Title: Best Management Practices Research in a Watershed with Swine Production Facilities - **NPB #02-042**

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Date Received: June 30, 2003

Abstract: The South Fork of the Iowa River drains a 215,000-acre watershed in north-central Iowa dominated by agricultural land uses. There are a number of swine-producing facilities in the area, plus several farm operations that include cattle grazing. In order to understand the water quality dynamics of a large watershed that contains a range of livestock operations, the National Soil Tilth Lab (USDA-ARS), with support from the National Pork Board, has been monitoring water quality and conducting watershed assessments in the South Fork since 2000. This project supported several activities to assess best management practices in the watershed, and monitor water quality. These activities have provided maps of conservation plantings and permanent vegetation in the watershed, identified a possible new site for demonstration and research on a new constructed wetland site, documented water quality across the watershed during 2002, and assessed a range of soil properties near the beginning of a long-term manure management research project.

Results show that about 10% of the watershed is planted in permanent vegetation, with most of these areas located in the lower riparian valleys of the watershed. Conservation Reserve Program plantings are also mapped, with many being riparian buffers for streams in the upper parts of the watershed. About 2000 water samples were collected and analyzed for nutrient concentrations. Some differences between years and between sub-basins were found, based on grab samples collected from 13 locations. These differences are probably due to varying amounts of seasonal rainfall and runoff. In-stream monitors were used to continuously measure temperature and dissolved oxygen near the outlet of Tipton Creek during summer 2002, and results showed the water to be of suitable quality for a range of game fish. A process-level study of manure management effects on soil properties was initiated at a long-term experimental site, which will allow interacting effects of manure application, rotation, and slope position to be identified in several years time. The initial results showed some interesting variations in the amount and quality of organic matter depending on slope position, with resulting improvement in soil structure (aggregate stability) at the lower slope position. This range of research activities provides important progress towards the long term goal of assessing best management practices and water quality in the South Fork watershed, which is becoming an important location for research activities on agricultural practices and environmental quality that are of interest to swine producers.

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Introduction: A wide range of agricultural and riparian best management practices can be effective at improving water quality within watersheds. But the issues involved in identifying what practices are most effective, and where and when they should be implemented, are complex. Unraveling these issues requires an assessment of ongoing and alternative practices at field and watershed scales. These efforts must be undertaken over multiple years so that effects of climate variation can be better understood. This approach will allow producers to implement conservation systems that will effectively protect soil and water quality. In this process, we must also ensure that manure management practices are implemented in a way that maintains or enhances the quality of soil resources. This also requires multi-year studies so that gradual responses of soils to management systems can be measured.

The Agricultural Research Service, with support from NPB, has been conducting watershed-scale in the South Fork of the Iowa River since 2000. The research reported here was multi-faceted, and aimed to continue research in the areas of watershed assessment and water quality monitoring, and enhance ongoing research on manure management strategies to include an assessment of key soil properties.

Objectives: There were four objectives to this research, listed as follows:

1. Maintain and expand the geographic database for Tipton Creek and Iowa River's South Fork by mapping and describing riparian buffers, constructed wetlands, and other conservation plantings.
2. Establish a riparian buffer research site, continuing work completed in a 2001 NPB grant.
3. Continue monitoring water flows and quality in Tipton Creek, and the South Fork of the Iowa River, incorporating the use of new multi-parameter probes.
4. Initiate research to compare long-term effects of manure application strategies on soil properties.

Materials & Methods: Procedures followed under each Objective are described separately, as follows.

Objective 1. To map conservation plantings and areas of permanent cover in the watershed, we obtained several geographic-data layers, including publicly available data based on remote sensing. These include the ISU-GAP data (available at http://ortho.gis.iastate.edu/), a state-wide land-cover map developed from 1992 Landsat remote-sensing data, and crop data layers from the USDA National Agricultural Statistics Service (NASS), which have been produced annually since 2000. We also obtained digitized common land unit (CLU) files from the Natural Resources Conservation Service (NRCS) and the Farm Service Agency (FSA) for Hamilton and Hardin counties, which contain crop-field boundaries (but no ownership information). This map data included information on the distribution of Conservation Reserve Program (CRP) acreage in the watershed. All mapped information has its limitations, due to errors, changes in land use, and inaccuracies/generalizations that result from classification of satellite remote-sensing data. Therefore we used two independent approaches to identify and map areas of permanent vegetation in the watershed, providing a way to examine the consistency between data sets. The first approach combined the ISU-GAP data and the CLU files. This combined map shows areas of permanent cover that were established long term, (at least since the early 1990s), together with recent plantings of permanent cover established under USDA's CRP. The second map shows the areas of permanent cover identified in the NASS crop data layer for 2002. This map data is primarily aimed at discerning areas of USDA commodity program crops, and therefore 'other' areas are not well differentiated, so that, for example, farmsteads are classified together with pastures. These two maps were compared for consistency, considering source-data differences.

