Magnitude and Cost of BMP Implementation: Strategic Planning for Michigan's Priority Subwatersheds

Prepared for:
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LimnoTech
Water Environment | Scientists Engineers

Magnitude and Cost of BMP Implementation: Strategic Planning for Michigan's Priority Subwatersheds

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Top cover photos (left to right): constructed wetland in the South Branch River Raisin subwatershed, riparian filter strips in the Nile Ditch subwatershed.

Bottom cover photos (left to right): grassed waterway in the Headwaters Saline River subwatershed, water and sediment control basins in the Lime Creek subwatershed.

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Acronyms

Agricultural Conservation Planning Framework (ACPF)

Alliance for the Great Lakes (AGL)

Best Management Practice (BMP)

Concentrated Animal Feeding Operations (CAFOs)

Cropland Data Layer (CDL)

Department of Environment, Great Lakes, and Energy (EGLE)

Domestic Action Plan (DAP)

Environmental Quality Incentives Program (EQIP)

Environmental Working Group (EWG)

Hydrologic Unit Code (HUC)

Michigan Department of Agriculture and Rural Development (MDARD)

Natural Resources Conservation Service (NRCS)

Nonpoint Source (NPS)

Total Phosphorus (TP)

U.S. Department of Agriculture (USDA)

Water and Sediment Control Basin (WASCOB)

Western Lake Erie Basin (WLEB)

1 INTRODUCTION

The Alliance for the Great Lakes (AGL) and LimnoTech, with guidance from MDARD and EGLE, developed agricultural conservation practice implementation strategies aimed at reducing NPS phosphorus loads from five priority subwatersheds in Michigan's Western Lake Erie Basin (WLEB): Headwaters Saline River (HUC 041000020401), S.S. LaPointe Drain (HUC 041000010206), Lime Creek (HUC 041000060105), Nile Ditch (HUC 041000020303), and Stony Creek-South Branch River Raisin (HUC 041000020202) (Figure 1). These subwatersheds were selected by MDARD and EGLE for more focused and accelerated activities including finer-scale water quality monitoring, completing agricultural inventories, prioritized BMP implementation, and assessing the costs associated with full implementation to achieve a 40 percent total phosphorus (TP) load reduction goal in each of the selected subwatersheds.

This work was preceded by and builds upon recent efforts by the AGL, in partnership with the Ohio Environmental Council and technical assistance from the Delta Institute and LimnoTech, to estimate the necessary acres of conservation practices and the associated costs required in Ohio and Michigan to meet the 40% TP reduction goal for the Western Basin. That analysis – like the one described here – utilized geospatial datasets and other information produced by the State of Michigan as part of an agricultural inventory process being executed in priority subwatersheds over the last several years. Joining these two initiatives together, this project sought to prioritize individual fields based on potential for elevated TP loading, create strategic agricultural best management practice (BMP) conservation scenarios at a localized subwatershed scale, estimate the level of adoption needed to achieve TP load reduction goals, and report the annualized costs associated with implementation. The project team consulted with MDARD and EGLE staff throughout this project to understand geospatial data and information provided, develop scenarios consisting of appropriate and implementable BMP targets, and to provide an independent critique of the methodology and results.

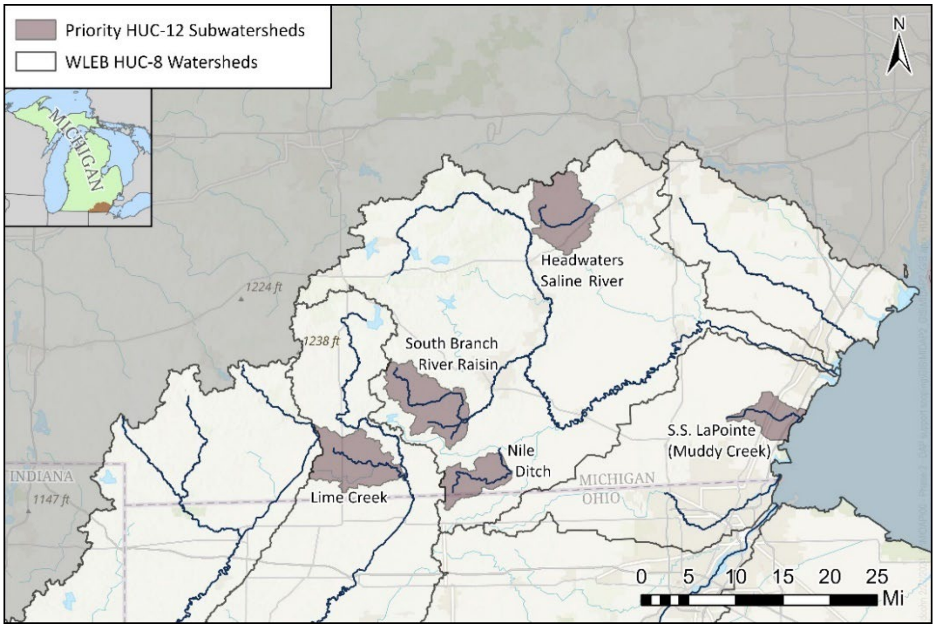

Figure 1. Overview map depicting five priority HUC-12 subwatersheds.

2 TECHNICAL APPROACH

The following provides an overview of the geospatial datasets and assumptions used to develop the hypothetical conservation scenarios, the field prioritization process, and scenario development for each of the priority subwatersheds. Geospatial datasets used are described below and included: output from the Agricultural Conservation Planning Framework (ACPF); field inventories completed using windshield surveys; a desktop analysis of livestock operation locations; and the presence of existing grassed waterways and riparian filter strips. Producing these datasets has been a priority action by the State in its efforts to create more focused implementation of activities to address NPS TP loading (State of Michigan 2021, State of Michigan 2024). The process of compiling the best available information regarding the potential for higher TP losses from agricultural fields and using it to prioritize farms for conservation measures represents an important component to achieving Michigan's 40% TP load reduction goal.

2.1 Agricultural Conservation Planning Framework

The ACPF tool – supported by USDA NRCS and other partners – utilizes high-resolution digital elevation models (DEMs) and other geospatial datasets to aid in agricultural conservation practice decision making. The Environmental Working Group (EWG) initiated use of ACPF in Southeast Michigan's subwatersheds by digitizing individual field boundaries from aerial photographs. ACPF applications were available for each of the five priority HUC-12 subwatersheds evaluated in this project. Available output from ACPF provided by EGLE included: maps of concentrated surface flow pathways; field slope, soil, and crop rotation characteristics; distance to surface waterbodies; a runoff risk metric; and prioritize locations for grassed waterways, nutrient removal wetlands, and water and sediment control basins (WASCOBs) within the priority subwatersheds.

2.2 Fall Tillage and Spring Residue

Windshield surveys were completed by Lenawee Conservation District staff under guidance from EGLE across over one-thousand fields spanning the Nile Ditch, Stony Creek-South Branch River Raisin, and LaPointe Drain HUC-12 subwatersheds. These surveys included two fall tillage surveys and two spring residue surveys. The windshield survey protocols were developed by EGLE's Nonpoint Source Program and involves visual field inspection during two key times of the year when field conditions are visible enough to record the tillage practice, use of a cover crop, presence of spring residue, and crop grown. Windshield survey results were not yet available for the Headwaters Saline River HUC-12 and those for the Lime Creek HUC-12 were not used in the field prioritization analysis due to quality concerns.

2.3 Cropland Data Layer

To supplement the information provided by the windshield surveys and in absence of the windshield survey information for a subset of the priority subwatersheds (i.e., Lime and Headwaters Saline), we used the most recent six years of crop rotations from the Cropland Data Layer (CDL) as compiled in the ACPF. Crop rotations that use only a mono-crop rotation (i.e., corn only or soybeans only) or that do not occasionally rotate hay or wheat, for example, may be at risk for elevated TP loading due to relatively greater amounts of P fertilizer or manure application or relatively lower amounts of residue left on the ground surface. A summary of the acres for different crop rotation patterns from the CDL is listed in Table 1 below. While monocrops of corn or soybeans were relatively infrequent, over half the fields never had wheat mixed into rotations of primarily corn and soybeans. On average across all six years, land in soybeans or corn made up 64% of the area evaluated, followed by alfalfa/hay/pasture (15%), wheat (11%), and idle/unplanted fields (8%).

Table 1. Summary of Cropland Data Layer information for agricultural fields in the five priority subwatersheds.

Crop rotation description	Acres	Percent
Continuous soybeans	3,375	5%
Continuous corn	794	1%
Corn-soybean rotation only	13,731	19%
Mostly corn-soybean rotation (one off year)	29,767	41%
Two or more years wheat, alfalfa/hay, or pasture	25,805	35%

2.4 Livestock Operations

Another component of the field prioritization process was an assessment of the potential for manure application based on proximity to livestock operations. Numerous livestock operations of varying sizes and animal type are present throughout the priority subwatersheds. This analysis relied on maps of regulated concentrated animal feeding operations (CAFOs) shown on an EGLE web dashboard, an interactive web map developed by Environmental Working Group (EWG), and Bean Creek watershed management plan (Blonde and Cleland 2019) to identify livestock operations. We also used satellite imagery to identify additional locations not represented in these three sources.

This analysis identified 102 livestock operation locations across the priority subwatersheds (Figures B-1 to B-3). No operations were identified in the LaPointe HUC-12 subwatershed. The South Branch River Raisin and Lime Creek subwatersheds both have relatively high densities of operations including regulated CAFOs. The Headwaters Saline River subwatershed also had relatively large number of operations, but none are regulated CAFOs. The Niles Ditch subwatershed had a low number of operations and no CAFOs, though one CAFO in Ohio sits within a few hundred feet of the watershed divide.

An additional geospatial analysis was performed using the livestock locations. This analysis involved creating a one-mile radius (buffer) around the livestock operations and determining which fields overlapped with this buffer (Figures B-1 to B-3). This field proximity to the priority operations was used as a proxy to determine likelihood that manure would be applied to a given field (i.e., the closer a field is to a livestock operation, the more likely it is to receive manure application, and vice versa). Our analysis assumes that fields closest to an operation are relatively more likely to receive manure applications due to the costliness in transporting most manures long distances and/or potential ownership of those fields by the livestock operator. However, as with other assumptions used during this project, the presence of manure application should be validated by conservation specialists when working with farmers.

2.5 Riparian Filter Strips, Grassed Waterways, and WASCOBs

Desktop analyses were completed to estimate the percentage of certain in-field and edge-of-field structural practices that were already adopted on fields where these BMPs are recommended based on either proximity to surface waterbodies (i.e., riparian filter strips) or based on suggestions by the ACPF tool (i.e., grassed waterways and WASCOBs).

The presence of vegetated filter strips in the area between crop fields and surface waterbodies (i.e., the riparian zone) functions to slow and distribute overland flow, resulting in both removal of particulate pollutants via settling / filtration and the reduction of dissolved pollutants via infiltration. When riparian filter strips are inadequate or absent, overland flow leaving cropland is discharged directly into surface waterbodies without opportunity for pollutant removal. Edge-of-field research in the WLEB indicates that approximately half of average annual TP loss from agricultural lands is from overland flow (Pease et al. 2018, Apostle et al. 2021), which suggests the importance of vegetated filter strips especially for fields prone to surface runoff during significant rain events.

A desktop analysis was performed to estimate the percentage of fields within a 50-foot distance of surface waterbodies that have an adequate (30-foot width) riparian filter strip. This was done by setting a 50-ft buffer on NHD+ scale streamlines (e.g., streams and creeks) and intersecting this buffer with the fields used in the field prioritization analysis. A total of 898 fields (32%) met this criterion. The project team then used geospatial measuring tools and manual inspection of recent satellite imagery to determine whether a 30-foot riparian filter strip was present and if the vegetation in that strip was mostly grass or similar ground cover. Trees, shrubs, or similar woody vegetation with potentially sparse understory vegetated density were not considered adequate because they do not meet NRCS conservation practice standard #393 (filter strip) requirements. Figure 2 shows example fields with adequate and inadequate riparian filter strips.

Figure 2. Example fields analyzed in priority subwatersheds depicting adequate (left, "YES") and inadequate (right, "NO") riparian filter strips.

Grassed waterways and WASCOBs within crop fields convey and/or slow concentrated overland flow that runs off during significant rain events into surface waterbodies. Grassed waterways and WASCOBs improve water quality through removal of particulate pollutants via settling and filtration and dissolved pollutants via infiltration. By slowing and/or spreading overland flow over a larger area, these practices also prevent field erosion and ephemeral gully formation in the areas of the field where implemented. These areas are prone to soil losses, especially when little or no surface residue is present.

A desktop analysis was performed to estimate the percentage of grassed waterways and WASCOBs recommended by the ACPF tool that are already implemented across the landscape of each priority subwatershed. The project team randomly selected approximately 25% of the grassed waterway recommendations in each subwatershed and 40% of the WASCOB recommendations and then used manual inspection of recent satellite imagery to determine whether these practices were present in the approximate locations suggested by ACPF. Figure 3 below shows example fields with grassed waterways and WASCOBs present and absent in the priority subwatersheds.

Figure 3. Example fields analyzed in priority subwatersheds depicting absence ("NO") and presence ("YES") of grassed waterways (left, green) or WASCOBs (right, purple) in approximate locations suggested by ACPF.

The geospatial analyses of existing riparian filter strips, grassed waterways, and WASCOBs was used when constructing the conservation scenarios to not overestimate the number of additional practices that might be installed (i.e., if a certain percentage were already implemented in the priority subwatersheds). As described above, about 25% of the fields with an ACPF-suggested grassed waterways and 40% of the ACPF-suggested WASCOBs were subsampled and compared against satellite imagery to confirm how often grassed waterways were present, and all fields within 50 feet of a NHD+ surface waterbody were analyzed for presence of riparian filter strips. Table 2 summarizes the results of these analyses.

