

SPECIAL APPLIED ISSUES SECTION

The influence of catchment land use on stream integrity across multiple spatial scales

J. DAVID ALLAN, DONNA L. ERICKSON AND JOHN FAY

School of Natural Resources and Environment, The University of Michigan, Ann Arbor MI 48109–1115, U.S.A.

SUMMARY

1. Despite wide recognition of the need for catchment-scale management to ensure the integrity of river ecosystems, the science and policy basis for joint management of land and water remains poorly understood. An interdisciplinary case study of a river basin in south-eastern Michigan is presented.
2. The River Raisin drains an area of 2776 km², of which some 70% is agricultural land. The upper basin consists of till and outwash, and both topography and land use/cover are diverse. The lower basin consists of fine textured lake deposits, is of low relief, and land use is primarily agricultural.
3. The River Raisin basin historically was a region of oak-savannah and wetlands. It was deforested, drained and converted to farmland during the mid-nineteenth century. Human population reached a plateau at about 1880, and then underwent a second period of growth after 1950, mainly in small urban areas. More recently, the amount of agricultural land has declined and forested land has increased, in accord with a general decline in farming activity.
4. It could be suggested that the influence of land use on stream integrity is scale-dependent. Instream habitat structure and organic matter inputs are determined primarily by local conditions such as vegetative cover at a site, whereas nutrient supply, sediment delivery, hydrology and channel characteristics are influenced by regional conditions, including landscape features and land use/cover at some distance upstream and lateral to stream sites.
5. Sediment concentrations measured during low flows were higher in areas of greater agriculture. In a comparison of two subcatchments, sediment yields were up to ten times greater in the more agricultural location, in response to similar storm events. A distributed parameter model linked to a geographical information system predicted that an increase in forested land cover would result in dramatic declines in runoff and sediment and nutrient yields.
6. Habitat quality and biotic integrity varied widely among individual stream sites in accord with patterns in land use/cover. Extent of agricultural land at the subcatchment scale was the best single predictor of local stream conditions. Local riparian vegetation was uncorrelated with overall land use and was a weak secondary predictor of habitat quality and biotic integrity.
7. Investigation of the regulatory agencies involved in land and water management in the basin revealed a complex web of overlapping political jurisdictions. Most land-use decision-making occurs at the local level of township, city or village. Unfortunately,

local decision-making bodies typically lack the information and jurisdictional authority to influence up- and downstream events.

Introduction

The joint management of land and water within entire catchments to ensure river 'health' is emerging as a popular, albeit largely undefined, response to the widespread recognition that river ecosystems are increasingly threatened (Benke, 1990; Boon, Calow & Petts, 1992; Allan & Flecker, 1993). Much of the rationale for river basin management derives from the idea that a catchment is a topographically and hydrologically defined unit. The present enthusiasm for ecosystem management (Grumbine, 1994) likely also contributes to the interest in basin management. Naiman (1992) argues for 'new perspectives on watershed management' that recognize the need to seek a balance among ecological, economic and social values within a long-term framework of sustainability and human use. Clearly this is an ambitious view, demanding co-ordination of activities that are spatially or temporally remote from one another, and requiring governing bodies to work together in novel partnerships. As shall be demonstrated below, even a meso-scale river basin (the River Raisin is fifth order at its mouth and drains *c.* 2800 km²) includes a bewildering number of units of government. The wavy topographic lines of river catchments bear little resemblance to the straight lines and right angles that demarcate political boundaries (Dodge & Biette, 1992). Reconciling catchment topography with jurisdictional authority is a central challenge of the catchment approach to river management.

Researchers increasingly are adopting a catchment-scale view of river ecology as well—hardly surprising, considering the many antecedents of this approach. The importance of the landscape and vegetation of the valley to its river was clearly articulated by Hynes (1975) and is an integral part of the river continuum concept (Vannote *et al.*, 1980). Landscape influences are reflected in a large body of research on allochthonous (external) *v* autochthonous (within-stream production) energy sources (e.g. Minshall, 1978; Webster & Benfield, 1986). In recent years the importance of spatial scale has attracted much interest within the field of ecology, both on theoretical grounds (Forman & Godron, 1986; Turner, 1989; Levin, 1992) and from the growing conviction that habitat fragmentation at

the landscape scale is an important and previously unappreciated causal agent in species decline (Noss, 1990).

River systems may prove to be especially suitable systems for the investigation of ecological processes across spatial scales. The stream order classification of geomorphologists (Horton, 1945; Strahler, 1964) provides a valuable framework for investigation of the hierarchical organization of river networks. Stream ecologists also recognize a hierarchical organization of microhabitats such as gravel, wood or leaf detritus, within larger habitat units such as riffles or pools, which in turn comprise a stream reach (Frissell *et al.*, 1986; Hawkins *et al.*, 1993). A reach is contained within a river segment, which is part of the catchment of a single tributary stream, and often is part of a larger river basin made up of many such tributaries (Fig. 1, top). A clear implication of this perspective is that local conditions are under some degree of regional influence, perhaps strongly so (Hildrew & Giller, 1994). However, there is only a limited understanding of the relative importance of local *v* regional factors. Certain processes, such as organic matter inputs, are likely to be primarily under local control, while others, such as sediment delivery and channel maintenance, must depend on factors influencing the delivery of water over some larger area (Fig. 1, bottom). A deeper understanding of these issues is necessary to resolve the spatial scale at which changes to the landscape should be evaluated for their impact upon the condition of river systems.

