Research Technical Completion Report

MEASURED AND SIMULATED NONPOINT SOURCE AGRICULTURAL POLLUTION EFFECTS: AN ECONOMIC-ECOLOGIC ASSESSMENT

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WATER for IDAHO

Idaho Water Resources Research Institute
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Moscow, Idaho 83843

January, 1990

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ABSTRACT

Monitored and simulated economic-ecological impacts from nonpoint source pollution were studied in the Tom Beall Creek watershed along Lapwai Creek in northern Idaho. Alternative farm practices including riparian vegetation management were evaluated as to their effectiveness in reducing cropland erosion and water pollution. A Geographic Information System (GIS) was used for the spatial analysis of Tom Beall Creek.

Water quality analysis for nutrients (nitrogen species and phosphorus) and suspended sediments revealed generally higher concentrations in Tom Beall Creek, a highly developed agricultural watershed than the West Fork of Sweetwater Creek which was minimally used for agricultural purposes. Highest concentrations occurred during spring runoff and were closely correlated with suspended sediment concentrations, especially phosphorus.

Riffle habitats in the West Fork Sweetwater Creek were composed primarily of unimpacted cobble-sized particles (12.7-20.54 cm) while similar habitats in Tom Beall Creek were heavily silted; the dominant particles usually ranged < 6.35 cm in diameter.

The insect community in Tom Beall Creek exhibited signs of eutrophication and heavy sedimentation by having relatively large densities and reduced species richness when compared to the insect community in the West Fork Sweetwater Creek. Midges (Chironomidae) and elmid beetles (Elmidae) were the dominant insects in Tom Beall Creek, while mayflies and stoneflies were abundant and diverse in the West Fork Sweetwater Creek.

Using simulation techniques, this study indicated that good riparian management is more efficient in reducing cropland erosion and water pollution than conservation compliance. If the yield penalties with conservation tillage are permanent and the current resource management system is conventional tillage, contour farming and wheat-pea rotation, then conservation compliance and good riparian management would reduce net farm income in the short term. The income reduction, however, would be more evenly spread among farmers with conservation compliance than with good riparian management.

INTRODUCTION

Nonpoint source pollution (NPS) is one of the most ubiquitous water quality problems facing the United States today. Since the passage of the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), national policy has fostered increased focus on nonpoint source pollution. NPS pollution can originate from multiple sources, express itself in numerous forms, and create multifaceted problems (Myers et al., 1985 and Vigon, 1985). Duda (1985) indicated that despite the billions of dollars invested in the control of point source discharges, nonpoint pollution problems are preventing the nation from achieving the goals of the Clean Water Act of 1977.

Agriculture is responsible for more NPS pollution that any other human activity in the nation (Myers et al. 1985). Onsite erosion resulting in offsite sedimentation represents the primary form of agricultural NPS (Vigon 1985). Both on and offsite consequences of erosion are economically detrimental. Additionally, at the national level, about 46% of the sediment, 47% of the total phosphorus, and 52% of the total nitrogen discharged into U.S. waterways comes from agricultural sources (Gianessi et al. 1986). Nitrogen and phosphorus in agricultural runoff result from extensive application of fertilizer. About 85% of Idaho's water quality problems have been attributed to NSP (Moore 1987).

Nonpoint source pollution from soil erosion impairs beneficial uses of water and increases the cost of municipal water treatment, maintenance of navigation channels, irrigation systems and reservoir storage capacity, and flood protection. It also degrades fish spawning and rearing habitat, reducing fish populations and the net economic value of commercial and recreational fisheries. Clark (1983) estimated sediment damage to America's fisheries alone (commercial, recreational, and others) at 500 million dollars annually. Damages from agricultural NSP have been estimated at between $2 and $6 billion, with a most likely estimate of $3 billion (Ribaudo 1986).

The ecological impacts of NPS pollution on freshwater ecosystems, especially lotic systems, is poorly understood. Heavy sedimentation in streams and rivers reduces faunal densities, species richness, and/or diversity by creating conditions favoring only a few select species (Wiederholm, 1984). Sediment deposition can drastically alter the structure of the benthic community, primarily through disrupting existing insect-substrate relationships (Brusven and Prather, 1974; Bjornn et al., 1977; and McClelland and Brusven, 1980). The impact of pesticides and nutrients on aquatic life is intuitively detrimental; however, empirical evidence of their precise impact is generally lacking in western agricultural watersheds. Brusven et al. 1986 and Brusven et al. 1987 conducted baseline monitoring studies in Lapwai Creek, Idaho, however.

The Palouse region of eastern Washington and northern Idaho is one of the most productive and highly erodible dryland wheat-producing regions of the United States. Due to steep topography and the occurrence of major storm events during periods of low residue cover, soil erosion on Palouse cropland often exceeds 11 million tons per year (USDA 1984). For this reason, the Soil Conservation Service (SCS) has targeted the Palouse region as a critical area for controlling erosion and NSP (USDA 1985, Duda 1985).

Several studies have estimated the physical and economic effects of management practices that reduce agricultural erosion and/or nonpoint source pollution. Cost effectiveness of alternative end-of-field treatments for reducing agricultural sediment and/or nutrient pollution of water has been evaluated in Idaho (Fitzsimmons et al. 1978, Lindeborg et al. 1975, Pope et al. 1983, Walker et al. 1986). These studies did not account for productivity losses due to erosion, however. Soil and/or nutrient losses with alternative conservation practices have been estimated with the Agricultural Nonpoint Source (AGNPS) pollution model (Crowder and Young 1985, Frevert and Crowder 1987, and Prato et al. 1989, Wu 1989). Land management practices were identified that minimized the cost of reducing sediment deposition in a small Illinois watershed (Braden and Johnson 1985). Conservation tillage was found to be the most cost effective tillage system for reducing: 1) soil erosion on most Iowa soils (Pope et al. 1983); 2) total soil erosion in Idaho's Tom Beall watershed (Shi 1987, Wu 1989); 3) and sediment/nutrient loadings to Illinois' Highland Silver Lake (Setia et al. 1988).

The offsite benefits of reducing cropland erosion have been documented in several studies. Strobehn (1986) concluded that the offsite benefits of USDA erosion control programs account for about two-thirds of the total program benefits; therefore, soil conservation programs should consider both offsite and onsite benefits.

Erosion control is the major policy objective of the Conservation Title of the Food Security Act (FSA) of 1985 (Leahy 1988). Indications that offsite damages of erosion exceed onsite damages

Strobehn et al. (1986) have stimulated interest in targeting FSA programs to control nonpoint source water pollution. Some targeting has already occurred. For example, in 1988, the Conservation Reserve Program (CRP) was modified to allow vegetative filter strips 20 to 30 meters wide adjacent to water bodies. Wolcott (1988) reported that the CRP is inefficient by showing that targeting CRP land on environmentally critical areas could provide significant water quality benefits at lower cost than the CRP. Taff and Runge (1988) argue that the CRP is inefficient because one policy instrument is being used to address several policy objectives. Due to increasing concern about the water quality impacts of agricultural production, bills have been introduced into Congress to include water quality criteria in the CRP. If the CRP is targeted on water quality, then the same treatment should be considered for the swampbuster and conservation compliance provisions of FSA (Reilly 1988). Assessment of the benefits and costs of alternative policies for reducing agricultural erosion and nonpoint source pollution has been hampered by inadequate information regarding the physical, biological and economic impacts of these policies at the watershed level.

In order to achieve a better understanding of nonpoint source pollution in a Palouse watershed and how to better manage it, the following objectives were undertaken: 1) to test and evaluate the Agricultural Nonpoint Source Pollution (AGNPS) model for the Tom Beall Creek Watershed; 2) to expand the existing Geographic Information System (GIS) for Tom Beall Creek Watershed to include information on riparian areas, water quality and the offsite impacts of water pollution; and 3) to test and refine an integrated resource assessment model for analyzing the effects of different best management practices on nonpoint source pollution in the Tom Beall Creek Watershed. Emphasis will be on including riparian areas and downstream impacts of erosion in the model, and to refine the biological and economic interpretation/evaluation of nonpoint source pollution based on the model.

STUDY AREA

Tom Beall Creek and a portion of the Sweetwater Creek watershed were investigated, both of which were located in the Lapwai Creek Drainage, located in Nez Perce County in northern Idaho (Fig. 1).

Most of our study involving on and offsite nonpoint source pollution investigations, was conducted in the Tom Beall watershed, a small tributary watershed draining into Lapwai Creek approximately 4 km from it's confluence with the Clearwater River. The Tom Beall watershed is approximately 4452 hectares in size and has an elevational range of 244 m to 671 m. Approximately 70% of the watershed is cropped, 30% is used for pasture or hayland.

All of the Tom Beall Creek watershed is located in the Nez Perce Indian Reservation. Presently, about one-third of the land in the watershed is Indian allotment land, the remaining two-thirds is privately owned. Most of the tribal-owned land is leased to approximately 16 farm operators.

The Tom Beall Watershed is a dryland farming area. The major crops are winter wheat, spring peas and spring barley. The typical crop rotations are winter wheat/spring peas and winter wheat/spring barley/peas. Other minor crops include Austrian winter peas, winter barley, spring peas and lentils. Southern slopes are extensively covered with Yellow Star Thistle, a noxious nonpalatable weed. The riparian area in this watershed is generally not well managed and is nonexistent along major reaches. Prior to 1989, the most common tillage method used in the Tom Beall Watershed was conventional tillage, which normally leaves minimum crop residues, thus leaving the soil in a highly erosive condition. Contour farming and cross slope farming are the most common land treatment practices.

The soils of the Tom Beall Watershed consist primarily of Naff-Palouse series (43%); Thatuna (21%); Linville, Broadax and others (36%). All these soils are highly erodible. The Naff series consists of deep, well-drained soils that formed in layered loess. The Thatuna series consists of deep, moderately well-drained soils that formed in deep loess. The Broadax series consists of deep, well-drained soils formed in loess on hills. The surface layer texture of all these soils is silt loam.

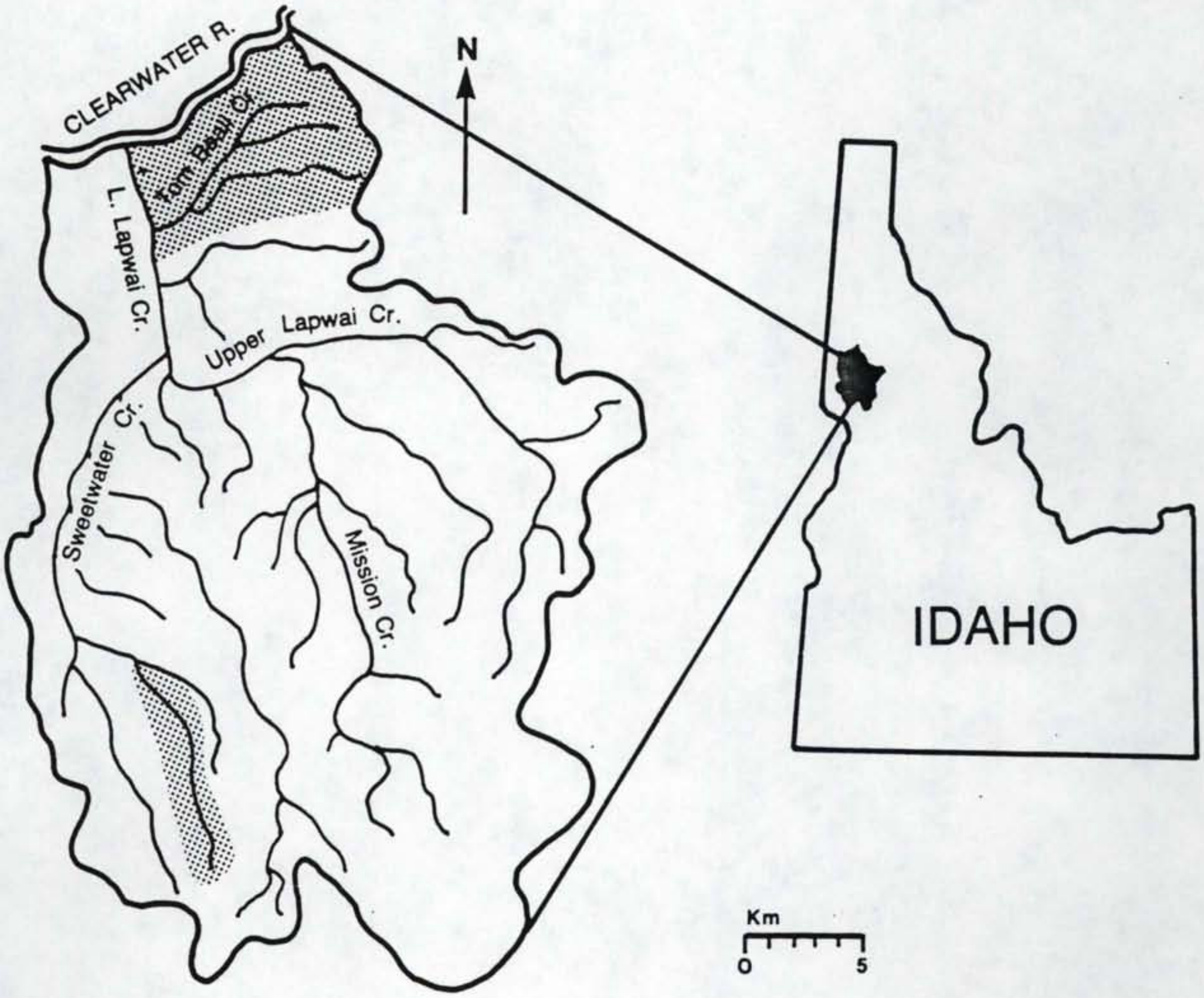

Figure 1. Tom Beall Creek and East Fork Sweetwater Creek study areas (shaded areas) in Lapwai Creek drainage.

