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# (Theme Overview) Preserving Water Quality: Challenges and Opportunities for Technological and Policy Innovations

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*Marc O. Ribaudo*

Nutrient pollution (Box 1) is a major environmental concern in the United States. Nitrates at levels harmful to human health are a growing problem in the surface- and groundwater used to supply drinking water. Degradation of freshwater, estuarine, and coastal aquatic ecosystem due to excessive levels of nitrogen and phosphorous is widespread. Recent headline-grabbing examples of nutrient pollution problems can be found in the Chesapeake Bay, the Des Moines River, the Gulf of Mexico, and Lake Erie. The U.S. nutrient problem is—to a very large degree—an agriculture problem. The productivity of the U.S. agricultural system is substantially fueled by large-scale nutrient flows that move nutrients from natural sources to fertilize crops and feed livestock. Because agricultural products do not fully remove nutrient inputs, flows of unused nutrients follow various pathways from fields and barnyards into ground and surface waters. Agriculture is responsible for a dominant share of the nitrogen discharges to surface water and leaching to groundwater. It is also a leading source of phosphorous in surface waters.

Box 1:
Nutrient pollution refers to water quality damages caused to water resources by various forms of nitrogen and phosphorous, which are essential nutrients for living organisms. Water pollution problems occur when the concentrations of these nutrients are elevated to harmful levels by human activity. Examples of this activity include densely populated urban areas, intensive agricultural production, and substantial energy production from fossil fuels.

The agricultural nutrient management problem is technologically, economically, politically, and institutionally complex. Nutrient flows from agricultural lands to water bodies are diffuse by nature, difficult to observe and measure at reasonable cost, and there is significant heterogeneity and weather induced stochasticity in the links between input use and polluting discharges. Policies for protecting water quality have therefore tended to focus on managing farming practices rather than environmental outcomes by encouraging the adoption of best management practices. But this highlights another key technological complexity, which is the tremendous spatial heterogeneity, at a sub-field level, in land quality, topography, and proximity to environmentally sensitive areas that exists in agricultural production. One result is tremendous fine-scale variability in cropping systems that can minimize nutrient losses to the environment while remaining competitive land uses. Another is high information, technology, and farm management requirements for such systems. A key economic complexity is that the U.S. agricultural economy is driven by multiple factors (consumer preferences, locations of high density populations, agricultural economic geography) to be nutrient intensive and to move nutrients to nutrient-sensitive environments.

While technological and economic complexities pose significant challenges, the greatest challenges are political and institutional. Agriculture's nutrient pollution problem is first and foremost a policy problem. Agriculture has been recognized as a leading cause of water quality problems for decades. That it remains so is not a consequence of a policy vacuum but that the policies that have been developed for agriculture have not been highly effective, especially considering the billions of dollars that have been devoted to addressing the problem. New water quality policies are needed for agriculture, but significant political and institutional constraints exist. Importantly, the political and institutional challenges extend beyond water quality policies for agriculture. Farm and energy policies have affected crop choices and crop acreage choices that are often detrimental to water quality. Solving nutrient pollution problems requires systemic change.

Emerging advances in precision technologies and the availability of "big data" have the potential to enable site-specific crop management and the development of more effective policies. Technologies for producing advanced biofuels from perennial grasses can lead to the diversification in crop production needed to reduce nutrient run-off. Growing recognition of the limits to relying on voluntary adoption of best management practices is leading to an interest in developing more performance-based and market-based policy approaches to incentivizing non-point pollution control. This includes designing policies that are better targeted to the sources of pollution and provide incentives related to environmental outcomes. It also includes developing markets for trading pollution credits between point and non-point pollution sources.

This special issue includes four papers that examine the challenges posed by current policies for protecting water quality cost effectively and role for technological and policy innovations in improving the effectiveness with which we do so. These papers were presented at the "Water Resources & Policy: Exploring the Risks, Benefits and Opportunities for Conservation" workshop on March 20, 2017, in Washington, D.C., organized by Mathew Interis, Madhu Khanna, Jerome Dumortier, Jonathan Coppess, Steven Wallander and Caron Gala on behalf of the Land, Water, and Environmental Economics Section of the AAEA. Funding and support was provided by the AAEA; the Economic Research Service; the Center for Behavioral and Experimental Agri-Environmental Research; the School of Public and Environmental Affairs, Indiana University-Purdue University Indianapolis; the Water Resources Research Institute, Mississippi State University; the Department of Agricultural and Consumer Economics, University of Illinois; and the Council on Food, Agricultural and Resource Economics.

Khanna describes the adverse impacts that agricultural production activities have had on water quality and soil carbon stocks, which have been exacerbated by renewable energy policies and commodity programs that have contributed to an expansion in cropland acreage and in land used to produce corn for food, feed, and biofuels. Various strategies can be used for reducing these adverse impacts, including adopting best management practices for nutrient management and switching from annual crops to perennials that have low input and tillage requirements. Emerging precision technologies and "big data" can enable site-specific crop management to tailor input applications to meet crop needs. The potential to produce advanced biofuels from perennial grasses could lead to cropland diversification and reduce run-off while providing low-carbon biofuels to displace fossil fuels. A mix of conservation, energy, and farm policies is needed to induce a switch to alternative production practices and crops beyond what might occur voluntarily. The paper discusses the challenges in designing cost-effective conservation policy due to the difficulties in measuring performance with non-point pollution, the need to prevent unintended consequences due to jointness of environmental impacts, and the need to consider behavioral factors that influence technology adoption decisions. It identifies several directions for future research including on the role of information technologies, big data, and data analytics coupled with integrated models in inform science-based conservation policy design.

Coppess discusses the history of conservation programs in the United States and the political and budget realities that have governed the size and composition of these programs, which have primarily taken two forms: land retirement programs and working land programs. The Conservation Reserve Program, which retires land from crop production, has historically been the largest program. The size of the program has varied over time, increasing in periods of low crop prices and decreasing in periods of high crop prices. There has been increased reliance on working land programs in recent years, but these programs are still relatively small in terms of cropland coverage. While the program has contributed to reducing soil erosion and sediment run-off, its effectiveness at reducing nutrient losses caused by tile-drained fields is likely to have been limited due to limited incentives for enrolling productive land in the program and retiring it from crop production. Working land programs that encourage adoption of best management practices for nutrient management on these lands have the potential to be more effective at reducing nutrient run-off from crop production. However, these programs are relatively small in scale. The paper discusses the budgetary constraints that affect conservation programs and alternative programs being considered by Congress to reduce the cost of achieving conservation goals.

Shortle describes the institutional structure of agricultural water quality policy in the United States as established by the Clean Water Act of 1972 and policy developments within that structure. The Clean Water Act nationalized the control of municipal and industrial point sources of water pollution and led to the establishment of strict regulations on these source that have been highly effective but also highly and unnecessarily expensive. The Act directed the states to take primary responsibility for the management of agricultural nonpoint source pollution and directed the USDA to provide technical and financial assistance for reducing agricultural nonpoint pollution. In contrast to the federal approach to point sources, states have largely pursued voluntary compliance programs that encourage and facilitate adoption of pollution control practices. Federal technical and financial assistance offered through USDA programs has been substantial, most notably through USDA's Water Quality Incentives program. While state and federal programs have had positive outcomes, they have not been up to the task of achieving established water quality goals, despite enormous spending. This is fundamentally a consequence of reliance on voluntary adoption of pollution controls incentivized by technical and financial assistance programs that do not direct resources in ways that get the most from public and private spending and that are subject to binding budget constraints. Shortle makes the case for policy innovations that introduce a mix of mandatory compliance strategies and better economic incentive mechanisms that target resources to practices and places within fields and watersheds and across watersheds to efficiently achieve water quality goals. He also argues that the water quality goals will be most effectively and cheaply achieved by policy innovations that integrate the control of point and nonpoint sources of pollution, in contrast to the existing structure, and suggests that water quality trading is a promising vehicle to attain the objective. The benefits of trading could include improved water quality and overall reductions in the costs of water pollution control.

Ribaudo parallels Shortle in identifying policy design flaws that limit the efficiency and effectiveness of agricultural nonpoint water pollution policies as a crucial problem and calling for policy innovations to improve the efficiency and effectiveness. Ribaudo focuses on specific strategies to improve the efficiency of USDA's voluntary participation programs for water quality protection. For better environmental outcomes given limited federal resources, Ribaudo stresses the importance of targeting funds to places and practices based on cost-effectiveness criteria, requiring resources devoted to water quality protection provide actual water quality improvements, the utilization of auctions to select program participants and their payments, and compliance incentives that make eligibility for participation in farm programs contingent on adoption of water quality protection practices. Ribaudo's requirement that resources devoted to water quality protection provide actual water quality improvements may seem an obvious need, but in it he recognizes flaws in current voluntary programs. One is that these programs provide assistance for adopting practices rather than for actual water quality improvements. This places the means before the ends. Farmers may sign up and implement practices in places that have little actual impact on water quality. A second flaw is that assistance is sometimes provided for actions a farmer might have taken without financial support. In this case, the assistance is fails an additionality test. To address these flaws, Ribaudo argues for shifting the focus of spending from practices to environmental performance and for formal consideration of additionality in the provision of technical and financial assistance.

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# Nexus between Food, Energy and Ecosystem Services in the Mississippi River Basin: Policy Implications and Challenges

Madhu Khanna

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*Keywords: Conservation policy, Energy crops, Nutrient run-off*

One of the great challenges for the US Corn Belt is increasing the productivity of food and fuel production while reducing nutrient runoff, which is a key contributor to hypoxia in the Gulf of Mexico. The Mississippi–Atchafalya River Basin (MARB) drains about 41% of the conterminous United States and includes the Corn Belt, which is one of the most productive farming regions in the world. The hypoxic zone in the Gulf is the second largest in the world; in the summer of 2017 it was equal in size to the state of New Jersey, the largest extent ever recorded. Excess nutrient run-off generated by tillage and fertilizer-intensive agricultural and livestock production in the MARB is estimated to contribute about 80% of dissolved inorganic nitrogen (N) and more than 60% of delivered phosphorus (P) in the Gulf of Mexico (White et al., 2014). The U.S. Environmental Protection Agency (2007) estimates that a 45% reduction in both N and P loadings from the MARB relative to the 1980–1996 average annual level is needed to achieve desired reductions in the size of the hypoxic zone.

