Assessing the total maximum daily load approach to water quality management
Leonard Shabman, PhD, and Kenneth Reckhow, PhD

The recent history of the total maximum daily load (TMDL) program is now well known, as is the debate it has engendered.¹ Most recently, when the U.S. Environmental Protection Agency (EPA) issued new rules governing all aspects of the TMDL process in July 2000, it was sued in federal court in the lawsuit, American Farm Bureau Federation v. Whitman (D.C. Cir, No. 00-1320 and consolidated cases, 7-18-00). Among the expressed concerns were that the data and models necessary to support a defensible TMDL approach to water quality management were lacking. Congress was following the debate and voted to impose a one-year moratorium on the rule in October 2000. In the same law, it commissioned the National Research Council (NRC) to study the adequacy of the available data and models necessary to support the TMDL program.

An eight member NRC committee met three times during a three-month period and heard the testimony of more than 40 interested organizations and stakeholder groups. The resulting NRC study represents the consensus opinion of the committee members. The report, “Assessing the TMDL Approach to Water Quality Management,” was released in June 2001 and is available for download or purchase at www.nap.edu/catalog/10146.html. EPA cited the NRC report when it announced that its TMDL rule would be subject to further public meetings and review. During fall 2001, EPA held listening sessions around the nation and is currently accepting written comments on the TMDL program. EPA also is reviewing the recommendations of the NRC report. A final release for the new rule is scheduled for March 2003.
The TMDL Philosophy

The TMDL program focuses our attention on ambient water quality standards for watersheds and relies on the states to achieve those standards. Interestingly, an ambient focus and reliance on state leadership characterized the 1965 Water Pollution Control Act. However, the 1972 Federal Water Pollution Control Act amendments directed the nation's water quality management programs toward federally prescribed, technology-based, control requirements for selected chemical pollutants from principally point sources. In some ways, the TMDL program returns the nation to the pre-1972 focus.

The general concept behind the TMDL approach is simple. States set ambient water quality standards (WQS) by defining a designated use appropriate for each water body and selecting a water quality criterion -- a surrogate -- to measure achievement of that designated use. Then, if the states' monitoring and assessment program finds that the WQS is not being attained, the water body is placed on the impaired waters list and a TMDL plan is required.

A TMDL is a calculation of the maximum amount of a pollutant that a water body can receive and still meet water quality standards. The TMDL plan also requires an allocation of load limits among regulated and unregulated sources and – perhaps – a plan of regulatory and budgetary actions to secure those load reductions – again relying on computer models. However, other stressors on water quality, such as flow and habitat alteration, lie outside this TMDL process.
The NRC Report
The report of the NRC committee endorsed the "watershed" and "ambient water quality focused approach" to water quality management called for in the TMDL program. The committee felt that available data and models were adequate to move such a program forward, if EPA and all stakeholders better understood the nature of the scientific enterprise and its application to the TMDL program. Nonetheless, the panel had many concerns about the program's design and made more than 20 recommendations for improving the foundation for the TMDL program. In this article we summarize the highlights of the NRC report.

Water Quality Standards: The TMDL program requires appropriate and measurable water quality standards for each water body. However, the Clean Water Act goals of waters that are “fishable and swimmable” and have “biological integrity” are not operational statements of designated uses. For example, a sufficiently detailed designated use might distinguish between beach use, primary water contact recreation and secondary water contact recreation. Meanwhile, in many areas of the United States, human activities have radically altered the landscape and aquatic ecosystems such that an appropriate designated use may not necessarily be the aquatic life condition that was present in a watershed’s pre-disturbance condition. Yet, “integrity” for setting water quality standards is often defined with reference to a pre-human disturbance condition. Therefore, the committee felt that EPA should encourage states to review the WQS for a listed water body to assure that the designated uses, and surrogate criteria to measure such use, are appropriate and attainable for the water body being assessed before a TMDL is initiated.
In addition, the committee report reminded the reader that determination of a designated use is a social decision. However, EPA has offered no guidance on what constitutes an acceptable analysis for setting a designated use in water bodies of different complexity and what decision criteria will be accepted as a basis for a use designation. The agency has provided little information on how to conduct socioeconomic analyses or how to incorporate such analyses in the use designation decision. This is significant because EPA retains the authority to approve state water quality standards.

**Data Analysis:** A water body assessment requires the interpretation of a limited amount of sample data to determine whether a violation of a water quality standard has occurred, that is whether the water is impaired. Few stakeholders recognize that assessing a water body is a hypothesis testing problem, where the hypothesis is that the water is (or is not) impaired. However, because few samples are taken, because there is variability in human activity and background conditions and because there will be measurement errors in the analysis of the collected samples, there inevitably must be some uncertainty and, therefore, mistakes made in the listing.