Riparian zone management has become one of the most visible and widely accepted applications of watershed management. A focus on protection of riparian corridors is well-grounded in current scientific knowledge of land–water interactions (Naiman & Décamps, 1990; Gregory *et al.*, 1991) and the multiple mechanisms through which terrestrial ecosystems influence streams and rivers (Sweeney, 1992). Recommendations for riparian buffer widths commonly are of the order of 10–100 m, and are based on a sound intuitive grasp of the processes that should be protected. Buffer widths may vary with stream size, stream order and ecosystem type. Sensible as these

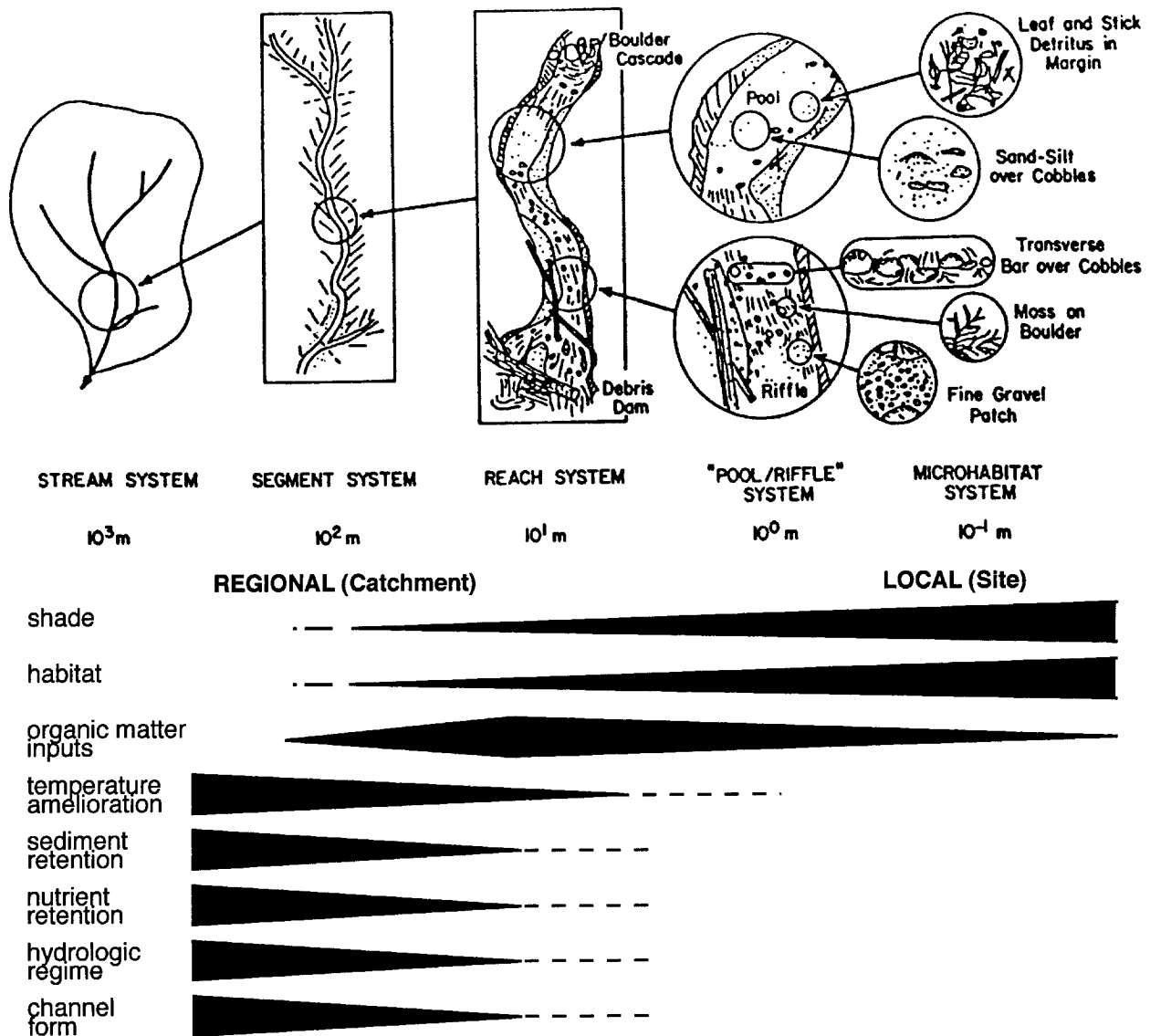


Fig. 1 Landscape influences on stream ecosystem structure and function across spatial scale. Top: hierarchical relationships among habitat and landscape features of streams. Multiple microhabitat units are found within each channel unit such as pool or riffle; multiple riffle/pool units comprise a stream reach; reaches are contained within river segments, which are part of a catchment, which often is a tributary within a larger river basin. From Frissell *et al.* (1986). Bottom: a speculative account of the influence exerted by local (tens to hundreds of metres) *v* regional (one to tens of kilometres) terrestrial vegetation over stream function. Some aspects of stream condition such as shade and inputs of CPOM require only local vegetation; others such as sediment trapping and hydrologic function likely are influenced by vegetation cover along the stream's length and possibly throughout the catchment.

recommendations may be, the scientific information arguing for or against a specified buffer width is limited (Osborne & Kovacic, 1993). Furthermore, the implicit message is that land use throughout the catchment can be ignored, or at least is of lesser importance, relative to riparian land use. This amounts to an assumption about scale and causality that is difficult to rationalize.

While riparian management practices are of critical importance to stream status, it can be argued that the broader issue of landscape influences across multiple spatial scales remains in need of further study. Human alteration of the land affects river ecosystems through multiple processes that likely operate at different spatial scales (Fig. 1). This study will attempt to distinguish the relative importance of local *v* regional, and

riparian *v* catchment-wide, influences of landscape pattern on stream ecosystems by examining physical, chemical and biological conditions at specific sites scattered through a fifth-order river basin in south-eastern Michigan. Changing patterns of land use and land cover are also investigated in an effort to understand the cultural and economic forces that underlie changes in ecological integrity. Lastly, the policy and planning framework that guides land management decisions within this basin is briefly examined. This paper represents a synthesis of ongoing work intended to provide an interdisciplinary basis for the study and management of river basins.