Ribaudo, Livingston, and Williamson (2012) show that, despite improvements, about 66% of corn acreage does not achieve the rate, timing, and method criteria that minimize environmental losses of nitrogen. Moreover, nutrients are typically applied at a uniform rate across spatially heterogeneous soil types and land quality, resulting in some areas having insufficient nutrients and others too much, where the excess is lost as run-off (Zilberman, Khanna, and Lipper, 1997). Determining the optimal mix of alternative nutrient management practices and the locations where they should be adopted is complicated by spatial heterogeneity in the agricultural landscape, asymmetric information about the costs of adoption, and uncertainty about the effect of climatic and biophysical factors in determining the environmental implications of adoption.

While much of the focus in the MARB has been on water quality, agricultural production in the region also impacts other ecosystem services, including greenhouse gas emissions and habitat for birds, pollinators, and natural enemies of agricultural pests. It is estimated that the application of conventional tillage practices after 1900 led to the loss of over half of the soil carbon stocks in agricultural soils in the US Corn Belt by mid-century (Matson et al., 1997; Parton et al., 2015). Tillage and rotation practices also affect biodiversity-related ecosystem services (McLaughlin and Mineau, 1995). Agricultural production is a source of greenhouse gas emissions from livestock production, direct energy and fertilizer use. Agriculture can also contribute to mitigating emissions from other sectors (particularly, the energy-intensive transportation and electricity-generating sectors). By providing bioenergy, agricultural production can enable the displacement of fossil fuels and offset carbon emissions by sequestering carbon in soil through plant growth. The choice of crops, rotation, and tillage practices and the soil and climatic conditions where they are adopted can influence the carbon intensity of the bioenergy generated, net carbon emissions, biodiversity, and habitat.

Bioenergy production in the region has primarily been in the form of corn ethanol, induced by the 2007 Renewable Fuel Standard (RFS). Acreage under corn has expanded as the share of corn diverted from food to biofuel production has grown to over 40%. Studies using satellite data show that grasslands in the vicinity of corn ethanol plants have declined due to the expansion of cropland acreage since 2007 (Wright et al., 2017).The direct carbon intensity of corn ethanol is lower than that of gasoline (Wang et al. 2012), However corn production is both fertilizer and tillage intensive and studies show that corn ethanol expansion has contributed to worsening the dead zone in the Gulf of Mexico (Donner et al., 2002; Hendricks et al., 2014). With land being used for both food and fuel production in the MARB, it is important to consider the optimal allocation of land among food and fuel crops as well as alternative management practices that can meet demands while protecting multiple ecosystem services in the region.

A number of practices and crops have been identified that can meet demands for food and fuel while controlling surface water runoff and erosion, reducing nutrient losses, and mitigating greenhouse gas emissions. These include conservation tillage; changes in nutrient application timing, rate, method, and form; and crop diversification (e.g., adding crop rotations, cover crops, and perennials) (Khanna and Zilberman, 1997; McIsaac et al., 2001; Friedrich, Derpsch, and Kassam, 2012). Precision farming technologies enable farmers to capture spatially referenced data about nutrient content and soil quality in the field and use computerized equipment that is precisely controlled by satellites to apply the right treatment in the right place at the right time. Emerging information-based technologies and "big" data can bring data from multiple sources to enable farmers to improve decision making and to manage multiple input applications according to in-field variations in production conditions. Other practices such as conservation tillage and cover crops can increase soil carbon sequestration and reduce run-off. The effects of these practices on input use, crop yields, and returns to land are site-specific (Khanna, Epouhe, and Hornbaker, 1999; Khanna, 2001; Khanna, Isik, and Zilberman, 2002).

Perennial grasses or energy crops, like miscanthus and switchgrass, are a promising feedstock for meeting the advanced biofuel component of the RFS. They have high yield per unit of land and large root systems that result in reduced soil erosion and run-off and significant amounts of soil carbon sequestration (Khanna et al., 2011; Housh, Khanna, and Cai, 2015; Vanloocke et al., 2017). Their yield and potential to sequester carbon in the soil differ across location and across different types of perennial energy crops. They also have the potential to substantially reduce the carbon intensity of transportation fuel. Dwivedi et al. (2015) estimate carbon savings of 130%–156% from miscanthus-based ethanol and of 97%–135% from switchgrass compared to gasoline, depending on location and soil quality, which influence crop yields and soil carbon sequestration levels. However, producing energy-crop-based biofuels is significantly more expensive than gasoline and unlikely to occur in the absence of significant policy incentives.

In general, the costs and ecosystem benefits of adopting conservation practices are site-specific due to the heterogeneity in growing conditions, soil quality, topography, and distance from water bodies. The optimal mix of practices therefore needs to vary spatially to maximize environmental benefits at least cost. Requiring all areas to reduce nitrate run-off or greenhouse gas emissions uniformly in the MARB would not be the most efficient strategy because not all areas contribute equally to the environmental outcome or have the same cost of abatement. Spatially varying the extent and mix of conservation practices adopted within and across watersheds can significantly lower the costs of soil carbon sequestration and reducing nutrient and sediment run-off (Rabotyagov et al. 2014a). Similarly, cost-effective locations for energy crop production vary across the region due to spatial differences in crop yields, soil carbon sequestration potential, and costs of converting land to these crops (Khanna et al., 2011; Chen, Huang, and Khanna, 2012).

However, even the lowest-cost strategy for achieving the hypoxia goal is estimated to cost approximately $2.7 billion per year in terms of lost profitability and will require implementing improved practices on about 18% of MARB cropland (Rabotyagov et al. 2014a). Housh, Khanna, and Cai (2015) estimate that converting 11% of cropland from corn and soybeans to perennial energy crop miscanthus in the Sangamon watershed in Illinois could reduce nitrate run-off by 9% at a cost of $95–$130 million dollars annually; this cost includes the loss in returns to farmers from converting land from its most profitable use and the costs of establishing cellulosic refineries to convert miscanthus to biofuel. Other studies show that fairly large-scale conversion of land would be needed to achieve relatively modest reduction in nitrate loadings; converting 40% of the corn acreage currently devoted to ethanol production in the MARB to miscanthus or switchgrass could reduce nitrate run-off by 5%–15% (VanLoocke et al., 2017). However, it is important to recognize that some of these practices also provide other environmental co-benefits, such as greenhouse gas mitigation. Housh et al. (2015) show that while converting 11% of cropland from corn (and corn ethanol) to miscanthus (and miscanthus-based ethanol) in the Sangamon watershed would reduce nitrate run-off by 9%, it would also reduce carbon emissions (through soil carbon sequestration and gasoline displacement) by over 35% relative to a baseline level with only corn ethanol. Using land to produce energy crops that displace coal would result in even larger greenhouse gas reductions. Khanna et al. (2011) find that converting less than 2% of Illinois cropland to bioenergy crops could provide bioelectricity to reduce carbon emissions from coal-fired power plants in Illinois by 11%.

Adopting alternative practices and perennial crops in some regions can occur voluntarily because it increases farm profitability (Khanna and Zilberman, 1997) or provides diversification benefits that reduce the riskiness of crop production (Miao and Khanna, 2017). Even without any government subsidy, an average of over 36% of U.S. acres are under conservation tillage (Conservation Technology Information Center, 2012). However, policy incentives are likely needed to induce a large-scale switch toward environmentally sustainable crops and crop production practices that can increase risks or impose irreversible sunk costs with uncertain returns (Song, Zhao, and Swinton, 2011; Skevas et al, 2016). Conservation programs seek to directly incentivize the adoption of environmentally friendly farm management practices (best management practices) by providing financial incentives. Other farm policies and energy policies can also influence incentives for adoption.

Evidence on the performance and cost-effectiveness of existing policies in achieving environmental outcomes is mixed. Conservation programs, such as the Environmental Quality Incentives Program (EQIP), provide incentives payments that are typically uniform across the landscape and are based on adopted practices rather than environmental performance outcomes; they are thus not well targeted to achieve specific environmental outcomes. These efforts are likely to be inefficient and costly because they do not recognize the differences in environmental impacts of the same set of practices due to differences in location, topography, weather, and soil conditions (Khanna and Farnsworth, 2006). A recent report from the U.S. Government Accountability Office (2017) notes the inefficiency of EQIP due to lack of information to target EQIP funds to optimize environmental benefits and to ensure that it funds the most cost-effective applications.

Conservation programs to induce environmentally friendly practices on enrolled land also run the risk of leakage or slippage as landowners expand production using conventional practices on other acres not enrolled in the program (Wu, 2000). Indirect land-use changes induced by an increase in crop prices due to diversion of corn to corn ethanol has the potential to lead to expansion of crop acreage and loss of carbon stored in soils and vegetation on grasslands and forestlands; this can erode the direct benefits in terms of greenhouse gas savings due to displacement of gasoline by biofuels (Fargione et al., 2008; Searchinger et al., 2008). Another concern with conservation programs is the lack of permanence of their environmental benefits (such as soil carbon sequestration). For example, land exiting the Conservation Research Program in response to high crop prices and converted to conventional crop production is estimated to lead to a large loss of stored carbon (Gelfand et al., 2011).

Farm programs such as subsidized crop insurance, designed to reduce the riskiness of agricultural income, can also affect input use and crop choices that have environmental consequences. Crop insurance can affect the use of inputs such as fertilizer and pesticides; the direction of these effects could be positive or negative. By reducing the need for risk-reducing inputs, crop insurance can reduce the amount of fertilizer and pesticide applications; however, by shifting acreage away from uninsured land uses like hay and pasture to insured crops like corn, crop insurance can also increase chemical use (Weber, Key, and O'Donoghue, 2016). Miao and Khanna (2017) show that the availability of subsidized crop insurance for conventional crops raises the returns to land needed to convert it to energy crop production.