The west branch of the East Fork of Sweetwater Creek (WSC), a third order stream, was used as a "check" stream to compare offsite water quality and biological responses from NPS pollution with Tom Beall Creek. Because all tributaries in Lapwai have had man-caused disturbances of one kind or another, the WSC cannot be construed as an "absolute" control. However, we contend that this portion of Sweetwater Creek has been least impacted by agricultural activities. The drainage area of this tributary is ca. 1,888 hectares. The drainage is primarily forested (ca. 70%), much of which has been selectively harvested over the last 20 years; approximately 20% is grazed or used as hay ground and 10% is cropped. The streambed in this reach is largely composed of rocks and rubble with clearly defined pools and riffles. Sediment impaction of the riffles is minimum.

MATERIALS AND METHODS

Geographic Information System-Spatial Mapping

Spatial watershed analyses were performed using the Professional Map Analysis Package (PMAP), a microcomputer based geographic information system (Spatial Information Systems, Inc., Omaha, NE). Hardware used included an IBM AT microcomputer and a Summagraphics MICROGRID II digitizer.

The Tom Beall Watershed encompasses areas on the Lapwai and Culdesac North (7.5 minute) USGS quadrangles. To determine the number and size of grid cells, the two quads were taped together and the corner coordinates of the study area were established. Since the current version of PMAP allows a maximum of 100 rows and columns, the longest axis was measured in digitizer units and divided by 100.

Elevation contours were digitized (using a 12.195 m contour interval) from USGS quadrangle maps and stored on a fixed drive. Elevation data were entered into the PMAP system and stored separately by contour. To process the final elevation map, each contoured elevation was added together to produce an elevation sum map (per cell summation of elevation values). This sum map was divided by a divisor map (contour frequency/cell) to determine the average elevation for each cell.

Tom Beall Creek and it's tributaries were digitized and entered into the PMAP system from the 7.5 minute quadrangle maps. The creek map was used as a pathway for soil erosion and to identify erosion zones as distance from creeks.

A map depicting the area of the Tom Beall Watershed was created by using the creek map as a target, and "spreading" the target uphill only over the elevation map. This process established a map containing only those areas uphill from the stream, thus eliminating areas outside the watershed.

The type and location of soils within the watershed were digitized from 1:2400 scale aerial photographs prepared by the Nez Perce Soil Conservation Service (SCS). To eliminate confusion over boundaries, soil types were digitized cell by cell, assigning cell values based on the dominant soil type. Composite soil data was then "TRACED" into PMAP.

The universal soil loss equation (USLE) was used to determine annual topsoil loss in tons per acre per year. Due to the integer storage technique of PMAP, the USLE was performed using compiled map values and an external program written in basic. Computed soil loss values were then re-entered into the Geographic Information Systems for spatial display and additional analysis. Soil loss values ranged from < 1 ton to 84 tons per year.

Using 1:24000 scale aerial photographs of the Tom Beall drainage, field areas were digitized using a cell by cell method (as employed for the soil map). Each field was identified with a unique value. Once fields were determined and entered into pMAP, current land use was identified using information supplied by the Nez Perce Office of the Agricultural Stabilization and Conservation Service (ASCS). The field map was then re-coded according to land use for the land use map.

Measured Offsite NPS Pollution Impacts

Water Quality. Water quality samples were taken seven times between August, 1986, to May, 1987, for nine water quality parameters: Kjeldahl Nitrogen, Nitrate-Nitrite, Ammonia, Total Phosphorus, Orthophosphate, Suspended Solids, Sulfate, Conductivity and Total Alkalinity. Most of these parameters are related directly or indirectly with agricultural pollution. Greatest sampling intensity was during March and April, 1987, because it was the primary runoff period and the time when fertilizers were being applied.

With the exception of suspended solids, water quality variables were analyzed by the Analytical Services Laboratory, University of Idaho, using standard analytical methods. Suspended solid concentrations were determined by taking three replicate 250 ml samples from the water column. In the laboratory, each replicate sample was filtered through a 0.45 micron glass filter, then dried and weighed to produce a gravimetric yielded mean for suspended solids (mg/L).

Benthic Insects and Habitat Analysis. Benthic insect samples were taken from Sweetwater Creek (WSC) and Lower Tom Beall (TBL) Creek with regular (0.093 m^2) and mini-Hess (0.025 m^2) bottom samples, respectively. The larger Hess sample was used in Sweetwater Creek because of larger substrate particles and generally larger stream size. Six samples were randomly taken from a riffle in WSC and four from TBL. All samples were adjusted to an equivalent area of 0.025 m^2 for standardization when making between-stream comparisons. Samples were taken monthly from April through August. Between site functional group, density and species richness comparisons were made using sample means.

The substrate confined within the perimeter of the Hess sampler was analyzed using an eight and five rank substrate classification scheme of Brusven and Meehan (1979) for two variables: dominant particle size and cobble embeddedness. The smaller the number, the smaller the particle size of the substrate and the greater degree of cobble embeddedness. The greater preponderance of sand and high levels of embeddedness are reflective of offsite, NPS pollution from sediments.

Simulation Analysis - Model Assessment

Separate simulation evaluations were made of the erosion vs. water pollution control and conservation compliance strategies. Both evaluations are based on the same physical and economic models, but use different resource management systems (RMSs), simulation periods and net returns. The erosion vs. water pollution control evaluation is based on the RMSs analyzed by Shi (1987). The conservation compliance evaluation is based on the RMSs specified by the Idaho Soil Conservation Service (SCS) and analyzed by Wu (1989). Data management, erosion, water quality and economic models, and the RMSs used in each evaluation are now discussed.

A computer-based Geographic Information System (GIS) was used to assemble and analyze the information on soil type, topography, water courses, cropping pattern, watershed and field boundaries, conservation practices and the movement of sediment and nutrients through the watershed (Shi 1987). The GIS was also used to estimate erosion rates and to organize the input data for the water quality model.

Erosion and Water Quality Models. Soil erosion rates are calculated for each field using the Universal Soil Loss Equation or USLE (Wischmeier and Smith 1978). The K (soil erodibility) and LS (length times slope) factors in the USLE come from soil and topographic maps. The R (rainfall) factor was obtained from meteorological sources (NOAA 1981). The C (cover) and P (practice) factors for each RMS come from the Idaho SCS. Estimates of ephemeral gully erosion are added to sheet and rill erosion rates to obtain total erosion rates for each field.

Simulated changes in water quality at the outlet of the watershed are evaluated using the AGNPS model (Young et al. 1987). This model simulates erosion, runoff, eroded and delivered sediment, nitrogen, phosphorus and chemical oxygen demand (COD) in runoff for individual storm events and land use practices. Chemical oxygen demand is the amount of oxygen required to oxidize organic and inorganic compounds in water (Setia and Magelby 1988). The AGNPS model was selected because it simulates water quality effects of alternative watershed management practices, it does not need to be calibrated to the watershed, and it is relatively easy to use.

Economic Model. Annualized net returns per hectare (ANRH) were estimated for each RMS using the Erosion Planning (EROPLAN) model with a 20 year evaluation period and a 4% real discount rate (Dept. of Agr. Econ. 1987). This discounted cash flow model estimates annualized net returns for each RMS by subtracting variable and fixed costs of production and onsite erosion damages from gross returns. Onsite damages are calculated based on an inverse linear relationship between crop yield and topsoil depth. The ANRH do not represent private net returns because farmers typically ignore onsite erosion damages and they do not represent social net benefits because offsite erosion damages are not considered. Site-specific information on offsite erosion damages is not available for Tom Beall watershed.

Fixed costs include machinery, fuel, lubrication and repair costs, but exclude the cost of land, owner-operator labor and management. Unit costs are estimated for an average size farm in the watershed (405 hectares) using the microcomputer budget management system (McGrann 1986). The cost of a given RMS is assumed to be the same for all fields in the watershed.

The ANRH are calculated both with and without cost sharing. Cost sharing rates in northern Idaho are $35 per hectare for minimum and reduced tillage and $49 per hectare for conservation tillage with residue management and no tillage for a maximum of two years. One-time cost sharing payments are $20 per hectare for contour farming, $21 per hectare for divided slope farming and $82 per hectare for permanent vegetation.

To qualify for wheat deficiency payments, (target price minus loan or market price, whichever is higher, times base production) farmers must set aside a portion of their wheat base acreage. Since the percentage set aside varies from year to year and it is not possible to determine the location of set-aside acreage for each year of the simulation, the location and amount of set-aside acreage are fixed at the levels observed in the first year of the simulation.

The evaluation of erosion vs. water pollution control compares two erosion control strategies and one water pollution control strategy. Erosion control strategies consist of RMSs that maximize annualized net return and achieve an erosion rate less than or equal to either 1T (T=11.2 MHY) or 1.5T on all fields in the watershed. The 1T limit is preferred by the Idaho SCS, however, the 1.5T limit is allowed whenever the 1T limit imposes an economic hardship on farmers. Erosion control strategies are evaluated for good and poor vegetative cover on non-cropland areas such as the creek, trees and shrubs, and non-cropped riparian areas adjacent to the creek. Overall, Tom Beall watershed currently has poor vegetative cover on riparian areas. Good vegetative cover can be established by planting grass, trees or shrubs. Conventional tillage with contour farming is the baseline RMS for this evaluation.

For the simulated water pollution control strategy, permanent vegetation is used on all fields adjacent to the creek (riparian zones), and/or filter strips, good vegetative cover on non-cropland areas and the most profitable RMSs on all remaining fields. Placing fields adjacent to the creek in permanent vegetation restricts the movement of sediment and nutrients to the creek. The water pollution control strategy is considered a riparian strategy because it entails good management of riparian areas. Table 1 summarizes the treatment of cropland and non-cropland areas for the three management strategies.

Eleven RMSs are evaluated: CTUD = conventional tillage with up-and-down hill cultivation; CTCS = conventional tillage with cross slope farming; CTCF = conventional tillage with contour farming; CTDS = conventional tillage with divided slope farming; MTCS = minimum tillage with cross slope farming; MTCF = minimum tillage with contour farming; MTDS = minimum tillage with divided slope farming; NTCS = no till with cross slope farming; NTCF = no till with contour farming; NTDS = no till with divided slope farming; and PV = permanent vegetation. All RMSs use the same fertilizer application rates, namely, 56 kg nitrogen/hectare and 22 kg phosphorus/hectare, and a fixed wheat-pea rotation. The AGNPS model allows only three fertilizer application rates (low, medium and high). Medium rates were used. CTCF is the baseline system for the erosion vs. water pollution control evaluation.

Wheat yields are reduced by 3% for minimum-tilled wheat and by 15% for no-tilled wheat relative to conventional tillage throughout the (1987-2007) evaluation period (Shi 1987). The inflation-adjusted target price for wheat and the market price for peas are used to calculate ANRH, namely, 16 cents/kg for wheat and 18 cents/kg for peas in 1987. Real prices and costs are assumed to remain constant in inflation-adjusted terms at their 1987 levels. All land in PV is assumed to have an ANRH of $148/hectare which equals the 1988 CRP rental rate in northern Idaho.

