I. Optimizing the Placement of Practices that Improve Water Quality Within a Watershed

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II. Abstract

There is an increasing need to design and implement best management practices (BMPs) that will effectively protect water resources. While BMPs can be put into practice in agricultural fields to minimize erosion and reduce nutrient losses, complementary practices located within riparian ecosystems are also being advocated and supported using public subsidies. Riparian buffers and constructed wetlands are the dominant examples of these practices; riparian buffers can intercept surface water runoff, but constructed wetlands are needed to intercept and treat tile drainage. Can the placement of these practices be optimized within a given watershed? The Tipton Creek watershed, a 50,000-acre catchment in north-central Iowa, was used as a case study. Hydrologic modeling of digital elevation data helped to identify where the best opportunities to intercept surface runoff waters exist along the stream network. Buffer placement was prioritized for streamside zones where overland flow should occur as distributed (sheet or rill) flows. Also, we identified those sites that qualify as possible CREP (Conservation Reserve Enhancement Program) wetlands in Iowa, which are aimed to treat tile-drainage waters.

Results of the analyses were produced as a series of maps, and a field review was carried out, assisted by locally stationed agency personnel, to evaluate the accuracy of the maps and their utility for planning purposes. The feedback from this review was positive. The maps were carefully compared to existing land use along the watershed's riparian corridor, and 12 specific sites were selected for review. While several of these sites had BMPs installed recently, several others were identified as priority sites for establishment of new riparian BMPs. Agency personnel are initiating landowner contacts to encourage voluntarily participation in USDA conservation programs for these sites. One conclusion from this study, supported by statistical analysis of terrain data, is that sensitive areas best suited for riparian BMPs tend to be relatively small in size (<1000 ft of length along the stream), and well distributed throughout the watershed. This may alleviate landowner concerns that watershed assessment technologies may target a small group of individuals to bear a disproportionate share of conservation investments. The analyses conducted only required existing data that is publicly available. Therefore similar analyses can be readily and inexpensively applied to other watersheds, and allow producers to identify locations where riparian buffers should effectively intercept nutrients, and those sites that should meet criteria for installation of CREP wetlands.

III. Introduction

There is an increasing need to design and implement best management practices (BMPs) that will effectively protect water resources. In watersheds with significant swine production, investments in BMPs will help swine producers be seen as environmental stewards, especially if environmental benefits can be demonstrated. One key to achieving water quality improvements is the targeting of sensitive areas for BMP installation (Norris 1993). This project shows how the siting of BMPs can be targeted at a watershed scale in a way that optimizes their effectiveness. It is focused on vegetated riparian buffers and constructed wetlands, and demonstrated on a watershed with significant swine production.

Riparian buffers have been widely advocated as a BMP for improving water quality. This practice is backed by federal policies targeting set-aside agricultural lands for environmental protection. Buffers may improve water quality by reducing the delivery of sediment, nutrients; and/or pesticides to waterways. Plant uptake, rooting, organic matter cycling, adsorption, and denitrification are all processes that may increase in riparian buffers, and contribute to improved water quality. But not all these processes will be equally effective in all locations; indeed most processes may be relatively ineffective in some places. Therefore a key task of the conservation planner is to identify sites where the environmental benefits of riparian buffers may be optimized. However, there is little guidance available on how to do this.

Many of the agricultural lands in the Midwest are tile drained, and riparian buffers generally cannot treat waters delivered to streams through artificial drainage systems. Constructed wetlands are being promoted as the best alternative to enhance water quality in these areas. Wetlands can be especially effective at removing nitrate through microbial processes. The USDA's Conservation Reserve Enhancement Program (or CREP, see www.fsa.usda.gov/dafp/cepd/crep/crephome.htm) was initiated in Iowa during 2001 to encourage installation of artificial wetlands in tile-drained areas. We therefore set out to identify those sites in the Tipton Creek watershed that meet criteria for participation in this program.

Here we demonstrate methods to identify critical areas for BMP placement in a watershed with intensive swine production. The swine industry is being pressured to show contributions towards improved environmental quality. Producer interests are served by support for research and demonstration on environmental issues. This project fills such a role, aiming to develop tools that can be regionally applied to locate BMPs. It also enhances the industry's involvement with ongoing watershed improvement efforts in an area with significant swine production.

IV. Objectives

1. Develop methods to identify and prioritize those areas within a watershed where vegetated riparian buffers and constructed wetlands have the greatest potential to improve water quality.

2. Demonstrate these methods in a test-case watershed in which impacts of swine production on water quality have been raised as a concern (Tipton Creek in north-central Iowa).

3. Recruit landowners in areas highlighted by the analysis to participate in a project for BMP demonstration and research.

V. Procedures

Objective 1

Separate procedures were developed to identify those sites best suited for riparian buffers and wetlands, and these are separately discussed below. Both methods, however, involved the use of digital terrain analyses (Moore et al. 1991; Wilson and Gallant 2000), which was applied to topographic data extracted from the National Elevation Database (US Geological Survey 2001). This database contains elevations on a 30-meter (100-ft) grid for the entire nation. The analysis calculates steepness and directions of slope, and then evaluates patterns of overland flows across the landscape, calculating and mapping the amount of *upslope contributing area* that could deliver overland flows to each grid-cell position. We carried out the analyses using TARDEM software (Tarboten 1997; or www.engineering.usu.edu/dtarb/tardem.html). The TARDEM method can distribute overland flows to two downslope cells, rather than just one. This allows realistic spreading of flows in convex portions of the landscape, a feature that most terrain analysis software lacks. Special procedures were used to force drainage towards existing streams and drains in the watershed, and constrain spreading flows in the stream network.

To identify sites best suited for riparian buffers, we wanted to identify where overland flows would enter streams, in particular as distributed sheet flows rather than channelized flows. In general, a buffer receiving runoff waters from a large upslope contributing area should provide greater benefit than one receiving runoff from a small upslope area. However, the capacity to trap runoff-delivered sediment within a buffer must also be considered. A buffer would be most effective where local slopes are relatively flat so that riparian grasses could readily slow the velocity of runoff. Therefore we wanted our analysis to highlight streamside locations that have both large upslope contributing areas and low slopes. These should be locations where runoff waters could be slowed by riparian buffer vegetation, encouraging infiltration and trapping of sediment.

The wetness index (Moore et al. 1991) is a terrain parameter that efficiently captures these criteria. The wetness index is given by:

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

in which A_s is the upslope contributing area per unit grid-cell width (m^2/m), and β is the land slope in degrees (tan β can be simply expressed as “rise over run”). Therefore the W index considers the amount of area contributing runoff water to a particular location and the local slope. One drawback is that W cannot be calculated for areas of zero slope, and therefore no W index can be displayed for completely flat areas.

In addition to the wetness index, we also mapped those streamside areas where erosion near the stream channel could be a water quality 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, stabilize banks, etc. 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 uses the same terrain parameters as *W*, and is equivalent the slope-length factor of the RUSLE (Wilson and Gallant 2000). After making these calculations on the elevation data, maps were constructed, as described below under *Objective 2*.

Identifying potential sites for installation of CREP wetlands required that we construct maps to highlight those areas where it is feasible to divert large tile flows to a constructed wetland. This occurs where a tile main (or drainage ditch below the tile) has a moderate grade. There must be enough grade so an impoundment will not impede (back up) tile flows upstream, but also enough available area to construct a broad but shallow wetland to achieve high rates of nutrient removal. These general goals are being formalized to screen possible wetland sites under Iowa's CREP program (T. Isenhart, written communication). Under the screening criteria the site must be located below a tile-drainage system that drains at least 500 acres (200 hectares) of cropland. Also, the local slope should be between 0.25% and 0.5%. Our approach was to construct maps that, upon detailed inspection, let us visually identify areas meeting the screening criteria. This involved digitizing drainage district maps available for the Tipton Creek watershed.

