IN SEARCH OF A COMMON WATER QUALITY MONITORING FRAMEWORK AND TERMINOLOGY

Robert C. Ward[1], Jos G. Timmerman[2], Charlie A. Peters[3] and Martin Adriaanse[4]

[1] Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado, USA;
[2] Institute for Inland Water Management and Waste Water Treatment (RIZA), The Netherlands
[3] U.S. Geological Survey, Middleton, Wisconsin, USA
[4] UNEP/GPA, The Hague, The Netherlands

Water quality monitoring, as a subject of interest to both water quality managers and researchers, involves a wide variety of highly integrated activities and functions. In turn, monitoring involves a number of disciplines (e.g. chemistry, biology, statistics, and hydrology). Furthermore, water quality monitoring is conducted by a wide variety of organizations with different missions (e.g. water quality management agencies, wildlife management agencies, natural resource management agencies, water research organizations, and water providers). The U.S. National Water Quality Monitoring Council and the UN/ECE Convention for Protection and Use of Transboundary Waters developed similar graphics to represent the integrated nature of monitoring activities and tasks, referred to, respectively, as a monitoring framework and a monitoring cycle. Both graphics clearly illustrate the diversity of disciplines and knowledge required to design, implement and operate water quality monitoring systems today. The logic and rationale behind each attempt to 'define' water quality monitoring, along with the terminology employed, is explored in the paper. Similarities embedded in the two efforts will be identified and discussed and differences will be examined to see if they can be resolved in a search for a common approach to water quality monitoring. Such an assessment of monitoring concepts and terms is viewed as a key component in achieving consistency and comparability in the data and information produced by water quality monitoring programs.

Keywords: Monitoring framework; monitoring cycle; monitoring terminology; data comparability.

INTRODUCTION

The United Nations Economic Commission for Europe (1996) and the U.S. National Water Quality Monitoring Council (2002) organized the highly diverse, yet strongly inter-connected, tasks associated with water quality monitoring into a structured format to facilitate harmonizing monitoring efforts with the ultimate goal of producing consistent and comparable data and information in support of fair and equitable management decision-making. Both efforts involved collaboration among a broad array of organizations to formulate a common understanding of monitoring. Communication of a common understanding of monitoring, in both cases, is enhanced by acceptance of a graphic, along with detailed descriptions, that portray the sequence of diverse tasks required to produce management relevant water quality information.

In both the European (as represented by the work of the UN Economic Commission for Europe) and U.S. (as represented by the work of the National Water Quality Monitoring Council) efforts to portray a common understanding of water quality monitoring, there are common elements and thinking as well as key differences. The purpose of this paper is to explore the history, logic and rationale behind both efforts to 'define' water quality monitoring. The exploration involves comparing the formation and presentation of the categories of monitoring tasks, contents of the tasks, and terminology employed. General similarities of the two efforts will be identified and discussed and differences will be examined. Such an assessment of monitoring frameworks and terms is viewed as a key component in developing a common frame of reference for achieving consistency and comparability in the data and information produced by water quality monitoring programs.

THE NEED FOR A COORDINATED APPROACH TO WATER-QUALITY MONITORING

Why do monitoring professionals in Europe and the United States feel, separately, the need to develop a monitoring framework or cycle to organize the design and operations of monitoring programs? The rationale tends to go something like this: "To design a water monitoring system that is information-goal oriented, as well as accountable for the information produced, the activities involved in monitoring must first be organized and coordinated." There is a general recognition that the activities involved in monitoring are not well balanced and connected with respect to producing management-oriented information. Thus, efforts in both Europe and the United States have attempted to provide a conceptual means for approaching organizing and coordinating monitoring efforts.

With the various types and purposes of monitoring that exist in the U.S. and Europe today (e.g. ambient, process, trend, biological, compliance, and groundwater), the difficulty in developing a common vision of what constitutes an organized water information (monitoring) system becomes obvious. Where is the common terminology for monitoring? Where is the common framework for approaching the task of producing consistent and comparable water data and information?

Past definitions of water monitoring tended to focus on the means for collecting data, the science involved in the laboratory, or the location of water in the hydrological cycle, and not on the information purpose for monitoring (ITFM, 1995). 'Credible data' laws, passed by several state legislatures in the U.S., reflect a need of elected bodies to define the nature of data employed in water quality management decision-making
(e.g. http://www.deq.state.mt.us/wqinfo/datamgmt/PDF/SufficientCredibleData.pdf).
The Federal Data Quality Act, passed as Section 515 of the Treasury and General Government Appropriations Act of 2001 (P.L 106-544, H.R. 5658), directed the Office of Management and Budget (OMB) to issue government-wide guidelines that "provide policy and procedural guidance to Federal agencies for ensuring and maximizing the quality, objectivity, utility, and integrity of information (including statistical information) disseminated by Federal agencies." (NCWRRI, 2003). The final OMB guidelines (http://www.whitehouse.gov/omb/fedreg/reproducible.html) discuss the relationship between this law and the Safe Drinking Water Act requirements for monitoring and reporting the quality of drinking water to citizens in ways that point to a general framework for monitoring water quality.

