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Agricultural Conservation Planning Framework: 3. Land Use and Field Boundary Database Development and Structure

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Abstract

Conservation planning information is important for identifying options for watershed water quality improvement and can be developed for use at field, farm, and watershed scales. Translation across scales is a key issue impeding progress at watershed scales because watershed improvement goals must be connected with implementation of farm- and field-level conservation practices to demonstrate success. This is particularly true when examining alternatives for "trap and treat" practices implemented at agricultural-field edges to control (or influence) water flows through fields, landscapes, and riparian corridors within agricultural watersheds. We propose that database structures used in developing conservation planning information can achieve translation across conservation-planning scales, and we developed the Agricultural Conservation Planning Framework (ACPF) to enable practical planning applications. The ACPF comprises a planning concept, a database to facilitate field-level and watershed-scale analyses, and an ArcGIS toolbox with Python scripts to identify specific options for placement of conservation practices. This paper appends two prior publications and describes the structure of the ACPF database, which contains land use, crop history, and soils information and is available for download for 6091 HUC12 watersheds located across Iowa, Illinois, Minnesota, and parts of Kansas, Missouri, Nebraska, and Wisconsin and comprises information on 2.74 × 10^6 agricultural fields (available through http://northcentralwater.org/acpf/). Sample results examining land use trends across Iowa and Illinois are presented here to demonstrate potential uses of the database. While designed for use with the ACPF toolbox, users are welcome to use the ACPF watershed data in a variety of planning and modeling approaches.

Core Ideas

- Water quality improvement must meet watershed goals through farm-level measures.
- Planning data can help better connect farm implementation and watershed outcomes.
- We developed a database to help develop watershed plans through farm-level options.
- The database is available for >6000 HUC12 watersheds in the US Midwest.

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In the Midwestern United States, agricultural land cover changes each year due to planned rotation of annual crops as well as responses of farm producers to shifts in agricultural markets and policy initiatives. Land use impacts of policies aimed to increase biofuel production, and to protect environmentally sensitive/erodible croplands using perennial cover, have garnered particular attention. Changes in agricultural crops/land cover are known to carry environmental consequences that affect hydrology (Zhang and Schilling, 2006), water quality (Hatfield et al., 2009; Johnes and Heathwaite, 1997), biological diversity (Kremen et al., 2007), and other ecosystem services (Lawler et al., 2014). Therefore, it is beneficial to document agricultural land cover and its rates of change to understand responses of watershed, landscape, and agroecosystem processes to changes in land use and to identify viable approaches that can be customized for local adoption and mitigate environmental impacts from agricultural production. The availability of consistent information and flexible approaches to identify conservation planning alternatives may help engage farm communities to address agricultural impacts on hydrology and water quality, thereby meeting needs to ensure environmental sustainability in agriculture.

Recently, US agricultural land cover has been tracked using classified remote sensing data. The USDA National Agricultural Statistics Service (NASS) has engaged in efforts to classify agricultural land cover each year and make that data public for selected states since 1997 and nationally since 2008. These efforts have been focused on mapping the areal extent of major commodity crops each year, and classification products, collectively named the Cropland Data Layer (CDL), are available online (USDA-NASS, 2016). However, classification of other, non-commodity-crop land cover types, particularly perennial cover (grass, hay, and pasture classes), has not been consistent, due to a focus on harvested commodities, the limited extent of

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Abbreviations: ACPF, Agricultural Conservation Planning Framework; CDL, Cropland Data Layer; DEM, digital elevation model; DEP, Daily Erosion Project; FSA, Farm Service Agency; gSSURGO, gridded Soil Survey Geographic database; HUC, Hydrologic Unit Code; NASS, National Agricultural Statistics Service; SSURGO, Soil Survey Geographic database; WBD, Watershed Boundary Dataset.

perennial cover types in much of the Midwest's croplands where development of the CDL was initiated, and changes in the quality and detail of training datasets that were obtained each year. Therefore, perennial land cover classes have shifted in terms of emphasis and naming convention several times during the CDL's period of record; further information can be found through the CDL website (USDA-NASS, 2016).

Despite these issues, CDL data have been used to show changes in land cover across agricultural regions of the United States. Using CDL data from 2006 to 2011, Wright and Wimberly (2013) found that 528,000 ha of perennial cover was converted to cropland across North Dakota, South Dakota, Nebraska, Iowa, and Minnesota; much of this conversion was shown to be associated with expiration of Conservation Reserve Program contracts when evaluated at the county level. Lark et al. (2015) evaluated CDL data from 2008 to 2012 to identify lands that had been converted from perennial cover to agricultural crops nationwide and found 1.21×10^6 ha of net conversion of perennial cover to cropland, with much of the cropland expansion occurring in the eastern Dakotas, west-central plains, and an area of northern Missouri and southern Iowa.

The earliest efforts to classify and map crop cover using satellite remote sensing data in the United States began in 1970s (Craig, 2010). In conducting CDL annual crop cover classifications, USDA-NASS has used data from several remote sensing platforms. The USDA-NASS CDL metadata (USDA-NASS, 2016) provides details showing how different combinations of data sources have been used. Since 2001, the first year of CDL data considered in the Agricultural Conservation Planning Framework (ACPF) database, those platforms have included (in general sequence) NASA's Landsat 5 (2001–2006 and 2009–2011) and Landsat 7 (2001–2007), India's AWIFS (2006–2010), NASA's MODIS (2007–2009), Europe's DMC constellation (2011–current), and NASA's Landsat 8 (2013–current). One key point is that the grid resolution of the classified CDL product was 56 m when India's AWiFS platform was used and 30 m in other years. Despite the year-to-year changes in data sourcing, high classification accuracies for commodity crops have been reported, ranging from 88 to 97%, except in 2001 and 2006, when accuracies of 81 to 83% were found (Stern et al., 2012). These accuracies do not apply, however, to the discernment of perennial cover types. That is, changes in grid resolution, variation in sensor performance, and changes in classification schema for noncommodity croplands make it difficult to obtain exacting detail on land cover change from year to year, particularly in answering questions about the types of perennial cover that have been changed in dominantly cropped landscapes. Therefore, small changes in perennial cover, which have shown disproportionate effects on watershed responses in terms of hydrology and water quality (Asbjornsen et al., 2014; Dosskey et al., 2010), are difficult to examine in close detail using CDL data. The previously published analyses we found (Lark et al., 2015; Wright and Wimberly 2013) applied neighborhood filters to minimize land cover classification error effects in pixel data. These results identified changes occurring at the margins of the US Corn Belt, where transitions into dominantly forested or grazed landscapes occur.

