Reprinted from the *Journal of Environmental Quality*

Stream-Watershed Relations in the Missouri Ozark Plateau Province[1]

MILES M. SMART, JOHN R. JONES, AND JEANNE L. SEBAUGH[2]

ABSTRACT

Water chemistry and algal chlorophyll values in Missouri Ozark streams were more strongly related to land-use practices on the watershed than bedrock geology or soil association. In general, concentrations of nutrients, chlorophyll, and most major ions were lowest in streams draining forests, intermediate in streams draining pastures, and highest in streams draining urban areas. In streams draining both forest and pasture areas, there was an exponential increase in the concentration of total P, total N, NO_3^--N, Na^+, Cl^-, and suspended chlorophyll *a* with an increase in percent pasture area on the watershed. These relations help identify the relative importance of land use on water chemistry and algal chlorophyll values, explain differences among streams in the region and enable us to approximate the impact of forest-pasture conversion on streams not yet affected.

Additional Index Words: land use, water chemistry, algal chlorophyll.

Smart, M. M., J. R. Jones, and J. L. Sebaugh. 1985. Stream-watershed relations in the Missouri Ozark Plateau Province. J. Environ. Qual. 14:77-82.

Watershed characteristics in the Missouri Ozark Plateau Province were examined to determine how land use practices (urban, pasture, and forest) and edaphic factors (bedrock geology and soil type) were related to water chemistry and algal chlorophyll values in streams of this region. The study was conducted because extensive tracts of forests in the Ozarks have been converted to pastures and urban area with unquantified effects on the streams. Our working hypothesis was that differences in limnological characteristics among streams could be related to differences in land use on their watersheds. This hypothesis is based on recent advances in stream ecology that have demonstrated that chemistry and productivity of streams are related to watershed characteristics and that land use can have a major effect on water quality (e.g., Likens et al., 1977; Hirose & Kuramoto, 1981).

METHODS AND MATERIALS

Twenty-one stations on 17 streams in an 11 county area of the Missouri Ozark Plateau Province were sampled from June 1978 to September 1979 (Fig. 1). Watersheds and streams were selected to represent the range of water quality and watershed conditions found in this region. Nine streams drained watersheds that had a uniform land use (either urban, pasture, or forest), bedrock geology, and soil association (Table 1). Each of the other 12 watersheds were composed of various combinations of urban, pasture, and forest areas that were 94 to 100% of a watershed (Table 2); remaining areas were primarily used for small-grain crops (e.g., winter wheat [*Triticum aestivum* L.] or oats [*Avena sativa* L.], but not row crops). Pasture and forest areas on the 21 watersheds ranged from 0 to 100%. Urban areas, however,

Table 1. Land use, geology, and soil associations of single land-use (reference) watersheds in the Missouri Ozarks.

Land use on the watershed	Bedrock geology	Soil association†	Area (km^2)
Urban 1	Limestone	VP	8.7
Urban 2	Limestone	VP	11.2
Urban 3	Limestone	VP	19.2
Forest 1	Dolomite	CL	1.1
Forest 2	Dolomite	CL	10.7
Forest 3	Dolomite	CL	12.3
Pasture 1	Limestone	VP	2.8
Pasture 2	Limestone	LC	5.8
Pasture 3	Limestone	LC	3.4

† From Scrivner et al., 1975. VP = Viration-Wilderness-Nixa-Clarksville and Pembroke-Wilderness-Goss; LC = Noedleye-Viration-Wilderness-Clarksville and Bado-Lebanon-Wilderness-Clarksville; CL = Lebanon-Wilderness-Clarksville-Goss-Bardley and Hobson-Coulstone-Clarksville.

[1] Contribution from the Missouri Agric. Exp. Stn. Journal Series no. 8646, Univ. of Missouri, Columbia, MO 65211. This research was supported by the Missouri Water Resour. Res. Center, Dep. of the Interior (Project no. A-111, MO), Missouri Agric. Exp. Stn. (Project no. 175), the Missouri Dep. of Conserv. and the Missouri Coop. Fishery Res. Unit. Received 1 Aug. 1983.

[2] Graduate research assistant, professor of fisheries and wildlife, and statistician, Agric. Exp. Stn., Univ. of Missouri, Columbia, respectiely. Current address of senior author is River Studies Center, Cowley Hall, Univ. of Wisconsin, La Crosse, WI 54601. Current address of last author is Statistical Reporting Service, USDA, Federal Building, Columbia, MO 65201.

