Chapter 4

Water Quality Monitoring: National Institute of Food and Agriculture–Conservation Effects Assessment Project

D.W. Meals, D.L. Osmond, J. Spooner, and D.E. Line

Water quality monitoring can be defined as any systematic effort to obtain an understanding of the physical, chemical, or biological characteristics of water via statistical sampling (Ward et al. 1986). Monitoring is typically conducted in support of water quality management and is the foundation of effective management actions. Monitoring provides the information that allows rational decisions to be made concerning identification of actual and emerging problems of water pollution, formulation of plans to protect water resources and set priorities for water quality management, development and implementation of water quality management programs, and evaluation of the effectiveness of management actions (UNEP WHO 1996). Water quality monitoring reveals fundamental knowledge about the generation, transport, and impact of pollutants; documents the nature and extent of water quality impairment; and provides the best evidence of progress in water quality restoration in impaired waters.

Water quality monitoring can be conducted for a variety of purposes (MacDonald et al. 1991; ITFM 1995; USDA 1996):

- Define water quality problem(s)
- Respond to emergencies
- Make wasteload allocations
- Determine fate and transport of pollutants
- Define critical areas
- Design management and regulatory programs
- Assess compliance with regulations
- Measure effectiveness of conservation practices
- Evaluate program effectiveness
- Analyze trends
- Provide data for model development, calibration, validation, and application
- Conduct research

The specific activities that comprise water quality monitoring differ substantially according to the purpose of monitoring. Monitoring to define a water quality problem, for example, may involve collection of a few observations at multiple stations at a critical time (like midday measurements of dissolved oxygen), whereas monitoring to analyze trends may require long-term sustained discharge and constituent concentration measurements at a watershed outlet.

(c) SWCS. For Individual Use Only

In the past, water quality monitoring was sometimes viewed by those initiating a program to be simply a practical exercise of deciding when and where to take water samples. Decades ago, several national assessments pointed to the need to take a rigorous scientific and systematic approach to water quality monitoring in order to efficiently meet the information needs of water quality management (NAS 1977; CEQ 1980; GAO 1981). Even so, water quality monitoring often was focused primarily on data collection itself, leading to a situation Ward et al. (1986) described as "data-rich but information-poor," where managers are overwhelmed with volumes of data but still cannot answer fundamental questions about the resource or make science-based management decisions. This observation was echoed by MacDonald (1994), who observed that monitoring projects were too often initiated with minimal forethought and resulted in poorly documented data that were never analyzed, provide little or no feedback to resource managers, and contribute little or nothing to our understanding of the systems being monitored.

The principal solution to these shortcomings is to link water quality monitoring directly to specific objectives. Ward et al. (1986) concluded that a monitoring effort must be viewed as a complete system from the beginning if it is to be effective. This implies that the system designer must see the monitoring program from the top down, i.e., starting with water quality goals supported by management objectives, which in turn imply monitoring objectives, which finally specify monitoring activities. Ward et al. (1990) stressed the need to customize monitoring efforts by defining the information that is desired and then designing the monitoring system to produce it. Dixon and Chiswell (1996) pointed out that the underlying questions of why monitoring is undertaken are often neglected. Asking why, however, leads to the essential step of formulating information goals. The choice of how to monitor is then constrained because only certain actions of sampling and data processing will achieve the information goals. Only after the goals of the program, the indicators of water quality, and the statistics to be used have been decided can the where and when of sampling be set.

The World Health Organization (UNEP WHO 1996) identifies the development of objectives as the critical element in water quality monitoring and stresses the importance of understanding the use to which the information collected will be put. It is essential that the design, structure, implementation, and interpretation of monitoring systems and data are conducted with reference to the final use of the information for specific purposes.

Clearly, establishment of objectives is the first—and arguably most important—step in design of water quality monitoring activities. Several authors have proposed a list of additional key steps in the design of a water quality monitoring system (Ward et al. 1986; MacDonald 1994; USDA NRCS 1996). Kwiatkowski (1991) emphasized the need to build statistical design and data analysis into a monitoring program from the start in order to convert data into useful information.

The National Water Quality Monitoring Council (2011) maintains a framework for water quality monitoring that includes six steps: (1) develop monitoring objectives, (2) design monitoring program, (3) collect field and laboratory data, (4) compile and manage the data, (5) assess and interpret the data, and (6) convey findings and evaluate the program. This framework emphasizes coordination and feedback at every step.

Water quality monitoring has long been an important part of water resource management in general and in nonpoint source watershed projects in particular. States regularly assess the quality of their waters and compliance with water quality standards through monitoring under Section 305(b) of the Clean Water Act (USEPA 2011a). States use monitoring data to identify impaired water bodies and to develop and assess total maximum daily loads under Section

(c) SWCS. For Individual Use Only

303(d) of the Clean Water Act (USEPA 2011b). All nonpoint source watershed projects funded under Section 319 of the Clean Water Act are presently required to document their effectiveness (e.g., pollutant load reductions) through some form of monitoring. Thus, over the past several decades, the main thrust of water quality monitoring has evolved from problem identification to documentation of water body status and/or trends to the present emphasis on accountability: Have programs been effective? Have resources been well spent?

While monitoring at the research level has documented the effectiveness of conservation practices in reducing pollutant delivery from farm and rangeland at the plot- or field-scale (e.g., Jokela et al. 2004; Richards and Baker 2002; Sharpley et al. 2006a, 2006b; Shepard 2005; Smith et al. 2006; Tomer and Burkart 2003), relatively few studies have adequately or successfully used monitoring to evaluate the cumulative effects of programs of conservation practices implemented at the watershed scale (Edwards et al. 1997; NRC 1999, 2000). One of the first attempts to do this was the Black Creek Project (1973 to 1984) in northeastern Indiana, which implemented structural management practices to reduce sediment and phosphorus (P) levels entering Lake Erie from agricultural activities (Morrison and Lake 1983). Monitoring results generated important information about the nature and behavior of nonpoint source pollutants but did not document substantial water quality improvement resulting from land treatment.

From 1978 to 1982, the USDA and the US Environmental Protection Agency (USEPA) conducted the Model Implementation Program in seven watershed projects across the United States to implement the agricultural and silvicultural nonpoint source pollution portions of water quality management plans developed under Section 208 of the Clean Water Act. The Model Implementation Program was designed to demonstrate and study efforts by the USDA and USEPA to address agricultural nonpoint source problems using existing USDA and USEPA programs; each project included some level of water quality monitoring. Evaluation of the Model Implementation Program Projects (North Carolina State University and Harbridge House, Inc 1983) showed that only one project was able to demonstrate statistically significant water quality improvement through monitoring at the watershed scale, although five projects documented water quality improvements from field and plot monitoring. Recommendations for future programs included longer project time periods, preimplementation planning and documentation, and systematic documentation of both land treatment/use and water quality.

The Rural Clean Water Program (RCWP) (1980 to 1995) was the largest and most comprehensive nonpoint source control program of the time that combined land treatment and water quality monitoring to document nonpoint source pollution control effectiveness at the watershed scale (USEPA 1992). While all of the 21 RCWP projects were expected to use some water quality monitoring to assess land treatment effectiveness, five projects were funded for more intensive monitoring and evaluation. A few of these five projects were able to document limited water quality response to land treatment, although none of the projects were successful in completely reversing water quality impairments. Important lessons learned concerning water quality and land treatment monitoring (Gale et al. 1993) included the following:

- Water quality monitoring is essential for determining project results and evaluating the effectiveness of land treatment.
- Monitoring and reporting of results is required to do the following:
  - Document progress toward water quality goals
  - Determine needs for further or different treatment
  - Maintain the interest of project participants

(c) SWCS. For Individual Use Only

    - Develop and transfer technology
    - Sustain congressional support
    - Assure credibility
- Land treatment and water quality monitoring guidance for nonpoint source programs should be established; minimum monitoring standards should be established to facilitate technically valid project evaluation.
- The cost of water quality monitoring is relatively low compared to the benefits of effective nonpoint source control.

From 1991 to 1994, the USDA Natural Resources Conservation Service conducted an analysis of Hydrologic Unit Area and Demonstration Project programs to determine progress toward improving and protecting water quality from agricultural nonpoint source pollution (Meals and Sutton 1996). Progress was assessed using three indicators: (1) farmer adoption of conservation practices and changes in agrichemical management, (2) use of models to simulate reductions in pollutant loadings, and (3) monitored water quality changes in receiving water bodies. The analysis concluded that most of the five-year projects were unable to document impacts through monitoring due to inadequate monitoring design and/or resources, lack of control for spatial and temporal variability, and other limitations. Direct assessment of project-level impacts through water quality monitoring failed because many of the monitoring activities were undertaken from external ongoing programs that had goals and capabilities poorly suited to project evaluation. Monitoring was not well-integrated into project operation and management; coordination and feedback were lacking.

