The Conservation Reserve Program as a Payments for Water Quality Case Study:

An Environmental Economic Analysis

by

Ashley L. Camhi

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Graduate Supervisory Committee:

Charles Perrings, Co-Chair
Joshua K. Abbott, Co-Chair
Jeffrey Englin
Osvaldo Sala
Rich Iovanna

ARIZONA STATE UNIVERSITY

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ABSTRACT

Payments for ecosystem services (PES) are transactions between landholders and the beneficiaries of the services their land provides. PES schemes are growing worldwide with annual transactions over ten billion dollars (Salzman et al., 2018). Much can be learned from looking at oldest and best funded PES schemes on working agricultural land. Initiated in 1985, the USDA's Conservation Reserve Program (CRP) is the oldest private conservation PES program in the United States. CRP incentivizes farmers to put their land into conservation through an annual payment. In Iowa, CRP has been a source of extra income and a way for farmers to buffer the fluctuating costs of cash crops, such as corn and soy. The dominance of agriculture in Iowa poses many challenges for water quality. A potential solution to the problem, implemented through CRP, is the use of conservation practices to mitigate the negative effects of agricultural run-off.

This dissertation considers three aspects of the problem:

1. the relationship between changes in land cover due to CRP enrollment and changes in water quality, controlling for a range of factors known to have an effect on the filtering role of different land covers;
2. the inter-annual variability in water quality measures and enrollment in different CRP conservation practices to examine the cost-effectiveness of specific conservation practices in mitigating lake sedimentation and eutrophication;
3. discrete choice models to identify what characteristics drive the enrollment by farmers into specific conservation practices.

Results indicate that land cover and CRP have different impacts on different indicators of lake water quality. In addition, conservation practices that were cost-effective for one water quality variable tended to be cost-effective for the other water quality variables. Farmers are making decisions to enroll in CRP based on the opportunity cost of the land. Therefore, it is necessary to alter financial incentives to promote productive land being putting into CRP through continuous sign-up. The United States Department of Agriculture (USDA) needs a more effective way to calculate the payment level for practices in order to be competitive with the predicted value of major crops.

This dissertation is dedicated to my loved ones that have supported me through my academic journey. My husband who supported me in my desire to go back to school to complete my doctorate. My mother for always reminding me that I can do anything I put my mind to. My aunt and uncle for telling me that I was perfect, whether I actually was or not. Cloey for being my silent guardian.

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CHAPTER 1: INTRODUCTION

Background

Payments for Ecosystem Services (PES)

Between 2001 and 2005 nearly 1,400 experts worldwide contributed to the development of the Millennium Ecosystem Assessment (MEA), which formalized the role of ecosystem services in social and environmental decision making. Following the MEA, the benefits from managed or natural ecosystems were characterized as ecosystem services of four types:

(1) Supporting services such as soil formation, photosynthesis, and nutrient cycling;
(2) Provisioning services such as the production foods, fuels, water, and fibers;
(3) Regulating services that affect climate regulation, water quality, water quantity; and
(4) Cultural services that include the non-consumptive recreational, spiritual, and aesthetic benefits of ecosystems and the species they support.

Since the MEA, payments for ecosystem services (PES) have exploded as a market-based policy tool for conservation. In its simplest sense, a PES scheme is a transaction between landholders and the beneficiaries of the services their land provides (Salzman et al., 2018). It is established on the principle that those who benefit from ecosystem services should pay for them, and those who contribute to generating these services should be compensated for providing them (Engel et al., 2008; Wunder and CIFOR, 2005). The main characteristics of a PES mechanism are that it is:

(1) a voluntary transaction where
(2) a well-defined ecosystem service (or land use likely to secure that service)
(3) is bought by a (minimum of one) service buyer
(4) from a (minimum of one) service provider
(5) payment being conditional on service provision (conditionality) (Wunder and CIFOR, 2005).

Physical Effectiveness, Additionality, Efficiency, and Cost-Effectiveness in PES Schemes

There are four key aspects to consider when evaluating a PES scheme: physical effectiveness, additionality, efficiency, and cost-effectiveness. Physical effectiveness identifies whether there has been an improvement in an ecosystem service as a result of a land use change. For the purposes of this dissertation, physical effectiveness is defined as a statistically significant positive effect on at least one water quality variable.

Additionality looks at whether or not land uses paid for under a PES scheme would exist in the absence of a payment. For example, would a farmer reforest an area without a payment for doing so? If so, then there is no additionality. Absent additional service provision there is no justification for payments to landholders. Claasen et al. (2018) estimate additionality for selected practices using propensity score matching to analyze data from the Agricultural Resource Management Survey. They found that greater than 95% of off-field structural practices (e.g., filter strips, riparian buffers) supported by payments were additional but that less than 50% of conservation tillage payments yielded additional adoption. Their results suggest that additionality is highest for practices that have high up-front cost, little or no on-farm benefit, or both.

But additionality can vary greatly. Mezzatesta et al. (2013) found high additionality for practices that take land out of crop production or otherwise impose costs while providing little on-farm benefit in the short run. They used survey data and found that additionality varied dramatically between practice types. Specifically, the percent additionality was highest for filter strips, hayfields, and cover crops, while it was lowest for conservation tillage.

Efficiency in PES schemes implies that the marginal benefits and marginal costs of service provision should be equal. The marginal cost of the service is the opportunity cost of the farmer. The opportunity costs of participation are those associated with the benefit foregone from alternative land activities (Wunder et al., 2008). The marginal benefit offered by such schemes is the value of the increment in service provision they induce. In practice, very few PES schemes base payments on the value of increments to ecosystem services.

Most PES schemes base payments on the cost of service provision, and test not the efficiency but the cost-effectiveness of service delivery. That is, they seek the least costly method for delivering a specific increment in service provision, or for meeting a particular environmental target. Cost-effectiveness looks at the least costly method for delivering a specific increment in service provision for meeting a particular environmental target.

Most recent studies of CRP have focused on additionality rather than cost-effectiveness (Claassen et al., 2014; Khanna, Madhu, and Yang, 2011; Mezzatesta, M., Newburn, D.A., Woodward, 2013). Yet, cost-effectiveness is particularly critical to examine in order to provide suggestions to program managers on how to achieve water quality targets at least cost.

The Conservation Reserve Program

Much can be learned from looking at the oldest and best funded PES schemes on working agricultural land. The two precursors are the Conservation Reserve Program (CRP) and European Union agro-environmental schemes[1].

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[1] The idea for PES schemes, specifically CRP, stems from agro-environmental schemes (AES) that have existed in Europe for decades. AESs were first introduced into the European Union's (EU) agricultural policy during the late 1980s as an option to be applied by EU Member States. According to the European Commission, "agro-environmental schemes (AES) provide payments to farmers who subscribe, on a voluntary basis, to environmental commitments related to the preservation of the environment and maintaining the countryside (2015)." An example of an AES program similar to CRP is in France. Two evaluations of this scheme reveal the challenge in effectiveness. Prince et al (2012) evaluated the effectiveness of French AES schemes to enhance farmland bird diversity on a national scale. The authors identified whether temporal trends in farmland bird abundance had been more positive in areas with higher landscape density of AES measures. They found that the areas that participated in the AESs did not greatly improve the bird diversity, except mildly for long-term declining bird species. In addition, Chabe-Ferret and Subervie (2013) analyzed the same program but focused on seven AESs, including plant buffer strips along rivers and streams. They propose that the AES subsidizing grass buffer strips could be socially efficient despite large windfall effects (they are making the tradeoff between additionality and windfall). They contend that these farmers would have adopted greener practices even if the AES had not been implemented; in other words, there are no additionality or windfall effects.

CRP is considered the oldest PES scheme in the United States. As such, CRP benefits from a wealth of data. Initiated in 1985, the CRP initially targeted the reduction of soil erosion caused by wind and water. Farms could voluntarily participate in two conservation practices designed to maintain groundcover and reduce soil erosion – one program introduced native species and the other introduced non-native species. In return for putting a piece of their land into what the United States Department of Agriculture (USDA) calls "retirement," farmers received a yearly payment based on the average opportunity cost of their land. Contract durations ranged between 10-15 years with a penalty for ending a contract before the expiration date (Food and Agricultural Policy Research Institute, 2007). Since then, the range of environmental objectives has grown. According to the Farm Service Agency's CRP Handbook, the CRP's objective is to encourage owners and operators to conserve and improve land resources in a cost-effective manner (United States Department of Agriculture Farm Service Agency, 2015).

In Iowa, CRP has been a source of extra income and a way for farmers to buffer the fluctuating costs of cash crops such as corn and soy. Not only does it allow farmers to derive income from land that is unsuitable for agricultural purposes, but also to add conservation practices to currently productive land. In 2016 there were 23.8 million acres in CRP nationally. Of the 800,000 acres added in that year, 128,212 were from Iowa—the most of any state. This brought the Iowa total to 1.6 million acres on approximately 52,800 farms (Doering, 2016).

The expansion of the goals of the CRP partly reflected growing public awareness of the off-site impacts of agricultural practices. The perception that water quality is compromised by agricultural practices, for example, is now widespread. In Iowa, the focus of this dissertation, upstream farmers were recently sued by the City of Des Moines residents for the damage caused by increased levels of pesticides and fertilizers in their drinking water (Hanson et al., 2016). While the case was unsuccessful, it demonstrates that there is an increasing recognition of the effects of off-site agricultural practices.

Most U.S. private land conservation programs rely on incentives to change farmer behavior. The alternative, regulations, are an unpopular way to address environmental problems in rural areas (Dowd et al., 2008; Dupont, 2010). The CRP operates exclusively through incentives. Nonetheless, evidence for the effectiveness of incentives aimed at water quality is lacking (State-EsPA Nutrient Innovations Task Group, 2009). This may be because initially mechanisms were poorly designed to impact water quality.

Based on the literature and experience with PES, the main policy concerns are physical effectiveness, cost-effectiveness and targeted participation. The scientific challenge becomes how to test for each. Each one of the chapters addresses this issue from a different angle. In the case of CRP and water quality in Iowa, Chapter 2 tests for physical effectiveness of the CRP. Chapter 3 tests for cost-effectiveness of CRP practices. Chapter 4 tests for the sensitivity of participation in different CRP practices based on a range of characteristics.

Summary of Chapters

This dissertation is broken up into five chapters, including the introduction (Chapter 1) and conclusion (Chapter 5). Chapter two demonstrates the relationship between changes in land cover due to CRP enrollment and changes in water quality, controlling for a range of factors known to have an effect on the filtering role of different land covers. Chapter three utilizes the inter-annual variability in water quality measures and enrollment in different CRP conservation practices to examine the cost-effectiveness of specific conservation practices in mitigating lake sedimentation and eutrophication. Chapter four uses discrete choice modeling to identify what characteristics drive the enrollment of farmers into specific conservation practices. The final chapter includes a summary of the three substantive chapter results, provides recommendations and policy implications, and identifies next steps for future research.

Chapter 2

Water quality in lakes offers the best measure of the physical effectiveness of CRP. While CRP does not have a specific goal to improve lake water quality, it does aim to improve water quality in the rivers feeding into lakes (L. Karlen Karlen et al., 1998). No research to date has looked at the impact of CRP on lakes and lake water quality in Iowa. The purpose of chapter two is to explore how CRP practices affect water quality. There exists little knowledge on the effect of the spatial distribution and quantity of vegetation types (crops vs. CRP land) on lake sedimentation and eutrophication. Chapter two considers the effect of crops, natural cover, and CRP on water quality in 135 lakes in Iowa between 2010 and 2015. Seven models of increasing specificity are analyzed using fixed effects, while other models were evaluated (random effects, Arellano-Bond estimator, first differences). Land cover and CRP have different impacts on different indicators of lake water quality. The amount of land in CRP is associated with improvements in lake water quality.

Chapter 3

Chapter three evaluates the cost-effectiveness of CRP practices in Iowa that target water quality, either alone or in combination with other environmental objectives. Since many of the outcomes associated with different CRP practices overlap there are limits to the conclusions that can be drawn about the cost-effectiveness of practices generating multiple benefits, but for more targeted practices, we are able to say which achieves a given increment in service provision at least cost.

Chapter 4

While many people have written about participation in CRP, there remains a gap in the literature regarding what drives enrollment in specific CRP practices. These drivers could be farm-specific, time-varying, or practice-specific factors. Understanding what leads to enrollment in specific conservation practices will allow the USDA to improve targeting for ecosystem service provision, in this case for water quality. Chapter 4 utilizes multiple discrete choice modeling methods to identify what independent variables drive farmers to enroll in different conservation practices. We are interested both in the way that the physical characteristics of farms determines the type of practice farmers are able to enroll in, and the way that farmers' choices are influenced by the CRP price structure and the opportunity cost of enrollment.

Policy Implications

Being one of the longest standing conservation programs, much research has already been conducted on the CRP. CRP is, in and of itself, an interesting topic for research. CRP attempts to address the issue of how to manage public goods or assets that exist on private land. There is a sizeable amount of public goods, biodiversity and ecosystem services, that flow from private lands. Since most ecosystem services are public goods, markets often do not exist to incentivize their protection. In addition, as CRP is an example of a PES scheme, a better understanding of the factors influencing enrollment and cost-effectiveness for CRP may carry over to other PES schemes. By having a clearer understanding of what works in CRP and why, we may be in a better position to understand what works in other schemes.

Market-based mechanisms for conservation alter an individual's or farmer's actions by compensating him or her for making land use decisions that are linked to ecosystem service provision. Climate regulation, water quality, and water quantity are the traditional services involved in these mechanisms. There is a wide range of activities that could lead to the creation, preservation, or maintenance of ecosystem services. For example, in a particular watershed these could be reforestation, avoided deforestation, agroforestry, natural regeneration, and/or silvopastoral systems. The results of such activities lead to collective outcomes: reduction of carbon dioxide emissions in the atmosphere, reduction of sedimentation, regularity of water flow, water source protection, or reduction of contamination. These outcomes are not mutually exclusive; thus, multiple ecosystem services can be maintained as a result of a given land use change.

The provision of ecosystem services has been most successfully accomplished through market-based mechanisms. Incentive-based policies address externalities by altering the economic incentives private actors face, while allowing those actors freedom to decide whether and how much to change their behavior. Most incentive-based mechanisms have been initiated through public policies, although privately negotiated incentive-based solutions also exist. An incentive-based mechanism is seen as a policy solution for realigning private and social benefits resulting from decisions related to the environment (Jack et al., 2007). In addition, since CRP is a publicly funded mechanism, a better understanding of farmer behavior can help ensure it is spent in a cost-effective way.

CHAPTER 2: LAND COVER AND THE CONSERVATION RESERVE PROGRAM: WATER QUALITY IN IOWA'S LAKES

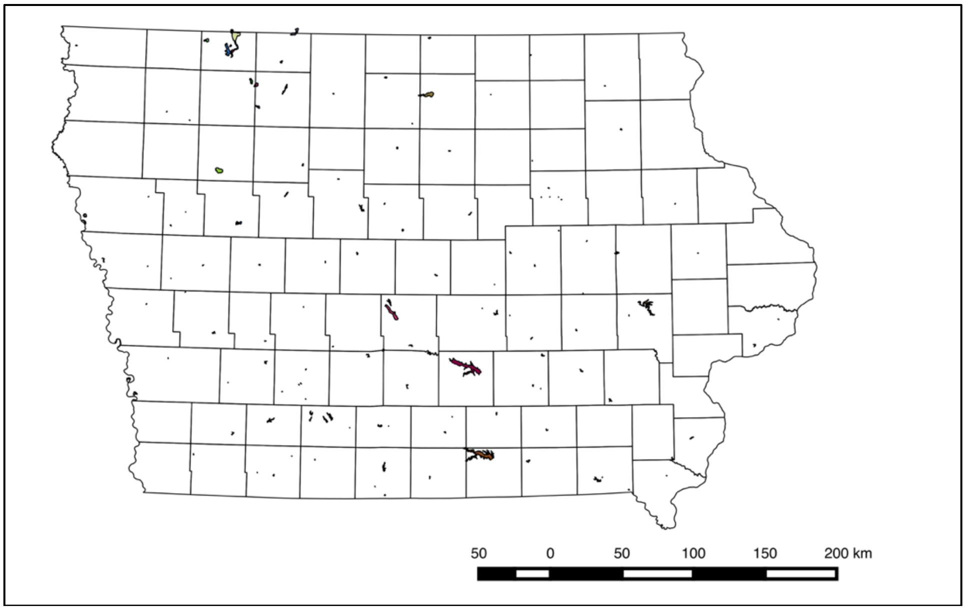
Introduction

As water moves through an agricultural landscape it can carry with it various sediments, fertilizers, and pesticides. Nutrient loads are strongly affected by hydrology and watershed characteristics such as soil type, land use, and land cover, all of which may vary with climate (Kosten et al., 2009). While the type of land cover is known to have an impact on how much residue in run-off ends up in waterways and water bodies, there is little information on the relative effectiveness of different vegetation types (crops, natural cover, and conservation land) in filtering sediments and nutrients (Tong and Chen, 2002). To date, most empirical studies of nutrient reductions from nonpoint sources have been relatively small scale, generally due to the daunting amount of data required to capture both the pollution processes—the fate and transport of pollutants—and the decisions of individual economic agents that determine land cover (A N Sharpley et al., 2009).

The challenge to water quality stems from the dominance of agriculture in many states. Iowa has lost proportionally more area of its native vegetation than any other U.S. state. Corn and soybeans occupy 63% of the state's total land area and 82% of its cropland (National et al., 2014). This has had large impacts on water quality. Forty six of one hundred and forty lakes in Iowa are on the impaired water list as a result of algae, turbidity, and pH (Iowa Department of Natural Resources, 2016). A potential solution to the problem, implemented through the CRP, is the use of various conservation practices to mitigate the negative effects of agricultural run-off. Water quality is explicitly targeted by a number of CRP practices, but is also indirectly affected by several others.

In 2001, research by Iowa State University and the Iowa State Limnology Lab on 132 lakes revealed that the primary value of lakes in Iowa is for recreation (Azevedo et al., 2003). The majority of the recreational lakes in Iowa are shallow, manmade lakes, with a few deeper, glacial lakes located in northern Iowa near Minnesota (see Figure 1). While CRP does not have a specific goal to improve lake water quality, it does aim to improve water quality in the rivers feeding into lakes (L. Karlen Karlen et al., 1998). In this chapter, the effect of the CRP on lake water quality is investigated for 135 lakes in Iowa, over the period 2010 to 2015.

Figure 1. Iowa's Lakes



Source: (Iowa Department of Natural Resources, 2018)

Table 1 demonstrates the average percentage of land cover within the lake watersheds. Most notable is that there has not been much change in gross land cover. Thus, if an effect of CRP is detected it will be via a change in a particular land cover.

Table 1. Change in Shares of Land Cover (2010-2015)

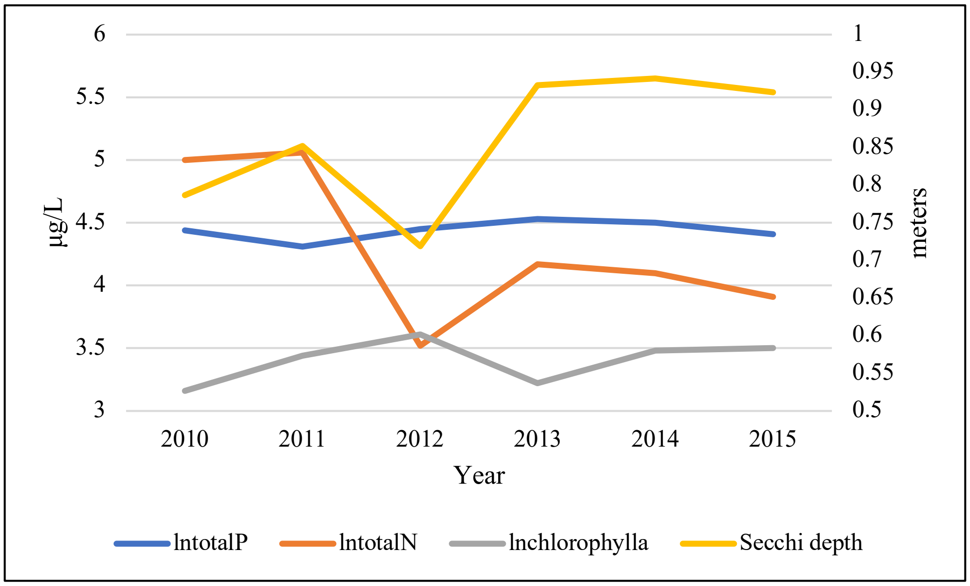
Year	Corn	Soy	Water	Developed	Grass Pasture	Forest Trees	Wetlands Shrublands	Other Crops
2010	0.22	0.16	0.17	0.09	0.20	0.11	0.02	0.03
2011	0.22	0.15	0.17	0.10	0.14	0.12	0.03	0.07
2012	0.21	0.15	0.18	0.11	0.15	0.12	0.03	0.05
2013	0.22	0.15	0.17	0.11	0.15	0.12	0.03	0.05
2014	0.20	0.16	0.18	0.11	0.15	0.12	0.03	0.06
2015	0.21	0.16	0.18	0.10	0.17	0.13	0.03	0.04

Recreational use privileges some water quality measures over others. Egan et al (2009) conducted a detailed analysis of the relationship between ten lake water quality measures in Iowa. They also explored lake users' perception of the importance of different indicators. They found that the diversity of land uses in the Iowa lake watersheds leads to a relatively low degree of collinearity among the physical and chemical water quality measures, with correlation coefficients ranging from -0.53 to 0.68, and typically lying below 0.4.

Based on these findings we selected four water quality variables from the Iowa State Limnology Lab. Secchi depth measures the depth at which the secchi disk in a lake can still be seen. Chlorophyll a is an indicator of phytoplankton plant biomass, which leads to greenness in the water. Total nitrogen is the sum of all dissolved and particulate forms of nitrogen: NH3 + NH4 being ammonium nitrogen deriving from fertilizer or anaerobic conditions, NO3 + NO2 being nitrates from aerobic nutrient contributions. Total phosphorus is the principal limiting nutrient that determines phytoplankton growth in freshwater systems (Egan et al., 2009).

While the percentage of CRP in lake watersheds overall is small, it doubled during the six-year study period from 1.7% to 3.4%. Focusing on four lake water quality characteristics—nitrogen, phosphorus, chlorophyll a and turbidity (reported as secchi depth)— there exists a slight decrease in the average value of phosphorus in the lakes, and a large decrease in nitrogen and turbidity over the study period. Improvement in turbidity is measured by an increase in secchi depth—the depth at which an 8 inch secchi disk can no longer be seen through the water (Davies-Colley and Vant, 1988). The only water quality characteristic to have worsened in the study period is chlorophyll a (Figure 2).

Figure 2. Average Value of Four Lake Water Characteristics (2010-2015)



In this chapter we consider the relationship between changes in land cover due to CRP enrollment and changes in water quality, controlling for a range of factors known to have an effect on the filtering role of different land covers. Section 2 identifies sources that were utilized to obtain the necessary data for the various analyses. It also goes through the seven model specifications and a justification for the different methods applied, ultimately using fixed effects for the core analysis. Section 3 focuses on the main results from the fixed effects model for the four lake water quality characteristics, highlighting overlap with the random effects results. Section 4 discusses how the results compare to other PES schemes and potential implications.

Data and Methods

The Iowa State Limnology Lab has consistently measured lake water quality characteristics three times during the summer (between June and September) since 2000. For this chapter, the average of the three samples was calculated. The four main water quality characteristics examined were phosphorus; nitrogen, specifically (Phenate)Ammonia Nitrogen ($NH3 + NH4^+$) as N; secchi depth as a proxy for turbidity; and chlorophyll a. Phosphorus and nitrogen are known to cause algae blooms. Chlorophyll a is contained in phytoplankton that in excess lead to algae blooms. Turbidity can be the result of algae or dissolved particles. Changes in these variables would demonstrate whether or not CRP and land covers are having an impact on lake water quality. In addition, lake depth, again taken as the average measurement for the summer, was also obtained from the Iowa State Limnology Lab for 2010 through 2015.

Data on land enrolled in CRP was provided as a geodatabase from the USDA Farm Service Agency (FSA) of land that entered into CRP between 2010 and 2015, both new contracts and re-enrollments. Specifically, these were shapefiles of land that entered into CRP through general and continuous sign-up each year. Raster level data for Iowa on land use cover was obtained from the USDA's National Agricultural Statistics Service (NASS). This dataset is a combination of information on crops from the USDA and land cover from the USGS National Land Cover Database (NLCD). Shapefiles for lakes and lake watersheds were obtained from the Iowa State Department of Natural Resources. All spatial data were converted to a non-spatial format using QGIS and Python.

Additional information on soil type was obtained from the U.S. Natural Resources Conservation Service Soil Survey Geographic 2014 and monthly precipitation information was gathered from the Iowa State Iowa Environmental Mesonet Climate Monitoring Stations. The closest weather station to each lake centroid was used; if there were two weather stations that were equidistant then the data was averaged. Information on the location of Confined Animal Feeding Operations (CAFOs) was obtained from Iowa Department of Natural Resources Animal Feeding Operations Database from 2006 to 2007 as point data. It is assumed that the location of the CAFOs is fixed through the study period.

Model Specification

The meta model for this analysis is as follows:

$$\mathrm{Log}(Y_{lt}) = \boldsymbol{\theta}_{\mathbf{lt}} + \beta_1\mathbf{X}_{\mathbf{1t}} + \beta_2\mathbf{X}_{\mathbf{2t}} + \beta_3\mathbf{X}_{\mathbf{3t}} + \beta_4\mathbf{X}_{\mathbf{4t}} + \beta_5\mathbf{X}_{\mathbf{5}} + \beta_6\mathbf{X}_{\mathbf{6}} + \beta_7\mathbf{X}_{\mathbf{7}} + \boldsymbol{\varepsilon}_{\mathbf{lt}} + \boldsymbol{\varepsilon}_{\mathbf{l}}$$

$\boldsymbol{\Theta}_{\mathbf{lt}}$ = constant

$\mathbf{X}_{\mathbf{1t}}$ = Share of grouped land covers: water, development, corn, other crops, wetlands and shrublands, forests and trees, and grass pasture (soy as omitted base)

$\mathbf{X}_{\mathbf{2t}}$ = Percentage CRP of crops: amount of CRP as a percentage of total land use in the lake watersheds

$\mathbf{X}_{\mathbf{3t}}$ = Percentage land cover as CRP: amount of CRP identified as a land cover times the share of that land use

$\mathbf{X}_{\mathbf{4t}}$ = Precipitation: monthly average of precipitation measured in millimeters

$\mathbf{X}_{\mathbf{5}}$ = CAFOs: dummy variable for presence/absence of CAFOs on a 30m x 30m pixel scale

$\mathbf{X}_{\mathbf{6}}$ = Soil Type: dominant soil type on a 30m x 30m pixel scale, non-time varying

$\mathbf{X}_{\mathbf{7}}$ = Lake Depth: measured in meters, an average of 3 samples during summer annually

There are seven regressions that were utilized for the four lake water quality characteristics for 135 lakes between 2010 and 2015. The model has increasing specification. The initial regression does not include land that is enrolled in the CRP program. This base model only looks at the amount of land that was in different land covers ($\beta_1\mathbf{X}_{\mathbf{1t}}$) from the USDA Cropland Data Layer. These land covers were grouped into seven categories - water, development, corn, other crops, wetlands and shrublands, forests and trees, and grass pasture. Soy was omitted as the base for analysis so that all others land cover results are measured in comparison to soy. The reasoning for the first model is to understand the role of land cover on the lake water characteristics when CRP is not taken into account. Land covers across the landscape have demonstrated both positive and negative impacts on lake water quality (Reed and Carpenter, 2002).