Here, we report on the development and structure of a database that can be used to track changes in land cover and cropping rotations at field and watershed (Hydrologic Unit Code [HUC]12; see Seaber et al., 1987) scales. The database is structured around individual farm fields as the unit of record, providing a framework that enables land use to be assessed at the same scale that agricultural land uses shift, at an annual time step, and at the scale at which conservation practices are implemented. This has provided an improved contextual frame by filtering and generalizing CDL data from pixel to field scale and enabled us to identify a majority cover of crop types in each agricultural field each year, then identify and classify a sequence of annual crop cover by field to identify and map the extent of dominant crop rotations. This should help to better understand how crop rotations and agricultural management may be changing at field and watershed scales. The database presently covers approximately 2.74×10^6 agricultural fields located in Iowa, Minnesota, Illinois, southwestern Wisconsin, eastern Kansas, and parts of Missouri and Nebraska, with ongoing efforts to expand the effort into wider areas of the US Corn Belt. The database is available and can be downloaded for any given HUC12 watershed, with agricultural land use data available for 6091 HUC12s to date. This spatial frame supports the primary intended use of the database, which is to help identify field-level opportunities for conservation practice placement as part of the ACPF, which is a precision conservation–based approach to watershed planning that follows concepts initially described by Tomer et al. (2013). Two additional papers have demonstrated watershed applications of the ACPF. The first described siting criteria for several conservation practices and proposed a simple method to compare nutrient reduction potentials of watershed planning scenarios composed of field-specific placements of multiple practices (Tomer et al., 2015b). The second proposed a riparian classification system that maps landscape-based opportunities for water quality improvement found along riparian corridors (Tomer et al., 2015a). The ACPF toolbox works within the ArcGIS 10.x (ESRI, 2016) environment and is available with documentation (Porter et al., 2017).

In addition to land use data, customized soils tables extracted from the NRCS SSURGO database (NRCS, 2016) are included in the ACPF database, allowing key soil parameters that help identify sensitive/marginal lands and conservation placement opportunities by soil map unit and by field. The ACPF database also provides the land use/crop rotation framework that is part of the Daily Erosion Project (DEP; Cruse et al., 2006), which is being updated to estimate sheet and rill erosion for presentation at the HUC12 watershed scale, using field-level hillslope data on crop cover, soil type, and slope distributions (Iowa State University, 2017). Application and use of these data beyond the ACPF and DEP are possible and not discouraged. Watershed modeling applications that utilize individual field boundaries to spatially discretize management system inputs and simulate field-level "hydrologic response units" have recently been implemented (Kalcic et al., 2015; Teshager et al., 2016)

The ACPF and DEP applications require high-resolution (nominally 1- to 5-m grid) digital elevation data, which are typically provided through LiDAR surveys. The ACPF software (Porter et al., 2017) includes utilities that help the user process elevation data for hydrologic continuity and develop and/or edit field boundary datasets and then populate crop cover history and soils information through automated downloads of land use and soils data. This paper describes the development of the ACPF land use and soils database.

Data Development Process

The process we followed in assembling field boundary and crop cover data was summarized for two HUC12 watersheds by Tomer et al. (2015b); a brief description is included in the Supplemental Material. Here, we fill in the details of the process to better document a database of multistate extent; in addition, we provide Supplemental Material for instructional purposes and to encourage expansion of this database's areal coverage. The temporal record of land cover within the ACPF database has been extended to 2015, with intent to continue annual updates as additional data become available. The data development process is summarized in a simplified flow diagram (Fig. 1).

Generation of Field Boundary Data

Field boundaries generated by the USDA Farm Service Agency (FSA) (often denoted as Common Land Unit [CLU] boundaries) were released to the public in 2006 and were used to develop the land use information. Conservation practices are planned and implemented within specific agricultural fields. Therefore, the ACPF land use/field boundary dataset was designed to provide the spatial framework to identify conservation practice placement opportunities watershed wide, on a field-specific basis. Removal of ownership, FSA program, and county-level attribution from the publicly available FSA data was part of the process, to remove outdated (>10-yr-old) information, protect landowner privacy, and ensure spatial integrity (see Supplemental Material). The original data were not contiguous by county but assembled from all agricultural fields managed by producers conducting USDA business in each county. That is, farmers may farm fields in multiple counties but only need to conduct business with the USDA in one county office. The Supplemental Material details the editing approach used to reassign fields in any county that were associated with a neighboring county's FSA office to the correct geographic county. For each county, this was done by overlaying all surrounding county office field feature classes and reassigning those fields from the surrounding counties that fell within the target county, and vice versa (Supplemental Material, Section 1). This process generated an intermediate product for each county containing only those agricultural fields whose centroids were located within that county boundary (Fig. 1, row 1).

The contiguous county-specific feature classes were next edited to align field boundaries with actual patterns of crop cover. The goal was to minimize the extent of agricultural fields that were planted to more than a single crop, so that crop rotations could be better elucidated by overlaying CDL data from consecutive years. It was clearly not necessary to edit all field boundaries, but we did want to identify fields most important to examine as candidates for editing. The fields chosen for editing were at least 16 ha (40 acres) in size, had an FSA-designated agricultural land use, and showed the dominant land cover (crop type) in 2009 was between 25 and 75% of the field (Fig. 1, row 2). Dominant 2009 land cover was calculated using the area of each field polygon and crop cover classifications of those USDA-NASS CDL cells centered in the polygon. This editing process

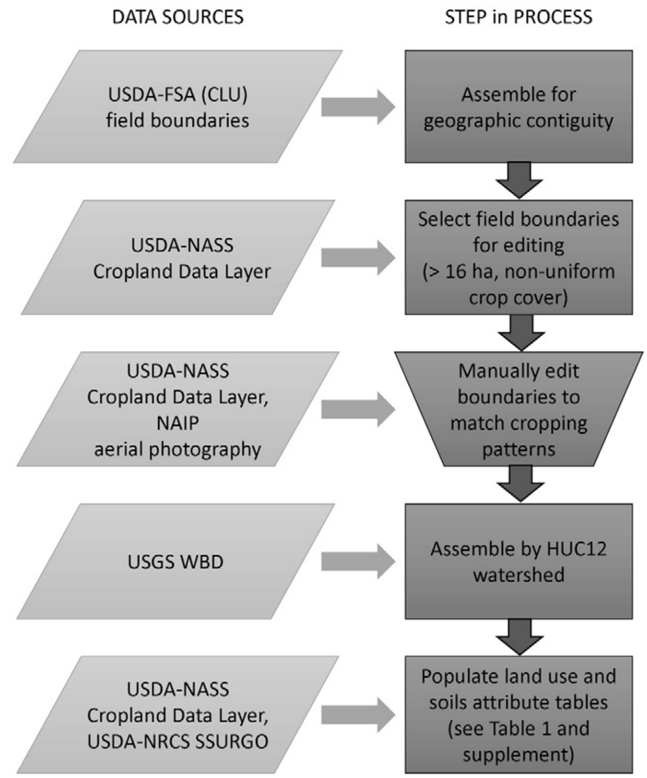

Fig. 1. Flow chart summarizing data sources and steps in Agricultural Conservation Planning Framework database development. Public data sources include USDA-NASS (2016) for the Cropland Data Layer, USDA-FSA (2017) for National Agricultural Imagery Program (NAIP) aerial photography, USGS (2012) for Watershed Boundary Dataset (WBD), and NRCS (2016) for the Soil Survey Geographic database (SSURGO). CLU, Common Land Unit.

involved toggling between CDL (USDA-NASS, 2016) and National Agricultural Imagery Program (USDA-FSA, 2017) imagery (Fig. 1, row 3) and is described and illustrated in greater detail in the Supplemental Materials.

Data Assembly for Watershed Analysis

The results of the field boundary editing process provided a set of county feature classes with agricultural field boundaries edited to accurately reflect cropping patterns. The ACPF conceptual framework (Tomer et al., 2013), database, and toolbox (Porter et al., 2017) were developed for use at the small watershed scale. The HUC12 watershed feature class of the USGS Watershed Boundary Dataset's (WBD; see USGS, 2012) provided the appropriate scale for use of the ACPF toolbox; hence, the by-county field boundary data were reassembled for use at this watershed scale (Fig. 1, row 4). The land use component of the ACPF database (Fig. 1, row 5) comprises watershed field boundaries, a crop history table, land use assignment table, and a collection of CDL rasters by year (Table 1; Porter et al., 2017). Additional ACPF database elements included the HUC12 watershed boundary from the WBD, a buffered watershed boundary extending 1000 m beyond the WBD boundary, USDA-NRCS gridded Soil Survey Geographic database (gSSURGO) soils data in raster format (NRCS, 2016), and three soils attribute tables that are described in the Supplemental Material.