As the successor to the RCWP, the USEPA Section 319 National Nonpoint Source Monitoring Program (NNPSMP) was established in 1991 to improve technical understanding of nonpoint source pollution, document the feasibility of nonpoint source pollution control, and scientifically evaluate effectiveness of watershed technologies designed to control nonpoint source pollution (Spooner et al. 2011). More than 25 projects included in the USEPA Section 319 NNPSMP conducted six to ten years of intensive water quality and land treatment monitoring following a nationally consistent set of guidelines that included specific guidance on water quality monitoring design. Some of the USEPA Section 319 NNPSMP projects have reported success in documenting effectiveness of grazing management, erosion and sediment control, nutrient management, urban runoff control, and stream restoration for improving water quality at the watershed scale (Lombardo et al. 2000; Meals and Dressing 2006; Spooner et al. 2011).

More recently, Tomer and Locke (2011) reviewed the USDA Agricultural Research Service (ARS) "Benchmark" Conservation Effects Assessment Project (CEAP) watershed studies, focusing on the application of monitoring to assess program effectiveness. The review noted a significant disconnect between practice-level monitoring that was often effective in documenting water quality improvements at the site level and watershed scale assessments that were often unable to document improvements. This situation was largely the result of four conditions: (1) conservation practices not targeted at critical sources; (2) sediments in streams originating from bank and channel erosion rather than field erosion; (3) time lag, legacy pollutants, and climate change masking the effects of implemented practices; and (4) land treatment addressing single contaminants without considering trade-offs among multiple contaminants. The authors recommended improved integration of monitoring and modeling studies as the best strategy for improving conservation and watershed science.

(c) SWCS. For Individual Use Only

Given the difficulty associated with using monitoring to evaluate conservation practice effectiveness at the watershed scale, it is instructive to consider how, or even if, these principles learned from past projects apply to the use of monitoring in the National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP).

Role of Water Quality Monitoring in the National Institute of Food and Agriculture–Conservation Effects Assessment Project

Active water quality monitoring was not a dominant component of the NIFA–CEAP watershed studies. The 2004 NIFA–CEAP program request for applications stated that because of the long period of record needed to document water quality conditions and trends and because of lag time in water quality response to land treatment, the projects were to be based primarily on existing data (USDA CSREES 2004, 2005, and 2006). In fact, the selection criteria set forth in the USDA NIFA request for applications included this requirement:

> The watershed must have a minimum of 5 years of existing water monitoring data (greater than 10 years is desirable). Priority will be given to those watersheds with longer data records that meet the following criteria:
>
> (a) Continuous stream discharge;
> (b) Measures of nutrient concentrations during both runoff and base flow sediment concentrations;
> (c) Water quality parameters (biological, chemical, physical);
> (d) Geo-referenced land use, including specific conservation practices, and terrain features; and
> (e) Water quality data at locations within the watershed that can support analyses to distinguish the effects of multiple conservation practices and biophysical features on water quality patterns and trends.

Although a few NIFA–CEAP watershed studies sponsored supplemental or continued water quality monitoring during their tenure, for the most part, each project became a retrospective study that relied on past monitoring data, often collected by several different agencies under different programs and designs, to serve project needs.

In this context, water quality monitoring played several different roles in the NIFA–CEAP watershed studies, including the following:

- Watershed characterization
- Project development
- Model calibration
- Research
- Trend detection
- Documentation of response to land treatment

(c) SWCS. For Individual Use Only

Summary of Water Quality Monitoring Activities in the National Institute of Food and Agriculture–Conservation Effects Assessment Project

The principal monitoring activities for each of the 13 NIFA–CEAP watershed studies are summarized in table 4.1. Specific details of project monitoring are included in Part II: Chapters 9 to 21 of this book.

All of the NIFA–CEAP studies used past monitoring data for some form of watershed characterization. Such characterization included documentation of water quality impairments, setting context by comparison to regional conditions, and identifying important spatial or temporal water quality patterns.

Several projects used water quality monitoring data to guide ongoing project development. The Calapooia Basin Project in Oregon, for example, used results of synoptic sampling across multiple subbasins to guide site selection for intensive studies of relationships between wildlife and land use. The Little Bear River Project in Utah supported monitoring that established a predictive relationship between turbidity and P concentration that has been used to facilitate continued P load estimation. An extensive database on nitrate-nitrogen (NO_3-N) concentration in agricultural irrigation wells contributed to understanding of the influence of agriculture on the regional aquifer in the Central Platte Natural Resources District Project in Nebraska.

Water quality monitoring data served a critical role in calibration and validation of simulation models for most of the NIFA–CEAP watershed studies. For example, the Cheney Lake Project in Kansas used past and contemporary water quality monitoring data to calibrate the Soil and Water Assessment Tool (SWAT) model used to evaluate the conservation practices implemented in the watershed. The Goodwater Creek Project in Missouri used long-term watershed-scale monitoring data for calibration and validation of their SWAT model and storm-event data from plot studies to calibrate the Agricultural Policy/Environmental eXtender Model (APEX) model. In the Eagle Creek Watershed Project in Indiana, researchers used extensive watershed outlet and subbasin monitoring data to support multisite, multivariate calibration of SWAT, an improvement over the more common discharge-only initial calibration procedure.

Past water quality data, collected in support of research, benefited several of the NIFA–CEAP studies by improving understanding of biophysical processes and by documenting the effectiveness of specific conservation practices. In the Walnut Creek Project in Iowa, monitoring data revealed the importance of stream bank erosion to the sediment load from the watersheds. Even with a decrease in row crop land and reductions in field erosion predicted by Revised Universal Soil Loss Equation (RUSLE), no change in Walnut Creek suspended sediment load was documented (Schilling et al. 2011). A 35 km (21.7 mi) stream walk survey revealed that 57% of stream banks were eroding in the Walnut and Squaw Creek watersheds. Geospatial analysis of water quality data in the Central Platte Natural Resources District Project in Nebraska was used to quantify spatial variability in groundwater NO_3-N concentrations and to estimate trends in NO_3-N levels in areas where monitoring intensity has decreased. Results of research in a past USDA Management Systems Evaluation Area Project in Missouri and an intensive water quality study on a dairy farm in New York under the USEPA Section 319 NNPSMP were used to design, select, and model conservation practices in the Goodwater Creek Watershed and the Cannonsville Reservoir NIFA–CEAP studies, respectively.

(c) SWCS. For Individual Use Only

Table 4.1
Summary of principal water quality monitoring activities of the National Institute of Food and Agriculture–Conservation Effects Assessment Project (NIFA–CEAP).

Project	Principal activities
Arkansas	• Trend monitoring using past data and new project tributary sampling: continuous discharge, fixed-interval grabs plus event sampling for sediment and nutrients at two stations, 1991 to 2004 • Additional NIFA–CEAP lake and groundwater monitoring since 2004
Georgia	• Trend monitoring, using past data and ongoing stations in seven nested subwatersheds for discharge and weekly sampling for sediment and nutrients, plus grab sampling for other variables since 1974
Idaho	• Upstream/downstream, pre- and post–best management practice monitoring at eight subwatershed stations for discharge, total suspended solids, and turbidity since 1999 • Trend monitoring at watershed outlet station for discharge and total suspended solids since 1988
Indiana	• Trend monitoring on main watershed outlet and three subbasin stations for sediment, nutrients, and atrazine since 1995 • Spatial/synoptic sampling at 11 stations, including base flow and events since 1995 • High-frequency event monitoring (occasional) • Reservoir monitoring for nitrogen, phosphorus, atrazine, and biota since 1976
Iowa	• Paired watershed monitoring of treated and untreated watersheds for sediment, nutrients, pesticides, and bacteria since 1995 • Upstream/downstream monitoring in treated and untreated watersheds to separate influence of natural processes versus land treatment
Kansas	• Before/after and trend monitoring in three subbasins for sediment, nutrients, and atrazine conducted by NIFA–CEAP since 2006 to compare with past monitoring before 2001 and assess trends • Trend monitoring at reservoir inlet since 2000
Missouri	• Trend monitoring at single watershed outlet station (from a Management Systems Evaluation Area program) for discharge, sediment, nutrients, and pesticides since 1997 • Trend monitoring under a Management Systems Evaluation Area program (1990 to 1997) at watershed, field, and plot scales with weekly and event sampling for discharge, sediment, nutrients, and pesticides
Nebraska	• Trend monitoring of irrigation wells in regional aquifer for nitrate since 1988 • Geospatial time-series monitoring on NIFA–CEAP study fields
New York	• Paired watershed monitoring to test best management practice effectiveness on a single dairy farm from 1993 to 2005 • Trend monitoring of watershed subbasins for discharge and phosphorus, 1992 to 2006 • Trend monitoring in the Cannonsville Reservoir
Ohio	• Long-term trend monitoring at a single watershed outlet station since 1982 for sediment and nutrients
Oregon	• Fixed-interval grab sampling at multiple subbasins for sediment, nitrogen, and phosphorus since 2000 • Macroinvertebrate and fish sampling at multiple subbasin reaches from 2001 to 2004 • NIFA–CEAP macroinvertebrate, amphibian, and bird surveys at multiple sites from 2004 to 2009
Pennsylvania	• Pretreatment and posttreatment and control subwatershed outlet monitoring for discharge, sediment, nutrients, macroinvertebrates, and fish from 1991 to 2003 • Treated and untreated stream reach monitoring for morphometry and riparian vegetation
Utah	• Past monitoring from a mix of above/below, and before/after grab sampling by multiple agencies, supplemented by discharge monitoring by the US Geological Survey; primarily monthly sampling for sediment and nutrients during base flow and some events from 1990 to 2004 • NIFA–CEAP monitored discharge and turbidity continuously since 2004

(c) SWCS. For Individual Use Only

Long-term data records may support the detection of water quality trends, and several NIFA–CEAP watershed studies used their monitoring databases for this purpose. In Ohio, a 30-year monitoring record in Rock Creek documented a significant decrease in P loads from the watershed. Long-term monitoring by the USDA ARS in the Little River Experimental Watershed in Georgia suggested a decreasing trend in P concentrations and an increasing trend for dissolved oxygen. Note that, as in both of these projects, detection of water quality trends is necessary but is not sufficient to evaluate watershed project effectiveness. Making the connection between trends and the implementation of conservation practices requires additional analysis.

