Optimizing the placement of riparian practices in a watershed using terrain analysis

M.D. Tomer, D.E. James, and T.M. Isenhart

ABSTRACT: Riparian buffers and constructed wetlands are best management practices (BMPs) that can improve water quality. However, these practices are not equally effective in all locations. Our objective was to develop maps to help plan the placement of BMPs in a watershed for water quality benefits. Tipton Creek, a 49,000-acre Iowa watershed, provided a case study. Buffer-placement maps, developed from analysis of 30 m (100 ft) elevation data, identified riparian locations with large wetness indices, where buffer vegetation could intercept sheet/rill flows from significant upslope areas. These sites were numerous, typically small (<200 m in length) and well distributed spatially. However results showed 57% of riparian grid cells would receive runoff from less than 0.4 ha (1 ac). Candidate wetland sites were also mapped by applying interpretive and automated techniques to terrain analyses results. A team of conservation professionals evaluated the planning utility of these maps in the field through consensus-seeking discussion. Buffer maps highlighted areas where, team members agreed, perennial vegetation could effectively intercept runoff and/or manage seasonal wetness. The review team also located three feasible wetland sites, which were all identified by an automated technique showing 12 candidate sites. The methods only required public data and should be applicable to other watersheds.

Keywords: Best management practices, conservation planning, Conservation Reserve Enhancement Program, constructed wetlands, riparian buffers, watershed management

There is an increasing need to design and implement best management practices (BMPs) that will effectively protect water resources. One key to achieving water quality improvements is to target sensitive areas for BMP installation (Maas et al., 1985; Norris, 1993). Planning tools that can guide the placement of BMPs in a watershed to optimize their effectiveness would be valuable. Vegetated riparian buffers and constructed wetlands are BMPs being prescribed to protect water resources. This project was undertaken to develop and evaluate a watershed-scale conservation-planning tool, in an Iowa watershed where these BMPs are being encouraged.

Riparian buffers have been widely advocated as a BMP for improving water quality. The practice is backed by federal programs such as the Conservation Reserve Program that targets sensitive agricultural lands for environmental protection (Lowrance et al., 2002). Studies assessing riparian processes and water-quality effects of riparian buffers have been thoroughly reviewed (Barling and Moore, 1994; Castelle et al., 1994; Dosskey, 2001; Fennessy and Cronk, 1997; Hill, 1996; Lowrance et al., 2002; Muscott et al., 1993; Norris, 1993). Buffers improve water quality by reducing the delivery of sediment, nutrients, and/or pesticides to waterways, and are most effective when complemented by in-field practices that limit the movement of contaminants across field edges (Barling and Moore, 1994). Sediment may be reduced through slowing of surface runoff waters by grass filters (Lee et al., 2001), and in many instances permanent vegetation can increase streambank stability (Shields et al., 1995). Nutrients that pass through or beneath buffers with water can be retained or transformed through plant uptake, immobilization, denitrification, and/or adsorption (Muscott et al., 1993), whereas adsorption and decomposition can remove pesticides (Reunsang et al., 2001). These mechanisms contributing to improved water quality are promoted by biological activity (e.g., plant growth, root density, and organic matter cycling), which is generally increased in riparian areas where water tends to be more readily available to plants. Perennial vegetation in riparian areas can encourage a suite of biological processes and the accompanying mechanisms that improve water quality (Muscott et al., 1993).

Not all riparian-zone processes that remove contaminants will be equally effective in all locations, and the reviewed literature bears this out. Plot experiments have commonly shown nutrient-removal efficiencies of at least 40% for phosphorus and sediment in runoff, and NO_3-N in surface or subsurface waters (Dosskey, 2001; Fennessy and Cronk, 1997; Hill, 1996; Muscott et al., 1993; note these efficiencies may be based on mass or concentration, depending on the study). While higher rates, even 100%, have been reported in the literature, lower rates have also been observed, usually due to site factors that limit residence time of water in the buffer (e.g., bypass flow, or too narrow a buffer). Castelle et al., (1994) recommended a minimum 15 m (50 ft) buffer width. The literature emphasizes that buffers will remove sediment more effectively than solutes, and that surface waters crossing a buffer must be distributed via sheet or rill flow, and not channelized. Contaminant removal is also improved if runoff water infiltrates as it crosses the buffer.

Given the importance of pathways and loading of contaminants through a buffer, a key task in conservation planning is to identify sites where the environmental benefits of buffers may be optimized. But there is little guidance available on how to do this, and few studies have addressed this question. Bren

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(1998) used a topographic analysis to show how buffer widths could be varied according to the amount of upslope contributing area. Thereby, one could determine the proportion of total land area that could be set aside for buffers, and buffer widths could be adjusted, essentially according to slope length and convergence. Broadly, priority sites for buffers would be those where wide buffers would be recommended because a large loading from runoff would be expected. Also, Fried et al. (2001) compared several methods of terrain analysis for their capacity to identify optimal locations for riparian buffers, using TAPES-G and DYNWET-G software (Wilson and Gallant, 2000). Landscape interpretation issues and effects of calculation methods on results were discussed in detail. Similar concepts were applied in this study, but recent algorithms were employed that better represent pathways of overland flow (Tarboten, 1997), and mapping procedures were specifically aimed to provide conservation planners a tool to help site riparian buffers.

Both natural and artificial hydrologic pathways can determine the effectiveness of riparian buffers for improving water quality. Riparian buffers generally cannot treat waters delivered to streams through artificial drainage systems (Muscott et al., 1994), yet more than 20 million ha (49 million ac) of the agricultural lands in the Midwest are tile drained (Zucker and Brown, 1998). Constructed wetlands could help treat nutrients delivered through field tiles or surface-water inlets, and can be particularly effective at removing nitrate through denitrification (Crumpton et al., 1993; Duncan and Groffman, 1994; Hammer and Knight,1994; Kadlec, 1995). The actual nitrate removal achieved will in part be determined by the fraction of the nitrate load intercepted within the watershed (Crumpton, 2001). With careful placement of restored or constructed wetlands, a significant portion of a watershed's flows can be intercepted, and the potential impact on concentrations and loads of nitrate can be maximized. This concept forms the basis for the Iowa Conservation Reserve Enhancement Program (or CREP; see USDA, 2001).