The second model includes land cover ($\beta_1\mathbf{X_{1t}}$) and introduces CRP as a percentage of total land cover in the lake watersheds ($\beta_2\mathbf{X_{2t}}$). This is a general measure to understand whether or not increasing the amount of land in CRP in a lake watershed would improve any of the four lake water quality characteristics. By adding CRP to the first model we are controlling for land cover and looking at CRP's impact holding land cover constant.

The third model builds on the analysis of the second model by introducing an interaction variable ($\beta_3\mathbf{X_{3t}}$). Through implementation of a probability transition model for land enrolled in CRP and land identified as different land cover types through the USDA Cropland Data Layer (CDL), it is clear that even once land was enrolled in CRP it shows up in the CDL as various land covers. For example, one might think that once land is enrolled in CRP it would show up as trees or grass, but in fact is some areas, particularly on the boundaries of other land covers, it is still identified by the CDL as being corn or another land cover type. Conservation practices, such as filter strips, are generally three meters wide, which is smaller than the CDL raster size, so it does not show up as a distinct land cover.

In addition, measurement errors occurred in the processing of the CDL. The USDA National Agricultural Statistics Service (USDA National Agricultural Statistics Service, 2018) describes these inaccuracies between 2010 and 2015, "The training and validation data used to create and accura[tely] assess the CDL has traditionally been based on ground truth data that is buffered inward 30 meters…This would be inconsequential if those edge pixels were similar in nature to the rest of the scene but they are not as they tend to be more difficult to classify correctly. Thus, the accuracy assessments as have been presented are inflated somewhat."

In order to understand if there is heterogeneity in the effects of CRP, a variable that interacts the amount of CRP identified as a land cover multiplied by the share of that land cover was created. Specifically, this is looking to see if CRP identified as a land cover is having an impact or if CRP coupled with a land cover may have a different impact than solely the amount of CRP. Holding the land cover and percent of CRP in the watersheds fixed, this regressor, ($\beta_3\mathbf{X}_{3t}$), identifies the marginal effect as a percentage of CRP identified as a particular land cover.

The fourth model begins to include other external variables that have been identified in the literature as highly likely to impact the four lake water quality characteristics. Specifically, this model introduces precipitation that was averaged from monthly data ($\mathbf{X}_{4t}$). Precipitation was broken up into the four seasons since the frequency and duration of precipitation during the year changes greatly. The impact of snow pack in the winter months was thought to have a different impact on lake water quality than spring and summer rains (Hoering, 2010; Rose et al., 2004).

The fifth model includes a dummy variable for the presence of concentrated animal feeding operations (CAFOs) (**X_5**). Fertilizer runoff from CAFOs is known to contain high levels of nitrogen and phosphorus (Burkholder et al., 2007; Hribar, 2010). While Iowa has put restrictions in place to regulate the amount of runoff, this remains important because of the quantity of operations in the state. This was included as a dummy variable because there is only data on CAFOs for one year. In addition, there is no available information on the size of the CAFOs.

Soil type (**X_6**) is written about consistently in the literature as having an impact on lake water quality (Detenbeck ’ et al., 1993; Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C. and Reddy, 1994) and as such is included as a critical variable in the sixth model. Soil type may be a proxy for two different variables: 1. The land cover that is able to grow on top of a particular soil and 2. The likelihood that a particular soil type contributes to an increase or decrease in runoff. This information was recorded as the dominant soil type.

The last model includes lake depth (**X_7**), which has also been identified as a key variable in understanding lake water quality due to mixing that occurs within lakes and distinct limnology of deep versus shallow lakes (University of Wisconsin, 2016). In addition, lake depth varies considerably in Iowa. The lakes in northern Iowa near Minnesota are glacial lakes and are much deeper than the manmade lakes that exist throughout the rest of the Iowa.

Estimators

Fixed effects with a one-year lag was initially utilized to test the hypothesis that the value of each lake water quality characteristic from the previous year was a predictor for the current year. In addition, oftentimes even after a conservation practice is introduced there may be a delay in seeing the results of it, particularly for lake water quality (Meals and Dressing, 2008). For the dynamic fixed effects model the lagged dependent variable was negative for phosphorus, nitrogen, and chlorophyll a and positive for turbidity. There is reason to question the validity of this model since we would expect the opposite results on the lag. This led us to investigate the Arellano-Bond estimator (Appendix A) as an alternative to fixed effects with a lag since through Arellano-Bond consistent estimators can be obtained utilizing past lags for IV estimation by first differencing (Cameron and Trivedi, 2009).

In order to avoid an endogeneity problem, the differenced unobserved time-invariant component of the Arrellano-Bond estimator should be unrelated to the second lag of the dependent variable and the lags thereafter. The test for serial correlation for the Arrelano-Bond estimator demonstrated that for all lake water quality variables we reject no autocorrelaton of order one, but cannot reject no autocorrelation for phosphorus, chlorophyll a, and turbidity of order two. Only for nitrogen was no autocorrelation rejected for order one and two. In addition, the lagged dependent variable was negative for phosphorus, nitrogen, and chlorophyll a, as well as being positive for turbidity, signaling a possible issue with this estimator.

After eliminating the dynamic models, we investigated whether it was more appropriate to use a fixed effects or random effects model. For all four of the dependent variables the robust Hausman test was performed to identify whether or not random effects was appropriate. All four tests strongly rejected the null hypothesis demonstrating that random effects was likely not the most appropriate estimator compared to fixed effects when cluster robust standard errors are used. Without cluster robust standard errors, the standard Hausman test rejects the null for chlorophylla and turbidity, but the null cannot be rejected for nitrogen and phosphorus. Since the random effects model is used when we assume the unobserved time invariant error is uncorrelated with the explanatory variables (Wooldridge, 2009), at minimum it is useful to compare the random effects results to fixed effects.

Lastly, first differences, first differences with a lag, fixed effects with a lag, and random effects with a lag were evaluated. When the time varying errors are serially uncorrelated, fixed effects is more efficient than first differencing. The results of fixed effects and first differences are similar in the four lake water quality measures. See Appendix A for the results of the additional regressions for the full specification model.

Results

The results of the fixed effects model are presented in Tables 2 through 5 reporting coefficients and significance in each of the seven specifications for each measure of water quality. The results of the seven models demonstrate distinct influences on the four water quality characteristics.

Table 2. Phosphorus, Fixed Effects

	(1) lntotalP	(2) lntotalP	(3) lntotalP	(4) lntotalP	(5) lntotalP	(6) lntotalP	(7) lntotalP
WATERSHARE	-0.124	-0.132	0.108	-0.0112	-0.0366	-0.0366	0.0330
	(-0.08)	(-0.08)	(0.05)	(-0.01)	(-0.02)	(-0.02)	(0.02)
DEVELOPEDSHARE	1.276**	1.119*	2.664	2.020	2.047	2.047	1.956
	(2.30)	(1.93)	(1.52)	(1.09)	(1.11)	(1.11)	(1.04)
WETLANDSSHRUBLANDSSHARE	0.560	0.829	0.754	0.0408	-0.0416	-0.0416	-0.113
	(0.59)	(0.81)	(0.52)	(0.03)	(-0.03)	(-0.03)	(-0.08)
FORESTTREESSHARE	-1.123	-1.298	-2.600	-2.833	-2.869	-2.869	-2.938
	(-0.94)	(-1.05)	(-1.50)	(-1.52)	(-1.53)	(-1.53)	(-1.57)
CORNSHARE	0.297	0.340	0.198	0.138	0.148	0.148	0.157
	(1.00)	(1.11)	(0.44)	(0.32)	(0.34)	(0.34)	(0.35)
GRASSPASTURESHARE	1.157**	0.971	1.402*	0.576	0.569	0.569	0.547
	(2.03)	(1.62)	(1.75)	(0.72)	(0.71)	(0.71)	(0.69)
OTHERCROPSSHARE	1.290*	1.111	2.707**	2.109*	2.141*	2.141*	2.136*
	(1.74)	(1.38)	(2.54)	(1.80)	(1.82)	(1.82)	(1.82)
PerCRPofCrops		0.545	0.537	0.605	0.606	0.606	0.603
		(0.98)	(0.91)	(0.87)	(0.86)	(0.86)	(0.86)
PerCornCRP			0.0000230	-0.0000322	-0.0000281	-0.0000281	-0.0000303
			(0.21)	(-0.26)	(-0.23)	(-0.23)	(-0.25)
PerGrassPastureCRP			-0.0000290	0.00000399	0.00000598	0.00000598	0.00000514
			(-0.40)	(0.06)	(0.08)	(0.08)	(0.07)
PerForestTreesCRP			0.000714	0.000825	0.000838	0.000838	0.000830
			(0.82)	(0.95)	(0.96)	(0.96)	(0.95)
PerWetlandsShrublandsCRP			-0.0000223	-0.00000164	0.000000631	0.000000631	0.00000458
			(-0.17)	(-0.01)	(0.00)	(0.00)	(0.04)
PerWaterCRP			-0.000716	-0.000945	-0.000958	-0.000958	-0.000975
			(-0.76)	(-0.90)	(-0.91)	(-0.91)	(-0.93)
PerDevelopedCRP			0.000453	0.000253	0.000274	0.000274	0.000276
			(0.26)	(0.14)	(0.15)	(0.15)	(0.15)
PerOtherCropsCRP			-0.000247*	-0.000231	-0.000236	-0.000236	-0.000244
			(-1.75)	(-1.53)	(-1.55)	(-1.55)	(-1.60)
Fall_Precip				0.0151*	0.0146	0.0146	0.0145
				(1.71)	(1.64)	(1.64)	(1.64)
Winter_Precip				-0.0251**	-0.0263**	-0.0263**	-0.0261**
				(-2.38)	(-2.50)	(-2.50)	(-2.47)
Spring_Precip				0.0129**	0.0128**	0.0128**	0.0131***
				(2.58)	(2.56)	(2.56)	(2.63)
Summer_Precip				-0.000957	-0.000859	-0.000859	-0.000467
				(-0.29)	(-0.26)	(-0.26)	(-0.14)
CAFO					0.164	0.164	0.173
					(1.31)	(1.31)	(1.39)
Alfisols						0	0
						(.)	(.)
Entisols						0	0
						(.)	(.)
Inceptisols						0	0
						(.)	(.)
Mollisols						0	0
						(.)	(.)
NoData						0	0
						(.)	(.)
Iowa LL Lake Depth							-0.0154
							(-0.50)
Constant	4.141****	4.190****	4.122****	4.263****	4.198****	4.198****	4.290****
	(9.58)	(9.04)	(7.18)	(7.32)	(7.18)	(7.18)	(7.07)
Observations	765	747	570	570	570	570	570
t statistics in parentheses	* p<0.10	** p<0.05	*** p<0.01	**** p<0.001			

Few significant results were found for phosphorus in the fixed effects model. This is consistent across all models (Arellano-Bond, random effects, etc.) that were tested, indicating that the role of CRP is less important for phosphorus than for nitrogen.

The main difference between the fixed effects and the random effects models for phosphorus is that the share of forests and trees as a land cover is highly significant across all specifications in the random effects model. The share of forests and trees has a strong effect in decreasing the levels of phosphorus in the lakes by decreasing the amount of water that enters the lake at any one time and mitigating the movement of phosphorus across the soil (Huang et al., 2013; Read et al., 2015). An increase in the amount or shares of forest and trees by 1% would lead to a decrease in the amount of phosphorus in a lake watershed on average by 186% in the random effects model.

Winter precipitation is negative and highly significant, while spring precipitation is positive and highly significant in the fixed effects and random effects models. Winter precipitation, which comes in the form of snow pack, has the result of decreasing the amount of phosphorus in lakes since the phosphorus is not as mobile, while precipitation during the spring increases the amount of phosphorus in the lakes. Heavy rains in the spring will increase the runoff of phosphorus from fertilizers placed on crops (Schippers et al., 2006). During the winter less fertilizer is used, in addition to the snow pack decreasing movement.

Dominant soil type and lake depth cannot be estimated for fixed effects, but in the random effects model entisols and inceptisols have the effect of decreasing the level of phosphorus in the lakes. Both soil types do not have highly defined soil horizons and thus have the result of reducing phosphorus since the land cover above the soils is likely to be a natural cover that reduces erosion thus decreasing runoff as well as the amount of phosphorus in the soils.

Table 3. Nitrogen, Fixed Effects

	(1) lntotalN	(2) lntotalN	(3) lntotalN	(4) lntotalN	(5) lntotalN	(6) lntotalN	(7) lntotalN
WATERSHARE	-20.52****	-18.46****	-15.15**	-7.304	-7.394	-7.394	-7.695
	(-4.16)	(-4.23)	(-2.35)	(-1.27)	(-1.29)	(-1.29)	(-1.32)
DEVELOPEDSHARE	-5.983**	-6.375***	-14.69****	-8.257**	-8.164**	-8.164**	-7.771**
	(-2.28)	(-2.64)	(-4.21)	(-2.43)	(-2.40)	(-2.40)	(-2.27)
WETLANDSSHRUBLANDSSHARE	-10.66****	-11.52****	-11.58***	-7.413**	-7.704**	-7.704**	-7.395**
	(-3.64)	(-4.00)	(-3.04)	(-2.31)	(-2.37)	(-2.37)	(-2.24)
FORESTTREESSHARE	-9.995**	-8.514**	-10.96**	-2.997	-3.123	-3.123	-2.828
	(-2.46)	(-2.14)	(-2.49)	(-0.70)	(-0.73)	(-0.73)	(-0.66)
CORNSHARE	0.387	0.511	0.288	0.409	0.444	0.444	0.405
	(0.46)	(0.59)	(0.30)	(0.42)	(0.45)	(0.45)	(0.41)
GRASSPASTURESHARE	-4.957***	-5.587***	-3.708*	-3.640*	-3.664*	-3.664*	-3.568*
	(-2.76)	(-3.11)	(-1.75)	(-1.76)	(-1.77)	(-1.77)	(-1.71)
OTHERCROPSSHARE	-4.030	-4.615*	-1.464	-2.517	-2.404	-2.404	-2.384
	(-1.65)	(-1.87)	(-0.50)	(-0.86)	(-0.83)	(-0.83)	(-0.82)
PerCRPofCrops		-9.670***	-6.666**	-5.168**	-5.164**	-5.164**	-5.152**
		(-3.27)	(-2.61)	(-2.48)	(-2.47)	(-2.47)	(-2.45)
PerCornCRP			-0.000581**	-0.000278	-0.000263	-0.000263	-0.000254
			(-2.00)	(-0.84)	(-0.79)	(-0.79)	(-0.77)
PerGrassPastureCRP			-0.000839****	-0.000792****	-0.000785****	-0.000785****	-0.000781****
			(-4.76)	(-3.90)	(-3.86)	(-3.86)	(-3.81)
PerForestTreesCRP			0.000249	0.00193	0.00198	0.00198	0.00201
			(0.16)	(1.36)	(1.39)	(1.39)	(1.41)
PerWetlandsShrublandsCRP			-0.000853***	-0.000767***	-0.000759***	-0.000759***	-0.000776***
			(-3.16)	(-3.06)	(-3.04)	(-3.04)	(-3.05)
PerWaterCRP			-0.000882	-0.00138	-0.00143	-0.00143	-0.00136
			(-0.60)	(-1.02)	(-1.05)	(-1.05)	(-1.01)
PerDevelopedCRP			0.00279	0.00277	0.00285	0.00285	0.00284
			(1.31)	(1.15)	(1.19)	(1.19)	(1.16)
PerOtherCropsCRP			-0.00102**	-0.00118**	-0.00119**	-0.00119**	-0.00116**
			(-2.27)	(-2.46)	(-2.50)	(-2.50)	(-2.40)
Fall_Precip				-0.0794****	-0.0810****	-0.0810****	-0.0806****
				(-4.16)	(-4.19)	(-4.19)	(-4.15)
Winter_Precip				-0.0435*	-0.0474**	-0.0474**	-0.0481**
				(-1.95)	(-2.08)	(-2.08)	(-2.12)
Spring_Precip				0.0369***	0.0367***	0.0367***	0.0353***
				(3.19)	(3.17)	(3.17)	(3.07)
Summer_Precip				0.0448****	0.0451****	0.0451****	0.0434****
				(6.79)	(6.85)	(6.85)	(6.44)
CAFO					0.581***	0.581***	0.543**
					(2.72)	(2.72)	(2.50)
Alfisols						0	0
						(.)	(.)
Entisols						0	0
						(.)	(.)
Inceptisols						0	0
						(.)	(.)
Mollisols						0	0
						(.)	(.)
NoData						0	0
						(.)	(.)
Iowa LL Lake Depth							0.0665
							(0.95)
Constant	10.92****	10.80****	10.79****	7.580****	7.349****	7.349****	6.954****
	(7.64)	(7.75)	(7.01)	(5.02)	(4.89)	(4.89)	(4.29)
Observations	765	747	570	570	570	570	570
t statistics in parentheses	* p<0.10	** p<0.05	*** p<0.01	**** p<0.001			

Of all four lake water characteristics, nitrogen is the only one where the percentage of CRP as crops is significant and has the result that a higher percentage of CRP leads to a decrease in the level of nitrogen in the lakes in both fixed effects and random effects models. The increase in the amount of CRP in a lake watershed by 1% would lead to a decrease in the amount of nitrogen in the respective lake by 515%.

An increase in the share of wetlands and shrublands and the share of grass pasture can lead to a decrease in the amount of nitrogen in the lakes. Similarly, an increase in the percent CRP as wetlands shrublands and the percent CRP as grass pasture can lead to a decrease in the amount of nitrogen in the lakes. An increase in the amount of CRP identified as wetlands would decrease the amount of nitrogen by .000776%. Wetlands are well known for their role in removing nitrogen, particularly nitrates, from agricultural drainage (Driscoll et al., 2003). Similarly, an increase in the amount of CRP identified as grass pasture would decrease the amount of nitrogen by .000781%.

Precipitation during all seasons is significant in both fixed effects and random effects models. During the fall and winter, an increase in precipitation, generally in the form of snow pack, leads to a decrease in nitrogen, since less nitrogen is applied during this time and the snow leads to a decrease in runoff. During the spring and summer an increase in precipitation from rainfall leads to an increase in nitrogen in the lakes compounded by an increase in the application of nitrogen-based fertilizers. The average precipitation during the fall and winter over the study period were 2.41 mm and 1.34 mm respectively. The average precipitation during the spring and summer during the study period were 3.60 mm and 5.00 mm respectively.

CAFOs are significant such that an increase in the number of CAFOs will lead to an increase in the amount of nitrogen. Manure runoff from discharging CAFOs often reaches surface water systems through surface runoff or infiltration. In 2007, the estimated animal manure in Iowa was 398,551 (1000 kg of N), higher than any other state besides Texas (United States Environmental Protection Agency, n.d.).

Table 4. Chlorophyll a, Fixed Effects

	(1) lnchlorophyll a	(2) lnchlorophyll a	(3) lnchlorophyll a	(4) lnchlorophyll a	(5) lnchlorophyll a	(6) lnchlorophyll a	(7) lnchlorophyll a
WATERSHARE	4.010	3.276	5.277	3.880	3.877	3.877	4.093
	(1.31)	(1.02)	(1.31)	(1.03)	(1.03)	(1.03)	(1.12)
DEVELOPEDSHARE	2.777**	2.275*	8.331***	7.497***	7.500***	7.500***	7.219***
	(2.23)	(1.84)	(3.37)	(3.20)	(3.20)	(3.20)	(3.07)
WETLANDSSHRUBLANDSSHARE	3.015**	3.023*	3.097	3.114	3.106	3.106	2.885
	(2.05)	(1.95)	(1.41)	(1.41)	(1.40)	(1.40)	(1.31)
FORESTTREESSHARE	2.774	2.541	5.007**	3.306	3.302	3.302	3.091
	(1.65)	(1.44)	(2.02)	(1.50)	(1.49)	(1.49)	(1.38)
CORNSHARE	0.0287	0.0148	-0.420	-0.333	-0.332	-0.332	-0.304
	(0.08)	(0.04)	(-0.78)	(-0.60)	(-0.60)	(-0.60)	(-0.54)
GRASSPASTURESHARE	1.672	1.086	0.431	1.577	1.576	1.576	1.508
	(1.60)	(1.09)	(0.36)	(1.25)	(1.25)	(1.25)	(1.20)
OTHERCROPSSHARE	2.950**	2.239	2.046	3.292*	3.295*	3.295*	3.281*
	(2.07)	(1.58)	(1.18)	(1.75)	(1.75)	(1.75)	(1.74)
PerCRPofCrops		0.446	-0.672	-1.200	-1.200	-1.200	-1.209
		(0.36)	(-0.41)	(-0.85)	(-0.85)	(-0.85)	(-0.86)
PerCornCRP			-0.000396**	-0.000429**	-0.000428**	-0.000428**	-0.000435**
			(-2.03)	(-2.09)	(-2.09)	(-2.09)	(-2.06)
PerGrassPastureCRP			0.000190*	0.000132	0.000132	0.000132	0.000129
			(1.82)	(1.23)	(1.23)	(1.23)	(1.21)
PerForestTreesCRP			0.00156	0.00107	0.00107	0.00107	0.00105
			(1.37)	(0.96)	(0.96)	(0.96)	(0.95)
PerWetlandsShrublandsCRP			-0.000130	-0.000176	-0.000176	-0.000176	-0.000164
			(-0.53)	(-0.74)	(-0.74)	(-0.74)	(-0.69)
PerWaterCRP			-0.00189*	-0.00119	-0.00119	-0.00119	-0.00124
			(-1.86)	(-1.17)	(-1.17)	(-1.17)	(-1.21)
PerDevelopedCRP			-0.000563	-0.000428	-0.000425	-0.000425	-0.000421
			(-0.21)	(-0.17)	(-0.17)	(-0.17)	(-0.17)
PerOtherCropsCRP			-0.0000559	-0.0000820	-0.0000825	-0.0000825	-0.000107
			(-0.20)	(-0.30)	(-0.30)	(-0.30)	(-0.39)
Fall_Precip				-0.00426	-0.00430	-0.00430	-0.00458
				(-0.42)	(-0.42)	(-0.42)	(-0.45)
Winter_Precip				0.0579****	0.0578****	0.0578****	0.0583****
				(3.68)	(3.61)	(3.61)	(3.63)
Spring_Precip				-0.0217***	-0.0217***	-0.0217***	-0.0207***
				(-3.04)	(-3.03)	(-3.03)	(-2.87)
Summer_Precip				-0.00776*	-0.00775*	-0.00775*	-0.00654
				(-1.88)	(-1.87)	(-1.87)	(-1.57)
CAFO					0.0167	0.0167	0.0433
					(0.13)	(0.13)	(0.30)
Alfisols						0	0
						(.)	(.)
Entisols						0	0
						(.)	(.)
Inceptisols						0	0
						(.)	(.)
Mollisols						0	0
						(.)	(.)
NoData						0	0
						(.)	(.)
Iowa LL Lake Depth							-0.0476
							(-1.32)
Constant	1.577*	1.909**	1.228	1.657	1.650	1.650	1.933*
	(1.92)	(2.26)	(1.19)	(1.63)	(1.63)	(1.63)	(1.88)
Observations	765	747	570	570	570	570	570
t statistics in parentheses	* p<0.10	** p<0.05	*** p<0.01	**** p<0.001			

For chlorophyll a, the percent of corn as CRP is highly significant in both fixed effects and random effects models. An increase in the amount of land that is enrolled in CRP and identified as corn by the USDA CDL leads to a decrease in the amount of chlorophyll a in the lakes. CRP is picked up as corn because particular CRP practices such as filter strips are only 3-4 meters across and thus not picked up by the satellite. This is further investigated in the Discussion section of this chapter.

Winter and spring precipitation are highly significant in both fixed effects and random effects models. Winter precipitation leads to an increase in chlorophyll a. In the winter months, a 1 mm increase in average precipitation will increase the amount of chlorophyll a in the lakes on average 5.83%. In contrast, during the spring months, a 1 mm increase in average precipitation will decrease the amount of chlorophyll a in the lakes by 2.07%.

Shares of land in the natural cover forest and trees is significant only in the random effects model. This means that as there is an increase in the share of forest and trees in the lake watersheds, there is a decrease in the amount of chlorophyll a in the lakes.

While not significant in the fixed effects model, in the random effects model entisols are highly significant. Since entisols possess less developed soil horizons they are unlikely to be good fit for crops, as such if there was a natural land cover above entisols it would lead to a decrease in runoff, reducing the amount of chlorophyll a in the lakes. Lastly, lake depth is highly significant in the random effects model – the deeper the lake the lower the amount of chlorophyll a found in the lake. An increase in lake depth by 1 meter will lead to a decrease in the amount of chlorophyll a in the lakes by 4.76%.

