Integrated Socio-Hydrological Modeling of and Understanding of Agricultural Conservation Practice Adoption in the Western Lake Erie Basin

Dissertation

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By

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Abstract

The 2016 revision to the Great Lakes Water Quality Agreement set forth water quality targets for Lake Erie. The revised binational agreement calls for a 40% reduction in Total Phosphorus (TP) and Dissolved Reactive Phosphorus (DRP) from 2008 loads from the Maumee River watershed to be met nine-years-out-of-ten. Previous studies have shown that widespread implementation of agricultural conservation practices (CPs) is needed to reach or approach these targets. Watershed modeling can play an important role in informing policies that aim to increase the adoption rates of agricultural CPs. However, watershed modelling efforts typically exclude important information derived from social science studies, such as farmer surveys (e.g., what factors affect farmers in adopting certain agricultural CPs). This work takes an interdisciplinary and multi-disciplinary approach to examine agricultural CP adoption in the Maumee River watershed to improve the integration between data derived from farmer surveys and watershed modeling and historically examine state efforts aimed to increase agricultural CP adoption across Ohio.

Conservation identities, perceived response efficacy of subsurface phosphorus placement, level of education, years of farming experience and other demographic, farm-operational, and psychological characteristics, derived from the farmer survey, were embedded into a SWAT model of the watershed. Modeled farm operations, created with

near field-level Hydrologic Response Units (HRUs) within the SWAT model, were assigned a modeled primary operator and assigned demographic, farm-operational, and psychological characteristics informed by the farmer-survey. Integrating the farmer survey data and the SWAT model allowed for novel approaches in targeting the placement of buffer strips and subsurface phosphorus fertilizer placement in the SWAT model. Model results indicate that near optimal water quality results can be obtained for both buffer strips and subsurface phosphorus placement even when constrained by farmer characteristics as compared to typical targeting scenarios focused solely on the physical characteristics of the landscape. Results also indicate that increasing the belief among farmers in the watershed that subsurface phosphorus placement is effective at reducing phosphorus discharge from their fields led to 4.8% and 7.5% less TP and DRP from the modeled baseline due to increasing the estimated adoption rate of the CP from 78.2% of agricultural land in the baseline to 88.0% in the high-efficacy scenario. Conversely, lower levels of perceived response efficacy were associated with increased discharges of TP and DRP from the watershed as compared to the model baseline.

Analyzing Ohio's soil and water conservation districts [formerly soil conservation districts] in the mid-twentieth century provides important insight into farmer-science-government relationships in Ohio. Across the mid-twentieth century, Ohio's eighty-eight soil conservation districts helped Ohio farmers and government experts in agricultural conservation transform both the physical and psychological landscape of agriculture across the state. Ohio's soil conservation districts, through agreements with the Soil Conservation Service, provided Ohio farmers access to knowledge as well as financial and technical aid to transform their farms according to agricultural conservation principles based in planning and maximizing production. By the end of 1963, 70,000 Ohio farmers were cooperating with their local soil conservation district in implementing farm plans designed by Soil Conservation Service technicians. Farm plans included agricultural conservation practices such as tile drainage, contour strip cropping, and terracing, to maximize the productive potential of the farm. Ohio farmers developed an understanding and desire to use their farmland to the best of its productive potential through the efforts of the state's soil conservation districts and their cooperation with the Soil Conservation Service and other agricultural organizations.

Dedication

To all that played a part in my educational journey…so far

Acknowledgments

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Publications

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Fields of Study

Major Field: Environmental Science

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Chapter 1. Evaluating the Efficacy of Targeting Options for Conservation Practice Adoption on Watershed-Scale Phosphorus Reductions

Abstract

Conservation identities of farmers in the Maumee River watershed, derived from farmer surveys, were embedded into a SWAT watershed model. This was done to improve the representation of the heterogeneity among farmers in the decision-making process related to the adoption of conservation practices. Modeled farm operations, created with near field-level Hydrologic Response Units (HRUs) within the SWAT model, were assigned a modeled primary operator. Modeled primary operators held unique conservation identities driven by their spatial location within the watershed. Five pathways of targeting the adoption of subsurface placement of phosphorus and buffer strips to HRUs within the watershed were assessed. Targeting pathways included targeting by HRU-level phosphorus losses, conservation identity of model operators, a hybrid approach combining HRU-level phosphorus losses and conservation identity of the model operator managing the HRU, and a proxy measure for random placement throughout the watershed. Targeting the placement of subsurface phosphorus application to all agricultural HRUs resulted in the greatest reduction in total phosphorus losses (32%) versus buffer strips (23%). For both conservation practices, targeting by HRU-level total phosphorus losses resulted in the most efficient rate of phosphorus reduction as measured by the ratio of phosphorus reduction to conservation practice adoption rates.

The hybrid targeting approach closely resembled targeting by phosphorus losses, indicating near optimal results can be obtained even when constraining adoption by farmer characteristics. These results indicate that by developing management strategies based on a combination of field-level information and human-operator characteristics, a more efficient use of limited resources can be used while achieving near maximal environmental benefits as managing solely based on field level information.

Introduction

Agriculture is a significant source of pollution impairing rivers, lakes, and oceans across the world (Deknock et al., 2019). This non-point source pollution can result in numerous environmental challenges including Harmful Algal Blooms (HABs; Paerl et al., 2018) and hypoxic dead zones (Porter et al., 2015) that cause socioeconomic problems throughout the globe (McCrackin et al., 2017). The Laurentian Great Lakes are no exception to these environmental and socioeconomic challenges (Wolf and Klaiber, 2017; Scavia et al., 2017). To lessen the impact agriculture has on nutrient loading to the Laurentian Great Lakes and, in particular, to Lake Erie, which has been affected by HABs of increasing severity since the early 2000s (Stumpf, 2016), current policies primarily promote the voluntary adoption of conservation practices (CPs; Holland et al., 2020. Kerr et al., 2016). In this approach to watershed management, human decision-makers are instrumental in the adoption and utilization of CPs to improve downstream water quality. However, research conducted on the watershed-scale effectiveness of CPs on reducing nutrient losses does not usually consider these human-actors and their heterogeneous beliefs and attitudes towards conservation (Evenson et al., 2021; Scavia et al., 2017).

Watershed models are a commonly used tool to assess the impact of agricultural management practices on nutrient runoff at larger scales than an individual agricultural field (Miller et al., 2020; Liu et al., 2017). In the Maumee River watershed (MRW), the largest Lake Erie watershed and the primary driver of HABs in Lake Erie (Stumpf, 2016; Maccoux et al., 2016), watershed models have evaluated the nutrient reduction benefits of individual and bundled-practice CPs (Martin et al., 2021; Scavia et al., 2017; Kalcic et al., 2016). Watershed models have been used to highlight how targeting CPs to fields that contribute the greatest amount of nutrients to the watershed outlet can be effective in reducing the impact of agriculture on nutrient and sediment loading (Martin et al., 2021; Parajuli et al., 2008). While this approach highlights variability in biophysical vulnerability, it does not account for the presence of heterogeneous decision-makers across agricultural landscapes. Targeting these hotspots, or critical source areas, in watershed models is generally a function of landscape characteristics such as slope and soil types, with decisions about what and where to implement management practices determined by the modeling team (Martin et al., 2021; Xu et al., 2019; Scavia et al., 2017). Because landowners and farm operators who manage these hotspots are not equally likely to actually implement the necessary practices in the designated locations, these models might over predict the impact of targeting strategies. This limitation suggests that rather than targeting CPs in watershed models solely based on the landscape characteristics, modeling teams could target by decision-maker characteristics, such as their attitude towards CPs, age, or gross income, or through a combination of landscape and decision-maker characteristics to simulate, more accurately, the probable spatial adoption of CPs in a watershed.

Many factors influence agricultural producers' beliefs, attitudes, and actions regarding their field-level management decisions (Liu et al., 2018; Ulrich-Schad, 2017) leading to heterogeneous decisions made among farmers in a specific region, even when operating in similar economic and political contexts (Karali et al., 2013; Chouinard et al., 2008). Farmers in the MRW are no exception to this (Burnett et al., 2018; Zhang et al., 2016). A non-exhaustive list of factors that influence decisions made by farmers in the MRW regarding their land management include a farmer's age, education, experience farming, and conservation identity (Burnett et al., 2018; Liu et al., 2018; Burton, 2014). Conservation identity is a strong indicator of a farmer's willingness to adopt CPs in the present or in the future, and, has been found to be the most predictive characteristics of future adoption for numerous CPs in the MRW (Burnett et al., 2018; Zhang et al., 2016). This indicates that farmers who hold greater conservation identities are more likely to adopt CPs than farmers with lower conservation identities. Grounded in identity theory, which indicates that person identities reflect individuals' understanding of themselves as having particular traits and qualities (McGuire et al., 2013), conservation identity is a function of the "good farmer" identity. Rather than an understanding or perception of their individual role or a CP's role in limiting nutrient loss, conservation identity aims to capture how farmers perceive and understand their own role as a farmer and what it means to be a "good farmer." Because identities of farmers are not necessarily linked to the physical characteristics of the fields they manage, targeting CP adoption to this farmer characteristic is a more realistic way of assigning CPs than solely focusing on land characteristics.

The Soil and Water Assessment Tool (SWAT), a common watershed model used in agricultural settings, generally ignores socio-economic factors in its modeling framework (Cools et al., 2011). Integrated modeling frameworks that bridge socio-economic factors and watershed models (Zomorodian et al., 2018; Liu et al., 2015; Yang et al., 2007), have been applied in watersheds around the world (Yazdi and Moridi; 2017; Daloğlu et al, 2014; Cools et al., 2011) including in the MRW (Liu et al., 2020; Wilson et al., 2018*)*. Although integrated modeling allows socio-economic characteristics to be accounted for in watershed models when using SWAT, these models must be externally linked, which leads to a series approach to model integration (Francesconi et al., 2016). In this series approach, socio-economic models are first developed and results from these models are then used to drive inputs for scenario simulations in SWAT.

The goals of this work are to describe an approach to embed the characteristics of human-operators into a calibrated SWAT model and evaluate the potential impact of incorporating characteristics of human-actors in CP targeting simulations. The three objectives of this work are (1) create modeled farm operations, (2) assign conservation identities based on a farmer survey to decision-makers of the modeled farm operations, and (3) compare targeting CP placement based on a combination of field-level phosphorus losses and human-operator conservation identities to solely targeting by field-level phosphorus losses.

Methods

Study Area

The MRW (Fig. 1) is the largest contributor of phosphorus to Lake Erie (Maccoux et al., 2016). Row crop agriculture dominates the watershed landscape, with approximately 80% of the land use in row-crop agriculture (Ohio EPA, 2010).

Figure 1: The MRW is approximately 17,000 km^2 in size and spans portions of Indiana, Michigan, and Ohio.

SWAT Model

The Soil and Water Assessment Tool (SWAT, revision 635; modified according to Kalcic et al. (2016)) is a process-based hydrological model that simulates hydrologic and nutrient fluxes within watersheds (Arnold et al., 1998). SWAT has been used in watersheds across the world including within the Great Lakes basins (Martin et al., 2021; Scavia et al., 2017; Muenich et al., 2016). Within the MRW, SWAT has been identified as the most appropriate watershed model among various watershed-modeling frameworks (Gebremarium et al., 2014). A recently developed and validated version of SWAT was used to simulate hydrology and nutrient dynamics within the MRW (Apostel et al., 2021; Kast et al., 2021a). This SWAT model was satisfactorily calibrated to nutrient and hydrology parameters between 2005 and 2015 at the USGS gauge #04193500, Table 1. Daily water quality and stream flow data used in calibration and validation were obtained from the National Center for Water Quality Research at Heidelberg University (ncwqr.org). Although the model was calibrated and validated at the single gauge, simulation results were compared to Edge-of-Field data of fields located upstream within the watershed. These comparisons showed the model was able to capture the range of water quality results upstream of the watershed outlet (Apostel et al., 2021).

	Statistic	Metric for Satisfactory Performance	Daily Calibration (2005-2015)	Monthly Calibration (2005-2015)	Daily Validation (2000-2004)	Monthly Validation (2000-2004)
Flow	NSE	>0.5	0.87	0.95	0.82	0.86
	PBIAS	< ±15%	-0.83	-0.88	-10.03	-10.11
Total Phosphorus	NSE	>0.35	0.58	0.52	0.46	0.44
	PBIAS	< ±30%	-3.76	-3.23	-18.53	-18.35
Dissolved Reactive Phosphorus	NSE	>0.35	0.62	0.67	0.63	0.73
	PBIAS	< ±30%	2.03	1.51	-9.89	-10.22
Sediment	NSE	>0.45	0.65	0.75	0.58	0.70
	PBIAS	< ±20%	1.62	2.06	-27.21	-26.09

Table 1: Monthly and daily calibration and validation statistics for the Maumee River SWAT model. All entries met the minimum criteria for 'Satisfactory' performance except monthly and daily sediment PBIAS validation (Apostel et al., 2021; Kast et al., 2021a).

The SWAT model used in this study consists of 24,256 Hydrologic Response Units (HRUs), the smallest spatial discretization in the modeling framework. The mean size of agricultural HRUs (84% of HRUs in the model) is 70.9 hectares (175.3 acres), comparable to that of the average farm-field size in Ohio (72.4 hectares), Indiana (106.8 hectares), and Michigan (82.9 hectares; USDA, 2017). For further information of model development, including near field-scale HRU delineation and model calibration and validation see Apostel et al. (2021).

<u>Creating Modeled Farm Operations and Assigning Conservation Identities to Modeled Primary Operators</u>

Modeled Farm Operations

Modeled farm operations (MFOs), approximating farm boundaries of farming operations found within the watershed, were created by aggregating agricultural HRUs.

HRUs included in each MFO were constrained by the county and model subbasin in which the HRUs were located thus allowing non-adjacent HRUs to be included in a MFO. Each MFO included between one and five HRUs, depending on the size of the operation. Modeled farm operation sizes were stratified within each county according to the percentage of farms in the county between 1 and 179 acres, 180 and 499 acres, 500 and 999 acres, and 1000 or more acres, according to the 2017 Agricultural Census (USDA, 2017; Table 5).

Assigning Conservation Identities to Modeled Primary Operators

Each MFO was assigned a modeled primary operator (MPO) who represented the operation's decision-maker on farm management practices. A survey of farmers within the watershed was used to derive characteristics of farmers in the region (Burnett et al., 2018; Zhang et al., 2016). Conservation identity was measured through seven survey items each on a 5-point Likert scale (Table 6). Respondents were asked to rate the importance of each item on their personal definition of a good farmer from 0 (not at all important) to 4 (very important; Burnett et al., 2018; McGuire et al., 2015; Arbuckle et al., 2013). The average score given to the seven survey items by the respondent was calculated to be the respondent's conservation identity. Survey respondents' conservation identities were grouped by zip code and aggregated to the county level. The maximum, mean, median, and standard deviation of conservation identities among survey respondents were calculated for each county. County-level distributions of conservation identities derived from this process were used to guide assignments of conservation identities to MPOs.

The existing CP use on each MFO per county in the calibrated SWAT model was estimated. Included in this calculation was the use of a cover crop, a grassed waterway, incorporation of nutrients after application, subsurface placement of nutrients, and continuous no-tillage on each HRU within a MFO. A standardized metric of CP adoption was created by dividing the number of CPs present on a MFO by the number of HRUs within the MFO. After standardized metrics of CP adoption were calculated for each model farm operation, model farm operations and their corresponding CP adoption metric value were segregated by county. Within each county, MFOs were ranked from the greatest standardized CP adoption metric to the least. Rankings of standardized CP adoption metrics among the MFOs were used to assign conservation identities of MPOs. Three-levels of conservation identities (weak, moderate, and high) were assigned based on this standardized CP adoption metric and county-level results of conservation identities from the farmer survey (Tables 7-9). The qualitative descriptors for the three levels of conservation identities were derived from Burnett et al. (2018). To translate these qualitative categorizations into quantitative values, it was assumed that measured values were equally distributed within each level and constrained by the possible ranges of conservation identities from the farmer survey. Weak conservation identities were assigned a random value between 0.00 and 1.33. Moderate conservation identities were assigned a random value between 1.34 and 2.66. High conservation identities were assigned a value between 2.67 and 4.00. This was completed to link equivalent results of the farmer survey directly to the farmer conservation identities applied to MFOs (i.e., a

MFO with an operator holding a conservation identity of 2.5 would be equivalent to a farmer respondent with a conservation identity score of 2.5).

Targeting CPs to Fields

Five alternative targeting approaches were used to apportion two separate CPs, 1) subsurface placement of inorganic phosphorus fertilizer (Subsurface P) and 2) buffer strips, throughout the watershed (Table 2 and Fig. 2). In each scenario, subsurface placement of inorganic phosphorus fertilizer was simulated by placing 99% of the fertilizer mass below the top 1 cm of soil. Buffer strips were sized at 2% of the field drainage area with 50% being concentrated flow and 25% being fully channelized.

The first targeting approach selected HRUs estimated to have the greatest total phosphorus (TP) loading rates in the baseline calibrated SWAT model, sometimes referred to as "critical source areas" (Evenson et al, 2021; Figure 17) The second targeting approach selected HRUs with the least TP loading rates. In these two approaches, agricultural HRUs were rank ordered from largest to smallest TP discharge rates (Figure 18). Rank orders with ties were used when two or more HRUs had similar TP discharge rates. The third targeting approach selected HRUs in MFOs with MPOs that were estimated to have the greatest conservation identities (Figure 19). For this targeting approach, conservation identities of MPOs were rank ordered from largest to smallest. Rank orders with ties were used when two or more HRUs managed by MPOs had similar conservation identities. The fourth targeting approach selected HRUs with the greatest TP loading rates that were managed by MPOs with the greatest conservation identities (Figure 20). For this targeting approach, each HRU rank order from the first and third targeting approaches were summed. Eleven scenarios that represented increasing adoption rates for each CP were run for each of these targeting approaches. CP adoption ranged from the baseline calibrated model adoption rate to 100% adoption on agricultural HRUs (Table 8). A one-to-one line was created for each CP from the adoption endpoints, Baseline Adoption and 100% Adoption. This one-to-one line was regarded as a proxy measure of randomly selecting HRUs to receive the CP, a fifth targeting approach. Unlike the previous four targeting approaches, this scenario assumes that results would lie on the one-to-one line between the Baseline Adoption and 100% Adoption scenarios and was not run directly in the SWAT model. This proxy measure represented the average results of thousands of simulations in which different sets of HRUs were randomly selected to receive the CP and was created in place of simulating a random assignment pathway.

Targeting Pathway	Description
Greatest Phosphorus Loading Rate HRUs	The agricultural HRUs with the greatest P runoff were targeted to receive the CP
Least Phosphorus Loading Rate HRUs	The agricultural HRUs with the least P runoff were targeted to receive the CP
Greatest Modeled Primary Operator Conservation Identity HRUs	The agricultural HRUs managed by the modeled primary operators with the greatest Conservation Identity were targeted to receive the CP
Greatest Phosphorus Loading Rate HRUs Managed by Modeled Primary Operators with the Greatest Conservation Identities	The agricultural HRUs with the largest aggregate rank order value were targeted to receive the CP

Table 2: Targeting pathways to apportion subsurface placement (Subsurface P) of inorganic phosphorus fertilizer and buffer strips within the watershed.

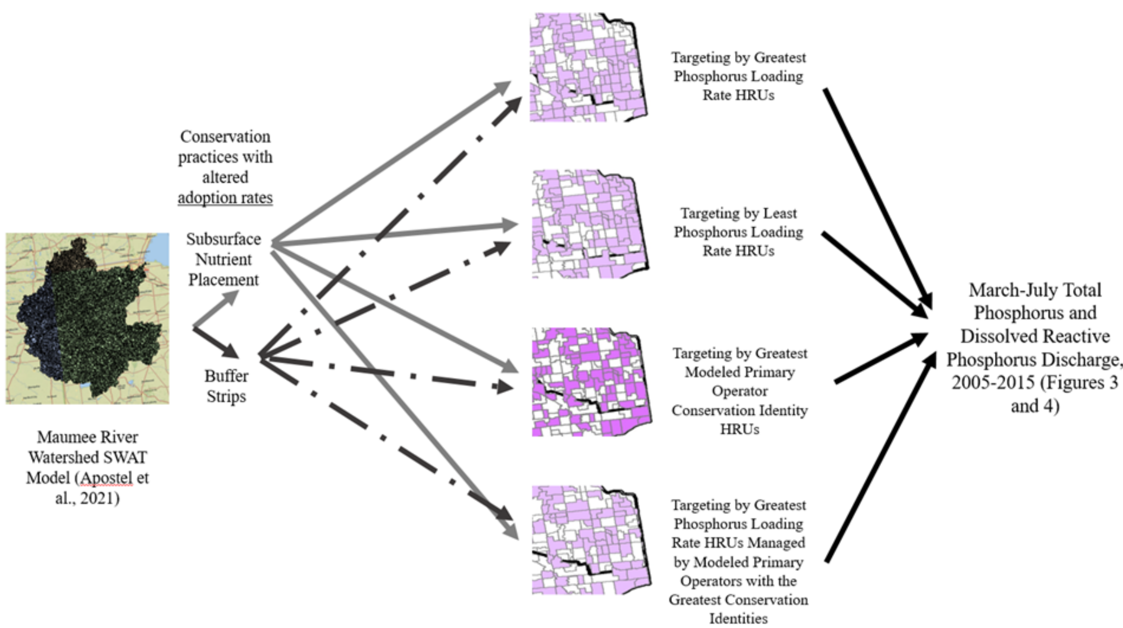

Figure 2: Conceptual schematic of simulation process.

