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Validation of paired watersheds for assessing conservation practices in the Upper Big Walnut Creek watershed, Ohio

K.W. King, P.C. Smiley Jr., B.J. Baker, and N.R. Fausey

Abstract: Impacts of watershed scale conservation practice adoption on sediment, nutrient, and pesticide losses and adjacent stream biota are not well understood. The objective of this study was to examine the suitability of selected paired watersheds to quantify hydrology, chemical, and ecology effects of conservation practice implementation for channelized and unchannelized watersheds in Upper Big Walnut Creek watershed, Ohio. Channelized watersheds were more similar in watershed characteristics than the unchannelized watersheds. One hydrology, eight water chemistry, and five fish community response variables were measured. Most response variables in both watershed pairs were moderately correlated ($r > 0.6$), but the minimum percent change required to detect a response difference was greater for the unchannelized watersheds. Detectable temporal trends in the difference between like response variables for the channelized and unchannelized watershed pairs were minimal. These results validate the paired watershed design and suggest that conservation practice induced changes in hydrology, water quality, and fish communities can be quantified.

Key words: Conservation Effects Assessment Project (CEAP)—fish communities—headwater watersheds—hydrology—nutrients—paired design—pesticides

Agricultural food production per unit area has increased substantially over the last few decades and continues to surpass the global human population growth rate (Matson et al. 1997). The recent success in food production is a result of intensive management practices that include high yielding crop varieties, drainage, irrigation, mechanization, fertilizers, and pesticides. The last 40 years has also seen a steady increase in the use of nitrogen, phosphorus, and pesticides (Tilman et al. 2002). The liberal use of nutrients and pesticides on cropland, while responsible for increasing global food supply, poses a substantial risk to terrestrial and aquatic ecosystems. Implementation of environmentally friendly conservation practices or best management practices are often accepted as the best methods for sustaining agricultural production and minimizing nonpoint source pollution (Ice 2004). In the United States, congressionally authorized spending on farm programs to preserve and protect natural resources is at record levels (Loftis et al. 2001). Federal dollars allocated through the 2002 Farm Bill aimed at funding conservation programs increased nearly 80% compared to the 1996 Farm Bill allocations (Mausbach and Dedrick 2004).

Conservation programs such as the Conservation Reserve Program, the Conservation Reserve Enhancement Program, the Environmental Quality Incentives Program, and the Wildlife Habitat Incentives Program are aimed at providing financial incentives to farmers in an effort to facilitate long-term adoption of conservation practices. Conservation practices that are promoted by these programs have generally been well tested at the smaller plot and edge of field scale (Mausbach and Dedrick 2004). Additionally, these studies have focused primarily on examining water chemistry and/or sediment responses. However, the question still remains as to the watershed scale impacts of implementation. Landowners and operators are hesitant to accept or adopt conservation practices that have not been proven effective, efficient, and/or economical (Ryan et al. 2003; Ribaudo et al. 2005).

One approach to quantify and evaluate watershed scale impacts of conservation practices is to use natural experiments or field studies. Different experimental designs for field studies are available that involve comparison of data collected before and after implementation of a treatment, comparison of data between sites with and without a treatment, or examining data relationships with a treatment gradient (Downes et al. 2002). One such experimental design is the paired watershed design. This experimental design is also known as the before-after-control-impact design and involves assessing the response of both a control watershed and an impact watershed before and after treatment (the implementation of conservation practices in this study). Paired watershed designs have been used to investigate the impacts of nitrogen management (Koerkle et al. 1997), phosphorus management (Bishop et al. 2005), tillage (Clausen et al. 1996), forest management (Wynn et al. 2000), prairie restoration (Schilling 2002), agroforestry practices (Udawatta et al. 2002), and riparian restoration (Meals 2001). The primary advantage of the paired design is that the use of the control watershed allows the effect of the treatment to be isolated from other potential factors (i.e., climate) that might result in a difference in response variables between watersheds (Downes et al. 2002).

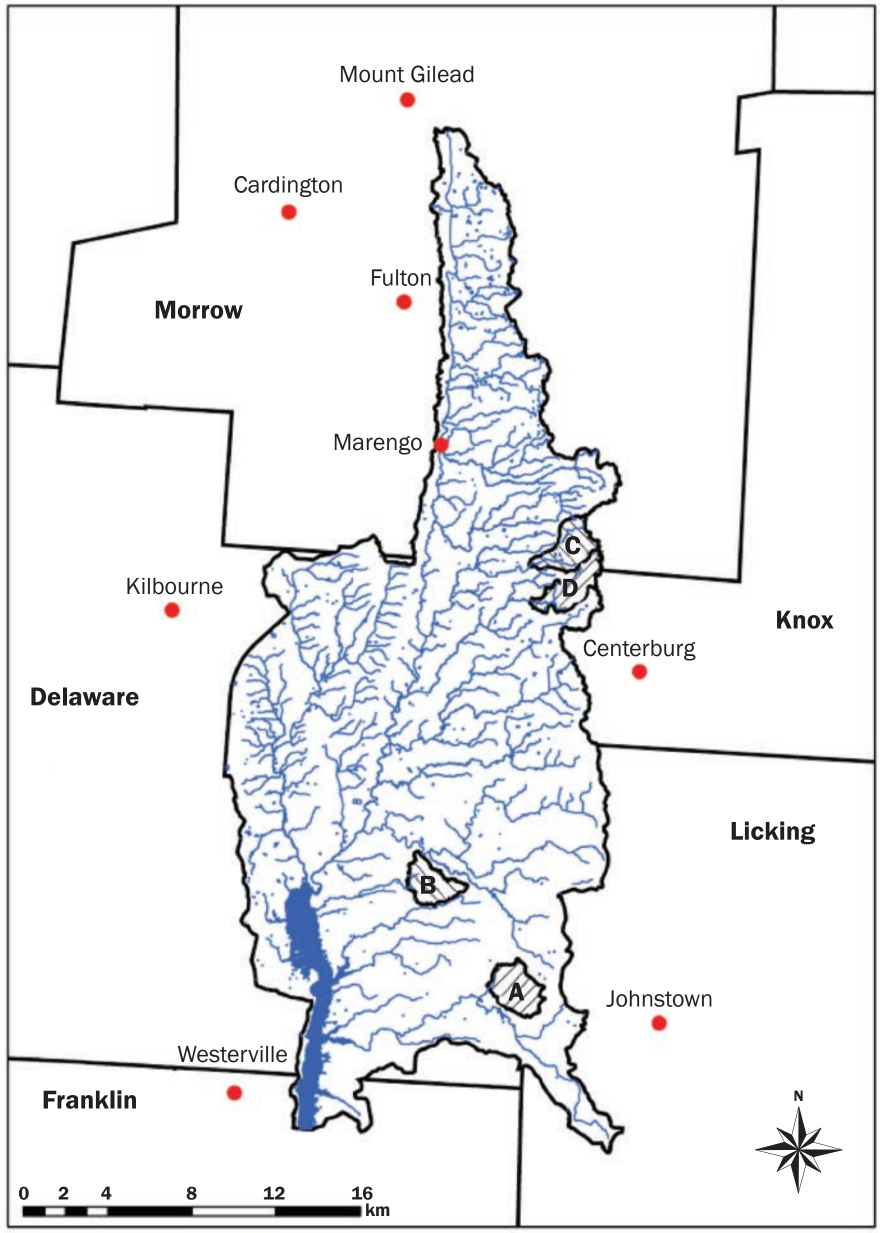
While the paired design is ideal for isolating treatment effects, its use in the agricultural arena has been very limited. In the few paired watershed experiments that have been conducted, the primary focus was on hydrology or water chemistry, with no known studies investigating aquatic ecological aspects. Fish communities within agricultural streams are expected to benefit from anticipated reductions of sediment, nutrient, and pesticide loadings following implementation of conservation practices. Laboratory studies evaluating the mortality of laboratory reared fishes have documented reductions in mortality with decreasing levels of sediment, nutrients, and pesticides (USEPA 1986; Waters 1995).

Kevin W. King is an agricultural engineer and **Peter C. Smiley Jr.** is a research ecologist at the Soil Drainage Research Unit, USDA Agricultural Research Service, Columbus, Ohio. **Barbara J. Baker** is a soil scientist at the Conservation Service Findlay Service Center, USDA Natural Resources, Findlay, Ohio. **Norman R. Fausey** is a soil scientist at the Soil Drainage Research Unit, USDA Agricultural Research Service.

However, field evaluations of the impacts of conservation practices (designed to reduce sediment, nutrient, and pesticide loadings) on fish communities are lacking despite the regular implementation of conservation practices and best management practices within agricultural watersheds (Bernhardt et al. 2005; Alexander and Allan 2006). Furthermore, aquatic ecological assessments are the driving force behind total maximum daily loads. Once established, watershed total maximum daily loads are often addressed with soil and water conservation practices aimed at reducing the impacts of land management on delivery of sediments, nutrients, and pesticides to adjacent waters. Combined hydrology, water chemistry, and ecology assessments are needed to provide a comprehensive understanding of the impacts of soil and water conservation practices on agricultural watersheds.