Additionally, renewable energy policies can affect crop choices in ways that are synergistic or conflicting with an environmental outcome. Producing ethanol from corn may mitigate greenhouse gas emissions by displacing gasoline but could increase acreage under corn and nutrient run-off. Excessive removal of corn stover for cellulosic biofuel production can lower soil carbon stocks but lead to overall mitigation of carbon emissions by displacing gasoline. Its impact on nitrate run-off could be positive or negative since sediment run-off could increase but nitrate leaching could decrease. Other choices could lead to complementary benefits, such as cellulosic biofuels and reduced nutrient run-off (Dwivedi et al., 2015; Housh et al., 2015; Vanloocke et al., 2017).

However, farm and energy policies are fairly blunt instruments for achieving conservation and can sometimes involve trade-offs between ecosystem impacts, as in the case of corn ethanol policy. Similarly, the cellulosic biofuel component of the RFS considers all cellulosic feedstocks that lead to biofuel that is 60% less carbon intensive than gasoline as being compliant with the standard. It does not distinguish among feedstocks such as corn stover, which may worsen water quality, and energy crops that improve water quality. It also does not incentivize the production of feedstocks that may achieve higher greenhouse gas savings than the 60% threshold if they are more costly to produce.

## Implications and Challenges for Conservation Policy

Studies show that the least-cost approach to achieving environmental targets beyond those achieved voluntarily or due to existing energy and farm policies would be performance-based incentives, such as a nitrate tax to reduce nitrate run-off or a carbon tax to reduce greenhouse gas emissions (Housh et al., 2015; Housh, Khanna, and Cai, 2015). These policies are better targeted to the sources of pollution, provide incentives related to environmental outcomes, and induce the most cost-effective options for pollution abatement. To prevent leakage, the coverage of these policies needs to be at an appropriate geographical scale. Alternatively, developing markets for trading pollution credits between point and non-point pollution sources could also incentivize the adoption of conservation practices. Several challenges arise in implementing this least-cost approach.

First, the non-point nature of these environmental impacts makes it particularly challenging to observe, monitor, and ascribe responsibility for nitrate run-off or soil carbon sequestration to fields/farmers. Targeting of policy incentives to the source of run-off is difficult to implement due to the absence of information and data needed to identify the sources of pollution and to measure their contribution to the pollution generated. These difficulties also arise due to the diffuse nature of the discharges, the heterogeneity in the links between input use and polluting discharges, the large land area over which discharges are transported before affecting water bodies, the effect of climatic and biophysical factors in determining the magnitude of the pollution, and difficulties in monitoring and measuring discharges. Moreover, the extent to which discharges from one land parcel impact a water body depend not only on management decisions on that parcel but also on those on upstream and downstream parcels. Efficiently designed policy incentives need to be spatially differentiated and targeted to specific land parcels rather than uniform across the landscape. Given the nature of nonpoint pollution, efficient policy design also requires that these incentives should be related to environmental performance outcomes and the marginal costs to farmers of reducing those impacts.

Second, agricultural production can impact multiple environmental services at the same time, improving some while worsening others, necessitating the consideration of trade-offs and synergies among environmental outcomes. When multiple environmental services arise jointly from the same acre of land, a single policy instrument may achieve more than one objective. Multiple policy instruments designed in isolation of consideration of multiple jointly determined ecosystem impacts of an activity could result in farmers obtaining multiple environmental credits/payments for the same activity. This has led to concerns about the possibility for credit stacking or “double dipping” by farmers who could receive compensation for providing many environmental services from the same activity on a parcel of land. However, determining “additionality” or credits generated for providing an ecosystem service beyond the level required for compliance in one environmental market is complicated and requires understanding of the complementarities and substitutability in the provision of these various environmental services.

Third, determining the optimal level of the nitrate tax or carbon tax needed to induce the adoption of practices needed to achieve desired environmental outcomes in the aggregate requires deeper understanding of the behavioral factors that influence technology adoption decisions by farmers. Conservation practices often impose upfront costs of equipment, machinery, and establishment and can increase or decrease the riskiness of crop yields. These factors can be major deterrents to converting land from annual crops to perennials. Perennials impose high establishment costs that have to be borne upfront if farmers are unable to obtain credit. Furthermore, perennial energy crops have a lifespan of 10–15 years and require a long-term commitment of land to the crop. They require 1–3 years for establishment, during which a farmer would incur fixed cost of establishing these crops and forgo returns that could have been earned under alternative use of that land (such as growing conventional crops). Without the access to subsidized crop insurance that is typically available for conventional crops, perennial crop production also involves risks that may differ from those associated with conventional annual crops. These may be higher than the risks of growing conventional crops in some areas and lower in other areas (see Miao and Khanna, 2014, 2017; Skevas et al., 2016).

The decision to convert land from existing uses to a perennial energy crop will therefore depend on location and farmers' risk and time preferences, the riskiness of alternative crops, and correlation among those risks as well as the presence of credit constraints and crop insurance. Studies suggest that farmers tend to be more risk averse than non-farm business owners and that their discount rates can be as high as 40% (Khanna et al., 2017; Miao and Khanna, 2017; Khanna, Louviere, and Yang, 2017). High degree of risk aversion and high discount rate, together with a constraint on credit, can raise the returns that farmers need or the penalties that need to be imposed to induce them to switch to a conservation practice. Policies that reduce upfront costs of adoption, such as establishment cost share subsidies, and those that reduce the risks associated with adoption may be more effective than per unit subsidies/taxes for pollution reduction/generation.

## Directions for Future Research to Inform Conservation Policy

The use of land for food and fuel production in the MARB has multiple and heterogeneous impacts on ecosystem services. The optimal allocation of this land among alternative crops and cropping practices to meet growing demands while protecting the environment cost-effectively requires spatially targeted policy incentives. The non-point nature of agricultural pollution as well as informational asymmetries between policy-makers and farmers make it challenging to identify the sources of environmental impacts since they can be related to production technologies or natural conditions. The presence of private information among farmers that is not available or verifiable by regulators can lead to moral hazard and adverse selection, which limit the ability of regulators to design targeted site-specific policies. Emerging advances in information and computing technologies coupled with ability to capture, store, and analyze massive volumes of data from millions of acres of cropland have the capacity to provide site-specific information about production decisions, environmental conditions, crop varieties, and yields. This "big" data coupled with modeling tools can enable analysts to quantify the environmental impacts of agricultural production activities. Future research is needed to determine how this capability can be used to guide science-based agro-environmental policy that has been constrained by the lack of data on farm management decisions.

Integrated biophysical and economic models offer the capability for quantifying the impact of land use choices on multiple ecosystem services at a fine spatial resolution, particularly when combined with the increasing availability of publically available remote sensing data on soil quality, land use, crop yields, and weather information. These integrated approaches can be used to determine whether a single or multiple policies are needed to optimally address multiple jointly determined externalities and how to design these policies to avoid redundancies, conflicting incentives, and unintended consequences. Models can also be used to determine additionally of environmental impact relative to a counter-factual baseline and site-specific contributions. However, using model-based outcomes for environmental regulation can be challenging for technical and practical reasons. A few studies have illustrated approaches for translating complex model outcomes to approximate biophysical relationships between observable decisions and unobservable environmental outcomes and using them to develop pragmatic approaches to implement performance-based policies (Yang, Khanna, and Farnsworth, 2005; Rabotyagov et al., 2014b). More research is needed to examine the performance of such approaches and to extend them to address multiple jointly produced ecosystem impacts of agricultural production decisions.

Lastly, behavioral economic approaches can be used to provide information on the role of economic and non-economic considerations that affect technology adoption decisions. These can indicate the extent to which the standard prescription for pricing externalities will be effective and the role that nudges, information provision, technical assistance, and risk mitigation can play in achieving desired outcomes cost-effectively. Further research is needed to understand how the effect of risk and loss aversion, time preferences, social and peer pressure, inattention, and search costs on conservation and land management choices can guide the design of conservation policies.

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# CBO Baseline and the Potential for Conflicts by Expanding CRP

Jonathan Coppess

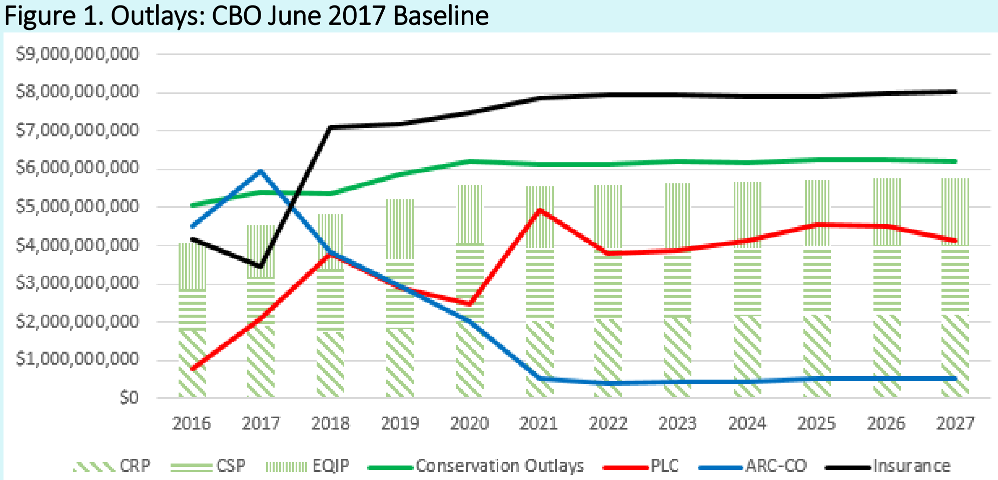
*JEL Classifications: Q20, Q25, Q28, Q58*
*Keywords: Budget, Conservation, Farm Bill*

The potential for conflict over conservation policy is arising as Congress works to reauthorize the programs contained in the Agriculture Act of 2014 (the "2014 Farm Bill"). Written at a time of high crop prices and intense political pressure on mandatory spending, the 2014 Farm Bill reduced the acreage cap for the Conservation Reserve Program (CRP) over multiple years to its current 24-million-acre level. Lower crop prices going into this re-authorization are contributing to calls seeking expansion of CRP acres and increasing the cap (Good, 2017). At the same time, pressure on farmers to reduce nutrient losses and water quality degradation continues to increase (Coppess, 2016). Congressional Budget Office (CBO) spending estimates, however, will again occupy a large role in farm bill deliberations, pitting priorities against each other; any expansion of the CRP will have to be offset with spending reductions from other programs and could pit them against the CRP.

