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Theme Overview: Agriculture and Water Quality in the Cornbelt: Overview of Issues and Approaches

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More than three decades have elapsed since the passage of the Federal Water Pollution Control Act with its stated goal of zero discharge of pollutants into the nation's waterways. Yet, water quality remains poor in many locations and considerable loading of pollutants continues. This is particularly true for agricultural sources of water pollution and is typified by the Upper Mississippi River Basin, where more than 1,200 water bodies appear on the current U.S. Environmental Protection Agency (EPA) listing of impaired waterways. Additionally, nitrate export from this region has been implicated as a significant cause of the hypoxic zone in the Gulf of Mexico, which covered nearly 20,000 km^2 in 1999 and more than 17,000 km^2 in 2006 (http://www.epa.gov/gmpo/nutrient/hypoxia_pressrelease.html). Although a substantial body of evidence on the effectiveness of agricultural conservation practices on water quality continues to be developed, the net effect of these programs and practices at the watershed scale is unclear. Increasingly, studies are being focused on the watershed (or landscape) scale and complex interactions between agricultural practices and inputs, the types and configuration of conservation practices on the landscape, and the resulting downstream water quality. While low cost methods to reduce agricultural non-point source pollution exist, large changes in water quality in agricultural regions are likely to be costly and met with resistance. This is because to achieve large changes in water quality, major alterations to land use or installation of expensive structural practices may be required, and the costs are borne directly by producers and landowners, or by the taxpayer.

Given the potentially large cost for significant improvements in water quality, it is critical to develop tools that can support cost-effective design of conservation policy and/or voluntary implementation of watershed plans focused on water quality. The following set of themed papers related to water quality and agriculture discuss these issues, with a specific focus on using integrated water quality and economic models to support better public policy and watershed-based solutions to these problems. The article following this one describes detailed field-scale data collected as part of a Conservation Effects Assessment Project supported by CSREES and ARS. In addition to assessing the effects of current conservation activities on water quality in these watersheds, data are used to calibrate a water quality model and are being integrated with economic cost information to study the optimal placement of additional conservation activities in the watershed. That article discusses the historical evolution of conservation activities in the three watersheds, the current water quality challenges in the watersheds, and the role that the integrated models can play in solving the problems.

In the third paper of the series, Secchi et al. employ a more aggregate unit of analysis (scale) for calibrating a watershed model and a biophysical carbon sequestration model and integrating them with economic data covering the entire state of Iowa. The focus of their analysis is on the potential unanticipated environmental effects of developing markets in ecosystem services that focus on a single service, such as carbon sequestration.

The final paper in the set addresses a different water quality issue: drinking water and nitrate levels. Specifically, the paper by Burkart and Jha considers whether it would be cost-effective for farmers to reduce nitrogen applications at the farm level, thereby reducing nitrate concentrations in the water supplies for residential consumers, rather than continue to treat the water in a denitrification plant prior to use.

In the remainder of this theme overview, we attempt to provide the casual reader with adequate background information on agricultural water quality problems, as well as the institutional framework within which these water quality problems in agriculture are currently managed. This includes a brief primer on the key pollutants, their sources, and the range of conservation methods that can attenuate their effects. It is also necessary to understand the fundamentals of the policy environment, which differs markedly from approaches taken in other industries. Specifically, voluntary actions are the focus of state and federal agency efforts under the requirements that they have to develop and implement Total Maximum Daily Loads (TMDLs). We briefly describe the TMDL process and note the range of federal and state conservation programs that provide funding for voluntary conservation efforts.