The objective of this manuscript is to validate the use of the paired watershed design to evaluate future watershed scale impacts of conservation practice implementation within the headwaters of the Upper Big Walnut Creek watershed, Ohio. The primary hypothesis is that the selected pairs of watersheds will be suitable for assessing the impacts of conservation practices (e.g., precision nutrient management and drainage water management) on the hydrology, sediment, water chemistry, and aquatic ecology of headwater streams in the Upper Big Walnut Creek watershed. A secondary hypothesis is that the effectiveness of the selected watersheds in assessing the impacts of conservation practices will differ between watershed types (i.e., channelized and unchannelized) and between time periods (i.e., between the nongrowing and growing seasons).

Figure 1
Upper Big Walnut Creek watershed and subwatersheds.



Methods and Materials

Upper Big Walnut Creek Watershed. The Upper Big Walnut Creek (UBWC) watershed is one of the 12 benchmark watersheds in the United States being evaluated as part of the USDA Agricultural Research Service component of the Conservation Effects Assessment Project (Mausbach and Dedrick 2004). The evaluation of conservation practices in this watershed is unique among USDA Agricultural Research Service watersheds because it involves the combined evaluation of the hydrological, chemical, and ecological responses of channelized and unchannelized headwater streams to conservation practices.

The UBWC watershed (figure 1) is an 11-digit watershed (HUC 05060001-130) located in central Ohio (latitudes 40°06'00" to 40°32'30", longitudes 82°56'00" to 82°42'00"). The watershed area is 492 km^2 (190 mi^2) and contains 467 km (290 mi) of perennial and intermittent streams that drain into Hoover Reservoir, which serves as a drinking water supply for approximately 800,000 residents in Columbus and surrounding communities. The UBWC was identified as a priority impaired watershed in the Ohio Environmental Protection Agency (EPA) (Ohio EPA 2004) 1998, 2000, and 2003 303(d) list of waterbodies that do not meet an established water quality standard. The majority of headwater streams in the watershed are impaired by nutrient enrichment, pathogens, and habitat degradation stemming from current agricultural management practices (Ohio EPA 2003, 2004).

Cropland for production agriculture comprises the largest land use classification within the watershed (approximately

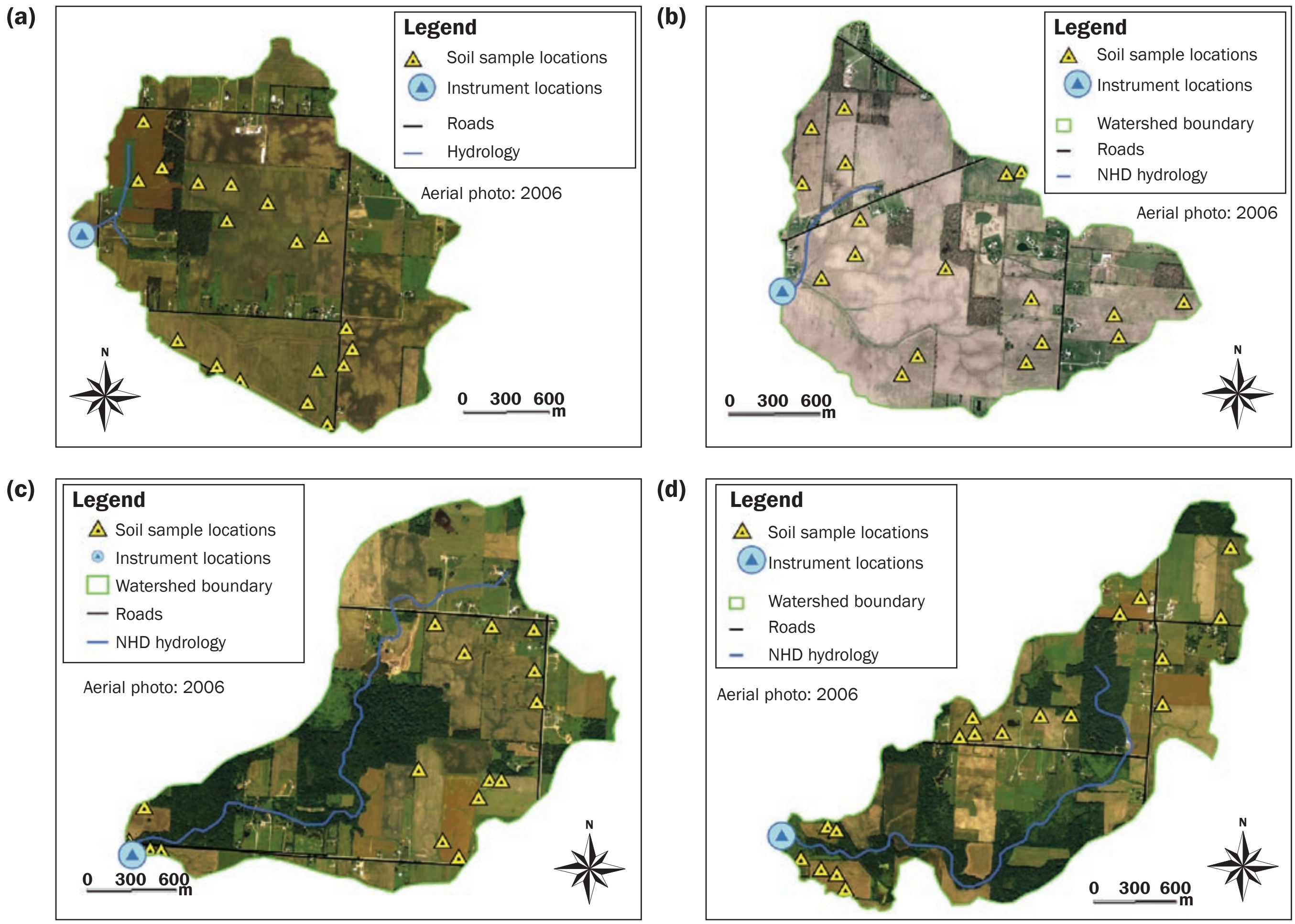
Figure 2
Channelized (a and b) and unchannelized (c and d) study sites within the Upper Big Walnut Creek watershed.

60%). The primary agricultural crops are corn, soybeans, and wheat. Management primarily includes conservation tillage, fertilization, and herbicide applications. An extensive portion of the watershed used for agricultural production is systematically tile drained, especially in the southern half of the watershed. In addition to crop production agriculture, a significant transition from agriculture to urban land use is occurring in the southwestern portion of the watershed. The urban land use component (approximately 15% of the watershed) is comprised of single- and multi-unit dwellings, parks, and golf courses. In addition, soils in the watershed are clayey, poorly drained, and consist primarily of Bennington-Pewamo-Cardington soil association (60%) and the Centerberg-Bennington association (20%).

The UBWC is located in the humid continental, hot summer climatic region of the United States. The climate provides for approximately 160 growing-degree days at a base temperature (temperature at which development ceases) of 0°C (32°F), generally lasting from late April to early to mid-October. Normal daily temperatures range from an average minimum of -9.6°C (14.7°F) in January to an average maximum of 33.9°C (93°F) in July. Thunderstorms during the spring and summer produce short duration intense rainfalls. Moisture in the form of frozen precipitation or snow averages 500 mm (19.7 in) annually and occurs primarily in the winter months (December to March). The 30-year normal rainfall recorded near the southwest portion of the watershed was 985 mm (38.8 in). Monthly distribution of rainfall exhibits a bimodal distribution with a primary peak in late spring and early summer and a secondary peak in late fall and early winter.

Experimental Watersheds. The experimental watersheds (A to D) are headwater subwatersheds located within the UBWC watershed (figure 1). One pair of channelized watersheds (A and B) and one pair of unchannelized watersheds (C and D) were identified and selected as experimental watersheds. Here channelized watersheds are defined as having some anthropogenic alteration; generally the stream channels in the channelized watersheds have been deepened and straightened to more rapidly and efficiently convey surface and/or subsurface drainage waters, whereas in the unchannelized watersheds the stream channels have developed under natural conditions (figure 2). Channelized headwater streams generally have a greater discharge capacity than unchannelized headwater streams. The southern portion of the UBWC watershed is dominated by minimal relief and large, systematic tile drained fields while the northern half of the watershed is characterized by smaller, more sloping fields and natural surface drainage.