The study system

The River Raisin basin is located in the south-eastern corner of Michigan and drains into Lake Erie (Fig. 2). It is representative of many agricultural and rural river systems of the lower Great Lakes region. Rumoured to be the 'most crooked river in the world,' the River Raisin's mainstem is 216 km long and drains an area of 2776 km². Its underlying geology is till and outwash in the upper basin and fine textured lake deposits in the lower basin (Fig. 3). Land use reflects underlying geology, with a predominance of agriculture in the lakeplain and a greater diversity of land use/cover in the upper basin (Fig. 4). Streams of south-eastern Michigan are biologically rich, and probably contain the highest biological diversity of many taxa for streams of Michigan. Thirty-four species of unionid mussels (Strayer, 1979) and eighty-four species of fish (Smith, Taylor & Grimshaw, 1981) have been reported from area streams. Water quality is considered good, although in severe droughts treated effluent can comprise as much as 60% of flow in the upper river (Manson, Bulkley & Allan, 1994). Forty-seven sites are approved NPDES (National Pollution Discharge Elimination System) permit locations (Fig. 5). About half of these are publicly owned treatment plants, and the remainder are small industries. Non-point source pollution, erosion and sedimentation are considered the primary water quality concerns (Manson *et al.*, 1994).

South-eastern Michigan was a region of forest, savannah and extensive wetlands prior to 1830. Human population growth in Lenawee County (Fig. 6), which comprises much of the River Raisin basin, is indicative of the historic transformation of

this region. Settlement proceeded rapidly from 1830, when Lenawee's population was 1400, until 1880, when the population reached nearly 50 000. More than a century ago, the settlement of the area was largely completed (Lindquist, 1990). Data from 1930 to the present for two townships, one urban and one rural, show that population growth since that time has occurred mainly in urban centres. Today, more than 134 000 people live within the Raisin basin, for an average of 48.3 individuals km⁻² (125 mi⁻²). This population remains mostly dispersed and rural, although suburban sprawl from nearby urban centres of Ann Arbor (109 000) and Detroit (> 3 million) is beginning to transform the north-eastern portion of the river basin.

Drainage of wetlands and removal of forests has transformed the landscape into one that is 70% agricultural. However, some individual catchments are less than 50% agricultural while others are more than 95% (Fig. 4). More than 4800 km of human-constructed drainage systems channel water into the River Raisin and its tributaries, resulting in a great reduction in wetland area (Manson *et al.*, 1994). The river is detained by more than fifty small dams and impoundments, although an accurate total is not known, nor has the number of historic dams no longer in evidence been determined.

The changing landscape

Erickson (1995) compared land use/cover estimates from 1968, 1978 and 1988 to examine changes in the patterns of agricultural, forest and urban lands. Ten townships were chosen from the forty-one that are wholly or partly within the Raisin basin, according to criteria designed to ensure that differing geologies and stream orders were included, and that the entire river basin was represented. In nine of the ten townships studied, agricultural land use declined and both forest and urban land uses increased over the 20-yr time interval. Abandonment of agricultural activity and some consolidation of farmland are the likely causes of the replacement of agricultural by forested land. Agricultural trends over several decades show that land is being taken out of production throughout the south-east Michigan region and within many areas of the Midwestern U.S.A. For instance, the number of farms in Lenawee County declined from 2558 in 1969 to 1387 in 1987, a 46% decrease. None the less, with

Table 1 Change in riparian land use/cover in five townships within the River Raisin basin between 1968 and 1988. Land use/cover area for 1968 and 1988 was determined manually from aerial photographs (Agricultural Conservation and Stabilization Service) projected onto 1:24 000 USGS topographic quadrangles. Areas for 1978 were determined using a GIS and the MIRIS (Michigan Resource Inventory System) database

Township	Riparian forest corridor area (ha)				Riparian forest corridor width (m)			
	1968	1978	1988	% change 1968–88	1968	1978	1988	% change 1968–88
Dover	259	399	438	+ 69%	59	95	106	+ 80%
Dundee	282	333	489	+ 73%	53	54	73	+ 38%
Fairfield	401	539	569	+ 42%	114	147	156	+ 37%
Manchester	507	635	728	+ 44%	106	184	211	+ 99%
Tecumseh-Clinton	376	446	514	+ 36%	105	111	134	+ 28%

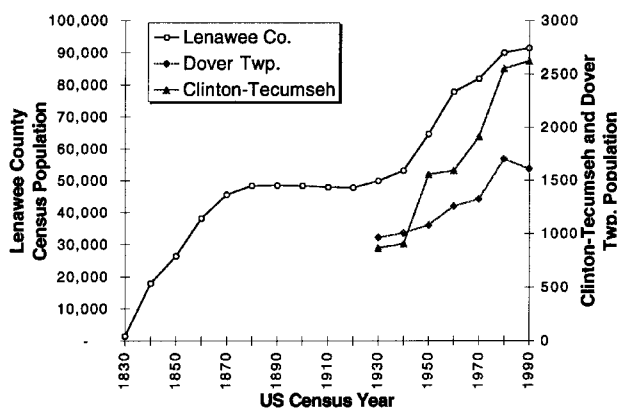


Fig. 6 Population growth in Lenawee County, the largest single county within the River Raisin watershed. Note the levelling off at about 1880, and further growth subsequent to 1940. Also note the different growth patterns between Clinton-Tecumseh Township, which contains two urban areas, and Dover Township, which is entirely rural.