Objective 2. We have approached this objective through the local NRCS and the South Fork Alliance. This has included several site reviews, however dredging of the upper portion of Tipton Creek, which significantly disturbed riparian areas, complicated progress on this objective during the past year. Although no riparian site has been selected, we are investigating the possible establishment of a new wetland research site, located down gradient from a station that monitors runoff from a farm field. This has included a site survey that can be used in the engineering design of a wetland.

Objective 3. Water quality monitoring was continued during 2002, with nearly 2,000 samples collected for analysis of sediment and nutrients (nitrate and total phosphorus). Samples were automatically collected on a daily basis at four permanent sites where flow was also monitored. These samplers collected additional samples during runoff events, which were triggered by increases in flow. Also, grab samples were collected at 13 locations (including the four permanent sites) every week or two. The grab samples were filtered for measurement of dissolved and total P.

An in-stream monitor was installed near the end of May. Manufacturers also provided two other models for evaluation (on loan) during much of the 2002 monitoring season. These units were mostly operating at the Tipton Creek station, although one was deployed at the Beaver Creek site for part of the season. These monitors recorded temperature, pH, conductivity, dissolved oxygen, and turbidity every ten minutes.

Objective 4. Soil samples were collected from the plots of a long-term manure management experimental site in early June 2002; with some repeat sampling in early September. The intent of this sampling was to determine baseline conditions of the soils at this experimental site. We will resample again after several years of experimental treatments, which include crop rotation, source of N (manure, commercial, or in combination with manure rate determined by its P content), and timing of application. Samples were collected from 0 to 8 inch depth, with upper, middle, and lower slope positions selected and sampled in each plot. Samples were analyzed for aggregate stability, exchangeable cations, and organic matter fractions. Aggregate stability was evaluated using a wet-sieving technique (Kemper and Rosenau 1986) Exchangeable cations were extracted using 0.2 M NH_4Cl, after removal of water-soluble salts (modified after Sumner and Miller 1996). A base solution (0.25 M NaOH) was used to extract organic matter contained in two humic-acid fractions that differ in degree of binding by polyvalent cations (Olk et al. 1996). These extractions were only carried out for upper and lower slope positions, and only for manure and commercial fertilizer treatments, because the procedures are time-consuming, and some of the methods had to be refined for these Iowa soils. Soil samples and humic acid fractions were analyzed for their elemental composition by automated combustion analysis. Light absorption of the humic acid fractions was determined at 465 nm by dissolving the fractions in 0.05 M $NaHCO_3$ (Chen et al. 1977).

Results:

Objective 1: Maps resulting from two assessments of permanent cover in the South Fork Watershed are shown in Fig. 1. The two maps are similar in appearance, and show that permanent vegetation typically occurs near the streams, particularly in the alluvial valleys in lower elevations of the watershed. The locations of new riparian buffers in the CRP program are apparent in both maps, and the remote sensing data in large measure confirm FSA maps of CRP buffer areas (based on visual comparison). Acreages of land-use classes are also reasonably consistent between the two maps (Table 1), considering the differences in data sources, survey purposes, and inherent data limitations (i.e., 30-m resolution, focus on crop areas in NASS classification, differences in survey timing). About 10% of the watershed area is in some form of permanent cover. The 2002 NASS data show less area in permanent cover, due to a combination of factors, including differences in classification and map accuracy, and changes in land use between 1992 and 2002. Wetland acreage, calculated using the ISU-GAP data, totals nearly 1700 acres, with most of this located in stream-side areas in the watershed's lower alluvial valleys. At this point we do not believe the NASS data can provide a viable assessment of wetland acreage.

Table 1. Acreages mapped under land use classes consisting of permanent vegetation, from three data sources. The total watershed area is about 215,500 acres. The acreages tallied in the first four rows are shown in the upper map of Fig. 1, while those tallied in the last two rows are shown in the lower map.

Type of cover	Classifies	Source	Area (acres)
CRP	CRP contracts	CLU (FSA, 2002)	2,998
Grassland	Pasture/CRP/Farmstead	Iowa GAP (1992)	19,767
Trees	Includes evergreens and hardwoods	Iowa GAP (1992)	3,489
Wetlands	All wet areas	Iowa GAP (1992)	1,667
Grassland	Pasture/CRP/Farmstead	NASS (2002)	17,121
Trees	All woodlands	NASS (2002)	3,672

Objective 2: A possible constructed-wetland site has been identified and surveyed. The site receives tile drainage from about 40 acres, which receive manure and are being monitored for runoff under ongoing NSTL research. This site provides the opportunity to evaluate nutrient reductions in a wetland receiving tile flow from manured cropland. We will investigate establishment of a wetland sized at 0.5 to 2% of the contributing cropland, as specified in Iowa's Conservation Reserve Enhancement Program (i.e., a 0.2 to 0.8 acre wetland). Engineering design needs to be pursued as yet, but ARS has engineers on staff nationally who can assist with this task.