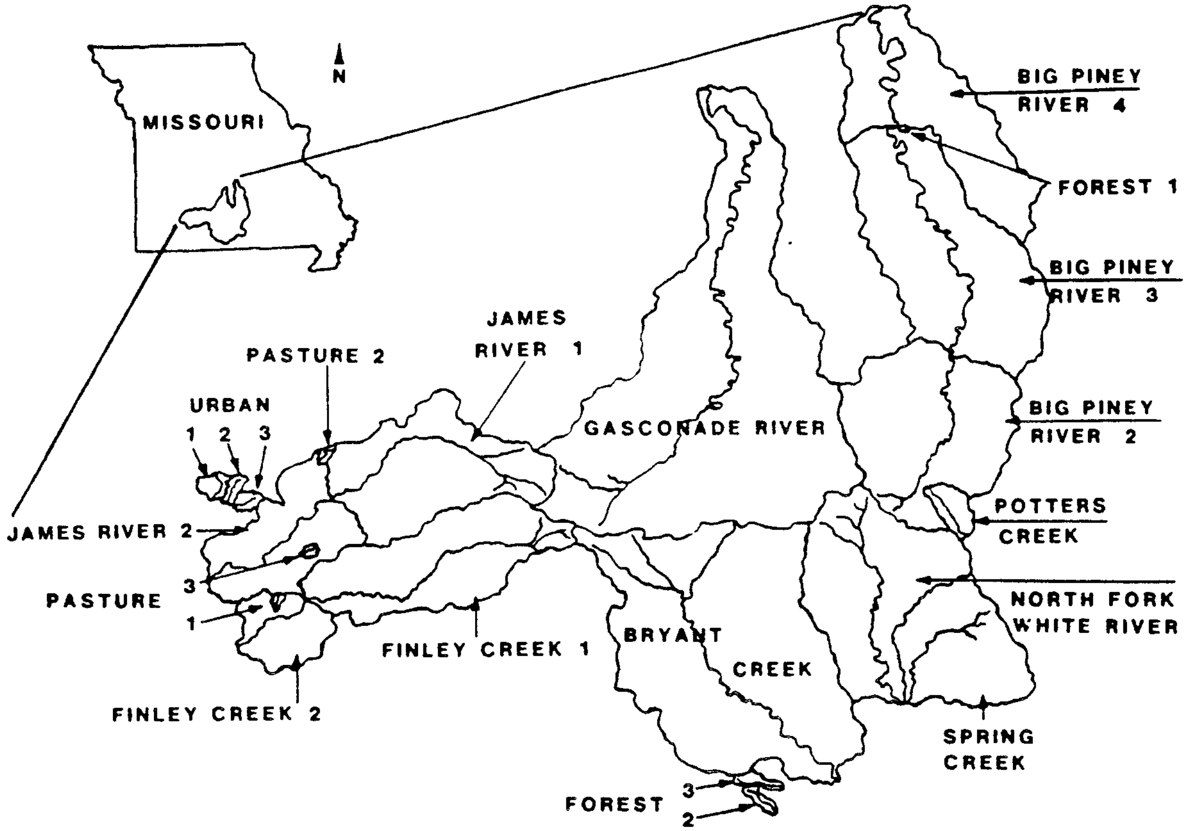

Fig. 1. Streams and watersheds in Missouri's Ozark Plateau Province.

occupied from 0 to 9% or 100% of any given watershed. The forested areas were mainly on dolomite watersheds and urban and pasture areas were primarily on limestone watersheds. Information on land use, bedrock geology, and soil associations were determined as described by Smart et al. (1981). Stream characteristics are given in Smart (1980) and Jones et al. (1981, 1984). There were no known anthropogenic point-source inputs of wastewater within the sampled reach of these streams.

Water was collected at middepth in the thalweg. Analyses were conducted within time limits specified in USEPA (1974) by the methods given in Table 3. All stream variables except temperature, turbidity, dissolved oxygen, alkalinity, and Ca were positively skewed and

Table 2. Area, land use (as percent), and mean concentration of water chemistry variables† in streams draining watersheds with several land uses in the Missouri Ozarks, summer 1979.

