The scientific method and data collection

Water is our most precious and arguably most undervalued natural resource. It is essential for life on our planet, for food production and economic development. Moreover, water plays a fundamental role in shaping weather and climate. However, with the growing global population, the planet's water resources are constantly under threat from overuse and pollution. In addition, the effects of a changing climate are thought to be leading to an increased frequency of extreme weather causing floods, landslides and drought. The need to understand and monitor our environment and its resources, including advancing our knowledge of the hydrological cycle, has never been more important and apparent. The best approach to do so on a global scale is from space. This lecture provides an overview of the major components in the scientific methods for data collection.

Sound water-resource management depends on the availability of reliable scientific data on which to base management decisions. To serve this purpose, data-collection and analysis activities should be governed by a clearly articulated monitoring design based on project objectives.

Thus, any scientifically valid water-quality investigation requires:

(1) data that accurately represent the water medium sampled under the intended spatial and temporal conditions,

(2) use of appropriate methods that yield impartial and reproducible results, and

(3) data of the type and quality to satisfy the purpose for which the data are collected.

Documenting the quality of environmental data in monitoring programs is essential and integral to the entire data-collection, and relates to how methods are selected, implemented, and quality-assured for water-quality-related field activities and laboratory analyses. Placing an emphasis on the quality of the data produced, rather than on a particular data-collection method, furthers comparability and interpretability of data within and among projects and fosters opportunities for collaboration and comparability among the scientific, regulatory, and governments (both local and national) with other managing bodies such as the NEMA (National environmental management authority). This is of particular concern for long-term monitoring programs that seek to discern environmental patterns over time and across sampling locations, and for data sharing and synthesis over local, regional, and national scales. Costly duplication of efforts often can be avoided when data-collection organizations use a standard practice for determining data comparability that is based on data quality. Emphasis on data quality also results in greater flexibility in methods selection and greater latitude in using and comparing new data-collection technologies as they become validated and available. Recently, new tools and guidance have become available to help organizations:

(a) determine the appropriate level of data quality needed for a given objective;

(b) quantify or otherwise measure and document the quality of the data collected; and

(c) select appropriate and compatible field and laboratory methods that will produce data of known and acceptable quality.

The availability of scientific tools is intended to improve the quality and transferability of data being collected, including data collected for purposes other than those for which the data were originally collected.

Determining field and laboratory methods from project objectives.

Accurate data, using the best possible methods, are useless if they do not address the study or program objectives. The strategy for collecting the data needed to meet the goals of a water-quality monitoring project involves a process that is interwoven iteratively with the scientific approach developed for the project as whole, with particular emphasis on monitoring objectives and study design, but also including managing and interpreting the data. Thus, the field and laboratory methods that should be used in a project will depend on the questions being asked, the decisions to be made based on the data collected, and the acceptable degree of risk in reaching an incorrect conclusion or decision.

To bring insight and intelligence to the monitoring effort, all project personnel should understand the purpose of the investigation and the study design. They also should understand project objectives sufficiently to determine when conditions exist that are adverse to fulfilling project objectives using pre-selected methods, and be cognizant of acceptable alternative approaches.

Defining Data-Collection tasks: Sampling and Analysis Plans.

The collection of scientifically defensible water-quality data depends not only on consistent implementation of appropriate methods based on project objectives, but also on clear instructions to the data collectors, meticulous documentation of the methods used, and data verification. Development of these project plans is an essential tool in the conduct of any environmental investigation and is an indispensable reference, both for the team charged with collecting the data and often for later interpretation and assessment of results. Although commonly treated as separate and independent operations, the field and laboratory components of the data collection process actually form a continuum in which the field and laboratory methods must be compatible with each other as well as project objectives. The evaluation of routine sampling and quality control methods, or development of new methods, is as important as the choice of analytical methods in terms of minimizing sample bias or interferences. As laboratory method-detection levels decrease, sample vulnerability to contamination tends to increase exponentially, and, consequently, field sampling methods must be able to maintain sample integrity to accommodate the heightened analytical sensitivity.

Field Methods.

A fundamental requirement for data collection activities involve an awareness and implementation of “good field practices;” for example, using standard procedures to prevent sample contamination, ensuring that data accurately reflect the characteristics of the sample collected, and integrating quality-control measures into all field activities. Standard quality-assurance procedures need to be examined, refined, and often customized project by project, according to known and anticipated site conditions, the resources and objectives of the investigation, and the data-quality requirements for the investigation. Thus, field methods must:

• Be capable of producing a sample without introducing a negative or positive bias to the data with respect to the detection level of the laboratory analytical method selected for the constituent(s) of interest;

• Incorporate quality-control measures to determine the range of variability to be associated with the sample data;

• Be thoroughly documented so that different methods can be compared with respect to the quality of the data they ultimately produce;

• Be consistently implemented, so that the data produced are comparable.

