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# Agro-hydrologic Landscapes in the Upper Mississippi and Ohio River Basins

**Keith E. Schilling · Calvin F. Wolter · Eileen McLellan**

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**Abstract** A critical part of increasing conservation effectiveness is targeting the "right practice" to the "right place" where it can intercept pollutant flowpaths. Conceptually, these flowpaths can be inferred from soil and slope characteristics, and in this study, we developed an agro-hydrologic classification to identify N and P loss pathways and priority conservation practices in small watersheds in the U.S. Midwest. We developed a GIS framework to classify 11,010 small watersheds in the Upper Mississippi and Ohio River basins based on soil permeability and slope characteristics of agricultural cropland areas in each watershed. The amount of cropland in any given watershed varied from <10 to >60 %. Cropland areas were classified into five main categories, with slope classes of <2, 2–5, and >5 %, and soil drainage classes of poorly and well drained. Watersheds in the Upper Mississippi River basin (UMRB) were dominated by cropland areas in low slopes and poorly drained soils, whereas less-intensively cropped watersheds in Wisconsin and Minnesota (in the UMRB) and throughout the Ohio River basin were overwhelmingly well drained. Hydrologic differences in cropped systems indicate that a one-size-fits-all approach to conservation selection will not work. Consulting the classification scheme proposed herein may be an appropriate first-step in identifying those conservation practices that might be most appropriate for small watersheds in the basin.

**Keywords** Nutrients · Hypoxia · Watershed classification · Hydrologic landscapes · Hydrologic regions · Conservation

K. E. Schilling (✉)
Iowa Geological Survey, University of Iowa, 340A Trowbridge Hall, Iowa City, IA 52242-1319, USA
e-mail: keith-schilling@uiowa.edu

C. F. Wolter
Iowa Department of Natural Resources, 900 East Grand, Des Moines, IA, USA

E. McLellan
Environmental Defense Fund, Washington, DC, USA

## Introduction

Nonpoint source pollution from nitrate-nitrogen (nitrate) and phosphorus (P) contributes to nutrient enrichment in local streams and lakes (Dodds and Welch 2000; USEPA 2013) and development of hypoxic (dead) zones in regional water bodies, including the Gulf of Mexico (Turner et al. 2008) and Chesapeake Bay (Russell et al. 2008). "Dead zones" that develop can be quite large; for example, in the Gulf of Mexico, the size of the hypoxia zone averaged 13,600 $km^2$ from 1998 to 2010, with a maximum size of 20,000 $km^2$ reported in 2010 (Turner et al. 2012). Recent assessments suggest that a 45 % reduction in total nitrogen (N) and P loads is needed to reduce the size of the hypoxia zone in the Gulf (USEPA 2008), and some have suggested as much as a 70 % reduction is needed (Liu et al. 2010).

Over the last two decades, many monitoring and modeling studies point to N and P lost from agricultural regions in the U.S. Midwest as dominant sources of nutrients delivered to the Gulf (e.g., Goolsby et al. 1999; Burkart and James 1999; Donner et al. 2003; Alexander et al. 2008; David et al. 2010; White et al. 2014; Robertson et al. 2013, 2014). Estimates suggest that 82 % of the nitrate delivered to the Gulf originates in the Upper Mississippi and Ohio Rivers (USEPA 2008). Reducing nutrient losses from these agricultural regions necessitates better approaches to conservation, especially in light of increasing demands for crop production and the impact of biofuels (Costello et al. 2009). Absent better approaches to conservation, nutrient losses, and their associated problems will increase. At the same time, public funding for conservation is likely to decline, making it even more important that conservation efforts are targeted to where they will be most effective. While in-field practices such as improved nutrient management, conservation tillage, and cover crops are likely to be beneficial everywhere, it is becoming increasingly recognized that meeting nutrient reduction goals will necessitate a suite of conservation practices across a range of landscape positions in order to trap and treat nutrients lost from crop fields (Iowa Nutrient Reduction Strategy [INRS] 2013). To be effective, these "trap and treat" practices must intercept nutrient flowpaths, and yet there is no readily available tool to assist conservation professionals in identifying, for a particular watershed, the dominant nutrient flowpaths and the priority "trap and treat" practices best suited to intercepting them. Herein, we use topographic and soils criteria to classify agricultural regions across watersheds in the Upper Mississippi and Ohio river basins according to dominant flowpaths and the corresponding priority conservation practices.

Watershed classification schemes have been developed for many purposes using a variety of data sets and techniques (e.g., Wolock et al. 2004; Oudin et al. 2008; Wagener et al. 2007; Santhi et al. 2008; Sawicz et al. 2011; McManamay et al. 2012). Sawicz et al. (2011) observed that classification strategies largely fall into two main categories: those that focus on the physical attributes of a watershed (Wolock et al. 2004; Ramachandra Rao and Srinivas 2006), or those that focus on some aspect of the watershed flow regime, particularly related to ecohydrology and freshwater ecosystems (Olden et al. 2012; Poff et al. 2010). Our study is more closely aligned with the former, stemming from pioneering work by Winter (2001) who introduced the idea of "hydrologic landscapes." In this approach, watersheds with similar climatic, topographic, and geologic characteristics are expected to exhibit similar hydrologic behavior. Wolock et al. (2004) used this concept along with principal component and cluster analysis to classify 43,931 small ($\sim$200 km$^2$) watersheds into 20 noncontiguous hydrologic landscape regions (HLR) in the United States. Santhi et al. (2008) later quantified the hydrologic characteristics of the HLRs of Wolock et al. (2004) with baseflow analysis.