Area, land use, and variable	Sampling location: James River, site 1	James River, site 2	Finley Creek, site 1	Finley Creek, site 2	Bryant Creek	Spring Creek	Potters Creek	North Fork, White River	Big Piney River, site 2	Big Piney River, site 3	Big Piney River, site 4	Gasconade River
Area, km^2	451.3	750.1	448.2	582.8	1165.3	303.1	38.3	486.1	544.6	1220.9	1679.5	1663.3
Urban, %	0.7	8.9	1.2	1.4	0.2	0.1	0	0.1	3.0	1.4	4.1	0.4
Pasture, %	62.1	65.5	70.3	73.9	33.4	13.6	34.1	39.8	49.3	33.8	27.6	55.4
Forest, %	37.0	24.4	24.1	20.6	65.5	86.3	59.9	59.4	45.6	63.5	67.2	40.3
Total P, mg/L	0.039	0.054	0.029	0.065	0.025	0.016	0.014	0.019	0.031	0.027	0.058	0.039
Total dissolved P, mg/L	0.027	0.031	0.018	0.049	0.010	0.012	0.008	0.013	0.019	0.018	0.047	0.025
Total N, mg/L	1.94	2.56	1.79	2.03	1.18	1.29	1.14	1.41	1.74	1.11	1.42	1.34
NO_3^--N, mg/L	0.45	0.79	0.52	0.62	0.22	0.21	0.23	0.17	0.20	0.14	0.16	0.17
NO_2^--N, mg/L	0.01	0.01	0.01	0.01	0.01	–‡	0.01	0.01	0.01	0.01	0.01	0.01
NH_4^+-N, mg/L	0.02	0.02	0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02
Ca^{2+}, mmol/L	0.88	1.14	1.07	1.14	0.92	0.75	0.51	0.77	0.82	0.65	0.66	0.76
Mg^{2+}, mmol/L	0.41	0.27	0.31	0.22	0.84	0.77	0.40	0.70	0.84	0.65	0.63	0.77
Na^+, mmol/L	0.13	0.17	0.11	0.12	0.03	0.02	0.04	0.03	0.11	0.06	0.07	0.09
K^+, mmol/L	0.08	0.08	0.07	0.08	0.06	0.04	0.05	0.05	0.07	0.06	0.06	0.08
Alkalinity, mg/L	131.0	145.5	140.0	138.5	190.5	154.5	112.0	161.0	171.5	139.5	135.5	153.0
SO_4^{2-}, mmol/L	0.05	0.11	0.01	0.02	0.01	0.01	0.04	0.03	0.04	0.08	0.06	0.03
Cl^-, mmol/L	0.15	0.15	0.12	0.15	0.06	0.03	0.07	0.05	0.08	0.13	0.09	0.12
SiO_2, mg/L	18.5	19.7	17.1	17.6	15.2	16.4	13.7	15.0	15.3	14.4	14.0	16.0
Turbidity, NTU§	3.4	11.9	2.2	4.9	1.9	0.7	0.6	1.3	1.4	2.5	3.5	5.6
Chlorophyll *a*												
Benthic, mg/m^2	43.0	–¶	31.3	52.3	132.8	63.8	48.3	61.9	62.1	29.8	36.9	64.6
Suspended, $\mu g/L$	3.8	8.7	2.3	3.5	3.3	1.6	1.5	1.9	4.1	2.6	3.3	3.8

† Geometric means for all variables except arithmetic means for Ca^{2+}, alkalinity, and turbidity.
‡ Concentration < 0.01 mg/L. § Nephelometric turbidity units. ¶ No data for this site.

Table 3. Stream variables analyzed and methods employed in the study of Ozark streams.

Variable	Units	Method	Reference
Alkalinity	mg/L	Potentiometric	USEPA, 1974
Calcium (Ca^{2+})	mmol/L	Atomic absorption	APHA, 1976
Chloride (Cl^-)	mmol/L	Titrimetric-mercuric nitrate	USEPA, 1974
Chlorophyll *a*			
Benthic	mg/m²	Trichromatic method	Yentsch & Menzel, 1963
Suspended	µg/L		Jeffrey & Humphrey, 1975
Magnesium (Mg^{2+})	mmol/L	Atomic absorption	APHA, 1976
Nitrogen			
Ammonia (NH_4^+-N)	mg/L	Electrometric	USEPA, 1974
Nitrate (NO_3^--N)	mg/L	Colorimetric-Hydrazine reduction	Barnes, 1959
Nitrate (NO_2^--N)	mg/L	Colorimetric-buffer color reagent	USEPA, 1974
Total	mg/L	Electrometric-persulfate oxidation	D'Elia et al., 1977
pH		Electrometric	APHA, 1976
Phosphorus			
Total dissolved	mg/L	Colorimetric-filtration, persulfate oxidation, ascorbic acid	USEPA, 1974
Total	mg/L	Colorimetric-persulfate oxidation, ascorbic acid	USEPA, 1974
Potassium (K^+)	mmol/L	Atomic emission	APHA, 1976
Silica (SiO_2)	mg/L	Colorimetric-molybdosilicate	APHA, 1976
Sodium (Na^+)	mmol/L	Atomic emission	APHA, 1976
Sulfate (SO_4^{2-})	mmol/L	Turbidimetric-barium sulfate	APHA, 1976
Temperature	°C	Glass thermometer	APHA, 1976
Turbidity	NTU†	Nephelometric	APHA, 1976

† Nephelometric turbidity units.

leptokurtic. These variables were transformed with $\log(x + 1)$ to satisfy normality assumptions of parametric statistical procedures. Relations between watershed characteristics and stream water chemistry and algal chlorophyll values were analyzed with a univariate analysis of variance, linear regression analysis, and multiple discriminant function analysis (MDFA) (Cooley & Lohnes, 1971; Helwig & Council, 1979). Data from stations located on the same stream (Table 2) were examined for auto-correlation and were determined not to influence correlation or regression analysis. Differences were considered statistically significant at $p \leq 0.05$.