71% of its land area in agriculture, Lenawee County was among the highest cash crop-producing counties in Michigan in 1993 (Michigan Department of Agriculture, 1994).

In total, forest area increased by over 13% in these ten townships from 1968 to 1988 (Erickson, 1995). An unplanned result of removing land from agriculture while in transition to suburbanization is that woody cover increases while land awaits development, especially in riparian areas. An increase in area and width of riparian forest areas was found in riparian corridors, and in forest connectivity along the riparian corridors, in five of the ten selected townships (Table 1). The area of riparian forest increased by 36–73%, while average riparian corridor width increased by 28–99%, respectively. Increased forest connectivity along riparian corridors occurred

simultaneously with the decline in agricultural land and increased urbanization.

Combining this information on changes in land use/cover with ownership records for the same years, Kleiman & Erickson (1995) examined the distribution and number of individual land holdings within two townships over a 20-yr period. Parcels within the riparian corridor were examined because the scenic qualities of rivers and woodlands likely are attractive to new rural residents (Ryan, 1995). Increasing rates of land parcelization (subdivision) were observed in both townships, paralleling the county-wide decrease in number of farms and total area farmed. Proximity to the river was related to parcelization, but proximity to roads had a much greater influence. A survey of local residents' economic and aesthetic perceptions of the value of riverfront land indicated that these were important factors in continued residential development within the riparian zone.

Soil erosion

Sediment yield is known to be high in rivers draining agricultural lands of the Midwestern U.S.A., and prior studies show the Raisin to have among the highest yields in southern Michigan (Cummings, 1984). Bright (1995) examined sediment concentrations under low flow conditions at twenty-nine sites throughout the Raisin basin over four seasons. Grab samples were filtered on to preweighed Gelman A/E 0.45 mm glass fibre filters and dry mass was determined following the methods of Gurtz, Webster & Wallace (1980). Sediment concentrations were

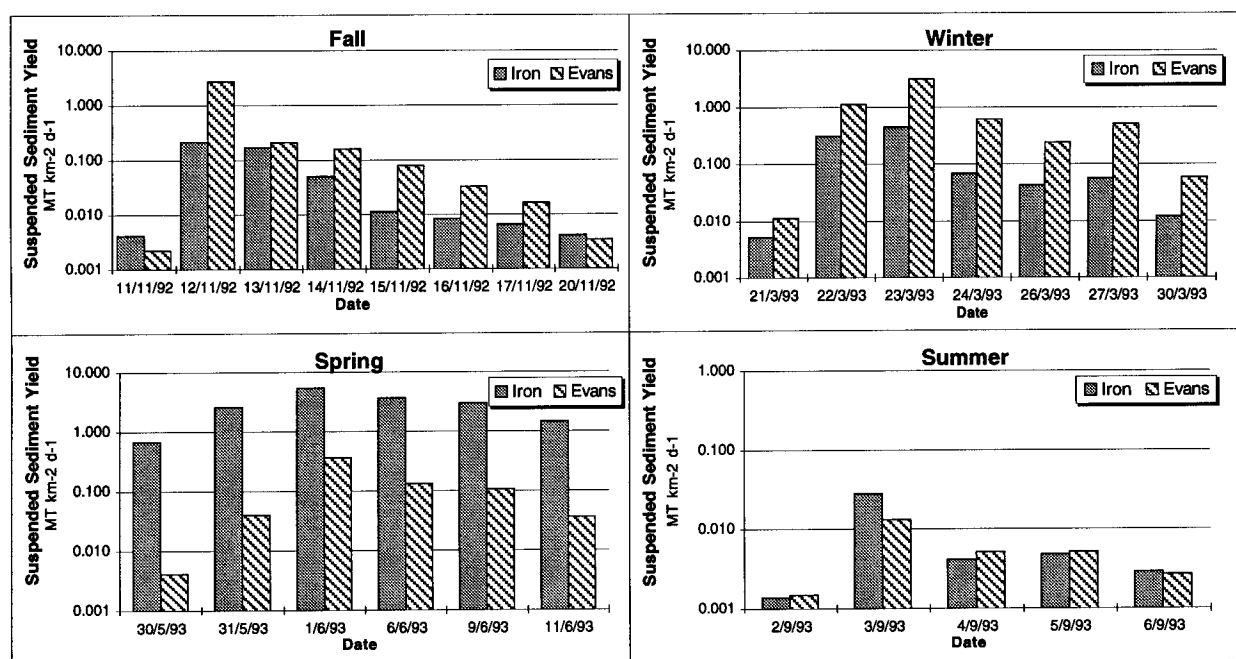


Fig. 8 Estimated sediment yield (metric tons $\text{km}^{-2} \text{d}^{-1}$) at Iron Creek and Evans Creek sampling sites in response to storms in four seasons of hydrologic year 1993. Note that highest yields are transported in fall and winter. From Bright (1995).

lowest in the upper-basin subcatchments of till geology and mixed land use, and highest in subcatchments of the lower basin situated within lakeplain soils and intensive agriculture (Fig. 7). Sediment concentrations were highest during summer sampling, evidently due to lower flows.

Sediment transport in response to storm events was examined using a paired watershed approach in two small catchments. Iron Creek and Evans Creek are both in the upper, glacial till portion of the River Raisin basin, and drain 5300 ha and 7800 ha, respectively. Iron Creek has a well-forested riparian and an apparently natural channel, and sites score high on biological and habitat assessment protocols (see below). Evans Creek was channelized in the 1940s, drain tiles appear frequently along its course, and sites score low on biological and habitat assessment protocols. Agricultural land use makes up 45% of the Iron Creek catchment, compared with 68% of the Evans catchment. As expected, much more sediment was transported by Evans than Iron in response to storm events (Fig. 8). Analysis of precipitation data established that sampled storm events in the two catchments were of similar intensity. For a fall storm (12 November 1992), the daily sediment yield was roughly ten times greater in Evans than in Iron Creek. The winter storm event

of 22 March 1993 resulted in two to five times higher sediment yields from Evans than Iron Creek. Fall and winter were the seasons in which most sediment export occurred, due to precipitation intensity and lack of vegetative cover.

