Received: 11 February 2021 | Accepted: 26 July 2021 | Published online: 24 August 2021

DOI: 10.1002/jeq2.20279

Journal of Environmental Quality

TECHNICAL REPORTS

Environmental Models, Modules, and Datasets

Factors affecting the placement of agricultural best management practices in the agricultural conservation planning framework (ACPF) toolbox in the mid-Atlantic region

Zachary M. Respess[1,2] | **Jonathan M. Duncan**[1]

[1] Dep. of Ecosystem Science and Management, Pennsylvania State Univ., University Park, PA 16802, USA

[2] Current address, Dep. of Crop and Soil Science, North Carolina State Univ., Raleigh, NC 27607, USA

Correspondence
Zachary M. Respess, Dep. of Crop and Soil Science, North Carolina State Univ., Raleigh, NC, 27607, USA.
Email: zmrespes@ncsu.edu

Assigned to Associate Editor Thomas Harter.

Abstract

There has been a recent push to conduct spatially explicit landscape planning at finer hydrologic unit scales to mitigate diffuse pollution. The Agricultural Conservation and Planning Framework (ACPF) helps identify potential locations for agricultural conservation practices by using high-resolution soils and elevation data. This spatially explicit approach attempts to identify runoff and nutrient pathways, but output may be influenced by user-specified parameters and the properties of the digital elevation model (DEM) being used. Here we assess differences in the density and location of conservation practices sited by the ACPF toolbox across three DEM resolutions in three agricultural catchments, each in distinct physiographies (Ridge and Valley, Piedmont, Coastal Plain) of the United States mid-Atlantic region. Output frequency did not vary much for contour buffer strips or water and sediment control basins (WASCOBs) across DEM resolution, particularly compared with landscape type. The DEM resolution was crucial for the density of grassed waterways but of little consequence for contour buffer strips. Placement density of WASCOBs and contour buffer strips varied by region. Grassed waterways are sited based on either discrete values or statistical distributions of stream power index (SPI). A higher density of grassed waterways was placed in lower relief landscapes when a single standard deviation threshold was applied. Using discrete SPI values for the grassed waterway tool generated more consistent output across watersheds than output based on statistical distributions. These and other reported findings can help guide user decisions in future applications of the ACPF toolbox, particularly across different areas of study.

1 | INTRODUCTION

Recent advances in the field of precision conservation sought to leverage spatial data in a GIS environment to help address the logistical constraints related to assessing mitigation opportunities over large land areas. Another aim of precision conservation is to provide enhanced water quality performance of conservation practices by matching practice design and location to site conditions. While scalable, use of these approaches relies heavily on data availability, and care should be taken to ensure the methodology used is robust. One example of an emerging tool in precision conservation is the Agricultural Conservation Planning Framework (ACPF). The ACPF, developed by Tomer et al. (2013), is part of a burgeoning

Abbreviations: ACPF, Agricultural Conservation Planning Framework; BMP, best management practice; CBS, contour buffer strips; CLU, common land unit; DEM, digital elevation model; HUC-12, 12-digit scale hydrologic unit; SCA, specific catchment area; SPI, stream power index; WASCOBs, water and sediment control basins.

Core Ideas

- ACPF inputs and terrain resolution were varied to assess effects on BMP placement.
- Practices are sited with discrete values or statistical distributions of terrain products.
- Distributions of terrain products change as a function of spatial resolution.
- Grass waterway results can be erroneous with standard deviation method.
- End users must understand these factors, but published guidance is sparse.

decision support landscape for agricultural land use planning. Version 3 of the ACPF toolbox (Porter et al., 2018) queries a collection of spatial data to locate potential areas for structural and/or vegetative best management practices (BMPs). Potential locations for BMPs are provided as output after a process of applying rule sets to the distributed spatial data that include terrain, soils, and field topology. A recently added feature of the toolbox enables visualizing results by discrete subcatchments to help secure stakeholder anonymity (Tomer, Porter, et al., 2020).

Although the ACPF was originally implemented in the U.S. Midwest, there is a potential to apply the same geospatial workflow elsewhere in the United States. In the past, using such spatially intensive approaches at extensive scales were precluded by a lack of high-resolution data and limited computing power, but these constraints are rapidly diminishing, making large river basin-scale assessment possible in many cases.

To provide some context about output from the ACPF toolbox, we maintain intended recommendations from tool developers, including the following: (a) The toolbox provides a suite of potential locations for conservation practices and is not meant to be a final "siting" tool for actual placement or design of conservation practices. (b) Since management resources are always limited, criteria are used to identify potential structural and/or vegetative practices to pursue. (c) Implementation of soil health practices and nutrient management on a majority of arable lands are a prerequisite and often the most cost effective first step to reduce diffuse losses. (d) Conservation practice codes can be interpreted generally, rather than prescriptively, to more broadly identify areas of potential concern.

While the would-be barriers to generating output from the ACPF toolbox are largely absent in the eastern United States given modern technological advances like LiDAR survey data availability, there still remains a time consuming, somewhat complex, and potentially subjective multistep process to arrive at output. This process includes (a) data acquisition, (b) data curation, and (c) data querying. To change a single aspect along this workflow may result in a change in the number or placement of output from the toolbox, yet to our knowledge, this has been largely unreported at this stage with the exception of Tomer, Van Horn, et al. (2020). Quantifying change in output given a change in any of these three factors remains an academic exercise at this stage, but the implications of findings are likely to extend well beyond this sphere as the ACPF toolbox has been gaining an active user base and been used in an expanding area, with a number of user forum respondents working outside the toolbox's home range of the Midwest.

Data development procedures required to utilize the ACPF toolbox contain a number of decisions that may be of consequence to final output. Such decisions can include user choice in what analysis to conduct or the characteristics of data used (e.g., digital elevation model [DEM] resolution). Notably, these differences can propagate onward throughout the workflow if they take place at an intermediate stage, ultimately leading to varying results (e.g., output from BMP tools). Factors that change results from the ACPF toolbox are important to identify and then characterize by assessing the nature and magnitude of resultant changes in final output.