## It Begins with the Baseline

Congressional attempts to control federal spending, reduce the deficient, and discipline the budget date to 1974 with the formation of the Congressional Budget Committees, the CBO, and the budget process (Porter, 1978; Walter, 1978). Congress went further in the 1980s with the Balanced Budget and Emergency Deficit Control Act of 1985 and more recently with "pay-as-you-go" (PAYGO) rules and the Budget Control Act of 2011 (Heniff, Rybicki, and Mahan, 2011; Heniff, Lynch, and Tollestrup, 2012). The combined effect of budget disciplines for mandatory spending programs, such as those contained in the farm bill, is a zero-sum legislative game under the CBO baseline. Each year, the CBO creates its baseline by projecting federal outlays for mandatory or entitlement programs over 10 years, assuming that the programs operate in the manner specified in the statute and without changes (2 U.S.C. §907). The PAYGO process enforces discipline for mandatory spending by requiring any changes to existing law that increase spending (or decrease revenues) above the baseline to be offset by corresponding changes that decrease spending (or increase revenues).

Figure 1. Outlays: CBO June 2017 Baseline




Source: Congressional Budget Office (June 29, 2017)

For the farm bill, CBO projects the 10-year outlays for the authorized mandatory programs, which includes commodity support, crop insurance, conservation and the Supplemental Nutrition Assistance Program (SNAP). The 2018 baseline, typically produced in March, would apply to the 2018 farm bill reauthorization process (Monke, 2017). The most recent CBO projections were published June 29, 2017; while not applicable to the next farm bill debate, these projections provide the best indications of the funding levels available to the farm bill (Coppess et al., 2017). CBO projects an increase in conservation spending from $5 billion to over $6 billion per fiscal year, with most of the outlays going to the CRP, the Conservation Stewardship Program (CSP), and the Environmental Quality Incentives Program (EQIP). Figure 1 illustrates CBO outlay projections for those programs as well as the entire conservation baseline. It also compares the projections for the major commodities programs—Price Loss Coverage (PLC) and Agriculture Risk Coverage, county (ARC-CO)—and for crop insurance. Together, commodities, crop insurance and conservation constitute the main mandatory spending items in the farm bill baseline that are directly applicable to producers.

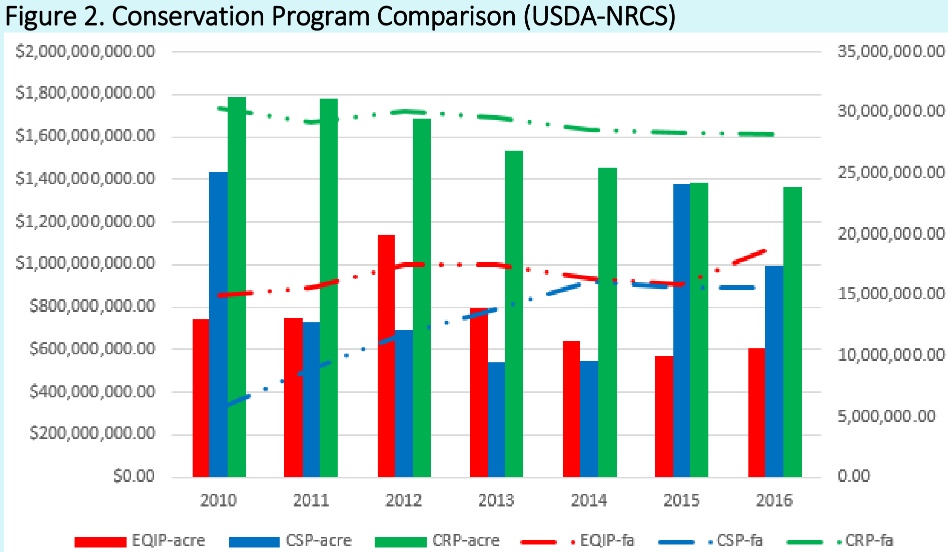
## Conservation Programs in the Farm Bill

The conservation programs and policies in the farm bill are built from the landmark provisions of the Food Security Act of 1985, which created the modern CRP and instituted conservation compliance (Coppess, 2016; Malone, 1986). Soil erosion was the primary concern underlying the 1985 provisions; CRP's 10-to-15-year rental payments were designed to remove highly erodible and environmentally sensitive land from production, coupled with compliance provisions that eliminated eligibility for Federal payments for breaking sod, farming highly erodible land without a plan to control erosion and draining wetlands (Malone, 1986). Congress subsequently added easement programs designed to restore and maintain wetlands as well as protect grasslands and farmland. Together, CRP and easement programs constitute reserve policy that seeks to achieve conservation goals by removing land from production. Since 1985, these programs have worked in conjunction with compliance to prevent production on the most sensitive land.

Congress created EQIP in the 1996 Farm Bill and CSP in 2002. Together they are known as working lands conservation programs, and both represented shifts in conservation policy. Instead of reserving land from production, these programs provide direct cash assistance to farmers for adopting conservation measures on land that remains in production. EQIP, for example, provides cost-share assistance to farmers who adopt specific conservation practices on their farm and has a heavy emphasis on livestock production and manure management. CSP looks to conservation across the entire farming operation, requiring a certain level of conservation to be eligible for the program and an agreement to increase conservation over the course of the five-year contract payments.

Data from the USDA's Natural Resource Conservation Service (NRCS) provides a comparison for CRP, EQIP, and CSP in terms of acres and outlays (NRCS, 2017). The CRP remains the largest program in terms of acres under contract and federal outlays, but it has been trending downward; the 2014 Farm Bill reduced its acreage cap to 24

Figure 2. Conservation Program Comparison (USDA-NRCS)




Source: USDA, Natural Resources Conservation Service, RCA Reports – Program Reports.

million acres. EQIP and the CSP (which is statutorily designed to grow by 10 million acres each year) have demonstrated increases in both acreage and outlays but remain lower than the CRP. Figure 2 charts NRCS data for the three programs in terms of acres under contract (active and completed) and federal financial assistance obligations for the most recent years (2010–2016).

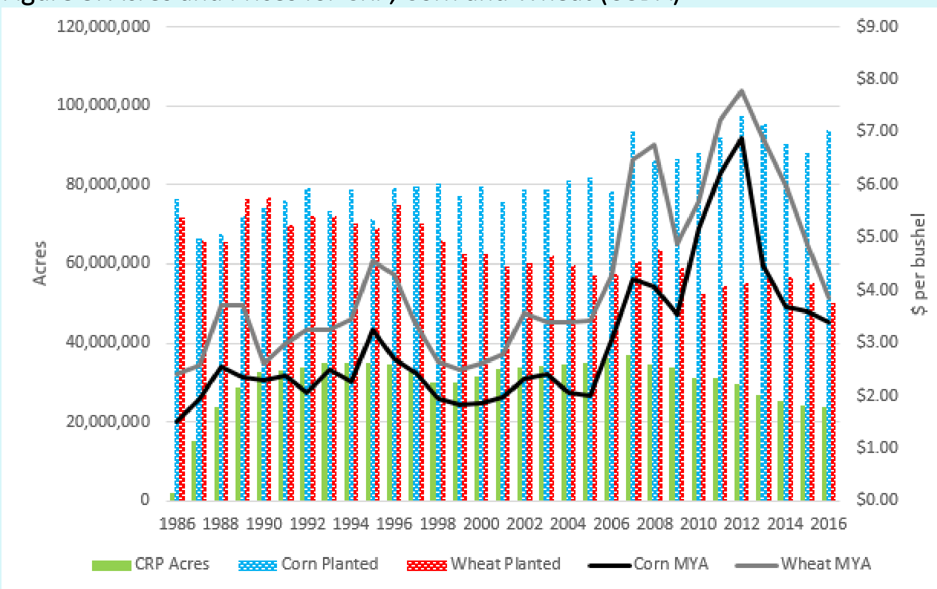
## Nutrient Loss, Water Quality, and Farm Bill Conservation Programs

The potential for conflict is rooted in these fundamental differences in conservation policies and the particular challenges from nutrient loss and water quality. The CRP has been designed primarily to control erosion by taking sensitive or highly erodible land out of production. Combined with compliance, the policies have demonstrated effectiveness in reducing soil erosion from farming (Claassen et al., 2017; Stubbs, 2014). Research has found, however, that commodity prices can create challenges for these policies. For example, CRP acres tend to decrease when prices are high, as land goes back into production (Morefield et al., 2016). In addition, compliance has been most effective when program benefits are expected to be the highest, which is often when crop prices are relatively low. CRP requires federal outlays for the rental payments but compliance, if it impacts the baseline at all, would be expected to reduce spending.

The CRP is a relatively blunt policy instrument that is limited and expensive. Removing land from production for 10–15 years is a long-term commitment. Market conditions, production issues (e.g., weather or drought), and prices can change significantly during that time, creating issues for the policy in operation. One example surfaces when drought strikes a region and farmers demand emergency haying and grazing on CRP acres that are otherwise precluded from commodity production (U.S. Department of Agriculture, 2017b). Another example is crop price pressures: High prices create demand to bring CRP acres back into production, which may have environmental consequences. Lower prices tend to increase demand from landowners to put acres into the program and may impact adjustment of cash rental rates to the lower prices as well as land values (Jones, 2017; Garr and Taylor, 2016).

The CRP is limited in part because it is expensive. By design, it also does not respond quickly to market conditions. Figure 3 charts CRP acres as reported by USDA's Farm Service Agency (FSA) with planted acres and marketing year average prices reported by USDA's National Agricultural Statistics Service (NASS) for corn and wheat. The figure provides only a snapshot of acreage responses to prices. For the upcoming farm bill debate, both prices and CRP acres have declined since the 2014 Farm Bill. These trends are notable because lower prices historically increase the demand for CRP acres but the 2014 Farm Bill lowered the acreage cap.