Table 5. Turbidity (Secchi Depth), Fixed Effects

	(1) lnsecchidepth	(2) lnsecchidepth	(3) lnsecchidepth	(4) lnsecchidepth	(5) lnsecchidepth	(6) lnsecchidepth	(7) lnsecchidepth
WATERSHARE	1.864	1.450	-1.555	-1.202	-1.206	-1.206	-1.390
	(0.69)	(0.50)	(-0.36)	(-0.26)	(-0.26)	(-0.26)	(-0.31)
DEVELOPEDSHARE	-1.518**	-1.448*	-1.978	-1.009	-1.005	-1.005	-0.766
	(-2.22)	(-1.93)	(-0.74)	(-0.38)	(-0.38)	(-0.38)	(-0.29)
WETLANDSSHRUBLANDSSHARE	-0.483	-0.448	-1.133	-0.487	-0.498	-0.498	-0.310
	(-0.36)	(-0.33)	(-0.53)	(-0.22)	(-0.23)	(-0.23)	(-0.14)
FORESTTREESSHARE	3.139**	2.823*	1.961	3.154	3.148	3.148	3.329
	(2.08)	(1.83)	(0.94)	(1.46)	(1.45)	(1.45)	(1.53)
CORNSHARE	-0.109	-0.109	-0.00433	0.0500	0.0515	0.0515	0.0275
	(-0.37)	(-0.35)	(-0.01)	(0.13)	(0.13)	(0.13)	(0.07)
GRASSPASTURESHARE	-1.044	-0.932	-0.975	-1.040	-1.041	-1.041	-0.983
	(-1.51)	(-1.19)	(-0.97)	(-0.99)	(-0.99)	(-0.99)	(-0.94)
OTHERCROPSSHARE	-1.025	-0.931	-1.574	-1.472	-1.467	-1.467	-1.455
	(-1.10)	(-0.89)	(-1.08)	(-0.93)	(-0.93)	(-0.93)	(-0.93)
PerCRPofCrops		2.064	1.728	1.839	1.839	1.839	1.846
		(1.49)	(1.16)	(1.25)	(1.25)	(1.25)	(1.27)
PerCornCRP			0.000326*	0.000329*	0.000330*	0.000330*	0.000335*
			(1.89)	(1.82)	(1.82)	(1.82)	(1.89)
PerGrassPastureCRP			0.000165**	0.000169**	0.000169**	0.000169**	0.000172**
			(2.31)	(2.36)	(2.36)	(2.36)	(2.43)
PerForestTreesCRP			0.000906	0.00103	0.00103	0.00103	0.00105
			(1.24)	(1.38)	(1.38)	(1.38)	(1.46)
PerWetlandsShrublandsCRP			0.000298*	0.000294*	0.000295*	0.000295*	0.000284*
			(1.86)	(1.84)	(1.84)	(1.84)	(1.79)
PerWaterCRP			0.00202**	0.00159*	0.00159*	0.00159*	0.00164*
			(2.33)	(1.78)	(1.78)	(1.78)	(1.80)
PerDevelopedCRP			-0.00132	-0.00138	-0.00138	-0.00138	-0.00138
			(-1.24)	(-1.32)	(-1.32)	(-1.32)	(-1.35)
PerOtherCropsCRP			0.000296	0.000287	0.000286	0.000286	0.000307
			(1.61)	(1.51)	(1.51)	(1.51)	(1.65)
Fall_Precip				0.00671	0.00664	0.00664	0.00688
				(0.79)	(0.78)	(0.78)	(0.81)
Winter_Precip				-0.0202*	-0.0203*	-0.0203*	-0.0208*
				(-1.85)	(-1.82)	(-1.82)	(-1.85)
Spring_Precip				0.00160	0.00159	0.00159	0.000754
				(0.23)	(0.23)	(0.23)	(0.11)
Summer_Precip				0.00418	0.00419	0.00419	0.00316
				(1.22)	(1.22)	(1.22)	(0.94)
CAFO					0.0238	0.0238	0.00103
					(0.18)	(0.18)	(0.01)
Alfisols						0	0
						(.)	(.)
Entisols						0	0
						(.)	(.)
Inceptisols						0	0
						(.)	(.)
Mollisols						0	0
						(.)	(.)
NoData						0	0
						(.)	(.)
Iowa LL Lake Depth							0.0406
							(1.35)
Constant	-0.456	-0.428	0.0472	-0.291	-0.300	-0.300	-0.541
	(-0.81)	(-0.69)	(0.06)	(-0.33)	(-0.34)	(-0.34)	(-0.63)
Observations	765	747	570	570	570	570	570
t statistics in parentheses	* p<0.10	** p<0.05	*** p<0.01	**** p<0.001			

When lake water transparency is high, the secchi depth is high. Secchi depth is measured the opposite of nitrogen, phosphorus, and chlorophyll a. This means that a positive result for a right-hand side variable has the effect of decreasing turbidity.

Corn identified as CRP for turbidity yields a similar result to chlorophyll a, which remains to be highly significant in both fixed effects and random effects models, with an increase of land cover going into conservation through CRP and identified as corn reducing turbidity. A 1% increase in the amount of CRP identified as corn will lead to a decrease in turbidity by 0.000335%, a small yet significant amount.

Turbidity is the only lake water quality characteristic where water, grass pasture, and wetlands shrublands identified as CRP are all significant. A 1% increase in the amount of CRP identified as water will lead to a decrease in turbidity by 0.00164%. This is for a similar reason to corn – land in CRP that is small and acting as a buffer is picked up by the satellite as water instead of CRP.

A 1% increase in the amount of CRP identified as wetlands shrublands will lead to a decrease in turbidity by 0.00284%. A 1% increase in the amount of CRP identified as grass pasture will lead to a decrease in turbidity by 0.000172%. Grass buffers have been shown to effectively provide reduction in runoff and sedimentation (Mankin et al., 2007).

All four – corn, water, grass pasture, and wetlands shrublands – identified as CRP are significant in both the random effects and fixed effects models. This means that one of the most critical opportunities for reducing turbidity is to put land into CRP to act as a buffer around the water bodies that feed into the lakes or the lakes themselves.

Unlike chlorophyll a, inceptisols are significant in the random effects model and have the result of reducing turbidity. In chlorophyll a, entisols were significant and reduced the amount of chlorophyll a. Yet both inceptisols and entisols do not have highly defined soil horizons and thus inceptisols have the result of reducing turbidity for the same reason that entisols reduce the amount of chlorophyll a in the lakes – the land cover above the soil is likely to be a natural cover that reduces erosion thus decreases the turbidity in the lakes.

Turbidity is the only water quality variable where precipitation does not seem to have an impact. A similar result (Kebede et al., 2006) found that low sensitivity of lakes to rainfall is typical for lakes with significant outflow. Lake depth is also highly significant in the random effects model – increasing lake depth leads to a decrease in turbidity. This is a similar result to a study of lakes done in the 1990s - lake mean depth held the most promise with respect to water quality prediction (Hatch, 1992).

Discussion and Conclusions

The results of our analysis demonstrate that land cover and CRP have different impacts on different indicators of lake water quality. CRP does not appear to have a major impact on phosphorus. None of the models estimated revealed a significant association between CRP practices and the level of phosphorus in the lakes between 2010 and 2015. This is not completely surprisingly since oftentimes phosphorus attaches to sediment and is not displaced in water. Phosphorus already accumulated within some watershed systems is such that even if phosphorus was no longer added to agricultural systems, there would be a considerable time-lag before improvements in water quality, or regeneration of diverse habitats, might become apparent. For example, construction of small wetlands to trap phosphorus in agricultural drainage waters of central Switzerland only retained 2% of the bioavailable phosphorus input (Sharpley et al., 2009).

While little results were found for phosphorus, increasing the amount of forests and trees in lake watersheds could have a positive impact. Since the number of conservation practices implemented in Iowa that includes trees is minimal, more cost-effective improvements can be taken for the other three lake water quality characteristics.

The story is different for the other three lake water quality characteristics. There exists a particularly strong association between the amount of land enrolled in CRP in the lake watersheds and nitrogen in the lakes. Nitrogen in the lakes derives from both CAFOs and cultivated land. So, CRP practices addressing either source would be expected to have a positive effect on lake quality. According to the results, the largest reduction in nitrogen would come from increasing the amount of land enrolled in CRP in the lake watersheds.

Amount of land in CRP had a positive impact on decreasing nitrogen. This is extremely critical since as of 2018 55% of the nitrogen load in the Missouri River comes from Iowa (Eller, 2018). In 2018, Iowa invested $420 million in those water quality improvements, including helping farmers plant cover crops, build terraces and tackle other conservation practices that hold nutrients in place.

Assessments of conservation practice impacts on reducing nitrogen and phosphorus contamination of Iowa’s surface waters reveal generally positive long-term impacts with wide ranges of impacts in the short-term (annually to single precipitation events) (Dinnes, 2004). Conflicting effects can also occur between nitrogen and phosphorus for a given conservation practice. Some forms are more potent in causing eutrophication than others, such as dissolved reactive phosphorus being more available for algae growth than particulate phosphorus.

Chlorophyll a, similar to phosphorus, is not improved by land covers or much of CRP, but there is a noticeable improvement in the level of chlorophyll a from CRP identified as corn. Corn identified as CRP is known to take the form of filter strips on the landscape. Chlorophyll a also seems to have a similar story for forests and trees utilizing the lens of the random effects model. Turbidity is impacted by the most types of land covers identified as CRP, but the impact was smaller.

Riparian buffers and wetlands may do little to reduce nutrient and sediment losses if they receive water volumes and nutrient loads beyond their capacity to treat due to the absence of other conservation practices within a contributing drainage area. This may be particularly true if concentrated flow frequently occurs from peak precipitation events. In such instances it is not the conservation practice that failed: the failure was due to not having designed and implemented a comprehensive conservation management plan (Dinnes, 2004). Strategies to reduce nitrogen and phosphorus losses may require the application of different conservation practices for the two nutrients.

PES contracts frequently look at whether payment led to a change in practice, not whether a change in practice had the desired impact on water quality. This is often due to a lack of baseline data, funds for monitoring, and a long enough time series to see an impact.

Two major disadvantages of conservation practices are that they are very costly to taxpayers and that in the decades that this model has been in use it has rarely achieved adoption at scales sufficient enough to significantly improve water quality (Dinnes, 2004).

We want to focus on the practices that do have an impact on water quality improvement. Those that do and are cost-effective are great targets for the USDA to promote. This will be directly addressed in the next chapter.

CHAPTER 3: IDENTIFYING COST-EFFECTIVE APPROACHES FOR TARGETED IMPROVEMENT OF WATER QUALITY FOR IOWA'S LAKES THROUGH THE USDA'S CONSERVATION RESERVE PROGRAM

Introduction

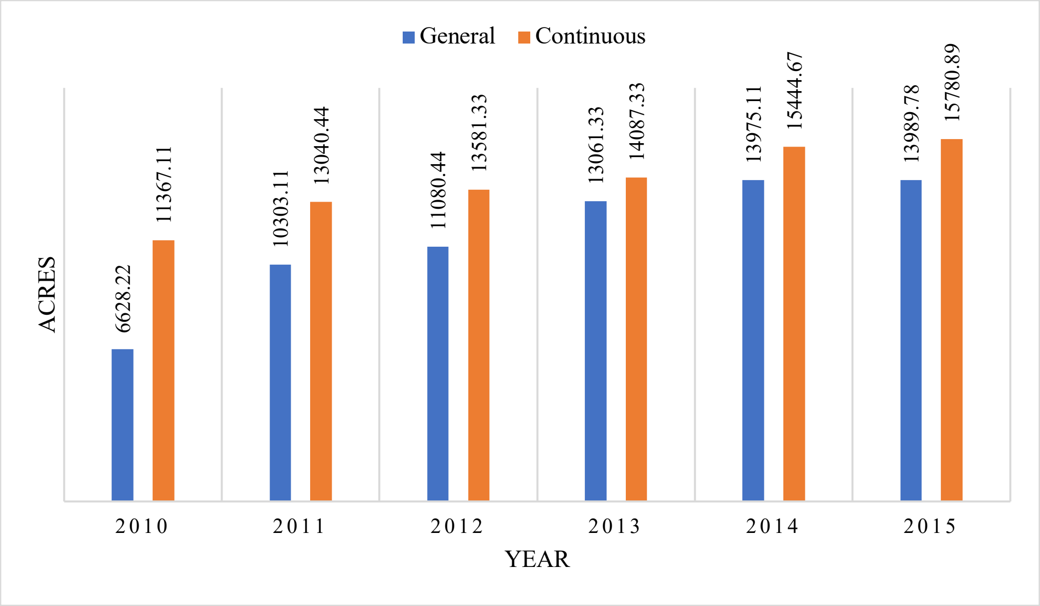
In the CRP a wide range of practices are used to enhance the provision of a specified set of ecosystem services (Table 6). In principle, the cost-effectiveness of service provision is assured by the sign-up mechanisms applied. Currently, there are two ways farmers can sign up to participate in the CRP: 'general sign-up' and 'continuous sign-up'. General sign-up includes mechanisms designed to assure cost-effective provision of services of uncertain value. Continuous sign-up has no mechanisms for cost-effectiveness but is restricted to services thought to be of high value.

Across the United States as a whole, the dominant form of sign-up is general. General sign-up has periods that are announced for when farmers can enroll. During sign-up, farmers submit offers for the amounts they are willing to accept to enroll acreage in the CRP. County Natural Resources Conservation Service (NRCS) offices calculate the maximum acceptable rental rate for the acreage being submitted (maximum payment rate) and offers are ranked at the national office using an environmental benefits index (EBI). According to the Farm Service Agency (FSA), offers selected are those that provide the greatest environmental benefits considering the cost of enrolling the acreage in the program (United States Department of Agriculture Farm Service Agency, 2015).

For continuous sign-up, farmers can enroll at any time. The practices available during general sign-up generally provide high environmental benefits to large areas when compared to the acreage on which the practice is implemented. The continuous sign-up process does not have a competitive evaluation process, and aims to enroll small, environmentally sensitive areas and target acreage (United States Department of Agriculture Farm Service Agency, 2015). The presumption is that continuous practices generate disproportionate benefits and as such do not need to go through a more formal process (R. Iovanna, personal communication, April 26, 2018). Appendix B provides a table of all of the conservation practices and what type of enrollment they fall under.

Interestingly, sign-up patterns in the study area, Iowa, are different from sign-up patterns in the Unites States more generally. Continuous sign-up enrollments account for only 25% of the acreage under CRP contract across the United States (Hellerstein, 2017). By contrast, continuous sign-up enrollments account for more than 50% of CRP acreage in Iowa. The share of continuous sign-up enrollments has been declining in Iowa. In 2010, 63% of land in CRP was in continuous sign-up, while in 2015 the share had fallen to 53% (see Figure 3). Regardless, it is still significantly above the national percentage of continuous sign-up land.

Figure 3. Number of Acres Enrolled in General and Continuous Sign-up in Iowa



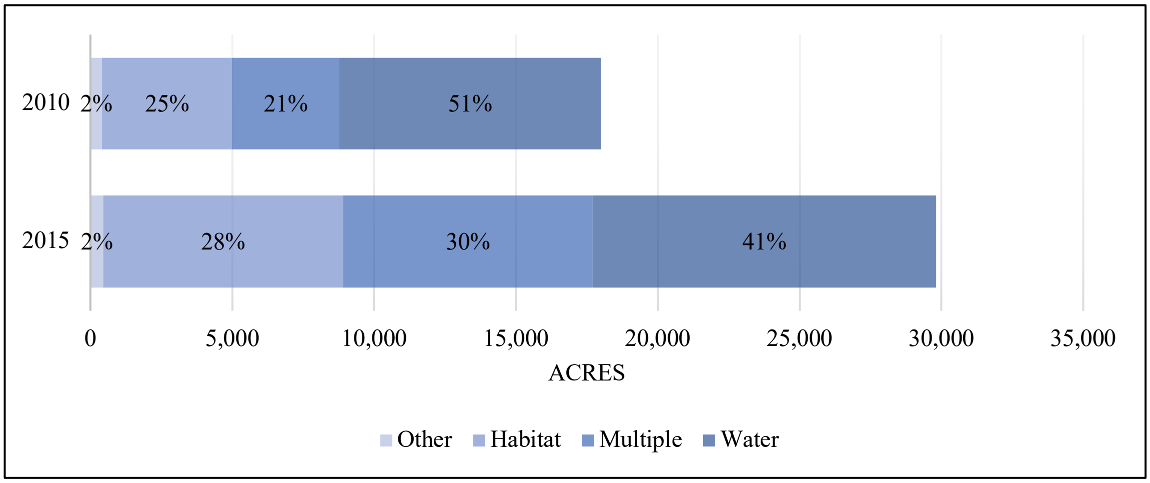
This chapter evaluates the cost-effectiveness of CRP practices in Iowa that target water quality, either alone or in combination with other environmental objectives. Since many of the outcomes associated with different CRP practices overlap there are limits to the conclusions that can be drawn about the cost-effectiveness of practices generating multiple benefits, but for more targeted practices, we are able to say which achieves a given increment in service provision at least cost. The 43 conservation practices included in this analysis were grouped into six categories based on the purported benefits (see Table 6 below). The information to group the conservation practices comes from the internal FSA CRP handbook (United States Department of Agriculture Farm Service Agency, 2015).

Table 6. Benefits and CRP Practices

Benefit	CRP Practices
Multiple benefits	CP1, CP2, CP3, CP3A, CP10, CP11, CP31
Habitat	CP4B, CP4D, CP9, CP12, CP25, CP33, CP36, CP37, CP38A, CP38B, CP38C, CP38D, CP38E, CP42
Erosion	CP5A, CP17A, CP17, CP24
Water Quality	CP8A, CP8, CP15A, CP15B, CP21, CP22, CP23, CP23A, CP27, CP28, CP29, CP30, CP39, CP40, CP41
Other	CP16A, CP18B, CP18C

There are two ways to look at the change in conservation practices over time. The first looks at change in acres over time. From Figure 4 it is clear that there was an increase in acres for all of the conservation practice groups. The second looks at the percentage of shares over time. There is a slight increase in shares of habitat conservation practices from 25% to 28%, an increase in multiple benefit conservation practices from 21% to 30%, and a decrease in shares of water targeted conservation practices from 51% to 41% between 2010 and 2015.

Figure 4. Acres and Shares in Conservation Practices



Within the grouped conservation practices, there is significant variation in the change in acres. Figures 5, 6, and 7, demonstrate the change in acres relative to 2010. For example, in the water targeted conservation practices, CP8A (Grass Waterways, Noneasement) doubled in acres while CP29 (Marginal Pastureland Wildlife Habitat Buffer) stayed relatively constant between 2010 and 2015.

Figure 5. Water Targeted Conservation Practices (Change in Acres, 2010 to 2015)

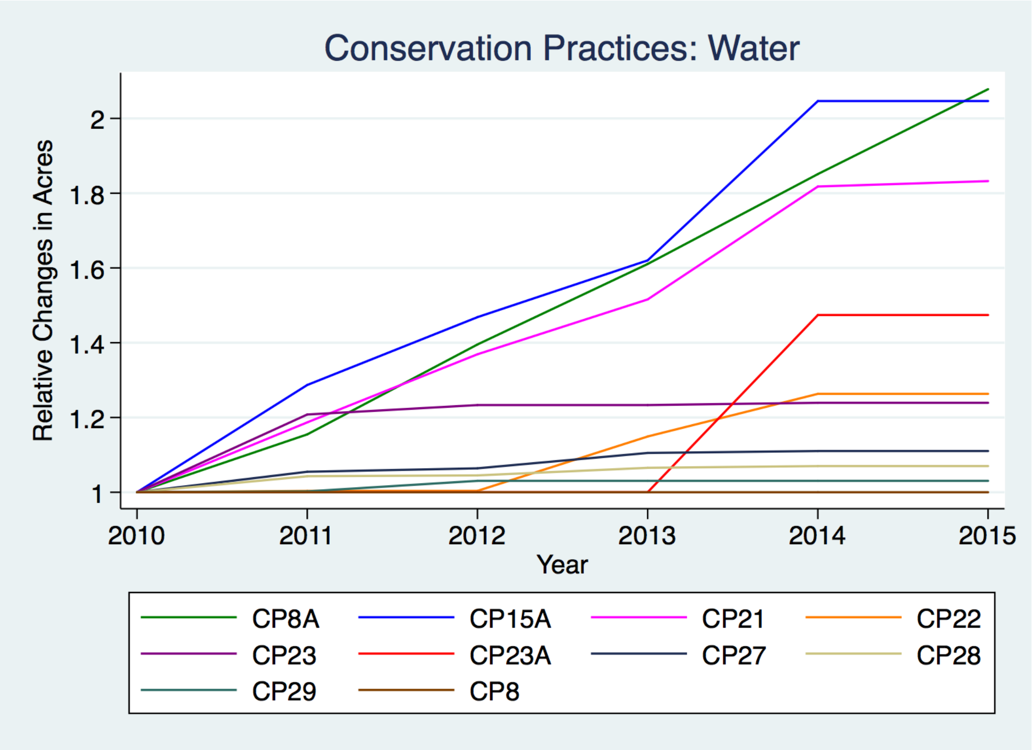


Figure 6. Multiple Environmental Targeted Conservation Practices (Change in Acres, 2010 to 2015)

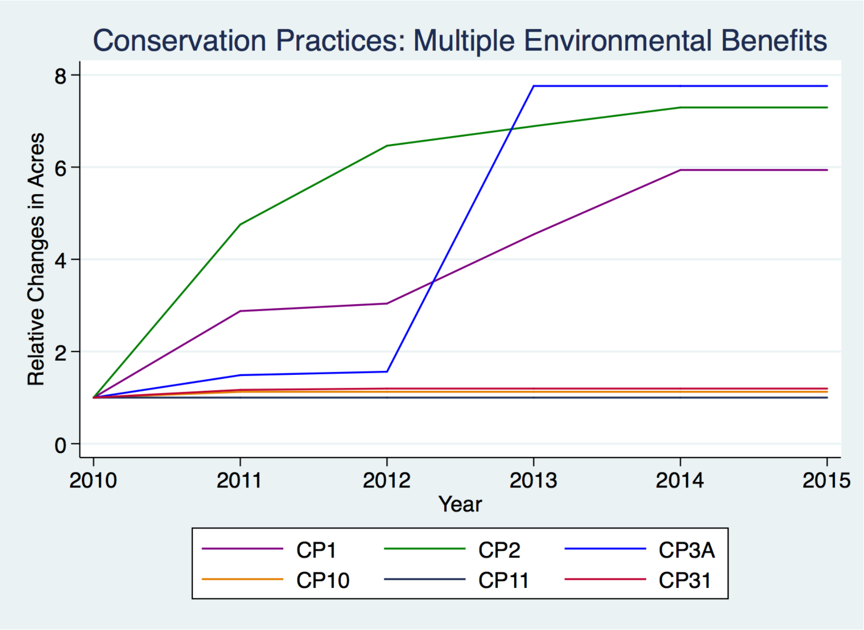
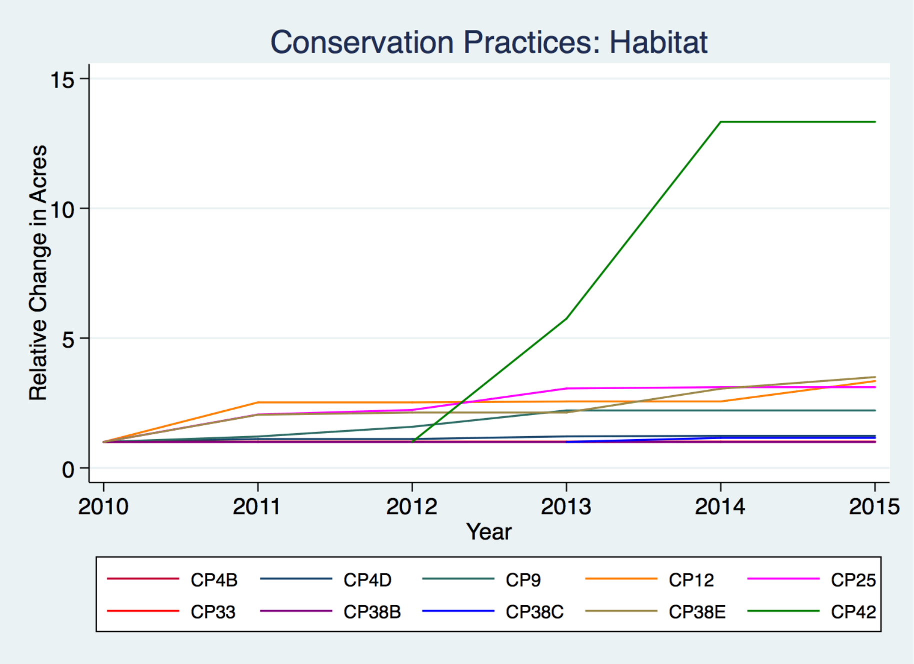


Figure 7. Habitat Targeted Conservation Practices (Change in Acres, 2010 to 2015)



In what follows we utilize inter-annual variability in water quality measures and enrollment in different CRP conservation practices to examine the cost-effectiveness of specific conservation practices in mitigating lake sedimentation and eutrophication. Section 2 identifies sources that were utilized to obtain the necessary data for the various analyses. It also addresses the model specification and a justification for the different estimators applied, ultimately using fixed effects and an Arellano-Bond estimator for the core analysis. Section 3 focuses on the main results for the most cost-effective conservation practices for the four lake water quality characteristics. Section 4 discusses the importance of the four water quality variables and the most cost-effective CRP practices for water quality improvement. Section 5 concludes with a discussion on cost-effectiveness of the CRP and conservation practices.

Data and Methods

Data

The Iowa State Limnology Lab has consistently measured lake water quality characteristics three times during the summer (between June and September) since 2000. For this study, the average of the three samples was calculated. The key water quality variables identified for 136 lakes for 2010-2015 were turbidity as secchi disk depth (m), chlorophyll a (µg/L), total phosphorus as P (µg/L), and (Phenate) Ammonia Nitrogen ($NH3 + NH4+$) as N (µg/L). Table 7 demonstrates the current averages for the four lake water quality variables and the thresholds that would likely result in algae blooms and health of fish populations. Chlorophyll a, phosphorus, and nitrogen are above the thresholds for harmful impact.

Table 7. Current Averages and Thresholds for Lake Water Quality Variables

Water Quality Variable	Current Average	Threshold
Turbidity (Secchi depth, meters)	1.08 meters	1 meter
Chlorophyll a (µg/L)	39.28 µg/L	20-25 µg/L
Total Phosphorus (µg/L)	108.41 µg/L	35 µg/L
(Phenate)Ammonia Nitrogen ($NH3 + NH4^+$) (µg/L)	108.52 µg/L	20-40 µg/L

Sources: (Burkart et al., 2008, 2004; Corporation, 2006; United States Environmental Protection Agency, 2018)

Additional information on soil type was obtained from the U.S. Natural Resources Conservation Service Soil Survey Geographic 2014 and monthly precipitation information was gathered from the Iowa State Iowa Environmental Mesonet Climate Monitoring Stations. The closest weather station to each lake centroid was used; if there were two weather stations that were equidistant then the data was averaged. This information was grouped into seasonal precipitation. Information on the location of Confined Animal Feeding Operations (CAFOs) was obtained from Iowa Department of Natural Resources Animal Feeding Operations Database from 2006 to 2007 as point data. It is assumed that the location of the CAFOs is fixed through the study period.

Data on land enrolled in CRP and information on specific conservation practices were provided as a geodatabase from the USDA FSA of land that entered into CRP between 2010 and 2015. Specifically, these were shapefiles of land that entered into CRP through general and continuous sign-up each year as well as those whose contracts ended. Amount paid to farmers on a per acre per conservation practice per year basis was provided by the

USDA FSA. Values were averaged by conservation practice to identify the amount paid to farmers per acre on a yearly basis.

Raster level data (30m x 30m) for Iowa on land use cover was obtained from the USDA's National Agricultural Statistics Service. This dataset is a combination of information on crops from the USDA and land cover from the USGS National Land Cover Database. Shapefiles for lakes and lake watersheds were obtained from the Iowa State Department of Natural Resources. All spatial data were converted to a non-spatial format using QGIS and Python.