In some ways, the need for credible-data and data-quality laws implies that the monitoring community has not established a common, well accepted, monitoring framework for producing information for management decision-making. This same point has been made in such reports as the Public Employees for Environmental Responsibility (1999), General Accounting Office (2000) and the National Research Council (2001). Currently the General Accounting Office is conducting a new study for the U.S. Congress to answer the following four questions:

1. What are the key entities that collect water quality and water resources data?
2. To what extent are these data collection efforts coordinated?
3. What steps can be taken to improve coordination in the data collection efforts of these and other groups?
4. What steps must be taken to permit integration of data from separate collection efforts to allow their use for any watershed management effort?

The European Union's Water Framework Directive, which addresses monitoring much more directly than the U.S. Clean Water Act (Habermann and Ward, 2002), distinguishes between surveillance monitoring, operational monitoring, and investigative monitoring. Surveillance monitoring is done to supplement and validate impact assessment procedures, for the design of future monitoring programmes, and for the assessment of long-term changes both in natural conditions and changes resulting from anthropogenic activities. This monitoring is done to keep track of changes in the water body. Operational monitoring is carried out for all those bodies of water, which on the basis of either the impact assessment or surveillance monitoring, are identified as being at risk of failing to meet their environmental objectives and for those bodies of water into which priority list substances are identified as being discharged. Investigative monitoring, finally, is carried out when the reason for any exceedance of standards is unknown, when surveillance monitoring indicates that the environmental objectives for a body of water are not likely to be achieved in order to ascertain the causes of the failing, or to ascertain the magnitude and impacts of accidental

pollution. This is what is generally called a survey. The above approach is very much procedural while the different types of monitoring are further specified and minimum frequencies are indicated in the Water Framework Directive.

Accurate, cost-effective and efficient assessment of the U.S. or European water resources—within and among watersheds— requires that monitoring entities work collaboratively and strive for comparability in methods and data management. Therefore, the design and implementation of assessment and management programs should be a cooperative product of the various monitoring agencies and organizations active in any given watershed. The first step toward being able to collaboratively and effectively employ the limited water monitoring resources is to agree on a common framework for monitoring that recognizes and addresses the objectives of each of the monitoring entities in a watershed.

MONITORING FRAMEWORK DEVELOPMENTS IN EUROPE AND U.S.

United States

Development of a monitoring cycle or monitoring framework, that is widely understood and accepted, has escaped the water monitoring profession for many years. In the U.S. the need for a monitoring framework was recognized shortly after Congress passed the Federal Water Quality Act of 1965, which required states to establish monitoring programs. Once the states initiated monitoring, with very little guidance, there were questions as to whether the monitoring programs were producing the information needed to comply with the law.

Snider and Shapiro (1976) developed a set of procedures for evaluating the operations of a water quality monitoring network. Such an evaluation, however, required that the operations be categorized and defined. The framework employed by Snider and Shapiro (1976) contained the following operations: 1) Network plan and design; 2) Personnel; 3) Facilities and equipment; 4) Sampling; 5) Quality assurance; 6) Data distribution and utilization; and 7) Agency interactions.

The U.S. Environmental Protection Agency (1977) described a 'Basic Water Monitoring Program' that was designed to provide 'a basic structure which, when realized, will contribute to a more effective use of our water monitoring resources.' The report addressed the following topics, one per chapter of the report: 1) Quality assurance; 2) Intensive survey program; 3) Ambient monitoring; 4) Effluent monitoring; 5) Proposed biological monitoring; and 6) Data interpretation and reporting.

Rickert and Hines (1975), in describing a framework for assessing water quality, included eight elements: 1) Delineation of river-quality problems; 2) Analysis of river hydrology; 3) Selection of assessment methods; 4) Identification, collection, and collation of required data; 5) Data analysis, method formulation, and the testing of predictive capability; 6) Forecasting impacts on planning alternatives; 7) Communication of results; and 8) Program evaluation.

Ward (1978), after reviewing the various purposes of monitoring associated with routine and special survey monitoring, proposed the concept of a 'water-quality information system' as a means of organizing the activities of monitoring around a clearly defined information goal. The activities included: 1) Network design; 2) Sample collection; 3) Laboratory analysis; 4) Data handling; 5) Data analysis; and 6) Information Utilization.