The LaPointe Drain and Headwaters Saline River subwatersheds were found to have relatively few fields with sufficient riparian filters, while the Lime Creek and Stony Creek-South Branch River Raisin had the highest adoption rates at 37% and 35%, respectively. A total of 550 of the 2086 ACPF-suggested grassed waterways were reviewed and results were compiled for each priority subwatershed. The Lime Creek subwatershed stood out with 47% of the locations suggested by ACPF as being good candidates for grassed waterways already having these practices implemented, while grassed waterways were nearly absent in the Nile Ditch and LaPointe Drain subwatersheds. The Lime Creek and Stony Creek-South Branch River Raisin also had the rates of implemented WASCOBs at about half of those suggested by ACPF, while no WASCOBs were identified near locations suggested by ACPF for the Headwaters Saline River and LaPointe Drain subwatersheds.

Table 2. Percentages of riparian filter strips, grassed waterways, and WASCOBs implemented within fields analyzed for presence or absence of these BMPs for each of the five priority subwatersheds.

HUC-12 Subwatershed	Sufficient Riparian Filters	Implemented Grassed Waterways	Implemented WASCOBs
Nile Ditch	28%	1%	33%
Stony Creek - S. Branch River Raisin	35%	17%	52%
Lime Creek	37%	45%	49%
LaPointe Drain	10%	1%	0%
Headwaters Saline River	9%	10%	0%

2.6 Phosphorus Modeling Approach

To estimate the baseline TP loading for each priority subwatershed, this analysis used predictions from two common watershed models: the Soil and Water Assessment Tool (SWAT) and Spatially-Referenced Regression on Watershed Attributes (SPARROW). Like the first phase of the Cost-to-Comply project, NHD+ catchment scale TP load estimates for non-agricultural sources (i.e., urban, natural, and wastewater) were based on a SPARROW model developed by USGS researchers (Robertson and Saad 2019). To represent the potential for variability in field-scale TP loading, this phase of work used SWAT-based TP loading estimates for agricultural areas. This hybrid modeling approach provides greater spatial resolution for agricultural parcels than the regression-based model approach by allowing for representation of the greater complexity of a mechanistic model without the time or resource constraints of developing a full watershed model.

We relied on hydrologic response unit (HRU) output from LimnoTech's Maumee River Watershed SWAT model to generate a TP yield distribution curve (Figure 4). This Maumee River Watershed application of the SWAT model has been enhanced over the years and used in several studies including Scavia et al. (2017), Wilson et al. (2018), Martin et al. (2021), and Kujawa et al. (2022). This analysis utilized annual average TP yields (kg/ha/yr) from the latest version of the model as used in by Martin et al. (2021). To ensure reasonableness of our SWAT model-based TP yield distribution curve, we compared the range of values (i.e., approximately 0.5-4.0 kg/ha/year) to both the NHD+ catchment scale SPARROW model's distribution of agricultural TP yields (Robertson and Saad 2019, Figure B-14) and edge-of-field monitoring-based TP yields reported in peer-reviewed literature by USDA ARS researchers (Pease et al. 2018, Figure B-15). Both the SPARROW model-based and edge-of-field monitoring-based comparisons showed favorable agreements with the TP yield distribution curve used in this study (Figure B-16).

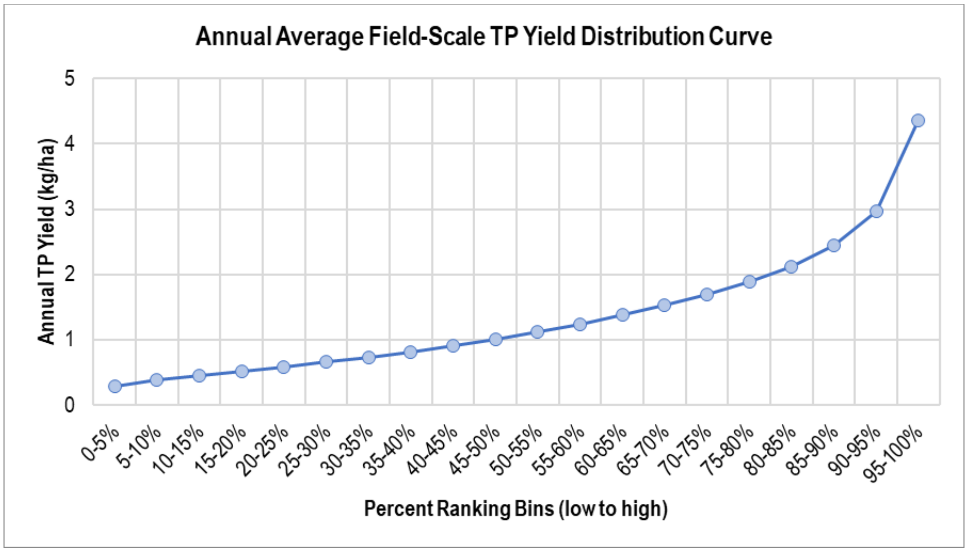

Figure 4. Annual TP yield distribution curve used to estimate loads for agricultural parcels in this study.

2.7 Field Prioritization

The field prioritization process completed during this study primarily aided in estimating baseline TP loading and projecting TP load reductions for strategic implementation scenarios, but it can also be used in future efforts to accelerate conservation adoption in the priority subwatersheds. The field prioritization process builds on work by EGLE and others piloted for the Bean Creek watershed management plan (Blonde and Cleland 2019, Cleary 2021).

As described above, several datasets were used in the final prioritization process to give each field in the priority subwatersheds a score based on its risk of potential elevated TP loading to the drainage system and eventually Lake Erie. An illustration of the nine characteristics used in this process, including traits that would result in relatively higher versus lower priority is illustrated in Figure 5. The detailed scoring system is detailed in Table 3 and resulted in a gradient of low-to-high scores for the nearly three-thousand agricultural parcels evaluated where a low score indicates lower likelihood or risk of TP losses, and a higher score indicates higher risk of TP losses. The criteria for scoring individual characteristics within each of the nine categories and the weighting to the overall score were determined based on the distribution of results from the geospatial analyses described above and based on feedback from MDARD and EGLE. For subwatersheds where information was not available for a given category, such as lack of windshield survey data for the Headwaters Saline River and Lime Creek, field scores were prorated based on the maximum possible score for those subwatersheds so that all fields in all subwatersheds were ranked on a scale of zero to one hundred. Based on the final distributions of scores, each agricultural parcel was assigned a baseline TP yield estimate using the TP yield distribution curve. Similar to the livestock operation analysis discussed above, Figure 5 is intended to serve as a starting point for conservation professionals to assess relative TP loss risk from a particular field.

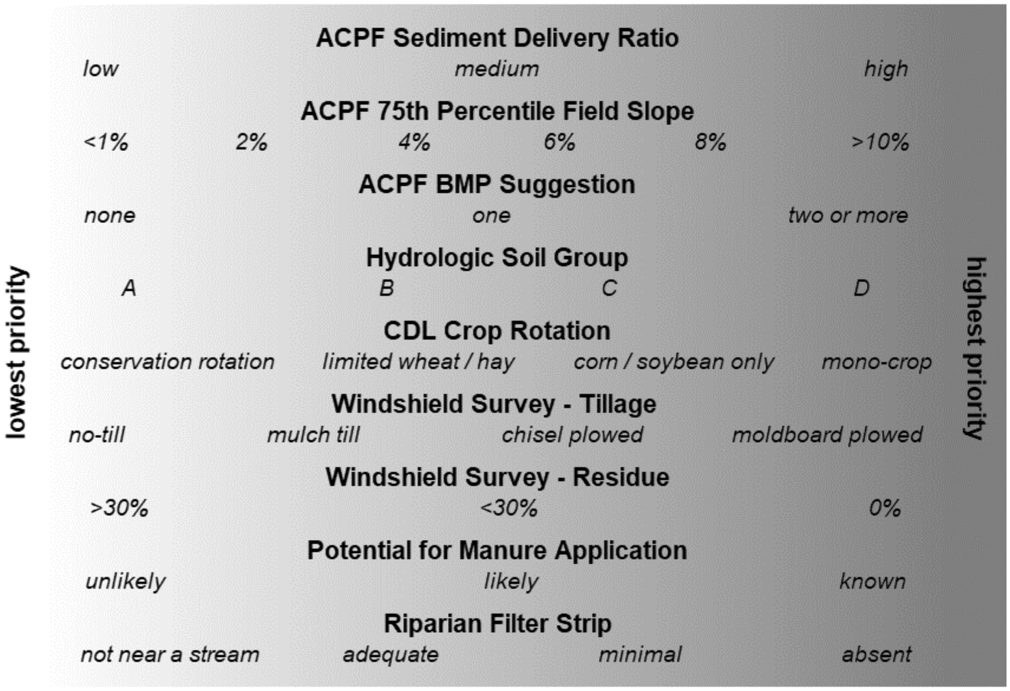

Figure 5. Illustration of the decision matrix used in the process to prioritize fields.

Table 3. Field prioritization scoring categories and weighting factors used in this study.

Category	Scoring Details	Weighting to Overall Score
ACPF Sediment Delivery Ratio	If >0.60, set to maximum of 15. Otherwise, linear interpolation to assign score of 1 to 10 based on sediment delivery ratio range (0.17 to 0.60).	15
ACPF 75th percentile slope	Score equal to 75th percentile slope, up to a maximum score of 10.	10
ACPF BMP suggestion	15 = two or more BMPs suggested 10 = one BMP suggested 0 = no BMPs suggested	15
Hydrologic Soil Group	10 = group D soils 8 = group C, A/D, B/D, or C/D soils 4 = group B soils 0 = group A soils	10
Cropland Data Layer rotation	10 = 5 or 6-year soybeans only 8 = 5 or 6-year corn only 7 = corn-soybean mix only 5 = corn-soybean with 1-year wheat, alfalfa/hay, or pasture 3 = 2-3 years wheat, alfalfa/hay, or pasture 0 = 4-6 years wheat, alfalfa/hay, or pasture	10
Windshield survey – fall tillage	10 = plowed or chisel plowed 5 = strip till or mulch till 0 = no-till or planted	10
Windshield survey – spring residue	10 = 0% residue 5 = less than 30% residue 0 = greater than 30% residue or planted with no-till method	10
Proximity to livestock operation	10 = within one mile 0 = not within one mile	10
Riparian filter strip assessment	10 = within 50-feet of surface waterbody and “no” filter 5 = within 50-feet of surface waterbody and “yes” filter 0 = not within 50-feet of surface waterbody	10
TOTAL		**100**

2.8 Scenario Development

Similar to earlier phases of this work, we constructed hypothetical conservation scenarios – and associated costs – that could be implemented in the priority subwatersheds. A total of nine different BMPs were included, representing a mix of in-field non-structural BMPs, in-field structural BMPs, edge-of-fields structural BMPs, and structural BMPs capturing runoff from multiple fields. Table 4 summarizes the BMPs selected and associated TP load reduction efficiencies, unit costs, and adoption level estimates. TP reduction efficiencies and adoption level estimates were informed by several studies completed over the last decade to assess agricultural nutrient management strategies in the WLEB by researchers with different academic and government institutions. These studies are summarized in the phase one report (AGL and OEC 2023). Current BMP implementation rates for riparian filter strips, grassed waterways, and WASCOBs were updated based on the results of the desktop analyses described in Section 2.5. Unit costs for individual BMPs were determined based on the USDA NRCS Environmental Quality Incentives Program (EQIP) 2024 practice standard payment schedules for Michigan (USDA NRCS 2024).

Consistent with methodology used in previous analyses, the scenarios we developed suggested the need for "stacking" multiple BMPs on a single agricultural parcel (e.g., up to three in-field BMPs plus one ore mor structural BMPs) to achieve the needed TP load reductions. Our approach of "stacking BMPs" uses a multiplicative approach, like that used in the Chesapeake Bay Program, which assumes incremental rather than additive reductions of individual BMPs (CPB 2018). Using the multiplicative approach, for example, if a field loses an average of 2.0 lbs of TP/acre and BMP1 reduces the TP loss by 20% (now 1.6 lbs TP/acre of original loss) and BMP2 reduces the remaining TP by 30% (now 1.12 lbs TP/acre of original loss), the overall remaining loss is 56% of the original load and an overall TP reduction efficiency of 44% rather than a simple addition of TP losses.

In recognition of the strategic conservation planning approach, the scenarios we developed sought to optimize the cost-effectiveness of conservation spending by stacking multiple BMPs on the areas identified from the field prioritization process as having the highest TP loading probability, thereby achieving greater TP reductions than a randomized implementation strategy. We also assumed the strategic scenarios would result in structural BMP placement as suggested by the ACPF tool, unless a BMP was already implemented in that location as identified from our analysis of riparian filter strips and grassed waterways. Lastly, the conservation scenarios created sought to implement higher proportions of the most cost-effective practices while limiting the magnitude of implementation of any one BMP based on feedback from MDARD, EGLE, and other conservation professionals knowledgeable about what BMPs are most likely to be adopted in certain areas. The increase in BMP adoption relative to current conditions was implemented for each scenario at a large enough scale so that the TP load reduction goals were achieved, which meant even the relatively lower scoring fields from the prioritization process were assigned new BMPs.

Table 4. BMP descriptions, TP removal efficiencies[1], unit costs, and adoption level estimates[2].