The above slope criterion (0.25 –0.5%) is aimed to screen sites that are most likely to qualify under more detailed criteria. First, the wetland must comprise 0.5 to 2% of the upslope contributing area to provide an adequate residence time for effective nutrient removal. Next, the amount of deep (> 3 ft) water must be less than 25% of the wetland area, to encourage the aquatic vegetation needed for effective nitrate removal from drainage water. Finally the wetland must be surrounded by a buffer providing at least a five feet drop to the wetland, to ensure the tile lines in the upslope contributing area will continue to drain freely after the wetland is installed. This buffer must be less than twice the wetland's size, which simply conserves funds used to purchase site easements. These restrictions on wetland, deep water and buffer areas result in a limited number of landscape positions that qualify for the program. In follow up to this project, we are undertaking the more difficult task of developing computer programs that may automatically identify those sites meeting these detailed criteria.

Objective 2

Under this objective we applied the above-described techniques to the Tipton Creek watershed. We constructed maps highlighting areas best suited for placement of vegetated riparian buffers and constructed wetlands, and then conducted a field review to verify their accuracy and utility.

The buffer and wetland placement maps were constructed separately. The riparian buffer maps were built to display: 1) upslope contributing areas; 2) streamside areas with high potential to trap sediment (high *W* index); and 3) streamside areas that may require erosion control measures (high *E* index). A moving-window approach was used to develop a set of maps at a scale sufficient for field use, with good detail in streamside areas.

The buffer placement maps were made in pairs to show Wetness and Erosion Index data side by side, highlighting the map cells immediately adjacent to the stream where buffers might be considered. Upslope-contributing-areas (A_s) were also displayed on the maps to help interpret the Wetness and Erosion Index data. The stream cells (which are between the streamside buffer cells) were set to display the relative rate of A_s accumulation to the stream, to indicate where the highest rates of stream inflow would occur during a surface runoff event. This displayed the A_s data used to calculate to the W and E indices, but without the influence of slope. Also, in upland areas, surface-runoff pathways were displayed to assist with orientation in the field.

A map of potential CREP wetland sites was constructed to show three features: digitized tile-drainage mains obtained from county records, sites with contributing areas of at least 500 acres, and areas with slopes between 0.25 and 0.5%. This map was carefully examined, and possible CREP wetland sites were identified and circled. A Subset of the maps are presented and discussed in the results section.

This set of maps was compiled into a booklet that was distributed to local agency (NRCS) personnel, and to members of the local watershed alliance, for provide the opportunity for external review and feedback from individuals familiar with the watershed. A field day was then scheduled to examine and evaluate the utility of the maps for planning purposes.

Objective 3

After the field review, the maps were closely compared to existing land cover using Iowa Department of Agriculture and Land Stewardship data and orthographic aerial photos. Specific locations were selected for possible recruitment. These locations were discussed with NRCS personnel, and current on-site practices were reviewed. A second field review was carried out to evaluate the probable eligibility of these sites for placement of BMPs, and evaluate their potential as a research site if a BMP was installed. NRCS was thereby provided with a list of sites and landowners for recruitment efforts. Some further considerations are discussed under the results section.

Water quality monitoring

In addition to the above-described work, water quality monitoring has continued at Tipton Creek and several locations within the South Fork of the Iowa River's watershed. Four permanent sampling stations were established, at the outlets of Tipton and Beaver Creeks, and two along the South Fork. Sampling of runoff events during 2001 was supplemented by periodic grab sampling at 13 sites across these basins. Samples were analyzed for total and dissolved phosphorus, and nitrate.

VI. Results

Objectives 1 & 2

Results of these objectives are effectively presented in map form (Figs 1-5, & 7). Figures 1 and 2 provide maps of the complete watershed. Sub-watersheds, locations of swine production facilities, patterns of overland flow, topography, and internally drained potholes are featured in Figure 1. Figure 2 displays Wetness and Erosion Index data for the entire watershed. The flattest parts of the watershed are shown to have either large (blue) or missing (white) W values, and small values of *E*. At this scale, the areas most susceptible to erosion occur along the slopes of the alluvial (stream) valley that occurs in the lower (eastern) portion of the watershed.

Figures 3-5 show three of the nine map pairs used to examine and prioritize streamside locations for buffer placement. Streamside cells display *W* (top map) and *E* (bottom map) data. Blue shading in the Wetness Index (top) map identifies areas with a high Wetness Index, and 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. Again, there are occasionally streamside areas with zero slope, where *W* cannot be calculated. In the Erosion Index (bottom) maps, green shades identify areas with a high Erosion Index where specific erosion control measures may be needed. The *E* maps show green shades for values greater than 2.5, which has been suggested as a threshold value for erosion susceptibility (Wilson and Gallant 2000). 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 install conservation measures than one dominated by pink and yellow shades (Figs. 3-5).

These maps (Figs 3-5) also include two kinds of information on contributing area to help interpret the buffer-cell (*W* and *E*) data, which are independent of local slope. Contributing area data in the uplands are highlighted using gray-scale shading to indicate patterns of overland flow and likely sources of runoff waters. Also, the stream-channel cells show red to yellow dots, indicating relative rates of streamside contributions or "A_s accumulation" within the stream. This considers both sides of the stream added together. Darker red dots indicate where the highest rates runoff contribution would occur during a rainfall event. The most channelized contributions were excluded, to emphasize delivery of distributed flows to the channel.

When using mapped data, the limitations of map scale must be considered. These analyses were based on 30 m grid cells (equivalent to 100 feet). Therefore it is not possible to use this data to resolve features smaller than 100 feet. Because the stream channel is less than 100 feet wide, we should not expect streambank features to influence these maps. Despite this, the Erosion Index maps often highlighted the outside edge of curves in the stream, particularly in the lower part of the watershed (see Fig. 3, bottom map). Steep bank-cuts were observed at several of these locations during our field review.

The general pattern of color shading in the streamside maps (Figs. 3-5) is quite varied, and this observation leads to an interesting conclusion. There are statistical procedures to help interpret these kinds of observations, and we employed one known as the correlogram (Fig. 6). This graph measures the similarity of a pair of observations (Y-axis) relative to the distance separating them (X-axis). Observations made adjacent to one another are usually more similar than a pair of observations made far apart; the correlogram indicates the degree to which a data set follows this general rule. Differences may be small on average (i.e., paired values may be similar), which gives a positive correlation that is most commonly seen at small, adjacent separation distances. Or differences may tend to be large (i.e., paired values may greatly differ) on average, giving a negative correlation that can often indicate cycles of variation in the data with distance. Values near zero indicate that differences are random. In this data set (Fig. 6), differences are essentially random at separation distances greater than 300 m (1000 ft). We conclude that sensitive areas tend to be relatively small in size (<1000 ft of length along the stream), and well distributed throughout the watershed. If this result is typical, it may relieve landowner concerns that watershed assessment technologies may single out individuals or small groups to bear a disproportionate share of investments in conservation.

The map indicating potential CREP wetland sites (Fig. 7) shows areas with contributing areas of at least 500 acres (200 ha – cells shaded dark blue), along with locations of county drainage mains (black lines), and an appropriate reclassification of slopes, with preferred slopes of 0.25 - 0.5% shown in light blue. From this map, we identified areas that have moderate slopes (between 0.25 and 0.5%) that are along 500-acre-contributing-area flow paths, which usually occurred below generally flat uplands (shown in white). These flow paths often coincide closely with tile drainage mains, as the map shows upon close inspection. Sites meeting these criteria are circled in green (Fig. 7).