The Intergovernmental Task Force on Monitoring Water Quality (1995a), after identifying five general purposes of monitoring, proposed a framework for water-quality monitoring consisting of the following components: 1) Purpose; 2) Coordinate/collaborate; 3) Design; 4) Implementation; 5) Interpretation; 6) Evaluate monitoring program; and 7) Communication. Lack of agreement on the generality of the proposed ITFM monitoring framework seems to be reflected in an ITFM (1997) report that defined a conceptual framework for ground water-quality monitoring.

More recently, the U.S. Environmental Protection Agency (2003) proposed ten elements that should be common to water monitoring and assessment programs operated by state agencies (Monitoring Program Strategy; Monitoring Objectives; Monitoring Design; Core and Supplemental Water Quality Indicators; Quality Assurance; Data Management; Data Analysis/Assessment; Reporting; Programmatic Evaluation; and General Support and Infrastructure Planning).

The National Water Quality Monitoring Council, a 35-member organization, co-chaired by the U.S. Geological Survey and the U.S. Environmental Protection Agency, currently shoulders the burden of developing a common, widely accepted, monitoring framework for the U.S.

Europe

Regular water quality monitoring was established in a few European countries in the 1950's and, by the late 1960s and 1970s, had been initiated in most of Western Europe (Meybeck 1989). Before this time, studies were conducted whenever pollution problems occurred, but slowly water managers came to realize that the studies were stretching out all over each country and that a more structured approach to information gathering was necessary. National legislation steered these developments. European-wide water legislation was initiated in 1975 as individual legislation on specific topics begin to appear: drinking water first, follow by polluting substances, fish waters, shellfish waters, bathing waters and groundwater (Blöch 1999).

The growing, and shifting, information needs had consequences for monitoring. In the 1950s and 1960s, information collected through monitoring was felt as essential for water management and the budgets for monitoring were rapidly growing. As the resulting information did not always satisfy the management needs, a more critical attitude towards monitoring was taken and by the end of the 1980s budgets became restricted, not in the least because the severe pollution situation no longer existed and political attention for water quality issues decreased. Furthermore, the increasing availability of information allowed scientists to better tune their monitoring networks and reduce the bulk of data without losing much of the information. As a result, much attention was focused on optimization of monitoring networks. This focus generated a series of Monitoring Tailor-made (MTM) conferences, held in The Netherlands, that began to seriously re-evaluate how society optimizes water quality monitoring.

In the 1990s, efforts were undertaken to improve monitoring of transboundary rivers. A monitoring framework was deemed an important feature of efforts to develop consistent and comparable data in support of transboundary management efforts. Groot and Villars (1995) and Niederlander, et.al (1996) provide discussion of the need for a common framework and suggest monitoring frameworks for use in the upcoming harmonization of monitoring programs. In the mean time, efforts to implement the UNECE Water Convention (UNECE 1992), covering large part of the European Union, especially after the enlargement, created a strong push to develop a common way to view water quality monitoring, i.e. a "monitoring cycle."

In the first MTM conference, Cofino (1994) outlines the need for enhanced quality in monitoring programs and presents a way of viewing monitoring as a cycle of activities. As the efforts in The Netherlands (including the MTM conferences) were merged with the UNECE Task Force goal of producing monitoring guidelines for transboundary rivers, a monitoring cycle resulted. It was first presented in UNECE (1996), but has been further discussed and refined in a number of papers (e.g. Adriaanse, 1996; de Jong and Timmerman, 1996; and UNECE, 2000). An overview of the monitoring framework thinking emerging from Europe during the 1990s is presented in Timmerman, et al (2000).

In 2000, the European Water Framework Directive was approved with strong guidelines provided for how water quality monitoring was to be undertaken (Timmerman, et al, 2002). Thus, the UNECE monitoring cycle was developed, collaboratively, before a stronger guidance for monitoring was required in Europe. The U.S. monitoring framework was developed, collaboratively, long after a major new water quality law was implemented in the U.S.

THE MONITORING CYCLE AND MONITORING FRAMEWORK

European Monitoring Cycle

The UN/ECE Task Force on Monitoring and Assessment (1996, 2000) provides a review of the monitoring guidance being implemented in Europe using a monitoring cycle to help make the connections needed to insure efficient and effective water quality monitoring within transboundary rivers. Quoting:

> "The process of monitoring and assessment should principally be seen as a sequence of related activities that starts with the definition of information needs, and ends with the use

of the information product. ... Successive activities in this monitoring cycle should be specified and designed based on the required information product as well as the preceding part of the chain. In drawing up programmes for the monitoring and assessment of river basins, riparian countries should jointly consider all stages of the monitoring process."

The cycle of monitoring activities is shown in Figure 1 .