Category	BMP Description	TP Removal Efficiency	Unit Cost	Lifespan	Baseline (2008) Adoption Level	Current (2020) Adoption Level
In-Field Management	No-Till	30%	$27/acre	1 year (annual)	32%	32%
	Cover Crops	25%	$62/acre	1 year (annual)	4%	8%
	Conservation Crop Rotation	25%	$11/acre	1 year (annual)	5%	5%
	Precision Nutrient Management	20%	$60/acre	1 year (annual)	20%	20%
In-Field Structural	Grassed Waterway	20%	$4/foot	20 years	≤13%	13%
	WASCOBs	20%	$11,452/acre	20 years	≤35%	35%
Edge-of-Field Structural	Filter Strips	35%	$216/acre	20 years	25%	30%
	Drainage Water Management	20%	$90/acre treated	20 years	0%	<1%
Multi-Field Structural	Constructed Wetlands	40%	$14,204/acre	20 years	0%	<1%

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[1] Bosch et al. 2011; Bosch et al. 2013; Bosch et al. 2014; Pyo et al. 2017; Sommerlot et al. 2013; Woznicki et al. 2015; Scavia et al. 2016; Wilson et al. 2017; Daggupati et al. 2015; USDA NRCS 2016; Keitzer et al. 2016; Yen et al. 2016; USDA NRCS 2017; Christopher et al. 2017; Merriman et al. 2018, Muenich et al. 2017; Martin et al. 2019; Martin et al. 2021

[2] Wilson et al. 2013; Burnett et al. 2015; USDA NRCS 2016; USDA NRCS 2017; Prokupy et al. 2017; Beetstra et al. 2018; Burnett et al. 2018; Wilson et al. 2018; State of Ohio 2020; Martin et al. 2021

3 RESULTS AND DISCUSSION

Results and brief discussion are provided below for the field prioritization analysis, estimates of baseline TP loading, and the implementation scenarios.

3.1 Field Prioritization Discussion

Results of the field prioritization process implemented on the priority subwatersheds are shown in Figures 6 through 9. Notably, the process does not factor in certain components that are not readily known such as landowner willingness to adopt and additional field characteristics like nutrient management (planning, soil testing, application technique, manure application rates) and tile drainage (presence, depth, spacing, diameter). These characteristics and those estimated by the approaches described above should be verified by the conservation professionals working with farmers in the WLEB on their conservation strategy.

Future enhancements to the field prioritization process could include integration of soil phosphorus levels or tile drainage system characteristics (should estimates become available), updated windshield survey results for priority subwatersheds where these data were not available, recent enhancements to the ACPF output such as a soil erosion vulnerability metric, and better accounting for current areas where BMPs are adopted (e.g., at a field or farm scale) should that information become available as part of improved tracking.

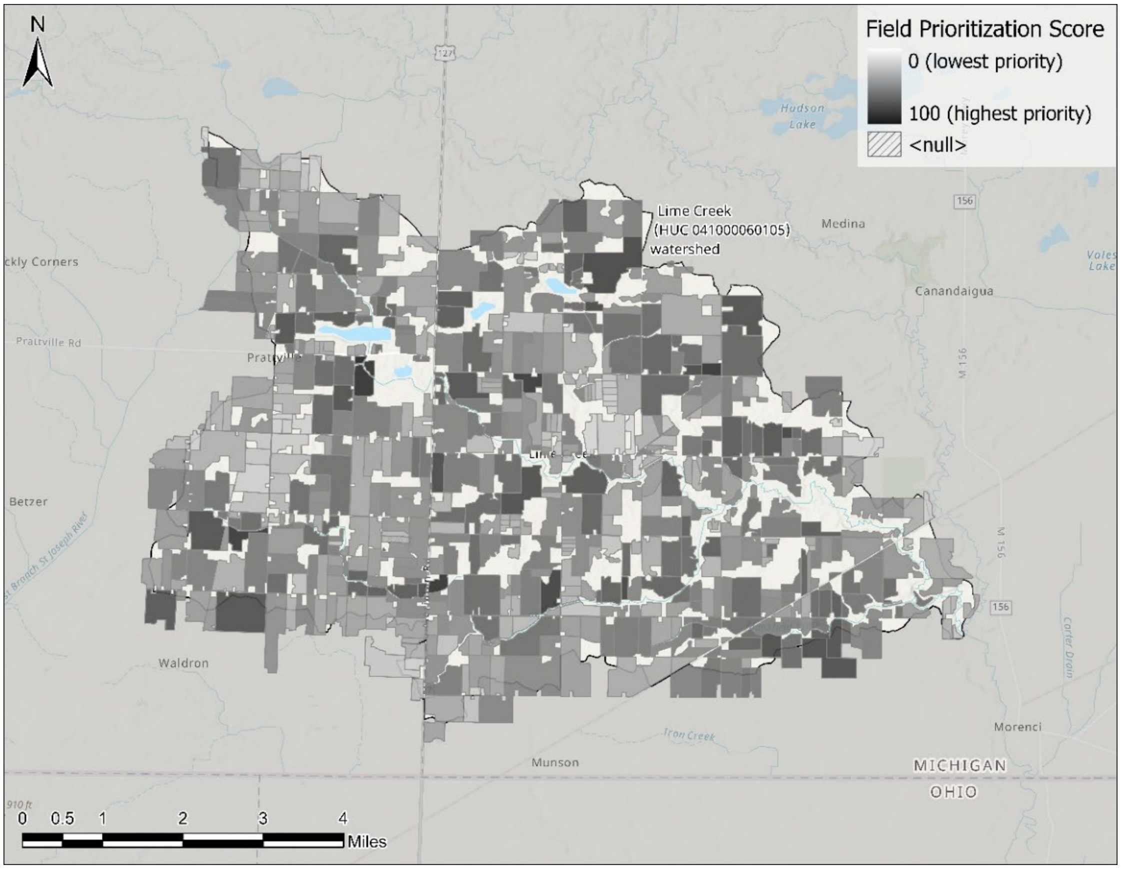

Figure 6. Field prioritization results for the Lime Creek subwatershed.

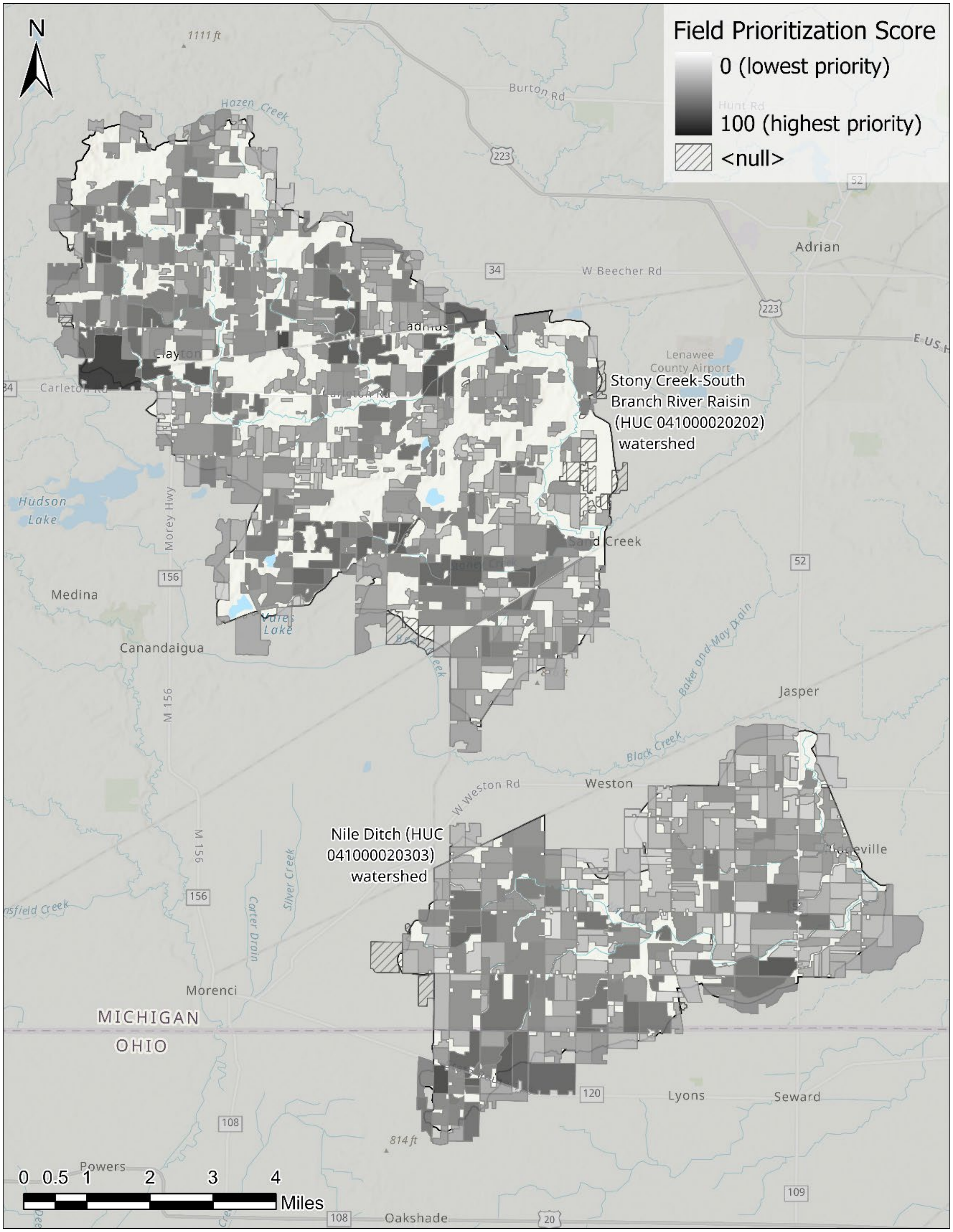

Figure 7. Field prioritization results for the Nile Ditch and Sony Creek-South Branch River Raisin subwatersheds.

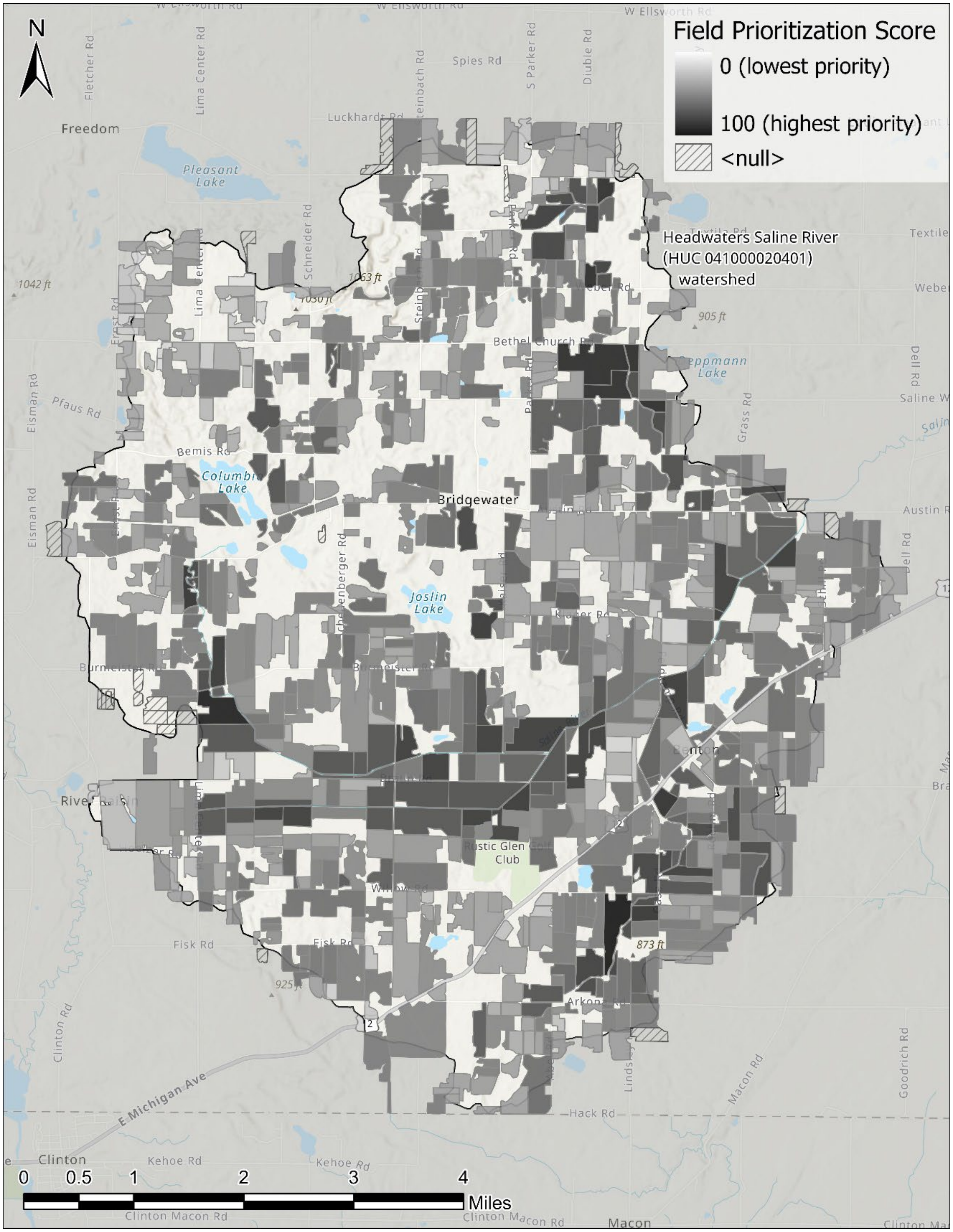

Figure 8. Field prioritization results for the Headwaters Saline River subwatershed.

