Watershed impact on stream water quality: A technique for regional assessment

Miles M. Smart, Terry W. Barney, and John R. Jones

ABSTRACT: Information on land use, land cover, geologic bedrock, and soil associations for 21 watersheds in the Missouri Ozark Plateau Province was extracted from generalized, readily available maps. Data sources, sampling procedures, and data base development were examined. This information was integrated with observations of stream water chemistry. Land use and cover information and stream water quality observations from the Spring Creek watershed were used to demonstrate a small-scale digital data base approach to a regional stream-watershed investigation.

A marked shift in basic land use patterns has occurred during the past two decades throughout the Missouri Ozark Plateau Province. Extensive tracts of forest have been converted to pasture; light industry has been established; summer-home developments and tourism have increased; and urban development has expanded. Recent research on the effects of watershed characteristics—land use, land cover, geology, soils—on stream water quality, determined that land use practices influence the chemical and algal chlorophyll concentrations in stream water (*14*). Other research found that factors that increase chemical concentrations and algal chlorophyll are associated with stream water quality problems in the Ozarks (*13*).

In the Ozarks, as in other physiographic regions, the watershed determines to a large extent the chemical and biological composition of streams (*4, 10, 11, 14*). An accurate assessment of watershed characteristics, therefore, is required to determine the relationships between watersheds and stream water quality, especially those watersheds that have only diffuse or nonpoint sources of pollution. Resource managers can effectively use detailed watershed data for site-specific analyses. However, regional investigations of multiple watersheds or large land areas often cannot make use of detailed watershed data because compilation and manipulation of the data involved are time-consuming and not cost-effective. Also, detailed information is frequently unavailable.

Our purpose here is to demonstrate the use of general watershed data in assessing the influence of watersheds on stream water chemistry. The Spring Creek watershed in Douglas County, Missouri, one of 21 watersheds in our regional study, serves as an example of how such an assessment can be made.

Study methods

We investigated 21 watersheds and streams in an 11-county region [6,706 square kilometers (2,589 square miles)] of south central Missouri (Figure 1). The watersheds are within the Salem Plateau and Springfield Plateau of the Missouri Plateau Province (*12*). In these watersheds we found 174.7 square kilometers (67.5 square miles) of urban area, 3,419.3 square kilometers (1,320 square miles) of forest, and 2,677.4 square kilometers (1,034 square miles) of pasture. The remaining area was in small-grain crops, winter wheat or oats. There were no row crops.

The largest watershed was 1,663.4 square kilometers (642 square miles), the smallest, 1.1 square kilometers (0.4 square miles). In any given watershed, urban land occupied from 0 to 21 percent of the total area. Three watersheds were 100 percent urban. Pasture and forest occupied from 0 to 100 percent of the total area in a given watershed, while small-grain crops occupied from 0 to 6 percent of a watershed's total area.

Spring Creek is typical of watersheds in the Salem Plateau. There are no known point-sources of chemicals. Land use con-

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

Miles M. Smart, formerly with the University of Missouri School of Forestry, is now a research associate at the River Studies Center, Cowley Hall, University of Wisconsin, La Crosse, 54601. Terry W. Barney is a research associate in the Geographic Resources Center, University of Missouri, Columbia, 65211. John R. Jones is an associate professor in the School of Forestry, Fisheries and Wildlife, 112 Stephens Hall, University of Missouri, Columbia, 65211. *This research was supported by the Missouri Water Resources Research Center, U.S. Department of the Interior (Project No. A-111, MO), Missouri Agricultural Experiment Station (Project No. 1760), Missouri Department of Conservation, and Missouri Cooperative Fishery Research Unit. This paper is a contribution from the Missouri Agricultural Experiment Station. Journal Series Number 8638.*

Reprinted from the Journal of Soil and Water Conservation
September-October 1981, Volume 36, Number 5

sists of 86.3 percent forest, 13.6 percent pasture, and 0.1 percent urban.

Stream water composition. We collected water samples about every 10 days from June 1978 to September 1979 and measured the physical characteristics of the streams according to standard techniques (*1, 5, 7, 16*). Linear regression enabled us to determine relationships between watershed characteristics and stream water composition. We divided the data into seasons to minimize temporal variation and to examine spatial differences with greater confidence. Most stream data were transformed by $\ln (X + 1)$ to satisfy assumptions of these parametric statistical procedures (*14*).

Watershed mapping. We compiled individual maps for each land use and land cover, soil association, and geologic bedrock type found within a watershed. These maps, in a transparent overlay format, were registered to a planimetric base map, digitized, and placed in computer storage. With the resulting data base, we computed the acreage of each characteristic within the watersheds for comparison with stream water chemistry observations.