Evaluation of Conservation Compliance. Optimal RMSs for achieving conservation compliance were determined by maximizing ANRH subject to the constraint that field-level erosion rates are less than or equal to 1T or 1.5T on all fields in the watershed. This is the same criterion used to determine the optimal RMSs for the erosion control strategies in the erosion vs. water pollution control evaluation. Yield penalties are 5% for reduced tillage (RT) and 15% for conservation tillage with residue management (CTRM) in the first year of the simulation (1988), and decrease at a linear rate until 1990. From 1991-2008, yields with RT and CTRM equal the yields with conventional tillage.

Since some of the cropland in the watershed is being converted from conventional tillage with contour farming (CTCF) to reduced tillage with contour farming (RTCF), both systems were used as baselines. A wheat-pea or wheat-barley-pea rotation is used in both baseline systems. The proportion of acreage in each rotation is based on current land use. Six alternative tillage-land treatment combinations are evaluated: CTUD = conventional tillage with up-and-down hill cultivation; CTCS = conventional tillage with cross slope farming; CTDS = conventional tillage with divided slope farming; RTCS = reduced tillage with cross slope farming; CRMCS = conservation tillage with crop residue management and cross slope farming; and CRMDS = conservation tillage with crop residue management and divided slope farming.

Nine crop rotations are evaluated: WB = winter wheat-spring barley; WP = winter wheat-spring peas; WBP = winter wheat-spring barley-spring peas; WBF = winter wheat-spring peas-fallow; WPWF = winter wheat-spring peas-winter wheat-fallow; WPWFR = WPWF followed by rape; WBWFR = winter wheat-spring barley-winter wheat-fallow-rape; WPWPS = WPWP followed by four years of grass seed; and WBWBS = WBWB followed by four years of grass seed. These RMSs were identified by SCS as the most practical RMSs for achieving conservation compliance in Tom Beall watershed. Fertilizer application rates for these RMSs are the same as those used in the erosion vs. water pollution control evaluation. Set-aside acreage and pasture were assumed to remain fixed in amount and location throughout the evaluation period (1988-2008).

Target prices are used for wheat and barley, namely: \$0.15/kg and \$0.11/kg in 1988; \$0.14/kg in 1989; and \$0.13/kg and \$0.09/kg in 1990, respectively. For the remainder of the evaluation period, wheat and barley prices are held constant at the 1990 inflation-adjusted target levels. Prices for spring peas, rape and grass seed are held constant, in inflation adjusted terms, at their 1988 market levels: \$0.19/kg for peas; \$0.24/kg for rape; and \$2/kg for grass seed, respectively.

RESULTS AND DISCUSSION

Geographic Information System Application

During the conducting of this study we attempted to identify, record and relate potential and realized NPS pollution parameters to nonpoint pollution source areas by assimilating data from specific maps, performing data analysis and creating new maps through spatial analysis integration. We view that the GIS contributes importantly to nonpoint source pollution studies concerned with on- and off-site economic-ecological, and sociological analysis of irrigated and dryland farming areas as well as other land used in Idaho and the Northwest.

A diagrammatic model protocol for nonpoint source pollution analysis employing GIS technique for Tom Beall Creek is given in Figure 2. Topography, soil type and land use are the primary on-site state variables. Figures 3 and 4 illustrate in a three-dimensional perspective, the topography, and erosion potential under existing practices for the Tom Beall watershed (Shi 1987).

Offsite NPS Pollution Analysis - Water Quality, Benthic Insects and Associated Habitats

Water Quality. In general, TBL contained higher concentrations of nutrients than WSC for the majority of dates sampled (Figs. 5, 6). According to Fail, et al. (1987) nitrogen species, particularly nitrate and ammonia, often reflect differences in land use between forested and agricultural watersheds. This was substantiated by generally higher concentrations of nitrate, ammonia and total Kjeldahl nitrogen for TBL creek, an agricultural watershed, and lower concentrations for WSC, a largely forested watershed. Unlike phosphorus, nitrogen compounds tend to leach more readily and are transported in ground water.

Total phosphorus and orthophosphate concentrations exhibited trends similar to that of the nitrogen species, being overall higher in Tom Beall Creek (Fig. 6). As phosphorus enters streams, predominantly with eroded soils and organic material (Dunne and Leopold, 1978), concentrations of these nutrients are closely associated with the concentration of suspended solids (Fig. 7). Due to differential attachment of nutrients to fine soil particles (Young et al. 1986), the exact nature of this phenomenon is complex and often masked.

Conductivity and total alkalinity represent dissolved ion concentration in water and a measure of the buffering capacity of the streams, respectively. Tom Beall Creek is a spring fed system, which

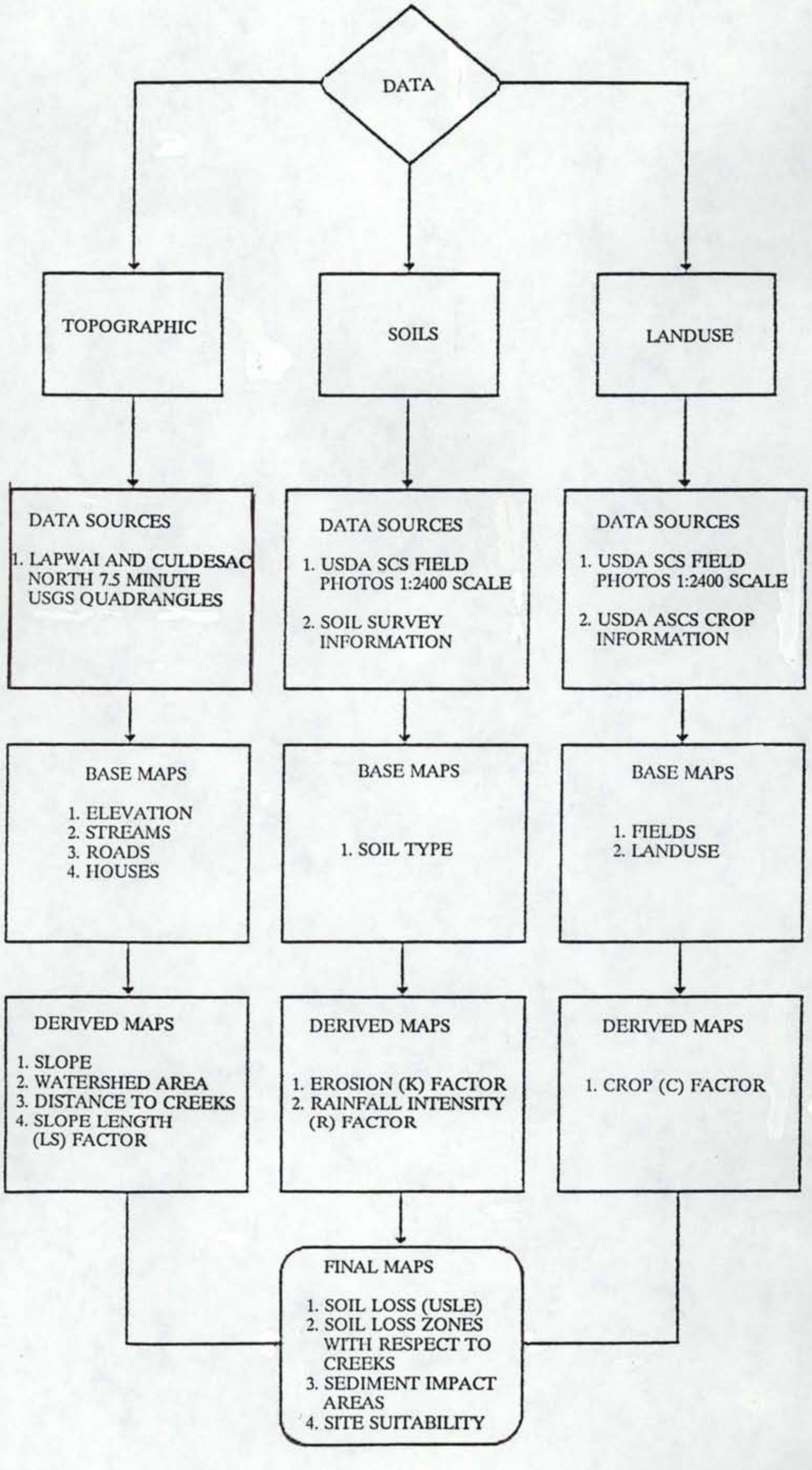

Figure 2. Diagrammatic model of GIS nonpoint pollution analysis in the Tom Beall watershed.

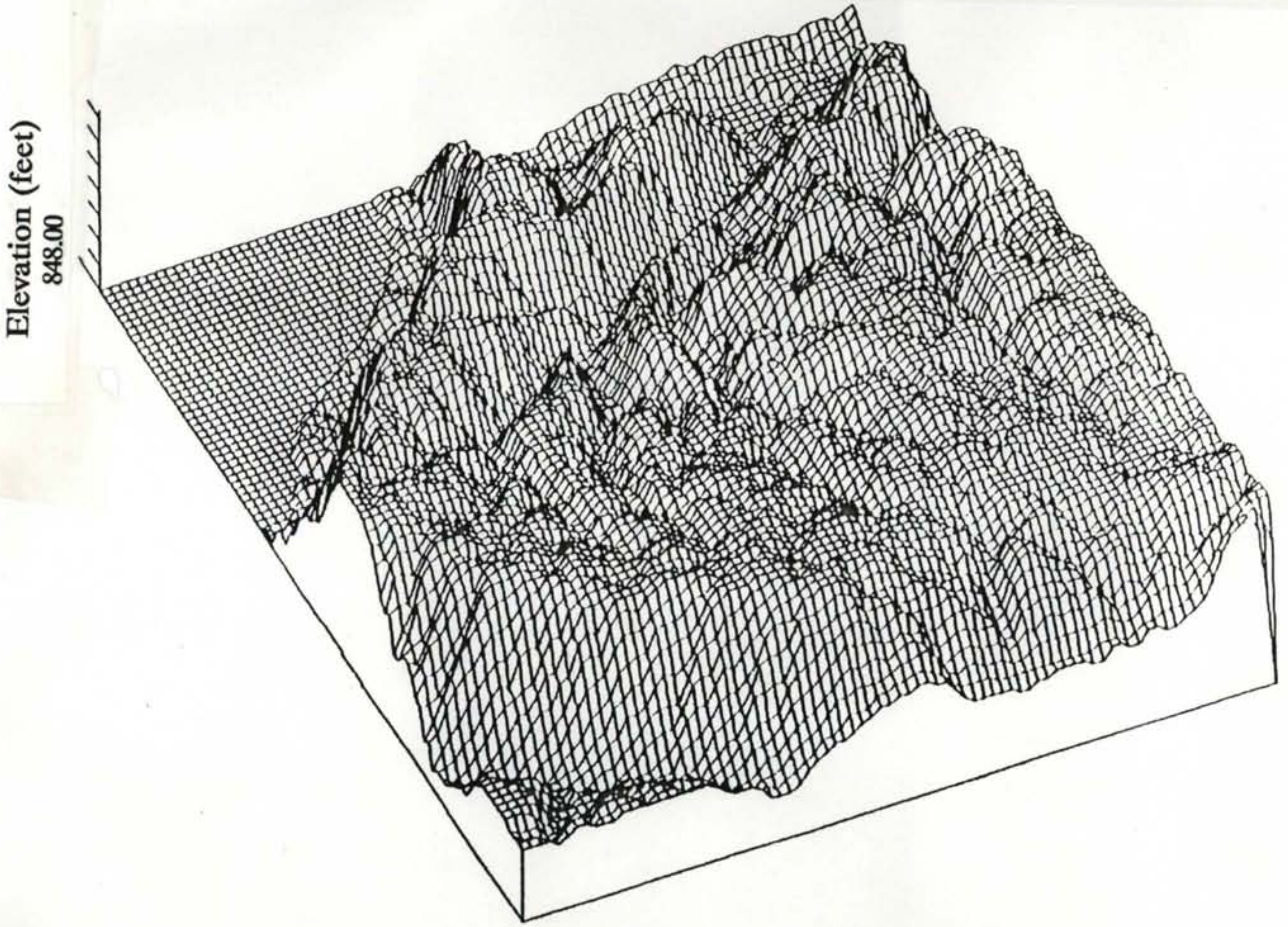

Figure 3. Topography in the Tom Beall watershed (45 degree viewing angle).