The file-geodatabase format used in ArcGIS (ESRI, 2016) has been used to house individual watershed databases (Table

1). Once in place, the watershed boundary is used to extract the field boundaries from all counties that intersect the watershed boundary. This collection is appended to form the field boundary feature class for the watershed (i.e., FB-HUC12id in Table 1). Fields that intersect with the HUC12 watershed boundary will partly extend outside the watershed. The ACPF database includes these field boundaries not completely within the WBD-defined watershed, in part because the WBD boundaries are subject to change based on analysis of high-resolution elevation data using hydrologic flow-routing tools accessible through the ACPF toolbox. The ACPF toolbox enables analysis of high-resolution digital elevation models (DEMs), with 2-m and 3-m cell sizes being common, in combination with the field boundary data, to identify field-specific conservation practice placement opportunities watershed wide. Using high-resolution DEMs supports the creation of terrain attributes at fine scales, including new topographically derived watershed (and subcatchment) boundaries. There is the likelihood that this newly derived watershed boundary will differ significantly from the boundary specified by the WBD. To ensure that the ACPF captures an area large enough to allow for new watershed boundaries to be derived, the WBD watershed boundary and the field boundary feature classes are aggregated and the result is buffered by 1000 m to create a buffered boundary, buf-HUC12id in Table 1. This buffered boundary feature class is used to extract the watershed raster data layers; land use, soils, and elevation.

Land use/land cover data include rasters extracted from the CDL (USDA-NASS, 2016) for the most recent 8 yr (2008–2015). (Note: *land cover* herein refers to annual crop cover data, whereas *land use* is a more general term including designations of crop rotations) These rasters are placed in the watershed file-geodatabase using the "wsCDL" prefix for each year, for example, "wsCDL2015" (Table 1). The CDL rasters included have been modified by passing a majority filter (ESRI, 2016) over the raster to reduce speckling.

Generating By-Field Land Use Attributes and Tables

The ACPF field boundary feature class (FB-HUC12id) contains only a unique polygon identification and an area (acre) attribute field on creation of the edited county-based files. Additionally, an agricultural land use summary attribute, "isAG," is included with the attribute table that is germane to the field boundary feature class, which is populated based on derived land use attributes (further described below). The isAG attribute field holds a designation for agricultural land use: 0, nonagricultural; 1, row crop; 2, pasture/grass/hay (Table 1). This attribute is populated based on the CDL data. During construction of the ACPF database, crop history and a 6-yr land use summary tables that can be joined to the field boundary feature class are added to the file-geodatabase. The content of these tables is detailed in Tables 2 to 5.

The crop history table (listed as CH_HUC12id in Table 1, detailed in Table 2) holds two attribute fields for each year of CDL land cover data in the database. These are the major land cover value and the percentage of an agricultural field that major land cover value comprises within each agricultural field, "maj15" and "pct15," respectively (Table 2). The major land cover for each field is calculated for each year of record, using a zonal statistics tool (ESRI, 2016) that identifies the number of grid cells in each cover class within the polygon. The majority cover comprises a code that is part of the CDL data; these codes are defined in Table 3. The count of the majority class is used to estimate area by

Table 1. Data layers included in the file geodatabase for each HUC12 watershed; modified from Porter et al. (2017). Note that "-HUC12id" is replaced in practice with an actual watershed address, e.g., 071000060201.

Name	Type	Description
Bnd-HUC12id	Polygon	Watershed boundary (USGS Watershed Boundary Dataset derived from the National Hydrography Dataset).
Buf-HUC12id	Polygon	Watershed boundary buffered out by 1000 m; base data are clipped to buffered extent to ensure coverage for all agricultural fields that may lie partly within watershed.
FB-HUC12id	Polygon	Agricultural field boundaries that have been manually edited (see Supplemental Material). The field boundary feature class contains an "isAG" column in the attribute table. Possible "isAG" values include: • 0 = nonagricultural (forest, water/wetland, urban, LT 15ac, and unassigned) • 1 = agricultural (comprising rotations of agricultural crops as classified by a 6-yr sequence of annual cover extracted from the FSA Cropland Data Layer (CDL) (USDA-NASS, 2016) • 2 = pasture/grass/hay
wsCDL2010 wsCDL2011 wsCDL2012 wsCDL2013 wsCDL2014 wsCDL2015	Thematic raster	USDA NASS CDLs for the most recent 6 yr. The filename ends with the 4-digit year that it represents.
CH_-HUC12id	Table	Crop history table derived from all available years of the NASS CDL; can be joined to field boundary layer by a unique FBndID. Contains information on crop rotation, majority crop, and % majority crop for each year in the dataset.
LU6_-HUC12id	Table	Land use table derived from the most recent 6 yr of the NASS CDL; can be joined to field boundary layer by a unique FBndID. See Table 3 for details.
Soils DATA:		
gSSURGO	Raster	USDA-NRCS 10-m soils raster (can be joined to three soil tables)
SurfHrz-HUC12id	Table	Surface horizon table
SurfTex-HUC12id	Table	Surface texture table
SoilProfile-HUC12id	Table	Soil profile table; contains attribute for subsurface depths
DEM-HUC12id (not included)	Continuous raster	A LiDAR-derived digital elevation model (DEM) of meter horizontal resolution. Must be generated by user and should be an unfilled DEM.

crop code and estimate percentage by comparing with the "acres" attribute from the field boundary feature class. Note that areas are typically given in acres in ACPF output to ease direct communications of results to stakeholders.

The 6-yr land use summary table (listed as LU6_HUC12id in Table 1, described in Tables 4–5) contains a set of tabular attribute fields that are populated using the most recent 6 yr of land cover data found in the crop history table (Table 2). The purpose of the land use summary table is to generally document agricultural crop rotations across each HUC12 watershed. Agricultural rotations can indicate where some conservation systems or practices may already be located or, in some cases, where new practices may be prioritized based on cropping intensity, use of perennials in rotation, and so on (see Tomer et al., 2015b). For each agricultural field polygon, the most recent 6 yr of CDL majority land cover are concatenated to provide the "CropRotatn" attribute based on its assigned rotation value, denoted "ROTVAL" (as defined in Table 3). During this process, the "CropSumry," "CCCount," and "MixCount" attributes are populated as well (Tables 4–5). The CropSumry provides a quick visual summary of number of years (out of six) that individual crops were dominant within that specific field polygon (per example field boundary records in Table 5). For example, "C4B2" represents 4 yr of corn (*Zea mays* L.) and 2 yr of soybean [*Glycine max* (L.) Merr] being dominant in the specified agricultural field. The CCCount attribute displays how many times a "CC" pair occurred in the CropRotatn string and identifies how many times corn was grown after corn in each agricultural field over the 6-yr period. This was to help document the extent of intensified corn production in the Upper Midwest. The MixCount attribute identifies

Table 2. Sample listing of attributes in the crop history table, most recent 6 yr.

