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Comparing riparian buffer design classification data among watersheds representing Iowa landscapes

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Core Ideas

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Core Idea 1: Thirty-two Iowa watersheds were delineated into riparian catchments

Core Idea 2: Riparian zones were classified using the Agricultural Conservation Planning Framework

Core Idea 3: Differences in riparian classes were observed among three Major Land Resource Areas

Core Idea 4: Multi-watershed comparison of riparian classes could assist regional planning efforts

Core Idea 5: CUST_CORE_IDEA_5 :No data available.

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Multi-watershed comparison of riparian classes could assist regional planning efforts

COMPARING RIPARIAN BUFFER DESIGN CLASSIFICATION DATA AMONG WATERSHEDS REPRESENTING IOWA LANDSCAPES

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Abbreviations: ACPF – Agricultural Conservation Planning Framework; AHL – Agro-hydrologic Landscape; ANOVA – analysis of variance (1-way); CZ – Critical Zone (riparian class); DVR – Deep-rooted vegetation (riparian class); HAC – height above channel; HUC – Hydrologic Unit Code; LLL – low-lying land (<1.5 m above channel); MLRA - Major Land Resource Area; MSB – Multi-species buffer (riparian class); PD – Poorly drained; SBS – Streambank protection (riparian class); SSG – Stiff-stemmed grasses (riparian class); WD – Well drained.

ABSTRACT

Riparian buffers can improve water quality, but watershed-scale evaluations of riparian buffering opportunities are rare. A landscape discretization tool called riparian catchments, part of the Agricultural Conservation Planning Framework (ACPF) Version 3, was applied to evaluate functional riparian settings for 32 headwater watersheds representing three Major Land Resource Areas (MLRAs) in Iowa. Riparian settings of 250-m length were classified based on height-above channel and upslope contributing area to show where to place buffers primarily designed to intercept runoff, treat nitrate in shallow groundwater, and/or protect streambanks. Riparian zones found below small riparian catchments were common, typically occupying >50% of streambank lengths in MLRA 103 (northern Iowa) and MLRA 108 (southeast Iowa). In these settings, narrow (6-10 m wide) buffers provide a buffer-to-contributing-area ratio of >0.02 to filter surface runoff, while providing streambank protection. This similarity occurred despite these two MLRAs having contrasting landscapes. Whereas the narrow buffers suggested are associated with ditches and flat terrain in MLRA 103, they occur below short slopes along streams that have well dissected the watersheds in MLRA 108. In MLRA 104 of east-central Iowa, headwater alluvial streams often had broad low-lying riparian zones, where wide buffers (>25 m) may be placed to help mitigate nitrate transport in shallow groundwater. The ACPF riparian catchments approach enabled cross-watershed analyses of riparian settings, while providing spatial data to inform watershed-scale riparian planning efforts.

INTRODUCTION

One important reason to develop and implement watershed improvement plans is to protect local streams and their associated aquatic ecosystems from nutrients, sediment, and other contaminants that originate from agricultural uplands (Barmuta et al., 2011). Riparian buffers can mitigate the delivery of agricultural contaminants to aquatic systems, through physical and biogeochemical processes that act on hydrologic flows near streams (Manzoni and Porporato, 2011). Riparian vegetation can also help protect streambanks from erosion, which is important because bank erosion often dominates sediment loads in watersheds (Purvis and Fox, 2016). By utilizing high-resolution data for analysis of watersheds and riparian corridors, riparian buffers can be designed recognizing the locations and relative opportunities to intercept hydrologic pathways and reduce pollutant loads carried by water before it enters a stream course (Kuglerová et al., 2014), considering a watershed's full stream network.

The Agricultural Conservation Planning Framework (ACPF) is a conservation planning approach (Tomer et al., 2013; Tomer et al, 2015b) and toolset (Porter et al., 2018) that utilizes high-resolution data to identify where conservation practices can be placed to help improve water quality in agricultural watersheds. Many of the practices suggested through use of the ACPF are located along ephemeral flow pathways, or at the edges of agricultural fields (Tomer et al., 2020). The ACPF also includes a functional riparian assessment that employs terrain analyses (Tarboton, 1997) and then classifies riparian zones based on near-stream elevations (relative to the channel), and size of the runoff-contributing area. Results propose riparian buffer designs that reflect site-specific opportunities to intercept runoff, influence shallow groundwater, and protect streambanks from erosion (Tomer et al., 2015a). The use of digital terrain analyses to map runoff-contributing areas for riparian assessment has been demonstrated previously (Jensco et al., 2009; Kuglerová et al., 2014). The ACPF has extended this capacity through an approach to classify and place buffers that are matched to landscape - based opportunities for water quality improvement in agricultural watersheds.

The riparian analysis in Version 3 of the ACPF utilizes a watershed discretization routine called 'riparian catchments' (Porter et al., 2018; Tomer et al., 2020;). The discretization involves dividing each stream reach into (nominally) uniform length segments, delineating the runoff-contributing area to each stream segment, then dividing the contributing area by the stream to provide separate a 'riparian catchment' along each side of each stream segment. Shorelines of lakes, reservoirs and wide rivers may (optionally) be merged with the streamline coverage prior to this process. This allows the riparian catchments to be delineated along all shorelines in a watershed, allowing landscape attributes to be mapped in a riparian management context watershed-wide, and riparian practices to be prioritized based on a whole-watershed approach.

The potential benefits of watershed-wide riparian planning have been discussed in the literature from a variety of perspectives including watershed water quality improvement (Manzoni and Porporato, 2011; Schilling et al., 2017), aquatic ecosystem restoration (Palmer et al., 2005; Kuglerová et al., 2014;), and economic efficiency (Tiwari et al., 2016). It is understood that each watershed is unique, and that watershed-scale conservation planning should reflect a watershed's unique characteristics, including riparian zones and riparian management opportunities. But at the same time, planning agencies can be more effective where regional opportunities and priorities for conservation can be identified and leveraged. Do riparian settings, as they vary in their functional potential for water quality management, vary among regions in a predictable way? A regional planning context could help conservation agencies understand the relative importance of riparian management in context with broader efforts for improvement of agricultural watersheds. This study explores the use of high-resolution data for analysis of riparian management opportunities, and, through multi-watershed comparison of results, asks what kinds of interpretations can be developed to inform riparian planning at regional scales. The objective of this paper is to characterize the distribution and extents of functional riparian settings among 32 watersheds representing landform regions of central and eastern Iowa. The term' functional riparian setting' refers to a classification of relative opportunities for runoff interception, shallow groundwater management, and streambank protection found along a watershed's stream network, described herein and available through the ACPF (Tomer et al., 2015a; 2020).

METHODS

Landscape regions and watershed selection

Thirty-two headwater watersheds in Iowa were randomly selected for analysis (Fig. 1). These Hydrologic Unit Code 12-digit (HUC12) watersheds were selected to represent three Major Land Resource Areas (MLRAs; Norton, 1937; USDA-NRCS, 2006; Olmernick and Griffith, 2014) and four Agro-Hydrologic Landscape classes (AHLs; Schilling et al., 2015). The three MLRAs together cover about 2/3 of Iowa (Fig. 1) and are briefly described as follows:

MLRA 103 in north-central Iowa is an area of recent glaciation (approx. 10,000 years ago) with limited stream development, and extensive cover (>75%) of agricultural row crops that are artificially drained. Landscapes with gentle slopes and topographic depressions (prairie potholes) are common. Dominant soils, at the Great Group level, are Hapludolls (Clarion and Nicollet series) and Haplaquolls (Webster and Canisteo series).

MLRA 104 in eastern Iowa exhibits somewhat older glacial landscapes (about 50,000 years ago) with greater stream development. There is a similar wide extent of row crops, and tile drainage is also common. Slopes are gentle but tend to be longer and more uniform than in MLRA 103. Hapludolls (Kenyon, Floyd Series), Argiudolls (Dinsdale series), and Haplaquolls (Clyde, Marshan series) are typical soils.

MLRA 108C in southeastern Iowa is an older, more incised landscape (glaciated about 500,000 years ago) with a greater mix of crop, pasture, and hardwood-forest land cover. Compared to MLRAs 103 and 104, owing to the more varied terrain and vegetation, MLRA 108C has a greater mix of Alfisols and Mollisols, and less extensive cropland (often <50%).

The AHL designations (Table 1) summarize soil drainage and slope classes of dominant soil map units found within HUC12 watersheds, which are abbreviated as either poorly drained (PD) or well drained (WD), followed by a range of slopes, in percent (i.e., PD<2, PD2-5, PD>5, WD<5, WD>5; see Schilling et al., 2015). Both landscape classification systems were originally intended to inform regional conservation program planning efforts; see Norton (1937) and Schilling et al. (2015). The 32 watersheds were selected to include four watersheds from each of eight combined classes of MLRA and AHL designations (Fig. 1). A fully balanced sampling design was not possible because the AHL classes were not all well represented among HUC12 watersheds in the three MLRAs considered here.

Assembly and processing of watershed data

The ACPF input databases (Tomer et al., 2017) were downloaded for these 32 watersheds through the ACPF website (North Central Region Water Network, 2020), and 2-m grid digital elevation models (DEMs) were obtained (University of Northern Iowa, 2016). Data processing and riparian analyses followed steps outlined by Porter et al. (2017) for use of the ACPF toolbox, which operates within ArcGIS® geographic software systems, Versions 10.3-10.6; AcrPro versions 1 and 2 (Esri, 2017). The DEMs were manually edited (hydro-enforced) to correct overland flow paths where bridges and roads (etc.) caused “false impoundments” in the DEM, using ACPF tools fully described by Porter et al. (2018). Briefly, hydro-enforcement comprises edits made to a DEM, which are dominantly ‘cuts’ made through false impoundments to enforce flow paths beneath bridges and through culverts and improve accuracy of subsequent terrain analyses. The user can review effects of the edits in correcting flow paths along streams and intermittent/ephemeral drainageways and adjust the edits in an iterative approach (Porter et al., 2018). Hydro-enforcement edits were made along flow paths with a minimum threshold of 2 ha (5 acres) contributing area. Perennial streams were designated next by manually interpreting aerial photography and shaded-relief imagery for each watershed, and then editing the “stream type” field in the flow network attribute table for each perennial reach (see Porter et al., 2018). The perennial stream designations enable ACPF users to define, for each watershed, where riparian buffers may be placed to protect aquatic life.

The ACPF databases with by-field land use and soil survey information (Tomer et al., 2017) were assembled with the edited DEM and perennial stream designation feature class to provide a complete input database for ACPF analysis of each watershed. The extent of artificial (tile) drainage was estimated and included all agricultural fields dominated (>90%) by low (<5%) slopes, or substantially covered (>40%) by dual Soil Hydrologic Groups (e.g., B/D).