Streams draining watersheds with a single land use, bedrock geology, or soil association were used as reference streams to describe relations between streams and their watersheds. Comparisons of water chemistry and chlorophyll values were made among the reference streams and between the reference streams and those streams draining watersheds with more than one land-use type (multiple land-use watersheds). To minimize the effect of temporal variation in these analyses, the data for all streams during both years were divided into seasons on the basis of sample date and water temperatures: 4 to 12°C in spring (3 March–14 May), 13 to 25°C in summer (15 May–8 September), and 8 to 16°C in autumn (9 September–19 December). Within these periods, streams were sampled approximately every 7 to 10 d. Samples were not collected during winter. Data were analyzed by season within year; when relations were consistent among the analyses, the summer 1979 data are presented as an example.

RESULTS AND DISCUSSION

Influence of Watershed Characteristics on Stream Water Chemistry

Water chemistry data from the reference streams were initially analyzed with MDFA to determine whether the streams would group according to land use, bedrock geology, or soil association. The MDFA computes canonical variables that are linear combinations of the water chemistry variables that maximize the differences between streams. Water chemistry variables in Table 4 were used as the discriminating variables and each data point consisted of the set of values observed on a given day during summer 1979.

For each season we found that streams that drained urban watersheds (hereafter referred to as urban streams) were grouped together and were distinctly separate from streams that drained forest watersheds (forest streams) and streams that drained pasture watersheds (pasture streams; Fig. 2a). Likewise, the three forest streams and three pasture streams were conjointly grouped, but were separate from urban streams. Because of the distinct classification, land use is considered the watershed characteristic having the strongest association with water chemistry. Had geology been the watershed characteristic most related to chemical concentrations, stream variables would have classified watersheds into two groups: limestone or dolomite. And, had soils been most strongly related to water chemistry, groupings would have been according to soil association (Table 1).

Table 4. Mean concentration of water quality variables in streams draining single land use watersheds in the Missouri Ozarks during summer 1979.

Variable		Land use: Urban $n = 45$	Pasture $n = 45$	Forest $n = 32$
Total P†	mg/L	0.106	0.046	0.020
Total dissolved P	mg/L	0.079	0.031	0.014
Total N	mg/L	11.5	3.37	0.92
NO_3^--N	mg/L	2.14	1.32	0.02
NO_2^--N	mg/L	0.10	0.01	0.01‡
NH_4^+-N	mg/L	0.10	0.02	0.02
Ca^{2+}	mmol/L	1.73	1.55	1.02
Mg^{2+}	mmol/L	0.28	0.13	0.94
Na^+	mmol/L	0.74	0.20	0.02
K^+	mmol/L	0.26	0.14	0.06
Alkalinity	mg/L	164.5	166.5	215.5
SO_4^{2-}	mmol/L	0.39	0.02	0.02
Cl^-	mmol/L	1.27	0.20	0.05
SiO_2	mg/L	17.3	19.9	17.3
Turbidity	JTU	6.0	3.4	1.1
Chlorophyll *a*				
Benthic	mg/m²	46.6	41.1	16.1
Suspended	µg/L	3.0	4.3	1.3

† Geometric means for all variables except arithmetic means for Ca^{2+}, alkalinity, and turbidity.
‡ Underlined means are not different at the 0.05 level of significance using a least significant difference test.

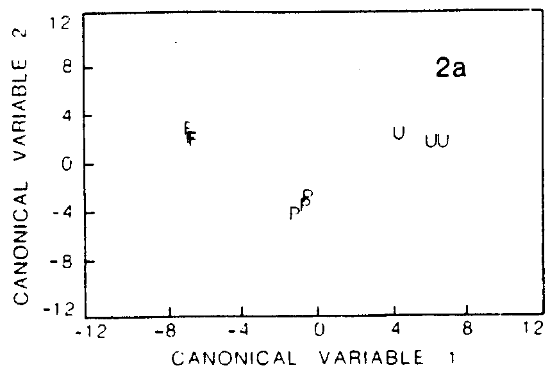

Fig. 2a. The separation of Ozark reference streams on the first two canonical variables based on 17 water chemistry variables. Mean values for summer 1979 are given for each stream where *F* = forest stream, *P* = pasture stream, and *U* = urban stream.