Results

Modeled Farm Operations and Modeled Primary Operator Conservation Identities

Across the watershed, 17,297 MFOs were created from the 24,256 HRUs in the SWAT model (Tables 5 and 7). Putnam County, Ohio had the largest number of MFOs while Whitley County, Indiana had the smallest, Table 3. The percentage of MFOs smaller than 180 acres and greater than 1000 acres varied by county with Williams County, Ohio having the largest number of MFOs less than 180 acres and Van Wert County, Ohio having the greatest number of MFOs larger than 1,000 acres, Table 5.

Modeled primary operators in Lucas County, Ohio had the highest average conservation identity while MPOs in Henry County, Ohio had the lowest average conservation identity (Table 9). Based on the conservation identity categorization presented in Section 2.3, a majority of the MPOs across the watershed were assigned a strong conservation identity (77.8%) while 21.0% and 1.2% of MPOs were assigned moderate and weak conservation identities, respectively (Table 7).

Targeting the Adoption of Subsurface Phosphorus Applications and Buffer Strips

Increasing the adoption of Subsurface P to 100% of agricultural HRUs from its adoption rate in the calibrated baseline (9%) led to a 31% reduction in TP and a 48% reduction in Dissolved Reactive Phosphorus (DRP; Fig. 3). Increasing the adoption of buffer strips to 100% of agricultural HRUs from its adoption rate in the calibrated baseline (31%) led to a 23% reduction in TP and a 19% reduction in DRP (Fig. 4).

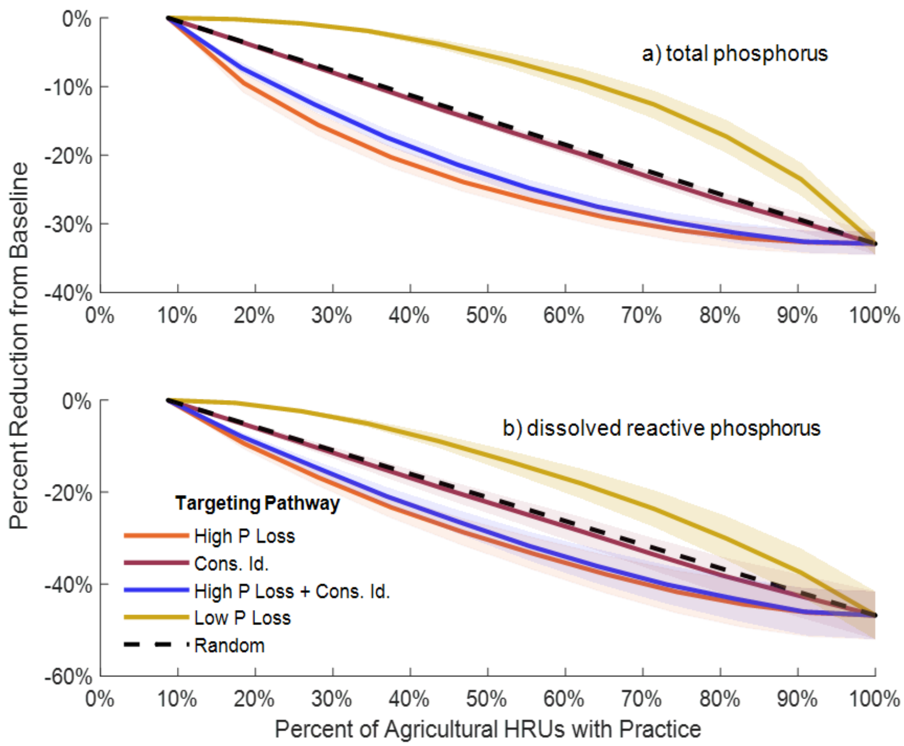

Figure 3: Reductions of a) total phosphorus and b) dissolved reactive phosphorus resulting from the adoption of Subsurface P by various targeting pathways. The most efficient phosphorus reduction rates result from the Greatest P Loss pathway, which is likely unattainable because of limited information and farmer participation. Similar phosphorus reduction efficiencies result from targeting the placement of Subsurface P by a combination of field-level information as well as farmer information, which is a more attainable management option. The maximum difference between the Greatest P Loss and Least P Loss targeting pathways is at 54.5% adoption of the CP indicating the adoption rate with the greatest uncertainty related to the effectiveness of the CP on reducing P loads from the watershed model

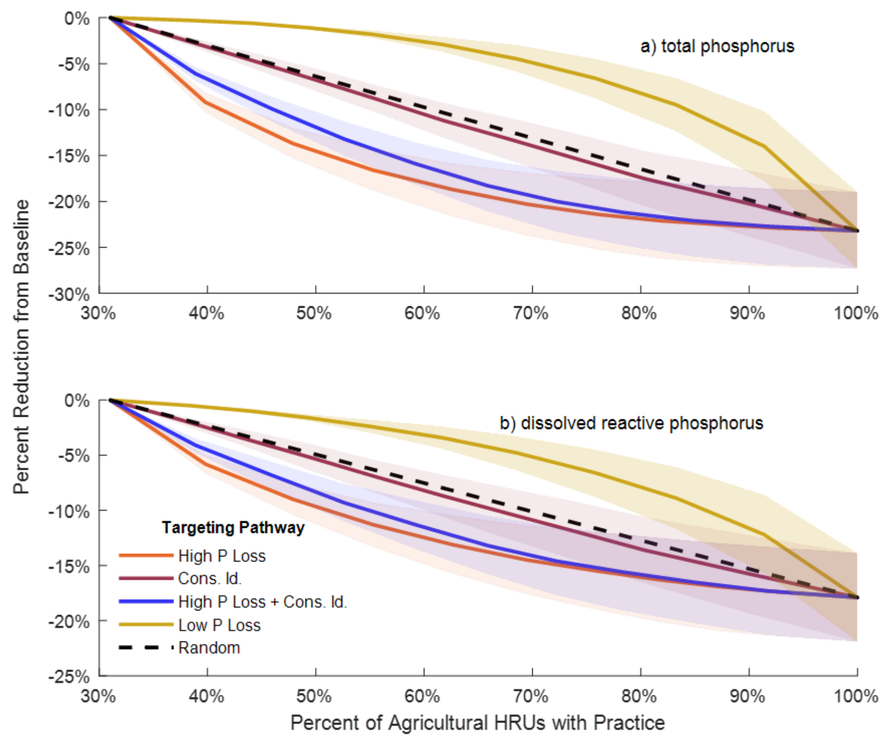

Figure 4: Reductions of a) total phosphorus and b) dissolved reactive phosphorus resulting from the adoption of buffer strips by various targeting pathways. Similarly to Subsurface P, achieving phosphorus reduction rates as indicated by the Greatest P Loss pathway may be unattainable and that targeting the placement of buffer strips by a combination of field-level information as well as farmer information achieves similar phosphorus reduction efficiencies. The maximum difference between the Greatest P Loss and Least P Loss targeting pathways is at 65.5% adoption of the CP, indicating the adoption rate with greatest uncertainty related to the effectiveness of the CP on reducing P loads in the watershed model.

Targeting the adoption of both CPs to the HRUs with the greatest TP loading rates resulted in the highest efficiency (phosphorus reduction/rate of CP adoption) in achieving phosphorus reductions. As expected, the lowest phosphorus reduction efficiencies were obtained when targeting the adoption of the CPs to the HRUs with the least TP loading rates. Targeting both CPs to the HRUs with the greatest MPO conservation identities resulted in similar phosphorus reduction efficiencies as randomly selecting HRUs to receive the CPs. Targeting both CPs by combining consideration of HRUs with large phosphorus losses and MPOs with high conservation identities resulted in the second highest efficiency in achieving phosphorus reductions (Figs. 3 and 4). The two most efficient approaches produced the greatest gains in TP and DRP load reduction from the initial increases from baseline adoption. In effect, for the scenario targeting CPs based on high runoff potential, each 1% increase in adoption of Subsurface P from the baseline (8.7%) to 18.5% adoption levels resulted in a decrease of TP loads by 1%. When conservation identities were considered alongside high runoff potential, each 1% increase in adoption of Subsurface P decreased TP loads by 0.77% as adoption rose from 8.7% to 18.2% of agricultural land area. This was expected because initially these practices were applied to fields with the greatest losses and thus where they would realize the greatest reductions. Similar trends were observed for DRP reductions for Subsurface P and for both TP and DRP reductions for buffer strips although the magnitudes of the decreasing phosphorus loading rates differed (Figs. 3 and 4).

Impacts of Watershed-Scale CP Adoption Efficacy in Reducing Phosphorus Losses

Targeting Adoption to HRUs with the Greatest Total Phosphorus Loading Rates Compared to Other Simulated Targeting Pathways

Since adoption rates of 54.5% for Subsurface P and 65.5% of buffer strips, respectively, resulted in the greatest difference in phosphorus reductions between targeting pathways, this adoption level was used to compare differences due to targeting options (Figs. 3 and 4). Targeting by the least phosphorus loading rates, as compared to targeting by the greatest phosphorus loading rates, resulted in approximately between

10% and 20% more TP and DRP discharged from the watershed. Targeting by the greatest phosphorus loading rates HRUs managed by MPOs with the greatest conservation identities resulted in approximately between 0.5% and 1.5% more TP and DRP discharged from the watershed, as compared to targeting by the greatest phosphorus loading rate HRUs (Fig. 5).

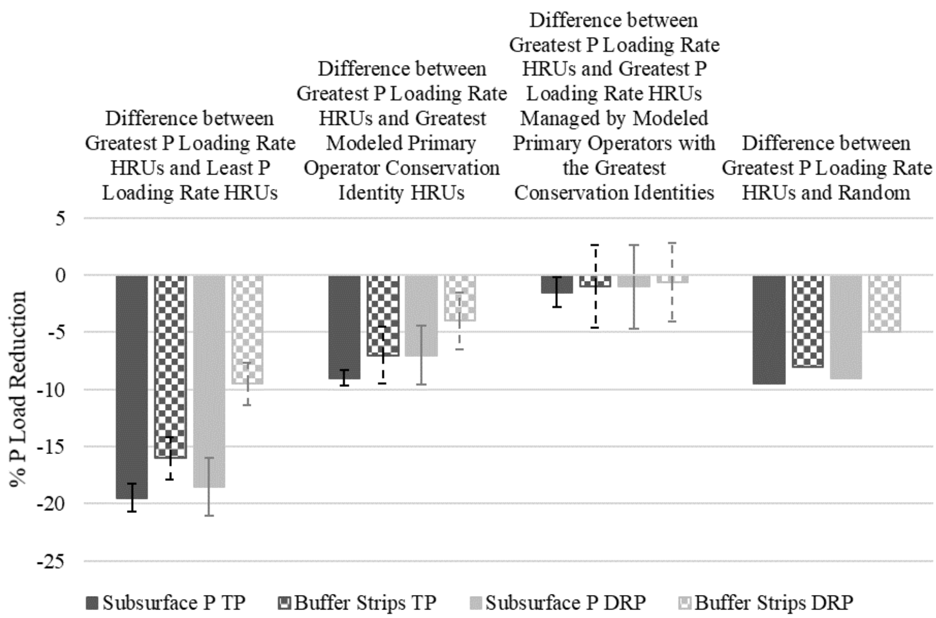

Figure 5: Percent difference in March-July TP and DRP loads discharged from the watershed through various targeting methods for subsurface placement and buffer strips at adoption rates resulting in maximum differences between the targeting methods (54.5% for subsurface placement and 65.5% for buffer strips). Results from the Greatest Phosphorus Loading Rate HRUs are used as the basis for comparisons.

Targeting Adoption to HRUs with High Total Phosphorus Loading Rates and to High Total Phosphorus Loading Rate HRUs Managed by Modeled Primary Operators with High Conservation Identities Compared to Simulated Targeting Pathways

The adoption rate of Subsurface P across the watershed with the largest difference in phosphorus reduction between targeting HRUs with the greatest TP losses to those with the greatest TP losses managed by MPOs with the greatest conservation identities

(28% adoption of Subsurface P) resulted in TP and DRP losses differing by 2.7% and 1.9%, respectively (Fig. 6). The adoption rate of buffer strips across the watershed with the largest difference in phosphorus reduction between targeting HRUs with the greatest TP losses to those with the greatest TP losses managed by MPOs with the greatest conservation identities (48% adoption of buffer strips) resulted in TP and DRP losses differing by 2.8% and 1.5%, respectively (Fig. 6).

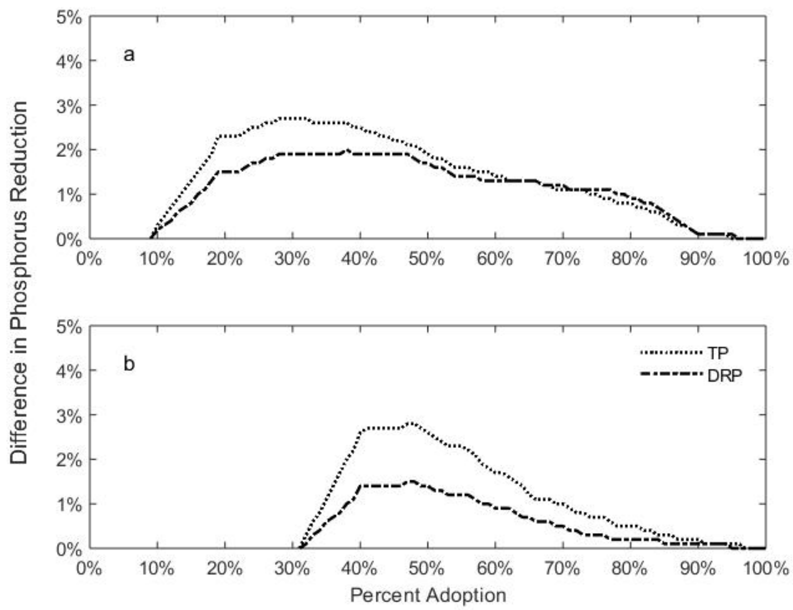

Figure 6: Differences in TP and DRP losses between targeting HRUs with the greatest TP losses and the HRUs with the greatest TP losses managed by modeled primary operators with the greatest conservation identities for (a) Subsurface P and (b) buffer strips across the spectrum of BMP adoption rates starting at the baseline level adoption and ending at 100% adoption.

Discussion

Integrating Farmer-Actors in Watershed Modeling of Agricultural Systems

Developing MPOs using results from farmer surveys and directly embedding them into a watershed model is a novel approach for integrated modeling analyses. In particular, the approach developed and used in this study is unique for evaluating the efficacy of CP adoption in agriculturally dominated watersheds. This approach allowed for representing over 17,000 unique MPOs. This large number of unique actors, or decision-makers, contrasts with the limited number of actors represented in agent-based models (ABMs) that have been integrated with watershed models. Ng. et al. (2011) integrated an ABM with a SWAT model of the Salt Creek watershed in Central Illinois; however, only 50 farmers were represented in the ABM due to the long computational time needed to run the model. In Ohio's Sandusky Watershed, Daloğlu et al. (2014) grouped the farmer agents into four farmer types that drove parameters influencing their adoption decisions in the ABM. Although this work developed methods to allow for a large number of unique actors a limitation is that these actors could not interact or learn from one another, a benefit common to ABMs of socio-ecological systems (Lippe et al., 2019; Daloğlu et al., 2014; Ng et al., 2011).

While an ABM has not been integrated with a model of the MRW, prior research has coupled economic and farmer behavioral attitudes with watershed models. Liu et al. (2020), focused on coupling a behavioral-economic model with a SWAT model of the MRW to assess how increases in cost-share payments for CP adoption and fertilizer taxes would affect nutrient losses within the watershed by way of increasing CP adoption. Martin et al. (2021) ran scenarios in SWAT models of the MRW guided by results from a survey of farmers in the watershed. Wilson et al. (2018), integrated results from a farmer survey taken within the MRW to a SWAT model of the MRW to assess how changes in farmer efficacies regarding cover crops and subsurface placement of nutrients reduce phosphorus discharge at various adoption levels of filter strips. This work improves upon these prior efforts in the MRW to develop a watershed model that includes socio-behavioral information of farmers in the watershed while also providing a basis to further simulate how socio-behavioral characteristics of farmers in the watershed can affect CP adoption and resulting changes in nutrient discharges, through the addition of MFOs and MPOs.

Adoption Rates of Subsurface P and Buffer Strips and Phosphorus Discharges

Increasing the adoption of Subsurface P to 100% resulted in 1.3-times and 2.1-times greater TP and DRP reductions from the watershed than by increasing the adoption of buffer strips across the watershed to 100%. Comparing DRP and TP, at 100% adoption of Subsurface P, DRP loss reductions were 1.5 times greater than TP loss reduction. In contrast, DRP loss reduction were 1.2 times less than TP loss reduction at 100% adoption of buffer strip indicating that buffer strips are more effective at reducing TP losses than DRP losses. This result agrees with Roberts et al. (2012) which found that buffer strips affected TP losses more than DRP losses in a variety of locations. Within the MRW, numerous watershed modeling studies have found that placing fertilizer nutrients in the subsurface is the most effective single in-field or edge-of-field practice in reducing nutrient runoff from the watershed at 100% adoption rates (Martin et al., 2021; Scavia et al., 2017). Results from this study confirm this result and show that across a spectrum of adoption rates, subsurface placement of P is more effective at reducing phosphorus discharge than buffer strips. Although subsurface placement of P was the more effective practice at reducing phosphorus discharge from the watershed, buffer strips provide additional environmental benefits that may be of interest to landowners and operators. These additional benefits include reducing soil erosion, providing greater soil moisture contents, and stabilizing ditch and river channels (Cole et al., 2020; Kavian et al., 2018; Borin et al., 2010).

Effectiveness of Targeting CP Adoption Pathways

As expected, targeting Subsurface P and buffer strips to HRUs with the greatest TP loading rates resulted in greater decreases in TP and DRP discharges from the watershed than randomly applying the CPs across the watershed (Martin et al., 2021; Scavia et al., 2017) and was the most efficient pathway in reducing nutrient losses. Although this pathway was the most efficient pathway in reducing TP and DRP across the watershed, limitations such as a lack of knowledge of the locations of these highest P loss fields in the environment affect the practicality of this approach to watershed management. Targeting the adoption of CPs to HRUs managed by MPOs with high conservation identities and through random selection had similar phosphorus reduction efficiencies. One explanation for these similar phosphorus reduction efficiencies is the little relation between farmers' conservation identity and runoff from their fields. Although farmers' psychological characteristics related to their identity as a farmer affects the practices used on their farms (Burnett et al., 2018; Zhang et al., 2016) they cannot greatly influence the physical features of their landscape (e.g., slope or soil type). Although these two targeting methods showed similar effectiveness in reducing TP and DRP losses, targeting by conservation identity resulted in slightly more advantageous outcomes. This may be due to model development, the linking of conservation identities to model farm operations, and the systematic selection of HRUs with greater amounts of CPs present through the targeting method than through the random adoption process.

Designing CP Adoption Programs to Improve Water Quality

Although targeting the adoption of CPs across the watershed by the TP losses from individual fields (HRUs) resulted in the most efficient pathway of reducing TP and DRP losses, economic, social, and political challenges exist in prioritizing these fields to receive CPs. One challenge in targeting CPs to these high phosphorus loss fields is identifying their locations. Although a variety of factors affect phosphorus runoff from agricultural fields such as fertilizer application methods and precipitation (Endale et al., 2019; Hanrahan et al., 2019), field-level characteristics are important in governing nutrient flow dynamics. For example, fields with high soil test phosphorus values have been found to contribute more phosphorus downstream than fields with low soil test phosphorus values (Duncan et al., 2017) indicating they are potential critical source areas of nutrient losses. This field-level data is generally proprietary information, which can lead to a lack of publicly available knowledge of where these high soil-test phosphorus fields are in the landscape. Because federal CP adoption programs are generally designed on a first-come, first-serve basis (Talberth et al., 2015), farmers with fields with the greatest risk of phosphorus loss may not have the chance or may decide to not enroll in a program.

Economic and social-psychological factors contribute to a farmer's willingness to participate in voluntary CP adoption programs (Yeboah et al., 2015; Reimer and Prokopy, 2014). These factors also contribute to the willingness of farmers within the

MRW to adopt various CPs to reduce phosphorus discharged to Lake Erie. In this setting, farmers with higher conservation identities are more likely to adopt various CPs (Burnett et al., 2018; Zhang et al., 2016). Thus, within the MRW, TP and DRP loss reductions due to increasing CP adoption rates likely more closely resemble TP and DRP reduction pathways as indicated when targeting by MPO conservation identities than the most efficient pathway of targeting by high P loss HRUs in the future (Figs. 3 and 4). This likely implies that in agriculturally dominated watersheds more efficient nutrient reduction pathways exist as the amount of phosphorus a field discharges is not the sole factor in a farmer determining whether to adopt a CP to reduce the nutrient discharge. However, if CP adoption programs, whether at the federal, state, or local level, focus on recruiting farmers that have high phosphorus loss fields and who have a strong or high conservation identities similar efficiencies in nutrient reductions can be achieved as by targeting CPs only to the greatest phosphorus loss fields (Figs. 3 and 4). An example of this approach to watershed management at the federal level is the Western Lake Erie Basin Initiative of the United States Department of Agriculture's Natural Resources Conservation Service (USDA-NRCS). Through this initiative, the USDA-NRCS screens applicants for funding through NRCS Environmental Quality Incentives Program (EQIP) with the applicants whose land is fully within the watershed and is vulnerable to nutrient discharge (i.e., higher soil test phosphorus values) being given higher ranking for funding (NRCS, 2016a; NRCS, 2016b).