The watershed characteristics were gathered from readily available, small-scale, generalized data sources. The land use and land cover maps were compiled from land use maps of Missouri prepared by the U.S. Geological Survey's land use and land cover mapping program. USGS data are compiled on planimetric base maps (1:250,000 scale). The classification hierarchy consists of 9 general level-I categories that are subdivided into 37 more specifically defined level-II categories (Table 1).

We used the level-I aggregations with one exception. We subdivided the level-II cropland and hay category into two level-III categories, cropland (grain crops) and hay and pasture. The separation was made using a false-color composite LANDSAT satellite image taken of the area on March 6, 1976. We registered the USGS land use map with the satellite image (1:250,000 scale). Areas on the image that fell within the boundaries of the level-II cropland and pasture category were manually interpreted (*3, 6*) to make the level-III separation.

Table 1. U.S. Geological Survey land use and land cover mapping program classification system (2).

Level I	Level II
1 Urban or built-up land	11 Residential
	12 Commercial and services
	13 Industrial
	14 Transportation, communications, and utilities
	15 Industrial and commercial complexes
	16 Mixed urban or built-up land
	17 Other urban or built-up land
2 Agricultural land	21 Cropland pasture
	22 Orchards, groves, vineyard, nurseries, and ornamental
	23 Confined feeding operations
	24 Other agricultural land
3 Rangeland	31 Herbaceous rangeland
	32 Shrub and brush rangeland
	33 Mixed rangeland
4 Forest land	41 Deciduous forest land
	42 Evergreen forest land
	43 Mixed forest land
5 Water	51 Streams and canals
	52 Lakes
	53 Reservoirs
	54 Bays and estuaries
6 Wetland	61 Forested wetland
	62 Nonforested wetland
7 Barren land	71 Dry salt flats
	72 Beaches
	73 Sandy areas other than beaches
	74 Bare exposed rock
	75 Strip mines, quarries, and gravel pits
	76 Transitional areas
	77 Mixed barren land
8 Tundra	81 Shrub and brush tundra
	82 Herbaceous tundra
	83 Bare ground tundra
	84 Wet tundra
	85 Mixed tundra
9 Perennial snow or ice	91 Perennial snowfields
	92 Glaciers

Our soil and geological data were extracted from statewide, generalized maps at a scale of 1:500,000. The soil associations were taken from the General Soil Map of Missouri (*15*). The straitigraphy was based on the Geologic Map of Missouri (*8*). The areas on both maps encompassing the study were photographically enlarged to 1:250,000 for digitizing and incorporation into the data base.

Mapping consisted of converting the watershed data to single-category, transparent overlays registered to a common base to facilitate digitizing the data. We compiled individual map sheets for each land use and land cover category, soil association, and bedrock type found within the watershed. Four land uses, 11 soil associations, and 8 bedrock formations were delineated and punch registered to a USGS planimetric base map. The watershed categories on each map consisted of darkened polygons on drafting film.

We created a computer data base for the watershed data by digitizing the maps with an automatic digital image scanning system. A video image of each map was digitized (turned into an array of numbers that represent the image to the computer) by an image-scanning device using background subtraction and dynamic thresholding techniques (*9*). The image scanner was interfaced with a computer where the digital image of each map was stored. Data base subroutines were then initiated to calculate the acreage in each category and tabulate acreages in the configurations shown in table 2. The compiled acreage figures for each watershed characteristic were used to determine relations between a stream and watershed.

Results and discussion

Land use in Ozark watersheds. Information in the watershed and stream water chemistry data bases were integrated and analyzed statistically to determine their relationships. In the end we used data on land use and land cover to demonstrate these relationships because these watershed characteristics proved more important than geology or soil associations in explaining differences in stream water composition (*14*). We developed regression equations to assess these relationships, using watershed and stream data from the 21 watersheds.

The area of urban land and pasture on a watershed were associated with increased concentrations of most chemicals in streams. As urban and pasture areas increased, chemical concentrations within streams increased. Correlation coefficients betwen these land use areas and total phoshorus, total nitrogen, nitrate nitrogen, chloride, sodium, and potassium, were greater than 0.64 ($P<0.05$) (*14*).

In contrast, we found significant inverse relations between forest land use and the concentration of most chemicals in the streams. As the area of forest land on a watershed increased, stream chemical concentrations declined. Correlation coefficients, the percentage of forest land and total phosphorus, total nitrogen, nitrate nitrogen, sodium, and potassium were greater than -0.63 ($P<0.05$) (*14*).

Spring Creek watershed. Land use and stream chemical and chlorophyll *a* concentrations in Spring Creek demonstrated watershed-stream relations.

