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WATER POLLUTION

WATER QUALITY MONITORING

As the United States moves to restore entire watersheds, not just to control pollution at the end of the pipe, the author of this article says it will have to pay more attention to water quality standards. He says water data and monitoring, both as to quantity and quality, are the key to doing this successfully in an era in which the focus is on watersheds, generally, and the physical and biological integrity, not just chemical, of our nation's aquatic resources. The author, a former assistant EPA administrator for water, offers examples of successful monitoring programs. He says the absence of numeric criteria makes it harder to effectively monitor and assess water quality against a valid baseline.

Water Data and Monitoring as Indispensable Tools to Manage Water Quality

BY G. TRACY MEHAN, III

Information-based environmental programs have many appealing aspects. They provide useful information for managers, be they in the private, public, or not-for-profit sectors. They overcome one of the classic reasons for market failure: asymmetric information. If designed carefully, they can be a cost-effective means of informing and incentivizing environmental programs and performance.

Data and water monitoring have a paramount role, in terms of qualitative and quantitative aspects of overall water management, including the natural flow regime, biological integrity, and adaptation to a changing and variable climate.

Two years ago, at the Sixth National Water Monitoring Conference, Lisa Jackson, administrator of the Environmental Protection Agency, speaking in her role at the time, as commissioner for New Jersey's environment, on the protection of that state's rich diversity of water resources offered the following observation:

> Supporting these resources in order to ensure continued use of the state's waters for these diverse needs requires understanding how the systems work and to collect data on a continuing basis that can be converted into information that is used in environmental resources management.

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> The foundation of this process is water quality monitoring.[1]

The administrator has it exactly right. Data and water monitoring, both as to quantity and quality, are foundational to water management especially in an era in which the focus has moved away from an almost exclusive preoccupation with end-of-the-pipe point source dischargers to a broader concern with watersheds, generally, and the physical and biological integrity, not just chemical, of our nation's aquatic resources.

For too long water quality management has been characterized by compartmentalization and the creation of artificial boundaries among and between various aspects of what should be a unified approach to water quality in terms of the chemical, physical, and biological integrity of the nation's waters. It has tolerated, even encouraged a bifurcated approach, allowing unnecessary polarities to dominate policy and practice: water quality versus quantity; land versus water; surface water versus groundwater; point versus nonpoint sources; energy versus water; and supply-side versus demand-side management.

The water policy community in America has struggled to implement the vision of John Wesley Powell, the great explorer of the Colorado River and second director of the U.S. Geological Survey, as articulated in his remarks to the Montana Constitutional Convention in 1889:

> I want to present to you what I believe to be ultimately the political system you have got to adopt in this country, and which the United States will be compelled sooner or later ultimately to recognize. I think each drainage basin in the arid land must ultimately become the practical unit of organization, and it would be wiser if you could immediately adopt a county system which would be convenient with drainage basins.[2]

The watershed approach can be described as ''a coordinating framework for environmental management that focuses public and private sector efforts to address the highest priority problems within hydrologically-defined geographic areas, taking into consideration both ground and surface water flow.''[3]

It is almost impossible to imagine implementing anything like a watershed approach without sufficient data, monitoring, and assessment of all aspects of water quantity and quality. Also, this kind of information is crucial to cost-effectively deploying what are always limited resources, personnel, and political capital.

Arid or humid, west or east of the 100th Meridian, the watershed approach makes sense even if tradition and constitutional system preclude jurisdictional arrangements contemplated by Powell. So it is necessary to work over, under, around, and through the political boundaries that appear to constrain watershed perspective. Water data and monitoring are the key to doing this successfully at varying temporal and spatial scales.

Having served in state and federal government for nearly 15 years, I appreciate the immense challenges of funding and maintaining any kind of data collection, monitoring or assessment program over the long haul. When times are tough, these are the environmental programs which are often cut first. I have long believed that the exact opposite should be the case, i.e., they should be the last to be cut.