Future Work

Although conservation identity has been shown to be a strong predictor of future CP adoption (Burnett et al., 2018) other socio-psychological, demographic, and economic conditions have been found to affect conservation decisions made by farmers (Prokopy et al., 2019; Liu et al., 2018). Using farmer surveys of the MRW, demographic factors such as age and gender and socio-psychological factors such as perceived conservation practice effectiveness at reducing nutrient losses can be linked with MPO conservation identities at the county-level to add further heterogeneity. With these more complete MPOs, an agent-based model can be developed to allow these heterogeneous MPOs to interact and learn from each other. Further, economic analyses on the cost-effectiveness of programs aimed to capture CP adoption trends presented in the targeting pathways can be completed. These economic analyses will provide policy insight for CP adoption programs that are most cost-effective in terms of their ability to reduce phosphorus losses from a watershed.

Conclusion

With limited financial resources, it is critical to develop programs that distribute support for CP adoption in ways that generate greater returns in terms of improved water quality. Agricultural CP programs that recruit farmers using dual criteria - targeting the highest phosphorus loading fields as well as those who are most willing to participate in CP programs- can nearly achieve the same phosphorus discharge reduction as programs that focus primarily on placing CPs on fields with the greatest phosphorus loss. An approach that accounts for behavioral factors in responses to program incentives is likely much more realistic than believing that all farmers are equally likely to implement conservation practices on their fields. In the MRW, as in other watersheds, locations of these high phosphorus discharge fields (or high conservation identity farmers) are not always known; however, effective outreach and programming can counteract this gap in knowledge by focusing on farmers who manage fields with higher soil phosphorus values and who hold favorable dispositions towards adopting CPs. This approach is particularly important in efficiently achieving downstream water quality improvement in schemes that rely on the voluntary adoption of CPs, as is the case in the MRW and throughout much of the world.

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Chapter 2. Using Farmer Survey Data to Inform Watershed Model Simulation Scenarios of an Agricultural Conservation Practice

Abstract

Farmer surveys and watershed models are important tools in analyzing the factors affecting farmer adoption of agricultural conservation practices and assessing their impact on downstream water quality. Here, we integrate human behavioral data into a watershed model to assess the water quality impacts of changing farmer beliefs regarding nutrient management, specifically subsurface phosphorus placement, an agricultural conservation practice. We embedded a SWAT model of the Maumee River watershed with information about decision-making characteristics of individual model operators based on results from a survey of farmers in the watershed, which resulted in a novel approach to simulating patterns of conservation practice adoption. This novel approach can aid in developing conservation adoption pathways that simulate more realistic conservation adoption patterns in watershed models than those relying solely on the physical features of the landscape. In the farmer survey, perceived response efficacy, an indicator of a belief that subsurface phosphorus placement is effective at reducing nutrient losses, was found to be significantly related to the adoption of the conservation practice, both individually and in combination with other variables. We estimated adoption of subsurface phosphorus placement in the SWAT model using different assumptions about the level of perceived response efficacy. Setting perceived response

efficacy to the highest possible value for all model operators resulted in discharge reductions from the baseline model of 4.8% for total phosphorus (TP) and 7.5% for dissolved reactive phosphorus (DRP) from the watershed in the critical high-loading season of March through July. This difference was due to increasing the estimated adoption rates of subsurface phosphorus placement from 78.2% of agricultural land in the baseline scenario to 88.0% in the high-efficacy scenario. Conversely, lower levels of perceived response efficacy were associated with increased discharges of TP and DRP from the watershed as compared to the model baseline. These results suggest that improving the performance and awareness of the efficacy of nutrient management practices through research, education, and outreach programs could lead to increased adoption in the watershed and reduced phosphorus discharged to Lake Erie.

Introduction

Non-point source pollution, originating from anthropogenic sources, degrades environmental health around the world with impacts such as increasing severity and occurrence of toxic algal blooms (HABs; Paerl and Barnard, 2020; Huang et al., 2020) as well as anoxic dead zones (Watson et al., 2016). Agriculture is a substantial contributor to global anthropogenic non-point source pollution with sediment and nutrient discharge being two physical and chemical pollutants of concern (Ezzati et al., 2020; Häder et al., 2020; Lizaga et al., 2020). In the Laurentian Great Lakes, non-point sources of pollution from industrial forestry and agricultural practices, as well as from urban stormwater have affected the chemical, biological, and ecological integrity of the system in both its present and historical states (Martin et al., 2021; Grbić et al., 2020; Guiry et al., 2020, Langston, 2017).

In Lake Erie, much present-day concern among residents focuses on the annual HAB that develops in the lake's Western Basin affecting water quality and the bodies of aquatic life (Briland et al., 2020; Wituszynski et al., 2017) and the socio-economics and public health of the human population in the surrounding region (Smith et al., 2019; Wolf and Klaiber., 2017). Lake Erie's HABs are driven by agricultural phosphorus runoff from the Maumee River watershed, the largest contributor of phosphorus to the lake (Maccoux et al., 2016; Stumpf et al., 2012). Because of this, legislative, media, and human inhabitants' attention has shifted to addressing agricultural crop and livestock practices in the watershed. In particular, to reduce the impact of agriculture on Lake Erie's HABs, agricultural producers in the region are encouraged to voluntarily modify their practices to limit nutrient discharge from their fields (Wilson et al., 2019; Akkari and Bryant, 2017). One approach at reducing nutrient discharge from agricultural fields is the adoption of conservation practices (CPs). CPs on the edge-of-field as well as in-field have been found to be effective at reducing both total phosphorus (TP) and dissolved reactive phosphorus (DRP) loads from agricultural fields in the Maumee River watershed as well as in watersheds throughout the world (Xue et al., 2020; King et al., 2018; Liu et al., 2017). Although CPs can reduce agriculture's impact on downstream water quality, agricultural producers that must decide whether to adopt them or not hold heterogeneous perceptions on their effectiveness. Further, agricultural producers have heterogeneous views of their own responsibility to protect downstream water quality, including those in the Maumee River watershed, thus affecting CP adoption rates (Prokopy et al., 2019; Burnett et al., 2018; Liu et al., 2018; Zhang et al., 2016; Burnett et al., 2015).

Factors Influencing Farmer Decision Making Related to Conservation Practices

Both environmental and non-environmental factors can influence a farmer's decision to adopt CPs (Liu et al., 2020; Prokopy et al., 2019; Ulrich-Schad et al., 2017; Zhang et al., 2016). Environmental conditions of a farm, such as soil types and drainage conditions, can aid in the determination of which CPs can be used effectively. Non-environmental as well as environmental conditions can influence whether or not a CP will be used (Ohio State University Extension, 2018; Prokopy et al., 2019; Liu et al., 2018). A non-exhaustive list of non-environmental factors affecting CP adoption includes demographic, psychological, and farm-operational characteristics. Demographic factors include those relating to an individual farmer such as age and education level. Psychological factors relate to how an individual farmer perceives or understands conservation as well as to their identity as a farmer, such as perceived control, self-efficacy, and conservation identity. Operational factors relate to the farm operation, such as farm size and gross income.

Individual-level factors such as those relating to demographic and psychological factors, and farm-operational factors can be considered motivators or barriers of CP adoption depending on the situation (Ranjan et al., 2019). Although these factors can both motivate and/or limit individual farmers in adopting CPs, they are not always significant in the decision-making process. For instance, psychological factors more frequently have a significant effect on CP adoption than demographic factors (Liu et al., 2018; Burton, 2014). In the Western Lake Erie Basin, Burnett et al. (2018) found that a greater number of psychological factors of farmers were significant predictors of cover crop adoption as compared to demographic factors. Similarly, Zhang et al. (2016) found that a greater number of psychological factors significantly affected the adoption of avoiding fall application of nutrients as compared to demographic factors. In contrast to these two CPs, Zhang et al. (2016) also found that more farm-operational and demographic factors were significant predictors of avoiding winter application of nutrients and delaying broadcast of fertilizer before a forecasted storm. Results from Burnett et al. (2018) and Zhang et al. (2016) indicate that the decision-making process related to adopting CPs is complex even within a similar geographic region.

Although individual-level and farm-operational factors can be important in determining whether a CP is adopted, it is unclear how altering these factors would influence downstream water quality. For instance, it is unknown how much less phosphorus would be discharged from a watershed if farmers have a greater understanding of the effectiveness of an individual CP to reduce pollution or if more farmers felt that engaging in agricultural conservation was a strong component of what made a "good farmer." Answering questions like these is important to guide potential investments in farmer outreach to alter psychological factors that influence CP adoption and thereby improve water quality, especially when agri-environmental policies rely on voluntary CP adoption.

Integrated Socio-Ecological Modeling and the SWAT Model

Integrated socio-ecological modeling is an approach that can simulate the downstream environmental impacts of changing upstream socio-economic factors that affect CP adoption (Zomorodian et al., 2018; Liu et al., 2015; Daloğlu et al., 2014a). Applications of watershed models, including the Soil and Water Assessment Tool (SWAT) and SPAtially Referenced Regression on Watershed Attributes (SPARROW), have generally not included socio-economic factors of agricultural producers in the modeling framework (Cools et al., 2011; Preston et al., 2009). This limits the ability of the models to examine the impact of changing socio-economic factors on downstream resources, and in turn, on our design of policies to alter the behavior of upstream agricultural producers to increase CP adoption.

SWAT is a semi-distributed hydrological model developed by the United States Department of Agriculture's Agricultural Research Service (Arnold et al., 1998). SWAT has been used to simulate nutrient dynamics in watersheds around the world (Tan et al., 2020), including in the United States (e.g., Gassman et al., 2017; Chen et al., 2017) and has been widely used in integrated modeling approaches (e.g., Nguyen et al., 2021; Hounkpè et al., 2019).

The goal of this work is to evaluate how changes in farmer psychological characteristics related to CP adoption affect downstream water quality using an integrated socio-ecological model that combines farmer CP adoption with SWAT. The three objectives are to (1) determine which factors are significant predictors of the likely future adoption of subsurface phosphorus placement among farmers in the Maumee River watershed and which factor is most influential, (2) link significant factors to a SWAT model of the watershed embedded with model operators, and (3) evaluate how changes in the most influential significant factor affecting the likely future adoption of subsurface phosphorus placement affect adoption rates of the conservation practice and resulting water quality discharged from the watershed.

Methods

Study Area

The Maumee River Watershed (Fig. 7) spans over 17,000 square kilometers in Indiana, Michigan, and Ohio and drains to Lake Erie's Western Basin near Toledo, Ohio. Historically, the watershed was dominated by forest and marsh swamps and wetlands that comprised the Great Black Swamp (Mitsch, 2017). In the nineteenth century the land was drained for agricultural production and presently the land use is predominantly agricultural with 80% of the land use in corn-soybean row crop agriculture (Ohio EPA, 2018).

Fertilizer application methods vary across the watershed. Approximately 60% of farmers in the basin work their fertilizers into the soil through incorporation after broadcasting, banding, or placement of in-furrow with seed (NRCS-CEAP, 2016; Prokup et al., 2017; Beetstra et al., 2018). Subsurface placement of phosphorus is one of the most effective CPs in reducing phosphorus loadings from the watershed particularly as the adoption rate of the CP increases (Martin et al., 2021; Kast et al., 2021b).

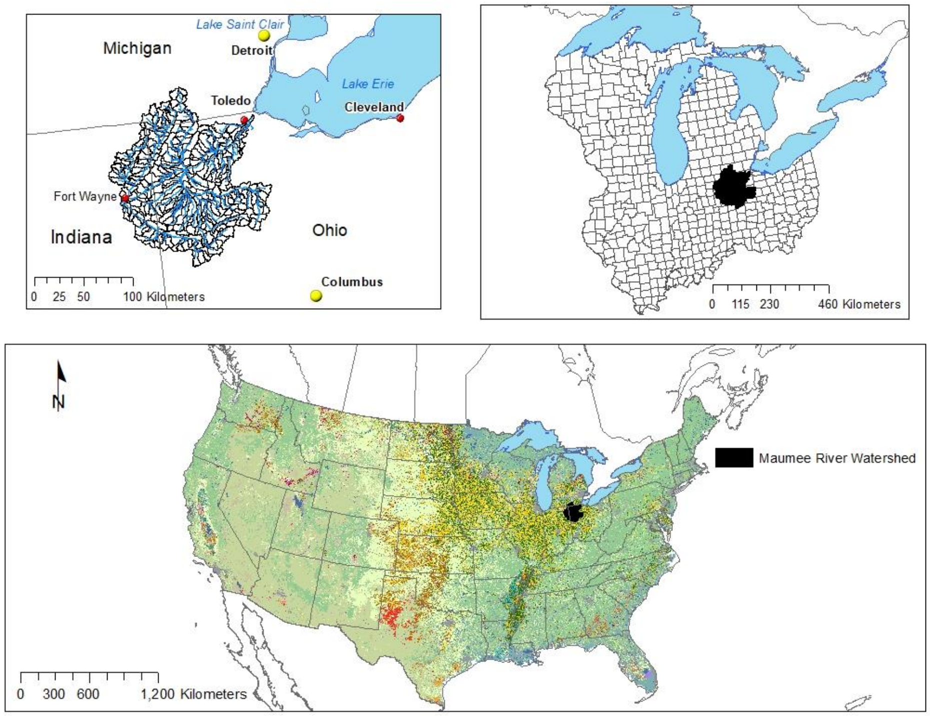

Figure 7: The Maumee River watershed is the largest watershed draining to Lake Erie and is dominated by row-crop agriculture

Farmer Survey and Data Analysis

A random sample of corn and soybean farmers within the Maumee River watershed (n = 7,500) received a survey between February and April 2014 (Burnett et al., 2018; Zhang et al., 2016) following Dillman's tailored design method (Dillman, 2000). Previous studies utilizing this farmer survey explored the adoption decision of cover crops, avoiding winter or fall fertilizer application, and delaying fertilizer broadcast application before a forecasted storm (Burnett et al., 2018; Zhang et al., 2016). In this study, subsurface placement of phosphorus was analyzed from the survey because of previous modeling work showing the strong performance of the CP in reducing phosphorus loads from the Maumee River watershed (Martin et al., 2021, Kast et al., 2021b). Similar to Burnett et al. (2018) and Zhang et al. (2016), two dependent variables from the farmer survey were measured, 1) farmer willingness to adopt the CP and 2) current farmer adoption of the CP. For subsurface phosphorus placement, respondents who had not yet adopted the CP indicated their willingness to adopt the CP on a scale from 0 to 3 (0: will never adopt, 1: unlikely to adopt, 2: likely to adopt, and 3: will definitely adopt). Current farmer adoption of subsurface phosphorus placement was measured by asking respondents to mark a box indicating they were already using the practice on their reported field. Respondents who indicated they were already using the CP were assumed to use the CP throughout their farm operation.

SPSS 26 for Windows was used for all data analysis related to the farmer survey. A hierarchical multinomial logistic regression was performed to test the proposed model of subsurface phosphorus placement adoption. Additionally, the regression was used to compare models including 1) operational factors, 2) operational and demographic factors, and 3) operational, demographic, and psychological factors. Eleven independent variables were included in the full multinomial logistic model. Operational variables included adjusted gross income and farm size. Demographic variables included age, years of experience in farming, and education level. Psychological variables included response efficacy of subsurface phosphorus placement, risk attitude, perceived control, perceived responsibility, self-efficacy, and conservation identity. Response efficacy of subsurface phosphorus placement was measured on a scale of 0 to 4 (Burnett et al., 2018; Zhang et al., 2016). Risk attitude was measured on a scale of 0 to 10 (Burnett et al., 2018; Zhang et al., 2016). Perceived control over nutrient loss was measured on a scale of 0 to 6 (Burnett et al., 2018; Zhang et al., 2016). Perceived responsibility to address local water quality issues was measured on a scale of -2 to 2 (Burnett et al., 2018; Zhang et al., 2016). Perceived self-efficacy of to alter current practices to limit nutrient loss was measured on a scale of -2 to 2 (Burnett et al., 2018; Zhang et al., 2016). Conservation identity was measured on a scale of 0 to 4 and based off the "good farmer" identity concept and scale (McGuire et al., 2015; Arbuckle, 2013; McGuire et al., 2013; Burton, 2004). For more information on how these variables were measured through the survey instrument as well as other variables measured in the survey see Burnett et al. (2018), Zhang et al. (2016), and Burnett et al. (2015).

Farmer Survey Response and Sample

Of the 7,500 farmers mailed a survey, 3,937 surveys were returned leading to an initial response rate of 53% (Burnett et al., 2018; Zhang et al., 2016). Of the returned surveys, 2,265 responses (adjusted response rate = 30.2%) were deemed valid and thus used in the analysis. Of the adjusted sample, approximately 52% only had a high school degree and approximately 98% of respondents were male. Survey respondents had an average age of 59 years and 37 years of farm experience. Most respondents (65%) had an annual gross farm income less than $100,000 while the average amount of agricultural land managed was 205 ha. For more information on the survey sample as well as initial analyses of survey results, see Burnett et al. (2018) and Zhang et al. (2016).

Multinomial Logistic Regressions on Farmer Adoption of Subsurface Phosphorus Placement

To identify a model that adequately explains farmers' willingness to adopt subsurface nutrient placement, three models using combinations of operational, demographic, and psychological variables were generated using multinomial logistic regression in a hierarchical modeling approach. In each model, a backward stepwise method was used to test the influence of all individual variables as well as all two-way interactions between the variables. The full model combining operational, demographic, and psychological variables was found to be a better model (R^2 = 0.178 (Cox and Snell), 0.201 (Nagelkerke), AIC = 3620.21, BIC = 3902.08; Table 3) than the model utilizing only operational and demographic variables (R^2 =0.040 (Cox and Snell), 0.045 (Nagelkerke), AIC = 3907.87, BIC = 4007.30; Table 10) and, depending on the model analysis variable of interest, for the model utilizing only operational variables (R^2 =0.020 (Cox and Snell), 0.023 (Nagelkerke), AIC = 2186.53. BIC = 2219.74; Table 11). The reference category in each model was the farmers who were unwilling to adopt subsurface nutrient placement. Farmers who were willing to adopt the CP and those that had already adopted the CP (Tables 3, 10-11) were the comparison categories.

The odds ratio was used to interpret the interaction and single variable terms similarly as described in Burnett et al. (2018). In this interpretation, if the odds ratio is greater than one, a positive relationship between terms exists, if the odds ratio is less than one, a negative relationship between terms exists, and if the odds ratio is close to one, then the terms are equally likely to occur. In the full model, response efficacy had the greatest odds ratio of the psychological variables in comparing unwilling to willing farmers (Odds Ratio = 2.51; Table 3). This indicates that among the variables of interest, the perceived effectiveness of the practice to improve water quality had the greatest impact on changing the odds of being willing to adopt subsurface nutrient application (as opposed to unwilling to adopt the CP). According to the interpretation from Burnett et al. (2018), the 2.51 odds ratio indicates that for every one-unit increase in response efficacy a respondent would be 2.51 times as likely to adopt subsurface phosphorus placement.

	Unstandardized	95% Confidence Interval		
Farmer Variables	Coefficient B (SE)	Lower	Odds Ratio	Upper
Unwilling farmers vs. willing farmers				
Intercept	-1.97 (0.85)*			
Adjusted Gross Income	-0.72 (0.35)*	0.25	0.49	0.96
Education	1.53 (0.95)	0.71	4.62	29.8
Total Farm Acres (1000s acres)	-1.44 (0.58)*	0.08	0.24	0.74
Age (10s years)	0.34 (0.05)	0.94	1.04	1.15
Experience (10s years)	0.56 (0.14)***	1.33	1.75	2.29
Response Efficacy	0.92 (0.30)**	1.41	2.51	4.48
Perceived Control	-0.30 (0.17)	0.53	0.74	1.03
Risk Attitude	0.26 (0.05)	0.92	1.03	1.14
Conservation Identity	-0.59 (0.18)	0.67	0.94	1.33
Self-Efficacy	0.12 (0.16)	0.83	1.13	1.54
Responsibility	0.14 (0.19)	0.79	1.15	1.68
Adjusted Gross Income x Risk Attitude	0.13 (0.07)*	1.00	1.14	1.30
Education x Total Farm Acres	0.26 (0.21)	0.86	1.30	1.96
Education x Age	-1.48 (0.11)	0.70	0.86	1.07
Education x Risk Attitude	-0.18 (0.07)*	0.72	0.84	0.97
Education x Conservation Identity	-0.10 (0.25)	0.56	0.90	1.48
Education x Self Efficacy	-0.06 (0.25)	0.58	0.94	1.55
Total Farm Acres x Conservation Identity	0.54 (0.22)*	1.12	1.71	2.61
Total Farm Acres x Responsibility	-0.54 (0.22)*	0.38	0.59	0.91
Experience x Response Efficacy	-0.22 (0.05)***	0.73	0.81	0.89
Response Efficacy x Perceived Control	0.15 (0.07)*	1.01	1.16	1.32

Continued

Table 3: Full multinomial logistic regression model summary comparing farmers unwilling to adopt subsurface nutrient placement to those willing to adopt the practice (n = 1,816).

