



AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

On optimal placement of best management practices in agricultural watersheds

Lyubov A. Kurkalova

Professor
Departments of Economics and Energy & Environmental Systems
North Carolina Agricultural & Technical State University
1601 E. Market St.
Greensboro, NC 27411
(336) 285-3348
Email: lakurkal@ncat.edu

*Selected Paper prepared for presentation at the Agricultural & Applied Economics Association's
2014 AAEA Annual Meeting, Minneapolis, MN, July 27-29, 2014.*

*Copyright 2014 by L.A. Kurkalova. All rights reserved. Readers may make verbatim copies of
this document for non-commercial purposes by any means, provided this copyright notice
appears on all such copies.*

ABSTRACT

This article presents analysis and synthesis of findings concerning the problem of cost-effective placement of best management practices (BMPs) emerging from NIFA CEAP and the USDA NRCS jointly-funded competitive grant projects, and future research needs. The synthesis focuses on two fundamental aspects of the cost-effectiveness problem: (1) how to assess the location- and farmer-specific costs of BMP implementation, and (2) how to decide on which BMPs need to be implemented and where within a given watershed so that a given water quality goal is achieved with the lowest possible policy outlay or a given conservation policy budget results in the best possible water quality improvement. We find that data availability remains a significant limiting factor for capturing within-watershed variability in the costs. Evolutionary algorithms have shown to provide workable ways to identify cost-effective BMP placement even for large, diverse watersheds and large numbers of potential BMPs. Future research needs include furthering the investigation, both conceptually and empirically, of the impact of the uncertainty in the BMP costs and water quality improvement benefits within the cost-effectiveness problem, and the development of the models that could consistently integrate the estimates of BMP cost components developed using alternative modeling approaches and/or attained under alternative economic conditions and for alternative geographic regions.

KEY TERMS

BMPs, Watershed management, Water quality economics, Optimization, Cost-effective BMP placement, Costs of BMPs

INTRODUCTION

Agricultural production is prone to generating nonpoint source pollution such as nutrient and pesticide runoff, erosion, and leaching which, most of the time, cannot be directly observed. Curbing and preventing water quality problems associated with nonpoint sources remain one of the imposing policy challenges faced by agriculture (Ogg and Keith, 2002, Claassen, 2009, Lichtenberg *et al.*, 2010). Most water pollution reduction programs in the U.S. targeted at agriculture are voluntary in that they offer financial and technical assistance to land operators for the adoption and use of cropland conservation and land management practices, commonly referred to as the Best Management Practices (BMPs). Designing the programs in a cost-effective way, i.e., focusing limited program resources on the farmers and the BMPs that provide the most water quality improvement per program dollar is becoming an ever more important practical issue with the conservation budgets being increasingly tightened at local, state, and federal levels (Shortle *et al.*, 2012). The growing attention to cost-effectiveness of achieving water quality improvements is exemplified by the recent interest in water quality trading that involves nonpoint sources (see, for example, the Featured Collection in the February 2011 issue of the *Journal of the American Water Resources Association*, Vol. 47, No.1). Although water quality trading and other alternatives that combine regulatory and voluntary approaches to agricultural pollution have been actively discussed and promoted by different government agencies (Ogg and Keith, 2002), voluntary programs relying on BMP payments remain the backbone of pollution control policies in U.S. agricultural-dominated watersheds (Claassen, 2009, Kling, 2011).

A standard approach to cost-effective policy (e.g., Babcock *et al.*, 1996) assumes that a conservation planner, such as a government agency or a non-profit group, has set aside a certain

amount of funding for a conservation program aimed to increase the adoption of BMPs in a watershed by selectively offering payments to farmers in the watershed in exchange for the adoption of BMPs. A further assumption is that farmers will adopt the BMPs if and only if the payments offered by the planner are equal to or exceed the opportunity costs of adopting the BMPs. An important question then is how to prioritize these payments in the watershed. In other words, which BMPs on which tracts of land should receive payments so that society gets the best water quality improvement possible given the program's budget? In standard economics terminology (see, e.g., Tietenberg, 2011), the allocation of funds and the corresponding placement of BMPs in the watershed achieved through such a program is called cost-effective, if maximum water quality improvement is achieved within the program budget.

The problem of designing and implementing cost-effective conservation programs remains a daunting task for a number of reasons, including the high costs associated with the policy maker's need to know location-specific benefits and costs of the BMPs (Horan and Shortle, 2011). The costs of BMP implementation are commonly farm-specific and reflect not only the natural farming conditions such as soil type, landscape, and weather, but also the personal values and attitudes towards profits, risks, and the environment, which may vary significantly among farm operators (Gelso *et al.*, 2008; Prokopy *et al.*, 2008). Pollution emissions from agricultural fields are largely unobservable and stochastic due to weather events that affect the fate and transport of pollutants via runoff or leachate from rain or melting snow. Further complicating the problem, the effectiveness of various BMPs for controlling water pollution is not fully understood as it varies with landscape, soil type, topography, climatic factors, cropping patterns, and farming practices (Rittenburg *et al.*, this issue).

To improve the understanding of how to optimally locate and sequence the placement of BMPs within a watershed to achieve water quality improvement goals, the National Institute of Food and Agriculture¹ – Conservation Effects Assessment Project (NIFA - CEAP) and the USDA Natural Resources Conservation Service (NRCS) jointly funded 13 competitive grant projects across the U.S. to investigate the linkages between various BMPs, and the resulting effects on water quality. The projects were competitively awarded in 2004-06 among the watersheds that had large, long-term data sets available at the time of application (Table 1). The fundamental goals of most of these projects, referred to as CEAP projects in this article, included the exploration of the economic and social factors related to adoption and proper maintenance of conservation practices, and identification of optimal placements of practices within the watersheds (Duriancik *et al.*, 2008).

A number of studies have summed up the various CEAP projects' results: NRCS (2004), Duriancik *et al.* (2008), the special November/December 2010 issue 65(6) of the *Journal of Soil and Water Conservation* dedicated to the CEAP competitive grant watershed projects, and Osmond *et al.* (2012a,b). Several CEAP projects' lessons related to economic and social factors affecting adoption and use of BMPs were summarized by Hoag *et al.* (2012). These authors noticed that the chances of BMP adoption increase if, among other things, the results of the implementation are visible on the farm, support for implementation is available from local, trusted networks of other farmers, conservation professionals, and agribusinesses, and when farmers feel that they are in control of BMP implementation. One of the major findings by Hoag *et al.* (2012) is that in most instances BMPs would not be adopted if the farmers' costs of implementation were not equal to or exceeded by the financial benefits coming from the changed farm profitability and/or cost share and other monetary incentives. Building on this observation,

¹ Formerly the Cooperative State, Research, Education, and Extension Service

and supplementing the Hoag *et al.* (2012) study's focus on individual producers, this article synthesizes the findings of the CEAP projects related to the optimal placement of BMPs within the watersheds. Therefore, this article presents analysis and synthesis of findings concerning the problem of cost-effective placement of BMPs emerging from the collective CEAP project experience, and identifies future research needs. The synthesis focuses on two fundamental aspects of the cost-effectiveness problem: (1) how to assess the location- and farmer-specific costs of BMP implementation, and (2) how to decide which BMPs need to be implemented and where within a given watershed so that a given water quality goal is achieved with the lowest possible policy outlay or a given conservation policy budget.