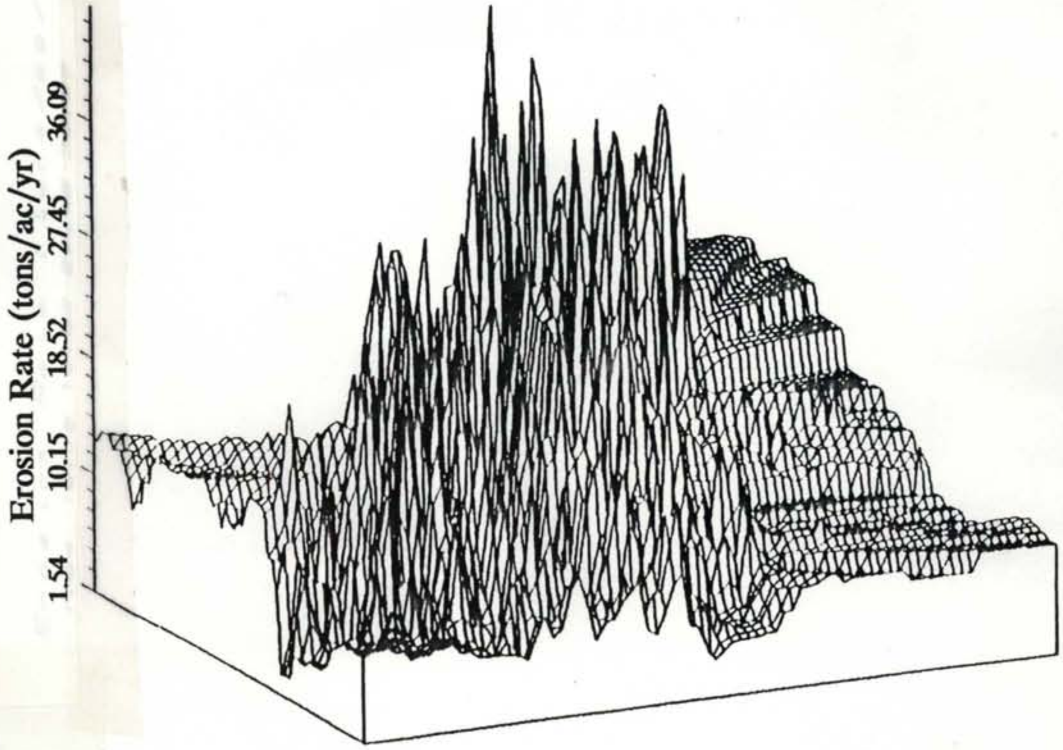

Figure 4. Erosion potential for current practices in the Tom Beall watershed.

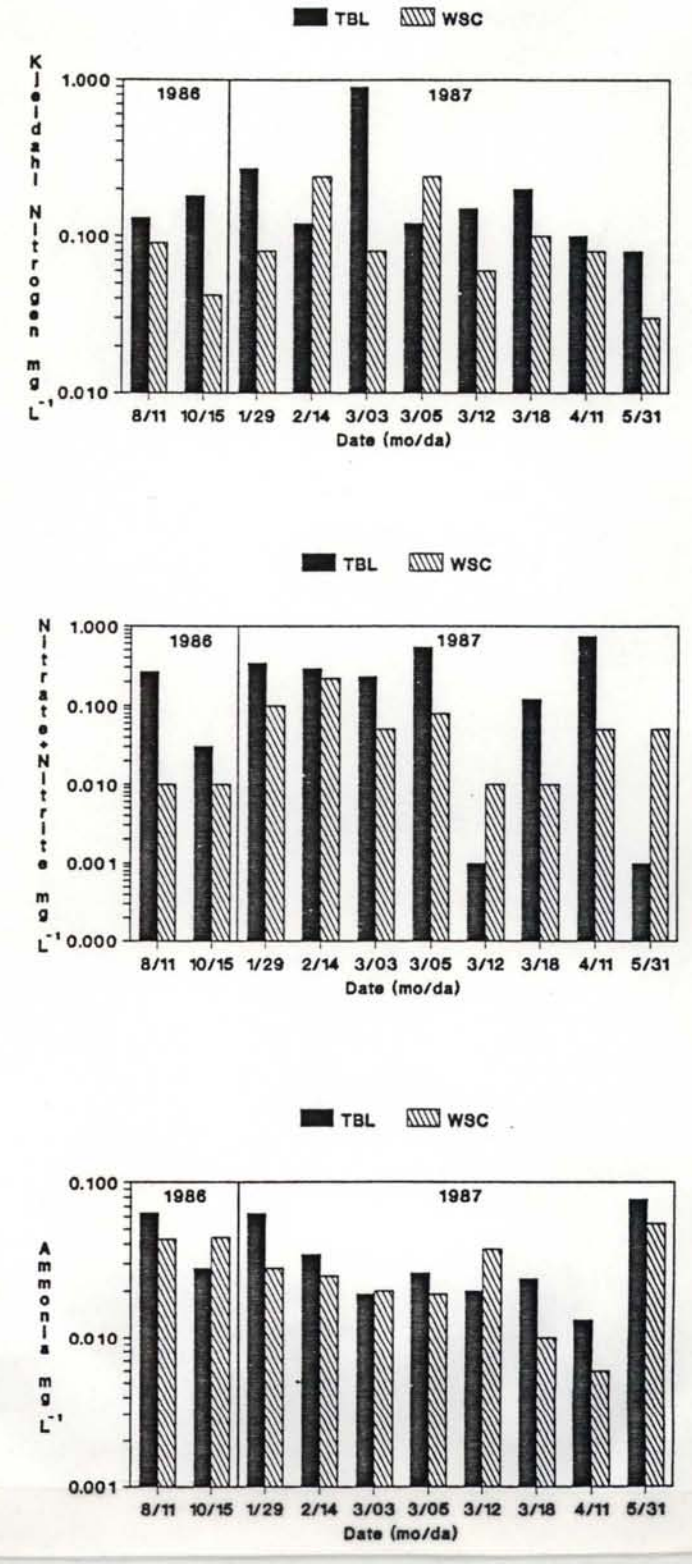

Figure 5. Concentration (mg/L) of Keldahl nitrogen, nitrate-nitrite, and ammonia at TBL (Tom Beall) and WSC (West Fork Sweetwater Creek) site.

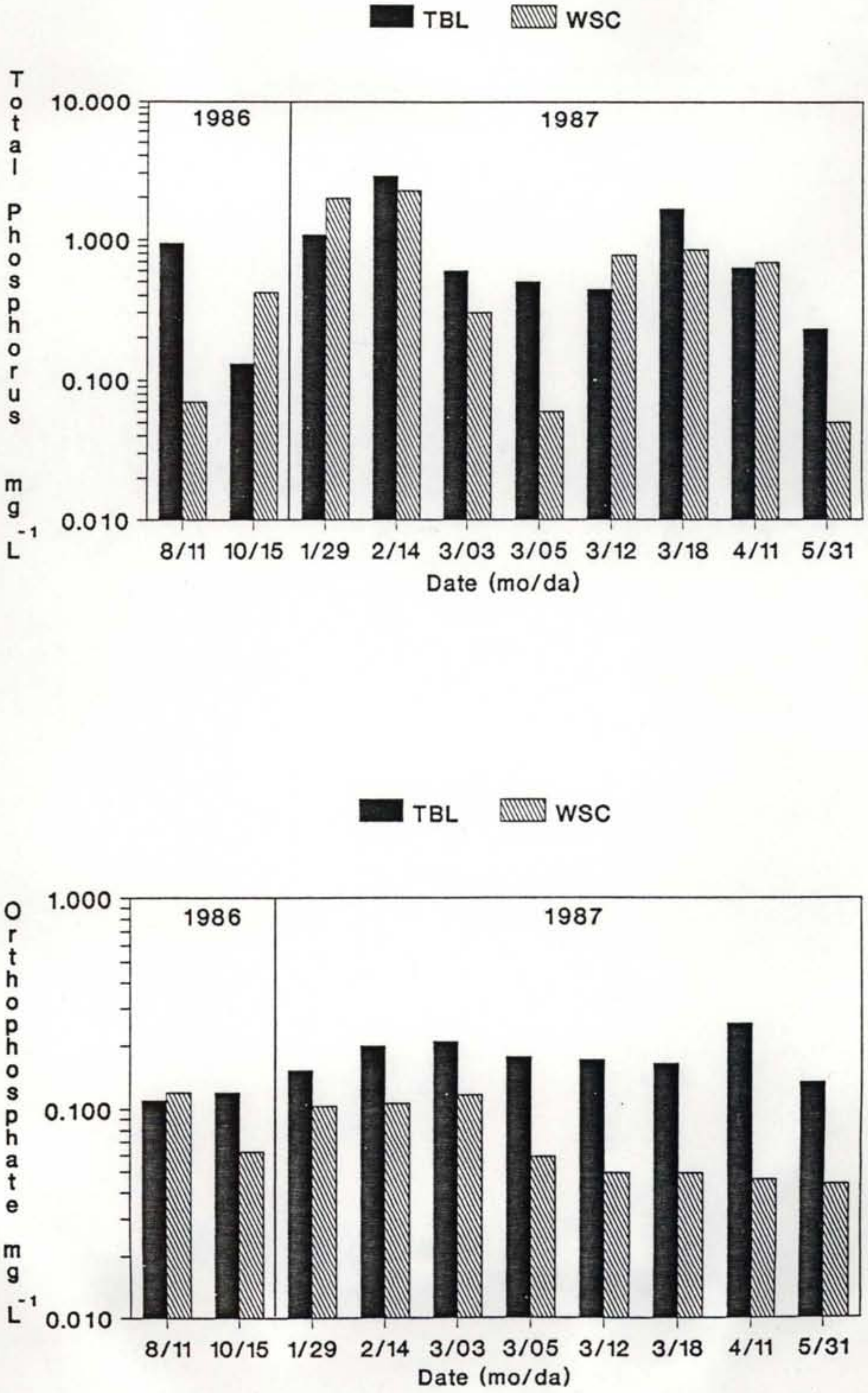

Figure 6. Phosphorus species concentration (mg/L) at the TBL and WSC sites.