Table 3 continued

Farmer Variables	Unstandardized Coefficient B (SE)	95% Confidence Interval Lower	Odds Ratio	Upper
Unwilling farmers vs. Adopted Farmers				
Intercept	-2.16 (1.02)*			
Adjusted Gross Income	0.20 (0.38)	0.58	1.22	2.58
Education	0.92 (1.02)	0.34	2.51	18.54
Total Farm Acres (1000s acres)	-0.80 (0.56)	0.15	0.45	1.34
Age (10s years)	-0.22 (0.09)*	0.67	0.81	0.96
Experience (10s years)	0.36 (0.17)*	1.03	1.43	1.98
Response Efficacy	0.61 (0.33)	0.96	1.84	3.50
Perceived Control	-0.34 (0.20)	0.48	0.71	1.06
Risk Attitude	0.06 (0.06)	0.94	1.06	1.19
Conservation Identity	0.35 (0.19)	0.98	1.42	2.06
Self-Efficacy	0.02 (0.16)	0.74	1.10	1.41
Responsibility	-0.04 (0.20)	0.65	0.96	1.42
Adjusted Gross Income x Risk Attitude	0.03 (0.07)	0.89	1.03	1.18
Education x Total Farm Acres	0.41 (0.19)*	1.03	1.51	2.21
Education x Age	0.21 (0.12)	0.97	1.24	1.57
Education x Risk Attitude	-0.08 (0.08)	0.79	0.92	1.07
Education x Conservation Identity	-0.84 (0.26)**	0.26	0.43	0.72
Education x Self Efficacy	0.62 (0.27)*	1.10	1.86	3.16
Total Farm Acres x Conservation Identity	0.27 (0.20)	0.88	1.32	1.96
Total Farm Acres x Responsibility	-0.21 (0.20)	0.55	0.81	1.21
Experience x Response Efficacy	-0.10 (0.06)	0.80	0.90	1.01
Response Efficacy x Perceived Control**	0.21 (0.08)	1.06	1.23	1.43

Note: Pseudo R^2 = 0.178 (Cox and Snell), 0.201 (Nagelkerke), model $X2$ (42) = 354.86, Intercept Only AIC = 3891.07, Final Model AIC = 3620.21, Intercept Only BIC = 3902.08, Final Model BIC = 3862.40
* p <0.05 ** p <0.01 *** p <0.001

SWAT Model

The Soil and Water Assessment Tool (SWAT, revision 635; modified according to Kalcic et al., (2016)) was used to simulate nutrient and hydrologic flows within the

Maumee River watershed. Among the available options for watershed models, it has been found to be the most appropriate model for the Maumee River watershed (Gebremarium et al., 2014) and has been used extensively in the region (e.g., Apostel et al., 2021; Martin et al., 2021).

The near field-scale SWAT model of the Maumee River watershed used in this study has been calibrated adequately to daily and monthly flow and nutrient loadings between 2005 and 2015. Model validation between 2000 and 2004 also achieved adequate statistics, with the exception of sediment loadings bias just out of range (Apostel et al., 2021; Table 1). Data used in observed nutrient and flow loadings were derived from USGS gauge #04193500 at Waterville, Ohio maintained by the National Center for Water Quality Research at Heidelberg University. For more information on the SWAT model used in this analysis see Apostel et al. (2021) and Kast et al. (2021a).

Linking Demographic, Psychological, and Operational Characteristics to Conservation Identities and Model Farm Operations in the SWAT Model

SWAT does not represent individual decision-makers in its framework. Rather it is singularly focused on land units by delineating watersheds into subbasins and hydrologic response units (HRUs; Arnold et al. 1998). Kast et al. (2021b) developed methods to embed model farm operators with unique conservation identities and model farms in the near field-scale SWAT model of the Maumee River watershed. This study expands on the approach developed by Kast et al. (2021b) by linking other demographic, operational, and psychological characteristics to model operators to represent more holistic decision-makers representative of the farmers in the watershed. Demographic, operational, and psychological characteristics found to be significant predictors of the future likely adoption of subsurface nutrient placement in the full multinomial logistic regression model (Table 3) were linked to model operator conservation identities based on the crosstabs of each individual factor and conservation identity from the farmer survey. Because model operators developed in Kast et al. (2021b) included representations of farmer conservation identities, this was the characteristic used to link additional operational, demographic, and psychological factors to the model operators. Age was assigned to the model operators after years of farm experience to ensure that no model operators were assigned an age value greater than their assigned years of farm experience. To further ensure age and years of farm experience were properly accounted for in the characteristics assigned to model operators, age was compared with the crosstabs of years of farm experience rather than conservation identity. Tables 12-19 show the breakdown of each variable added to the model operators compared to conservation identity or experience based on results from the farmer survey. Distributions of each variable added to the model operators in the SWAT model were consistent with the distribution of results for each individual corresponding variable from the farmer survey.

SWAT Model Scenario Development

Psychological characteristics found to be significant predictors of subsurface nutrient placement adoption ($p = 0.05$) in the full multinomial logistic regression (in terms of the individual variable) were used as a basis for scenario development (Table 3). For each variable meeting this condition the corresponding characteristic in the model operators were increased or decreased by one unit at a time until all model operators had the largest or smallest characteristic value based on the farmer survey, at which point it was held constant through the remaining scenario development. This was done so that a model operator could not be assigned a value for the corresponding variable exceeding the bounds of the value set from the farmer survey (i.e., response efficacy ranges from 0 to 4 in the survey item so response efficacies for model operators could not exceed 4 or fall below 0, Table 4).

Scenario	Response Efficacy of Subsurface Phosphorus Placement Mean Value
Baseline Likely Future Adoption	2.6 (0.96)
RE1	0.0 (0.00)
RE2	0.16 (0.37)
RE3	0.75 (0.71)
RE4	1.6 (0.90)
RE5	3.4 (0.78)
RE6	3.8 (0.43)
RE7	4.0 (0.16)
RE8	4.0 (0.00)

Table 4: Average (standard deviation) of response efficacy values assigned to 17,297 model operators in the SWAT simulations. A response efficacy of 0.0 indicates the lowest response efficacy value while 4.0 represents the highest response efficacy value.

Calculating Adoption Probability for Model Operators and Assigning SWAT Model CP Adoption

Significant predictors in the full multinomial logistic regression (reported in section 2.2.2) were included in the regression equation used to generate adoption probabilities. For each model operator in the SWAT model an adoption probability was calculated. To determine if the model operator adopted subsurface nutrient placement on all HRUs in their respective model farm operation a number was randomly drawn from a uniform distribution U[0,1]. If the predicted adoption probability was larger than the randomly drawn number, it was assumed that the model operator would adopt the CP across their model operation. If the predicted adoption probability was smaller than the randomly drawn number then it was assumed the CP would not be adopted by the model operator (Liu et al., 2020). Five-hundred sets of randomly drawn numbers for each model operator were pulled for each scenario. The first set of randomly drawn numbers in this matrix was used to compare to the predicted adoption probabilities and determine model CP adoption.

SWAT Model Simulation and Analysis

A baseline likely future adoption scenario as well as alternative scenarios were simulated between 2005 and 2015 with a five-year warm up period typical for SWAT simulations. The baseline likely future adoption scenario was generated from the assigned modeled primary operator characteristics as described in sections 2.4 and 2.6. Run on a daily timescale, results from the model simulation were output at the monthly level. TP and DRP loads from March-July for each scenario were analyzed, as this is the critical time-period for phosphorus discharge from the watershed driving HAB development in Lake Erie (Stumpf et al., 2012). Subsurface placement of inorganic phosphorus fertilizer was simulated by placing 99% of the fertilizer mass below the top 10 mm of soil within each HRU selected to receive the practice (Kast et al., 2021b; Martin et al., 2021).

Results

SWAT Model Scenarios

Because response efficacy was the only psychological variable in the full model (Table 3, *Unwilling farmers vs. willing farmers*) whose singular terms were significant predictors of being willing to adopt subsurface phosphorus placement, watershed modeling scenarios centered on the variable. Eight SWAT model scenarios were developed by adjusting the level of response efficacy values of the model operators. These alternative scenarios were developed and compared to a baseline scenario of likely future adoption where 77% of farmers adopted subsurface phosphorus placement and all assigned operational, demographic, and psychological variables of the model operators remained constant (Table 3). Although SWAT model scenarios focused on altering response efficacy values of model operators, all significant predictors from the full model (Table 3, *Unwilling farmers vs. willing farmers*) were used in generating probabilities that a model operator would adopt subsurface phosphorus placement.

Water Quality Impacts of Changing Response Efficacy of Subsurface Phosphorus Placement

Altering the response efficacy of model operators while holding other characteristics constant, as in the Baseline Likely Future Adoption, resulted in subsurface phosphorus adoption rates ranging from 47.3% to 89.2% (Fig. 8). When all model operators were assigned a response efficacy value of 4 (scenario RE8), the highest possible value, 88.0% of the agricultural land in the SWAT model was selected to adopt the practice (Fig. 8). This adoption rate of the CP resulted in an average decrease of 4.8% and 7.5% in March-July TP and DRP loads, respectively from the watershed between

2005 and 2015 as compared to the Baseline Likely Future Adoption (Fig. 9). Conversely, when all model operators were assigned a response efficacy value of 0 (scenario RE1), the lowest possible value, 49.6% of the agricultural land in the SWAT model was selected to adopt the practice (Fig. 8). This adoption rate resulted in an average increase of 12.7% and 20.3% in March-July TP and DRP loads, respectively from the watershed between 2005 and 2015 as compared to the Baseline Likely Future Adoption (Fig. 9).

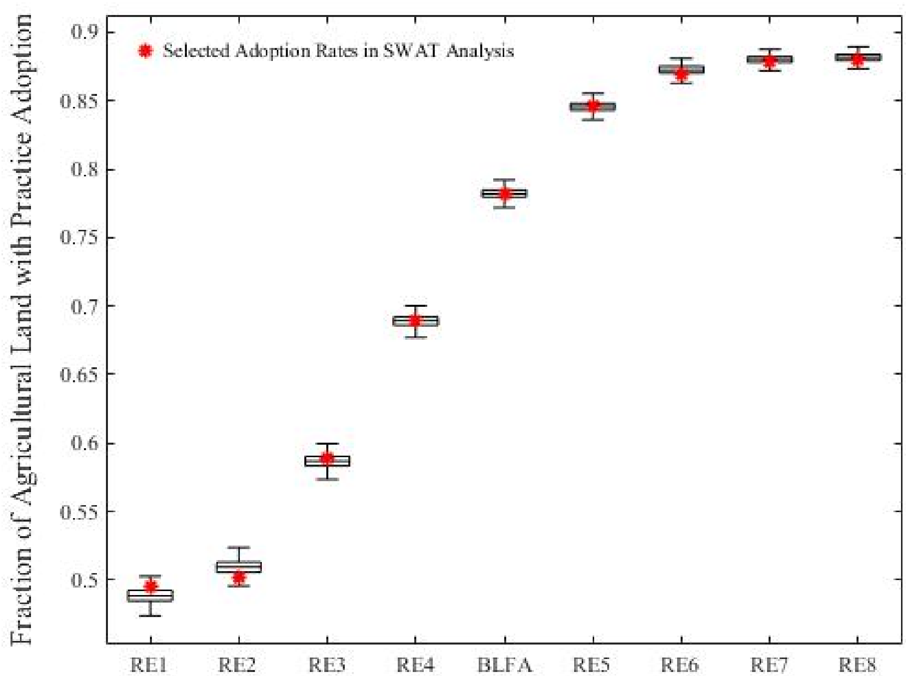

Figure 8: Subsurface phosphorus practice adoption rates from 500 random draws from a uniform distribution. Red stars indicate the practice's adoption rate simulated in the SWAT scenarios.

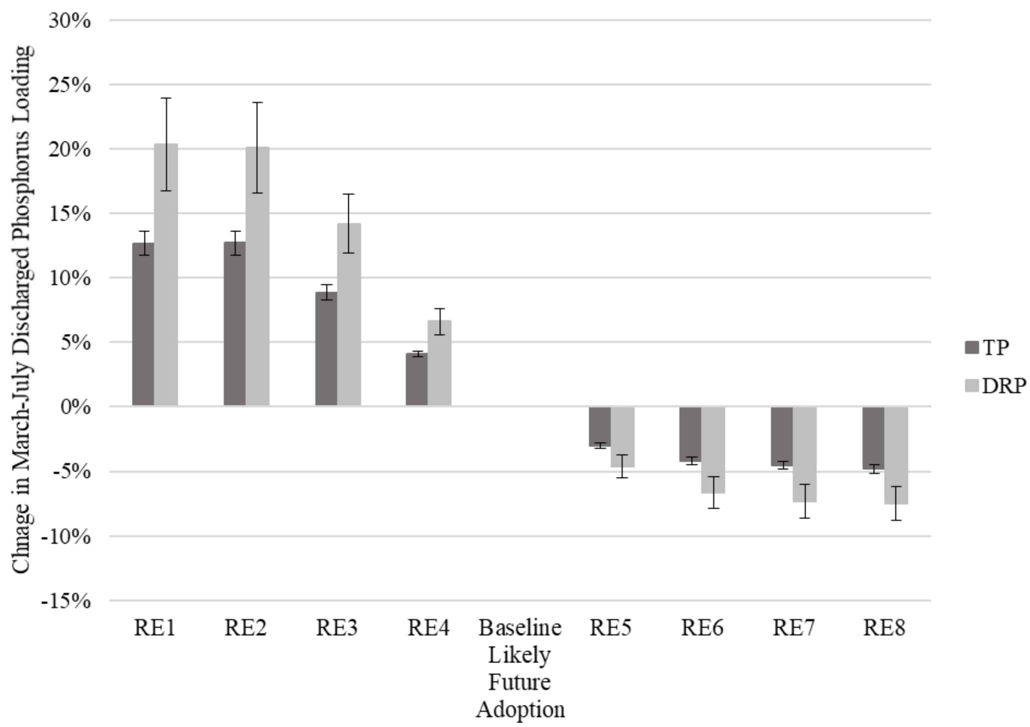

Figure 9:Average changes in March-July Total Phosphorus and Dissolved Reactive Phosphorus loadings when changing SWAT model operators' response efficacy of subsurface phosphorus placement.

Discussion

Impact of Altering Response Efficacy of Subsurface Nutrient Placement on Water Quality

Although response efficacy, on its own, had the highest odds ratio of any significant term in the multinomial logistics regression (2.51), the factor was found to have significant interactions with several others (Table 3). The interaction between response efficacy and perceived control over nutrient loss resulted in an odds ratio that was 1.46 times that of the interaction between response efficacy and years of farming experience (Table 3). Importantly, the former interaction had an odds ratio greater than one while the latter had an odds ratio less than one. This suggests that these interactions have opposite effects on the willingness of farmers in the watershed to adopt the CP. In other words, future adoption of subsurface phosphorus placement was more likely to occur with farmers who hold greater self-efficacy values related to nutrient losses from their fields and those with less experience farming when response efficacy is increased. To understand variables impacting the adoption of this CP more fully, future work should explore the mechanisms between these interactions, as well as the other interacting terms between operational, demographic, and psychological factors significantly affecting adoption.

Previous work in the watershed indicates that the future likely adoption of subsurface phosphorus placement could be as high as 68% (Martin et al., 2021). The baseline likely future adoption of the practice in this work is 78% of agricultural land (~74% of model operators) indicating that approximately 26% of farmers in the watershed do not plan on adopting subsurface placement of phosphorus as a management practice in the future. A limitation of this study is that several factors, such as the price of practice implementation, as well as more robust operational and demographic factors are excluded from the regression. Factors not considered in this work that have been found to significantly affect conservation practice adoption include economic factors and a greater number of farm operational and demographic factors, such as crop yields, marketing engagement, and owning livestock (Prokopy et al., 2019; Liu et al., 2018; Zhang et al., 2016).

These results indicate that outreach efforts to increase the belief that subsurface phosphorus placement is effective at reducing nutrient discharges from their fields could increase the future adoption of this practice on an additional 10% of agricultural land in the watershed (78% to 88%, Fig. 8). Because subsurface phosphorus placement of phosphorus has been found to be one of the most effective CPs for dissolved phosphorus this potential increased adoption ceiling would lead to greater reductions of phosphorus discharges from the watershed, which in turn would result in reduced HABs in Lake Erie (Fig. 9).

<u>Farmer Typologies, Education Outreach, and Changing Farmer CP Beliefs and Adoption</u>

Results from this study suggest that educating farmers about the effectiveness of individual CPs, such as subsurface phosphorus placement, on reducing nutrient discharges may greatly influence their future adoption in the region. By increasing the belief of the effectiveness of subsurface phosphorus placement across the watershed by one unit out of four, the potential maximum-future likely adoption of the CP increases from 78% to 88% which in turn would lead to 5% greater reduction in DRP discharge from the watershed (Figs. 8-9). However, educating farmers on the effectiveness of the CP may not affect all farmers in the region similarly. Developing farmer typologies is an important approach to understanding the various groups of farmers in a region and how they may behave or view agricultural conservation differently (Daxini et al., 2019; Daloğlu et al., 2014b; Barnes and Toma, 2012). Upadhaya et al. (2021) developed four typologies for farmers in Iowa and found that each farmer type was motivated by different factors in adopting agricultural conservation practices, suggesting that different methods of educational outreach would affect each farmer-group differently. Tailoring the educational experience and subject matter (e.g., financial impacts of engaging in agricultural conservation, effectiveness of agricultural conservation practices on crop yields or nutrient losses) to each farmer type may thus be needed to effectively reach a wider audience and affect views on agricultural conservation practices.

Future Work

Developing and embedding holistic model operators into watershed models can provide watershed modeling a new approach in assessing the downstream impacts of altering agricultural practices. With this approach, an agent-based model or a decision-making model can be developed within the watershed modeling framework. Utilizing a decision-making model or agent-based model in conjunction with a watershed model could allow for the quantitative assessment of various theories of human decision-making on downstream water quality.

While this study focused on a single CP, subsurface phosphorus application, future work can explore the adoption motivators and barriers for other CPs such as buffer strips, cover crops, and drainage water management. By examining the decision-making factors that farmers undertake for these and other CPs, more complex model operators can be created leading to further heterogeneity in CP adoption decisions in the watershed model. Further, land characteristics and economic factors affecting CP adoption can be integrated to create a wide base of variables in which a CP adoption decision can be made for model-operators.

Conclusion

Understanding the drivers and barriers that lead to farmer adoption of CPs is critical in reducing the impact of agriculture on downstream water quality. However, understanding key barriers and motivators that increase adoption of CPs is not enough.

Quantifying water quality impacts in response to changing these key factors is important and can be estimated by using data from farmer surveys and other social science studies to inform watershed modeling scenarios. This knowledge can guide policymakers in distributing limited resources for agricultural conservation, outreach and education with the goal of increasing farmer CP adoption to critical thresholds based on water quality impacts. These funding mechanisms and educational outreach programs will be critical in the Maumee River watershed, as in the rest of the United States, if a reliance on voluntary adoption of CPs is to be continued.

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Chapter 3. "The Rainbow Comes Down in Ohio": Soil Conservation Districts and Agricultural Conservation in Ohio, 1942-1964

Abstract

This chapter examines farmer-science-government relationships in Ohio through studying Ohio's soil conservation districts in the mid-twentieth century. Between 1942 and 1964, each of Ohio's eighty-eight counties formed soil conservation districts. The soil conservation districts, through agreements with the Soil Conservation Service, provided farmers access to new knowledge about their fields and new approaches to land management based in land planning as well as financial and technical aid to transform their farms to embrace agricultural conservation. Farmers used their local soil conservation district as a conduit to receive access to government expertise in agricultural management and planning. In return, government employees received willing cooperators to install agricultural conservation practices in a planned, systematic fashion. Across the mid-twentieth century, Ohio's soil conservation districts helped transform both the physical and psychological landscape of agriculture in the state by bringing farmers and government experts together.

Introduction

> To do all we believe must be done, every farm in these districts and in other districts to come, must apply those practices necessary to insure a permanent, prosperous agriculture. It's a big job- a tremendously important job.