Figure 1. The European Water-Monitoring Cycle (UNECE TFMA 2000)

The monitoring cycle is based on the assumption that adequate information and public access to the information are necessary pre-conditions for the protection and use of transboundary waters and for the implementation and enforcement of the UNECE Water Convention. The ultimate goal of monitoring is to provide the information needed to answer specific questions in decision-making. Thus, the most critical step in developing a successful, tailor-made and cost-effective monitoring program is the clear definition and specification of information needs. The term "information needs" means a precise question on which information has to be provided within a certain context. Information needs have to be specified to such an extent that design criteria for the monitoring and assessment system can be derived.

After the specification of the information needs, assessment strategies are required to design and operate monitoring programs in such a way that the desired information is obtained. Strategies define the approach and the criteria needed for a proper design of the monitoring program. Thus they imply the translation of information needs into monitoring networks.

The design and operation of monitoring programs includes many aspects, such as field measurements, sampling (sample collection, pretreatment, method of storage and transport), chemical analysis and data collection. Therefore, in the process equal attention should be paid to all those elements. The design of a monitoring program includes the selection of parameters, locations, sampling frequencies, field measurements and laboratory analyses.

Data produced by monitoring programs should be validated, archived and made accessible. The actual goal of data management is to convert the data into information that will meet the specified information needs and the associated monitoring objectives. The combined use of data from multiple sources makes high demands on the data exchange and the data management system used.

Reporting is the final step in the gathering of information and links this process to the information users. The main issue here is to present the (interpreted) data in an accessible way. How this information is to be presented strongly depends on the audience that is addressed. Reports should be prepared on a regular basis. A report is not necessarily printed on paper, any form, like oral or digital, can be appropriate. The content of the report, varying from transferring data analyses to a brief overview of the conclusions, the frequency, and the level of detail depend on the use of information. For instance, technical staff will need detailed reports more frequently than policy makers. For a complete description of the monitoring cycle, refer to UNECE Task Force on Monitoring and Assessment (2000).

With approval of the Water Framework Directive in 2000, efforts are underway to develop more detailed monitoring guidance. A WFD Common Implementation Strategy on monitoring was prepared by Working Group 2.7 (http://forum.europa.eu.int/Public/irc/env/wfd/library). The guidance is focused on the design of monitoring programs that satisfy WFD Articles 8 and 11 and Annex V. The guidance provides a common understanding of monitoring terms and concepts; selection of indicators/constituents to measure; identification of water bodies to sample as well as location and sampling frequencies; and examples of good national monitoring programs. The guidance also notes what the reader will not find: determination of reference conditions; development of assessment and classification systems; monitoring of wetlands; and data analysis and reporting. Current efforts are directed at implementing the strategy. Although referred to in the document, the monitoring cycle is not included as a common framework.

U.S. Monitoring Framework

The U.S. National Water Quality Monitoring Council, established in 1997, was created for the following purpose:

> "The purpose of the Council is to provide a national forum for coordination of consistent and scientifically defensible methods and strategies to improve water quality monitoring, assessment, and reporting. The Council promotes partnerships to foster collaboration, advance the science, and improve management within all elements of the water quality monitoring community, as well as to heighten public awareness, public involvement, and stewardship of our water resources."

In its work to develop consistent and scientifically defensible water quality data and information, the need for a widely agreed upon monitoring framework was recognized. A framework was deemed useful to:

- Guide the activities of the National Water Quality Monitoring Council and Methods and Data Comparability Board (Board) by identifying, connecting, and prioritizing specific aspects of the various framework elements;
- Facilitate communication among professionals and volunteers working in different aspects of monitoring (e.g. laboratory analysis and data analysis/interpretation);
- Guide the design of water quality monitoring programs to insure that all components are included, balanced, connected, and collectively focused on producing information; and
- Respond to the need for a warehouse of consistent information on water monitoring design methodologies (e.g. provide "one-stop shopping" for the water monitoring community charged to produce consistent and comparable information for fair and equitable management decision-making).

The Council defines a 'monitoring system', or framework, by the flow of "information" through a series of sequential activities, each of which carefully builds upon the earlier steps to ultimately produce and convey water information. Before the flow of information can begin, on an operational level, the information goals must be defined along with a monitoring strategy designed to meet the goals. A monitoring design must be completed to guide operations involved in obtaining the desired information.

Once operation of a monitoring system starts, the flow of water information begins at the interface between the water and monitoring system personnel - the collection of the sample. Measurements are made, either in the field or on the sample in a laboratory, to convert the water's properties into numbers. The measurements can be physical, chemical or biological in nature. Thus, collecting data in the field and laboratory is a major, i.e. costly and time consuming, activity involved in a monitoring framework.

Data are stored in an electronic data storage and retrieval system. Such a component, within an information system, acknowledges that data records require careful organization, in a timely fashion, for data analysis and interpretation. It is important that the data in the data storage system include sufficient descriptive information, about the data ("meta data"), so that data can be shared and compared among managers and the public. Managing data, thus, represents a major 'cog' in a monitoring framework.