Discretizing riparian catchments

Land areas contributing to riparian zones along perennial stream reaches in each watershed were discretized into riparian catchments, with a (default) 250-m riparian segment length selected (Fig. 2, steps A and B). In this process, individual perennial stream reaches are defined from stream initiation points to upper stream confluences, and then successively between stream confluences down to the watershed outlet. Each reach is then divided into that number of equal-length sections of channel that is as close as possible to 250 m (Porter et al., 2018). There is then an adjustment of these sections, by reach, to reduce differences in their straight-line lengths. This step lengthens the sections where the channel is sinuous and shortens sections where the channel is straight, in order to reduce inherent bias toward delineating smaller riparian catchments above sinuous stream sections. After this adjustment, segment (straight line) and channel (sinuous) lengths are recorded for each section and listed in the riparian catchment attribute table. Contributing areas are then defined along each riparian section using the 'watershed' command (Esri, 2017), and then split by the channel itself to be delineated as riparian catchments. Identifiers are assigned to each riparian catchment based on stream reach, reach segment, and right/left side of the stream (Fig 2B). Headwater catchments that contribute to stream initiation points are also delineated. Headwater catchments present limited opportunities for riparian buffers to reduce delivery of agricultural pollutants to streams. See Porter et al. (2018) and Tomer et al. (2020) for further details on delineation of riparian catchments.

ACPF riparian classification

For each riparian catchment, riparian settings were assessed based on the size of the riparian catchment and relative elevations within the riparian zone. A 'height above channel' (HAC) tool in the ACPF was used to map the difference in elevation between each grid cell and the channel, considering the overland flow path from each cell to the stream as determined by terrain (flow direction) analysis. The HAC results are then used to derive a 'low-lying land' (LLL) width for each riparian catchment, which is defined as the area where the land surface is within 1.5 m of the stream channel elevation (illustrated in Fig. 2C), divided by the riparian segment length (Fig. 2D). A cross-classification that considers the area of each riparian catchment and the LLL width is applied to determine the ACPF riparian class (Fig. 2E). The size of the riparian catchment indicates the relative magnitude of overland flows delivered to the riparian zone, while the width of the LLL indicates the extent to which riparian vegetation, through rooting activity (Dosskey et al., 2010), could stimulate denitrification and thereby decrease nitrate in shallow groundwater. The classification criteria (Tomer et al., 2015a) were devised based on several reviews and meta-analyses of riparian buffer research literature (Mayer et al., 2007; Liu et al., 2008; Schultz et al., 2009; Dosskey et al., 2010; Dosskey et al., 2011). The process involves calculating two buffer widths, one for runoff interception and one for managing shallow groundwater (Fig 2D), then comparing the two values (Fig. 2E). Where the LLL width is >25 m, an opportunity to manage shallow groundwater quality using riparian vegetation is inferred and the ACPF-suggested buffer width may be based on the LLL width, from 25 m to a maximum of 50 m (see Mayer et al. 2007; Tomer et al. 2015). If the LLL is <25m, then the ACPF-suggested buffer width is equal to the runoff interception buffer width. The buffer width needed for runoff interception is assumed to be 0.02 times the mean runoff path length (based on Dosskey et al., 2011). That is, riparian catchment area times 0.02, divided by riparian segment length, gives a runoff-interception buffer width (Fig. 2D), but within a range of 6 to 90 m. Where the LLL width is >25 m, then the greater of the two widths is provided as the ACPF-suggested buffer width. The ACPF riparian classification also provides a suggested vegetation type. Results are meant to show relative opportunities to intercept runoff, influence shallow groundwater, and protect stream banks across a watershed's riparian settings. Riparian catchments (excluding headwater catchments) were classified into four functional riparian settings (Fig. 2F), following Tomer et al. (2015).

1) Critical Zone/Multi-species buffer (CZ/MSB) classes indicate where riparian practices can be designed to treat shallow groundwater and intercept runoff. These riparian zones are below riparian catchments where the runoff-interception width is >10 m, and the LLL width is >25 m. The larger of the two widths is the ACPF-suggested buffer width. The CZ designation is applied to the largest of these riparian catchments, from among those that sum to comprise half the total area of all riparian catchments when ranked by size in descending order.
2) Stiff-stemmed grasses (SSG) buffer class is found where the runoff interception width is >10 m, but the LLL width is < 25 m. The runoff interception buffer width is the ACPF-suggested buffer width. The key opportunity for water quality improvement in SSG riparian zones is runoff interception.
3) Deep rooted vegetation (DRV) class is found where the runoff interception width is <10 m, but the LLL width is >25 m. There is an opportunity to manage shallow

groundwater with riparian vegetation, but runoff contributions to the riparian zone are limited because of the small size of the source-area (i.e., riparian catchment).

4) Stream bank protection (SBS) class is found where the runoff interception width is <10 m and the LLL width is <25 m. The runoff interception width is the ACPF-suggested buffer width. A narrow zone of buffer vegetation (6-10 m) to protect against bank erosion is suggested along these streambanks.

Assembling Watershed Data and Statistical Analysis

Riparian catchment data (area and LLL-width) and classification results were tabulated for each watershed, along with the length of each riparian segment, channel length along that segment, stream order, and the size of each riparian catchment. These results were aggregated to list the following response variables by watershed for statistical analysis:

- The extent of each functional riparian buffer type, as a proportion of total riparian lengths. However, these were summed using only first and second order stream reaches in each watershed, because not all watersheds had higher order streams and we sought to limit any bias on buffer-type distributions due to differences in stream order. Buffer type distributions for first and second order streams were similar (not shown) and combined for a single analysis.
- The total area of ACPF-suggested riparian buffers were tabulated as a proportion of total watershed area. This included data for all riparian catchments and stream orders. For each riparian catchment, the suggested buffer area is the product of suggested buffer width times segment length.

- The proportion of headwater catchments found in each watershed was tabulated as a proportion of watershed area.

Statistical analyses were conducted to determine if/how the eight combined MLRA-AHL landscape classes significantly explained the observed variation in the watershed response variables. The results were subject to a one-way analysis of variance (ANOVA) among the eight combined classes, with four (‘replicate’) watershed observations in each class. If the ANOVA result was significant ($p<0.05$), a set of 17 contrasts were run to determine how differences among MLRA, AHL, or combined MLRA-AHL landscape classifications were responsible for the significant ANOVA result. These contrasts are listed in Table 2 and illustrated in Fig. 3. Data were log-transformed prior to analysis. Where significant, contrasts identified multiplicative differences among the landscape groupings. In presenting differences in buffer type distributions by landscape region, we only present significant contrasts that were found for all four buffer classes, because the proportional class data sum to 1.0 and thus are not independent.

Relationships among the response variables were also explored using simple correlations and regression analyses. Watershed drainage density (length of perennial streams in km divided by watershed area in km^2) was considered as a possible variable explaining variation in the watershed response variables.

RESULTS AND DISCUSSION

Characterization of Watersheds and Riparian Catchments

The 32 watersheds (Table 3) varied in size from about 4,200 to nearly 15,000 ha, based on summed areas of the riparian and headwater catchments. The combined length of streambanks in these watersheds varied by nearly an order of magnitude, from about 32 to 220 km (note 1 km of stream has 2 km of stream bank). Stream order at the watershed outlets varied from first to fourth order, as one watershed in MLRA 103 only had one first-order stream reach, while another watershed in MLRA 108 had 117 first order reaches, with headwater catchments above each initiation point (Table 3). The differences in stream order and streambank lengths also led to a wide range in number of riparian catchments among the 32 watersheds, from 104 to 1132. In practice, when developing riparian catchments for individual watersheds, ACPF users may reduce the number of riparian catchments by lengthening the default segment length (up to 500 m); or may select a short segment length (i.e., down to 100 m) to increase the number of catchments.

The extent of tile drainage in each watershed was estimated from the area of agricultural fields that had >90% extent of slopes that were <5%, and/or had >40% extent of soil map units with dual soil hydrologic groups (e.g., B/D; see Tomer et al., 2015b; Porter et al., 2018). This query provides an estimate of the likely maximum extent of tile drained fields in each watershed. This extent of tile drainage varied from 92% in three watersheds found in MLRA 103 with a PD<2 AHL class, down to 33% in one watershed in MLRA 108C with a WD>5 AHL class (Table 3).

Statistical Results

Because the proportions of streambank length found among the buffer classes must sum to 1.00, individual buffer class results are clearly not independent, and we therefore only report contrasts that were significant among all four buffer-type classes (Table 4). That is, contrasts that are significant across all four riparian classes offer the strongest evidence of truly different distributions of riparian settings among landform regions. Differences among all classes occurred for three MLRA contrasts, numbers 1, 2, and 9 (Table 4; Fig. 4). The plotted classification results (Fig. 4) show that the streambank protection class (SBS) are generally more common along stream bank lengths of first and second order streams among MLRA 103 and 108C watersheds, than in MLRA 104. This similarity results from short slopes along incised streams in watersheds in MLRA 108C, and small riparian catchments that were common along straightened ditches in MLRA 103, where landscape's low relief leads to sparse pathways of concentrated flow. In MLRA 104, particularly among watersheds with low slopes and/or poorly drained soils, stream incision is less common, and riparian zones typically had >25 m of low-lying land (LLL), which led to the DRV riparian class being common (Fig. 4). The CZ/MSB classes were also common in MLRA 104 where >25 m widths of LLL are found in relatively large riparian catchments. Accordingly, contrast values (shown with 95% confidence intervals in Table 4) indicated SSG and SBS riparian settings were less common in MLRA 104 than in MLRAs 103 and 108C, again because MLRA 104 has less incised streams, and thus, a greater extent of low-lying riparian zones with extents of LLL of >25 m being common. The relative dominance of CZ/MSB and DRV buffer classes in MLRA 104 indicates that wide riparian buffers designed to reduce nitrate in shallow groundwater can be more commonly placed in MLRA 104 than in MLRAs 103 or 108C.

The above-described contrasts in riparian buffer classifications only considered headwater watersheds (i.e., no inlet streams into the watershed) and riparian zones along first and second order streams. Classifications along higher order streams will depend on a range of factors, including watershed shape (which affects the watershed area draining to higher order streams), and the stream order found below the outlet, which can affect stream incision and distribution of alluvial deposits in the watershed (discussed by Knox, 2006). We reviewed results for third and fourth order streams in these watersheds and found that among 880 riparian catchments that were positioned above higher order streams and that exhibited low relief in the riparian zone (i.e., had >25 m of LLL), 64% of them were in MLRA 104, which shows consistency with the above-described results for lower-order streams. However, land areas in riparian catchments draining to higher order streams were affected by AHL designation. That is, of 12 watersheds with well-drained (WD) AHL designations, only one had <15% of the watershed area positioned above third and fourth order streams. Whereas, out of 20 watersheds with poorly drained (PD) AHL designations, only six had >15% of the watershed area located above third and fourth order streams. This suggests classifications associated with smaller riparian catchments (DRV and SBS classes) may be less common along higher order streams in WD AHL watersheds than in PD AHL watersheds. Higher order streams accounted for 21-49% of total watershed stream length among WD AHL watersheds (median of 15%), and 3-45% among PD AHL watersheds (median of 22%).

Significant contrasts for proportion of watershed in headwater catchments and the proportion of watershed suggested for riparian buffers are listed in Table 5. Watersheds in the youngest and least-sloping terrain tended to have larger areas (as proportion of watershed) in headwater catchments compared to older, more incised landforms (Table 5, contrasts 1, 3, 5, 6 & 10). However, contrasts 8 and 15 were two exceptions, both indicating that PD2-5 AHL watersheds in MLRA 104 had relatively small areas in headwater catchments. Edge-of field conservation practices may be more important for improving water quality in headwater catchments, where opportunities for riparian buffer protection are limited.