America needs to invest ''patient capital'' for the long run in water data, monitoring, assessment, and, yes, analysis. Dr. Robert Hirsch, former Chief Hydrologist for the U.S. Geological Survey, long has emphasized the importance of patience and analysis in this crucial area of water management.

Given the inevitable limitations on resources, the pressure to evaluate performance or results coming from policymakers and citizens, and the need to inform the work of the many and varied stakeholders involved in watershed protection—public, private, and nonprofit—almost all other priorities in the National Water Program are secondary to the necessity of developing sound water quality standards and a system of monitoring progress, or lack thereof, against those standards.

This may sound extreme, but water managers cannot earn the support of the public and their elected state and federal representatives, unless they can demonstrate clearly what progress has been made and how to pinpoint the next steps to cost-effectively restore the waters of the United States.

The political pendulum swings back and forth. The stock market goes up and down. Budgets expand and shrink . . . and shrink. Through it all, water managers need to be able to document facts on the ground or in the water more precisely, so managers and policymakers can factor in the evolving realities and adapt accordingly.

Although a good part of my career has been focused on water quality, I distinctly recall the problems of data gaps on water use during my work as a private attorney for the state of Missouri on Missouri River diversion and management issues. If Mark Twain really did say that whiskey is for drinking, and water is for fighting, he had to be thinking of the Missouri.

Since passage of the Flood Control Act of 1944 and the building of six main-stem dams, controversy has persisted between upper basin states, lower basin states, Indian tribes, recreation, navigation, agriculture, water utilities, the Army Corps of Engineers, and the Fish and Wildlife Service.

Many times I found myself lamenting the absence of a good water census or accounting of water use on that interstate stream split between state jurisdictions following either the Prior Appropriation or the Riparian doctrines with overlapping claims for federal and tribal reserved water rights.

Sound data and information would not have resolved all disagreements, but they would certainly have informed the discussions, established facts and clarified issues.

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[1] Lisa Jackson, New Jersey commissioner of the environment, *Commissioner Jackson's Talking Points-National Water Conference,* undated, p. 1. The author wants to thank Leslie McGeorge of the New Jersey Department of Environmental Protection for sharing Administrator Jackson's remarks.

[2] Quoted in Daniel Kemmis, *This Sovereign Land: A Vision of Governing the West* (Island Press 2001), p. 177. Evidently, the presentation did not go all that well according to the environmental historian, Donald Worster who describes the event in *A River Running West: The Life of John Wesley Powell* (Oxford 2001), p. 481, citing the *Proceedings and Debate of the Constitutional Convention [Montana],* pp. 920-23 (in footnote 17).

[3] NACWA[National Association of Clean Water Agencies] Strategic Watershed Task Force, *Recommendations For A Viable and Vital 21st Century Clean Water Policy*, Oct. 18, 2007, p. 6, citing various EPA sources.

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Can't We All Just Agree?

If there was one federal function on which all-left, right, and center might agree, one would think it would be maintaining robust, state-of-the art data collection, monitoring, and assessment necessary for the management of our nation's waters. Americans always have looked to the federal government as the indispensable collector, custodian, and generator of most economic, employment, and trade information. It seems appropriate that all parties, regardless of their political or ideological bent, should support maintaining consistent data sets over time to guide environmental and natural resources management and policy for that most precious of commodities, water.

Can't we all just agree on that? Evidently, not.

For many years the U.S. Geological Survey (USGS) has had a difficult time, through good economic times as well as bad, maintaining a nationwide system of stream gauges across America's waterways. What could be more basic to good management and policy than measuring flow, again, over extended time frames?

J. Michael Norris, Coordinator of USGS's National Streamflow Information Program ,[4] notes that it is the *instability* in the network, not simply the number of stream gauges,[5] which is the most problematic in terms of discontinuity in the collection and analysis of data over time.