Currently the data analysis approaches used by the states do not test a hypothesis about the condition of a water body and are incapable of reporting and controlling for possible listing mistakes. Potentially erroneous listings, and failures to list impaired waters, may be widespread. Therefore the Committee recommended a two-part listing process that will lead to improved data acquisition and employ defensible statistical procedures before a water body is listed for a TMDL. Water bodies that are currently listed without adequate data and analysis of those data should be reexamined.
Models and Their Use: At present, EPA expects a TMDL plan for all listed waters, and that plan is often based on complex mathematical models to relate control actions to reduced pollutant loads and then relate pollutant load reduction to the surrogate for the designated use. Such modeling of complex watershed processes is a still-developing art, and thus model prediction error cannot be avoided. The TMDL that results from uncertain model predictions must include a margin of safety (MOS) in all calculations; the magnitude of this MOS is required by EPA to reflect model prediction uncertainty. However, under current practice, the MOS is typically an arbitrarily chosen adjustment to the TMDL that has no relation to model prediction error. Thus, the intended purpose of a MOS, to justify added water quality protection to address prediction uncertainty, is undermined by current practice. To address this, the committee recommended that prediction uncertainty analysis be the basis for the margin of safety determination whenever models are used to support TMDL decisions.

This being said, models that relate stressors to water quality criteria should be appropriate for the information and issue of concern. In a number of these cases, the available data and knowledge support only the simplest of analyses/models. EPA and the states need to recognize that it is generally prudent to begin (and perhaps, end) modeling for a TMDL in a with a simple model compatible with a data-poor situation. A large, complex model cannot substitute for the lack of knowledge about watershed processes or for inadequate data for implementing the model. In some cases mental – models will suffice. In other words, in some situations experienced water professionals can form a model in their minds about the watershed and make decisions based on that rather than using computer models.
Making Progress: Making progress toward achieving water quality goals will require a full recognition of the multiple stressors, including more than chemical pollutants discharged from point sources or from overland runoff. The committee was critical of the failure to include stressors such as flow and habitat alterations in the TMDL program and recommended that this be done. For example, changes in the hydrologic regime associated with development activities can destabilize stream banks and this can increase loads of sediment and nutrients.

The number and complexity of the interactions of multiple stressors, combined with model prediction uncertainty, means that we need to avoid the temptation to make assurances that specific actions will result in attainment of particular water quality standards. Until we begin working on the water quality problem, we cannot be sure what the correct solutions are, or even what designated uses we should be seeking. In complex systems we need to act in order to learn; adaptive implementation is a concurrent process of action and learning. Learning requires (1) continued monitoring of the waterbody to determine how it responds to the actions taken and (2) carefully designed experiments in the watershed. If we do not design learning into what we attempt, we are not doing adaptive implementation. Therefore, there needs to be an increased commitment to monitoring and experiments in watersheds that will lead to learning.

Also, adaptive implementation will not move ahead without a new understanding of “sound science” – the termed used by EPA and all other stakeholders. The planning sequence of
moving from data to analysis to information is supposed to give decision-makers confidence that the sometimes-costly actions to address a water quality problem are justified. A desire for this confidence is often behind the call for “sound science” in the TMDL program. However, the ultimate way to improve the scientific foundation of the TMDL program is to incorporate the scientific method, not simply the results from analysis of particular data sets or models, into TMDL planning.

The scientific method starts with limited data and information from which a tentatively held hypothesis about cause and effect is formed. The hypothesis is tested and new understanding and new hypotheses can be stated and tested. By definition, science is a process of continuing inquiry. Thus, calls to make policy decisions based on “the science,” or calls to wait until “the science is complete,” reflect a misunderstanding of science. Decisions to pursue some actions must be made, based on a preponderance of evidence, but there may be a need to continue to apply science as a process (data collection and tools of analysis) in order to minimize the likelihood of future errors.

**Conclusion:** The nation’s lawmakers were concerned that a paucity of data and models made it impossible for the states to comply with TMDL program requirements and meet water quality standards. The NRC report recommendations address this concern. Chapters in the report discuss the data and information required to set water quality standards, to list waters as impaired and to develop TMDLs (including the identification of pollution sources). Each chapter goes into considerable detail about the monitoring, modeling and statistical analysis methods needed to collect data and convert it to information and to assess and reduce uncertainty in both the listing process and TMDL
development and implementation. The committee concluded that there are creative ways to accommodate this uncertainty while moving forward in addressing the nation's water quality challenges.

Leonard Shabman, PhD, is professor of environmental economics at Virginia Tech. He can be reached via e-mail at shabman@vt.edu. Kenneth Reckhow, PhD, is a professor of civil and environmental engineering at Duke University. Reckhow served as chair of the National Research Council's Committee to Assess the Scientific Basis of the Total Maximum Daily Load Approach to Water Pollution Reduction. He can be reached via e-mail at reckhow@duke.edu.