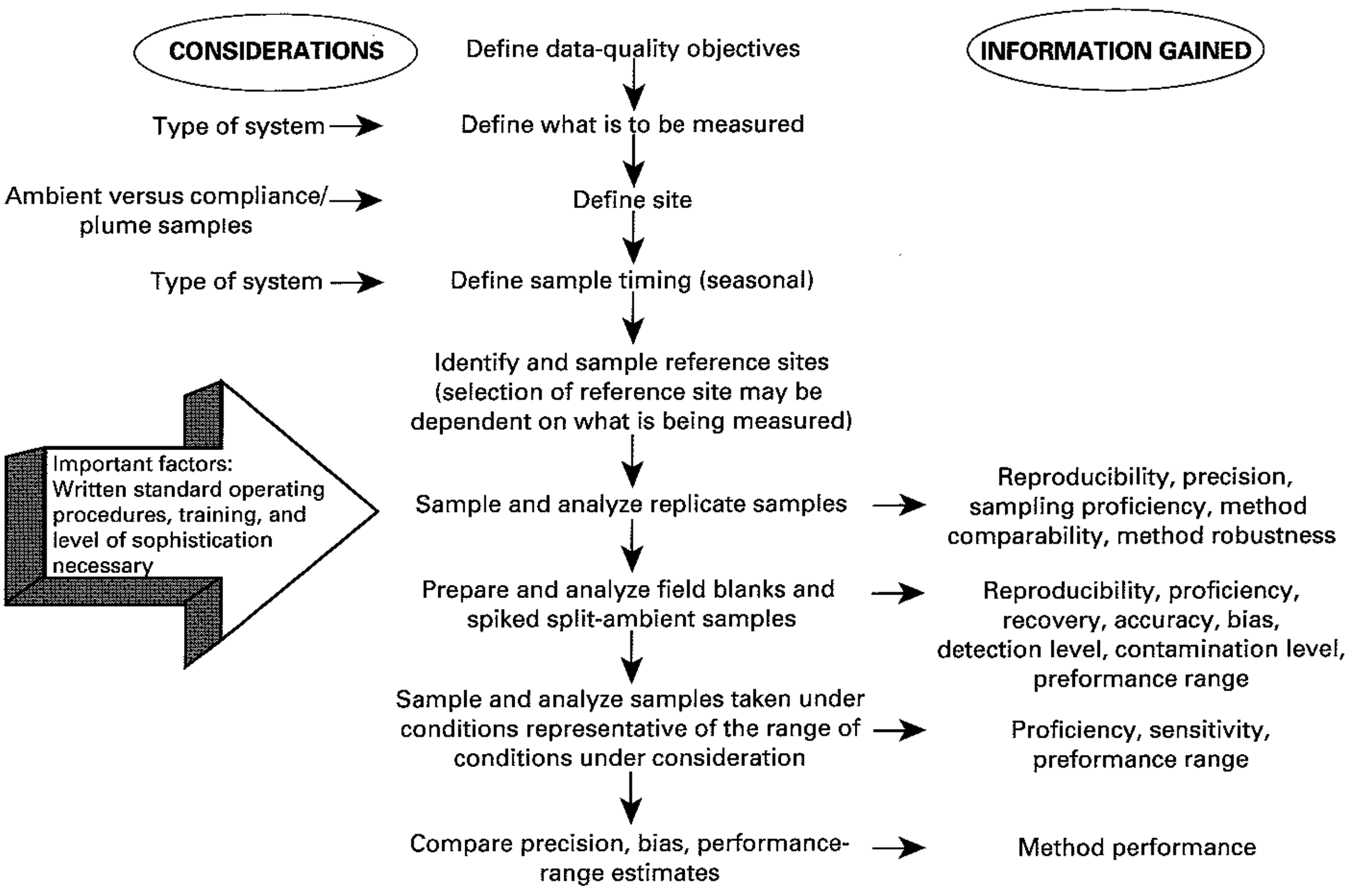

Figure 3. Procedural steps in relation to developing performance criteria for in situ methods.

comparability. Similarly, if one method consistently yields a statistically lower or higher measurement than another (bias), then this, too, would be a basis for defining comparability. Most probable values are used to calculate relative bias between methods. Field blanks also would be important in examining method comparability when samples are analyzed. If the field blank from one method yields higher background levels of the measurement of interest than a second method, then this could suggest more inherent contamination (bias) in the first method and probably less sensitivity or a higher detection limit. Depending on the DQO's, the first method may or may not be comparable to the second method. For example, if the objective is to measure a given chemical in the millligram-per-liter range and two different methods result in trip blanks that have 0.005 and 0.5 milligram per liter of the analyte, then both methods may provide comparable data. Alternatively, if the objective is to measure the chemical in micrograms per liter, then the first method would have less bias (more accurate) than the second, and the two methods would not have yielded comparable results.

An additional component for comparing field methods is to sample a range of test sites that includes the extremes of environmental conditions likely to be encountered by using the method. At each test site, both methods should obtain several measurements to evaluate precision, performance range, and potential interferences of the methods (bias) (fig. 4). Two methods may be fairly comparable in some types of sites or under certain conditions and not others. For example, an impeller-type current-velocity probe yields measurements similar to those obtained by using an ultrasound probe under low- to intermediate-flow conditions in streams and rivers. At higher flows, however, turbulence and wave eddies increase pro-peller friction in the impeller probe, which results in consistently lower current velocity readings than the ultrasound probe. Such information can be used to quantify the range over which the two methods (instruments in this case) yield comparable results and where they do not.

An example that demonstrates the importance of testing several environmental conditions would be a recent USGS nutrient preservation study, in which several nutrients were measured in a range of different types of ambient-water samples. Each water sample was examined in side-by-side tests by using different preservation procedures. The results of that study are robust because a range of nutrients and a range of ambient sample types were examined. However, the comparability of different preservation methods under non-ambient conditions (waste-water effluents, for example) is unknown and likely to be different than that observed for ambient samples in which natural

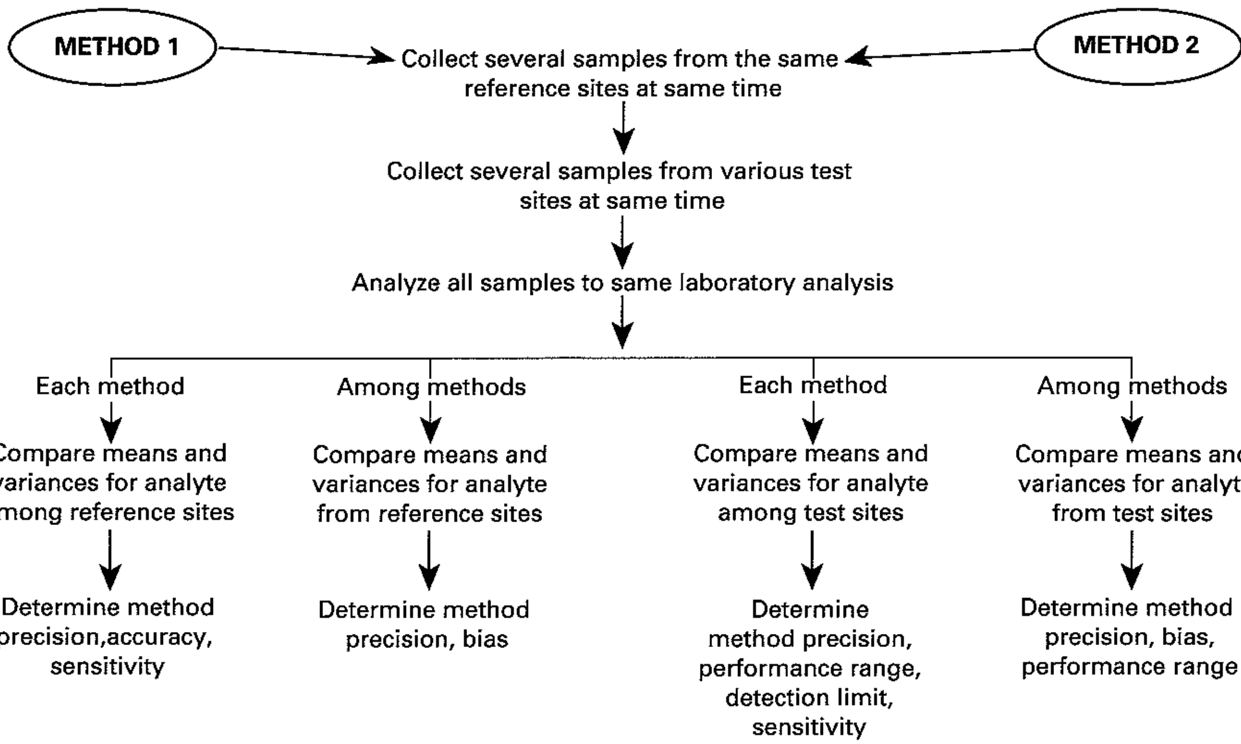

Figure 4. Scheme for comparing field methods that involve sampling and subsequent analyte analysis.

microbiological activity was low. Comparability of nutrient preservation methods for nonambient samples will require additional study.

