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TECHNICAL REPORT

Environmental Models, Modules, and Datasets

The Agricultural Conservation Planning Framework Financial and Nutrient Reduction Tool: A planning tool for cost effective conservation

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Abstract

We have developed an add-on tool for use with the Agricultural Conservation Planning Framework (ACPF) that features a multistate financial analysis and field-scale nitrogen (N) reduction tool for use when analyzing different ACPF conservation scenarios. Financial and expected field-scale N loss data are used to calculate total long-term cost and cost effectiveness of various conservation plans. Unique to the ACPF Financial and Nutrient Reduction Tool is the ability to identify individual treatment areas for each practice evaluated, allowing users to create combinatorial conservation planning scenarios drawing from multiple ACPF-identified conservation practices. Financial data account for direct long-term annualized costs for best management practice (BMP) installation and management in Iowa and Minnesota. Opportunity costs of BMPs that retire cropland are spatially determined according to weighted-average crop productivity indices and land rent relationships. The tool quantifies the N requirements for each field, based on 6-yr land-use data, and evaluates the proportion of N likely to be lost from the field as nitrate load via leaching. Financial analyses that can be accomplished by using the ACPF are illustrated in case study watershed scenarios in Iowa and Minnesota. In Iowa, featured scenarios range from 26 to 31% reduction in total nitrate, for a total cost between US$0.580 million and $2.3 million per year, respectively. In Minnesota, example scenarios range from 28 to 51% total nitrate reduction, for total costs of $1.7 million to $2.1 million per year. Tradeoffs in BMP selection related to N reduction outcome and cost are also demonstrated.

Abbreviations: ACPF, Agricultural Conservation Planning Framework; ACPF FiNRT, Agricultural Conservation Planning Framework Financial and Nutrient Reduction Tool; BMP, best management practice; CPI, crop productivity index; HUC, hydrologic unit code; MLRA, major land resource area; MRTN, maximum return to nitrogen.

1 | INTRODUCTION

Water quality efforts in the United States have been hindered by inadequacies in best management practice (BMP) implementation and coordination at watershed scales, resulting in a lack of spatially effective placement of BMPs to efficiently reduce nutrient and sediment loss (Moiaisi et al., 2020; Tomer & Locke, 2011). Efficiently and effectively guiding the implementation of proven BMPs at watershed scales is one of the primary challenges for state-level nutrient reduction strategies (Christianson et al., 2018). In the U.S. Cornbelt region, a precision conservation planning tool, called the Agricultural Conservation Planning Framework (ACPF), has emerged as a key tool for conservation partners to guide biophysically efficient conservation opportunities at watershed scales (Lewandowski et al., 2020).

The ACPF is first and foremost a heuristic framework based on conservation principles and practices that aim to improve soil and water quality in ways that in the aggregate improve overall watershed health (Tomer et al., 2013). As per Tomer et al. (2013, 2015), water quality improvement is a multiscale synergistic process. The concept begins at field scales where the primary tenants of soil management involve practices that minimize erosion, build soil organic matter and carbon, and limit loss of excess nutrients. Controlling water at field scales involves managing drainage, protecting areas of concentrated overland flow within fields, and intercepting sheet flow with enhanced zones of infiltration and soil water storage. Beyond field scales, watershed connectivity is enhanced downstream via different modes of capturing subsurface drainage using impoundments, drainage water redirection, and managing variable source areas. Finally, riparian management recognizes the role of riparian vegetation in mediating the health of the overall hydrologic system. This framework is not prescriptive but rather allows for the biophysical identification of field-level opportunities to site-suitable and effective conservation practices within small watersheds (Zimmerman et al., 2019).

The ACPF Financial and Nutrient Reduction Tool extends the results of ACPF conservation practice results to identify, analyze, and map different watershed-scale scenarios of BMP opportunities and estimates nutrient reduction outcomes and financial costs associated with conservation scenarios. Financial data are essential for conservation planning at all scales and are relevant to all planning partners and landowners alike (Tyndall & Roesch, 2014). Landowners and farmers need field-level cost data for planning capital expenditures relative to their individual farm-level conservation plans and for weighing the potential use of conservation funding (Tyndall et al., 2013). Watershed-level organizations, as well as state and federal agencies, require an understanding of the aggregate, long-term cost of conservation opportunities at watershed scales to efficiently allocate limited technical and financial resources and create innovative conservation finance tools (Bose et al., 2019). Directly incorporating field-level BMP cost data into watershed-scale, spatially targeted conservation analysis will create a more robust and actionable perspective on the conservation planning process (Srinivas et al., 2020).

Core Ideas

- The Agricultural Conservation Planning Framework (ACPF) is a spatially explicit watershed planning tool for identifying best management practice (BMP) opportunities.
- Combining financial data with spatial BMP planning is critical to cost-effective land use.
- The ACPF Financial and Nutrient Reduction Tool accounts for establishment, long-term management, and opportunity costs of land.
- Opportunity cost of land is spatially explicit and can be estimated using county soil rent data.

This case study addresses the opportunity to include costs and expected outcomes by demonstrating an innovative GIS-based dataset and two ACPF add-on toolboxes that integrate financial BMP cost data and nitrate reduction data into the ACPF. These toolboxes, collectively called the ACPF Financial and Nutrient Reduction Tool (ACPF FiNRT; "fine art"), allow conservation planners to estimate the total costs of various conservation scenarios involving hydrologic unit code (HUC) 12 (i.e., the 12-digit scale hydrologic unit code) watersheds in Iowa and Minnesota and to analyze field- to watershed-scale cost-effectiveness. This tool, coupled with the ACPF, can provide conservation planners and landowners with important information and empower more certain decision-making.