The article is organized as follows. After presentation of a formal set up of the cost-effective placement problem, the major concepts used throughout the study are explained, and the sources of information for the study are detailed. Next, the lessons learned from the CEAP studies concerning the costs of BMPs and the identification of cost-effective practice placements are presented. The last section summarizes and identifies future research needs.

COST-EFFECTIVE CONSERVATION PROGRAM

To formally introduce the concept of a cost-effective conservation program, assume that a watershed is divided into S sites (tracts of land) indexed by s , on each of which P alternative, mutually exclusive BMPs (or suites of BMPs) indexed by p could be implemented. Let l_s be the size of site s in m^2 , and B be the total water quality benefit of implementing the BMPs in the watershed, such as the reduction in a nutrient loading at the watershed outlet. The benefit is assumed to be a function of watershed characteristics and, importantly, of land areas x_{sp} devoted

to BMPs p , $p = 1, \dots, P$, on sites s , $s = 1, \dots, S$. We will refer to the sets x_{11}, \dots, x_{SP} as

conservation plans or BMP placements. By definition, $\sum_p x_{sp} \leq l_s$ for all $s = 1, \dots, S$.

Let c_{sp} be the per m^2 cost of practice p on site s . Then the total cost of a conservation plan is given by $\sum_{s,p} c_{sp} x_{sp}$. Ideally, the conservation planner would place the BMPs so that the total benefit – water quality – is maximized and the cost – the total cost of implementing the BMPs – is minimized. Therefore, two interrelated problems are considered - maximizing water quality subject to a given cost constraint, C_0 , or the counterpart problem of minimizing the cost of achieving a given water quality target, B_0 . Both problems are referred to as cost-effectiveness problems in environmental economics (see, e.g., Tietenberg, 2011). The first problem is formally stated as

$$\underset{x_{11}, \dots, x_{SP}}{\text{Max}} B(x_{11}, \dots, x_{SP}) \quad \text{s.t.} \quad \sum_{s,p} c_{sp} x_{sp} \leq C_0, \quad \sum_p x_{sp} \leq l_s, \quad (1)$$

and the second problem is stated as

$$\underset{x_{11}, \dots, x_{SP}}{\text{Min}} \sum_{s,p} c_{sp} x_{sp} \quad \text{s.t.} \quad B(x_{11}, \dots, x_{SP}) \geq B_0, \quad \sum_p x_{sp} \leq l_s. \quad (2)$$

Equations (1) and (2) are referred to as cost-effectiveness analysis (CEA). The placement of BMPs $x_{11}^*, \dots, x_{SP}^*$ that provides a solution to the CEA is Pareto-optimal, i.e.,

$$B(x_{11}, \dots, x_{SP}) \leq B(x_{11}^*, \dots, x_{SP}^*) \quad \text{and} \quad \sum_{s,p} c_{sp} x_{sp} \geq \sum_{s,p} c_{sp} x_{sp}^* \quad \text{for all possible BMP placements } x_{11}, \dots, x_{SP}.$$

When Equation (1) is solved for multiple values of C_0 , then the functional relationship, called the Pareto frontier, can be constructed. The Pareto frontier illustrates the trade-offs amongst the two competing objectives, the maximum water quality benefit and the minimum cost of achieving it. The same frontier could be derived by solving Equation (2) for multiple values of

B_0 . The shape and the range of the Pareto frontier provide valuable information for policy makers concerning the potential consequences of funding a conservation program at alternative levels.

Throughout this article we assume that the function/water quality model $B(x_{11}, \dots, x_{SP})$ is known. Admittedly, developing the understanding of the function $B(x_{11}, \dots, x_{SP})$ is a tremendous task by itself, and many CEAP studies used a variety of techniques to develop, improve, and/or calibrate the water quality models in their respective study watersheds. The discussion below concentrates on the economics side of the CEA epitomized in the evaluation of BMP costs and finding optimal BMP placements.

In the case of $P = 1$ and the water quality function being additively separable across sites, i.e., represented by the sum of the site-specific functions each one of which is independent of the other sites' BMPs, $B(x_{11}, \dots, x_{S1}) = \sum_s b_{s1} x_{s1}$, where b_{s1} , $s = 1, \dots, S$, are known constants, the solution to Equation (1) can be found simply using the following intuitive procedure (e.g., Babcock *et al.*, 1996): rank-order all sites by the benefit-to-cost ratio b_{s1} / c_{s1} from the highest to the lowest, and place the BMP on the sites consecutively from the top of the list until the total program budget C_0 is exhausted. Linear programming or calculus-based constrained optimization techniques provide solutions to the CEA when $P > 1$.

Most CEAP projects incorporated more realistic water quality functions (i.e., complex water quality models) that typically greatly complicate the identification of cost-effective BMP placement. If one could estimate the benefits and costs of all potential BMP placements, solving the CEA problem would be simple. However, in reality, such an approach is rarely feasible because of the combinatorial number of the placements to evaluate. One remedy in this case has

been in replacing the CEA problem with a benefit-cost analysis (BCA). The BCA in this setting is the problem of evaluating the costs, water quality benefits, and, sometimes, measures of variation in costs and/or benefits, for a predetermined set of BMP placements, usually referred to as scenarios. The scenarios are often chosen based on external information such as expert opinion or planner and/or farmers' preferences. The comparison of the scenarios using a set of metrics may or may not lead to a clear ranking of the scenarios. Nevertheless, BCA commonly provides very valuable information for further analysis and discussion.

Several CEAP teams embraced another, recently introduced remedy for the CEA in the case of large P and a realistic water quality function— the use of evolutionary algorithms (EAs). More details on these optimization tools that provide a systematic way for searching through large choice sets are discussed below.

SOURCES OF INFORMATION ABOUT THE CEAP PROJECTS

Data used for analysis in this study were shared by the CEAP project teams during watershed site visits that occurred near the completion of each CEAP project. Additional data were gathered by reviewing the final project results available at the USDA's Current Research Information System web page

(http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/nra/ceap/?&cid=nrcs143_014164, accessed April 2014). When needed, the major agricultural economics database AgEcon (<http://ageconsearch.umn.edu> , accessed April 2014) was checked for reports, conference papers, and similar publications. For the sake of brevity, the individual CEAP projects are referred to by the abbreviated name of the state in which the study watershed is located. NE CEAP and OH

CEAP did not have economics components. Brief summaries of the CEAP economics studies referenced in this article are provided in the Appendix and in Osmond *et al.* (2012a).

