6908

Text of Keynote Speech delivered to:

STOCKHOLM WATER SYMPOSIUM
August 10-14, 1993.
Stockholm, Sweden

Global Water Pollution: Challenges and Opportunities

EDWIN D. ONGLEY, National Water Research Institute, Canada Centre for Inland Waters, Environment Canada, P.O. Box 5050, Burlington, Ontario L7R 4A6, CANADA

ABSTRACT

At the 1972 Stockholm Conference on Environment, the world community called for a standing watch on global trends in key environmental sectors. From this concern grew the United Nations "Global Environment Monitoring System" (GEMS). Surface and groundwater quality is one component (GEMS/Water). Global patterns of surface water pollution have been summarized by GEMS for the UNCED process. The continuing inability of much of the Third World, especially many rapidly industrializing nations, to collect the type of data which permit useful assessment, coherent environmental management, and which can guide investment decisions, remains a critical problem. Water data programmes are fragmented, often collect the wrong type of information, and are inefficient both in information and in cost. The challenge of the next decade is to rethink how water quality data are collected and used, and to take advantage of new capabilities that can revolutionize the information effectiveness and cost-efficiencies of data and assessment programs at the national level. Through its global programme of data assessment and capacity building GEMS/Water provides a framework for achieving synergy and progress in the field of water quality.

INTRODUCTION

When I was first approached to address the 1993 Stockholm Water Symposium I was asked to speak on global patterns of water pollution. The request reflected my responsibility, on behalf of the Government of Canada, for the Global Data Centre and for the (Canadian) UNEP and WHO Collaborating Centres that are associated with the water quality component of UNEP's Global Environment Monitoring System (hereafter: GEMS/Water). However, global patterns of water quality have been summarized by others (Meybeck et al. 1989; WHO/UNEP 1991) as part of the UNCED process and, having carried out GEMS/Water missions in many parts of the world, I believe that there is a more useful message to be conveyed to this important meeting.

The challenge is not one of cataloguing the major water quality issues by region or by continent -- these are, with some important exceptions, well known, as are the institutional and financial barriers that inhibit their resolution. The challenge of the 21st Century is much more fundamental and, in my opinion, amounts to no less than a need to radically change the scientific and managerial paradigms that govern the business of water quality management. In the Third World, existing paradigms inhibit the collection and synthesis of useful data to such an extent that not only is the ability to assess water quality seriously compromised in many countries, but more importantly, they erode the capability of national governments to make cost-effective judgements about water quality management, water resource policy development, and investment options.

What follows is a critical review of where we stand in the field of water quality monitoring and assessment. The views expressed in this paper are quite personal and do not necessarily reflect the views or policies of the Government of Canada, UNEP, WHO or the other UN Agencies that cooperate within the GEMS Programme.

THE GEMS/WATER PROGRAMME

First, however, let me review for you briefly, the GEMS/Water Programme inasmuch as it has provided an unparalleled window into the data programmes and managerial concerns of a large number of national water quality agencies. The GEMS family of programmes, part of the United Nations Earthwatch Programme, is organized by the United Nations Environment Programme (UNEP). GEMS/Water, begun in 1977, is implemented by the World Health Organization (WHO) with the cooperation of the World Meteorological Organization (WMO) and UNESCO. It is not a funding programme; it is an international cooperative programme now involving 56 countries which voluntarily submit raw data from their national surface and ground water quality monitoring programmes, to the Global Data Centre as part of a world-wide observing network.

GEMS/Water is much more than a global database. It provides technical guidance, carries out training in water quality monitoring and assessment, has performed two international interlaboratory comparison exercises, and assists in data interpretation by providing training and standardized computer software. But above all, GEMS/Water has worked with many national and international institutions and donor agencies world-wide in order to achieve synergy and progress in the field of water quality monitoring and assessment.

Over the years, GEMS/Water has evolved with the progress in the field. Following an international review in 1990, the Programme has moved strongly into enhanced data assessment and capacity building. Capacity building focuses on further strengthening of national capabilities, including enhanced quality control and assurance, data management, and new techniques such as biological and sediment-quality monitoring (WHO 1991).