Our objectives were to: 1) develop methods to identify and prioritize areas within a watershed where vegetated riparian buffers and constructed wetlands have the greatest potential to improve water quality, and 2) evaluate these methods in a test-case watershed through a field review with conservation planners. The intent was to develop methods that can readily be adapted for trial and application in other areas, and therefore only publicly available data was used in this project.

Methods and Materials

The Tipton Creek watershed occupies 20,000 ha (49,000 ac), and is located on glacial-till terrain of the Des Moines lobe (Prior 1991) in north-central Iowa. Soils are poorly drained, and dominated by the Clarion-Nicollet-Webster Soil Association (Typic and Aquic Hapludolls, and Typic Haplaquolls). Internally drained potholes are common and artificial drainage has been widely installed to allow agricultural production. About 90% of the land use is for corn (*Zea mays* L.) and soybean (*Glycine* max (L.) Merr.) production, with concentrated livestock feeding facilities also being common. Given this intensity of agricultural land use, riparian buffers and constructed wetlands are appropriate measures to complement in-field practices that control nonpoint source pollution.

Separate procedures were developed to identify those sites best suited for riparian buffers and wetlands. Both methods, however, involved use of digital terrain analyses (Moore et al., 1991; Wilson and Gallant, 2000), which was applied to topographic data from the National Elevation Database (NED; see U.S. Geological Survey, 2001). This database contains elevations on a 30 m (100 ft) grid for the entire United States. Although finer spatial detail could be advantageous, higher resolution data are not available in much of Iowa. Custom mapping to obtain finer-scale data across this large watershed was cost prohibitive. The origin of the digital elevation model data is also important, and the national elevation database originates from digitized topographic quadrangle maps. Quadrangle maps were originally prepared at 1:24000 scale, similar to USDA soil surveys that are a standard basis for conservation planning. The actual terrain characteristics, the contour interval of the quadrangle map, and the grid interpolation method are likely to affect the quality of the derived digital Elevation Model for terrain modeling purposes. Coverage of the Tipton Creek watershed requires use of eight quadrangle maps, which were photogrammetrically prepared based on 1973 imagery (U.S. Geological Survey, 2001). The quadrangles were all mapped with contour intervals of 10 feet (3 m), with five-foot (1.5 m) contours included in flat upland areas. Rasterization by the U.S. Geological Survey (USGS) was based on an 8-directional interpolation algorithm, with subsequent smoothing. Results from this project may only be extendable to areas where National Elevation Database data originate from sources of similar resolution.

The terrain analysis calculates steepness and directions of slope for each grid cell location, and then evaluates patterns of overland flow across the landscape, calculating and mapping the amount of upslope contributing area that could potentially deliver overland flows to each grid cell position. These analyses were carried out using TARDEM software (Tarboten, 1997). The TARDEM method can distribute overland flows from one grid cell position to two downslope cells, rather than just one. This improvement allows realistic spreading of flows in convex portions of the landscape, a feature often lacking in terrain analysis software. Several calculation artifacts discussed by Fried et al. (2001) may be overcome with this approach.

The stream map was extracted from the National Hydrography Database (USEPA, 1995). It was overlaid onto rectified digital photographic maps. The match between the hydrography and stream locations evident on the photomaps was excellent, although some minor editing was done to update the locations of several drainage ditches. To facilitate the terrain analysis, stream locations were 'burned in' to the elevation data. This forced overland flows toward the streams from neighboring cells, and minimized parallel flows directions immediately adjacent to the stream network. Flows within the stream network were also constrained to the eight cardinal directions and within the stream network so that no spreading of flows occurred from stream channels. With these steps, upslope-contributing areas for riparian grid cells (grid cells that neighbor stream network grid cells) represented flows from upslope and not from along the stream channel.

Sites best suited for riparian buffers occur where overland flows would be contributed from large upslope areas, and pass across riparian areas as distributed (sheet or rill) flows. A buffer receiving runoff waters from a large upslope contributing area provides a greater potential benefit than one receiving runoff from a small upslope area. However, for buffers to be most effective, local slopes should also be relatively flat so that riparian vegetation can readily slow the velocity of runoff, encouraging infiltration and trapping of sediment, and discouraging gully formation. The intent of our analysis was therefore to highlight riparian grid cells that have both large upslope contributing areas per unit length of stream, and low slopes. The wetness index (W; see Moore et al., 1991) is a terrain parameter that captures these criteria, and is given by:

$$W = \ln\left(\frac{A_s}{\tan\beta}\right) \quad (1)$$

where: A_s is the upslope contributing area per unit grid cell width (m^2/m), and β is the land slope in degrees ($\tan\beta$ equals percent slope divided by 100).

In addition to the wetness index, streamside areas were mapped to highlight areas where erosion adjacent to stream channels could be a concern. This information could be used to prioritize erosion control, either in the design of buffers, or through other practices to control channelized flows into the stream, and stabilize banks. The erosion index (E) is given by:

$$E = \left(\frac{A_s}{22.13}\right)^{0.4}\left(\frac{\sin\beta}{0.0896}\right)^{1.3} \quad (2)$$

This index is calculated from the same terrain parameters as W, and is equivalent to the slope-length factor of Revised Universal Soil Loss Equation (Wilson and Gallant, 2000). It highlights steep sites with large upslope contributing areas.