RESULTS AND DISCUSSION

Various versions of the BMP cost evaluations, BCAs and/or CEAs were incorporated in the majority of the CEAP projects (Table 1). Our discussion proceeds from the synthesis of the CEAP project findings relating to the costs of BMPs to the lessons learned concerning the identification of the economically optimal BMP placements.

Costs

The concept of BMP cost. The notion of cost is well developed in economic theory, but the concept is much harder to capture empirically. Equations (1) and (2) require estimates of opportunity costs c_{sp} of BMPs, i.e., the estimates of what farmers *need to give up* to install and maintain BMPs. The distinction of who bears the cost (farmer, society as a whole/taxpayers through government subsidized programs, taxpayers in a certain state if a program is subsidized by the state, etc.) is of secondary, yet still significant, importance. The greatest difficulty with estimating costs empirically is that most of the time the BMP costs are location-, time -, and farmer-specific. Therefore, BMP costs can be affected by changing economic conditions, policies, education, location, and outreach programs (Pannell *et al.*, 2006).

Based on the relative ease of estimation in dollar terms, the present discussion distinguishes between two generic components of the overall costs, explicit and implicit. Explicit costs include estimates based on corresponding engineering specifications, such as installation and maintenance costs. These costs are commonly labeled “engineering” in economic assessments (e.g., Lubowski *et al.*, 2006). Explicit costs also include the opportunity cost of the land taken

out of production that could be measured via the corresponding foregone production net returns (economic benefits minus costs).

In contrast, implicit costs are much harder to express in dollar terms. Implicit costs include those stemming from the hesitancy of a farmer to make irreversible investments in the face of uncertainty and the desire to retain options for future land-use decisions (Schatzki, 2003). An aversion to risk may mean that farmers would not change the current, known practices to the new ones even if the expected net returns are greater, but there is perceived or true uncertainty about the net returns (Parks, 1995). The cost of learning about an unfamiliar BMP is also an implicit cost (Pannell *et al.*, 2006). Depending on the farmer's socio-economic characteristics such as age, education, income, involvement in local affairs, etc., and the BMP in question, the cost of learning could be as low as spending an hour on the extension website or as high as dedicating a tract of land to try the practice for several years without the expectation of immediate economic returns. Empirically, the impact of a factor contributing to the implicit costs is commonly quantified via statistical models which predict how much the probability of the BMP adoption changes with the change in the variable representing the factor (Soule *et al.*, 2000; Prokopy *et al.*, 2008).

CEAP studies of BMP costs. Most CEAP studies attained BMP cost estimates, and many analyzed the explicit and implicit components (Table 1). The estimates have been developed for barnyard improvements and riparian buffers (NY CEAP); varying versions of conservation tillage (KS CEAP); cropland protection, conservation tillage, contour farming, conversion to forest, conversion to wetland, nutrient management, terraces and diversions, vegetative buffers, waste management, runoff control (IN CEAP); grassed waterways (MO CEAP); suites of BMPs which included optimal grazing and a buffer and differing poultry litter application rates, timing,

and litter characteristics (AR CEAP); terraces and grassed waterways (GA CEAP); tillage practices, land retirement, gully plugs and buffer strips (ID CEAP); and BMP suites which included alternative conservation tillage systems, contour farming, grassed waterways, terraces, reduction in nitrogen fertilizer applications, and land retirement (IA CEAP).

Several important lessons emerge from the projects' experiences. The first and perhaps most significant lesson is that developing cost data is costly. Most studies spent significant resources on attaining the estimates, as there is no nation-wide source of cost data presently available to researchers or conservation planners. Although state-average engineering costs in general are accessible via the cost-share rules and protocols employed by NRCS, these were of limited use for the studies that needed to capture within-watershed cost variability for watersheds that were contained in their entirety within the corresponding state's boundaries. Developing regional or even nation-wide BMP cost databases would be welcomed by both the research and policy communities as such data would significantly reduce the resources needed for future CEA studies and assessments.

A second lesson is that local farmer and conservation community connections matter. The projects that were successful in developing location-specific estimates had consistently strong and trusting connections with farmers, local NRCS personnel, Soil and Water Conservation Districts, and local farmer organizations.

A third lesson is that reporting detailed cost component data facilitates the transferability of estimates. Most of the projects that attained cost estimates provided detailed descriptions of the data construction. Several projects went further and documented components of the explicit costs. For example, the MO CEAP (Intrapamong *et al.*, 2008) provided detailed information on the cost computation formulas together with production input price data that went into estimation

of net returns with and without grassed waterways. Such detailed data descriptions allow estimation of similar BMP costs at other time periods when, for example, crop, fertilizer, or energy prices change. While the dependency of the BMP costs on location and topography has been recognized for a long time (e.g., Lichtenberg *et al.*, 2010), the dependency on crop and production input prices has drawn the researchers' attention only recently. Notably, Reimer *et al.* (2012b) comments that farmers surveyed about the use of BMPs in the IN CEAP watershed mentioned the changes in crop prices and production inputs among the factors influencing the decisions on BMP adoption.

The NY CEAP (Rao *et al.*, 2012) reported the costs broken down into installation, maintenance, and loss of income due to the land taken out of production. In absence of otherwise good estimates, one can transfer the NY BMP costs to other locations by using, if applicable, the same installation costs, adjusting the maintenance costs in accordance with the local wages and/or fuel prices, and adjusting the opportunity cost of land removed from production upward or downward depending on whether the land in question is more or less productive than that studied in Rao *et al.* (2012).

Another argument for careful consideration of the various components of BMP costs is implied by the findings of the ID CEAP (Tosakana *et al.*, 2010). Their survey of over 1,500 farmers in the Northwest found that the surveyed farmers viewed maintenance costs of gully plugs and buffer strips as more important than the corresponding installation costs. This finding on importance of maintenance costs is echoed in the UT CEAP study Jackson-Smith *et al.* (2010) which estimated that a sizable proportion of BMPs may not be properly maintained. It remains to be investigated how transferable these findings are to other geographic regions and/or long-term BMP. However, if the perception of greater importance of maintenance versus installation costs

turns out to be wide-spread, the two cost components may need to be treated differently by conservation program planners for the programs to be designed cost-effectively.

A fourth lesson is that implicit costs vary significantly across space and farmers. The IN CEAP (Prokopy *et al.*, 2008) synthesized fifty-five recent studies on the determinants of BMP adoption that impact the implicit, farm- and farmer-specific costs. Using the vote count methodology, the study identified important farmer characteristics reflecting capacity, attitudes, and environmental awareness, as well as farm characteristics that were consistently found to impact adoption of BMPs.