WILL "BUSINESS AS USUAL" ACHIEVE PROGRESS?

Whereas the First World has had the luxury of dealing with water quality problems sequentially -- fecal pollution, eutrophication, acidification, toxic contaminants -- the Third World is facing all these simultaneously. However, a common observation amongst water quality professionals is that many water quality programmes, especially in the Third World, collect the wrong parameters, from the wrong places, using the wrong substrates and at inappropriate sampling frequencies, and produce data that are often quite unreliable; the data are not assessed or evaluated, and are not sufficiently connected to realistic and meaningful programme, legal or management objectives. This is not the fault of the Third World; more often it results from inappropriate technology transfer and an assumption by recipients and donors that the data paradigm developed by the First World is appropriate in the Third World.

Sustainable development, especially in the Third World, requires fundamental questioning about the business of water quality management. The temporal compression of issues in the Third World and limited financial resources puts a premium on "getting it right" quickly. Unfortunately, many Third World countries, with unwitting help from donors, are reproducing the mistakes made by the First World over the past 30 years.

The Data Problem

Data Collection and National Programme Objectives: In many countries, data collection is largely disconnected from the users of data. Data programmes are, therefore, inefficient, have poorly defined or unrealistic objectives, and are not broadly useful to environmental management agencies nor for water resource policy development. At the political level, data programmes are considered expendable and are being reduced or eliminated in many countries. Many governments are neither convinced that data programmes can be effective, nor that water quality data are essential for water resource management. Consequently, national capacity to generate essential data is diminished.

Do Agencies Sample the Correct Parameters or the Correct Media? Many agencies focus on conventional parameters such as major ions. While some major ions can have health implications, they are often quite irrelevant to the important water quality issues (e.g. fecal contamination and toxics). The focus on major ions is rooted in institutional inertia, lack of funding and/or expertise to do anything differently, lack of understanding of the alternatives and, most commonly, a failure to clearly define the objectives of data programmes. The focus on major ions, although relatively cheap to analyze, represents a net loss of economic efficiency because: (1) water samples are usually collected and analyzed much more frequently than is necessary, (2) the data, once analyzed, are rarely systematically examined and, (3) major ions do not form a basis for planning and management of water resources.

There are few data on toxic substances (especially organic contaminants) in many rapidly industrializing countries. Data segregated by continent show little microbiological information for surface waters in many African, Latin American and Asian countries where fecal pollution is severe. World-wide, we continue to see an almost exclusive focus on sampling of the water phase when it is now well known that many industrial and agricultural contaminants are found partially or exclusively on solids, to the point that analysis of water samples produces misleading or completely erroneous results for concentration levels and inferred toxicity of these substances.

It is alarming that many rapidly industrializing countries have little or no information on which to base health protection and resource management policies for most categories of contaminants. For "simple" parameters such as heavy metals, values are so method dependent and prone to error (Cohen 1991; Windom et al. 1991) that values are often meaningless.

How Reliable are National Data Programmes? Reliability of data is ensured through **quality control and quality assurance (QC/QA)**. In the United States, for example, QC/QA concerns have led to rigorous certification procedures for government and private laboratories. For Donors, deficient or non-existent QC/QA programmes in many developing countries, especially for more difficult parameters (industrial and agricultural chemicals, metals, etc.), poses serious problems for investment and rational decision-making. While many agencies in developing countries contract university labs for more complex analyses, experience shows that university participation is no guarantee of reliable data.

The cost of unreliable data in investment and management decisions is difficult to calculate, especially as agencies are either unaware of QC/QA failure, or refuse to admit to it. Failures in QA/QC lead to costly management errors. Lesage and Jackson (1992) refer to "several million dollars" as the price for QC/QA failure in one groundwater contamination example in eastern Canada. The annual cost to national and donor programmes in the Third World must be in the hundreds of millions of dollars, if not more. Major development programmes are compromised and donor funds wasted by use of unreliable data.