> We need your help- *whoever* you are, or *wherever* you are. To get the job done will require "The everlastin' teamwork of every bloomin' soul." Then we can say again, with pride and assurance, "The Rainbow Comes Down in Ohio." – T.C. Kennard, Soil Conservation Service Ohio State Soil Conservationist, 1943[1]

On March 25, 1942, residents from Clark and Highland Counties journeyed to Columbus, Ohio to meet with the Ohio Soil Conservation Committee. Attendees from across the two counties presented their case to the Committee in favor of a petition, which had been circulated within each respective county, calling for the creation of a local soil conservation district. Farmers and agricultural landowners in attendance spoke about how a soil conservation district could fulfill their numerous needs and desires. Clark County landowner, J. Lynn Gower, told the Committee that "land use issues should be approached from the scientific standpoint" and that having soil surveys and soil maps, a service that would be provided by a soil conservation district, would be of great utility. Another Clark County landowner, Guy Tuttle, detailed his belief to the Committee that a soil conservation district in the county would help secure better cooperation among farmers, especially in regard to issues related to land drainage and soil erosion. The state's current drainage laws, he argued, were insufficient. Highland County landowner, E.E. West, explained his experience with the Civilian Conservation Corps to the Committee. He focused on the benefits he experienced on his farm through their aid in planning agricultural conservation practices such as contour cultivation and strip

[1] T.C. Kennard presented a paper at the 1943 annual meeting of the Geography Section of the Ohio Academy of Science. His remarks were reprinted as a journal article. Kennard, T.C., 1943. Soil Conservation Districts in Ohio. Ohio Journal of Science, 43. 262

cropping. West felt that a soil conservation district in the county would continue to provide technical aid to engage farmers in conservation efforts once the Corps finished their farm demonstration work and left their county camp.[2]

Examining Ohio's soil conservation districts across the mid-twentieth century provides important insights into the relationship between agriculture and government, the role of science and technology in changing the agricultural landscape, and the changing relationship between farmers and their land. I argue that mid-twentieth relationships forged between Ohio farmers, Ohio soil conservation districts, and federal government experts in agricultural conservation were critical in industrializing Ohio's agricultural landscape. That is, greater crop yields were achieved with less farmland in crop production, farm plots were deconstructed from the whole and into zones based off soil capabilities for drainage and erosion losses which were then used to guide specific management practices to maximize crop production. Across the period, agricultural conservation, or land management practices purposely designed and placed within a particular agricultural area or zone in a field to maximize, or at the very least maintain,

[2] There is some discrepancy on which potential soil conservation districts had hearings in front of the Ohio Soil Conservation Committee on March 25, 1942. Official hearing minutes from the Committee indicate that only Highland and Clark counties had hearings on this date. On March 26, 1942, official hearing minutes from the Committee indicate Columbiana County had their hearing in front of the Committee. However, an accounting of Ohio's soil conservation districts from the Ohio Department of Natural Resources contends that all three counties had their hearings in front of the Committee on March 25, 1942. Ohio Soil Conservation Committee (1942, March 25). Hearing on Petition of Clark County for the Creation of a Soil Conservation District. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1942, March 26). Hearing on Petition of Columbiana County for the Creation of a Soil Conservation District. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1942, March 25). Hearing on Petition of Highland County for the Creation of a Soil Conservation District. Ohio Department of Agriculture Archives, Reynoldsburg, OH.
King, C.C. (Ed.), 1990. *A Legacy of Stewardship: The Ohio Department of Natural Resources, 1949-1989.* Ohio Department of Natural Resources, Columbus, OH, 147.

potential agricultural production, were promoted and installed across a wide swath of Ohio farmland because Ohio's soil conservation districts served as a connective tissue between Ohio farmers and Soil Conservation Service technicians.[3]

Analyzing the relationship between the federal government, Ohio farmers, and Ohio's soil conservation districts across the mid-twentieth century indicates a cooperative approach employed between the groups to achieve goals of increasing agricultural conservation practice adoption. Similar cooperative approaches between the federal government and other "industrialized" sectors were prevalent in the United States during the period. In *Cleaning up the Great Lakes: From Cooperation to Confrontation*, historian Terrence Kehoe details the cooperative approach the government took with industry, particularly in respect to downstream water quality issues stemming from industrial activities, across the mid-twentieth century. He underscores that the relationship among businesses, state water pollution boards, and state and federal government officials was a cooperative one, working to reduce pollution. Similarly, the relationship that developed between Ohio farmers and federal government experts in agricultural conservation revolved around the tenets of volunteerism, localism, and administrative expertise.[4]

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[3] Ohio State University extension specialist, R.H. Blosser spoke for many in the agricultural community when he wrote that "every time a farmer applies some lime or fertilizer or raises a legume crop, he is practicing conservation. On most farms conservation farming means the application of more practices that will preserve the farm as a producing unit." Blosser, R.H., 1950. Farm Organizations and Income in Relation to Soil Conservation, Coshocton County, Ohio. Bulletin No. 214. Department of Rural Economics and Rural Sociology, Columbus, OH, 1.

[4] Kehoe, T., 1997. *Cleaning up the Great Lakes: From Cooperation to Confrontation*. Northern Illinois University Press, 5-8.

Cooperative pragmatism, the term coined by Kehoe describing the relationship between businesses and government employees, that persisted up until the 1960s in the Great Lakes region, was similarly found in the agricultural sector as evidenced through Ohio's soil conservation districts. An important difference between the cooperative pragmatism discussed by Kehoe and what was found in Ohio's soil conservation districts was the use of informal agreements in the former while formal and informal agreements were the norm in the latter. Each of Ohio's soil conservation districts signed formal agreements with agencies and individuals in the United States Department of Agriculture.[5]

The end goal of the relationship between farmers and federal government officials was to increase the adoption of agricultural conservation practices that aimed to improve the productive capability of the land. Ohio's soil conservation districts were organized and run by willing and interested local farmers and landowners and recruited farmers who were willing to engage in the districts' efforts. The leaders of each soil conservation district developed programs and plans that fit the specific needs of farmers and land in their district. Government experts form the Soil Conservation Service lent their knowledge and skills in implementing agricultural conservation to farmers who cooperated with their soil conservation district.[6]

Establishing Ohio Soil Conservation Districts

> In soil conservation districts the farmers themselves decide
> what they want to do to improve their land and water

[5] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts." Ohio Soil Conservation Committee, Columbus, OH, 30-34, 41-63.
[6] Heft, F.E., 1966. "Ohio Soil & Water Conservation Districts in Action," Ohio Soil Conservation Committee, Columbus, OH, 4-6. Heft, F.E., 1953.

> resources, and how they want to go about it. Then they proceed along this course, working together and utilizing all the available facilities and services they can command. - Hugh Hammond Bennett, Chief of the Soil Conservation Service, 1946[7]

Ohio farmers and state and federal government employees, including experts in agricultural conservation, worked cooperatively through formal channels to oversee the establishment of soil conservation districts across the state and to provide access to the technical knowhow related to agricultural conservation that experts wanted, and that at least some farmers desired. Indeed, Ohio farmers were willing and eager participants in the growing relationship with the government across the mid-twentieth century as it related to the soil conservation districts. Farmers and agricultural landowners initiated the process of forming a district, formally approving a district's formation, and staffed and led the districts in creating programs to entice and increase farmer engagement with their local soil district and thus involvement in agricultural conservation.[8]

Soil erosion concerns stemming from the amount of soil lost from agricultural lands in the Great Plains and the economic toll these losses caused prompted the federal government to engage more purposefully in agricultural conservation efforts towards the end of the early twentieth century. In 1933, legislation and executive orders signed by President Roosevelt placed soil erosion and its impacts squarely in the sphere of the federal government. The Civilian Conservation Corps, established by executive order,

[7] Hugh Hammond Bennett, "The Development of Natural Resources The Coming Technological Revolution on the Land" (Engineering and Human Affairs Conference, Princeton, New Jersey, October 2, 1946).
[8] Heft, F.E., 1956, "On the Land," 4-6. Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 30-34, 41-63.

provided employment opportunities for young men throughout the country to aid in protecting the environmental resources of the country, including soil on farmsteads. The Soil Erosion Service housed within the Department of Interior, established by National Industrial Recovery Act, sought to demonstrate the practical benefits of utilizing soil saving practices to farmers in regions critically hit by soil erosion. Secretary of the Interior, Harold L. Ickes placed Hugh Hammond Bennett in charge of the Soil Erosion Service. Following the dust storms of 1935 and their clouding Washington's skies, Bennett advocated for creating a permanent agency that was focused on soil conservation. Bennett's advocacy helped in securing the passage of the Soil Conservation Act of 1935 which established the Soil Conservation Service.[9]

Chief among the concerns of the newly formed agency was how to engage with and encourage the use of soil conservation measures. The federal government had been engaging in farm demonstration projects since the early twentieth century to promote certain agricultural practices viewed positively by federal government employees and demonstrate their benefits to individual farmers. Dr. Seaman Knapp initiated the first Demonstration farm in Texas on behalf of the Department of Agriculture. Knapp, working on the farm of Walter C. Porter, transformed a portion of the farm to be managed under the instructions and watchful eyes of employees of the Bureau of Plant Industry. The purpose of the demonstration farm was the "place a practical object lesson before the farm masses, illustrating the best and most profitable methods of producing the

[9] Helms, D., 1992. *Readings in the history of the Soil Conservation Service*. No. 1. US Department of Agriculture, Soil Conservation Service, Economics and Social Science Division, NHQ, 2-8.

standard farm crops." Although the federal government had experience in forming demonstration farms, not all in the Department of Agriculture thought they were the most effective approach to increase interest in soil conservation. Assistant Secretary of Agriculture, M.L. Wilson, proposed that creating local, governmental entities of the state, in which the people of the local entity would direct soil conserving activities, would be a better approach than following the demonstration farm path. From Wilson's idea sprang the 1937 Standard Soil Conservation Districts Law beginning the development of soil conservation districts throughout the country. Between 1937 and 1939, thirty-seven states had enacted a soil conservation law and eighty-eight million acres of land were organized in a soil conservation district.[10]

Although national momentum was trending towards creating local soil conservation districts to improve how agriculture was practiced in the 1930s, the process ran into headwinds in Ohio's General Assembly. In 1937 and 1939, introduced state legislation allowing Ohio to establish procedures for forming soil conservation districts failed due to hesitancy on behalf of Ohio's agricultural education professionals. Agricultural extension officials from The Ohio State University feared soil conservation districts would upend and diminish the importance of agricultural extension work. In 1941, Substitute House Bill 646 passed both chambers of Ohio's General Assembly and was signed into law by Governor John W. Bricker on June 5th, 1941. Ohio's third attempt

[10] Kozlowski, Gerald, "Porter Farm," Handbook of Texas, Texas State Historical Association, May 1, 1995, https://www.tshaonline.org/handbook/entries/porter-farm. Knapp, S.A., 1910. *The Farmer's Cooperative Demonstration Work*. 1909 Yearbook of Agriculture, US Department of Agriculture, Washington D.C., 153. Morgan, R., 1966. *Governing Soil Conservation: Thirty Years of the New Decentralization*. The Johns Hopkins University Press, 323.

at allowing for the creation of local soil conservation districts succeeded and resulted in Ohio becoming the 42nd state in the nation passing such legislation. Critically, the Ohio Soil Conservation District Enabling Act created a committee, the Ohio Soil Conservation Committee (OSCC), to oversee the formation of local soil conservation districts.[11]

The OSCC acted as the gatekeeper for interested state farmers and agricultural landowners in creating soil conservation districts and gaining access to government experts in agricultural conservation. The OSCC, in its membership, brought together experts and leaders in agriculture and agricultural conservation across the state. The Dean of the College of Agriculture at The Ohio State University, John F. Cunningham, led the OSCC as its first chairman. The Ohio Director of Agriculture, John T. Brown, lent his knowledge of statewide agricultural trends and practices to the committee. And three "ably qualified" farmers, John Grierson of Highland County, Cosmos Blubaugh of Knox County, and Harry Silcott of Fayette County, appointed by Governor John W. Bricker, brought individual farmer credence to the OSCC.[12]

These five men, in working together on the OSCC, showcased the budding ties between the state government and farmers. Although the composition of the inaugural OSCC demonstrated the close ties between farmers and government officials they were

[11] James, E.H., 1965. *The History of the Soil and Water Conservation Movement in Ohio: A Field Study*. Thesis. The Ohio State University, Columbus, OH. Sub. H.B. 646, 39th General Assembly, 1941 Reg. Sess. (Ohio, 1941).

[12] In 1955, the Ohio Soil Conservation Committee's membership grew from five to seven members with the addition of a fourth Governor-appointed farmer member and the Director of the Ohio Department of Natural Resources. Heft, F.E., 1956. "Ohio Soil Conservation Committee, Ohio's Conservation Story 'On The Land,'" Columbus, OH, 4, 7-8. Heft, F.E., 1966, "Ohio Soil & Water Conservation Districts in Action", 3, "New Soil Conservation Program Under Way." Ohio Farm Bureau News. March 1942. "New Law to Help Farmers Save Soil." Ohio Farm Bureau News. September 1941.

not just empty symbols for the growing relationship. A primary task of the OSCC was to hold hearings for potential soil conservation districts once interested farmers and agricultural landowners obtained the requisite number of signatures from agricultural landowners on a petition calling for a formation of a district.[13]

Attendees in the hearings focused discussion on several topics ranging from land use to landowner perceptions on the need for a soil conservation district. Petitioners from Medina County presented information on land use and farms across the county as well as on individual county farms to the OSCC. Petitioners from Highland and Hocking County described their past experiences working with the Civilian Conservation Corps in implementing soil saving practices. Petitioners from Ashland, Huron, and Summit described the benefits they felt would come to their community, and individually, if a soil conservation district was to be formed in their respective counties.[14]

Discussions related to information brought up by petitioners in their hearings with the OSCC served as the foundation for the Committee in understanding why the petitioners wanted to form a soil conservation district. However, the OSCC was not only interested in understanding the motivations for forming a soil conservation district. Members of the OSCC were also concerned about understanding any opposition to

[13] Heft, F.E., 1956. "Ohio Soil Conservation Committee, Ohio's Conservation Story 'On The Land,'" Columbus, OH, 4, 7-8.
[14] Ohio State Soil Conservation Committee (1944, March 16). Ashland County Soil Conservation Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Hearing on Petition of Highland County, 1942. Ohio Soil Conservation Committee (1943, December 30). Hocking Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1945, June 15). Huron Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1944, April 14). Medina County Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1946, May 8). Summit Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH.

establishing a soil conservation district among each of the petitioning groups. Cunningham noted in a hearing with petitioners from Athens County that this [opposition to the petition] was a question the committee liked "to ask of each delegation" typically towards the end of each hearing.[15]

Figure 10: Civilian Conservation Corps, Company 1521, Camp Muskingum. Company 1521 was based in Zanesville, Ohio and were focused on implementing soil conservation efforts on private land in Muskingum County. Company 1521 was attached to the Soil Conservation Service after the agency was established in 1935.[16]

Although the OSCC screened petitions for petitioning farmers and agricultural landowners desiring a conservation district it was the people in the proposed district, particularly agricultural landowners, who ultimately decided if a soil conservation district would be formed. A referendum was held in the proposed boundary of a petitioning soil conservation district after a potential soil conservation district received a favorable judgement from the OSCC. Only landowners in the proposed district were eligible to vote in the referendum. In almost every proposed district, the predominantly white, older, male, and rural electorate met the threshold of 65% voting in favor of establishing a soil

[15] Ohio Soil Conservation Committee (1946, April 5). Athens Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH.
[16] National Archives Photo no. 35-MOPB-5. "CCC Camps in Ohio", *Civilian Conservation Corps Legacy,* Edinburg, VA. https://ccclegacy.org/CCC_Camps_Ohio.html.

conservation district in their first attempt with at least 24 soil conservation districts receiving at least 95% of the vote in favor of its formation. The requirement that only landowners in the proposed district were eligible to vote in the respective referendum highlighted the view within the agricultural community, particularly those who farmed and those who were involved in agricultural trade organizations, such as the Ohio Farm Bureau, that agricultural issues could be and should be only determined by those involved in agriculture. And to farmers, as well as members of the OSCC, soil conservation districts were an agricultural issue. In a hearing with the OSCC on March 26, 1942, delegates from Columbiana County raised concerns that "if unincorporated villages were allowed to vote some two or three thousand additional voters [in Columbiana County] would be involved who are not primarily concerned with the problems at hand."[17]

Urban residents and downstream non-agricultural communities were also interested in the successful formation of a soil conservation district even as they were excluded from the decision-making process regarding a district's formation. In their hearing with the OSCC, businessmen, elected officials, and members representing village clubs presented their positive views on a potential soil conservation district in Brown County and the positive impact a district would have on water supply issues. John T. Brown, speaking for the OSCC in their hearing with Belmont County petitioners,

[17] Heft, F.E., 1956, "On the Land," 8. H.B. 646, 39th General Assembly, 1941 Reg. Sess. (Ohio, 1941). Hearing on Petition of Clark County, 1942. Hearing on Petition of Columbiana County, 1942. King, C.C., 1990. *A Legacy of Stewardship*. Ohio Department of Agriculture Archives, Reynoldsburg, OH- data compiled in Table 23.

indicated that fishermen in Lake Erie were supportive of soil conservation districts due to their ability to reduce erosion issues affecting the lake.[18]

Excluding the more urban populace and those downstream who were not landowners in the determining the fate of a proposed soil conservation district was a protectionary measure on behalf of the agricultural community. An entity organized by and run by farmers, with the aid of government experts, allowed farmers to determine what they felt was most important to affect the land they were most intimately familiar with. The farmer-led and constructed organizational procedure and structure were a cornerstone of the soil conservation districts. Hugh Hammond Bennet, in describing the functions of soil conservation districts, noted that it would be the "farmers themselves" who would decide how they would improve their land. To what must have been much delight by Bennett, Ohio farmers became ingrained into their soil conservation districts and their union with the federal government, by way of the districts, became self-sustaining.[19]

Although those in the agricultural community viewed soil conservation districts as an agricultural issue, it was known that upstream actions would affect those downstream. Recent experiences stemming from the Dust Bowl, particularly dust clouding the Ohio skies, showed farmers and non-farmers alike that agricultural management affected more than just agricultural landowners. And that by establishing and working with soil

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[18] Ohio State Soil Conservation Committee (1944, December 14). Belmont Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio State Soil Committee (1944, September 15). Brown County Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH.

[19] Bennett, H.H., 1946, "The Development of Natural Resources." Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts."

conservation districts, the increasing use of agricultural conservation practices by farmers would affect all in a county.[20]

Differences existed among farmers in the reasons why a soil conservation district was desired, in part due to geography. Petitioners in Belmont, Muskingum, and Washington Counties, in the southeast portion of the state, primarily described farm issues related to soil erosion. While petitioners in Hancock and Mercer Counties, in the northwest portion of the state, voiced the need to solve issues related to land drainage in addition to soil erosion. The geographic distribution of petitioner concerns across the state were driven in part due to geologic events tens of thousands of years prior to the creation of the OSCC. Glacial movements during the Wisconsinan, Illinoian, and Pre-Illinoian Glaciation events scarred the foundations of Ohio's soil. Glacial movement did not protrude into southeastern Ohio, which left unconsolidated soil on hilly slopes, good ingredients for soil erosion. Across northwest Ohio glacial movements in the Wisconsinan event led to changes in regional hydrology. Lake Maumee, a precursor to Lake Erie, stretched across the northwestern portion of Ohio into northeastern Indiana. Lake Maumee's standing water created conditions for clay particles to form, which then became the predominant soil type in the exposed region when Lake Maumee retreated northeastward and evolved into Lake Erie. The Great Black Swamp arose from the ashes

[20] "Dust Storm's Shroud Moves Eastward, Blanketing City." Mansfield News-Journal. March 21, 1935. "Dust Storm Horrors Described; Animals And Men Both Hurt." Chillicothe Gazette. July 7, 1936. "Dust Turns Day Into Night, Closes Schools, Blocks Roads." The Cincinnati Enquirer. February 18, 1937. Worster, D., 2004. *Dust Bowl: The Southern Plains in the 1930s*. Oxford University Press. Bennett, H.H., 1946, "The Development of Natural Resources."

of Lake Maumee's western edges due to the poor drainage capabilities of the newly formed clay soils.[21]

Although geologic conditions affected the agronomic issues farmers faced, farmer experience in engaging in agricultural conservation affected when farmers went to the OSCC to form a soil conservation district. One of the strongest desires among petitioning farmers and landowners in forming a soil conservation district was to receive technical aid and assistance in planning and implementing agricultural conservation practices. Elson Sigrist, a farmer in Ashland County, Ohio, exclaimed to the OSCC that "if we could get someone in our county to assist us with this work [planning agricultural conservation] it would benefit those who are convinced of the worth of soil conservation measures and those who are not, in that they will become educated by observation of the results of good practices." Here, Sigrist, indicated that he and many farmers in Ashland County did not have the needed knowledge or expertise to fully embrace agricultural conservation practices. An issue that would be solved with a soil conservation district and access to experts from the Soil Conservation Service.[22]

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[21] Hearing on Petition of Belmont County, 1944. Ohio Soil Conservation Committee (1944, February 24). Muskingum County Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1945, March 29). Washington County Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation Committee (1945, February 1). Hancock Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Ohio Soil Conservation District (1944, August 3). Mercer County Soil Conservation District Hearing. Ohio Department of Agriculture Archives, Reynoldsburg, OH. Morse, H.H., Bone, S., 1957. "Understanding Ohio Soils," Ohio State University Agricultural Extension Service Bulletin 368, Columbus, Ohio. Bleuer, N.K., Moore, M.C., 1971. Glacial stratigraphy of the Fort Wayne area and the draining of glacial Lake Maumee. *Proceedings of the Indiana Academy of Science,* 81, 195-209. Herdendorf, C.E., 2013. Research overview: Holocene development of Lake Erie. *Ohio Journal of Science,* 112, 24-36.
[22] Hearing on Petition of Ashland County, 1944.