Drainage density and distributions of ACPF-suggested buffer widths both affect the proportions of watershed areas suggested for buffers by the ACPF. Most of the significant contrasts for buffer extent were associated with small buffer extents of MLRA 103 watersheds (Table 5, Contrasts 1, 5, 6, and 7). In MLRA 103 watersheds, narrow buffer widths associated with SBS riparian classes were common, and drainage density was least (Tomer et al., 2020), providing less stream bank length for buffer placements. The area of riparian buffers suggested by the ACPF, as a percentage of the watershed, ranged from 0.9% in an MLRA 103, PD<2 watershed, to 4.4% in an MLRA 104, PD<2 watershed. Obviously, watersheds with small drainage density have relatively less length of stream bank, and relatively fewer opportunities for placement of riparian practices compared to watersheds with greater drainage densities. We plotted ACPF suggested buffer extents against watershed drainage density by MLRA (Fig. 5). Results show riparian management opportunities indeed vary with drainage density, and that this effect of drainage density may differ among landscape regions. However, regression equations (shown in Fig. 5) are not statistically different, given the limited number of watershed observations per landscape region.

Graphics comparing watershed results

Data visualization is challenging for multi-watershed datasets of ACPF results. We plotted data from selected watershed results to show an example approach for visualization (Figs. 6 and 7). For one selected watershed in seven of the eight combined MLRA-AHL class, widths of LLL and runoff interception (0.02 x mean path length) are plotted against one another by riparian catchment (Fig. 6: note the WD<5 AHL is omitted to improve scale/readability). These plots show how the data used to classify the functional riparian settings were distributed among selected watersheds. Low lying riparian zones of wide extent were typical in MLRA 104 watersheds with poorly drained (PD) AHL classes. The increased frequency of riparian zones with narrow LLL widths and short slopes, resulting in SBS riparian classification to emphasize streambank protection, are clearly shown for MLRAs 103 and 108C (Fig. 6). Broad, low-lying riparian landscapes result from limited stream incision and/or stream straightening, and are common in MLRA 104 watersheds with PD<2 and PD2-5 AHL designations (Fig. 6).

Cumulative distributions of riparian catchment areas (in descending order) are plotted with cumulative ACPF-suggested buffer areas for the same seven watersheds (Fig. 7). The effect of headwater catchment areas on the proportion of the watershed that can benefit from riparian practices can be seen, because riparian catchment areas, as a proportion of the whole watershed, sum to a value less <1.0 because headwater catchments are omitted. Steeper accumulations of riparian-buffer area (dotted lines in Fig. 7) that coincide with a small accumulation in watershed-area treated (where solid lines flatten out, Fig. 7) occur in watersheds with more extensive DRV riparian settings in MLRA 104 with poorly drained AHL designations.

SUMMARY AND CONCLUSION

This multi-watershed assessment evaluated functional riparian settings for 32 watersheds representing landscape regions dominant in central and eastern Iowa. A landscape discretization tool that is part of ACPF version 3, called riparian catchments, was used to delineate and classify riparian zones. Riparian zones were classified to identify relative opportunities for using riparian buffer vegetation to intercept runoff, moderate groundwater nitrate, and protect streambanks. Small riparian catchments where only narrow buffers (6-10 m wide, SBS-type) were suggested to protect streambanks were most common in many watersheds, particularly in MLRAs 103 and 108C. In MLRA 104, headwater alluvial streams are often found with broad low-lying riparian zones, where use of wider buffers could be used more effectively to mitigate nitrate loss via groundwater.

In applying ACPF riparian analysis toward watershed planning, additional information should be considered for making decisions on new riparian practices. That is, we recommend ACPF riparian buffer typing results be used to supplement information from other types of riparian and river corridor assessments, which can include visual assessment of riparian conditions (Bjorkland et al. 2001; USDA-NRCS, 1998), geomorphic assessment of channel stability and movement (e.g., Sear et al., 2009), and, particularly for larger rivers, floodplain mapping (e.g., Jafarzadegan and Merwade, 2017). Results of ACPF riparian analyses indicate how buffer design may be matched to actual opportunities to minimize contributions of bank sediment, direct runoff, and shallow-groundwater nitrate to a stream. This information must be considered in context with challenges to riparian management indicated by surveys of current ecological and geomorphic conditions, and stakeholder priorities for watershed improvement.

Results of ACPF analyses across multiple watersheds provide datasets for research approaches using spatial and/or terrain analyses to characterize riparian management opportunities. Our intent here was to present an example multi-watershed analysis and motivate additional research. Results suggest that the potential role of riparian practices in water quality improvement may vary substantially among watersheds, and that there is some potential to characterize this variation regionally. However, riparian settings in watersheds are affected by natural stream development and impacts of human modification on drainage and stream course development. Both affect riparian management options and priorities on a watershed-specific basis. We encourage watershed scientists and landscape ecologists to explore the use of riparian catchments for landscape- and watershed-scale research. Use of the ACPF riparian assessment tools for implementation of riparian practices, in any given watershed, will be most effective when combined with survey data on current stream corridor conditions.

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100% because headwater catchments are excluded. One landscape group (WD<5 in MLRA 104) is omitted to allow better scale/readability.

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Table 1. Agro-Hydrologic Landscapes (AHLs) groupings are established by cross-classifying general categories of soil drainage (PD: poorly drained; WD: well drained) and slope (<2%, 2-5%, and >5% for poorly drained soils, <5% and >5% for well drained soils). Based on Schilling et al. (2015), the groupings infer dominant hydrologic flow paths (surface, subsurface) and types of conservation practices that can mitigate agricultural nutrient losses. Note that PD>5 AHL watersheds are rare in most of Iowa.

	-------------Poorly drained soil--------------		Well drained soil
Slopes >5%	PD>5%		WD>5%
Slopes <5%	PD<2%	PD2-5%	WD<5%

Table 2. Listing of statistical contrasts that were run among Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classes. Fig. 2 provides an illustrative key to these contrasts, meant to identify how riparian management opportunities for water quality improvement may vary among landscape regions.

Contrast ID	**Contrast Type**	**Contrast**
1	MLRA (among multiple AHLs)	103 vs 104 (among PD<2 & PD2-5 AHLs)
2		104 vs 108C (among PD2-5 & WD>5 AHLs)
3	AHL (among multiple MLRAs)	PD<2 vs PD2-5 (among MLRAs 103 & 104)
4		PD2-5 vs WD>5 (among MLRAs 104 & 108C)
5	MLRA (within one AHL)	103 -vs104 (within PD<2 AHL only)
6		103 vs 104 (within PD2-5 AHL only)
7		103 vs 108C (within PD2-5 AHL only)
8		104 vs 108C (within PD2-5 AHL only)
9		104 vs 108C (within WD>5 AHL only)
10	AHL (within one MLRA)	PD<2 vs PD2-5 (within MLRA 103 only)
11		PD<2 vs PD2-5 (within MLRA 104 only)
12		PD<2 vs WD<5 (within MLRA 104 only)
13		PD<2 vs WD>5 (within MLRA 104 only)
14		PD2-5 vs WD<5 (within MLRA 104 only)
15		PD2-5 vs WD>5 (within MLRA 104 only)
16		WD<5 vs WD>5 (within MLRA 104 only)
17		PD2-5 vs WD>5 (within MLRA 108C only)

Table 3. Summary data on watersheds and riparian catchments for 32 watersheds selected to provide four watersheds representing each of eight groups of combined Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classifications.

Watershed ID	MLRA-AHL	Area (ha)	Stream order	Streambank length (km)	Sinuosity (km km^{-1})	Riparian catchments (count)	Headwater catchments (count)	Headwater catchments (ha)	Proportion tile drained
50303	103-PD2-5	9091	4	92.2	1.46	550	33	5603	0.873
50305		4964	3	63.9	1.32	332	14	2325	0.808
20403		6363	3	48.6	1.14	224	7	2478	0.910
40705		4547	3	32.4	1.51	196	6	2860	0.758
90101	103-PD<2	6957	2	31.4	1.09	136	2	2209	0.871
40401		8376	3	54.3	1.24	270	7	2859	0.917
61301		10934	3	63.6	1.26	329	20	6639	0.923
50404		7081	1	21.0	1.23	104	1	2218	0.920
60403	104-PD2-5	4320	4	78.3	1.19	382	29	1262	0.618
11202		6962	3	73.5	1.26	376	14	2234	0.794
50901		9561	3	102.9	1.23	514	25	3413	0.768
20301		13488	2	142.5	1.32	750	19	4247	0.880
40302	104-PD<2	8424	4	79.7	1.24	388	15	2525	0.935
10401		8294	3	58.4	1.06	252	6	1681	0.915
20501		13861	3	118.7	1.20	577	17	4382	0.913
20703		6290	3	74.5	1.24	374	11	1510	0.863
50804	104-WD>5	5567	3	55.7	1.17	258	15	1891	0.710
51403		6643	3	90.3	1.23	440	26	2020	0.871
80402		8777	3	93.1	1.19	444	25	3330	0.421
50807		12330	3	107.4	1.16	494	16	3082	0.678
60209	104-WD<5	4862	3	62.6	1.17	302	22	1618	0.431
50503		6482	3	57.4	1.22	294	17	2442	0.781
51401		9833	4	114.2	1.19	540	34	3255	0.901
60201		10687	3	104.8	1.29	550	31	3581	0.680
70101	108C-PD2-5	14952	4	180.7	1.19	886	62	5561	0.827
70303		9597	4	216.6	1.28	1132	117	3050	0.505
70403		5489	4	100.7	1.33	558	50	2027	0.426
60601		9458	4	91.1	1.27	468	22	3956	0.568
80602	108C-WD>5	10544	4	174.1	1.13	818	75	3311	0.500
90403		10760	4	201.4	1.19	958	75	2694	0.508
90604		5107	3	76.8	1.21	378	25	1541	0.530
60101		10803	4	153.7	1.20	746	40	3162	0.331

Table 4. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in extent among all four functional riparian classes. Extent of riparian classes was measured as proportion of total watershed streambank length. The three significant contrasts that were significant across all four classes were between groups of watersheds located in different Major Land Resource Areas (MLRA). The 95% confidence intervals (in parentheses) all excluded 1.0. Values indicate multiplicative differences between groups of watersheds. Contrasted data are plotted in Fig. 4, and the full list of contrast IDs are found in Table 2.

Contrast ID and type		**Functional Riparian Settings**			
		CZ/MSB	**SSG**	**DRV**	**SBS**
MLRA (among AHLs)					
1	103 - 104 (PD<2, PD2-5)	0.45 (0.22-0.93)	1.65 (1.04-2.62)	0.51 (0.28-0.94)	2.05 (1.42-2.94)
2	104 - 108C (PD2-5, WD>5)	4.35 (2.12-8.90)	0.55 (0.34-0.87)	3.98 (2.17-7.28)	0.46 (0.32-0.66)
MLRA (within 1 AHL)					
9	104 - 108C (WD>5)	7.09 (2.58-19.5)	0.49 (0.25-0.94)	7.56 (3.21-17.8)	0.54 (0.32-0.90)

Table 5. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in proportion of watershed in headwater catchments, and proportion of watershed suggested for riparian buffers by ACPF results. Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) landscape classes both showed significant contrasts ($p < 0.05$), with 95% confidence intervals (shown in parentheses) that excluded 1.0. Values indicate multiplicative differences between groupings. The full list of contrast IDs are found in Table 2.