In our study, we utilize the hydrogeomorphic concepts of HLRs to assist with conservation targeting—in particular targeting of "trap and treat" conservation practices—at a regional scale. Since agricultural areas have been implicated as the dominant source of nutrients to the Gulf of Mexico, efforts are needed to better match agricultural conservation practices to cropland conditions at the landscape scale of the Upper Midwest. This paper presents a framework to classify approximately 11,000 small watersheds in the Upper Mississippi and Ohio River basins based on the hydrologic characteristics of agricultural cropland areas in each watershed. We use the term "agro-hydrologic" region to note that our analysis is exclusively focused on the hydrology of cropland areas in a watershed. Our goal is to provide watershed managers and conservation professionals with a visual tool to rapidly identify the suite of conservation practices most appropriate for reducing nutrient losses from cropland areas in their watershed.

## Methodology

Our study focused on the 492,000 km$^2$ Upper Mississippi River and 421,000 km$^2$ Ohio River basins in the U.S. Midwest whose rivers drain portions of 7 and 11 states, respectively (Fig. 1). The confluence of the rivers is located near Cairo, Illinois. The glacial history of the region, which has played an important role in controlling landforms and surface deposits, is also shown in Fig. 1. Much of the Upper Mississippi River basin (UMRB) and northern portion of the Ohio River basin were glaciated during the Pleistocene. The extent of recent Wisconsin glaciation ($<\sim$15,000 years B.P.) occupies a smaller area compared to the maximum glacial extent. Recently glaciated areas are typically dominated by level and poorly drained terrain whereas older glacial landscapes are characterized by rolling hills and well-developed drainage (Prior 1991). Beyond the extent of maximum glaciation, soils overlie shallow bedrock dominated by sedimentary lithologies. Likewise, a portion of southwest Wisconsin and surrounding areas was not glaciated ("Driftless Area"; Fig. 1).

We used existing geographic information system (GIS) geodatabases available for the United States for characterizing agro-hydrologic landscapes in the Upper Mississippi and Ohio River basins. Our classification system for croplands included divisions based on drainage class and slope obtained from the gridded SSURGO (gSSURGO) soils geodatabase from the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) web site (http://datagateway.nrcs.usda.gov/). The drainage class attribute in the geodatabase contains eight classes of drainage characteristics ranging from excessively drained to very poorly drained. We divided the attribute table into those soils considered well drained (Excessively Drained, Somewhat Excessively Drained, Well Drained, and Moderately Well Drained) and poorly drained (Very Poorly Drained, Poorly Drained, and Somewhat Poorly Drained). We performed a conditional command on the gSSURGO


**Fig. 1** Location of Mississippi and Ohio river basins in the United States

grid to divide the two drainage classes into two slope categories (≤5 and >5 %), thereby creating a watershed classification scheme with four categories based on high and low slopes and poor and well-drained soils. We further subdivided the low slope/poorly drained classification into two slope classes (<2 and 2–5 %) to better differentiate these land areas (Table 1). The slope classifications represent standard NRCS soil mapping ranges in many Midwestern states and were an easily searchable field in the gSSURGO database. Moreover, the slope classifications have hydrologic and land management significance. Infiltration and poor surface drainage are dominant hydrologic characteristics in flatter regions (<2 % slope) whereas runoff processes and integrated drainage would dominate in steeply sloping regions (>5 % slope). The mid-slope range (2–5 % slope) would likely have elements of both hydrology end members. Differences in common management practices are also reflected in the slope classes, with practices such as subsurface pattern tiling commonly associated with low slopes (<2 %) and terraces primarily constructed on steeply sloping agricultural lands according to NRCS guidance.

**Table 1** Typical cropland characteristics found in agro-hydrologic landscape regions

| | Poorly drained soils | | Well-drained soils |
|---|---|---|---|
| Slopes >5 % | Farming on sloping lands in old glacial landscapes, thin loess or paleosols, high runoff potential | | Farming on sloping lands underlain by shallow bedrock or sands, potential karst, baseflow-dominated with high runoff potential during storm events |
| Slopes <5 % | Dissected (slopes $2 < x < 5$ %) | Non-dissected (slopes <2 %) | Farming on sand plains, floodplains, terraces, infiltration-dominated system, high baseflow |
| | Farming on upland divides and stepped terraces, high runoff potential with tiling along waterways | Farming on hydric soils, widespread artificial drainage | |

We utilized the 2012 crop data layer from the same NRCS web site to obtain a grid of crop ground for each state. Crop ground included corn, soybeans, oats, and other commodities classified as crops by USDA, among which corn and soybeans were the dominant crops in each state evaluated. Cropland areas were tabulated within the 12-digit hydrologic unit code (HUC12) watershed boundary dataset to obtain the total areas and percentages of cropped areas within these small watersheds (size ranges between 10,000 and 40,000 acres, or approximately 40–162 $km^2$) in the Upper Mississippi and Ohio River basins. The crop ground grid was multiplied by the five soil/slope categories to obtain unique Soil Crop grids for each category in the HUC12 watersheds. The unique grid areas and various category percentages were tabulated for all watersheds. Individual HUC12 watersheds were classified as belonging to a certain agro-hydrologic landscape region if more than 50 % of the cropland in a watershed was characterized by a certain soil/slope condition. Some watersheds, often located at the boundary between landscape regions, were not characterized by a dominant agro-hydrologic landscape and these were unclassified. All together, there were 11,010 HUC12 watersheds evaluated in our analysis, including 5,733 in the UMRB and 5277 in the Ohio River basin (Table 2).