2 | MATERIALS AND METHODS

To operationalize the conceptual framework, the ACPF has a geodatabase component, which includes field boundaries derived from the USDA Farm Service Agency and updated manually; land-use data from the USDA National Agricultural Statistics Service (NASS) Cropland Data Layer; gSSURGO soils data; and watershed boundary data from the USGS (Tomer et al., 2017). These datasets are made available at the HUC 12 watershed scale. The ACPF data archive site currently holds data for almost 12,000 HUC 12 watersheds throughout 10 states within the Upper and Lower Mississippi River basins (ISU GIS Facility, 2020). A layer that is not included in the database is a LiDAR-derived digital elevation model that must be generated by the user (Porter et al., 2018). The LiDAR data are often 1–3 m in resolution; presently, Iowa has 2-m LiDAR available, and Minnesota has 1- and 3-m LiDAR available. The ACPF Toolbox is used to perform hydro-conditioning, terrain processing, and hydro-enforcement of elevation data to accurately represent hydrologic flow routing (Porter et al., 2018). Secondarily, the ACPF Toolbox is used to delineate the perennial stream network and catchments (Porter et al., 2018). The ACPF Toolbox then aids the user in the distillation of this complex geospatial data to characterize field runoff risk subsurface drainage potential and riparian areas to identify riparian area functions by perennial stream reach (Tomer et al., 2013). Taken cumulatively, this information allows the user to site suitable BMPs in high-risk areas to reduce watershed nutrient and sediment loss (Porter et al., 2018). The ACPF currently sites nine BMPs, including bioreactors, contour buffer strips, drainage water management, farm ponds, grassed waterways, nutrient removal wetlands, riparian buffers, saturated buffers, and water and sediment control basins. Altogether, this framework, data, and the ArcGIS toolbox make it possible for conservation planners to spatially identify opportunities for discrete conservation practices within watersheds (Tomer et al., 2015). Input data for use in the ACPF ArcGIS Toolbox can be found and downloaded at https://acpf4watersheds.org/. To add analytical value to the ACPF, we introduce two ACPF add-on tools that allow users to estimate nutrient reduction outcomes and financial costs associated with conservation scenarios.

2.1 | Nitrate leaching potential and reduction from BMPs dataset

To account for nitrate leaching potential, the ACPF FiNRT estimates nitrogen (N) fertilizer application and nitrate-N yield for each field using the Estimate Field Nitrogen Requirements & N Load Tool (http://cnrc.agron.iastate.edu/). By default, this tool uses input data from maximum return to N (MRTN) calculations (Sawyer, 2006); however, users can modify the crop-specific N fertilizer rates to suit their needs and/or incorporate locally relevant data. The default MRTN input data are based on calculating the return to N application and finding the MRTN at selected prices of N and corn directly from recent research data from across the U.S. Cornbelt region (Sawyer, 2006). For each field in agricultural production, N application is estimated annually for the 6-yr crop rotation based on the default MRTN data or user-chosen rates. To assess nitrate leaching potential, we used data from the Iowa Nutrient Reduction Strategy (2017), which combined estimates of surface and subsurface water yield with nitrate-N concentration estimates at the major land resource area (MLRA) level.

To estimate nitrate reduction from potential BMP implementation, the ACPF FiNRT uses data aggregated in state-level nutrient reduction strategies to determine average and standard deviations for nitrate reduction efficiencies by BMP (INRS, 2017; Lawrence & Benning, 2019; MNNRS, 2014). Using the mean percent nitrate reduction efficiencies from nutrient reduction strategies allows for N load, N-load reduction potential from BMPs, and cost per kilogram of N reduced per BMP to be estimated in the ACPF FiNRT (Supplemental data S1).

2.2 | Integrating financial data into conservation scenario analysis using the ACPF FiNRT

Prior to using the APCF FiNRT, the user must run the ACPF toolbox to produce the suite of potential BMPs that are available for the watershed of interest. Geographic information system layers for individual or combinations of the BMPs can be used as inputs to the ACPF FiNRT to conduct financial calculations and nitrate reduction estimations. The ACPF FiNRT contains two toolboxes: (a) Estimate Field Nitrogen Requirements, and (b) Analyze Conservation Scenario N Load. The Estimate Field Nitrogen Requirements toolbox uses 6-yr, field-level, land-use data and MRTN default data or user-supplied N fertilizer rates to estimate N application at the field and watershed level. Potential nitrate loading from each field in kilograms is generated by calculating potential leaching using methods and results informed by methods developed by Lawlor et al. (2008) and included in the INRS (2017), which summarize nitrate leaching potential at the MLRA scale. The Analyze Conservation Scenario N Load step uses the ACPF-generated conservation scenarios and quantifies the expected nitrate load reduction and financial costs. Nitrate load reductions in kilograms; total costs at the watershed scale and aggregated practice scale; and cost-effectiveness, which is total annual cost divided by kilograms of nitrate reduced at the watershed scale and aggregated practice scale, are generated. Note that the ACPF FiNRT presents data in English units, not metric. We have converted all units to metric for the purposes of this paper. Additional information about each toolbox is below.

2.3 | ACPF FiNRT: Estimate field N requirements

The goal of estimating field N requirements is to quantify potential nitrate load at the field- and watershed level. This is an important first step because the tool calculates the amount of N at the field level that may be lost as nitrate. This ArcGIS-based tool requires two primary datasets from the ACPF file geodatabase: the field boundaries shapefile and the land-use table. Default data are provided for N fertilization rate in kilograms for a variety of cropping systems. Using these data (field boundaries, land use, and N application), the tool quantifies the N requirements for each field and evaluates the proportion of that N that is likely to be lost from the field via leaching as nitrate.