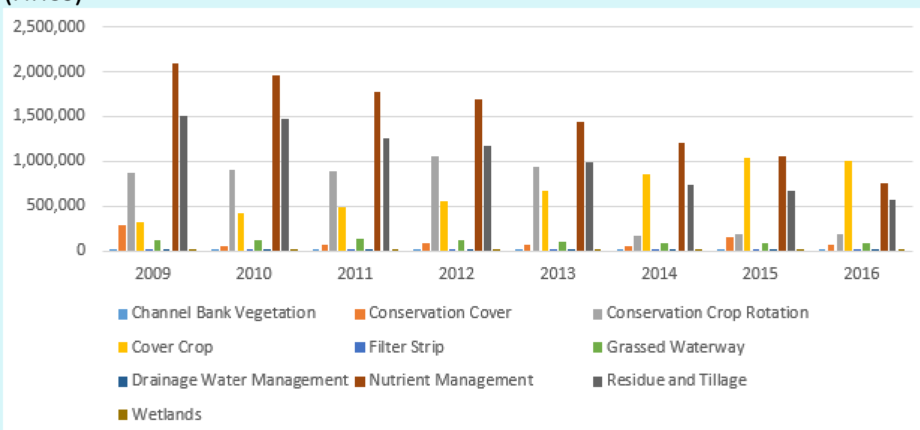
Figure 3. Acres and Prices for CRP, Corn and Wheat (USDA)




Source: CRP Acres, USDA 2017a; planted acres and MYA prices, USDA-NASS Quick Stats.

Nutrient loss—and the water quality degradation that results—is a conservation issue directly tied to production: Farms lose nutrients that are applied to grow crops. The fields that are most likely to export nutrients are the most productive lands, drained by subsurface tiles and fed by sufficient rains (Coppess, 2016). Putting land into the CRP would certainly reduce nutrient export as well as soil erosion (Morefield et al., 2016). Intuitively, however, rain-fed, tile-drained, productive fields are the least suitable for 10-to-15-year retirement and the least likely to go into the program. As such, the CRP provides limited effectiveness for helping farmers reduce nutrient losses. Conservation compliance is also less effective in addressing nutrient loss for similar reasons. The tile-drained, productive farms losing nutrients are less likely to be highly erodible; nitrogen loss, at least, is predominantly due to subsurface tile rather than surface erosion. Conservation plans to control erosion to meet compliance are less likely to address nitrogen losses. Finally, the vast majority of these lands were drained long before compliance was put in place and are thus likely to be exempt from compliance.

Figure 4. Acres Receiving EQIP Funding for Selected Water Quality Practices (NRCS)



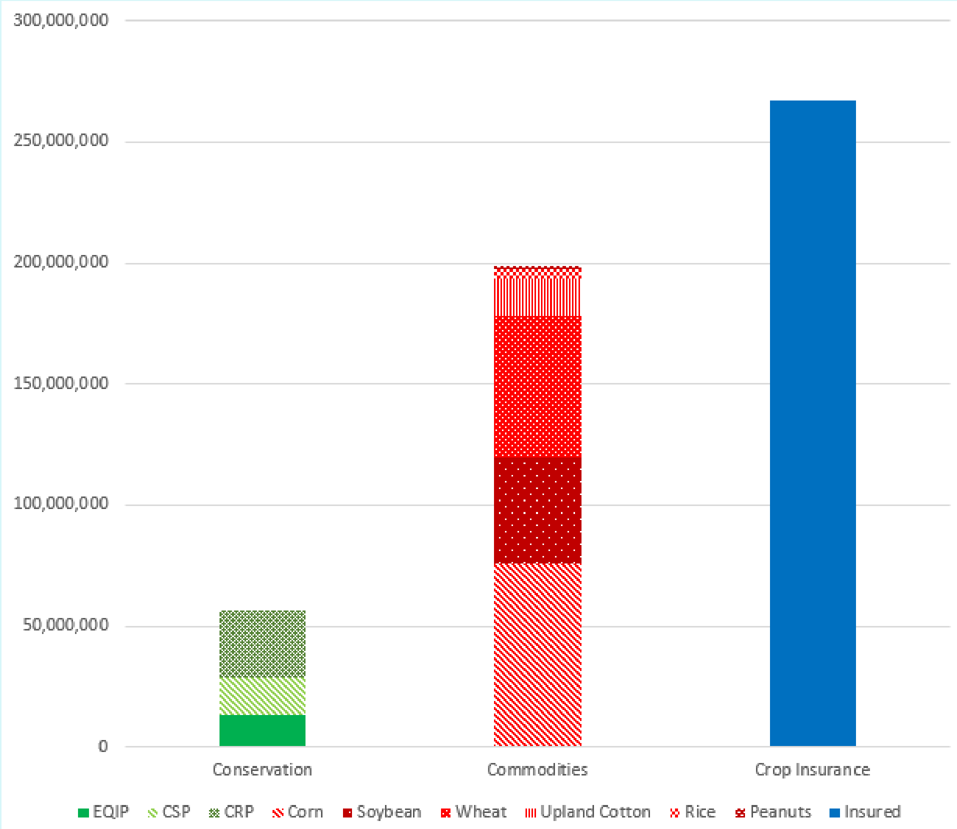

Source: USDA, Natural Resources Conservation Service, RCA Reports – Program Reports.

The gap between the nutrient loss challenge and the CRP or compliance is where working lands conservation programs would be expected to have the most impact. EQIP provides a straightforward example because it provides cost-share assistance for specific conservation practices within categories, notably nutrient management in crop production. Examples include cover crops, residue and tillage management, filter strips, grassed waterways, drainage water management, and wetlands work. The biggest challenge for working lands programs when it comes to nutrient loss, however, is one of scale and scope: the 2012 Census of Agriculture indicates over 48 million tile-drained acres spread across 217,931 farms (U.S. Department of Agriculture, 2016). The CSP averaged 15.8 million acres (2010–2016) while selected EQIP practices reach relatively few acres. Figure 4 charts acres receiving EQIP funds for selected water quality practices. All practices were on fewer than 2.5 million acres in any year, and NRCS notes accompanying the data indicate that land unit acres may be counted multiple times.

## Challenges and Opportunities for the Next Farm Bill

The CBO baseline creates a zero-sum policy scenario, including for conservation programs; changes that require additional outlays for one program will require offsets out of other programs. If Congress wants to increase the CRP acreage cap, the baseline cost could be substantial. For example, the national average per acre rental payment from 2010 to 2016 was $61.28, increasing from $50.76 per acre in 2010 to $72.61 per acre in 2016 (U.S. Department of Agriculture, 2017a). Adding a million acres to the CRP at that national average rental rate could cost $614 million in the baseline (over 10 years). The last period of sustained low crop prices coincided with the 2002 Farm Bill, which set the CRP acreage cap at 39.2 million acres. Returning the CRP to that acreage cap at the average national rental rate of $61.28 per acre could cost over $933 million per year or $9.3 billion over the 10-year baseline. Using the CBO's June baseline, the CSP baseline is only $18 billion from 2018 to 2027. EQIP's baseline is lower at $16.5 billion, and 60% of EQIP funds are designated for livestock. The zero-sum game's cost for adding CRP acres could be devastating to one or both working lands programs.

Figure 5. Program Acreage Comparison (USDA)




Source: Conservation acres from USDA, Natural Resources Conservation Service, RCA Reports – Program Reports; Commodities are CBO payment acres (85% of base acres); Crop insurance acres, RMA net acres insured, summary of business (all averaged, 2010–2016).

The potential from increasing CRP is where a significant conflict could arise, especially as it pertains to the need to address nutrient loss in the Mississippi River Basin. Under current budget disciplines, Congress cannot expand CRP acres without harming working lands programs unless it takes the even more politically difficult (and unlikely) path of seeking cuts outside of Title II, such as from commodities or crop insurance. From a conservation perspective, such a conflict over federal funds has far-reaching implications for programs that, combined, reach far fewer acres than either farm programs or crop insurance. Figure 5 compares average acres under conservation contracts from 2010 to 2016 with average base acres receiving commodities program payments and average acres insured. Notably, base acres and insured acres are both subject to conservation compliance provisions. It is also notable that the total conservation acres under contract compares to the estimated 48 million tile-drained cropland acres.

Because an intra-conservation conflict under the baseline would be expected to create a significant setback, the situation calls for creativity, especially as it concerns the CRP. This discussion highlights how the traditional program design that retires whole fields for 10–15 years may not be the best policy option for conservation goals such as nutrient loss reduction. If Congress and interest groups want to avoid this conflict, they will need to seek out creative solutions, which would probably need to incorporate working lands concepts into any expansion of CRP acres.

Senator John Thune (R-SD) has introduced legislation that could provide an alternative to traditional CRP enrollment. Called the Soil Health and Income Protection Program (SHIPP), his proposal would provide for shortterm (3–5 years) reserved acres with a maximum of 15% of the cropland on a farm (Thune, 2017; S.499, 2017). The shorter contract period would make the program more responsive to market conditions. In addition, it permits some harvesting activities on the acres while under contract. From a baseline perspective, the proposal is designed to reduce the costs of enrolling acres. For one, it would limit rental payments to 50% of the average rental rate for the county. Senator Thune’s proposal has some historical precedent as well. Early farm bills used conservation rental payments to rent land out of production for a single crop year, but this policy was part of controversial efforts to control production through limiting acres.

Other alternatives could also be considered. Congress has previously incorporated nontraditional concepts in the program. For example, the 2002 Farm Bill added a pilot program for enrolling wetland and buffer acreage, revised by the 2008 Farm Bill, including for wetlands designed to provide nitrogen removal. While these were also long-term reserve policies within the CRP, they do point to the potential for creative solutions in the program. Certainly shorter-term and lower-cost options could be considered, especially for buffer or grassed waterway acres, but these may not increase effectiveness for nitrogen loss from subsurface tile.