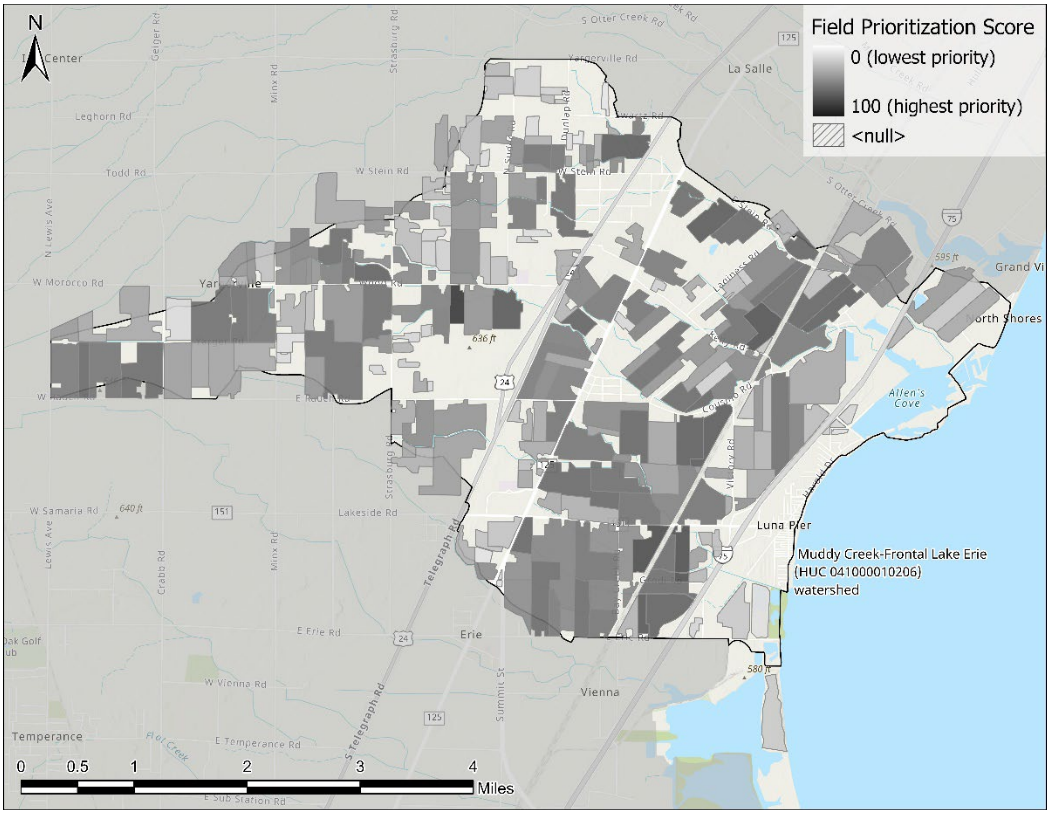

Figure 9. Field prioritization results for the S.S. LaPointe Drain subwatershed.

3.2 Model Baseline TP Load Estimates

Average annual baseline TP load estimates for each of the priority subwatersheds, including a breakdown between the load estimated for agricultural lands and other sources, is summarized in Table 5. The Nile Ditch and LaPointe Drain HUC-12s had relatively lower TP loads due to the smaller areas of these subwatersheds compared to the other three subwatersheds. Minor point sources were associated with the Lime Creek, South Branch River Raisin, and LaPointe Drain subwatersheds. The Lime Creek subwatershed had the greatest proportion of its total load from agricultural lands, while the LaPointe Drain subwatershed had the lowest proportion of its total load from agriculture due to relatively higher loading estimated from urban/developed NPS and the Luna Pier WWTP point source.

Table 5. Baseline TP load estimates (MT/year) for priority subwatersheds

HUC-12 Subwatershed	Total	Agricultural Land	Non-Agricultural Land	Point Sources
Nile Ditch	6.74	5.83	0.91	0
Stony Creek - South Branch River Raisin	13.05	10.03	2.48	0.54
Lime Creek	16.98	13.44	3.26	0.28
LaPointe Drain	10.24	6.72	3.22	0.30
Headwaters Saline River	14.60	12.28	2.32	0

3.3 Implementation Scenarios

Table 6 summarizes the magnitude of implementation for nine BMPs, TP load reduction estimates, and costs associated with three hypothetical conservation scenarios for the combined five priority HUC-12 subwatersheds. Tables A-1 to A-3 in the appendix provide a more detailed breakdown of this information for each of the priority subwatersheds individually. Overall, the results suggest that TP load reductions on the order of 45–49% could be achieved at a cost of $8.6–9.3 million per year for the combined five priority subwatersheds. Relative to the total NPS TP load reduction planned in Michigan’s DAP update (i.e., 222 MT/year), the TP load reductions from these five priority subwatersheds could account for as much as 14% of that total NPS load reduction need.

These strategically placed conservation scenarios seek to optimize the cost-effectiveness of conservation spending by stacking multiple BMPs in areas of the subwatersheds where the field prioritization results suggested relatively high probability for elevated TP loading, thereby achieving greater TP reductions than a randomized implementation strategy. The scenarios also relied on the ACPF tool for optimally placing several of the structural BMPs represented. When we constructed a second set of three conservation scenarios using a randomized approach for assigning BMPs at a similar magnitude as the optimally planned scenarios, it suggested lower TP load reductions of 40-44% (compared to 45-49% for targeted placement of practices) for a similar cost of $8.6–9.3 million per year. Tables A-4 to A-7 in the appendix provide a detailed breakdown of the information for the random scenarios. This trend is similar to our previous analyses that found targeting conservation practices to highest potentially loading fields results in greater cost efficiency.

Table 6. Comparison of BMP implementation rates (area and percent of agricultural land impacted), TP reductions, and annual costs for three strategic implementation scenarios.

Category	BMP Description	Strategic Scenario 1		Strategic Scenario 2		Strategic Scenario 3	
In-Field Management	Continuous No-Till	47,320 acres	53%	25,475 acres	28%	49,218 acres	55%
	Cover Crops	34,734 acres	39%	47,280 acres	53%	39,384 acres	44%
	Conservation Crop Rotation	45,402 acres	50%	23,866 acres	27%	50,623 acres	56%
	Precision Nutrient Management	56,861 acres	63%	67,436 acres	75%	67,436 acres	75%
Edge-of-Field Structural	Riparian Filter Strips	539 acres		539 acres		267 acres	
	Drainage Water Management	16,307 acres	18%	13,696 acres	15%	8,370 acres	9%
In-Field Structural	Grassed Waterways	133 miles		133 miles		82 miles	
	Water & Sediment Control Basins	20 acres		20 acres		10 acres	
Multi-Field Structural	Constructed Wetlands	734 acres		836 acres		180 acres	
-	**TP Reduction**	**49%**		**47%**		**45%**	
-	**Annual Cost**	**$8,613,000**		**$9,302,000**		**$8,812,000**	

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APPENDIX A: SUPPLEMENTAL TABLES

Table A-1: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for strategic scenario #1.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	6,670	8,750	11,857	8,651	11,392	acres
	Cover Crops	3,726	5,885	9,986	5,790	9,347	acres
	Conservation Crop Rotation	7,698	12,684	11,301	6,549	7,169	acres
	Precision Nutrient Management	7,949	13,150	15,055	8,795	11,912	acres
Edge-of-Field Structural	Riparian Filter Strips	82	127	155	63	113	acres
	Drainage Water Management	779	1,910	3,857	7,105	2,657	acres
In-Field Structural	Grassed Waterways	20	19	15	14	65	miles
	Water & Sediment Control Basins	1.0	9.2	4.6	0.1	5.4	acres
Multi-Field Structural	Constructed Wetlands	16	124	216	0	378	acres
-	**TP Reduction**	**50%**	**46%**	**49%**	**40%**	**58%**	
-	**Annual Cost**	**$1,034,000**	**$1,739,000**	**$2,290,000**	**$1,273,000**	**$2,278,000**	

Table A-2: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for strategic scenario #2.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	2,649	3,726	6,924	5,092	7,084	acres
	Cover Crops	5,650	10,220	12,860	7,647	10,904	acres
	Conservation Crop Rotation	3,628	6,224	5,973	2,976	5,065	acres
	Precision Nutrient Management	11,334	15,209	17,230	10,971	12,694	acres
Edge-of-Field Structural	Riparian Filter Strips	82	127	155	63	113	acres
	Drainage Water Management	379	1,082	2,927	7,105	2,204	acres
In-Field Structural	Grassed Waterways	20	19	15	14	65	miles
	Water & Sediment Control Basins	1.0	9.2	4.6	0.1	5.4	acres
Multi-Field Structural	Constructed Wetlands	60	124	216	58	378	acres
-	**TP Reduction**	**48%**	**43%**	**47%**	**39%**	**56%**	
-	**Annual Cost**	**$1,254,000**	**$1,918,000**	**$2,400,000**	**$1,453,000**	**$2,278,000**	

Table A-3: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for strategic scenario #3.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	6,924	9,198	12,512	8,931	11,654	acres
	Cover Crops	4,441	7,217	11,211	6,518	9,997	acres
	Conservation Crop Rotation	10,603	12,907	11,808	7,936	7,369	acres
	Precision Nutrient Management	11,334	15,209	17,230	10,971	12,694	acres
Edge-of-Field Structural	Riparian Filter Strips	44	67	75	25	56	acres
	Drainage Water Management	379	727	2,383	3,270	1,611	acres
In-Field Structural	Grassed Waterways	13	13	9	9	38	miles
	Water & Sediment Control Basins	0.5	4.9	2.7	0.1	2.3	acres
Multi-Field Structural	Constructed Wetlands	30	40	46	29	35	acres
-	**TP Reduction**	**49%**	**42%**	**45%**	**39%**	**49%**	
-	**Annual Cost**	**$1,322,000**	**$1,833,000**	**$2,289,000**	**$1,466,000**	**$1,900,000**	

Table A-4: Comparison of BMP implementation rates (area and percent of agricultural land impacted), TP reductions, and annual costs for three random implementation scenarios.

Category	BMP Description	Random Scenario 1		Random Scenario 2		Random Scenario 3	
In-Field Management	Continuous No-Till	44,950 acres	50%	25,743 acres	29%	49,756 acres	55%
	Cover Crops	35,974 acres	40%	47,735 acres	53%	39,298 acres	44%
	Conservation Crop Rotation	45,073 acres	50%	24,735 acres	27%	49,885 acres	55%
	Precision Nutrient Management	55,855 acres	62%	66,792 acres	74%	66,792 acres	74%
Edge-of-Field Structural	Riparian Filter Strips	573 acres		573 acres		287 acres	
	Drainage Water Management	17,239 acres	19%	13,214 acres	15%	8,032 acres	9%
In-Field Structural	Grassed Waterways	135 miles		135 miles		77 miles	
	Water & Sediment Control Basins	19 acres		19 acres		10 acres	
Multi-Field Structural	Constructed Wetlands	734 acres		836 acres		180 acres	
-	**TP Reduction**	**44%**		**42%**		**40%**	
-	**Annual Cost**	**$8,572,000**		**$9,308,000**		**$8,764,000**	

Table A-5: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for random scenario #1.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	7,581	9,689	11,616	8,091	7,972	acres
	Cover Crops	6,318	8,371	9,150	5,754	6,381	acres
	Conservation Crop Rotation	7,829	10,065	11,291	7,880	8,008	acres
	Precision Nutrient Management	9,249	12,561	14,056	9,861	10,129	acres
Edge-of-Field Structural	Riparian Filter Strips	94	129	159	75	116	acres
	Drainage Water Management	2,836	3,724	4,405	2,452	3,822	acres
In-Field Structural	Grassed Waterways	15	30	32	11	47	miles
	Water & Sediment Control Basins	2.5	4.7	3.9	1.8	6.2	acres
Multi-Field Structural	Constructed Wetlands	16	124	216	0	378	acres
-	**TP Reduction**	**48%**	**43%**	**44%**	**34%**	**51%**	
-	**Annual Cost**	**$1,308,000**	**$1,883,000**	**$2,204,000**	**$1,295,000**	**$1,881,000**	

Table A-6: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for random scenario #2.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	4,820	5,944	6,633	4,703	3,643	acres
	Cover Crops	8,117	10,595	12,100	8,214	8,709	acres
	Conservation Crop Rotation	4,585	5,311	6,326	4,264	4,249	acres
	Precision Nutrient Management	10,994	14,806	16,891	11,397	12,704	acres
Edge-of-Field Structural	Riparian Filter Strips	94	129	159	75	116	acres
	Drainage Water Management	2,074	2,888	3,228	2,014	3,011	acres
In-Field Structural	Grassed Waterways	15	30	32	11	47	miles
	Water & Sediment Control Basins	2.5	4.7	3.9	1.8	6.2	acres
Multi-Field Structural	Constructed Wetlands	60	124	216	58	378	acres
-	**TP Reduction**	**46%**	**41%**	**42%**	**33%**	**48%**	
-	**Annual Cost**	**$1,462,000**	**$1,996,000**	**$2,359,000**	**$1,475,000**	**$2,016,000**	

Table A-7: Detailed BMP implementation, TP reduction, and annual cost breakdown by priority subwatershed for random scenario #3.