Improving the reliability of data is undeniably one of the major challenges faced by developing countries as they look towards the 21st Century, yet investment in QC/QA by donors and multilateral lending agencies is not sufficiently visible to merit funding on its own and is often overlooked in development programmes. It is illogical that multilateral agencies make major institutional demands, yet ignore the basic building blocks of reliable data programmes. We find that many national water agencies are receptive to QC/QA programmes as part of capacity building and are capable of carrying out QC/QA, but lack the knowledge and the funds to implement and sustain QC/QA programmes. Although funding is extremely limited in GEMS/Water, access to QC/QA procedures is a major motivating factor for country participation in GEMS/Water.

For Donors, fifteen to twenty percent of all funds for data programmes should be explicitly invested in QC/QA within the framework of capacity building. Development funds should be contingent upon national agencies demonstrating appropriate capabilities in QC and acceptance of external QA protocols. Recognizing the need for several levels of QC/QA that reflect the needs and capabilities of national agencies, GEMS/Water is developing a framework strategy for a global QC/QA programme that is consistent with ISO/ECE 25 and ISO 9000, and would meet many of the concerns of donor agencies.

Mobilizing Data The inability to mobilize data for management and policy purposes is the second most serious deficiency (QC is the first) identified by participating agencies in

GEMS/Water. Where databases exist, they tend to be designed for archiving rather than for mobilizing and interpreting data. Data mobilization can achieve widespread economies: (1) systematic data interpretation identifies parameters and stations that can be reduced or eliminated (programme optimization); (2) inherent problems in data collection and analytical programmes are identified; (3) data can be brought to bear on important issues; and (4) commonality of simple software amongst national agencies promotes institutional cohesion.

For water quality management we have found that the major requirement is for numerical analysis and statistical processing of spatially referenced data. Water quality databases pose a particular problem in that metadata are an important part of the database and need to be included as part of numerical analysis. To provide developing countries with this capability GEMS/Water has adapted Environment Canada's RAISON software for use by water quality agencies in the Third World. This is an integrated, PC-based package, with database, spreadsheet, statistical, mapping and graphical tools and links to full GIS systems and to commercial databases. With minimum training requirements and inexpensive hardware, RAISON/GEMS is being installed as funds become available.

The role of Geographical Information Systems (GIS) merits special comment. The information industry has successfully promoted GIS as core technology and donors have been very active in installing GIS in many countries. While GIS is a powerful tool, donors seem to be unaware of the limitations of GIS, ignore the problems of sustaining this type of high technology in many Third World locations, and do not consider other more sustainable and less costly alternatives that more closely match recipient's needs. Unfortunately, the use of GIS can become nothing more than an expensive exercise in mapping and there is the real possibility that GIS can become the high tech extension of the same kind of unfocused data collection often attributed to traditional water quality data programmes.

Rationalizing Laboratory Facilities It is an unfortunate but inescapable fact that certain types of data, especially metals and toxic organic contaminants, required for health, planning and regulatory purposes in the Third World, are currently beyond the technical, institutional and financial capabilities of many agencies. These are complicated analyses with exacting technical requirements and require much more than a chemist and apparatus. Many of you will have seen metals analyses being carried out in rooms with lead-based paints peeling from the wall, and donated equipment incapacitated for lack of spare parts, reagents or trained personnel. Too often equipment is donated without consideration of sustainability.

This situation arises from four factors. One is the understandable desire of national agencies to have the latest in hardware technology -- GC's, AA's, GCMS, etc.. but without the technical and financial resources to sustain this capability. The second is the failure of donors to realistically look at the real data needs and at more suitable and, sometimes, lower technology methods of obtaining appropriate data. Thirdly, there is Donor competition and, fourthly, there is a the need to consider alternatives to unsustainable high-tech installations in each country. One alternative is to establish Regional Reference Centres that would ensure stability and critical mass of personnel, maintain a range of analytical apparatus in good repair, and ensure correct and consistent analytical data through application of internationally acceptable QC/QA protocols. These Centres would support national capacity building through analytical training and QC/QA at the country level. They would also provide the quality control that is often lacking in donor programmes. I could envisage a small service-oriented network of such Centres, potentially operated within a private sector framework, that would play a key role in bringing national data programmes into the 21st Century.