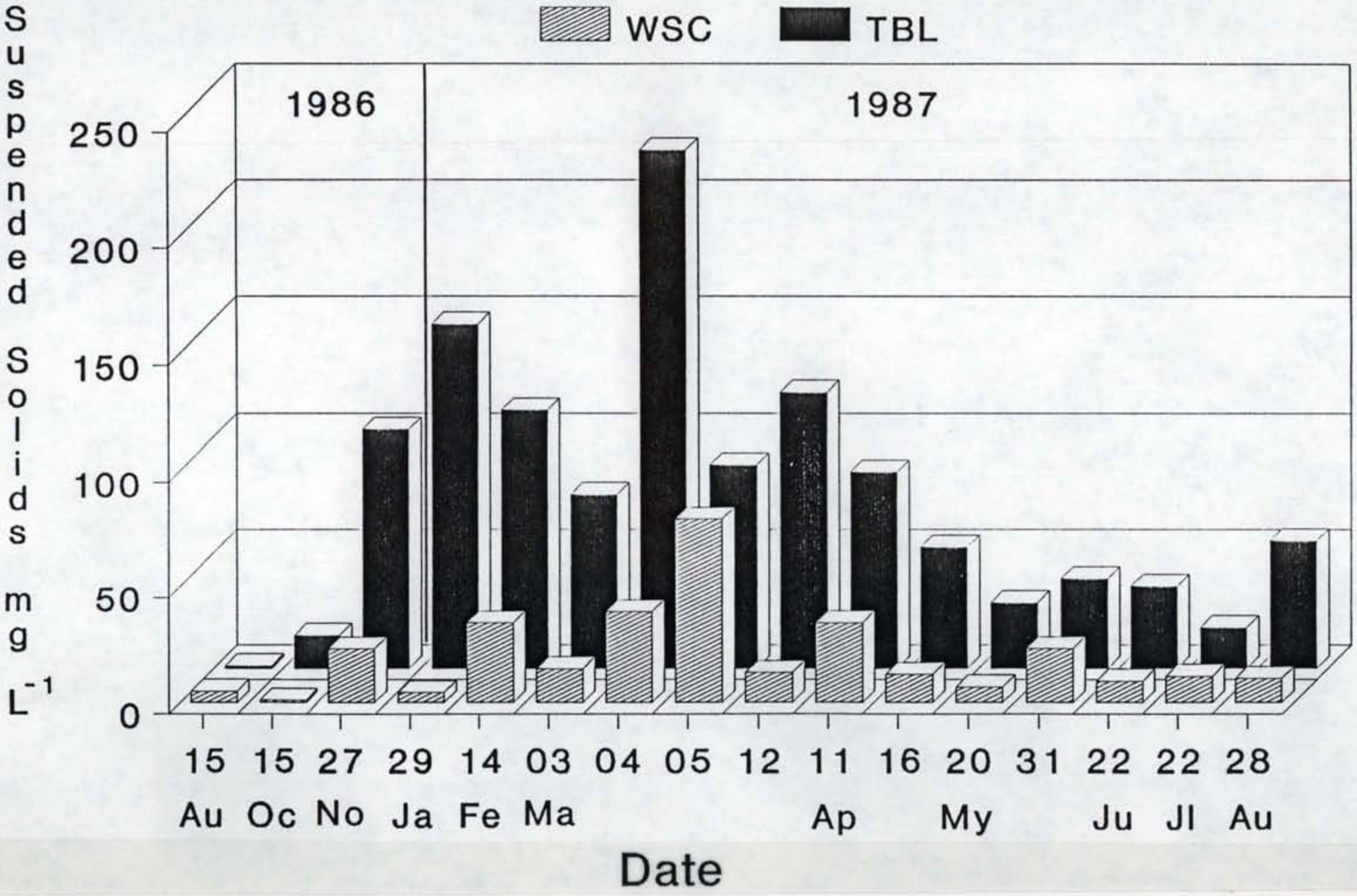

Figure 7. Suspended sediment concentrations (mg/L) at the TBL and WSC sites.

in part may contribute to the higher conductivity and alkalinity values compared to WSC (Fig. 8). Sulfate ion concentrations, however, were similar for both watersheds (Fig. 8). In contrast, low alkalinity values reflect a reduction in the stream's buffering capacity. The relationship of how these parameters might relate to localized effects of acid rain, if even present, are not known due to the lack of precipitation chemistry information for the area.

In-Stream Habitat. In-stream habitat measurements taken concurrent with benthic insect samples measured the dominant particle size, embeddedness of cobbles, and substrate size surrounding cobbles between streams (Figs. 9-11). Dominant substrate size composition in WSC was 12.7-20.54 cm and 2.54-6.35 cm in TBL, indicating the substrate was dominated by cobbles and rubble in WSC, and appreciably smaller substrate particles in TBL.

Dominant substrate size differences reflect differences in parent geologic materials, hydraulic properties of the streams, basin morphology and land-use practices. The substrate in TBL was more impacted by sediments than in WSC as reflected in the five embeddedness classes (Fig. 10). Thirty-one and 34% of the sampled areas were 1/4 to 1/2 embedded in sediment in TBL, while 76% of the cobbles were unembedded in WSC indicating a high level of surface roughness and favorable habitat for invertebrate colonization. The embedding particles surrounding cobbles were also of larger diameter in WSC than TBL (Fig. 11), providing further physical evidence of potential interstitial inhabitation of benthic insects that are weak or poor burrowers. Heavy impaction by silt and sand of pristine riverine substrates is indicative of nonpoint pollution from adjoining lands where farming, logging and grazing practices contribute sediment to the stream, hence reducing the overall habitat quality to support diverse aquatic benthic communities. Similar findings have been reported by several workers (Brusven and Prather 1974, Luedtke et al. 1976, Bjornn et al. 1977, and McClelland and Brusven 1980). Additionally, greater substrate roughness (by virtue of larger substrate size and reduced embeddedness values) at the WSC site allow for more efficient entrainment of coarse (CPOM) and fine (FPOM) particulate organic matter which serve as an important invertebrate food for many benthic invertebrates.

Benthic Insects. The benthic insect community in TBL exhibited classical signs of eutrophication by virtue of a specialized community composed of relatively high numbers and reduced species richness (Figs. 12-13) as compared to the WSC site. Greater temporal variation in ordinal densities

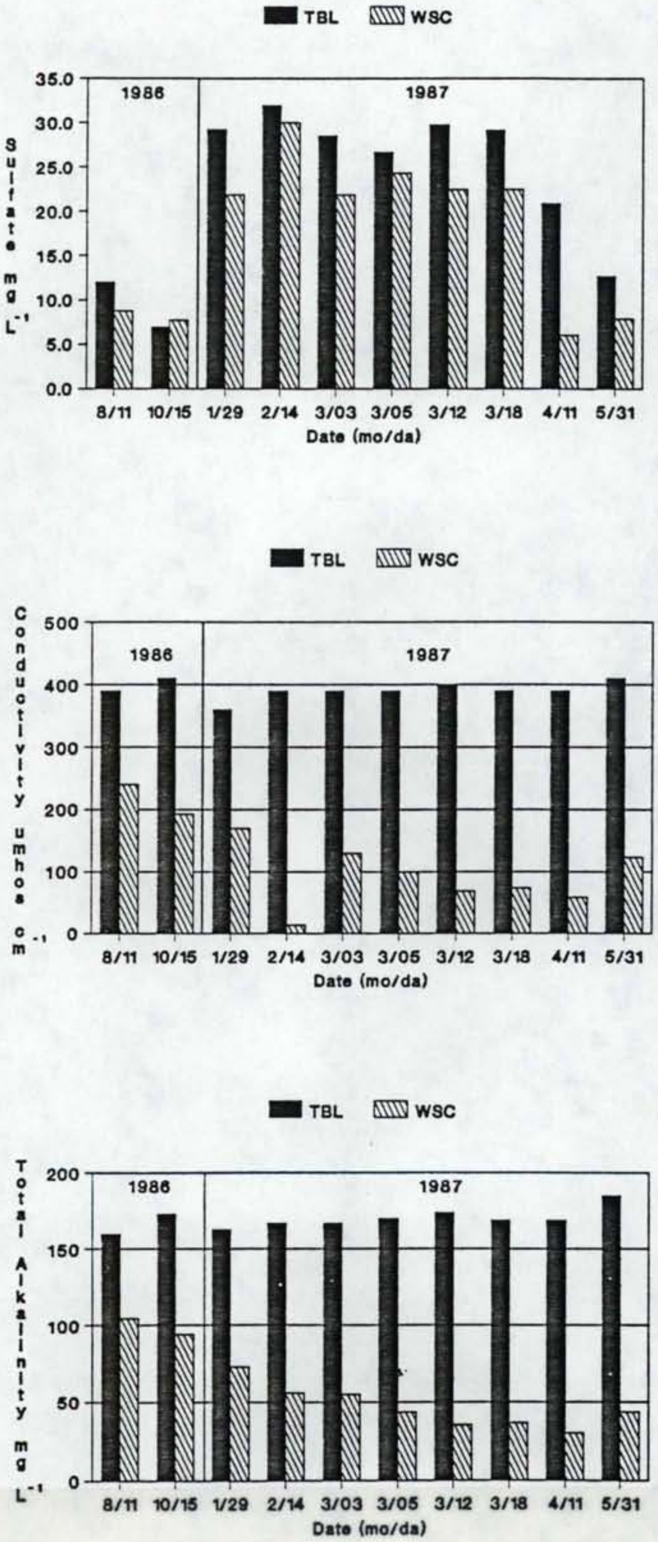

Figure 8. Sulphate ion concentration (mg/L), conductivity (umhos) and total alkalinity (mg/L) for TBL and WSC sites.

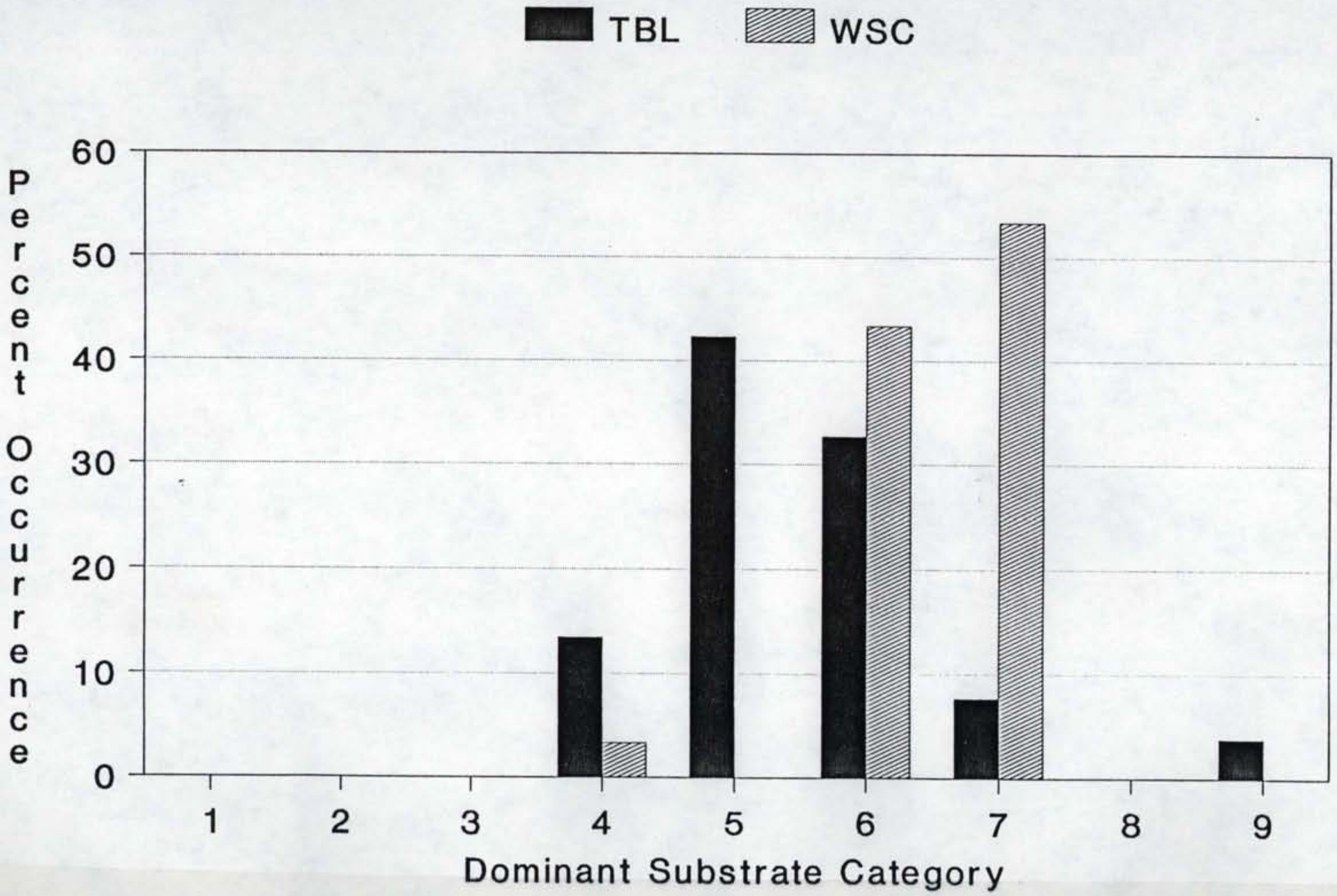

Figure 9. Dominant substrate size composition as percent occurrence of substrate categories for TBL and WSC sites.