After applying these calculations to the elevation data, maps were constructed to depict classified W and E data for the riparian grid cells, using ARC/INFO software (ESRI, 2002). A moving-window approach provided a series of maps of a scale large enough for field use, highlighting W and E results for the riparian grid cells, identified by a one cell expansion of the stream network. These buffer placement maps were produced in pairs to show classified Wetness and Erosion Index data side by side. As the maps are intended as an interpretive aid in the conservation planning process, they were designed to highlight areas where a conservation planner should consider recommending riparian buffers for water quality benefits. The classification of the W and E data was based on histograms of data from the riparian grid cells, considering threshold values that had been reported in the literature (e.g., Wilson and Gallant, 2000).

Upslope contributing areas (A_s) were also displayed on the maps in two ways to help interpret the classified data displayed for the riparian grid cells. First, the stream-network cells were set to display the relative amount of contributing area (A_s) accumulated by the stream, indicating where the highest rates of stream inflow should occur during a surface runoff event. This involved mapping the increase in A_s for each stream-network grid cell and dividing by the cell width (30 m). This effectively sums the A_s values used to calculate to the W and E on both sides of the stream. Second, in upland areas, surface-runoff pathways (and their contributing areas) were shown to assist with field orientation and interpretation.

The spatial variability of terrain-attribute data (A_s, W, and E) of the riparian grid cells was analyzed to help interpret their spatial patterns in the watershed. Correlograms (Haan, 1977) were plotted, and standard deviations of the plotted autocorrelation estimates were estimated by a technique described by Box and Jenkins (1970). The autocorrelation length (maximum separation distance at which a pair of values are correlated) was estimated using a robust semivariogram technique described by Meek (2001).

Potential sites for Iowa CREP wetlands are located where it is feasible to intercept agricultural tile drainage in a constructed or restored wetland without interfering with the drainage rights of nearby lands. This occurs where a tile main, open drain, or small stream has a moderate grade; large enough so an impoundment will back up flows a relatively small distance upstream, but small enough so the impoundment provides shallow water that can become vegetated. These areas generally have slopes between 0.25% and 0.5%. Sites must also be located to intercept tile drainage from at least 200 ha (500 ac) of cropland. Here, these are denoted as screening criteria. Additional criteria have been established for the Iowa CREP to assure the feasibility and effectiveness of candidate wetland sites. First, the wetland must cover 0.5% to 2% of the upslope contributing area to provide adequate capacity for nutrient removal. Second, the amount of deep (i.e., at least 0.9 m or 3 ft) water must be less than 25% of the wetland area, to encourage the aquatic plants needed for a carbon source to denitrify drainage water. Third, the wetland must be buffered to assure the vested drainage rights of upstream landowners. For this analysis, a buffer providing a 1.5 m (5 ft) drop to the wetland was assumed to ensure free drainage of the upslope contributing area after wetland installation. Finally, the buffer's size must be restricted to conserve funds used to purchase site easements; for this analysis a maximum 2:1 ratio of buffer to wetland was selected. The restrictions on wetland, deep water and buffer areas result in a limited number of landscape positions that qualify for the program.

Our initial approach was to construct a wetland placement map that, upon detailed inspection, allowed areas meeting the screening criteria to be identified. Drainage district maps for the Tipton Creek watershed were obtained from county engineering offices and tile-main locations were digitized by hand. A single map was constructed by overlay to show tile-drainage mains, sites with contributing areas of at least 200 ha (500 ac), and areas with slopes between 0.25% and 0.5%. This map was examined, and based on visual interpretation, possible CREP sites were identified and circled.

A field review was carried out to verify the accuracy and utility of these buffer and wetland placement maps. The maps were compiled into a booklet that was distributed to local personnel of the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS), and members of a local watershed alliance, to encourage feedback from individuals familiar with the watershed. A field day was then scheduled to evaluate the utility of the maps for planning purposes. Local staff from USDA-NRCS, from a nongovernment conservation group, and from the Iowa CREP program participated in the field review. Possible wetland and buffer sites located throughout the watershed were visited and discussed amongst the participants, and compared to the mapped information.

After the field review, the buffer placement maps were closely compared to existing land cover using rectified photomaps, in order to identify specific riparian sites where buffers should be considered, and that were presently being farmed. Current riparian practices and possible landowner recruitment for buffer installations at these sites were discussed with USDA-NRCS personnel.

Based on further discussion of the initial wetland placement map, we developed a method to automatically identify all points meeting the CREP wetland screening criteria, and test these points to determine which ones would meet wetland and buffer area requirements. If successful, such a process could be expanded to quickly identify possible CREP sites in all 37 counties in the Iowa CREP where available digital elevation model data are of comparable quality. A program was written to identify all grid cells with contributing areas between 200 and 1500 ha and slopes between one quarter and one half percent. For each of these possible impoundment sites, the amount of upslope area within 1.5 and 3.0 m (5 and 10 ft) elevation (to represent wetland and buffer areas for a hypothetical CREP wetland) was calculated, and these areas were compared to the total upslope contributing area. Those cells with between 0.5 and 2.0 percent wetland area, and with buffer areas less than twice the wetland size, were tabulated as potential CREP wetlands. The deep water requirement was not evaluated, anticipating that design modifications (e.g.; grading, use of multiple pools) could often be employed to meet this criterion. The program was written in the ARC programming language Avenue®. Results provided a second wetland placement map that was compared to the initial (visually interpreted) wetland map, and those sites identified as the best CREP wetland opportunities during the field review.

Results and Discussion

The Tipton Creek watershed exhibits patterns of topography and stream drainage (Figure 1) that are typical of the Des Moines lobe. Internally drained potholes are common. Straight drainage ditches dominate the stream network in the upper part of the watershed. In the eastern, lower part of the watershed, there is an alluvial valley occupied by a meandering Tipton Creek. Maps displaying W and E indices for the entire watershed were also produced (not shown), which showed the flat upland areas to have high values for wetness and low values for erodibility. Areas most susceptible to erosion occurred along the slopes of the alluvial valley in the eastern part of the watershed.