A relatively little studied aspect of implicit costs, relating to farmers' perceptions, has been accentuated in several CEAP studies. The results of PA CEAP (Armstrong *et al.*, 2012) suggest that stream flow regularity affects landowners' perceptions and attitudes concerning water quality problems. IN CEAP study Reimer *et al.* (2012b) investigated the relationship between farmers' perceptions about BMPs characteristics and adoption, with a focus on four BMPs (cover crops, conservation tillage, grassed waterways and filter strips). The perceived relative economic and other personal advantage, compatibility with existing farming practices, and observability of either practice or its results were found to be most important in increasing the adoption of the BMPs in the study watershed.

The UT CEAP (Jackson-Smith and McEvoy, 2011) investigation of lasting impacts of different extension approaches underscored the long-term nature of both farmers' learning about water quality problems and the BMP adoption process in general. While the time dimension of the water quality modeling, function $B(x_{11}, \dots, x_{sp})$ in the present discussion, has been recognized widely, the changing magnitudes of BMP costs due to improved knowledge about the practices

and environmental awareness have not been considered explicitly in the CEA analyses, and are yet to be incorporated in future modeling.

BMP placement assessments

Three projects, NY CEAP (Rao *et al.*, 2012), KS CEAP (Langemeier *et al.*, 2010), and AR CEAP (Rodriguez *et al.*, 2011a) conducted the BCAs for 7, 6, and 10 scenarios, respectively. The water quality effects were modeled using the Variable Source Loading Function model (Schneiderman *et al.*, 2007) in the NY CEAP, and the Soil and Water Assessment Tool model (SWAT) (Arnold *et al.*, 1998; Arnold and Forher, 2005) in the KS CEAP and the AR CEAP BCAs.

Four projects carried out CEAs. IN CEAP (Oliver, 2008) conducted a CEA using the additively separable water quality functions derived from the BMP effectiveness estimates reported in various sources. ID CEAP (Tosakana *et al.*, 2007) used the Water Erosion Prediction Project model (Flanagan and Nearing, 1995; Flanagan *et al.*, 2007) for a CEA by applying a “brute force” approach of evaluating all possible combinations of placements of 4 BMPs on a relatively small number of land tracts in a watershed. The AR CEAP (Rodriguez *et al.*, 2011b) and IA CEAP (Rabotyagov *et al.*, 2010a,b) used the EAs in combination with SWAT to derive Pareto optimal frontiers.

The first important finding concerning the optimal placement of BMPs is that evolutionary algorithms provide viable means for identifying cost-effective policies. The EAs are stochastic optimization tools that provide methodological ways to search through large numbers of possibilities by attempting to mimic the process of biological evolution. The EAs have only recently begun to be applied to integrated watershed modeling systems (Srivastava *et al.*, 2002;

Veith *et al.*, 2003). The OR CEAP (Whittaker *et al.*, 2009) suggested a novel hybrid genetic algorithm for derivation of Pareto frontiers. The empirical assessments of the AR CEAP and IA CEAP showed that solving for cost-effective BMP placement in a reasonable amount of time is indeed possible even with a large number of BMPs and in a watershed divided into a realistically large number of sites. Rodriguez *et al.* (2011b) applied the EAs for identification of the cost-effective placements of $P = 35$ BMPs on a total of $S = 461$ sites to derive two Pareto optimal frontiers. The Rabotyagov *et al.* (2010a, b) studies applied the EAs for the cases of $P = 32$ BMPs with the total number of tracts S as high as 1,312 to derive several Pareto frontiers.

A second finding is that the trade-offs between total conservation program costs and optimal water quality improvements achieved through targeted BMP placements could be large. For example, Rabotyagov *et al.* (2010b) used the Pareto frontiers derived to estimate the marginal abatement costs that could be interpreted as the cost of an additional water pollution reduction brought about by a conservation program, provided the BMPs are placed cost-effectively. Under 2005 land use conditions, these costs were estimated to increase from \$0.5 per kg of N for a 10% nitrate reduction goal to \$4.2 per kg of N for a 30% nitrate reduction goal to \$42.7 per kg of N for a 50% nitrate reduction goal for the study watershed. The study also found that as the nutrient reduction targets increase the optimal BMP mix shifts from mulch-till to suits that include no-till, grassed waterways, and terraces. These results have important implications for conservation policy design and implementation, suggesting that the sets of BMPs that are optimal under a given level of program funding may no longer be optimal under alternative levels of program funding.

A third finding is that careful identification of the appropriate baseline for a BCA or a CEA is necessary. The implicit assumption in the CEA Equations (1) – (2) is that in considering the

problem of placement of new BMPs, the conservation planner knows exactly the baseline, i.e., current land use that includes the BMPs that have already been installed. Several CEAP projects pointed to significant difficulties that may be encountered while determining the baseline. As with BMP costs, the projects that relied on long-term effective connections to the local farming and conservation community had less difficulty acquiring the needed baseline data. The UT CEAP (Jackson-Smith *et al.*, 2010) showed that caution must be exercised when relying on the formal USDA NRCS records for determining the current BMP use. The study also found the probability of maintenance of structural practices was greater than that of management practices in the study watershed.

The IA CEAP (Rabotyagov *et al.*, 2010b) pointed to the importance of identifying the baseline for the CEA by explicitly comparing the CEA outcomes under land use conditions: one corresponding to the 2005 snapshot of the study watershed, and the other - predicted under the futures crop prices that favor corn over soy and are expected to draw more marginal land from land retirement into intensive crop production. The impact of the alternative baseline was shown to be dramatic, as demonstrated by the changes in the shapes and the ranges of the Pareto frontiers estimated, total minimum costs of achieving nutrient reductions, and in the suites of BMPs that make up cost-effective placements.

A fourth important finding is that water quality and economic uncertainties alter the cost-effective BMP placements considerably and need to be explicitly considered. With a growing theoretical literature on economic risk and water quality protection in agriculture (see, e.g., Bosch and Pease, 2000), more empirical assessments are needed. Several CEAP studies contributed to closing this gap. The BCA conducted by the AR CEAP (Rodriguez *et al.*, 2011a) found that ranking of BMP scenarios differed considerably if the standard metrics of scenario

evaluation, total net returns (profits from production), and total reduction in phosphorus losses are supplemented with the measures of net return risks, where the risks originate from the impacts of the uncertain weather on Bermuda grass yields. The results of the study suggest that adding BMPs such as buffer zone and poultry litter applications to the current farming practices could increase the variability of net returns. As most economic agents prefer certain economic outcomes to uncertain ones, the findings of Rodriguez *et al.* (2011a) imply that traditional, explicit measures of costs may not capture the full opportunity costs of adopting BMPs, and the implicit costs related to risk aversion may be important in solving for cost-effective BMP placements.