Role of the Private Sector I am unconvinced in some developing countries that the government sector will be able to achieve, in the near to middle term, significant and sustainable progress without private sector involvement.

CHANGING THE DATA PARADIGM

The data paradigm, especially in the First World, is data intensive, chemistry focused, science driven, high tech, well funded, and rests on the scientific and legal premise that with enough data all water quality issues are capable of an unambiguous resolution. In the United States the paradigm reflects a highly litigious society in which "more and better" data is the currency of the legal process. Protocols of US agencies reflect this paradigm, and one must question whether this approach is suited to the Third World. Even in the United States there is now recognition that this paradigm has led to a "data rich, information poor" situation which public agencies are now vigorously attempting to change.

The Fallacy of "Accuracy" Under the data paradigm we assume that numbers produced by careful laboratories are "accurate". By extension, we assume that interpretation of such data conveys "accuracy". Usually overlooked and often unknown, however, are all the other factors that produce variance; --- field error, methods differences, unknown representativeness of single samples, cross-sectional and downstream dynamic variability in aquatic systems due to hydraulic, biotic and chemical factors, and unsampled variability in the time interval between field samples, etc.. Unsampled variance is particularly critical for sediment-associated phenomena (phosphorus, metals and many trace contaminants) that are conveyed downstream in large quantities over short periods of time which rarely coincide with field sampling programmes. One can demonstrate that for some management purposes such as calculation of loadings, random numbers can produce values within the normal error of expensively produced laboratory data (Ongley, 1993). The practical implication of uncertainty in water quality data is that our ability to interpret, model, predict and manage water quality is inherently less reliable than our paradigm would have us believe.

Alternatives to Fixed-Site Monitoring Monitoring traditionally uses a fixed-site, fixed interval approach. The alternative is a "**survey**" approach in which data are intensively collected for a finite period in one place (e.g. a river basin) before moving on to a different location. Sampling is designed so that data represent natural and anthropogenic factors in the watershed. Surveys force agencies to set data objectives and tend to eliminate the intellectual and programme paralysis associated with repetitive, fixed-site monitoring. Surveys are particularly suited for water resource assessment purposes. Public health monitoring and certain types of regulatory monitoring, however, require a different approach, should focus on narrowly defined objectives, and should be independent of other types of monitoring.

Alternatives to Chemical Monitoring While the First World is moving away from the "chemistry" paradigm, the Third World tends to remain fixed in this 1960's approach to water quality with its expensive analytical requirements. The traditional data paradigm is partly to blame; however another reason is the export by the First World of chemical by chemical regulatory procedures. Not only is this approach very expensive and requires a level of sophistication not normally found in developing countries, it has not proven to be especially effective for environmental protection in the First World and is being replaced with a combination of chemical and toxicological protocols.

Europe has demonstrated the value of biology in management of organic pollution -- one of the most widespread water quality management issues in the Third World. For contaminant management, a significant reduction in chemical analysis can be achieved by using simple biological screening tools. In addition to technical merit, biological protocols reduce costs, increase efficiency, need only low investment in materials and facilities, and match the skills that are abundantly available in the Third World.

Alternatives to Traditional Parameters For many contemporary issues such as toxic contaminants, water agencies must move away from the traditional, fixed interval sampling of water, to a multi-media sampling protocol with associated toxicity testing. For agencies that now sample only water, this approach will enhance useful information without extra cost.

Proxy Data The real uncertainty in data suggests that there is merit in using unconventional methods and proxy data which are less expensive and equally "reliable". For example, for hydrophobic chemicals that normally exist in low solute concentrations, real time turbidity records together with occasional measurement of suspended sediment chemistry can, with use of partitioning coefficients, provide reasonable estimates of particulate versus solute concentrations. Sediment monitoring programmes, especially those that focus on chemical flux, should radically rethink the practice of sediment monitoring (Ongley 1992).