Our field review was carried out in early February 2002, and the review team found the maps to be consistent in their interpretation and useful for field review and planning tool. Several sites were identified for follow up evaluation during this review.

Objective 3

Twelve sites were identified from field reviews and comparison of buffer and wetland placement maps with documented land use (Fig. 8). This information was cross-referenced with field maps maintained by local agencies, and we found that a number of the sites identified had installed riparian buffers within the last two years. The remaining sites were visited, and follow up efforts were planned as follows. Landowners of four potential buffer sites will be contacted as the farmer's planting season workload eases during summer. One of these sites could be considered as a research site, if the landowner is willing to install a buffer and allow research activity on his property. Two possible CREP wetland sites were identified, except their current land use is pasture. This presents a short-term problem with eligibility. Pastures will become eligible for CREP participation under new USDA rules that will take effect near the end of summer 2002. Follow up with these two landowners is planned when the new rules take effect.

Water quality monitoring

Monitoring results for 2001 are summarized in Figures 9 and 10. The seasonal trend (Fig. 9) shows that the timings of phosphorus and nitrate-N concentrations in stream water are quite different. This results from phosphorus being delivered to streams in runoff, whereas nitrate is delivered with tile flows. Concentrations typically exceed water quality standards of 0.1 mg/L for total P (for risk of stream eutrophication) and 10 mg/L for nitrate-N (for drinking water). This is only one year of data; no strong conclusions can be drawn, and no statistically significant differences occurred. In particular, Tipton Creek, which has the greatest density of swine production facilities compared to the other two watersheds, did not show the greatest concentrations of P in stream water in 2001 (Fig. 10). Also, nitrate-N concentrations were similar across the watersheds when comparing the permanent sites. However results do indicate that water quality concerns are well founded, and should be addressed across the South Fork watershed.

Summary of benefits from this research

Pork producers will benefit from the results of this study over short- and longer-term time frames. In the shorter term, a planning tool has been developed to assist with BMP placement in a watershed with intensive swine production. This may result in installation of wetland and riparian practices at locations that can optimize water quality benefits. The analyses conducted only required existing data that is publicly available. Therefore similar analyses can readily and inexpensively be applied to other watersheds. This would, within a reasonable time frame, allow many producers to identify locations where riparian buffers should effectively intercept nutrients, and those sites where wetlands could treat tile drainage.

A local watershed group, which includes environmental- and producer-group representatives in its membership, has been kept up to date with this project and was provided copies of the field-planning guide. This has increased the visibility of NPB's support for new projects aimed at environmental improvement. The scope of this benefit was broadened as results of this project were presented to the NRCS, and at National Meetings of the Soil and Water Conservation Society and the Association for Landscape Ecology.

Tools developed in this project demonstrate how site-specific technologies could be expanded from their current focus on agricultural production to include conservation planning. In the longer term, such technologies could help agricultural producers achieve environmental goals with greater efficiency. We have shown that sensitive sites that should be favored for BMP installation tend to be small and well distributed across a test watershed. This finding suggests that watershed assessment technologies would not necessarily place the burden of environmental programs on a small group of producers, but rather could help reveal strategies to share the responsibility for resource conservation across the agricultural community. Stream monitoring further suggests that this watershed's water quality problems will be best addressed through a broad-based effort.

VII. Acknowledgements

David James provided invaluable assistance with GIS analysis and map construction. Gary Hilmer and Marv Hoffman of the NRCS provided local field expertise. David Webber assisted with digitization and data collection.

VIII. References

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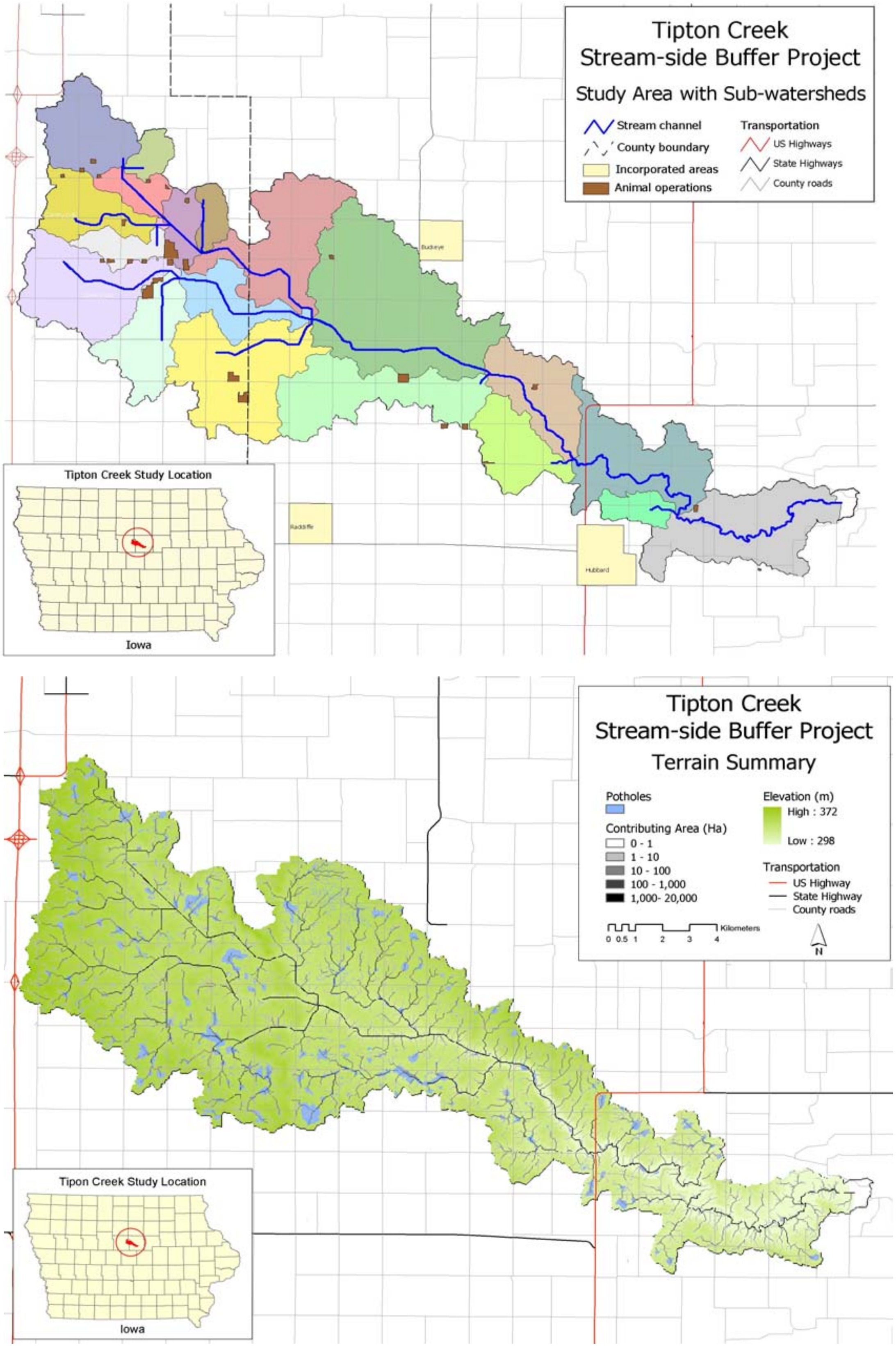
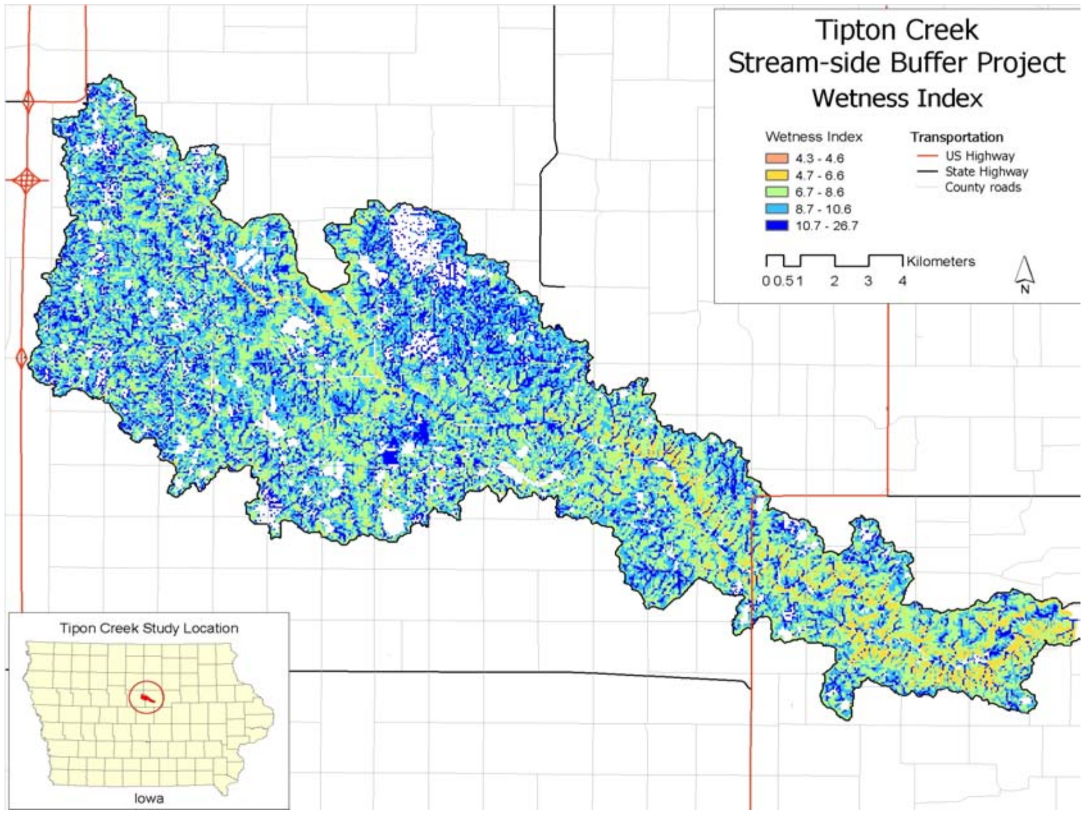