Output also has the potential to vary for certain tools that allow for a range of user-supplied parameters in the graphical user interface. The flexibility granted by this feature may help attempts to adapt the ACPF toolbox to local conditions (Nelson et al., 2018), which can be favorable in certain cases. Intuitively then, tools with flexible parameter(s) are potential loci of variance. While parameter choices are designed to allow output to vary, examples that quantify output across the range of choices available are sparse in the existing literature.

Of the suite of input data used by the ACPF toolbox, high resolution (<5 m grid size) elevation data is perhaps the most influential. Previous work demonstrated how terrain metrics calculated from DEMs are sensitive to differences in the length scale used for grid cells (Callow et al., 2007; Wu et al., 2008). These studies predate the ACPF, but they consider the terrain metrics used in the GIS toolbox (slope, specific catchment area, and related metrics) and provide empirical descriptions of sensitivity. Although these effects are described in previous works, it remains unclear how significantly the number and location of sited conservation practices will change when using the ACPF. For instance, the standard deviation, mean, and distributional range of the stream power index (SPI) will likely change with horizontal resolution, but will grassed waterways, which depend on SPI, follow different spatial patterns as a consequence?

Robust documentation and support are provided by the developers of the ACPF in many forms. While the developers and user community have outlined a number of influential factors in previous works, a comparison of ACPF output across a range of DEM resolutions and BMP siting criteria is yet to be

TABLE 1 Notable characteristics for the three test watersheds in this study

	Ridge and Valley Mahantango Creek	Piedmont Conewago Creek	Coastal Plain Headwaters Great Coharie Creek
Area	11,600 ha	13,600 ha	9,100 ha
Land use (2016 National Land Cover Database by % area)	26.6% cropland 27.1% pasture/hay 38.8% deciduous forest 6.3% developed land	28.0% cropland 14.8% developed 29.2% deciduous forest 12.9% pasture/hay	54.7% cropland 7.3% developed 14.9% woody wetland
Average relief (NED, 2018)	13.7%	5.1%	0.9%
Dominant soil order(s) (Soil Survey Team, 2018)	Inceptisols, Ultisols	Allisols, Inceptisols	Ultisols
Soil drainage class coverage by Hydro Group (SSURGO)	A: 46.9% B: 26.7% C: 15.4% D: 10.3%	B: 56.9% C: 16.2% C/D: 15.1% D: 6.1%	A: 34% B: 25% C: 20.2% B/D: 19.2%
Annual rainfall (PRISM Climate Group, 2018)	105 cm	103 cm	121 cm
Geology (Horton et al., 2017)	Sandstone ridges. Fractured Shale valley	Diabase, Mudstone, Arkose, Sandstone, & Conglomerate	Deep marine sediments

presented in the literature. This study investigates the effect of these two factors on ACPF output to provide examples to the user community.

This study's main focus is to describe the primary effects on BMP placement output when using the ACPF. This involves a three-part analysis to vary the main controls on output previously identified: physiographic region, elevation data length scale, and flexible user-supplied rule sets. Apart from these three explicitly discussed factors, sensitivity to less-evident controls will be described if detectable. The study design was constructed to answer the following questions:

1. How does BMP placement and frequency change with changing DEM resolution holding all else equal for individual 12-digit scale hydrologic units (HUC-12s)?
2. How will BMP output change when applying the ACPF in different landscapes?
3. How will conservation practice tools that support a range of possible user-supplied values respond to the above site and DEM resolution conditions when different values are provided?

2 | MATERIALS AND METHODS

A single HUC-12 was selected in each of three different physiographic provinces: Ridge and Valley, Piedmont, and Coastal Plain (Figure 1). The ACPF GIS toolbox was used to place inventories of potential BMPs for each HUC-12s across multiple DEM resolutions and rule sets. A summary of the three test HUC-12s is provided in Table 1.

2.1 | Geodatabase construction

Separate ACPF databases specific to each watershed were constructed by combining the bare earth DEM, fields, soils, and crop history data using the utility scripts in the version 3 of the toolbox (Porter et al., 2018). The general structure and development of these data largely follow Tomer et al. (2017). Additional development steps and supplemental information are provided here in brief, beginning first with elevation data procurement and processing. For the two HUC-12s in Pennsylvania, unthinned LiDAR surface returns were acquired through Pennsylvania Spatial Data Access and interpolated to 1-, 2-, and 5-m DEMs using the nearest neighbor method. Interpolation and all subsequent analysis were conducted using ArcMap 10.6 (ESRI, 2019). For the low-relief catchment in the Coastal Plain, DEMs were downloaded directly from the data service provider as 1.5-m (5-ft), 3-m (10-ft), and 6.1-m (20-ft) DEM products through the North Carolina Spatial Data Download online portal (sdd.nc.gov).

Bare earth DEMs were modified to remove flow impediments by lowering cell elevation values along small vector "cutlines" that are digitized by the user. This process of hydrologic correction was conducted using the "Manual cutter and dam builder" tool to remove artificial impediments to flow such as roads or bridges. After the initial conditioning, each DEM was filled to remove remaining flow sinks and create hydrologically corrected DEMs. This process is consistent with the hydrological enforcement techniques detailed in the ACPF toolbox's user guide (Porter et al., 2018). The resultant hydro-corrected DEMs were used to create the necessary array of terrain metrics including slope, specific catchment