2.4 | ACPF FiNRT: Analyze conservation scenario N load

The goal of analyzing conservation scenario N load is to estimate nitrate load reduction from implementing BMPs. The ArcGIS-based tool requires six primary datasets from the ACPF file geodatabase: field boundaries shapefile, land-use table, field N requirements table, gSSURGO soils raster, flow direction raster, and flow accumulation raster. In addition to the six pieces of required input data, the ACPF FiNRT allows users to select the BMP layers they would like to include in the scenario. Within the ACPF FiNRT tool, each BMP layer generated from the ACPF has its own designated field. All BMP layers are optional; only BMPs being considered for a certain scenario are included in the tool. These input data come from the layers created through the previous steps in the ACPF toolbox. Users may add all BMP features in a layer, or they may select specific BMP features in the layer for consideration in the tool. This allows users to focus on one specific BMP, on achieving a specific nutrient reduction or cost threshold, or on creating a combined scenario that incorporates multiple BMP types.

2.5 | Calculations within the ACPF FiNRT to generate feature classes

To calculate nitrate load and reduction, catchments are derived for each BMP included in the scenario; catchments are defined as the area above each individual BMP, from which the water in the catchment is intercepted by the BMP. Once the tool identifies these catchments, it creates a feature class that provides summary information at the field level for the attributes related to nitrate load reductions. Fields in the individual BMP watersheds are examined to extract nitrate load characteristics as calculated above by the Field Nitrogen Requirements tool. The N-load-per-hectare value is applied to row-crop areas, in the portion of the field in the BMP catchment, to estimate by-field nitrate load for the affected hectares. The aggregate of these N load parameters across the individual BMP catchments is created to generate a new nutrient summary feature class, which provides summary information at the practice level for the attributes related to nitrate load reductions.

To calculate the costs associated with BMPs, estimated direct costs, as annualized direct establishment and management costs, are used for each BMP feature in the BMP feature class (Table 1). Opportunity costs for area of land removed from production for relevant practices in the BMP feature class are estimated using state-specific, soils-based crop productivity indices. In this case study, the watersheds are in Iowa and Minnesota, and therefore the Iowa CSR2 and Minnesota crop productivity index (CPI) values and the MLRA-level average cropland rental rate are used to generate a dollar amount per productivity index point. This is done within the tool. For Iowa, CSR2 values are extracted from 10-m gSSURGO soils raster for land occupied by a BMP. The area-weighted mean CSR2 value for each practice feature is calculated, and then the annual opportunity costs are calculated as weighted mean CSR2 × MLRA-level rent per CSR2 point. A similar process is undertaken for Minnesota data. Minnesota CPI values gathered from Soil Survey tables (Soil Survey Staff, 2022) are area weighted for each BMP and then multiplied by MLRA-level rent per CPI point. For land cover areas designated as permanent pasture, pasture rent data are used.

2.6 | Direct and opportunity cost and nitrate reduction datasets

2.6.1 | Direct costs

To integrate cost datasets into the ACPF, state-specific comprehensive enterprise budgets reflecting 2021 costs (US$) for ACPF-supported BMPs were constructed. Updated enterprise budgets for several of the BMPs were originally developed by Christianson et al. (2013) for use with Iowa Nutrient Reduction Strategy scenario assessments (INRS, 2017). The enterprise budgets used for the ACPF FiNRT can be found in the Supplemental data (S2). Across all BMPs, four primary categories of cost are accounted for (a) design, site preparation, and establishment; (b) short- and long-term management, maintenance, and/or replacement; (c) annual overhead cost, and (d) for relevant BMPs, annual opportunity cost of land.

Using standard discounted cash flow techniques, a partial budget analysis was conducted for each BMP to quantify the direct cost of establishing and managing the BMP over a 20-yr time-period using a real 2% discount rate. Following Tyndall et al. (2013), the direct cost data were then annualized using a capital recovery procedure to allow for comparative analysis with other farm-level production costs. Table 1 displays average (default) annualized direct costs in Iowa and Minnesota (2021 US$) for 11 BMPs.

2.6.2 | Opportunity costs of land

To calculate opportunity costs for BMPs in the ACPF that require the use of cropland (e.g., riparian buffers, contour buffer strips, nutrient removal wetlands, and farm ponds), the ACPF FiNRT accounts for spatially explicit long-term costs of land by calculating area-weighted land rent loss as a proxy opportunity cost (e.g., Zimmerman et al., 2019). Forgone land

TABLE 1 Annual average direct establishment and management costs for 11 Agricultural Conservation Planning Framework best management practices (BMPs) in Iowa and Minnesota

BMP	Basic cost parameters accounted for in assessment	Annual cost per hectare or otherwise designated unit[a]	
		IA	MN
		2021 US$	
In-field practices			
Multipurpose contour prairie strip[b]	site preparation; seed mix (high diversity w/forbs); planting; mowing for establishment; periodic mowing/burning for management; monitoring	77	69
Contour buffer strip	site preparation; seed mix (usually one or two different species); planting; mowing for establishment; periodic mowing for management; monitoring.	72	67
Cover crops[c]	seed (usually cereal rye or mix); planting (aerial or broadcast); termination (herbicide or mechanical); monitoring	180	173
Grass waterways[d]	site preparation (including land grading and outlet stabilization); erosion control during establishment; seed mix (high diversity with forbs); maintenance; monitoring	230	232
Edge-of-field or downstream practices			
Riparian buffer: multispecies	site preparation; tree and shrub nursery stock; grass seed mix (high diversity); planting trees and grass; mowing for establishment; periodic mowing/burning for management; monitoring	193	210
Riparian buffer: vegetative	site preparation; grass seed mix (usually low diversity mix); planting; mowing for establishment; periodic mowing/burning for management; monitoring	101	99
Vegetative filter strip	site preparation; seed mix (usually low diversity mix); planting; mowing for establishment; periodic mowing/burning for management; monitoring	101	99
Nutrient-removal wetlands[e]	engineering design; site planning, engineering and preparation; excavation and soil movement; tile redirection; installation of structures; planting; seed costs for wetland; seed costs for buffer; mowing buffer for establishment; mowing buffer for management; monitoring	4,066	4,076
Bioreactors[f]	engineering design; excavation; tile pipe, wood chips, and control gate purchase; installation and yearly adjustment/ maintenance; site surface planting; seed mix (usually one or two species); annual groundskeeping, replacement costs at end of practice life; monitoring	5,451/bioreactor	5,451/bioreactor
Saturated buffers[g]	engineering design; site preparation; seed mix (usually similar to vegetative or riparian buffer strips); planting; mowing; excavation for tile drainage pipes; control structure purchase and installation; connection tile pipe; control gate yearly maintenance; monitoring	887/buffer	887/buffer
Farm pond (embankment)[h]	engineering design; dam building and general excavation; spillway piping; pond sealer; embankment conservation cover planting; seed mix (usually —one or two species); annual groundskeeping, monitoring	2,912	2,912