At the point when sufficient data are available to support analysis for an identified information goal, data analysis and interpretation, via graphical presentation, statistics, modeling, or some combination of these, takes place. The choice of data analysis methodology depends upon the information sought; however, there are no widely accepted 'standard' data analysis or interpretation methods that result in consistent and comparable information for management purposes. Ideally, the data analysis methods have been identified prior to sampling and peer reviewed so that the data are collected in direct support of the data analysis methodology, and recognizing the assumptions inherent in data analysis methodologies. Thus, interpreting the data for the purposes intended represents a 'cog' in the monitoring framework.

The results of the data analysis are incorporated into reports, or made available on the internet, for use by water quality managers and/or the public. Conveying information and results to information users may take many forms, depending upon the information need, timeliness sought, and the management style of the decision maker. Again, there are no 'standard' methods for reporting and conveying water quality information from monitoring programs.

The components of monitoring can be graphically represented as a 'framework' as in Figure 2.

Figure 2. – NWQMC Proposed Framework for Water-Quality Monitoring Programs

The graphical representation of the framework includes six interconnected primary elements (or 'cogs') held together by the three C's (collaborate, communicate, coordinate). The National Water Quality Monitoring Council is currently developing the information infrastructure (Information Technology) to permit data, and information about data, to move seamlessly around the framework. The framework provides the common basis for using information technology to manage monitoring operations in a highly integrated manner.

Thus, the development of a monitoring framework has been a long time, but elusive, goal of the monitoring community. The need for a well-defined and widely agreed upon monitoring framework has been reinforced by much of the "information revolution" thinking that was initially articulated by Naisbitt (1982) and the rapid development of information technology that followed.

SIMILARITIES AND DIFFERENCES IN THE MONITORING CYCLE AND MONITORING FRAMEWORK

Similarities in the two monitoring constructs begin with the emphasis upon identifying the information goals of the monitoring effort as well as preparing, and documenting, a formal monitoring system design targeted to meet the information goals. Similarities continue with the sample collection, laboratory analysis, data handling, data analysis and interpretation, and reporting, although the exact words used to describe elements of monitoring are different (see direct comparison in Table 1).
A similarity between the two monitoring constructs arises from the fact that neither effort contains, at the present time, an agreed upon glossary of terms associated with its implementation and use. Monitoring frameworks, by portraying a common view of the major components of a monitoring

system, facilitate development of a common vocabulary across 'cogs', disciplines, agencies, and countries. This aspect of monitoring frameworks can be seen in the glossary developments currently underway by the NWQMC as well as by the WFD guidelines development efforts. The NWQMC effort can be reviewed at: http://water.usgs.gov/wicp/acwi/monitoring/glossary.html.
Now the question arises, can there be one glossary for the science and management of water quality monitoring systems, in English, for the world?

UNECE Monitoring Cycle	U.S. Monitoring Framework
Information Needs	Develop Monitoring Objectives
Assessment Strategies Monitoring Programs	Design Monitoring Program
Data Collection	Collect Field and Lab Data
Data Handling	Compile and Manage Data
Data Analysis	Assess and Interpret Data
Assessment and Reporting	Convey Results and Findings
Information Utilization Water Management	Understand, Protect, Restore Our Waters (Center wording on Framework Graphic)

Table 1. Direct Comparison of Elements of the UNECE Monitoring Cycle with Elements of the U.S. Monitoring Framework

Another similarity is the mixing of design and operational activities in the graphics. This results from, in general, the thinking of monitoring as a program that must first be designed and then operated – moving toward one information product. Monitoring within 'routine' water quality management, however, may be viewed as having many information products, thus 'design' steps or cogs generally occur with much less frequency than production of information products. Ward, et. al (1990) separate design of a monitoring system from its definition operationally. In other words, they view the highly repetitive operations of monitoring, from sample collection to reporting, as being the focus of design. Design is not viewed as a routinely repetitive aspect of the day-to-day operation of a monitoring program. Designs must be updated, but they are not repeated as frequently as, for example, a sample is collected. The monitoring cycle and monitoring framework, in this sense, both mix design with operation.

The major difference between the UNECE monitoring cycle and the U.S. monitoring framework is the inclusion, in the U.S. version, of the outer ring of collaboration, communication and cooperation – the three C's. The U.S. emphasis on the three C's stems, in many ways, from the fractured way water management is organized at all levels of government. For example, besides water quality management programs operated under the U.S. Environmental Protection Agency, the U.S. Forest Service, the National Park Service, the Bureau of Land Management, the Corps of Engineers, the Bureau of Reclamation, the Natural Resources Conservation Service, the U.S. Geological Survey, fifty state agencies, Native American tribes, and volunteers also need and independently acquire water quality data and information. Thus, to avoid duplication and waste of taxpayer funds, the agencies are encouraged to coordinate monitoring efforts. The National Water Quality Monitoring Council is one means for such cooperation.