Figure 1. General and terrain summary maps of Tipton Creek watershed.



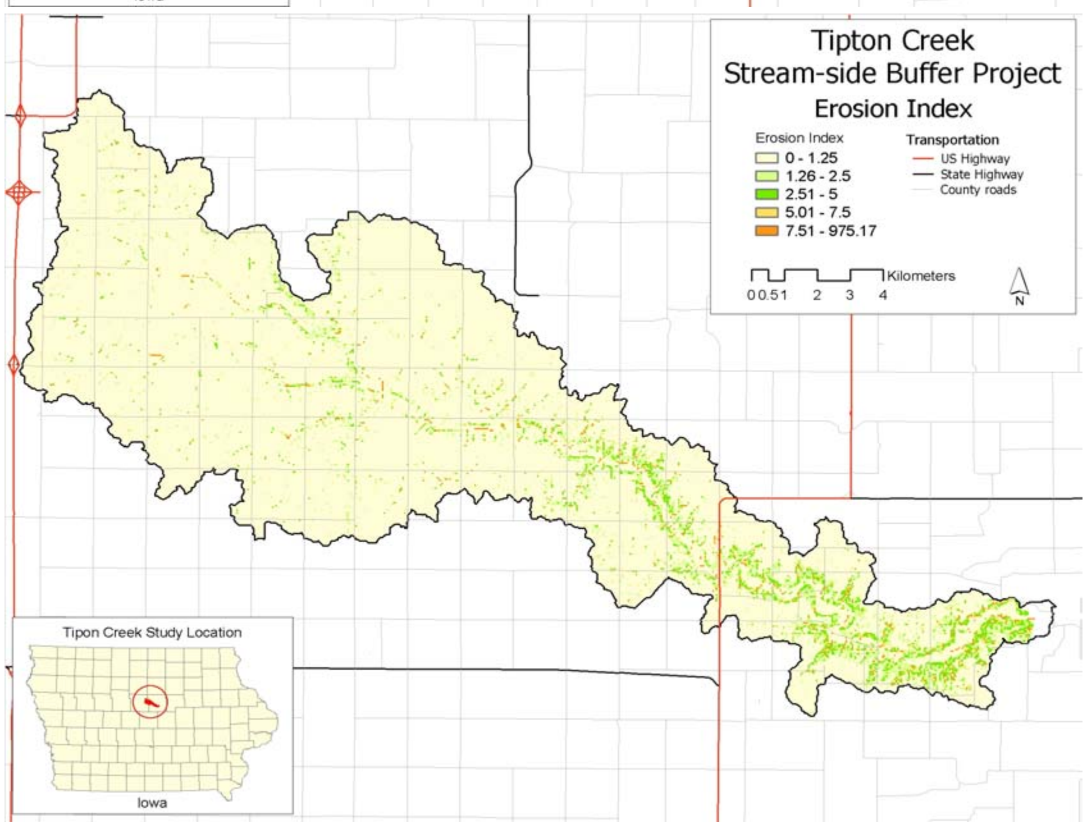
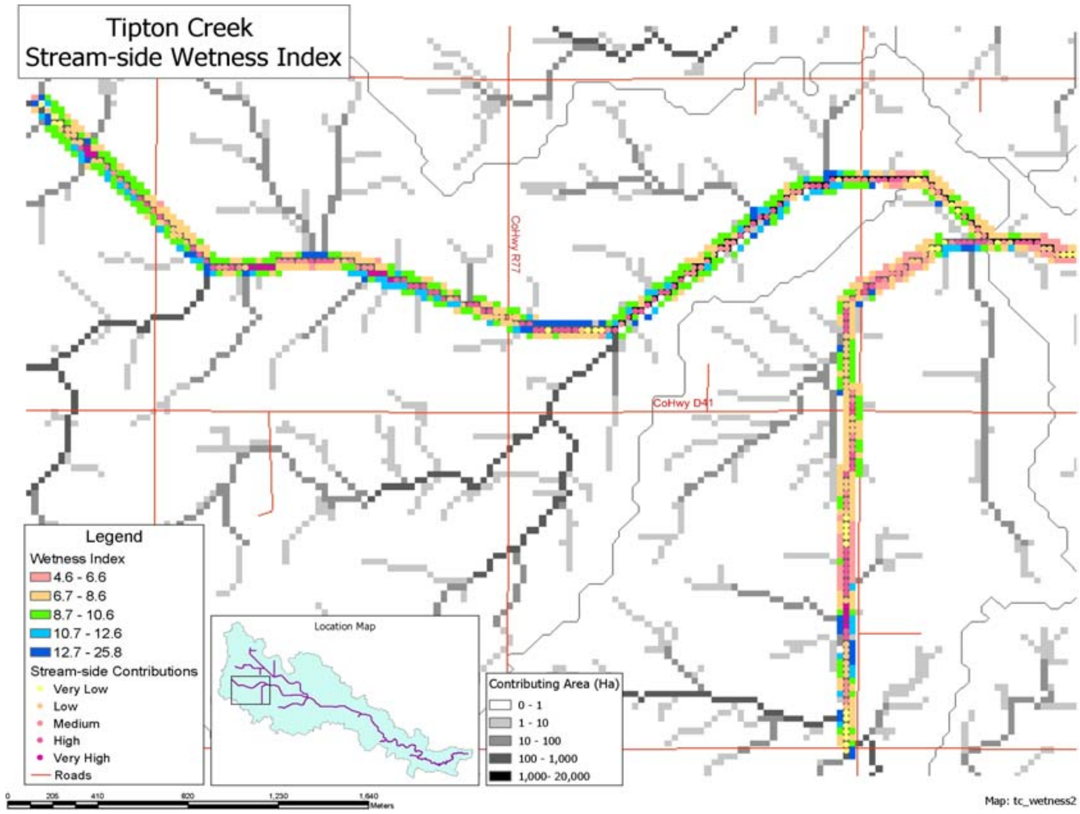


Figure 2. Wetness and Erosion Index maps for Tipton Creek watershed.