While there has been a net loss of 600 gauges between 1970 and 2008, there also was ''a swing of about 1,500 streamgages [*sic*].'' The current network is approximately 7,600 gauges. Gauges usually are lost when one or more of USGS's 850 funding partners are short of funds. Since the USGS has no funds to keep them operating, the gauge is lost to the system. The program is at only 23 percent of full funding in 2010.

The bottom line? The USGS stream gauging effort has been less than robust, relative to the objective scientific need, and has actually lost ground. It is prey to instability in the network because of erratic, decreasing funding.

Clean Michigan Initiative. The state of Michigan[6] faced the usual problems of anemic or even nonexistent funding for ambient water and other kinds of monitoring, even in the go-go years of the 1990s.

Then Gov. John Engler (R) and then the legislature, included $45 million in a Clean Michigan Initiative bond issue within the $675 million to be raised through general obligation bonds[7] for environmental cleanup and protection. The governor believed strongly that things were getting better in terms of conventional water pollution, and he wanted to document that progress. He also understood that efficient, performance-based management of any kind required good information or metrics to be successful.

Fortunately, this innovative approach to public financing of a fundamental water program passed muster with the Michigan voters in 1998, along with the entire bond issue.

State general revenues are in the tank and will remain so far some time, recovering only slowly and unlikely to return to pre-recession levels in the opinion of this writer at least. Creative, dedicated revenue-sourcing will be a necessity, not an option, in terms of monitoring and other environmental programs.

The Clean Michigan Initiative funds were to provide an increase of approximately $3 million a year to implement a 1997 strategy for surface water quality monitoring relating to fish contaminants, water chemistry, sediment chemistry, biological integrity, wildlife contaminants, bathing beaches, inland lake quality and eutrophication, stream flow, and volunteer monitoring.[8]

Gary Kohlhepp of the Michigan Department of Natural Resources and Environment has indicated the program is going strong and, despite the serious economic conditions in Michigan, Clean Michigan Initiative monitoring funds have not been diverted to other priorities.[9] In fact, the program has been spending less than anticipated and funding is likely to continue through 2016, at which time the issue of continuity in program funding will, once again, present itself.

A Rude Awakening

While serving as assistant EPA administrator for water, I received a rude awakening as to the difficulty the National Water Program has in evaluating and assessing the condition of the waters of the United States with anything resembling scientific rigor, at least enough to satisfy Congress, the White House Office of Management and Budget, the upper management, and scientists at EPA.

At the time, EPA Administrator Christine Todd Whitman was pushing hard to issue the landmark *Draft Report on the Environment 2003*.[10] However, it became clear the scientists and experts in the Office of Research and Development and others throughout the agency simply could not endorse the aggregation of the data generated by the states, under the relevant sections of the Clean Water Act for purposes of a national assessment.

The Clean Water Act was then thirty-one years old, and the National Water Program had, as fully intended by Congress, primarily focused on end-of-the-pipe discharges[11] from point sources and not enough on the entire watershed including nonpoint sources as well as physical and biological threats. Historically, ambient water quality monitoring and assessment were not a priority given the initial focus on discharges at the end of the pipe and technology-based standards, just as Congress had intended.

For instance, in 2000, states reported to EPA that they monitored the water quality of only 20 percent of

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[4] http://water.usgs.gov/osw/lost_streamgages.html

[5] E-mail from J. Michael Norris to G. Tracy Mehan, III, April 7, 2010.

[6] The author served as director of Michigan's Office of the Great Lakes, 1993-2001.

[7] For more information on Michigan's monitoring program, *see* http://www.michigan.gov/dnre. Click on ''Water,'' then ''Water Quality Monitoring,'' and, finally, ''Assessment of Michigan Waters'' to find ''Monitoring Elements.''

[8] *See* http://www.michigan.gov/deq/0,1607,7-135-3313_3686_3728-32609—,00.html.

[9] E-mail from Gary Kohlhepp to G. Tracy Mehan, III, April 12, 2010.

[10] The old EPA website for this report is now defunct. However, both this report as well as the more recent *EPA 2008 Report on the Environment* are available at http://www.epa.gov/roe/downloads.htm.