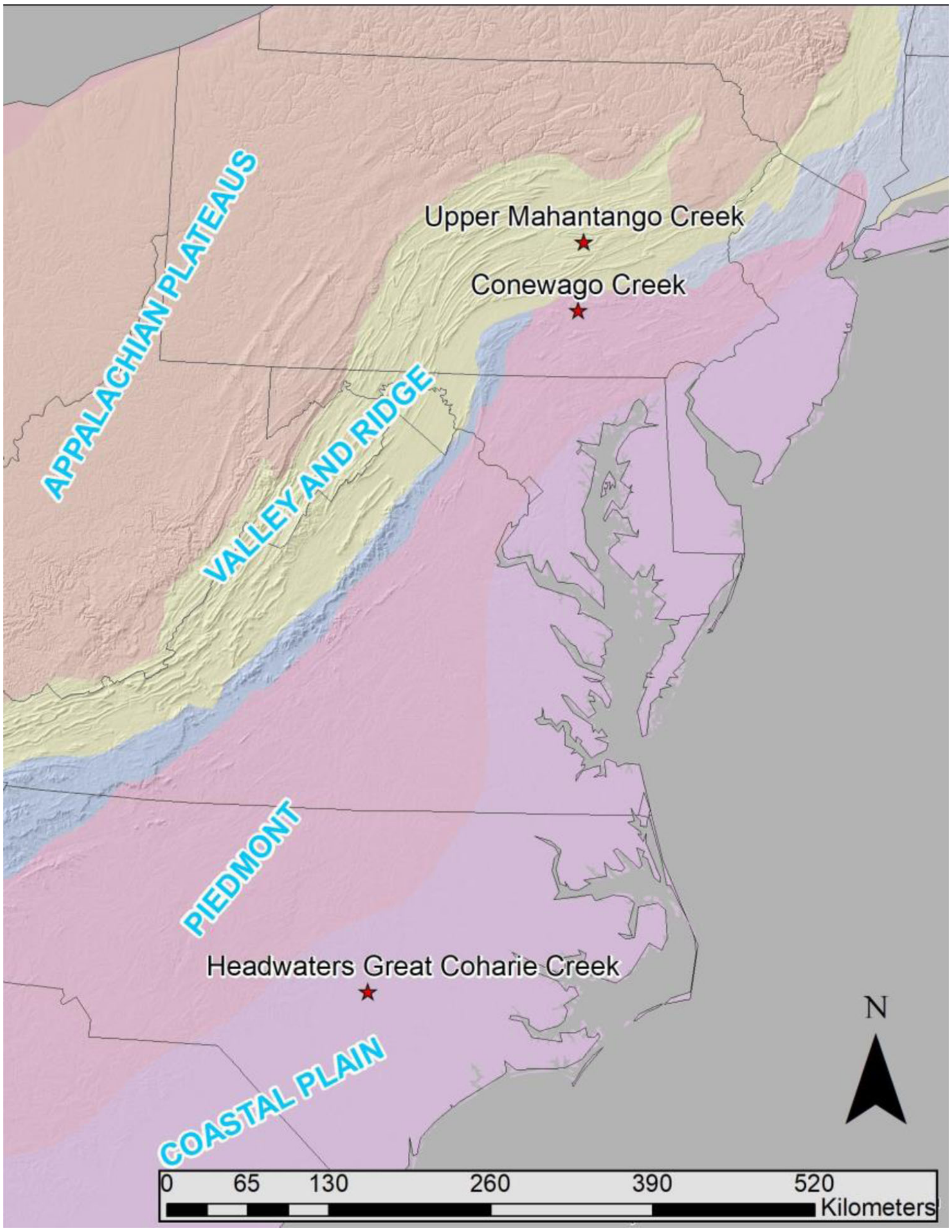

FIGURE 1 Test HUC-12s and physiographic provinces within the mid-Atlantic region of the United States. Site selection emphasized headwater catchments that have been described in previous studies either in academic literature or by public/national agencies

area (SCA), and stream power index. These terrain products were used to complete the ACPF process at each resolution. Each of the SCA-derived metrics are calculated from flow directions partitioned by the D-infinity method (Tarboton, 1997) included in TauDEM Version 5 (Tarboton, 2019). A representation of the stream network was created for each HUC-12 by adjusting the preliminary flow network to match a best estimate of the perennial stream extent for each HUC-12. This process involves estimating stream initiation points for each segment using a stream drop algorithm (Peucker & Douglas, 1975) and then either extending or trimming accordingly while referencing a hillshade raster and/or a high resolution orthomosaic to best estimate drainage network extent and alignment to the channel. Stream extent was terminated at the same longitudinal extent across each resolution treatment.

Agricultural field polygons were manually digitized using aerial imagery with a horizontal resolution of 1 m or better to reflect the most recent field extent. Outside the ACPF data service area, which covers most of the Midwest, legacy (ca. 2008) common land unit (CLU) polygons need to be acquired elsewhere or users must create field boundaries from scratch. The difference in data development times is negligible between these two scenarios since legacy CLU polygons will require extensive editing to reflect the field boundaries as interpreted from imagery. In our case, we acquired legacy CLU polygons in 2017 from a commercial entity GisDataDepot, which is now defunct. Data purchased from this third-party provider had no attribute information. Even with this dataset in hand, extensive geometry editing was needed in all three study sites to update ca. 2008 CLU polygons to ACPF ingestible field boundaries that reflect current land use patterns. Given that the HUC-12s in this study were outside the data service area, soils data and by-field crop history data were obtained by using utility scripts in the ACPF version 3 toolbox (Porter et al., 2018). The 'isAG' attribute was populated for each polygon to record a 2 for pasture, 1 for row crop, and a 0 for fields not in agricultural use or smaller than 2 ha in size. The bulk of this process was automated with the "Update Edited Field Boundaries" utility tool informed by the most recent 6 yr of crop history data (USDA-NASS, 2017). The resulting field classification was then manually edited through cross-validation with NAIP imagery (USDA-FSA, 2019). Agricultural land classification and polygon geometry for extracted field boundaries were maintained across all levels of analysis so that field number and extents were consistent between resolution treatments. The 2-ha threshold represents the lowest acreage value that can be specified in the ACPF toolbox, yet some agricultural fields were below this threshold in each of the study areas.