FBndID	maj10	pct10	maj11	pct11	maj12	pct12	maj13	pct13	maj14	pct14	maj15	pct15
F071000081509_1	121	70	122	30	121	60	121	50	176	55	121	50
F071000081509_2	1	96	1	96	1	96	5	95	1	96	5	100
F071000081509_3	5	71	1	90	5	90	1	90	5	84	1	86
F071000081509_4	141	86	141	86	141	86	141	86	141	74	141	82
F071000081509_5	176	92	176	77	176	89	176	78	176	82	176	90
F071000081509_6	176	56	176	38	176	60	176	77	176	69	176	78
F071000081509_7	5	58	1	85	5	100	1	100	5	91	5	100
F071000081509_8	5	94	1	100	5	100	1	100	5	92	5	97
F071000081509_9	5	91	1	94	5	94	1	96	5	97	1	95

Table 3. Coding used to identify crop cover type and major land cover classes in the USDA-NASS Cropland Data Layer (CDL) data (see maj[yr] codes in example records listed in Table 2), and reassigned ROTVAL codes used in the 6-yr crop sequence string (CropRotatn), which are found in the LU6_-HUC12id table (examples given in Table 5).

Land cover class	NASS CDL code	ROTVAL
Soybeans	5	B
Corn	1,12,13	C
Forest/shrub land	63,64,70,141–143	F
Sorghum	4	G
Idle cropland/fallow	61	I
Double-crop system	225–254	L
Grass/pasture/alfalfa/hay	36,37,60,62,176	P
Other crops	All others	R
Water/wetlands	83,87,92,111,112,190,195	T
Developed	82,121–124	U
Wheat	22–24	W
Barren	65,81,88,131	X

Table 4. Summary of attributes listed in the LU6_-HUC12id table included in the file geodatabase.

Attribute name	Description
FBndID	Unique field boundary polygon identifier
Acres	Area in acres calculated by software
GenLU	Rule-based general land use assignment. Crop rotation for agricultural fields
CropRotatn	Crop rotation string with a single value of ROTVAL representing the last 6 yr of the major land use in each agricultural field
CropSumry	String showing counts of distinct crop cover (ROTVAL) in the CropRotatn string (see text)
CCCount	Count of occurrences of continuous corn, "CC," in the CropRotatn string (out of 6 yr)
MixCount	Count of occurrences when percent of major land cover fell below 75% in each agricultural field (out of 6 yr of annual data)

Table 5. Example listing of LU6_-HUC12id table records including classified land use records for each agricultural field polygon ID, generated from 6 yr of crop cover data in each field. See Table 4 for definitions of column headers.

FBndID	Acres	GenLU	CropRotatn	CropSumry	CCCount	MixCount
F071000081509_1	2.3	LT 15 ac	UUUUPU	P1U5	0:6	6:6
F071000081509_2	25.7	Corn/soybean with continuous corn	CCCBCB	C4B2	2:6	0:6
F071000081509_3	46.6	Corn/soybean	BCBCBC	C3B3	0:6	1:6
F071000081509_4	19.4	Forest	FFFFFF	F6	0:6	1:6
F071000081509_5	48.8	Pasture	PPPPPP	P6	0:6	0:6
F071000081509_6	16.9	Pasture	PPPPPP	P6	0:6	4:6
F071000081509_7	7.7	LT 15 ac	BCBCBB	C2B4	0:6	1:6
F071000081509_8	8.3	LT 15 ac	BCBCBB	C2B4	0:6	0:6
F071000081509_9	86.3	Corn/soybean	BCBCBC	C3B3	0:6	0:6
F071000081509_10	57.8	Soybean/perennial rotation	PCBCBB	C2B3P1	0:6	5:6

the number of years (out of six) in which the percentage of the dominant use falls below 75%. This attribute provides an indication of whether the associated agricultural field remains in a mixed agricultural use condition and is used during the crop rotation assignment process.

The general land use attribute, "GenLU" in the 6-yr land use summary table, carries a suggested management class for each agricultural field over the most recent 6 yr. For agricultural land, the GenLU attribute represents a crop rotation. The values in this tabular column are generated through a rule-base script that examines the CropRotatn string for patterns and counts of distinct crop values. In some cases, the script uses the CropSumry, CCCount, and MixCount attributes to determine which general land use class to assign. A portion of the script used to assign the general land use value for corn and soybean rotations is shown in the Supplement Material (Section 2). The value for the isAG attribute, found in the field boundary feature class, is also assigned at this point. The GenLU classes are presented below, in the section "General Land Use Classification."

The general land use values that are assigned are suggestions. More detailed examination by users with local knowledge may find that an alternative general land use class should be applied to a given set of agricultural fields based on customized queries, which the database structure does enable. An example of a populated "LU6" table is shown in Table 5. The crop history ("CH") and land use (LU6) tables may be used in queries and mapping sessions by joining the field boundary feature class using the "FBndID," the unique field boundary feature identifier.

Compilation of Soils Tables for ACPF Analysis

The NRCS SSURGO database (NRCS, 2016) is a high-level relational database comprising a large number of tables and conveying a large number of nested relational data to represent changes in a number of soil properties across the landscape and with depth below the surface. Currently, extraction of combined data types for detailed analyses requires specialized database management skills. Options for end-user data extractions to meet common types of queries are being built by NRCS to improve the utility of SSURGO data. For the ACPF database, we have included the gSSURGO soils raster (NRCS, 2016), identified a set of key soil attributes contained in the SSURGO database relevant to conservation practice siting, and built customized data extractions for ACPF analyses that identify field- and watershed-scale conservation opportunities. These extractions comprise three tables that are named in Table 1 and are detailed in the Supplemental Material (Section 3). The scripts include several depth-weighted functions that give results used in ACPF conservation practice siting tools. Not all attributes listed are used directly in the ACPF toolbox (Porter et al., 2017), but they are included to provide information that conservation planners may find useful for hydrologic/ecological interpretations.

Availability and Status

The ACPF database is available online through the North Central Region Water Network (2017) website. Individual HUC12 watershed data may be downloaded in the ESRI file-geodatabase format by navigating to the ACPF Watershed Database; Land Use Viewing and Data Download application available via a link on the ACPF page. We recommend use of the above portal for access to the ACPF toolbox and user's manual (Porter et al., 2017), to participate in discussion forums and learn of software updates, issues, and workarounds.

As of publication, the ACPF/DEP database covers all of Iowa and Illinois, dominant agricultural regions of Minnesota, eastern Kansas, and smaller areas of adjoining states (Fig. 2). Expansion toward the east to include the western Lake Erie basin is anticipated during 2017. Again, utilities included in the ACPF toolbox (Porter et al., 2017) can be used to fully develop ACPF databases for watersheds not covered by the area currently available. In addition, once downloaded, ACPF utilities provide the capacity to update land use and rotation information as annually updated CDL crop-cover data become available. We intend to update the ACPF database on annual updates of source data (i.e., CDL and gSSURGO database).

Major Characteristics Of The Database

General Land Use Classification

We devised a general land use classification scheme that can be applied across much of the central United States. Initial versions of the land use classes focused on corn and soybean rotations, but a more generalized scheme was necessary when we worked with cropping sequences in the plains of eastern Kansas, where a longer growing season provides a wider variety of crops and cropping sequences, including double cropping and fallow years across this area, which exhibits an east-to-west climatic transition from subhumid to semiarid. The General Land Use (GenLU; Tables 4–5) is assigned to each agricultural field in a watershed, based on the majority land use, as derived from the CDL, for each of 6 yr, currently 2010 to 2015. The land use codes are concatenated into a string indicating a 6-yr sequence of crop cover, for example, "CBCCCB," and examined to determine a rotational classification. This classification is based on the frequency of dominant crops across the 6 yr, occurrence of three crops (corn, soybean, wheat [*Triticum aestivum* L.]) that are regionally dominant, and (in some cases) the percentages of majority cover. A General Land Use is selected to generally indicate a crop rotation system or a nonagricultural use; the classes are given as follows, and example watershed results are shown in Fig. 3.