A different aspect of uncertainty was the focus of the IA CEAP (Rabotyagov *et al.*, 2010a) that compared the Pareto frontiers constructed for two alternative water quality improvement metrics. In the construction of one frontier the water quality improvement targets were set in terms of the mean annual nitrogen loadings, while in the construction of the other frontier it was assumed that specified nitrogen loadings targets must be met under every potential weather realization. The study found the total cost of achieving weather-resilient solutions to be significantly greater, with the additional total cost increasing with the water quality improvement target. Similar to Rodriguez *et al.* (2011a), Rabotyagov *et al.* (2010a) pointed to a broader need for development of robust cost-effective policies that account for the inherently uncertain nature of the BMP effectiveness for controlling agricultural pollution.

CONCLUSIONS

Both conservation practitioners and water resource and economics literature continue emphasizing the need to design policies to address agricultural nonpoint source water pollution

in a cost-effective way. We have analyzed and synthesized the findings of the CEAP projects concerning two important aspects of such policy making, evaluation of BMP implementation costs, and the identification of cost-effective placements of BMPs within a given watershed. The CEAs conducted showed significant trade-offs between the total conservation program costs and water quality improvements achieved through optimal BMP placements. Evolutionary algorithms have demonstrated workable ways to identify cost-effective BMP placements even for large, diverse watersheds and large numbers of potential BMPs. This computational capacity opens up possibilities for conducting various previously unquantifiable assessments such as whether changes in the level of a conservation budget significantly affect which sets of practices would be most cost-effective and/or which geographic regions within the watershed are to be enrolled in the optimally designed program.

Our analysis suggests that while close contacts with farmers and local conservation specialists greatly facilitate the acquisition of land use, farming practices, and cost information, in general, data availability remains a significant limiting factor for capturing the within-watershed variability in BMP costs and for finding cost-effective BMP placements. A potential solution to this challenge may lay in encouraging the practice of detailing the BMP cost components explicitly in the literature or by other means. The detailed documentation would assist in transferability of existing BMP cost estimates to alternative geographic regions such as those that have different labor or land costs, and the adaptability of the estimates to alternative economic conditions such as changing energy or crop prices.

Another notable finding underscored by the collective experience of the CEAP projects is that both explicit and implicit costs matter. With the large and growing literature that identifies social, cultural and logistical barriers to the adoption of BMPs, a crucial, yet unanswered,

research question remains on how to consistently integrate the probabilistic functional relationships that describe the impact of farm and farmer characteristics on implicit costs with the models that conventionally evaluate the explicit costs in dollar terms.

The importance of developing reliable BMP cost estimates that capture the full heterogeneity in economic, human, and natural conditions extends well beyond the simplest form of the voluntary BMP payment policy considered in this article. Cost information is of crucial importance for the more elaborate policies exemplified by the Environmental Quality Incentives Program and the Conservation Security Program (Horan and Claassen, 2007). Furthermore, as Horan and Shortle (2011) demonstrated, regulators cannot construct cost-minimizing markets for water quality without knowing individual producers' pollution abatement costs.

ACKNOWLEDGMENTS

The author is grateful to the CEAP teams for sharing and candidly discussing the results of their projects during and after site visits. This study was funded through the USDA-NIFA Funded CEAP Synthesis Project NO: 2007-51130-03992.

REFERENCES

- Armstrong, A., R. C. Stedman, J. A. Bishop, P. J. Sullivan. 2012. What's a stream without water? Disproportionality in headwater regions impacting water quality. *Environ. Manage.* 50(5): 849-860.
- Arnold, J.G., and N. Fohrer. 2005. Current capabilities and research opportunities in applied watershed modeling. *Hydrological Processes* 19:563-572.

- Arnold, J.G., R. Srinivasan, R.S. Muttiah, and J.R. Williams. 1998. Large area hydrologic modeling and assessment part I: Model development. *Journal of American Water Resources Association* 34(1):73-89.
- Babcock, B.A., P.G. Lakshminarayan, J. Wu, D. Zilberman. 1996. The economics of a public fund for environmental amenities: a study of CRP contracts. *Amer. J. Agr. Econ.* 78: 961–971.
- Bosch, D.J, and J.W. Pease. 2000. Economic risk and water quality protection in agriculture. *Review of Agricultural Economics* 22(2): 438-463.
- Brooks, R.P., S.E. Yetter, R.F. Carline, J.S. Shortle, J.A. Bishop, H. Ingram, D.Weller, K. Boomer, R. Stedman, A. Armstrong, K. Mielcarek, G. Constanz, S. Goslee, T. Veith, D. Piechnik. 2011. Analysis of BMP implementation and performance and maintenance in Spring Creek, an agriculturally-influenced watershed in Pennsylvania. Final report to U. S. Department of Agriculture, National Institutes of Food and Agriculture, Conservation Effects' Assessment Project (CEAP), Washington, DC. 66pp.
- Claassen, R. 2009. Cost-effective conservation programs: the role of economics. *J. Soil Water Conserv.* 64(2): 53A-54A.
- Durancik, L.F., D. Bucks, J.P. Dobrowolski, T. Drewes, S.D. Eckles, L. Jolley, R.L. Kellog, D. Lund, J.R. Makuch, M.P. O'Neill, C.A. Rewa, M.R. Walbridge, R. Parry, and M.A. Weltz. 2008. The first five years of the Conservation Effects Assessment Project. *J. Soil Water Conserv.* 63(6): 185A-197A.
- Flanagan D.C., Nearing, M.A. (Eds). 1995. USDA–water erosion prediction project hillslope profile and watershed model documentation. NSERL Report No. 10, USDA–ARS National Soil Erosion Research Laboratory: West Lafayette, IN.