The importance of the various water chemistry variables in discriminating between reference streams can be evaluated with the total structure coefficients between each individual water chemistry variable and each canonical variable. Differences in the concentrations of Na^+, SO_4^{2-}, NO_3^--N, Cl^-, total N, Ca^{2+}, NO_2^--N, and total P among the nine reference streams were most important in the separation along horizontal axis (Table 5; canonical variable 1 in Fig. 2a). Differences in concentrations of Mg^{2+}, SO_4^{2+}, SiO_2, and NO_3^--N were most important in the separation of the stream types along the vertical axis (canonical variable 2 in Fig. 2a).

Concentration of Chemicals in Streams

SINGLE LAND-USE WATERSHEDS

The classification of streams based on land use was not surprising because of consistent differences in chemical concentrations and algal chlorophyll values among the reference streams (Table 4), and because of the established link between land use and stream water chemistry in other geographic areas (e.g., Haith, 1976; Hirose & Kuramoto, 1981). Certain variables differed by an order of magnitude or greater among the stream types. Differences were especially evident in concentrations of the variables that were important discriminating variables in the MDFA (Table 5). In general, concentrations were lowest in forest streams, intermediate in pasture streams, and highest in urban streams.

Nitrate and SO_4^{2-} are examples of ions that were differentially related to land use in a way that made the reference streams distinct from each other (Table 4). Urban streams were characterized by high NO_3^--N and SO_4^{2-} concentrations, pasture streams had high NO_3^--N and low SO_4^{2-} concentrations, and concentrations of both chemicals were comparatively low in forest streams. In a multiple discriminant function analysis, with land use as the criterion, measurements of these two chemicals alone provided enough information to correctly separate and classify the streams 83 to 98% of the time, depending on the season.

Table 5. Total structure coefficients between the discriminating variables and the first two canonical variables for the multiple discriminant function analysis among reference streams in summer 1979.

Variables	Canonical variable 1 (*x* axis)	Canonical variable 2 (*y* axis)
Total P	0.60	--†
Total dissolved P	0.57	--
Total N	0.71	--
NO_3^--N	0.78	−0.46
NO_2^--N	0.61	--
NH_4^+-N	0.38	--
Ca^{2+}	0.69	−0.26
Mg^{2+}	−0.55	0.71
Na^+	0.90	--
K^+	0.40	--
Alkalinity	−0.44	0.27
SO_4^{2-}	0.80	0.47
Cl	0.73	0.28
SiO_2	--	−0.45
Turbidity	--	--
Chlorophyll *a*		
Benthic	0.33	--
Suspended	0.25	−0.38

† Not significant at $P \leq 0.01$.

The order of magnitude differences in the concentrations of NO_3^--N and SO_4^{2-} among stream types may be related to cycling processes of these elements on the watersheds. In deciduous forests, most N is in soil organic matter and vegetation and it turns over slowly so that only small amounts of N are susceptible to loss from the system (Mitchell et al., 1975; Vitousek et al., 1979). The potential for nutrient loss on watersheds that are continually subjected to change, such as urban and pasture, is increased through accelerated turnover, mineralization and nitrification, and reduced vegetative uptake (Vitousek & Melillo, 1979). Low SO_4^{2-} concentrations in forest and pasture streams are expected because S is accumulated by chemical immobilization in soils and a relatively minor amount is cycled by the vegetative components (Johnson et al., 1981). The high concentration of SO_4^{2-} in urban streams is probably due to nonpoint anthropogenic sources.

There were also significant differences in the concentrations of Na^+ and Cl^- among the three stream types (Table 4) so that in a MDFA, with land use as the criterion, these two variables alone correctly classified the streams 83 to 100% of the time, depending on the season. The high concentrations in urban streams are attributed to anthropogenic inputs (Feth, 1981). The greater chemical content of pasture streams is likely the combined response from an absence of vegetation (Likens et al., 1977) and inputs from agricultural activities such as grazing livestock (Smolen & Shanholtz, 1980; Scheppers & Francis, 1982).

Not all chemical concentrations in the streams were, however, related to land use practices; some were related to bedrock geology. Concentrations of Mg^{2+} and alkalinity were greatest in streams that were underlain with dolomite. These streams also drained forested watersheds (Table 1). Forest streams contained equal concentrations of Ca^{2+} and Mg^{2+} (Ca^{2+}/Mg^{2+} ratio = 1.05, Table 4), which is the approximate proportion of these elements expected from the weathering of dolomite. In contrast, the other stream types were underlain primarily by limestone ($CaCO_3$, Table 2) and had runoff containing Ca^{2+} in excess of Mg^{2+} (Ca^{2+}/Mg^{2+} ratio = 5.8 in urban and 11 in pasture streams). Differences in alkalinity were likely the result of differences in the concentration of $Mg(HCO_3)_2$ among stream types. Magnesium compounds are generally more soluble than their calcium counterparts.