Agriculture and Water Quality Primer

Production of food and fiber have inevitable impacts on land and water resources. Conservation practices are intended to reduce those impacts, ideally with as little effect on the productive and ecosystem service capacities of the land. The critical questions for planning and implementation of effective conservation systems are then: What water quality pollutants are of primary concern and what types of conservation practices will provide benefits for various environmental impacts? Here, briefly, we provide generic answers to these questions that are most pertinent to agricultural watersheds in the Corn Belt generally, and Iowa and the Upper Mississippi Basin, specifically. Through this discussion, we emphasize key differences among specific pollutants, in terms of the hydrologic pathways from field to stream, and the types of conservation practices that can minimize their transport to receiving waters. The primary pollutants of concern in the Corn Belt include nitrate-nitrogen, phosphorous and sediment, and pathogens.

Nitrates-Nitrogen

Nitrate-nitrogen (NO_3-N) is a key pollutant of concern for its potential widespread impact on both public health and ecosystem function. Nitrate-nitrogen is readily leached through soils to groundwater and enters surface water systems directly by groundwater flow and through the subsurface drainage systems (tile drains), which were installed across large areas of poorly drained Midwestern soils beginning about 100 years ago. These drainage systems have allowed the Midwest to become the highly productive agricultural area that it is today, while short-circuiting the much slower, natural groundwater pathway to the stream. Concentrations of nitrate-nitrogen in drainage and stream water often exceed 10 mg NO_3-N /L, resulting in losses exceeding 20 kg N/ha in some years (Tomer et al., 2003). Regional nitrogen budgets for the Mississippi River Basin have implicated tile-drained regions of the Midwest as disproportionately contributing to N loads to the Gulf (Burkart and James, 1999). Nitrogen fertilizer is commonly applied to corn, at rates varying from 100 to 200 kg/ha. The efficiency of N uptake by the crop varies because of environmental conditions. Nitrogen losses are most prevalent in early Spring when crops are not present or are too small to effectively immobilize the available nitrate.

The problem of nitrate-nitrogen export is not solely caused by N fertilizer management or any other single factor, but rather it is a combination of soil management practices and physical, chemical, and biological characteristics of the soil, along with temperature and precipitation patterns (Dinnes et al., 2002). As a result, reducing nitrate loss is more than a matter of reducing N-fertilizer rates and improving timing of applications (Jaynes et al., 2004). Effective practices to control N losses include diversified crop rotations that increase use of forages and improved nitrogen management (including improved timing and rates of application, and use of nitrification inhibitors). Improved engineering of aging drainage infrastructure, and use of wetlands, cover crops, and denitrification walls or subsurface drainage bioreactors are other alternatives that have been shown effective. Because nitrate in extensively tiled areas is transported to streams primarily in subsurface drainage water, any filtering ability of riparian buffers and edge of field filter strips will be bypassed.

Phosphorous and Sediment

Surface runoff is the dominant mechanism that transports phosphorus, sediment, and pesticides and bacteria from agricultural fields, as opposed to the subsurface pathways of nitrate. Ecological impacts of P and sediment include eutrophication and sedimentation of receiving waters. Phosphorus losses from agricultural fields may be only a fraction of those observed for N (< 1 kg/ha.yr is commonly reported), but such losses can have major implications for the ecological integrity of lakes and streams. Phosphorus runoff from agricultural fields is largely controlled by soil P concentrations and crop residue cover (Sharpley et al., 2002). Residue cover encourages infiltration and discourages erosion. To improve phosphorus management at watershed scales, the use of "P indices" are being implemented that identify soil erodibility, soil P concentrations, residue management practices, and proximity to streams, to rank fields for runoff P losses. These indices can be used to target conservation practices to control P losses (Birr and Mulla, 2001) via reduced tillage, limited manure or fertilizer applications, terraces, vegetated filter strips, and/or riparian buffers. These practices are known to reduce erosion and phosphorus. Watershed responses to these conservation practices may be less than initially expected because streambank erosion, rather than agricultural fields, can contribute significant amounts of sediment and phosphorus to streams and rivers. These sources may result from past management activities.