Finally, some of the NIFA–CEAP watershed studies were able to use past or contemporary monitoring data to document a water quality response to conservation practice implementation. An intensive paired watershed study of prairie restoration in Walnut Creek in Iowa, conducted under the USEPA Section 319 NNPSMP, showed significant decreases in NO_3-N levels in groundwater and in stream flow in response to cropland retirement and establishment of native prairie. The Rock Creek Project in Ohio combined past long-term water quality monitoring data with land use and agricultural management data to attribute significant downward trends in discharge, suspended sediment, P, and nitrogen (N) concentrations, and loads to widespread implementation of conservation tillage and improved nutrient management in the watershed. Monitoring data in the Spring Creek Project in Pennsylvania suggested that implementation of riparian buffers, stream crossings, and bank stabilizations effectively reduced sediment loading in watershed streams and improved substrate composition and both fish and macroinvertebrate communities in treated reaches.

Results: Contributions to Knowledge/Science from Water Quality Monitoring

Despite the fact that water quality monitoring was a secondary component of most of the NIFA–CEAP watershed studies, monitoring results provided important contributions to knowledge about the application of monitoring for land treatment project assessment. It should be noted that several of the most successful monitoring efforts were conducted under the auspices of other programs (e.g., the original New York paired watershed study was funded through the USEPA Section 319 NNPSMP), and while the results of such projects contributed significantly to their respective NIFA–CEAP studies, the monitoring was conducted entirely outside of the NIFA–CEAP program.

Six of the NIFA–CEAP studies were able to use monitoring data to successfully document changes in water quality attributed to land treatment; in most cases, this monitoring largely preceded the NIFA–CEAP studies themselves:

- Although target sediment total maximum daily load has not been met in the Paradise Creek Watershed Project in Idaho, statistically significant decreases in sediment loading from rural areas of the watershed were documented by the NIFA–CEAP (Brooks et al. 2010). These changes were attributed primarily to the implementation of minimum tillage through a 30-year federal program to reduce erosion and perennial grasses through the Conservation Reserve Program (CRP).
- Results of the paired watershed study in the Walnut and Squaw Creek Watersheds Project in Iowa indicated that prairie restoration in an agricultural watershed significantly reduced NO_3-N concentrations and loads in surface water. Planting ~25% of the Walnut Creek

(c) SWCS. For Individual Use Only

Watershed in native prairie resulted in a reduction of NO_3-N of ~1.2 mg L^{-1} in Walnut Creek over 10 years and 8 to 12 mg L^{-1} in some subbasins (Schilling and Spooner 2006).

- In the Central Platte Natural Resources District Project in Nebraska (1987 to 2003), monitoring data from agricultural irrigation wells showed that average groundwater NO_3-N concentrations in the primary aquifer beneath the terrace decreased from 26.4 to 22 mg NO_3-N L^{-1} at a slow but statistically significant rate of 0.26 mg NO_3-N L^{-1} y^{-1} (18%). This decrease was attributed to increased N removal by increased crop yields and to conversion of furrow-irrigation to sprinkler irrigation (Exner et al. 2010).
- Long-term monitoring in the Rock Creek Watershed in Ohio documented significant decreasing trends in flow and suspended solids, total P, soluble reactive P, NO_3-N, and total Kjeldahl N concentrations, attributed to widespread implementation of conservation tillage and improved fertilizer management. Continued monitoring under the NIFA–CEAP confirmed that most of these trends have continued through 2008, but soluble reactive P has increased sharply over the last 13 years, probably due to changes in fertilizer application timing and methods (Richards and Baker 2002; Richards et al. 2007, 2008) and increased installation of tile drains.
- A New York paired watershed study documented significant decreases in event P loads resulting from manure management, rotational grazing, and improved infrastructure conservation practices implemented on a single farm (Bishop et al. 2005). This project was funded by the USEPA Section 319 NNPSMP, and results were later used to support assessment and modeling in the New York Cannonsville Reservoir NIFA–CEAP.
- In the Spring Creek Watershed (PA), suspended sediment concentrations decreased during baseflow and stormflow after riparian treatments (Carline and Walsh 2007). A significant reduction in fine sediments in the stream substrate and an increase in macroinvertebrate density were also observed in treated streams following restoration.

Several of the NIFA–CEAP watershed studies were successful in applying plot- and field-scale studies to advance understanding of relationships between hydrologic processes and pollutant loss at the watershed level. In the Goodwater Creek Project in Missouri, nested monitoring at plot and field scale provided critical information about both herbicide losses as a function of timing of application relative to storm events on different cropping systems and about water and pollutant behavior on claypan soils. Results documented the central problem of finding a balance between reducing erosion and herbicide losses through cropping systems that minimize both pollutants simultaneously. Using their extensive historical monitoring data, the Nebraska NIFA–CEAP developed geospatial analysis techniques that can use irrigation well data, even if samples were infrequent and inconsistent, to better characterize the spatial distribution of the shallow groundwater NO_3-N concentrations and response to land treatment.

Some NIFA–CEAP watershed studies used monitoring data to help identify pollutant sources and understand critical watershed processes. Suspended sediment and stream channel monitoring in the Walnut Creek Project in Iowa suggested that the lack of documented change in sediment load following prairie restoration could be due to the highly seasonal pattern of sediment export, the fact that stream power was not reduced by the treatment, failure to address stream bank erosion, and long-term sediment storage in floodplains and stream channels. A major finding of the Rock Creek NIFA–CEAP in Ohio was that, despite reductions in particulate P and suspended sediment due to increased conservation tillage, large hydrologic events combined with some other agricultural management activities (such as broadcast fertilization due to the conservation tillage system)

(c) SWCS. For Individual Use Only

can greatly affect total nutrient losses, as seen by increasing losses of dissolved reactive P, total Kjeldahl N, and chloride, even when conservation practices are implemented. Biological monitoring in the Calapooia Basin NIFA–CEAP in Oregon revealed several important ecological responses to hydrology and land management: (1) native fish species use seasonal streams and ditches for refuge and reproduction; (2) ephemeral streams draining native wet prairie had the greatest macro invertebrate taxa richness, independent of habitat; (3) perennial cover greatly increased amphibian habitat; and (4) greater species richness for winter birds occurred in areas with higher tree/shrub cover, but the presence of conservation practices had no effect on bird species richness.

Two NIFA–CEAP watershed studies developed alternative indicators of water quality response to treatment through monitoring. Rather than using traditional chemical water quality metrics, the Little Bear River Watershed Project in Utah combined aerial video imagery with geographic information system analysis to compare 1992 and 2007 stream bank/stream channel conditions to evaluate the effects of land treatment on riparian condition, an important project objective. In the Spring Creek NIFA–CEAP in Pennsylvania, biological monitoring in restored stream reaches showed that direct measures of a stressor (e.g., percentage of fines in stream substrates) and simple biological density metrics were more responsive to land treatment than were more traditional broad biological variables, such as diversity indices. Improvements in stream biological communities due to riparian treatment were seen not in community metrics but in simple organism density data.

Monitoring activities in several of the NIFA–CEAP watershed studies revealed the importance of spatially and temporally distributed monitoring. Nested monitoring stations in the Goodwater Creek Watershed in Missouri provided water quality data that contributed to identification of critical management areas. Synoptic sampling of multiple subbasins in the Calapooia Basin in Oregon supported the selection of study sites for relating land management to biological communities. The Walnut Creek Project in Iowa observed that important spatial variations in water quality may be masked when integrated into a larger watershed. High NO_3-N concentrations from an untreated upstream station would have obscured decreased NO_3-N levels in the downstream drainage if monitoring had occurred only at the watershed outlet. On a fine temporal scale, both the Walnut Creek Watershed Project in Iowa and the Goodwater Creek Watershed Project in Missouri were NIFA–CEAP studies that noted that fixed-interval autosampling can either miss or significantly underestimate transient peaks in herbicide losses that occur in the first flush of storm events. On a longer time scale, the Spring Creek Watershed in Pennsylvania noted that water quality response to treatment can be significantly affected by year-to-year hydrologic variation. In Spring Creek, indicators showed delayed response to conservation practices due to low-flow years in a hydrologically losing stream highly susceptible to drought. The affected stream demonstrated fewer positive changes in biota and took a longer monitoring period to detect the changes than did the wetter stream

Finally, monitoring data collected from Walnut Creek in Iowa prior to the NIFA–CEAP provided definitive data on lag time in the groundwater system response to implementation of conservation practices. Mean groundwater travel time to the surface drainage network in the watershed was estimated to be 10 years, with a range from 2 days to 308 years (Schilling and Wolter 2007). Researchers estimated that 10% to 22% of restored prairie areas contributed groundwater to streams in the Walnut Creek Watershed within the 10-year project period. Despite this relatively small contribution, the project was able to document significant reductions in stream NO_3-N concentrations in response to prairie restoration, and researchers anticipate additional NO_3-N reduction as reduced NO_3-N groundwater from additional watershed area reaches the stream network.