(Continues)

TABLE 1 (Continued)

Note. Costs presented here do not include opportunity costs. All financial assessment was conducted over a 20-yr period using a 2% real discount rate.

[a]All costs have been calculated using standard discounted cash flow analysis and annualized over a 20-yr period using a real 2% discount rate. Values are rounded to nearest dollar. Opportunity costs where relevant and indirect costs not considered here. These data will be updated annually. Caveat: The costs presented by the Agricultural Conservation Planning Framework Financial and Nutrient Reduction Tool serve as baseline estimates and are meant to be informative rather than prescriptive.

[b]Prairie strip costs being modeled represent a CP 43 prairie strip economy mix. Burning is assumed to be the primary long-term management.

[c]Cover crop modeled is winter cereal rye (*Secale cereal* L.), planted with aerial seeding, and chemically terminated. Costs can vary depending on species or mix being planted and choice of planting and termination. It is assumed that cover crops do not have an effect on cash crop yield.

[d]Costs for grassed waterway assumes grading and outlet stabilization; cost could be considerably less than presented if these actions are not required. Tall fescue is the grass choice; costs of seed may vary depending on species.

[e]Costs of nutrient removal wetlands can vary considerably depending on overall scale, engineering design needs, initial site conditions, and amount of earth and rock moving required.

[f]The cost of a bioreactor depends upon the drainage area being treated and the scale of trench. This assessment assumes a 20-ha drainage area and two control structures.

[g]The cost of saturated buffers is based on 305 m of connecting tile to route drainage from 12.15 ha and one control structure. Assumes a carbon source is present.

[h]Assumes pond is an embankment style pond, 2.1-m depth capacity. Pond sealant not considered; if needed would add ~$700 per year to cost.

rent is estimated via an area-weighted land rent calculation determined using state-specific crop productivity indices and MLRA-level rent data. Major land resource areas are geographically associated land resource units, meaning they have similar patterns of soils, climate, water resources, and land uses (USDA-SCS, 1981). In Iowa, the Corn Suitability Rating data layer (CSR2) indexes the inherent soil productivity of each soil series relative to corn production in Iowa and is scaled from 5 to 100 for the least to most productive soils, respectively (Miller & Burras, 2015). In Minnesota, CPI ratings are used to provide a relative soil ranking for row crop production of one soil against that of another over a period of time (Regents of the University of Minnesota, 2018). These ratings range from 0 to 100, with higher numbers indicating a higher production potential (Regents of the University of Minnesota, 2018). Other states have other productivity indices that may be relevant as the tool expands.

To account for rent data, area-weighted averages for county data were aggregated at MRLA levels to calculate an average MLRA level per hectare rent. In Iowa, cash rental rates for high, medium, and low cropland in all Iowa counties and for pasture, hay, and oat production land were gathered from the Iowa State University Extension and Outreach AgDecision Maker (e.g., Plastina et al., 2021). In Minnesota, the land rental data were extracted from FINBIN, a regularly updated database of farm record summaries of over 2,000 Minnesota farms (Bau et al., 2020). Rental rates were summarized at the MLRA level to increase the spatial resolution of opportunity costs and to align with variations in biophysical characteristics of the landscape more closely (see Supplemental data S3).

2.7 | Demonstration case studies

To demonstrate the utility of the ACPF FiNRT, two HUC 12 watersheds, one in Iowa and one in Minnesota, were selected and run using two different conservation scenarios. These scenarios were developed to examine the application of the ACPF FiNT to estimate nitrate reduction and associated costs in the watersheds for simple comparative, demonstrative purposes. Scenario 1 (S1) represents a watershed-wide, uniform application of rye cover crops on all corn (*Zea mays* L.)/soybean [*Glycine max* (L.) Merr.] hectares, and Scenario 2 (S2) demonstrates three nitrate-reduction BMPs (bioreactors, saturated buffers, and nutrient removal wetlands) that are generated using a spatially targeted approach. Although these conservation scenarios both demonstrate the value of BMP application, they differ in their implementation strategy: S1 applies cover crops ubiquitously to examine potential benefits from conservation with no explicit spatial determination or land being removed from production, whereas S2 uses ACPF placement results for BMPs that have been identified as having a nitrate reduction benefit and involves practices that require crop land retirement.

2.7.1 | Upper Big Creek watershed, Boone County, IA

To demonstrate the utility of the ACPF and its new financial and nitrate reduction data in the context of conservation planning, the Upper Big Creek watershed in Boone County, IA, was analyzed as a case study. This HUC 12 watershed (Figure 1) is ~11,741 ha and is a low-relief watershed, located on the Des Moines Lobe in central Iowa. Greater than 90% of the land area within the Upper Big Creek watershed is used for agricultural production, mainly (+95%) row-crop corn and soybean. Because of the biophysical characteristics and agricultural system, a large proportion of the watershed has subsurface tile drainage, and excess nitrate in surface waters from nonpoint sources has contributed to algal blooms at the terminus of the watershed in Big Creek Lake (Kiel & Pierce, 2011).