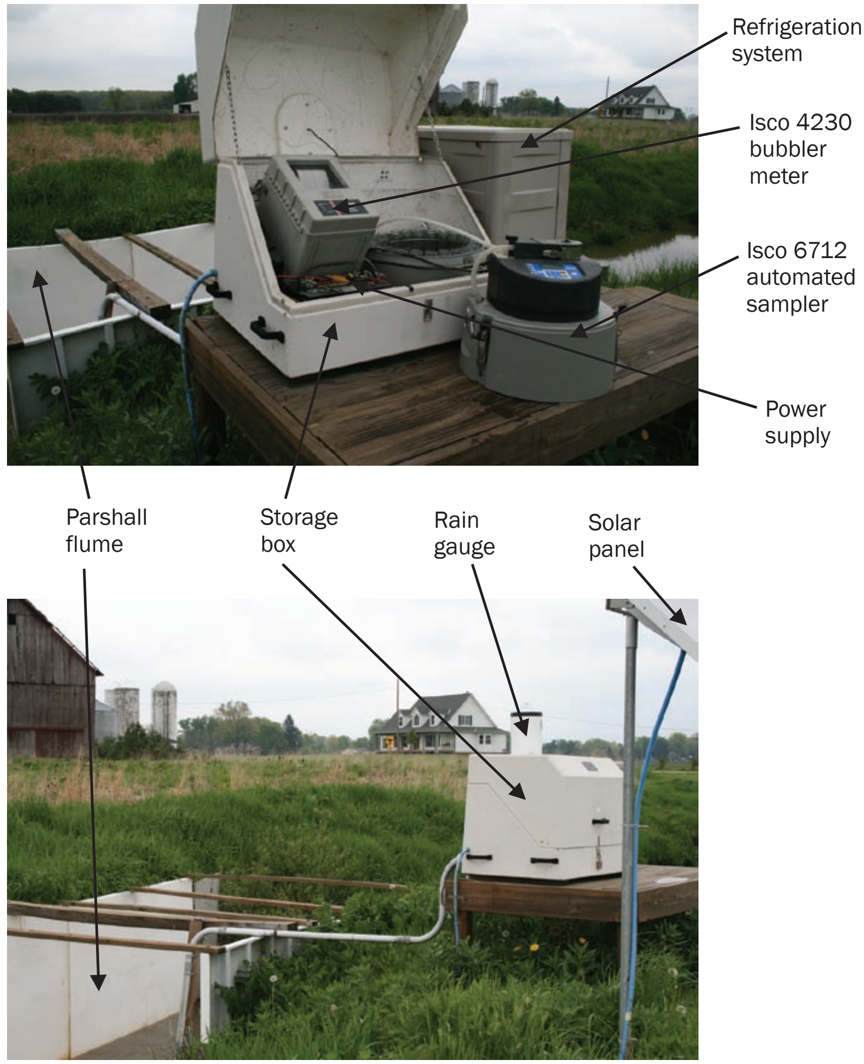
Figure 3
Schematic of the four experimental watersheds (a to d) with streams, instrument locations, and soil sampling sites.



Each pair of watersheds was selected based on qualitative assessments of watershed size, agronomic practices, land use (primarily crop production agriculture), topography, dominant hydrologic processes, and potential willingness of landowners within the watersheds to enroll in conservation programs. The channelized watersheds are representative of eastern Midwest tile drained watersheds and the unchannelized watersheds better represent natural drained systems. The selected watersheds range in size from 389 to 454 ha (960 to 1,120 ac) and contain mostly row-crop agriculture within the watersheds. Both channelized watersheds contain narrow riparian zones consisting mostly of herbaceous riparian vegetation and exhibit the straightened, over-enlarged, trapezoidal channels typical of agricultural drainage ditches in the midwestern United States (figures 2a and 2b). Both unchannelized watersheds possess forested riparian zones with sinuous channels and variable bank heights as would be expected within headwater streams that have not been subjected to channelization for agricultural drainage (figures 2c and 2d). Agricultural practices in the selected watersheds are representative of those in the larger UBWC watershed. Primary crops are corn, soybeans, and wheat managed with conservation tillage, fertilizer, and pesticide applications. Additionally, owner/operator willingness to cooperate for experimental manipulation was considered to be high in all selected sites. This criterion was critical to help ensure that experimental manipulations could be implemented in the future within the treatment watersheds.

Data Collection and Analysis. Paired Watershed Characteristics. Watershed characteristics of size, relief, shape, and landuse type were assessed using geographic information system analysis tools. Watershed boundaries were identified using digital elevation models and ESRI (ESRI, Redlands, California) 3D Spatial Analyst software. The digital elevation model data for 7.5-minute units correspond to the USGS 1:24,000- and 1:25,000-scale topographic quadrangle map series for all of the United States and its territories. Each 7.5-minute digital elevation model was based on 30- by 30-meter data spacing with the Universal Transverse Mercator Zone 17 projection. The paired study watersheds (A-D) were delineated using higher resolution county data when available. Parameters of drainage area, relief, watershed slope, total stream length, drainage density, elongation (the ratio of the square root of the drainage area and the basin length), and circularity (the ratio of basin's drainage area to the area of a circle with an identical perimeter as the basin) were calculated with ArcGIS Version 9.0 (ESRI). Landuse types within each watershed were determined from 2002 orthophotos obtained

Figure 4
Hydrology and water quality sampling equipment located at the outlet of each watershed site.



from Landsat imagery at a 30 meter resolution (figure 3).

Soil sampling was conducted in 2005 within the agricultural fields of each watershed to assess soil type and other soil property characteristics. Soil cores were collected at two different locations for each of the three major soil types within each watershed. At each location, cores were collected within three depth strata (0 to 15 cm, 15 to 30 cm, and 30 to 60 cm [0 to 6 in, 6 to12 in, and 12 to 24 in]). Bulk density (g cm^{-3}) was determined using the core method outlined by Blake and Hartge (1986). A modified wet sieving procedure was used for determination of percentage water stable aggregates (Kemper and Rosenau 1986). Available water capacity (cm^3 cm^{-3}) of soil was calculated from the difference in volumetric moisture content of soil at -0.033 and -1.5 MPa (1/3 and 15 bar) (Klute 1986). Total soil carbon (%) was determined by dry combustion using a CE Elantech CN analyzer (model NC 2100). Mean values of soil properties were calculated from the 18 samples (i.e, two locations x three depths x three soil types) collected within each watershed.

Hydrology and Water Chemistry. In 2004, the outlet of each watershed was equipped with a 2.4 m (8 ft) Parshall flume, Isco 4230 bubbler meter (to record stage), Isco 6712 automated water sampler, and Isco 674 tipping bucket rain gauge (figure 4). Stage and precipitation were recorded on a 10-minute interval. Stage was converted to discharge from a developed, site specific stage-discharge relationship. Water samples were collected by automated samplers and weekly grab samples. Automated samplers were used from mid-March to December until the sampling lines were frozen. Automated samples were collected on a 1-mm (0.04-in) volumetric flow depth interval with each sample bottle comprised of four aliquots. For a three week period, following the spring planting season, each sample bottle was analyzed. Throughout the remainder of the year, samples collected during the week were combined to form a weekly composite sample. Weekly grab samples were also collected throughout the year, except during periods of drought or freezing. All samples were collected in midstream where a well-mixed condition was assumed to occur.

Following collection, all samples were handled according to US Environmetnal Protection Agency (USEPA) method 353.3 for nitrogen analysis, USEPA method 365.1 for phosphorus analysis (USEPA 1983), and USEPA method 525.2 for pesticide analysis (USEPA 1995). Samples were stored below 4°C (40°F) and analyzed within 28 days. Samples were vacuum filtered through a 0.45 μm (1.8 × 10^{-5} in) pore diameter membrane filter for analysis of dissolved nutrients and suspended solids. Concentrations of nitrate plus nitrite (NO_3+NO_2-N) and dissolved reactive phosphorus (PO_4-P) were determined colorimetrically by flow injection analysis using a Lachat Instruments QuikChem 8000 FIA Automated Ion Analyzer. NO_3+NO_2-N was determined by application of the copperized-cadmium reduction, and PO_4-P was determined by the ascorbic acid reduction method (Parsons et al. 1984). Total nitrogen and total phosphorus (TP) analyses were performed in combination on unfiltered samples following alkaline persulfate oxidation (Koroleff 1983) with subsequent determination of NO_3-N and PO_4-P. From this point forward, NO_3+NO_2-N will be expressed as NO_3-N, and PO_4-P will be used synonymously with dissolved reactive phosphorus (DRP).