**Table 2** Number of HUC12 watersheds and percentage of land areas included in the agro-hydrologic regions in the Upper Mississippi and Ohio River basins

| | Upper Mississippi River Basin | | Ohio River Basin | |
|---|---|---|---|---|
| Classification type (>50 % of basin) | No. of basins | Percentage of total | No. of basins | Percentage of total |
| Poorly drained, <2 % slope | 1,520 | 26.5 | 812 | 15.4 |
| Poorly drained, 2–5 % slope | 996 | 17.4 | 637 | 12.1 |
| Poorly drained, >5 % slope | 9 | 0.2 | 1 | 0.0 |
| Well drained, <5 % slope | 1,491 | 26.0 | 1,502 | 28.5 |
| Well drained, >5 % slope | 610 | 10.6 | 1,476 | 28.0 |
| No dominant classification | 1,107 | 19.3 | 849 | 16.1 |
| Total number | 5,733 | | 5,277 | |

## Results and Discussion

Cropland areas are not evenly distributed in the Upper Mississippi and Ohio River basins (Fig. 2). Small watersheds in the Upper Mississippi basin are more heavily cropped than those in the Ohio, as land areas are dominated by more than 60 % cropland in large portions of Iowa, Illinois, Indiana, and southern Minnesota compared to a preponderance of watersheds in Kentucky, West Virginia, southern Ohio, and western Pennsylvania with less than 10 % cropland. This distinction is important because our classification scheme applies to cropland acres only.

Croplands in watersheds in the UMRB are dominantly characterized by low slopes (<5 % slope) and moderate to well-drained soils (Figs. 3, 4). Croplands in some watersheds in northeast Missouri and portions of Illinois, Iowa, Indiana, and Ohio were also characterized by poorly drained conditions. In contrast, croplands in the east and southeast portion of the Ohio River basin are located on much steeper slopes (>14 %) and tend to be well to excessively well drained. Cropland in the Driftless Area of southwest Wisconsin, southeast Minnesota, northeast Iowa, and northwest Illinois (Omernick 1987) has similar soil and slope characteristics to cropland conditions in the Ohio River basin, and the area stands in contrast against the gently sloping terrain in the glaciated Midwest (Fig. 3).

We combined the soil and slope conditions to classify agro-hydrologic regions in the Upper Mississippi and Ohio River basins (Fig. 5). Throughout the region, most HUC12 watersheds can be characterized by a dominant agro-hydrologic condition (>50 % of the cropland area), although some watersheds do not have a dominant cropland condition and these are noted in gray in Fig. 5. These areas are primarily located in the boundary areas between classification categories, and as such, the cropland hydrologic conditions tend to be a proportional mix of the neighboring categories.

### Upper Mississippi River Region

Of the watersheds with a dominant agro-hydrologic landscape in the UMRB, 26.5 % (1,520 watersheds) are characterized by low slopes (<2 %) and poor drainage (Table 2). Cropland in these watersheds tends to be located on recently glaciated terrain with poor surface drainage and hydric soils. Artificial drainage is widespread to drain perennially or seasonally wet soils for cropland production, and export of nitrate from these drained landscapes is particularly severe (Schilling et al. 2012). A similar percentage of watersheds in the UMRB (26.0 %) are characterized by well-drained cropland soils with low slopes (slopes <5 %). These areas have also been recently glaciated but soils are dominated by coarser deposits (sand and/or gravel), typical of outwash plains, such as those found in the Anoka Sand Plain of Minnesota and the Central Sand Plains of Wisconsin. It is important to note that the percentage of watershed land under cropland differs greatly in