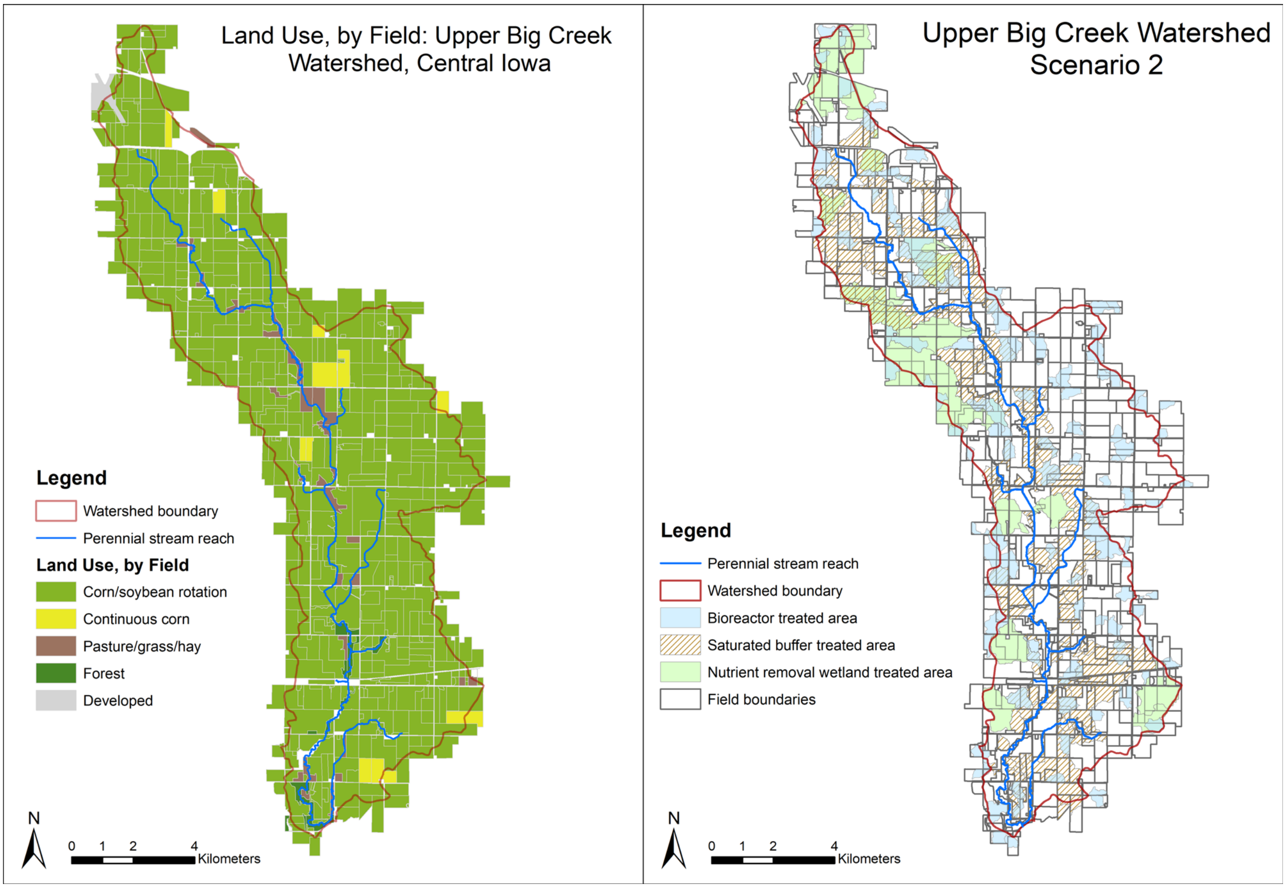

FIGURE 1 Upper Big Creek watershed land use (map on left) and spatially targeted best management practice (BMP) placement Scenario 2 (map on right). Targeted BMPs include bioreactors, nutrient removal wetlands, and saturated buffers. Yields a nitrate load reduction of 26% for the watershed, assuming all BMPs are implemented on the landscape

2.7.2 | Middle South Fork Watonwan River watershed, Watonwan County, MN

The ACPF FiNRT analysis was also conducted on the Middle South Fork Watonwan River watershed, Watonwan County, MN. This HUC 12 watershed (Figure 2) is ~11,240 ha and is a low-relief watershed, located on the Des Moines Lobe in south-central Minnesota. Approximately 90% of the land area within the Middle South Fork Watonwan River watershed is used for agricultural production, mainly row-crop corn and soybean. Due to its predominantly agricultural land use, subsurface tile drainage is common, resulting in water quality impairments in the Watonwan River, South Fork (Plevan et al., 2020).

3 | RESULTS AND DISCUSSION

Within the Upper Big Creek watershed, S1 placed rye cover crops on all 10,758 ha of corn/soybean land, whereas S2 assessed a spatially targeted conservation approach using the ACPF. In S2, the ACPF was used to site areas where nutrient removal wetlands, bioreactors, and saturated buffers would be suitable. As shown in Figure 1, S2 consists of 104 ha of nutrient removal wetlands, 118 bioreactors, and 45 km of saturated buffers.

The resulting nitrate load reduction, total cost, cost-effectiveness, number of fields with conservation practices, and hectares removed from cultivation were calculated and are shown in Table 2. Covering all corn/soybean hectares in cover crops achieved a 31% reduction in nitrate load at an annual cost of ~$2.3 million. Yet under the targeted conservation scenario, nitrate load was reduced by 26% and at a much lower annual cost (~$581,000), and cost-effectiveness also improved. In S2 more farmland was taken out of production (136 ha in S2 compared with 0 ha in S1); yet overall, fewer identified fields were affected by conservation management, which could mean fewer farmers and landowners involved.