[11] Thus, EPA's National Water Program focused primarily on technology-based effluent limitations on publicly-owned treatment works and categories of industrial dischargers.

their total miles of rivers and streams, 40 percent of their lake acres and estuary miles.[12] Moreover, state standards and assessment methods vary, which made it impossible to use data to reach national-scale conclusions.

The first *Draft Report on the Environment* had hoped to address the condition of U.S. waters and watersheds, but eventually it concluded that ''at this time, there is not sufficient information to provide a national answer to this question with confidence and credibility.''[13]

This conclusion mirrored similar ones made by the General Accounting Office (as it used to be called), the National Research Council of the National Academies, and the H. John Heinz II Center for Science, Economics, and the Environment.

On my way out the door of EPA, I published an editorial in a research journal and offered the following observation:

> Water monitoring and assessment programs in the United States are at a historic turning point. We have collected years of data of all types and sources, yet today we cannot describe, in a scientifically defensible way, the quality of our waters. Moreover, we cannot quantify the progress we have made to date in cleaning those waters, nor where we need to go to fix remaining problems. We run the risk of 'flying blind' when it comes to making decisions about how best to address water quality problems and allocate our limited resources for cleanup, pollution prevention, and restoration. It is time to turn our national water-monitoring program in a new direction.[14]

Fortunately, Whitman and Deputy Administrator Linda Fisher understood, completely, that this condition could not persist in the era of watershed management. Notwithstanding the pressures of September 11, which immediately inserted homeland and water security into everyone's job descriptions and scrambled budgets for a few years, the administrator demonstrated her resolve by leaving the tough language in the *Draft Report on the Environment 2003* and directing new resources into data collection and monitoring, enhancing existing efforts and opening new opportunities.

From my perch as assistant administrator for water, and in light of the lessons learned regarding the *Draft Report*, the chronic underfunding of state and interstate monitoring required putting more resources into Clean Water Act Section 106 funding which today, while still modest, is a big improvement over the past.

Again, any extra dollars usually go exclusively to enforcement, permitting, and the like. Hopefully, we were able to begin a change in that traditional state of affairs.

Flying Blind No More

Today, water managers, policymakers and the broader public are more aware, more committed to better information, data, monitoring, and assessment, reflecting a greater appreciation of the complexity of our challenges in managing watersheds and source water protection areas for drinking water at landscape scale.

Last year 122,599 people worldwide visited local streams, rivers, lakes, and other water bodies in celebration of World Water Monitoring Day which is sponsored by the Water Environment Federation and the International Water Association. This was a 67 percent increase over 2008.[15]

In 2006, I had the pleasure of addressing[16] the New Jersey Water Monitoring and Assessment Technical Workshop. Leslie McGeorge of the New Jersey Department of Environmental Protection and her colleagues at USGS packed the house at the Rutgers EcoComplex. It was a most impressive gathering, one that is being emulated by water monitoring councils across the country.

To Achieve the Common Goal

In that speech I outlined four things the water community needed to do to achieve the common goal of better monitoring for better water management in the new age of information. I believe these items represent a solid baseline to ''gauge'' our progress over time (if I may use that term).

First, we needed to continue to provide the resources necessary to strengthen state monitoring, assessment, and standards programs so that they can generate comprehensive, comparable, and sound water information. EPA and the states have made substantial progress. Congress and EPA have provided an increment of over $60 million over the last five years to states implementing their monitoring strategies.

Second, we must develop and promote the use of multiple monitoring tools such as statistically-based surveys, predictive monitoring, and remote sensing to support the full range of water quality decisions. Statistically based surveys, for example, provide a scientifically rigorous way to sample a subset of waters and then provide an estimate of the quality of all waters. However, such surveys cannot answer all of our water quality information questions. No one size fits all. That must be kept in mind.

Third, we must improve electronic data systems to manage and share monitoring information and make data more accessible to the public.