Model Specification

Equation 1. Generalized Model

$$\mathrm{Log}(Y_{lt}) = \boldsymbol{\theta}_{\mathbf{lt}} + \beta_1\mathbf{X}_{\mathbf{1t}} + \beta_2\mathbf{X}_{\mathbf{2t}} + \beta_3\mathbf{X}_{\mathbf{3t}} + \beta_4\mathbf{X}_{\mathbf{4}} + \beta_5\mathbf{X}_{\mathbf{5}} + \beta_6\mathbf{X}_{\mathbf{6}} + \boldsymbol{\varepsilon}_{\mathbf{lt}} + \boldsymbol{\varepsilon}_{\mathbf{l}}$$

Key independent variables were included in the regression analysis. $\mathbf{X}_{\mathbf{1t}}$ is an acre-based variable of the conservation practices. This is key to understanding the role that each individual conservation practice has on the lake water quality variables. $\mathbf{X}_{\mathbf{2t}}$ is land cover in acres grouped into seven categories - water, development, corn, other crops, wetlands and shrublands, forests and trees, and grass pasture. Soy was omitted as the base for analysis. Land cover was included in the model to be able to hold fixed the changes in land covers as land is going in and out of CRP practices. Land covers across the landscape have demonstrated both positive and negative impacts on lake water quality (Reed and Carpenter, 2002). $\mathbf{X_{3t}}$ introduces precipitation (millimeters) that was averaged from monthly data. Precipitation was broken up into the four seasons since the frequency and duration of precipitation during the year changes greatly. The impact of snow pack in the winter months was thought to have a different impact on lake water quality than spring and summer rains (Hoering, 2010; Rose et al., 2004). $\mathbf{X_4}$ is a dummy variable for the presence of concentrated animal feeding operations (CAFOs). Fertilizer runoff from CAFOs is known to contain high levels of nitrogen and phosphorus (Burkholder et al., 2007; Hribar, 2010). While Iowa has put restrictions in place to regulate the amount of runoff, this remains important because of the quantity of operations in the state. This was put in as a dummy variable because there is only data on CAFOs for one year. In addition, there is no available information on the size of the CAFOs. Soil type ($\mathbf{X_5}$) is the dominant soil type on a 30m x 30m pixel scale. It is written about consistently in the literature as having an impact on lake water quality (Detenbeck ' et al., 1993; Sharpley, A.N., Chapra, S.C., Wedepohl, R., Sims, J.T., Daniel, T.C. and Reddy, 1994) and as such is included as a critical independent variable. Soil type may be a proxy for two different variables: 1. The land cover that is able to grow on top of a particular soil and 2. The likelihood that a particular soil type contributes to an increase or decrease in runoff. Lastly, lake depth ($\mathbf{X_6}$), is measured in meters, an average of 3 samples during summer annually. It is included since it has been identified as a key variable in understanding lake water quality due to mixing that occurs within lakes and the distinct limnology of deep versus shallow lakes (University of Wisconsin, 2016). In addition, lake depth varies considerably in Iowa. The lakes in northern Iowa near Minnesota are glacial lakes and are much deeper than the manmade lakes that exist throughout the rest of the Iowa.

Estimators

For all four water quality variables the Hausman and robust Hausman tests were run. Each one rejected the null hypothesis, concluding that the random effects models would not be appropriate. A fixed effects approach was utilized focusing on the 'within' estimation.

We had reason to believe lags were appropriate to include in our analysis. Oftentimes even after a conservation practice is introduced there may be a delay in seeing the results of it, particularly for lake water quality (Meals et al., 2010). In addition, water quality variables are known to operate on different time scales. For example, phosphorus operates on slower time scales than nitrogen. When fertilizer or manure phosphate contacts soil, various reactions begin occurring that make the phosphate less soluble and less available (Pagliari et al., 2017).

Since the results of fixed effects with a lag are biased and inconsistent, this information was not included in the analysis (Nickell, 1981). This led us to investigate the Arellano-Bond estimator since through Arellano-Bond consistent estimators can be obtained utilizing past lags for IV estimation by first differencing (Cameron and Trivedi, 2009). In order to avoid an endogeneity problem, the differenced unobserved time-invariant component of the Arrellano-Bond estimator should be unrelated to the second lag of the dependent variable and the lags thereafter. For the Arellano-Bond estimator the test for the critical assumption of no error correlation as well as the test for overidentifying restrictions was performed. All water quality variables passed the test for zero autocorrelation. Chlorophyll a and turbidity did not pass the test for overidentifying restrictions.

Comparing fixed effects and an Arellano-Bond estimator allowed us to think about the impact conservation practices that include grasses versus trees would have on lake water quality since it is believed that forest buffer zones over time have the potential to trap as much or more sediment as grasses. If we were to assume that dynamics do not matter than fixed effects would yield the most useful results and we would focus solely on contemporaneous practices.

Fixed effects and Arellano-Bond estimators were utilized to control for the effects of spatially omitted variables that influence water quality outcomes.

Results

The detailed results of the fixed effects and Arellano-Bond models are presented in Tables 8 through 15 reporting coefficients for each measure of water quality and the subsequent cost-effectiveness in dollars per microgram per liter or dollars per centimeter of water.

Conservation practices targeting water quality are those designed to have a positive impact on water quality. Conservation practices targeting other environmental benefits address erosion, habitat conservation or restoration, or a combination of environmental benefits. It is interesting to note that in almost all cases, practices aimed at other environmental benefits turn out to be more cost-effective in achieving water quality improvements than practices specifically targeting water quality.

Table 8. Phosphorus, Water Quality - Conservation Practices

		lntotalP		**Cost-Effectiveness ($/µg/L)**		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP8Aacre	Grass Waterways, Noneasement	-0.00806*** (.0027062)	-0.0155**** (.0028304)	285.25	148.33	Continuous
CP27acre	Farmable Wetlands Pilot Wetland		-0.0341** (.0153846)		67.24	Continuous
CP29acre	Marginal Pastureland Wildlife Habitat Buffer		-0.0342**** (.006309)		22.41	Continuous
CP28acre	Farmable Wetlands Pilot Buffer	-0.00497* (.0029012)	0.0577** (.0291523)	457.52	-39.41	Continuous
CP22acre	Riparian Buffer		0.0211**** (.0054734)		-59.56	Continuous

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are five water quality targeted conservation practices that bear a statistically significant relationship to changes in phosphorus. Of those, three reduce phosphorus, one increases phosphorus, and one flips signs between the fixed effects and the Arellano-Bond estimator. Of the three practices that demonstrate a reduction of phosphorus, *Marginal Pastureland Wildlife Habitat Buffer* is the most cost-effective utilizing the Arellano-Bond estimator.

Table 9. Phosphorus, Other Benefits - Conservation Practices

		lntotalP		**Cost-Effectiveness ($/μg/L)**		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP10acre	Vegetative Cover – Grass – Already Established		0.422** (.1898508)		-3.21	General
CP4Dacre	Permanent Wildlife Habitat, Noneasement	0.00434** (.0021611)	0.00957* (.0051423)	-292.73	-132.75	General
CP38Cacre	SAFE - Trees	0.0108* (.0062261)		-149.05		Continuous
CP42acre	Pollinator Habitat	0.0253**** (.0069301)	0.0378** (.0157364)	-73.28	-49.05	General and Continuous
CP17acre	Living Snow Fence	0.101 (.0156219)		-27.87		Continuous
CP33acre	Habitat Buffers for Upland Birds		-0.887** (.4054073)		1.99	Continuous
CP3Aacre	Hardwood Tree Planting		-0.0105**** (.0022366)		149.68	General
CP9acre	Shallow Water Areas for Wildlife	-0.0162** (.0063377)	-0.0189* (.0105352)	116.78	100.10	Continuous

t statistics * $p<0.10$ ** $p<0.05$ *** $p<0.01$ **** $p<0.001$

There are eight conservation practices targeted at other environmental benefits that bear a statistically significant relationship to changes in phosphorus. Of those, three are associated with reductions in phosphorus and five are associated with increases in phosphorus. Of the three practices associated with reductions in phosphorus, *Habitat Buffers for Upland Birds* is the most cost-effective utilizing the Arellano-Bond estimator.

Table 10. Nitrogen, Water Quality - Conservation Practices

		lntotalN		Cost-Effectiveness ($/µg/L)		
CP #	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP21acre	Filter Strips	-0.0138*** (.0048526)	-0.0233** (.00929)	167.45	99.18	Continuous
CP28acre	Farmable Wetlands Pilot Buffer		-0.127** (.0575695)		17.89	Continuous
CP15Aacre	Establishment of Permanent Vegetative Cover (Contour Grass Strips), Noneasement	-0.0714**** (.0143207)	-0.0928**** (.0202893)	25.41	19.55	Continuous
CP29acre	Marginal Pastureland Wildlife Habitat Buffer	-0.119**** (.0159608)	-0.103**** (.0172665)	6.43	7.43	Continuous
CP22acre	Riparian Buffer	0.0263*** (.0094622)	0.0535** (.0222663)	-47.74	-23.47	Continuous
CP27acre	Farmable Wetlands Pilot Wetland		0.114*** (.0385071)		-20.09	Continuous

t statistics * $p<0.10$ ** $p<0.05$ *** $p<0.01$ **** $p<0.001$

There are six water quality targeted conservation practices that bear a statistically significant relationship to changes in nitrogen. Of those, four reduce nitrogen and two increase nitrogen. Of the four practices that reduce nitrogen, *Marginal Pastureland Wildlife Habitat Buffer* is the most cost-effective utilizing the Arellano-Bond estimator.

Table 11. Nitrogen, Other Benefits - Conservation Practices

		lntotalN		Cost-Effectiveness ($/µg/L)		
CP #	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP38Cacre	SAFE – Trees	-0.0628**** (.014526)	0.105**** (.0394257)	25.61	-15.31	Continuous
CP12acre	Wildlife Food Plot		0.157*** (.0584005)		-9.20	General
CP5Aacre	Field Windbreak Establishment, Noneasement		0.311** (.129768)		-7.51	Continuous
CP17acre	Living Snow Fence	0.178**** (.0453416)	0.669** (.268843)	-15.80	-4.20	Continuous
CP31acre	Bottomland Timber Establishment on Wetlands		-2.986**** (.4467012)		0.77	Continuous
CP16Aacre	Shelterbelt Establishment, Noneasement		-1.328**** (.1783832)		1.54	Continuous
CP38Eacre	SAFE – Grass		-0.0117**** (.0020451)		162.87	Continuous
CP25acre	Rare and Declining Habitat		-0.00711** (.0031965)		218.52	General
CP1acre	Establishment of Permanent Introduced Grasses and Legumes	-0.00268** (.0011077)		598.24		General

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are nine conservation practices targeted at other environmental benefits that that bear a statistically significant relationship to changes in nitrogen. Of those, five are associated with reductions in nitrogen, three are associated with increases in nitrogen, and one flips signs between the fixed effects and the Arellano-Bond estimator. Of the five practices that are associated with a reduction in nitrogen, *Bottomland Timber Establishment on Wetlands* is the most cost-effective utilizing the Arellano-Bond estimator.

Table 12. Chlorophyll a, Water Quality - Conservation Practices

		lnchlorophylla		Cost-Effectiveness ($/µg/L)		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP29acre	Marginal Pastureland Wildlife Habitat Buffer	0.0366**** (.010645)		-57.33		Continuous
CP23acre	Wetland Restoration		0.0744*** (.0238162)		-78.07	Continuous

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are two water quality targeted conservation practices that that bear a statistically significant relationship to changes in chlorophyll a. Both are associated with an increase in chlorophyll a.

Table 13. Chlorophyll a, Other Benefits - Conservation Practices

		lnchlorophylla		Cost-Effectiveness ($/µg/L)		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP2acre	Establishment of Permanent Native Grasses		-0.00345* (.0017645)		1,229.81	General
CP31acre	Bottomland Timber Establishment on Wetlands		-0.641*** (.2258281)		9.88	Continuous
CP3Aacre	Hardwood Tree Planting	-0.0113**** (.0020413)	-0.0175**** (.0031915)	380.75	245.85	General
CP33acre	Habitat Buffers for Upland Birds		0.582** (.27607)		-8.32	Continuous
CP42acre	Pollinator Habitat	-0.0312**** (.0077805)		162.67		Continuous and General
CP12acre	Wildlife Food Plot	0.115** (.0465478)	0.144**** (.031649)	-34.43	-27.50	General
CP5Aacre	Field Windbreak Establishment, Noneasement	0.138*** (.0414169)	0.206**** (.0312934)	-46.36	-31.05	Continuous
CP38Cacre	SAFE - Trees	0.0506**** (.0086597)		-87.09		Continuous
CP9acre	Shallow Water Areas for Wildlife	0.0345*** (.0106725)		-150.11		Continuous

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are nine conservation practices target at other environmental benefits that bear a statistically significant relationship to changes in chlorophyll a. Of those, four are associated with reductions in chlorophyll a and five are associated with increases in chlorophyll a. Of the four practices associated with a reduction in chlorophyll a, *Bottomland Timber Establishment on Wetlands* is the most cost-effective, utilizing the Arellano-Bond estimator.

Table 14. Turbidity, Water Quality - Conservation Practices

		lnsecchidepth		**Cost-Effectiveness ($/cm)**		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP23acre	Wetland Restoration	-0.00287** (.0028684)		528.93		Continuous
CP21acre	Filter Strips	-0.00436** (.004364)		379.62		Continuous
CP27acre	Farmable Wetlands Pilot Wetland		-0.0303***		54.14	Continuous
CP23Aacre	Wetland Restoration, Non-Floodplain	-0.0161**** (.0161162)		93.87		Continuous
CP29acre	Marginal Pastureland Wildlife Habitat Buffer	-0.0319*** (.0318874)	-0.0346****	17.19	15.85	Continuous
CP22acre	Riparian Buffer		0.0132**		-68.12	Continuous

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are six water quality targeted conservation practices that bear a statistically significant relationship to changes in turbidity. Of those, five reduce turbidity and one increases turbidity. Of the five practices that reduce turbidity, *Marginal Pastureland Wildlife Habitat Buffer* is the most cost-effective utilizing the Arellano-Bond estimator. The change in depth is related to the increase in visibility for every centimeter of water.

Table 15. Turbidity, Other Benefits - Conservation Practices

		lnsecchidepth		**Cost-Effectiveness ($/cm)**		
CP#	**Conservation Practice**	**FE**	**AB**	**FE**	**AB**	**Sign-up Category**
CP25acre	Rare and Declining Habitat	-0.0013* (.001296)		856		General
CP3Aacre	Hardwood Tree Planting	-0.00749*** (.007493)	-0.0118**** (.001871)	150.13	95.3	General
CP31acre	Bottomland Timber Establishment on Wetlands	-0.143**** (.143212)	-0.352**** (.0964039)	11.57	4.70	Continuous
CP38Cacre	SAFE - Trees	0.0908**** (-.0908427)		-12.68		Continuous
CP5Aacre	Field Windbreak Establishment, Noneasement	0.105**** (-.1054222)	0.127**** (.0237566)	-15.92	-13.17	Continuous
CP42acre	Pollinator Habitat	0.0226**** (-.0226005)	0.0316* (.016221)	-58.7	-41.98	General and Continuous
CP17acre	Living Snow Fence	0.0330** (-.0329907)		-61.02		Continuous
CP10acre	Vegetative Cover – Grass – Already Established	0.00416* (.0022607)		-233.12		General

t statistics * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

There are eight conservation practices aimed at other environmental benefits that are significantly associated with changes in turbidity. Of those, three are associated with reductions in turbidity and five are associated with increases in turbidity. Of the three practices associated with reductions in turbidity, *Bottomland Timber Establishment on Wetlands* is the most cost-effective utilizing the Arellano-Bond estimator.

Discussion

Using estimates of the marginal impact of a change in land area committed to the various CRP practices on three main water quality indicators, we calculated the cost of moving each indicator by a small amount. This provides a partial assessment of the cost-effectiveness of the practice. Many practices are aimed at a mix of environmental benefits, and there is nothing that can be said about their cost-effectiveness in achieving targets other than for water quality. The cost of meeting one of a number of outcomes targeted by a conservation practice does not indicate whether the practice is otherwise good or bad. An additional caveat is that many practices apply only in a limited set of conditions—along watercourses, field margins, around wetlands, etc. So, although a practice might, on average, be the most cost-effective at achieving an improvement in one or more water quality measures, it might not be an option under most conditions.

It is also important to keep in mind just how much this analysis can tell us. Since we used a unit increment in water quality we are only looking at where the marginal acres are occurring. Cost-effectiveness may change as you improve water quality using a specific conservation practice leading to diminishing marginal cost-effectiveness. This all depends on the relative size of the area under each conservation practice and how much candidate land is available for expansion.

The range of costs identified is very wide—certainly much wider than might be expected from differences in payments made for various practices. Nor was a match found between practices thought to have the greatest impact on water quality and cost-effectiveness. It was found, however, that practices that were cost-effective for one indicator tended to be cost-effective for other indicators. *Marginal Pastureland Wildlife Habitat Buffer* was found to be the most cost-effective among the practices specifically targeting water quality at delivering improvements in all three indicators. *Bottomland Timber Establishment on Wetlands* was found to be the most cost-effective among practices targeting a wider range of environmental benefits at delivering improvements in two of the three indicators (Table 16).

Table 16. Most Cost-Effective Conservation Practices

Water Quality	CP #	Conservation Practice	Amount (US$)
Water Quality Benefit			
Phosphorus	29	Marginal Pastureland Wildlife Habitat Buffer	22.41 µg/L
Nitrogen	29	Marginal Pastureland Wildlife Habitat Buffer	7.43 µg/L
Turbidity	29	Marginal Pastureland Wildlife Habitat Buffer	15.85 cm
Other Benefits			
Phosphorus	33	Habitat Buffers for Upland Birds	1.99 µg/L
Nitrogen	31	Bottomland Timber Establishment on Wetlands	0.77 µg/L
Turbidity	31	Bottomland Timber Establishment on Wetlands	4.70 cm

These estimates may be used to calculate the minimum cost of achieving any targeted change in water quality. For example, the current average phosphorus load is 39.28 µg/L while the threshold is 25 µg/L. The lowest cost of moving an average lake back to the threshold using *Marginal Pastureland Wildlife Habitat Buffers* would be $320.01/acre.

Marginal Pastureland Wildlife Habitat Buffer is part of the continuous sign-up of the CRP; farmers can enroll at any time and it is not subject to the EBI. According to the FSA CRP Handbook, the objectives of the practice are to: “remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and subsurface flow by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body" (United States Department of Agriculture Farm Service Agency, 2015). The conservation practice involves a strip of vegetation between 20 and 120 feet adjacent or parallel to a seasonal stream, a perennial stream, wetlands, or a permanent water body. It comprises native grasses, wildflowers, and shrubs to intercept sediment, nutrients, and pesticides. Cropland, forestland, and woodland are not eligible for marginal pastureland, meaning that this practice is not impacting the most productive land.

While *Marginal Pastureland Wildlife Habitat Buffers* are the most cost-effective of the practices targeting water quality, two conservation practices targeting multiple benefits, rather than water quality alone, were actually less costly: *Bottomland Timber Establishment on Wetlands* and *Habitat Buffers for Upland Birds*. An increase in *Habitat Buffers for Upland Birds* at $1.99/acre would lead to a decrease in phosphorus of 1 μg/L, costing $28.42/acre to return to the phosphorus threshold. An increase in *Bottomland Timber Establishment on Wetlands* at $.77/acre would lead to a decrease in nitrogen of 1 μg/L. All of these practices are only options for farms with certain physical features.

Bottomland Timber Establishment on Wetlands is focused on reforestation in wetlands, providing shelter for waterfowl and wildlife as well as controlling flooding, soil erosion, and pollution. According to the FSA CRP Handbook, *Bottomland Timber Establishment on Wetlands* is meant to establish and provide long-term viability of a bottomland hardwood stand of trees, and control erosion, reduce pollution, restore and enhance wetlands, promote carbon sequestration, and provide wildlife habitat (United States Department of Agriculture Farm Service Agency, 2015).

Habitat Buffers for Upland Birds is intended to provide food and cover for quail and upland birds in cropland areas with secondary benefits of reducing erosion, increase soil and water quality, and protecting and enhancing on-farm ecosystems. It can have a minimum width of 30 feet and a maximum width of 120 feet (United States Department of Agriculture Farm Service Agency, 2015).This conservation practice is really not targeted at water but ends up having a positive impact on phosphorus. According to the NRCS Habitat Buffers for Upland Birds Program Sheet, habitat buffers for upland birds are strips of vegetation established around the edges of crop fields to provide habitat for bobwhite quail, ring-neck pheasant, and other upland birds.

Buffers can be established around field edges on any eligible cropland. They can be planted along one or more sides of a field, however establishing a buffer around the entire field is highly encouraged. It is considered year-round habitat, and as such, should be considered "hands off" from any farming operations. It also supports diverse vegetation, which are more likely to uptake phosphorus (United States Department of Agriculture Farm Service Agency, 2015). In design, *Habitat Buffers for Upland Birds* is quite similar to CP29: it acts as a grass buffer around farmland. Both are part of the continuous sign-up process, allowing farmers to enroll at any time and not subject to the EBI.

What was surprising is that a number of conservation practices expected to be cost-effective in improving water quality were not. CP15A, CP8A, and CP21 are the three water targeted conservation practices expected to be at least relatively cost-effective. Each has expanded dramatically between 2010 and 2015. We found CP15A (*Establishment of Permanent Vegetative Cover, Contour Grass Strips, Noneasement*) to be significant for nitrogen at \$19.55/µg/L under Arellano-Bond and at \$25.41/µg/L under fixed effects. The practice is part of the continuous sign-up and meant to establish strips of permanent vegetative cover following the contour on eligible cropland alternated with wider cultivated strips. It is meant to reduce erosion and control runoff yet had little impact on turbidity. CP8A (*Grass Waterways, Noneasement*) is only significant for phosphorus at \$148.33/µg/L under Arellano-Bond and \$285.25/µg/L under fixed effects. Through continuous sign-up, its goal is to improve water quality by establishing grass waterways to convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding.

Based on the literature, we would also have expected CP21 (*Filter Strips*) to have a large impact on water quality and to be cost-effective. Yet, CP21 was significantly associated with improvements in water quality only for nitrogen at \$99.18/µg/L under Arellano-Bond and \$167.45/µg/L under fixed effects, and so was cost-ineffective for both. It was also significant for turbidity at \$379.62/meter under fixed effects—again cost-ineffective—but not for phosphorus or chlorophyll a. While *Filter Strips*, like other practices that take land out of cultivation, may well satisfy the criterion of additionality (Claassen et al., 2018), and may have a relatively low opportunity cost to farmers, there was no evidence that they are able to improve water quality cost effectively.

Among habitat focused conservation practices, CP42 (*Pollinator Habitat*) increased by 15 times between 2010 and 2015. It was associated with statistically significant improvements in phosphorus at 49.05/µg/L under Arellano-Bond and $73.28/µg/L under fixed effects and in chlorophyll a at $162.67/µg/L under fixed effects, but it was also found to be associated with statistically significant deterioration in turbidity. It is the only conservation practice that exists in both general and continuous sign-up.

For conservation practices with multiple environmental benefits CP1, CP2, and CP3A all increased between six and eight times over the study period. CP1 (*Establishment of Permanent Introduced Grasses and Legumes*) is one of the oldest conservation practices and was only significant for nitrogen at $598.24/µg/L under fixed effects. CP1 is meant to establish or maintain existing permanent introduced grasses and legumes and is part of the general sign-up but can fall under continuous sign-up in approved wellhead protection areas. CP2 (*Establishment of Permanent Native Grasses*) is also one of the oldest conservation practices and was only significant for chlorophyll at $1,229.81/µg/L under Arellano-Bond. CP2 is meant to establish or maintain existing vegetative cover of native grasses and is part of the general sign-up but can fall under continuous sign-up in approved wellhead protection areas. Lastly, CP3A (*Hardwood Tree Planting*) was significant for turbidity, chlorophyll a, and phosphorus – turbidity at $9,529.58/meter under Arellano-Bond and $15,013.22/meter under fixed effects, chlorophyll at $245.85/µg/L under Arellano-Bond and $380.75/µg/L under fixed effects, and phosphorus at $149.68/µg/L under Arellano-Bond. CP3A is meant to establish and maintain a new stand or an existing stand of predominantly hardwood trees in a timber planting. It is also part of the general sign-up unless in a wellhead protection area when it is eligible for continuous sign-up.

The water and multiple environmental benefits conservation practices that we would have thought would have been cost-effective that were not are all part of the general sign-up. One challenge with the EBI for general sign-up is that the assignation of points is informed by, but does not rely on, measures of the ecosystem services that cropland retirement may provide. This assignation is based on a mixture of expert opinion, scientific data, and stakeholder inputs (Hellerstein, 2017).

Among our most surprising findings is a statistically significant but negative relationship between CP22 (*Riparian Buffers*) and three of the four water quality variables. *Riparian Buffers* and *Marginal Pastureland Wildlife Habitat Buffers,* the most cost-effective of the practices targeted at water quality, are defined exactly the same except for one thing: CP22 utilizes trees for restoration while CP29 utilizes grasses. There are three potential explanations for the perverse relationship between *Riparian Buffers* and water quality: 1. *Riparian Buffers* do reduce runoff, but net flows are increasing for other reasons. This could happen if *Riparian Buffers* were being added to areas where runoff is rapidly increasing due to processes not reflected in our data. 2. *Riparian Buffers* increase runoff in the short term. When trees are planted there may be short term effects due to the removal of existing vegetation. 3. *Riparian Buffers* increase runoff in the long term. Planting trees along rivers and streambanks is primarily for the purpose of stabilization of streambanks and the provision of habitat for aquatic organisms and wildlife, the loss of understory results in increased runoff.

According to the NRCS Riparian Buffer Conservation Plan, riparian forest buffers are normally established concurrently with other practices as part of a resource management system for a conservation management unit. For example, adjoining streambanks or shorelines must be stabilized before or in conjunction with the establishment of the buffer (streambank and shoreline protection). To maintain proper functioning of a planting, excessive water flows and erosion must be controlled upslope of the riparian forest buffer (filter strip, diversion, critical area planting, residue management).

On the job sheet for *Riparian Buffers* there are actually three purposes noted: 1. Create shade to lower water temperature to improve aquatic habitat; 2. Provide detritus and large woody debris for aquatic and terrestrial organisms; and 3. Remove nutrients, sediment, organic matter, pesticides and other pollutants from surface runoff and subsurface flow to reduce pollution and protect surface water and subsurface water quality. Water quality improvement is not the primary goal of CP22 (*Riparian Buffers*).

Conclusions

Four main conclusions can be drawn from this chapter.

The first conclusion is that a lexicographic ranking can be applied to CRP conservation practices. This is a useful process that can be utilized to look at cost-effectiveness of these practices. This chapter included all conservation practices, both those in general and continuous sign-up. The most cost-effective practices were all part of the continuous sign-up process. According to Hellerstein (2017), "There is little research considering the effectiveness of continuous sign-up." In addition to the lack of a competitive mechanism, continuous sign-up (by design) focuses on parcels that tend to do one thing very well. If the proportion of CRP in continuous sign-up increases, this is likely to lead to forgoing enrollment of acreage that does a number of things well, but nothing "very well"—the kind of acres that an EBI will identify (Hellerstein, 2017). This should be taken into account went considering a sole focus on improving water quality.

The second conclusion is that practices can be identified for which the data suggests there is an impact on physical effectiveness. Both positive and negative impacts on key water quality variables were identified for various conservation practices. This is an essential component for calculating the cost-effectiveness of the conservation practices.

The third conclusion is that due to the restrictions on the implementation of individual conservation practices, it may be necessary to look at conservation practices that are not the most cost-effective. For example, *Marginal Pastureland Wildlife Habitat Buffer* is only applicable where there is pasture and not cropland. In this case, utilizing the ranking of cost-effectiveness, looking to the next most cost-effective practice could be useful for cropland areas.