Not all Ohio farmers were lacking the required expertise to engage in agricultural conservation. Mid-twentieth century farmers in northwest Ohio had generational knowledge and experience in implementing one type of agricultural conservation practice: land drainage. Land drainage knowledge was passed down through generation after generation of farmers and landowners, whom in the mid-nineteenth century began to drain the Great Black Swamp. Over the course of approximately fifty years, the extensive wetland system was drained and transformed into productive agricultural land with surface and subsurface drainage techniques.[23]

In contrast to farmers in northwest Ohio, farmers in south-central and southeastern Ohio did not have a pool of generational knowledge to help implement agricultural conservation practices. The strong desire for technical aid from south-central and southeastern Ohio farmers led counties in these portions of the state to establish soil conservation districts earlier than other regions. In contrast, soil conservation districts in northwest Ohio were typically on the latter end of establishing soil conservation districts. Henry, Lucas, and Putnam counties established soil conservation districts in 1954, 1963, and 1956, respectively, and were three of the last four counties in the state to form a district.[24]

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[23] Farmers in northwest Ohio engaged in both extensive surface and subsurface drainage practices to reduce the water table of their fields. Kaatz, M., 1955. The Black Swamp: A Historical Geography. *Annals of the Association of American Geographers*. Wilhelm, P., 1984. Draining the Black Swamp: Henry and Wood Counties, Ohio. *Northwest Ohio Quarterly*. Mollenkopf, J., 1999. *The Great Black Swamp: Historical Tales of 19th Century Northwest Ohio*. Lake of the Cat Publishing. Mollenkopf, J., 2000. *The Great Black Swamp II: More Historical Tales of 19th Century Northwest Ohio*. Lake of the Cat Publishing.
[24] Tables 21-22.

Planning Maketh Production

> The land use capability map showed the need for surface drainage on my Wadsworth and Mahoning silt loam soils. The District technician worked with me in constructing grass waterways, diversions, terraces, 'W' ditches and bedding systems. Every acre is now being more effectively used. - Leonard J. Clark, Ohio Soil Conservation District farmer-cooperator, 1956[25]

Bringing scientific approaches and new technology to agricultural land management was a key function of the soil conservation districts. Both Ohio farmers and government experts desired to use their land resources effectively and efficiently for crop production. Scientific approaches to land management promoted by the soil conservation district, and their cooperating federal partners, centered around two nodes that worked in tandem to provide Ohio farmers an improved baseline to work with to improve their productivity.[26]

The first node was formal planning of the farm. Soil conservation districts worked to aid farmers in developing a deeper understanding of their land, knowledge that Ohio farmers craved. Clark County landowner, J. Lynn Gower believed that by conducting soil surveys and maps, soil conservation districts could provide detailed information to farmers on the soils of their farm which in turn could be used to help farmers most efficiently use their land resources for crop production. Creating knowledge about the soils of individual and district farms was crucial for Ohio's soil conservation districts and

[25] Heft, F.E., 1956. "On the Land," 32.

[26] The scientifically driven vision of agricultural conservation and its relation to planning was borne out of larger views on conservation driven by Progressive ideology in the early twentieth century. The Progressive vision relied on using rational planning to efficiently use resources. Batie, S.S., 1985. Soil Conservation in the 1980s: A Historical Perspective. Journal of Agricultural History, 59.

Soil Conservation Service technicians in developing farm plans. Farm plans developed by soil conservation districts and Soil Conservation Service technicians were created with the goal of using farmland to the best of its productive potential.[27]

The second node was using approaches and technology promoted by researchers and government experts shown to make farmland more arable and productive. Soil conservation districts and Soil Conservation Service technicians designed drainage systems and structures for farm fields that were too wet and farm ponds for farms that struggled in accessing required water supplies. Soil saving methods such as contour stripping were designed and implemented on farm fields that were prone to soil erosion. Leaders of Ohio's soil conservation districts felt a responsibility to their neighboring farmers, and to the country, to help farmers improve crop production by engaging in farm planning techniques and increasing the arable land a farmer had access to.[28]

Ohio farmers viewed soil conservation districts and their work to improve agricultural land management as an intra-communal activity and a responsibility for the agricultural community. Soil conservation district Board of Supervisors were elected by farmers most interested in and intrigued by a soil conservation district. The first chairman and secretary of the Highland County Soil Conservation District, Herbert Williams and E.E. West, respectively, were both active participants in the district's hearing with the OSCC, when petitioners were seeking permission from the OSCC to put a proposed district in the county to a referendum. Forming a district work program and agenda was

[27] Heft, F.E., 1956, "On the Land," 14-21, 27-31.
[28] Hearing on Petition of Clark County, 1942. Heft, F.E., 1956, "On the Land," 14-21, 27-31.

the first task for a soil conservation district's Board of Supervisors. Williams and the rest of the Highland County Soil Conservation District proposed five aspects to the district first work plan. Improving land and using the land to its productive potential were common threads through the work plan. These land management tenets were not unique to the Highland County Soil Conservation District. The Darke Soil Conservation District's Board of Supervisors aimed to "improve and maintain the farming conditions within the District" through their work plan. Soil conservation district work plans indicated to potential cooperators that those leading the district sought to address issues most pressing to local farmers and that district leaders felt they had a responsibility to their neighbors to help improve their land.[29]

[29] Highland County Soil Conservation District (July 13, 1942). Minutes of the District Supervisors' Meeting. Highland County Soil Conservation District Archives. Hillsboro, OH. Hearing on Petition of Highland County, 1942. Darke Soil Conservation District, "Proposed Work Program and Plan of The Darke Soil Conservation District of Ohio." Darke County Soil and Water District Archives, Greenville, OH. Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 15-17.

Figure 11: Clark Soil Conservation District's First Board of Supervisors were placed in charge of setting the agenda and work plan for the district.[30]

Soil conservation district Board of Supervisors did not act alone in their work to help their neighbors in improving their farmland. The Soil Conservation Service joined soil conservation districts in their efforts to achieve their work plan. And it was through the formal cooperation between the Soil Conservation Service and soil conservation districts that critical agricultural conservation technology was introduced more widely to Ohio farmers. Soil conservation districts signed Memorandum of Understandings with the Soil Conservation Service and the United States Secretary of Agriculture after electing a Board of Supervisors and creating a work plan. The staffing of a Soil Conservation Service technician to each soil conservation district served as a main provision afforded to each soil conservation district through the agreement. In exchange, soil conservation districts agreed that the technician would only be available to aid farmers cooperating with the district. The formal agreement also established the roles in

[30] Heft, F.E., 1966. "Ohio Soil & Water Conservation Districts in Action," 24.

which a Soil Conservation Service technician would serve a soil conservation district. Roles the technician filled included making needed soil and land surveys, helping cooperators prepare and implement conservation plans for their farms, and aiding cooperators in tasks for which the cooperator did not have the necessary skills of knowledge.[31]

Providing knowledge about the farm to farmers cooperating with their soil conservation district was an important outcome of the relationship between the Soil Conservation Service and Ohio's soil conservation districts and served as the basis for formal farm planning. Soil and land use surveys conducted by Soil Conservation Service technicians provided Ohio farmers standardized information about their farming operations. Ohio farmers received maps from their soil conservation district after a soil survey was conducted that showed the spatial locations and described the conservation characteristics of their soils. Zones within each farm field were classified into one of eight classes according to their soil's susceptibility to erosion and ability to drain to "determine the extent to which each acre may be used to its maximum limit." Soil conservation technicians used information derived from soil surveys to formulate farm plans for farmer-cooperators of a soil conservation district. For example, Clinton Soil Conservation District cooperator, Roy J. Stuckey, installed three tile drainage outlet structures, two new bridges, and a new creek channel, based on the recommendations the

[31] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 44-53. Fulton County Soil Conservation District and United States Department of Agriculture. Memorandum of Understanding between the Fulton County Soil Conservation District State of Ohio and the United States Department of Agriculture." March 11, 1949. Fulton County Soil Conservation District Archives, Wauseon, OH.

Soil Conservation Service technician derived from the land use map created for Stuckey's farm.[32]

Figure 12: Soil surveys conduction by Soil Conservation Service technicians provided important information that was used to guide farm plans for each cooperator with their soil conservation district.[33]

Services provided by Soil Conservation Service technicians to Ohio soil conservation district cooperators demonstrated the practical impacts of engaging in agricultural conservation practices. Soil Conservation Service technicians customized farm plans for farmers based off the unique needs of the land they tilled. Seneca County Soil Conservation District cooperator, Robert Ladd, constructed a farm pond that was designed by the Soil Conservation Service and proved of upmost importance a year after construction when Ladd's farm was faced with drought conditions. Ladd used water

[32] Heft, F.E., 1956, "On the Land," 10-11, 20.
[33] Heft, F.E., 1956, "On the Land," back-cover.

stored in the constructed pond as a water supply for 60 cattle on his farm that would have otherwise perished due to a lack of water. Defiance County Soil Conservation District cooperator, Paul Clinker, introduced tile drainage to sixteen acres of his farm through the advice of the district and Soil Conservation Service technician and saw more than satisfactory results even in the face of older farmers dismissing the effectiveness of tile drainage on his land.[34]

Stewards of the Land: District Efforts to Engage Farmers in Agricultural Conservation

> Thou shalt inherit the Holy Earth as a faithful steward, conserving its resources and productivity from generation to generation. Thou shalt safeguard thy fields from soil erosion, thy living waters from drying up, thy forests from desolation, and protect thy hills from over-grazing by thy herds, that thy descendants may have abundance forever. If any shall fail in this stewardship of the land thy fruitful fields shall become sterile stony ground and wasting gullies, and thy descendants shall decrease and live in poverty or perish from off the face of the earth. - Walter C. Lowdermilk, soil conservationist, 1939[35]

Ohio soil conservation districts did not act alone, nor with just the Soil Conservation Service, in encouraging farmers to engage in agricultural conservation efforts. Strong formal and informal cooperation between the soil conservation districts, Ohio's Cooperative Extension Service, agricultural organizations such as the Ohio Farm Bureau, and private companies emerged as an important factor in bringing farmers into the fold. Ohio farmers were not legally required to participate in programs organized by or engage

[34] Heft, F.E., 1956, "On the Land," 13, 15.
[35] Walter Lowdermilk coined the "11th Commandment" when he spoke by radio in Jerusalem. "Walter C. Lowdermilk, Conservationist, Is Dead." New York Times. May 9, 1974. Heft, F.E., 1956, "On the Land," 9.

in the service provided by the soil conservation districts. Because farmer participation was voluntary the districts employed numerous strategies to entice farmers to become cooperators. Field days and farm demonstrations hosted in conjunction with the Cooperative Extension Service showcased the positive impacts farmers could receive by utilizing agricultural conservation practices in their operations. State agricultural organizations elevated the profile of farmers and their operation who engaged in agricultural conservation efforts. Local and national competitions pitted farmers, and soil conservation districts, against one another in their agricultural conservation skills and commitment.[36]

The principles of land stewardship underlaid the foundations for the efforts soil conservation districts undertook to increase farmer participation. Land stewardship meant engaging in land management practices that would lead to providing a productive farm for future generations to Ohio farmers and soil conservation district Board of Supervisors. Seneca Soil Conservation District cooperator, Robert Ladd, proudly acknowledged that the farm pond installed with the help of his local soil conservation district would allow the farm to be passed down to his children at a more productive level than when he received the land. Farmers strove to engage in land stewardship not only for economic and familial reasons but also for religious purposes. Religious identity, primarily Christian identity, was an important driver of land stewardship among Ohio farmers and the broader agricultural community. Farmers, farm organizations, and state

[36] Heft, F.E., 1956, "On the Land," 38-43. Heft, F.E., 1966. "Ohio Soil & Water Conservation Districts in Action," 5-6, 11, 13, 16, 19, 21.

government entities used religious connotations and allegories to promote land stewardship across the state. The Ohio Soil Conservation Committee included the 11th Commandment, proposed by Dr. Walter C. Loudermilk, in their Handbook for District Supervisors that was sent to each of the state's soil conservation districts. Soil conservation districts worked to help farmers achieve their land stewardship ideals through land use planning derived from scientific approaches of land management. Science in this case was also put in the service of religion.[37]

Figure 13: Land stewardship was important for Ohio farmers both spiritually and economically. Efforts undertaken by the Clark County Soil Conservation District in educating local clergymen on the importance of soil stewardship aided in transforming Ohio farmers' relationship to their land.[38]

Working in conjunction with the Cooperative Extension Service allowed for soil conservation districts to showcase the impact of their work to large audiences. Leading and cooperating in field days, fly-over and on-fields tours, farm demonstrations and curriculum development allowed soil conservation districts to proselytize proper land management and agricultural conservation across the state. Cooperating farmers, and

[37] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 7-11. Heft, F.E., 1956, "On the Land," 5-6, 9, 13, 24.
[38] Heft, F.E., 1966, "Ohio Soil & Water Conservation Districts in Action," 16.

even those who were not, were both touched by soil conservation district efforts in increasing educational awareness of the impacts one could have by working with a district. The Second Frontier Demonstration, hosted by the Licking County Soil Conservation District was one of the most successful education events hosted by the Ohio soil conservation districts in terms of the number of attendees. On October 2, 1947, over 75,000 visitors journeyed to the farms of George Lantham and John Rodman, just outside Brownsville, Ohio, where they witnessed two farms completely transformed to fully embrace agricultural conservation. The Licking Soil Conservation District worked with Lantham and Rodman to install tile drainage, terracing and strip cropping methods, a water storage reservoir, a dozen acres of trees, and a new property fence to follow the natural contours of the land.[39]

[39] "Celebrating Soil & Water's 75th Anniversary." *Conservation Notes*, Volume 77, Issue 1. 2019. 1,3. https://lickingswcd.com/file_download/inline/e105041b-5b97-47e1-b65a-809403789924. Heft, F.E., 1956, "On the Land." Heft, F.E., 1966, "Ohio Soil & Water Conservation Districts in Action," 11. "Tuscarawas Farmers Study Saving Soil." Ohio Farmer. August 21, 1943. "Columbiana SCS Tours." Ohio Farmer. October 7, 1944.

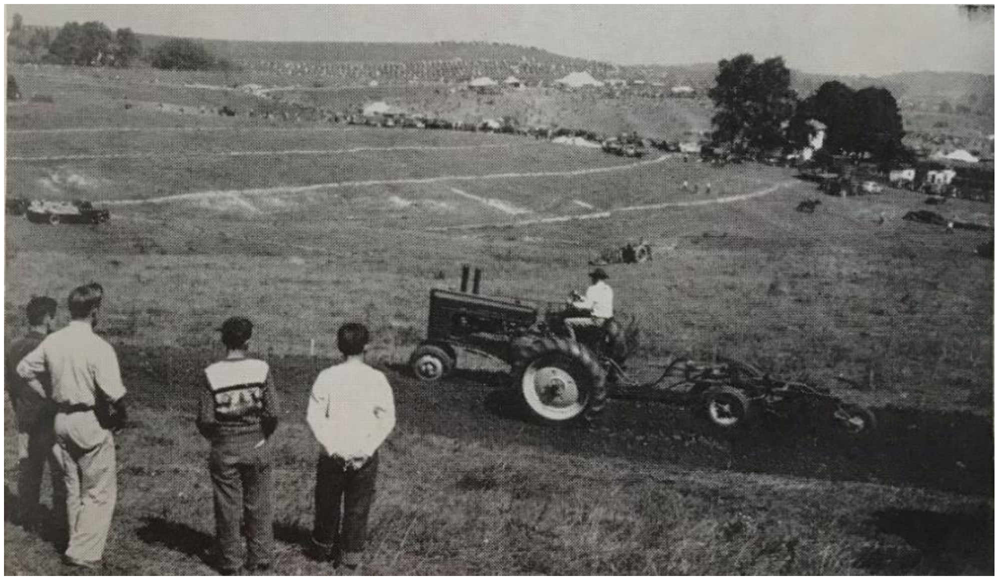

Figure 14: Field days and farm demonstrations hosted by Ohio soil conservation districts with the cooperation of the Cooperative Extension Service fulfilled the educational duties of the soil conservation districts and worked to portray the benefits of engaging in agricultural conservation efforts.[40]

Soil conservation districts worked to ease the financial burden of engaging in agricultural conservation in addition to working to raise the educational awareness of its benefits. Formal agreements with the Soil Conservation Service provided soil conservation districts access to specialized machinery that could be used in conservation efforts. And cooperators with their soil conservation district received access to these machines at discounted rates. In 1943 the Highland County Soil Conservation District made a Corsicana terracer for $1.00 per day, a lime spreader for $0.10 per ton, slip spreader of $0.25 per day, rotary scraper for $0.75 per day, and a No. 1 Caterpillar terracer for $2.00 per day available to their farmer-cooperators.[41]

[40] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 31.
[41] Highland County Soil Conservation District (February 10, 1943). Minutes of the District Supervisors' Meeting. Highland County Soil Conservation District Archives. Hillsboro, OH

Ohio soil conservation districts in cooperation with each other as well as agricultural organizations and private businesses sought to provide prestige to farmers who cooperated with their soil conservation district. Ohio agricultural newspapers and magazines raised the profiles and wrote in high esteem of farmers who cooperated with their soil conservation district. Articles about farmer-cooperators focused on the impact that the implementation of agricultural conservation practices had on crop yields and health of the land. Highlighting success stories of farmers cooperating with their soil conservation district implicitly encouraged other farmers to engage with their district and, importantly, move farmer thinking towards accepting land management approaches preached by soil conservation districts. Contests and competitions hosted by soil conservation districts and in cooperation with private businesses and agricultural organizations worked to further elevate the status of farmers engaging in agricultural conservation. Cash and award prizes became talking points not only for farmers across the state but also for the soil conservation districts themselves. Contests in which farmers and Ohio soil conservation districts competed were not constrained only to within Ohio's borders. In 1947 the Goodyear Tires and Rubber Company established the Goodyear Awards. The Goodyear Awards were targeted specifically towards the soil conservation districts and were created to improve the "awareness on the part of the soil conservation district supervisors of their obligations and opportunities," The national competition saw members the Board of Supervisors of winning soil conservation districts as well as one district farmer-cooperator awarded a trip to Arizona to visit the Goodyear research farm and learn about the agricultural efforts being undertaken.[42]

Increasing Agricultural Conservation Practice Adoption and the Changing of Ohio's Agricultural Landscape

> Terracing and contour farming, as part of my conservation farm plan, helped me put my farm on a productive basis as a tenant farmer in Salem township, Shelby County. My Soil Conservation District with its technical assistance has assisted me in raising my corn yields from 20 bushels per acres to an average of 70 bushels. - Paul Staley, farmer-cooperator with the Shelby County Soil Conservation District, 1956[43]

Soil conservation district efforts in engaging with farmers and agricultural landowners resulted in changing both agricultures' physical and psychological landscape across the state. The marriage between government experts in agricultural conservation and farmers created through the soil conservation districts allowed a systematic approach to land management and farm planning to flourish and provided benefits to both parties. Farmers received needed technical aid to increase crop productivity and government experts received access to land to demonstrate the importance of "proper" land management. The mutualism between farmers and government experts furthered the industrialization of agriculture in the state. Crop yields increased while land allotted for crop production decreased. Agricultural management was homogenized across the

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[42] "Ohio Conservation Field Days: August 23 and 24." Ohio Farm Bureau News. August, 1949. "Portage Farmer Wins Wood County Tractor Contest." Bradner Advocate. August 2, 1951. "30 Tractors, Attachments To be Used in Field Day." The Union County Journal. August 23, 1948. Heft, F.E., 1956. "On the Land," 40-41. Heft, F.E., 1966. "Ohio Soil & Water Conservation Districts in Action," 9-10, 12-13. "District Wins Goodyear Award; Two Enjoy Trip." Heppner Gazette Times. January 30, 1964. Farmer Award Winners Return From Trip." Courier Northerner. December 24, 1948.

[43] Heft, F.E., 1956, "On the Land," 27.

landscape based off the desires and knowledge of Soil Conservation Service technicians working with local soil conservation districts. And a production-maximizing view of agriculture further permeated across Ohio farmers.[44]

Ohio's physical agricultural landscape underwent dramatic changes in the mid-twentieth century with the help of the local soil conservation districts. Farmland that was too wet to farm was drained both on the surface and underground, new water storage structures dotted the farmscape, contouring and terracing planting methods reduced soil losses, and a cropping structure based off scientific principles led to systematic planning and implementation of farming practices. By the end of 1955, 2,653,789,900 feet of drainage tile, 34,808 acres of surface drainage, 8,649 farm ponds, 188,661 acres of contour farming, and 1,910 miles of terraces were installed on the land of farmer cooperators with the Ohio soil conservation districts. By the end of 1966, 70,000 Ohio landowners had cooperated with their local soil conservation district in implementing agricultural conservation. 20,000 acres of grass waterways were installed and 1,000,000 acres of pasture were improved on farms across the state. Harry C. Moore, a cooperator with the Clark County Soil Conservation District, witnessed great changes to his farm due his interaction with his district. Moore saw the transformation of a 30-acre swampy portion of his farm into productive land due to "an open ditch, constructed according to the plans and under the supervision of the technicians of my district."[45]

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[44] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 30. Heft, F.E., 1956, "On the Land," 13-38

[45] Heft, F.E., 1956, "On the Land," 6, 15-20, 27-30. Heft, F.E., 1966. "Ohio Soil & Water Conservation Districts in Action," 4-5.