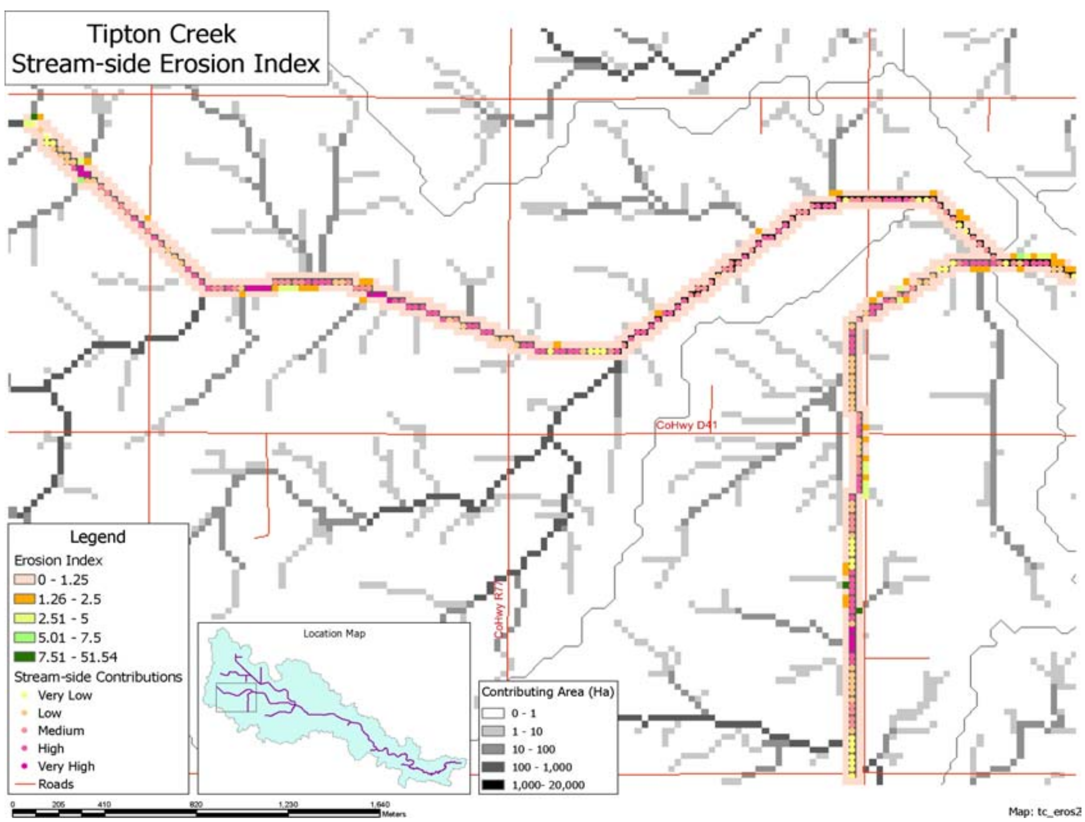


Figure 3. An example buffer placement map in the upper portion of Tipton Creek watershed.

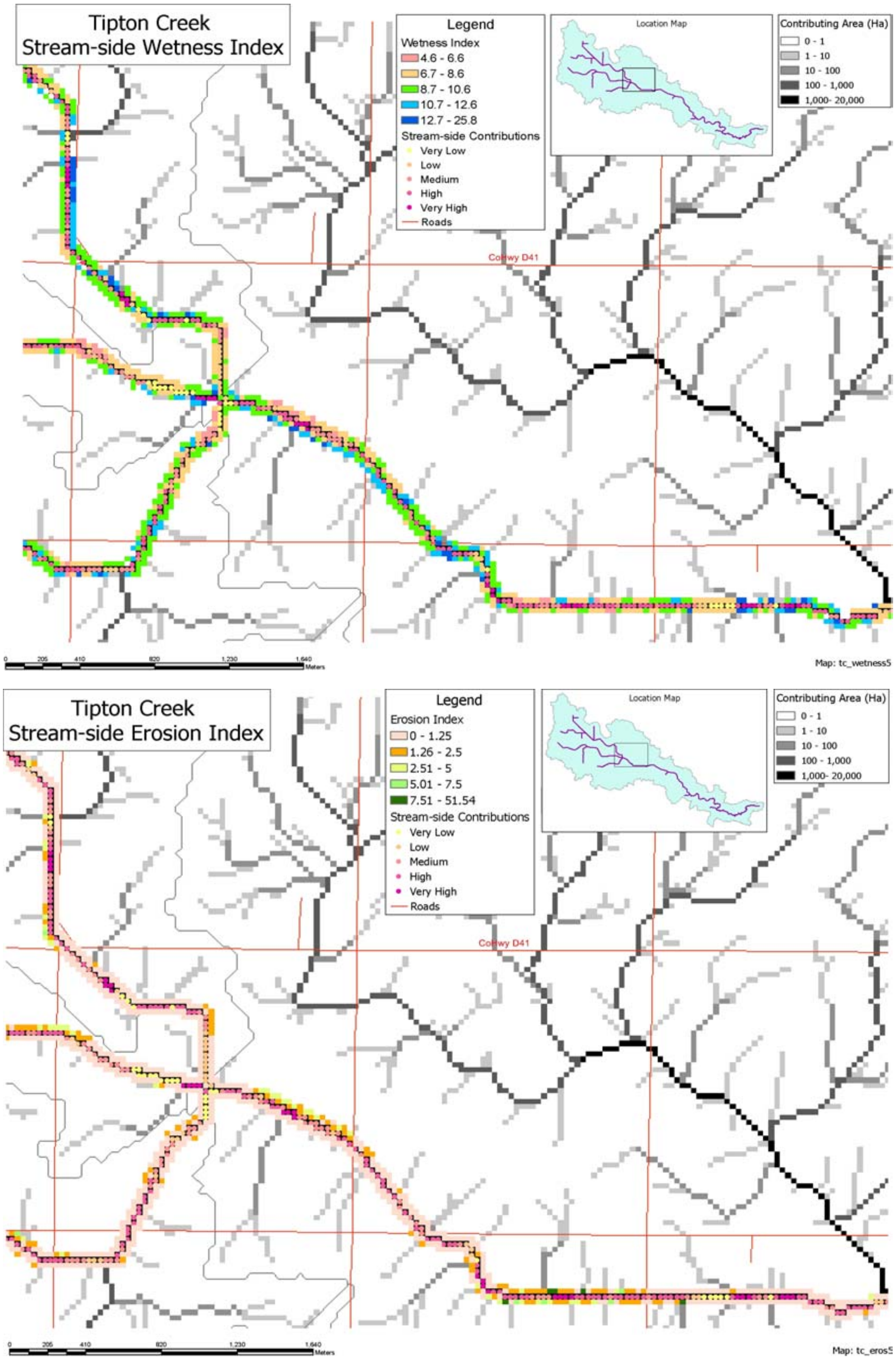


Figure 4. An example buffer placement map in the middle portion of Tipton Creek watershed.