Agri-environmental programs produce environmental gain only when the practices funded would not be adopted without the incentive provided by the program (Smith and Weinberg, 2004). According to Claassen et al. (2014), for structural practices (e.g., grass waterways, riparian buffers), it is relatively easy to establish that a practice has not already been installed. For management practices (e.g., conservation tillage, nutrient management), however, it may be difficult or impossible to confirm that a practice is being adopted for the first time. Additionality is always a concern when thinking about land retirement programs, since one would think that it would be in the farmers best interest to enroll marginal land. Lubowski (2003) suggests that about 15% of the land enrolled in the CRP would have shifted to a non-crop land use in any case.

Lack of additionality in CRP practices can be seen by the lack of cost-effectiveness. Both practices that are really expensive in the right direction (improving water quality) or in the wrong direction (worsening water quality) are unlikely to be additional.

Lastly, it is important to note that there were many conservation practices that did not demonstrate significance, showing no impact or negative impact on water quality. For those practices, there is a need for additional tests to further demonstrate cost-effectiveness.

CHAPTER 4: CRP PRACTICES AND FARMER DECISION MAKING

Introduction

The Conservation Reserve Program (CRP), like many other agri-environment schemes, is voluntary. Farmers cannot be compelled to participate. Therefore, it is necessary to understand how farmers' voluntary decisions to enroll in conservation practices, and what conservation practices in which to enroll, are shaped by a range of farm characteristics, time-varying factors, and the specific features of individual conservation practices.

Different factors affect decision making for participation in the CRP. Farmers are presumably choosing to enroll land into CRP as opposed to the next best alternative based in large part on the opportunity cost of the land. The determinants of opportunity cost are therefore extremely important.

In an ideal world one might know the opportunity cost directly through a recent sale of the land on the agricultural land market or be able to estimate the opportunity cost through a farmland hedonic price function analysis. For example, Bastian et al. (2002) utilize GIS measures to estimate the impact of amenity and agricultural production land characteristics on price per acre for a sample of Wyoming agricultural parcels[2]. However, due to absence of data on land transactions the hedonic method cannot be used to value the opportunity

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[2] They identify that remote agricultural lands, including wildlife habitat and scenic vistas, command higher prices per hectare in Wyoming than those whose landscape is dominated by agricultural production.

cost of agricultural lands in Iowa. Therefore, we must rely upon indirect measures of the quality of the land endowment as the proximate drivers of opportunity cost, including variables such as erodibility, corn suitability, and land cover. For example, low levels of erodibility may lead to low enrollment in CRP; a farmer would want to utilize high quality, flat soil to maximize production of crops.

The literature is replete with studies assessing the factors which influence farmers' adoption of conservation practices (Baumgart-Getz et al., 2012; Hynes and Garvey, 2009; Knowler and Bradshaw, 2007; Prokopy et al., 2008). Some of this literature has specifically explored farmers' willingness to participate in agri-environmental programs (Mishra and Khanal, 2013). Purvis et al. (1989) examined farmers' willingness to participate in a filter strip program and showed that their decisions were determined by the yearly conservation practice payments, perceptions of environmental change, and farm opportunity cost. Loftus and Kraft (2003) reported that farmers who rely less on farm-generated income as a percentage of total household income, and those informed about the eligibility of their land for the CRP tended to be more willing to participate in CRP involving filter strips.

The main driver of participation in CRP is farmers seeking to maximize their return per acre. Stern et al. (2012) conducted an analysis of the main crops in Iowa and land moving in and out of CRP. They utilized a county level analysis across Iowa's 99 counties. Since they did not have access to farm level data on enrollment in CRP, as we do, they used the USDA NASS to calculate acreage estimates for each crop by county using surveys conducted by NASS. The amount of land enrolled in CRP was determined by the amount of money appropriated for CRP. As prices for corn increased, farmers removed some land from CRP and put the land back into crop production – as would be expected if they were making decisions based on their expected opportunity cost.

Patterns of farmer participation in CRP impact the effectiveness of the program. As of October 2001, CRP was not very effective in targeting environmentally sensitive land, and enrollment in many states was very low in the continuous CRP, where enrollment is ongoing (Senate, 2002). An understanding of the factors that motivate farmers to participate in CRP is helpful to policy makers in improving the design and implementation in order to encourage cost-effectiveness (Yang and Isik, 2004).

To date, no analysis looks at farmers' enrollment decisions across individual conservation practices. Past work has focused on characteristics that lead to the enrollment in the CRP but have ignored the choice of which practices to enroll in. Given the evidence offered in the previous chapter that the practices differ considerably in targeted services, physical effectiveness, and cost-effectiveness, this is a notable oversight. Theoretically farmers have forty-eight different conservation practices to choose from. The complexity of having two sign-up types, general and continuous, creates an initial dichotomy since continuous practices can be enrolled in at any point relatively easily while farmers seeking enrollment in general practices are selected through a periodic reverse auction. In addition, some conservation practices utilize marginal land while others actually remove productive land from use. Grouping such heterogeneous practices together is not an effective way to understand the means in which farm-level heterogeneity, such as land cover type, corn suitability, and levels of erodibility, may cause farmers to make substantially different enrollment decisions.

Our model looks at the question of substitution between alternative practices, conditional on a farmer deciding to commit some of their land to a specific CRP practice. Section 2 provide background on the changes in the CRP in Iowa, enrollment practices, and how they were impacted by the market. Section 3 explains the three major groups of characteristics, and six relevant hypotheses associated with our analysis. Section 4 discusses the result of four models of increasing complexity, multinomial models with and without alternative specific constants. It also provides a discussion of how our hypotheses faired against our results. Section 5 concludes with recommendations for CRP managers and opportunities for future research.

Background

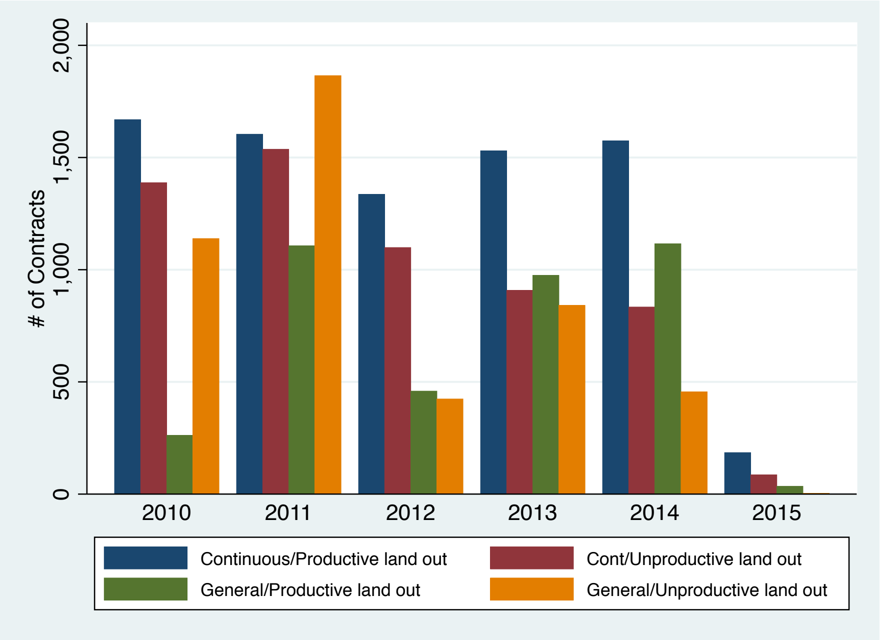
There are currently two ways farmers can sign-up to participate in the CRP: ‘general sign-up’ and ‘continuous sign-up’. General sign-up includes mechanisms designed to assure cost-effective provision of services of uncertain value. Continuous sign-up has no mechanisms for cost-effectiveness but is restricted to services thought to be of high value.

Across the United States as a whole, the dominant form of sign-up is general. General sign-up has pre-announced enrollment periods. During sign-up, farmers submit offers for the amounts they are willing to accept to enroll acreage in the CRP. County NRCS offices calculate the maximum acceptable rental rate for the acreage being submitted (maximum payment rate) and offers are ranked at the national office using an environmental benefits index (EBI). According to the Farm Service Agency (FSA), offers selected are those that provide the greatest environmental benefits considering the cost of enrolling the acreage in the program (United States Department of Agriculture Farm Service Agency, 2015).

For continuous sign-up, farmers can enroll at any time. The practices available during continuous sign-up generally provide high environmental benefits to large areas when compared to the acreage on which the practice is implemented. The continuous sign-up process does not have a competitive evaluation process, and aims to enroll small, environmentally sensitive areas and target acreage (United States Department of Agriculture Farm Service Agency, 2015). The presumption is that continuous practices generate disproportionate benefits and as such do not need to go through a more formal process (R. Iovanna, personal communication, April 26, 2018).

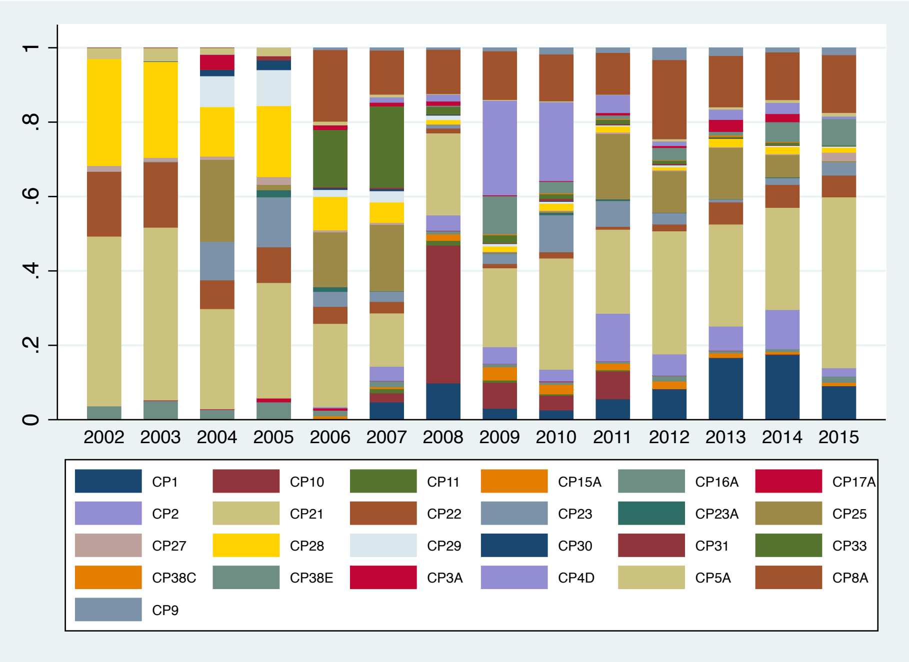
Our analysis divides CRP contracts into four groups: two types of sign-up (continuous and general) and two types of practices (ones that take productive land out of use and ones that take unproductive land out of use). While total contracts and acres in CRP in Iowa had an overall decrease over our time series, 2010 to 2015, (Figure 8), there were more dramatic changes in the categories of contracts. Specifically looking at the top 25 practices, 85% of overall contracts, the number of new contracts or renewals signed fluctuated, with a high level of sign-up across all practices in 2011, particularly practices that went through general sign-up and contracted on unproductive land. This is likely the result of the percentage of practices that the FSA chose to accept through the reverse auction that year. Practices that went through continuous sign-up and took land out of production stayed relatively constant over the time series, while practices that went through continuous sign-up and took out unproductive land gradually decreased. These changes are a motivating factor for how sign-up and the type of land under contract have an impact on decision making.

Figure 8. CRP Enrollment by Farm and Enrollment Type: New and Renewed Contracts (2010-2015). *Note that the data for 2015 are incomplete.*



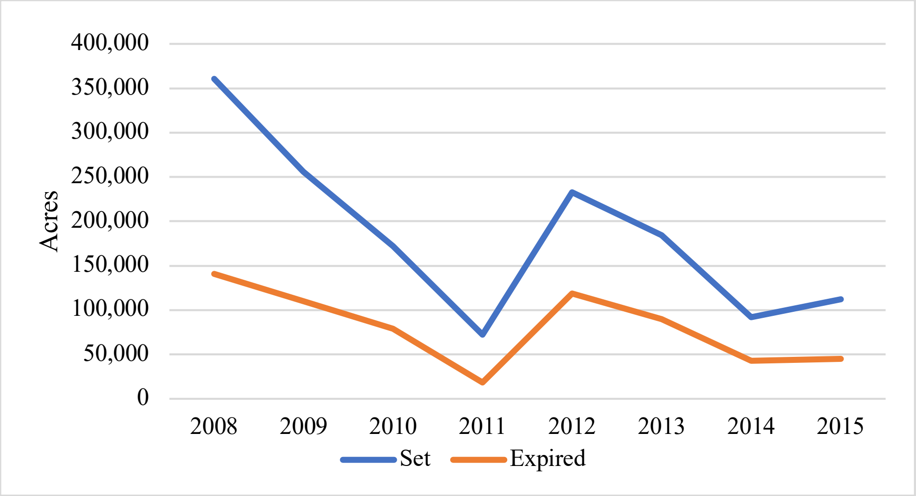
Looking at specific conservation practices (Figure 9), there are significant changes in sign-up during the 2010 to 2015 time series. In 2008 there was a major increase in CP10, Grass Already Established. In 2011 there was a major increase in CP10 and CP2, at the same time there was a major increase in overall land enrolled. Most notably CP25, Rare and Declining Habitat, had a high level of sign-up, where it had been low the previous three years. Two changes occurred around that time: 1. Sign-up 32, REX extension starting in 2006 and 2. General sign-up 33 in 2006 (Bennett, 2011).

Figure 9. Enrollment (Shares) in CRP Practices by Year



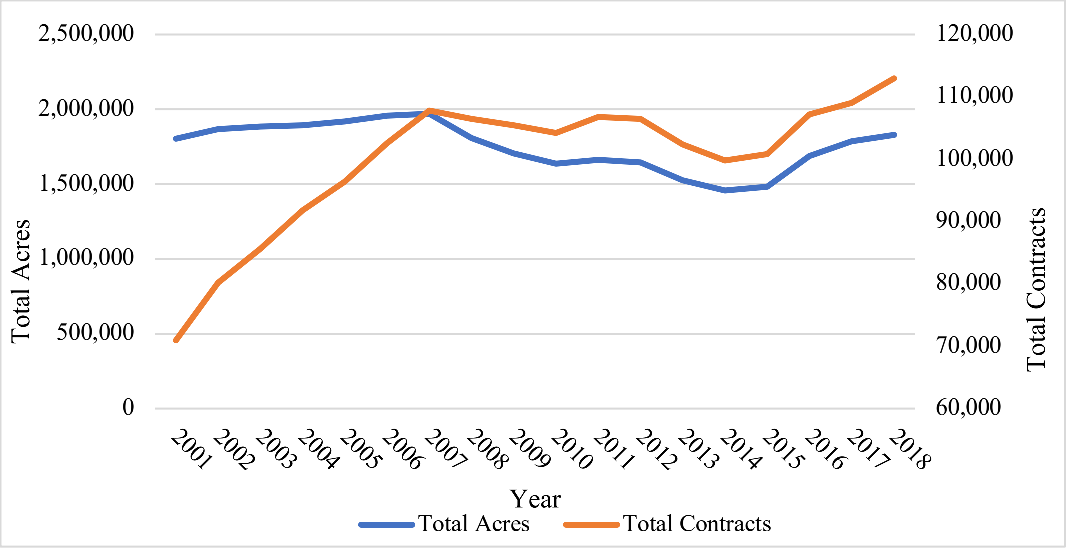
Between 2007 and 2010 many CRP contracts across the United States, upwards of 28 million acres, were set to expire (Figure 10). In order to lessen the impact, in 2006 the FSA offered holders of contracts set to expire the opportunity to re-enroll or extend their contracts. This was known as REX. Sign-up 32 denotes early re-enrollment of 2007-2010 expiring general sign-up contracts under the 2006 REX offer (Appendix D). Holders of approximately 82% of expiring contract acres were approved for re-enrollment or extension (USDA Farm Service Agency, 2007).

Figure 10. CRP Contracts Set to Expire and Expired CRP Land



Also, in 2006, the total number of CRP contracts for the state of Iowa went up and the total acres in CRP in Iowa went down during the time period when there was an increase in corn prices (Figure 11). After 2006 the number of contracts and number of acres mirror each other, with a decrease between 2006 and 2014, steadily increasing after 2014 to present.

Figure 11. Iowa CRP: Total Contracts and Total Acres

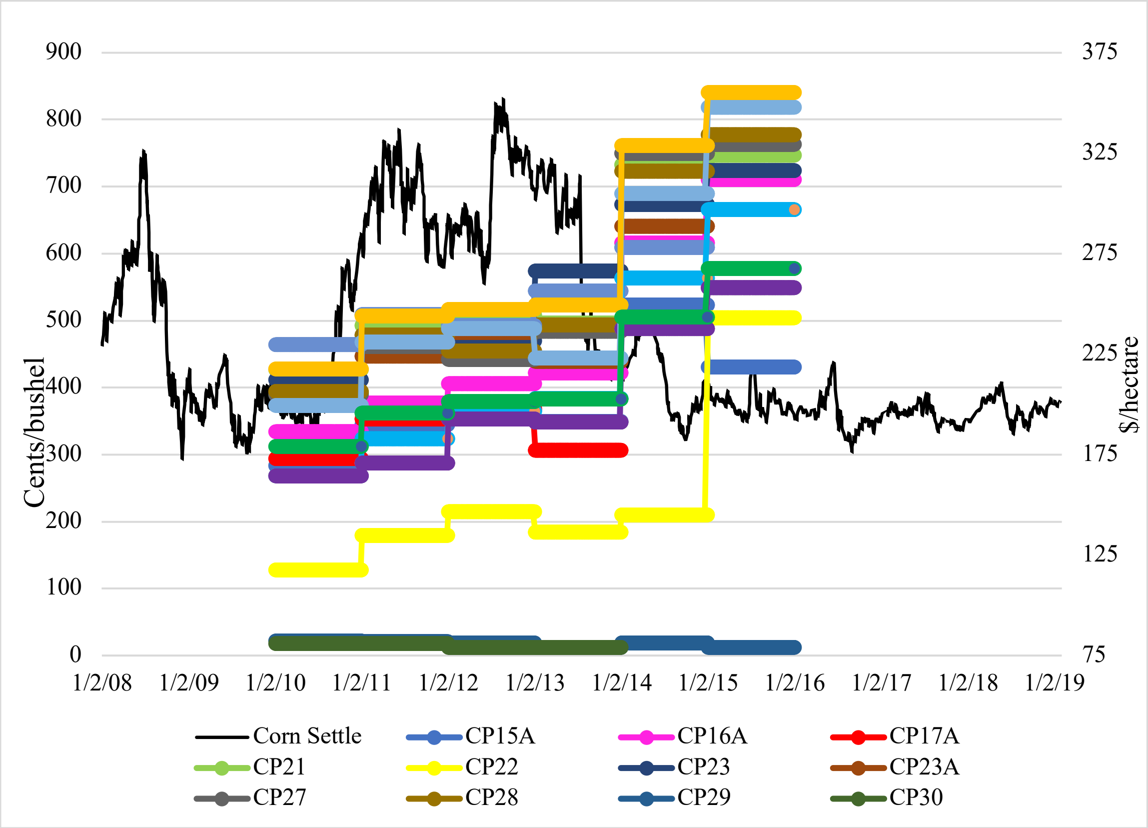


Farmers utilize corn futures to make decisions about whether to continue to keep their land in productivity or enroll in CRP. We may therefore expect the FSA, which establishes the prices for continuous practices and accepts contracts for the general sign-up, to adjust CRP practice prices with corn futures. Yet the FSA utilizes a 3-year average county rental rate to establish CRP payment levels. This means that the CRP prices are likely to respond to movements in corn futures prices in a sluggish manner. Figure 12 demonstrates just that. The black line represents continuous corn futures. There was a sharp rise and then decrease of corn futures between 2010 and 2015. Corn futures begin diminishing in 2013.

Figure 12 looks at the fourteen conservation practices out of the top twenty-five chosen by farmers that went through continuous sign-up alongside the change in corn futures. The colored lines in Figure 12 represent the average payment for individual practices in each year. We would expect the price of conservation practices to go up when corn futures rise, yet this is not the overall trend across the practices. The 3-year average county rental rate used to establish CRP payment levels created a lag compared to markets, particularly in 2013, which took a long time to correct. This is not beneficial for the competitiveness of CRP with crops during times of rising corn/soy prices and can result in “overpaying” during periods of falling corn/soy prices (Personal communication, Curt Goettsch, FSA).

There are few peer reviewed articles that look at the impact of the change in corn futures on CRP, none of which look at specific CRP practices. One article estimates a significant, negative correlation between corn spot prices and CRP enrollment, which is what we would expect (Gill-Austern, 2011). They suggest that corn spot prices become more significant as the time lag grows larger. Prices are initially insignificant with a time lag of one year, significant at the 10 percent level with a time lag of two years, significant at the 5 percent level with a time lag of three years and significant at the 1 percent level when unobserved state statistics are taken into account with a time lag of three years (Gill-Austern, 2011).

Figure 12. Corn Futures and Continuous Conservation Practices



Source: (Quandl, 2019)

Data and Methods

In order to understand farmer decision making we have specified and estimated a CRP enrollment choice model. Variables included in the model can be broken into three groups:

farm characteristics, time-varying characteristics, and practice characteristics (Tables 18 and 19).

Farm characteristics include corn suitability rating (CSR), land cover, and erodibility. CSR acts as an indication of how likely the land is to be put into production. CSR data were obtained from the Iowa State University Extension at a 30m to 30m pixel level for all land in Iowa for 99 counties from 2010 to 2015. CSR was binned into 5 categories: very poor, poor, good, very good, excellent (Personal communication, Dr. C. Lee Burras, Professor of Agronomy at Iowa State University). This was later combined into three measures: bad (very poor and poor), average (good), and good (very good and excellent). CSR was aggregated based on the average per farm.

Land cover is important since specific conservation practices can only be implemented on certain land types, such as wetlands for marginal land, grasslands for bird habitat, etc. Current land cover also provides an indication of the opportunity cost of the land, i.e. by whether or not a substantial share of acreage is currently in intensive agriculture or not. As in previous chapters, land cover shares were grouped into eight different categories: corn, soy, water, developed, grasslands, wetlands, forest, and miscellaneous. Soy was always omitted as the base category, so all land cover results are in reference to soy.

Raster level data for Iowa on land use cover were obtained from the USDA’s National Agricultural Statistics Service (NASS). This dataset is a combination of information on crops from the USDA and land cover from the USGS National Land Cover Database (NLCD). All spatial data were converted to a non-spatial format using QGIS and Python.

The erodibility of land effects whether it is likely to be marginal land or good for sustained production. Highly erodible land (HEL) is measured by the most dominant erodibility type on a farm. Soil map units and an erodibility index (EI) are used as the basis for identifying HEL. A soil map unit with an EI of 8 or more is designated as HEL. The EI of a soil map unit is determined by dividing the potential erodibility for each soil map unit by the soil loss tolerance value established for the soil. A soil map unit with an EI less than 8 is non-highly erodible land (NHEL) (USDA, 2013). Data were obtained from the NRCS Natural Resources Inventory at the 30m to 30m pixel level for all land in Iowa for 99 counties from 2010 to 2015. Erodibility was aggregated based on the average per farm.

Table 17 demonstrates the land cover types associated with the three classes of erodibility. All erodibility classes include both cultivated and non-cultivated land. 41% of NHEL is in land that is being cultivated (corn and soy), while 30% of HEL is in land that is being cultivated (corn and soy). The main land covers in areas not under cultivation are grass and forest. Undetermined erodibility (UHEL) is mostly land that is not in cultivation, with 70% in grasslands and forest. We expect HEL land to be more steeply sloped than NHEL land.

Table 17. Land Cover Associated with Erosion Categories

Erodibility Type	% Corn	% Soy	% Grassland	% Forest	% Developed
HEL	17	13	49	9	0
NHEL	26	15	44	0	6
UHEL	11	7	58	12	0

Time-varying characteristics look at two measurements of corn futures: year-long average and year-long coefficient of variation (CV). Corn futures are utilized by farmers to make costly commitments about what to do with their land. Since CRP contracts are for 10 to 15 years, corn futures act as a useful tool to think about how much a farmer could profit from keeping his or her land in production versus enrolling in CRP and receive a fixed payment per year for 10 to 15 years without adjustment.

Information on continuous corn futures was sourced from the Chicago Market Exchange. Continuous corn futures are multiple futures combined creating a daily average value, regardless of when the corn futures were initiated. In actuality there are five corn futures contracts scheduled for each year—with deliveries in March, May, July, September, and December. December is the new-crop contract, whereas the other four contracts trade the harvest of the preceding year. Average yearly corn futures take the average of the daily corn future quotes for each year for a ten-year period and the CV for corn futures takes the ratio of the annual standard deviation to the mean and shows the extent of volatility in relation to the mean of the annual corn futures.

Utilizing the Personal Consumption Expenditures Price Index key monetary variables were deflated to 2010, including CRP payment and corn futures (U.S. Bureau of Economic

Analysis, 2019). In addition, these variables were standardized, rescaled to have a mean of zero and a standard deviation of one.

Table 18. Farm and Time-Varying Characteristics Variables

	Mean	***Variance***	***Min***	***Max***
FARM CHARACTERISTICS				
Corn Suitability Rating (CSR)				
Bad	.0684281	.0637458	0	1
Average	.4322893	.2454158	0	1
Good	.4992826	.25	0	1
Land Cover				
Soy	.1347688	.054227	0	1
Corn	.2080725	.0767675	0	1
Water	.0044161	.0008638	0	1
Developed	.0432057	.0122186	0	1
Grasslands	.4757453	.101065	0	1
Forests	.0683465	.0192219	0	1
Wetlands	.0264519	.0264519	0	1
Miscellaneous	.0303542	.0083149	0	1
Erodibility				
Highly erodible Land	.5566155	.2467951	0	1
Not Highly Erodible Land	.4016583	.2403293	0	1
Undetermined	.0417261	.0399851	0	1
TIME-VARYING CHARACTERISTICS				
Corn Futures				
Year-long average	561.4383	14269.71	376.7768	694.8879
Year-long CV	14.16356	32.08671	4.354174	20.88397

Data Sources: (Quandl, 2019; USDA National Agricultural Statistics Service, 2018)

We are only examining farms that chose the top 25 conservation practices during 2010 to 2015. We do not observe decisions of non-participants of CRP in our data.

The unit of analysis was a farm, measured in acres. Farms could consist of one to several parcels. For those farms that had more than one practice the primary practice was utilized, meaning the most prevalent conservation practice on a farm by acreage. For all farms, 85% had land in only one conservation practice. These 25 practices can be broken down into which fall under general vs. continuous sign-up and practices that take land out of production and those that do not (Table 19).

Data on conservation practice payments includes extensions and renewals as well as new contracts. The chosen practice by each farmer has a CRP payment that is the real marginal value. For the 24 other non-chosen practices the payment per practice was calculated from the average of all new contracts per year for that particular practice.

Data on land enrolled in CRP was provided as a geodatabase from the USDA of land that entered into CRP between 2010 and 2015, both new contracts and re-enrollments. Specifically, these were shapefiles of land that entered into CRP through general and continuous sign-up each year.

Conservation practice characteristics include annual average payment amount, sign-up type, and practices that take productive or unproductive land out of use. Practice payment amount varies considerably within and between practices that go through continuous and general sign-up. Practice sign-up type, general and continuous, have different enrollment processes, which change the nature of the enrollment decision. For example, farmers enrolling in continuous practices are price takers while general enrollment practices utilize a reverse auction that selects on a lower price.