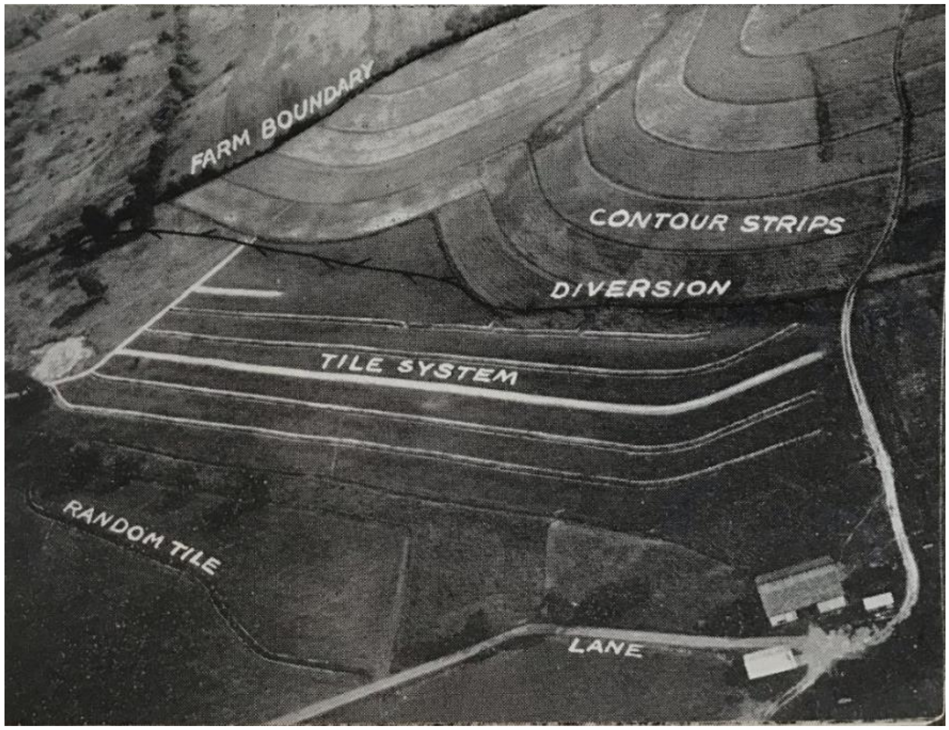

Figure 15: Technical aid provided by the Soil Conservation Service, in cooperation with Ohio soil conservation district, helped with farm planning. Here is an image of a farm cooperating with their soil conservation district. A systematic drainage tile system and contour strips were installed with the aid of the district.[46]

A key consequence of the alterations to the physical landscape- themselves an important effect of farmers cooperating with their soil conservation district- was an increase in agricultural productivity. Between 1939 and 1963, corn and wheat yields increased 30% and 58%, respectively, while land allotted to corn and wheat production decreased 5% and 25%, respectively, across the state. Increased crop yields across the period cannot solely be attributed to the efforts of the soil conservation districts and their working with farmers to increase agricultural conservation practice adoption. Technological innovations stemming out of World War II and needs during the War effort were critical factors in creating markets and demand for increased agricultural

[46] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 9.

products. However, soil conservation districts played the important role of aiding farmers apply these new technologies, such as new inorganic fertilizers, to their fields. Increased production with decreasing land allotment for crop production was characteristic of the production-maximizing vision of agriculture.[47]

The production-maximizing view of agriculture promoted by Soil Conservation Service technicians and by extension Ohio's soil conservation districts affected more than just crop yields and the amount of land dedicated to crop production. Cooperators with Ohio soil conservation districts were required to follow the farm plan developed by Soil Conservation Service technicians and approved by the district's Board of Supervisors. Soil Conservation Service technicians and district board members were thus responsible for defining which agricultural management practices were valid "conservation" practices and which were not. Implementing the production-maximizing view of agriculture influenced the agricultural conservation practices Soil Conservation Service technicians included in farm plans. Fields that were too wet were guided to install systematic tile

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[47] 1940 Census of Agriculture, 1943. Volumes 1 and 2. First, Second, and Third Series State Reports. Part 10, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. 1945 Census of Agriculture, 1947. Volume 1. State Reports and County Statistics with U.S. Summary. Part 10, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. 1950 Census of Agriculture, 1952. Volume 1. Counties and State Economic Areas. Part 3, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. 1954 Census of Agriculture, 1956. Volume 1. Counties and State Economic Area. Part 10, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. 1959 Census of Agriculture, 1961. Volume 1. Geographic Area Series. Part 10, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. 1964 Census of Agriculture, 1967. Volume 1. Geographic Area Series. Part 10, Ohio. [Washington D.C.]: United States Department of Agriculture, National Agricultural Statistics Survey. Accessed Online from Mann Library at Cornell University. Kinkela, D., 2011. *DDT and the American Century: Global Health, Environmental Politics, and the Pesticide that Changed the World.* The University of North Carolina Press.

drainage or surface diversion systems. Fields that were susceptible to great soil losses were guided to install contours, plant soybeans, and include more pasture. The promotion of certain agricultural management practices by Soil Conservation Service technicians based on the specific needs of the land and the use of these practices by Ohio soil conservation district cooperators led to a homogenization of land management practices on farms across Ohio.[48]

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[48] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 14. Highland County Minutes of the District Supervisors' Meeting, July 1942

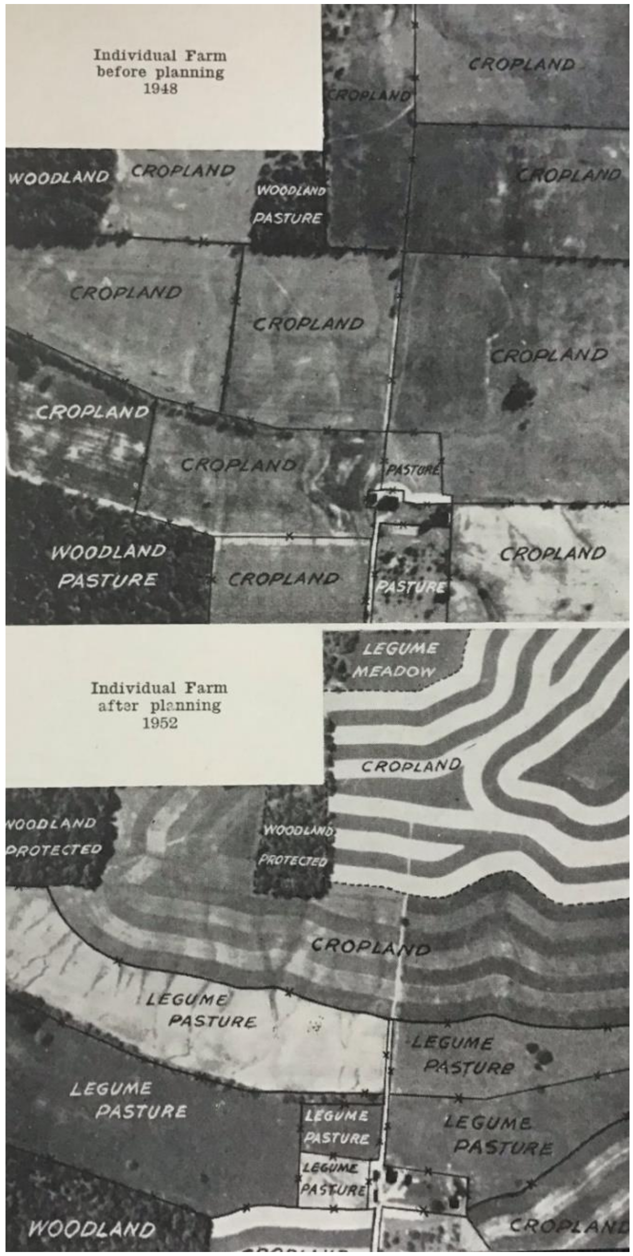

Figure 16: Farmers who cooperated with their soil conservation district received farm plans designed by agricultural experts from the Soil Conservation Service to maximize the farm's production.[49]

Ohio farmers working with their soil conservation district on implementing agricultural conservation practice developed a new vision of what "good" farming looked

[49] Heft, F.E., 1953. "Handbook for Supervisors of Soil Conservation Districts," 8.

like. “Good” farming became focused on utilizing land to the best of its productive potential to meet both individual and community needs rather than on toiling to provide adequate yields for personal family use. Desires among Ohio farmers, the federal government, and soil conservation districts to use and promote scientific approaches to agricultural management were paramount to developing and spreading this new vision. Farmers and the federal government wanted greater crop productivity. Greater crop productivity meant larger profits for farmers and a larger supply of food and crops for the federal government. Ohio farmers were “awakened to the depletion and erosion of soil and benefits of good land use on their farms” through their cooperation with their soil conservation district.[50]

Conclusion

> By the turn of the century our nation will have a population of 350 million- the population of India in 1951- a year of critical food shortage in that country. With increased markets in underdeveloped nations and rising world population there will be an even greater demand for food and fiber. - John F. Kennedy, 35th President of the United States of America, 1960[51]

The relationship forged by Ohio farmers and federal government experts in agricultural conservation through Ohio’s soil conservation districts was critical in expanding the use of agricultural conservation practices across the state and cultivating a more industrialized farm and farmer. Industrial notions first made their way into the ideas

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[50] Heft, F.E., 1956, “On the Land,” 44-47. Danbom, D., 1995. *Born in the Country: A History of Rural America*. The Johns Hopkins University Press.

[51] Papers of John F. Kennedy. Pre-Presidential Papers. Senate Files, Box 910, “Iowa, 26 June 1960.” John F. Kennedy Presidential Library. Accessed online at https://www.jfklibrary.org/archives/other-resources/john-f-kennedy-speeches/iowa-19600626.

and practice of American agriculture in the early-twentieth century. Historian of Technology, Deborah Fitzgerald, demonstrates the influence of these industrial notions in Montana farming operations in *Every Farm a Factory: The Industrial Ideal in American Agriculture*. Fitzgerald shows that farmers were encouraged to operate larger farms and use new technologies such as tractors to increase their wheat production to maintain or increase profits. Although soil conservation districts in Ohio and throughout the United States did not serve as the genesis of industrialized farming, they served as important mechanisms to further agriculture's industrialization. Agricultural conservation practices promoted by government experts and adopted by cooperators of soil conservation districts led to greater efficiency in crop production and a change in farmer mindset where it was desired to use every acre of agricultural land and water resources "within its capability…deriving the maximum benefits indefinitely." Ohio farmers were not simply observers in the changing agricultural landscape in the state. Ohio farmers were change agents. Ohio farmers demonstrated their interest and desire to engage in farm management practices based on the scientific principles of planning and technology to increase crop yields through their interactions with the Ohio Soil Conservation Committee and their local soil conservation district.[52]

[52] I am using industrial notions similarly to "industrial ideal" as discussed by Deborah Fitzgerald in *Every Farm A Factory: The Industrial Ideal in American Agriculture.* Fitzgerald, D., 2003. *Every Farm a Factory: The Industrial Ideal in American Agriculture*. Yale University Press. Ohio farmers were not unique in their desire and leadership in advancing industrialized agriculture in the United States. J.L. Anderson shows that Iowa farmers were similarly leaders in calling for an advancing industrialized methods of agriculture planning post World-War II. Anderson, J.L., 2009. *Industrializing the Corn Belt: Agriculture, Technology, and Environment, 1945-1972.* Northern Illinois University Press.

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Appendix A. Supplemental Information for Chapter 1

State	County	Number of Modeled Farm Operations < 180 Acres	Number of Modeled Farm Operations Between 180-499 Acres	Number of Modeled Farm Operations Between 500-999 Acres	Number of Modeled Farm Operations > 1000 Acres
IN	Adams	657	59	61	31
IN	Allen	934	57	80	36
OH	Allen	699	94	62	31
OH	Auglaize	570	114	45	23
MI	Branch	10	0	0	0
OH	Defiance	868	101	68	29
IN	DeKalb	858	90	34	27
OH	Fulton	708	121	74	24
OH	Hancock	847	151	57	32
OH	Hardin	320	56	27	16
OH	Henry	898	169	95	27
MI	Hillsdale	805	98	34	16
MI	Lenawee	273	37	18	10
OH	Lucas	157	26	10	6
OH	Mercer	372	87	39	17
IN	Noble	118	15	3	6
OH	Paulding	894	161	64	44
OH	Putnam	992	184	96	49
OH	Seneca	18	3	2	1
OH	Shelby	40	15	5	2
IN	Steuben	223	28	6	7
OH	Van Wert	852	164	69	51
IN	Wells	49	8	1	5
IN	Whitley	2	0	0	0
OH	Williams	1,016	123	66	36
OH	Wood	401	75	30	17
OH	Wyandot	65	15	8	4

Table 5: Size and county-level proportions of modeled farm operations embedded in the SWAT model.

A good farmer is one who…	Not important at all	Slightly Important	Somewhat Important	Important	Very Important
…considers the health of waterways that run through or along their land to be their responsibility	0	1	2	3	4
…minimizes soil erosion	0	1	2	3	4
…minimizes nutrient runoff into waterways	0	1	2	3	4
…thinks beyond their own farm to the social and ecological health of the watershed	0	1	2	3	4
…maintains or increases soil organic matter	0	1	2	3	4
…manages for both profitability and minimization of environmental impact	0	1	2	3	4
…puts long-term conservation of farm resources before short-term profits	0	1	2	3	4

Table 6: Survey questions used in calculating the conservation identity for each respondent. Reproduced from McGuire et al. (2015), and Arnold et al. (2017).

State	County	% Low Conservation Identity-Survey	% Medium Conservation Identity-Survey	% High Conservation Identity-Survey	Number of Modeled Primary operators with Low Conservation Identity	Number of Modeled Primary operators with Medium Conservation Identity	Number of Modeled Primary operators with High Conservation Identity
IN	Adams	0	31	69	0	250	558
IN	Allen	1	21	78	12	234	861
OH	Allen	1	21	78	9	186	691
OH	Auglaize	4	16	80	30	120	602
MI	Branch	0	9	91	0	1	9
OH	Defiance	0	24	76	0	256	810
IN	DeKalb	0	17	83	0	177	832
OH	Fulton	0	27	73	0	250	677
OH	Hancock	1	25	74	13	269	805
OH	Hardin	1	19	80	6	79	334
OH	Henry	3	23	74	34	272	883
MI	Hillsdale	0	6	94	0	57	896
MI	Lenawee	0	8	92	0	27	311
OH	Lucas	0	13	87	0	25	174
OH	Mercer	1	20	79	5	103	407
IN	Noble	0	24	76	0	34	108
OH	Paulding	0	16	84	0	186	977
OH	Putnam	2	20	78	27	264	1,030
OH	Seneca	1	24	75	0	6	18
OH	Shelby	0	9	91	0	6	56
IN	Steuben	0	26	74	0	69	195
OH	Van Wert	3	29	68	37	330	769
IN	Wells	0	23	77	0	14	49
IN	Whitley	0	14	86	0	0	2
OH	Williams	3	23	75	31	279	931
OH	Wood	1	25	74	5	131	386
OH	Wyandot	2	17	81	2	16	74

Table 7: Distributions of conservation identities assigned to modeled primary operators based on conservation identity category. Low, medium, an high categorizations of conservation identities were derived from Burnett et al. (2018).

Scenario	Subsurface Placement	Buffer Strips
Baseline	1,778	6,318
10% Adoption: High Conservation Identity	3,608	7,566
20% Adoption: High Conservation Identity	5,411	8,835
30% Adoption: High Conservation Identity	7,238	10,080
40% Adoption: High Conservation Identity	9,048	11,337
50% Adoption: High Conservation Identity	10,871	12,581
60% Adoption: High Conservation Identity	12,761	13,812
70% Adoption: High Conservation Identity	14,482	15,053
80% Adoption: High Conservation Identity	16,321	16,338
90% Adoption: High Conservation Identity	18,348	18,533
100% Adoption: High Conservation Identity	20,357	20,357
10% Adoption: High P Loss	3,767	8,093
20% Adoption: High P Loss	5,712	9,741
30% Adoption: High P Loss	7,640	11,256
40% Adoption: High P Loss	9,533	12,737
50% Adoption: High P Loss	11,428	14,155
60% Adoption: High P Loss	13,293	15,471
70% Adoption: High P Loss	15,136	16,657
80% Adoption: High P Loss	16,894	17,740
90% Adoption: High P Loss	18,626	18,869
100% Adoption: High P Loss	20,357	20,357
10% Adoption: High P Loss and High Conservation Identity	3,715	7,919
20% Adoption: High P Loss and High Conservation Identity	5,609	9,354
30% Adoption: High P Loss and High Conservation Identity	7,507	10,710
40% Adoption: High P Loss and High Conservation Identity	9,381	12,045
50% Adoption: High P Loss and High Conservation Identity	11,255	13,409
60% Adoption: High P Loss and High Conservation Identity	13,058	14,704
70% Adoption: High P Loss and High Conservation Identity	14,871	15,958
80% Adoption: High P Loss and High Conservation Identity	16,676	17,270
90% Adoption: High P Loss and High Conservation Identity	18,482	18,654
100% Adoption: High P Loss and High Conservation Identity	20,357	20,357
10% Adoption: Low P Loss	3,536	7,823
20% Adoption: Low P Loss	5,266	8,949
30% Adoption: Low P Loss	7,026	10,037
40% Adoption: Low P Loss	8,869	11,224
50% Adoption: Low P Loss	10,733	12,538
60% Adoption: Low P Loss	12,630	13,966
70% Adoption: Low P Loss	14,525	15,440
80% Adoption: Low P Loss	16,452	16,958
90% Adoption: Low P Loss	18,398	18,609
100% Adoption: Low P Loss	20,357	20,357

Table 8: Number of HRUs selected to receive the corresponding CP for each simulation in the SWAT model.

State	County	Mean Conservation Identity of Modeled Primary Operators	Minimum Conservation Identity of Modeled Primary Operators	Maximum Conservation Identity of Modeled Primary Operators
IN	Adams	3.01	1.67	4.00
IN	Allen	2.98	0.01	3.99
OH	Allen	3.06	0.02	3.99
OH	Auglaize	3.02	0.04	3.99
MI	Branch	3.19	1.66	3.90
OH	Defiance	3.02	1.33	4.00
IN	DeKalb	3.05	1.25	3.99
OH	Fulton	2.95	1.34	3.99
OH	Hancock	3.04	0.47	4.00
OH	Hardin	3.04	0.31	3.99
OH	Henry	2.94	0.12	3.99
MI	Hillsdale	3.19	1.19	3.99
MI	Lenawee	3.25	1.47	3.99
OH	Lucas	3.31	1.60	3.99
OH	Mercer	3.03	0.14	3.99
IN	Noble	3.09	1.44	3.99
OH	Paulding	3.08	1.34	4.00
OH	Putnam	2.99	0.00	4.00
OH	Seneca	3.03	1.46	3.82
OH	Shelby	3.19	1.41	3.99
IN	Steuben	3.12	1.40	3.99
OH	Van Wert	2.97	0.35	3.99
IN	Wells	2.99	1.41	3.92
IN	Whitley	3.20	2.98	3.43
OH	Williams	3.00	0.02	3.99
OH	Wood	2.98	0.44	4.00
OH	Wyandot	3.00	0.98	3.95

Table 9: Distribution of conservation identities assigned to modeled primary operators.

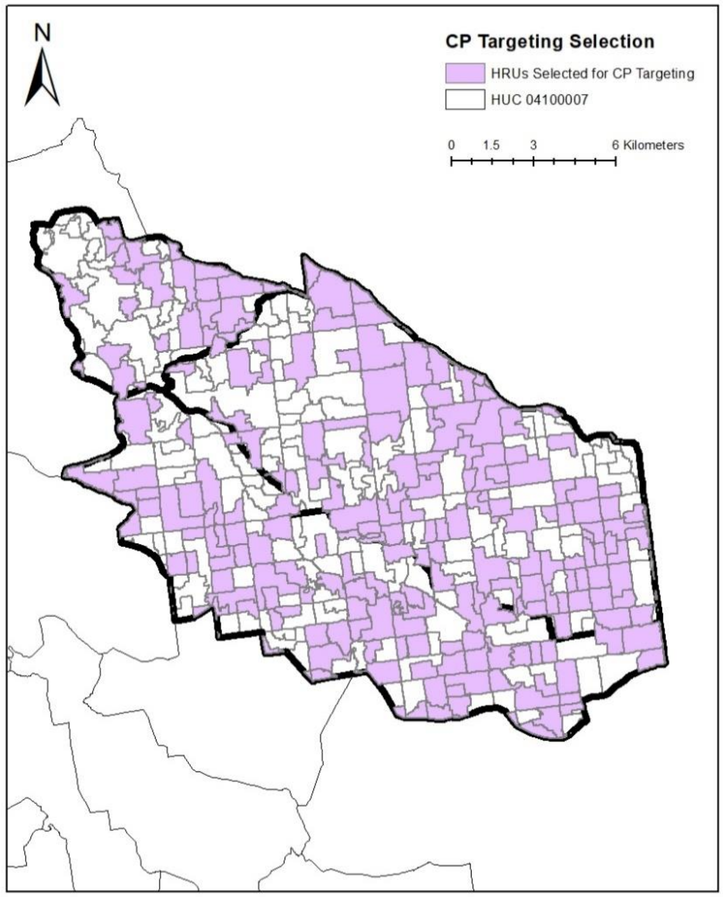

Figure 17: CP Targeting by the Greatest Phosphorus Loading Rate HRUs. Outlined in bold are three HUC 12s (041000071101, 04100007112, and 041000071103) in the Auglaize watershed (04100007). SWAT model HRUs highlighted are the HRUs that were selected to receive the CP.