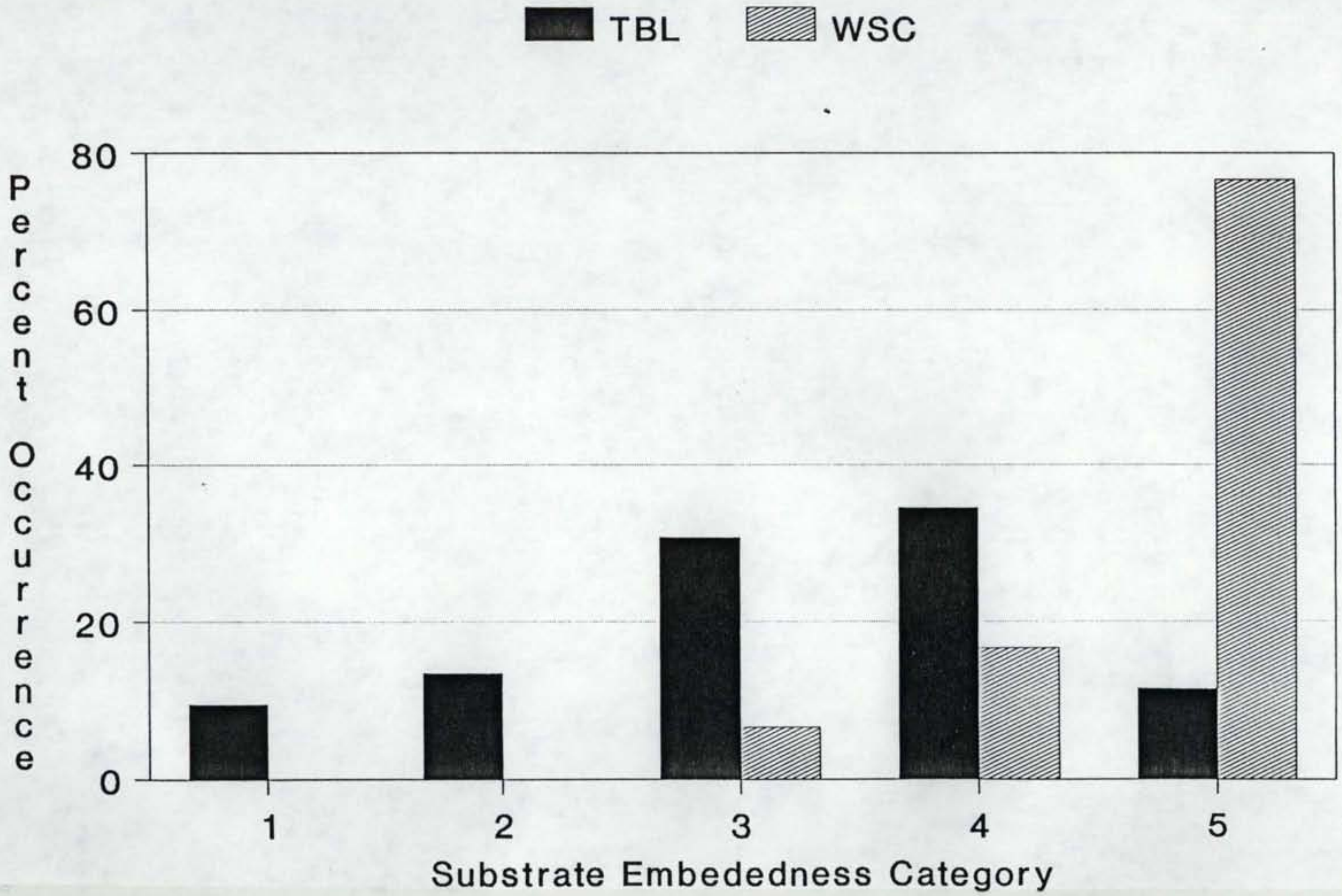

Figure 10. Percent occurrence of ranked cobble-embeddedness condition for substrates in TBL and WSC sample sites.

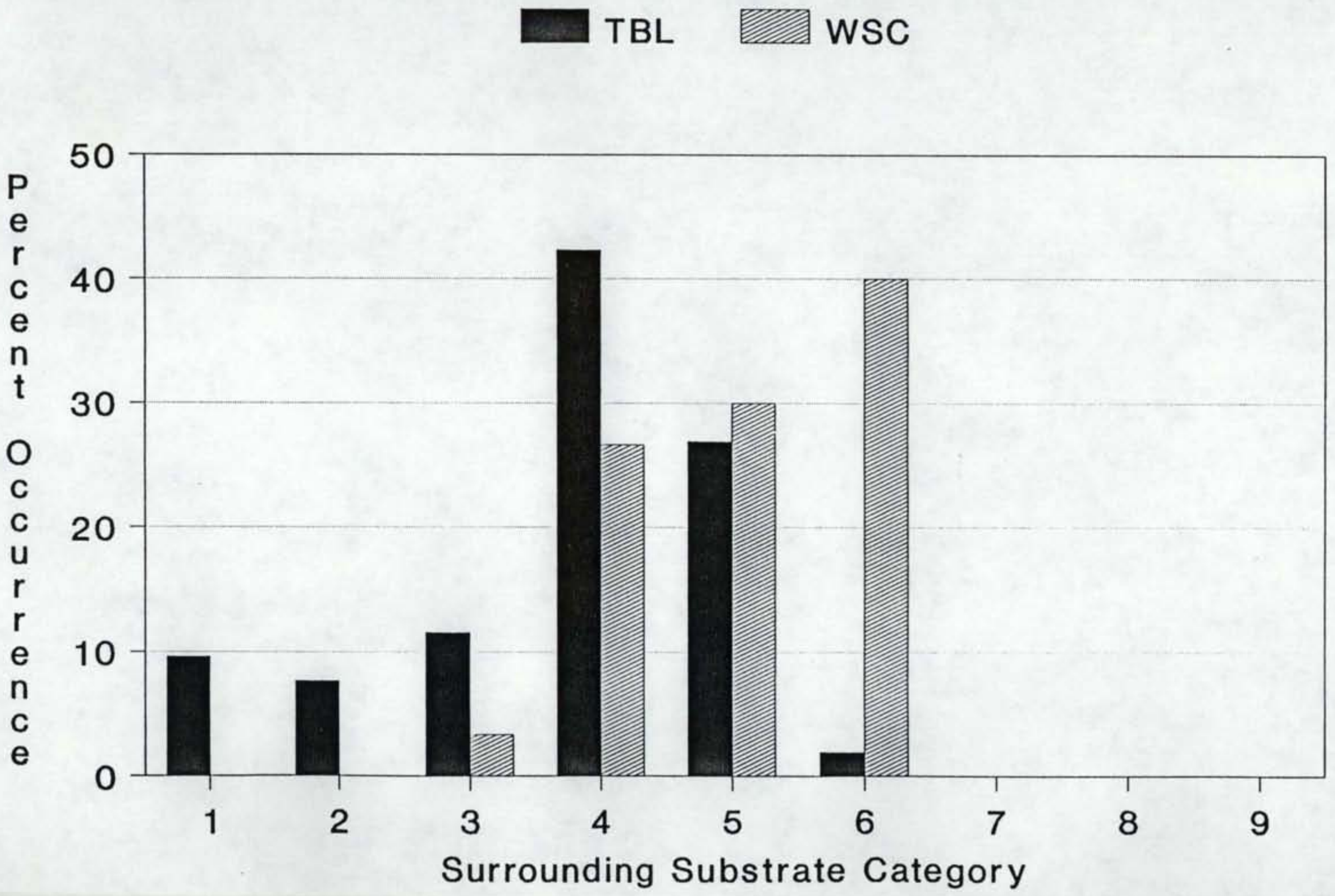

Figure 11. Percent occurrence of substrate particle-size classes surrounding cobble-sized rocks or larger in TBL and WSC sites.

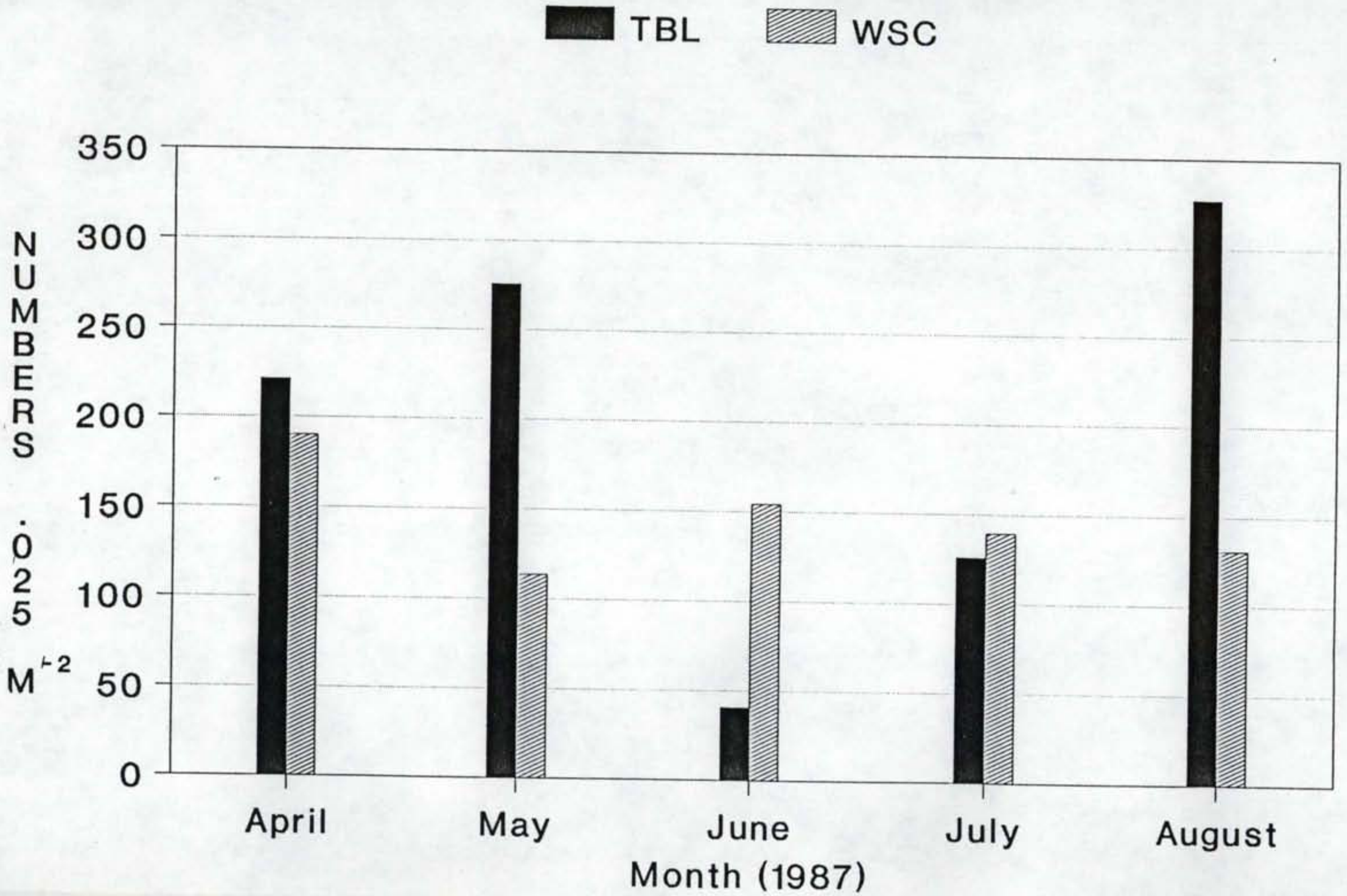

Figure 12. Mean invertebrate density at TBL and WSC sample sites.