These first three items should be amended to incorporate Dr. Hirsch's wise counsel that patience, a long-term commitment to analyzing trends, especially relative to wet weather issues such as nonpoint source pollution and stormwater,[17] is critical to success.

''The water quality issues of today didn't come about overnight and they will not end overnight,'' opines Dr. Hirsch. There ''has to be a dedication to taking action over many years and continuing to monitor and evaluate over many years.'' Indeed, ''The current focus on 'results' can cause us problems because the results we

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[12] For a fuller discussion, see G. Tracy Mehan, III, *Monitoring Is the Key*, Water Environment & Technology (WE&T), November 2003, p. 24.

[13] *Id.*

[14] G. Tracy Mehan, III, ''Better Monitoring for Better Water Management,'' Editorial, Water Environment Research (Water Environment Federation), January/February 2004, pp. 3-4.

[15] http://www.worldwatermonitoringday.org/About/2-17-2010_News_Release.html.

[16] G. Tracy Mehan, III, *Water Monitoring In the Age of Information*, Remarks, New Jersey Water Monitoring and Assessment Technical Workshop (New Jersey Water Monitoring Council), April 20, 2006. These remarks were the basis for my article of the same title which appeared in ECOStates (The Environmental Council of the States), Spring 2006, pp. 21-24, accessible at http://www.ecos.org/files/2196_file_ECOStates_Spring_2006.pdf.

[17] E-mail from Robert M. Hirsch to G. Tracy Mehan, III, April 20, 2010.

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seek in water quality will take time, and monitoring is the only way we will determine if we are moving forwards or away from our goals.''

Fourth, and perhaps most importantly, we must build stronger partnerships at the federal, state, and local levels, and with volunteer organizations to facilitate the sharing of comparable data and the use of multiple monitoring tools.

The National Water Quality Monitoring Council, which sponsored its Seventh National Monitoring Conference[18] in Denver this year, drawing more than a thousand attendees, double the number two years ago, is a great example of the essential partnerships we need to develop and nurture. So are the dozens or more state and regional monitoring councils. Money is a necessary but not a sufficient condition of success. Without effective coordination and pooling of resources and expertise, it will be impossible to accomplish the mission.

Ferries in North Carolina. One example of collaboration, ingenuity, and the blending of low-tech and high-tech approaches to monitoring is the FerryMon program which has utilized ferries crossing the Neuse River and Tamlico Sound in North Carolina, on regular routes, equipped with a system for continuous collection of water samples and water quality data since 2000.[19]

One ferry makes 40 crossings daily along the Neuse River.

''Ferries fill an important gap between traditional estuarine monitoring, where you go out once a week or once a month in small boats, and mooring-based offshore monitoring programs,'' said Hans Paerl, professor at the University of North Carolina at Chapel Hill's Institute of Marine Sciences.

FerryMon is commissioned by the North Carolina Department of Environmental and Natural Resources in partnership with Duke University Marine Laboratory and the state Department of Transportation (NCDOT) Ferry Division. It has a water quality monitoring system ''about the size of a washing machine'' which is installed on three NCDOT ferries.

According to Robert Ellison, writing in Water & Waste Digest, the heart of this system is a YSI 6200 data acquisition system, interfaced with a small, hardy YSI 6600 multiparameter monitoring sonde customized for FerryMon.

The sonde does not require much attention or maintenance, except every 10 to 14 days. It allows FerryMon to document variations in estuary and coastal waters and to detect algal bloom only a few hundred meters across, raising a red flag for state and local officials.

Hans Paerl also argues that FerryMon has provided more evidence that nutrient-input controls are important and that the total maximum daily load or TMDL is ''justifiable.''

FerryMon is reliable, inexpensive and has been able ''to create accurate, high-resolution baseline data sets to observe how water quality, water conditions and ocean life change in the same area over long periods of times,'' says Paerl.

These developments are powerful indicators that a viable network or community of interest, at a national scale, now has formed around data collection, monitoring and assessment, encompassing government at all levels as well as the private and not-for-profit sectors.