- Flanagan, D.C., Gilley, J.E., Franti, T.G., 2007. Water Erosion Prediction Project (WEPP): Development history, model capabilities, and future enhancements. *Trans. ASABE* 50(5), 1603-1612.
- Gelso, B.R., J.A. Fox, and J.M. Peterson. 2008. Farmers' perceived costs of wetlands: effects of wetland size, hydration, and dispersion. *Amer. J. Agr. Econ.* 90(1): 172-185.
- Hoag, D., A.E. Luloff, and D.L. Osmond. 2012. Lessons learned from the NIFA-CEAP: How farmers and ranchers make their decisions on conservation practices. NC State University, Raleigh, NC.
- Horan, R.D., and R. Claassen. 2007. Targeting green payments under a budget constraint. *Land Economics.* 83(3): 319-330.
- Horan, R.D., and J.S. Shortle. 2011. Economic and ecological rules for water quality trading. *J. Am. Water Resour. As.* 47(1): 59-69.
- Intarapapong, W., C. Baffaut, R. Broz, W. Kurtz, L. McCann, and S. Anderson. 2008. Goodwater Creek Watershed: Economic analysis of a representative farm. Departmental Report, 17 pp. Department of Soil, Environmental and Atmospheric Sciences, University of Missouri, Columbia, Missouri.
- Jackson-Smith, D.B., M. Halling, E. de la Hoz, J.P. McEvoy, and J.S. Horsburgh. 2010. Measuring conservation program best management practice implementation maintenance at the watershed scale. *J. Soil Water Conserv.* 65(6): 413-423.
- Jackson-Smith, D. and J. McEvoy. 2011. Assessing the long-term impacts of water quality outreach and education efforts on landowners in the Little Bear River watershed in northern Utah. *Journal of Agricultural Education and Extension* 17(4): 341-353.

- Jang, T., G. Vellidis, J.B. Hyman, E. Brooks, L.A. Kurkalova, J. Boll, and J. Cho. 2013. Model for prioritization best management practice implementation: Sediment load reduction. *Environmental Management*, 2013, 51: 209-224.
- Kling, C.L. 2011. Economic incentives to improve water quality in agricultural landscapes: some new variations on old ideas. *American J. Agric. Econ.* 93(2): 297-309.
- Langemeier, M.R., N. Nelson, P. Parajuli, and S. Perkins. 2010. An examination of the tradeoff between net return, risk, and water quality for crop rotation in South Central Kansas. Paper presented at the Southern Agricultural Economics Association Meeting, Orlando, FL, February 2010.
- Lichtenberg, E., J. Shortle, J. Wilen, and D. Zilberman. 2010. Natural resource economics and conservation: contributions of agricultural economics and agricultural economists. *American J. Agric. Econ.* 92(2): 469-486.
- Lubowski, R.N., A.J. Plantinga, and R.N. Stavins. 2006. Land-use change and carbonsinks: econometric estimation of the carbon sequestration supply function. *J. Environ. Econ. Management* 51: 135-152.
- NRCS, 2004 – CEAP projects fact sheet, web page address available one step from <http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/nra/ceap/ws/> (accessed April 2014)
- Ogg, C.W., and G.A. Keith. 2002. New federal support for priority watershed management needs. *J. Am. Water Resour. As.* 38(2): 577-586.
- Oliver, A.C. 2008. A Watershed-Scale Cost-Effectiveness Model of Agricultural Best Management Practices for Improving Water Quality. M.S. Thesis. Purdue University, West Lafayette, IN.

- Osmond, D.L., D.W. Meals, D.L.K. Hoag, and M. Arabi. 2012a. How to build better agricultural conservation programs to protect water quality: The National Institute of Food and Agriculture – Conservation Effects Assessment Project Experience. Soil and Water Conservation Society, Ankeny, Iowa.
- Osmond, D.L., D.W. Meals, D.L.K. Hoag, M. Arabi, A. Luloff, G. Jennings, M. McFarland, J. Spooner, A. Sharpley, and D. Line. 2012b. Improving conservation practices programming to protect water quality in agricultural watersheds: Lessons learned from the National Institute of Food and Agriculture – Conservation Effects Assessment Project. *J. Soil Water Conserv.* 67(5): 122A-127A.
- Pannell, D.J., G.R. Marshall, N. Barr, A. Curtis, F. Vanclay, and R. Wilkinson. 2006. Understanding and promoting adoption of conservation practices by rural landholders. *Australian J. Experimental Agric.* 46: 1407-1424.
- Parks, P. 1995. Explaining 'irrational' land use: risk aversion and marginal agricultural land, *J. Environ. Econ. Manage.* 28 (1): 34–47.
- Prokopy, L., K. Floress, D. Klotthor-Weinkauff, and A. Baumgart-Getz. 2008. Determinants of Agricultural BMP Adoption: Evidence from the Literature. *J. Soil Water Conserv.* 63(5): 300-311.
- Rabotyagov, S.S., M. Jha, and T.D. Campbell. 2010a. Nonpoint source pollution reduction for an Iowa watershed: an application of evolutionary algorithms. *Canadian Journal of Agricultural Economics* 58: 411-431.
- Rabotyagov, S.S., M. Jha, and T.D. Campbell. 2010b. Impact of crop rotations on optimal selection of conservation practices for water quality protection. *J. Soil Water Conserv.* 65(6): 369-380.

- Rao, N.S., Z.M. Easton, D.R. Lee, and T.S. Steenhuis. 2012. Economic analysis of best management practices to reduce watershed phosphorus losses. *J. Environ. Qual.* 41:855-864.
- Reimer, A.P., A.W. Thompson, and L.S. Prokopy. 2012a. The multi-dimensional nature of environmental attitudes among farmers in Indiana: implications for conservation adoption. *Agric. Hum. Values* 29: 29-40.
- Reimer, A.P., D.K. Weinauf, and L.S. Prokopy. 2012b. The influence of perceptions of practice characteristics: An examination of agricultural best management practice adoption in two Indiana watersheds. *J. Rural Studies* 28: 118-128.
- Rittenburg, R.A., A.L. Squires, J. Boll, E.S. Brooks, Z.M. Easton, T.S. Steenhuis. Present issue. Targeting BMPs for agricultural nonpoint source pollution: Concepts and a review. *J. Am. Water Resour. As.*
- Rodriguez, H.G., J. Popp, E. Gbur, and I. Chaubey. 2011a. Environmental and economic impacts of reducing total phosphorus runoff in an agricultural watershed. *Agricultural Systems* 104: 623-633.
- Rodriguez, H.G., J. Popp, C. Maringanti, and I. Chaubey. 2011b. Selection and placement of best management practices used to reduce water quality degradation in Lincoln Lake watershed. *Water Resources Research* 47.
- Schatzki, T. 2003. Options, uncertainty, and sunk costs: an empirical analysis of land use change, *J. Environ. Econ. Manage.* 46 (1): 86-105.
- Schneiderman, E.M., T.S. Steenhuis, D.J. Thongs, Z.M. Easton, M.S. Zion, G.F. Mendoza, M.T. Walter, and A.C. Neal. 2007. Incorporating variable source area hydrology into curve number based watershed loading functions. *Hydrol. Processes* 21:3420-3430.