Atrazine, simazine, and metolachlor residues were determined using gas chromatography and a Varian Instruments Saturn 2200 Gas Chromatography Mass Spectrometer. Following collection, samples were stored at 4°C (40°F) until processing, generally within seven days. Two hundred milliliters (6.76 fl oz) of sample was vacuum filtered (Fisherbrand 42.5-mm [1.67-in] diameter

Glass Fiber Filter G6) and stored below 4°C (40°F) until extraction. Prior to extraction, the filtered sample was fortified with 1-ml (0.0338 fl oz) methanol and terbuthylazine standard at a final concentration of 500 μg L^{-1} (ppb). The sample was then extracted using 10-ml (500-mg) Varian Bond Elut C-18 cartridges preconditioned with methanol. The extract was eluted with four 0.5-ml (0.0169 fl oz) aliquots of ethyl acetate, dried under N_2 gas and reconstituted with 1-ml ethyl acetate containing 100 μg L^{-1} phenanthrene-d10 as internal standard. Samples were then stored at 0°C (32°F) until analysis. Two-μl (0.00067 fl oz) of sample were injected by splitless mode into a Varian CP-Sil 8 CB Low Bleed Column (30-m × 0.25-mm ID) using a Varian CP-8400 autosampler. Helium was the carrier gas at 1-ml min^{-1}. The oven temperature program consisted of temperature ramping from 55°C to 300°C (131°F to 572°F) at various time intervals with an injector temperature of 280°C (536°F). Analyte analysis was conducted with the mass spectrometer and monitoring the masses for atrazine (mass-to-charge ratio [m/z] 200), metolachlor (m/z 162) and simazine (m/z 138). Matrix spikes were prepared by adding a concentrated mixture of the analytes to ultrapure water for a final concentration of 500 μg L^{-1}. Extraction recovery for the three analytes was 100%±5%. No analytes were detected in blanks.

All pollutant loads (e.g., nitrate) were calculated by multiplying the analyte concentration by the measured water volume for that respective sample and summing on a monthly basis. The volume of water associated with any one sample was determined using the midpoint approach, i.e., the temporal midpoint between each sample was determined and the volume of water calculated for that time duration. The analyte concentration was assumed to be representative over that specific flow duration.

Fish Communities. Fishes were sampled from two sites within each watershed. Each site was 125 m (410 ft) long and located near the locations of the automated water samplers and flumes. One sampling site was located at the watershed outlet, and the second sampling site was at least 150 m (492 ft) upstream. Fish were collected three times a year in the spring (May to June), summer (July to August), and fall (September to November) in 2005 and 2006. Block nets were set at the upstream and downstream borders of the sites prior to sampling. Fishes were sampled with a backpack electrofisher (100 to 150 volts, 60 Hz, DC current) and seine (2 m × 4 m, 0.32 cm mesh size [6.5 ft × 13.1 ft × 0.13 in mesh size]). Electrofishing began at the downstream border of a site and proceeded upstream. Care was taken to ensure that all habitat units within each site were sampled thoroughly during electrofishing. Five seine samples that were equally distributed throughout each site were also collected. Selected pools and slow flowing areas were sampled with a haul, while fast flowing riffle areas were sampled using the seine as a block net and kicking into the seine. Fishes that could be identified in the field were sorted by species, counted, and released. Unidentifiable fishes were euthanized with MS-222 (tricaine methanesulfonate), fixed with a 10% formalin solution, and returned to the laboratory for subsequent identification.

Fish response variables were calculated for each watershed during each sampling period by compositing data from the two sampling sites collected in the spring, summer, and fall. Fish species richness is the number of fish species captured and describes the diversity of the fish communities. Fish abundance is the number of fishes captured and provides information on the amount of fishes within the watersheds. The percentage of headwater fishes, omnivores, and insectivores are indicators of the abundance of fishes with similar habitat requirements or feeding strategies. Specifically, headwater fishes are those fishes expected to be found in first to third order streams in the midwestern United States, such as creek chub, white suckers, and orangethroat darters (Ohio EPA 2002). Omnivores are those fishes that eat plant and animal matter) and insectivores are those fishes that eat insects and other invertebrates.

Statistical Analyses. Effective use of paired watershed design requires that paired watersheds should (1) be similar in physical characteristics (Downes et al. 2002), (2) have moderate correlations (i.e., greater than 0.6) in response variables between paired watersheds (Loftis et al. 2001), (3) lack the presence of a temporal trend in the difference in response variables between control and impact watersheds prior to the impact (Stewart-Oaten and Murdoch 1986), and (4) exhibit minimal effect sizes needed to detect a significant change. Thus, validation of the experimental design selected for our study required the use of four data analysis approaches.

First, the similarity in watershed characteristics between paired watersheds was examined. Specifically, we examined the similarity between response variables describing the the size and shape (i.e., drainage area, slope, relief, total channel length, surface drainage density, elongation, circularity), land use (i.e., percentage urban, agriculture, shrub/scrub, wooded, wetland), and soil characteristics (i.e., percentage soil types present, bulk density, water holding capacity, percentage water stable aggregates, total carbon) of the watersheds. Similarity in watershed response variables between paired watersheds was evaluated by calculating the total or mean of each response variable. The difference in each response variable was calculated, and those totals or means that were within 25% of each other were considered to indicate similarity between watershed pairs. Our methodology provided objective a priori criteria for the assessment of the similarity in watershed characteristics between unreplicated watershed pairs.

Secondly, the relationships in hydrology, water chemistry, and fish communities between paired watersheds were assessed with simple linear regression analyses to determine the degree of correlation present between paired watersheds. Specifically, correlations in one hydrology variable (discharge volume), eight water chemistry variables [loadings of suspended solids, NO_3-N, total nitrogen, DRP, TP, metolachlor, simazine, and atrazine], and five fish community variables (species richness, abundance, percentage headwater fishes, percentage omnivores, and percentage insectivores) between watershed pairs were examined.

Thirdly, temporal trends in the differences between paired watersheds in hydrology, water chemistry, and fish community response variables were examined using the Daniels Test for Trend (Conover 1999). The Daniels Test for Trend was selected because it examines the relationship between the difference in a response variable between pairs and time period. Since the watersheds are close in proximity, any climate impacts should be buffered. The Daniels Test for Trend involves using the Spearman rank correlation to calculate the correlation between the difference in hydrology, water chemistry, and fish community response variables between watershed pairs and time period. Correlation coefficients with p-values less than 0.05 indicate the occurrence of a temporal trend for a particular response variable. Specifically, response variables with positive correlation coefficients and significant p-values ($p < 0.05$) indicate an increasing difference in the response variable between paired watersheds over time. Conversely, variables with negative correlation coefficients and significant p-values ($p < 0.05$) indicate a decreasing difference in response variables between paired watersheds over time. Additionally, the Daniels Test for Trend does not require long term data sets like many of the parametric statistical techniques that are specifically designed for the analyses of time series data (although more confidence can be gained from longer data sets).

Fourthly, the minimum percent change required to detect a significant difference in hydrology, water chemistry, and fish community response variables before and after the implementation of conservation practices was calculated. Analysis of covariance (ANCOVA) will be employed to statistically analyze post treatment results because it is commonly used in the analyses of paired watershed designs (Clausen and Spooner 1993). The minimum percent change required to detect a significant difference on the slope and intercepts of the paired watershed regressions before and after implementation of conservation practices was calculated with the following formulas (Clausen and Spooner 1993; Galeone 1999):

$$\frac{S_{xy}^2}{d^2} = \frac{n_1 n_2}{n_1 + n_2}\left[\frac{1}{F\left(1 + \frac{F}{n_1 + n_2 - 2}\right)}\right], \tag{1}$$

$$\textit{minimum percent change required} = \left(\frac{d}{\bar{x}}\right) \times 100, \tag{2}$$

where n_1 and n_2 are, respectively, the sample size before and after a conservation practice is implemented. In this case (before conservation practice implementation), the hydrology and water chemistry sample sizes were 24 (14 for the growing season and 10 for the nongrowing season), and the fish communities sample size was six. In addition, the sample sizes are anticipated to remain the same after conservation practice implementation. F is the F value for the variance ratio at 1 and ($n_1 + n_2$ - 3) degrees of freedom based on the significance level desired, and S^2_{xy} is the calculated variance from the first two years of sampling. Based on measured data and a 0.05 significance level, equation 1 was solved for the minimal difference, d, which was then used in equation 2 along with $\bar{x}$ (the mean of a response variable from the control watershed) to determine the minimum percent change required (Clausen and Spooner 1993; Galeone 1999). All statistical tests were conducted using SigmaPlot 9.0 (Systat Software 2004a) and SigmaStat 3.1 for Windows (Systat Software 2004b).

Results and Discussion

Watershed Characteristics. Nineteen physical, land use, and soil parameter indices were used to evaluate the similarity in channelized paired watersheds while twenty parameters were used for the unchannelized watersheds (table 1). The different number of parameters was a result of the number of dominant soil types in each watershed pair. In general, the watershed characteristics in each pair of watersheds were similar. Thirteen of nineteen watershed response variables were similar between channelized watersheds while ten of twenty response variables were similar between unchannelized watersheds. Those response variables that were not similar were still within the same magnitude between paired watersheds. For the channelized watersheds, two of the size and shape parameters did not meet the 25% similarity criteria. Similarity in channel length was within 38.5% while surface drainage density was within 53.7%. The remaining four parameters that did not meet the criteria in the channelized watersheds comprised less than 10% of either soil type or land use and were not considered significant for this study. For the unchannelized watersheds, three of the seven size and shape parameters (total channel length, surface drainage density, and circularity) did not meet the similarity criteria. However, differences in these parameters were less than 40%. Differences in the land use categories were a result of the magnitudes in each watershed and were not considered significant to the study. The primary differences in similarity were with respect to soil type. None of the four primary soil types in the unchannelized watershed pair met the 25% criteria. The discrepancy in soil types was attributed to difficulties in joining adjacent county soil surveys and to different land forms. The unchannelized watersheds are situated on a physiographic and glacial divide. Despite these differences, all soil property parameters for both the channelized and unchannelized watersheds met the similarity criteria.