Similar results were found in Minnesota as were observed in Iowa. In the Middle South Fork Watonwan River watershed (Figure 2), S1 placed rye cover crops on all 10,116 ha of corn/soybean land, whereas S2 used the ACPF to illustrate

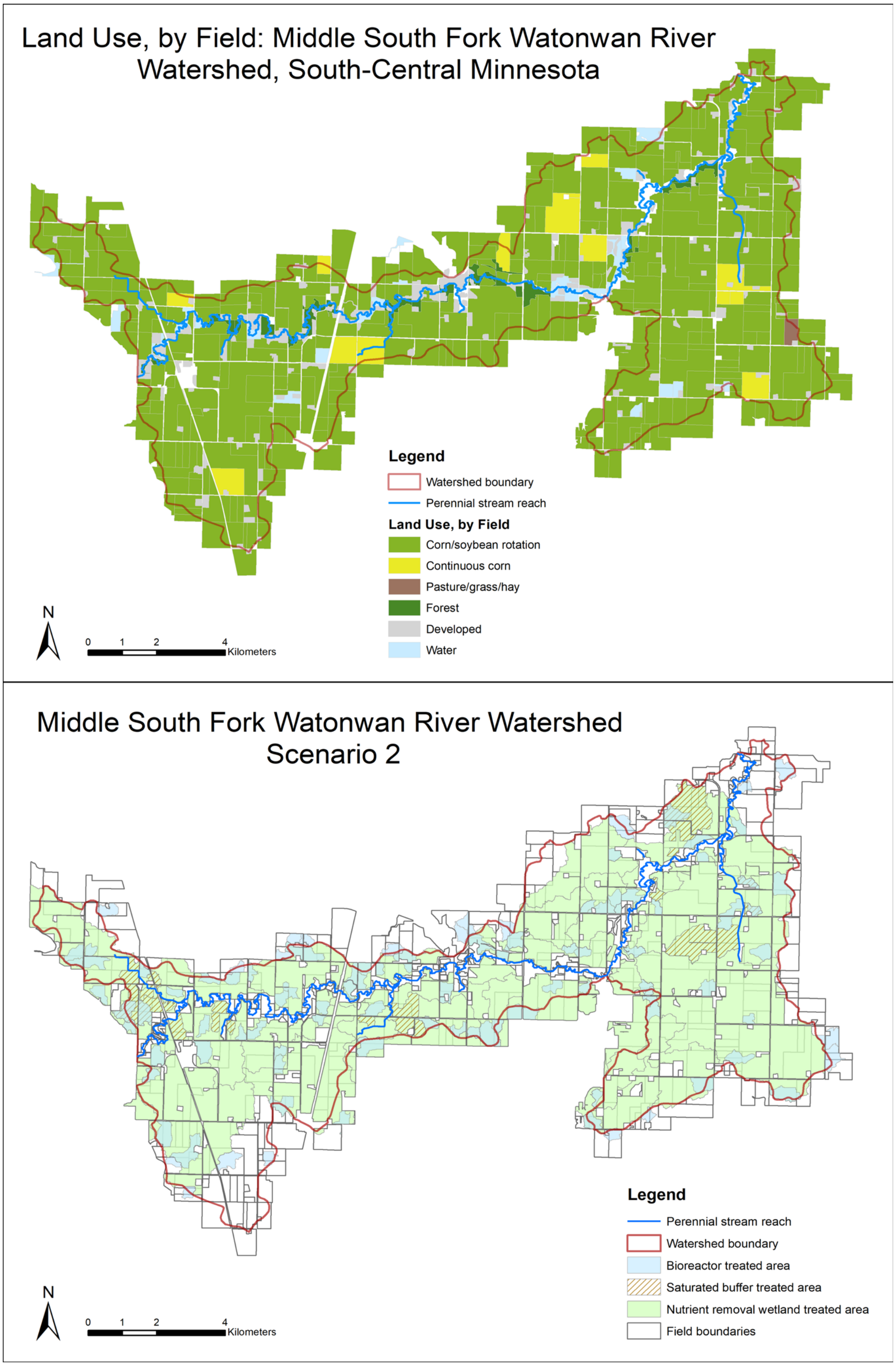

FIGURE 2 Middle South Fork Watonwan River watershed (top map) and spatially targeted best management practice (BMP) placement Scenario 2 (bottom map). Targeted BMPs include bioreactors, nutrient removal wetlands, and saturated buffers. Yields a nitrate-load reduction of 28% for the watershed, assuming all BMPs are implemented on the landscape

a spatially targeted conservation approach. In S2, the ACPF was used to site areas suitable for nutrient removal wetlands, bioreactors, and saturated buffers. As shown in Figure 2, S2 consists of 353 ha of nutrient removal wetlands, 96 bioreactors, and 13 km of saturated buffers.

Table 3 outlines the resulting nitrate load reduction, total cost, cost-effectiveness, number of fields with conservation practices, and hectares removed from cultivation that were calculated for the Middle South Fork Watonwan River watershed. Covering all corn/soybean hectares in cover crops

TABLE 2 Outcomes for practices used in Scenario 1 (S1) and Scenario 2 (S2) in the Upper Big Creek watershed

Scenario	Nitrate reduction	Total yearly cost	Average cost of nitrate reduced	Fields with BMPs	Land removed from cultivation
	kg (%)	2021 US$	US$ kg^{-1}		ha
S1: total (cover crops only)	105,577 (31)	$2,295,313	21.87	456	0
S2: total	86,762 (26)	$580,733	3.56	220	136
Wetlands	29,569 (9)	$479,567	16.38	18	104
Bioreactors	24,093 (7)	$71,409	3.14	118	0
Saturated buffers	33,100 (10)	$29,757	1.41	84	32

Note. The N-load reductions assume that stacked conservation practices have a multiplicative effect (Lazarus et al., 2014). Total cost includes both direct and opportunity costs where applicable. The last three rows are a breakdown of the best management practices (BMPs) included in S2.