Whether practices take productive land out of use versus operating on marginal or unproductive land is one of the most critical factors for deciding to enroll in CRP. If a farmer is going to take out land that could be good for production, it will likely require a much larger financial incentive than if the practice requires him or her to enroll marginal land into CRP. No study to date has looked at the difference between practices that take land out of production versus those that do not. This information is not readily available from the USDA. It was obtained from an expert at the FSA in Iowa based on over two decades of experience working with farmers and the CRP (Personal communication, Curt Goettsch, FSA).

Table 19. Top 25 Practice Characteristics

Conservation Practice	**Mean**	**General or Continuous (G or C)**	**Taking land out of production or not (P, NP)**
* 21 Filter Strips	0.277	C	P
8A Grass Waterway, Noneasement	0.140	C	NP
25 Rare and Declining Habitat	0.102	G	NP
1 Established Permanent Introduced Grasses and Legumes	0.095	G	P
2 Established Permanent Native Grasses	0.081	G	P
4D Permanent Wildlife Habitat, Noneasement	0.067	G	NP
23 Wetland Restoration	0.048	C	NP
22 Riparian Buffer	0.032	C	P
10 Vegetative Cover, Grass Already Established	0.028	G	NP
38E SAFE Grass	0.026	C	NP
9 Shallow Water Areas for Wildlife	0.019	C	NP
15A Established Contour Grass Strips, Noneasement	0.018	C	P

28 Farmable Wetlands Program, Buffer	0.017	C	NP
3A Hardwood Tree Planting	0.013	G	NP
33 Habitat Buffers for Upland Birds	0.009	C	NP
16A Shelterbelt Establishment, Noneasement	0.008	C	NP
5A Field Windbreak, Noneasement	0.004	C	NP
29 Marginal Pastureland Wildlife Habitat Buffer	0.003	C	NP
27 Farmable Wetlands Program, Wetland	0.003	C	NP
31 Bottomland Timber Establishment on Wetlands	0.003	C	NP
23A Wetland Restoration, Nonfloodplain	0.003	C	NP
38C SAFE Trees	0.002	C	NP
11 Vegetative Cover, Trees Already Established	0.002	G	NP
17A Living Snow Fence, Noneasement	0.001	C	NP
30 Marginal Pastureland Wetland Buffer	0.001	C	NP

* Base

Discrete choice studies are based on a random utility maximization (RUM) framework where the landowner will switch from one use to another if the net expected returns from doing so, minus conversion costs, exceed the returns from the alternative uses (McFadden, 1981). Discrete choice models specify the probability that an individual chooses an option among a set of alternatives. In practice, we cannot know all factors affecting individual choice decisions as their determinants are partially observed or imperfectly measured. Therefore, discrete choice models rely on stochastic assumptions and specifications to account for unobserved factors related to a) choice alternatives, b) taste variation over people and over time, and c) heterogeneous choice sets (Baltas and Doyle, 2001). Assuming a distribution for the unobserved portion of farmers' utility leads to a probabilistic model where for any given set of observed variables, a particular option may or may not be chosen depending on the realization of the random component (Lubowski, 2003). Assuming the unobserved (random) heterogeneity in decision making is additive and distributed as a type 1 extreme value, the multinomial logit model results (Train, 2003).

In order to get a complete sense of the impact of different variables on enrollment in the top 25 conservation practices we looked at two discrete choice models with two degrees of complexity. We estimated a multinomial logit with and without alternative specific constants. The model without alternative specific constants controls for unobserved heterogeneity in four groups defined by whether the practice went through general or continuous enrollment and whether it removes productive land from intensive use or not. The alternative specific conditional logit goes a step further by absorbing any time-invariant, practice-specific heterogeneity in the constants. For example, some conservation practices may generate significant on-farm benefits and (perhaps as a result) offer relatively low payments. Failing to capture this practice-specific information in the alternative specific conditional logit could lead to biased estimation of the coefficient associated with CRP payments. In addition, some practices come bundled with additional financial benefits such as rental rate incentives and cost share payments. The model with alternative specific constants was necessary in order to understand the role that the payment received for different conservation practices had on enrollment in those practices. This model picks up unobserved time-invariant characteristics of particular practices that might be correlated with the observables. Therefore, it is a more robust model than the multinomial logit without alternative specific constants.

All models were estimated in Stata. The omitted base for the conditional logit is continuous enrollment and productive land practices. For the alternative specific conditional logit, the omitted base was CP 21, Filter Strips. This was chosen as the omitted base because it was the most chosen practice across all farms in the models.

The random utility function for this analysis is as follows:

No Farm Characteristics (Without and With Alternative Specific Constants)

Model 1:

$U_{fpt} = \theta_{prod=1,cts=0} + \theta_{prod=0,cts=0} + \theta_{prod=0,cts=1} + \alpha(prod,cts)*Pmt_{pt} + \beta(prod,cts)*FutureAvg_{t} + \gamma(prod,cts)*FutureCV_{t} + \epsilon_{fpt}$

Model 2:

$U_{fpt} = \theta_{p} + \alpha(prod,cts)*Pmt_{pt} + \beta(prod,cts)*FutureAvg_{t} + \gamma(prod,cts)*FutureCV_{t} + \epsilon_{fpt}$

Where:

$\alpha(prod,cts) = \alpha_0 + \alpha_1 prod + \alpha_2 cts$

$\beta(prod,cts) = \beta_1 prod + \beta_2 cts$

$\gamma(prod,cts) = \gamma_1 prod + \gamma_2 cts$

U_{fpt} = Expected utility of farmer *f* for practice *p* at time *t*

cts = 1 for continuous sign-up and = 0 otherwise

prod = 1 if the practice takes land out of productivity and = 0 otherwise

$\theta_{prod=1,cts=0}$ = 1 if the practice takes land out of productivity and went through general sign-up and = 0 otherwise

$\theta_{prod=0,cts=0}$ = 1 if the practice does not take land out of productivity and went through general sign-up and = 0 otherwise

$\theta_{prod=0,cts=1}$ = 1 if the practice does not take land out of productivity and went through continuous sign-up and = 0 otherwise

θ_p = alternative (practice) specific constant relative to omitted category CP 21 (Filter Strips)

Pmt_{pt} = Conservation practice payment: Average per practice

$FutureAvg_t$ = Corn Futures: Year-long average

$FutureCV_t$ = Corn Futures: Year-long coefficient of variation

Where subscript f = farm-varying, p = alternative-varying (practice), and t = time-varying

Farm Characteristics (Without and With Alternative Specific Constants)

Model 3:

$$U_{fpt} = \theta_{prod=1,cts=0} + \theta_{prod=0,cts=0} + \theta_{prod=0,cts=1} + \alpha(prod,cts,csravg,csrgood,HEL,NHEL)*Pmt_{pt} + \beta(prod,cts)*FutureAvg_t + \gamma(prod,cts)*FutureCV_t + \mu_1(prod,cts)*CSRAvg_f + \mu_2(prod,cts)*CSRGood_f + \rho_1(prod,cts)*HEL_f + \rho_2(prod,cts)*NHEL_f + \eta_1(prod,cts)*Corn_f + \eta_2(prod,cts)*Water_f + \eta_3(prod,cts)*Dev_f + \eta_4(prod,cts)*Grass_f + \eta_5(prod,cts)*Wetland_f + \eta_6(prod,cts)*Forest_f + \eta_7(prod,cts)*Misc_f + \epsilon_{fpt}$$

Model 4:

$$U_{fpt} = \theta_p + \alpha(prod,cts,csravg,csrgood,HEL,NHEL)*Pmt_{pt} + \beta(prod,cts)*FutureAvg_t + \gamma(prod,cts)*FutureCV_t + \mu_1(prod,cts)*CSRAvg_f + \mu_2(prod,cts)*CSRGood_f + \rho_1(prod,cts)*HEL_f + \rho_2(prod,cts)*NHEL_f + \eta_1(prod,cts)*Corn_f + \eta_2(prod,cts)*Water_f + \eta_3(prod,cts)*Dev_f + \eta_4(prod,cts)*Grass_f + \eta_5(prod,cts)*Wetland_f + \eta_6(prod,cts)*Forest_f + \eta_7(prod,cts)*Misc_f + \epsilon_{fpt}$$

Where:

$\alpha(prod,cts) = \alpha_0 + \alpha_1 prod + \alpha_2 cts$

$\beta(prod,cts) = \beta_1 prod + \beta_2 cts$

$\gamma(prod,cts) = \gamma_1 prod + \gamma_2 cts$

$\mu_1(prod,cts) = \mu_{11} prod + \mu_{12} cts$

$\mu_2(prod,cts) = \mu_{21}prod + \mu_{22}cts$

$\rho_1(prod,cts) = \rho_{11}prod + \rho_{12}cts$

$\rho_2(prod,cts) = \rho_{21}prod + \rho_{22}cts$

$\eta_1(prod,cts) = \eta_{11}prod + \eta_{12}cts$

$\eta_2(prod,cts) = \eta_{21}prod + \eta_{22}cts$

$\eta_3(prod,cts) = \eta_{31}prod + \eta_{32}cts$

$\eta_4(prod,cts) = \eta_{41}prod + \eta_{42}cts$

$\eta_5(prod,cts) = \eta_{51}prod + \eta_{52}cts$

$\eta_6(prod,cts) = \eta_{61}prod + \eta_{62}cts$

$\eta_7(prod,cts) = \eta_{71}prod + \eta_{72}cts$

U_{fpt} = Expected utility of farmer *f* for practice *p* at time *t*
cts = 1 for continuous sign-up and = 0 otherwise
prod = 1 if the practice takes land out of productivity and = 0 otherwise
csravg = 1 if CSR is average and = 0 otherwise
csrgood = 1 if CSR is average and = 0 otherwise
HEL = 1 if erosion is highly erodible and = 0 otherwise
NHEL = 1 if erosion is non-highly erodible and = 0 otherwise
$\theta_{prod=1,cts=0}$ = 1 if the practice takes land out of productivity and went through general sign-up and = 0 otherwise
$\theta_{prod=0,cts=0}$ = 1 if the practice does not take land out of productivity and went through general sign-up and = 0 otherwise
$\theta_{prod=0,cts=1}$ = 1 if the practice does not take land out of productivity and went through continuous sign-up and = 0 otherwise
θ_p = alternative (practice) specific constant relative to omitted category CP 21 (Filter Strips)
Pmt_{pt} = Conservation practice payment: Average per practice
$FutureAvg_t$ = Corn Futures: Year-long average
$FutureCV_t$ = Corn Futures: Year-long coefficient of variation
$CSRAvg_f$ = 1 if Corn Suitability Rating is average and = 0 otherwise
$CSRGood_f$ = 1 if Corn Suitability Rating is good and = 0 otherwise

HEL_f = 1 if erosion is highly erodible land and = 0 otherwise

$NHEL_f$ = 1 if erosion is non-highly erodible land and = 0 otherwise

$Corn_f$ = 1 if land cover is corn and = 0 otherwise

$Water_f$ = 1 if land cover is water and = 0 otherwise

Dev_f = 1 if land cover is developed and = 0 otherwise

$Grass_f$= 1 if land cover is grassland and = 0 otherwise

$Wetland_f$= 1 if land cover is wetland and = 0 otherwise

$Forest_f$= 1 if land cover is forest and = 0 otherwise

$Misc_f$= 1 if land cover is miscellaneous and = 0 otherwise

Where subscript f = farm-varying, p = alternative-varying (practice), and t = time-varying

There are five key hypotheses for this chapter:

1. Farmers with high opportunity cost land (in terms of corn and soy productivity) are less likely to enroll in practices that retire productive land than farmers with less valuable land for farming.

This hypothesis assumes that payment is held constant. There are three different methods to test this hypothesis by looking at corn suitability rating, erodibility, and land cover.

First, we looked at the interaction of all practices that take productive land out of use with the different levels of corn suitability, $prod*CSRAvg_f$ and $prod*CSRGood_f$. We expected the signs for both $prod*CSRAvg_f$ and $prod*CSRGood_f$ to be negative relative to the omitted base of $CSRBad_f$. The interaction $prod*CSRGood_f$ is likely more negative than $prod*CSRAvg_f$.

Second, we examined the interaction of all practices that remove productive land from use with the seven different land cover types, $prod*Corn_f$, $prod*Water_f$, $prod*Dev_f$, $prod*Grass_f$, $prod*Wetland_f$, $prod*Forest_f$, *and* $prod*Misc_f$. For $prod*Corn_f$ we would expect the sign to be negative since it is associated with high productivity land and would reduce enrollment, although since it is in comparison to $prod*Soy_f$ it is difficult to say since farms often utilize a corn-soy rotation on the same land. For $prod*Water_f$, $prod*Dev_f$, $prod*Grass_f$, $prod*Wetland_f$, $prod*Forest_f$, and $prod*Misc_f$ we would expect the sign to be positive relative to the omitted base of $unprod*Soy_f$.

Third, we analyzed the interaction of all practices that take productive land out of use with the different levels of erodibility, $prod*HEL_f$ and $prod*NHEL_f$. For $prod*HEL_f$ we would expect the sign to be positive and for $prod*NHEL_f$ we would expect the sign to be negative relative to the omitted base of $unprod*UHEL_f$. As stated above, $UHEL_f$ is mostly land that is not under cultivation, while $NHEL_f$ has a larger percentage of land that is under cultivation than HEL_f.

2a. Farmers are less likely to enroll in practices that retire productive land, the higher the expected future price of corn and soy (as measured by average corn and soy futures).

This hypothesis can be addressed in two different ways, by looking at practices that take productive land out of use and practices that go through continuous sign-up.

First, we looked at the interaction of practices that take productive land out of use and average corn futures, $prod*FutureAvg_t$. For $prod*FutureAvg_t$ we would expect the sign to be negative relative to the omitted base of $unprod*FutureAvg_t$. Looking at the interaction of practices that take productive land out of use and average corn futures we expect that practices that take productive land out of use would be greatly impacted by what farmers expect the market to do.

Second, we looked at the interaction of practices that go through continuous sign-up and average corn futures, $cts*FutureAvg_t$. For $cts*FutureAvg_t$ we would expect the sign to be negative relative to the omitted base of $gen* FutureAvg_t$. We expect this result because continuous practices can be enrolled at any time and as such are more likely to mimic the market.

2b. Farmers are more likely to enroll in practices that retire productive land, the higher the expected coefficient of variation for price of corn and soy (as measured by corn and soy futures).

This hypothesis is addressed by looking at practices that take productive land out of use, specifically the interaction of practices that take productive land out of use and corn futures coefficient of variation, $prod*FutureCV_t$. For $prod*FutureCV_t$ we would expect the sign to be positive relative to the omitted base of $unprod*FutureCV_t$. Higher CV should provide a reason for risk-averse farmers to enroll in CRP on productive land since it is a guaranteed payment.

3. The price elasticity of supply is higher as the quality of land increases (as measured by CSR and erodibility).

There are two different methods to test this hypothesis by looking at corn suitability rating and erodibility.

The first method can be measured through the interaction of payment with different levels of corn suitability, $csravg*Pmt_{pt}$ and $csrgood*Pmt_{pt}$. For both $csravg*Pmt_{pt}$ and $csrgood*Pmt_{pt}$ we would expect the signs of the coefficient to be positive relative to the omitted base of $csrbad*Pmt_{pt}$.

We believe that a high corn suitability rating means the land is more valuable for intensive agricultural production. Therefore, we would expect farmers to be more sensitive to the CRP payment for whether to retire high-quality land relative to less productive land.

The second method can be measured through the interaction of payment with varying levels of erodibility, HEL_f*Pmt_{pt} and $NHEL_f*Pmt_{pt}$. For both HEL_f*Pmt_{pt} and $NHEL_f*Pmt_{pt}$ we expect the sign to be positive relative to the omitted base of $UHEL*Pmt_{pt}$. We expect the coefficient on HEL_f to be larger than $NHEL_f$, since we know that around 60% of $NHEL_f$ is unproductive and 70% of HEL_f is unproductive.

Non-highly erodible land is a proxy for ability to keep land in production by planting corn and soy since the land it unlikely to erode. As the price varies, farmers will be less price sensitive to highly erodible land, and the elasticity of supply will lower.

As stated above, $UHEL_f$ is mostly land that is not under cultivation, while $NHEL_f$ has a larger percentage of land that is under cultivation than HEL_f. But both $NHEL_f$ and HEL_f have a large percentage of land under cultivation, 41% and 30% respectively. Therefore, it may be difficult to distinguish between the two.

4. The price elasticity of supply is higher for practices that take land out of production, than for practices involving unproductive land.

This hypothesis can be measured through the interaction of payment with conservation practices that take productive land out of use, $prod*Pmt_{pt}$. We would expect the sign to be positive relative to the omitted base category $unprod*Pmt_{pt}$. This means that farmers would be more price elastic to practices that take land out of production compared to those that do not. This is an interaction of payment and practice type, as opposed to hypothesis three which considers an interaction of payment and farm characteristics.

5. The price elasticity of supply is higher for practices with continuous sign-up.

This hypothesis can be measured through the interaction of payment with conservation practices that go through continuous sign-up, $cts*Pmt_{pt}$. We expect the price elasticity of supply to be higher for practices in continuous sign-up compared to general sign-up.

This is an interaction of payment and practice type similar to hypothesis four, as opposed to hypothesis three which is an interaction of payment and farm characteristics. As the payments vary, farmers will be more price sensitive to land in continuous sign-up, and elasticity of supply will higher. As such, we expect the sign to be positive. We would expect practices that go through continuous sign-up to have higher payment amounts since the payment determination mechanisms between general and continuous sign-up are so different. General sign-up involves a bidding process. By selecting farmers that are willing to enroll at lower payments, general sign-up practices will appear less price sensitive.

Results and Discussion

As mentioned above, four models of increasing complexity were utilized for this analysis. Table 20 shows the results of tests that demonstrate the relative performance of the models and the relative improvement and statistical support for the increasingly complex models.

The maximized log-likelihood values cannot be used alone as an index of fit because they are a function of sample size but can be used to compare the fit of different coefficients. As our models increase in complexity, the log-likelihood also increases, in this case getting closer to zero.

McFadden's pseudo-R^2 measures goodness-of-fit. Values of .2 to .4 are considered highly satisfactory (McFadden, 1977). All of our models have pseudo-R^2 values above .4. Both conditional logit models (Models 1 and 3) are slightly better than the pseudo-R^2 for the alternative specific conditional logit models (Models 2 and 4).

Lastly, Akaike's information criterion (AIC) and the Bayesian information criterion (BIC) are used for model prediction. For both AIC and BIC lower amounts signify that the models are a better fit. As our models increase in complexity (from Model 1 to 4), both AIC and BIC decrease, signifying that the more complex model is a better fit than the previous model.

Table 20. Model Performance

Model #	Log-Likelihood	pseudo-R^2	AIC	BIC
1	-35,498.97	0.5084	71017.93	71130.3
2	-28,987.17	0.4616	58036.34	58384.69
3	-26,738.94	0.5890	53549.88	53950.66
4	-23,152.01	0.5700	46418.02	47052.6

Tables 21 and 22 demonstrate the results of the four models. The first two models exclude farm characteristics while the second two models include farm characteristics. Both tables include the conditional and alternative specific conditional logit results.

Table 21. No Farm Characteristics, Conditional Logit and Alternative Specific Conditional Logit

Model 1. Conditional Logit		**Model 2. Alternative Specific Conditional Logit**	
	Coef.		**Coef.**
Continuous Xunproductiveland	-2.915**** (.053)		
General Xproductiveland	2.389**** (.038)		
General Xunproductiveland	3.018**** (.036)		
paymentreal (base)	3.361**** (.037)	paymentreal (base)	4.760**** (.063)
Xproductiveland	-0.955**** (.033)	Xproductiveland	-2.438**** (.067)
Xcontinuous	-0.384**** (.040)	Xcontinuous	0.976**** (.064)
Futures: yearlong average (interactions)			
Xproductiveland	-0.141**** (.028)	Xproductiveland	-0.168**** (.035)
Xcontinuous	-0.052* (.028)	Xcontinuous	-0.087*** (.033)
Futures: coefficient of variation (interactions)			
Xproductiveland	-0.097**** (.025)	Xproductiveland	-0.149**** (.030)
Xcontinuous	0.096**** (.025)	Xcontinuous	0.100**** (.029)

z statistics in parentheses * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

Table 22. Farm Characteristics, Conditional Logit and Alternative Specific Conditional Logit

Model 3. Conditional Logit		**Model 4. Alternative Specific Conditional Logit**	
	Coef.		**Coef.**
Continuous Xunproductiveland	-1.489**** (.114)		
General Xproductiveland	-2.489**** (.167)		

General Xunproductiveland	-1.026**** (.167)		
paymentreal (base)	1.727**** (.061)	paymentreal (base)	3.560**** (.079)
Xproductiveland	-0.394**** (.036)	Xproductiveland	-2.015**** (.071)
Xcontinuous	-1.086**** (.048)	Xcontinuous	0.051 (.070)
Xcsraverage	1.299**** (.056)	Xcsraverage	0.831**** (.051)
Xcsrgood	2.530**** (.060)	Xcsrgood	1.629**** (.058)
Xhighlyero	2.571**** (.048)	Xhighlyero	1.989**** (.049)
Xnonhighlyero	3.060**** (.051)	Xnonhighlyero	2.274**** (.049)
Futures: yearlong average (interactions)			
Xproductiveland	-0.081*** (.031)	Xproductiveland	-0.126**** (.036)
Xcontinuous	-0.220**** (.037)	Xcontinuous	-0.132**** (.041)
Futures: coefficient of variation (interactions)			
Xproductiveland	-0.070*** (.028)	Xproductiveland	-0.130**** (.032)
Xcontinuous	0.055* (.033)	Xcontinuous	0.118**** (.037)
Corn Suitability Rating: Class 2, Average			
Xproductiveland	-0.260**** (.066)	Xproductiveland	-0.161** (.068)
Xcontinuous	-1.146**** (.098)	Xcontinuous	-0.542**** (.092)
Corn Suitability Rating: Class 3, Good			
Xproductiveland	-0.247**** (.076)	Xproductiveland	-0.144*** (.079)
Xcontinuous	-1.426**** (.112)	Xcontinuous	-0.177* (.109)
Erodibility: Highly Erodible Land			
Xproductiveland	0.169* (.095)	Xproductiveland	-0.171* (.104)
Xcontinuous	-4.287**** (.117)	Xcontinuous	-3.268**** (.116)
Erodibility: Not Highly Erodible Land			
Xproductiveland	-0.098 (.098)	Xproductiveland	-0.389**** (.108)
Xcontinuous	-3.012**** (.126)	Xcontinuous	-1.709**** (.129)
Land Cover: Corn			
Xproductiveland	0.086 (.110)	Xproductiveland	0.137 (.118)
Xcontinuous	0.242* (.150)	Xcontinuous	0.186 (.158)

Land Cover: Water			
Xproductiveland	-0.481 (.594)	Xproductiveland	-0.566 (.659)
Xcontinuous	2.342*** (.911)	Xcontinuous	2.420*** (.971)
Land Cover: Developed			
Xproductiveland	0.772**** (.199)	Xproductiveland	0.712*** (.220)
Xcontinuous	-0.842*** (.266)	Xcontinuous	-0.968**** (.285)
Land Cover: Grassland			
Xproductiveland	0.969**** (.090)	Xproductiveland	0.925**** (.096)
Xcontinuous	-2.045**** (.118)	Xcontinuous	-2.046**** (.125)
Land Cover: Wetlands			
Xproductiveland	1.805**** (.252)	Xproductiveland	1.563**** (.277)
Xcontinuous	-1.691**** (.313)	Xcontinuous	-1.411**** (.333)
Land Cover: Forest			
Xproductiveland	1.048**** (.151)	Xproductiveland	0.920**** (.159)
Xcontinuous	-2.034**** (.189)	Xcontinuous	-1.939**** (.197)
Land Cover: Miscellaneous			
Xproductiveland	2.398**** (.213)	Xproductiveland	2.544**** (.228)
Xcontinuous	-5.752**** (.337)	Xcontinuous	-5.835**** (.359)

z statistics in parentheses * p<0.10 ** p<0.05 *** p<0.01 **** p<0.001

We now evaluate our hypotheses. Note that all hypotheses involving farm characteristics can only be tested using Models 3 and 4.

1. Farmers with high opportunity cost land (in terms of corn and soy productivity) are less likely to enroll in practices that retire productive land than farmers with less valuable land for farming.

The interactions $prod*\text{CSRAvg}_f$ and $prod*CSRGood_f$ were negative and significant for Models 3 and 4 as we hypothesized. These are compared to a base which is $CSRBad_f$. CSR is a measure of the relative quality of productive land. The hypothesis that farmers are less likely to commit productive land to CRP the higher the CSR of that land holds true.

The interactions of $prod*Dev_f$, $prod*Grass_f$, $prod*Wetland_f$, $prod*Forest_f$, and $prod*Misc_f$ were positive and significant across Models 3 and 4 as we hypothesized. These land covers are in areas that do not take productive land out of use. The interaction of $prod*Corn_f$ was positive but insignificant and the interaction of $prod*Water_f$ was negative but insignificant It is not unexpected that $prod*Corn_f$ was positive but insignificant because we utilized $prod*Soy_f$ as the base category. In practice, corn-soy act as a single cropping system, where farmers use a corn-soy rotation.

We hypothesized that $prod*HEL_f$ would be positive and $prod*NHEL_f$ would be negative relative to the omitted base of $unprod*UHEL_f$. The interaction $prod*HEL_f$ was positive and significant in Model 3 and negative and significant in Model 4. We did not anticipate a negative and significant interaction for $prod*HEL_f$ as seen in Model 4. The interaction $prod*NHEL_f$ was negative for Models 3 and 4, but only significant in Model 4, which is what we hypothesized.

2a. Farmers are less likely to enroll in practices that retire productive land, the higher the expected future price of corn and soy (as measured by average corn and soy futures).

Since we know that farmers look at corn futures when making long-term decisions, such as signing a 10- to 15-year CRP contract, we hypothesized that farmers would be less likely to enroll in CRP, specifically practices that take their land out of production, if corn futures are increasing. This hypothesis is confirmed; the interaction $prod*FutureAvg_t$ was negative and significant across Models 1 through 4. We also find that the interaction $cts*FutureAvg_t$ was negative and significant across Models 1 through 4 as we hypothesized.

2b. Farmers are more likely to enroll in practices that retire productive land, the higher the expected coefficient of variation for price of corn and soy (as measured by corn and soy futures).

For $prod*FutureCV_t$ we expected the sign to be positive relative to the omitted base of $unprod*FutureCV_t$. Higher CV should theoretically make risk-averse farmers (without perfect insurance and hedging opportunities) more likely to take the "sure thing" of the CRP contract on their productive lands. However, this hypothesis was rejected; the interaction $prod*FutureCV_t$ was negative and significant for Models 1 through 4.