Unchannelized pairs exhibited a greater slope and surface drainage density and were more elongated than channelized pairs (table 1). Differences in slope and surface drainage density were a result of location in the UBWC watershed. The channelized and unchannelized watershed pairs have different geologic periods (Devonian versus Mississippian) and were situated in different glacial (ground moraine versus end moraine) and physiographic regions (till plain versus glaciated low plateau). Land use within all watersheds was predominantly agriculture (table 1), primarily corn and soybean crop production. Additionally, channelized watersheds had lesser amounts of wooded areas within each watershed than unchannelized watersheds. Channelized watersheds contained mostly Bennington and Pewamo soil types, while unchannelized streams contained mostly Cardington and Bennington soil types (table 1).

Hydrology. The range of measured precipitation during the two-year period of record was analyzed based on the assumption that precipitation is the driving force for hydrologic relationships. In turn, hydrology functions as a dominant factor in sediment, nutrient, and pesticide transport and the structure of stream biota. Monthly precipitation in 2005 and 2006 followed a bimodal distribution with primary peaks in the winter and secondary peaks in summer (table 2), which was in contrast to the historical precipitation distribution in which the primary peak occurs in the summer and secondary in the winter. Measured precipitation in the 2005 and 2006 growing and nongrowing seasons suggests that the precipitation was in the upper end of the range with less than 50% chance of being equaled or exceeded (figure 5). The 2006 growing season precipitation had less than a 20% chance of being equaled or exceeded while the 2005 nongrowing season only had a 4% chance of being equaled or exceeded. The ideal calibration period would span the full range of expected values (Reinhart 1967), but capturing the

Table 1
Similarity in watershed characteristics between channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed.

	Channelized			Unchannelized		
	A	B	Percent difference	C	D	Percent difference
Size and shape characteristics						
Drainage area (ha)	454	389	**15.4**	439	428	**2.5**
Mean watershed slope (degrees)	0.24	0.29	**18.9**	0.41	0.42	**2.4**
Relief (m)	15.8	19.2	**19.4**	41.1	50.4	**20.3**
Total channel length (m)	677	1,000	38.5	10,212	6,950	38.0
Surface drainage density (m ha^{-2})	1.5	2.6	53.7	23.3	16.2	35.9
Elongation (dimensionless)	0.77	0.68	**12.4**	0.59	0.52	**12.6**
Circularity (dimensionless)	0.59	0.54	**8.8**	0.52	0.37	33.7
Land use classification						
Urban land use (%)	0.1	0.1	**0.0**	0.2	0.1	66.7
Agriculture land use (%)	95.3	88.9	**6.9**	72.3	64.9	**10.8**
Shrub/scrub land use (%)	0.0	0.1	200.0	0.4	0.8	66.7
Wooded land use (%)	4.5	10.4	79.2	26.6	33.3	**22.4**
Wetland land use (%)	0.1	0.3	100.0	0.4	0.9	76.9
Soil characteristics						
Amanda (%)	NA	NA	NA	15.5	7.0	75.6
Bennington (%)	47.3	52.9	**11.2**	13.0	32.3	85.2
Centerburg (%)	6.5	0.9	151.4	NA	NA	NA
Cardington (%)	NA	NA	NA	53.2	36.7	36.7
Pewamo (%)	46.2	46.2	**0.0**	2.5	10.9	125.4
Mean bulk density (g cm^{-3})	1.32	1.30	**1.5**	1.32	1.20	**9.5**
Mean water holding capacity (cm^3 cm^{-3})	0.30	0.27	**10.5**	0.26	0.24	**8.0**
Mean percentage water stable aggregates (%)	70.9	64.5	**9.5**	70.5	77.0	**8.8**
Mean percentage total carbon (%)	1.4	1.2	**15.4**	1.36	1.71	**22.8**

Notes: Percent difference is defined as the absolute difference between like watersheds divided by the mean of like watersheds. Variables considered similar (less than 25% difference) are highlighted in bold.

upper end of the range is more valuable for quantifying sediment, nutrient, and pesticide transport. The largest impacts are generally associated with extreme precipitation events, especially in the case of sediment transport (Coppus and Imeson 2002) and water chemistry (Haith and Duffany 2007; King et al. 2007).

A positive relationship ($p < 0.05$) in discharge volume was observed between the channelized and unchannelized watershed pairs during the growing and nongrowing seasons in 2005 and 2006 (figure 6). The strong correlations ($r > 0.9$) in volumetric discharge between paired watersheds (figure 6) during the nongrowing season suggests that hydrological shifts resulting from implementation of conservation practices should be readily detected during this time period. Unchannelized watersheds also

Table 2
Measured mean monthly precipitation (mm) for channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed.

	2005		2006	
Month	Channelized	Unchannelized	Channelized	Unchannelized
Jan	197.4	213.2	62.7	87.2
Feb	28.8	34.2	33.7	40.6
Mar	41.8	44.3	73.0	67.5
Apr	79.4	98.7	69.1	69.0
May	48.8	60.4	73.3	115.6
Jun	37.4	56.0	88.7	90.8
Jul	79.5	92.2	101.5	253.0
Aug	165.6	129.1	54.9	64.7
Sept	85.4	94.8	94.5	77.9
Oct	17.7	38.6	111.8	117.5
Nov	69.1	74.4	56.7	66.8
Dec	18.6	22.4	71.3	66.5
Annual	869.2	958.2	890.9	1,117.0

Figure 5

Exceedance probability plot of annual growing and nongrowing season precipitation from the National Climatic Data Center, Westerville, Ohio, gauge (1951 to 2006).

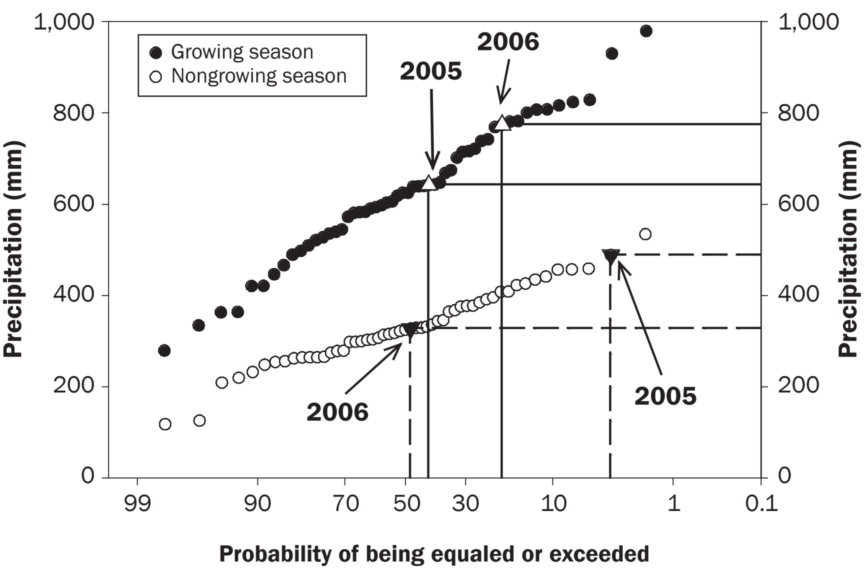


Table 3

Hydrology and water chemistry response variable correlation coefficients from the Daniels Test for Trend for channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed.

Response variable	Channelized	Unchannelized
Hydrology		
Discharge (mm)	**0.577**	**–0.568**
Water chemistry (loadings)		
Suspended solids (kg ha^{-1})	–0.075	–0.123
Nitrate-nitrogen (kg ha^{-1})	–0.017	–0.254
Total nitrogen (kg ha^{-1})	–0.010	–0.216
Dissolved reactive phosphorus (kg ha^{-1})	0.159	**–0.593**
Total phosphorus (kg ha^{-1})	0.247	**–0.502**
Metolachlor (g ha^{-1})	0.260	–0.030
Simazine (g ha^{-1})	0.105	–0.089
Atrazine (g ha^{-1})	0.357	**0.577**

Note: Bolded values indicate a significant correlation coefficient (p < 0.05).

exhibited strong correlations in volumetric discharge during the growing seasons, but channelized watersheds did not. This suggests that greater discharge volumes may be required to detect an effect during the growing season in channelized watersheds compared to the unchannelized watersheds. The stronger hydrologic correlations during the nongrowing season were attributed to the similarity in surface conditions and vegetation across paired watersheds during this period. During the growing season, factors such as tillage and crop variety may have also impacted discharge results. Tillage impacts infiltration potential while evapotranspiration, interception, and runoff retardation differ among crops.