TABLE 3 Outcomes for practices used in Scenario 1 (S1) and Scenario 2 (S2) in the Middle South Fork Watonwan River watershed

Scenario	Nitrate reduction	Total yearly cost	Average cost of nitrate reduced	Fields with BMPs	Land removed from cultivation
	kg (%)	2021 US$	US$ kg^{-1}		ha
S1: total (cover crops only)	167,041 (51)	2,136,962	12.81	362	0
S2: total	91,902 (28)	1,675,454	12.17	130	391
Wetlands	79,959 (24)	1,584,152	23.82	17	353
Bioreactors	5,420 (2)	53,573	10.30	96	0
Saturated buffers	6,524 (2)	37,729	11.06	17	38

Note. The N-load reductions assume that stacked conservation practices have a multiplicative effect. Total cost includes both direct and opportunity costs where applicable. The last three rows show a breakdown of the best management practices (BMPs) included in S2.

achieved a 51% reduction in nitrate load at an annual cost of ∼$2.1 million. Under the ACPF targeted conservation scenario, nitrate load was reduced by 38% and at a lower annual cost (∼$1.7 million). Cost-effectiveness also improved in S2. In S2 more farmland was taken out of production (391 ha in S2 compared with 0 ha in S1); yet overall, much fewer identified fields were affected by conservation management.

From a planning perspective, the case study watersheds provide a number of example findings that are useful for watershed planners and partners to create and evaluate biophysically effective, affordable, and socially viable watershed management plans. As described in Gesch et al. (2020), with the aid of the ACPF, conservation plans can be collaboratively developed between watershed partners including landowner and farmer input regarding the ACPF modeling process and results so as to determine multiscale water protection goals and the biophysically and practicably appropriate practices to address them. Specific action-oriented objectives as modeled via ACPF scenarios then gauge the scale and patterns of BMP application needed to meet desired watershed goals relative to nutrient loss reduction (Gesch et al., 2020). Part of the deliberation standards regarding any conservation plan is initial budget limits and assessing the longer-term capacity of watershed partners to acquire and allocate scarce resources.

Directly facilitating this process, the ACPF FiNRT calculates total annual costs (direct and opportunity) of a conservation scenario, total number of fields affected, total land area retired from production, and two types of cost-effectiveness: one based on total percent nitrate load reduction and the other based on cost of unit load reduction. Cost-effectiveness assessments are objective measures of allocative efficiency and, in this case, are calculated by dividing the total present value cost of a BMP by total biophysical effect associated with the use of the conservation practice across the relevant time period. Cost-effectiveness as a decision criterion has been demonstrated to be necessary to maximizing conservation impact across a range of activities, which is critical when financial and technical service resources are scarce (Pienkowski et al., 2020).

As per Gesch et al. (2020), ACPF scenarios identify potential combinations of practicable conservation practices that can reasonably be expected to meet watershed goals as set by watershed partners, including farmers. The ACPF by itself does not provide output to prioritize specific scenarios because prioritization, deliberation, choice determination, and identifying modes of fostering buy-in involve social and economic factors (Lewandowski et al., 2020). In both case study watersheds, the ACPF FiNRT was used to demonstrate two different approaches (objectives) to achieving a certain level of nutrient loss reduction (goals) and generate numerous financial and BMP scale data that further guide watershed planners and partners to assess the viability of a given plan.

In each case watershed, S2 demonstrates a spatially targeted conservation plan that features multiple BMPs (nutrient retention wetlands, bioreactors, and saturated buffers), versus S1, which demonstrates a uniform application of one BMP (cover crops). In the Upper Big Creek watershed, both scenarios achieve relatively similar reductions in nitrate (S1 achieves a 31% reduction or 105,577 kg of nitrate N; S2 achieves a 26% reduction or 86,762 kg of nitrate N), but S2 does so at only 25% the total cost of S1. As such, S2 features a considerably more cost-effective outcome, with an average cost of \$3.56 kg^{-1} nitrate N reduced (compared with \$21.87 kg^{-1} nitrate N for S1). The conservation plan in S1 involves a total of 456 farm fields and conceivably would involve more landowners voluntarily electing to participate in conservation. Nonetheless, because S1 features only cover crops, no farmland is removed from production. The conservation plan in S2 involves slightly less than half the number of fields as S1 (220 farm fields); yet it also involves effectively permanently removing 104 ha of farmland from production for nutrient reduction wetlands.

Similarly, the Middle South Fork Watonwan River watershed scenarios accomplish comparable reductions in nitrate (S1 achieves a 51% reduction or 167,041 kg of nitrate N; S2 achieves a 28% reduction or 91,902 kg of nitrate N). Although S1 achieves a higher nitrate N reduction, S2 is only 78% the total cost of S1. Additionally, S2 is slightly more cost-effective, with an average cost of \$\$12.17 kg^{-1} nitrate N reduced, whereas in S1 the average cost is \$12.81 kg^{-1} nitrate N reduced. The cover crops in S1 cover 362 farm fields but do not take any farmland out of production. The BMPs in S2 involve slightly over one-third of the fields required for S1 (130 fields) but also require a total of 391 ha of farmland to be removed from production.

All of the data generated by the ACPF FiNRT provide planners the ability to evaluate potential total costs versus available funding and funding potential in the context of overall goals. Evaluating cost-effectiveness at both the watershed and practice scale are key factors in landowner deliberation, adoption, and long-term management of BMPs (Tyndall et al., 2013).