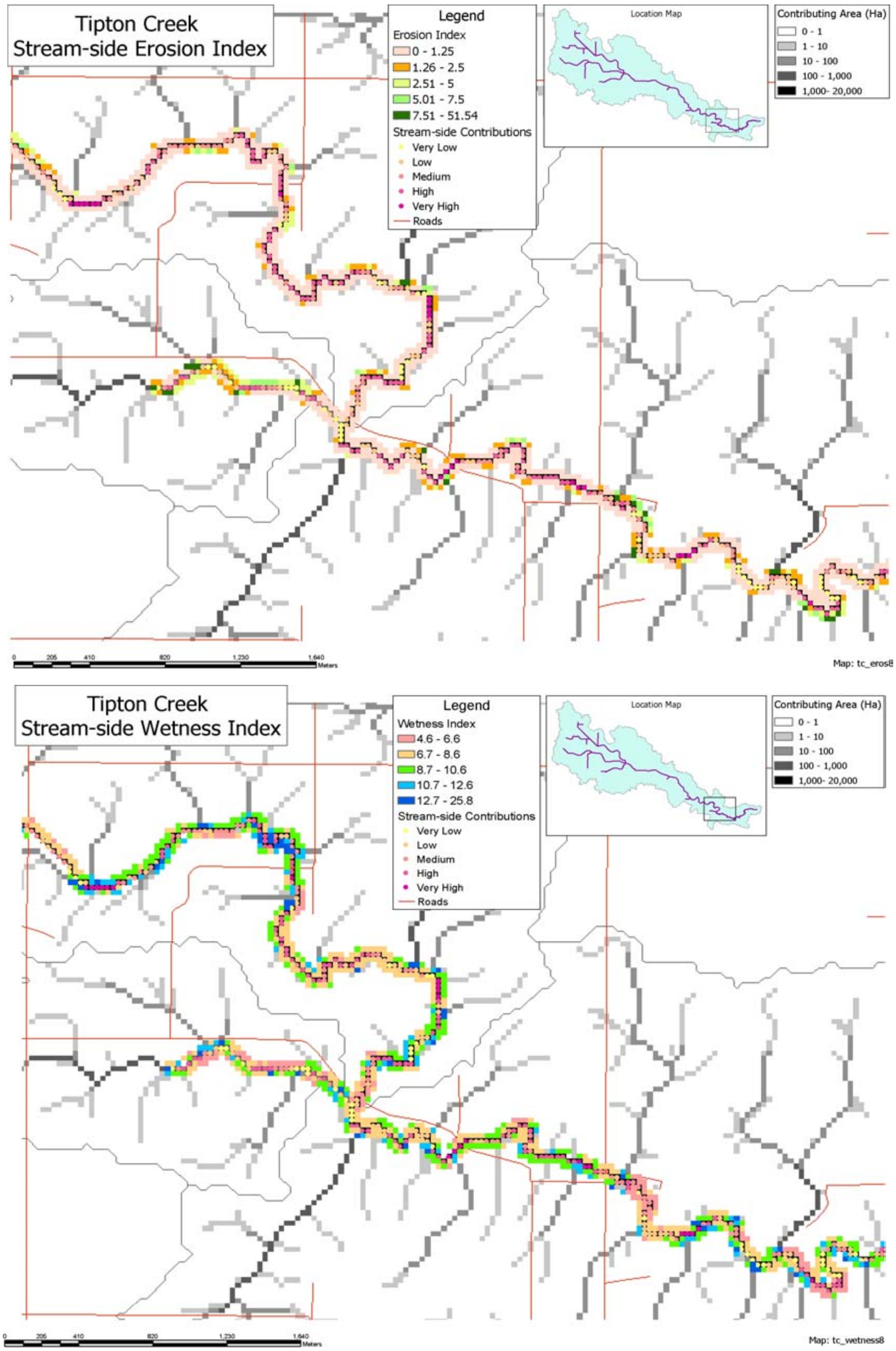


Figure 5. An example buffer placement map in the lower portion of Tipton Creek watershed.

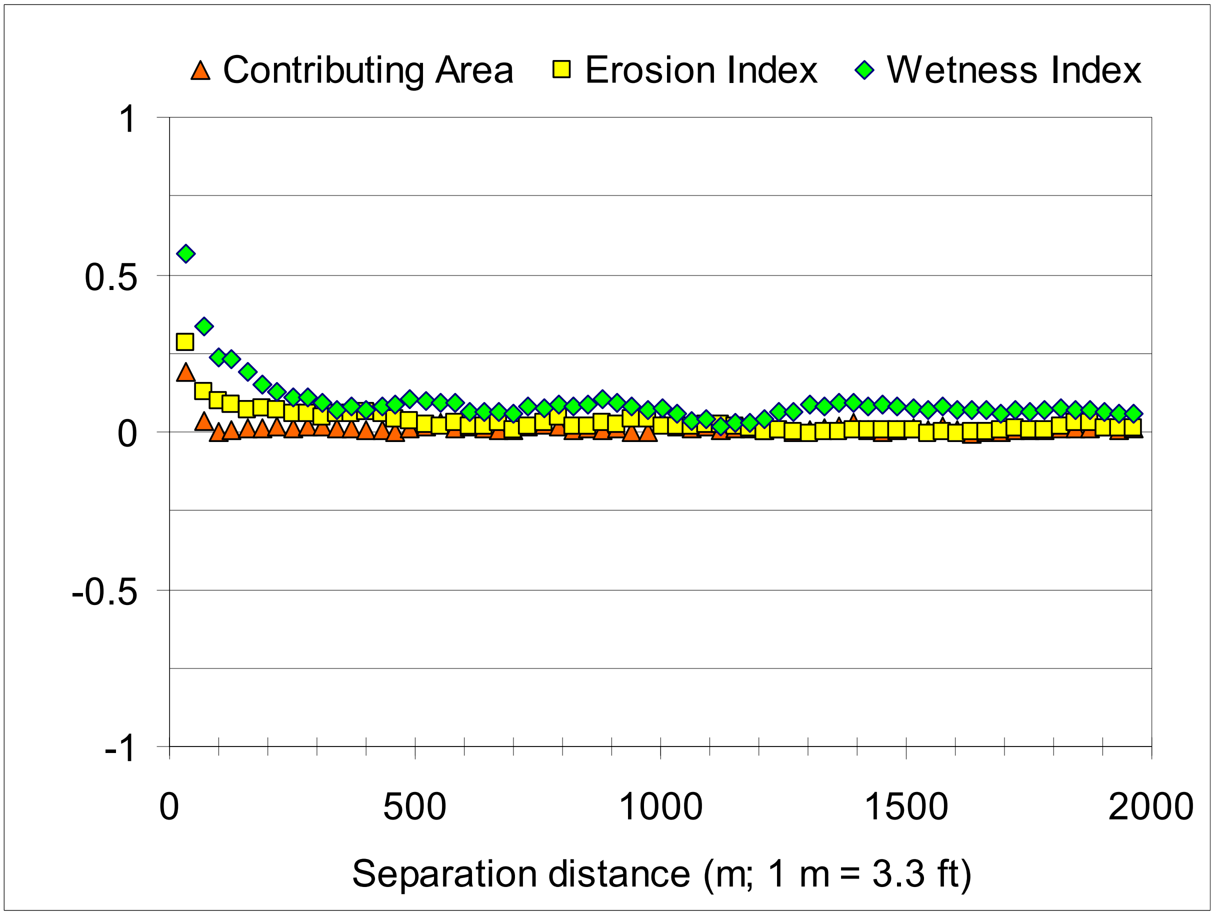


Figure 6. Spatial correlogram plot of streamside cell terrain parameters.