The comparison of field methods that include in situ measurements needs to be handled somewhat differently from that above (fig. 5). Because samples are not collected, it is even more critical that the methods to be compared include measurements in the same locations and at the same time. This is because method results, in this case, often pertain to a narrowly defined region in space and time. For example, an in situ pH measurement will be relevant for a certain vertical stratum of water, at a certain horizontal or transect location, and only for a very restricted time period that spans perhaps 1 to 2 hours (or less in some eutrophic systems). After sampling in a different vertical stratum, a different horizontal location, or morning instead of afternoon, the same method could yield a significantly different measurement result. Therefore, if the objective is to determine comparability between a certain pH probe/meter and a certain pH test-strip paper, then the two methods would need to sample side by side at all sites. Only then can interferences that result from various site factors (table 2) be sufficiently controlled to examine method comparability. As discussed for field methods in which samples are collected, reference sites and a range of test sites are equally important in determining performance criteria and examining method comparability for in situ field measurements.

Institution Framework for Examining Field-Method Comparability

Field-method comparability tests require a certain degree of resources, in particular trained personnel to collect samples or to make measurements at the different standard and test sites. If follow-up laboratory work is required to obtain a measurement, then laboratory resources (equipment and trained people) also need to be available. Given the resources needed to examine comparability of field methods, it is imperative that a system be in place that will adequately store and manage such information so that others can use the results. Furthermore, it should be clear that reference sites are extremely valuable in evaluating the performance criteria and the method comparability of a given method. Therefore, reference sites (possibly regional ones) must be identified, cataloged, and easily accessible so that other users or methods can choose appropriate sampling locations.

The Methods and Data Comparability Board (MDCB) is intended to carry out the institutional functions described above (Technical Appendix H). The

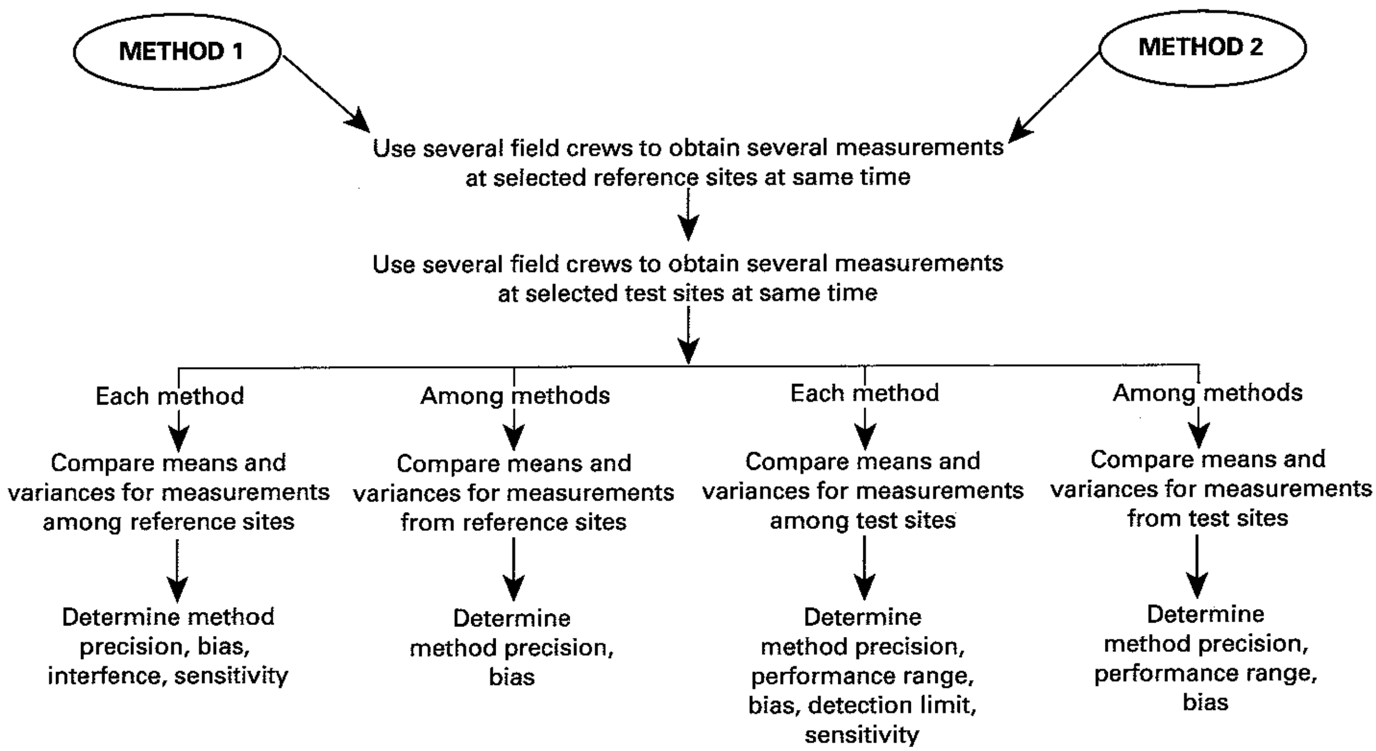

Figure 5. Scheme for comparing field methods involving in situ measurements (no sample collection).

MDCB, as mandated in the Charter, would store and manage information that pertains to method-performance criteria and results of any tests of method comparability. Furthermore, the MDCB would identify and catalog reference-site information that would be easily accessible for users, agencies, and the public.

One issue in this regard is how field methods should be classified for ease of organization and accessibility. Several possible classification schemes are matrix (sediment, freshwater, saltwater, ground water), type of analyte or measurement (metal, nutrient, current velocity, pH), and submethod or procedure (sampling, preservation, measurement procedure if done in situ). It is likely that the primary level of classification should be the measurement or analyte because this is the primary topic of interest for which users would want information (table 3). Under this classification would be a subclassification according to submethod or procedure because this is typically the next critical level of interest to users. Finally, a given procedure for an analyte would be classified according to the matrix and (or) type of site. Within a given type of site or matrix, tests of comparability would specify the types of samples examined (ambient, surface grabs, depth-integrated composites, flow-proportioned composites). Alternatively, protocols could be set up by geographic/region area and (or) by type of habitat/parameters being measured.

It is envisioned that certain subprocedures may pertain to more than one analyte. For example, several metals are routinely preserved with nitric acid. If an alternate preservation method, as well as nitric acid was tested for comparability by using the metal cadmium, then it may not be necessary to repeat that test for metals with similar properties; for example, copper or zinc. The type of matrix or site also may be unique for a given field-method measurement. For example, certain physical habitat measurements, such as stream velocity, temperature, benthic substrate particle size, and gradient, may be independent of the type of site or matrix. A similar sampling or measurement method may be used for all sites. In these cases, it is desirable to denote such information for all relevant types of sites even though a comparability test included only a certain subset of available types of sites or matrices.