Continuous (corn, soybean, corn/soybean, or wheat). A strict classification of 6 yr of plantings with one annual crop as the dominant land cover classification. (isAG = 1)

Perennial rotation (corn, soybean, corn/soybean, or wheat). A mixed rotation that is restricted to the dominant crop and pasture/hay classes. The intent is to identify agricultural fields that include a grass/legume crop in the 6-yr rotation. (isAG = 1)

Annual rotation (corn, soybean, corn/soybean, or wheat). A mixed rotation restricted to the dominant crop and other nondominant annual crops. The intent is to identify agricultural fields that include annual crops in the 6-yr rotation. (isAG = 1)

Fallow rotation (corn, wheat). A mixed rotation restricted to the dominant crop and at least one fallow year. (isAG = 1)

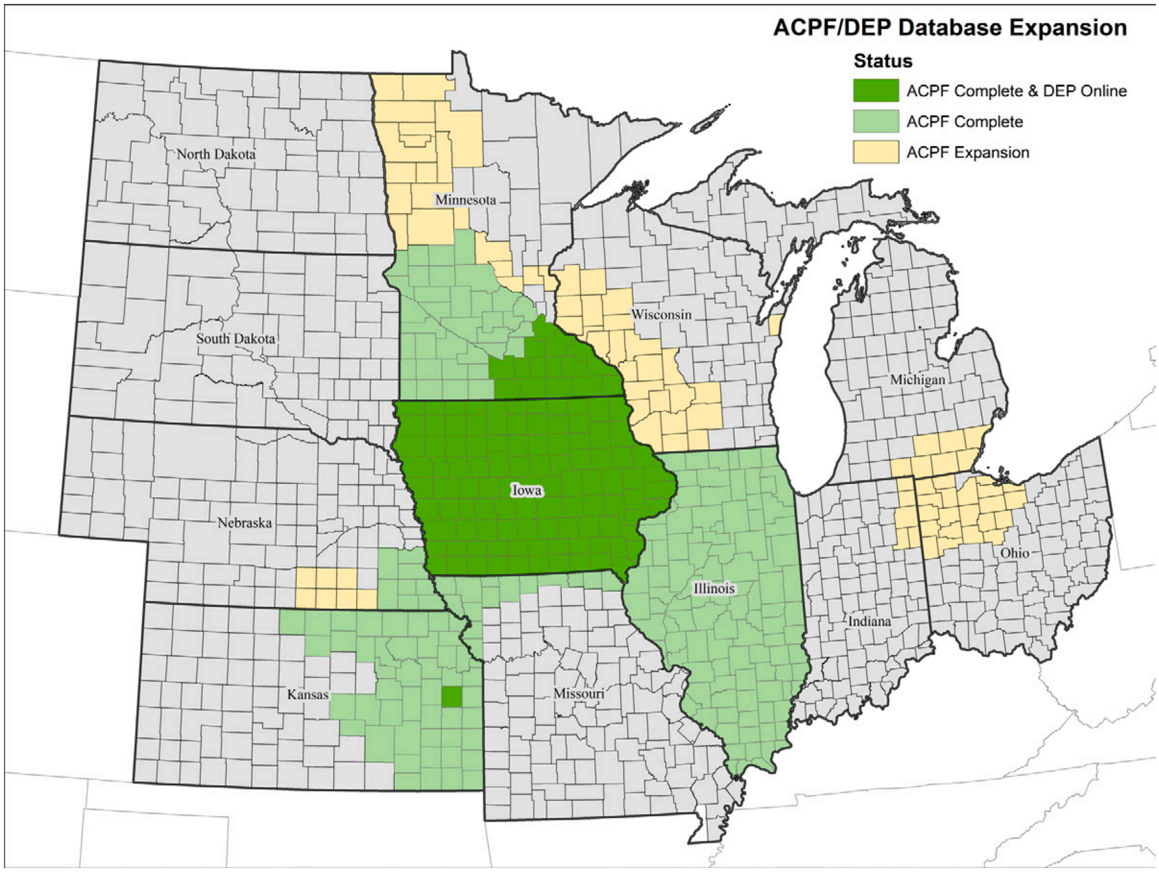

Fig. 2. Current extent of Agricultural Conservation Planning Framework (ACPF)/Daily Erosion Project (DEP) database coverage, plus areas targeted for expansion. Small polygons within each state delineate counties.

Wheat/soybean rotation. A classification restricted to wheat and soybean plantings in the 6-yr rotation. (isAG = 1)

Wheat/soybean/(corn, sorghum) rotation. A mixed rotation restricted to wheat, soybean, and corn or sorghum with at least 1 yr of each crop. (isAG = 1)

Wheat double-crop rotation. A mixed rotation that contains at least 1 yr of wheat and another crop in an annual growing season. The intent is to identify agricultural fields that include a double-crop planting in the 6-yr rotation. (isAG = 1)

Pasture. This class requires the dominant land cover to be pasture at least 5 of the past 6 yr. The Pasture class consists of a variety of continuous perennial cover classes due to aforementioned issues with CDL classified data. It can include; pasture, alfalfa, grass/legume hay, sod, and other herbaceous cover. This class may also identify fields with a mix of forest and pasture cover classes, indicating in some cases pastured woodlots. (isAG = 2)

Mixed agriculture. A mixed rotation of agricultural classes: corn, soybean, wheat, pasture, and other crops. The intent is to identify fields that are under agricultural production but do not fit in the above classifications of 6-yr rotations. (isAG = 1)

Flood-prone cropland. A mixed rotation of agricultural classes: corn, soybean, pasture, and other row crop that included at least 1 yr in which the dominant cover class was "Water." The intent is to identify agricultural fields that are undergoing agricultural production but may be subject to periodic flooding. (isAG = 1)

Forest. At least 4 yr of the dominant land cover classification as "Forest." The Forest class consists of Deciduous Forest, Evergreen Forest, Forest, and Mixed Forest NASS CDL classes. (isAG = 0)

Water/wetland. At least 4 yr with the dominant land cover classification as "Water." The Water class consists of Open Water, Wetlands, Woody Wetlands, and Herbaceous Wetlands NASS CDL classes. (isAG = 0)

Urban. At least 4 yr with the dominant land cover classification as "Urban." The Urban class consists of High, Medium, and Low Intensity Developed NASS CDL classes. (isAG = 0)

LT 15ac. Identified features that are less than 6.07 ha (15 acres) in area and typically too small for reliable classification using classified data on >30-m pixels. These are often farmsteads, but small fields in agricultural production are also included. (isAG = 0)

Unassigned. All other delineated fields with land cover records that failed to match any of the above classifications. (isAG = 0)