Contrast ID and type		Proportion of watershed in	
		Headwater catchments	**Suggested riparian buffers**
	MLRA (among AHLs)		
1	103 - 104 (PD<2, PD2-5)	1.53 (1.27-1.84)	0.43 (0.33-0.58)
	AHL (among MLRAs)		
3	PD<2 - PD2-5 (103, 104)	1.29 (1.07-1.56)	
	MLRA (within 1 AHL)		
5	103 - 104 (PD<2)	1.61 (1.24-2.09)	0.46 (0.30-0.69)
6	103 - 104 (PD2-5)	1.45 (1.12-1.89)	0.41 (0.28-0.62)
7	103 - 108C (PD2-5)		0.52 (0.34-0.78)
8	104 - 108C (PD2-5)	0.71 (0.54-0.92)	
	AHL (within 1 MLRA)		
10	PD<2 - PD2-5 (103)	1.36 (1.05-1.77)	
12	PD<2 - WD<5 (104)		1.87 (1.25-2.82)
15	PD2-5 - WD>5 (104)	0.76 (0.58-0.99)	

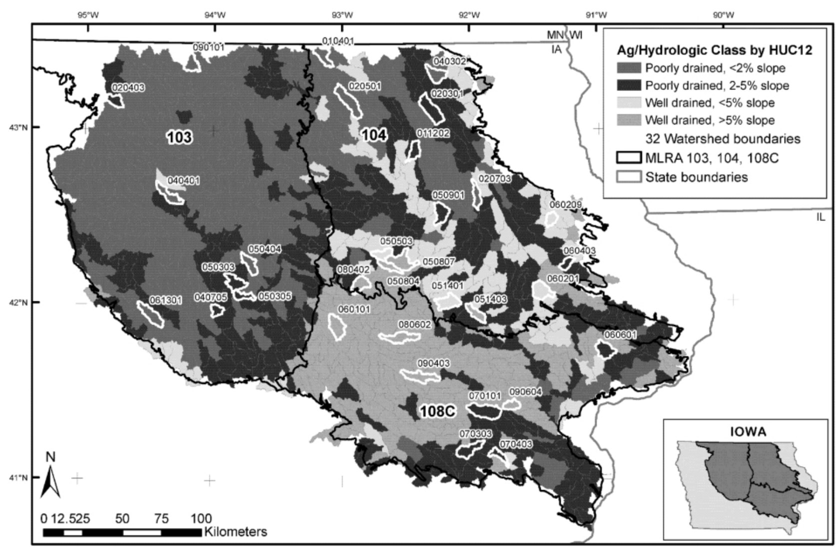

Figure 1. Map figure showing three Major Land Resource Areas (MLRAs) and the Agro-hydrologic landscape (AHL) designations of HUC12 watersheds found within those MLRAs. Locations of 32 watersheds selected for this study are also shown.

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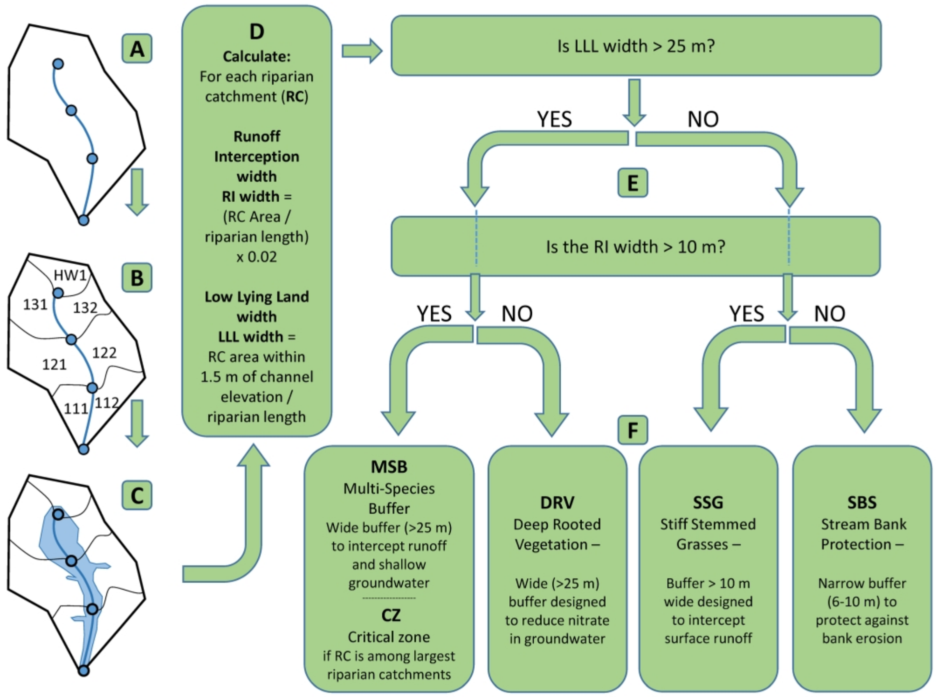

Figure 2. Flow diagram representing process of riparian catchment delineation and riparian classification in the Agricultural Conservation Planning Framework (ACPF). Steps include: A- stream reach segmentation; B- riparian catchment delineation and identification; C- Low Lying Land (LLL, where elevations are within 1.5 m of the channel) mapped; D- calculate LLL and runoff interception widths; E- compare results from D with threshold values, and F- assign riparian function class. See text.

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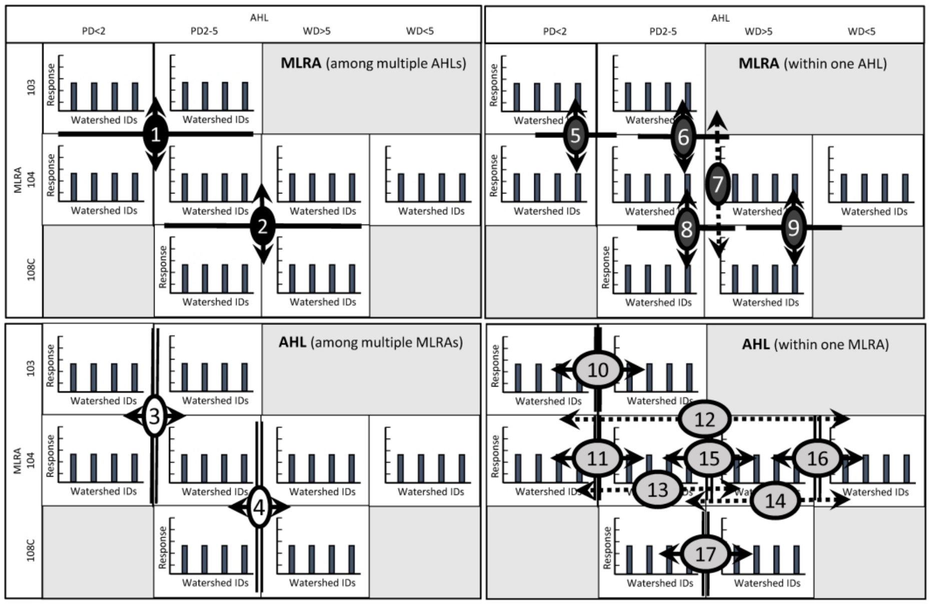

Figure 3. Key to identify 17 statistical contrasts conducted among Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) groupings, which are listed in Table 2. Four groups of plots are shown to distinguish groupings of contrasts, these are labelled in the upper right corner of each plot and listed in Table 2.

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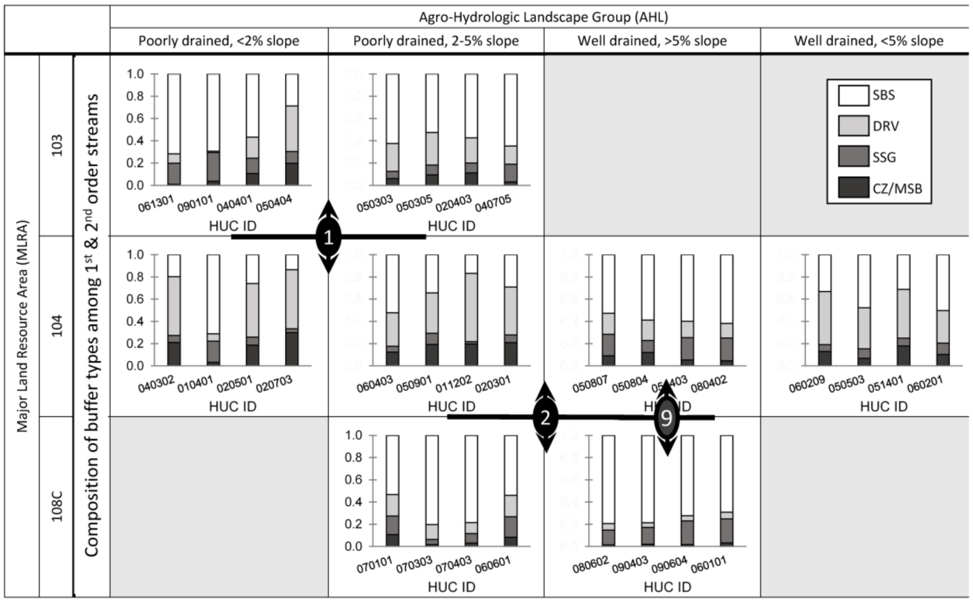

Figure 4. Distributions of riparian functional classes among 32 study watersheds, grouped by Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) classes. Results are expressed as a proportion of streambank lengths of first and second order streams in each watershed. Significant contrasts (p<0.05) are shown and are listed in Table 4. See Table 2 and Fig. 3 for the full list of contrasts tested.

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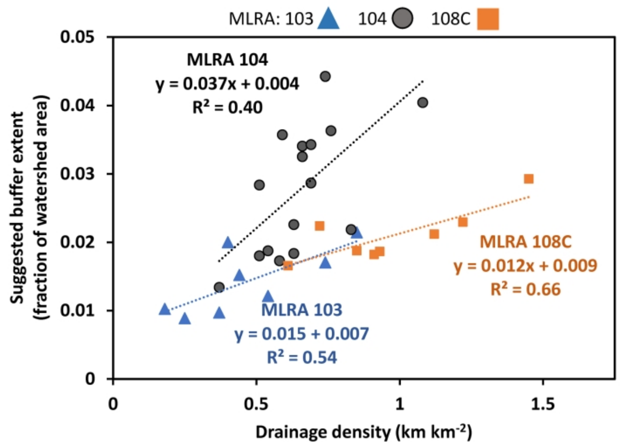

Figure 5. Regression relationships between drainage density and suggested buffer extent for watersheds representing three Major Land Resource Areas (MLRAs) in Iowa. Although greater buffer extents were found in MLRA 104 (see Table 5), the regression equations shown are not significantly different.