Category	BMP Description	Nile Ditch	Stony / S. Br. River Raisin	Lime Creek	LaPointe Drain	Headwaters Saline	
In-Field Management	Continuous No-Till	8,614	11,084	12,458	8,399	9,200	acres
	Cover Crops	6,992	8,940	10,103	6,539	6,723	acres
	Conservation Crop Rotation	8,442	11,551	12,478	8,229	9,184	acres
	Precision Nutrient Management	10,994	14,806	16,891	11,397	12,704	acres
Edge-of-Field Structural	Riparian Filter Strips	52	69	75	34	57	acres
	Drainage Water Management	1,305	1,684	2,124	905	2,015	acres
In-Field Structural	Grassed Waterways	9	19	17	7	25	miles
	Water & Sediment Control Basins	1.3	2.6	2.2	1.1	3.0	acres
Multi-Field Structural	Constructed Wetlands	30	40	46	29	35	acres
-	**TP Reduction**	**45%**	**40%**	**40%**	**33%**	**42%**	
-	**Annual Cost**	**$1,483,000**	**$1,967,000**	**$2,219,000**	**$1,462,000**	**$1,634,000**	

APPENDIX B: SUPPLEMENTAL MAPS AND FIGURES

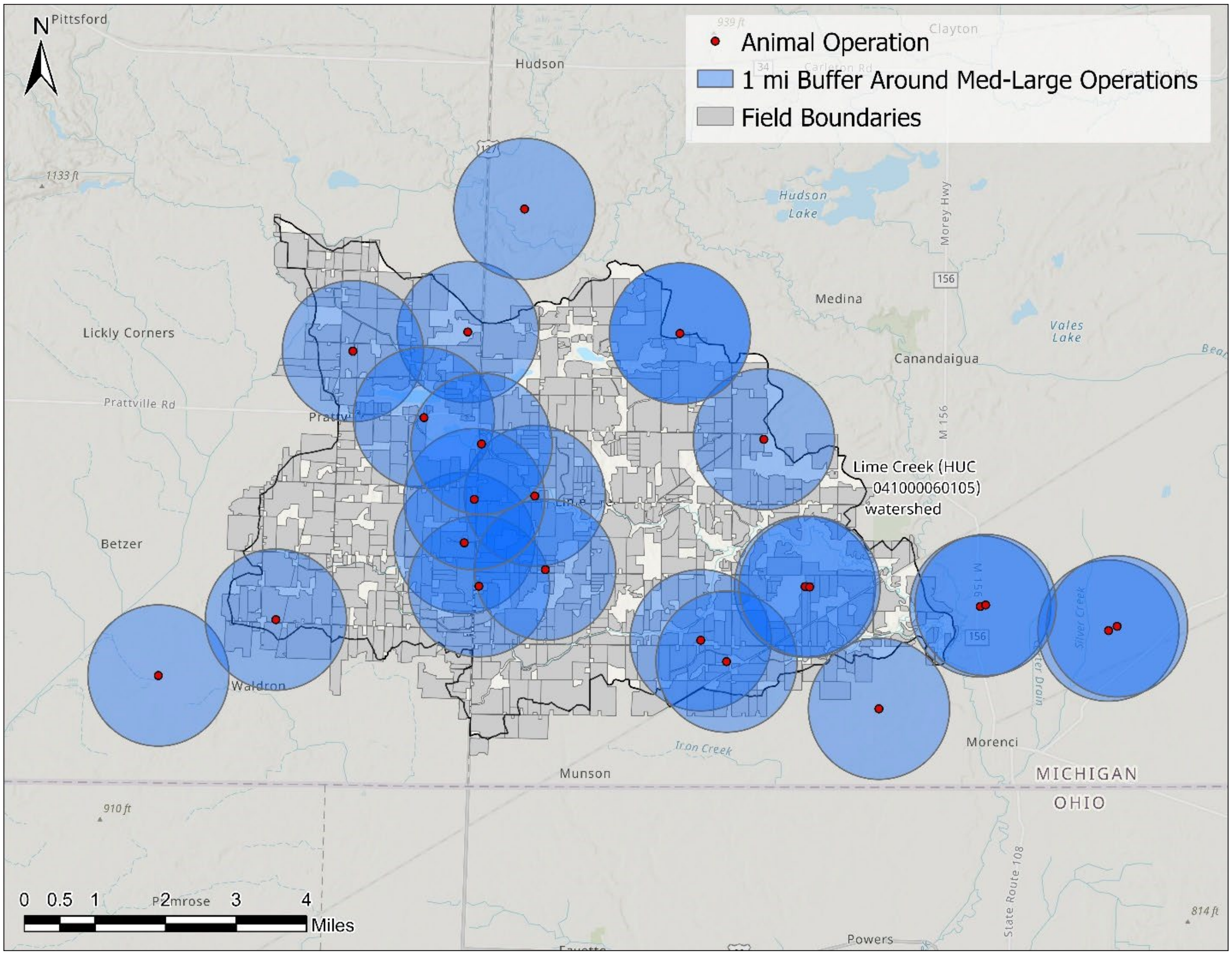

Figure B-1: Livestock operations identified in the Lime Creek subwatershed.

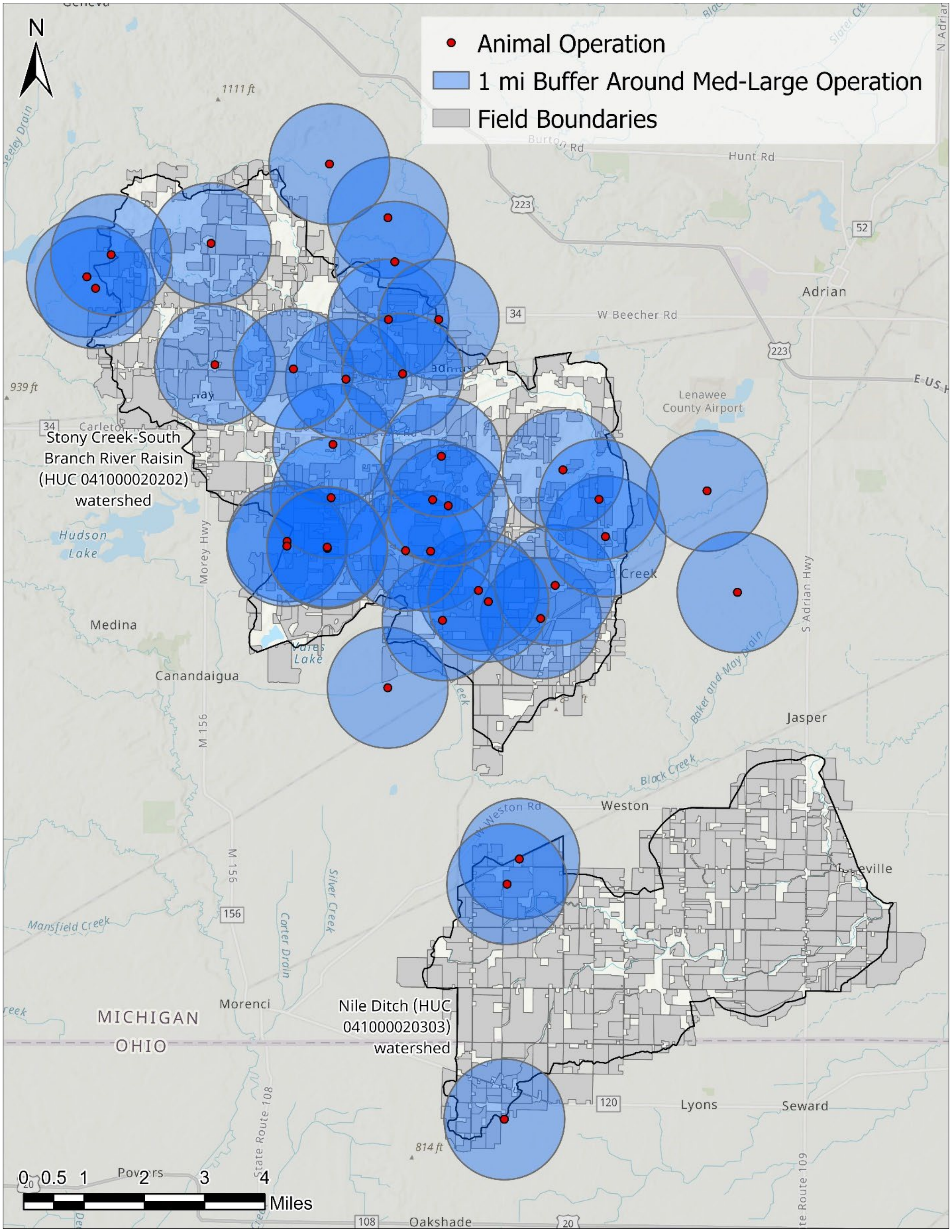

Figure B-2: Livestock operations identified in the Nile Ditch and Sony Creek-South Branch River Raisin subwatersheds.

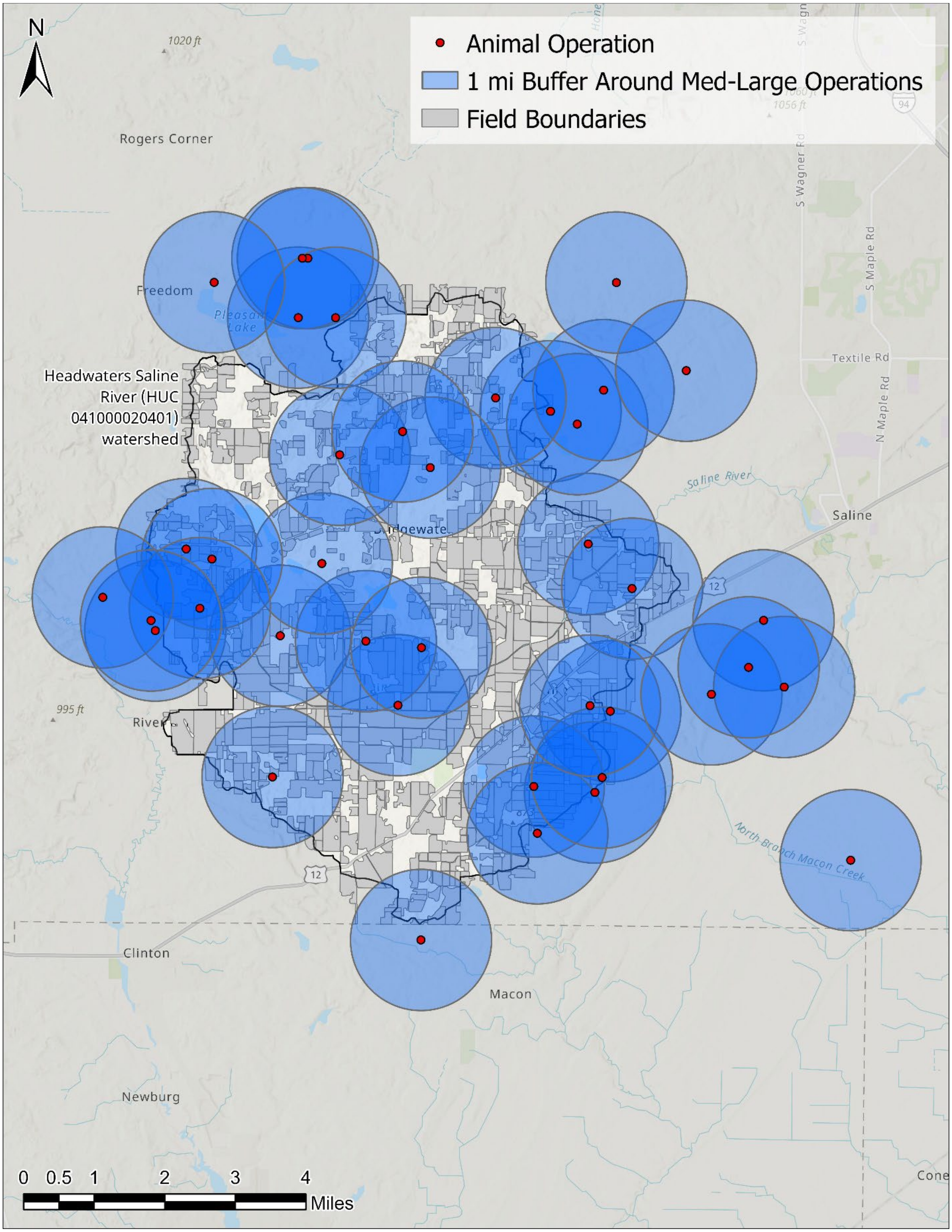

Figure B-3: Livestock operations identified in the Headwaters Saline River subwatershed.

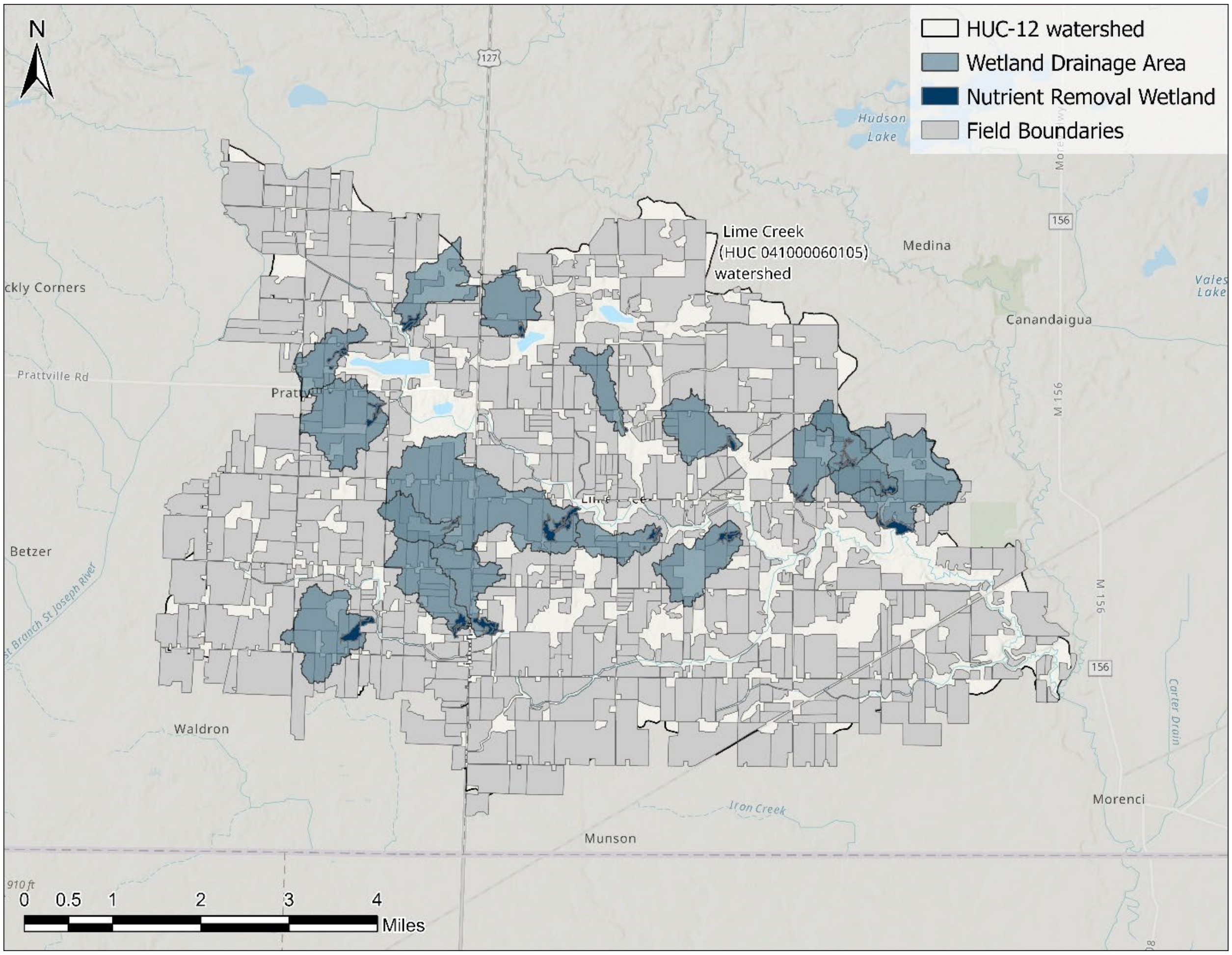

Figure B-4: Locations suitable for nutrient removal wetlands derived from ACPF for the Lime Creek subwatershed.