Concentrations of chemicals and chlorophyll *a* in Spring Creek were generally low (Table 3). Depending upon the season, average concentrations of total phosphorus ranged from 7.6 to 19.9 milligrams per cubic meter; nitrate nitrogen, from 110.7 to 190.3 milligrams per cubic meter; calcium, from 1.18 to 1.91 milliquivalents per liter; and planktonic chlorophyll *a*, from 1.28 to 2.79 milligrams per cubic meter. We attribute these low concentrations to the large forested area on the watershed.

Table 2. Area (square kilometers) of watershed characteristics for Missouri's Spring Creek.

	Watershed Type			
Characteristic	*Urban*	*Pasture*	*Forest*	*Total*
Land use	0.3	41.2	261.6	303.1
Geology				
Jefferson City dolomite	0.2	10.8	55.6	66.6
Gasconade dolomite	0.1	2.2	23.6	25.9
Roubidoux formation (dolomite)	0.0	28.1	182.3	210.4
Soil associations				
Wilderness-Clarksville-Coulstone	0.0	7.4	107.2	114.6
Lebanon-Hobson-Clarksville	0.1	0.3	2.0	2.4
Hartville-Ashton-Cedargap-Nolin	0.2	0.5	2.3	3.0
Captina-Clarksville-Doniphan	0.0	33.0	150.1	183.1
Geology and soil associations				
Jefferson City dolomite and Wilderness-Clarksville-Coulstone	0.0	3.1	22.3	25.4
Jefferson City dolomite and Lebanon-Hobson-Clarksville	0.1	0.2	1.5	1.8
Jefferson City dolomite and Hartville-Ashton-Cedargap-Nolin	0.1	0.0	0.2	0.3
Jefferson City dolomite and Captina-Clarksville-Doniphan	0.0	7.5	31.7	39.2
Gasconade dolomite and Wilderness-Clarksville-Coulstone	0.0	0.1	6.2	6.3
Gasconade dolomite and Lebanon-Hobson-Clarksville	0.0	0.0	0.0	0.0
Gasconade dolomite and Hartville-Ashton-Cedargap-Nolin	0.1	0.0	1.2	1.3
Gasconade dolomite and Captina-Clarksville-Doniphan	0.0	2.1	16.2	18.3
Roubidoux formation and Wilderness-Clarksville-Coulstone	0.0	4.2	78.6	82.8
Roubidoux formation and Lebanon-Hobson-Clarksville	0.0	0.5	0.1	0.6
Roubidoux formation and Hartville-Ashton-Cedargap-Nolin	0.0	0.9	0.5	1.4
Roubidoux formation and Captina-Clarksville-Doniphan	0.0	23.4	102.2	125.6

Table 3. Seasonal concentrations of representative water quality variables in the stream draining Missouri's Spring Creek watershed.*

Variable	*Spring*	*Early Summer*	*Late Summer*	*Autumn*
Total phosphorus ($mg \cdot m^{-3}$)	15.5	17.4	19.9	7.6
Total nitrogen ($mg \cdot m^{-3}$)	470	882	1,224	871
Nitrate nitrogen ($mg \cdot m^{-3}$)	190.3	110.7	158.0	158.1
Potassium ($meq \cdot 1^{-1}$)	0.01	0.06	0.04	0.07
Calcium ($meq \cdot 1^{-1}$)	1.18	1.28	1.63	1.91
Chloride ($meq \cdot 1^{-1}$)	0.04	0.03	0.02	0.03
Sulfate ($meq \cdot 1^{-1}$)	0.03	0.02	0.01	0.01
KSP ($\mu mhos \cdot cm^{-1}$)	234.2	358.3	337.8	362.3
Planktonic chlorophyll a ($mg \cdot m^{-3}$)	2.78	1.28	2.06	2.79

*Values are geometric means except calcium.

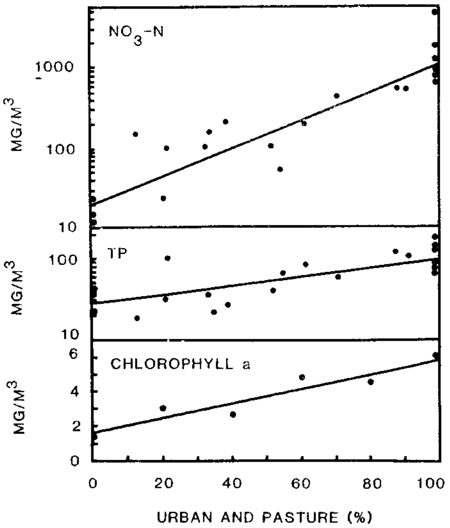

Figure 2. Stream concentrations of nitrate nitrogen, total phosphorus and planktonic chlorophyll a associated with urban and pasture land uses in selected Missouri watersheds during late summer. Empirically derived equations: ln nitrate nitrogen = 0.040 (% urban + pasture) + 3.085, $r = 0.91$, $n = 21$; ln total phosphorus = 0.012 (% urban + pasture) + 3.379, $r = .66$, $n = 21$; planktonic chlorophyll a = 0.041 (% urban + pasture) + 1.762, $r = 0.95$, the 21 sample stations were grouped according to land use at 0, 20, 40, 60, 80, and 100%.