Sediment and nutrient losses from agriculture, therefore, can result in a legacy of impacts within watersheds, necessitating a long-term commitment to their amelioration. For example, elevated nitrate concentrations in groundwater have been shown to remain for decades (Rodvang and Simpkins, 2001). Also, phosphorus accumulations in sediment may have a legacy, providing a long-term, internal loading source of mineral P to the water column (Christophoridis and Fytianos, 2006) and may ultimately affect groundwater P concentrations (Burkart et al., 2004).

Bacterial Pathogens and Livestock Concerns

Livestock is an important economic component of U.S. agriculture, accounting for over 60% of agricultural sales. Production estimates for 2005 include 72.6 million hogs, 10.9 million beef cows, 3.1 million milk cows, 150 million egg layers, and 131 million broilers for the 12-state North Central Region. In the Midwest, swine are increasingly produced in concentrated animal feeding operations (CAFOs) making manure management increasingly important, both as a source of nutrients for subsequent crops and as a potential environmental problem. CAFOs are also important in poultry and beef production. Potential water quality issues arising from manure application are nitrate leaching and loss in tile drainage networks, and loss of phosphorus and pathogens in overland runoff. Conservation practices seek to prevent accumulation of excess nutrients (nutrient management plans), reduce and/or treat runoff from feed lots, and mitigate runoff from manured fields (buffers, filter strips). Several studies suggest that increasing CAFO size offers certain economic advantages in production, but increases the amounts of manure applied to land near the CAFO, which increases the risk of loss of excess nutrients (Kellogg et al., 2000).

Bacterial pathogens that threaten water quality include Escherichia coli O157:H7, Salmonella, Enterococcus, Listeria, and Campylobacter. Pathogenic protozoa include Cryptosporidium and Giardia. Although these microorganisms cause disease in humans, they are commonly carried in livestock without visible symptoms. Because of the difficulty and cost involved in screening water samples for these pathogens, public health and water supply authorities have long relied upon indicator bacteria. In the past, fecal coliforms tests filled this function, but two indicators are now being promoted by U.S. EPA, Escherichia coli and Enterococcus. Quick and reliable tests for both of these microorganisms are now available and the presence of these bacteria has been correlated with the presence of disease-causing microorganisms. Measured E. coli densities in stream water can be evaluated against EPA's current standards, but the identification of the E. coli sources is more complex and important to developing effective watershed management strategies. Microbial source tracking is an emerging technology that allows the source animal to be determined. Potential sources in most watersheds include wildlife, farm animals, and humans.

Heterogeneity of Conservation Practices

There is a wide range of conservation practices used on agricultural land intended to provide water quality benefits, including engineered structures, edge-of-field practices, in-field nutrient and crop residue management practices, and land retirement. Government programs since the

1930s have promoted installation of conservation practices on agricultural lands. Much of the early focus of conservation practices was specifically on soil conservation, where the goal was to preserve the soil and to maintain its productivity.

Structural practices that have been used for controlling soil loss and the formation of gullies include terraces, grassed waterways, sediment basins, and grade stabilization structures. Terraces are used to decrease the length of the hill-slope to reduce rill erosion and the formation of gullies. Many early conservation practices were intended, in part, for water conveyance to improve trafficability, and thereby maximize agricultural production. In addition to structural practices, there are a variety of in-field management practices such as contour farming and strip cropping and tillage management, such as conservation tillage and no-till. Also, in some areas marginal lands that are highly susceptible to soil loss have been taken out of agricultural production and converted back to perennial vegetation.

Over the past thirty years, there has been an increased concern related to the overall water quality impacts of agriculture, including nutrient, pesticide, and pathogen loss from agricultural lands. Some conservation practices have been installed with an intended purpose of reducing the export of these contaminants. Two of these are buffer systems (riparian or grassed) and the reintroduction of wetlands back into the landscape. In addition, relative to nutrient losses, there has been an emphasis on appropriate nutrient management practices within agricultural fields to reduce the application of excess nutrients.