A second issue that pertains to the institutional framework is that of defining or characterizing adequate method training. As explained earlier, satisfactory training and demonstrated proficiency are essential elements of all methods, particularly field methods. Furthermore, certain field methods or procedures require significantly more sophisticated training and expertise than others. The level of training and expertise needs to be clearly indicated for a given field method so that other users can evaluate the proficiency of different field personnel and the resulting data.

In the MDCB Charter (Technical Appendix H), one of the stated objectives is to evaluate the need for a certification or proficiency testing program for field methods much like that already proposed for laboratory analytical methods under the U.S. Environmental Protection Agency's Environmental Monitoring Methods Council. A certification program for field methods will require a large commitment of resources initially, and the specifics are undetermined at this time owing to the complexity of this issue and the many types of field methods used. A more realistic goal would be to have the MDCB be the repository of the information that pertains to training requirements and the level of expertise necessary for various field methods. Once enough methods are formally characterized with respect to performance criteria, it would be realistic to embark on a certification or proficiency testing program.

Table 3. Suggested hierarchical classification scheme for organizing performance criteria and comparability information for field methods

Classification	Description	Examples			
1	Analyte or measurement	Phosphorous	pH	Stream velocity	Fish species Richness
2	Type of method procedure	Preservation	Meter/probe	Meter	Electrofishing
3	Type of matrix or site	Ground water	Surface water	Streams	River
		Flow proportioned	Depth integrated	0 6 depth	Composite

TECHNICAL APPENDIX O

PERFORMANCE-BASED METHODS SYSTEM FOR BIOLOGICAL COLLECTION METHODS— A FRAMEWORK FOR EXAMINING METHOD COMPARABILITY

Relations of Analytical Performance-Based Characteristics to Biological Systems

Historically, chemical analytical data have been considered to be more quantitative than ecological or toxicological data, and correspondingly greater emphasis has been placed on such quality-control aspects as precision and bias. Recently, many biological methods have been refined and standardized such that truly quantitative data are obtained, as well as certain quality-control characteristics. The two fields, however, may be fundamentally different in that an objective statement of method accuracy (defined below), which is usually available in chemical laboratory methods, may not be available for biological field methods; that is, although a given analytical method can be tested to see if it accurately measures the amount of an analyte (by means of spiking into clean water, for example), there are no such external standards by which to judge the accuracy of a given biological collection method or a given toxicological method. Scientists cannot presently devise a treatment or sample with known toxicity value (independent of the method used) or spike a water sample with an absolute level of toxicity. Similarly, we may not be able to devise a site with a known level of impairment (independent of the method used) or "spike" a system with a known level of impairment. Instead, biological testing and collection methods have often relied on deciding, a priori, that a particular method yielded "accurate" results (that is, the reference method) with which results of other methods were compared.

With the introduction of the concept of performance-based methods systems (PBMS) in laboratory testing, particularly for chemical analytical data, it is apparent that a similar framework may be useful for examining comparability of field and laboratory biological data-collection methods. For example, in evaluating sediment or solid-phase toxicity, the American Society for Testing and Materials (1993) and the U.S. Environmental Protection Agency (1990; written commun., 1994) have developed biological toxicity test methods that have certain known performance criteria. They are currently recommending a PBMS approach to evaluate such toxicity; modifications of the recommended procedures are acceptable if it is shown that the performance criteria, as set by the recommended reference procedure, are met. In this case, method comparability is achieved by meeting specific performance criteria, such as negative control organism survival, growth of control organisms, and test endpoint precision, that have been established for a "reference method" developed under a specific regulatory program (USEPA TSCA, FIFRA, NPDES). Thus, the concept of PBMS is used in some aspects of biological laboratory testing.

Components of the Performance-Based Methods System Approach

Several performance parameters must be characterized for a given method to utilize a PBMS approach. These parameters include method precision, bias, performance range, interferences, and matrix applicability. These parameters, as well as method accuracy, are typically demonstrated in analytical chemistry systems through the use of blanks, standards, spikes, blind samples, performance evaluation samples, and other techniques to compare different methods and eventually to derive a reference method for a given analyte. Many of these performance parameters are applicable to biological laboratory and field methods and other prelaboratory procedures as well. It is known that a given collection method is not equally accurate over all ecological conditions even within a general aquatic system classification (streams, lakes, estuaries). Therefore, assuming a given method is a "reference method" on the basis of regulatory or programmatic reasons does not allow for possible translation or sharing of data derived from different methods because the performance characteristics of different methods have not been quantified. Furthermore, most biological methods have not had adequate analysis to provide a "crosswalk" to allow interpretation of results between different protocols. The following section draws parallels between aspects of PBMS developed for laboratory analytical chemistry methods and biological laboratory methods. The subsequent section discusses biological field methods.

Performance-Based Methods System and Biological Laboratory Methods

Several conceptual similarities exist between chemical and biological laboratory methods with respect to quality-assurance (QA) concepts and method-comparability issues (table 1). In this section, many significant parallels are drawn between analytical and biological laboratory methods within the context of PBMS. Several performance parameters essential to a PBMS framework will be considered below.

Precision

Laboratory chemistry systems measure method precision through the use of replicate sample measurements over a range of analyte concentrations. High replicability or reproducibility of a given sample measurement indicates high method precision. High method precision is clearly an important criterion for any method because this ensures reproducible results and increases statistical power of inference testing in intersample comparisons. Discrimination among samples is more likely with a method that has high precision.

Precision is an important performance parameter for biological aquatic toxicity testing as well. Similar to laboratory chemical testing, precision is measured by examining replicate measures of a given biological endpoint (for example, number surviving, growth, number of offspring produced) in which certain reference materials (sodium chloride, copper sulfate, cadmium chloride, sodium pentachlorophenol) are used. In chemical testing, precision is increased by modifying the instrumentation of the method or reagent modifications and through the use of calibration methods. To increase precision of a method in toxicity testing, an analogous procedure is used. Some method modifications used to increase the precision of a method in toxicity tests include the development of a more consistent, reliable food source in chronic toxicity testing (such as in the 7-day *Ceriodaphnia* survival and reproduction test); development of a standard dilution or control laboratory water (U.S. Environmental Protection Agency, 1990); and improved organism culturing techniques to ensure adequate organism health and consistent genetic composition within a given test (U.S. Environmental Protection Agency, 1989). A method that has a lower test precision relative to a published or programmatic method by using the same species and endpoint (defined as the reference method by the given program), is generally regarded as less useful, although other criteria may come into play [U.S. Environmental Protection Agency, 1990; J., Diamond, T., Abrahamson, and D., Reish,Tetra Tech, Inc., written commun. (ASTM E–47.01), 1994].

Laboratory methods for processing of biological field samples and capturing raw data also are concerned with method precision. For example, laboratory operations have distinct components that can have associated quality assurance program activities (table 2). Two component laboratory procedures for benthic macroinvertebrate sampling programs include subsampling and taxonomy. Subsampling is performed with preserved samples in the laboratory in this example. QA-design requirements do not differ between performing subsampling in the field and the laboratory, although adverse weather conditions could interfere with field-subsampling methods. Table 2 presents QA-design requirements for laboratory taxonomy to the genus or species level, although lower level taxonomy (that is, family) can be performed in the field by an experienced taxonomist.

Precision, accuracy, and bias are characterized in biological laboratory analyses of field-collected samples through a variety of mechanisms (table 3). Not unlike chemical laboratory methods, biological methods rely on replicate measures to characterize precision and accuracy. Although method precision is

Table 1. Translation of some performance criteria, derived for laboratory analytical systems, to biological laboratory systems

Performance criteria	Analytical chemistry methods	Biological methods
Precision	Duplicate and replicate samples	Multiple taxonomic identifications of one sample; split sample for sorting, identification, enumeration; multiple subsamples.
Bias	Spiked samples; standard reference materials; performance evaluation samples.	Taxonomic reference samples; "spiked" organism samples
Performance range	Standard reference materials at various concentrations; evaluation of spiked samples by using different matrices.	Efficiency sorting procedures under different sample conditions.
Interferences	Knowledge of chemical reactions involved in procedure; spiked samples; procedural blanks	Detrital material, mud in sorting animals; identification of young life stages; taxonomic uncertainty.
Method detection limit	Standards, instrument calibration	Organism-spiked samples; level of identification.