Contributing area, and wetness and erosion index data were extracted for riparian grid cells. Results showed nearly a quarter (23.2%) of the riparian grid cells would not receive any upslope runoff during a rainfall event, based on the resolution of the 30 m elevation data (Figure 2). Also, 57% of the riparian grid cells would receive runoff from at most 0.4 ha (1 ac). This may indicate that narrow buffers would suffice to intercept surface runoff along much of the stream network. However, about 6% of the riparian grid cells receive runoff from more than 10 ha (25 ac) of upslope contributing area. A buffer's assimilative capacity for nutrients could most easily become exceeded at these sites. Thirty-one of these grid cells (0.8% of the total) receive runoff from more than 100 ha (250 ac). Tile drainage mains discharge to the stream network at many locations with such large contributing areas.

About half (48.6%) of the riparian grid cells have W values greater than 8.6, and about a quarter (22.9%) have value exceeding 10.6. Values of W in the 8 to 10 range have been used as a threshold to map "partial contributing areas" where streamflow is generated during and after storms (e.g., Wilson and Gallant, 2000). Nearly 6% of the riparian grid cells had a zero slope and thus no calculated W (Figure 2). About 11% of the riparian grid cells had E index values greater than 2.5 (Figure 2), which has been suggested as a threshold value for erosion susceptibility (Wilson and Gallant, 2000).

Nine pairs of map were developed to provide full coverage of the stream network, and used to classify and prioritize streamside locations for buffer placement based on Wetness and Erosion Indices. Two examples are shown in Figures 3 and 4. Riparian grid cells displaying W (top map) and E (bottom map) data are classified using threshold values given above. Blue shading in the Wetness Index (top) map identifies areas with a high Wetness Index (>10.6), and, presumably, a high potential to filter sediment from runoff water in a streamside buffer. Pink and yellow shades indicate a low potential for interception of runoff waters, with green being intermediate. In the Erosion Index (bottom) maps, green shades identify areas with a high Erosion Index (E > 2.5) where specific erosion control measures may be needed. A streamside area that, between the pair of maps, is dominated by blue and/or green shades should therefore be a more effective place to invest in conservation measures than

Figure 1
General and terrain summary maps of Tipton Creek watershed, showing topography, locations of internally drained potholes, and the stream network.

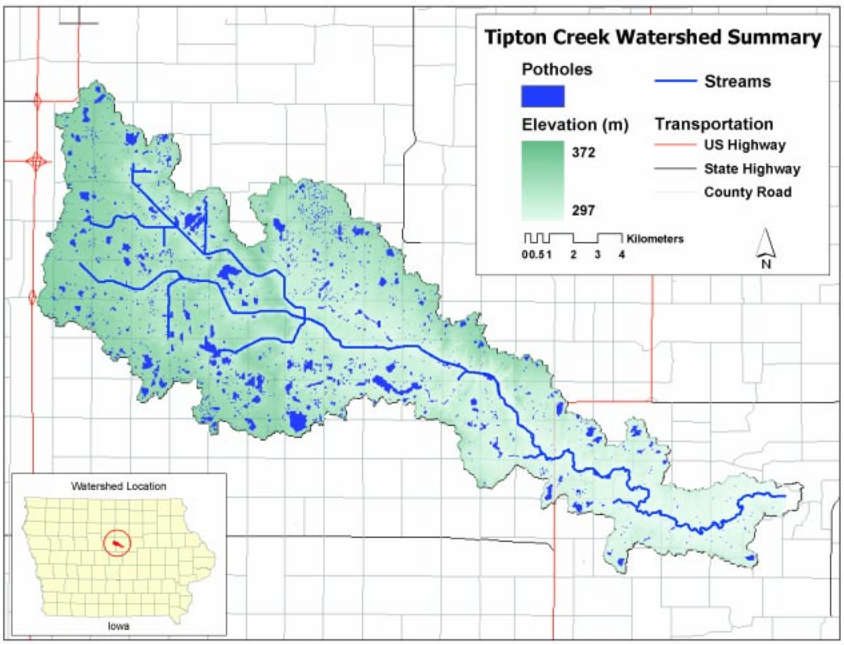
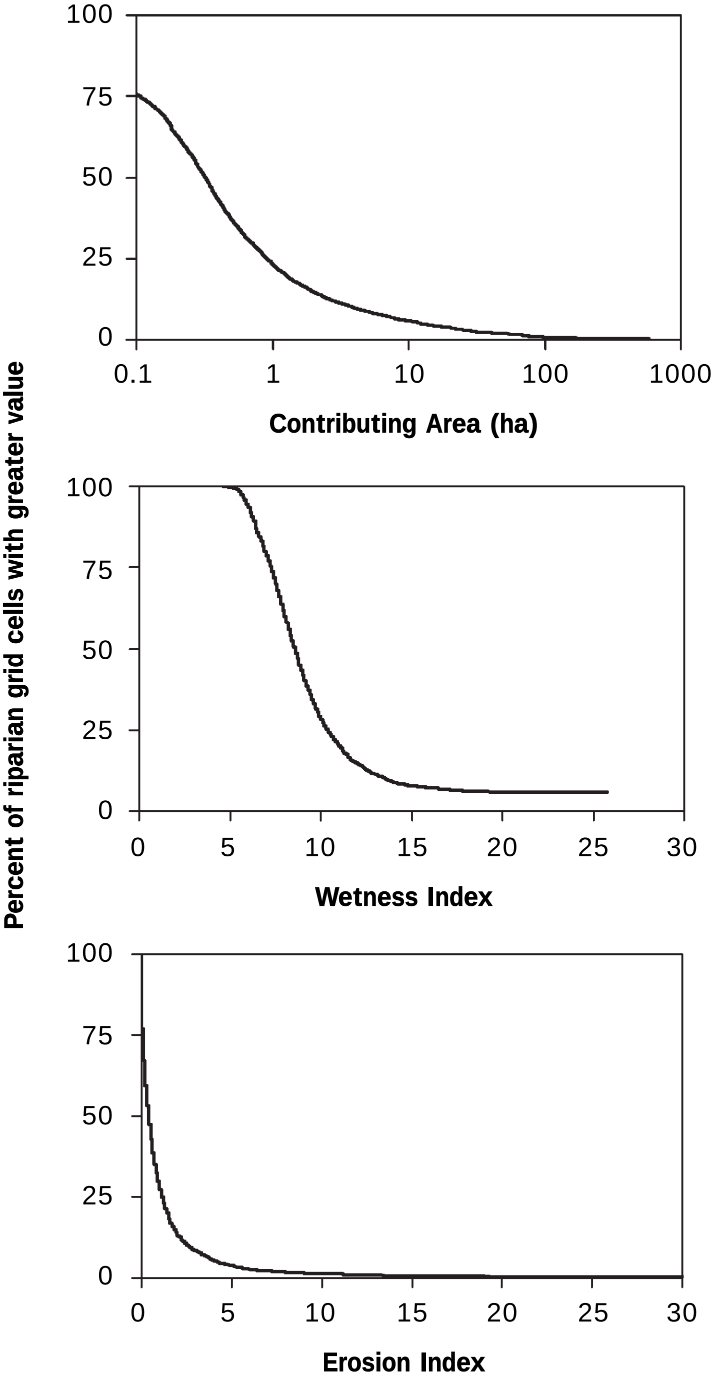