3. The price elasticity of supply is higher as the quality of land increases (as measured by CSR and erodibility).

We expected that farmers with land with a higher CSR rating would need a higher payment to enroll in practices, due to the higher opportunity cost of enrollment in CRP. For both $csravg*Pmt_{pt}$ and $csrgood*Pmt_{pt}$ the coefficients were positive and significant for Models

3 and 4, as we hypothesized. This suggests that the price elasticity of supply is higher as the quality of land increases (as measured by CSR).

When looking at erodibility, HEL_f*Pmt_{pt} and $NHEL_f*Pmt_{pt}$ were expected to have positive signs, which they do. This is likely because the base, $UHEL_f$, is mostly land that is not in cultivation, while HEL_f and $NHEL_f$ both have high percentages of land that are under cultivation.

4. The price elasticity of supply is higher for practices that take land out of production, than for practices involving unproductive land.

We believed farmers would be more price elastic when productive land is affected by the practice as compared to marginal land. Looking at the interaction $prod*Pmt_{pt}$, our results demonstrate that the interaction is negative and significant for Models 1 through 4. We hypothesized that the interaction would be positive, and this hypothesis is therefore rejected. That means that the price elasticity of supply is lower for practices that take land out of production, than for practices involving unproductive land.

5. The price elasticity of supply is higher for practices with continuous sign-up.

Practices that are enrolled through continuous sign-up interacted with payments, $cts*Pmt_{pt,}$ are negative compared to the base $gen*Pmt_{pt}$ in Models 1 and 3 and positive in Models 2 and 4. We expected the sign to be positive, meaning that the price elasticity of supply is higher for practices with continuous sign-up. Therefore, the evidence is ambiguous with the alternative specific conditional logit models agreeing with the hypothesis, but only weakly (and insignificantly for Model 4).

Conclusions

Farmers' voluntary decisions to enroll in particular CRP practices are shaped by a range of factors including market conditions, farm and landscape characteristics, and specific features of individual conservation contracts. Our main findings are that:

- farmers are less likely to commit productive land to CRP as the quality of land increases (as measured by CSR);
- farmers are less likely to enroll in CRP, specifically practices that take their land out of production, if corn futures are increasing;
- the price elasticity of supply is higher as the quality of land increases (as measured by CSR); and
- the price elasticity of supply is, surprisingly, lower for practices that take land out of production, than for practices involving unproductive land.

These findings have several potentially valuable implications for thinking about CRP policy design. First, holding price constant, farmers are more likely to choose a practice that is implemented on unproductive land than one that takes productive land out of use. However, this tendency potentially dilutes the additionality (and cost-effectiveness) of

CRP, depending on the efficacy of the underlying changes in practices (if any) on the unproductive land. In order to incentivize farmers to substitute toward practices involving productive lands CRP managers may need to either increase the relative payment for these practices or find ways to increase their attractiveness through other non-price incentives, such as technical assistance.

This is extremely important when thinking about the implications for improving water quality since marginal land is unlikely to be the main contributor to the water quality problems faced in Iowa. Enhancing enrollment of lands suited to intensive use in corn and soy production may enhance the additionality and physical effectiveness of CRP contracts, but at the cost of greater outlays to farmers. Whether this would yield more cost-effective provision of water quality and other ecosystem services likely depends upon the particulars of the program design. Our model provides a valuable simulation tool for considering how changes in program design – especially payment structure across practices – may affect farmers' choices of CRP practices across the spectrum of farm quality.

Second, the current use of the 3-year average county rental rate to determine prices for CRP practices in continuous sign-up fails to adequately match farmers' adaptive responsiveness to changes in the price prospects of commodity crops. Given our findings that farmers react in economically rational ways to contemporaneous changes in futures markets in their CRP enrollment decisions, the use of lagged rental rates to set CRP payments tends to drastically overpay in periods of anticipated commodity price slides, with correspondingly drastic underpayment in periods of steep price increases. This may induce a countercyclical ‘boom-bust’ variability in CRP enrollment in productive lands practices above and beyond what would already occur if CRP payments adjusted to commodity prices in a less sluggish manner. Whether greater smoothing of CRP enrollment patterns is desired as a policy objective depends in part on the extent to which USDA desires to use CRP practices on productive lands as a form of insurance for risk-averse farmers as opposed to a means to secure a stable flow of reliable ecosystems services across the landscape.

Third, on a related point, managers may consider shortening the 10- to 15-year contract length for continuous sign-up practices taking productive land out of production or perhaps consider offering variable length contracts for the same CRP practice. This would give farmers the flexibility to make shorter-term decisions while potentially allowing CRP to increase the cost-effectiveness of its contracts. Most practices in continuous sign-up can see improved water quality benefits in a shorter period of time than the current contract lengths. This would also improve targeting of different ecosystem services.

Future Research

It is important to note the limitations to this analysis. Characteristics specific to the farmer, such as total household income, tenancy structure (i.e. owner operated vs. leased), date until retirement, and many other potentially relevant variables are not readily available and are thus unobserved in our analysis. This unobserved farmer heterogeneity could be correlated with land characteristics and therefore our estimates should not be taken causally and predictions from our model should be viewed with caution. Given the absence of important farm and (especially) farmer-level data, model predictions could be improved by developing a random parameters logit specification. This model would incorporate heterogeneity in the responses of farmers as a function of observable farm-level characteristics – potentially yielding more robust predictions of farmers' substitution patterns.

Our main contribution is in analyzing heterogeneous practices in order to better target outcomes for physical effectiveness and cost-effectiveness. This is the first paper that has disaggregated conservation practices in order to improve the understanding of the determinants of the opportunity cost of the CRP.

CHAPTER 5: CONCLUSION

This dissertation addresses three key questions about the water quality goals of the CRP program in Iowa:

1. What are the effects of crops, natural cover, and CRP conservation practices on lake water quality;
2. How does cost-effectiveness differ between CRP practices that target water quality, either alone or in combination with other environmental objectives; and
3. Assuming farmers enroll in CRP, what types of practices are they choosing and what factors do those practices possess?

These questions target the physical effectiveness, cost-effectiveness, and characteristics of CRP practices aimed at lake water quality in Iowa. The study is motivated by the recent sharp increase in Iowa's contribution to nitrogen pollution of the Mississippi and Missouri rivers, and hence to the 'dead zone' in the Gulf of Mexico. Iowa is currently responsible for more than half of the nitrogen load in the Missouri. This represents an increase in emissions of around 50 percent since 2003, 90 percent of which is due to crop cultivation in the state (Jones et al., 2018). This is despite the efforts of the Conservation Reserve Program to encourage farmers to reduce the flow of agricultural nutrients to waterways.

The results on the physical effectiveness of CRP reported in Chapter Two show that while CRP conservation practices aimed at water quality had little impact on phosphorus, chlorophyll a, or turbidity in the study period, they did have a large impact on the nutrient of greatest concern, nitrogen. Given the potential impact of the program on nitrogen, we then considered which CRP practices were cost-effective in reducing nitrogen in Chapter Three, and what factors affected the amount of land enrolled in CRP in the lake watersheds in Chapter Four.

In Chapter Three we explored the cost-effectiveness of the different CRP practices targeting water quality. We expected practices offered through the general sign-up to be amongst the most cost-effective since they go through a reverse auction designed to be cost-effective. However, while thirty percent of conservation practices were found to have a statistically significant positive effect on at least one water quality variable in Iowa's lakes, many were cost-ineffective relative to practices that go through continuous sign-up. Because they had only a weak effect on water quality, the cost per unit improvement in water quality was high. Moreover, many of the least cost-effective conservation practices were found to be offered through general sign-up.

Understanding what leads to enrollment in specific conservation practices will allow the USDA to improve targeting for ecosystem service provision, in this case for water quality. In Chapter Four we found that farmers' voluntary decisions to enroll in particular CRP practices were shaped by a range of conditions, including particular farm characteristics, specific features of individual conservation contracts, crop prices, and the price of conservation contracts. Specifically, we found that farmers were less likely to commit productive land to CRP as the quality of land increased; that they were less likely to enroll in CRP practices that took land out of production if corn futures were increasing; and that the price elasticity of supply (enrollment) was higher as the quality of land increased. Interestingly, we also found that the price elasticity of supply was lower for practices that took land out of production than for practices involving unproductive land.

Implications for science and policy

The implications of our individual findings are reported in each chapter. Here we offer a brief summary and discuss the broader implications of our findings for the management of nitrogen pollution of waterways. In the CRP Handbook, the CRP's stated objective is to encourage owners and operators to conserve and improve land resources in a cost-effective manner (United States Department of Agriculture Farm Service Agency, 2015). Our results show that a number of CRP practices targeting lake water quality have a limited impact, and that the incentives for farmers to enroll in cost-effective practices that do improve water quality are weak. The following are suggestions for policy improvement:

1. Aim for a better balance between the price of practices offered through continuous sign-up and the opportunity cost of land taken out of production—the marginal net revenue of crop production. This may be through shortening contract lengths, or through adjustable contract prices. Chapter Four demonstrated that farmers were more likely to choose a practice implemented on unproductive land than on productive land. This is partly because the prices of conservation practices that take land out of production are frequently below the opportunity cost of the land. Matching the price of

practices that provide improvements in water quality and take productive land out of use would increase the incentive for farmers to enroll in them.

2. Adjust the 3-year average county rental rate used to determine prices for CRP practices in continuous sign-up. The current use of lagged rental rates to set CRP payments tends to drastically overpay in periods of anticipated commodity price slides, with correspondingly drastic underpayment in periods of steep price increases. Adjusting to a 1-year average county rental rate could greatly improve farmers willingness to choose practices that take productive land out of use.
3. Promote practices that are shown to be cost-effective. The FSA as an institution spends a good deal of its efforts going out into the field to promote enrollment in specific practices. Based on our results, FSA could deploy its team to work with farmer cooperatives and individual farmers to boost enrollment in cost-effective practices.
4. Undertake measures to improve the cost-effectiveness of cost-ineffective practices. One way to do this might be to allow practices to move between continuous and general sign-up. Practices that are targeted at water quality and are currently cost-ineffective are good candidates to move from continuous sign-up to general sign-up. This would result in lowering the cost of delivering ecosystem service provisions.
5. Adjust the Environmental Benefits Index (EBI) used for general sign-up to focus on physical impacts that meet the water quality objectives of the USDA. One option would be to create a subset of characteristics specifically focused on water quality that address in more detail the outcomes that the CRP program is looking to achieve (more of a focus on conditionality).

6. Since many conservation practices are only applicable in limited biophysical conditions, identify the cost-effectiveness of the sub-set of practices that meet those conditions. For example, the Marginal Pastureland Wildlife Habitat Buffer practice is only applicable where there is pasture and not cropland, it is not an option in many situations. In this case, the ranking of practices by target, biophysical conditions, and cost-effectiveness would provide useful information.

As with PES schemes in general, the main concerns with CRP are whether it offers additionality, whether it is offers the hoped-for impacts on the supply of ecosystem services, and whether it is cost-effective. While we were unable to directly test for additionality, we were able to test the physical effectiveness and cost-effectiveness of particular practices, and the factors affecting the supply of land in conservation. We were able to do this because of the availability of detailed data on enrollment, payments, contracts, and, most importantly, on water quality. While the monitoring of water quality is not undertaken as part of the CRP, it is critical to the assessment of both physical effectiveness and cost-effectiveness. Few PES schemes elsewhere benefit from monitoring data in the same way. Nevertheless, evaluation of CRP performance would be simpler if additional data were generated on the value of land for farms that are not enrolled in the CRP, detailed ownership information (owner, operator, and owner-operator), and socio-economic data at the farm level (as opposed to the randomized surveys conducted by USDA NASS).

Steps for Future Research

As with any research, there are opportunities to improve on the work that has been done. For Chapter Two we could compare our results to a Soil and Water Assessment Toil (SWAT) analysis. This would provide an opportunity to validate our results using hydrological data.

For Chapter Three future research should look at non-marginal changes related to cost-effectiveness of conservation practices. There is also a need to look at the heterogeneity and spatial specificity of particular conservation practices on the landscape. In addition, there needs to be further research into why many of the practices that are targeted at improving water quality were not physically effective or cost-effective.

For Chapter Four future research should look at other models that allow for heterogeneity of behavioral responses by farmers with a given set of farm characteristics. In addition, the role of social capital should be looked into since we know that many farmers make decisions about what conservation practices to enroll in based on what their neighbors are doing.

Lastly, tests for additionality of conservation practices is greatly needed. It is necessary to understand whether conservation practices induce farmers to undertake conservation measures that they would not otherwise do.

Implications for a wider understanding of PES schemes

CRP is one of the oldest examples of a PES scheme, albeit one that is better served by data than almost any other example. We would expect that the factors influencing additionality and cost-effectiveness in CRP likely apply to other PES schemes. By having a clearer understanding of what works in CRP and why, we may be in a better position to understand what might work and why in other schemes.

As with many other PES schemes, CRP attempts to incentivize farmers to produce public goods on private land. It does so by providing landholders with an incentive to change land use. Additionally, monitoring within the program focuses on whether the payment led to the change in practice, not whether the change in practice had the desired impact on water quality. This is often due to a lack of baseline data, funds for monitoring, and a long enough time series to see an impact. In practice, very few PES schemes base payments on the value of increments to ecosystem services. Our research was able to quantify the impact of CRP on a change in an ecosystem service, water quality, because water quality data were available from other sources. Since conditionality is a key aspect of a successful PES scheme, continued evaluation of changes in ecosystem services, as opposed to adherence to contracts, is necessary (Goldman-Benner et al., 2012). The main implication of our work for other PES schemes is that evaluation of physical effectiveness or cost-effectiveness depends on the generation of data on the impact of practices on the environmental variable of interest.

A further implication is that enrollment depends on the existence of payments that track the opportunity cost of changes in land use. This affects both the mean level of payments (they need to be at least as great as the opportunity cost) and their time profile (they need to change as the opportunity cost of land changes). Long contracts supported by inflexible payments may induce landholders to abandon contracts in mid-term.

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APPENDIX A

CHAPTER TWO WATER QUALITY FULL RESULTS

Phosphorus

	RE **lntotalP**	RE + Lag **lntotalP**	FE **lntotalP**	FE + Lag **lntotalP**	FD **D.lntotalP**	FD + lag **lntotalP**	AB **lntotalP**
WATERSHARE	-0.208	-0.114	0.033	-1.831			-0.257
	(-0.30)	(-0.23)	-0.02	(-0.76)			(-0.08)
DEVELOPEDSHARE	-1.2	-0.665	1.956	2.577			6.375
	(-0.78)	(-0.83)	-1.04	-0.98			-1.54
WETLANDSSHRUBLANDSSHARE	-0.103	0.945	-0.113	-0.221			0.767
	(-0.09)	-0.82	(-0.08)	(-0.10)			-0.31
FORESTTREESSHARE	-1.861****	-0.528*	-2.938	-5.502**			-2.229
	(-4.36)	(-1.72)	(-1.57)	(-2.37)			(-0.85)
CORNSHARE	0.176	0.149	0.157	-0.0758			0.415
	-0.41	-0.31	-0.35	(-0.16)			-0.76
GRASSPASTURESHARE	-0.309	0.123	0.547	1.039			1.931
	(-0.73)	-0.35	-0.69	-0.7			-1.21
OTHERCROPSSHARE	0.509	0.284	2.136*	2.375			3.294*
	-1.12	-0.95	-1.82	-1.32			-1.77
L.lntotalP		0.625****		-0.0527		0.959****	0.0574
		-11.53		(-1.07)		-69.74	-0.43
D.WATERSHARE					0.536	1.804	
					-0.23	-0.75	
D.DEVELOPEDSHARE					-0.949	-0.425	
					(-0.41)	(-0.17)	
D.WETLANDSSHRUBLANDSSHARE					0.307	0.247	
					-0.19	-0.15	
D.FORESTTREESSHARE					-3.469*	-2.507	
					(-1.82)	(-1.25)	
D.CORNSHARE					0.366	0.345	
					-0.9	-0.88	
D.GRASSPASTURESHARE					0.351	0.262	
					-0.4	-0.3	
D.OTHERCROPSSHARE					1.926	1.695	
					-1.53	-1.34	
PerCRPofCrops	0.109	-0.314	0.603	0.639			2.283*
	-0.17	(-0.82)	-0.86	-0.62			-1.76
D.PerCRPofCrops					1.136	1.361	
					-1.31	-1.52	
PerCornCRP	-0.0000982	-0.0000836	-0.0000303	0.000136			0.000352
	(-0.75)	(-0.68)	(-0.25)	-0.57			-1.46
PerGrassPastureCRP	-0.0000473	-0.00000469	0.00000514	-0.00000538			0.000237*
	(-0.93)	(-0.13)	-0.07	(-0.05)			-1.69
PerForestTreesCRP	0.000794*	-0.0000054	0.00083	0.00138			0.00164
	-1.71	(-0.02)	-0.95	-1.51			-1.16
PerWetlandsShrublandsCRP	-0.0000849	-0.0000796	0.00000458	-0.000137			0.00025
	(-0.77)	(-0.73)	-0.04	(-0.67)			-1.15
PerWaterCRP	-0.00127	-0.00106	-0.000975	-0.00138			-0.00109
	(-1.29)	(-1.20)	(-0.93)	(-1.43)			(-1.32)
PerDevelopedCRP	0.000624	0.000142	0.000276	0.00346			-0.0000796
	-0.56	-0.23	-0.15	-1.2			(-0.03)
PerOtherCropsCRP	-0.000193	0.0000521	-0.000244	-0.000165			0.000087
	(-1.53)	-0.47	(-1.60)	(-0.96)			-0.41
D.PerCornCRP					-0.00000906	0.00000506	
					(-0.04)	-0.02	
D.PerGrassPastureCRP					-0.0000224	-0.0000145	
					(-0.17)	(-0.10)	
D.PerForestTreesCRP					0.000283	0.00065	
					-0.24	-0.58	
D.PerWetlandsShrublandsCRP					-0.0000659	-0.0000661	
					(-0.35)	(-0.34)	
D.PerWaterCRP					-0.00145*	-0.00163*	
					(-1.77)	(-1.90)	
D.PerDevelopedCRP					-0.000652	-0.000568	
					(-0.26)	(-0.23)	
D.PerOtherCropsCRP					-0.00029	-0.000278	
					(-1.62)	(-1.51)	
Fall_Precip	0.0174**	0.0208**	0.0145	0.0155			0.00491
	-2.13	-2.01	-1.64	-1.33			-0.41
Winter_Precip	-0.0253**	-0.0228*	-0.0261**	-0.0263**			-0.0308**
	(-2.41)	(-1.73)	(-2.47)	(-2.32)			(-2.55)
Spring_Precip	0.0149***	0.00566	0.0131***	0.0106**			0.00857
	-3.01	-0.83	-2.63	-2.1			-1.38
Summer_Precip	0.000101	-0.00914**	-0.000467	-0.0042			-0.0058
	-0.03	(-2.00)	(-0.14)	(-1.01)			(-1.22)
D.Fall_Precip					0.014	0.0154*	
					-1.55	-1.69	
D.Winter_Precip					-0.0249**	-0.0231**	
					(-2.23)	(-2.01)	
D.Spring_Precip					0.00927*	0.00934**	
					-1.96	-1.97	
D.Summer_Precip					-0.000592	-0.000244	
					(-0.19)	(-0.08)	
CAFO	0.0332	0.0044	0.173	0.142			0.344**
	-0.33	-0.09	-1.39	-1.12			-2.54

D.CAFO					0.341**	0.307*	
					-2.12	-1.76	
Alfisols	0	0	0	0			
	(.)	(.)	(.)	(.)			
Entisols	-0.687***	-0.243**	0	0			
	(-3.28)	(-2.17)	(.)	(.)			
Inceptisols	-0.756***	-0.350****	0	0			
	(-3.17)	(-3.98)	(.)	(.)			
Mollisols	-0.202	-0.0361	0	0			
	(-1.58)	(-0.68)	(.)	(.)			
NoData	-0.202	-0.0521	0	0			
	(-0.74)	(-0.59)	(.)	(.)			
D.Dominant Soil Type					0		
					(.)		
Dominant Soil Type						0.0480***	0.917***
						-2.95	-2.65
Iowa LL Lake Depth	-0.0583****	-0.0252****	-0.0154	0.00153			-0.00612
	(-4.35)	(-3.45)	(-0.50)	-0.04			(-0.13)
D.Iowa LL Lake Depth					-0.00013	0.000642	
					(-0.01)	-0.03	
Constant	5.178****	1.940****	4.290****	4.853****			0
	-14.6	-5.05	-7.07	-5.22			(.)
Observations	570	467	570	467	458	458	358

Nitrogen

	RE	RE + Lag	FE	FE + Lag	FD	FD + lag	AB
	lntotalN	**lntotalN**	**lntotalN**	**lntotalN**	**D.lntotalN**	**lntotalN**	**lntotalN**
WATERSHARE	0.287	-0.806	-7.695	-0.665			-1.134
	-0.31	(-0.80)	(-1.32)	(-0.08)			(-0.10)
DEVELOPEDSHARE	-2.045	-1.566	-7.771**	-4.491			1.798
	(-1.63)	(-1.30)	(-2.27)	(-0.67)			-0.18
WETLANDSSHRUBLANDSSHARE	-2.347	-2.632	-7.395**	-4.268			-0.842
	(-1.20)	(-1.19)	(-2.24)	(-0.84)			(-0.13)
FORESTTREESSHARE	-0.801	-1.19	-2.828	-0.342			6.537
	(-1.09)	(-1.41)	(-0.66)	(-0.05)			-0.8
CORNSHARE	-0.0256	-0.73	0.405	0.418			0.91
	(-0.03)	(-0.70)	-0.41	-0.4			-0.8
GRASSPASTURESHARE	0.418	0.261	-3.568*	-3.34			-3.787
	-0.5	-0.25	(-1.71)	(-1.02)			(-1.00)
OTHERCROPSSHARE	0.688	0.453	-2.384	-2.771			-1.546
	-1.04	-0.62	(-0.82)	(-0.70)			(-0.33)
L.lntotalN		0.149**		-0.185****		0.719****	-0.165*
		-2.43		(-3.48)		-22.73	(-1.80)
D.WATERSHARE					-7.342	3.719	
					(-0.88)	-0.47	
D.DEVELOPEDSHARE					8	19.33***	
					-1.53	-2.82	
D.WETLANDSSHRUBLANDSSHARE					-0.0969	1.275	
					(-0.02)	-0.35	
D.FORESTTREESSHARE					10.56**	18.00****	
					-2.05	-3.91	
D.CORNSHARE					0.515	0.234	
					-0.6	-0.31	
D.GRASSPASTURESHARE					-1.358	-0.582	
					(-0.66)	(-0.31)	
D.OTHERCROPSSHARE					1.036	1.644	
					-0.33	-0.57	
PerCRPofCrops	-1.990*	-0.983	-5.152**	-4.278			-2.664
	(-1.94)	(-1.04)	(-2.45)	(-1.22)			(-0.38)
D.PerCRPofCrops					-2.702	1.748	
					(-0.84)	-0.69	
PerCornCRP	0.000239	0.000207	-0.000254	-0.000756			-0.00175***
	-1.04	-0.92	(-0.77)	(-1.42)			(-2.60)
PerGrassPastureCRP	-0.0000909	-0.000106	-0.000781****	-0.000750**			-0.00123***
	(-1.33)	(-1.30)	(-3.81)	(-2.37)			(-2.87)
PerForestTreesCRP	0.00121*	0.00143**	0.00201	0.000894			0.00112
	-1.9	-2.19	-1.41	-0.44			-0.48
PerWetlandsShrublandsCRP	-0.000251	-0.0000161	-0.000776***	-0.000731*			-0.00136**
	(-1.30)	(-0.07)	(-3.05)	(-1.81)			(-2.12)
PerWaterCRP	-0.00125	-0.00106	-0.00136	-0.000223			-0.00107
	(-0.84)	(-0.81)	(-1.01)	(-0.15)			(-0.64)
PerDevelopedCRP	0.0000747	0.000262	0.00284	0.00393			0.0115*
	-0.07	-0.2	-1.16	-0.92			-1.85
PerOtherCropsCRP	-0.0000296	-0.0000136	-0.00116**	-0.00123*			-0.00225***
	(-0.10)	(-0.04)	(-2.40)	(-1.88)			(-3.24)
D.PerCornCRP					-0.0005	-0.0000773	
					(-1.19)	(-0.21)	
D.PerGrassPastureCRP					-0.000618*	-0.000123	
					(-1.89)	(-0.39)	
D.PerForestTreesCRP					0.00254	0.00511**	
					-1.12	-2.54	
D.PerWetlandsShrublandsCRP					-0.000554	-0.000232	
					(-1.20)	(-0.55)	
D.PerWaterCRP					-0.000555	-0.00145	
					(-0.29)	(-0.73)	
D.PerDevelopedCRP					0.00204	0.00313	
					-0.5	-0.88	
D.PerOtherCropsCRP					-0.00144***	-0.000874**	
					(-3.24)	(-2.14)	
Fall_Precip	-0.0821****	-0.0817****	-0.0806****	-0.139****			-0.145****
	(-5.13)	(-4.20)	(-4.15)	(-5.11)			(-5.07)
Winter_Precip	-0.0486**	-0.0334	-0.0481**	-0.0293			-0.0137
	(-2.23)	(-1.32)	(-2.12)	(-1.17)			(-0.52)
Spring_Precip	0.0363****	0.0568****	0.0353***	0.0280**			0.0342**
	-3.77	-4.48	-3.07	-2.16			-2.39
Summer_Precip	0.0469****	0.0454****	0.0434****	0.0546****			0.0597****
	-8.33	-5.77	-6.44	-6.84			-6.88
D.Fall_Precip					-0.0655***	-0.0478**	
					(-3.12)	(-2.55)	
D.Winter_Precip					-0.0582**	-0.0263	
					(-2.04)	(-0.94)	
D.Spring_Precip					0.0591****	0.0477****	
					-5.05	-4.2	
D.Summer_Precip					0.0409****	0.0316****	
					-5.81	-5.09	
CAFO	-0.0224	-0.0539	0.543**	0.652**			0.693
	(-0.22)	(-0.52)	-2.5	-2.29			-1.54

D.CAFO					0.915**	0.687*	
					-2.06	-1.78	
Alfisols	0	0	0	0			
	(.)	(.)	(.)	(.)			
Entisols	-0.133	-0.000983	0	0			
	(-0.53)	(-0.00)	(.)	(.)			
Inceptisols	-0.16	-0.19	0	0			
	(-0.64)	(-0.76)	(.)	(.)			
Mollisols	0.0135	-0.0175	0	0			
	-0.08	(-0.10)	(.)	(.)			
NoData	0.201	0.337	0	0			
	-0.69	-1	(.)	(.)			
D.Dominant Soil Type					0		
					(.)		
Dominant Soil Type						0.269****	1.361
						-6.91	-1.35
Iowa LL Lake Depth	-0.0160***	-0.0181***	0.0665	0.00915			0.0864
	(-2.61)	(-2.63)	-0.95	-0.09			-0.88
D.Iowa LL Lake Depth					0.0950*	0.065	
					-1.66	-1.23	
Constant	4.417****	3.802****	6.954****	6.540**			0
	-6.95	-4.8	-4.29	-2.43			(.)
Observations	570	467	570	467	458	458	358