It was the need to cooperate on transboundary rives in Europe that led to the UNECE monitoring cycle (under the Convention of Protection and Use of Transboundary Waters, 1992). The goal of the Convention was to have management of transboundary waters be a collective responsibility of joint countries and the design of supporting monitoring programs be a joint exercise. Collaboration, communication and coordination were implicit priorities in the Convention.

While both graphics employs 'arrows' to connect monitoring components, the arrows are defined differently. The monitoring cycle is clear in its sequence of monitoring events, while the monitoring framework uses arrows to convey both the connection of 'cogs', but also the feedback deemed critical to smooth connections among monitoring components. Thus, the monitoring framework has large arrows embedded in the graphic to illustrate the major flow of activity through monitoring, but it also employs a faded arrow, moving backward, to denote feedback.

Another difference appears in the connections to management. The monitoring cycle includes a box to emphasize water management as the key driving force behind efforts to harmonize monitoring concepts and terminology. The monitoring framework appears to be more general in that it contains no reference to management. The center wording implies management is taking place, but it also permits the framework to be applied to monitoring conducted as part of a research program, completely separate from direct management information needs. This last point, however, is often one of contention – research thrives in the area of uncertainty while management, in many of its information needs, seeks consistency and comparability in information development and use.

DISCUSSION

A conceptual way to view the complexities and connections of the many components of a water quality information system is a key step in harmonizing diverse water quality monitoring efforts for the purpose of producing consistent and comparable water quality data and information. The UNECE monitoring cycle and the U.S. monitoring framework are quite similar, in many ways. This similarity comes from a number of factors.

First, there has been a maturing of the science behind design and operation of water quality monitoring systems. This maturation comes through the efforts of a number of organizations over the past 10 years. For example, the Monitoring Tailor-made Workshops, sponsored by RIZA and others, and the National Monitoring Conferences, sponsored by the NWQMC in the U.S., provide a forum for dialogue between monitoring professionals from many disciplines, many agencies and many countries. This dialogue fosters understanding and questioning, which, in the end forces monitoring professionals to examine their understanding of monitoring. The proceedings from these meetings contribute to wider knowledge of monitoring from a common discussion.

Second, governments are facing ever tighter budgets as the expectation of citizens, regarding water quality, is growing. The resulting pressure to obtain excellent water quality data and information with a minimum of funding forces agencies and professionals to seek ways to share information. Sharing data and information requires a level of consistency and comparability not needed when each country, agency and discipline can afford to collect its own, unique, data and information. As agencies talk to each other about sharing, more commonality emerges, which, in turn, is reflected in common monitoring constructs.

Third, monitoring designers and operators seek accountability for the data and information they are expected to produce. Such accountability requires that a monitoring system be well defined and operated, from data collection to reporting. Thus, use of a well accepted monitoring framework, by those designing and operating monitoring systems, permits clear accountability to the state-of-the-art of the monitoring profession.

Fourth, in the field of monitoring, the word ‘evaluate’ is most often applied to items such as sampling procedures and laboratory operations. When a monitoring program is to be evaluated, it is useful to have a framework to follow in conducting an evaluation. As the U.S. and UNECE framework graphics clearly illustrate, the process of evaluation should be applied to all facets of the monitoring process. In addition to evaluating each step of the process, we should also step back and examine the program as a whole. The evaluation process should reveal not only the strengths and weaknesses of the individual steps but the process as a whole. In other words, even if the individual steps appear to be well designed and implemented, does the process as a whole accomplish the expected information goals? Monitoring program evaluation, in many ways, is using the entire monitoring framework to carefully examine each aspect of the monitoring effort individually and, then, collectively. Thus, in many ways, to use the monitoring framework, itself, is to evaluate a monitoring program.

Beyond similarities and differences, monitoring cycles and frameworks, given their more holistic and systematic view of monitoring, provide a template with which to envision a systematic use of modern information technology in ‘managing’ monitoring systems and the ‘products’ they produce. Such a view of monitoring would not be unlike the perspective currently utilized in modern businesses around the world. The term often used to describe business applications of modern information technology is ‘supply chain software’. Such software is designed to give business managers insight into all facets of a company, from personnel management to inventory control to

profit analysis. A translation of the concept to monitoring could envision the monitoring cycle and monitoring framework providing a structure around which a total software package could be constructed to seamlessly move information and data, about the operation and products of monitoring, in a highly interconnected chain of events, leading to scientifically sound, highly efficient, water quality information acquisition and distribution.