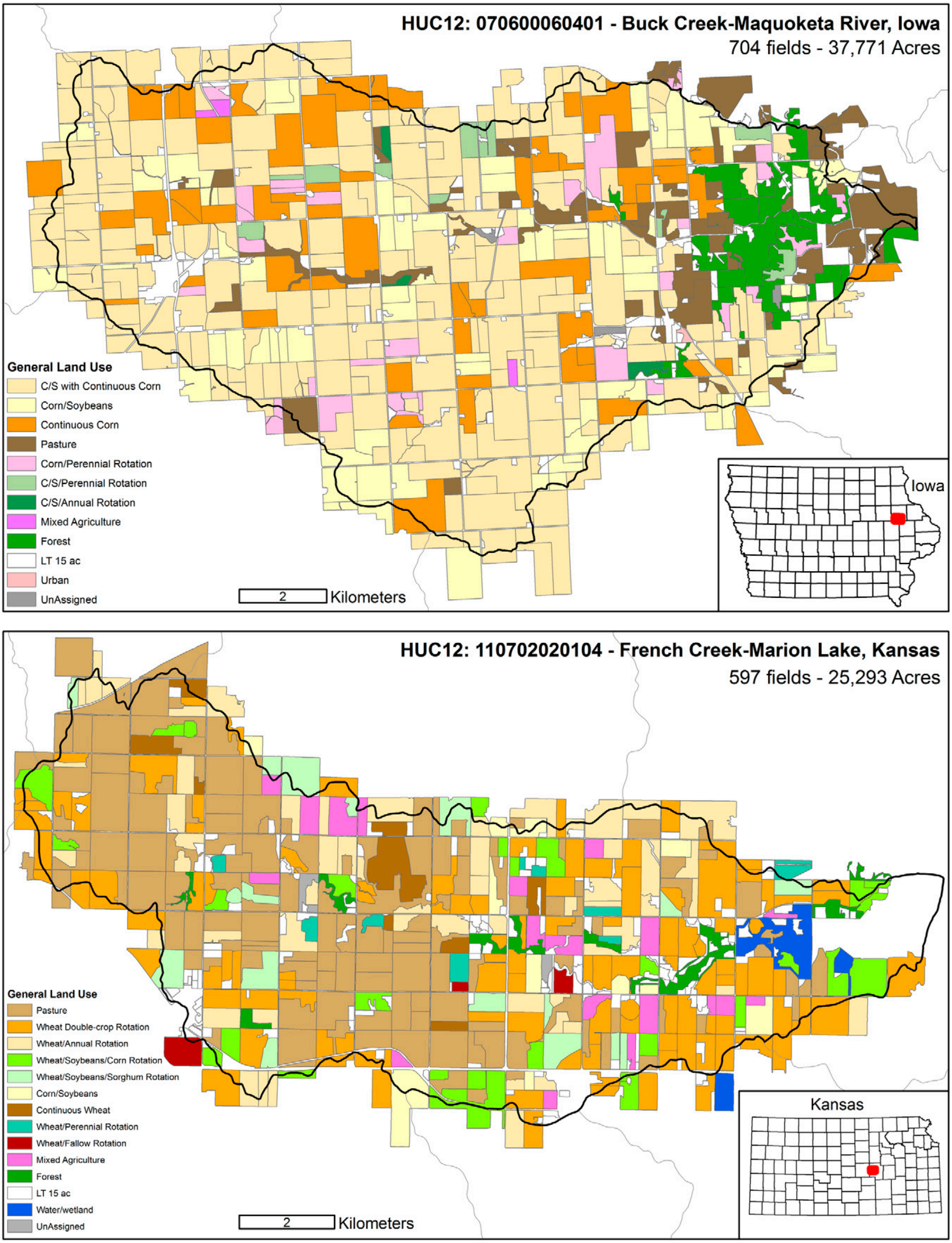

Fig. 3. Example maps of HUC 12 watersheds in Iowa and Kansas showing crop rotation results, 2010–2015.

Two example watersheds are shown (Fig. 3) to illustrate the flexibility of this classification system in identifying dominant crop rotations in different cropping regions of the Midwest. In both these watersheds, dominant crop rotations are readily identified, as are the extents of perennial cover, diverse cropping systems, and the use of perennials in rotation. In many watersheds, this information can help local planners identify opportunities and priorities for expanding conservation and for watershed improvement.

Compiled Field-level Crop History Data for Iowa and Illinois

We present information compiled statewide for Iowa and Illinois from the ACPF database (Tables 6–8) using data on agricultural fields that are assigned a 1 or 2 in the IsAG attribute. The data indicate land use change (Table 6) during the period of record; however, decreases in several rotation classes (i.e., corn/soybean, other rotations, mixed agriculture) may reflect improvements in both satellite technology and land cover classification efforts (leading to increases in the frequency of >75% dominant cover among agricultural fields). Increases in 2-yr corn/soybean rotations, continuous corn, pasture, and inclusion of wheat in rotation were recorded from 2010 to 2015, compared with 2001 to 2006. Changes in the way that perennial cover was classified during 2001 to 2015 probably influence the estimated extent of pasture expansion in these two states.

The extent of dominant rotations and land uses for Iowa and Illinois are more fully populated for 2010 to 2015 (Tables 7 and 8). These data summarize land use for approximately 20×10^6 ha of agricultural land and include the number of agricultural fields managed under each land use system/rotation. A 2-yr rotation of alternating corn and soybean crops is dominant, occupying nearly half the agricultural land in these two states. The extent of cropland in which corn was produced in consecutive years

Table 6. Land use classes and general change during the period of Cropland Data Layer availability for Iowa and Illinois.

Crop rotation	% Agriculture 2001	Hectares 2001–2006	Hectares 2010–2015	% Change	% Agriculture 2015	Agriculture land % change
	%	ha	ha	%	%	%
Corn/soybeans	39.57	7,886,370	9,572,374	21.38	45.63	6.05
Corn/soybean with continuous corn	30.22	6,021,645	6,134,932	1.88	29.24	–0.97
Pasture	10.64	2,120,253	2,497,947	17.81	11.91	1.27
Corn/soybean other rotations	12.23	2,437,693	1,042,909	–57.22	4.97	–7.26
Continuous corn	0.43	86,315	794,517	820.48	3.79	3.35
Wheat double-crop rotation	2.43	484,757	615,824	27.04	2.94	0.50
Wheat/soybean/corn rotations	0.29	58,306	157,808	170.66	0.75	0.46
Mixed agriculture	3.99	794,704	109,167	–86.26	0.52	–3.47
Flood-prone cropland	0.19	38,545	54,437	41.23	0.26	0.07
Agriculture acres		19,928,589	20,979,915	5.3		

Table 7. Numbers of agricultural fields and hectares exhibiting major crop rotations across Iowa, 2010–2015.

General land use	Field count	Hectares
	no.	ha
Corn/soybean	194,920	5,419,739
Corn/soybean with continuous corn	98,070	2,887,893
Pasture	74,460	1,668,039
Corn/soybean /perennial rotation	22,234	484,187
Continuous corn	12,123	415,025
Corn/soybean with continuous soybean	9,336	237,240
Corn/perennial rotation	6,385	133,053
Mixed agriculture	3,896	67,014
Corn/soybean /fallow rotation	1,657	41,153
Flood-prone cropland	1,342	31,260
Soybean/perennial rotation	838	21,154
Corn/soybean /annual rotation	867	17,490
Wheat/soybean/corn rotation	340	6,994
Corn/annual rotation	172	3,911
Wheat double-crop rotation	91	2,682
Soybean/annual rotation	10	145
Wheat/soybean rotation	4	55
Wheat/fallow rotation	1	18
Total	426,746	11,437,053

Table 8. Numbers of agricultural fields and hectares exhibiting major crop rotations across Illinois, 2010–2015.