Science versus Management The data paradigm flows from the larger scientific paradigm that underpins our quest for knowledge. The consequence, especially in advanced countries, is that monitoring is implicitly linked to scientific investigation -- especially the need for precise quantification of issues. Too often the scientific response to a management problem is that we need to mount an intensive data and research programme. Yet many management and policy concerns can be adequately resolved from lower level data. As scientists we are unhappy with approximate solutions with large margins of error. Yet in the real world, costly scientific programmes often end up with just that -- approximate solutions with large margins of error and/or uncertainty. The outcome may well be an increase in our scientific knowledge of the problem but not necessarily a better management decision. Conversely, regulatory authorities often set inflexible water quality standards which are quite unrealistic in a medium as dynamic as water.

One unfortunate consequence of our data paradigm is the illusion of "accuracy" when the management solution to a problem is attained through numerical modelling. Often, data programmes are mounted to support the modelling activity when the information required to make a management decision is much less sophisticated and, sometimes, is only a matter of common sense. While modelling can be very useful, it often conveys to managers an unwarranted degree of "confidence".

The influence of science on our data paradigm places other types of blinkers on the cost-effectiveness of data programmes. Cost-benefit analysis of data programmes, especially in the water quantity field, usually address alternatives to producing the same kind of data by alternative methods or by other agencies. I have never seen an analysis that examines the cost of data collection relative to the minimum amount of data required to make the types of management judgements for which the data programme was intended. For example, is a ten percent improvement in data reliability worth the 30-40% increase in cost of the data programme, and would it materially change or enhance managerial decisions? Alternatively, can one make, for example, 90% of the management decisions with only 50% of the existing data programme?

In summary, agencies often do not clearly distinguish between data requirements for managing, versus data required to increase knowledge of the issue. Regulators have unrealistic expectations of data programmes. For donors and national agencies, failure to make these distinctions results in data programmes that are more expensive than needed for management purposes, and not sophisticated enough for scientific needs.

Expert Systems and Technology Transfer Possibly the most fundamental shift in our paradigm will be the inclusion of knowledge as part of our working database. This will have profound implications for the transfer of expertise from North to South and as an alternative for "hard" data in data-poor environments. Knowledge-based analysis frees us, to a great extent, from the excesses of the data paradigm by offering alternatives to conventional numerical modelling with its expensive data requirements. The revolution in knowledge engineering now makes it possible to capture and codify the expertise and experience of knowledgeable professionals (the "knowledge domain") within Expert Systems. Used independently of, or with numerical models, Expert Systems offer an entirely new form of decision-support capability which explicitly considers uncertainty and produces judgemental decisions about, for example, water quality management options. They are especially useful for "what if" scenario testing for in situ problems and for policy development. For donors, this new technology holds the key to much more effective investment decisions.

CONCLUSIONS

The challenge of the next decade is to rethink the paradigm under which water quality data are collected and used, and to take advantage of some of the advances that can revolutionize water management programmes at the national level. In addition to necessary institutional change these advances will include: a shift from a science to a management paradigm as the basis for data collection; greater emphasis on data reliability together with an explicit approach to uncertainty; economical screening methods to reduce costly organic chemistry; rationalization of capital-intensive laboratories; use of information technologies which offer cheap and effective methods for deploying data; and application of artificial intelligence both as a means of technology transfer and for use in data-poor countries.

The cost of progress is not great and is vastly outweighed by the cost of failing to achieve significant progress in this field. For example, we estimate the cost of QC/QA training for water quality agencies in 30-40 countries at $5 million with an annual maintenance cost of $1 million. A dramatic improvement in data mobilization capabilities in the developing world, using inexpensive software and hardware, can be achieved with an investment of under $10 million.

The GEMS/Water Programme, now involving 56 countries from all continents, provides a focus for water quality monitoring and assessment through its data activities and capacity building programmes. It offers a unique, global forum for achieving cohesion and synergy between multilateral and donor agencies on the one hand, and a broad spectrum of recipients, on the other.

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