Better understanding the total number of fields involved in a conservation scenario and the total area of land to be retired contributes to a more comprehensive analysis of the scale of landowner and farmer involvement, the distribution and type of short and long-term costs, and available technical support. All of these factors are relevant to determining modes and scale of outreach and fostering the necessary conservation buy-in at relevant scales.

The utility of deliberative and actionable conservation planning information provided by decision support tools such as the ACPF and the ACPF FiNRT depend on the quality of the modeling and the output (Duncan et al., 2021). Because the ACPF is not a temporally dynamic process model but rather a heuristic planning tool, the modes of validation and verification are largely based on examining whether the model is accurately identifying areas of resource concern and potential locations for BMPs. Other studies using the ACPF relied on site visits and/or visual assessments of water conveyances such as culverts (ground truthing, e.g., Hood [2020]) and using aerial or ground-truthed photographs (Hood, 2020; Rundhaug et al., 2018; Tomer et al., 2015) to verify ACPF outputs. Additionally, Ranjan et al. (2019) provide an overview of modes of involving farmers and landowners in the field verification process; such involvement fosters stakeholder trust in the decision support tools being used and the processes of their use. Validation of resource concerns and BMP practice suitability by site visits and assessments by conservation professionals is a critical step when using decision support tools such as the ACPF and ACPF FiNRT in watershed management.

Another component of verification is assessment that scenario outputs are reasonable, given other published data and information. What qualifies as reasonable in this case is determined by the default or user-defined values for nitrate reduction efficiency, N load, and direct and opportunity costs per unit of the BMPs being assessed. For all scenarios, the estimated nitrate reduction is within the bounds of the initial default nitrate reduction efficiency parameters, which were set by the Iowa Minnesota and Iowa Nutrient Reduction Strategy meta-analysis of BMP effectiveness (Lawrence & Benning, 2019; MNNRS, 2014) and the expected N load as per the MRTN in the 103 MLRA, which includes the case study watersheds in Iowa and Minnesota (see Supplemental S4). The concomitant cost estimations were determined as reasonable based on prior analysis (for Upper Big Creek, see Zimmerman et al. [2019]) and hand-calculations of direct costs using ACPF FiNRT BMP area data and the cost information presented in Table 1.

Planners need to be aware of the timing, nature, and permanence of BMP costs. The ACPF FiNRT annualizes total costs over a 20-yr timeframe, which, while useful for comparative analysis (Tyndall & Roesch, 2014), can mask fundamental differences in the timing of BMP costs (Janke et al., 2021). Cover crops featured in S1 are annual expenditures, whereas the nutrient removal wetlands, bioreactors, and saturated buffers featured in S2 all have significant upfront costs associated with design, site preparation, structural materials, and establishment. Nutrient removal wetlands, as noted above, have substantial opportunity costs for the landowners affected. All three practices also have variable lifespans and expected replacement costs. Ultimately, as noted here from a decision support perspective, it is important to recognize that the variability in the distribution of costs across landowners and across time are essential considerations, in addition to comparisons of costs and cost-effectiveness.

The costs of BMPs will change over time in real terms. Direct and opportunity cost estimates provided by the ACPF FiNRT are static baseline costs and are based on current price conditions. To capture these potential annual changes, these data will be updated within the ACPF FiNRT on an annual basis. More broadly, however, conservation planners should expect unique supply and demand–related market dynamics relative to costs of BMPs. In the short run, if conservation efforts increase, it is possible or perhaps even likely that the costs of various practices will increase due to regional competition for technical and contracting services as well as for critical materials like seed and nursery stock for vegetation-based practices (Tyndall et al., 2021). In the long run, however, continued research and development would be expected to enhance available technologies. Likewise, it would be expected that the supporting infrastructure for conservation, including expanded material supplies and contracting capacity, would grow to meet demand (Tyndall et al., 2021). At watershed scales throughout the region, costs may also fall due to the benefits of experience gained, shared resources and information among conservation partners, and economies of scale (Hayes et al., 2016).

4 | CONCLUSION

Enhancing environmental outcomes in agricultural landscapes is an ongoing process in U.S. Corn Belt states like Iowa and Minnesota. Decision support tools, like the ACPF and its ACPF FiNRT, offer new opportunities for conservation planning at increased resolutions, across watershed- and field-level scales, and with increasingly robust geospatial data. Although Iowa and Minnesota have a wealth of publicly available geospatial data, published information and tools to estimate fertilizer application, and assessments of nutrient reduction potential from BMPs, other states across the Corn Belt are rapidly developing similar capacities. The ACPF and the ACPF FiNRT allow conservation planners to harness these data to evaluate and consider several critical aspects of conservation planning at watershed scales: menus of BMP opportunities for landowners, expected nitrate reduction, number of fields affected, area of land removed from production, total cost (direct and opportunity), and cost-effectiveness. It also provides context for broader conservation planning analysis regarding farmer and landowner preferences, trade-offs, ecosystem services beyond water quality (e.g., habitat, recreation, aesthetics), available technical and financial support, and more. Although the ACPF and ACPF FiNRT are not prescriptive models, they are opening new discussions and sparking new ways of thinking about conservation and watershed planning.

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AUTHOR CONTRIBUTIONS

Emma E. Bravard: Formal analysis; Methodology; Validation; Writing – original draft; Writing – review & editing. Emily Zimmerman: Formal analysis; Methodology; Project administration; Software; Validation; Writing – original draft; Writing – review & editing. John C. Tyndall: Conceptualization; Funding acquisition; Methodology; Project administration; Supervision; Writing – original draft; Writing – review & editing. David James: Methodology; Software; Validation; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

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