Table 2. Examples of laboratory Quality Assurance design requirements for reduction of probability of error

Protocol component	Design requirement
Subsampling	Proper equipment. Training. Standard operating procedures Proper laboratory facilities. Proper oversight supervision
Taxonomy	Proper training. Up-to-date literature. Adequate dissecting microscope Adequate compound microscope. Reference collection Voucher collection. Predetermined taxon-specific level of identification. Proper oversight supervision (by a skilled scientist)

recognized as a basic requirement of biological collection methods, few laboratory methods have actually documented precision or accuracy estimates.

Bias

The degree to which there is bias in a given laboratory analytical method is defined through the use of spiked or fortified samples, standard reference materials, and performance-evaluation samples. A similar process is utilized to detect bias in biological toxicity testing. For example, reference-toxicant- and blind-performance-evaluation samples are routinely used to detect possible bias or procedural problems with a given test method and biological endpoint (U.S. Environmental Protection Agency, 1990). However, unlike analytical chemistry testing, the biological toxicity test result is compared with a range of "normal" values generated by multiple laboratories that used quality control charts and repeated testing over an extended time period. The "true," or theoretical, value for a given method and toxicant is determined by a consensus of different laboratories that perform the test and is not a truly independent standard as it is in analytical testing. Thus, method bias in toxicity testing is a relative criterion. For example, samples that have low toxicity when the *Daphnia magna* acute toxicity test method and survival as the endpoint are used (U.S. Environmental Protection Agency, 1990) show greater intralaboratory and interlaboratory variability and bias than samples that contain a higher toxicant concentration. The USEPA has used a similar QA program as part of their discharge monthly report (DMR) studies. In this case, method bias is related to the consensus of participating laboratories and varies somewhat over the range of toxicity present. Method bias also may be related to the type of toxicant as well (for example, copper sulfate as compared with sodium chloride), although this has not been quantified at this time.

Bias in laboratory processing of field-collected samples has been assessed by using techniques similar to chemical and toxicological testing. This is a performance criterion that has received increasing consideration in biological laboratory QA procedures (U.S. Environmental Protection Agency, written commun., 1994). For example, taxonomic and enumeration bias of plankton or macroinvertebrate samples can be determined by "spiking" blind samples with organisms of

Table 3. Examples of laboratory quality component routines that can be used for benthic macroinvertebrate samples

Protocol component	Data quality component	Characterization
Subsampling	Precision	Compare metric values between split samples and (or) replications
Taxonomy	do	Multiple identifications by different taxonomists on single, randomly selected sample.
	Accuracy	Achieved by expert verification or comparison with reference collection
Subsampling	do	Recheck of sample residue for missed specimens
	Bias	Randomly selected grid squares; specimens removed to end of grid

known identification and then submitting them to the routine sample-processing procedure. Similarly, performance-evaluation samples could be derived that contain known taxonomic composition and are processed along with actual field samples. Several types of laboratory procedures can be evaluated in this way Positively identified macroinvertebrates can be added to a synthetic sample that has water, detritus, and no macroinvertebrates to evaluate bias in sorting, as well as taxonomic identification procedures. Alternatively, after sorting macroinvertebrates, the sample residue can be resorted to quantify the number and types of organisms missed or underestimated in typical sorting procedures. Clearly, the above procedures are applicable only for samples that are brought back to the laboratory for processing. Data that are collected in the field only, such as many fish identifications/enumerations, habitat information, or certain physicochemical measurements, require similar performance-parameter characterization but need to be handled differently. Biological field methods of this type are covered later in this technical appendix. Field methods, in general, are treated in Technical Appendix N. Further documentation of bias is needed for many biological methods to evaluate method comparability adequately.

Performance Range and Interferences

To evaluate the usefulness of a given method or protocol and to define comparability between or among methods, the method's performance over a range of conditions must be known. Toxicology has used this concept to express certain test-acceptability criteria. Most of these criteria are driven by the biological requirements of the test species used. For example, a toxicity test in which rainbow trout are studied has a prescribed temperature range that considers the natural thermal limits of this species, thus reducing this source of interference. Similar constraints may be imposed for other physical and chemical water-quality characteristics, such as pH, hardness, and osmotic pressure, or grain size in the case of solid phase tests (American Society for Testing and Materials, 1993). There is some debate as to whether performance range and interferences are explicitly acknowledged and measured for many toxicity test methods For example, a given sediment sample may appear to be toxic owing to an inappropriate grain size for the test species that would be indistinguishable from a true chemical toxicity effect. Similarly, a waste-water effluent may appear to be toxic owing to suboptimal osmotic pressure or nutrient balance that would be indistinguishable from chemical toxicity Most American Society for Testing and Materials methods discuss potential interferences for each method. For other programs, however, this is an issue that appears to be dealt with in the context of programmatic or regulatory necessities rather than in the context of PBMS.

Biological laboratory procedures also are very much subject to the type of performance range and interferences. For example, certain macroinvertebrate sorting procedures were developed, in part, to reduce bias and interferences that result from detrital material or certain sediments present However, certain taxonomic classifications (that is, species) may be inappropriate or unknown for some groups of organisms owing to limited knowledge and lack of identification procedures. Similarly, young life stages of many species (whether examined in the field or in the laboratory) are difficult to identify, thus posing a potential interference. Although some aspects of performance range and interferences have been identified for certain biological laboratory methods, to a large extent, these need to be documented.

Multimedia Applicability

The media or matrix of the sample can have a profound effect on method accuracy and precision Similar to analytical chemistry testing, biological toxicity testing handles this issue by providing different procedures for different matrices—aquatic vs. solid phase and freshwater vs. estuarine vs. marine conditions However, finer aspects of the matrix or media are not necessarily acknowledged in toxicity test methods. For example, the presence of suspended solids could represent a potential interference for some test species and pose a media problem.

In biological laboratory work, certain macroinvertebrate sample-processing procedures may be most accurate and precise if samples are collected from certain types of benthic substrates. For example, sorting efficiency and accuracy can be profoundly affected by the type of substrate collected and the abundance of detrital material. Although this issue is well-known to biologists, many biological laboratory methods have not explicitly quantified matrix applicability for given sample processing procedures.

Biological Field Methods

Field biological collection methods could benefit from a PBMS approach. Indeed, many performance parameters, which are common to any PBMS approach, have been addressed to some extent and are informally recognized during development of specific biological field methods. Better quantification of performance parameters for different methods could provide a useful framework with which to judge method comparability

To demonstrate the usefulness of PBMS, precision is taken as an example of a performance parameter. Method precision could pertain to many aspects or subprocedures used in biological assessments. For example, interest could be in precision with respect to specific metrics at a given site by using replicate samples taken from the site. Alternatively, concern may be with precision in terms of specific metrics across reference sites in a given ecoregion and within a specific stream reach classification. Finally, interest may be in precision with respect to an assessment score among replicate samples at a site or among reference sites.

The primary difficulty with these precision measures is that they also are dependent on the precision of laboratory methods used. This is a common problem with many prelaboratory methods because prelaboratory performance is based on a laboratory-defined endpoint. In these cases, the only way to compare performance parameters, such as precision or interferences for different prelaboratory methods, is to keep the laboratory methods constant. Unfortunately, this type of comparison has rarely been done for any prelaboratory methods. Examples might include the USGS nutrient preservation study and the U.S. Forest Service (USFS) macroinvertebrate laboratory analysis method.