(c) SWCS. For Individual Use Only

Lessons Learned

Application of Water Quality Monitoring to National Institute of Food and Agriculture–Conservation Effects Assessment Project Objectives

This synthesis first examined how water quality monitoring was applied by the case study projects to address the central NIFA–CEAP objectives. The 2004 NIFA–CEAP program request for applications (USDA CSREES 2004) required projects to address four central questions, of which three could potentially be addressed by the collection of water quality data through monitoring:

- Within the hydrologic and geomorphic setting of a watershed, how do the timing, location, and suite of implemented agricultural conservation practices affect surface water and/or groundwater quality at the watershed scale?
- What are the relationships among conservation practices implemented in a given watershed with respect to their impacts on water quality? Are the effects additive, contradictory, or independent?
- What is the optimal set of conservation practices and what is the optimal placement within the watershed in order to achieve water quality goals or to provide acceptable reductions in water quality impairments?

Water quality monitoring among the NIFA–CEAP watershed studies had limited success in documenting the effects of implemented agricultural conservation practices on surface water or groundwater quality at the watershed scale. As noted previously, fewer than half of the projects were able to demonstrate improvements in water quality that could be attributed to the implementation of conservation practices at the watershed level. Most of these monitoring efforts, however, were specifically designed to evaluate water quality response to treatment and were supported by past programs outside the NIFA–CEAP. For example, 28 years of past monitoring data in the Paradise Creek Watershed in Idaho showed statistically significant decreases in sediment loading from rural areas of the watershed, resulting from the implementation of minimum tillage and perennial grasses. The Walnut Creek Project in Iowa, which documented some reduced NO_3-N levels in response to prairie restoration, and the Cannonsville Reservoir Project in New York, which demonstrated significant P reductions in response to implementation of a suite of conservation practices on a single farm, were both paired watershed studies funded by the USEPA Section 319 NNPSMP. Reductions in sediment and total P export from the Rock Creek Watershed in Ohio were first noted in a 20-year data record from monitoring supported by a collaboration of investigators from several universities under the Lake Erie Agricultural Systems for Environmental Quality study (1975 to 1995). Declines in groundwater NO_3-N levels in the Central Platte Natural Resources District in Nebraska, attributed to increases in crop yields and improvements in irrigation management, were documented through agricultural irrigation well data collected from 1987 to 2003 under a state-mandated monitoring program. It is worth noting also that these monitoring programs involved collection of data over a long monitoring period, generally longer than the duration of the NIFA–CEAP watershed studies themselves. So, for these projects, the notion of reliance on past water quality monitoring for program evaluation was, in fact, critical to documenting changes in water quality.

However, the other NIFA–CEAP studies were generally not successful documenting effectiveness of conservation practices through water quality monitoring. In some cases, water quality changes or trends were observed through monitoring but could not be linked to the

(c) SWCS. For Individual Use Only

implementation of conservation practices. This was mainly because the monitoring programs were not specifically designed to evaluate response to treatment but were designed to serve other goals. Long-term monitoring in the Little River Experimental Watershed in Georgia suggested a decreasing trend in P concentrations and an increasing trend for dissolved oxygen, but these trends could not be attributed to changes in agricultural management. In other cases, no changes or trends could be detected in the water quality record. Despite almost 20 years of herbicide monitoring in Missouri's Goodwater Creek Watershed, for example, no trends were observed in atrazine concentration. Similarly, long monitoring records in the Little Bear River Project in Utah and the Cheney Lake Watershed in Kansas revealed no statistically significant changes in sediment or nutrient concentrations or loads over time.

Water quality monitoring among the NIFA–CEAP watershed studies generally did not address the issues of relationships among conservation practices in a watershed with respect to impacts on water quality. Monitoring to meet this objective must be carefully designed and the past monitoring programs were usually not intended to meet this kind of objective. Most of the new or continued monitoring in the case study projects was conducted at a watershed or subwatershed scale that did not allow the effects of individual practices or combinations of practices to be detected. Although some projects included monitoring data on individual practices that supported or informed the application of the practice in the watershed, water quality monitoring was not used to investigate specific interactive relationships between multiple practices. The Cannonsville Reservoir Project in New York had conclusive data on the effectiveness of a suite of conservation practices on a single farm in a small watershed, but did not monitor these practices individually within the study watershed or after implementation in the wider watershed. Data from an earlier USDA ARS Management Systems Evaluation Area project provided understanding of the effects of some individual practices under conditions in the Goodwater Creek Watershed in Missouri, but did not address issues of relationships among practices, except to note the potential conflict between reduced tillage and herbicide runoff.

Water quality monitoring did not inform the questions of the optimal set of conservation practices and their optimal placement in the watershed. In a relatively short-term program such as the NIFA–CEAP, this question would be essentially impossible to answer directly through water quality monitoring; this objective was primarily addressed through modeling. Note however, that because modeling required monitoring data for calibration and validation, monitoring did contribute to this objective, at least indirectly. It should also be noted that both the Cheney Lake Project in Kansas and the Goodwater Creek Project in Missouri employed water quality monitoring data in combination with modeling to identify critical pollutant source areas and to assess, albeit retrospectively, the appropriateness of past placement of conservation practices in the watershed. Both projects found that conservation practices had not been efficiently targeted to the most critical source areas in the watershed.

For the most part, the few NIFA–CEAP watershed studies that were successful in relating water quality change to conservation practice implementation evolved out of monitoring programs such as the USEPA Section 319 NNPSMP that were in fact designed specifically to document response to treatment. The flip side of this picture, however, is that in most cases, past external monitoring efforts applied to NIFA–CEAP studies were not effective in detecting response to treatment or addressing the NIFA–CEAP questions, largely because the monitoring was not designed to do so. Rather than continue to waste resources on monitoring that does not achieve program goals, we must learn from the NIFA–CEAP and other watershed programs

(c) SWCS. For Individual Use Only

and do a better job in the future. In order to answer fundamental questions and achieve program goals, monitoring must be carefully designed and implemented with those questions and goals in mind.

Detecting Water Quality Response to Treatment through Monitoring

This synthesis examined how the experiences of the case study NIFA–CEAP watershed studies with water quality monitoring can inform the detection of water quality response to the implementation of conservation practices.

Water quality monitoring must be designed to meet project objectives. Detecting change in pollutant concentrations or loads is difficult without a proper monitoring strategy. A proper monitoring strategy that takes the following into consideration:

- A monitoring strategy to detect water quality improvements from conservation practice implementation should be designed to generate accurate measurements of pollutant concentrations and loads and to account for climatic variations, pollutant delivery processes, and lag times in system responses. Infrequent fixed-interval grab samples for concentration, coupled with sparse flow measurements cannot generate adequate data to assess project effects.
- To link water quality with land-use changes, it is important to monitor the pollutants that land treatment addresses. In the Eagle Creek Watershed Project in Indiana, most conservation practices focused on sediment and erosion control, while nutrients were the primary water quality constituents being monitored. Similarly, monitoring in the Goodwater Creek Project in Missouri focused on atrazine, while most historical conservation practices had addressed sediment problems.
- Realistic indicators must be selected to measure conservation practice responses. In the Spring Creek Project in Pennsylvania, direct measurement of a stressor (percentage of fines in stream sediments) and biological density metrics were better choices to look for responses to treatments than were aquatic community metrics.
- Monitoring efforts need to be sustained for a sufficient duration to detect changes in response to land treatments. As illustrated by 30 years of water quality monitoring during the Rock Creek Project in Ohio, documenting changes in water quality can take decades. Drought delayed detection of water quality changes in the Spring Creek Project in Pennsylvania; these changes would not have been documented if monitoring had ended as originally scheduled.
- Sampling frequency and duration must be sufficient to obtain accurate estimates of pollutant concentrations and loads considering water quality variability, both before and after the application of conservation practices.
- A monitoring strategy must be suited to the hydrologic regime and pollutant delivery processes. Pollutants delivered primarily with surface runoff will require a different monitoring strategy than the one for pollutants delivered via subsurface flow or tile drainage.
- Monitoring schedules must be adapted to adequately represent pollutant concentrations during runoff events (e.g., sediment, nutrients, pesticides) versus base flow (e.g., NO_3-N). For example, observed herbicide concentrations remained constant at the Walnut Creek Watershed outlet in Iowa, despite a documented ~28% reduction in herbicide applications. The fixed-interval sampling schedule probably missed highly episodic herbicide export in runoff events. In the Goodwater Creek Project in Missouri, monitoring for atrazine losses

(c) SWCS. For Individual Use Only

required intensive storm-event monitoring coinciding with herbicide application schedules. In the Little Bear River Project in Utah, historical fixed-interval sampling completely missed the storm events that were important for sediment and nutrient transport. Flow proportional sampling is often the best approach to adequately capture patterns of pollutant delivery.