In order to define data-collection tasks for field personnel, a Sampling and Analysis and Quality-Assurance Project Plans are best developed iteratively and as a team. These plans should specify:

(a) the types and minimum number of quality-control samples to be collected;

(b) the qualifications and training needed by data collectors and other project personnel; and (c) a safety plan that specifies site-specific known or anticipated hazards. In addition, a list of required minimum data elements.

When samples are collected from the field for laboratory analysis, they should be handled, preserved, and stored as indicated in the Sampling and Analysis and Quality-Assurance Project Plans and by the laboratory performing the analysis.

Laboratory Methods.

Laboratory methods should meet many of the same attributes listed above for field methods. Accurate and complete documentation of records is necessary. The project's sampling and QA plans should stipulate any non-routine laboratory sample-handling procedures in addition to the analytical methods selected. In particular, laboratory methods should:

• Be conducted in an independently accredited laboratory.

• Meet the precision, accuracy, bias, sensitivity, and other data-measurement and data-quality requirements defined for the project in the matrices analyzed.

• Incorporate on-going Quality Assessments/ Quality Checks protocols that document the quality of data generated.

• Be thoroughly documented and validated.

• Be consistently implemented by trained analysts using appropriately calibrated equipment • Ensure that sample holding times and preservation conditions are not exceeded. Method performance in certain matrices (e.g., certain types of wastewater effluent, groundwater, leachates, or even some drinking waters high in dissolved solids) may be far different (poorer) than those same method characteristics based on laboratory reagent water or other relatively simple matrices. Unless a laboratory conducts rigorous quality-control analyses on the matrix it is analysing (which is now required in many newer compliance methods and should allow comparability to be assessed more easily), one cannot assume that the performance characteristics reported for the method have been achieved by a given organization or program. Therefore, it is imperative that a laboratory archive permanent records of its on-going performance of a method.

Data Integrity.

Data integrity is critical because data accuracy is paramount to judging environmental compliance with applicable laws and for making correct management decisions. To regulatory authorities, data integrity issues are perhaps the most serious of all violations because such questions lead to the suspicion of fraud. To non-regulatory agencies, data integrity is equally important, since data generated is the basis for scientific and policy decisions that extend from local jurisdictions to the national level.

The lack of data integrity refers not only to incorrect data but also to misleading or missing data, to statements that are incomplete, misleading, or withheld, and to initials or signatures that are misleading or not properly executed. These problems may lead to data being deemed unusable, suspicion of fraud, and valuable resources wasted. A signature on any sampling or analysis record (e.g., field and laboratory notebooks, sample chain-of-custody forms) indicates that the signer has entered information or data accurately, reviewed the document, agree with its content, and has confirmed to the best of their ability its completeness and conformance to established standards or procedures. A signature also indicates that the signer has proper knowledge and training to review the document being signed. Data-entry mistakes are a common cause of data-integrity loss, and should be remedied by a rigorously implemented system of independent checks and audits of hand-written or electronic data entries and computer-generated data tables or graphics.

Future Directions.

With the increasing awareness of potentially widespread health and environmental effects of various human-made chemicals and biological pathogens, there has been greater attention placed on monitoring new analytes and/or developing better technologies for detecting known contaminants at lower concentrations. Many of these require new technologies, necessitate extensive method development and validation. Validation of laboratory methods for new analytes is difficult because appropriate reference methods and reference materials are often lacking. A much wider array of reference materials, in different realistic matrices, will be needed to help validate new methods. Another challenge is demonstrating method comparability and performance criteria that meet regulatory objectives. Moreover, existing field methods and quality-assurance procedures for sample and data collection for these emerging analytes need to be evaluated and adjusted or new methods developed and tested. The attention on homeland security, as well as other emergency situations, has also increased the demand for rapid methods and/or technologies that can measure analytes in situ. In many cases, private vendors are developing test kits or other rapid techniques, which analyze constituents that are generally measured using traditional laboratory methods. A challenge in these cases is demonstrating method comparability and satisfactory method performance that meets regulatory objectives. The increasing usefulness of remote sensing technologies to detect water quality patterns is another of the many areas that may change the way in which environmental data are collected in the future.

Documentation of methods performance and data quality in data-collection activities for water-quality monitoring studies is the scientific foundation for collaboration and comparability among public and private-sector investigations. By documenting the quality of data obtained using given data collection methods, it is also possible for other organizations to determine whether those data are suitable for their use. The selection of appropriate field and laboratory methods is driven by the need to ensure that project objectives are fulfilled. Determining a project's measurement-quality requirements is facilitated through a systematic process to determine data-quality objectives, and is implemented by active use of project-developed sampling and quality-assurance plans. Finally, confidence in the quality and impartiality of the data collected must be ensured through a rigorous system of quality-assurance protocols, training, performance and data audits, and peer review. With the advent of more affordable and usable technologies at our disposal, data-collection methods will become more refined, resource-efficient, and, perhaps more automated. Regardless of the methods used, however, the basic principles of data collection outlined in this lecture remain the same. Consistent use of these principles will improve the quality and usability of environmental data, thereby enhancing the water management goal of improving the quality of information used in environmental decision-making.

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