To illustrate the analogy further, note the following description of a supply chain software supplier, Viewlocity:

> "**About Viewlocity -** Viewlocity is a global provider of Supply Chain Event Management (SCEM) solutions. Our TradeSync™ Suite allows companies to monitor their extended supply chain for events and exceptions that could impact their ability to fulfill customer orders, satisfy inventory needs, and manage shipping requirements. When exceptions are detected, Viewlocity's products notify the affected parties, recommend corrective actions, and enable collaborative resolution."

Are monitoring system managers able to view the operations of all 'cogs' in the manner a business is now able to view its supply chain? Effective and efficient monitoring of water quality in the U.S. and Europe requires that monitoring designers and managers 'connect' the cogs in the monitoring cycle/framework with modern information technology. This will, in turn, facilitate quality control/quality assurance, method comparability, accountability for meeting information goals, data sharing, and overall monitoring system management.

CONCLUSION

By comparing the U.S. and UNECE monitoring graphics, this paper has highlighted considerable convergence of thinking on the components of a total water quality information system. This convergence provides those involved in monitoring design and operation a common basis for advancing the science and technology employed in monitoring. This is ever more important if the monitoring process is considered as a whole system, which is more that its constituting parts being performed in a proper manner. Thus, it is easy to conclude that monitoring cycles and frameworks raise the communication platform for monitoring, providing a much higher plane for future improvements in the ability to produce consistent and comparable water quality data and information.

The differences that can be found between the frameworks reflect the differences in situation in which the framework should be applied. In this respect, it may not be so important to strive for a common worldwide framework as well as striving for basic principles that may be applied differently in different situations. The view of a monitoring program as one system that can be evaluated can be considered a basic principle. The other essential issue is the need for a common terminology around the different elements of the monitoring framework or cycle.

REFERENCES

Adriaanse, M. 1996. Tailor-made Guidelines; A Contradiction in Terms? Proceedings of Monitoring Tailor-made II, an international workshop on information strategies in water management held Sept. 9-12, 1996, in Nunspeet, The Netherlands, published by The Institute for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, The Netherlands. Pages 391-399.

Blöch, H., 1999. The European Union Water Framework Directive: taking European water policy into the next millennium. Water Science and Technology 40(10): 67-71

Cofino, W.P. 1994. Quality Management of Monitoring Programs. Proceedings of Monitoring Tailor-made, an international workshop on monitoring and assessment in water management, held 20-23 September 1994, Beekbergen, The Netherlands, published by RIZA, The Netherlands Institute for Inland Water Management and Waste Water Treatment, Lelystad, The Netherlands. Pages 178-187.

de Jong, J. and J. G. Timmerman. 1996. Opening and Introduction to MTM II. Proceedings of Monitoring Tailor-made II, an international workshop on information strategies in water management held Sept. 9-12, 1996, in Nunspeet, The Netherlands, published by The Institute for Inland Water Management and Waste Water Treatment (RIZA), Lelystad, The Netherlands. Pages 1-4.

General Accounting Office. 2000. Water quality: Key EPA and State decisions limited by inconsistent and incomplete data. GAO Report Number GAO/RCED-00-54, March 15, Washington, D.C.

Groot, S. and M.T. Villars. 1995. Monitoring Water Quality in the Future, Volume 5: Organisational Aspects. Ministry of Housing, Spatial Planning and the Environment, Distribution Office, O.O. Box 351, 2700 AJ Zoetermeer, The Netherlands.

Intergovernmental Task Force on Monitoring Water Quality – ITFM.1995a. The Strategy for Improving Water-Quality Monitoring in the United States, Final Report of the Intergovernmental Task Force on Monitoring Water Quality, Open File Report 95 – 742, U.S. Geological Survey, Reston, VA (http://water.usgs.gov/wicp/itfm.html)

Intergovernmental Task Force on Monitoring Water Quality – ITFM. 1995b. Performance-based approach to water quality monitoring. In: Strategy for Improving Water Quality Monitoring in the U.S., Appendix M, Open File Report 95-742, U.S. Geological Survey, Reston, VA. (http://water.usgs.gov/wicp/itfm.html)

Intergovernmental Task Force on Monitoring Water Quality – ITFM. 1997. Conceptual Frameworks for Ground-Water-Quality Monitoring. Ground Water Focus Group. (http://water.usgs.gov/wicp/gwfocus.pdf)

Job, Charles A. 2002. Data Elements for Reporting of Water Quality Results. Proceedings of the Third National Water Quality Monitoring Conference, Madison, WI, May 19 – 23, 2002 (http://www.nwqmc.org/NWQMC-Proceedings/Opening-Page.pdf)

Habermann, C. and R.C. Ward. 2002. Comparing water quality monitoring requirements in European and U.S. laws. Proceedings of the Third National Water Quality Monitoring Conference, Madison, WI, May 19 – 23, 2002 (http://www.nwqmc.org/NWQMC-Proceedings/Opening-Page.pdf)

Meybeck, M., 1989. Surface water quality: global assessment and perspectives. Pages 173-185 in: Zebidi, H. (ed.). Proceedings of the international conference on world water resources at the beginning of the 21st century.