We have also learned that some agricultural practices have effects that were not intended. Subsurface drainage was used historically to enhance productivity of poorly drained lands, but these production benefits are offset by the environmental impacts of increased export of nitrate-nitrogen from these drainage networks. Surface inlets to subsurface drain systems also create a direct conduit for surface water to enter streams effectively bypassing riparian buffers or wetlands. Much of the agricultural landscape has been altered through stream straightening channelization. Stream straightening and subsurface drainage have significantly altered the hydrology of the landscape, which has led to significant streambank stability problems in many areas. So, while many of the conservation practices mentioned above may reduce soil loss from agricultural fields, if they do not significantly reduce water flow in the streams, the stream power is not reduced. As a result, rather than carrying sediment from fields, the streams may erode sediment from the streambed and streambanks.

While there is a wide range of practices that can be used on agricultural lands for providing water quality benefits, many times the locations within the watershed where practices are implemented have not been specifically targeted to achieve the greatest reduction of contaminants in downstream water bodies. This is likely the result of the voluntary enrollment in federal conservation programs combined with ineffective targeting technology. Recent advances in remote sensing and geographic information systems offer an opportunity for dramatic improvements in our ability to target conservation practice installation in large watersheds. With the limited amount of resources available for conservation practices, there will likely be increased importance on targeting implementation to those areas where there may be the greatest benefit from a water quality perspective. One program that has used targeting with some effectiveness is the Conservation Reserve Program (CRP), which targets land choices based on an environmental benefits index. While the effects of CRP on soil quality, carbon storage, and wildlife have been assessed, the aggregate effects at the watershed scale are less understood.

Finally, it is important to understand that water quality monitoring in the United States is done by a variety of state and federal agencies, including USGS and USEPA, and many municipal and commercial water supply entities, but the great majority of streams and rivers are not routinely monitored. Thus, in many cases, the actual level of pollutants is simply unknown.

The Policy Environment: TMDLs and Voluntary Implementation

Voluntary cost-share and incentive programs sponsored by USDA and States are large in geographic scale and fiscal commitment (over $4.5 billion was spent in 2005 by USDA-funded programs alone). These programs generally provide varying incentives to farmers for the installation of structural or management practices described above. The criteria for participant eligibility vary from program to program, and conservation compliance provisions require that landowners who farm on highly erodible land undertake some conservation activities in order to be eligible for other government incentives or subsidies. In addition to the largest program, the CRP, there is a cost-share program entitled the Environmental Quality Incentive Program, which provides cost share to producers willing to install various conservation structures or practices on their farms. Notably, the 2002 Farm Bill contained a new program the Conservation Security Program a watershed-based initiative intended to compensate farmers for adopting conservation practices. Like the CRP, which covers the full cost of retiring land from production, the program was intended to cover the full cost of adopting conservation practices (rather than less than 100% of the cost as traditional cost share programs do), but the focus of the Conservation Security Program is on land that stays in production. However, funding constraints have prevented the program as it was initially envisaged from being fully implemented.

Ironically, while there are large conservation programs funded and administered through USDA, the primary law that addresses nonpoint source agricultural pollution loadings is under the auspices of the U.S. Environmental Protection Agency (EPA) via the Clean Water Act. Rather than assign standards and require that sources implement changes in production or invest in abatement technology to meet those standards, as has been the norm for air and water quality problems stemming from point sources, the Total Maximum Daily Load (TMDL) approach was adopted. Under the TMDL framework, states are responsible for compiling lists of water bodies not meeting their designated uses, which are then reported as "impaired waters." The sources of impairment vary across locations. For example, Iowa has 213 water bodies on the list and pathogens (bacteria) are the leading cause of listing, accounting for about 20% of the impaired water bodies, with sediment/turbidity accounting for about 10%. Nationally, it has been estimated that 40% of rivers and estuaries fail to meet recreational water quality standards because of microbial pollution (Smith & Perdek, 2004).