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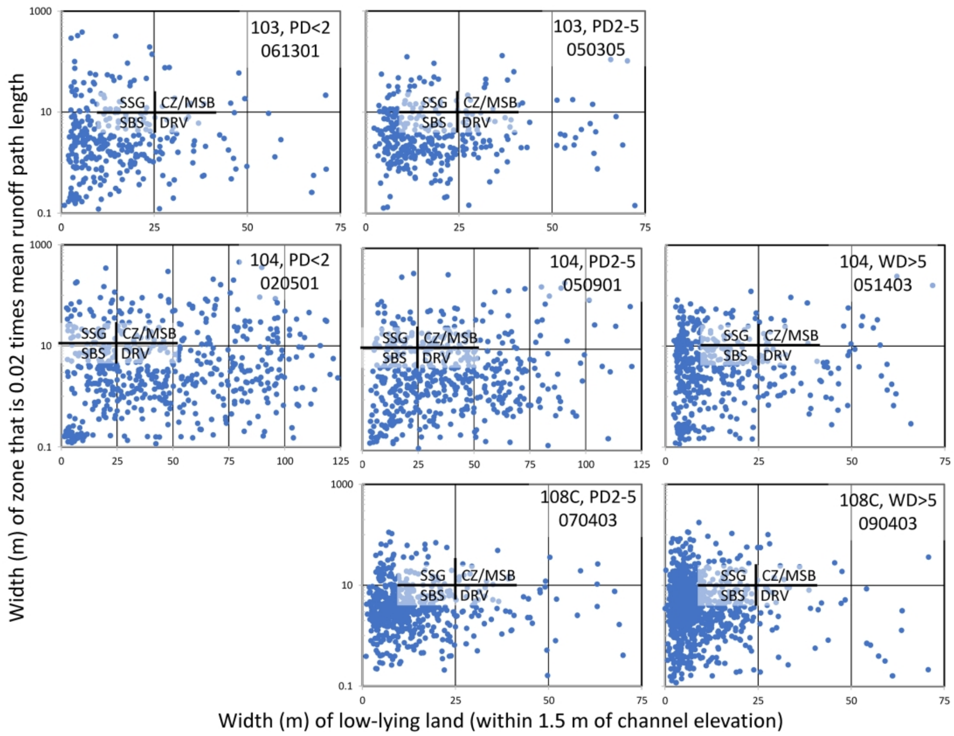

Figure 6. Plots of Low-lying land (LLL) versus runoff interception (0.02 times mean path length) widths for example watersheds in each of seven combined Major Land Resource Area (MLRA) – Agro-hydrologic landscape (AHL) groupings. The division among functional riparian buffer classes (SSG – Stiff stemmed grasses; CZ/MSB – Critical Zone/Multi-species buffer; SBS – Stream bank protection; CRV – Deep-rooted vegetation; see text) is shown for reference. One landscape group (WD<5 in MLRA 104) is omitted to allow better scale/readability.

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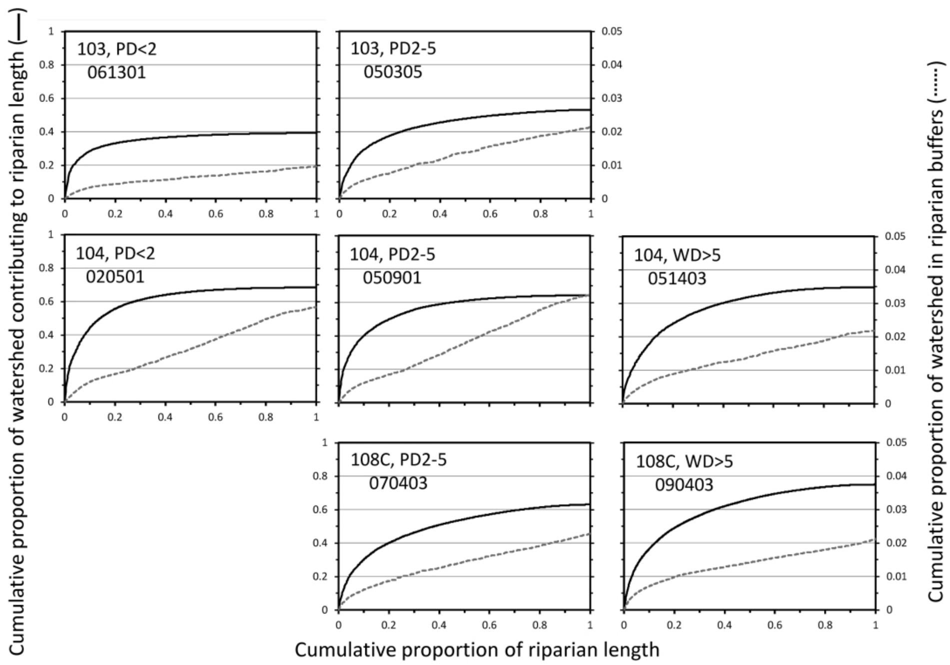

Figure 7. Plots of cumulative watershed area and cumulative area suggested for riparian buffers against cumulative streambank length for example watersheds in each of seven combined MLRA-AHL landscape groupings. Cumulative watershed areas do not sum to 100% because headwater catchments are excluded. One landscape group (WD<5 in MLRA 104) is omitted to allow better scale/readability.

254x190mm (300 x 300 DPI)

Core ideas:

Thirty-two Iowa watersheds were delineated into riparian catchments

Riparian zones were classified using the Agricultural Conservation Planning Framework

Differences in riparian classes were observed among three Major Land Resource Areas

Multi-watershed comparison of riparian classes could assist regional planning efforts

COMPARING RIPARIAN BUFFER DESIGN CLASSIFICATION DATA AMONG WATERSHEDS REPRESENTING IOWA LANDSCAPES

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Abbreviations: ACPF – Agricultural Conservation Planning Framework; AHL – Agro-hydrologic Landscape; ANOVA – analysis of variance (1-way); CZ – Critical Zone (riparian class); DVR – Deep-rooted vegetation (riparian class); HUC – Hydrologic Unit Code; LLL – low-lying land (<1.5 m above channel); MLRA - Major Land Resource Area; MSB – Multi-species buffer (riparian class); PD – Poorly drained; SBS – Streambank protection (riparian class); SSG – Stiff-stemmed grasses (riparian class); WD – Well drained.

ABSTRACT

Riparian buffers can improve water quality, but watershed-scale evaluations of riparian buffering opportunities are rare. A landscape discretization tool called riparian catchments, part of the Agricultural Conservation Planning Framework (ACPF) Version 3, was applied to evaluate functional riparian settings for 32 headwater watersheds representing three Major Land Resource Areas (MLRAs~~.~~) in Iowa. Riparian settings of 250-m length were classified based on height-above channel and upslope contributing area to show where to place buffers primarily designed to intercept runoff, treat nitrate in shallow groundwater, and/or protect streambanks. Riparian zones found below small riparian catchments were common, typically occupying >50% of streambank lengths in MLRA 103 (northern Iowa) and MLRA 108 (southeast Iowa). In these settings, narrow (6-10 m wide) buffers provide a buffer-to-contributing-area ratio of >0.02 to filter surface runoff, while providing streambank protection. This similarity occurred despite these two MLRAs having contrasting landscapes. Whereas, the narrow buffers suggested are associated with ditches and flat terrain in MLRA 103, they occur below short slopes along streams that have well dissected the watersheds in MLRA 108. In MLRA 104 of east-central Iowa, headwater alluvial streams often had broad low-lying riparian zones, where wide buffers (>25 m) may be placed to help mitigate nitrate transport in shallow groundwater. The ACPF riparian catchments approach enabled cross-watershed analyses of riparian settings, while providing spatial data to inform watershed-scale riparian planning efforts.

INTRODUCTION

One important reason to develop and implement watershed improvement plans is to protect local streams and their associated aquatic ecosystems from nutrients, sediment, and other contaminants that originate from agricultural uplands (Barmuta et al., 2011). Riparian buffers can mitigate the delivery of agricultural contaminants to aquatic systems, through physical and biogeochemical processes that act on hydrologic flows near streams (Manzoni and Porporato, 2011). Riparian vegetation can also help protect streambanks from erosion, which is important because bank erosion often dominates sediment loads in watersheds (Purvis and Fox, 2016). By utilizing high-resolution data for analysis of watersheds and riparian corridors, riparian buffers can be designed recognizing the locations and relative opportunities to intercept hydrologic pathways and reduce pollutant loads carried by water before it enters a stream course (Kuglerová et al., 2014), considering a watershed's full stream network.

The Agricultural Conservation Planning Framework (ACPF) is a conservation planning approach (Tomer et al., 2013; Tomer et al, 2015b) and toolset (Porter et al., 2018) that utilizes high-resolution data to identify where conservation practices can be placed to help improve water quality in agricultural watersheds. Many of the practices suggested through use of the ACPF are located along ephemeral flow pathways, or at the edges of agricultural fields (Tomer et al., 2020). The ACPF also includes a functional riparian assessment that employs terrain analyses (Tarboton, 1997) and then classifies riparian zones based on near-stream elevations (relative to the channel), and size of the runoff-contributing area. Results propose riparian buffer designs that reflect site-specific opportunities to intercept runoff, influence shallow groundwater, and protect streambanks from erosion (Tomer et al., 2015a). The use of digital terrain analyses to map runoff-contributing areas for riparian assessment has been demonstrated previously (Jensco et al., 2009; Kuglerová et al., 2014). The ACPF has extended this capacity through an approach to classify and place buffers that are matched to landscape -based opportunities for water quality improvement in agricultural watersheds.

The riparian analysis in Version 3 of the ACPF utilizes a watershed discretization routine called 'riparian catchments' (Porter et al., 2018; Tomer et al., 2020;). The discretization involves dividing each stream reach into (nominally) uniform length segments, delineating the runoff-contributing area to each stream segment, then dividing the contributing area by the stream to provide separate a 'riparian catchment' along each side of each stream segment. Shorelines of lakes, reservoirs and wide rivers may (optionally) be merged with the streamline coverage prior to this process. This allows the riparian catchments to be delineated along all shorelines in a watershed, allowing landscape attributes to be mapped in a riparian management context watershed-wide, and riparian practices to be prioritized based on a whole-watershed approach.

The potential benefits of watershed-wide riparian planning have been discussed in the literature from a variety of perspectives including watershed water quality improvement (Manzoni and Porporato, 2011; Schilling et al., 2017), aquatic ecosystem restoration (Palmer et al., 2005; Kuglerová et al., 2014;), and economic efficiency (Tiwari et al., 2016). It is understood that each watershed is unique and that watershed-scale conservation planning should reflect a watershed's unique characteristics, including riparian zones and riparian management opportunities. But at the same time, planning agencies can be more effective where regional opportunities and priorities for conservation can be identified and leveraged. Do riparian settings, as they vary in their functional potential for water quality management, vary among regions in a predictable way? A regional planning context could help conservation agencies understand the relative importance of riparian management in context with broader efforts for improvement of agricultural watersheds. This study explores the use of high-resolution data for analysis of riparian management opportunities, and, through multi-watershed comparison of results, asks what kinds of interpretations can be developed to inform riparian planning at regional scales. The objective of this paper is to characterize the distribution and extents of functional riparian settings among 32 watersheds representing landform regions of central and eastern Iowa. The term' functional riparian setting' refers to a classification of relative opportunities for runoff interception, shallow groundwater management, and streambank protection found along a watershed's stream network, described herein and available through the ACPF (Tomer et al., 2015a; 2020).

METHODS

Landscape Regions and ~~W~~watershed selection ~~and discretization~~

Thirty-two headwater watersheds in Iowa were randomly selected for analysis (Fig.~~ure~~ 1). These Hydrologic Unit Code 12 digit (HUC12) watersheds were selected to represent three Major Land Resource Areas (MLRAs; Norton, 1937; USDA-NRCS, 2006; Olmernick and Griffith, 2014) and four Agro-Hydrologic Landscape classes (AHLs; Schilling et al., 2015). The three MLRAs together cover about 2/3 of Iowa (Fig. 1) and are briefly described as follows:~~.~~

~~In north central Iowa,~~ MLRA 103 in north-central Iowa is an area of recent glaciation (approx. 10,000 years ago) with limited stream development, and extensive cover (>75%) of agricultural row crops that are artificially drained. Landscapes with gentle slopes and topographic depressions (prairie potholes) are common. Dominant soils, at the Great Group level, are Hapludolls (Clarion and Nicollet series) and Haplaquolls (Webster and Canisteo series).