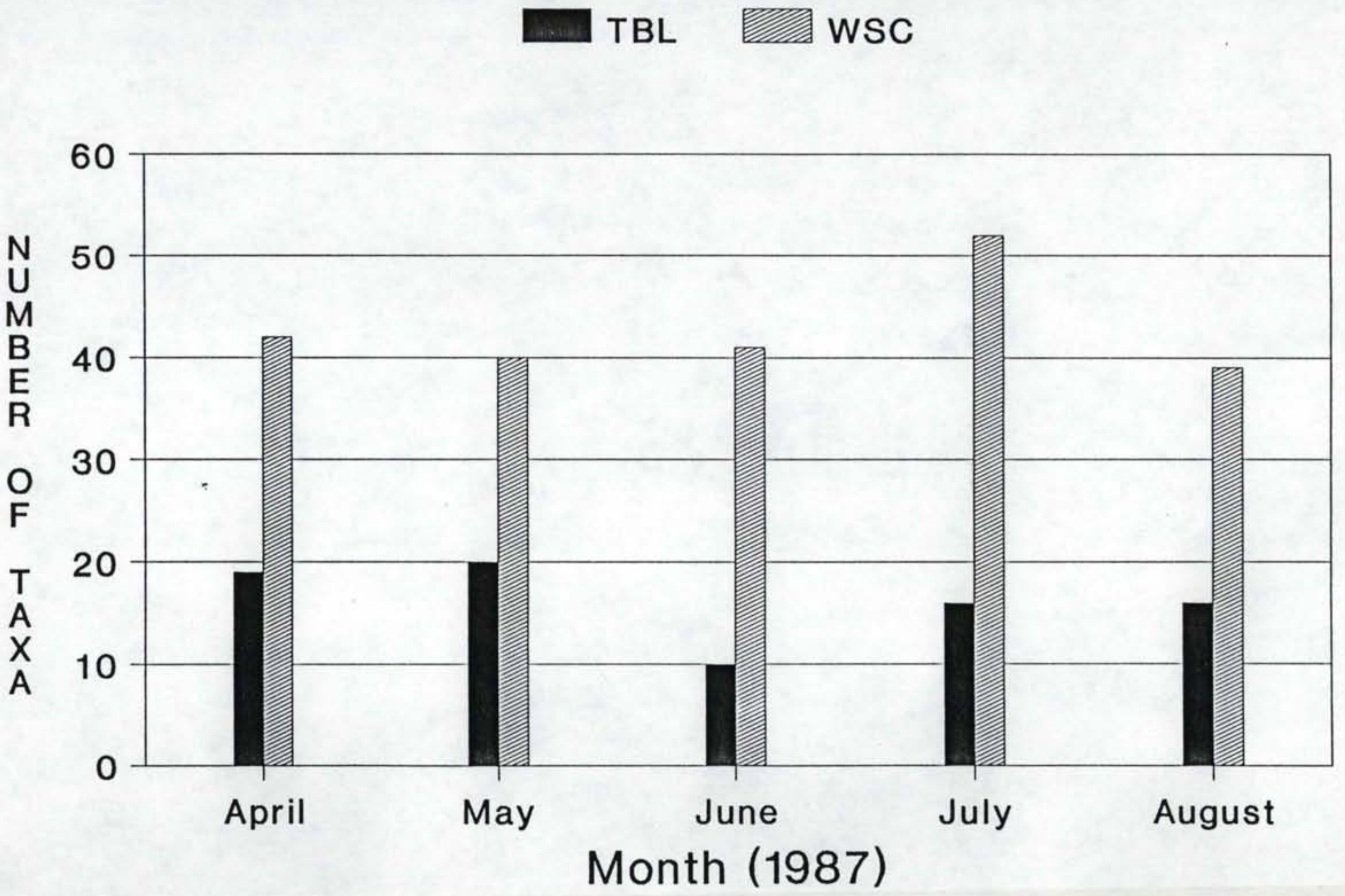

Figure 13. Invertebrate taxa richness at the TBL and WSC sample sites.

and community structure and function (Figs. 14-15) are also indicative of biological stress at the TBL site.

Given higher taxa richness at the WSC site along with more equitable and constant particulate organic matter (POM) resources, it is likely that allochthonous energy sources are processed more orderly and efficiently at the WSC than at the TBL site.

Valiela (1971) proposed that steady-state community levels achieved under stressful conditions would be at a much lower level of organization than communities in less stressful environments. This lower level of organization optimizes the ability of the stressed community to respond/rebuild following a severe perturbation (Odum, 1981). Following these perturbations, energy that would normally be available for maintenance and production is diverted to repair and recovery, hence, inhibit organizational development, and potentially cause the resetting of the community to an earlier developmental state. Thus, in general, with decreasing levels of pollution, functional complexity and overall species richness of the affected community would be expected to increase (Rabeni et al. 1985).

Nonpoint source pollution from agricultural perturbations may in part be reflected through energy resource-use inefficiency within a watershed, hence be described through functional analysis of the impacted communities as proposed by Odum, 1981. We propose, however, that because of the potentially diverse nature of nonpoint agricultural pollution ranging from bioenergetic disruptions to acute and chronic toxicity from pesticides, that evaluation of functional disorder should not be the only means for assessing NPS pollution from a biological perspective. Only with increasing knowledge of specific habits, habitat needs and other physical and biological requisites of aquatic life can more reliable assessments of NPS pollution impacts be possible.

Benthic community responses can also be used to illustrate the effectiveness of remedial actions undertaken to minimize watershed perturbations, thus allowing NPS pollution impacts to be assessed in a measure greater than by just water quality analysis alone.

Simulation--Economic-Water Quality Analysis of Management Alternatives

Erosion vs. Water Pollution Control. Treatment of cropland and noncropland areas and alternative management strategies for Tom Beall watershed are given in Table 1. Table 2 shows the

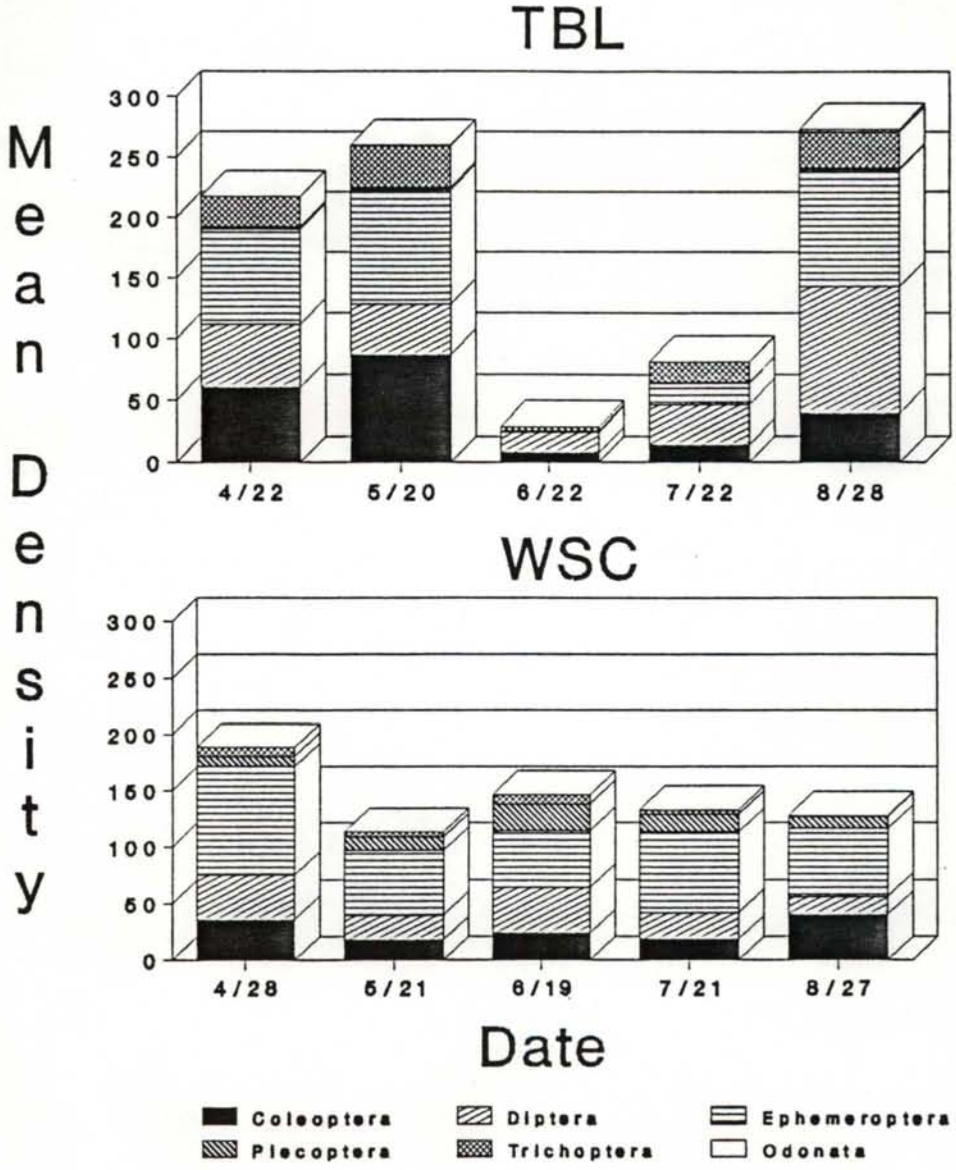

Figure 14. Mean insect ordinal density/0.025m^{-2} at the TBL and WSC sample sites, April-August, 1987.

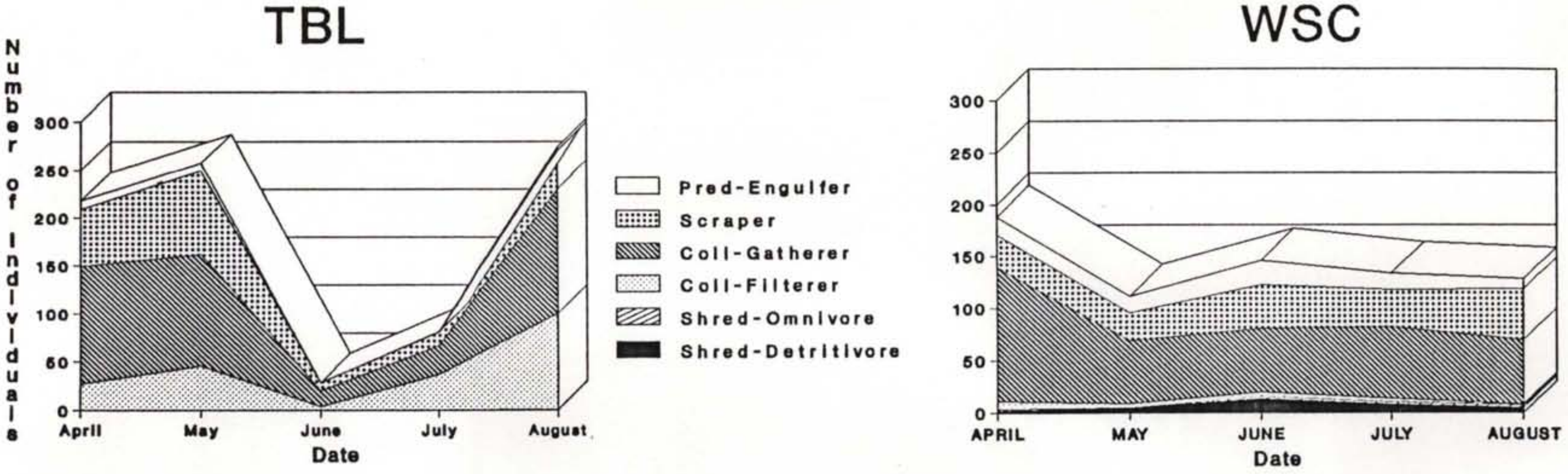

Figure 15. Mean benthic insect functional group density/$0.025m^{-2}$ at the TBL and WSC sample sites, April-August, 1987.

Table 1. Treatment of cropland and non-cropland with alternative management strategies, Tom Beall watershed.

Strategy	Cropland Riparian Fields[a]	 Non-riparian Fields[b]	Vegetative Cover, Non-cropland
1T & 1.5T	RMSs that satisfy erosion limit	RMSs that satisfy erosion limit	poor good
Riparian	Permanent vegetation	RMSs that maximize net returns per hectare	good

[a]Fields adjacent to creek.

[b]Fields not adjacent to creek.

Table 2. Cropland area in optimal resource management systems for alternative management strategies, Tom Beall watershed.

	Erosion Control Strategy					
	1T		1.5T		Riparian Strategy	
System	Area (hectares)	Area Percent	(hectares)	Area Percent	(hectares)	Percent
MTCF[a]	684	19.22	1,561	43.86	3,018	85.82
MTDS[b]	500	14.05	296	8.33	0	0
NTCF[c]	673	18.91	808	22.72	0	0
NTDS[d]	145	4.07	283	6.82	0	0
PV[e]	1,556	43.75	610	17.14	540	14.18
Total	3,558	100	3,558	100	3,558	100

[a] Minimum tillage with contour farming.

[b] Minimum tillage with divided slope farming.

[c] No tillage with contour farming.

[d] No tillage with divided slope farming.

[e] Permanent vegetation.

cropland area in the optimal RMSs for the erosion and water pollution control (riparian) strategies. Forty-four percent of the total area in the watershed is in PV for the 1T strategy, 17% for the 1.5T strategy and 14% for the riparian strategy. The cropland area not treated with PV in the riparian strategy is in MTCF because it has the highest ANRH. Between the 1T and 1.5T strategies, the proportion of acreage in MTCF, NTCF and NTDS increases and the proportion of acreage in MTDS and PV decreases. The watershed area in each RMS is the same with and without cost sharing because cost sharing does not change the optimal RMSs.