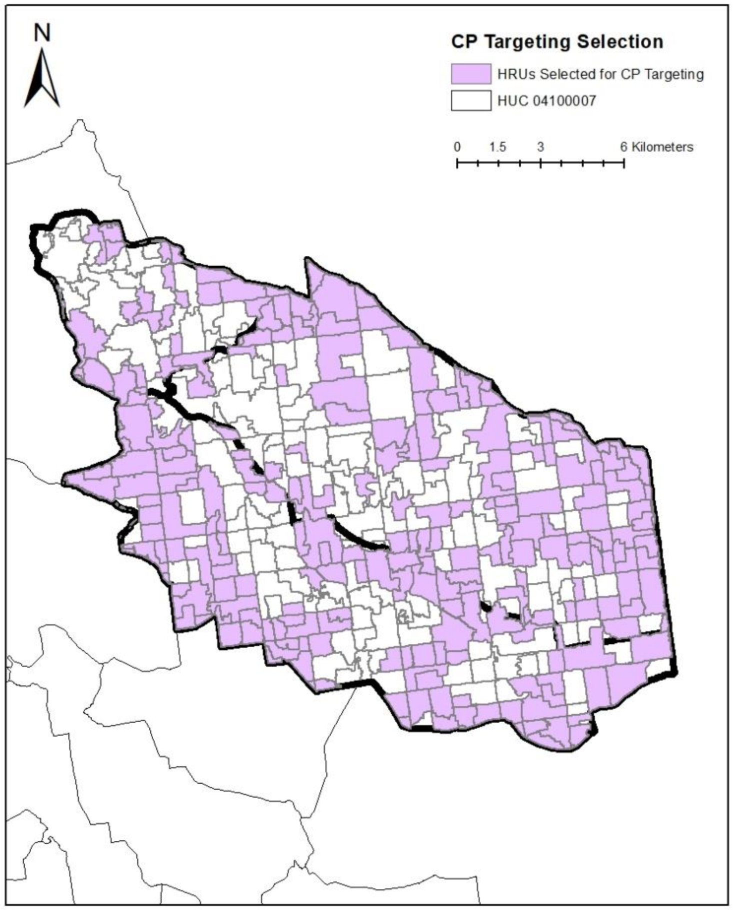

Figure 18: CP Targeting by the Least Phosphorus Loading Rate HRUs. Outlined in bold are three HUC 12s (041000071101, 04100007112, and 041000071103) in the Auglaize watershed (04100007). SWAT model HRUs highlighted are the HRUs that were selected to receive the CP.

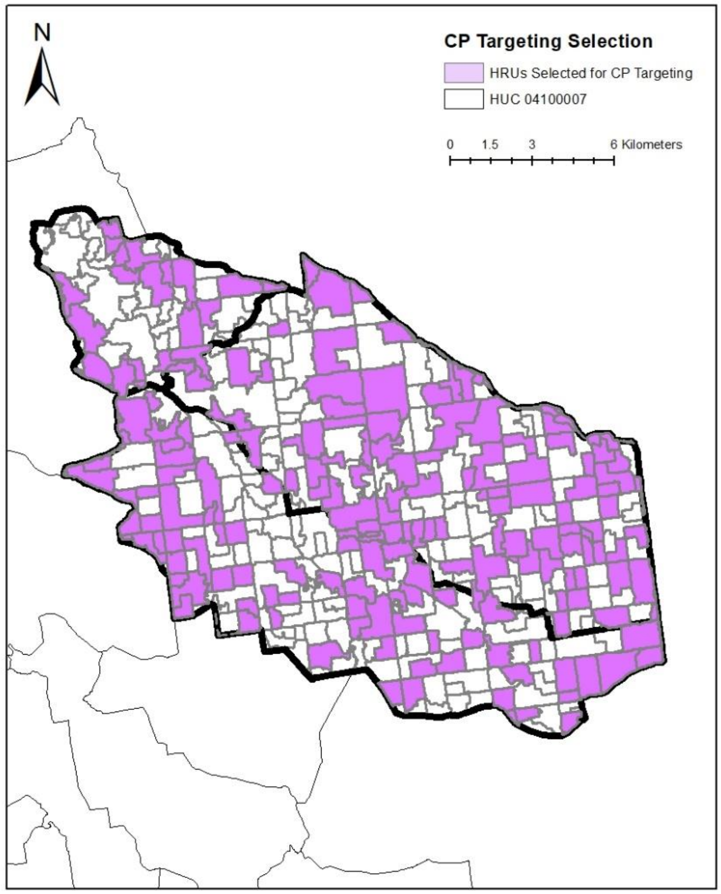

Figure 19: CP Targeting by the Greatest Modeled Primary Operator Conservation Identity HRUs. Outlined in bold are three HUC 12s (041000071101, 04100007112, and 041000071103) in the Auglaize watershed (04100007). SWAT model HRUs highlighted are the HRUs that were selected to receive the CP.

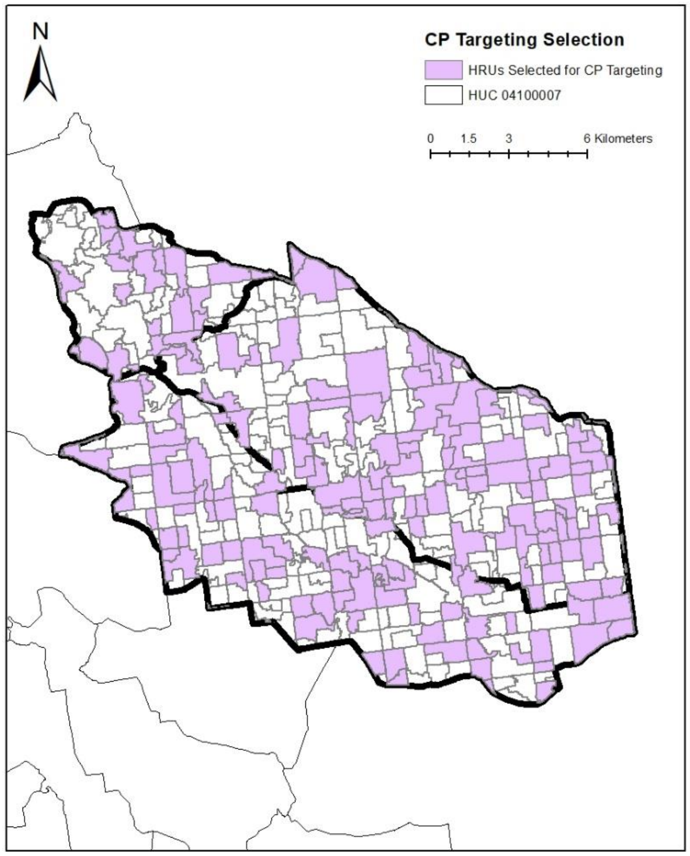

Figure 20: CP Targeting by the Greatest Phosphorus Loading Rate HRUs Managed by Modeled Primary Operators with the Greatest Conservation Identity. Outlined in bold are three HUC 12s (041000071101, 04100007112, and 041000071103) in the Auglaize watershed (04100007). SWAT model HRUs highlighted are the HRUs that were selected to receive the CP.

Appendix B. Supplemental Information for Chapter 2

Farmer Variables	Unstandardized Coefficient B (SE)	95% Confidence Interval Lower	Odds Ratio	Upper
Unwilling farmers vs. willing farmers				
Intercept	0.27 (0.37)			
Adjusted Gross Income	0.00 (0.14)	0.76	1.00	1.31
Education	0.08 (0.61)	0.33	1.09	3.59
Total Farm Acres	-0.51 (0.33)	0.31	0.60	1.16
Age	0.05 (0.06)	0.92	1.05	1.19
Experience	0.07 (0.07)	0.93	1.07	1.22
Education x Total Farm Acres	0.23 (0.20)	0.84	1.26	1.87
Education x Age	-0.09 (0.10)	0.75	0.91	1.11
Total Farm Acres x Experience	0.08 (0.09)	0.90	1.08	1.29
Unwilling farmers vs. adopted farmers				
Intercept	0.85 (0.44)			
Adjusted Gross Income	0.39 (0.15)**	1.11	1.47	1.96
Education	-1.32 (0.66)*	0.07	0.27	0.96
Total Farm Acres	-0.87 (0.33)**	0.22	0.42	0.80
Age	-0.19 (0.09)*	0.70	0.83	0.99
Experience	0.14 (0.08)	0.98	1.15	1.35
Education x Total Farm Acres	0.45 (0.19)*	1.09	1.57	2.26
Education x Age	0.17 (0.11)	0.96	1.19	1.48
Total Farm Acres x Experience	0.22 (0.09)*	1.05	1.25	1.49

Note: Pseudo R2 = 0.040 (Cox and Snell), 0.045 (Nagelkerke), model X2 (16) = 75.41
* p <0.05 ** p <0.01 *** p <0.001

Table 10: Multinomial logistic regression including operational and demographic factors (n = 1,851)

Farmer Variables	Unstandardized Coefficient B (SE)	95% Confidence Interval Lower	Odds Ratio	Upper
Unwilling farmers vs. willing farmers				
Intercept	0.69 (0.10)***			
Adjusted Gross Income	0.01 (0.14)	0.77	1.01	1.32
Total Farm Acres	-0.24 (0.10)*	0.65	0.79	0.96
Unwilling farmers vs. adopted farmers				
Intercept	0.15 (0.11)			
Adjusted Gross Income	0.48 (0.14)***	1.23	1.62	2.14
Total Farm Acres	0.00 (0.00)	0.84	0.99	1.17

Note: Pseudo R2 = 0.020 (Cox and Snell), 0.023 (Nagelkerke), model X2 (4) = 38.54
* p <0.05 ** p <0.01 *** p <0.001

Table 11: Multinomial logistic regression including operational factors (n = 1,871)

Responsibility Scores	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
-2 to -1.01	4%	0%	0%
-1 to -0.01	26%	3%	1%
0	26%	12%	1%
0.01 to 1	39%	75%	63%
1.01 to 2	4%	11%	35%

Table 12: Cross-tabs of farmer survey comparing perceived responsibility to conservation identity

Perceived Control Scores	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
< 1	9%	0%	1%
1 to 1.99	30%	10%	3%
2 to 2.99	22%	29%	18%
3 to 3.99	26%	38%	39%
4 to 4.99	13%	18%	30%
5 to 6	0%	5%	9%

Table 13: Cross-tabs of farmer survey comparing perceived control to conservation identity

Response Efficacy Scores	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
0	22%	5%	2%
1	22%	17%	8%
2	35%	38%	25%
3	17%	34%	47%
4	4%	7%	19%

Table 14: Cross-tabs of farmer survey comparing perceived response efficacy of subsurface phosphorus placement to conservation identity

Risk Attitude Scores	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
0	17%	3%	2%
1	25%	5%	3%
2	0%	13%	5%
3	33%	13%	9%
4	8%	10%	11%
5	8%	26%	23%
6	8%	13%	13%
7	0%	8%	19%
8	0%	6%	10%
9	0%	2%	2%
10	0%	1%	3%

Table 15: Cross-tabs of farmer survey comparing risk attitude to conservation identity

Adjusted Gross Income Category	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
0	48%	60%	67%
1	52%	40%	33%

Table 16: Cross-tabs of farmer survey comparing a binary adjusted gross income category to conservation identity. Respondents were grouped into two categories: 1) adjusted gross income < \$100,000 and 2) adjusted gross income ≥ \$100,000

Education Category	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
0	26%	29%	31%
1	74%	71%	69%

Table 17: Cross-tabs of farmer survey comparing a binary education category to conservation identity. Respondents were grouped into two categories: 1) No college education and 2) At least some college education

Years of Reported Experience	Conservation Identity		
	0 to 1.33	1.34 to 2.66	2.67 to 4.00
0-9	0%	5%	3%
10-19	17%	9%	6%
20-29	13%	13%	13%
30-39	17%	26%	27%
40-49	17%	29%	30%
50-59	30%	12%	15%
60-69	4%	5%	5%
70-79	0%	1%	1%

Table 18: Cross tabs of farmer survey comparing years of reported farming experience to conservation identity

Age Group	Years of Reported Experience							
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79
20-29	21%	7%	0%	0%	0%	0%	0%	0%
30-39	39%	52%	12%	2%	0%	0%	0%	0%
40-49	18%	21%	49%	13%	2%	0%	0%	0%
50-59	11%	12%	28%	65%	31%	9%	0%	0%
60-69	7%	6%	8%	17%	57%	36%	17%	0%
70-79	4%	2%	3%	3%	10%	50%	46%	53%
80-89	0%	0%	0%	1%	0%	4%	37%	35%
90 +	0%	0%	0%	0%	0%	0%	0%	12%

Table 19: Cross-tabs of farmer survey comparing age to years of reported farming experience

	Adjusted Gross Income	Total Farm Acres	Age	Education	Experience	Response Efficacy	Perceived Control	Risk Attitude	Conservationist Identity	Self-Efficacy	Responsibility
Adjusted Gross Income	1	-0.37**	0.05*	0.05*	-0.03	-0.07**	-0.06**	-0.15**	-0.07**	-0.01	-0.03
Total Farm Acres	-0.37**	1	-0.08**	-0.06**	0.06*	0.04	0.05*	0.15**	0.04	-0.02	0.04
Age	0.05*	-0.08**	1	0.13**	0.58**	0.06*	0.00	-0.03	0.07**	-0.02	-0.02
Education	0.05*	-0.06**	0.13**	1	0.25**	-0.03	-0.02	-0.06**	-0.1	-0.00	-0.03
Experience	-0.03	-0.06*	0.58**	0.25**	1	0.11**	0.04*	-0.03	0.09**	-0.02	-0.02
Response Efficacy	-0.07**	0.04	0.06*	-0.03	0.11**	1	0.17**	0.09**	0.31**	0.19**	0.25**
Perceived Control	-0.06**	0.05*	0.00	-0.02	0.04*	0.17**	1	0.16**	0.29**	0.22**	0.25**
Risk Attitude	-0.15**	0.15**	-0.03	-0.07**	-0.03	0.09**	0.16**	1	0.20**	0.17**	0.17**
Conservationist Identity	-0.07**	0.04	0.07**	0.09	0.09**	0.31**	0.29**	0.20**	1	0.28**	0.49**
Self-Efficacy	-0.01	-0.02	-0.02	-0.02	-0.02	0.19**	0.22**	0.17**	0.28**	1	0.44**
Responsibility	-0.03	0.04	-0.02	-0.02	-0.02	0.25**	0.25**	0.17**	0.49**	0.44**	1

Note: * $p < 0.05$ ** $p < 0.01$

Table 20: Pearson Correlation Matrix for Independent Variables (n = 1,960)

Appendix C. Supplemental Information for Chapter 3

District	Organized	Order	District	Organized	Order
Highland	4/18/1942	1	Shelby	2/23/1946	48
Clark	4/24/1942	2	Vinton	2/23/1946	49
Columbiana	4/24/1942	3	Scioto	5/4/1946	50
Butler	5/25/1942	4	Athens	5/6/1946	51
Coshocton	5/25/1942	5	Fayette	6/4/1946	52
Morrow	6/1/1942	6	Auglaize	6/29/1946	53
Noble	7/14/1942	7	Lake	7/10/1946	54
Guernsey	10/22/1942	8	Summit	7/12/1946	55
Monroe	10/27/1942	9	Madison	7/25/1946	56
Tuscarawas	11/14/1942	10	Clinton	8/17/1946	57
Richland	2/27/1943	11	Portage	9/5/1946	58
Meigs	4/2/1943	12	Knox	2/18/1947	59
Logan	5/17/1943	13	Wayne	3/3/1947	60
Clermont	8/21/1943	14	Ross	4/4/1947	61
Fairfield	8/21/1943	15	Williams	4/12/1947	62
Miami	12/9/1943	16	Sandusky	7/2/1947	63
Champaign	2/2/1944	17	Holmes	7/25/1947	64
Adams	2/12/1944	18	Lawrence	9/27/1947	65
Warren	2/15/1944	19	Hardin	4/10/1948	66
Licking	2/29/1944	20	Wyandot	9/7/1948	67
Carroll	2/29/1944	21	Lorain	11/23/1948	68
Medina	3/3/1944	22	Fulton	12/11/1948	69
Jackson	3/7/1944	23	Montgomery	12/30/1948	70
Hocking	3/18/1944	24	Pike	1/26/1949	71
Jefferson	3/20/1944	25	Ashtabula	1/28/1949	72
Greene	3/30/1944	26	Preble	1/31/1949	73
Ashland	4/8/1944	27	Seneca	2/10/1949	74
Muskingum	4/21/1944	28	Van Wert	2/15/1949	75
Delaware	4/22/1944	29	Wood	2/26/1949	76
Geauga	6/24/1944	30	Defiance	3/10/1949	77
Perry	6/27/1944	31	Paulding	3/18/1949	78

Continued

Table 21: Organization of Ohio Soil Conservation District by Date of Ohio Soil Conservation Committee Approval. Dates are based on the passage of a referendum asking if a soil conservation district should be formed

Table 21 continued

District	Organized	Order	District	Organized	Order
Morgan	8/4/1944	32	Cuyahoga	4/5/1949	79
Pickaway	9/9/1944	33	Trumbull	12/6/1949	80
Mercer	9/20/1944	34	Stark	3/7/1950	81
Brown	10/6/1944	35	Mahoning	6/16/1950	82
Gallia	12/9/1944	36	Ottawa	1/8/1952	83
Belmont	2/10/1945	37	Erie	3/30/1953	84
Crawford	3/6/1945	38	Henry	11/9/1954	85
Hamilton	4/7/1945	39	Darke	3/26/1955	86
Union	5/1/1945	40	Putnam	1/24/1956	87
Harrison	5/26/1945	41	Lucas	12/12/1963	88
Allen	6/1/1945	42			
Franklin	8/15/1945	43			
Huron	8/17/1945	44			
Washington	8/27/1945	45			
Marion	9/7/1945	46			
Hancock	1/10/1946	47			

District	Order	District	Order	District	Order
Highland	1	Perry	29	Ross	59
Clark	4	Morgan	33	Williams	58
Columbiana	7	Pickaway	32	Sandusky	62
Butler	5	Mercer	31	Holmes	61
Coshocton	2	Brown	34	Lawrence	65
Morrow	3	Gallia	40	Hardin	63
Noble	6	Belmont	35	Wyandot	66
Guernsey	8	Crawford	37	Lorain	68
Monroe	9	Hamilton	36	Fulton	69
Tuscarawas	10	Union	39	Montgomery	70
Richland	67	Harrison	38	Pike	72
Meigs	11	Allen	64	Ashtabula	74
Logan	12	Franklin	44	Preble	71
Clermont	13	Huron	42	Seneca	73
Fairfield	15	Washington	41	Van Wert	82
Miami	14	Marion	43	Wood	75
Champaign	16	Hancock	46	Defiance	76
Adams	18	Shelby	48	Paulding	77
Warren	17	Vinton	45	Cuyahoga	78
Licking	24	Scioto	53	Trumbull	79
Carroll	23	Athens	47	Stark	80
Medina	27	Fayette	51	Mahoning	81
Jackson	20	Auglaize	60	Ottawa	83
Hocking	21	Lake	50	Erie	84
Jefferson	19	Summit	49	Henry	85
Greene	22	Madison	52	Darke	86
Ashland	25	Clinton	54	Putnam	87
Muskingum	26	Portage	55	Lucas	88
Delaware	28	Knox	56		
Geauga	30	Wayne	57		

Table 22: Districts in order of their organization. Data from Earl Hugh James, "The History of the Soil and Water Conservation Movement in Ohio: A Field Study," Thesis. The Ohio State University, 1965. 59.

District	% Voting in Favor of Establishment	District	% Voting in Favor of Establishment	District	% Voting in Favor of Establishment
Highland	69.5	Perry	N/A	Ross	97.2
Clark	88	Morgan	98.9	Williams	77.4
Columbiana	93	Pickaway	85.8	Sandusky	N/A
Butler	88	Mercer	89.7	Holmes	67
Coshocton	95	Brown	95.2	Lawrence	97.5
Morrow	73	Gallia	> 96	Hardin	98
Noble	95	Belmont	96.2	Wyandot	87
Guernsey	N/A	Crawford	84.5	Lorain	96.5
Monroe	N/A	Hamilton	>95	Fulton	93.6
Tuscarawas	N/A	Union	96.6	Montgomery	96.1
Richland	N/A	Harrison	91	Pike	99
Meigs	N/A	Allen	>96	Ashtabula	96.0
Logan	N/A	Franklin	97.7	Preble	93
Clermont	N/A	Huron	71.8	Seneca	89
Fairfield	83.4	Washington	94.4	Van Wert	65.0
Miami	96.4+	Marion	N/A	Wood	93.8
Champaign	N/A	Hancock	72.5	Defiance	82.4
Adams	N/A	Shelby	89.4	Paulding	84.4
Warren	97.9	Vinton	100	Cuyahoga	100
Licking	93.8	Scioto	99.4	Trumbull	90.3
Carroll	93.4	Athens	>93	Stark	77
Medina	96.9	Fayette	N/A	Mahoning	91.9
Jackson	95.5	Auglaize	86.5	Ottawa	70.7
Hocking	96.3	Lake	89.3	Erie	90.9
Jefferson	95.9	Summit	99.5	Henry	N/A
Greene	96.4	Madison	99.3	Darke	N/A
Ashland	87.7	Clinton	66.9	Putnam	N/A
Muskingum	N/A	Portage	>99	Lucas	N/A
Delaware	N/A	Knox	94.6		
Geauga	97.4	Wayne	95		

Table 23: Reported referendum results for each county when the referendum to form a soil conservation district was approved. Data based on documents sent from the Ohio Department of Agriculture from a FOIA request.