- Spatial distribution of monitoring is important; spatially distributed monitoring and synoptic sampling can be essential to measuring water quality response to land treatment, especially when treatment is not uniformly distributed in the watershed. Water quality improvements may be easier or quicker to detect in small subbasins in reasonable time frames compared to large basins. Spatial variation in water quality changes are sometimes masked when integrated into a larger watershed.

In general, focused paired watershed monitoring studies, such as those carried out in New York, Iowa, and Pennsylvania watersheds under previous programs, were more successful in linking conservation practices to water quality effects than were broad, large-watershed sampling programs. Although large watershed sampling programs may successfully detect changes or trends in water quality, it is usually not possible to link such changes to implementation of conservation practices without a deliberately designed monitoring program.

Plot- and field-scale monitoring may be critical to develop an understanding of pollutant loss and delivery processes and hydrologic factors necessary to understanding water quality response at the watershed level. Several projects, including the Goodwater Creek Watershed in Missouri and the Little River Experimental Watershed in Georgia, had success in applying plot- and field-scale studies to gain understanding of relationships between pollutant loss and hydrologic processes at the watershed level. This research has been conducted over years as part of dedicated USDA ARS activities at these two locations.

In order to demonstrate statistical significance, large reductions in pollutants and long monitoring periods may be necessary to account for high variability in water quality and long lag times in system response. In the Cheney Lake Project in Kansas, monitoring did not document any water quality trends with statistical significance because the combination of sampling frequency, duration, explanatory variables monitored, and types of samples used in the monitoring program was not adequate to detect the small reductions in suspended sediment and P loads predicted by modeling, given the hydrologic variability of the watershed.

Monitoring programs should be designed on the basis of reasonable expectations of water quality change—be realistic about the capability of conservation practices. Implementation of a few practices in a large watershed or of small-scale practices, such as narrow buffers, will be unlikely to yield large changes in water quality at the watershed level. In the Spring Creek Watershed in Pennsylvania, the narrow grass buffers and riprap stream bank armoring that watershed farmers were willing to accept were not sufficient to achieve what project investigators believed was the full water quality or habitat restoration potential; response metrics must be selected to detect incremental water quality changes, not just full restoration. In other words, the definition of success matters!

Changes in land use and management must be considered when trying to measure conservation practice impacts. Increased atrazine losses were observed in the Goodwater Creek Watershed in Missouri, despite improved management of herbicide applications, because of a concurrent increase in no-tillage acreage and expansion of corn acreage. Data on farming systems, such as split-application of herbicides, were insufficient to explain monitoring results. Increases in dissolved P concentrations in the Rock Creek Watershed in Ohio, despite docu-

(c) SWCS. For Individual Use Only

mented reductions in suspended sediment and total P resulting from conservation tillage, were not understood until changes in fertilizer application methods and timing associated with conservation tillage were fully appreciated; farmers started applying fertilizer in the fall and on the surface. Additionally, the role of tile drains in delivering dissolved P has recently been recognized. Lack of monitoring of farming systems and implemented conservation practices can impair detection and understanding of trends and changes observed in water quality data. Furthermore, in very long-term monitoring, installed practices may degrade or be modified or abandoned—this must be known to interpret water quality results.

How to Design and Conduct Water Quality Monitoring in Watershed Projects

This synthesis has examined how NIFA–CEAP experiences can inform the future application of water quality monitoring to watershed conservation projects and programs.

It is extremely challenging to rely on past water quality data—especially broad-scale watershed surveillance monitoring—for present analyses. Historical water quality data should be evaluated critically before commencing a project as past data may not be usable for present purposes. While evaluating historical data, the following concepts should be considered:

- Objectives of past monitoring are not always consistent with current goals. Because, for example, the water quality monitoring during the Little Bear River Hydrologic Unit Area Project in Utah was not specifically designed to determine the effects of conservation practices on water quality, the available data were inadequate to support the objectives of the later NIFA–CEAP, even though the database looked impressive at the outset.
- The Cheney Lake Project in Kansas noted that the lack of consistent water quality monitoring data in advance of implementation of key conservation practices reduced the ability of researchers to relate changes in water quality to land treatments. Despite application of reasonably rigorous statistical techniques, monitoring has not documented water quality trends with statistical significance; the monitoring program was not capable of detecting the small (<10%) changes predicted by modeling. In reality, it is doubtful that any monitoring program could detect such a small change in real-world water quality.
- Although long-term water quality monitoring can provide a very rich dataset, water quality data may be difficult to interpret when there are changes in analytical methodology and sampling protocols (e.g., manual wet chemistry versus autoanalyzers, refrigerated versus nonrefrigerated samplers) over the monitoring period.
- Monitoring agencies, strategies, locations, frequencies, and variables may change over the years. Thus the utility of an apparently large historical data record may be less than initially apparent; historical data must be examined closely to ensure that it can answer the questions required by the contemporary project.
- The Rock Creek NIFA–CEAP in Ohio was successful in using a long historical data record because the program was run by a single entity on a consistent sampling regime, and they conducted parallel analyses, statistical tests, and rigorous quality assurance/quality control to verify that changes in methodology did not influence the quality of their data over time. This long-term record was made possible by secure, dedicated funding from both state and private sources.

(c) SWCS. For Individual Use Only

- The Central Platte Natural Resources District NIFA–CEAP in Nebraska was an exception to the generally low utility of past broad-scale monitoring data. The historical monitoring and reporting requirements for irrigation well water under the Nebraska Ground Water Management and Protection Act requirements provided a high-quality database that could support evaluation of trends in NO_3-N contamination and could provide a spatially explicit database for relating changes in N and irrigation management.
- Historical water quality data could be useful and should be used in documenting and understanding water quality impairments. Some impairments, such as low dissolved oxygen in the Little River Experimental Watershed streams in Georgia, may be natural and may not be a product of land-use practices. The temperature impairment of the Willamette River could not be addressed by work in the ephemeral streams of Calapooia Basin in Oregon because those streams stopped flowing by the time temperatures were impaired in the Willamette River.
- When multiple organizations or agencies are involved in monitoring, it is critical that a central data collection system be established with clear communication among the collaborators. For example, the Spring Creek Project team in Pennsylvania was uncertain about the location and status of all the water quality data because of the multiple organizations involved.

The water quality variables selected for monitoring should match the water quality problem, the pollutant sources, and the conservation practices being implemented. In the Calapooia Basin in Oregon, streams were monitored for sediment and nutrients, whereas the Willamette River is impaired for temperature and *E. coli*. In the Little River Experimental Watershed in Georgia, most conservation practices focused on erosion control and sediment delivery, although nutrients were the primary water quality constituent being monitored.

An understanding of the watershed hydrologic system is essential for effective monitoring. In the Little Bear River Project in Utah, water diversion and irrigation management complicated monitoring for nutrient loads. In the Walnut Creek Project in Iowa, documentation of groundwater travel times showed that water from only ~20% of restored prairie areas reached the stream during the monitoring period, suggesting that greater water quality changes could occur in the future. Hydrologic variability makes understanding pollutant loads under different conditions difficult to sort out.

Climatic variability may overwhelm pollutant delivery processes so that effects of conservation practices are difficult to assess. In the Little River Experimental Watershed in Georgia, severe thunderstorms overwhelmed terrace design; as a result, there was significant sediment influx to streams. In the Paradise Creek Watershed in Idaho, warming winter temperatures have led to fewer freeze-thaw cycles and may have reduced sediment transport from fields to streams (Brooks et al. 2010).

An understanding of the watershed physiography is also essential to effective monitoring. At Walnut Creek in Iowa, a stream walk determined that 57% of Walnut Creek had eroding banks, while only 17% of Squaw Creek banks were eroding. Because much of the sediment in the Walnut Creek Watershed is derived from stream bank erosion, prairie conversion had almost no effect on watershed sediment export. An initial watershed assessment in the Little Bear River Project in Utah showed that the upper portion of the watershed had different land use, soils, and hydrology compared to the lower portion, and as a result, should be monitored differently. This kind of assessment would have high value as part of initial watershed characterization to guide the design of a monitoring program.

(c) SWCS. For Individual Use Only

Look for creative or alternative indicators of response to treatment. The Little Bear River Project in Utah used aerial video imagery to compare 1992 to 2007 stream bank/stream channel conditions to evaluate the effects of land treatment on riparian condition, even though it did not address traditional chemical water quality standards. The Spring Creek Project in Pennsylvania used topographic flow path analysis to reveal where concentrated runoff from source areas would bypass buffer/filter strip treatment zones; the actual entry point of runoff from a source to stream was often different from the simple straight-line entry point. This process can be used to identify and locate critical source areas, to locate intercepting treatment practices, and interpret in-stream monitoring data.