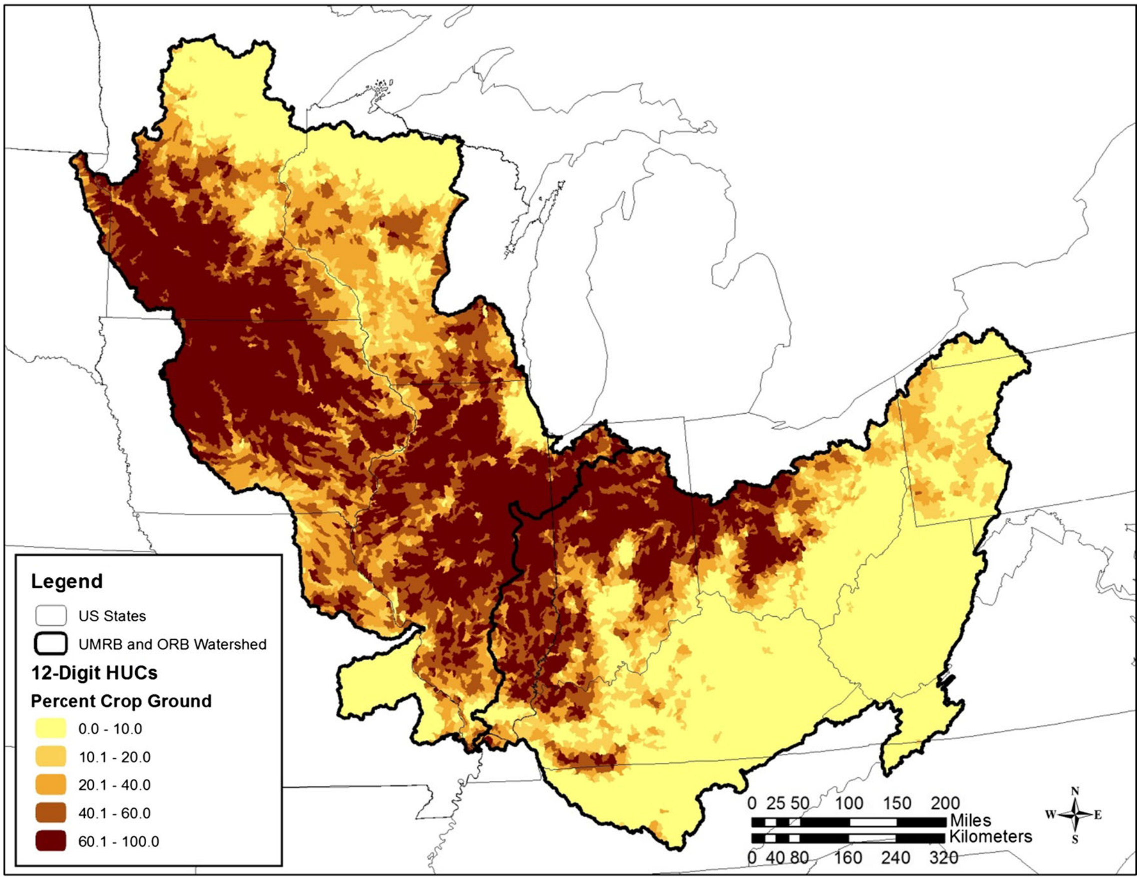


**Fig. 2** Percentage of land in cropland in HUC12 watersheds in the Upper Mississippi and Ohio River basins

the region, so comparing the number of watersheds classified in a category does not reflect the amount of land being cropped. The vast majority of land in the poorly drained, low slope category is being cropped (>60 %) compared to less than 10 % of the land in the well-drained category.

Beyond the extent of recent Wisconsin glaciation, the landscape in the UMRB consists of dissected till plains and rolling hills. In this older glacial landscape, crop production is typically concentrated on upland divides and along lowland areas (slopes 2–5 %) where poorly drained soils are developed in silty loess and fine-grained glacial till. This region is particularly prevalent in northwest Missouri, and at the margins of poorly drained low sloping ground in southern Illinois and Indiana (Fig. 5). Some areas captured in this category are associated with glacial moraines and ice-marginal features.

Croplands in well-drained, highly sloping terrain are the dominant conditions in 10.6 % of the UMRB and are primarily concentrated in the Driftless Area (Fig. 5). This area is characterized by shallow carbonate bedrock, often with karst topography, with cropland typically underlain by very permeable and well-drained soils. Since our agro-hydrologic classification did not include shallow bedrock criteria explicitly, cropland conditions associated with permeable bedrock are included in this category. There are also other watersheds classified in this category in the UMRB that do not fit this conceptual model (south-central Iowa, scattered locations elsewhere), and these are typically associated with major river valleys with coarse-textured floodplains and terraces, and steeply sloping bluffs containing wind-blown sand. Although the substrate may be different (shallow rock or wind-blown sand), potential pollutant losses from farming these high slopes and permeable soil conditions would not be substantially different.

There are very few watersheds in the UMRB with a majority of cropland characterized by poorly drained soils and high slopes (slopes >5 %) (Table 1). They are located along the basin divide in southern Iowa and are associated with a dissected pre-Illinoian landscape composed of thin loess overlying dense glacial till (Schilling et al. 2013). Although one may view this to be a very minor classification, we have extended the analysis to HUC12 areas in western and southern Iowa and northwest Missouri and found the category describes croplands in this portion of the Missouri River basin. Hence, we included this