After this series of data preparation steps, separate geodatabases containing all necessary input data were created for three DEM resolutions across the three study areas. The ACPF toolbox was then run on for each of the nine geodatabases to create an inventory of potential conservation practices for each of the HUC-12s using a range of parameters for the grassed waterways and water and sediment control basins (WASCOBs) tools as they contained flexible parameters in the graphical user interface. Contour buffer strips were also tested with the geodatabases but had no adjustable parameters.

2.2 | Rule set manipulation

Rule set manipulation was conducted for the grassed waterway and WASCOBs by supplying a range of values to each ACPF tool. Identical input data were supplied for each iteration, meaning all other variables (field boundary geometry/classification, stream extent, DEM resolution) were held constant. The specific rule sets that were manipulated are described below.

Grassed waterways are installed to reduce risk of concentrated flow (gully) erosion. The ACPF suggests sites for grassed waterways within row crop fields at contiguous locations of above a certain SPI threshold. Grassed waterways were sited based on standard deviations above the mean value of a SPI raster where SPI = ln[Specific Catchment Area × tan(Local Slope)]. For a grassed waterway to be identified, pixels must have a SPI above the given threshold for at least 50 m of contiguous length. Notably, interior gaps below the SPI threshold are overlooked if the gap is no more than two pixels. We chose to run the grassed waterway tool at for each DEM resolution at each site using SPI cutoffs 2, 2.5, and 3 standard deviations. A stream power threshold of 3 standard deviations above the mean is a typical baseline for placement, but an individual assessment of rule set sensitivity was conducted to assess siting frequency at this threshold and lower at each DEM resolution. In practice, users would choose higher values to get fewer sites of highest priority. Importantly, the SPI raster was clipped to the extent of the surface water divide (cells upslope of the HUC-12s pourpoint) to keep pixels in the default 1-km buffer outside the HUC-12 from influencing the terrain metric's distribution.

Contour buffer strips (CBS) are installed to reduce surface runoff and sheet or rill erosion by establishing perennial strips of grass on contour. The ACPF suggests a site for CBS within crop fields with sufficient slope. Then, layout of CBS is determined by ACPF following NRCS guidelines basing design/layout on field grade. In addition, a minimum area must be covered for there to be adequate room for these practices. Contours are generated for each field through mask creation from a slope raster by using pixel values between 4 and 15%. Buffer length must exceed 100 m to be sited. Variable spacing of 76, 61, or 46 m (250, 200, or 150 feet) was determined by the third quartile slope values of the pixels within the agricultural field boundary polygon. Areas along buffers strips were deleted if intercepted by flow paths >.81 ha (2 acres). We did not manipulate parameters for this tool. A 4.6-m (15-ft) buffer width was chosen, but this parameter choice does not influence the density of CBS. As with the other two ACPF tools, this practice was identified at three different DEM resolutions for each of the three HUC-12s.

Water and sediment control basins are installed to attenuate surface water and sediment prior to their exit from the field. These are the smallest impoundments in the ACPF and are sited highest up in the landscape. The ACPF suggests a site for WASCOBs based on interpreting a pooled area estimate that would result from an embankment being created at sample sites throughout the HUC-12. The user can supply bank height values for this embankment, meaning the suitability of WASCOBs will depend in part on this decision. We varied the embankment height parameter by supplying values of 1.0, 1.2, 1.3, and 1.5 m. Output from the WASCOB tool with pooled areas in farmstead, roads, and other features were considered erroneous and were deleted. Notably, there are recommended embankment heights that vary depending on the local conditions. A 2018 publication by Nelson and colleagues recommends an embankment height of 1.0 m for low relief landscapes and 1.3 m for those with moderate relief. As suggested by the authors, use of recommended parameters can serve as a preliminary attempt to create a baseline of practices to better tailor the ACPF to local settings (Nelson et al., 2018).

TABLE 2 Results of resolution and parameter treatment. Summary statistics (mean and SD of slope and SPI) and placement density of the BMPs considered are presented for each of the three HUC-12s across three DEM resolutions. Practice densities are in units of no. km^{-2} of field area

		Ridge and Valley (Mahantango)			Piedmont (Conewago)			Coastal Plain (Headwaters GCC)		
BMP or data layer	**Rule set used**	**1 m**	**2 m**	**5 m**	**1 m**	**2 m**	**5 m**	**1.5 m (5 ft)**	**3 m (10 ft)**	**6.1 m (20 ft)**
Slope avg. (% rise)		16.4	16.3	16.0	8.3	7.9	7.6	3.5	2.7	2.1
Slope SD (% rise)		12.8	12.7	12.3	7.4	7.0	6.2	4.8	3.7	2.8
SPI Avg.		5.5	5.9	6.3	3.6	4.2	4.9	2.1	2.5	3.0
SPI SD		2.3	2.12	1.9	2.3	2.2	2.0	2.3	2.3	2.1
Grassed waterways	3 SD	0.42	0.49	0.36	9.06	4.34	0.68	22.26	10.52	4.31
Grassed waterways	2.5 SD	4.77	3.61	2.26	21.90	11.00	3.53	39.07	19.67	9.32
Grassed waterways	2 SD	14.00	10.03	5.57	43.05	23.85	10.17	66.49	33.71	17.27
Contour buffer strips	4.6 m (15 ft) width	27.28	27.70	26.58	23.82	23.49	22.46	0.54	0.51	0.61
WASCOBs	1 m bank	2.87	2.85	3.50	4.90	5.05	4.82	0.54	0.56	0.07
WASCOBs	1.2 m bank	2.72	2.81	3.59	5.27	5.02	4.82	0.34	0.15	0
WASCOBs	1.3 m bank	2.85	2.75	3.32	5.20	4.77	4.14	0.24	0.15	0
WASCOBs	1.5 m bank	2.68	2.79	3.02	4.64	4.57	4.24	0.20	0.07	0

Note. BMPs, best management practices; DEM, digital elevation model; HUC-12s, 12-digit scale hydrologic units; SPI, stream power index; WASCOB, water and sediment control basin.