How Monitoring is Related to Other Project Activities

This synthesis considered relationships between NIFA–CEAP water quality monitoring and other activities.

Water quality monitoring data are essential to the development and application of models. Water quality (and other) data are necessary to parameterize, calibrate, and validate simulation models, such as the SWAT and the Annualized Agricultural Non-Point Source Pollution (AnnAGNPS) models. In addition, monitoring data can provide the basic understanding of hydrologic and water quality patterns that can be useful in applying informal "rule of thumb" judgments of the reasonableness of model calibration and validation. Historical data are appropriate to use, as long as they have been collected at appropriate locations and by acceptable methods. In the Eagle Creek Watershed Project in Indiana, monitoring data collected at several locations within a watershed and for a variety of appropriate water quality variables allowed the use of multivariate calibration, which gave superior results to calibration with separate calibrations for flow and individual constituents.

Insufficient monitoring data can impair model application. Results of SWAT modeling in the Cannonsville Reservoir Project in New York were limited by the availability of precipitation data from only a single weather station in the modeled watershed.

No matter how rigorous the water quality monitoring program, it will be impossible to link observed changes in water quality to land treatment without equally rigorous monitoring of conservation practice implementation and management activities. Most broad watershed monitoring programs, especially past programs but also contemporary efforts, lack the essential companion conservation practice and agricultural management data necessary to attribute observed changes in water quality to changes in management on the land. Acquiring and using spatially explicit land treatment data has been a major challenge and stumbling block for the NIFA–CEAP watershed studies, mainly due to USDA confidentiality policies as well as the age of some of the land treatment programs. Some projects exerted special effort to acquire such data and were successful. The Walnut Creek Project in Iowa conducted field surveys to document the existence and location of structural conservation practices. The Eagle Creek Watershed Project in Indiana combined information from USDA Natural Resources Conservation Service records, remote-sensing data, and farmer interviews to glean an accurate picture of conservation practice implementation in the watershed. Even when original implementation is reasonably well documented, knowledge of practice operation and maintenance is usually entirely lacking or is very difficult to obtain. A detailed analysis in the Little Bear River Project in Utah showed that significant numbers of practices implemented prior to the CEAP were either deteriorated, abandoned, or nonexistent; these findings emphasized the need for development of more robust

(c) SWCS. For Individual Use Only

and accurate systems for tracking BMP implementation and maintenance over periods of time (Jackson-Smith et al. 2010).

These observations suggest that central project activities—land treatment, monitoring, and modeling—must be linked and conducted in a coordinated manner that permits and encourages feedback among these components. None of these critical activities should be conducted in isolation, with respect to time, space, and personnel. Project personnel in the Eagle Creek Watershed Project in Indiana observed that project activities needed to be synchronized in a logical sequence so that intermediate results contributed fully to the final outcome. In that project, the economic analysis was conducted early in the project and, therefore, did not benefit from the watershed modeling simulations that were conducted later in the project. The Spring Creek Project in Pennsylvania found that it was necessary to design and conduct water quality monitoring—including selection of appropriate metrics—with understanding of the land treatment process in mind. In that project, the 1 m (3 ft) stream buffer that landowners would accept was not enough for the stream to achieve full restoration potential. Knowledge of this limitation was key in interpreting the basic metrics to assess the effects of conservation practices on the stream biological community, where more sophisticated biological indices were not effective. In the Calapooia Basin in Oregon, an economic analysis conducted entirely separate from watershed monitoring or conservation activities provided results that were of very limited utility to the project goals.

Recommendations: What Would Make Water Quality Monitoring Better?

Based on the lessons learned from the case-study NIFA–CEAP watershed studies, this synthesis recommends the following steps to improve the application of water quality monitoring to evaluate the effectiveness of conservation practice implementation:

- Design conservation practice monitoring to meet objectives. Monitoring of individual practice performance can help validate models, understand combined practice effects, and extrapolate practice effects to the watershed level. These items should be considered when designing practice monitoring:
  - Demonstrate effectiveness of specific conservation practices through site-specific monitoring.
  - Document practices that are acceptable to landowners.
  - Consider practice design, operation, and maintenance.
  - Understand that input/output and edge-of-field are appropriate designs.
  - Understand that university farms and/or research stations can play important roles.
- Design water quality monitoring to meet objectives. Monitoring at the watershed level to evaluate effectiveness of conservation programs is more than taking some samples at the watershed outlet. If not done well, resources can be wasted. These items should be considered when designing water quality monitoring:
  - Account for sources of variability—weather, geophysical characteristics, pollutant generation, and land management—to obtain water quality data that can be used to evaluate the effects of treatment.
  - Designs for monitoring effectiveness of conservation programs that can control for effects of weather and other sources of variability include paired-watershed, above/below, and multiple subbasins.

(c) SWCS. For Individual Use Only

- Collect water quality and flow data according to an appropriate design, at sufficient frequency, and for sufficient duration to meet data quality requirements, if pollutant load data are required for project evaluation. Infrequent fixed-interval grab samples for water quality variables coupled with sparse flow measurements cannot generate adequate load data.
- Collect land use, agricultural management, and practice operation/maintenance data concurrently in order to be able to attribute observed water quality patterns to land treatment. This information must be compiled for the drainage area contributing to each water quality monitoring location.

- Follow good monitoring practices. Good monitoring is necessary but is also complex, technically challenging, and expensive. Resources spent on poor design and execution are often wasted. Use these suggestions to follow good monitoring practices:
  - Provide accurate measurements of pollutant concentration and load; fixed-interval sampling may not capture storm events when most export occurs.
  - Monitor the pollutant(s) being treated and important covariates.
  - Account for variability, including variability in the watershed, climate, and pollutant generation.
  - Match monitoring to the hydrologic system and pollutant delivery pathway(s).
  - Match the sensitivity of the monitoring program to the required precision and level of expected change.
  - Capture temporal patterns, e.g., storm events, seasons.
  - Capture spatial variation; focus on small watersheds.
  - Select realistic indicators to measure conservation practice responses.
  - Continue long enough to overcome lag time; most monitoring is too short in duration to detect changes due to the presence of legacy pollutants and other factors.
  - Employ a monitoring regime capable of detecting response to treatment; infrequent (e.g., monthly or quarterly) sampling is generally not sensitive enough to detect small changes with statistical confidence.
- Use care in relying exclusively on historical water quality data:
  - It is extremely challenging to rely on past water quality data for present-day analyses, especially when ancillary data (e.g., land treatment) are not available.
  - Historical water quality data should be evaluated critically as they may not be usable for contemporary purposes.
  - Realistic evaluation of historical data should be part of the project planning/proposal process.
- Consider project scale. Water quality changes are easier to detect and explain in a reasonable time frame in a small watershed compared to a large basin. Compared to small watersheds, the extent of practice implementation in large basins may be small relative to pollutant sources, opportunities for pollutant transport and storage are more complex, lag time between treatment and response is likely to be long, and land management activities are more difficult to track.
- Couple water quality monitoring and land-use/management tracking; studies must account for changes in land use and management when evaluating conservation practice impacts over time. To successfully combine water quality monitoring and land-use/management tracking, consider the following:

(c) SWCS. For Individual Use Only

  - Data on farming systems and agricultural management (e.g., split application of herbicides) are essential to explain monitoring results.
  - In long-term monitoring, installed practices may degrade, be modified, or be abandoned—this must be known to understand monitoring results.
  - Information on conservation practice operation and maintenance is critical in long-term projects.
  - Oversight activity by the conservation practice contracting agency may need to be extended beyond the initial installation period.
  - No matter how rigorous the water quality monitoring, it will be impossible to link observed changes in water quality to land treatment without equally rigorous land treatment and management monitoring.
  - Knowledge of land use, management, and conservation practices is absolutely essential to understand the effectiveness of conservation programs. Such data are often unavailable due to confidentiality.
  - Land use/management tracking must be reported at the same drainage scales as the water quality monitoring and must be done at least annually.
- Integrate water quality monitoring, simulation modeling, and conservation practice implementation into coordinated activities that encourage communication and feedback among project participants throughout the project.

Certainly not all of these recommendations are new or even particularly startling. Similar points have been made in previous program assessments over previous decades, including the RCWP (Gale et al. 1993), the USDA Hydrologic Unit Area Project and Demonstration Project (Meals and Sutton 1996), and the USEPA Section 319 NNPSMP (Spooner et al. 2011). After so many programs and so many resources expended, it is time to take these lessons seriously, to learn from our collective experiences, and to move forward to improve the way we apply conservation measures to protect water quality and the way we strive to measure our success. Adoption of the recommendations made in this chapter—and in other chapters of this book—will contribute to improving our future efforts.

Finally, it must be pointed out that the goals and expectations for improving our understanding of the relationships between watershed setting and the timing, location, and selection of conservation practices cannot be effectively addressed without extensive knowledge of the timing, location, and identification of the practices implemented in the watershed by landowners. Until the veil of confidentiality is lifted sufficiently so that researchers can understand the nature of the land treatment as well as they understand the nature of receiving water quality, these goals cannot be achieved. Newly revised USDA protocols for data sharing should improve the ability to obtain much better land-use information.