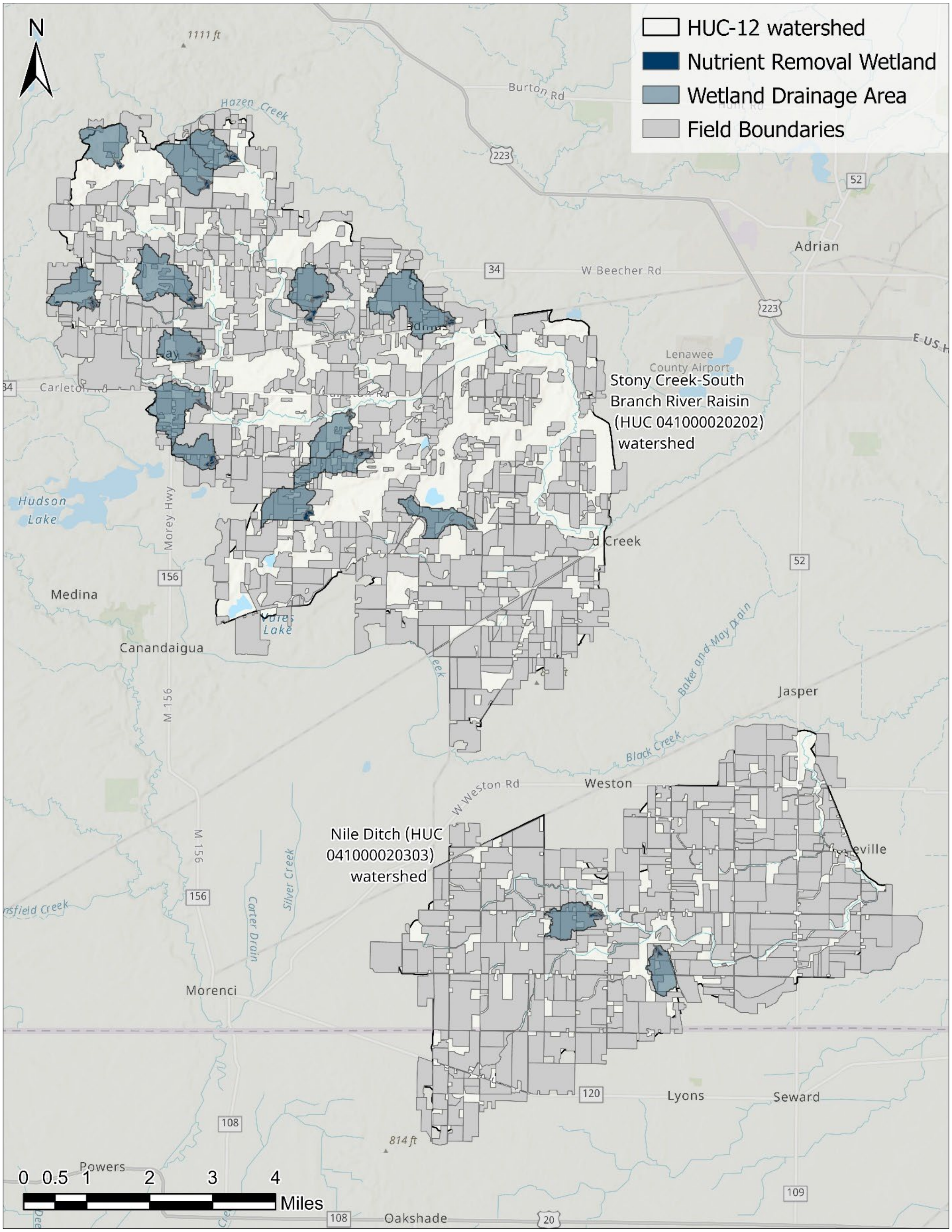

Figure B-5: Locations suitable for nutrient removal wetlands derived from ACPF analysis for the Nile Ditch and Sony Creek-South Branch River Raisin subwatersheds.

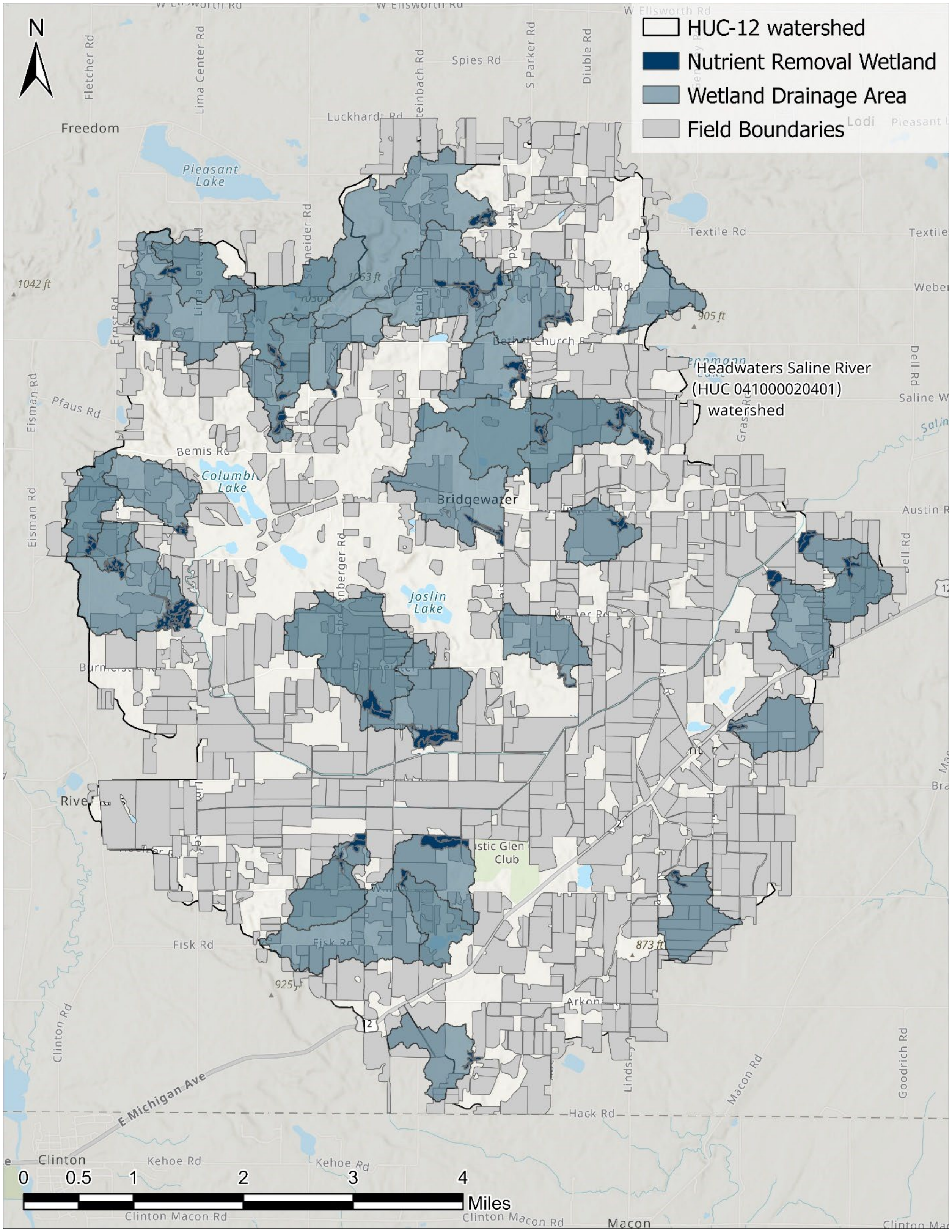

Figure B-6: Locations suitable for nutrient removal wetlands derived from ACPF for the Headwaters Saline River subwatershed.

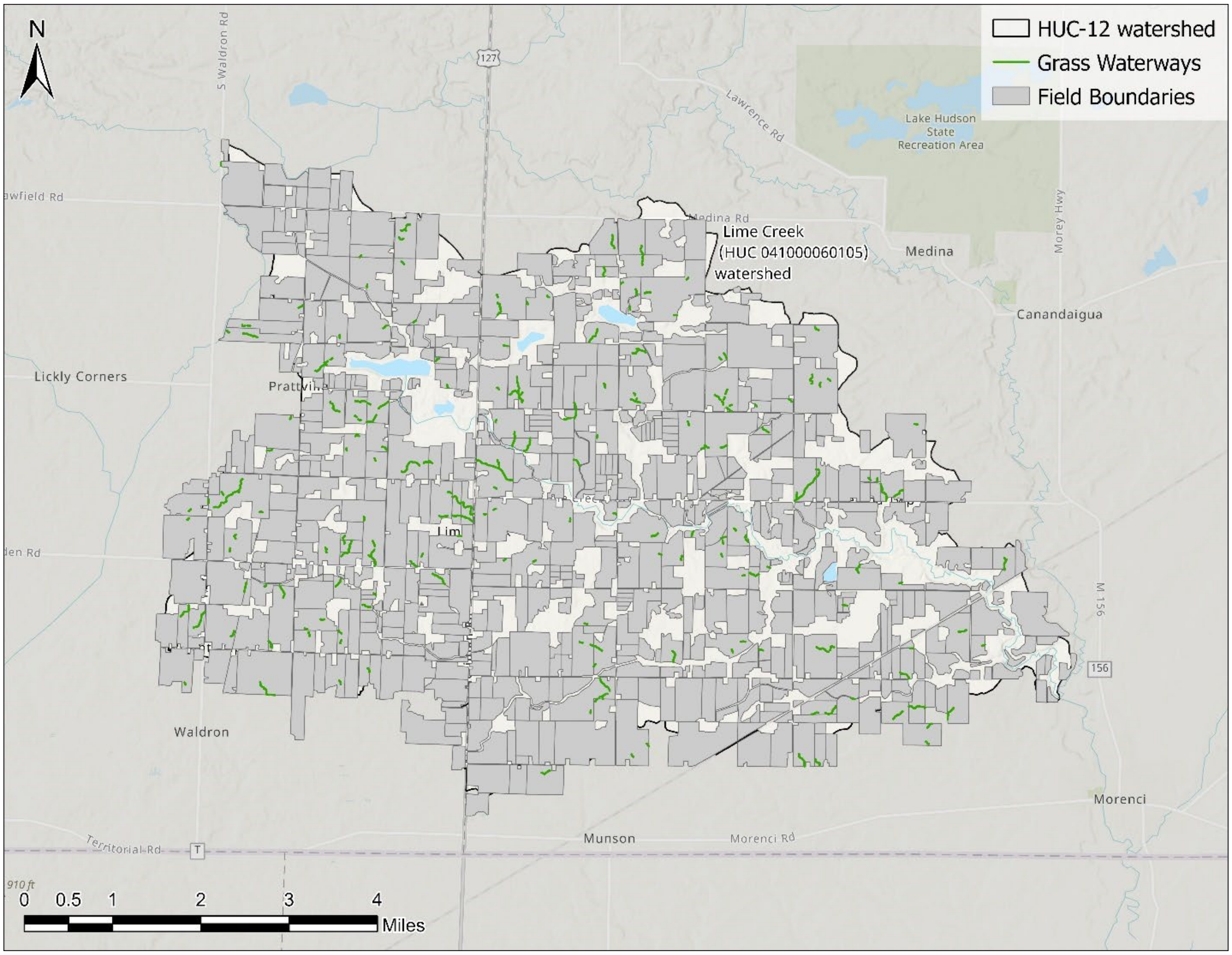

Figure B-7: Locations suitable for grassed waterways derived from ACPF for the Lime Creek subwatershed.