By establishing relative field method precision among methods, it is possible to derive a precision criterion, to designate a reference method that meets this criterion, and thereby to quantify method comparability. Other performance criteria, such as performance range, potential interferences, and matrix applicability, also would be used to quantify biological field-method comparability. Some of this information is published, but much of this knowledge is incorporated in an informal manner and not quantified within the framework of the method itself. As an example, several published sources discuss advantages and disadvantages of different sampling devices, such as various nets, dredges, bottle samplers, and appropriate environmental conditions for which these devices should be used; for example, Burton (1992) for sediment collection, Peckarsky (1984) for macroinvertebrates; and Bryan (1984) for fish. Such information should be quantified for field methods to judge method comparability better. The form would depend on the particular procedural step as shown in table 4. To define a reference method for a given biological field procedure, it is imperative that the specific range of environmental conditions are quantitatively defined. For example, in macroinvertebrate bioassessment methods, performance range has been addressed qualitatively by considering the size of the stream, its specific hydrogeomorphic reach

Table 4. Progression of a generic bioassessment field and laboratory method and corresponding steps requiring performance criteria characterization

Step	Procedure	Examples of performance criteria
1	Sampling device	Performance range—Efficiency in different habitat types Bias—Exclusion of certain taxa Interferences—Matrix or physical limitations
2	Sampling method	Performance range—Limitations in certain habitats or matrices Bias—Sampler (person) efficiency
3	Field sample processing (subsampling, transfer, preservation)	Precision—Of measures among splits of subsamples Accuracy—Of transfer process Performance range—Of preservation and holding time
4	Laboratory sample processing (sieving, sorting)	Precision—Among split samples Accuracy—Of sorting method; equipment used Performance range—Of sorting method dependent on sample matrix Bias—Of sorting certain taxonomic groups or organism sizes
5	Taxonomic enumeration	Precision—Split samples Accuracy—Of identification/counts Performance range—Dependent on taxonomic group and (or) density Bias—Counts and identifications

classification, and general habitat features (riffle areas, shallow depth). Such factors as current velocity, stream depth, and substrate size have been quantified or characterized to specify the range of conditions over which a particular method yields a certain level of precision and bias. Different methods then could be classified according to their applicable performance range, and further aspects of method comparability could be determined by examining preestablished performance criteria.

Derivation of Performance Criteria to Evaluate Bioassessment Method Comparability

In performing biological field methods or any prelaboratory method, two fundamental concerns are of interest—that the sample taken and analyzed is representative of the site or the population of interest and that the data obtained are an accurate reflection of the sample collected and analyzed. The first concern is addressed through appropriate field sampling and protocols procedures (including site selection, sampling device, sample preservation) that are dictated, to a certain extent, by the data-quality objectives (DQO's). The second concern is addressed by using appropriate laboratory or analysis/protocols procedures. This is conducive to a PBMS approach because it is somewhat analogous to a laboratory analytical chemistry PBMS—performance parameters, such as accuracy, precision and bias, can be quantified as discussed earlier.

The concern of sample representativeness for biological field methods is a complex one that will involve many components, each with its own set of performance parameters (table 4). For clarity, it may be best to subdivide a field-collection procedure into several compartments; for example, sampling/reference-site selection sampling device(s), sampling method, field subsampling/processing; and sample preservation/transport/storage (fig. 1). Many variations of each component may be in use. For example, in benthic macroinvertebrate assessments, several different methods or submethods are used, even for the same type of field sites (table 5).

What constitutes a representative sample has been debated for many field situations. Indeed, representativeness itself is dependent, in part, on the DQO's and what, when, and how a measurement is taken. For example, it is well established that many benthic samples may be needed from a stream bottom to obtain reasonable 95-percent confidence intervals for macroinvertebrate density, whereas few benthic samples

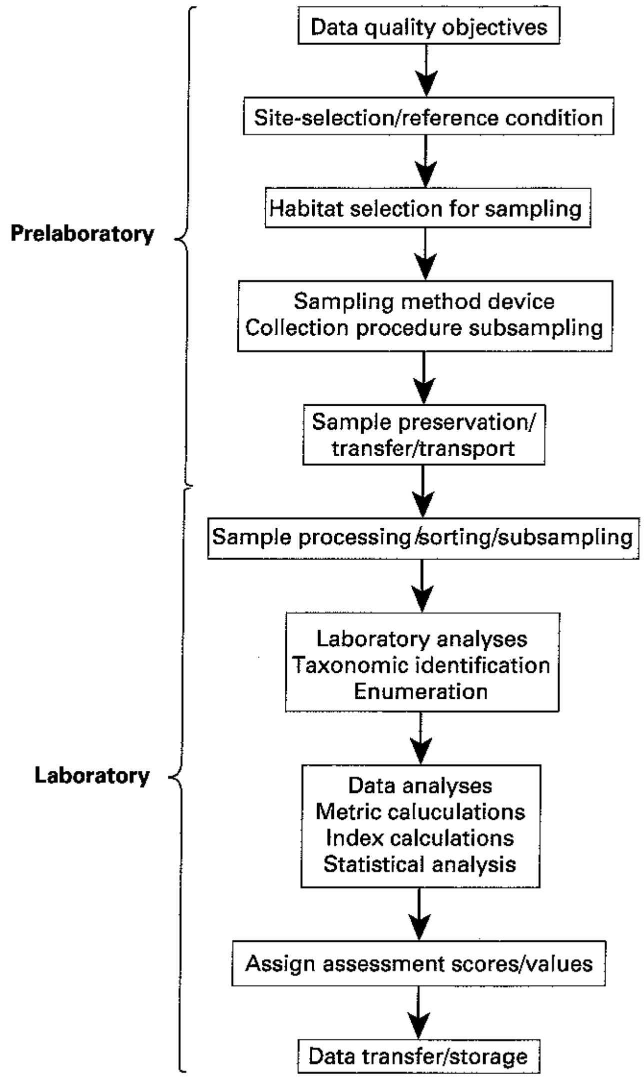

Figure 1. Flow diagram of a typical biassessment methodology in the context of performanced-based methods system.

may be needed to characterize species richness in a given habitat type (U.S. Environmental Protection Agency, 1989); thus, there is more assurance that a representative sample has been obtained if the number of species desired are present compared with the number of individuals per unit area. For many types of sampling equipment and habitat conditions, power analyses have been performed. This type of information needs to be collated and synthesized with similar information for other aspects of field sampling (tables 4, 5).

One way to judge sample representativeness is to examine the precision of a given measure or metric by analyzing multiple collections from the same location by using the same collection and processing procedures. If the measure of interest displays an unacceptable degree of variability among replicates (as determined by the

Table 5. Benthic macroinvertebrate assessment for wadable streams: sample methodological variations in the context of the performance-based methods system

Site/habitat sampled	Collection procedure	Field variations	Preanalysis variations (for all field methods)
All available habitats (riffles, pools, flats, and so forth) or riffles only	Kick net	Period of kicking Intensity of kicking Net mesh size Number of kicks per site	Subsampling methods: Number of grids. Number of organisms. No subsampling
	Colonization baskets	Mesh size Colonization time Number of baskets per site Media in baskets	Taxonomic level: Genus/species. Family Varies with group.
	Hester-Dendy	Number of plates per site Colonization time	Use of tissue dyes.
Riffle areas only	Surber	Period of substrate Handling Intensity of handling Number of samples per site	Sieve size/screens.
	Hess	Period of substrate Handling Intensity of handling Number of samples per site	Sorting procedures: Sucrose gradient. Other.
	Common to all procedures.	Sample container Size Transfer of sample to containers	

DQO's), then sampling methods and (or) processing procedures may need to be modified The USGS National Water Quality Assessment (NAWQA) Program (U.S. Geological Survey, 1993) examined this issue in setting up their stream sampling program.

In the case of biological collection methods, many measures or metrics are potentially available for the same sample. Together, these measures may form an index or score and, eventually, a narrative rating of status (fig. 2). Certain measures, such as density, may exhibit considerable variability among replicate samples, while other measures, such as species and richness measures, may not. This information could be used to determine which measures or metrics should be examined by using a given sampling protocol and DQO's

For biological collection methods, method comparability could be determined if one knows how a particular metric of interest or assessment score behaves under different environmental conditions (impaired vs. reference sites, different habitat types, different seasons). Such information (obtained through repeated sampling at different times in the same location and sampling in different habitats and locations) would yield estimates of procedural bias, precision, interferences, and performance range (table 6).