Objective 3: A summary of water quality data from 2002 is presented in Figs. 2 and 3, and in Table 2. The figures present nutrient concentration data from grab samples collected at 13 locations every 1-2 weeks during 2002. The phosphorus concentrations did not show the distinct seasonal pattern that occurred in 2000 and 2001, when increased concentrations occurred early in the growing season (Tomer 2002). This is probably explained by less early-season precipitation and runoff during 2002. There were several runoff events near mid summer of 2002, however, that showed increased P concentrations (Fig. 2). Nitrate concentrations also showed less of a seasonal pattern than in the previous two years, but remained quite high throughout the year (greater than 10 mg/L). Peak concentrations still occurred in June, consistent with previous years. Considering the grab-sample data from 2001 and 2002, several significant differences occurred (Table 2), each with less than a 5% probability of error: 1) Across all the streams, the average NO_3-N concentration was greater in 2002 than in 2001; 2) Across all the streams, average total and dissolved P concentrations were greater in 2001 than in 2002; and 3) During 2002, the average NO_3-N concentration in Tipton Creek was larger than the other two sub-basins. These outcomes could largely result from differences in hydrology (see discussion).

Table 2. A summary of average nutrient concentrations for 2001 and 2002, with basin-specific data included for 2002. The data are for grab samples only, collected every week or two at 13 locations across the watershed. Superscript letters indicate where average differences were significantly different between years (all sub-basins), and among basins during 2002 (see preceding text).

Parameter	2001 all sub-basins	2002 all sub-basins	2002 Tipton Creek	2002 South Fork	2002 Beaver Creek
	mg/L				
NO_3-N	15.7^{b}	17.8^{a}	20.9^{a}	16.7^{b}	14.8^{b}
Total P	0.26^{a}	0.09^{b}	0.10	0.07	0.10
Dissolved P	0.12^{a}	0.04^{b}	0.04	0.04	0.05

Multi-parameter probes were installed at two locations during the 2002 growing season, and provided good-quality data for temperature, pH, conductivity, and dissolved oxygen. Turbidity measurements were a challenge however due to rapid algal fouling of the light sensor, which required cleaning and calibration at least twice per week. Despite this difficulty, we obtained good turbidity readings during several runoff events that accounted for as much as 63% of the variation in sediment concentrations, which shows the potential of this technology. The sensors also provided good-quality data on temperature and dissolved oxygen, which showed distinct diurnal (day to night) variations, and indicated the physical environment is suitable for a range of game fish.

Objective 4: Results from this research were intended to provide baseline data for a later evaluation of the long-term effects of manure application on soil properties. Aggregate stability is a general indicator of physical qualities of the soil associated with good aeration, root penetration, infiltration, and 'manageability'. Results from our 2002 sampling (Table 3) indicate the soil to be of good quality, with generally at least one third of the soil consisting of stable aggregates. The lower-slope soils showed somewhat greater aggregate stability, and this is fairly typical. Otherwise the soils were quite uniform and show no treatment effects, and none were expected at this early stage of the experiment.

Exchangeable cations extracted from these soils also showed no treatment or slope-position effects (Table 4). There is a possible concern that sodium applied in manure could adversely affect soil properties (such as those indicated by aggregate stability). These results show that current concentrations of exchangeable sodium in these soils are very small, with no detectable increase from a single year's manure application. Sodium would have to comprise perhaps 10% of the total cation balance before negative impacts on soil properties would result. The data show a clear dominance of divalent cations (Ca and Mg), which have a positive influence on soil aggregation and structure.

Table 3. Aggregate stability of soils one year into a long-term manure management experiment near Buckeye IA (average data from four replicate plots).

Slope Position	Timing	N Source	Percent water-stable aggregates >0.25 mm Continuous Corn	Corn-bean rotation
Upper	Fall	Manure	35.1	
		Commercial	37.1	
		Manure+commrcl	33.6	
	Spring	Manure	33.1	31.6
		Commercial	36.2	35.3
		Manure+commrcl	27.1	
	NA	Control	33.6	29.2
Mid	Fall	Manure	36.2	
		Commercial	37.9	
		Manure+commrcl	35.8	
	Spring	Manure	36.2	34.1
		Commercial	34.6	28.5
		Manure+commrcl	35.9	
	NA	Control	41.7	29.7
Lower	Fall	Manure	40.7	
		Commercial	39.5	
		Manure+commrcl	42.9	
	Spring	Manure	43.8	36.8
		Commercial	46.5	39.8
		Manure+commrcl	37.0	
	NA	Control	46.9	41.5

Table 4. Exchangeable cations extracted from the surface soils of a long-term manure management experiment near Buckeye IA, using 0.2 M NH_4Cl after removal of water-soluble salts. As expected, there were no significant differences after one year of treatment. Data represent an average of four replicate samples.