MULTIPLE LAND-USE WATERSHEDS

The mean concentration of chemicals in streams draining watersheds with more than one land-use type was generally intermediate between concentrations measured in forest and pasture streams and least similar to the urban streams (Tables 2 and 4). Water chemistry in Ozark streams varied along a continuum according to land-use practices on the watersheds. The MDFA (Fig. 2b) demonstrates that streams with more than one land use on the watershed were grouped intermediate to the forest and pasture streams and were distinctly separate from the urban streams. The variables in Table 2 were used as the discriminating variables in this anlaysis. Streams with > 40% forest on their watershed were similar to one another and were positioned closer to forest streams than those with ≥ 60% pasture area (Fig. 2b).

To examine more closely the influence of forest and pasture land-use practices on stream water chemistry and chlorophyll values, watersheds with > 1.4% urban area were eliminated from the analysis (James River site 2, Big Piney sites 2 and 4, and urban streams). This provided a range of land uses from 0 to 100% pasture and 0 to 100% forest with no watershed having > 1.4% urban area (Tables 1 and 2). Seasonal mean values of water chemistry and chlorophyll were then used to characterize the limnological condition of the various streams in correlation and regression analyses against land use. This approach to assessing stream-watershed relations emphasizes comparisons across stream systems by focusing on variation among streams to determine large-scale generalizations (Collins & Sprules, 1983).

A strong correlation was found between the mean concentration of total P, total N, NO_3^--N, Na^+, Cl^-, and suspended chlorophyll *a* in these streams and the percent pasture on the watershed during summer 1979 (Fig. 3). These relations are exponential [thus, the log(x + 1) transformation of the y-axis]; intercepts (0% pasture) approximate mean values measured in the forest streams (Fig. 3, Table 4). Because of the nature of these relations, the actual increase in the concentration of these variables with an increase in pasture is not as great between 0 and 40% pasture as it is between 40 and 100% pasture. Therefore, the effect that additional pasture area will have on stream water chemistry and chlorophyll values depends on the relative proportion of forest and pasture areas on the watershed.

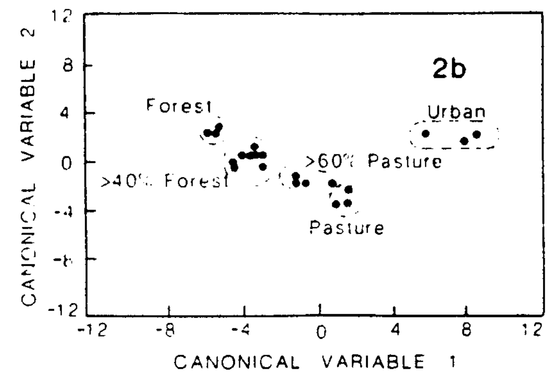

Fig. 2b. The separation (and relationship) of Ozark streams along a continuum of land uses on the first two canonical variables based on 17 water chemistry variables. Mean values for summer 1979 are given for each stream with stream enclosed by dashed lines having similar types of land use.

Analyses of data from other seasons resulted in regression equations with slopes that were similar to those obtained for the summer 1979 data. The similarity of the slopes indicates that relations between land use and stream water chemistry are consistent over time. An exception was that only during spring 1979 stream temperature was significantly related to percent pasture area [r = 0.92, °C = 10.0 + 0.04 (% pasture)]. Pasture