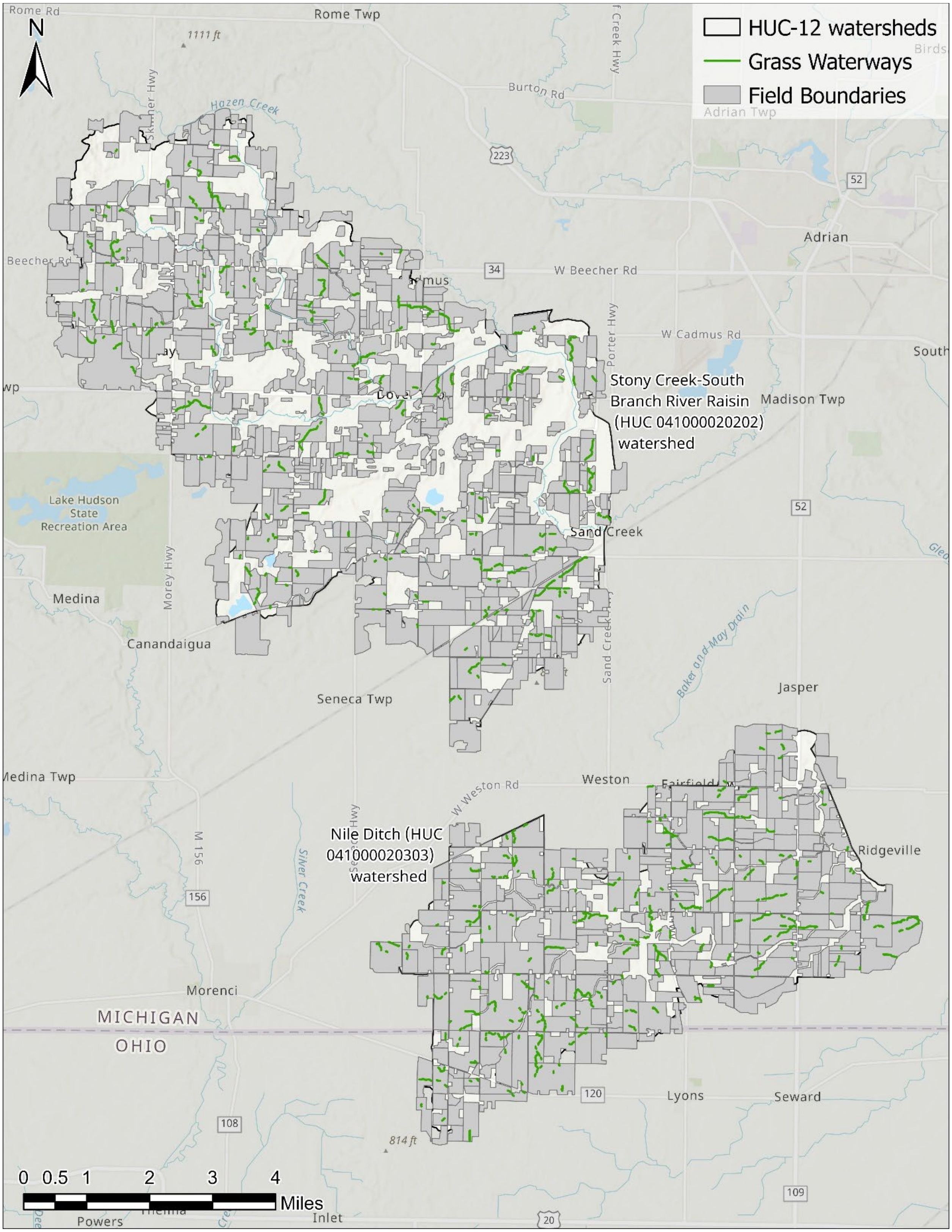

Figure B-8: Locations suitable for grassed waterways derived from ACPF analysis for the Nile Ditch and Sony Creek-South Branch River Raisin subwatersheds.

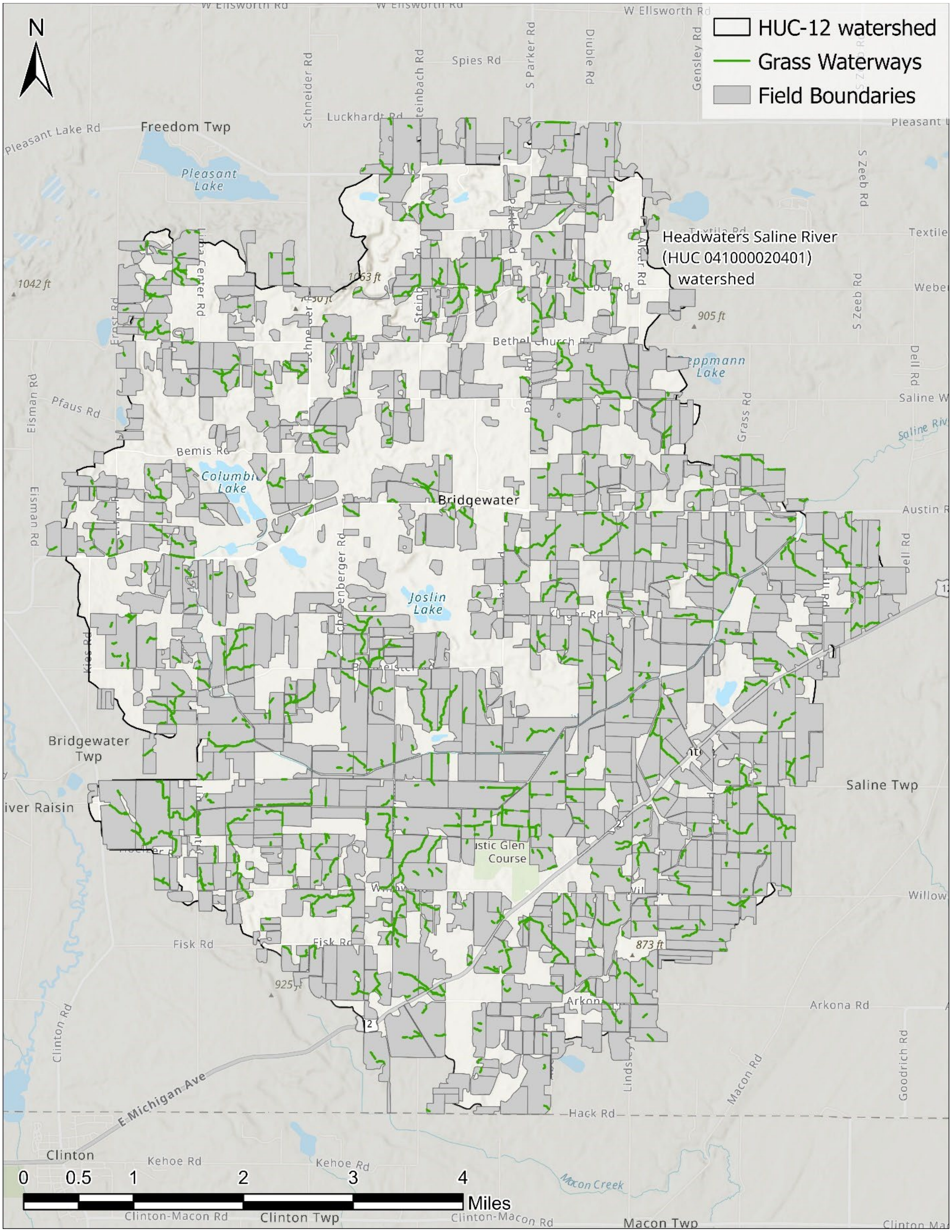

Figure B-9: Locations suitable for grassed waterways derived from ACPF for the Headwaters Saline River subwatershed.

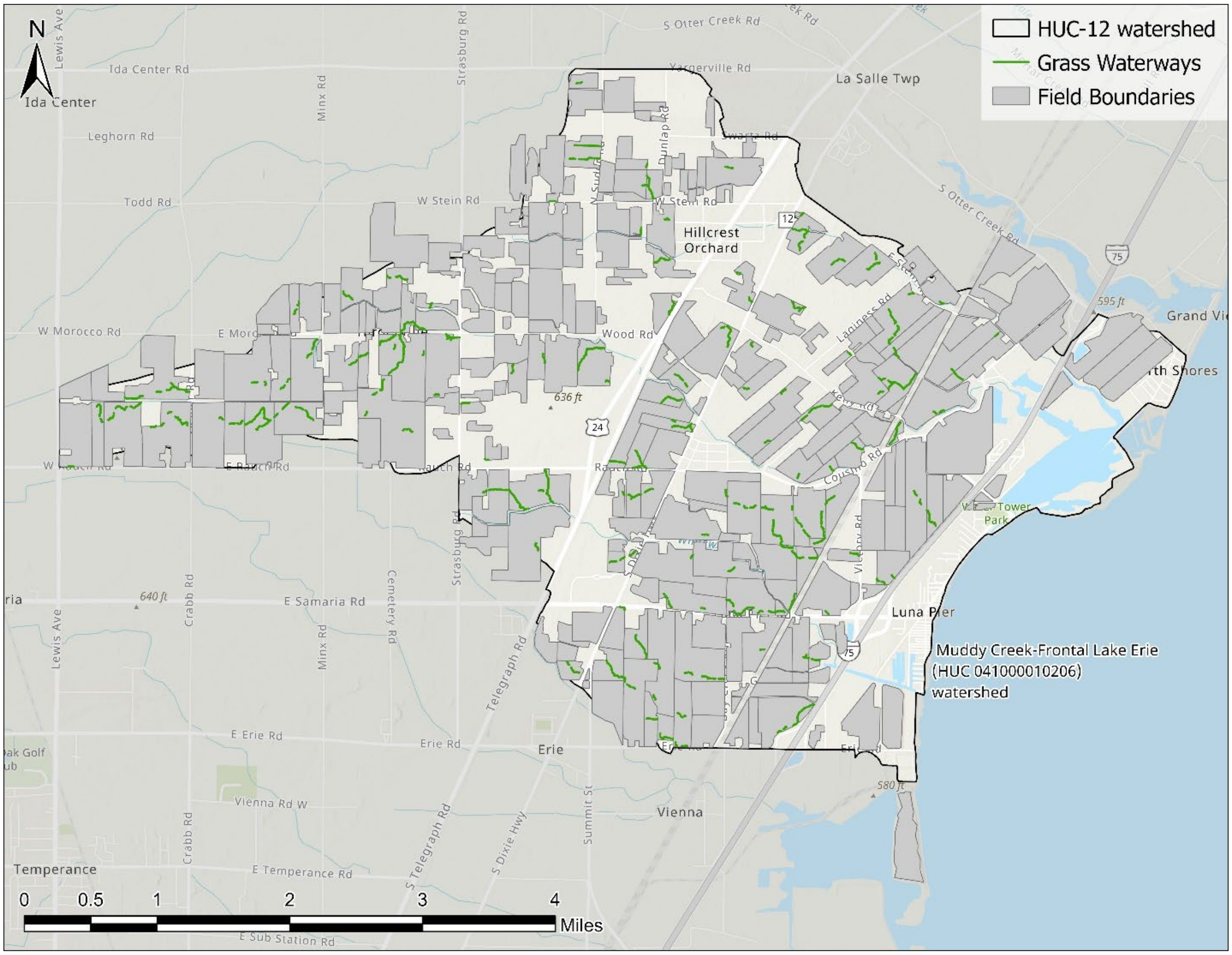

Figure B-10: Locations suitable for grassed waterways derived from ACPF for the S.S. LaPointe Drain subwatershed.

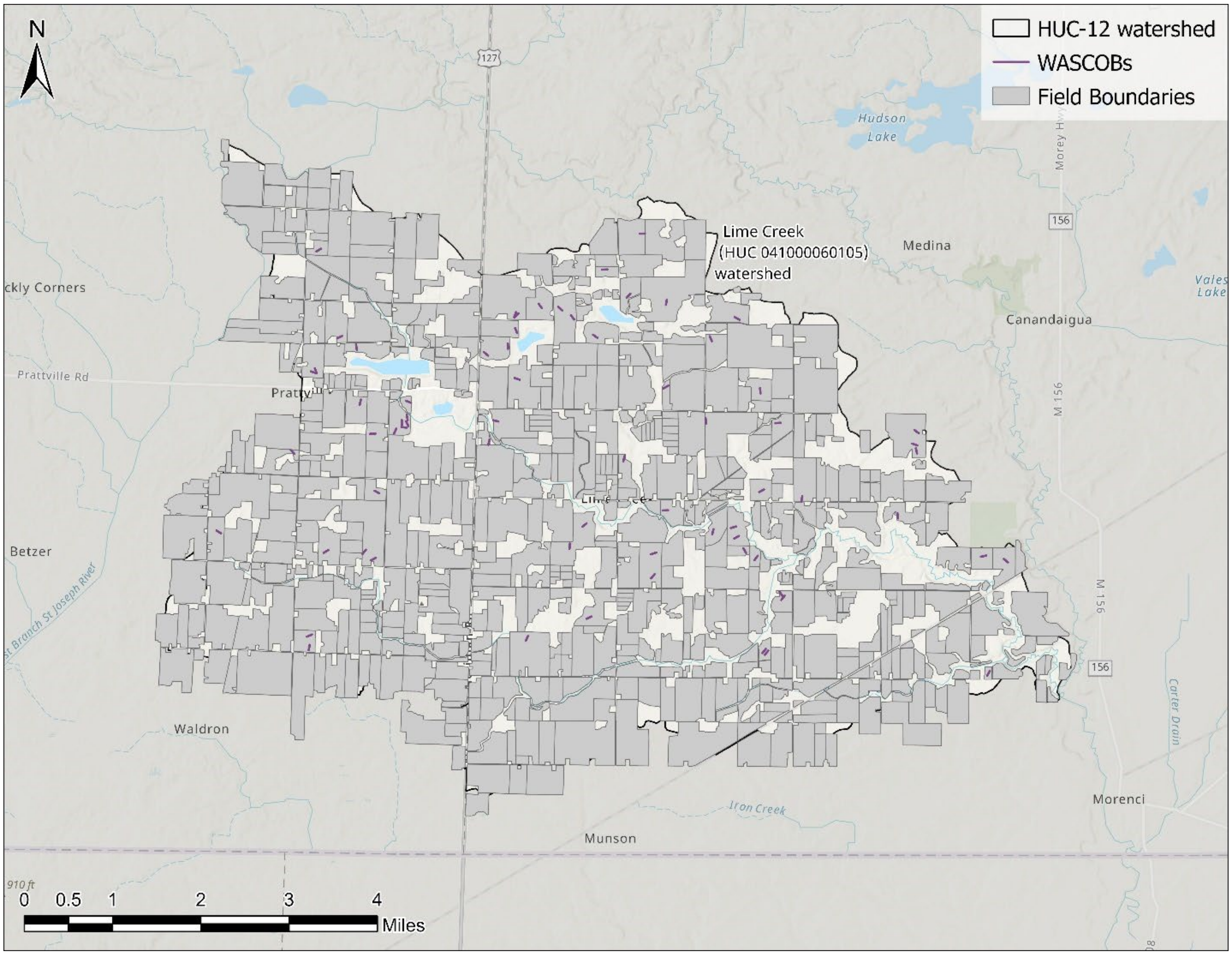

Figure B-11: Locations suitable for WASCOBs derived from ACPF for the Lime Creek subwatershed.