Note that water bodies are viewed as impaired only if they do not meet their "designated use." Thus, two water bodies can be equally contaminated with only one being listed as impaired if their designated uses are different (e.g., boatable vs. swimmable). This is part of what makes the TMDL rules so difficult to interpret and why a simple indication of whether a water body is listed or not is not necessarily a good indication of its level of water quality.

Once a water body has been identified as not meeting its designated use, the state is required to identify the sources of the impairment and the "maximum allowable daily load" of pollutants that would eliminate the impairment. Finally, states are to suggest reductions for the various pollutant sources that would allow the watershed to reach the TMDL. Importantly, there is no regulatory authority by the states or EPA to require that these reductions occur. Thus, the institutional environment in which nonpoint source water quality reductions may occur is fundamentally voluntary.

In the TMDL process, modeling and monitoring can play important roles in allocating pollutant loads to various sources, such as helping to determine the relative contributions of row crops, CAFOs, and urban sources to loads of nutrients and bacteria observed in large watersheds. Two models, the Soil and Water Assessment Tool and the Hydrological Simulation Program-FORTRAN models are most often used to support TMDL assessments (Benham et al., 2006). These models combine GIS-based spatial data of watershed physical features with information on cropping systems, animal densities, fertilizer and pesticide use, and point sources. For non-point source pollutants, conservation practices are a key to developing mitigation strategies that allow watersheds to meet TMDL goals. Since TMDLs may be designed to mitigate multiple pollutants (e.g., nitrate and bacteria), combinations of conservation practices may be necessary to achieve the necessary improvements in water quality.

Final Remarks

The purpose of this overview is to introduce readers to the set of water quality problems associated with row-crop agriculture and livestock operations in the Corn Belt and Upper Mississippi River Basin. The problems are complex, with a great many individual decentralized decision makers contributing, both positively and negatively, to their solutions. Adding to these complex problems are the ever-changing demands on agriculture to supply food, feed, fiber, and fuel. These demands are leading to new questions and concerns related to agriculture and may allow for some solutions that are economically viable and environmentally beneficial. Some concerns are related to potential use of marginal lands for row crop agricultural production and increasing continuous corn acreage to supply the bioeconomy. At the same time, the bioeconomy, particularly if cellulose biofuels become feasible, may provide opportunities for more diversified cropping systems that have environmental benefits. Associated with some of these issues is the increasing importance of agribusiness through decisions such as siting of CAFOs and ethanol plants. Siting decisions should consider the potential environmental impacts of these facilities both from a water quality and water quantity perspective.

In the remaining three papers of this water quality theme, the authors describe how data and models can be used to characterize the problems, model the underlying biophysical and economic processes, and ultimately (hopefully) contribute to solutions. Given the policy environment described above one of voluntary-based action and a myriad of conservation programs with diverse goals and ever-present funding constraints we believe that models of water quality processes carefully integrated with economic models are essential, both to assess existing programs, and more importantly, to design and implement cost-effective approaches to meeting society's water quality goals. These modeling efforts will be difficult and will appropriately come under a great deal of scrutiny.

The complexity of the ecology and the social issues (including a host of topics not addressed here such as international trade agreements, rural community viability, rural-urban conflicts, etc.) indicate a need for additional research that considers the breadth of the systems involved at scales that are appropriate. For example, much of our current knowledge of the efficacy of conservation practices is based on field scale research which cannot be simply "scaled-up" to understand the workings at watershed levels. While current research efforts are beginning at this more challenging scale, definitive results will be, in many cases, many years off.

Before we leave the reader to dive into the three following papers, we note a final thorny point concerning the potential for significant "legacy" problems possibly hiding in groundwater supplies. Over many decades of agricultural activity, we have added nutrients and other effluents to groundwater systems that have undoubtedly not yet emerged at the surface. When and where such pollutants will appear is not clear, but if conservation programs are designed only with current pollutant contributions in mind, our efforts may well fall short due to these legacy sources.

For More Information

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