Figure 2

Frequency distributions of Contributing Area (A_s, top), Wetness Index (W, center), and Erosion Index (E, bottom) for riparian grid cells adjacent to the stream network.



one dominated by pink and yellow shades (Figures 3 and 4).

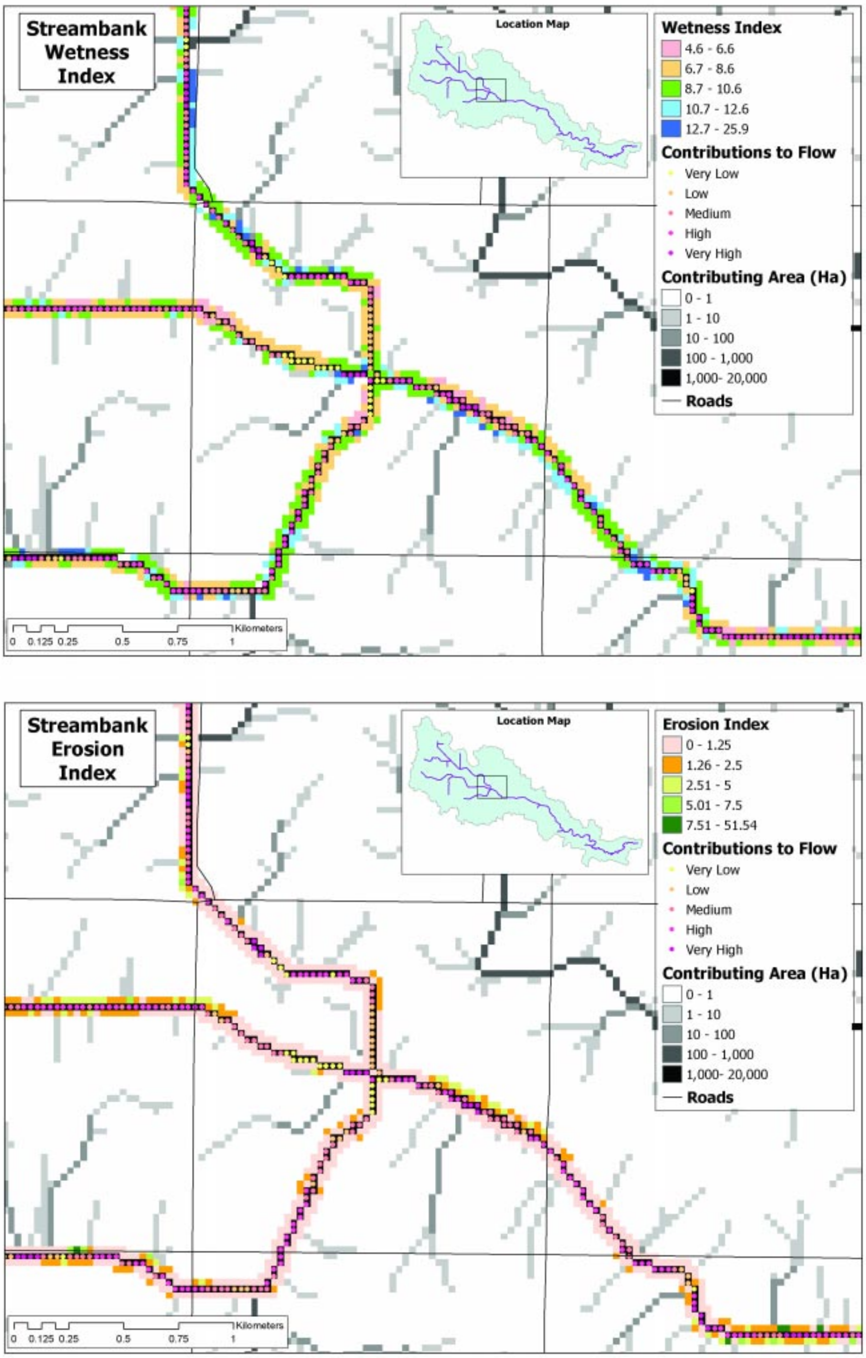
These maps (Figures 3 and 4) also show information on contributing area to help interpret the buffer-cell (W and E) data, without the influence of local slope. Uplands are gray scale shaded to indicate patterns of overland flow and potential source areas of runoff waters. Also, the stream-channel cells show red to yellow dots, indicating the relative amount of contributing area (A_s) that could deliver surface runoff to the stream at that location. This considers both sides of the stream added together, and is based on a five-cell moving average. Darker red dots indicate where the highest rates runoff contributions would occur during a rainfall event. The highest classification is for those streamside areas exceeding the 90% of the drainage density for the watershed of 2650 m^2/m (8700 ft^2/ft), whereas the lowest classification is 20% of that value. The drainage density is the area of watershed, divided by the length of all digitized stream segments.