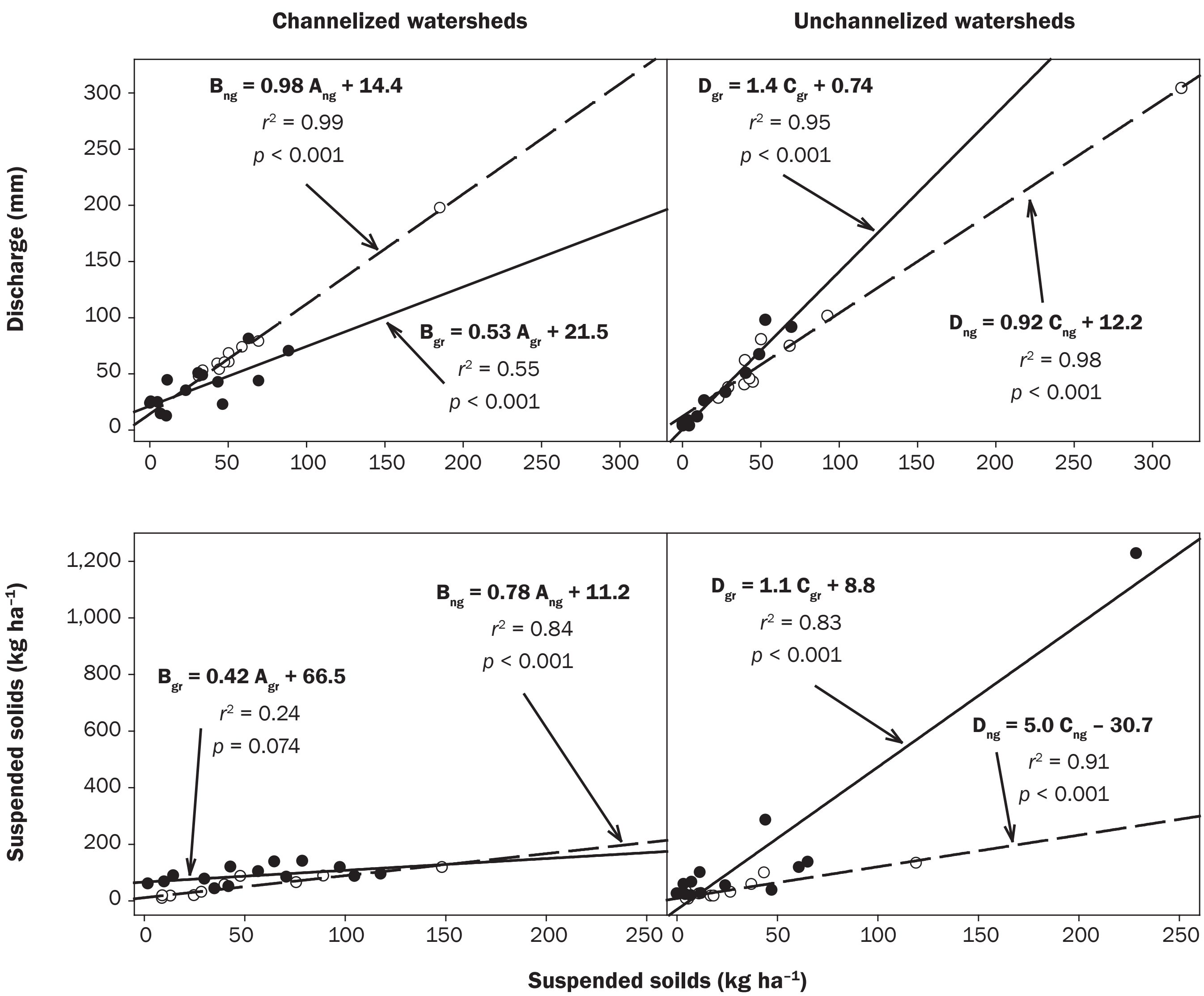
The Daniels Test for Trend (p < 0.05) indicated that the differences in discharge volume between the channelized watersheds increased through time, while a decreasing trend in the differences in discharge volume occurred between the unchannelized pair (table 3). The evidence of a temporal trend in volumetric discharge prior to the implementation of conservation practices suggests that (despite the well-defined relationship between watershed pairs) any observed changes after implementation of nutrient and pesticide management may not be solely attributed to the practices. These mixed responses suggest caution should be used when interpreting the hydrological responses to conservation practices. It is suspected that the observed trends would not be detected with a longer data set. Additionally, the use of monthly data also tends to add variability to the calculations. Using an annual time step would be preferable, but given the life expectancy of the project (approximately six years), a monthly time step is the largest permissible time step that provides sufficient data.

The calculated effect size required to detect a change in discharge volume varied by season and watershed pair (table 4). As suggested by the strong correlations during the nongrowing season, less change in discharge volume will be required to detect an effect in both watershed pairs during the nongrowing season. For example, a 6% change in discharge volume will be required to detect a difference for the channelized pair compared to 15% for the unchannelized pair. In contrast, detecting a discharge volume change in the growing season will require a greater effect size, 37% and 32% for the unchannelized and channelized watersheds, respectively (table 4). The increase in effect size needed during the growing season compared to the nongrowing season was attributed to scatter incurred from different crops and management. However, it should be noted that this study was not designed to isolate or relate the responses to current watershed or management characteristics. Increasing the sample size by combining all seasonal data resulted in minimum effect sizes that were less than those needed in the growing season but greater than the nongrowing season (table 4). The percent change needed when all months were considered (17%) was identical for both watershed pairs.

Water Chemistry. In general, correlations in sediment and nutrient loads (figures 6 and 7) between paired watersheds were stronger than those for pesticides (figure 8). Positive relationships (p < 0.05) were observed in suspended solids between channelized watersheds for the nongrowing season and between unchannelized watersheds during

Figure 6

Monthly hydrology and suspended solids relationships between channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed for the 2005 and 2006 growing (solid circles) and nongrowing seasons (open circles).



both seasons (figure 6). Positive relationships were also observed for all nutrients in channelized watersheds during the nongrowing season and in the unchannelized watersheds during both seasons (figure 7). Similarity in sediment and nutrient response was attributed to similarity in land use and management. Additionally, positive relationships in metolachlor during the nongrowing season and simazine during the growing season were noted in channelized and unchannelized watersheds; however a positive relationship in simazine was observed only in the unchannelized watersheds in the growing season (figure 8). Figures 6 to 8 show that the majority (10/16 and 13/16 for channelized and unchannelized watersheds, respectively) of the correlation coefficients for sediment, nutrients, and pesticides were greater than 0.6, with many relationships having correlation coefficients greater than 0.9. With the exception of TP in the unchannelized pair, all sediment and nutrient relationships were stronger during the nongrowing season compared to the growing season. The stronger relationships during the nongrowing season were attributed to similarity in land management following harvest. For hydrology, sediment, and nutrient loss, the poorest relationships were measured in the channelized watersheds during the growing season. The poor relationships for suspended solids, TP, and DRP were likely a result of differing crop rotations in the watersheds.

Many of the pesticide relationships were not significant because of the limited number of data points (as a result of an ongoing treatment) that actually impacted the response. A special Environmental Quality Incentives Program conservation program targeting atrazine application within the entire UBWC watershed began in 1999. In the channelized watersheds, the treatment watershed (B) had greater than 75% participation in the program while the nontreatment watershed (A) had less than 25% participation. With respect to the unchannelized watersheds, both watersheds were managed similarly with respect

Table 4
Calculated minimum percent change (growing season, nongrowing season, and all sampling periods) required to detect a significant effect of conservation practices on hydrology and water chemistry response variables in channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed.

Response variable	Channelized	Unchannelized
Growing season (n = 14)		
Discharge	37	32
Suspended solids	42	42
Nitrate-nitrogen	16	100
Total nitrogen	21	82
Dissolved reactive phosphorus	32	166
Total phosphorus	60	76
Metolachlor	6	87
Simazine	110	85
Atrazine	6	81
Nongrowing season (n = 10)		
Discharge	6	15
Suspended solids	34	367
Nitrate-nitrogen	9	31
Total nitrogen	7	28
Dissolved reactive phosphorus	13	69
Total phosphorus	18	56
Metolachlor	51	33
Simazine	21	38
Atrazine	83	84
All sampling periods (n = 24)		
Discharge	17	17
Suspended solids	30	204
Nitrate-nitrogen	8	36
Total nitrogen	10	33
Dissolved reactive phosphorus	21	91
Total phosphorus	31	95
Metolachlor	6	58
Simazine	80	69
Atrazine	6	66

to atrazine application. Pesticide measurements collected during the period of record (2005 to 2006) reflect the treatment period. Having the treatment period precede the before or calibration period is not the ideal situation, but it is a valid approach (Clausen and Spooner 1993). It is anticipated that once compensation for alternative herbicides expires, the farm operators will resume the use of atrazine, thus permitting the calibration period to be quantified. During this study period (2005 to 2006), simazine was one of the acceptable alternative herbicides for use as part of the special Environmental Quality Incentives Program. Significant relationships for simazine were observed for both watershed pairs during the growing season. Thus, alterations in simazine application or implementation of practices that would affect simazine transport should be detectable and quantifiable.