~~In eastern Iowa,~~ MLRA 104 in eastern Iowa exhibits somewhat older glacial landscapes (about 50,000 years ago) with greater stream development. ~~and a~~There is a similar wide extent of row crops, ~~with~~ and tile drainage is also common. Slopes are gentle but tend to be longer and more uniform than in MLRA 103. Hapludolls (Kenyon, Floyd Series), Argiudolls (Dinsdale series), and Haplaquolls (Clyde, Marshan series) are typical soils.

~~In southeastern Iowa,~~ MLRA 108C in southeastern Iowa is an older, more incised landscape (glaciated about 500,000 years ago) with a greater mix of crop, pasture, and hardwood-forest land cover. Compared to MLRAs 103 and 104, owing to the more varied terrain and vegetation, MLRA 108C has a greater mix of Alfisols and Mollisols, and less extensive cropland (often <50%).

The AHL designations (Table 1) summarize soil drainage and slope classes of dominant soil map units found within HUC12 watersheds, which are abbreviated as either poorly drained (PD) or well drained (WD), followed by a range of slopes, in percent (i.e., PD<2, PD2-5, PD>5, WD<5, WD>5; see Schilling et al., 2015). Both landscape classification systems were originally intended to inform regional conservation program planning efforts; see Norton (1937) and Schilling et al. (2015). The 32 watersheds were selected to include four watersheds from each of eight combined classes of MLRA and AHL designations (Fig. 1). A fully balanced sampling design was not possible because the AHL classes are not all well represented among HUC12 watersheds in ~~a given~~ the three MLRAs considered here.

Assembly and processing of watershed data

The ACPF input databases (Tomer et al., 2017) were downloaded for these 32 watersheds through the ACPF website (North Central Region Water Network, 2020), and 2-m grid digital elevation models (DEMs) were obtained (University of Northern Iowa, 2016). Data processing and riparian analyses followed steps outlined by Porter et al. (2017) for use of the ACPF toolbox, which operates within ArcGIS® geographic software systems, Versions 10.3-10.6; AcrPro versions 1 and 2 (Esri, 2017). The DEMs were manually edited (hydro-enforced) to correct overland flow paths where bridges and roads (etc.) caused “false impoundments” in the DEM, using ACPF tools fully described by Porter et al. (2018). Briefly, hydro-enforcement comprises edits made to a DEM, which are dominantly ‘cuts’ made through false impoundments to enforce flow paths beneath bridges and through culverts and improve accuracy of subsequent terrain analyses. The user can review effects of the edits in correcting flow paths along streams and intermittent/ephemeral drainageways and adjust the edits in an iterative approach (Porter et al., 2018). Hydro-enforcement edits were made along flow paths with a minimum threshold of 2 ha (5 acres) contributing area. Perennial streams were designated next by manually interpreting aerial photography and shaded-relief imagery for each watershed, and then editing the “stream type” field in the flow network attribute table for each perennial reach (see Porter et al., 2018). The ~~riparian~~ perennial stream designations enable ACPF users to define, for each watershed, where riparian buffers may be placed to protect aquatic life.

The ACPF databases with by-field land use and soil survey information (Tomer et al., 2017) were assembled with the edited DEM and perennial stream designation feature class to provide a complete input database for ACPF analysis of each watershed. The extent of artificial (tile) drainage was estimated and included all agricultural fields dominated (>90%) by low (<5%) slopes, or substantially covered (>40%) by dual Soil Hydrologic Groups (e.g., B/D).

Discretizing riparian catchments

Land areas contributing to riparian zones along perennial stream reaches in each watershed were discretized into riparian catchments, with a (default) 250-m riparian segment length selected (Fig. 2, steps A and B). In this process, individual perennial stream reaches are defined from stream initiation points to upper stream confluences, and then successively between stream confluences down to the watershed outlet. Each reach is then divided into that number of equal-length sections of channel that is as close as possible to 250 m (Porter et al., 2018). There is then an adjustment of these sections, by reach, to reduce differences in their straight-line lengths. This step lengthens the sections where the channel is sinuous and shortens sections where the channel is straight, in order to reduce inherent bias toward delineating smaller riparian catchments above sinuous stream sections. After this adjustment, segment (straight line) and channel (sinuous) lengths are recorded for each section~~, to be~~ and listed in the riparian catchment attribute table. Contributing areas are then defined along each riparian section using the 'watershed' command (Esri, 2017), and then split by the channel itself to be delineated as riparian catchments. Identifiers are assigned to each riparian catchment based on stream reach, reach segment, and right/left side of the stream (Fig 2B). Headwater catchments that contribute to stream initiation points are also delineated. Headwater catchments present limited opportunities for riparian buffers to reduce delivery of agricultural pollutants to streams. See Porter et al. (2018) and Tomer et al. (2020) for further details on delineation of riparian catchments.

ACPF Riparian ~~Zone~~ Classification

For each riparian catchment, riparian settings were assessed ~~through a cross-classification between~~based on the size of the riparian catchment and ~~the width of "low-lying land" (LLL)~~relative elevations within the riparian zone. A 'height above channel' (HAC) tool in the ACPF was used to map the difference in elevation between each grid cell and the channel, considering the overland flow path from each cell to the stream as determined by terrain (flow direction) analysis. The HAC results are then used to derive a 'low-lying land' (LLL) width~~,~~ for each riparian catchment, which is defined as the area where the land surface is within 1.5 m of the stream channel elevation (illustrated in Fig. 2C), divided by the riparian segment length (Fig. 2D). ~~Under this~~ A cross-classification that ~~,~~considers ~~-~~the area of ~~a~~ each riparian catchment and the LLL width is applied to determine the ACPF riparian class (Fig. 2E). The size of the riparian catchment indicates the relative magnitude of overland flows delivered to the riparian zone, while the width of the LLL indicates the extent to which riparian vegetation, through rooting activity (Dosskey et al., 2010), could stimulate denitrification and thereby decrease nitrate in shallow groundwater. The classification ~~scheme~~ criteria (Tomer et al., 2015a) w~~as~~ere devised based on several reviews and meta-analyses of riparian buffer research literature (Mayer et al., 2007; Liu et al., 2008; Schultz et al., 2009; Dosskey et al., 2010; Dosskey et al., 2011). The process involves calculating two buffer widths, one for runoff interception and one for managing shallow groundwater (Fig 2D), then comparing the two values (Fig. 2E). ~~The LLL is mapped using a height-above-channel tool in the ACPF; an LLL width is then calculated for each riparian catchment.~~ Where the LLL width is >25 m, an opportunity to manage shallow groundwater quality using riparian vegetation is inferred and the ACPF-suggested buffer width may be based on the LLL width, from 25 m to a maximum of 50 m (see Mayer et al. 2007;

Tomer et al. 2015). If the LLL is <25m, then the ACPF-suggested buffer width is equal to the runoff interception buffer width. The buffer width needed for runoff interception is assumed to be 0.02 times the mean runoff path length (based on Dosskey et al., 2011). That is, riparian catchment area times 0.02, divided by riparian segment length, gives a runoff-interception buffer width (Fig. 2D), but within a range of 6 to 90 m. Where the LLL width is >25 m, then the greater of the two widths is provided as the ACPF-suggested buffer width. The ACPF riparian classification also provides a suggested vegetation type. Results are meant to show relative opportunities to intercept runoff, influence shallow groundwater, and protect stream banks across a watershed's riparian settings. Riparian catchments (excluding headwater catchments) were classified into four functional riparian settings (Fig. 2F), following Tomer et al. (2015).

1) Critical Zone/Multi-species buffer (CZ/MSB) classes indicate where riparian practices can be designed to treat shallow groundwater and intercept runoff. These riparian zones are below riparian catchments where the runoff-interception width is >10 m, and the LLL width is >25 m. The larger of the two widths is the ACPF-suggested buffer width. The CZ designation is applied to the largest of these riparian catchments, from among those that sum to comprise half the total area of all riparian catchments when ranked by size in descending order.
2) Stiff-stemmed grasses (SSG) buffer class is found where the runoff interception width is >10 m, but the LLL width is < 25 m. The runoff interception buffer width is the ACPF-suggested buffer width. The key opportunity for water quality improvement in SSG riparian zones is runoff interception.

3) Deep rooted vegetation (DRV) class is found where the runoff interception width is <10 m, but the LLL width is >25 m. There is an opportunity to manage shallow groundwater with riparian vegetation, but runoff contributions to the riparian zone are limited because of the small size of the source-area (i.e., riparian catchment).
4) Stream bank protection (SBS) class is found where the runoff interception width is <10 m and the LLL width is <25 m. The runoff interception width is the ACPF-suggested buffer width. A narrow zone of buffer vegetation (6-10 m) to protect against bank erosion is suggested along these streambanks.

Assembling Watershed Data and Statistical Analysis

Riparian catchment data (area and LLL-width) and classification results were tabulated for each watershed, along with the length of each riparian segment, channel length along that segment, stream order, and the size of each riparian catchment. These results were aggregated to list the following response variables by watershed for statistical analysis:

- The extent of each functional riparian buffer type, as a proportion of total riparian lengths. However, these were summed using only first and second order stream reaches in each watershed, because not all watersheds had higher order streams and we sought to limit any bias on buffer-type distributions due to differences in stream order. Buffer type distributions for first and second order streams were similar (not shown) and combined for a single analysis.
- The total area of ACPF-suggested riparian buffers were tabulated as a proportion of total watershed area. This included data for all riparian catchments and

stream orders. For each riparian catchment, the suggested buffer area is the product of suggested buffer width times segment length.

- The proportion of headwater catchments found in each watershed was tabulated as a proportion of watershed area.

Statistical analyses were conducted to determine if/how the eight combined MLRA-AHL landscape classes significantly explained the observed variation in the watershed response variables. The results were subject to a one-way analysis of variance (ANOVA) among the eight combined classes, with four (‘replicate’) watershed observations in each class. If the ANOVA result was significant ($p<0.05$), a set of 17 contrasts were run to determine how differences ~~in~~ among MLRA, AHL, or ~~both~~ combined MLRA-AHL landscape classifications were responsible for the significant ANOVA result. These contrasts are listed in Table 2~~1~~ and illustrated in Fig. 3~~2~~. Data were log-transformed prior to analysis. Where significant, contrasts identified multiplicative differences among the landscape groupings. In presenting differences in buffer type distributions by landscape region, ~~because the proportional class data sum to 1.0 and thus are not independent,~~ we only present significant contrasts that were found for all four buffer classes, because the proportional class data sum to 1.0 and thus are not independent.

Relationships among the response variables were also explored using simple correlations and regression analyses. Watershed drainage density (length of perennial streams in km divided by watershed area in km^2) was considered as a possible variable explaining variation in the watershed response variables.

RESULTS AND DISCUSSION

Characterization of Watersheds and Riparian Catchments

The 32 watersheds (Table 3~~2~~) varied in size from about 4,200 to nearly 15,000 ha, based on summed areas of the riparian and headwater catchments. The combined length of streambanks in these watersheds varied by nearly an order of magnitude, from about 32 to 220 km (note 1 km of stream has 2 km of stream bank). Stream order at the watershed outlets varied from first to fourth order, as one watershed in MLRA 103 only had one first-order stream reach, while another watershed in MLRA 108 had 117 first order reaches, with headwater catchments above each initiation point (Table ~~2~~3). The differences in stream order and streambank lengths also led to a wide range in number of riparian catchments among the 32 watersheds, from 104 to 1132. In practice, when developing riparian catchments for individual watersheds, ACPF users may reduce the number of riparian catchments by lengthening the default segment length (up to 500 m); or, may select a short segment length (i.e., down to 100 m) to increase the number of catchments.