Progress in this area is palpable. Michigan, New Jersey, and North Carolina are just three places where great work is well underway. Great things also are happening in California and Minnesota.

USGS, a world-class research institution, continues to do great work, despite limited resources, in its National Water Quality Assessment Program (NAWQA).[20]

I am serving on my third committee on the Mississippi River, the Gulf of Mexico, and the Clean Water Act for the National Research Council. My colleagues and I have benefited tremendously from USGS modeling and targeting of ''hot spots'' or high-priority areas relative to nutrients delivered to the Gulf of Mexico. This kind of work is indispensable for cost-effective targeting of limited conservation dollars in the Mississippi River Valley.

Mississippi River Basin Initiative. Recently, the U.S. Department of Agriculture announced its new Mississippi River Basin Healthy Watersheds Initiative[21] to be implemented by its Natural Resources Conservation Service which is designed to ''help producers in selected watersheds in the Mississippi River Basin voluntarily implement conservation practices that avoid, control, trap nutrient runoff; improve wildlife habitat; and maintain agricultural productivity.''

The Mississippi River Basin Healthy Watersheds Initiative will direct an additional $80 million each fiscal year, FYs 2010-2013 into selected watersheds (8-digit hydrologic unit code or HUC). It was the work of USGS scientists and modelers who have provided the ability to do this kind of targeting effectively for the benefit of the Mississippi River and the Gulf of Mexico.

Drinking water utilities are working with NOAA and other partners to downscale global climate circulation models for use in specific watersheds and service areas for purposes of adapting to climate change and variability.

Did I mention that stationarity is dead?

Dr. Hirsch, and other international experts[22] have written that ''stationarity'' no longer can serve as ''a central default assumption in water-resource risk assessment and planning.'' Given climate variability, ''Rapid flow of such climate-change information from the scientific realm to water managers will be critical for planning, because the information base is likely to change rapidly as climate science advances during the coming decades,'' write Hirsch et al. Also, while modeling is important it can never replace observations. It only can synthesize them. ''In a nonstationarity world, continuity of observations is critical.'' This is another

[18] http://acwi.gov/monitoring/.

[19] Robert M. Ellison, ''Gathering Comprehensive Water Quality Data,'' Water & Wastes Digest (http://www.wwdmag.com), January 2010, pp. 40-42.

[20] For an overview of NAWQA's accomplishments and challenges, see National Research Council, *Opportunities To Improve The U.S. Geological Survey National Water Quality Assessment Program* (National Academy Press 2002).

[21] http://www.nrcs.usda.gov/programs/mrbi/mrbi_overview.html

[22] P.C.D. Milly, Julio Betancourt, Malin Falkenmark, Robert M. Hirsch, Zbigniew W. Kundzewicz, Dennis P. Lettenmaier, and Ronald J. Stouffer, ''Stationarity Is Dead: Whither Water Management?'', Science, Feb. 1, 2008, Vol. 319, pp. 573-574.

argument for robust data, monitoring, and assessment programs in the water sector.

National Aquatic Resource Surveys. EPA, working with partners all over the country, have made great strides with its National Aquatic Resource Surveys,[23] such as those for wadeable streams, coastal and estuarine conditions, and lakes. This is a big improvement since the days of the *Draft Report on the Environment 2003.* More of these statistically-valid, probability-based surveys are coming into the public domain.

Technology also is coming to the rescue. New sensor technology and continuous monitoring, the ''wave of the future for water monitoring for many parameters,'' says New Jersey's Leslie McGeorge, will enable cost-effective ways of providing useful information where and when water managers need it. These breakthroughs will greatly aid in the assessment of our progress in attaining water quality standards and information on what factors might be causing exceedances of applicable criteria.

New sensors are now available for a reasonable cost of approximately $5,000, says Chuck Spooner of EPA's Office of Oceans, Wetlands and Watersheds.