The Erosion Index maps often highlighted the outside edge of stream meanders in the lower part of the watershed (see Figure 4, bottom map). This was surprising because these analyses were based on 30 m (100 ft) grid cells, and we did not expect to identify streambank features at this scale. However, high, steep bank-cuts were observed at several of these locations during the field review. Essentially, the map highlighted several large steep slopes where a stream meander cut right into a glacial-till escarpment at the margin of the alluvial valley.

A correlogram was plotted for the riparian grid cell data (Figure 5). This shows the degree of similarity of paired observations (Y-axis) relative to the distance separating the pair (X-axis). Observations adjacent to one another are typically similar compared to pairs of observations made far apart; the correlogram indicates the degree to which a data set follows this general rule. Similar values at small, adjacent separation distances result in a positive correlation. At larger separation distances, correlations may be near zero (indicating random differences), or negative (indicating large differences that often result from a trend or cycling in variation). Analysis of this data set (Figure 5), showed differences are random at separation distances greater than 135 m (440 ft) for A_s, and at about 200 m (650 ft) separation distances for the W and E data. The larger autocorrelation lengths for W and E are greater due to an apparent influence of slope (see Equations 1 and 2) on spatial pattern. This means sensitive areas tend to be relatively small in size (<650 ft of length along the stream), and well distributed throughout the watershed. If typical, this may relieve landowner concerns that this kind of watershed assessment may single out individuals or small groups to bear a disproportionate share of investments in conservation buffers.

A wetland placement map based on a visual

Figure 3
An example pair of buffer placement maps along the upper part of Tipton Creek.