A number of models have been developed to estimate runoff and the transport of sediments and nutrients in response to a storm event of specified magnitude. When coupled to a geographical information system (GIS) containing information on land use, soils, hydrography and topography, these distributed parameter (cell-based) hydrologic models can evaluate how different land use scenarios affect sediment and nutrient delivery. Fay (1996) applied the AGNPS (agricultural non-point source) model (Young *et al.*, 1987) to one catchment within the Raisin basin, the Saline River. The Saline catchment was subdivided into cells of 16 ha for modelling purposes. ERDASTM GIS software was used to overlay and recode existing statewide and national databases (Table 2) into the twenty-two spatially referenced input variables required by the AGNPS model (Table 3). Using equations based on the Universal Soil Loss Equation and a set of hydrologic equations developed for an earlier non-point model (CREAMS: Knisel, 1980), the AGNPS model simulates runoff, sediment and nutrient trans-

Table 2 Statewide and national databases used to derive AGNPS input variables

Database	Scale	Source
1978 land use/ cover	1:15 840	MIRIS (Michigan Resource Inventory System)
Soils association	1:15 840	MIRIS, NRCS (Natural Resources Conservation Service)
Hydrography	1 : 24 000	MIRIS
Topography	1 : 250 000	USGS (United States Geological Survey) (3-Arc Second Digital Elevation Model data)

Table 3 The twenty-two spatially distributed variables required by the AGNPS model. Those factors marked with an asterisk were set to their default values () and all others were obtained from the databases listed in Table 2

AGNPS database		
Cell identification number	Channel side slope	Fertilization application index*
Receiving cell number	Manning's roughness coefficient	Fertilization incorporation factor*
Runoff curve number	Soil erodibility ('K') factor	Point source indicator*
Slope	Cropping ('C') factor	Gully source level*
Slope shape*	Practice ('P') factor*	Chemical oxygen demand factor
Slope length	Surface condition constant	Impoundment factor*
Field slope length	Cell aspect	
Channel slope	Soil texture	

port from the catchment to a downstream point or outlet cell in response to a storm of a specified magnitude. This model has been found to apply well to conditions of the Midwestern U.S.A. (Young *et al.*, 1987; Gordon & Simpson, 1990).

The main value of this model is its ability to explore how alternative scenarios, such as changing land use/cover or the addition of forested riparian buffer strips of different widths, might influence non-point source runoff. Using a storm intensity with a 25-yr recurrence (3.71 inches in 24 h, which last occurred in December, 1965) to illustrate the impacts of an extreme event, runoff intensity, sediment yield and nutrient concentrations were estimated for present land use. Fay (1996) then separately examined three sets of alternative scenarios representing increased urban, forest and

agricultural land area, respectively. Under the assumption that the expansion of a particular land type will most likely occur contiguous to existing land of that type, five buffers in increments of 100 m were added around existing urban, forest or agricultural cell clusters to a maximum expansion of 500 m. The relative impacts predicted by each of the urban, forest and agricultural expansion scenarios were then used to compute average rates of increase or decrease for each output variable per unit land converted into the specified land type. Here responses are averaged over five successive 100 m expansions. It should be noted that responses ultimately reach an asymptote, and in principle one could attempt to control for the land use category that is converted, but these issues are beyond the scope of the present analysis.

As expected, runoff volume in response to a storm event increased when urban or agricultural land cover was expanded, and decreased when forest cover was increased (Fig. 9). Sediment yields increased dramatically with agricultural expansion, increased less dramatically under urban expansion, and were reduced by the expansion of forested land cover. Predicted nutrient (nitrogen and phosphorus) yields, which are affected by increased runoff and sediment yield but do not include fertilizer application rates in this scenario, increased substantially with urban and agricultural expansion, and were reduced by expansion of forest cover. The usefulness of this modelling approach lies primarily in the ease with which one can explore the relative response of these output variables to changing land use, rather than in precise forecasting of actual yields.

Habitat quality and biological integrity

To determine whether habitat quality and biological assemblage composition differed among individual stream sites in relation to land use, a habitat index (MDNR, 1991) and the Index of Biotic Integrity (IBI: Karr, 1991) were estimated for each of twenty-three sites distributed through the upper half of the basin. The habitat index is obtained by summing nine individual metrics, each of which is a visual assessment of some aspect of habitat, substrate or bank conditions. The IBI is obtained by summing ten individual metrics based on the frequency of occurrence of various taxonomic and functional groups within the fish assemblage of a site, determined by backpack electrofishing

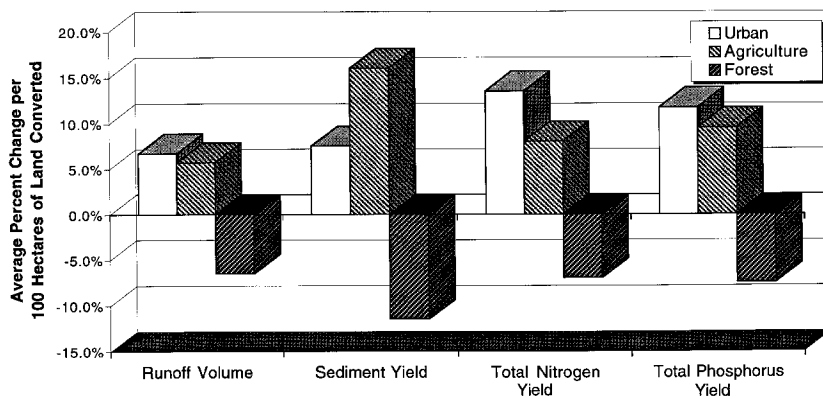


Fig. 9 Per cent change in runoff volume, sediment yield, and total nitrogen and phosphorus yield within the Saline catchment of the River Raisin basin, predicted by the AGNPS model per km² of land converted from present use to either urban, agricultural, or forested land cover. From Fay (1996).