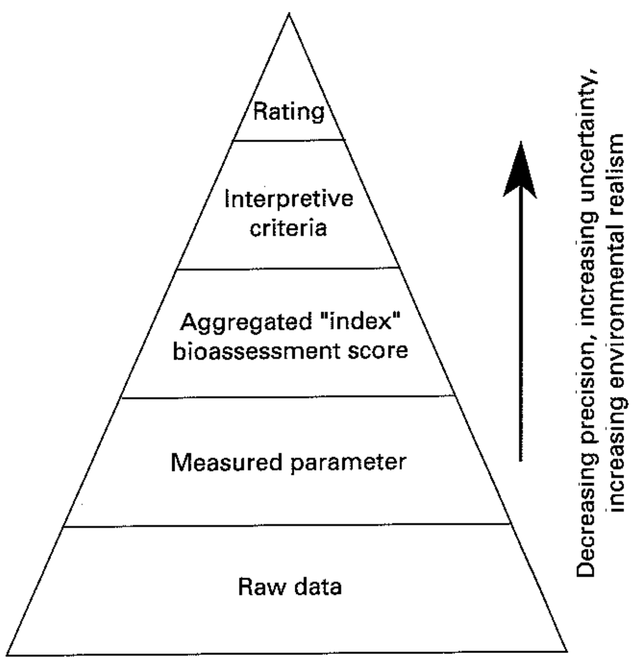

Figure 2. Data manipulation hierarchy of field-collected biological samples.

Table 6. Examples of ways in which various performance criteria could be addressed for biological collection methods

Performance criteria	Example of method requirement
Precision	Multiple reference sites; multiple samples within a site.
Bias	Reference "test" sites that provide consistent results
Performance range	Reference sites in different hydrogeomorphic regions; sampling different habitat types; efficiency of sampling device under different habitat conditions
Interferences	Knowledge of sampling device performance range; reference condition results; organism instar/size, sexual maturity–sampling index period
Multimedia applicability	Performance range of sampling device; applicability of metrics to different regions, habitats

Data Quality

Objectives of the data users will define which measure(s) and what environmental conditions should be used to determine comparability among methods. DQO's also will dictate how similar certain performance parameters need to be to consider two methods, and the data obtained, comparable. It is quite possible that two methods may be very comparable for certain measures of interest and not others. Knowing this, one could use data for those measures where different methods are comparable. This is the advantage of using a PBMS approach. The key is that performance characteristics are defined for each method and that the data user has access to comparability information when reviewing the data.

As mentioned above, many data levels are often available within a typical biological assessment (fig. 2). In addition to comparing certain metrics or indices among methods, it is possible (and sometimes necessary) to compare assessments or ratings. This is especially useful when the field-collection and the laboratory-analysis methods vary among two different procedures such that the two methods do not share specific metrics or indices in common. The most accessible procedure for comparing bioassessment methods is a side-by-side examination of assessment results [D. Lenat, North Carolina Department of Environmental Management, written commun., 1993; Indicators Task Group, written commun. (Draft Issue Paper), 1994]. A discussion of assessment comparability based on stream benthic macroinvertebrate and fish sampling is provided in the ITFM Indicators Task Group (Draft Issue Paper) [written commun., 1994]. Relevant to the present discussion, this paper shows that the paramount performance parameters in assessments are sensitivity or discriminatory power and consistency or reproducibility. Assessments that have greater sensitivity and reproducibility are judged to be more reliable than other assessments. Another result relevant to this discussion is that two assessments may be comparable for some types of sites or levels of impairment and not others.

Defining Performance Criteria for Biological Collection Methods

Biological collection methods (like chemical collection methods) utilize test sites and sites that comprise a known reference condition or reference sites (Technical Appendix F). In many ways, the reference condition is analogous to a chemist's blank; it represents the biological condition when minimum impairment (that is, minimum anthropogenic stressor) is present. Clearly, the chemical blank is a highly controlled entity that is dependent on the matrix, the analyte, and the analytical method being used. Similarly, the biological method blank or reference condition consists of carefully chosen sites that meet certain a priori criteria and is specific for a certain environmental stratum or regime (ecoregion, habitat, season).

An important first step of any biological collection method is to characterize performance parameters by using a given reference condition. This has been done, in part, by several States, some USEPA programs, and the NAWQA Program. In several different ecoregions, reference sites were sampled by using a prescribed method. In some cases, sites were sampled in more than 1 year so that a measure of temporal precision would be obtained for each metric and the assessment score as a whole. Measures for all reference sites within a given region were then compiled to derive the reference-condition characteristics for that region. If this approach is used in different ecoregions, one can obtain quantification of several important performance parameters (table 6). The following specific issues can be addressed for a given field method in this way:

- Precision for a given metric or assessment score across replicate reference sites within an ecoregion.

- Temporal precision for a given metric or score under reference conditions within an ecoregion.
- Bias of a given metric and (or) method owing to differences in ecoregions or habitats.
- Performance range of a given method across different ecoregions.
- Potential interferences to a given method that are related to ecoregional or habitat qualities.
- Relative precision of a given metric or score across reference sites in different ecoregions.

To examine comparability, the methods of interest need to be performed at the same reference sites and preferably at the same time (same seasons and similar conditions). The more reference sites mutually sampled, the better the test of comparability. If one method, for example, yields greater variability (less precision) in the same measure or in assessment scores among reference sites within an ecoregion than another method, then this might be a basis to define a performance criterion for precision. One can then determine method comparability and select an appropriate method, given certain DQO's.

The discussion thus far has been limited to reference sites and conditions. We still do not know how a given method performs over a range of impaired conditions. Unfortunately, we do not have available sites with different known levels of impairment or analogous standards by which to create a calibration curve for a given collection method. However, we can choose sites that have known stressors (urban runoff, metals, grazing, sediments, pesticides) and examine performance parameters for different methods at those sites. Because we cannot guarantee different sites with the same level of impairment within a region, we can examine precision of a method by taking and analyzing multiple samples from the same location.

To compare collection methods, we recommend using the raw metric values, composited multimetric scores, or percentage differences from reference values for each sample. One of the challenges in determining method comparability for bioassessments is that the endpoint or assessment scoring procedure may be intimately related to the type of field procedure used. Differences between methods may be reflected in the taxonomic level used to identify collected organisms and ultimately the actual metrics measured. The result is often a different scoring method to go along with the difference in sampling methods. This type of challenge is less common in analytical chemistry work. Prelaboratory methods (for example, sample collection, preservation) may be independent of the corresponding laboratory methods to a large degree; that is, different prelaboratory methods can then be subjected to the same laboratory analysis to compare prelaboratory methods. The discussion provided in the ITFM Indicators Task Group (Draft Issue Paper) [written commun., 1994] addresses this problem for bioassessments.