In each of the three HUC-12s of interest, the total number of locations sited was recorded for each practice across three DEM resolutions and a range of possible siting parameters. Field boundary polygons, stream extent, hydrologic conditioning technique, and rule sets were all held constant for each of the three DEM treatments. The density of each practice was calculated by dividing the frequency of output by the effective agricultural area of each HUC-12. This "effective area" is the combined area of field boundary polygons with centroids within the catchment boundary. For grassed waterways and CBS, the effective area only considers row crop polygons, but WASCOBs includes both pasture and row cropped fields.

3 | RESULTS AND DISCUSSION

3.1 | How was each BMP affected by the test scenarios?

Results from watersheds in each physiographic province with differing DEM resolution and input parameters show marked differences (Table 2). General findings related to practice densities are briefly discussed here, preceding a detailed description of our findings for each conservation practice. Practice density results depicted in Figure 2 suggest a number of trends to discuss. The DEM size appears crucial for the density of grassed waterways but of little consequence for CBS. We suspect it is necessary to use a DEM <5 m for the WASCOB tool. The placement density of WASCOBs and CBS were appropriately differentiated by region, suggesting that the ACPF tools are robust for use across regions. Initially, differentiation by region occurred for grassed waterways, but counterintuitively since a higher density of grassed waterways were identified in lower relief landscapes. This is because grassed waterway output was generated using a discrete value rather than the standard deviation method for the SPI threshold. Opting to use the discrete SPI method resulted in output from grassed waterways to be differentiated by region when an identical SPI threshold was chosen as a cutoff value. Doing this made the charts reflect the broader regional differences in grassed waterway placement (as WASCOBs and CBS appear to) as more grassed waterways were identified in higher relief landscapes. Of the three ACPF tools considered, grassed waterways were the most sensitive to both DEM resolution and input parameter chosen.

3.2 | Contour buffer strips

Contour buffer strips were relatively insensitive to resolution but differed substantially across the three study areas primarily due to relief. When normalized by area in row crop, CBS across all nine test scenarios ranged from 0.51 to 27.7 km^{-2}. Within each study site, practice density was largely similar across DEM horizontal resolution. The CBS placement density reflects field slope, which changed minimally with DEM resolution. Both standard deviation and mean slope decreased as DEM resolution increased for all sites. Regarding CBS placement, the density of practices was comparable across DEM resolution regardless of the region (Figure 2). Overall

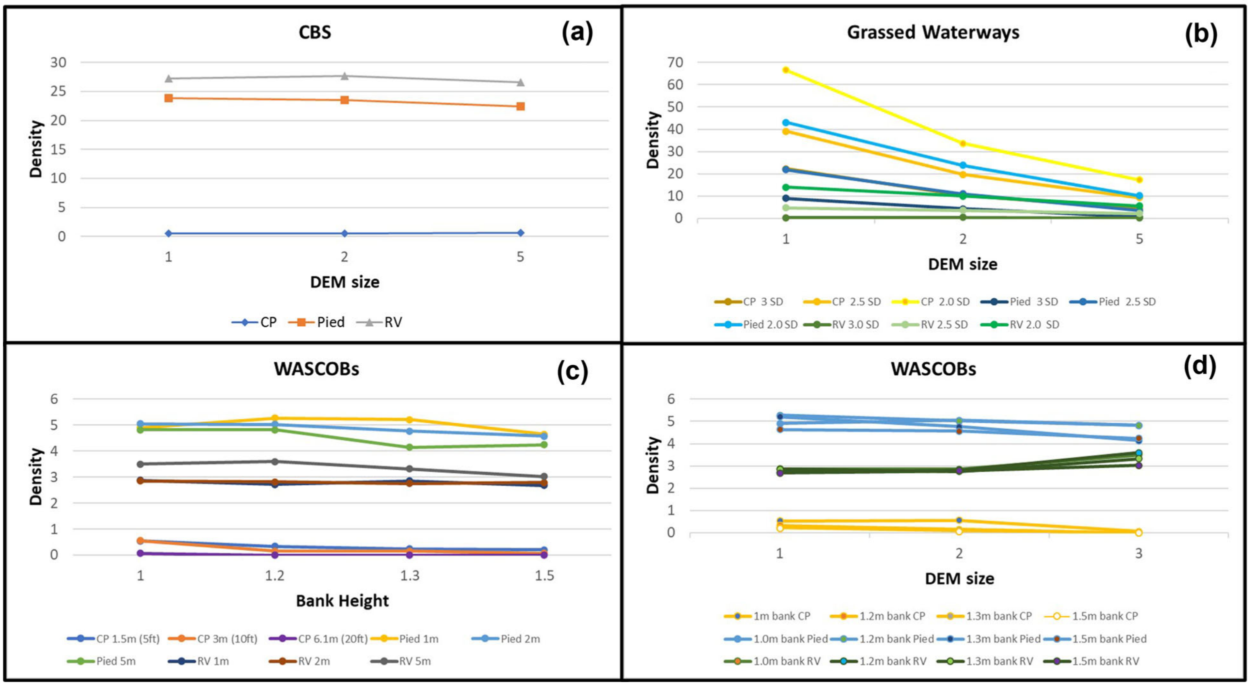

FIGURE 2 Graphical depiction of Agricultural Conservation Planning Framework results for (a) contour buffer strips (CBS), (b) grassed waterways, (c) water and sediment control basins (WASCOBs) at various bank heights, and (d) WASCOBs across digital elevation model (DEM) resolutions and bank heights. Results were reported as densities to normalize between sites with different amounts of agricultural area. Sites span Coastal Plain (CP), Piedmont (Pied), and Ridge and Valley (RV) physiographic regions and various DEM sizes were assessed

output density was largely insensitive to the changes in discrete values of slope pixels.