over 100 m reaches during summer. As reported more fully by Roth, Allan & Erickson (1996), both the IBI and the habitat index varied with location. Highest values of both indices were recorded in the northern and western headwater streams, which also are locations of less agriculture, more wetlands and more forest. As is evident by comparison of Figs 3 and 4, these differences in land use appear to be strongly influenced by differences in surficial geology across the river basin. Land use was found to be a strong predictor of biological and habitat integrity (Fig. 10). The percentage agricultural land cover upstream of a site explained half of the variance in IBI and fully 75% of the variance in the habitat index. This study provided support for the hypothesis that intensive agricultural land use results in degraded stream habitat, which in turn has an adverse impact on the fish fauna.

Because altered land use can influence instream conditions via multiple processes operating at different spatial scales (Fig. 1), land use/cover were estimated at several spatial scales to ask whether site-specific habitat and biotic indices were better predicted from local or regional measures. The range of spatial scales included ground surveys at a site along a 150 m stream reach, aerial photograph measurements from 1500 m stream segments, and GIS analyses of riparian and catchment-wide land use for the entire region upstream of a site. Data collected at the reach to segment scale could reflect 'local' conditions, and data collected over the entire upstream region (whether the riparian corridor or entire catchment) could reflect 'regional' conditions.

Attempts to identify the spatial scale at which human modification of land use most affects stream

habitat and biota indicate; first, that catchment-wide land use is of greater importance than local or riparian land use; and second, that the study design as reflected in the distribution of study sites can greatly influence results. A study that used twenty-three sites distributed across seven tributary subcatchments of the Raisin basin (Saline, Upper River Raisin, Goose, Iron, Evans, South Branch and Black Creek) found the habitat index and IBI to correlate strongly with regional land use throughout the catchment upstream of a site (Table 4). Correlations became progressively weaker as spatial scale was reduced, and riparian vegetation at local sites was not a significant predictor of local habitat or biotic conditions (Roth *et al.*, 1996). Interestingly, when a multiple regression was used to investigate which combination of landscape measurements best predicted habitat and biotic conditions at a site, land use throughout the upstream subcatchment was the only significant variable, and riparian vegetation surveyed at the stream site was the only (marginally significant) additional variable. It was also observed that when correlations between land use/cover were derived at different scales, they faded to non-significance as the spatial difference between scales increased. Estimates of land use at the scales of subcatchment and stream reach were uncorrelated, presumably because they were the most divergent scales of measurement (e.g. the amount of forested land in a 30 m wide buffer along a 150 m stream reach was uncorrelated with the extent of forest cover in the catchment including that stream reach). In all likelihood the local-scale measurement entered second into the multiple regression because it added truly independent information.

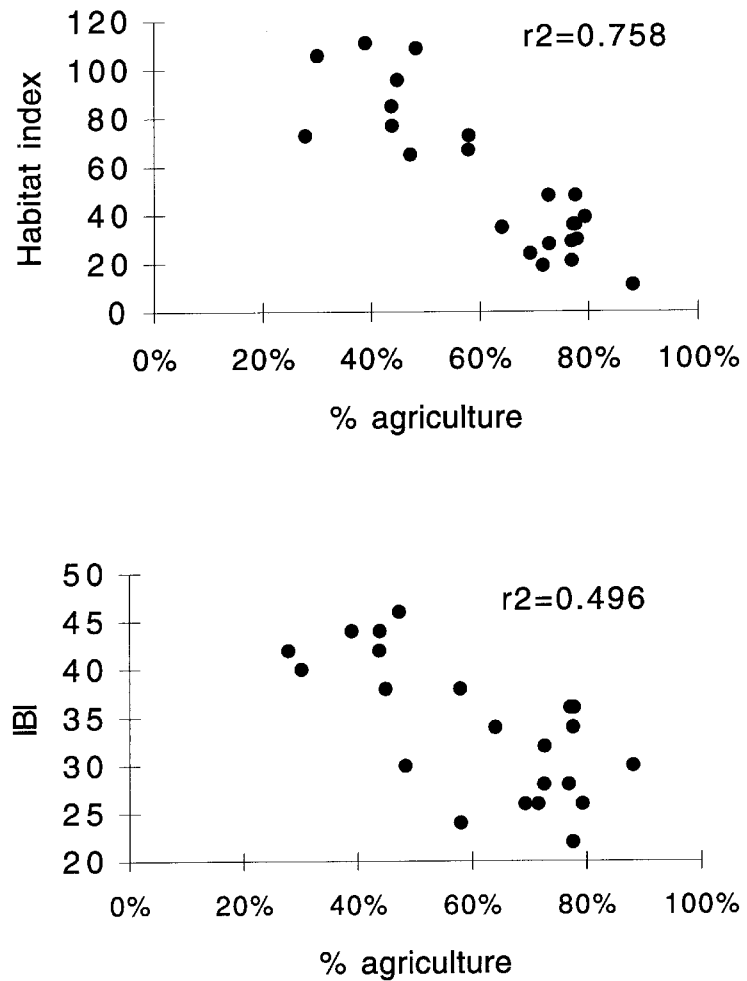


Fig. 10 Both habitat quality (top panel) and the fish assemblage as assessed by the Index of Biotic Integrity (bottom panel) declined as the upstream catchment area devoted to agriculture increased. From Roth (1994).