Slope Position	Timing	N Source	Continuous corn Ca	Mg	Na	K	Corn-soybean rotation Ca	Mg	Na	K
			--------------------cmol (+) kg^{-1} soil-----------------							
Upper	Fall	Manure	7.72	2.09	0.06	0.28				
		Commercial	7.98	2.17	0.06	0.21				
		Manure+commrcl	7.66	2.05	0.06	0.26				
	Spring	Manure	7.26	1.91	0.06	0.33	2.01	1.40	0.05	0.20
		Commercial	9.36	1.95	0.06	0.18	3.84	1.39	0.05	0.18
		Manure+commrcl	5.98	2.23	0.06	0.25				
	NA	Control	8.79	2.03	0.06	0.23	4.20	1.74	0.06	0.21
Mid	Fall	Manure	7.62	2.20	0.06	0.27				
		Commercial	8.63	1.98	0.07	0.21				
		Manure+commrcl	8.94	2.11	0.06	0.30				
	Spring	Manure	7.27	1.95	0.07	0.21	2.27	1.74	0.06	0.20
		Commercial	9.24	1.76	0.06	0.25	4.50	1.71	0.05	0.18
		Manure+commrcl	8.64	2.05	0.06	0.26				
	NA	Control	9.16	1.84	0.06	0.27	4.93	1.90	0.06	0.21
Lower	Fall	Manure	8.34	2.07	0.06	0.25				
		Commercial	8.08	2.03	0.06	0.27				
		Manure+commrcl	7.59	1.78	0.07	0.33				
	Spring	Manure	8.24	2.17	0.06	0.50	2.17	2.48	0.06	0.25
		Commercial	7.35	2.22	0.07	0.24	5.25	2.44	0.06	0.23
		Manure+commrcl	7.13	2.19	0.06	0.22				
	NA	Control	8.18	2.13	0.06	0.34	6.67	3.47	0.06	0.22

Organic matter analyses showed that soils in the lower-slope position had more total carbon (C) and nitrogen (N) than did soils in the upper-slope position (Table 5). This difference was most clear under corn-soybean rotation, where there were smaller C and N levels than in the continuous corn soils. We believe this difference is due to soil variation in the experimental area, rather than rotation.

As expected, the short history of experimental treatments did not influence soil C and N levels. An unknown amount of C in all soils may be inorganic carbonate instead of organic matter; a procedure for distinguishing these two C forms is being evaluated. Two humic acid fractions were extracted from the soils to allow study of the true humus. In previous research the mobile humic acid (MHA) fraction responded in quantity and chemical nature to crop management and it affected nutrient cycling in rice and cotton soils (Olk et al. 1996, 1998; Olk and Cassman 1995). The calcium humate (CaHA) fraction is an older fraction stabilized by polyvalent cations that is intermediate between the MHA and whole soil organic matter. In this study, both humic fractions had higher N and hydrogen concentrations in the lower-slope soils than in the upper-slope soils (Table 5), suggesting a less decomposed state of the lower-slope humus. This was confirmed by light absorption, with lower-slope soil fractions absorbing less light at 465 nm than the upper-soil fractions (Olk et al. 1996). The type of N fertilizer did not consistently affect any measured humic property. Combined, the MHA and CaHA accounted for greater proportions of total soil organic N in the upper-slope soils than in the lower-slope soils (28% and 12%, respectively), suggesting that organic matter in the lower soils is moderately-well stabilized.

Table 5. Chemical characteristics of whole soil and humic acid fractions. Values are means of three field replicates for the spring 2002 sampling, 0-6 inch depth.

Slope position	N source	Whole soil %C[1]	Whole soil %N[1]	Mobile humic acids %N[2]	Mobile humic acids %H[2]	Mobile humic acids E_4[3]	Calcium humates %N[2]	Calcium humates %H[2]	Calcium humates E_4[3]
		Corn-soybean rotation							
Upper	Manure	1.23	0.06	5.50	5.68	2.02	3.63	4.31	6.91
	Commercial	1.26	0.06	5.50	5.56	2.33	3.44	4.08	7.02
Lower	Manure	3.32	0.28	5.83	5.89	1.33	3.74	4.33	5.80
	Commercial	3.34	0.24	5.97	5.90	1.36	4.34	4.60	4.77
		Continuous corn rotation							
Upper	Manure	2.50	0.16	5.29	5.60	2.35	3.05	3.86	7.58
	Commercial	2.52	0.18	5.15	5.51	2.55	3.06	3.89	7.70
Lower	Manure	4.34	0.30	5.94	5.89	1.24	3.68	4.30	5.61
	Commercial	3.83	0.30	5.89	5.85	1.34	3.86	4.46	5.64

[1] Concentration units are in percent of total soil mass (dry matter basis).
[2] Concentration units are in percent of that humic fraction.
[3] Optical density units (1/(g HA-carbon mL^{-1})).