Visual inspection at the site level showed spatial agreement of CBS locations across DEM resolutions in most cases for all three study sites. Occasional site-specific differences observed across DEM resolution are noted here briefly. Concentrated flow pathways >0.81 ha were arranged differently across resolution. Since these features are used to delete portions of contours at the end of the CBS script, lower SCA values at finer DEM resolutions tended to cause fewer instances of buffer strip segmentation by deletion. Increasing DEM resolution also led to higher standard deviation and higher average slope, which was reflected in viewing the mask area for pixels within the 4–15% range (Supplemental Figure S2). At finer DEM resolutions, slope pixels in the 4–15% range covered similar, but more variable, areas. This visual observation is expected given the highest standard deviation of slope always occurred at 1 m (Table 2). Even though pixels in the 4–15% range were less uniform, this rarely influenced CBS results since these instances were isolated to only a pixel or two. Recall that gaps <0.20 ha are filled for noise reduction purposes in ACPF's CBS tool, meaning noise covering a few pixels will not be detrimental to CBS output. Considering the density and location at the site level was largely the same, 1-to-5-m DEMs are expected to be appropriate for this particular tool. That said, we do suggest selecting a 2-m DEM based on observations for WASCOBs and grassed waterways.

3.3 | WASCOBs

The WASCOB density ranged from 2.68 to 3.59 km^{-2} in the Ridge and Valley, 4.14 to 5.27 km^{-2} in the Piedmont, and 0 to 0.54 km^{-2} in the Coastal Plain. Varying the value for the WASCOB bank height parameter resulted in a range of output densities. When normalized by area, WASCOBs across sites ranged from 0.07 to 5.05 km^{-2} when a 1-m bank height was specified and from 0 to 4.57 km^{-2} when a 1.5-m bank height was specified. For every watershed at each of the three DEM resolutions, the highest density of WASCOBs was observed for lower bank height values of either 1.0 or 1.2 m (Table 2). When viewed graphically (Figure 2), the greatest difference in WASCOB density was between region, suggesting the physical watershed properties dominate placement density of WASCOBs. This is evidence of the robustness of the routines used by ACPF to identify WASCOB opportunities. It appears that 5-m DEMs are unsuited for WASCOB identification given the marked differences between 5-m output and output from 1- and 2-m DEMs (Figure 2). The footprint and accuracy of catchment area delineation may well be the culprit for the deviation in WASCOB placement density seen at 5 m. Water and sediment control basins are rarely identified in Coastal Plain and only at lower bank heights. Placement density are approximately the same in Ridge and Valley and Piedmont, but changing bank height changes the spatial distribution on a site-by-site basis even though the overall densities are comparable. Some of the trends above were investigated by examining output at smaller scales.

At the site level, several observations helped give context to the range of WASCOB output density. The density of WASCOBs appears to be insensitive to bank height, but the placement at the site level differed. That is, the landscape positions occupied by WASCOBs changed with bank height although the total number placed was comparable overall. It is unclear at this point whether this observation will hold for other HUC-12s in these regions. It is also noteworthy that similar bank heights (e.g., 1.0 and 1.2 m) resulted in co-located WASCOBs in some cases. The highest density occurring at lower bank heights (1.0 or 1.2 m) is reflective of more WASCOB sample points being dropped from potential placement when “flooded out” as user supplied bank height increases and inundated area increases upstream.

3.4 | Grassed waterways

Of the three BMPs considered in this study, grassed waterways were the most sensitive to changes in DEM resolution and parameter choice. Grassed waterways were least differentiated by region when the standard deviation method was used. Regarding DEM resolution, the highest grassed waterway densities occurred at finer resolutions. For parameter choice, grassed waterway density always increased at the lowest standard deviation threshold as expected, but striking differences in output density were seen across the physiographic regions. Using the same 2 standard deviation threshold, the densities of the Ridge and Valley, Piedmont, and Coastal Plain were 14.0, 43.1, and 66.5 km^{-2} respectively. This large difference is unintuitive as erosion control practices like grassed waterways should be of a priority in higher relief landscapes, which is the inverse of what was observed. Recall that mean slopes were 16.3, 7.9, and 2.7% for the Ridge and Valley, Piedmont, and Coastal Plain at the intermediate DEM resolutions (Table 2). Since the standard deviation method was used instead of specifying a discrete value, the same parameter choice ascribed substantially different thresholds in terms of a discrete SPI value across the different study sites. For example, at the intermediate DEM resolution, applying the same standard deviation threshold of 3 resulted in SPI cutoffs of 12.6, 10.8 and 9.4 for the Ridge and Valley, Piedmont, and Coastal Plain, meaning use of the standard deviation threshold method resulted in ascribing more restrictive thresholds in higher relief landscapes of the Piedmont and Ridge and Valley. Moreover, this discrepancy widens as values supplied by the user become more restrictive. We suspect this to be the most dominant mechanism behind the pronounced differences in grassed waterway densities across study areas. Of course, this can be circumvented entirely by specifying a value cutoff instead, which may be chosen by more objective methods such as Tomer, Van Horn, et al. (2020), who suggested selecting a SPI value based on a function of drainage density. Choosing a discrete SPI value when running the grassed waterway tool appeared to avoid unintended consequences. For example, providing a SPI threshold of 10.0 when using 2-m DEMs resulted in grassed waterway length densities of 0.78, 1.36, and 1.41 km km^{-2} for the Coastal Plain, Piedmont, and Ridge and Valley (Supplemental Figure S3). Given this, we recommend using discrete SPI values as cutoffs when using the grassed waterway tool when conducting ACPF analysis across multiple sites (hydrologic units) as it eliminates counterintuitive, and likely erroneous, differences in output that can occur when using the standard deviation method, even when the same threshold is chosen.