The extent of tile drainage in each watershed was estimated from the area of agricultural fields that had >90% extent of slopes that were <5%, and/or had >40% extent of soil map units with dual soil hydrologic groups (e.g., B/D; see Tomer et al., 2015b; Porter et al., 2018). This query provides an estimate of the likely maximum extent of tile drained fields in each watershed. This extent of tile drainage varied from 92% in three watersheds found in MLRA 103 with a PD<2 AHL class, down to 33% in one watershed in MLRA 108C with a WD>5 AHL class (Table 3~~2~~).

Statistical Results

Because the proportions of streambank length found among the buffer classes must sum to 1.00, individual buffer class results are clearly not independent, and we therefore only report contrasts that were significant among all four buffer-type classes (Table 4~~3~~). That is, contrasts that are significant across all four riparian classes offer the strongest evidence of truly different distributions of riparian settings among landform regions. Differences among all classes occurred for three MLRA contrasts, numbers 1, 2, and 9 (Table 4~~3~~; Fig. ~~3~~4). The plotted classification results (Fig. ~~3~~4) show that the streambank protection class (SBS)~~, with suggested buffer widths that are narrow (6-10 m), dominate among~~ are generally more common along stream bank lengths of first and second order streams ~~in~~ among MLRA 103 and 108C watersheds, ~~and~~ than in ~~WD>5 AHL watersheds in~~ MLRA 104. This similarity results from short slopes along incised streams in watersheds in MLRA 108C~~ (and WD>5 watersheds in MLRA 104)~~, and -small riparian catchments that were common along -straightened ditches in MLRA 103, where landscape's low relief leads to ~~with~~ sparse pathways of concentrated flow.~~s in MLRA 103 watersheds.~~ In MLRA 104, particularly among watersheds with low slopes and/or poorly drained soils, stream incision is less common, ~~DRV classes, which occur where the riparian zone has~~and riparian zones typically had >25 m ~~width~~ of low-lying land (LLL), ~~are generally more~~which led to the DRV riparian class being common -(Fig. ~~3~~4).~~,~~ ~~as are~~The CZ/MSB classes were also common in MLRA 104 where >25 m widths of LLL ~~associated with~~are found in relatively large riparian catchments~~ and >25 m width of LLL~~. ~~The~~ Accordingly, contrast values (shown with 95% confidence intervals in Table ~~3~~4) ~~suggest~~ indicated SSG and SBS riparian settings~~, where LLL is <25 m, are more~~ were less common in MLRA 10~~3~~4 than in MLRAs 103 and 108C, ~~4,~~ ~~while~~ again because MLRA 104 has less incised streams, and thus, a greater extent of low-lying riparian zones ~~,~~ with extents of LLL of >~~-~~25 m being common. The ~~(~~relative dominance of CZ/MSB and DRV buffer ~~types)~~classes in MLRA 104 ~~, compared to MLRA 103 and MLRA 108.~~ Indicates that wide ~~R~~riparian buffers designed to reduce nitrate in shallow groundwater can be more commonly placed in MLRA 104 than in MLRAs 103 or 108C.

The above-described contrasts in riparian buffer classifications only considered headwater watersheds (i.e., no inlet streams into the watershed) and riparian zones along first and second order streams. Classifications along higher order streams will depend on a range of factors, including watershed shape (which affects the watershed area draining to higher order streams), and the stream order found below the outlet, which can affect stream incision and distribution of alluvial deposits in the watershed (discussed by Knox, 2006). We reviewed results for third and fourth order streams in these watersheds and found that among 880 riparian catchments that were positioned above higher order streams and that exhibited low relief in the riparian zone (i.e., had >25 m of LLL), 64% of them were in MLRA 104, which shows consistency with the above-described results for lower-order streams. However, land areas in riparian catchments draining to higher order streams were affected by AHL designation. That is, of 12 watersheds with well-drained (WD) AHL designations, only one had <15% of the watershed area positioned above third and fourth order streams. Whereas, out of 20 watersheds with poorly drained (PD) AHL designations, only six had >15% of the watershed area located above third and fourth order streams. This suggests classifications associated with smaller riparian catchments (DRV and SBS classes) may be less common along higher order streams in WD AHL watersheds than in PD AHL watersheds. Higher order streams accounted for

21-49% of total watershed stream length among WD AHL watersheds (median of 15%), and 3-45% among PD AHL watersheds (median of 22%).

Significant contrasts for proportion of watershed in headwater catchments and the proportion of watershed suggested for riparian buffers are listed in Table 54. Watersheds in the youngest and least-sloping terrain tended to have larger areas (as proportion of watershed) in headwater catchments compared to older, more incised landforms (Table 54, contrasts 1, 3, 5, 6 & 10). However, Contrasts 8 and 15 were two exceptions, both indicating that PD2-5 AHL watersheds in MLRA 104 had relatively small areas in headwater catchments. Edge-of field conservation practices may be more important for improving water quality in headwater catchments, where opportunities for riparian buffer protection are limited.

Drainage density and distributions of ACPF-suggested buffer ~~classes and~~ widths both affect the proportions of watershed areas suggested for buffers by the ACPF. Most of the significant contrasts for buffer extent were associated with small buffer extents of MLRA 103 watersheds (Table 54, Contrasts 1, 5, 6, and 7). In MLRA 103 watersheds, narrow buffer widths associated with SBS riparian classes were common, and drainage density was least (Tomer et al., 2020), providing less stream bank length for buffer placements. The area of riparian buffers suggested by the ACPF, as a percentage of the watershed, ranged from 0.9% in an MLRA 103, PD<2 watershed, to 4.4% in an MLRA 104, PD<2 watershed. Obviously, watersheds with small drainage density have relatively less length of stream bank, and relatively fewer opportunities for placement of riparian practices compared to watersheds with greater drainage densities. We plotted ACPF suggested buffer extents against watershed drainage density by MLRA (Fig. 54). Results show riparian management opportunities indeed vary with drainage density, and that this effect of drainage density may differ among landscape regions. However, regression equations (shown in Fig. 5~~4~~) are not statistically different, given the limited number of watershed observations per landscape region.

Graphics comparing watershed results

Data visualization is challenging for multi-watershed datasets of ACPF results. We plotted data from selected watershed results to show an example approach for visualization (Figs. 6~~5~~ and ~~6~~7). For one selected watershed in seven of the eight combined MLRA-AHL class, widths of LLL and runoff interception (0.02 x mean path length) are plotted against one another by riparian catchment (Fig. 6~~5~~: note the WD<5 AHL is omitted to improve scale/readability). These plots show how the data used to classify the functional riparian settings were distributed among selected watersheds. Low lying riparian zones of wide extent were typical in MLRA 104 watersheds with poorly drained~~in~~ (PD) AHL classes. The increased frequency of riparian zones with narrow LLL widths and short slopes, resulting in SBS riparian classification to emphasize streambank protection, are clearly shown for MLRAs 103 and 108C (Fig. 6~~5~~). Broad, low-lying riparian landscapes result ~~results~~ from limited stream incision and/or stream straightening, and are common in MLRA 104 watersheds with PD<2 and PD2-5 AHL designations (Fig. ~~5~~6).

Cumulative distributions of riparian catchment areas (in descending order) are plotted with cumulative ACPF-suggested buffer areas for the same seven watersheds (Fig. 7~~6~~). The effect of headwater catchment areas on the proportion of the watershed that can benefit from riparian practices can be seen, because riparian catchment areas, as a proportion of the whole watershed, sum to a value less <1.0 ~~as~~ because headwater catchments are omitted. Steeper accumulations of riparian-buffer area (dotted lines in Fig. 7~~6~~) that coincide with a small accumulation in watershed-area treated (where solid lines flatten out, Fig. ~~6~~7) occur in watersheds with more extensive DRV riparian settings in MLRA 104 with poorly drained AHL designations.

SUMMARY AND CONCLUSION

This multi-watershed assessment evaluated functional riparian settings for 32 watersheds representing landscape regions dominant in central and eastern Iowa. A landscape discretization tool that is part of ACPF version 3, called riparian catchments, was used to delineate and classify riparian zones. Riparian zones were classified to identify relative opportunities for using riparian buffer vegetation to intercept runoff, moderate groundwater nitrate, and protect streambanks. Small riparian catchments where only narrow buffers (6-10 m wide, SBS-type) were suggested to protect streambanks were most common in many watersheds, particularly in MLRAs 103 and 108C. In MLRA 104, headwater alluvial streams are often found with broad low-lying riparian zones, where use of wider buffers could be used more effectively to mitigate nitrate loss via groundwater.

In applying ACPF riparian analysis toward watershed planning, additional information should be considered for making decisions on new riparian practices. That is, we recommend ACPF riparian buffer typing results be used to supplement information from other types of riparian and river corridor assessments, which can include visual assessment of riparian conditions (Bjorkland et al. 2001; USDA-NRCS, 1998), geomorphic assessment of channel stability and movement (e.g., Sear et al., 2009), and, particularly for larger rivers, floodplain mapping (e.g., Jafarzadegan and Merwade, 2017). Results of ACPF riparian analyses indicate how buffer design may be matched to actual opportunities to minimize contributions of bank sediment, direct runoff and shallow-groundwater nitrate to a stream. This information must be considered in context with challenges to riparian management indicated by surveys of current ecological and geomorphic conditions, and stakeholder priorities for watershed improvement.

Results of ACPF analyses across multiple watersheds provide datasets for research approaches using spatial and/or terrain analyses to characterize riparian management opportunities. Our intent here was to present an example multi-watershed analysis and motivate additional research ~~among readers~~. Results suggest~~s~~ that the potential role of riparian practices in water quality improvement may vary substantially among watersheds, and that there is some potential to characterize this variation regionally. However, riparian settings in watersheds are affected by natural stream development and impacts of human modification on drainage and stream course development. Both affect riparian management options and priorities on a watershed-specific basis. We encourage watershed scientists and landscape ecologists to ~~trial a variety of approaches to riparian assessment using~~explore the use of riparian catchments ~~as a platform~~ for landscape- and watershed-scale research. Use of the ACPF riparian assessment tools for implementation of riparian practices, in any given watershed, will be most effective when combined with survey data on current stream corridor conditions.

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FIGURES AND TABLES

List of Figures

1. Map figure showing three Major Land Resource Areas (MLRAs) and the Agro-hydrologic landscape (AHL) designations of HUC12 watersheds found within those MLRAs. Locations of 32 watersheds selected for this study are also shown.

~~1.~~2. Flow diagram representing process of riparian catchment delineation and riparian classification in the Agricultural Conservation Planning Framework (ACPF). Steps include: A- stream reach segmentation; B- riparian catchment delineation and identification; C- Low Lying Land (LLL, where elevations are within 1.5 m of the channel) mapped; D- calculate LLL and runoff interception widths; E- compare results from D with threshold values, and F- assign riparian function class. See text.