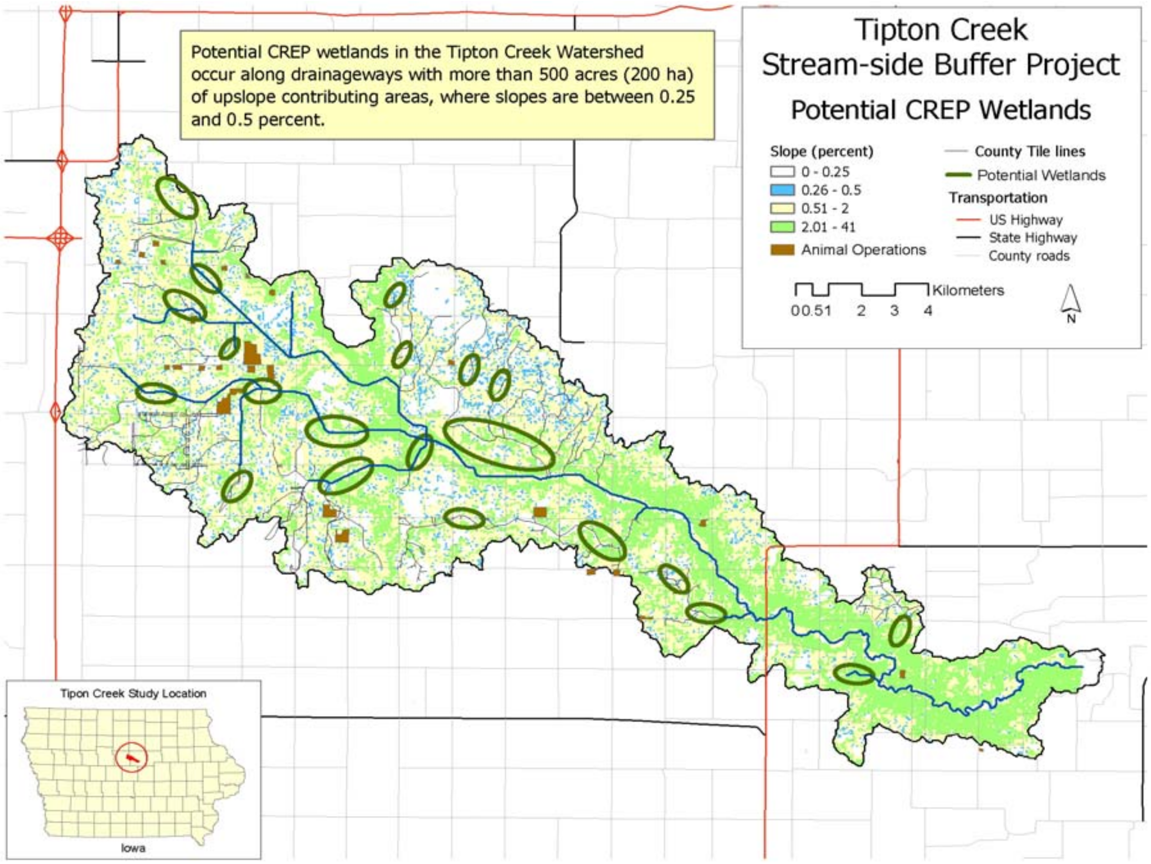


Figure 7. Map indicating potential locations for CREP wetlands in the Tipton Creek watershed.

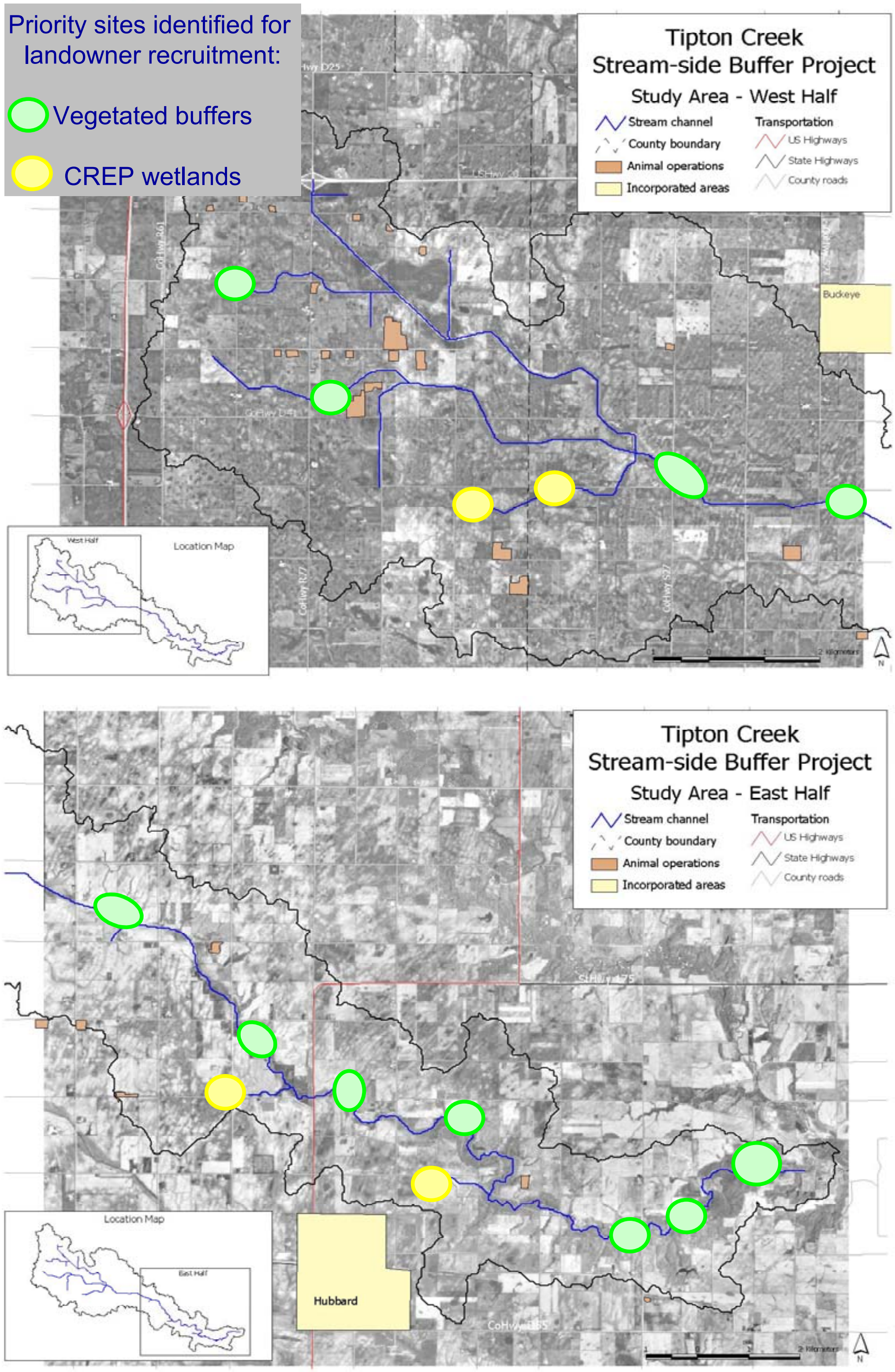


Figure 8. Priority sites identified for review and possible landowner recruitment for BMP installation.