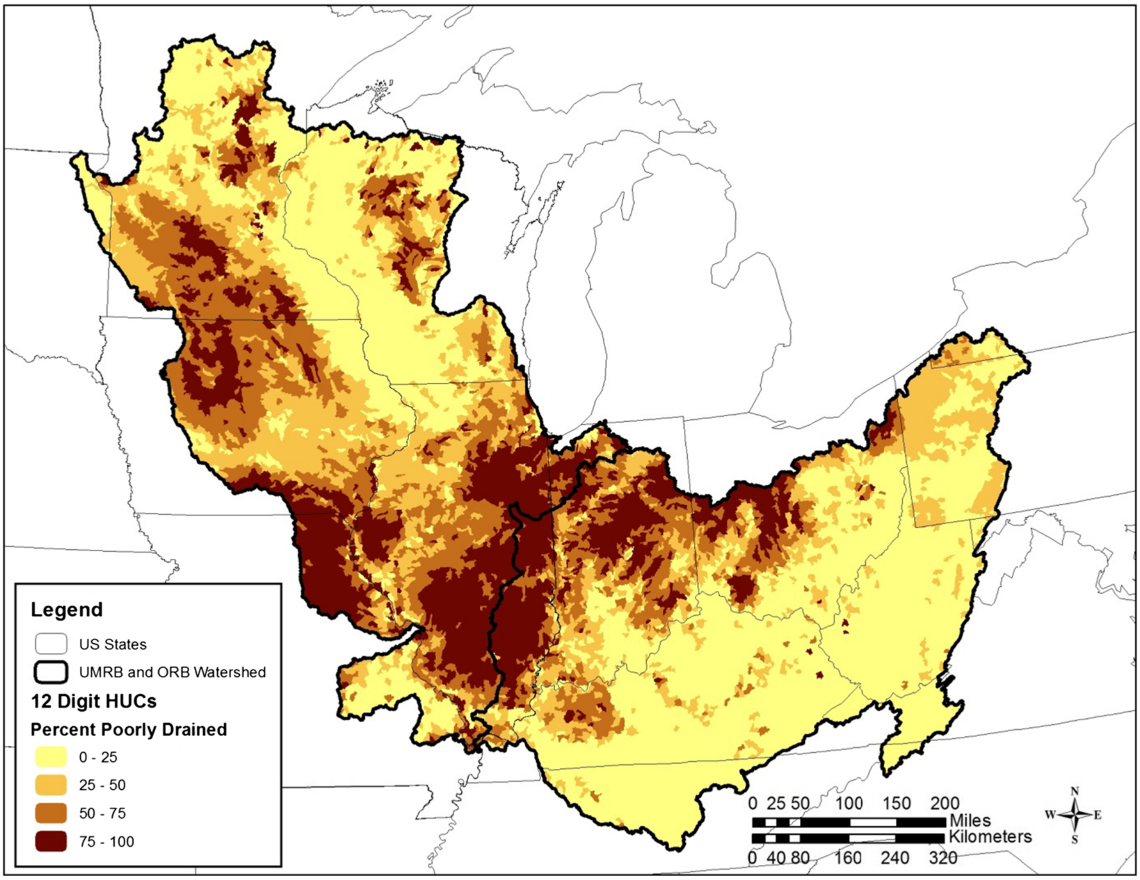


**Fig. 3** Dominant drainage class for soils in HUC12 watersheds in the Upper Mississippi and Ohio River basins

category in our analysis because, while it does not apply to many watersheds in the Upper Mississippi and Ohio River basins, it is important in other areas of the agricultural Midwest.

## Ohio River Basin Region

Cropland in the Ohio River basin is primarily associated with well-drained areas across a range of slope conditions (~57 % well drained; Table 2). It is important to note, however, that many of the watersheds in the eastern portion of the Ohio River basin characterized by these conditions include less than 10 % cropland. Hence, what little cropland is present in these watersheds is mainly associated with well-drained soils, located principally along river valleys (slopes often <5 %) or in areas typified by shallow, permeable bedrock (slopes often >5 %). In either case, the cropland will be vulnerable to increased potential for subsurface leakage of pollutants to groundwater, such as nitrate.

Poorly drained HUC12 watersheds in Ohio and Indiana are associated with recently glaciated terrain, and croplands in these areas are similar to those found in Iowa and Illinois. However, the proportion of poorly drained watersheds in the Ohio River basin (15.4 and 12.1 %) is substantially less than those observed in the UMRB (26.5 and 17.4 %; Table 2).

## Pollutant Pathways in Different Agro-hydrologic Landscapes

A description of the farming practices and pollutant pathways for the agro-hydrologic classification scheme is provided in Table 1. Each of the agro-hydrologic regions denoted in Table 1 represents a combination of slope and drainage classes that influence not only where cropland areas are located in a watershed but the dominant hydrologic flow paths for nutrient losses from these cropped areas. In regions dominated by high relief (slopes greater than or equal to 5 %) and poorly drained soils, farming done on sloping lands will be dominated by surface water runoff. Pollutants lost primarily by runoff will be the primary concern, including sediment and phosphorus. In highly sloping areas underlain by well-drained soils, most precipitation infiltrates into the ground but occasional large events will result in excessive runoff due to the high slopes.