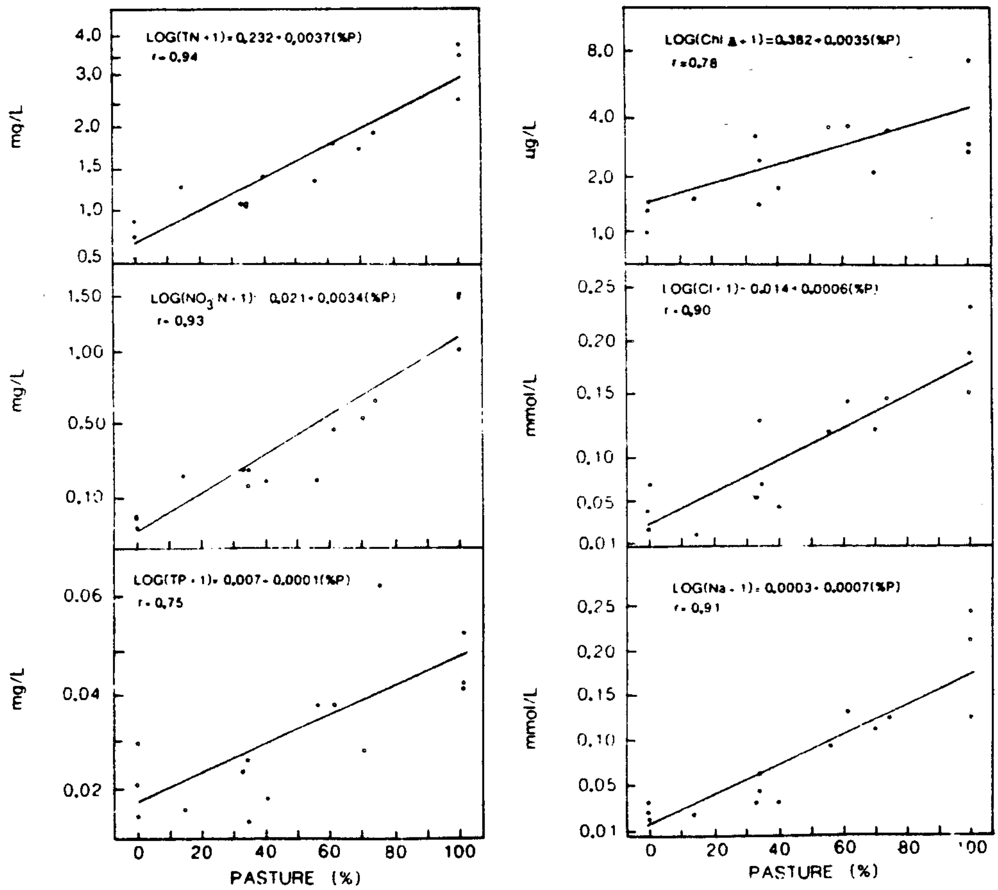

Fig. 3. Linear regressions between mean summer (1979) concentrations of selected water chemistry variables and suspended chlorophyll *a* and pasture area on the watersheds. Each watershed has < 1.4% urban area.

streams likely warm faster in the spring because of less canopy cover and higher soil temperatures. The relation was not significant during summer when mean temperatures in all streams averaged about 20°C.

These relations present a continuum of stream response to forest and pasture land uses that is consistent among seasons and powerful enough to be distinguished from other watershed characteristics contributing to among stream variation in a given season. Such generalizations help identify the relative importance of these land-use practices on water chemistry and algal chlorophyll values and begin to explain differences among streams in the region. In addition, these relations also enable us to approximate the relative impact of forest-pasture conversion on streams not yet affected.

Assessment of Land Use and Stream Ecology

Conventional criteria suggest that canopy cover is a primary determinant of ecological processes in streams by controlling energy input to the system. Headwater streams in forests are generally well shaded and heterotrophic. As stream size increases (orders 4-6), greater insolation is thought to favor autochthonous processes (Vannote et al., 1980), especially when accompanied by increased nutrient concentrations in currents that do not scour algae (Horner & Welch, 1981; Triska et al., 1983; Jones et al., 1984). Our data indicate, however, that land use can also influence autotrophic processes in headwater streams by affecting insolation and nutrient concentrations. During summer 1979, forest streams (canopy cover and low nutrient concentrations, Table 4) had mean benthic and suspended chlorophyll values that were significantly lower than values in urban and pasture streams (generally no canopy and greater nutrient levels; Table 4). All these streams can be considered as headwaters (orders 1-3). These data support the findings of Minshall (1978) that autotrophy is of primary importance in streams where shading by streamside vegetation is minor. We also found suspended chlorophyll and nutrient concentrations in medium-sized Ozark streams (orders 5-6, one 3) increased as a function of percent pasture and decreased as a function of percent forest (Fig. 3). Other factors being equal, streams draining pastures in the Ozarks are more productive than streams draining forests. Thus, within a given region, land use can affect the degree of autotrophic processes and probably the structure and function of the streams.

ACKNOWLEDGMENT

We thank M. Kaiser, T. R. Finger, G. S. Henderson, C. F. Rabeni, and R. G. Rada for their helpful editorial comments and J. N. Burroughs for computer programming.

REFERENCES

American Public Health Association. 1976. Standard methods for the examination of water and wastewater. 14th ed. American Public Health Association, New York.

Barnes, H. H. 1959. Inorganic nitrogen: Nitrate. p. 113-125. *In* Apparatus and methods of oceanography. Interscience Publishers, New York.

Collins, N. C., and W. G. Sprules. 1983. Introduction to large-scale comparative studies of lakes. Can. J. Fish. Aquat. Sci. 40:1750-1751.