Total annual erosion and net farm income are determined for the three management strategies (Table 3). Net farm income for the baseline is calculated assuming conservation compliance is not achieved. Total annual erosion decreases 77% for the 1T strategy, 62% for the 1.5T strategy and 47% for the riparian strategy. Reducing erosion rates on all fields to less than or equal to 1T causes net farm income to decline by 19.8% without cost sharing and 17.6% with cost sharing relative to baseline income. When field erosion rates are limited to 1.5T, net farm income decreases 12.2% without cost sharing and 9.2% with cost sharing. Net farm income decreases 4.5% without cost sharing and 1.1% with cost sharing for the riparian strategy. Total annual erosion is 39 to 131% greater and net farm income is 9 to 20% higher with the riparian strategy than with the erosion control strategies. Although net farm income is higher with than without cost sharing, total erosion is the same because cost sharing does not alter the choice of RMSs.

The last column in Table 3 shows the erosion reduction efficiency for each management strategy. This efficiency measures the decrease in net farm income (without cost sharing) divided by the decrease in total erosion relative to the baseline. The riparian strategy is the most efficient strategy because it results in the lowest reduction in net farm income per kilogram of erosion reduction. However, the riparian strategy is less equitable than the erosion control strategies because net income would decrease for farms with fields adjacent to the creek and increase for farms with fields away from the creek. Since net farm income is lower with the riparian strategy than with the baseline practices, it is not possible to improve the total welfare of farmers by redistributing income.

The water quality effects of the three management strategies are evaluated by comparing the levels of total sediment, total nitrogen, total phosphorus and soluble chemical oxygen demand (COD) for four storm events: 10, 25, 50 and 100-years, each lasting 24 hours (Table 4). Sediment,

Table 3. Total annual soil erosion, net farm income and erosion reduction efficiency for alternative management strategies, Tom Beall watershed.

Strategy	Soil Erosion[a] (10^3 kg)	Net Farm Income: With Cost Sharing	Net Farm Income: Without Cost Sharing	Erosion Efficiency[b] (\$/kg)
		-------------($)-------------		
Baseline (CTCF[c])	134,014	795,092	789,974	--
1T	30,591	655,003	633,232	1.84
1.5T	50,884	722,138	693,706	1.40
Riparian	70,666	786,297	760,648	0.56

[a] Calculated with USLE.

[b] Decrease in net farm income (without cost sharing) divided by decrease in total erosion relative to baseline.

[c] Conventional tillage with contour farming.

Table 4. Water quality effects of alternative management strategies, Tom Beall watershed.

Pollutant	Storm Event	Vegetative Cover, Non-cropland	Baseline	Erosion Control Strategy		Riparian Strategy
				1T	1.5T	
Sediment (10^3 kg)	10	poor	14,072	2,247	3,153	--
		good	--	1,101	1,972	3,489
	25	poor	21,781	3,960	5,552	--
		good	--	1,990	3,526	6,164
	50	poor	26,297	5,024	7,052	--
		good	--	2,560	4,521	7,863
	100	poor	31,321	6,244	8,779	--
		good	--	2,630	5,682	9,832
Nitrogen[a] (kg)	10	poor	17,747	4,096	5,367	--
		good	--	2,307	3,672	5,790
	25	poor	25,138	6,449	8,427	--
		good	--	3,719	5,885	9,180
	50	poor	29,233	7,767	5,225	--
		good	--	4,519	7,156	11,157
	100	poor	33,658	9,274	12,145	--
		good	--	5,460	8,568	13,322
Phosphorus[a] (kg)	10	poor	8,850	2,024	2,638	--
		good	--	1,177	1,836	2,918
	25	poor	12,569	3,201	4,237	--
		good	--	1,836	2,918	4,566
	75	poor	14,640	3,907	5,084	--
		good	--	2,259	3,578	5,555
	100	poor	16,805	4,613	6,073	--
		good	--	2,730	4,284	6,638
Chemical Oxygen Demand (kg)	10	poor	42,038	22,266	27,566	--
		good	--	15,334	20,807	20,195
	25	poor	60,821	34,600	42,791	--
		good	--	25,562	33,572	32,811
	75	poor	70,941	41,379	51,170	--
		good	--	31,258	41,049	39,919
	100	poor	81,439	48,534	60,020	--
		good	--	37,283	48,816	47,498

[a] Adsorbed to sediment plus soluble.

nitrogen, phosphorus and COD levels increase with storm intensity, but at a decreasing rate. The percentage decrease in pollution is highest for a 10-year storm and lowest for a 100-year storm, and is about 10 percentage points greater with good than poor vegetative cover on non-cropland areas. Percentage reductions in pollution are highest for sediment followed by nutrients and COD. Average reduction in all four pollutants is 49% with poor vegetative cover and 70% with good vegetative cover for the 1.5T strategy and 68% with poor cover and 80% with the good cover for the 1T strategy. The riparian strategy reduces average water pollution by 61% which is less than either erosion control strategy with good vegetative cover.

The pollution reduction efficiency averaged over the four storm events and the decrease in net farm income (without cost sharing) per unit reduction in pollution are compared for the three management strategies (Table 5). The riparian strategy is more efficient than the 1T and 1.5T strategies, and the 1.5T strategy is more efficient than the 1T strategy. The 1T strategy is the least efficient strategy because net farm income decreases proportionately more than pollution.

Conservation Compliance. The optimal RMS for all fields consists of RTDS with either WP or WPWPS (Table 6). RTDS is optimal for all fields because it has the highest annualized net returns per acre and satisfies both compliance standards. Half of the cropland is in WP and half is in WPWPS for the 1T standard and 70% is in WP and 30% is in WPWPS for the 1.5T standard. Changes in total erosion and net farm income vary with respect to the compliance standard and the baseline (Table 7). Erosion decreases 71% for 1T and 67% for 1.5T relative to CTCF, and 33% for 1T and 25% for 1.5T compared to RTCF. Net farm income increases 11% for 1T and 16% for 1.5T with respect to CTCF but decreases 4% for 1T and 0.65% for 1.5T relative to RTCF. Optimal RMSs and total erosion are unaffected but net farm income is slightly higher with than without cost sharing.

The average efficiency of erosion reduction measures the change in net farm income per kg of erosion reduction relative to the baselines (last column in Table 7). A negative (positive) average efficiency indicates that net farm income increases (decreases) as erosion is decreased. Average efficiency of erosion reduction decreases between 1.5T and 1T for both baselines and is negative for the CTCF baseline and positive for the RTCF baseline.

The water quality effects of the two conservation compliance standards are evaluated by

Table 5. Average pollution reduction efficiency for alternative management strategies, Tom Beall watershed[a].

Pollutant	Erosion Control Strategy 1T	Erosion Control Strategy 1.5T	Riparian Strategy
	$/kg		
Sediment	9.70	6.48	2.30
Nitrogen[b]	7.37	5.25	1.95
Phosphorus[b]	14.82	41.14	3.80
Chemical Oxygen Demand	4.45	3.55	1.05

[a] Decrease in net farm income (without cost sharing) per unit reduction in pollution relative to conventional tillage with contour farming, averaged over four storm events.

[b] Adsorbed to sediment plus soluble.

Table 6. Cropland area in optimal resource management systems for alternative Conservation compliance standards, Tom Beall watershed.

System		Conservation Compliance Standard			
		1T		1.5T	
Tillage and Land Treatment	Rotation	Area (Hectares)	Percent	Area (Hectares)	Percent
RTDS[a]	WP[b]	1,175	50.40	1621	69.68
RTDS[a]	WPWPS[c]	1,152	49.50	706	30.32

[a] Reduced tillage with divided slope farming.

[b] W = winter wheat, P = spring peas.

[c] S = four years of grass seed.

Table 7. Total annual soil erosion, net farm income and erosion reduction efficiency for alternative conservation compliance standards, Tom Beall watershed.

	Soil Erosion		Net Farm Income		Erosion
Standard	Total (10^3 kg)	Percent[c]	Total[d] ($)	Percent[c]	Efficiency[e] ($/kg)
Baseline (CTCF)[a]	132,009	-	406,476	-	-
1.5T	43,549	-67.01	470,372	15.72	-0.73
1T	38,929	-70.51	452,880	11.42	-0.50
Baseline (RTCF)[b]	58,370	-	473,458	-	-
1.5T	43,549	-25.39	470,372	-0.65	0.21
1T	38,929	-33.31	452,880	-4.35	1.06

[a] Conventional tillage with contour farming.

[b] Reduced tillage with contour farming.

[c] Percent change relative to baseline.

[d] Without cost sharing.

[e] Change in net farm income (without cost sharing) divided by change in total erosion relative to baseline.

comparing the levels of total sediment, total nitrogen, total phosphorus, and soluble COD for four storm events: 10, 25, 50 and 100-years, each lasting 24 hours. Total pollution increases with respect to storm intensity but at a decreasing rate. The percentage reduction in each pollutant, averaged over the four storm events, is substantially greater relative to the CTCF baseline than relative to the RTCF baseline (Table 8). Improvements in water quality are very similar for the 1T and 1.5T standards. Sediment shows the greatest reduction and COD the least reduction relative to the baselines.

Average efficiency of pollution reduction measures the change in net farm income per unit reduction in pollution relative to the baselines (Table 9). A negative (positive) efficiency implies that net farm income increases (decreases) per unit reduction in pollution. Pollution reduction is efficient relative to CTCF but inefficient relative to RTCF. Average pollution efficiency decreases from the 1T standard to the 1.5T standard, and with respect to storm intensity (not shown in the table) for both baselines.

Table 8. Percent reduction in water pollution for alternative conservation compliance standards, Tom Beall watershed[a].

	Conservation Compliance Standard				
	Relative to CTCF			Relative to RTCF	
Pollutant	RTCF	1T	1.5T	1T	1.5T
Sediment	66	86	84	57	54
Nitrogen[b]	54	77	75	49	45
Phosphorus[b]	53	76	74	49	44
Chemical Oxygen Demand	0	10	6	10	6

[a] Average reduction for all storm events.

[b] Adsorbed to sediment plus soluble.

Table 9. Average pollution reduction efficiency for alternative conservation compliance standards, Tom Beall watershed[a].

	Conservation Compliance Standard			
	Relative to CTCF		Relative to RTCF	
Pollutant	1T	1.5T	1T	1.5T
	\$/kg			
Sediment	-14.70	-19.57	28.66	4.30
Nitrogen[b]	-2.79	-3.96	3.89	0.66
Phosphorus[b]	-6.69	-9.39	7.96	1.32
Chemical Oxygen Demand	-8.80	-20.09	3.89	0.97

[a] Change in net farm income (without cost sharing) per unit reduction in pollution relative to baseline, averaged over four storm events.

[b] Adsorbed to sediment plus soluble.

CONCLUSIONS

From a research point of view, we recommend an approach that involves both measuring (monitoring) and simulating the effects of alternative management strategies to reduce nonpoint pollution from agricultural lands. An integrated systems framework that has both land and water subsystems is an essential starting point in order to develop, test and refine predictive models.

While water quality is the traditional end measurement in offsite economic impact analysis, particularly as it relates to human uses, physical habitat characteristics of streams and rivers and their associated biotic communities are also important. We recommend the latter's inclusion in order to provide a more complete ecosystem assessment of NPS pollution from an economic-environmental standpoint.

This study indicates that achieving conservation compliance in Idaho's Tom Beall watershed would result in less total cropland erosion and less sediment/nutrient pollution of Tom Beall Creek than good management of riparian areas. Good riparian management is more efficient in reducing cropland erosion and water pollution than conservation compliance. If the yield penalties with conservation tillage are permanent and the current resource management system is conventional tillage, contour farming and a wheat-pea rotation, then conservation compliance and good riparian management would reduce net farm income. The income reduction would be more evenly spread among farmers with conservation compliance than with good riparian management. If yield penalties from conservation tillage dissipate within three years and the current resource management system is conventional (reduced) tillage, contour farming and wheat-pea and wheat-barley-pea rotations, then conservation compliance would result in higher (lower) net farm income. Therefore, the efficiency of conservation compliance in Ton Beall watershed is very sensitive to the magnitude and longevity of yield penalties with conservation tillage systems and the current mix of conventional and conservation tillage systems operative in the watershed.

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