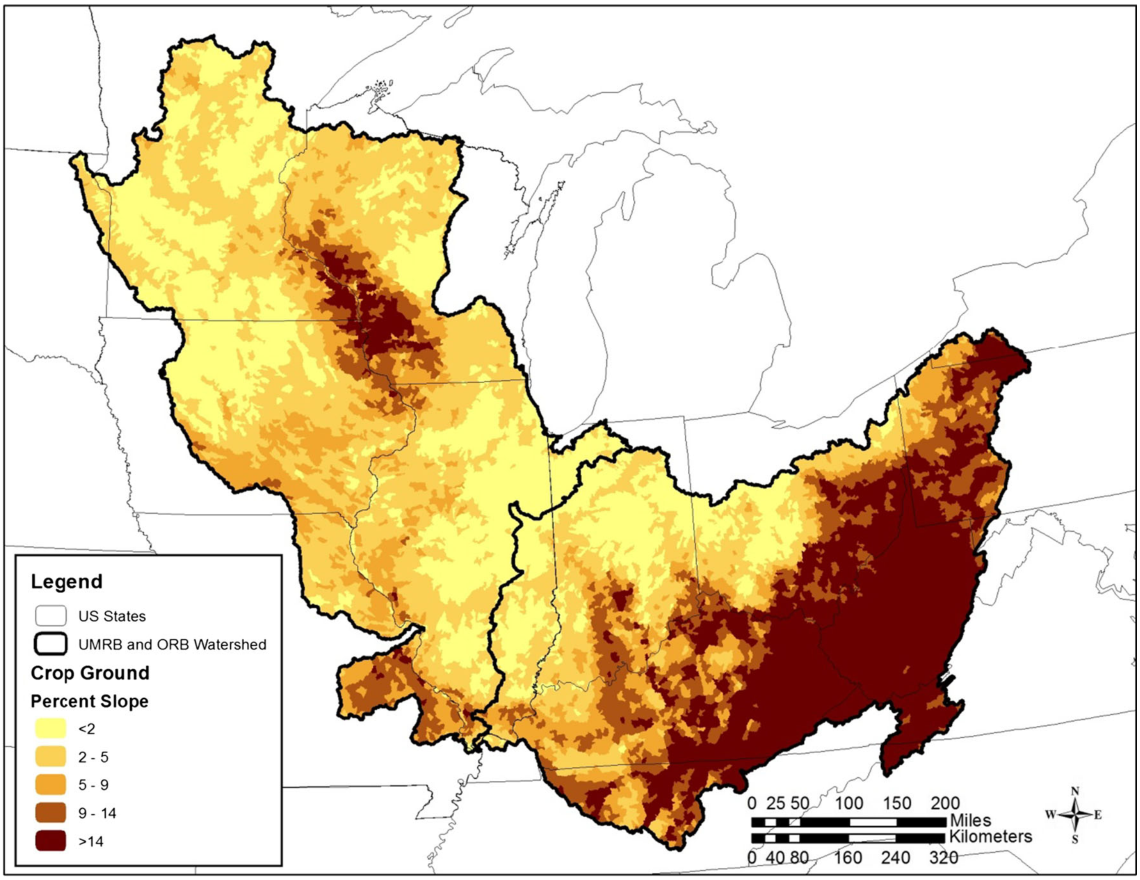


**Fig. 4** Dominant slope classes for soils in HUC12 watersheds in the Upper Mississippi and Ohio River basins

Watershed hydrology in these settings will be dominated by subsurface flow and nitrate losses, but the large events may still result in episodic and severe sediment erosion and phosphorus losses. In well-drained, low sloping regions, excessive runoff is less of a concern, and the hydrology of croplands is dominated by infiltration and subsurface flow. Nitrate losses are the dominant pollutant of concern in these areas, although soluble phosphorus losses can be significant in some areas (Tomer et al. 2008).

In low slope areas with poorly drained soils, our classification scheme divides the regions based primarily on the age of glaciations. In older glacial landscapes (older than Wisconsin age, or >15,000 years BP), farming is concentrated on the interfluves between drainages and along floodplains and terraces. Because of poor infiltration characteristics, surface runoff remains a concern in these regions. Perennial vegetation is often present along sloping drainages and waterways but subsurface drainage is also common along these low areas to reduce soil wetness and improve crop production (Schilling et al. 2013). Phosphorus and sediment from runoff and nitrate losses from subsurface drainage of upland farm areas contribute to pollutant losses from this agro-hydrologic region. In contrast, the hydrology of croplands located in flat, poorly drained areas typical of recent glaciations is dominated by artificial drainage via widespread ditches and subsurface tiles. Nitrate losses are a critical concern in this agro-hydrologic region, but contributions from soluble P losses are increasingly being recognized (Kleinman et al. 2011).

## Conservation Planning Tool

Our central purpose for classifying cropland areas in the Upper Mississippi and Ohio River basins was to improve identification of appropriate agricultural conservation practices—particularly "trap and treat" practices that intercept nutrient flowpaths—for watersheds at a macro-scale across the region. We can use the initial classification tool proposed herein to guide the conservation planning process (Table 3). It should be noted that we consider reducing inputs of nitrogen and phosphorus to be a conservation priority across the entire region and not limited to a specific agro-hydrologic classification. Efforts to address nutrient losses from in-field practices, such as adjusting fertilizer rates and timing of application, have been the