- Shortle, J., M. Ribaud, R. Horan, and D. Blandford. 2012. Reforming Agricultural Nonpoint Pollution Policy in an Increasingly Budget-Constrained Environment. *Environmental Science and Technology*. 46 (3), pp 1316–1325.
- Soule, M.J., A. Tegene, and K.D. Wiebe. 2000. Land tenure and the adoption of conservation practices. *American J. Agric. Econ.* 82(4): 993-1005.
- Srivastava, P., J.M. Hamlett, P.D. Robillard, and R.L. Day. 2002. Watershed optimization of best management practices using AnnAGNPS and a genetic algorithm. *Water Resources Research* 38(3):1-14.
- Tietenberg, T. 2011. *Environmental and natural resource economics* (9th Edition). Prentice Hall.
- Tosakana, N., L. Van Tassel, J.D. Wulforst, J. Boll, R. Mahler, and E. Brooks. 2007. Determinants of the adoption of best management practices by inland northwest farmers. Selected paper at the 2007 Western Agricultural Economics Association Meetings, Portland, OR. July 2007. Abstract: *Journal of Agricultural and Resource Economics* 32(3).
- Tosakana, N.S.P., L.W. Van Tassel, J.D. Wulforst, J. Noll, R. Mahler, E.S. Brooks, and S. Kane. 2010. Determinants of the adoption of conservation practices by farmers in the Northwest Wheat and Range Region. *J. Soil Water Conserv.* 65(6):404-412.
- Veith, T.L., M.L. Wolfe, and C.D. Heatwole. 2003. Optimization procedure for cost-effective BMP placement. *J. Am. Water Resour. As.* 39(6): 1331–1343.
- Whittaker, G., Jr., R. Confesor, S. M. Griffith, R. Fare, S. Grosskopf, J. J. Steiner, G. W. Mueller-Warrant and G. M. Banowetz. 2009. A hybrid genetic algorithm for multiobjective problems with activity analysis-based local search. *European J. Oper. Res.* 193: 195–203.

TABLE 1. Evaluation of BMP Costs and Cost-Effectiveness in CEAP Projects. Check marks indicate the specific aspects of the cost-effectiveness analysis addressed in the listed studies.

CEAP state, project years	Watershed	Study	BMP Costs			Benefit -cost analysis	Cost-effectiveness analysis		
			Estimates attained	Explicit factors	Implicit factors		Estimates attained	Trade -offs	Methods
NY, 2005-10	Cannonsville Reservoir	Rao <i>et al.</i> (2008)	✓	✓		✓			
KS, 2006-11	Cheney Lake	Langemeier <i>et al.</i> (2010)	✓			✓			
IN, 2006-11	Eagle Creek Watershed	Oliver (2008)	✓			✓	✓	✓	✓
		Prokopy <i>et al.</i> (2008)			✓				
		Reimer <i>et al.</i> (2012a)			✓				
		Reimer <i>et al.</i> (2012b)			✓				
MO, 2005-10	Goodwater Creek Watershed	Intrapapong <i>et al.</i> , (2008)	✓	✓					
AR, 2005-10	Lincoln Lake	Rodriguez <i>et al.</i> (2011a)	✓			✓			
		Rodriguez <i>et al.</i> (2011b)	✓	✓		✓	✓	✓	✓
UT, 2004-09	Little Bear River	Jackson-Smith and McEvoy (2011)			✓				
GA, 2005-10	Little River	Jang <i>et al.</i> (2013)	✓						
OR, 2006-11	Lower Calapooia River	Whittaker <i>et al.</i> (2009)							✓

ID, 2004-08	Paradise Creek	Tosakana <i>et al.</i> (2007)	V	V		V	V	V	
		Tosakana <i>et al.</i> (2010)		V	V				
PA, 2006-10	Spring Creek	Brooks <i>et al.</i> (2011)			V				
		Armstrong <i>et al.</i> (2012)			V				
IA, 2004-08	Walnut Creek and Squaw Creek	Rabotyagov <i>et al.</i> (2010a)	V			V	V	V	V
		Rabotyagov <i>et al.</i> (2010b)	V			V	V	V	V
		Kling (2011)							V

APPENDIX: BRIEF SUMMARIES OF CEAP ECONOMICS STUDIES

NY CEAP (Rao *et al.*, 2012) developed multiple year cost estimates for the net present value analysis of seven alternative BMP implementation scenarios in the watershed. Multiple components of the costs for two practices ($P = 2$), barnyard improvements and riparian buffers, including installation, maintenance, and the loss in income due to land taken out of production, were evaluated. A one-farm study watershed was subdivided into $S = 68$ land tracts that differ in current land use and/or wetness indices, but analysis was restricted to a smaller number of units as those representing deciduous forest, water, and rural roads were excluded.

KS CEAP (Langemeier *et al.*, 2010) quantified economic and water quality outcomes of six crop rotations under varying tillage intensity (conventional, reduced, or no-till) for an 18-year simulation and used the yearly average net return as a measure of relative profitability of one cropping system versus another. The analysis was carried out for one, most common soil in the watershed, i.e., $P = 3$ and $S = 1$ in this study.

IN CEAP economics studies are documented in Oliver (2008), Prokopy *et al.* (2008), and Reimer *et al.* (2012a, b). Oliver (2008) used cost estimates from various publications for $P = 10$ common BMPs (cropland protection, conservation tillage, contour farming, conversion to forest, conversion to wetland, nutrient management, terraces and diversions, vegetative buffers, waste management, runoff control) and the set of $S = 24$ farm and concentrated animal feeding operations to solve the cost-effectiveness problem similar to Equation (2) for 5 alternatively defined metrics of water quality representing the concentrations of atrazine, N, P, sediment, and E.coli. A water quality constraint was set up as a soft constraint to model potential penalties and rewards when pollutant concentration was lowered less and more than required by the constraint, respectively. The water quality function is additive across the sites, and is loosely associated with

the study watershed. The tradeoffs between the various levels of the water quality target and the minimum cost of achieving the target were evaluated.

Prokopy *et al.* (2008) synthesized fifty-five studies on the determinants of BMP adoption in the U.S conducted from 1982 to 2007. The study analyzed the impact of various measures of farmer capacity, attitude, and environmental awareness, as well as farm characteristics on the observed adoption of BMPs. The paper finds that farmer and farm characteristics such as education levels, capital, income, farm size, access to information, positive environmental attitudes, environmental awareness, and utilization of social networks impact the probability of adopting BMPs more often positively, rather than negatively, suggesting that the costs of BMP adoption may be lower for farms and farmers of the listed characteristics.

Reimer *et al.* (2012a) conducted 32 in-depth, semi-structured interviews with agricultural producers in the study watershed to investigate the relationships between multiple dimensions of environmental attitudes (farm as business, off-farm environmental benefits, and stewardship) and the adoption of four BMPs (conservation tillage, cover crops, grassed waterways, and filter strips). The study found that time and direct monetary constraints were commonly important factors deterring the adoption of the BMPs.