However, another study which sampled six sites along each of only three tributaries (Evans, Iron and one tributary of South Branch [Hazen]) found weaker relationships between stream integrity and land use overall. Only local riparian conditions were significant predictors of between-site variation in habitat and biotic conditions (Lammert, 1995). Specifically, Lammert examined extent of agricultural and forested land upstream of a site in three categories: the entire subcatchment, within a 250 m streamside buffer, and within a 100 m buffer. The maximum variation in IBI scores explained by her land-use measurements was only about 25% using the 100 m buffer, and the correlation became weaker as the spatial scale was expanded (Table 5). Thus, Lammert found that the most local scale of land use measurement was the best predictor of stream condition.

These contrasting results are the consequence of differing scales of the study design, coupled with differences in the scale of dependency of the various benefits (such as shade *v* sediment control) that landscape vegetation conveys to river systems. Because the study of Roth *et al.* (1996) sampled seven subcatchments and two to four sites per subcatchment, its design was best suited to detecting larger-scale spatial effects. In contrast, Lammert's study examined six sites at each of three subcatchments, resulting in a greater ability to discriminate local conditions but less ability to detect regional effects. The contrasting results of Roth *et al.* (1996) and Lammert (1995) are complementary in pointing to the influence of both local and regional-scale land cover over site conditions as reflected in the IBI and habitat index, and indicate that the mechanisms of local and regional influence are different (cf.

Table 4 Correlations (R^2) between the Index of Biotic Integrity (IBI), derived from fish collections, and a Habitat Index (HI), assessed visually, with extent of agricultural land use measured at various spatial scales. * = $P < 0.05$, ns = not significant. From Roth (1994).

		150 m reach ¹	1.5 km segment ²	Stream length ³	Entire catchment ⁴
Habitat Index	R^2	0.164 ns	0.160 ns	0.533*	0.758*
Index of Biotic Integrity	R^2	0.017 ns	0.073 ns	0.378*	0.496*

¹Ground survey of woody vegetation measured to a lateral distance of 30 m within a 150 m reach at each site where habitat and biological data were collected.

²30 m forested buffer on each side of stream for a distance 1 km upstream and 0.5 km downstream of site, determined from aerial photographs at 1 : 5000 scale.

³Per cent agricultural land use within 50 m buffers each side of stream for entire distance upstream of site, determined using a GIS at 1 : 24 000 scale.

⁴Per cent agricultural land use in entire subcatchment upstream of site, determined using a GIS at 1 : 24 000 scale.

Table 5 Correlations (R^2) between the Index of Biotic Integrity (IBI), derived from fish collections, and a Habitat Index (HI), assessed visually, with measures of land use/cover at several spatial scales. Fish were sampled from 100-m reaches at six study sites in each of three small catchments (eighteen sites in total). Land use was quantified beginning at each site and extending to the stream origin, using 100 m buffers (each side of stream), 250 m, and for the entire subcatchment. * = $P < 0.05$, ns = not significant. From Lammert (1995)

Land use	Spatial scale	Correlation with IBI	Correlation with HI
Agricultural	100 m buffer	0.224*	0.221*
	250 m buffer	0.088 ns	0.023 ns
	Subcatchment	0.001 ns	0.035 ns
Forested	100 m buffer	0.276*	0.292*
	250 m buffer	0.223	0.127 ns
	Subcatchment	0.014	0.009 ns

¹Land use/cover area determined manually from aerial photographs (Agricultural Conservation and Stabilization Service) projected on to 1 : 24 000 USGS topographic quadrangles.

²Land use/cover area determined using a GIS with MIRIS database.

Fig 1). It also appears that the regional landscape plays the greater part. However, the tentative and speculative nature of this interpretation, and the need for further studies that incorporate multiple spatial scales, should be emphasized.

River basin planning and management

A complex web of overlapping and fragmented political jurisdictions oversees land management within the river basin (Fig. 11). Regulatory agencies actively involved in land and water management include federal, state, county, and city or village branches of government. The sheer number of planning agencies inhibits co-ordination, and regional planning lacks the authority to influence land-use decision-making. Most land-use decision-making occurs at the local level of township, city and village, due to Michigan's strong 'home-rule' land-use planning provisions. Unfortunately, local decision-making bodies typically lack the information and the jurisdictional authority to influence up- and downstream events. At the local level where actual land-use planning occurs, any sense of identity of the catchment as an organizing element of the landscape is weak or absent. An examination of land-use planning documents for ten townships within the Raisin basin (Erickson, 1995) found that all have some form of zoning map, land-use plan, or development plan, conforming to Michigan requirements that all local jurisdictions have a general development plan that addresses future zoning. However, many plans are out of date, lack detail or are not binding because townships have the authority to grant variances. Protection of open space or riparian areas does not exist in most townships studied, and little specific planning attention is given to the river and its tributaries. The observed increase in cover in riparian areas (Table 1) apparently is not due to regulatory or incentive-based programmes from local governments, but to decisions of individual land owners tied to increasing economic and aesthetic values of wooded landscapes.