Chlorophyll a

	RE	RE + Lag	FE	FE + Lag	FD	FD + lag	AB
	ln chlorophyll a	**ln chlorophyll a**	**ln chlorophylla**	**ln chlorophyll a**	**D.ln chlorophyll a**	**ln chlorophyll a**	**ln chlorophyll a**
WATERSHARE	-0.388	-0.528	4.093	2.44			4.015
	(-0.56)	(-0.88)	-1.12	-0.57			-0.89
DEVELOPEDSHARE	-1.782	-1.122	7.219***	-3.77			-0.185
	(-1.09)	(-0.81)	-3.07	(-0.88)			(-0.03)
WETLANDSSHRUBLANDSSHARE	1.11	4.274***	2.885	1.099			5.604
	-0.71	-2.75	-1.31	-0.43			-1.57
FORESTTREESSHARE	-1.619**	-0.905	3.091	-0.356			4.022
	(-2.57)	(-1.48)	-1.38	(-0.13)			-1.41
CORNSHARE	-0.0321	0.47	-0.304	-0.265			0.07
	(-0.06)	-0.76	(-0.54)	(-0.53)			-0.12
GRASSPASTURESHARE	-0.388	0.496	1.508	0.67			1.538
	(-0.68)	-0.78	-1.2	-0.44			-0.91
OTHERCROPSSHARE	0.499	0.59	3.281*	2.053			3.041
	-0.67	-1.07	-1.74	-1			-1.35
L.lnchlorophylla		0.306****		-0.162****		0.865****	-0.139
		-5.19		(-3.65)		-35.76	(-1.30)
D.WATERSHARE					3.236	6.361*	
					-0.82	-1.7	
D.DEVELOPEDSHARE					6.322*	6.654*	
					-1.86	-1.77	
D.WETLANDSSHRUBLANDSSHARE					5.243*	4.658	
					-1.79	-1.6	
D.FORESTTREESSHARE					3.558	5.612**	
					-1.29	-2.01	
D.CORNSHARE					0.155	0.129	
					-0.27	-0.24	
D.GRASSPASTURESHARE					1.605	1.28	
					-1.13	-0.94	
D.OTHERCROPSSHARE					3.145	2.344	
					-1.58	-1.23	
PerCRPofCrops	0.541	0.025	-1.209	-0.969			1.387
	-0.63	-0.04	(-0.86)	(-0.43)			-0.46
D.PerCRPofCrops					0.357	0.989	
					-0.18	-0.51	
PerCornCRP	-0.000527***	-0.000366**	-0.000435**	-0.000329			0.000183
	(-3.10)	(-2.17)	(-2.06)	(-1.00)			-0.52
PerGrassPastureCRP	-0.00000489	0.0000175	0.000129	0.00000295			0.000420**
	(-0.08)	-0.33	-1.21	-0.02			-2.32
PerForestTreesCRP	0.000549	-0.0000876	0.00105	0.00192			0.00104
	-0.9	(-0.15)	-0.95	-1.29			-0.53
PerWetlandsShrublandsCRP	-0.000295	-0.000530***	-0.000164	-0.000298			-0.000107
	(-1.55)	(-3.00)	(-0.69)	(-0.94)			(-0.36)
PerWaterCRP	-0.000419	0.000806	-0.00124	-0.00158			-0.00123
	(-0.40)	-0.65	(-1.21)	(-1.42)			(-1.22)
PerDevelopedCRP	0.00105	0.00077	-0.000421	0.00148			-0.00244
	-0.84	-0.83	(-0.17)	-0.37			(-0.64)
PerOtherCropsCRP	-0.0000886	0.000147	-0.000107	-0.000389			-0.0000777
	(-0.51)	-0.82	(-0.39)	(-1.17)			(-0.21)
D.PerCornCRP					-0.000163	-0.000142	
					(-0.72)	(-0.63)	
D.PerGrassPastureCRP					0.000361***	0.000326**	
					-2.68	-2.25	
D.PerForestTreesCRP					-0.000882	0.000111	
					(-0.64)	-0.08	
D.PerWetlandsShrublandsCRP					-0.000207	-0.00022	
					(-0.92)	(-0.96)	
D.PerWaterCRP					-0.000435	-0.000911	
					(-0.45)	(-0.82)	
D.PerDevelopedCRP					-0.00289	-0.00225	
					(-1.20)	(-0.98)	
D.PerOtherCropsCRP					0.000292	0.00023	
					-0.84	-0.71	
Fall_Precip	0.00146	0.000761	-0.00458	0.00537			-0.00306
	-0.15	-0.06	(-0.45)	-0.43			(-0.21)
Winter_Precip	0.0648****	0.0485***	0.0583****	0.0520***			0.0376**
	-4.37	-2.77	-3.63	-3.12			-2.24
Spring_Precip	-0.0190***	-0.0229***	-0.0207***	-0.0174**			-0.0283****
	(-2.61)	(-2.64)	(-2.87)	(-2.31)			(-3.46)
Summer_Precip	-0.0106***	-0.00197	-0.00654	-0.00846*			-0.0124**
	(-2.61)	(-0.40)	(-1.57)	(-1.77)			(-2.32)
D.Fall_Precip					-0.0116	-0.00632	
					(-0.95)	(-0.52)	
D.Winter_Precip					0.0432**	0.0437***	
					-2.5	-2.68	
D.Spring_Precip					-0.0316****	-0.0282****	
					(-4.41)	(-4.08)	
D.Summer_Precip					-0.00634	-0.00555	
					(-1.51)	(-1.34)	

CAFO	0.128	0.104	0.0433	0.00565			0.155
	-1.18	-1.22	-0.3	-0.03			-0.78
D.CAFO					0.172	0.0395	
					-0.85	-0.23	
Alfisols	0	0	0	0			
	(.)	(.)	(.)	(.)			
Entisols	-0.682***	-0.670****	0	0			
	(-2.88)	(-3.37)	(.)	(.)			
Inceptisols	-0.635**	-0.580***	0	0			
	(-2.21)	(-2.85)	(.)	(.)			
Mollisols	-0.192	-0.145	0	0			
	(-1.34)	(-1.18)	(.)	(.)			
NoData	0.236	0.207	0	0			
	-1.41	-1.31	(.)	(.)			
D.Dominant Soil Type					0		
					(.)		
Dominant Soil Type						0.125****	0.736
						-5.36	-1.54
Iowa LL Lake Depth	-0.0544****	-0.0372****	-0.0476	-0.0436			-0.0183
	(-6.41)	(-4.22)	(-1.32)	(-1.14)			(-0.24)
D.Iowa LL Lake Depth					-0.0104	-0.00927	
					(-0.24)	(-0.21)	
Constant	4.394****	2.813****	1.933*	4.125***			0
	-9.69	-5.68	-1.88	-3.23			(.)
Observations	570	467	570	467	458	458	358

Turbidity

	RE **lnsecchidepth**	RE + Lag **lnsecchidepth**	FE **lnsecchidepth**	FE + Lag **lnsecchidepth**	FD **D.lnsecchidepth**	FD + lag **lnsecchi depth**	AB **lnsecchi depth**
WATERSHARE	-0.335	-0.0194	-1.39	0.852			-1.934
	(-0.45)	(-0.05)	(-0.31)	-0.31			(-0.56)
DEVELOPEDSHARE	1.287	-0.264	-0.766	1.046			1.003
	-0.82	(-0.28)	(-0.29)	-0.23			-0.19
WETLANDSSHRUBLANDSSHARE	-1.312	-1.534	-0.31	-1.834			-3.390*
	(-0.74)	(-1.24)	(-0.14)	(-0.88)			(-1.67)
FORESTTREESSHARE	0.758*	0.275	3.329	0.35			-4.057*
	-1.93	-1	-1.53	-0.11			(-1.75)
CORNSHARE	0.172	-0.0287	0.0275	-0.0884			-0.363
	-0.48	(-0.07)	-0.07	(-0.21)			(-0.69)
GRASSPASTURESHARE	-0.322	-0.0664	-0.983	-1.091			-2.672**
	(-0.62)	(-0.17)	(-0.94)	(-0.80)			(-2.37)
OTHERCROPSSHARE	-0.383	-0.469	-1.455	-2.544			-4.988***
	(-0.72)	(-1.38)	(-0.93)	(-1.46)			(-3.10)
L.lnsecchidepth		0.578****		0.0521		0.717****	0.116
		-11.9		-0.77		-20.57	-1.24
D.WATERSHARE					-0.177	-1.723	
					(-0.06)	(-0.68)	
D.DEVELOPEDSHARE					0.267	0.696	
					-0.11	-0.29	
D.WETLANDSSHRUBLANDSSHARE					-2.565	-1.88	
					(-1.63)	(-1.33)	
D.FORESTTREESSHARE					-1.122	-1.242	
					(-0.54)	(-0.63)	
D.CORNSHARE					-0.192	-0.138	
					(-0.49)	(-0.39)	
D.GRASSPASTURESHARE					-2.172***	-1.633**	
					(-2.75)	(-2.10)	
D.OTHERCROPSSHARE					-3.339***	-2.590**	
					(-2.86)	(-2.34)	
PerCRPofCrops	0.722	-0.448	1.846	-0.81			-1.146
	-0.91	(-1.02)	-1.27	(-0.67)			(-0.66)
D.PerCRPofCrops					0.722	0.499	
					-0.85	-0.6	
PerCornCRP	0.000260**	0.0000255	0.000335*	0.000133			-0.000135
	-2.16	-0.27	-1.89	-0.53			(-0.57)
PerGrassPastureCRP	0.000043	-0.0000411	0.000172**	0.00005			-0.000009
	-0.85	(-1.15)	-2.43	-0.45			(-0.06)
PerForestTreesCRP	-0.000104	-0.0000862	0.00105	-0.0000392			-0.000714
	(-0.25)	(-0.28)	-1.46	(-0.04)			(-0.66)
PerWetlandsShrublandsCRP	0.000330**	0.000339***	0.000284*	0.000454**			0.000347*
	-2.14	-2.82	-1.79	-2.29			-1.81
PerWaterCRP	0.00167**	0.0000314	0.00164*	0.00185			0.00160**
	-2.48	-0.05	-1.8	-1.64			-2.04
PerDevelopedCRP	-0.00138	-0.000105	-0.00138	-0.0025			-0.00222
	(-1.58)	(-0.20)	(-1.35)	(-1.31)			(-1.04)
PerOtherCropsCRP	0.0000542	-0.000159	0.000307	0.000142			0.000352
	-0.39	(-1.30)	-1.65	-0.68			-1.54
D.PerCornCRP					0.00016	0.0000987	
					-0.98	-0.82	
D.PerGrassPastureCRP					0.000111	0.0000587	
					-1.12	-0.54	
D.PerForestTreesCRP					0.000638	0.000272	
					-0.77	-0.35	
D.PerWetlandsShrublandsCRP					0.000374**	0.000288*	
					-2.49	-1.96	
D.PerWaterCRP					0.00111	0.00105	
					-1.59	-1.55	
D.PerDevelopedCRP					-0.0018	-0.0017	
					(-1.29)	(-1.20)	
D.PerOtherCropsCRP					0.000309*	0.000173	
					-1.87	-1.11	
Fall_Precip	0.00854	0.0025	0.00688	0.0125			0.00484
	-1.1	-0.29	-0.81	-1.33			-0.41
Winter_Precip	-0.0133	-0.0356***	-0.0208*	-0.0275**			-0.0323***
	(-1.24)	(-2.76)	(-1.85)	(-2.45)			(-2.91)
Spring_Precip	-0.0043	0.0103	0.000754	0.0075			0.0129**
	(-0.65)	-1.63	-0.11	-1.18			-2.1
Summer_Precip	-0.0000837	0.00880**	0.00316	0.0113***			0.0108***
	(-0.03)	-2.14	-0.94	-2.84			-2.7
D.Fall_Precip					-0.00881	-0.00878	
					(-1.05)	(-1.05)	
D.Winter_Precip					-0.0295***	-0.0248**	
					(-2.73)	(-2.41)	
D.Spring_Precip					0.00589	0.00358	
					-1.2	-0.77	
D.Summer_Precip					0.00446	0.00525*	
					-1.55	-1.89	
CAFO	-0.098	-0.000419	0.00103	-0.0977			-0.0557

	(-1.03)	(-0.01)	-0.01	(-0.57)			(-0.25)
D.CAFO					-0.0779	0.0622	
					(-0.33)	-0.19	
Alfisols	0	0	0	0			
	(.)	(.)	(.)	(.)			
Entisols	0.239	-0.0759	0	0			
	-1.34	(-0.59)	(.)	(.)			
Inceptisols	0.733****	0.188*	0	0			
	-3.56	-1.92	(.)	(.)			
Mollisols	0.176	0.0389	0	0			
	-1.41	-0.55	(.)	(.)			
NoData	-0.228	-0.109	0	0			
	(-1.23)	(-1.13)	(.)	(.)			
oD.Dominant Soil Type					0		
					(.)		
Dominant Soil Type						-0.00372	0.403
						(-0.48)	-1.26
Iowa LL Lake Depth	0.0621****	0.0331****	0.0406	0.0223			0.00418
	-8.87	-6.8	-1.35	-0.78			-0.13
D.Iowa LL Lake Depth					0.00696	0.00748	
					-0.4	-0.33	
Constant	-0.732**	-0.291	-0.541	-0.303			0
	(-2.21)	(-0.99)	(-0.63)	(-0.24)			(.)
Observations	570	467	570	467	458	458	358

APPENDIX B

CONSERVATION PRACTICE AVERAGE PAYMENTS ($) AND AVERAGE SIZE (ACRE)

Practice #	Conservation Practice	Enrollment Type	Price per Acre per Year ($)	Average Contract Size (Acre)	Contract Size Price ($)
1	Establishment of Permanent Introduced Grasses and Legumes	General sign-up (continuous sign-up in approved wellhead protection areas)	174.79	48.18	8420.95
2	Establishment of Permanent Native Grasses	General sign-up (continuous sign-up in approved wellhead protection areas)	168.79	44.95	7587.48
3	Tree Planting	General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)	161.84	23.04	3728.92
3A	Hardwood Tree Planting	General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)	171.16	24.97	4273.3
4B	Permanent Wildlife Habitat (Corridors), Noneasement	General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)	156.95	25.89	4063.22
4D	Permanent Wildlife Habitat, Noneasement	General sign-up (under certain conditions as continuous sign-up)	138.36	42.52	5883.49

5A	Field Windbreak Establishment, Noneasement	Continuous	254.49	6.09	1550.27
8A	Grass Waterways, Noneasement	Continuous	250.39	5.05	1264.08
9	Shallow Water Areas for Wildlife	Continuous	206.03	7.28	1499.29
10	Vegetative Cover – Grass – Already Established	General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)	147.61	55.37	8173.36
11	Vegetative Cover – Trees – Already Established	General	135.84	21.19	2878.05
12	Wildlife Food Plot	General	157.51	44.19	6961.17
15A	Establishment of Permanent Vegetative Cover (Contour Grass Strips), Noneasement	Continuous	197.78	11.72	2318.52
15B	Establishment of Permanent Vegetative Cover (Contour Grass Strips) on Terraces	Continuous	201.86	9.86	1990.34
16A	Shelterbelt Establishment, Noneasement	Continuous	222.52	1.94	431.83
17A	Living Snow Fences, Noneasement	Continuous	200.33	3.45	691.52
21	Filter Strips	Continuous	251.93	9.28	2338.99
22	Riparian Buffer	Continuous	136.87	13.03	1783.83
23	Wetland Restoration	Continuous	231.06	39.29	9078.18
23A	Wetland Restoration, Non-Floodplain	Continuous	230.04	79.98	18398.77

24	Establishment of Permanent Vegetative Cover as Cross Wind Trap Strips	Continuous	176.52	56.96	10054.58
25	Rare and Declining Habitat	General	169.38	38.35	6494.72
27	Farmable Wetlands Pilot Wetland	Continuous	249.7	21.16	5282.58
28	Farmable Wetlands Pilot Buffer	Continuous	247.64	17.47	4326.82
29	Marginal Pastureland Wildlife Habitat Buffer	Continuous	83.47	8.86	739.22
30	Marginal Pastureland Wetland Buffer	Continuous	80.1	13.37	1071.19
31	Bottomland Timber Establishment on Wetlands	Continuous	251.89	17.95	4521.94
33	Habitat Buffers for Upland Birds	Continuous	192.61	8.36	1609.42
35E	Emergency Forestry – Softwood – New	Continuous	199	22.17	4411.17
37	Duck Nesting Habitat	Continuous	241.08	35.86	8645.72
38A	SAFE – Buffers	Continuous	210.34	12.8	2692.35
38B	SAFE – Wetlands	Continuous	177.71	34.63	6153.43
38C	SAFE – Trees	Continuous	175.31	13.81	2420.92
38E	SAFE – Grass	Continuous	207.74	35.77	7430.24
39	Farmable Wetland Program Constructed Wetland	Continuous	221.55	16.8	3723.09
41	Farmable Wetland Program Flooded Prairie Wetland	Continuous	199.11	12.17	2422.55

42	Pollinator Habitat	General and Continuous	201.91	24.81	5009.9

APPENDIX C

DESCRIPTION OF CRP CONSERVATION PRACTICES

CP1: Establishment of Permanent Introduced Grasses and Legumes
- Establish or maintain existing permanent introduced grasses and legumes
- Enhance environmental benefits
- General sign-up (continuous sign-up in approved wellhead protection areas)

CP2: Establishment of Permanent Native Grasses
- Establish or maintain existing vegetative cover of native grasses
- Enhance environmental benefits
- General sign-up (continuous sign-up in approved wellhead protection areas)

CP3: Tree Planting
- Establish new or maintain existing stand of trees in a timber planting
- Enhance environmental benefits
- Multipurpose forest benefits
- General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)

CP3A: Hardwood Tree Planting
- Establish and maintain a new stand or an existing stand of predominantly hardwood trees in a timber planting
- Enhance environmental benefits
- Multipurpose forest benefits
- General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)

CP4B: Permanent Wildlife Habitat (Corridors), Noneasement
- Establish a permanent wildlife corridor between two existing wildlife habitat areas
- Enhance the wildlife
- 66 to 200 feet in width
- General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)

CP4D: Permanent Wildlife Habitat, Noneasement
- Establish new or maintain existing permanent wildlife habitat cover
- Enhance the wildlife
- General sign-up (under certain conditions as continuous sign-up)

CP5A: Field Windbreak Establishment, Noneasement
- Establish windbreaks
- Reduce cropland erosion (wind erosion)
- Enhance wildlife habitat
- Continuous sign-up

CP8A: Grass Waterways, Noneasement

- Establish grass waterways
- Convey runoff from terraces, diversions, or other water concentrations without causing erosion or flooding
- Improve water quality
- Should not exceed width of 100 feet
- Continuous sign-up

CP9: Shallow Water Areas for Wildlife

- Develop or restore shallow water areas for wildlife
- The practice must include an adequate buffer of perennial vegetation to protect the water quality and provide wildlife habitat
- Should not exceed 10 acres per tract
- Continuous sign-up

CP10: Vegetative Cover – Grass – Already Established

- CP10 eligible to be offered before March 14, 2011
- Grass cover is already established
- Pollinator habitat and wildlife water development
- Enhance environmental benefits
- General sign-up (unless in a wellhead protection area when it is eligible for continuous sign-up)

CP11: Vegetative Cover – Trees – Already Established

- CP11 eligible to be offered before March 11, 2011
- Trees are already established
- Enhance environmental benefits
- General sign-up

CP12: Wildlife Food Plot

- Establish annual or perennial wildlife food plots
- Enhance wildlife and wildlife habitat
- Prevent degradation of environmental benefits
- Should not exceed five acres in size
- General sign-up

CP15A: Establishment of Permanent Vegetative Cover (Contour Grass Strips), Noneasement

- Establish strips of permanent vegetative cover generally following the contour on eligible cropland alternated with wider cultivated strips
- Reduce erosion and control runoff
- Minimum width is 15 feet, maximum of 30 feet
- Continuous sign-up

CP15B: Establishment of Permanent Vegetative Cover (Contour Grass Strips) on Terraces

- Establish vegetative cover on terraces
- Enhance water quality and reduce soil erosion
- Not to develop or establish wildlife habitat
- Maximum cannot exceed 60 feet including the buffer
- Continuous sign-up

CP16A: Shelterbelt Establishment, Noneasement

- Establish shelterbelts on a farm or ranch
- Enhance wildlife habitat, save energy, protect farmsteads or livestock areas
- Continuous sign-up

CP17A: Living Snow Fences, Noneasement

- Establish living snow fences
- Manage snow, reduce wind erosion, provide living screen, enhance wildlife habitat
- Continuous sign-up

CP21: Filter Strips

- Remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and subsurface flow by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body
- Must be immediately adjacent or parallel to a seasonal stream, a stream having perennial flow, wetlands, a permanent water body like a lake or pond
- The minimum acceptable width is 20 feet
- The maximum average width is 120 feet
- Continuous sign-up

CP22: Riparian Buffer

- Remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and subsurface flow by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body
- Improve habitat for aquatic organisms
- Habitat for wildlife
- Must be immediately adjacent or parallel to a seasonal stream, a stream having perennial flow, wetlands, a permanent water body like a lake or pond
- Minimum size is 35 feet in width and maximum size is 180 feet
- Continuous sign-up

CP23 Wetland Restoration

- Restore the functions and values of wetland ecosystems that have been devoted to agricultural use
- Increase sediment trapping efficiencies, improve surface and ground water quality, prevent excess erosion, provide habitat, reduce flood flows
- Continuous sign-up

CP23A: Wetland Restoration, Non-Floodplain
- Restore the functions and values of wetland ecosystems that have been devoted to agricultural use
- Located outside the 100-year floodplain
- Increase sediment trapping efficiencies, improve surface and ground water quality, prevent excess erosion, provide habitat, reduce flood flows
- Continuous sign-up

CP24: Establishment of Permanent Vegetative Cover as Cross Wind Trap Strips
- Establish one or more strips of permanent vegetative cover resistant to wind erosion
- Reduce on-farm wind erosion, trap wind-borne sediments, protect public health and safety
- Continuous sign-up

CP25: Rare and Declining Habitat
- Restore the functions and values of critically endangered and threatened habitats
- Includes trees, grasses, prairies, etc.
- Wetlands in Iowa
- General sign-up

CP27: Farmable Wetlands Pilot Wetland
- Restore the functions and values of wetlands that have been devoted to agricultural use
- Hydrology and vegetation must be restored to the maximum extent possible
- Retire chronically wet cropland
- Protect soil from erosion, improve water quality, and enhance habitat
- Maximum size is 40 acres
- Continuous sign-up

CP28: Farmable Wetlands Pilot Buffer
- Provide a vegetative buffer around wetlands (CP27) to remove sediment, nutrients, and pollutants from impacting the wetland and to provide wildlife habitat for the associated wetland
- Protect soil from erosion, improve water quality, and enhance habitat
- 100,000 acres in any one state
- Minimum size is 30 feet surrounding a wetland
- Maximum size is 4 times the size of the wetland
- Must be enrolled with CP27 or CP41

- Continuous sign-up

CP29: Marginal Pastureland Wildlife Habitat Buffer
- Remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and subsurface flow by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body
- Stabilize stream banks, reduce flood damage, restore and enhance wildlife habitat
- Must be immediately adjacent or parallel to a seasonal stream, a stream having perennial flow, wetlands, a permanent water body like a lake or pond
- Minimum width is 20 feet and the maximum width is 120 feet
- Continuous sign-up

CP30: Marginal Pastureland Wetland Buffer
- Remove nutrients, sediment, organic matter, pesticides, and other pollutants from surface runoff and subsurface flow by deposition, absorption, plant uptake, denitrification, and other processes, and thereby reduce pollution and protect surface water and subsurface water quality while enhancing the ecosystem of the water body
- Goal is to enhance water quality, reduce nutrient and pollution levels, and improve wildlife habitat
- Must be immediately adjacent or parallel to a seasonal stream, a stream having perennial flow, wetlands, a permanent water body like a lake or pond
- Minimum width is 20 feet and the maximum width is 120 feet
- Continuous sign-up

CP31: Bottomland Timber Establishment on Wetlands
- Establish and provide long-term viability of a bottomland hardwood stand of trees
- Control erosion, reduce pollution, restore and enhance wetlands, promote carbon sequestration, wildlife habitat
- Continuous sign-up

CP33: Habitat Buffers for Upland Birds
- Provide food and cover for quail and upland birds in cropland areas
- Secondary benefits are reducing erosion, increase soil and water quality, and protecting and enhancing on-farm ecosystems
- Minimum width is 30 feet and the maximum width is 120 feet
- Continuous sign-up

CP35E: Emergency Forestry – Softwood – New
- Establish a stand of trees in a timber planting
- Enhance environmental benefits
- Continuous sign-up

CP37: Duck Nesting Habitat

- Enhance duck nesting habitat on the most duck-productive areas of Iowa, Minnesota, Montana, North Dakota, and South Dakota to restore the functions and values of wetland ecosystems that have been devoted to agricultural use
- Continuous sign-up

CP38A: SAFE – Buffers

- State acres for wildlife enhancement
- A specified habitat can be restored and maintained
- Continuous CRP sign-up

CP38B: SAFE – Wetlands

- A specified habitat can be restored and maintained
- Continuous sign-up

CP38C: SAFE – Trees

- A specified habitat can be restored and maintained
- Continuous sign-up

CP38D: SAFE – Longleaf Pine

- A specified habitat can be restored and maintained
- Continuous sign-up

CP38E: SAFE – Grass

- A specified habitat can be restored and maintained
- Continuous sign-up

CP39: Farmable Wetland Program Constructed Wetland

- Develop a constructed wetland to treat effluent from row crop agricultural drainage systems
- Reduce nutrient and sediment loading and improve other water quality benefits
- Wildlife habitat
- Minimum of 25% of the upstream watershed is comprised of row crop agricultural drained land
- Maximum size is 40 acres per tract
- Continuous sign-up

CP41: FWP Flooded Prairie Wetland

- Restore the functions and values of wetlands that have been subject to the natural overflow of a prairie wetland
- Hydrology and vegetation must be restored
- Located in Prairie Pothole region (part in Iowa)
- 20 contiguous acres
- Continuous sign-up

CP42: Pollinator Habitat

- Establish habitat
- Support a diversity of pollinator species
- At least .5 acres
- General and continuous sign-up

APPENDIX D

RELEVANT CRP SIGN-UP PERIODS

Sign-up Periods

31 Continuous October 1, 2005- September 30, 2006

32 REX April 2006, June 2006 Expiring Contracts

33 General March 22, 2006 - April 28, 2006

35 Continuous October 1, 2006- September 30, 2007

36 Continuous October 1, 2007- September 30, 2008

37 Continuous October 1, 2008 - September 30, 2009

38 Continuous October 1, 2009 - September 30, 2010

39 General August 2, 2010 - August 27, 2010

40 Continuous October 1, 2010 – September 30, 2011

41 General March 14, 2011 – April 15, 2011

42 Continuous October 1, 2011 – September 30, 2012

43 General March 12, 2012 – April 13, 2012

44 Continuous 2013

45 General May 20, 2013 and ended June 14, 2013.

46 Continuous 2014

47 Continuous 2015

48 Continuous 2016

49 General December 1, 2015 to February 26, 2016.

50 Continuous 2017

51 Continuous 2018

Note: Contracts expire at the end of the fiscal year, September 30th.