Discussion:

Objective 1: Results of two surveys of permanent vegetation were consistent, and showed that many of the riparian-valley areas in the lower part of the watershed have been in permanent vegetation for some time (since before the 1990s). Both surveys also showed that about 10% of the watershed is in permanent vegetation. Conservation Reserve Program plantings in riparian areas identified by USDA records were well-confirmed by 2002 remote sensing data. These results provide an excellent basis to evaluate the placement of permanent vegetation for its potential to intercept and filter runoff, and then prioritize sensitive areas that, if targeted for new plantings, could increase that potential.

Objective 2: A site survey for a possible small-scale constructed wetland was carried out. This site may provide the opportunity to evaluate a wetland's capacity to improve the water quality of tile discharge and runoff from a field receiving swine waste.

Objective 3: Water monitoring results from 2002 provide an additional year of data, which showed some differences from 2001, and differences in average nitrate concentrations amongst three sub-basins. All these differences could result from hydrology. There was less discharge in 2002 than in 2001 (about one third less), and in particular fewer runoff events during spring. The spring runoff events increased sediment and phosphorus concentrations during 2001, and (in effect) diluted the nitrate. There were also differences in runoff among the three sub-basins during 2002. The least runoff occurred from Beaver Creek, which also had the smallest average nitrate concentrations. It is apparent that nitrate can be removed from streams during low flow conditions by natural processes (Tomer et al. 2003). The largest discharge occurred from the upper South Fork, where nitrate may have been somewhat diluted. This leaves the intermediate discharge from Tipton Creek to carry the largest average nitrate concentration. With the difference in discharge, however, the upper South Fork station discharged the largest load of nitrate-N (24 kg/ha versus 21 kg/ha from Tipton creek).

NSTL technical staff gained valuable experience with the maintenance of in-stream monitors. The first year was a "trial run" with these probes, and in 2003 only one of these probes is installed, this year within a dedicated chamber at the lower South Fork station (where long-term deployment is planned). The quality of the fishery resource is an important concern to local residents, and data from the in-stream monitors indicated there was essentially no threat to fish from high temperature or low oxygen during 2002 at the Tipton Creek station.

Objective 4: A unique database has been developed to document soil properties near the beginning of a long-term manure management experiment. Towards the end of this experiment there will be a rare opportunity to document effects of manure management practices on a range of soil properties, which should be of real benefit to pork producers. These early results showed fairly uniform conditions, although lower-slope soils had greater aggregate stability and organic matter contents as is typical. Differences in soil texture between the slope positions could contribute to these results. Results also suggest that compared to upper-slope soils, lower-slope soils can better stabilize young humus, inhibiting its otherwise rapid decomposition. Therefore nutrient release from organic matter during the growing season might be more gradual in lower-slope than in upper-slope soils, where a greater proportion of the humus is older and highly stabilized. In upper slope soils, nutrient release during decomposition of crop residues and animal manures may be particularly important, and manure applications should be an effective option for increasing organic matter levels. But such effects of rotation and animal manure can only be evaluated after additional years of application, followed by a repeat of these types of analyses.

Lay Interpretation: This project has supported research in the South Fork of the Iowa River watershed, where swine and other livestock are being produced, and water resource concerns have been raised. These activities are aimed to document the hydrology and water quality in the watershed, and evaluate effects of conservation practices and manure management. Key results from the work include:

1. Collaborative research was initiated at a long-term manure management experimental site to help us understand long-term effects of manure on soil properties. Several soil properties that vary with landscape position may be influenced by manure application. This multi-year research, when completed, may identify the types of soil that benefit most from manure application.
2. In-stream monitors showed that temperature and dissolved oxygen conditions in Tipton Creek posed no threat to fish during 2002.
3. During 2002, there were differences in water quality between sub-basins that could be attributed to differences in amounts and timing of runoff events, rather than land use. Smaller nutrient concentrations may occur from areas with greater stream discharge, effectively due to dilution, or from drier areas producing little stream discharge, where biological processes can remove nutrients from the slow-moving stream water.
4. Mapping of permanent vegetation in the watershed has been completed, to help us understand the distribution of conservation plantings in the watershed and their potential effect on water quality.
5. A possible new constructed wetland research site was identified.