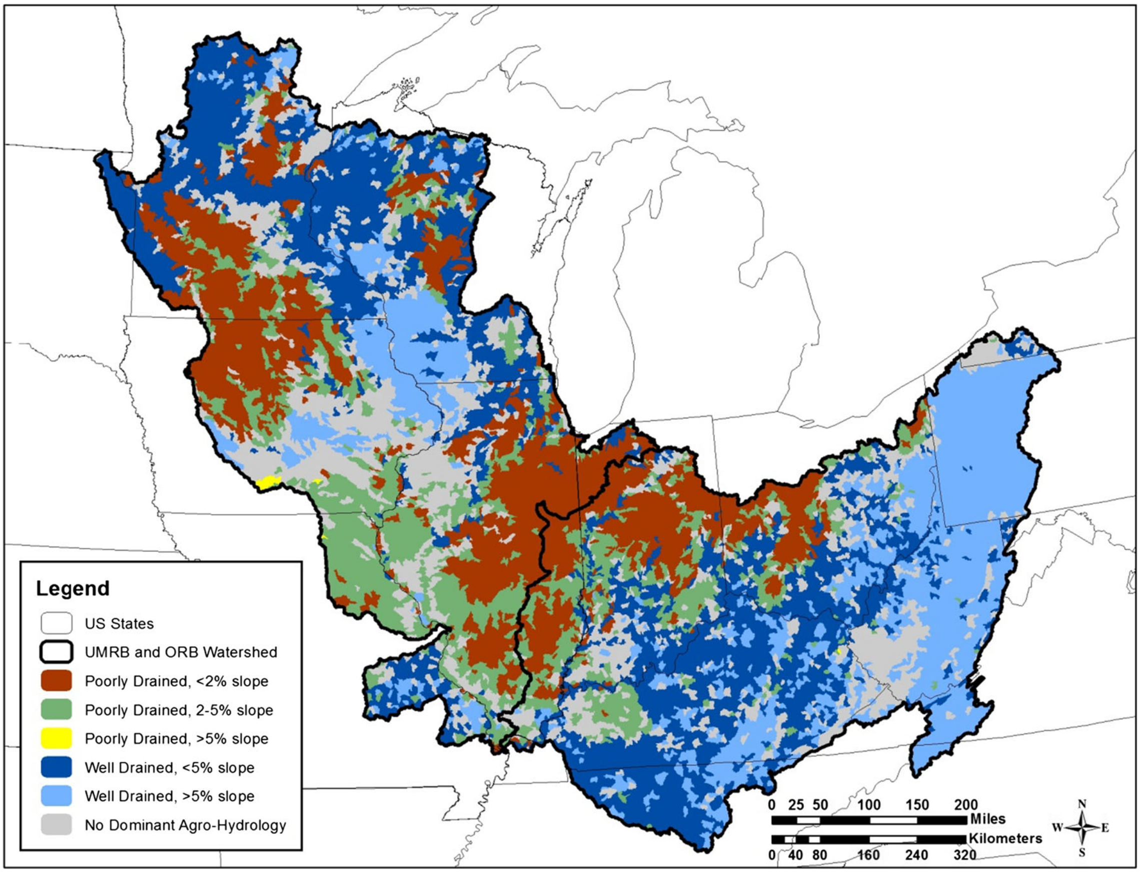


**Fig. 5** Classification of cropland in agro-hydrologic region watersheds in the Upper Mississippi and Ohio River basins

focus of considerable work (e.g., Dinnes et al. 2002; INRS 2013) and are thus not discussed herein. Similarly, recent work by Tomer et al. (2013) emphasized improving soil health as an underlying critical conservation priority in watershed planning. We concur with this assessment and believe that improving soil health through reduced tillage, better nutrient and manure management, and diversified rotations should be encouraged in all cropland areas in the Upper Mississippi and Ohio River basins; as a result, we have not included these practices in our framework. Instead, our framework focuses mainly on providing guidance for the use of edge-of-field or beyond-field (downstream) practices in the various agro-hydrologic regions, as these practices will be critical to achieving water quality goals (McLellan et al. in press) and must be targeted carefully in order to be effective.

In watersheds where cropland is characterized by poorly drained soils with higher slopes (greater than 5 % slopes or 2–5 %), control of surface runoff becomes increasingly important (Table 3). Practices such as grass waterways, terraces, contour filter strips, and installation of farm ponds serve to slow or capture runoff and reduce downstream delivery of sediment and phosphorus. Nitrogen export from these agro-hydrologic landscapes is also a concern, and placement of perennial filter strips in cropped fields (Zhou et al. 2010) or saturating grass waterways (Schilling et al. 2013) can be used to intercept and reduce leached nitrogen through enhanced denitrification. Installation of riparian buffers in these sloping landscape areas is critical to reduce overland nutrient and sediment delivery to streams (Dosskey 2001) and to intercept subsurface nutrient discharge (Lowrence et al. 1995). In all high sloping regions, including those with well-drained soils, cover crops, living mulches, and perennial cover can reduce soil erosion and loss of P (Kasper et al. 2008), although cover crops are also effective for reducing leaching of soluble nitrogen and P in all landscape regions.

In well-drained agro-hydrologic regions, downward movement of water and nutrients through permeable soils is the dominant transport pathway, with nutrients being discharged to rivers primarily through deeper subsurface flow. As a result, there are few opportunities for edge-of-field treatment, meaning that conservation efforts must be focused both upstream and downstream. Therefore, although in-field source control strategies for cropland such as improved nutrient management are useful everywhere,

**Table 3** Conservation practices suitable for agro-hydrologic landscape regions

| | Poorly drained Soils | | Well-drained Soils |
|---|---|---|---|
| Slopes >5 % | Grass waterways, contour filter strips, terraces, ponds, riparian buffers, cover crops | | In-field source controls important, riparian buffers, springs, seeps, floodplain reconnection, in-stream practices |
| Slopes <5 % | Dissected (slopes $2 < x < 5$ %) | Non-dissected (slopes <2 %) | In-field source controls important, 2-stage ditches, floodplain reconnection, off-channel wetlands |
| | Grass waterways, filter strips, ponds, cover crops, riparian buffers, wetlands, bioreactors | Drainage water management, treatment wetlands, bioreactors, 2-stage ditches | |

they become critically important in these regions. Likewise, in these regions, there is a critical need for conservation practices which enhance in-stream nutrient processing, such as reconnection of rivers to their floodplains (Noe and Hupp 2009), backwaters (James 2010) and wetland complexes (Evans et al. 2007), creation of in-stream processing sites (Groffman et al. 2005), or increasing off-channel complexity (Gooseff et al. 2007). Off-channel wetlands can also provide opportunities to reduce downstream nutrient delivery (Mitsch et al. 2005). In cropland situated in permeable bedrock or karst terrain, springs and seeps can also be targeted for enhanced nutrient processing (O'Driscoll and DeWalle 2009).