Figure 3 and table 7 show how two different methods could be compared by using reference-condition and test-site data. Two different ecoregions or habitat types are assumed in this layout. More habitats or ecoregions would improve determination of the performance range and biases for a given biological collection method. Five reference sites are assumed for each ecoregion; this is a compromise between effort and cost required and resultant statistical power. More reference sites (15 or more) would further refine method precision, performance range, and, possibly, discriminatory power. At least three reference sites in a given region should be considered to be a minimum to evaluate

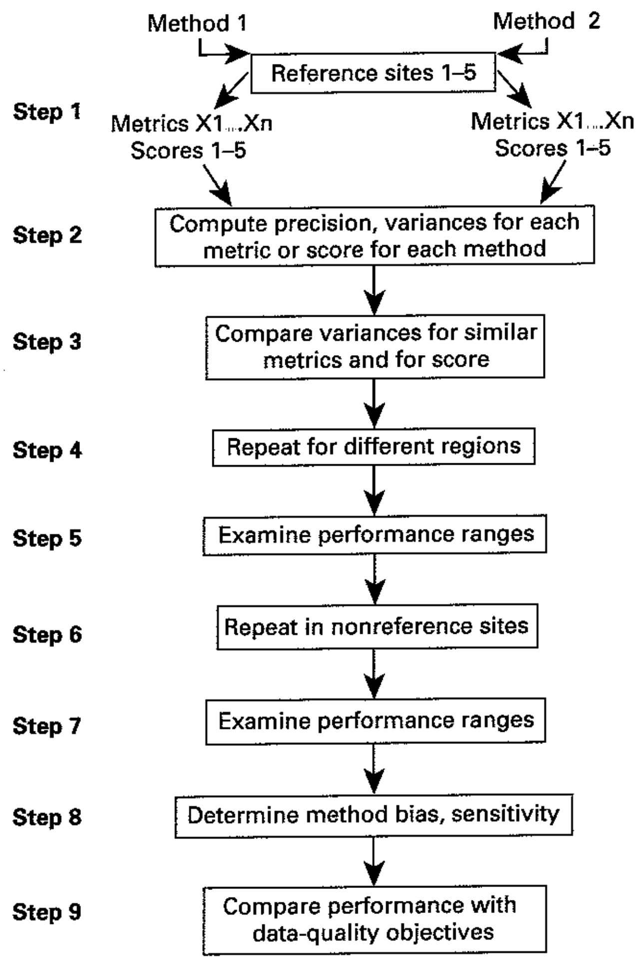

Figure 3. How two different field bioassessment methods could be examined to determine method comparability.

Table 7. Recommended process for documentation of performance parameters and comparability of two different bioassessment methods

[Five reference sites are assumed in this layout, but one could have a minimum of three sites for each region]

Endpoint	Region 1				Region 2			
	Reference numbers 1–5		impaired or test site		Reference numbers 1–5		Impaired or test site	
	Method 1, mean variance	Method 2, mean variance	Method 1	Method 2	Method 1, mean variance	Method 2, mean variance	Method 1	Method 2
$Metric_1$	$\mu_1 \pm s_1$	$\mu_2 \pm s_2$	m	p	$a_1 \pm d_1$	$a_2 \pm d_2$	c	q
$Metric_n$								
Assessment score	$\chi_1 \pm q_1$	$\chi_2 \pm q_2$	z	v	$b_1 \pm f_1$	$b_1 \pm f_2$	e	r

The following comparisons refer to the parameters specified above and are designed to yield various performance characteristics of a biological-field-collection method.

- Compare s_1 with s_2 for a given metric to determine relative precision of the metric for the two methods and an unimpaired condition.
- Compare s_1 with d_1 and s_2 with d_2 to determine how metric variability may change with a region A relatively high variability in a given metric within a region or compared with another region for the same method would suggest a certain performance range and bias for the metric
- Compare $m\mu_1$ with $p\mu_2$ to determine discriminatory power of a given metric by using the two methods in region 1. A ratio closer to 1 0 would signify little difference in the metric between an impaired site and the reference condition in region 1 for that method. The utility of the metric would be questionable in this case. Do the same type of analysis by comparing c/a_1 and q/a_2 for region 2
- Compare $m\mu_1$ with c/a_1 and $p\mu_2$ with q/a_2 to determine relative discriminatory power, performance range, and bases of a given metric and sampling method across regions A similar ratio across regions for a given metric may indicate the robustness of the method and the metric A ratio near 1.0 in one region and not in another for a given method and metric would indicate possible utility limitations or a limited performance range for that metric
- Compare q_1 with q_2 and f_1 with f_2 to determine overall method variability at unimpaired sites in each region High variability in the score for one method compared to another method in a given region would suggest lack of comparability and (or) different applicable data-quality operations for the two methods.
- Compare q_1 with f_1 and q_2 with f_2 to determine relative variability in assessment scores in the two regions. A consistently low score variability for a given method across regional reference sites would suggest method rigor and potential sensitivity.
- Compare resultant scores for a given method and region deleting apparently variable or insensitive metrics to determine metric redundancy and to determine relative discriminatory power at impaired sites.
- Individual assessment scores for reference sites and impaired sites within each region can be compared between methods by using regression to determine if there is a systematic relation in scores between the two methods.

method precision. Given the usually wide variation of natural geomorphic conditions and landscape ecology, even within supposedly "uniform" ecoregions, it is desirable to examine 10 or more reference sites in a region (Technical Appendix F).

A range of impaired sites within a region is suggested to sufficiently characterize a given method. It is important that impaired sites meet the following criteria:

- They are very similar in habitat and geomorphometry to the reference sites examined
- They are clearly receiving some chemical, physical or biological stressor(s) and have for some time (months at least)
- Impairment is not obvious without sampling; that is, the sites should not be heavily impaired.

The first criterion is suggested to reduce potential interferences owing to habitat differences between the test site and the reference sites. In this way, the reference site will serve as a true blank as discussed earlier. If one wanted to assess comparability of collection methods to detect physical habitat impairment, then this could be done by examining sites with different habitat deficiencies (for example, siltation, channelization, or lack of riparian vegetation) and no chemical stressors

The second criterion is necessary to ensure the likelihood that the test site is indeed impaired As discussed previously, it may not be known a priori that a given site is impaired. In this sense, accuracy cannot always be guaranteed for biological field methods. By selecting sites with no stressors (that is, wilderness, protected watersheds), as well as sites with known stressors (as discerned through laboratory toxicity tests, for example, using those stressors), we can increase our ability to test the accuracy of a given method Potential test sites might be a body of water that receives naturally high concentrations of chemical stressors, downstream of a point-source discharge known to contain toxic concentrations of pollutants, a water body that has been colonized by exotic "pest" species (for example, zebra mussel, grass carp), or downstream from a nonpoint-source pollutant (that is, sediment and nutrient enrichment from grazing). The test site must have measured data for the stressor(s) before biological sampling to document potential cause for impairment.

The third criterion is necessary to have a good test of comparability in terms of method sensitivity and performance range. A severely impaired site (that is, a site with a preponderance of one or two species or a site apparently devoid of aquatic life) is generally recognized as such with little or no formal sampling. This result was observed in comparing bioassessments [ITFM Indicators Task Group, written commun. (Draft Issue Paper), 1994]. Widely different assessment procedures typically yielded the same interpretation at such sites. A much better test of method sensitivity or detection limit, as well as its performance range, is to examine sites with some, but not severe, impairment present. To ensure that a given test site is somewhat, but not severely, impaired, one must rely on information that concerns the stressor(s) (second criterion). Ideally, it would be beneficial to examine several test sites in a given region, each with different stressors present and (or) different levels of the same stressor. Such a sampling design would enable the user to derive more precise estimates of the performance range and any biases of the method or its assessment scoring system.

Recommended Process for Documentation of Performance Parameters

Table 7 summarizes the suggested test design and recommended analyses that compose the process for documenting performance characteristics of a given method and the degree of data comparability between two or more methods. It should be stressed that the process outlined in table 7 is not one that needs to be implemented with every study. Rather, the process should be done programmatically at least once for every method to document the limitations and range of applicability of the methods. Performance characteristics, such as precision, bias, and performance range are quantified for a given biological collection of methods by sampling several (at least five) reference and test sites (nonreference sites) within at least three different ecoregions during the same time or index period (table 7). Thus, for developing performance characteristics for a given method, data from a total of at least 30 sites sampled within a brief time period (preferably within no more than a 2-week period) are needed. Performance characteristics are obtained by analyzing several properties of the data collected for a given method (table 7), which includes the within-ecoregion variability for a given metric or final score by using reference-site data for each ecoregion separately and among-ecoregion variability for a given metric or score by using reference site data from all ecoregions together. In addition, estimates of collection-method sensitivity or discriminatory power are obtained by comparing testsite data with reference site data within each ecoregion. The performance range of the method can then be defined by comparing the sensitivity of the method over the different ecoregions sampled. Once performance characteristics are defined for a given method, performance criteria can be established, as well as scientifically feasible data-quality objectives. As a result, a second collection method that demonstrates similar or better performance characteristics is able to meet the established performance criteria. Thus, the data generated by the second method are comparable to those generated by the first method, and data from the two methods can be used together with confidence.