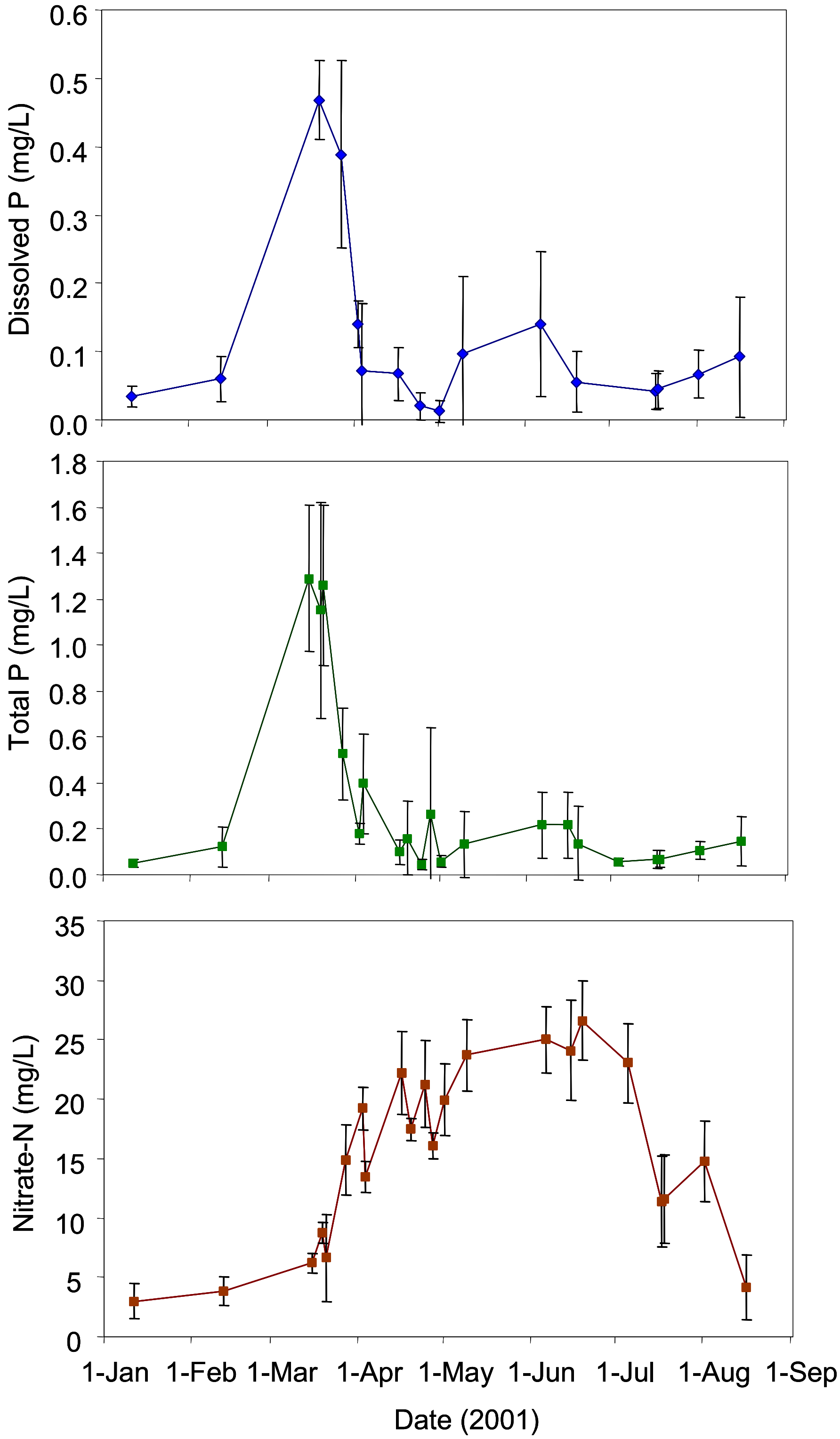


Figure 9. Seasonal trend of water quality data collected at 13 sites across the South Fork watershed. Means for each date of sampling are shown, with error bars indicating =/- one standard deviation.

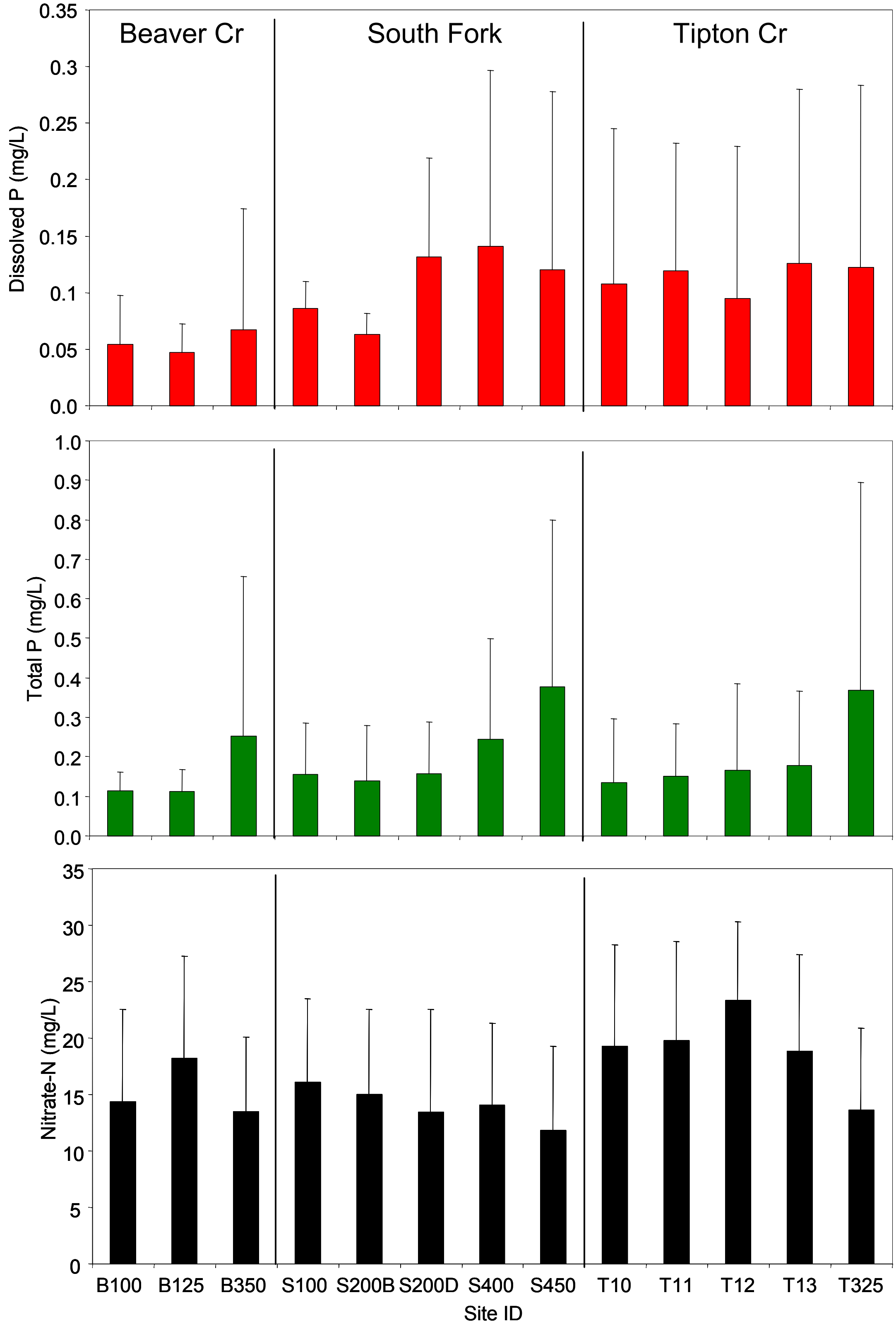


Figure 10. Water quality data (mean, with the error bar indicating one standard deviation) at thirteen monitoring sites, separated by watershed. Locations are arrayed upstream to downstream within each watershed.