Just recently, Congress has passed legislation authorizing a national water census by means of the SECURE Water Act.[24] The driver for the law appears to be climate change and adaptation, but there are a host of long-standing reasons why this kind of legislation should have been passed decades ago. Basically, it is designed to increase the acquisition and analysis of water-related data to assess long-term availability of water resources and much more.

So maybe we will be flying blind no more.

The Role of Numeric Criteria

As we move to restore entire watersheds, not just control pollution at the end of the pipe, we are going to have to pay more attention to water quality standards, specifically numeric criteria, most especially for nutrients. Many states are implementing criteria to include biological measures that also are critical to restoring the full integrity of the U.S. and state waters.

Criteria using biological measures are critical for defining and interpreting water quality using metrics beyond those that are chemical and physical.

EPA's Spooner has said, ''Biology measured through variations in distributions of organisms and the relative abundance of different classes of organisms gives new insights, including giving a sense of the importance of long-term exposures to varying conditions. The benthic macroinvertabrates or algae live in the stream all year around and reveal the assaults of extremes that infrequent trips to sample sites might miss.''[25]

Many states do have narrative criteria but that requires use of ''best professional judgment'' in the writing of water permits which means it does not get done very often, given the uncertainty and inevitable controversy of such a subjective approach. Without numeric criteria Total Maximum Daily Loads (TMDLs), a kind of pollution budget required under the Clean Water Act for impaired waters,[26] lack rigor and credibility.

Finally, the absence of numeric criteria makes it harder to effectively monitor and assess water quality against a valid baseline.

A recent report of the State-EPA Nutrient Innovations Task Group offers this information.[27] Of the more than 16,500 municipal publicly-owned treatment works (POTWs) or wastewater systems, only 4 percent have numeric limits for nitrogen.

Some 43.5 percent of POTWs have limits for ammonia which, unfortunately, does not reduce overall nitrogen loadings since nitrates and nitrites continue to be discharged. Only 9.9 percent have numeric limits for phosphorus.

If you back out the publicly-owned treatment works in the Chesapeake Bay watershed and the Great Lakes, these figures probably drop even lower since there are now in place cutting-edge numeric criteria for the Bay. The Great Lakes has regulated phosphorus for many years pursuant to the Great Lakes Water Quality Agreement between the United States and Canada as well as the Clean Water Act.

In other words, there are relatively few numeric criteria for nutrients which threaten not only freshwater, but our priceless marine waters such as the Gulf of Mexico. In the case of the Gulf, there are no nitrogen numeric criteria anywhere-not for the northern Gulf or upstream including the Ohio and Mississippi Rivers.

It seems the development of adequate ambient water quality monitoring programs and numeric criteria for nutrient water quality standards go hand in hand. Indeed, permitting, TMDLs, and effective targeting of conservation subsidies, as well as monitoring, all start with adequate standards in the first instance. Water managers, wastewater utilities, farm extension agents, and watershed groups all need a gyroscope, so to speak, to guide or direct effective programs across the board. That comes back to numeric criteria for water quality standards.

Conclusion

This article has described where we were, where we are and where we might be going in terms of water data, monitoring, assessment, and analysis, over long periods of time, across all programs, quantitative and qualitative. It aimed to explore the convergence of the Age of Information and the era of watershed management. Hopefully, it has provided some perspective on the topic and, even more importantly, prompted new thinking on the subject.

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[23] http://www.epa.gov/owow/monitoring/nationalsurveys.html.

[24] S. 2156 was passed as part of The Omnibus Public Land Management Act of 2009, Title 9501 of Pub. L. No. 111-11 (59 DEN A-8, 3/31/09).

[25] E-mail from Charles S. Spooner to G. Tracy Mehan, III, April 22, 2010.

[26] ''Impaired'' waters are those not meeting applicable water quality standards and requiring additional control for point sources, over and above technology-based effluent limitations.

[27] State-EPA Nutrient Innovations Task Group, *An Urgent Call To Action-Report of the State-EPA Nutrient Innovations Task Group,* August 2009, p. 14, available at http://www.epa.gov/waterscience/criteria/nutrient.

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