In determining whether two collection methods give comparable results, note that method comparability is based, for the most part, on the relative magnitude of the reference site variances within and between ecoregions. We explicitly are not basing comparability on actual assessment scores because different methods may have different scoring systems. Likewise, we do not base method comparability on comparison of the actual metric values because some sampling methods may explicitly ignore certain taxonomic groups compared to other methods. However, if the user is especially interested in how different methods compare for a given metric, then this can be easily incorporated into the test design by comparing mean values for regional reference sites by using a paired t-test or nonparametric equivalent.

Although we do not base method comparability on the actual numeric scores because the true score is unknown, one may be able to detect a systematic relation of one method score with another method score by means of regression analyses by using data from this test design. If two methods show significant comparability based on similar performance parameters as discussed earlier, then it is possible to numerically relate scores of one method to the other. This situation would present a clear benefit of pursuing method comparability.

Actual mean scores or metric values are used in this test design only as a ratio between the impaired site and the regional reference value. This ratio is compared among methods to assess sensitivity and accuracy. Because impairment can only be judged relative to a reference or attainable biological condition in the absence of stressors, the score or metric at the impaired test site is not an absolute value and must be related to the appropriate reference-condition value.

Each method is described in the context of specific performance parameters, which include precision, bias, performance range, and sensitivity. Accuracy also is addressed to the extent that the test sites chosen are likely to be truly impaired on the basis of independent factors (presence of chemical stressors or suboptimal habitat features). A method that exhibits greater score variability among ecoregional reference sites may suggest less method precision in general. This would be translated as reduced certainty in the results of a given collection method. For certain DQO's, reduced certainty in the results may be satisfactory if the method has other advantages, such as reduced costs and short time to perform. The ITFM Indicators Task Group [written commun. (Draft Issue Paper), 1994] gives some basis to make these judgements and how to make such trade-offs.

The following example shows how two different methods can be compared with respect to different metrics or community measures for stream benthic macroinvertebrates. Both methods used the same sampling procedure and the same personnel at the same sites at the same times. The difference in the two methods pertained to the subsample sizes used for the laboratory and data analyses. In one method, a 100-organism random subsample was used, and in the other, a 300-organism random subsample was used. Table 8 summarizes the results of the two methods.

Differences in metrics or scores between the two methods are expressed as relative percent differences (RPD). It is evident that certain measures or metrics exhibit more variation between the two methods than others; however, all RPD's are less than 25 percent, which suggests good agreement between the two methods. These data suggest that under the sampling conditions and with the personnel performing the study, both subsampling procedures yielded comparable results.

Probably of greatest interest to those using biological collection methods and their results is the sensitivity or discriminatory power of the method; that is, how well does a given method detect marginally or moderately impaired sites? The suggested test design does not adequately address this question because only a few impaired sites are sampled for each region. However, if the test sites are carefully chosen (by using the second and third criteria discussed above), then one may have some indications of relative method sensitivity. A method that yields a larger ratio of test-site score to reference score would indicate less discriminatory power or sensitivity; that is, the test site is perceived to be similar to or better than the reference condition and, therefore, not impaired. If, however, the intent is to screen many sites to prioritize "hot" spots or significant impairment problems in need of corrective management action, then a method that is inexpensive and quick and tends to show impairment when significant impairment is actually present would be used. In this case, the DQO's dictate a low priority for discriminatory power and a high priority for accuracy in the decision; that is, a purportedly impaired site is truly impaired

Applicable performance range and bias are two other important performance parameters that relate

Table 8. Calculation of differences in Relative percent difference between two different subsample sizes from the same sample

[A, 100-organism subsample; B, 300-organism subsample. Data from unpublished U.S. Environmental Protection Agency study in southern New Hampshire]

Metric	Subsample		Relative percent difference
	A	B	
Number of taxa	25	31	21.4
Hilsenhoff biotic index	4.4	4.5	0.2
Ratio of scrapers to filter collectors	36.7	32.4	12.4
Ephemeroptera, plecoptera, trichoptera/chironomidae	75.9	80.8	6.3
Percent of contribution of dominent taxon	27.5	28.1	2.2
Ephermeroptera, plecoptera, trichoptera index	9	11	20
Shredders/total	9.3	7.7	18.8
Hydropsychidae/total trichoptera	92.3	94.1	1.9
Total score	34	34	0

directly to the overall utility of a given method and its comparability to other methods. These two parameters are characterized by sampling in different ecoregions that, by definition, have different physical habitat characteristics. The results of a comparison of a method that shows a higher precision among reference sites in one ecoregion or hydrogeomorphic basin/watershed compared with another similar biological method may be useful information for deciding where or when a given method should or should not be used. Similarly, a metric or score that exhibits a consistent bias related to certain measured habitat features would help the user decide the types of sampling situations in which a particular method may be appropriate. Clearly, the true performance range of a given method is complicated by the fact that several subprocedures or methods compose a field protocol (fig. 1; tables 1, 4). Each subprocedure has its own performance range. In principle, the performance range of a collection method is best characterized by examining the results over a range of habitat types appropriate to the sampling device being used. Such an examination also would be more likely to reveal method biases that could affect method precision and sensitivity.

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ACRONYMS USED IN THESE TECHNICAL APPENDIXES

ACWDPU	Advisory Committee on Water Data for Public Use
ACWI	Advisory Committee on Water Information
AMSA	Association of Metropolitan Sewerage Agencies
AMWA	Association of Municipal Water Administrators
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
BCI	Biotic Condition Index
BEST	Biomonitoring of Environmental Status and Trends Program (NBS)
CD-ROM	Compact Disc-Read Only Memory
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CNAEL	Committee on National Accreditation of Environmental Laboratories
CWA	Clean Water Act
DMIS	Data Management and Information Sharing Task Group
DMR	Discharge Monthly Report
DQO	Data Quality Objective
EMAP	Environmental Monitoring and Assessment Program (USEPA)
EMMC	Environmental Monitoring Management Council
EPA	Environmental Protection Agency
FGDC	Federal Geographic Data Committee
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FIPS	Federal Information Processing Standard
GAO	Government Accounting Office
GIS	geographic information system
GWFG	Ground Water Focus Group
HUC	Hydrologic Unit Codes
IACWD	Interagency Advisory Committee on Water Data
IBI	Index of Biologic Integrity
ICI	Invertebrate Community Index
ISO	International Standards Organization Guide
ITFM	Intergovernmental Task Force on Monitoring Water Quality
MDCB	Methods and Data Comparability Board
NAWQA	National Water Quality Assessment (USGS)
NBS	National Biological Service
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRC	National Research Council
NRCS	National Resources Conservation Service
NRDC	National Resources Defense Council
NWIS	National Water Information System
OMB	Office of Management and Budget
OPPE	Office of Policy, Planning, and Evaluation (USEPA)
OST	Office of Science and Technology (USEPA)
OWDC	Office of Water Data Coordination (USGS)
PBMS	performance-based methods system
QA/QC	quality assurance/quality control
RBP	Rapid Bioassessment Protocol
RCRA	Resource Conservation and Recovery Act
RF3	river reach file
RPD	relative percent difference
SAB	Science Advisory Board
SCS	Soil Conservation Service (Note: In 1994, the SCS became the National Resources Conservation Service)
STORET	STOrage and RETrieval System (USEPA)
TSCA	Toxic Substances Control Act
TVA	Tennessee Valley Authori
USACE	U.S. Army Corps of Engineers
USDA	U.S. Department of Agriculture
USDOI	U.S. Department of the Interior
USEPA	U.S. Environmental Protection Agency
USFS	U.S. Forest Service
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
WATSTORE	National WATer Data STOrage and REtrieval
WDNR	Wisconsin Department of Natural Resources
WEF	Water Environment Federation
WICP	Water Information Coordination Program