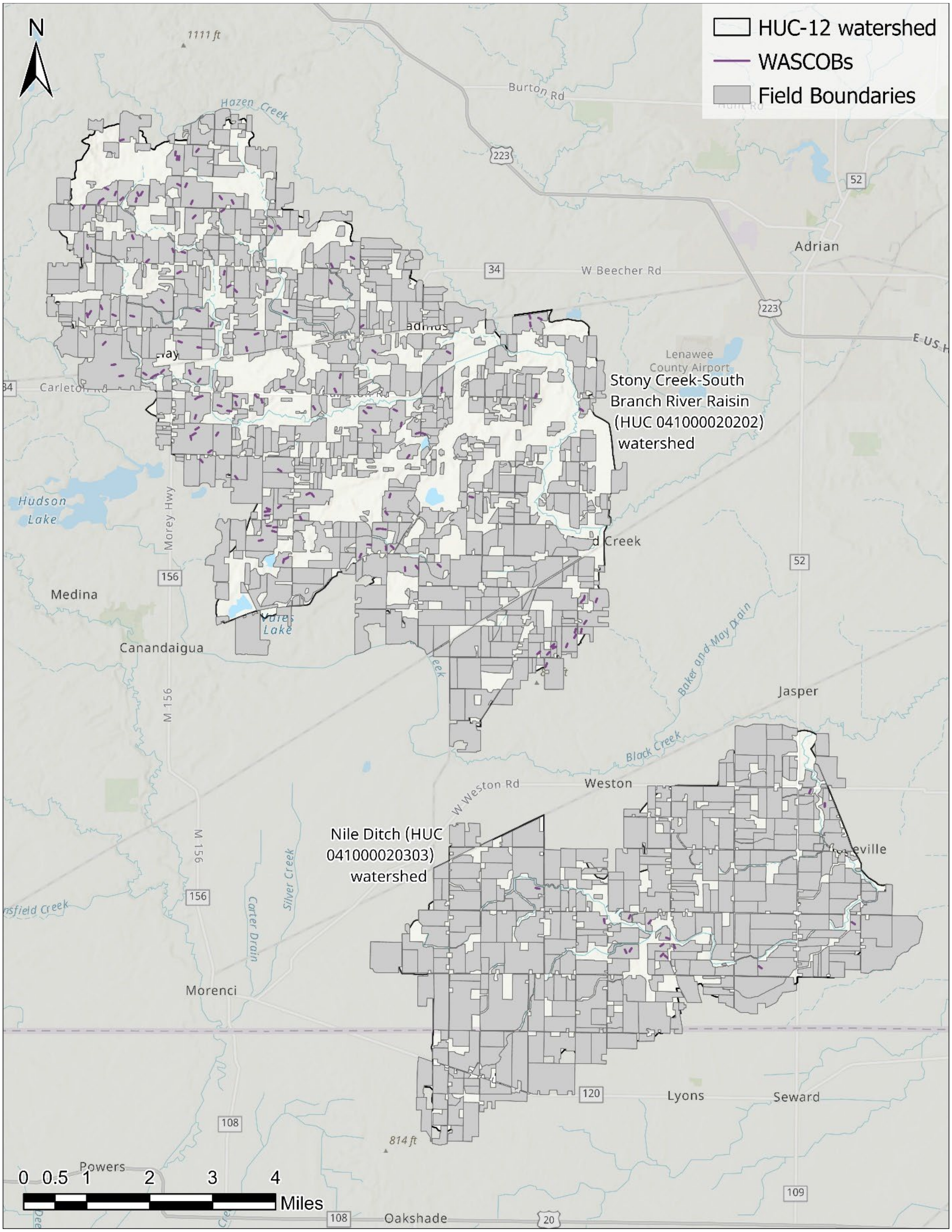

Figure B-12: Locations suitable for WASCOBs derived from ACPF analysis for the Nile Ditch and Sony Creek-South Branch River Raisin subwatersheds.

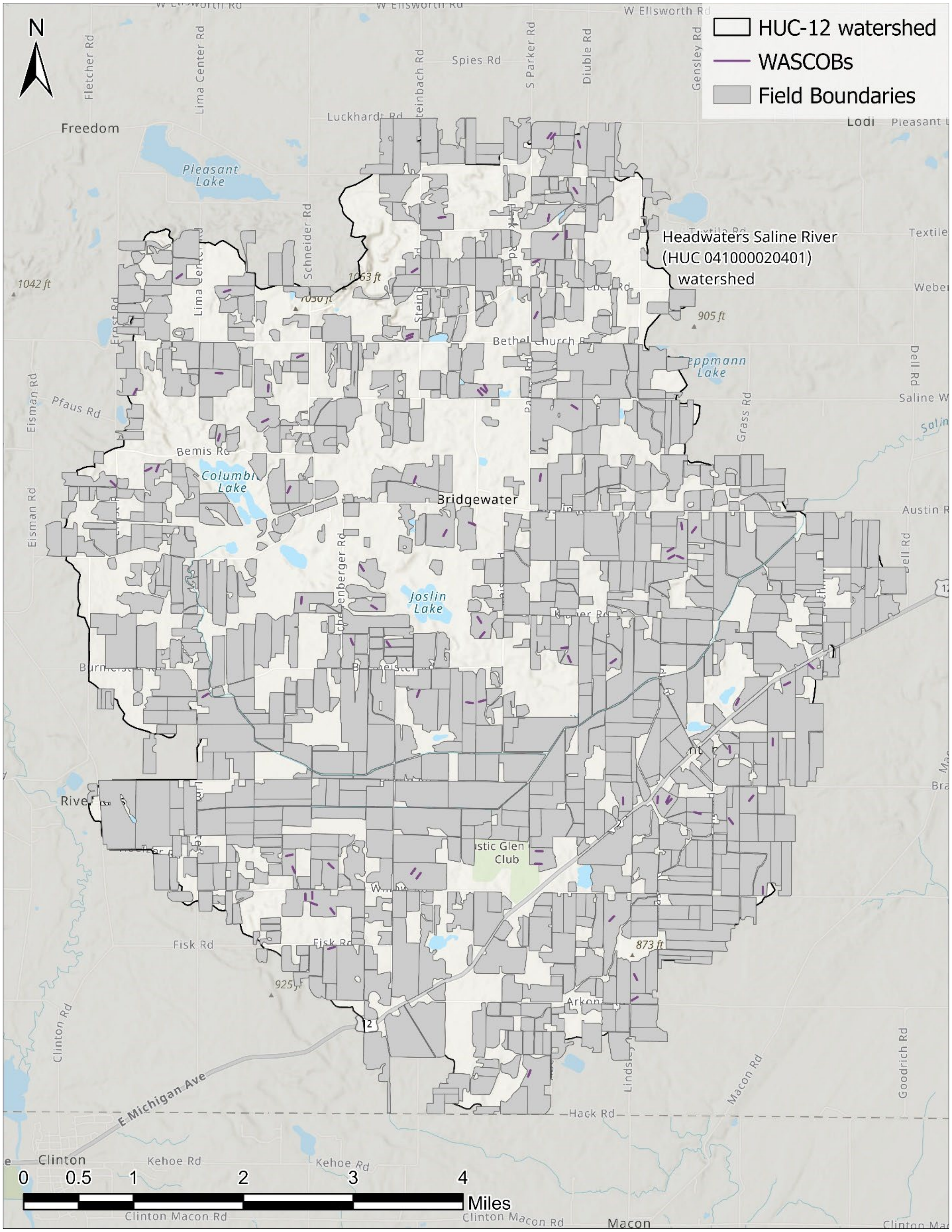

Figure B-13: Locations suitable for WASCOBs derived from ACPF for the Headwaters Saline River subwatershed.

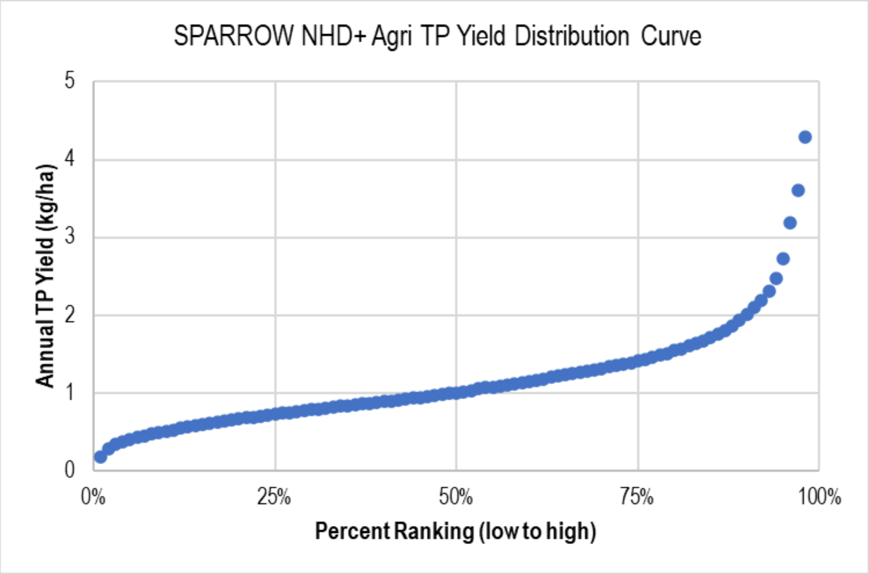

Figure B-14: TP yield distribution curve produced for agricultural sources from NHD+ catchment scale output from the USGS SPARROW model for areas draining to the WBLE (derived from Robertson and Saad 2019).

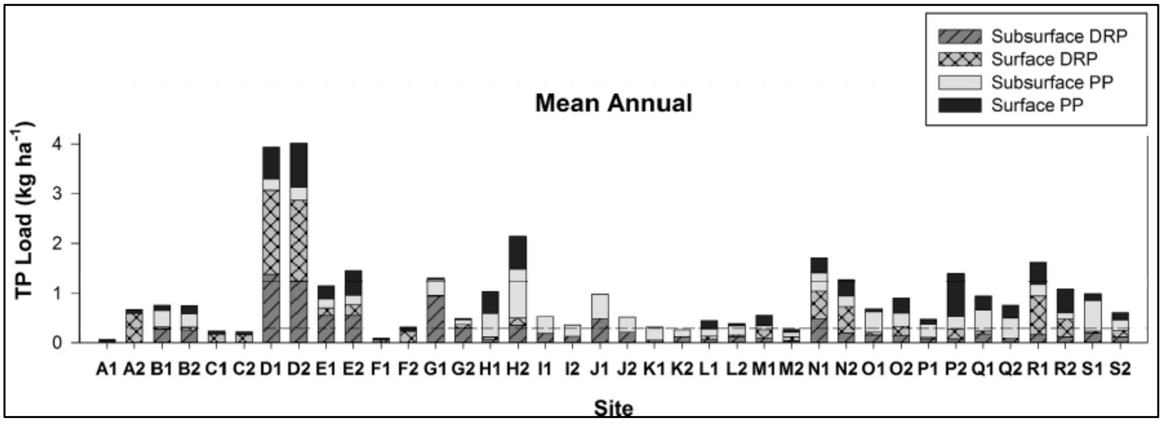

Figure B-15: TP yields reported for 38 edge-of-field sites in northwest Ohio (reproduced from Pease et al. 2018).

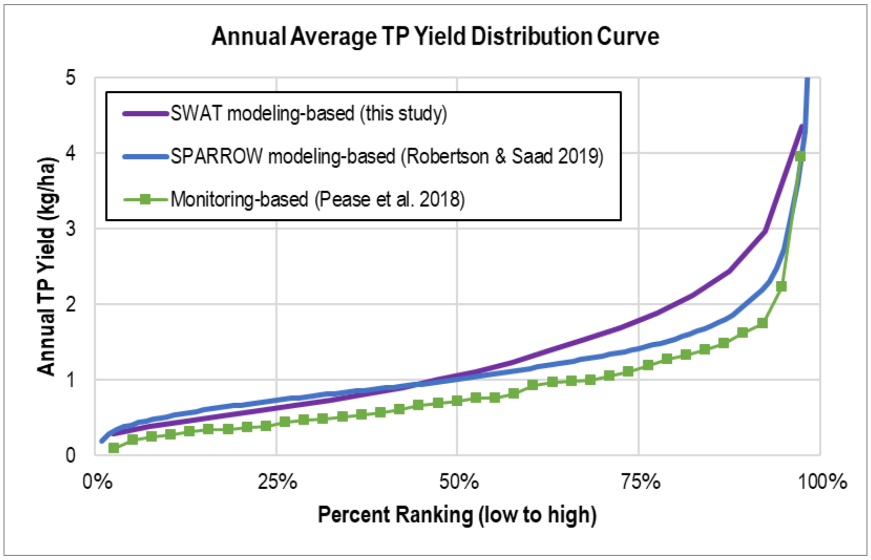

Figure B-16: Comparisons of two independent TP yield distribution curves and the TP yield distribution curve used to estimate loads for agricultural parcels in this study.