Watersheds with more than 50 % of croplands found on flat (<2 % slope), poorly drained soils are dominated by intensive cropping and widespread artificial surface and subsurface drainage. These areas have been implicated as primary sources of nitrogen delivery to the Gulf of Mexico (David et al. 2010). In watersheds dominated by artificial drainage, conservation practices are needed that retain water in the soil profile (controlled drainage; Thorp et al. 2008) or pass the nitrogen-laden water though subsurface carbon filters (bioreactors; Jaynes et al. 2008), or resaturated buffers (Jaynes and Isenhart 2013). Use of restored or constructed wetlands to intercept and treat subsurface drainage water is often very effective for nitrogen reductions in these poorly drained areas (Crumpton et al. 2008; Kovacic et al. 2000). Drainage ditches can be enhanced for nitrogen removal by creation of artificial benches (2-stage ditches; Roley et al. 2012) or weirs (Kroger et al. 2011), or by improving vegetation establishment (Strock et al. 2010). Overall, strategies for conservation siting in low sloping, poorly drained agro-hydrologic regions are focused primarily on reducing nitrogen export from widespread artificial drainage.

In watersheds with no dominant agro-hydrologic classification, watershed hydrology consists of both surface and subsurface pathways, and BMPs from multiple classes in Table 3 will be needed to reduce nutrient losses. In these watersheds, more detailed mapping of land characteristics (i.e., slope and drainage) may be needed to focus BMP selection at the more local scale. Tomer et al. (2013) used slope and terrain characteristics derived from a 1-m digital elevation model to improve siting criteria for conservation practices within HUC112 watersheds and a method such as this may be appropriate for those HUC12 watersheds without a dominant agro-hydrology.

We envision our map delineating the locations of different agro-hydrologic landscapes (Fig. 5) and the table which links these landscapes to priority conservation practices (Table 3) being useful to conservation professional and watershed managers seeking to identify appropriate conservation practices from an often-overwhelming array of choices. Narrowing the scope of choice can sometimes be the best strategy for making decisions (Iyengar and Lepper 2000; Schwartz 2000). While it is common supposition to think that more choice is better, sociological research suggests that people can have difficulty managing complex choices, experiencing what Iyengar and Lepper (2000) call "choice overload." Having too much choice often leads to indecisiveness about what option or choice might be best and dissatisfaction with the choice that they make (Iyengar and Lepper 2000; Schwartz 2000). Our study is intended to provide a scientific basis for BMP selection, reducing potential "choice overload" and thereby encouraging conservation adoption. We believe that the agro-hydrologic classification of cropland areas in the HUC12 watersheds across the Upper Mississippi and Ohio River basins provides a framework for improving the initial, first-cut consideration of appropriate conservation practices for a watershed. This allows limited resources to be used more effectively to reduce nutrient loss, and sets the stage for the use of other conservation targeting tools which can identify potential practice locations at the smaller (within-watershed) scale (e.g., Tomer et al. 2013).

While our study focused on the Upper Mississippi and Ohio River basins, similar analyses could be conducted in other regions where spatially explicit land cover, slope, and drainage data are available. Further, we note that the choice of spatial data for use in the development of agro-hydrologic regions may be location specific. In our example from the Upper Mississippi and Ohio River basins, slopes and drainage classes were important variables because of the glacial history of the area. In other locations, it is possible that other variables such as sand content, overburden thickness, or bedrock types may be important distinguishing characteristics in developing agro-hydrologic regions.

## Conclusions

In this study, we developed a GIS framework to classify 11,010 small watersheds in the Upper Mississippi and Ohio river basins based on soil permeability and slope characteristics of agricultural cropland areas in each watershed. Although the amount of cropland in any given watershed varied from <10 to >60 %, we could essentially collapse the characteristics of the cropland areas into five main categories, with slope classes of <2, 2–5, and >5 %, and soil drainage classes of poorly and well drained. Watersheds in the UMRB were dominated by cropland areas in low slopes and poorly drained soils, whereas less-intensively cropped watersheds in Wisconsin and Minnesota (in the Upper Mississippi basin) and throughout the Ohio River basin were overwhelmingly well drained.

Hydrologic differences in cropped systems in the Upper Mississippi and Ohio river basins indicate that a one-size-fits-all approach to conservation selection will not work. Poorly drained croplands will require a different suite of practices than well-drained croplands, likewise for different slope conditions. Consulting the classification scheme proposed herein may be an appropriate first-step in identifying those "trap and treat" conservation practices that might be most appropriate for an individual HUC12 watershed in the basin. Once the agro-hydrologic landscape and attendant priority practices have been identified for a watershed, additional assistance for finer-scale conservation placement may be sought.

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