~~2.~~3. Key to identify 17 statistical contrasts conducted among Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) groupings, which are listed in Table 2. Four groups of plots are shown to distinguish groupings of contrasts, these are labelled in the upper right corner of each plot and listed in Table 2

~~3.~~4. Distributions of riparian functional classes among 32 ~~HUC12~~ study watersheds, grouped by Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) classes. Results are expressed as a proportion of streambank lengths of first and second order streams in each watershed. Significant contrasts ($p<0.05$) are shown and are listed in Table 4. See Table 2 and Fig. 3 for the full list of contrasts tested.

~~4.~~5. Regression relationships between drainage density and suggested buffer extent for watersheds representing three ~~Iowa~~ Major Land Resource Areas (MLRAs) in Iowa. Although greater buffer extents were found in MLRA 104 (see Table ~~4~~5), ~~T~~the regression equations shown are not significantly different.

~~5.~~6. Plots of Low-lying land (LLL) versus runoff interception (0.02 times mean path length) widths for example watersheds in each of ~~eight~~ seven combined Major Land Resource Area (MLRA) ~~-~~– Agro-hydrologic landscape (AHL) ~~landscape~~ groupings. The ~~D~~division ~~between~~ among functional riparian buffer classes (SSG – Stiff stemmed grasses; CZ/MSB – Critical Zone/Multi-species buffer; SBS – Stream bank protection; CRV – Deep-rooted vegetation; see text) is shown for reference. One landscape group (WD<5 in MLRA 104) is omitted to allow better scale/readability.

~~6.~~7. Plots of cumulative watershed area and cumulative area suggested for riparian buffers against cumulative streambank length for example watersheds in each of ~~eight~~ seven combined MLRA-AHL landscape groupings. Cumulative watershed areas do not sum to 100% because headwater catchments are excluded. One landscape group (WD<5 in MLRA 104) is omitted to allow better scale/readability.

List of Tables

1. Agro-Hydrologic Landscapes (AHLs) groupings are established by cross-classifying general categories of soil drainage (PD: poorly drained; WD: well drained) and slope

(<2%, 2-5%, and >5% for poorly drained soils, <5% and >5% for well drained soils). Based on Schilling et al. (2015), the groupings infer dominant hydrologic flow paths (surface, subsurface) and types of conservation practices that can mitigate agricultural nutrient losses. Note that PD>5 AHL watersheds are rare in most of Iowa.

2. Listing of statistical contrasts that were run among Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classes. Fig. 2 provides an illustrative key to these contrasts, meant to identify how riparian management opportunities for water quality improvement may vary among landscape regions.

3. Summary data on watersheds and riparian catchments for 32 watersheds selected to provide four watersheds representing each of eight groups of combined Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classifications. ~~Summary of riparian catchment data for 32 watersheds.~~

4. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in extent among all four functional riparian classes. Extent of riparian classes was measured as proportion of total watershed streambank length. The three significant contrasts that were significant across all four classes were between groups of watersheds located in different Major Land Resource Areas (MLRA). The 95% confidence intervals (in parentheses) all excluded 1.0. Values indicate multiplicative differences between groups of watersheds. The full list of contrast IDs are found in Table 2.

5. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in proportion of watershed in headwater catchments, and proportion of watershed suggested for riparian buffers by ACPF results. Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) landscape classes both showed significant contrasts ($p < 0.05$), with 95% confidence intervals (shown in parentheses) that excluded 1.0. Values indicate multiplicative differences between groupings. Contrasted data are plotted in Fig. 4, and ~~T~~the full list of contrast IDs are found in Table 2.

Table 1. Agro-Hydrologic Landscapes (AHLs) groupings are established by cross-classifying general categories of soil drainage (PD: poorly drained; WD: well drained) and

slope (<2%, 2-5%, and >5% for poorly drained soils, <5% and >5% for well drained soils). Based on Schilling et al. (2015), the groupings infer dominant hydrologic flow paths (surface, subsurface) and types of conservation practices that can mitigate agricultural nutrient losses. Note that PD>5 AHL watersheds are rare in most of Iowa.

	---------------Poorly drained soil---------------		Well drained soil
Slopes >5%	**PD>5%**		**WD>5%**
Slopes <5%	Not dissected (<2%) **PD<2%**	Dissected (2-5%) **PD2-5%**	**WD<5%**

Table ~~1~~2. Listing of statistical contrasts that were run among Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classes. Fig. 2 provides an illustrative key to these contrasts, meant to identify how riparian management opportunities for water quality improvement may vary among landscape regions. ~~Listing of statistical contrasts that were run among MLRA and AHL classes. Fig.2 provides an illustrative key to these contrasts.~~

Contrast ID	Contrast Type	Contrast
1	MLRA (among multiple AHLs)	103 vs- 104 (among PD<2 & PD2-5 AHLs)
2		104 vs- 108C (among PD2-5 & WD>5 AHLs)
3	AHL (among multiple MLRAs)	PD<2 vs- PD2-5 (among MLRAs 103 & 104)
4		PD2-5 vs- WD>5 (among MLRAs 104 & 108C)
5	MLRA (within one AHL)	103 -vs-104 (within PD<2 AHL only)
6		103 vs- 104 (within PD2-5 AHL only)
7		103 vs- 108C (within PD2-5 AHL only)
8		104 vs- 108C (within PD2-5 AHL only)
9		104 vs- 108C (within WD>5 AHL only)
10	AHL (within one MLRA)	PD<2 vs- PD2-5 (within MLRA 103 only)
11		PD<2 vs- PD2-5 (within MLRA 104 only)
12		PD<2 vs- WD<5 (within MLRA 104 only)
13		PD<2 vs- WD>5 (within MLRA 104 only)
14		PD2-5 vs- WD<5 (within MLRA 104 only)
15		PD2-5 vs- WD>5 (within MLRA 104 only)
16		WD<5 vs- WD>5 (within MLRA 104 only)
17		PD2-5 vs- WD>5 (within MLRA 108C only)

Table 3~~2~~. Summary data on watersheds and ~~R~~riparian catchments ~~data~~ for 32 watersheds selected to provide four watersheds representing each of eight groups of combined Major Land Resource Area (MLRA) and Agro-Hydrologic Landscape (AHL) classifications.

Watershed ID	MLRA-AHL	Area (ha)	Stream order	Streambank length (km)	Sinuosity (km km^{-1})	Riparian catchments (count)	Headwater catchments (count)	Headwater catchments (ha)	Proportion tile drained
50303	103-PD2-5	9091	4	92.2	1.46	550	33	5603	0.873
50305		4964	3	63.9	1.32	332	14	2325	0.808
20403		6363	3	48.6	1.14	224	7	2478	0.910
40705		4547	3	32.4	1.51	196	6	2860	0.758
90101	103-PD<2	6957	2	31.4	1.09	136	2	2209	0.871
40401		8376	3	54.3	1.24	270	7	2859	0.917
61301		10934	3	63.6	1.26	329	20	6639	0.923
50404		7081	1	21.0	1.23	104	1	2218	0.920
60403	104-PD2-5	4320	4	78.3	1.19	382	29	1262	0.618
11202		6962	3	73.5	1.26	376	14	2234	0.794
50901		9561	3	102.9	1.23	514	25	3413	0.768
20301		13488	2	142.5	1.32	750	19	4247	0.880
40302	104-PD<2	8424	4	79.7	1.24	388	15	2525	0.935
10401		8294	3	58.4	1.06	252	6	1681	0.915
20501		13861	3	118.7	1.20	577	17	4382	0.913
20703		6290	3	74.5	1.24	374	11	1510	0.863
50804	104-WD>5	5567	3	55.7	1.17	258	15	1891	0.710
51403		6643	3	90.3	1.23	440	26	2020	0.871
80402		8777	3	93.1	1.19	444	25	3330	0.421
50807		12330	3	107.4	1.16	494	16	3082	0.678
60209	104-WD<5	4862	3	62.6	1.17	302	22	1618	0.431
50503		6482	3	57.4	1.22	294	17	2442	0.781
51401		9833	4	114.2	1.19	540	34	3255	0.901
60201		10687	3	104.8	1.29	550	31	3581	0.680
70101	108C-PD2-5	14952	4	180.7	1.19	886	62	5561	0.827
70303		9597	4	216.6	1.28	1132	117	3050	0.505
70403		5489	4	100.7	1.33	558	50	2027	0.426
60601		9458	4	91.1	1.27	468	22	3956	0.568
80602	108C-WD>5	10544	4	174.1	1.13	818	75	3311	0.500
90403		10760	4	201.4	1.19	958	75	2694	0.508

90604	5107	3	76.8	1.21	378	25	1541	0.530
60101	10803	4	153.7	1.20	746	40	3162	0.331

Table 4~~3~~. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in extent among all four functional riparian classes. Extent of riparian classes was measured as proportion of total watershed streambank length. The three significant contrasts that were significant across all four classes were between groups of watersheds located in different Major Land Resource Areas (MLRA). The 95% confidence intervals (in parentheses) all excluded 1.0. Values indicate multiplicative differences between ~~watershed~~ group~~ing~~s of watersheds. Contrasted data are plotted in Fig. 4, and ~~T~~the full list of contrast IDs are found in Table 2~~1~~.

Contrast ID and type		**Functional Riparian Settings**			
		CZ/MSB	**SSG**	**DRV**	**SBS**
MLRA (among AHLs)					
1	103 - 104 (PD<2, PD2-5)	0.45 (0.22-0.93)	1.65 (1.04-2.62)	0.51 (0.28-0.94)	2.05 (1.42-2.94)
2	104 - 108C (PD2-5, WD>5)	4.35 (2.12-8.90)	0.55 (0.34-0.87)	3.98 (2.17-7.28)	0.46 (0.32-0.66)
MLRA (within 1 AHL)					
9	104 - 108C (WD>5)	7.09 (2.58-19.5)	0.49 (0.25-0.94)	7.56 (3.21-17.8)	0.54 (0.32-0.90)

Table 5~~4~~. Contrasts between pairs of landscape groups that showed differences ($p < 0.05$) in proportion of watershed in headwater catchments, and proportion of watershed suggested for riparian buffers by ACPF results. Major Land Resource Area (MLRA) and Agro-hydrologic Landscape (AHL) landscape classes both showed significant contrasts ($p < 0.05$), with 95% confidence intervals (shown in parentheses) that excluded 1.0. Values indicate multiplicative differences between groupings. The full list of contrast IDs are found in Table 2~~1~~.

Contrast ID and type		**Proportion of watershed in**	
		Headwater catchments	**Suggested riparian buffers**
	MLRA (among AHLs)		
1	103 - 104 (PD<2, PD2-5)	1.53 (1.27-1.84)	0.43 (0.33-0.58)
	AHL (among MLRAs)		
3	PD<2 - PD2-5 (103, 104)	1.29 (1.07-1.56)	
	MLRA (within 1 AHL)		
5	103 - 104 (PD<2)	1.61 (1.24-2.09)	0.46 (0.30-0.69)
6	103 - 104 (PD2-5)	1.45 (1.12-1.89)	0.41 (0.28-0.62)
7	103 - 108C (PD2-5)		0.52 (0.34-0.78)
8	104 - 108C (PD2-5)	0.71 (0.54-0.92)	
	AHL (within 1 MLRA)		
10	PD<2 - PD2-5 (103)	1.36 (1.05-1.77)	
12	PD<2 - WD<5 (104)		1.87 (1.25-2.82)
15	PD2-5 - WD>5 (104)	0.76 (0.58-0.99)	