Recommended Protocol: Water Quality Monitoring for Assessment of Conservation Practice Effectiveness

Successful water quality monitoring requires a certain level of expertise; monitoring is more than simply collection and analysis of a few water samples. Design of a water quality monitoring program may require contributions from hydrology, chemistry, geology, biology, statistics, and other disciplines. Although most aspects of a water quality monitoring program should be

(c) SWCS. For Individual Use Only

designed for each specific application, there are certain elements or steps that all monitoring programs should consider and address, including the following items:

- Identify water quality problem(s). In most watershed land treatment projects, the water quality problem(s) should be identified during the formulation of the project plan. Understanding the water quality problem to be approached through land treatment is essential to guide the development of an appropriate monitoring plan.
- State monitoring objectives. A clear statement of monitoring objectives that are germane to the water quality and land treatment objectives is necessary to identify what attributes must be measured to assess the achievement of those objectives. This process should include consideration of information expectations and how monitoring information will contribute to management decisions.
- Establish a statistical design. The design of a monitoring program—what, where, when, and how to collect and analyze water quality data—depends primarily on the monitoring objectives and must be established early in the planning process. In general, certain designs are suitable for certain objectives and situations. For example, to determine the pollutant reduction performance of an individual conservation practice, storm event monitoring in an input/output or above/below design might be used to assess the reductions in pollutant concentration or load caused by the practice. Above/below design refers to stream monitoring that occurs above the treatment area and then again below the treatment area, which allows water quality comparison interpretation of the effectiveness of the practice. Such a design might also be repeated in series to assess the relationships among conservation practices installed in series to determine if effects are additive, independent, or contradictory. If the principal objective is to monitor compliance with a total maximum daily load, intensive monitoring at the watershed outlet to estimate annual pollutant load could be used. Alternatively, to determine how the timing, location, and suite of implemented agricultural conservation practices affect surface water and/or groundwater quality at the watershed scale, these designs might be used:
  - Paired watershed with pretreatment and posttreatment monitoring periods
  - Above-and-below watersheds with pretreatment and posttreatment monitoring periods
  - Multiple watersheds
  - Trend monitoring

  At this stage, plans for statistical analysis of monitoring data must also be considered, including characterization of the variability (including seasonality) of the population to be sampled, specific statistical procedures to be applied, and the minimum detectable change (Spooner et al. 1987) desired from the monitoring program.
- Determine study scale. The scale of a monitoring program depends on monitoring objectives, available time and resources, and the type of water resource. The choice of study scale is directly related to monitoring design. Evaluation of practice effectiveness might be done at either the plot or field scale, whereas monitoring to assess watershed program effectiveness should be done at the watershed scale.
- Define specific components. Before monitoring begins, these specific components of the program must be completed:
  - Select variables to be monitored that are appropriate to program objectives, pollutant sources, water quality problem(s), and land treatment plans
  - Determine the appropriate sample type, e.g., grab versus composite versus continuous

(c) SWCS. For Individual Use Only

  - Identify appropriate variables to assist with quantifying the hydrologic and meteorologic variability, such as stream discharge, stage height, precipitation, and groundwater table depth
  - Identify sampling locations based on project objectives, statistical design, pollutant sources, land treatment plans, and site selection criteria that define a location's suitability to collect required data
  - Determine the sampling frequency based on system variability and desired level of precision; the choice of sampling frequency is a major determinant of a monitoring program's ability to document changes in water quality
  - Determine station type based on information to be collected, e.g., stream discharge, chemical concentration, biological community
  - Specify sample collection and analysis protocols to ensure consistent field and laboratory procedures over the life of the project
  - Define budget and personnel constraints
- Coordinate with land use/land treatment tracking. When water quality monitoring is conducted to assess the effectiveness of a land treatment program, land use, land management, and conservation practice status must be tracked as well. Such a tracking program must be coordinated spatially and temporally with the water monitoring.
- Incorporate quality assurance/quality control measures. All monitoring activities must be coordinated in a comprehensive quality assurance and quality control program that assures the collection of useful data of high and consistent quality. Even if an official Quality Assurance Project Plan is not required for a project, preparation of such a plan is extremely useful as a roadmap that specifies how a monitoring plan is to be accomplished and managed so that resulting data are of known and acceptable quality (USEPA 2006).
- Manage monitoring data. All monitoring data must be stored, validated, and managed in a consistent framework that addresses data integrity and traceability, facilitates distribution and analysis, and provides safe storage. This is especially true in long-term monitoring projects where personnel and technology may change over time. Data in a management system must include sufficient metadata so that it can be shared and compared among managers and the public.
- Develop information reporting procedures. Reporting plans should address the content, format, and frequency of reports. This should include analysis of the ability of reports to meet management expectations and to provide ongoing feedback to the project.

References

Bishop, P.L., W.D. Hively, J.R. Stedinger, M.R. Rafferty, J.L. Lojpersberger, and J.A. Bloomfield. 2005. Multivariate analysis of paired watershed data to evaluate agricultural best management practice effects on stream water phosphorus. Journal of Environmental Quality 34:1087–1101.

Brooks, E.S., J. Boll, A.J. Snyder, K.M. Ostrowski, S.L. Kane, J.D. Wulfhorst, L.W. Van Tassel, and R. Mahler. 2010. Long-term sediment loading trends in the Paradise Creek watershed. Journal of Soil and Water Conservation 65(6):331-341, doi:10.2489/jswc.65.6.331.

Carline, R.F., and M.C. Walsh. 2007. Responses to riparian restoration in the Spring Creek Watershed, Central Pennsylvania. Restoration Ecology 15(4):731–742.

(c) SWCS. For Individual Use Only

CEQ (Council on Environment Quality). 1980. Final Report of the Interagency Task Force on Environmental Data and Monitoring. Available from National Technical Information Service, US Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161.

Dixon, W., and B. Chiswell. 1996. Review of aquatic monitoring program design. Water Research 30(9):1935-1948.

Edwards, D.R., T.C. Daniel, H.D. Scott, P.A. Moore, J.F. Murdock, and P.F. Vendrell. 1997. Effect of BMP implementation on storm flow quality of two northwestern Arkansas streams. Transactions of the American Society of Agricultural Engineers 40(5):1311-1319.

Exner, M.E., H. Perea-Estrada, and R.F. Spalding. 2010. Long-term response of groundwater nitrate concentrations to management regulations in Nebraska's Central Platte Valley. The Scientific World Journal 10:286-297.

Gale, J.A., D.E. Line, D.L. Osmond, S.W. Coffey, J. Spooner, J.A. Arnold, T.J. Hoban, and R.C. Wimberley. 1993. Evaluation of the Experimental Rural Clean Water Program. National Water Quality Evaluation Project, EPA-841-R-93-005. Raleigh, NC: North Carolina State University Water Quality Group, Biological and Agricultural Engineering Department.

GAO (General Accounting Office). 1981. Better Monitoring Techniques are Needed to Assess the Quality of Rivers and Streams. Report CED-81- 30. Washington, DC: US General Accounting Office.

ITFM (Intergovernmental Task Force on Monitoring Water Quality). 1995. The Strategy for Improving Water Quality Monitoring in the United States. Final report of the Intergovernmental Task Force on Monitoring Water Quality. Washington, DC: Intergovernmental Task Force on Monitoring Water Quality.

Jackson-Smith, D.B., M. Halling, E. de la Hoz, J.P. McEvoy, and J.S. Horsburgh. 2010. Measuring conservation program best management practice implementation and maintenance at the water shed scale. Journal of Soil and Water Conservation 65(6):413-423, doi:10.2489/jswc.65.6.413.

Jokela, W.E., J.C. Clausen, D.W. Meals, and A.N. Sharpley. 2004. Effectiveness of agricultural best management practices in reducing phosphorous loading to Lake Champlain. *In* Lake Champlain: Partnerships and Research in the New Millennium, ed. T.O. Manley, P.L. Manley, and T.B. Mihuc, 39-53. Dordrecht, The Netherlands: Kluwer Academic Publishers.

Kwiatkowski, R.E. 1991. Statistical needs in national water quality monitoring programs. Environmental Monitoring and Assessment 17:253-271.

Lombardo, L.A., G.L. Grabow, J. Spooner, D.E. Line, D.L. Osmond, and G.D. Jennings. 2000. Section 319 Nonpoint Source National Monitoring Program Successes. Raleigh, NC: North Carolina State University Water Quality Group, Biological and Agricultural Engineering Department.

MacDonald, L.H., A.W. Smart, and R.C. Wissmar. 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. Region 10. EPA/910-9-91-001. Seattle, WA: United States Environmental Protection Agency.

MacDonald, L.H. 1994. Developing a monitoring project. Journal of Soil and Water Conservation 49(3):221–227.

Meals, D.W., and S.A. Dressing. 2006. Measuring project and program effectiveness. *In* Lessons Learned from the National Nonpoint Source Monitoring Program. 14th National Nonpoint Source Workshop, September 24-28, Minneapolis, MN.

Meals, D.W., and J.D. Sutton. 1996. Assessment of Progress in Selected Water Quality Projects of USDA and State Cooperators. Washington, DC: USDA Natural Resources Conservation Service Quality Management and Program Evaluation Division.