Watershed-scale research on water quality and agricultural management requires a range of approaches and activities. A diversity of information is needed to analyze a watershed, identify actual problems and their relationship with terrain, soils, hydrology, climate, and management, and then develop practical recommendations for improvement. The goals of this wide-ranging research are long term, and therefore the different avenues of research must be pursued concurrently to provide results within a practical time frame. Pork producers are making a tangible contribution towards improved understanding of the interactions between agricultural management and water quality through support of this project.

Acknowledgements: With sincere thanks, the author acknowledges essential contributions to this work made by a number of individuals. Dr. Dan Olk collaborated closely on Objective 4 and contributed part of the text of this report. David James assisted with geographic analyses reported under Objective 1, and generated the maps shown in Fig. 1. Colin Greenan managed the soil and water sampling programs under Objectives 3 and 4, managed the water quality data, and produced Figs. 2 and 3. Hydrologic stations were established and maintained by Kevin Cole and Jeff Nichols. Jennifer Boeckmann carried out organic-matter analyses for Objective 4. Dawn Luppes and Patrick Murphy provided assistance in water sampling and analyses under Objective 3. The NSTL analytical laboratory, under direction of Amy Morrow, conducted nutrient analyses. Special thanks to Colin Greenan and David DenHaan for their assistance in completing the cation extractions.

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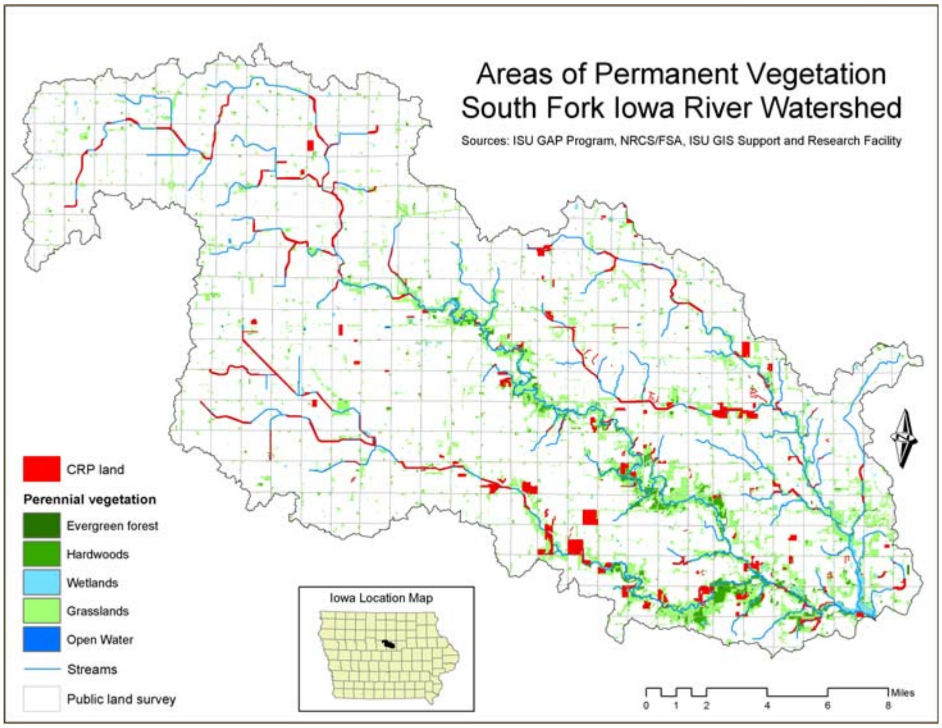