At the site level, we observed differences in both spatial extent and connectivity between SPI pixels of a certain threshold. Both spatial extent and connectivity were assessed as individual grassed waterway features are produced only where SPI values exceed the specified threshold and this connection is sustained for a minimum of 50 m. Given that SPI discontinuities occur more often at finer resolutions, these operations may have contributed to grassed waterway density to increase at finer resolutions. Decreasing DEM resolution for the three study sites led to greater connectivity between areas above the SPI threshold, yet overall, these regions covered less area and tended to terminate at lower hillslope positions. Higher SCA values at lower DEM resolutions combined with higher local slopes resulted in mapped patterns of SPI above a given threshold to be narrower and less connected but extend further up the hillslope. At finer DEM resolutions, the SPI pixels above a given threshold extend further up the hillside, but connectivity between pixels tends to decrease along flow paths (Supplemental Figure S1). This follows observations by Sørenson and Seibert (2007), who described mapped patterns of flow paths converged sooner on the hillslope with closer spacing in the latitudinal direction, creating a more “dendritic” appearance as DEM resolution sharpened. Visually interpreting SPI values above certain cutoff values suggested grassed waterway output was predominantly driven by spatial extent rather than continuity in a majority of cases. While notable, the degree of influence of coverage and connection of SPI was not quantified. This would likely be landscape specific, meaning factors such as relief or hillslope shape (slope breaks, discontinuities, etc.) are expected to be influential and warrant further study.

3.5 | Reproducibility of results

The fidelity and characteristics of data products produced by the ACPF toolbox can be considered a direct consequence of data development routines and decisions made by end users. In this section, we discuss efforts made to limit variance in this study. Before this more detailed discussion, we note briefly that we found the 2-m DEM to be the most appropriate for all three of the sites. By extension, we expect a 2-m DEM to be best suited for future applications of ACPF in the eastern United States. In practice, we recognize elevation products may differ region by region, but using a common DEM will be beneficial for comparisons across sites. For the purposes of using the ACPF toolbox, a 2-m DEM should provide adequate precision for ACPF analysis while avoiding excess storage and processing demands that may occur at finer resolutions. Additional properties of elevation data will continue to be a priority for those in the ACPF user community to understand in relation to output. Although not varied as part of this study, factors such as interpolation method, vertical accuracy, the spacing of surface returns, and the presence or absence of thinning during stages of DEM development may prove consequential to final output from the ACPF toolbox despite being at the other extreme of the workflow. These factors may often vary across LiDAR delivery zones and other artificial boundaries, making this of potential interest to ACPF users working in locations where these conditions fluctuate.

Data development routines in the ACPF resulted in improved field boundary and stream reach datasets for each study site, yet importantly, the process of defining the spatial extent of fields and stream layers was uncertain at times. We suspect this to be an area for future investigation as differences in feature geometry for field boundary or stream reach datasets may produce varying results from the ACPF toolbox. Although uniform across all treatments in this study, decisions involving stream reach and field boundary extent are expected to affect output to some degree, warranting a brief discussion.

For field boundaries, the overall extent of agricultural area was well captured, but uncertainty stemmed from decisions on whether to subdivide or merge polygons under certain scenarios. Variance and uncertainty associated with field boundary delineation can influence both in-field BMP placement/frequency and feature specific tabular data like slope statistics and runoff risk. As such, differences in field boundary delineation can lead to significant differences in output and to field-level statistics. For example, choosing to lump together or subdivide a large agricultural area with a flat upslope and steep toeslope would see significant differences in assigned risk if it is portrayed as a single field vs a collection of fields. Complexity of this decision-making process is expected to increase with farm field heterogeneity, which differs between hydrologic units and regions within them. In this study, the Piedmont and Ridge and Valley HUC-12s commonly had strip cropping and were considerably smaller than those in the Coastal Plain, where strip cropping was absent. Differences in field size are important to consider for a couple of reasons:

1. Excluding fields smaller than 2 ha (5 acres) in size as a necessary step in the ACPF disproportionately affects HUC-12s with smaller fields.
2. How field boundaries are drawn will influence the by field slope statistics. This can occur systematically by subdividing fields or lumping areas together but can also vary at the individual level with multiple technicians creating field boundaries. Given the multiple variables involved, feature extraction via heads up digitization can be made more transparent by stipulating criteria used. These factors and considerations are especially important to communicate when multiple end users are cooperating with one another. By following explicit guidelines (e.g., specifying field boundaries must not cross farm roads), individuals tasked with extracting field boundaries can be more consistent overall.

3.6 | Use of the ACPF in the mid-Atlantic region of the United States

After database construction, the ACPF can be freely applied to HUC-12s in the eastern United States, but there are a few notable features worth discussing. Karst prevalence in the upper Chesapeake Bay watershed complicates the creation of the stream network, particularly when area accumulation-based methods are used. Relative to midwestern agriculture, the farms and field sizes are smaller in our study areas in the eastern United States. The two Pennsylvanian HUC-12s considered here have complex heterogeneous cropping patterns that complicate field boundary delineation. Generally, there is also higher relative development intensity in the eastern United States, which will make hydro enforcement of some HUC-12s more demanding due to a higher frequency of artificial flow sinks in the bare surface DEM. To deal with these differences, ACPF practitioners can access a growing body of user support documentation, both from the developers and user community, which focuses on making the output more congruent with local settings.

4 | CONCLUSION

Placement density of conservation practices varied primarily across regions. This suggests the siting methods used for these three ACPF tools are robust in the eastern United States. That said, grassed waterways only appear to be robust across regions when a discrete SPI value is provided. Given this, we recommend using a discrete value if using the ACPF grassed waterway tool on multiple HUC-12s. We found DEMs <5 m to be suitable for running the WASCOB tool. Contour buffer strips appeared to be robust to DEM choice between 1 and 5 m as density and location were similar across this range. Based on these findings, using DEMs with a 2-m horizontal resolution should be appropriate for conducting ACPF analysis in the eastern United States to provide satisfactory precision without increasing storage and processing demands in most applications. While the analytical capacity for using the

ACPF in the eastern United States seems to exist, it remains unclear what adaptations should be made for use in basins and landscapes that differ from the Midwest. Users will need to contend with this acute challenge with the help of local knowledge and expertise. These and other efforts should be pursued by user groups to leverage local knowledge and preferences throughout the outreach and planning process.