Morrison, J., and J. Lake. 1983. Environmental Impact of Land Use on Water Quality Black Creek Project−Final Report. Fort Wayne, IN: Allen County Soil and Water Conservation District.

NAS (National Academy of Sciences). 1977. Analytical studies for the US Environmental Protection Agency, vol. 4: Environmental Monitoring. Washington, DC: National Academy of Sciences.

NRC (National Research Council). 1999. New Strategies for America's Watersheds. Washington, DC: National Academy Press.

(c) SWCS. For Individual Use Only

NRC. 2000. Watershed Management for Potable Water Supply: Assessing the New York City Strategy. Washington, DC: National Academy Press.

North Carolina State University and Harbridge House, Inc. 1983. The Model Implementation Program: Lessons Learned from Agricultural Water Quality Projects. Washington, DC: Public Information Office, USDA.

Richards, R.P., and D.B. Baker. 2002. Trends in water quality in LEASEQ rivers and streams (northwestern Ohio), 1975-1995. Journal of Environmental Quality 31:90-96.

Richards, R.P., D.B. Baker, and J.P. Crumrine. 2007. Increased Dissolved Phosphorus Loading to Lake Erie from Agricultural Watersheds. GLPF Workshop, December 18, 2007 (powerpoint presentation). Tiffin, OH.

Richards, R.P., D.B. Baker, J.P. Crumrine, J.W. Kramer, E. Ewing, and B.J. Merryfield. 2008. Thirty-year trends in suspended sediment in seven Lake Erie tributaries. Journal of Environmental Quality 37:1894-1908.

Schilling, K.E., and J. Spooner. 2006. Effects of watershed-scale land use change on stream nitrate concentrations. Journal of Environmental Quality 35:2132-2145.

Schilling, K.E., and C.F. Wolter. 2007. A GIS-based groundwater travel time model to evaluate stream nitrate concentration reductions from land use change. Environmental Geology 53:433–443.

Schilling, K.E., T.M. Isenhart, J.A. Palmer, C.F. Wolter, and J. Spooner. 2011. Impacts of land cover change on suspended sediment transport in two agricultural watersheds. Journal of the American Water Resources Association 47(4):672-686.

Sharpley, A.N., J.P. Schmidt, and L. Hergert. 2006a. Nutrient management practices. *In* Environmental Benefits of Conservation on Cropland: The Status of our Knowledge, ed. M. Schnepf and C. Cox, 149-193. Ankeny, IA: Soil and Water Conservation Society.

Sharpley, A.N., T.C. Daniel, G. Gibson, L. Bundy, M. Cabrera, J.T. Sims, R. Stevens, J. Lemunyon, P.J.A. Kleinman, and R. Parry. 2006b. Best management practices to minimize agricultural phosphorus impacts on water quality. USDA ARS Publication 163. Washington, DC: US Government Printing Office.

Shepard, R. 2005. Nutrient management planning: Is it the answer to better management? Journal of Soil and Water Conservation 60(4):171-176.

Smith, T.A., D.L. Osmond, and J.W. Gilliam. 2006. Riparian buffer width and nitrate removal in a lagoon-effluent irrigated agricultural area. Journal of Soil and Water Conservation 61(5):273-281.

Spooner, J., R.P. Maas, M.D. Smolen, and C.A. Jamieson. 1987. Increasing the sensitivity of nonpoint source control monitoring programs. *In* Monitoring, Modeling, and Mediating Water Quality, ed. S.J. Nix and P.E. Black, 243-257. American Water Resources Association, TPS-87-2.

Spooner, J., D.E. Line, D. Meals, G.L. Grabow, and D.L. Osmond. 2011. 2011 Summary Report: Section 319 National Monitoring Program Projects, Nonpoint Source Watershed Project Studies. Raleigh, NC: North Carolina State University Water Quality Group, Biological and Agricultural Engineering Department.

Tomer, M.D., and M.R. Burkart. 2003. Long-term effects of nitrogen fertilizer use on ground water nitrate in two small watersheds. Journal of Environmental Quality 32:2158-2171

Tomer, M.D., and M.A. Locke. 2011. The challenge of documenting water quality benefits of conservation practices: A review of USDA-ARS's Conservation Effects Assessment Project watershed studies. Water Science & Technology 64(1):300–310.

UNEP WHO (United Nations Environment Programme, World Health Organization). 1996. Water Quality Monitoring. A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes, ed. J. Bartram and R. Balance. London, UK: United Nations Environment Programme, World Health Organization.

USDA. 1996. National Handbook of Water Quality Monitoring, Part 600 National Water Quality Handbook. USDA Natural Resources Conservation Service, Washington, DC.

USDA CSREES (Cooperative State Research, Education, and Extension Service). 2004. Evaluating the Effects of Conservation Practices on Water Quality within the Biophysical Setting of a

(c) SWCS. For Individual Use Only

Watershed. Fiscal Year 2004 Supplemental Request for Applications, Integrated Research, Education, and Extension Competitive Grants Program–National Integrated Water Quality Program. Washington, DC: USDA Cooperative State Research, Education, and Extension Service.

USDA CSREES. 2005. Conservation Effects Assessment Project (CEAP): Evaluating the Effects of Conservation Practices on Water Quality within the Biophysical Setting of a Watershed. FY 2005 Supplemental Request for Applications, Integrated Research, Education, and Extension Competitive Grants Program–National Integrated Water Quality Program. Washington, DC: USDA Cooperative State Research, Education, and Extension Service.

USDA CSREES. 2006. Conservation Effects Assessment Project (CEAP): Evaluating the Effects of Conservation Practices on Water Quality within the Biophysical Setting of a Watershed. FY 2006 Supplemental Request for Applications, Integrated Research, Education, and Extension Competitive Grants Program–National Integrated Water Quality Program. Washington, DC: USDA Cooperative State Research, Education, and Extension Service.

USEPA (United States Environmental Protection Agency). 1992. Ten Years of Controlling Agricultural Nonpoint Source Pollution: The RCWP Experience. The National Rural Clean Water Program Symposium. EPA/625/R-92/006. September 13-17, Orlando, FL.

USEPA. 2006. EPA Requirements for Quality Assurance Project Plans. (re-issue of 2001 publication). EPA/240/B-01/003. Washington, DC: United States Environmental Protection Agency, Office of Environmental Information. http://www.epa.gov/quality/qs-docs/r5-final.pdf.

USEPA. 2011a. Water Quality Assessment and Total Maximum Daily Loads Information. http://www.epa.gov/waters/ir/.

USEPA. 2011b. Clean Water Act Section 303. Water Quality Standards and Implementation Plans. http://water.epa.gov/lawsregs/guidance/303.cfm.

Ward, R.C., J.C. Loftis, and G.B. McBride. 1986. The "data-rich but information-poor" syndrome in water quality monitoring. Environmental Management 10(3):291-297.

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

Suggested Reading

There are several sources of further information on design and operation of water quality monitoring, including the following:

Brakensiek, D.L., H.B. Osborn, and W.J. Rawls. 1979. Field Manual for Research in Agricultural Hydrology. USDA Agriculture Handbook 224.

Clausen, J.C., and J. Spooner. 1993. Paired watershed study design. 841-F-93-009. Washington, DC: United States Environmental Protection Agency, Office of Water.

MacDonald, L.H. 1994. Developing a monitoring project. Journal of Soil and Water Conservation 49(3):221–227.

Mesner, N., and G. Paige. 2011. Best Management Practices Monitoring Guide for Stream Systems. Publication B-1213. Laramie, WY: University of Wyoming.

National Water Quality Monitoring Council. 2011. The Monitoring Framework. http://acwi.gov/monitoring/about_the_framework.html.

UNEP WHO (United Nations Environment Programme World Health Organization). 1996. Water Quality Monitoring. A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programmes. ed. J. Bartram and R. Balance. London, UK: United Nations Environment Programme, World Health Organization.

USDA. 1996. National Handbook of Water Quality Monitoring, Part 600 National Water Quality Handbook. Washington, DC: USDA Natural Resources Conservation Service.

(c) SWCS. For Individual Use Only

USEPA (United States Environmental Protection Agency). 1997. Monitoring Guidance for Determining the Effectiveness of Nonpoint Source Control Projects. EPA 841-B-96-004. Washington, DC: Office of Water.

USEPA. 2005. Handbook for developing watershed plans to restore and protect our waters. EPA 841-B-05–005. Washington, DC: United States Environmental Protection Agency, Office of Water.

USGS (United States Geological Survey). 2003. Chapter A2. Selection of Equipment for Water Sampling. National Field Manual for the Collection of Water-Quality Data, Book 9 Handbooks for Water-Resources Investigations. Reston, VA: United States Geological Survey Techniques for Water Resource Investigations.

USGS. 2008. Chapter A6. Guidelines for Field Measurement. National Field Manual for the Collection of Water-Quality Data, Book 9 Handbooks for Water-Resources Investigations. Reston, VA: United States Geological Survey Techniques for Water Resource Investigations.

(c) SWCS. For Individual Use Only