Cooley, W. W., and P. R. Lohnes. 1971. Multivariate data analysis. John Wiley & Sons, Inc., New York.

D'Elia, C. F., P. A. Steudler, and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22:760-764.

Feth, J. H. 1981. Chloride in natural continental water—a review. USGS Water-Supply paper 2176. U.S. Geological Survey, Washington, DC.

Haith, D. A. 1976. Land use and water quality in New York rivers. J. Environ. Eng. Div. Am. Soc. Civ. Eng. 102:1-15.

Helwig, J. T., and K. A. Council. 1979. SAS user's guide. Statistical Analysis Systems Institute, Inc., Cary, NC.

Hirose, T., and N. Kuramoto. 1981. Stream water quality as influenced by land use patterns in the Kakioka Basin, Japan. J. Environ. Qual. 10:184-188.

Horner, R. R., and E. B. Welch. 1981. Stream periphyton development in relation to current velocity and nutrients. Can. J. Fish. Aquat. Sci. 38:449-457.

Jeffrey, S. W., and G. F. Humphrey. 1975. New spectrophotometric equations for determining chlorophylls *a, b, c*, and c_2 in higher plants, algae and natural phytoplankton. Biochem. Physiol. Pflanz. 167:191-194.

Johnson, D. W., G. S. Henderson, and D. E. Todd. 1981. Evidence of modern accumulations of adsorbed sulfate in an east Tennessee forested Ultisol. Soil Sci. 132:422-426.

Jones, J. R., M. M. Smart, and J. N. Burroughs. 1984. Factors related to algal biomass in Missouri Ozark streams. Verh. Int. Ver. Theor. Angew. Limnol. 22:(In press).

Jones, J. R., B. H. Tracy, J. S. Sebaugh, D. H. Hazelwood, and M. M. Smart. 1981. Biotic index tested for ability to assess water quality of Missouri Ozark streams. Trans. Am. Fish. Soc. 110:627-637.

Likens, G. E., F. H. Bormann, R. S. Pierce, J. S. Eaton, and N. M. Johnson. 1977. Biogeochemistry of a forested ecosystem. Springer-Verlag, New York.

Minshall, G. W. 1978. Autotrophy in stream ecosystems. BioScience 28:767-771.

Mitchell, J. E., J. B. Waide, and R. L. Todd. 1975. A preliminary compartment model of the nitrogen cycle in a deciduous forest ecosystem. p. 41-57. *In* F. G. Howell et al. (ed.) Mineral cycling in southeastern ecosystems. Conf. 740513. U.S. Energy Research and Development Administration, Washington, DC.

Scheppers, J. S., and D. D. Francis. 1982. Chemical quality of runoff from grazing land in Nebraska: I. Influence of grazing livestock. J. Environ. Qual. 11:352-354.

Scrivner, C. L., J. C. Baker, and B. S. Miller. 1975. Soils of Missouri—a guide to their identification and interpretation. University of Missouri Extension Division, Columbia, MO.

Smart, M. M. 1980. Stream-watershed relationships in the Missouri Ozark Plateau Province. Ph.D. dissertation. University of Missouri, Columbia.

Smart, M. M., T. N. Barney, and J. R. Jones. 1981. Watershed impact on stream water quality: A technique for regional assessment. J. Soil Water Conserv. 35:297-300.

Smolen, M. D., and V. O. Shanholtz. 1980. Agricultural land use: Effects on the chemical quality of run off. Bull. 125. Virginia Water Resources Research Center, Blacksburg, VA.

Triska, F. J., V. C. Kennedy, R. J. Avanzino, and B. N. Reilly. 1983. Effect of simulated canopy cover on regulation of nitrate uptake and primary production by natural periphyton assemblages. p. 129-159. *In* T. D. Fontaine and S. M. Bartell (ed.) Dynamics of lotic ecosystems. Ann Arbor Science Publishers, Ann Arbor, MI.

U.S. Environmental Protection Agency. 1974. Methods for chemical analysis of water and wastes. USEPA Rep. 624/6-74-003. U.S. Government Printing Office, Washington, DC.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The river continuum concept. Can. J. Fish. Aquat. Sci. 37:130-137.

Vitousek, P. M., J. R. Gosz, C. C. Grier, J. M. Melillo, W. A. Reiners, and R. L. Todd. 1979. Nitrate losses from disturbed ecosystems. Science 204:469-474.

Vitousek, P. M., and J. M. Melillo. 1979. Nitrate losses from disturbed forests: Patterns and mechanisms. For. Sci. 25:605-619.

Yentsch, C. S., and P. W. Menzel. 1963. A method for the determination of phytoplankton chlorophyll and phaeophytin by fluorescence. Deep Sea Res. 10:221-231.