Naisbitt, J. 1982. Megatrends. New York: Warner Books.

National Research Council. 2001. Assessing the TMDL Approach to Water Quality Management. National Academy Press, Washington, D.C.

National Water Quality Monitoring Council. 2002. Proceedings of the Third National Monitoring Conference. Held May 19-23, 2002, Madison, Wisconsin. (http://www.nwqmc.org/NWQMC-Proceedings/Opening-Page.pdf)

Niederlander, H.A.G., J. Dogterom, P.H.L. Buijs, R. Hupkes, and M. Adriaanse. 1996. State of the Art on Monitoring and Assessment of Rivers. Prepared for the UN/ECE Task Force of Monitoring & Assessment by RIZA, Institute for Inland Water Management and Waste Water Treatment, ECE Task Force project-secretariat, P.O. Box 17, 8200 AA Lelystad, The Netherlands.

North Carolina Water Resources Research Institute - NCWRRI. 2003. The Data Quality Act: A revolution in the role of science in policy- making or a can of worms? Water Resources Research Institute News, Number 341, May/June, pages 6-8. (http://www2.ncsu.edu/ncsu/wrri/news/index.html)

Public Employees for Environmental Responsibility (PEER). 1999. Murky Waters: Official Water Quality Reports are all Wet. Report Number 27, PEER, 2001 S Street, N.W., Suite 570, Washington, D.C. 20009-1125, May (www.peer.org)

Rickert, D.A. and W.G. Hines. 1975. A Practical Framework for River-quality Assessment. U.S. Geological Survey Circular 715-A, U.S. Department of Interior, Washington, D.C.

Shnider, R.W. and E.S. Shapiro. 1976. Procedures for Evaluating Operations of Water Monitoring Networks. U.S. Environmental Protection Agency, Environmental Monitoring Series No. EPA-600/4-76-050, September.

Timmerman, J.G., J.J. Ottens and R.C. Ward. 2000. The information cycle as a framework for defining information goals for water-quality monitoring. Environmental Management, Vol. 25(3):229-239.

Timmerman, J.G., R.M.A. Breukel, and P.J.M. Latour. 2002. Implementation of monitoring requirements for the new European water policy. Proceedings of the Third National Water Quality Monitoring Conference, Madison, WI, May 19 – 23, 2002 (http://www.nwqmc.org/NWQMC-Proceedings/Opening-Page.pdf)

UNECE, 1992. Convention on the Protection and Use of Transboundary Water Courses and International Lakes. Helsinki, Finland.

UNECE Task Force on Monitoring and Assessment. 1996. Guidelines on Water-quality Monitoring and Assessment of Transboundary Rivers. RIZA, Institute for inland Water Management and Waste Water Treatment, UN/ECE Task Force on Monitoring and Assessment project-secretariat, P.O.Box 17, 8200 AA Lelystad, The Netherlands. Report No. 96.034

UNECE Task Force on Monitoring and Assessment. 2000. Guidelines on Monitoring and Assessment of Transboundary Rivers. RIZA, Institute for Inland Water Management and Waste Water Treatment, UN/ECE Task Force on Monitoring and Assessment project-secretariat, P.O. Box 17, 8200 AA Lelystad, The Netherlands (ISBN 9036953200)

U.S. Environmental Protection Agency. 1977. Basic Water Monitoring Program. U.S. Environmental Protection Agency Report No. EPA 440/9-76-025, Washington, DC.

U.S. Environmental Protection Agency. 1994. Guidance for the Data Quality Objectives Process, Environmental Protection Agency, EPA QA/G-4. Quality Assurance Division, NCERQA, Office of Research and Development. Cincinnati, OH.

U.S. Environmental Protection Agency. 2003. Elements of a State Water Monitoring and Assessment Program. Report No. EPA 841-B-03-003, Assessment and Watershed Protection Division, Office of Wetlands, Oceans and Watershed, U.S. Environmental Protection Agency, Washington, D.C. 20460. (http://www.epa.gov/owow/monitoring/repguid.html)

Ward, R.C., J.C. Loftis and G.B. McBride. 1990. Design of Water Quality Monitoring Systems. New York: Van Nostrand Reinhold, 231 pages.

Ward, R.C. 1978. Regulatory Water Quality Monitoring: A Systems Perspective. Report Number EPA-600/7-78-228, Environmental Monitoring and Support Laboratory, U.S. Environmental Protection Agency, Las Vegas, Nevada, November.