ACKNOWLEDGMENTS

This work was funded in part by the Natural Resources Conservation Service, U.S. Department of Agriculture, under the Regional Conservation Partnership Program award number NR184532XXXXC004 to Environmental Defense Fund.

AUTHOR CONTRIBUTIONS

Zachary M Respess: Formal analysis; Methodology; Writing-original draft; Writing-review and editing. Jonathan M. Duncan: Conceptualization; Methodology; Resources; Writing-review and editing.

CONFLICT OF INTEREST

The authors have no conflicts of interest.

ORCID

Zachary M. Respess https://orcid.org/0000-0002-4809-4881

REFERENCES

Callow, J. N., Van Niel, K. P., & Boggs, G. S. (2007). How does modifying a DEM to reflect known hydrology affect subsequent terrain analysis? *Journal of Hydrology*, *332*(1–2), 30–39. https://doi.org/10.1016/j.jhydrol.2006.06.020

ESRI. (2019). *ArcGIS products and support*. ESRI. https://www.esri.com

Horton, J. D., San Juan, C. A., & Stoeser, D. B., (2017). *The State Geologic Map Compilation (SGMC) geodatabase of the conterminous United States (ver. 1.1, August 2017)* (USGS Data Series, 1052). USGS.

NED. (2018). *National elevation dataset, 10m grid*. https://datagateway.nrcs.usda.gov

Nelson, J., Lewandowski, A., Nelson, J., & Tomer, M. D. (2018). Landscape-specific adaptations of the ACPF: Guidance on customizing the Agricultural Conservation Planning Framework (ACPF) GIS toolbox. https://acpf4watersheds.org/files/2019/03/ACPF-Adaptations-Nelson.pdf?x70997

Peucker, T. K., & Douglas, D. H. (1975). Detection of surface-specific points by local parallel processing of discrete terrain elevation data. *Computer Graphics and Image Processing*, *4*(4), 375–387. https://doi.org/10.1016/0146-664X(75)90005-2

Porter, S. A., Tomer, M. D., James, D. E., & Van Horn, J. D. (2018). Agricultural Conservation Planning Framework ArcGIS toolbox user's manual version 3.1.. USDA-ARS National Laboratory for Agriculture and the Environment. https://erc.cals.wisc.edu/acpf/files/2018/08/Agricultural-Conservation-Planning-Toolbox-UsersManual_v3.pdf

PRISM Climate Group. (2018). *Annual precipitation normals 1981–2010, 4km grid*. https://prism.oregonstate.edu

Soil Survey Team, (2018). *SSURGO soils dataset and attribute information*. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx

Sørensen, R., & Seibert, J. (2007). Effects of DEM resolution on the calculation of topographical indices: TWI and its components. *Journal of Hydrology*, *347*(1–2), 79–89. https://doi.org/10.1016/j.jhydrol.2007.09.001

Tarboton, D. G. (1997). A new method for the determination of flow directions and upslope areas in grid digital elevation models. *Water Resources Research*, *33*(2), 309–319. https://doi.org/10.1029/96WR03137

Tarboton, D. G. (2019). *Terrain analysis using digital elevation models (Taudem version 5)*. Utah Water Research Laboratory, Utah State University. http://hydrology.usu.edu/taudem/taudem5/support.html

Tomer, M. D., James, D. E., & Sandoval-Green, C. M. J. (2017). Agricultural conservation planning framework: 3. Land use and field boundary database development and structure. *Journal of Environmental Quality*, *46*(3), 676–686. https://doi.org/10.2134/jeq2016.09.0363

Tomer, M. D., Porter, S. A., James, D. E., Boomer, K. M. B., Kostel, J. A., & Mclellan, E. (2013). Combining precision conservation technologies into a flexible framework to facilitate agricultural watershed planning. *Journal of Soil and Water Conservation*, *68*(5), 113A-120A. https://doi.org/10.2489/jswc.68.5.113A

Tomer, M. D., Porter, S. A., James, D. E., & Van Horn, J. D. (2020). Riparian catchments: A landscape approach to link uplands with riparian zones for agricultural and ecosystem conservation. *Journal of Soil and Water Conservation*, *75*(4), 94A-100A. https://doi.org/10.2489/jswc.2020.1220A

Tomer, M. D., Van Horn, J. D., Porter, S. A., James, D. E., & Niemi, J. (2020). Comparing Agricultural Conservation Planning Framework (ACPF) practice placements for runoff mitigation and controlled drainage among 32 watersheds representing Iowa landscapes. *Journal of Soil and Water Conservation*, *75*(4), 460–471. https://doi.org/10.2489/jswc.2020.00001

USDA-FSA. (2019). *National Agricultural Imagery Program*. USDA Farm Service Agency. https://nrcs.box.com/v/naip

USDA-NASS. (2017). *Cropland data layer*. USDA National Agricultural Statistics Service. http://nassgeodata.gmu.edu/CropScape

Wu, S., Li, J., & Huang, G. H. (2008). A study on DEM-derived primary topographic attributes for hydrologic applications: Sensitivity to elevation data resolution. *Applied Geography*, *28*(3), 210–223. https://doi.org/10.1016/j.apgeog.2008.02.006

SUPPORTING INFORMATION

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

How to cite this article: Respess ZM, Duncan JM. Factors affecting the placement of agricultural best management practices in the Agricultural Conservation Planning Framework (ACPF) toolbox in the mid-Atlantic region. *J Environ Qual*. 2021;*50*:1135–1144. https://doi.org/10.1002/jeq2.20279