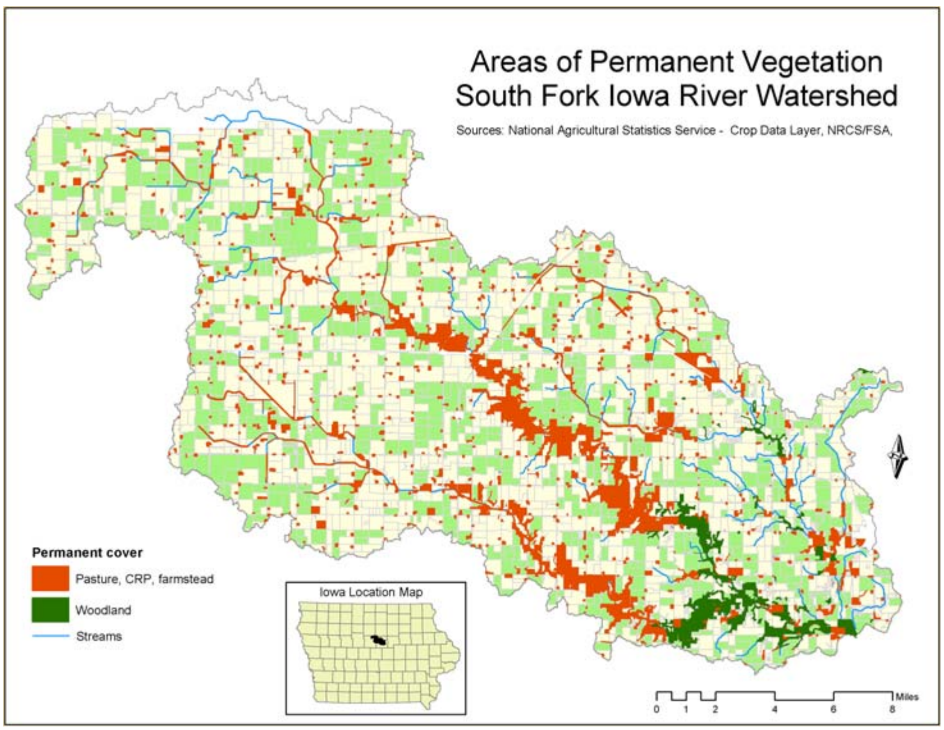

Figure 1. Two assessments of permanent vegetation areas for the South Fork Watershed. Upper map: Permanent vegetation mapped in the early 1990s (ISU-GAP), plus recent additions indicated by CRP lands (USDA-FSA). Lower map: Permanent cover mapped by the National Agricultural Statistics Service using 2002 remote sensing data (Hamilton and Hardin Counties) shows grassland, pasture, and farmsteads classified together, plus woodland. The distribution of corn (light yellow) and beans (light green) during 2002 is also shown.

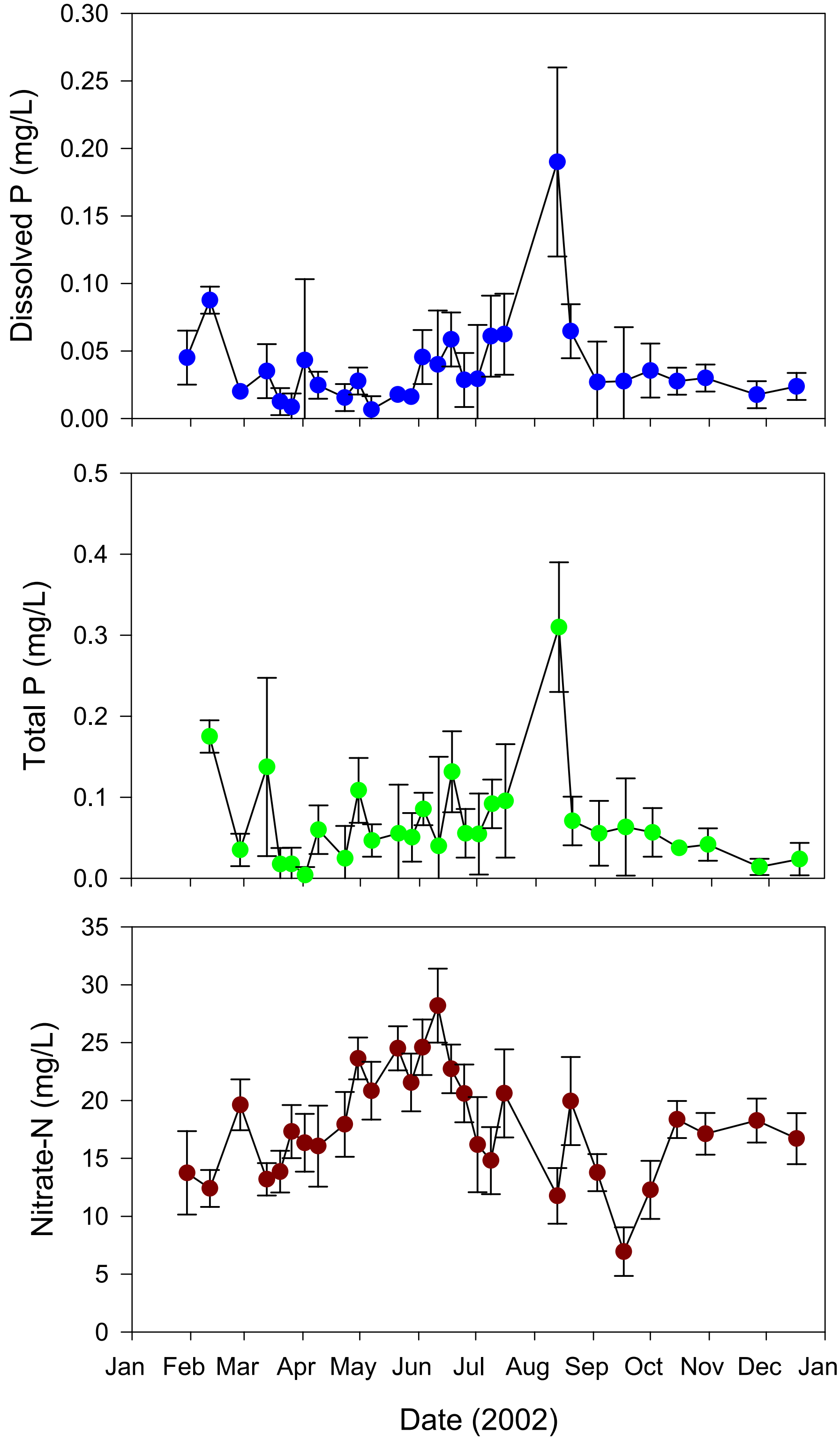

Figure 2. Seasonal pattern of nutrient concentration data during 2002, obtained from grab samples at 13 sites across the South Fork watershed. The plotted symbols show the average value for each date, and the error bars indicate plus/minus one standard deviation.