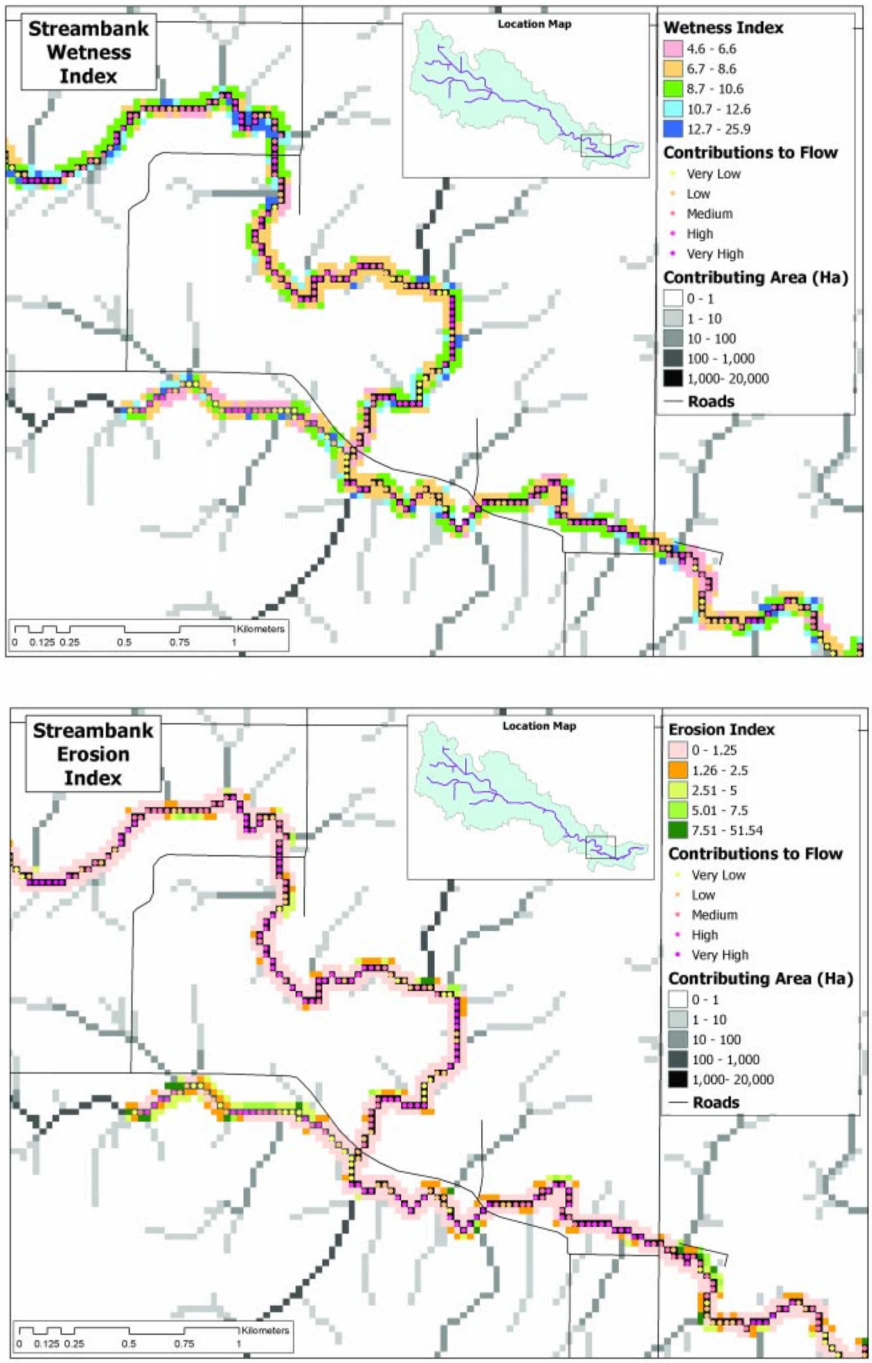


interpretation of contributing area (> 200 ha or 500 ac), slopes (0.25% - 0.5%), and locations of drainage mains was prepared. It typically highlighted broad areas of overland flow accumulation that are topographically located between glaciated uplands and sites of natural channel incision. These sites were fairly common because the glacial terrain of the Des Moines lobe is young enough that natural stream networks are not well developed. Flow paths calculated using the elevation data typically coincided closely with locations of digitized tile drainage mains. Twenty-two potential CREP wetland sites were identified on this map, which were well distributed across the watershed.

The field review was carried out on February 26, 2002, and included 22 buffer placement sites, and 20 of the 22 sites identified on the wetland placement map. The review tour began at the mouth of the watershed and proceeded upstream. Riparian sites showing large *W* values were all quite flat, with slopes less than 2%. About half these sites occurred below ephemeral waterways, or below concave slope features that would deliver larger amounts of runoff from uplands than convex or linear features. The other half of these sites were flat (<1% slopes) alluvial valley locations that were some distance (>50 m or 150 ft) from toeslopes. These sites, often in pasture, would be expected to exhibit shallow seasonal water tables that would influence management. The flat relief and proximity to the stream would also make effective tile drainage difficult at these sites. Water quality benefits would be expected from management of buffer or pasture vegetation at both kinds of sites, provided rotational grazing of riparian pastures with restricted access of cattle to streams. Within these interpretations, review participants by consensus found the buffer placement maps to be generally consistent and useful as a tool for field review and conservation planning. Although these maps were developed from watershed-scale calculations applied to part of a national elevation database, participants could use the maps to evaluate runoff patterns and the suitability of riparian BMPs at the scale of field planning. Map interpretation was not immediately intuitive to all review participants, but with discussion everyone agreed on their good accuracy and potential utility.

The wetland placement map that was based on visual interpretation of slopes and drainage areas was less efficient in identifying wetland sites. Four of the 22 sites on this map were identified as having excellent potential for constructed wetlands. However, for one of these sites the 200 ha (500 ac) contributing area threshold was actually several hundred m down gradient, and therefore this site was technically not eligible for CREP. Therefore three possible CREP wetlands were identified. There were four other sites that appeared suitable, but these were crossed by roads and could not be considered, because realignment or upgrade of roads is not within the purview of CREP funding. On the remaining sites it was judged there

Figure 4
An example pair of buffer placement maps along the lower part of Tipton Creek.



was not sufficient local relief to ensure free drainage of contributing uplands. Potential flooding of drainage ditches contributed to rejection of several of these sites in the uppermost reaches of the watershed.

A terrain analysis program to automatically delineate potential sites for CREP wetlands identified 147 grid cells (possible impoundment sites) in the watershed that met the slope and contributing area screening criteria. Of these locations, 21 passed both wetland and buffer area requirements. The wetland sites, including the buffer (areas within 3 m elevation of the hypothetically impounded grid cell) were mapped, and a number of these overlapped. Twelve of these sites were selected to eliminate the overlap (Figure 6). All 12 sites were within areas identified on the visually interpreted wetland placement map. If all of 12 wetlands were to be installed, they would occupy 105.5 ha of wetland area, plus 175.8 ha of buffer, and intercept tile drainage from 7923 ha of upslope area, or 40% of the Tipton Creek watershed. The 12 sites effectively identified the three best CREP sites selected during the field review. Four of the twelve sites were within one of the larger areas circled on the visually interpreted map, where reviewers recognized an excellent potential for a large CREP wetland with several pools. The other two possible CREP wetlands identified during the field review were also among the twelve delineated through the automated method. The remaining six sites occurred where flooding of roads and/or ditches would make wetland installation problematic. The three possible CREP sites were identified for possible landowner recruitment pending finalization of contracting specifications, and eligibility rules under the new farm program.

Several riparian buffer sites were also identified for follow-up evaluation during the field review. However, landowners in the watershed had broadly participated in USDA programs encouraging riparian buffer establishment, and it was not easy to find many sites to recommend for new buffers. A comparison of the buffer placement maps with current land use (interpreted from 1994 orthophoto quads), identified 11 possible sites for new buffers. But after reviewing the most recent USDA-NRCS records of buffer plantings, only four possible buffer sites were identified for follow-up efforts to recruit voluntary participation in conservation buffer programs.

Summary and Conclusion

Planning maps were developed at a watershed scale, and used to identify sites for wetland and riparian practices where water quality benefits should accrue. The maps provided a useful tool to aid site review and field interpretation, but could not replace these critical aspects of conservation planning. The analyses were carried with only existing data that are publicly available. Therefore similar analyses could readily be applied to other watersheds where digital elevation model data of similar quality are available, to assist

Figure 5
Spatial correlograms of terrain parameters for the riparian grid cells. Note the number of grid cells exceeds 5300, and that standard errors of the plotted autocorrelation estimates are less than 0.025.