Reimer *et al.* (2012b) used in-depth interviews of 45 producers in the study watershed to elicit how their perceptions about the characteristics of four BMPs (conservation tillage, cover crops, grassed waterways, and filter strips) affect the adoption. The study finds that perceived relative advantage (or disadvantage) (financial and otherwise) and compatibility (or incompatibility) with existing farming practices are important for adoption (or non-adoption) of all BMPs considered. The ability to observe the practice and/or its impacts on water quality also

increases the adoption of the BMPs. Perceived risk and complexity were found to be important in limiting the adoption of conservation tillage only.

The MO CEAP (Intrapapong *et al.*, 2008) evaluated the economic outcomes of a single BMP, grassed waterways, by comparing a watershed's representative farm's net returns with and without grassed waterways. The representative farm was developed based on the area-average farm physical characteristics (cropland area, crop rotations, tillage, and fertilizer and pesticide applications) and socioeconomic data obtained from a sample of 18 operators that agreed to participate in the survey. The costs of the BMP were broken down into establishment, maintenance, and the loss of income due to the land taken out of production ($P = 1$ and $S = 1$ in this study).

Economic findings from the AR CEAP are documented in Rodriguez *et al.* (2011a, 2011b). Rodriguez *et al.* (2011a) conducted a BCA for ten scenarios that differ in the use of suites of BMPs by bermudagrass producers. Optimal grazing and a buffer were part of each suite, with the scenarios differing by poultry litter application rates, timing, and litter characteristics. The costs of each scenario were computed using budget analysis. The analysis was carried out for $S = 69$ sub-basins within the study watershed. The analysis quantified the impact of the BMPs on not just expected net returns and phosphorus losses, but also on the variability of those stemming from the uncertainty about future weather. The goal of the watershed analysis was to identify the scenario that had greater total phosphorus reduction with less variability in NR when compared to baseline. The study found, among other things, that adding BMPs to current bermudagrass production systems could lead to increased net returns variability.

Rodriguez *et al.* (2011b) conducted a CEA for $P = 35$ BMPs that vary in pasture management, buffer zones, and poultry litter application practices. A total of $S = 461$ pasture

areas were considered for implementation of the BMPs. Cost data were derived from multiple sources, including the NRCS conservation practice manuals; the estimates explicitly accounted for the loss in yield due to pasture area reduction. The study used a nondominated sorting genetic algorithm to develop multiple cost-effective allocations of BMPs, and to evaluate the tradeoff between the total cost and the decrease in total phosphorus as well as that between the total cost and the decrease in total nitrogen.

In the UT CEAP, Jackson-Smith *et al.* (2011) evaluated the long-term effects of extension activities on farmers' decisions to participate in conservation activities. They found that the chances of participation in the program increased with previous relationships between farmers and program staff and one-on-one visits with landowners, while the impacts of demonstration projects and peer-to-peer social diffusion processes were found to be of less importance.

In the GA CEAP the costs of terraces and grassed waterways were developed, and these were subsequently used by Jang *et al.* (2013). The cost estimates were attained in close collaboration with the local NRCS District Conservationist.

In the OR CEAP, Whittaker *et al.* (2009) developed a hybrid genetic algorithm for derivation of a Pareto optimal set. The new method was illustrated in an application that uses field experimental data to calculate the Pareto optimal set depicting the tradeoffs between the maximum nitrogen runoff reduction and the minimum reduction in profit because of a tax imposed on fertilizer use.

Tosakana *et al.* (2010) and Tosakana *et al.* (2007) document ID CEAP economics results. The former study used a survey of 1,500 farmers to investigate what farm and farmer characteristics affect the adoption of BMPs and how important the perceived costs are for adoption of gully plugs and buffer strips. Tosakana *et al.* (2010) found that perceived

effectiveness of the practice was positively associated with the adoption. The adoption of gully plugs was found to be positively affected by the size of the farm, and negatively by the proportion of leased land. They also found that the components of the explicit BMP costs were not perceived to be equally important by the farmers: installation costs were not viewed as important by the farmers as the maintenance costs in the study region.

Tosakana *et al.* (2007) developed detailed cost-of-production budgets through personal interviews for four farmers in the watershed to investigate the cost-effectiveness of $P = 4$ BMPs, gully plugs and buffer strips, each paired with mulch tillage or no-till. In the analysis, the fields of the farmers were subdivided into smaller tracts of land based on hillslopes and current farming practices. The CEA problem of type (2) was solved for varying levels of desired reduction in sediment load.

In the PA CEAP, Brooks *et al.* (2011) and Armstrong *et al.* (2012) reported on landowners' perceptions and attitudes towards water quality problems and the ways to address the problems. Brooks *et al.* (2011) analyzed the results of a survey of riparian landowners to explore the factors that affect the adoption of riparian buffers. The buffers' perceived unsightly appearance, and significant land and time commitments were identified as obstacles to buffer adoption. The perceived improved understanding of stream water quality was associated with a greater willingness to adopt riparian buffers.

Armstrong *et al.* (2012) examined the relationship between stream flow regularity and riparian landowners' perceptions and attitudes towards water quality problems. The study found that landowners with intermittent and ephemeral streams are less likely to manage their properties for riparian or stream protection than those with regularly flowing streams.

Rabotyagov *et al.* (2010a, b) and Kling (2013) reported on IA CEAP economics results. Kling (2013) explored the potential use of observable proxies to support implementation of cost-effective policies in the case when the emissions from the fields and effectiveness of BMPs are not directly observable. A case study used evolutionary algorithms to construct Pareto frontiers for a non-CEAP watershed.

Rabotyagov *et al.* (2010a) considered two versions of the nitrogen reduction target in the CEA problem (2), one weather-resilient, i.e., that to be met under every weather realization, and the other – to be met on average. Some $P = 32$ BMP suites that included alternative conservation tillage systems, contour farming, grassed waterways, terraces, reduction in nitrogen fertilizer applications, and land retirement were considered for a total of $S = 1,312$ land tracts. The study used evolutionary algorithms to identify cost-effective allocations of BMPs for specific water quality targets, and to evaluate the tradeoff between the total cost and mean nitrogen loading reductions as well as that between the total cost and nitrogen loadings reductions met in all of the 20 simulated weather years.

Rabotyagov *et al.* (2010b) considered two metrics of water quality in the CEA problem (2), total phosphorus loading and nitrate-nitrogen loading, and investigated how the corresponding Pareto optimal frontiers changed with changing crop prices. Two land-use scenarios were considered: current conditions, and future conditions for crop prices that favor corn over soy and are expected to draw more marginal land into production. The same set of $P = 32$ BMP suites as in Rabotyagov *et al.* (2010a) was considered, and the number of land tracts was $S = 1,213$ for the baseline scenario, and $S = 1,206$ for the alternative land-use scenario. The study found that the Pareto frontiers change with the land use baseline. Moreover, the mix of cost-effective BMPs depended significantly on land use.