At its core, the CRP makes rental payments to landowners for conservation benefits or environmental services. In the traditional setting, these come from the landowner agreeing to place a field under permanent perennial cover for 10–15 years and not producing a commercial crop on it. Working lands programs have demonstrated alternative conservation policy designs, such as cost-share assistance for planting cover crops or other practices. A creative combination from a nutrient loss perspective would be to use the CRP to rent cover crop acres in a single crop year or over multiple crop years at significantly reduced rental rates. This would add acres to the CRP but with a much lower baseline impact. It would also achieve conservation goals during the fallow months between crops but permit the farmer to continue producing on the land.

## Summary

The CBO baseline creates the potential for conflicts over programs in the next farm bill. For conservation policy, in particular, increasing CRP acres would come at a significant cost in the CBO baseline that would have to be offset. Using other conservation programs to provide those offsets could create conflicts among supporters of the different programs. As discussed, this could pit working lands conservation program spending against reserve program spending if the CSP or EQIP are reduced to pay for the CRP. The potential for conflict over these programs in a farm bill debate should counsel a search for creative solutions that help achieve a variety of conservation goals. Incorporating working lands policy concepts into an expansion of CRP acres might prove successful on multiple fronts.

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# Policy Reforms Needed for Better Water Quality and Lower Pollution Control Costs

James Shortle

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*Keywords: Agriculture, Clean Water Act, Nonpoint source pollution, Stormwater, Water quality, Water quality trading*

Water pollution control has been a top environmental policy priority for decades, an area of significant state and federal regulation, and the focus of enormous public and private spending. Yet significant water quality problems remain. For example, a recent U.S. Environmental Protection Agency (EPA) assessment finds that 46% of U.S. rivers and streams are in poor biological condition, 25% are in fair condition, and only 28% are in good condition (EPA, 2016). This situation is in large degree due to fundamental flaws in the nation's water quality policy architecture, with highly uneven regulation of polluting sectors. The same architecture has resulted in pollution controls that are unnecessarily expensive, to the point that the incremental costs of additional water quality protection exceed the benefits (Olmstead, 2010). Innovations in water quality policy are essential to improve the effectiveness and economic efficiency of water quality protection. Agriculture is at the center of necessary reforms. With some exceptions, agriculture is lightly regulated under the existing architecture yet a major cause of remaining water quality problems. It is also a vastly underutilized source of comparatively low cost pollution reductions (EPA, 2001).

**Point versus Nonpoint Pollution**
Pollution sources are commonly differentiated as point or nonpoint sources. Point sources discharge pollutants directly into receiving waters through a pipe or other discrete conveyance. Pollutants from nonpoint sources follow diffuse and often complex pathways from their point of origin to receiving waters. For example, nitrogen applied to farm fields may be removed in surface runoff, leach into groundwater, or enter the atmosphere as a gas later to return to the Earth's surface with wet (rain, snow) or dry (dust) deposition.

## Agriculture and Water Quality

The most recent EPA National Water Quality Inventory lists agricultural nonpoint source (NPS) (see Box) pollution as the leading cause of water quality impairments on surveyed rivers and streams, the third-largest cause for lakes, the second largest for wetlands, and a major contributor to contamination of estuaries and groundwater (EPA, 2017). Of particular concern is nutrient pollution, which the EPA describes as "one of America's most widespread, costly and challenging environmental problems" (EPA, 2009). Plant nutrients are essential for healthy aquatic ecosystems, but human activities (agriculture, fossil fuel combustion, industrial processes, human settlements) can increase nutrients (especially nitrogen (N) and phosphorous (P)) above "natural levels," leading to reduced biodiversity, diminished productivity of commercial and sports fisheries, loss of waterfowl habitat, various disamenities from algal blooms, and—in some cases—risks to human health from elevated nitrates in drinking water and toxic algae. High-profile examples of nutrient pollution are found in the Chesapeake Bay, Florida Everglades, Gulf of Mexico, and Lake Erie, but water quality degradation from excess nutrients is widespread. For example, more than two of every five river and stream miles have nutrient levels that are too high (EPA, 2016).

Although the causes of specific nutrient pollution problems vary from place to place, agriculture is a pervasive contributor and often the major source of excess nutrients. Farmers typically apply nutrients in synthesized fertilizers or animal manures to increase output. In some regions with high livestock densities, manure may be applied to cropland and pasture land as much to dispose of it as to increase fertility. Surface runoff, leaching, and other natural process move nutrients from barnyards, fields, and pastures into water resources. Surface runoff also moves sediment to water resources, with the result that sediment pollution problems sometimes accompany nutrient problems.

The Chesapeake Bay is a leading case study for nutrient and sediment pollution. The largest estuary in the United States, the Chesapeake has ecological, economic, cultural, and historical significance. It has also been highly stressed by human settlement and agricultural and industrial activity, particularly by nutrients and sediments. The Chesapeake Bay Program (2017) estimates that agricultural NPS pollution contributes 42% of N and 55% of P entering the bay. Agriculture is also the leading source of sediments (S) entering the bay, contributing 60%.

The bay has been a focus of research on nutrient pollution and a focus of significant nutrient pollution policy initiatives and spending for nutrient pollution control since the 1980s. Insufficient progress toward water quality goals led the EPA to issue a Total Maximum Daily Load (TMDL) for the bay in 2011. TMDLs are limits on pollution loads required by the Clean Water Act (CWA) for waters that do not meet water quality standards. The bay TMDL requires the six states in the 64,000-square-mile watershed and the District of Columbia to reduce N, P, and S from managed sources by 26%, 24%, and 15% by 2025 compared to 2009 levels. The reductions required for agricultural NPS pollution for N, P, and S are 36%, 30%, and 29% respectively.

## Agricultural Nonpoint Source Policy

A fundamental question facing policy-makers now is how to bring about the changes in farming practices and agricultural systems needed to achieve water quality goals. The technological means, conventionally known as Best Management Practices (BMPs), for substantially reducing nutrient and sediment pollution from agriculture are well known. Missing are the policy mechanisms necessary to bring about sufficient BMP adoption. Some BMPs have private benefits that may lead farmers to adopt them, but—in general—pollution control in agriculture is costly. With farmers seeking to survive and thrive in competitive agricultural markets, some combination of carrots and sticks is required to achieve established goals.

The policy architecture of water quality protection in the United States is defined by the 1972 CWA, legislation that nationalized the control of point sources (PS) of pollution by requiring PS dischargers to obtain and comply with discharge permits that set effluent limits. The CWA assigned responsibility for control of NPS pollution, of which agriculture is by far the most important, to the states. Municipal stormwater and confined animal feeding operations (CAFOs) were initially treated as NPS pollution under the CWA, but urbanized areas and CAFOs exceeding certain size thresholds have been redefined as PS pollution and are regulated as such.

Agricultural NPS policies implemented by the states typically emphasize voluntary adoption of BMPs, with programs to educate farmers about problems and solutions, and to facilitate BMP adoption by providing technical and financial support (Shortle et al., 2012). The limited effectiveness of this approach has led some states to include certain mandatory elements, typically in the form of modest technology standards (Kling, 2013). In such cases, voluntary adoption is typically the default approach, with limited regulatory enforcement unless triggered by some event.

While the states have legal responsibility for agricultural NPS pollution, the most significant investments in controlling the problem come from U.S. Department of Agriculture conservation programs authorized by federal farm legislation (Shortle and Uetake, 2015). The most significant is the Environmental Quality Incentives Program (EQIP), which was established in 1996 to provide technical and cost-shared financial assistance for the installation of conservation practices.

CWA regulations have been effective in reducing PS discharges. While federal and state agricultural NPS programs have had positive effects, they generally fall short of what is needed to achieve water quality goals (Shortle et al., 2012). The Chesapeake Bay once again serves to illustrate. Comprehensive time series data on PS and NPS pollution loads to specific bodies of water is generally not available, but decades of research have provided exceptional data for the bay, indicating the relative effectiveness of PS versus agricultural NPS policies. Consistent with the policy architecture described above, municipal and industrial PS pollution have been subject to increasingly stringent regulations, while agricultural NPS pollution has been addressed largely through voluntary approaches.

Table 1. Chesapeake Bay Pollution Reductions: 1985–2009

| Sector* | Nitrogen | Phosphorous | Sediment |
|---|---|---|---|
| Agriculture (Nonpoint) | 20% | 4% | 26% |
| Urban Stormwater Runoff | -16% | -4% | 5% |
| Urban Wastewater and Combined Sewer Overflows | 41% | 60% | 50% |
| Total Basin Wide | 24% | 25% | 20% |

Notes: *Excludes septic systems, forests, and atmospheric deposition to tidal and nontidal waters.
Source: Chesapeake Bay Program (2017) – Loads to Chesapeake Bay Simulated Using CBP Phase 5.3.2 Watershed Model.

Table 1 provides estimates of changes in pollution loads to the bay between 1985 and 2009. Agricultural NPS loads have declined over the period. Agricultural programs have certainly played a role in this reduction, but reductions in cropland acres and economic and technological developments that improve the private benefits of certain BMPs (e.g., no-till, soil testing) are also factors. In percentage terms, the agricultural NPS N and S reductions are about half those for urban wastewater sources, and a small fraction of the urban wastewater P reductions. To fully appreciate the differences, it is important to recognize that the urban population of the watershed has grown steadily and substantially (34% between 1985 and 2016).

Urban stormwater trends are contrary to the PS and agricultural NPS trends, reflecting the substantial growth of urban areas in the bay watershed and limited regulation of urban stormwater as NPS pollution after the enactment of the 1972 CWA. Stormwater, like agriculture, is a major target of the Chesapeake Bay TMDL.

Limitations of the current policy architecture are also well illustrated by Lake Erie (International Joint Commission, 2014). Prior to the 1970s, excess nutrient loads and severe eutrophication greatly reduced the lake's value for fishing, water supply, and aesthetics. Phosphorous from municipal sewage treatment plants was the leading cause. Regulations and investments beginning in the 1970s reduced phosphorous loads by more than half by the mid-1980s. However, nutrient problems returned in the early 2000s and have become more severe since, punctuated by widespread harmful algal blooms. While a variety of factors contributed to the relapse, increased dissolved P (a highly potent form) from nonpoint sources, particularly agriculture, play a leading role.