General land use	Field count	Hectares
	no.	ha
Corn/soybean	172,049	4,148,592
Corn/soybean with continuous corn	88,931	2,610,203
Pasture	43,929	828,854
Wheat double-crop rotation	33,470	612,882
Corn/soybean with continuous soybean	18,313	397,004
Continuous corn	10,889	379,156
Corn/soybean /perennial rotation	10,343	175,390
Wheat/soybean/corn rotation	7,731	149,121
Corn/soybean /fallow rotation	2,337	48,769
Corn/perennial rotation	2,365	48,091
Mixed agriculture	2,449	42,107
Corn/soybean /annual rotation	1,045	28,265
Flood-prone cropland	842	23,155
Soybean/perennial rotation	1,103	20,047
Corn/annual rotation	625	16,508
Soybean/annual rotation	205	4,304
Wheat/soybean rotation	54	1,248
Wheat/fallow rotation	11	231
Wheat/perennial rotation	3	34
Wheat/annual rotation	2	31
Wheat/soybean/sorghum rotation	1	9
Total	396,697	9,534,001

exceeded 25% of the cropland acres; however, the extent of continuous corn (grown all 6 yr) covers <5% of the total cropland. The extent of fallow in rotation probably reflects crop failure under drought or excessive wetness in Iowa and Illinois, which prevented access for planting in significant areas during 2013. The data indicate that fields covered by pasture or by perennial cover in rotation occupy 20% of the agricultural land in Iowa and 11% in Illinois. The difference is largely because much of southern Illinois is under forest cover, rather than under pasture as in southern Iowa. Areas of flood-prone cropland may identify agricultural fields for which production of annual crops is not consistently profitable, suggesting lower net economic costs associated with conservation implementation on (at least parts of) these fields.

Crop cover has changed annually across Iowa and Illinois, with areas in corn increasing under a significant trend from 2001 to 2015 (Fig. 4). Areas in soybeans and in grass/pasture cover classes decreased during this time; the trend was significant ($p < 0.05$) for grass/pasture, which declined by 12% from 2001 to 2015, but the trend was not significant for soybean ($p = 0.10$) (Fig. 4). Although differences between corn and soybean cover declined after 2011, there were still about 2.5×10^6 ha more land under corn than soybean in 2015, compared with a difference of less than 650,000 ha in 2001 (Fig. 4). Corn cover was negatively correlated with both soybean cover ($R = -0.73$) and grass/pasture cover ($R = -0.59$), but annual soybean and grass/pasture cover were not correlated with one another ($R = -0.01$). A multiple regression equation showed annual corn cover was associated ($R^2 = 0.89$) with both soybean cover and grass pasture cover, but the soybean-cover regression coefficient (−0.78) was significantly less (i.e., more negative; $p < 0.05$) than the grass/pasture-cover regression coefficient (−0.40). This suggests that reduced use of soybean in rotation and, to a lesser extent, land use conversion both contributed to increases in corn cover. However, we caution that localized differences in land use change are important to confirm and interpret this result with clear insight. It is beyond our scope here to delve into local detail, but there are illustrations of this point in the literature. In Iowa, while documenting a statewide trend from corn/soybean rotation to consecutive years of corn production from 2001 to 2010, Stern et al. (2012) showed succinct patterns in rotational changes using county-level data. And as previously mentioned, Lark et al. (2015) identified southern Iowa as an area in which conversion of perennial cover to annual crops was readily detectable during the past decade.

The land use data have limitations. In particular, the CDL (USDA-NASS, 2016) does not convey information on the extent of winter cover crops used in rotations, although this may become possible with further research to evaluate the capacity of current remote sensing platforms to map late season greenness and provide accurate data on winter cover crop extent. Also, the 30-m grid resolution of remote sensing data does not enable the presence of many conservation practices to be determined from the data described here. However, a number of structural practices (e.g., terraces, sediment control basins) and practices composed of perennial vegetation (buffers, grassed waterways) can be identified on aerial photographs and digitized. This can provide important information for watershed planners to identify areas without conservation practices, as well as where producers have already installed practices that contribute to watershed health. It is also clear that agricultural field boundaries are not static but can change in any year. The ACPF toolbox (Porter et al., 2017) includes tools to edit (i.e., split or combine) existing field boundaries and update land use and crop history tables (Table 1) accordingly.

Summary

The ACPF database has been designed to provide general land use and soil survey information at the field level across a multistate region, to support conservation planning efforts using high resolution data and the ACPF toolbox (Porter et al., 2017). The consistency of this baseline spatial information at field level accesses publicly available data and helps ensure derived information to identify precision conservation–based practice

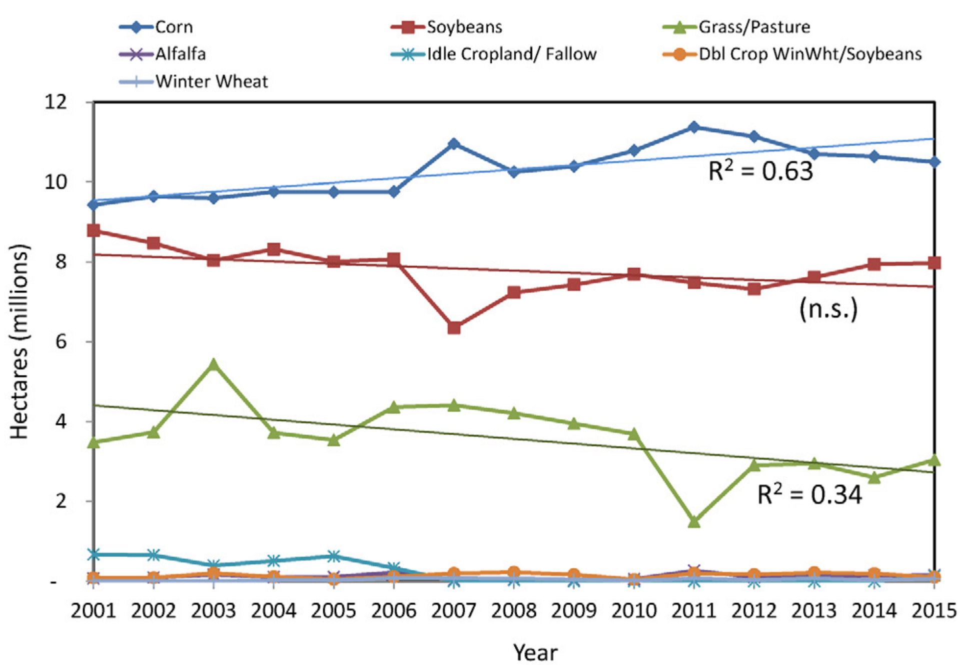

Fig. 4. Crop cover data plotted on an annual basis for Iowa and Illinois, 2006–2015, based on summations of field-level crop cover data contained in the crop history table (CH_-HUC12id), combined with field polygon areas accessed through the field boundary feature class (FB-HUC12id); linkage was provided using the FBndID identifier (see Table 1).

placement options across agricultural fields, watersheds, landscape regions, and states can be done in a consistent way. Trends in agricultural rotations and annual land cover can be examined using agricultural field boundaries to filter classified pixel data to enhance analysis results across a range of spatial scales. Multiyear data are included to identify dominant crop rotations across and area covering 6091 HUC12 watersheds.