The majority of chemical response variables did not exhibit a significant correlation ($p < 0.05$) between watershed differences and time period (table 3). Three significant correlations between differences in water chemistry response variables and time period were observed in unchannelized watersheds, and none were observed in channelized watersheds. Specifically, atrazine exhibited an increasing trend ($p < 0.05$) while DRP and TP exhibited a decreasing trend in the difference between unchannelized watersheds (table 3). These results suggest that observed changes in atrazine, DRP, and TP following implementation of conservation practices aimed at impacting nutrient and pesticide losses within unchannelized streams may not be solely attributable to the practices. If future management changes result in significant reductions in these three response variables, additional analysis may be required to isolate and attribute the findings solely to the conservation practices.

Table 4 shows that minimum percent change required to detect a significant treatment effect for suspended solids within the channelized pair during the nongrowing season was less than the growing season. In contrast, the minimum percent change for suspended solids in the unchannelized watersheds during the nongrowing season was nearly an order of magnitude greater than that during the growing season. The minimum percent change for nutrients was less during the nongrowing season compared to the growing season for both watershed pairs (table 4). The percent change required for pesticides varied by season and watershed pairs. In the channelized watersheds, the minimum percent change for metolachlor and atrazine during the growing season was less than the nongrowing season with simazine exhibiting the opposite seasonal trend in the channelized watersheds. The minimum percent change for atrazine during the growing season was slightly less than the nongrowing season within the unchannelized watersheds (table 4). With the exception of metolachlor and atrazine for channelized watersheds, and suspended solids and atrazine for unchannelized watersheds, all water chemistry response variables showed a smaller minimum percent change required for the nongrowing season compared to the growing season. Increasing the sample size (e.g., combining the growing and nongrowing season data) did not substantially decrease the minimum percent change required for the majority of the water chemistry variables (table 4).

These findings suggest that changes resulting from planned conservation practices aimed at reducing pollutant loadings will be easier to detect in the channelized watersheds compared to the unchannelized watersheds. This may be a result of more consistent similarity in watershed size and shape parameters, landuse and soil characteristics. For example, if nitrate-nitrogen was the pollutant of inter-

Figure 7

Monthly NO_3-N, total nitrogen, dissolved reactive phosphorus, and total phosphorus relationships between channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed for the 2005 and 2006 growing (solid circles) and nongrowing seasons (open circles).

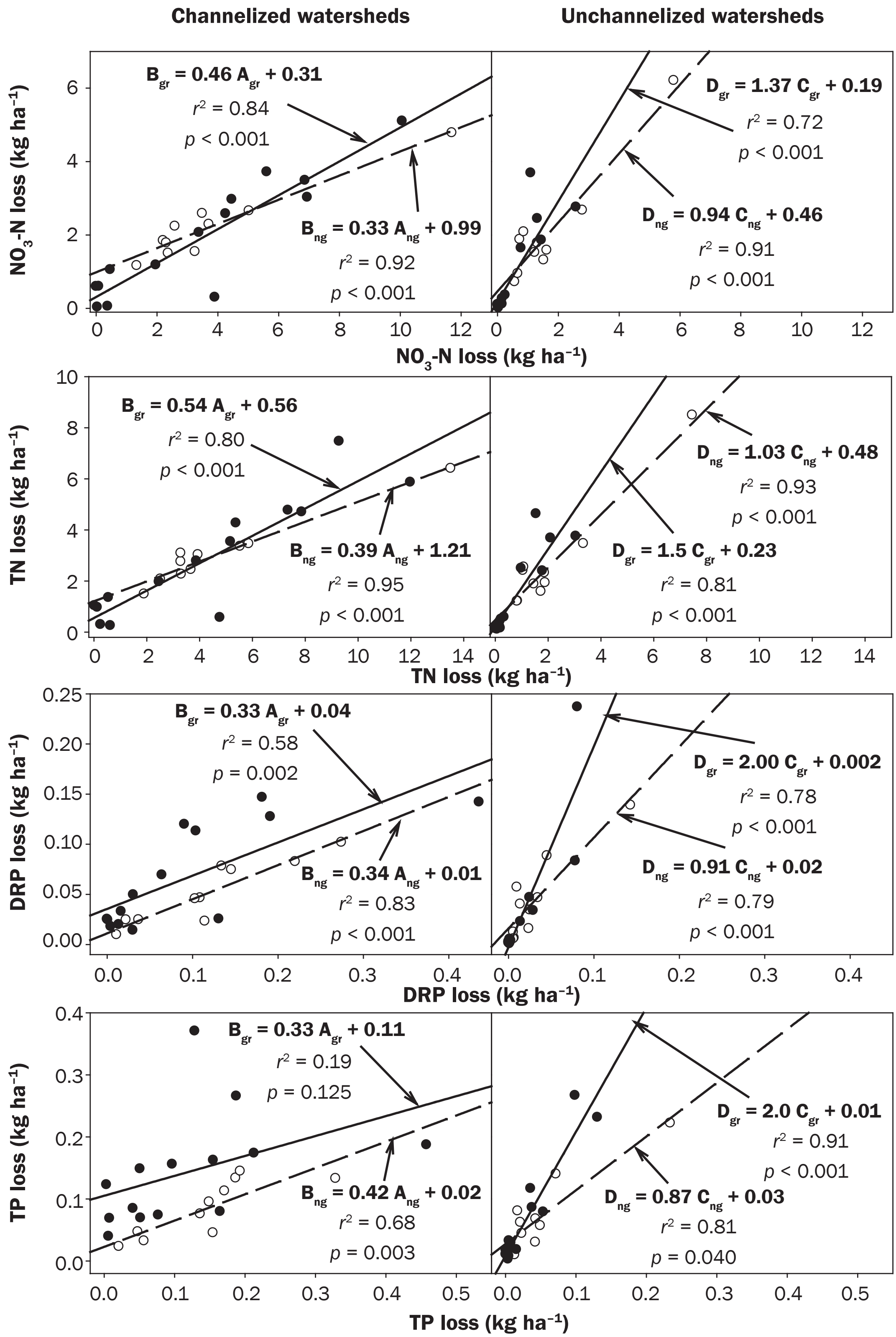
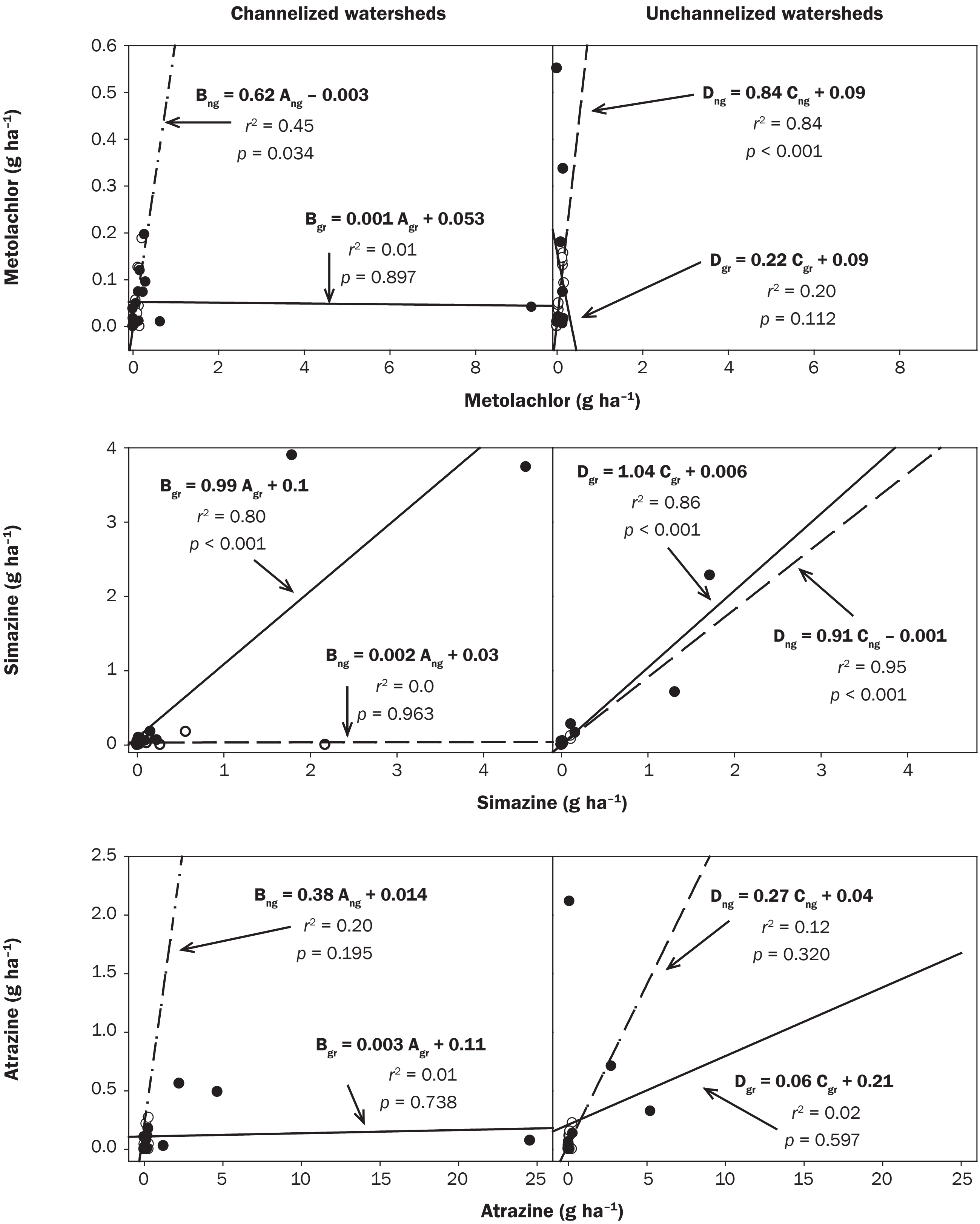