## Improving Effectiveness and Efficiency Part I

The voluntary approach to agricultural NPS pollution emerged from traditional soil and water conservation programs that provide farmers with technical and cost-shared financial assistance to implement conservation practices. In theory, conservation practices provide private benefits to farmers (e.g., improved soil productivity), motivating their interest in adoption, and societal benefits that justify public assistance. Given that some soil and water conservation practices serve to protect water quality and the large societal investments in the infrastructure for providing support for conservation, expanding the scope of conservation programs to include water quality objectives makes good sense. There are, however, fundamental limitations of the approach for water quality protection.

One limitation is that conservation programs typically have multiple goals. These goals are always not complementary, with the result that resources for water quality protection must compete with resources for other objectives within conservation budgets, and some practices supported by these programs are at odds with water quality goals. The USDA Natural Resource Conservation Service allocated obligated almost $2.4 billion out of a total of $5.7 billion for practices that at least in part improved water quality during 2009–2015 (U.S. Government Accountability Office, 2017). Most of this amount (75%) was for practices that addressed environmental concerns in addition to water quality.

A second limitation is that resources allocated to water quality protection through conservation programs are not adequately targeted in space. Efficient use of scarce public funds would prioritize critical source areas (e.g., particular watersheds and locations within them) to achieve the “biggest bang for the buck.” Existing conservation programs provide very limited discretion for spatial targeting. Also important to efficient water quality protection is the effectiveness and cost of the practices utilized. A study of the costs to agriculture of the Chesapeake Bay TMDL found that prioritizing practices based on their cost-effectiveness along with crude spatial targeting could reduce annualized costs of achieving the required agricultural N and P load allocations across the six bay watershed states by 27%–80% compared to the costs of the Phase I watershed implementation plans developed by the states with little consideration to cost-effectiveness (Kaufman et al., 2014).

Finally, a fundamental limitation of the current approach is that it relies on payments to farmers. This essentially holds water quality protection hostage to the amount of public conservation spending. Conservation investments are already budget-constrained, with demand for funds routinely in excess of supply. The importance of this restriction is likely to increase as federal and state discretionary budgets are increasingly squeezed by entitlements and unfunded pension obligations (Shortle et al., 2012).

Fundamentally, the traditional voluntary compliance model for water quality protection makes water quality protection in agriculture supply driven rather than demand driven. Details of pollution control investments that are funded by the public and of fundamental importance to water quality protection depend on the choices individual farmers make about whether or not to participate in water quality programs and the control practices they are willing to adopt from the menu supported by those programs. This kind of system can assure desired water quality outcomes and efficiency in the use of public funds only if the payment model can effectively limit funding to critical source zones and to water quality practices that are cost-effective, induce eligible farmers to adopt the most efficient practices even when there are few or no private benefits from their use, and allocate sufficient public funds to get the job done. This is not the existing system.

## Improving Effectiveness and Efficiency Part II

Innovations in agricultural NPS policies are crucial if they are to be effective, efficient, and make good use of public funds. Before discussing options, it is important to identify another compelling reason for policy reform. Smart initiatives for reducing water pollution from agriculture could also substantially improve the overall economic efficiency of water quality protection. The U.S. policy architecture is not only ineffective in controlling NPS pollution, it is also grossly inefficient, with far more than required being spent to achieve the resulting water quality benefits. For example, based on a review of benefit-cost studies, Olmstead (2010) concludes that the incremental benefits of the CWA exceeded the incremental cost through the late 1980s, but the reverse has been true since then. This is not because of low benefits from water quality protection but because of highly inefficient policy. PS regulations implemented under the CWA prevent utilization of least-cost control technologies and have until recently prevented cost-reducing allocations of abatement across alternative sources to exploit differences in marginal abatement costs. The United States has ended up relying on very high-cost pollution abatement from heavily regulated PS pollution, while lower-cost agricultural NPS pollution goes largely unregulated.

Key elements of better policies for agriculture include switching from an incentive model in which farmers are paid to implement pollution-reducing farming practices to one in which payments are received for actual or expected improvements in water quality (pay-for-performance), switching from a resource allocation model that targets limited resources to high-priority problems in high-priority places (targeting), utilizing payment mechanisms that minimize payments in excess of farmers’ willingness to accept, and shifting from a pay-the-polluter model to more of a polluter-pays approach (Shortle et al., 2012). Further, there are situations in which regulatory mandates make good economic sense. For example, bans on certain harmful practices or mandates for prevention practices that are known to be cost-effective in environmentally sensitive locations in watersheds with significant or chronic water quality problems may sometimes be the cheapest way to achieve water quality protections. The best strategies will likely entail mixes of incentives and regulatory constraints (Shortle et al., 2012).

These types of innovations should be considered for both USDA agri-environmental programs and for state agricultural NPS programs. The presence of both types implies opportunities for and likely benefits from federal and state coordination, which would likely require federal policy reforms that enable greater flexibility in the way that USDA Natural Resource Conservation Service programs are delivered so that they can be tailored to local needs and state and local policies. Another important federal policy reform would be to expand conservation compliance requirements in both federal and state programs. In the case of the federal government, this would make participation in income support programs contingent on water quality compliance (Claassen et al., 2004). State and local governments provide various economic benefits to agriculture—such as use-value taxation and purchase of developments—typically without requiring an environmental quid pro quo (Shortle and Uetake, 2015).

Addressing the overall efficiency of water quality protection requires shifting from the current paradigm in which PS and NPS pollution are managed separately to one in which they are managed jointly at watershed scales. The most obvious way to achieve integration is through water quality trading (WQT) programs that impose caps on aggregate pollution loads applicable to PS and NPS pollution and allow trading between sources of both types to allocate pollution reductions efficiently among types. As one indicator of the potential cost savings, the EPA (2001) estimated that expanded use of water quality trading between PS and NPS pollutors could reduce compliance costs associated with TMDL regulations by $1 billion or more annually between 2000 and 2015, but this estimate understates the potential gains. A recent study for the Chesapeake Bay estimates that trading between urban and municipal polluters and agricultural NPS sources could reduce Chesapeake Bay TMDL compliance costs by as much as $1.2 billion annually (Van Houtven et al., 2012). This estimate reflects enormous differences in control costs between comparatively expensive PS controls and comparatively cheap agricultural NPS controls. Urban stormwater costs are especially large.

Several dozen WQT initiatives have been developed in some form since the mid-1980s. These initiatives include planning exercises and pilot and active programs. Agriculture is addressed in many of these initiatives, and almost all are within the United States. Most programs have been developed since the mid-1990s, prompted by the interest of state water quality authorities in cost-effective approaches to TMDL compliance, encouraged and supported by EPA policy guidance and EPA and USDA technical and financial support. Most programs manage nutrients, especially phosphorous. A particularly noteworthy trading program outside the United States is the Lake Taupo nitrogen program in Waikato, New Zealand, which is the only trading program devoted exclusively to agricultural sources.

The most noted feature of WQT programs developed to date is the lack of trading activity. Most have had few if any trades, and there are no major success stories like those for air emissions trading. However, assessments indicate that in many instances these programs suffer from limited investment in the development of successful trading platforms, design flaws, and an absence of economic fundamentals needed to drive trades (Fisher-Vanden and Olmstead, 2013). Further, the CWA is itself a significant institutional barrier to efficient markets due to restrictions that prevent fully realizing potential gains from trade (Fisher-Vanden and Olmstead, 2013). But while there are no “great” successes in agricultural WQT, several programs suggest that the mechanism has potential as an element of better water quality policy (Shortle, 2013). Phosphorous trading programs on the Greater Miami River in Ohio and the South Nation River in Ontario, Canada, and the Lake Taupo nitrogen trading program in New Zealand are especially encouraging examples of WQT programs that include agriculture (Shortle, 2013). Taken together, these highly innovative programs demonstrate that carefully designed, context-sensitive markets can produce economically and environmentally beneficial trading activity (Shortle, 2013).

## Summary

Agriculture is a leading cause of remaining water quality problems in the United States. Efficiently managing the water quality impacts of agriculture is first and foremost a policy problem. Decades of research on relationships between farming systems and water quality and technologies to reduce agricultural nonpoint pollution provide the sector with a substantial technological toolkit for water quality protection. The policy challenge is to induce the implementation of the right practices in the right places (within fields and watersheds) to achieve water quality goals at least cost. The existing policy architecture relies excessively on voluntary implementation of controls by farmers, focuses on effort rather than outcomes, and allocates scarce resources inefficiently across places and sectors. Common-sense policy reforms identified in this article offer pathways to improve water quality and reduce the social costs of water pollution control.

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# Conservation Programs Can Accomplish More with Less by Improving Cost-Effectiveness

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The U.S. Department of Agriculture (USDA) has a long history of supporting the adoption of conservation practices, mostly through conservation programs that provide both financial and technical assistance to farmers for addressing water quality and other resource-related issues on farms. After substantial increases in conservation funding under the 2002 and 2008 Farm Acts, funding held steady under the 2014 Farm Act, and increases are not anticipated in the near future.

Regardless of future conservation program budgets, cost-effectiveness is an important determinant of how much conservation programs actually accomplish in terms of environmental services. A program is cost-effective when payments go to farmers to support practices that deliver the largest environmental gain relative to adoption and maintenance cost. The more cost-effective a program is, the greater the benefits from a given budget. Research suggests that the cost-effectiveness of conservation programs can vary widely depending on how much is paid to which farmers for taking what actions (Shortle et al., 2012). Given that most USDA conservation programs are subject to budget constraints, the environmental gain that a program can leverage is maximized when payments are just large enough to encourage adoption by those farmers who can provide the greatest environmental benefits at least cost.

The challenge is to improve cost-effectiveness within the current structure of the USDA's suite of conservation programs, which includes the Environmental Quality Incentives Program (EQIP), Conservation Stewardship Program (CSP), Regional Conservation Partners Program (RCPP), Conservation Reserve Program (CRP), Agricultural Conservation Easement Program (ACEP), and Conservation Technical Assistance (CTA). These programs are voluntary, relying on farmers to approach the USDA to enroll and to choose which resource issues to address. Most of these programs employ a benefit-based ranking procedure based on some type of benefit-cost scoring. The Environmental Benefits Index (EBI) of the CRP is an example. However, the specifics vary by program and even within programs, as states or even counties can establish their own ranking procedures for addressing self-identified resource priorities. The U.S. General Accounting Office has recently concluded that EQIP funds are not being targeted to resource issues where they are needed most (U.S. Government Accountability Office, 2017).