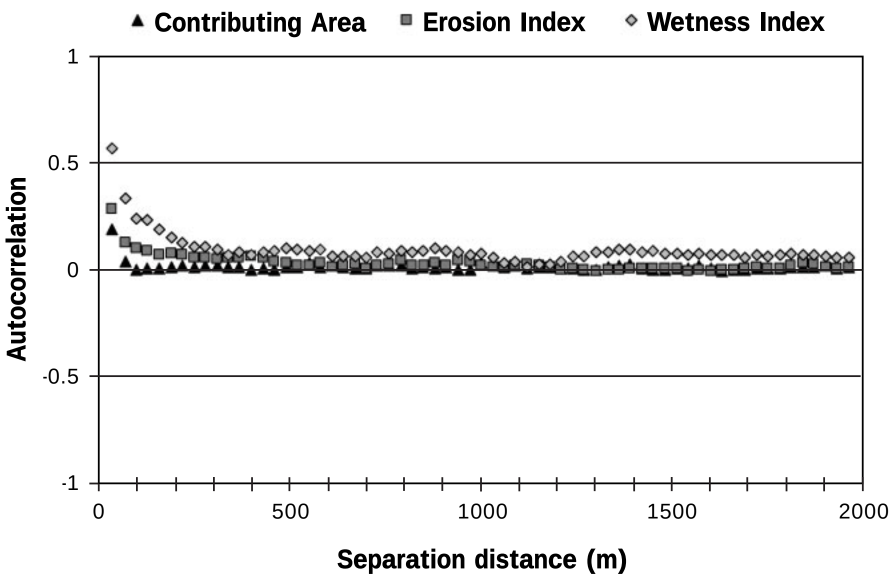
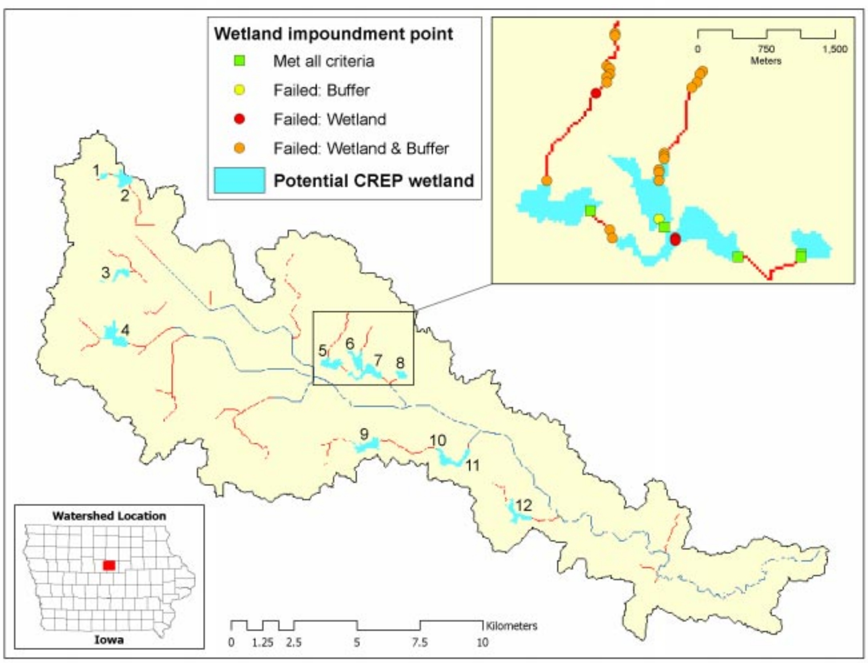


Figure 6
Map of sites that met criteria for Conservation Reserve Enhancement Program (CREP) wetlands in the Tipton Creek watershed. The blue shading denotes wetland and buffer areas. The inset shows a set of the 147 potential wetland impoundment sites that met screening criteria. Of 21 sites that passed wetland and buffer sizing criteria, these twelve sites were selected to eliminate overlaps.



producers and conservation planners in identifying locations where riparian buffers and wetlands can most effectively improve water quality. Field studies should be undertaken in various settings, both in and beyond north-central Iowa, to examine the utility and limitations of terrain analyses for developing BMP placement strategies. The glacial terrain of the Des Moines lobe, with its undulating terrain and its natural stream network being poorly defined, presents challenges to the application of terrain analysis. Therefore, these methods should be applicable to other landscapes where natural drainage patterns are more fully developed provided digital elevation model data are of similar quality. The 30 m scale and source quadrangle map provided a digital elevation model of suitable quality for this study, although a finer resolution (e.g., 10 to 20 m grid) could be of further benefit in this and other watersheds. The effects of scale and landscape on the utility of these types of maps are possible areas for further investigation.

It is hypothesized that similar methods could be developed to prioritize conservation needs across the broader landscape, including in-field practices. Tools developed here demonstrate that use of spatial technologies in agriculture could be expanded from a focus on production to include conservation. Eventually, such approaches could help agricultural producers achieve environmental goals with greater efficiency. In this study, sensitive sites favored for installation of riparian buffers were small and well distributed across a test watershed. Therefore, at least for riparian buffers, application of watershed assessment technologies would not necessarily bias programs and place the burden of conservation on a small group of producers, but rather could help reveal strategies to effectively share responsibilities for resource conservation among producers. However, an analysis based on the same data sources, but aimed to identify sites for constructed wetlands, could identify a small set of sites where a few landowners could potentially provide pollution control services to their upslope neighbors. Partly for this reason, Iowa CREP provides a strong financial incentive to landowners volunteering to provide this service.

This study demonstrates that terrain analysis can provide watershed-scale assessments for placement of conservation practices, and can be helpful in conservation planning at the field scale. These techniques therefore offer an opportunity to bridge the gap between conservation efforts at farm and watershed scales, and allow field-scale conservation efforts to be prioritized to provide benefits at the watershed scale. This linkage could be further strengthened where important non-point pollutants, sources, and pathways are clearly identified with respect to land use practices, allowing the approach described here to assist with implementation of total maximum daily loads. Other applications could include evaluation of configurations of existing BMPs in watersheds, and how alternative conservation program criteria or priorities could impact the placement of practices with respect to landscapes, watersheds, and landowners.

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