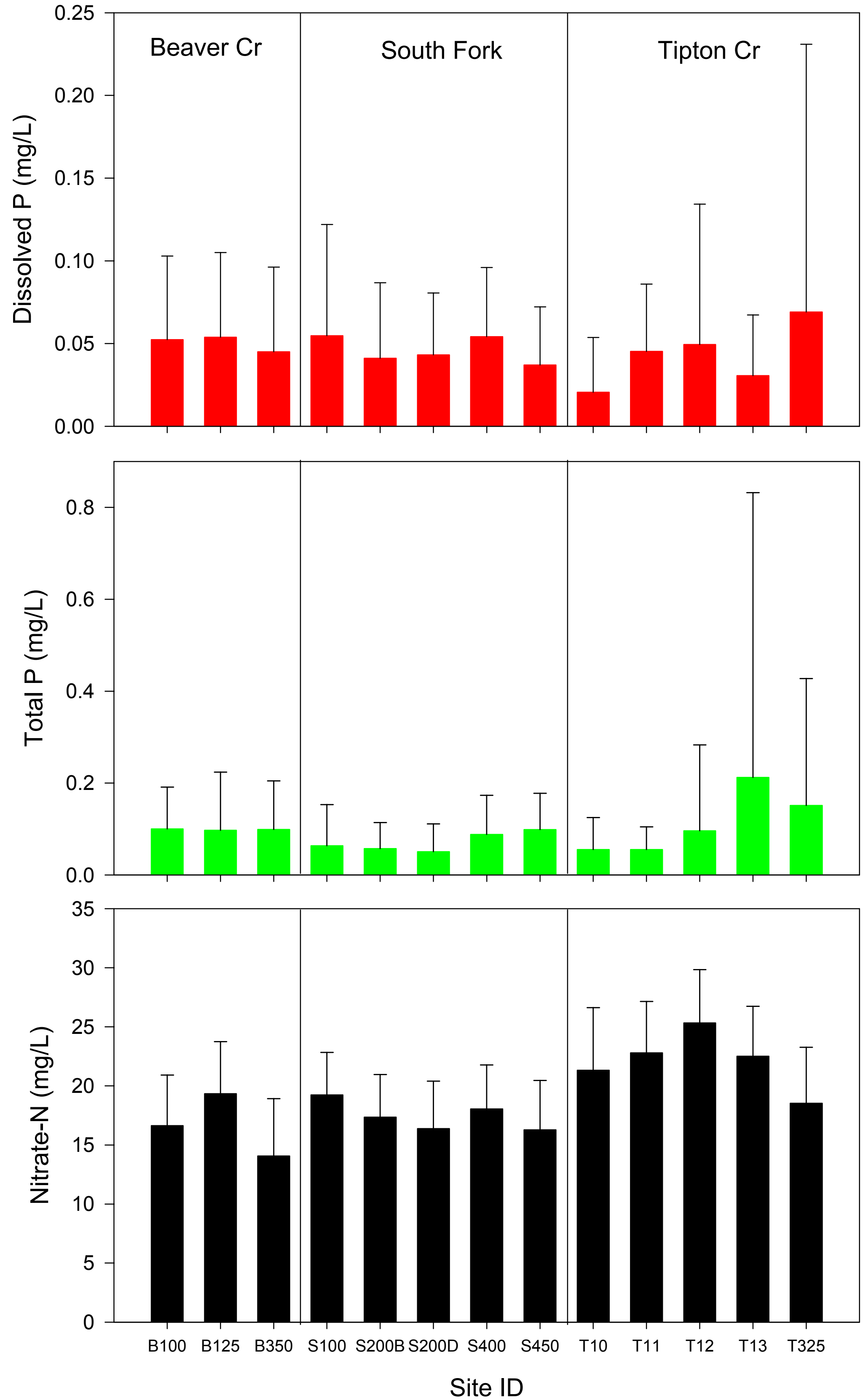

Figure 3. Average nutrient concentrations during 2002 at each of 13 stream sampling sites across the South Fork watershed. Error bars indicate one standard deviation. The locations are arrayed upstream to downstream within each of three sub-basins.