What effect altering land use in the Spring Creek watershed might have on water chemistry and algal biomass can be assessed using the empirical regression equations developed from our entire watershed-stream data base for late summer (Figure 2). If the area in urban and pasture uses in the watershed rose from 13 percent (present condition) to 75 percent, average total phosphorus would increase to about 70 milligrams per cubic meter, a 25 percent increase over the present average concentration. Likewise, nitrate nitrogen would increase to about 440 milligrams per cubic meter, a 180 percent increase, and planktonic chlorophyll *a* would increase to about 5 milligrams per cubic meter, a 140 percent increase.

Alternatively, if the forest area in the watershed increased from 86 percent (present condition) to 100 percent, chemical and chlorophyll concentrations would decline. For example, during late summer, estimated total phosphorus concentrations would be 29 milligrams per cubic meter; nitrate nitrogen, 21 milligrams per cubic meter; and planktonic chlorophyll *a*, 1.8 milligrams per cubic meter.

Streams draining forest areas unaffected by human activity likely represent the background level of stream chemical concentrations in the Missouri Ozarks. These levels probably could not be reduced.

Conclusions

Land use and land cover in the Spring Creek watershed demonstrate the use of general watershed data acquisition, processing, and digital data base development for a regional stream-watershed investigation. This method of assessing land use and land cover can be used for any watershed characteristic for which general maps are available. It can also provide an accurate, readily obtainable data base that may include as many watershed characteristics as needed for a specific investigation. The methodology is appropriate for either regional or large-area studies.

The watershed data generated by this method are useful in themselves. Moreover, when integrated with stream water observations, these data provide a valuable tool with which to assess stream-watershed relations and to predict changes in streams that may occur as the result of watershed alterations.

REFERENCES CITED

1. American Public Health Association. 1976. *Standard methods for the examination of water and wastewater* (14th ed.). New York, N.Y. 1,193 pp.
2. Anderson, R. R., E. E. Hardy, J. T. Roach, and R. E. Witmer. 1976. *A land use and land cover classification system for use with remote sensor data.* Prof. Paper 964. U.S. Geo. Surv., Washington, D.C. 28 pp.
3. Barney, T. W., C. J. Johannsen, and D. Barr. 1977. *Mapping land use from satellite images: User's guide.* Univ. Mo., Columbia. 45 pp.
4. Curry, R. R. 1972. *Rivers—a geomorphic and chemical overview.* pp. 9-32 In R. T. Oglesby, C. A. Carlson, and J. A. McCann [eds.] *River Ecology and Man.* Academic Press, New York, N.Y.
5. 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.
6. Elifrits, C. D., T. W. Barney, D. J. Barr, and C. J. Johannsen. 1978. *Mapping land cover from satellite images: A basic, low-cost approach.* Final Rpt. to NASA (Contract NAS 8-31767). Univ. Mo., Columbia.
7. Environmental Protection Agency. 1974. *Methods for chemical analysis of water and wastes.* EPA-624/6-74-003. Washington, D.C. 298 pp.
8. Missouri Geological Survey. 1979. *Geologic map of Missouri.* Rolla.
9. Hotrabhavananda, T. 1980. *Development of automated techniques for creating a natural resources information system.* Ph.D. diss. Univ. Mo., Columbia.
10. Hynes, H.B.N. 1975. *The stream and its valley.* Verh. Int. Verein. Limnol. 19: 1-15.
11. Likens, G. E., and F. H. Bormann. 1974. *Linkages between terrestrial and aquatic ecosystems.* Bioscience 24: 447-456.
12. McBride, T. D. 1977. *Landforms of Missouri.* Dept. Geog., Univ. Mo., Columbia.
13. Ryck, R. M. 1974. *Missouri stream pollution survey.* Aquatic Series No. 8. Mo. Dept. Cons., Jefferson City. 37 pp.
14. Smart, M. M. 1980. *Stream-watershed relations in the Missouri Ozark Plateau Province.* Ph.D. diss. Univ. Mo., Columbia. 170 pp.
15. Soil Conservation Service, U.S. Department of Agriculture, and Missouri Agricultural Experiment Station. 1977. *General soil map—Missouri.* Columbia, Mo.
16. Strickland, J.D.H., and T. R. Parsons. 1972. *A manual of sea water analysis.* Bull. No. 167. Fish. Res. Bd. Can., Ottawa, Ont. 310 pp. ☐