Figure 8

Monthly metolachlor, simazine, and atrazine relationships between channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed for the 2005 and 2006 growing (solid circles) and nongrowing seasons (open circles).



est, then in order to measure a significant ($p < 0.05$) impact throughout the year, a planned conservation practice would need to reduce the loading by 8% in the channelized watershed compared to 36% in the unchannelized watershed. The above findings also suggest that changes resulting from planned conservation practices will be easier to detect during the nongrowing season compared to the growing season. If only the growing season was of interest, reductions for nitrate-nitrogen would need to be 16% for the channelized watersheds and 100% for the unchannelized watersheds. Similarly, if only impacts during the nongrowing season were of interest, a 9% reduction would be required for the channelized watersheds compared to 31% for the unchannelized watersheds. The variability in effect size required to measure differences in the growing and nongrowing seasons were attributed to vegetation, management, and storm types and intensity differences in the two seasons.

Table 5
Simple regression, Daniels Test for Trend, and minimum percent change analysis results for fish community response variables in channelized and unchannelized watershed pairs within the Upper Big Walnut Creek watershed.

Statistical test and response variables	Channelized	Unchannelized
Regression correlation coefficients		
Species richness	**0.826**	0.697
Abundance	−0.241	0.373
Percentage headwater fishes	0.560	**0.907**
Percentage omnivores	0.022	**0.844**
Percentage insectivores	−0.516	0.705
Daniels Test for Trend correlation coefficients		
Species richness	0.441	0.116
Abundance	0.200	−0.143
Percentage headwater fishes	−0.314	−0.771
Percentage omnivores	0.543	0.257
Percentage insectivores	**−0.943**	−0.771
Minimum percent change		
Species richness	29	37
Abundance	276	116
Percentage headwater fishes	<1	<1
Percentage omnivores	<1	3
Percentage insectivores	<1	<1

Note: Bolded values indicate a significant correlation coefficient ($p < 0.05$).

Fish Communities. For simple regression analysis, the only significant correlation ($p < 0.05$) between channelized watersheds was a positive correlation in fish species richness (table 5). Significant positive correlations in percentage headwater fishes and percentage omnivores were observed within unchannelized watersheds (table 5). In addition, only fish species richness for the channelized watersheds had a correlation coefficient greater than 0.6; however, four fish community response variables for the unchannelized watersheds had correlation coefficients greater than 0.6. The Daniels Test for Trend ($p < 0.05$) indicated that only the percentage insectivores fish community response variable within channelized watersheds exhibited a significant (negative) trend during the first two years of sampling. Species richness and abundance response variables indicate larger effect sizes will be required to detect changes resulting from implementation of conservation practices compared to percentage headwater fishes, omnivores, and insectivores. Additionally, the effect size of fish community response variables within the channelized watersheds may need to be larger than the effect sizes required within unchannelized watersheds. Because of the high correlation (at least for unchannelized watersheds) and the lack of trends for both the channelized and unchannelized watersheds, the correlation results (table 5) suggest that the fish community response variables should be suitable for evaluating the effects of conservation practices in the UBWC watershed with the paired watershed experimental design.

The greatest minimum percent change required was observed for fish abundance in both watershed pairs (table 5). The remaining fish community response variables had a minimum percent change of less than 40% in both watershed types and were comparable to values observed for the hydrology and water chemistry variables in table 4. Similar to the correlation results, the minimum percent change results in table 5 imply that fish community responses to conservation practices with the use of the paired watershed design will be feasible. Despite the expected variability in ecological response variables, even minor changes to the fish community response variables induced by conservation practices should be detectable.

Summary and Conclusions

Combined hydrology, water chemistry, and ecology assessments are needed to provide a comprehensive understanding of the impact of soil and water conservation practices on agricultural watersheds. Hydrology, water chemistry, and fish community data were collected from one channelized pair and one unchannelized pair of watersheds in the Upper Big Walnut Creek, Ohio, watershed during 2005 and 2006 to validate a paired watershed design for future assessment of conservation practices. A unique approach that included four different analyses was used to validate the two pairs of watersheds. The four criteria used in the validation approach were to investigate: (1) similarity in physical aspects of the watersheds, (2) correlations between control and treatment watersheds for each response variable, (3) temporal trends in response variable differences between paired watersheds, and (4) minimum percent differences required to detect a significant change resulting from the treatment. Based on this two-year data set and subsequent analysis, the following summary points for each of the above criteria can be highlighted:

- The similarity analysis, while simplistic, confirms the qualitative assessment of the watersheds prior to selection and instrumentation of the watersheds. The channelized pair was generally more similar than the unchannelized pair. The similarity in watershed physical characteristics, land use, and soils within each watershed pair supports the selection of these experimental watersheds. Based on watershed similarity, measured differences in paired watershed hydrology, water chemistry, and stream communities following implementation of conservation practices should primarily be a result of management practices rather than an impact of large-scale differences in watersheds. The similarity also suggests that if management practices are similar within paired watersheds, then well-defined relationships in hydrology, water chemistry, and ecological response variables should also be expected.

- Moderate correlations ($r > 0.6$) were observed for the majority of the hydrology, water chemistry, and fish community response variables in both channelized and unchannelized paired watersheds. Correlations were generally stronger in the unchannelized watersheds compared to the channelized watersheds. The strongest correlations were found for the hydrology and sediment/nutrient load variables. Pesticides had the weakest relationships, which were partially a result of on-going treatments in the watershed pairs. The moderate relationships for hydrology, sediment, and nutrients suggest that minimal to moderate effect sizes will be required to detect significant ($p < 0.05$) change. It was speculated that longer data sets and/or the ability to analyze annual results may improve the correlations.
- Differences in most response variables between paired watersheds did not exhibit significant temporal trends. More temporal trends were detected in the unchannelized watershed pair than the channelized watershed pair. Detection of a trend does not negate the use of a particular response variable for that watershed pair. Instead, it suggests that additional analyses should be performed before attributing shifts in the response variable solely to the treatment.
- The estimated effect sizes required to detect a significant impact of conservation practices was less for the channelized watersheds than the unchannelized watersheds. There was also a noted difference between the growing and nongrowing seasons. The differences were most likely a result of differences in crops and management, riparian vegetation, and seasonal storm types and intensities. A range of effect sizes was estimated and was dependent upon the specific response variable. Based on the estimated effect sizes, the likelihood of detecting significant ($p < 0.05$) changes following implementation of conservation practices is somewhat small except for a small subset of response variables. Even though the treatment response may or may not be significant, quantification of the treatment can still be accomplished.

Overall, these findings validate the suitability of the paired watersheds for future assessment of soil and water conservation practices targeted to impact hydrology, suspended solids, nutrient and pesticide loss, and fish communities. However, it should be noted that within each watershed pair, investigation of the validation criteria was somewhat mixed depending on the selected response variable. These mixed responses suggest future interpretation of the responses may require additional analyses to confirm the observed result from the paired watershed analyses. Validating the suitability of the paired watersheds provides confidence in future assessments of conservation practices within these subwatersheds.

In addition to the implications for future studies within the Upper Big Walnut Creek, this study also possesses some broader implications for investigators studying the watershed scale impacts of conservation practices. First, this study identifies water quantity/quality and fish community response variables that will be most effective in detecting impacts of conservation practices and other watershed alterations on headwater watersheds in the Midwestern United States. Specifically, this research highlights the need to be comprehensive in selecting response variables in order to obtain holistic understanding of the impacts of conservation practices. Secondly, the results suggest that the paired design will be an effective design for headwater watersheds in the Midwestern United States, with the requirement that care must be taken to ensure that watershed pairs are as similar as possible with respect to watershed characteristics and management. Finally, the unique validation approach and statistical analyses outlined in this manuscript may be a useful technique for other scientists planning to use the paired design to assess the impacts of conservation practices.

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