The database is available for download by individual HUC12 watershed (North Central Region Water Network, 2017). However, the capacity for simultaneous ACPF analyses on multiple contiguous watersheds has been confirmed by several users. Watershed-specific results generated from ACPF analyses that identify precision conservation planning options are being compiled by watershed planners in several states. Individuals are invited to explore the utility of this data for watershed conservation planning and modeling activities to support multiple purposes.

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Data Citation

North Central Region Water Network. 2017. Watershed Planning Tool: Agricultural Conservation Planning Framework (ACPF). http://northcentralwater.org/acpf/.

References

Asbjornsen, H., V. Hernandez-Santana, M. Liebman, J. Bayala, J. Chen, M. Helmers, C.K. Ong, and L.A. Schulte. 2014. Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. Renew. Agric. Food Syst. 29(2):101–125. doi:10.1017/S1742170512000385

Craig, M. 2010. A history of the Cropland Data Layer at NASS. USDA-NASS. https://www.nass.usda.gov/Research_and_Science/Cropland/CDL_History_MEC.pdf (accessed 1 Sept. 2016.

Cruse, R., D. Flanagan, J. Frankenberger, B. Gelder, D. Herzmann, D. James, W. Krajewski, M. Kraszewski, J. Laflen, J. Opsomer, and D. Todey. 2006. Daily estimates of rainfall, water runoff, and soil erosion in Iowa. J. Soil Water Conserv. 61(4):191–199.

Dosskey, M.G., P. Vidon, N.P. Gurwick, C.J. Allan, T.P. Duval, and R. Lowrance. 2010. The role of riparian vegetation in protecting and improving chemical water quality in streams. J. Am. Water Resour. Assoc. 46(2):261–277. doi:10.1111/j.1752-1688.2010.00419.x

ESRI. 2016. ArcGIS for desktop documentation. http://desktop.arcgis.com/en/documentation/ (accessed 7 Sept. 2016).

Hatfield, J.L., L.D. McMullen, and C.S. Jones. 2009. Nitrate-nitrogen patterns in the Raccoon River basin related to agricultural practices. J. Soil Water Conserv. 64(3):190–199. doi:10.2489/jswc.64.3.190

Iowa State University. 2017. Daily erosion project. https://dailyerosion.org/ (accessed 20 April 2017).

Johnes, P.J., and A.L. Heathwaite. 1997. Modelling the impact of land use change on water quality in agricultural catchments. Hydrol. Processes 11:269–286. doi:10.1002/(SICI)1099-1085(19970315)11:3<269::AID-HYP442>3.0.CO;2-K

Kalcic, M.M., I. Chaubey, and J. Frankenberger. 2015. Defining Soil and Water Assessment Tool (SWAT) hydrologic response units (HRUs) by field boundaries. Int. J. Agric. Biol. Eng. 8(3):69–80.

Kremen, C., N.M. Williams, M.A. Aizen, B. Gemmill-Herren, G. LeBuhn, R. Minckley, L. Packer, S.G. Potts, T. Roulston, I. Steffan-Dewenter, D.P. Vazquez, R. Winfree, L. Adams, E.E. Crone, S.S. Greenleaf, T.H. Keitt, A.M. Klein, J. Regetz, and T.H. Ricketts. 2007. Pollination and other ecosystem services produced by mobile organisms: A conceptual framework for the effects of land use change. Ecol. Lett. 10:299–314. doi:10.1111/j.1461-0248.2007.01018.x

Lark, T.J., J.M. Salmon, and H.K. Gibbs. 2015. Cropland expansion outpaces agricultural and biofuel policies in the United States. Environ. Res. Lett. 10:044003. doi:10.1088/1748-9326/10/4/044003

Lawler, J.J., D.J. Lewis, E. Nelson, A.J. Plantinga, S. Polasky, J.C. Withey, D.P. Helmers, S. Martinuzzi, D. Pennington, and V.C. Radeloff. 2014. Projected land-use change impacts on ecosystem services in the United States. Proc. Natl. Acad. Sci. USA 111(20):7492–7497. doi:10.1073/pnas.1405557111

NRCS. 2016. Description of gridded soil survey geographic (gSSURGO) database. USDA Natural Resources Conservation Service. http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/geo/?cid=nrcs142p2_053628 (accessed 7 Sept. 2016).

Porter, S.A., M.D. Tomer, D.E. James, and K.M.B. Boomer. 2017. Agricultural Conservation Planning Framework ArcGIS Toolbox User's Manual. Ver. 2.1. http://northcentralwater.org/acpf/.

Seaber, P.R., F.P. Kapinos, and G.L. Knapp. 1987. Hydrologic unit maps. USGS Water Supply Paper 2294. US Gov. Print. Office, Washington, DC.

Stern, A.J., P.C. Doraiswamy, and E.R. Hunt, Jr. 2012. Changes in crop rotation in Iowa determined from the United States Department of Agriculture, National Agricultural Statistics Service cropland data layer product. J. Appl. Remote Sens. 6:063590. doi:10.1117/1.JRS.6.063590

Teshager, A.D., P.W. Gassman, S. Secchi, J.T. Schoof, and G. Misgna. 2016. Modeling agricultural watersheds with the Soil and Water Assessment Tool (SWAT): Calibration and validation with a novel procedure for spatially explicit HRUs. Environ. Manage. 57(4):894–911. doi:10.1007/s00267-015-0636-4

Tomer, M.D., K.M.B. Boomer, S.A. Porter, B.K. Gelder, D.E. James, and E. McLellan. 2015a. Agricultural Conservation Planning Framework: 2. Classification of riparian buffer design types with application to assess and map stream corridors. J. Environ. Qual. 44:768–779. doi:10.2134/jeq2014.09.0387

Tomer, M.D., S.A. Porter, K.M.B. Boomer, D.E. James, J.A. Kostel, M.J. Helmers, T.M. Isenhart, and E. McLellan. 2015b. Agricultural Conservation Planning Framework: 1. Developing multi-practice watershed planning scenarios and assessing nutrient reduction potential. J. Environ. Qual. 44(3):754–767. doi:10.2134/jeq2014.09.0386

Tomer, M.D., S.A. Porter, D.E. James, K.M.B. Boomer, J.A. Kostel, and E. McLellan. 2013. Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. J. Soil Water Conserv. 68(5):113A–120A. doi:10.2489/jswc.68.5.113A

USDA-FSA. 2017. Aerial photography: Imagery catalogs. USDA Farm Service Agency. https://www.fsa.usda.gov/programs-and-services/aerial-photography/imagery-products/imagery-catalogs/index (accessed 27 Feb. 2017).

USDA-NASS. 2016. Cropland data layer: Metadata. USDA National Agricultural Statistics Service. https://www.nass.usda.gov/Research_and_Science/Cropland/metadata/meta.php (accessed 1 Sept. 2016).

USGS. 2012. Watershed Boundary dataset. http://nhd.usgs.gov/wbd.html (accessed 10 Mar. 2013).

Wright, C.K., and M.C. Wimberly. 2013. Recent land use change in the western Corn Belt threatens grasslands and wetlands. Proc. Natl. Acad. Sci. USA 110(10):4134–4139. doi:10.1073/pnas.1215404110

Zhang, Y.K., and K.E. Schilling. 2006. Increasing streamflow and baseflow in Mississippi River since the 1940s: Effect of land use change. J. Hydrol. 324(1–4):412–422. doi:10.1016/j.jhydrol.2005.09.033