We use water quality to frame the discussion of improving program cost-effectiveness. In general, water quality is still impaired in places where agricultural nonpoint pollution is the dominant source. While programs have helped many farmers adopt conservation measures that produce a variety of ecosystem services, the concentration of best practices necessary for improving water quality in impaired watersheds has generally not occurred through voluntary programs alone (Kling, 2011; Osmond et al., 2012; Shortle et al., 2012).

One of the challenges for improving cost-effectiveness is that the interface between agriculture and the environment is extensive and heterogeneous (Nowak, Bowen, and Cabot, 2006). Thousands of individual resources—including rivers and streams, wetlands, lakes, estuaries, and groundwater—can be affected by agricultural production. The benefits associated with increasing the supply of ecosystem services vary widely. The environmental effect of individual farms (even individual fields) may vary widely depending on the mix of crop and livestock commodities produced, topography, soils, landscape position, and the specific production and conservation practices already in use.

A number of policy design features could potentially be implemented with current conservation programs. Some have been used on a small scale or in a single program, and others have been proposed for past Farm Bills.

## Targeting

Focusing conservation efforts to regions with high levels of impairments (potentially high benefits), fields within watersheds that contribute a disproportionate amount of pollutants, and practices that tend to be most cost-effective in reducing pollution would be a formula for increasing the overall cost-effectiveness of a program (Babcock et al., 1997). In many cases, the confluence of vulnerable resources and environmentally risky practices produces situations in which a large share of pollution originates on a relatively small number of farms and fields (Ribaudo, 1989; Nowak, Bowen, and Cabot, 2006; Diebel et al., 2008). In the Mississippi River Basin, for example, 10% of cropland is estimated to contribute 30% of the entire nitrogen load from cultivated cropland to the Gulf of Mexico (White et al., 2014). It would seem that targeting these settings would enhance program cost-effectiveness.

Geographic targeting of impaired watersheds to address water quality issues has been a staple of USDA conservation efforts for many years. The Rural Clean Waters Program (1980s) and the President's Water Quality Initiative (1990s) are two examples. Effective targeting requires that monitoring data, models, or other measurement tools identify those particular settings where large environmental gains can be attained at relatively low cost. From a cost-effectiveness standpoint, successful targeting also requires the most cost-effective practices to be employed on those farms that can reduce pollutants at the lowest cost. Achieving this is much more difficult when programs are voluntary, however. Farmers who can provide the most cost-effective control may not enroll in programs or may want to address other issues on their farms that more directly affect their net returns.

Collecting the information necessary to effectively target conservation entails costs for program agencies. Such costs are important to consider when evaluating the overall benefits of a targeting program.

## Additionality

Improvements in environmental quality can be attributed to conservation payments only if farmers would not have adopted the practice without the payment. Such practices are said to be additional. Additionality depends on the characteristics of conservation practices. Practices with high adoption costs relative to private benefits (directly realized by the farmer) or those that are difficult to reverse are more likely to be additional (require conservation payment to be adopted) than practices with high private benefits relative to adoption costs (Claassen, Duquette, and Smith, 2017). Conservation tillage is an example of a practice with generally high private benefits that many farmers have adopted without any financial assistance from government programs. Providing financial assistance for conservation tillage when it would have been adopted anyway could reduce overall program efficiency. On the other hand, structural and off-field practices such as fencing, terraces, and vegetative buffers have high implementation costs and/or low private benefits. Such practices have been found to be mostly additional (Claassen, Duquette, and Smith, 2017).

The cost-effectiveness of existing conservation programs could be improved if information on additionality were considered in determining eligibility for financial support and support rates. Predicting which farmers need assistance to adopt a practice and which do not is difficult due to asymmetric information, differences in local resource conditions, and differences in farmer ability and attitude toward environmental protection. One approach could be to establish a practice baseline in a region that reflects local non-additional practices (practices farmers tend to adopt on their own). Practices eligible for financial assistance could be limited to those believed to be most additional.

Potential benefits of additional and non-additional practices could be considered along with the costs. It is possible that a practice that tends to be non-additional generates much higher environmental benefits than a practice that is clearly additional. Supporting a high-benefit non-additional practice with cost shares may actually be more cost-effective (Claassen, Duquette, and Smith, 2017).

## Auctions

When farmers have more information about practice implementation costs than the buyers (asymmetric information), the potential exists for them to receive a payment in excess of what is actually needed when a single "price" is offered for the adoption of that practice. This reduces overall program cost-effectiveness. Auctions are a mechanism that can counter this behavior. When there is one buyer (USDA) and many sellers (farmers), auctions can facilitate competition between participants that can improve cost-effectiveness (Hellerstein, Higgins, and Roberts, 2015).

Specifically, farmers simultaneously offer (or "competitively bid") a level of performance (components in a contract) and their required level of compensation. The managing agency then selects the offers that provide the most environmental benefit at least cost until the budget or acreage goal is exhausted. Farmers who seek "excessive profit" from their offer risk being outcompeted by other bidders. Accordingly, farmers have an incentive to make an offer that is closer to their willingness to accept (generally an amount that just covers costs) than they might otherwise, thus increasing their chances of being awarded a contract. For auctions to be effective, costs and benefits of ecosystem services should vary across potential participants and there should be enough potential sellers to spur competition (increasing the likelihood that high bids will not be accepted).

Auctions have been successfully used in the general sign-up of the Conservation Reserve Program. In EQIP, bidding down (taking a lower cost-share) is forbidden by Congress, due to concerns that small or resource-limited farmers cannot compete with larger farms (based on experience when bidding down was allowed). The only option for competing would be in terms of the level of environmental services that could be provided. A bundle of practices with high environmental benefits would be accepted before a contract with the same cost but with lower environmental benefits. This type of bidding also increases cost-effectiveness, although maybe not to the degree it would if costs were also biddable.

## Performance-Based Payments

Even with design features such as targeting and auctions to promote cost-effectiveness, there is still the issue of attracting into the program those farmers who can provide the most environmental gain at the least cost. For example, if farmers who can provide the most pollution reduction at the lowest cost do not apply for a contract in a program that uses an auction, then an opportunity for getting the most out of program resources is lost. Without adequate compensation, farmers motivated by profit likely have little incentive to voluntarily undertake actions that provide few benefits to them (Claassen, Cattaneo, and Johansson, 2008). One way to address this issue is to base financial assistance on performance rather than on a portion of implementation cost.

In general, paying for performance (e.g., amount of nutrient loss reduced) is more cost-effective than basing payments on practice costs (Ribaudo, Horan, and Smith, 1999; Ferraro and Simpson, 2002; Savage and Ribaudo, 2016). Importantly, those farmers who can provide the most abatement at the lowest cost have the largest economic incentive to act. This means that farmers who may not have traditionally participated in conservation programs might have a strong incentive to do so. In addition, performance-based payments could provide greater flexibility in how a particular environmental service is produced. Practice-based payments tend to limit choice to those practices that are cost-shared, while performance-based policies award innovations that lower costs. Savage and Ribaudo (2016) estimated that payments based on nutrient reductions in the Chesapeake Bay Watershed would achieve a water quality goal at a much lower cost than payments based on practice costs, even with targeting. Field-level measurement tools for estimating environmental performance are needed with performance-based policies. Such tools, including the NRCS's Nutrient Tracking Tool, are being developed and are currently being used in water quality trading (a pay-for-performance policy) and other programs.

## Compliance Incentives

Another way to motivate farmers with the potential to provide high levels of pollutant reduction is to expand USDA compliance provisions to cover nutrient management. Compliance provisions require farmers to meet some minimum standard of environmental protection on environmentally sensitive land as a condition for eligibility for many federal farm program benefits, including conservation and commodity program payments, crop insurance subsidies, and disaster payments. Under current compliance requirements, farm program benefits could be denied to producers who fail to implement and maintain an approved soil conservation system on highly erodible land, convert highly erodible grasslands to crop production without applying an approved soil conservation system, or convert a wetland to crop production. Proposals have been made to require the development and implementation of a nutrient management plan to receive program benefits.

Compliance creates an incentive for farmers benefitting from USDA programs to take stock of their management choices and to make changes if the costs of implementing conservation systems are less than the potential loss of program benefits. An analysis of a hypothetical nutrient compliance policy found that farms that receive the most program benefits per acre also tend to have the highest excess nitrogen application rates (nitrogen supplied relative to crop need) (Ribaudo, Key, and Sneeringer, 2016). A nutrient compliance policy would therefore produce an incentive for farms with the greatest risk of nitrogen loss to at least consider developing a nutrient management plan and to possibly seek assistance from conservation programs or other service providers. A caveat is that the farmer must have an expectation that the provision will be enforced. The cost to the government of such a provision would likely be relatively small (primarily enforcement) and could have significant benefit.

## Community Conservation

Another approach would be to work directly on strengthening stewardship values in farmers through extension and outreach. “Community conservation” engages all farmers in an impaired watershed to work on solutions in a group setting. Community recognition of environmental performance and the demonstration of innovativeness and entrepreneurship in managing a farm could increase conservation-oriented thinking on the part of those who were traditionally motivated primarily by profit (Burton, Kuczera, and Schwarz, 2008; Reimer, Thompson, and Prokopy, 2012). McGuire, Morton, and Cast (2013) found that ownership of the environmental impairment issue, collaborative development of mitigation efforts, and group celebration of project successes led to leadership development and increased commitment in environmental efforts in an Iowa watershed. Neighbor-to-neighbor exchange, rather than traditional extension, was the most important source of information. Peer pressure could become a strong incentive to adopt conservation measures consistent with the community’s conservation goal.

## Summary

Investments in targeting and measurement tools, technical assistance and outreach, and research on policy design may improve the cost-effectiveness of delivering improved environmental quality through conservation programs. Weighing the costs of such investments against the potential long-term economic gains of improved program cost-effectiveness can help chart a course of action.

## For More Information

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