In conclusion, a catchment approach to the study of this Midwestern U.S.A. river system indicates that water quality, habitat and biotic integrity of the river are strongly influenced by land use. It can be suggested that human alteration of the landscape affects the riverine ecosystem via multiple processes operating over different spatial scales, which at present are little understood. The present results suggest that management of local and riparian conditions will provide some benefits, but that regional landscape conditions may be of greater importance; hence, managers and planners must think in terms of catchments and river basins (Doppelt *et al.*, 1993). Unfortunately,

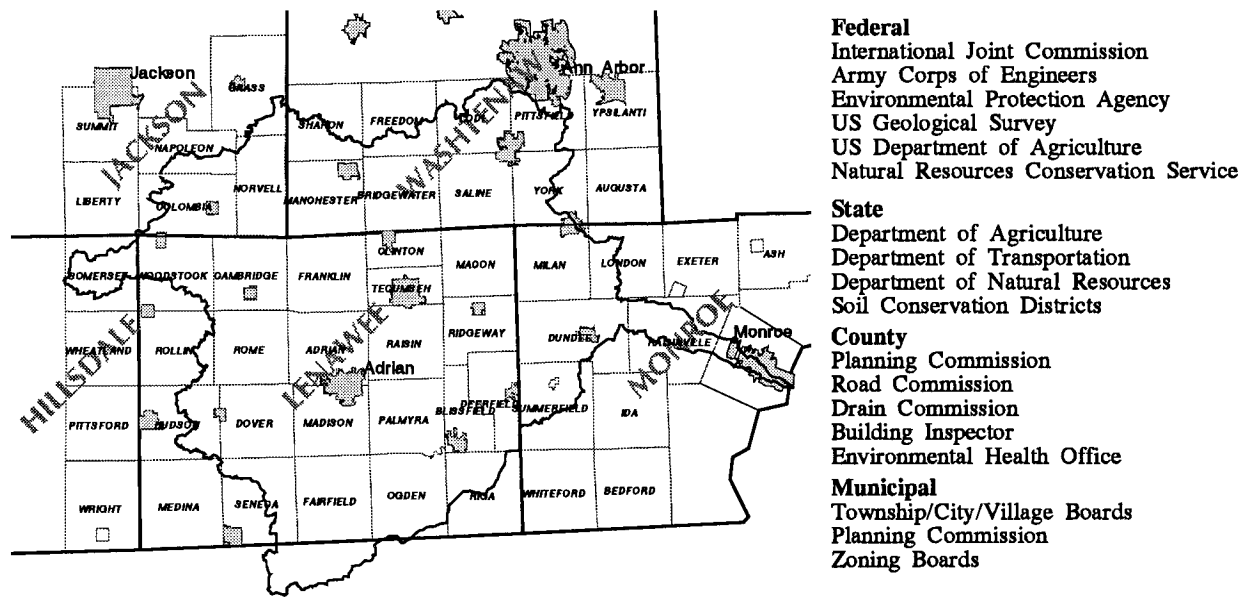


Fig. 11 Agencies with authority in the River Raisin Watershed. Most land-use planning occurs at the lowest levels of government. This basin includes five counties, forty-one townships, six cities and ten villages. See Manson *et al.* (1994) for a full description.

the jurisdictional complexity of governmental responsibility for a river basin, and the investment of planning authority primarily at the local level, together present serious obstacles to any effort to manage entire river basins. Regional authority and accountability are critical needs in order to protect river systems and their associated landscapes.

Acknowledgments

Funding for this study was provided by a Rackham grant from the University of Michigan and by the U.S. Department of Agriculture under the McIntire-Stennis Cooperative Forestry Research Act (P.L. 87-778). Land use/cover data were provided by the Michigan Department of Natural Resources via a cooperative agreement. Funding for initial GIS and policy analysis was provided by the Global Change and Population-Environment Dynamics Programs of the University of Michigan. We thank Ethan Bright, Richard Kleiman, Mary Lammert, David Lytle, Cindy Manson, Melinda Milos, Janet Norman, Nancy Roth, Robert Ryan, Kristen Schroeder, as well as many unsung helpers, for their assistance in gathering data. We thank Robin Abell, Ethan Bright, Mary Lammert, Charles Lindquist, Nancy Roth, Robert Ryan and Tom Van Wagner for their constructive comments on an earlier draft of this

paper, and Lucinda Johnson and two anonymous reviewers for their helpful reviews.

References

- Allan J.D. & Flecker A.S. (1993) Biodiversity conservation in running waters. *BioScience*, **43**, 32-43.
- Benke A.C. (1990) A perspective on America's vanishing streams. *Journal of the North American Benthological Society*, **9**, 77-88.
- Boon P.J., Calow P. & Petts G.E. (1992) *River Conservation and Management*. John Wiley & Sons, New York.
- Bright E. (1995) *Relationships between land use and water quality parameters during lowflow and stormflow conditions in the River Raisin watershed, southeastern Michigan, USA*. MS thesis, University of Michigan, 119 pp.
- Cummings T.R. (1984) *Estimates of dissolved and suspended substance yield of stream basins in Michigan*. United States Geological Survey, Water Resources Investigation Report 83-4288, Reston, VA.
- Dodge D.P. & Biette R.M. (1992) River protection in Ontario, Canada: a case for holistic catchment management. *River Conservation and Management* (eds P. J. Boon, P. Calow and G. E. Petts), pp. 443-51. John Wiley & Sons, New York.
- Doppelt B., Scurlock M., Frissell C. & Karr J. (1993) *Entering the Watershed: A New Approach to Save America's River Ecosystems*. Island Press, Washington D.C.

- Erickson D.L. (1995) Rural land-use and land-cover change: implications for local planning in the River Raisin Watershed (USA). *Land Use Policy*, **12**, 223–36.
- Farrand W.R. & Bell D.L. (1982) Quaternary geology of Southern Michigan. *Michigan Geological Survey Division Map*, 1:500 000.
- Fay J.P. (1996) *Using GIS to model nonpoint pollution in an agricultural watershed in southeastern Michigan*. MS thesis, The University of Michigan, 55 pp.
- Forman R.T.T. & Godron M. (1986) *Landscape Ecology*. John Wiley & Sons, New York.
- Frissell C.A., Liss W.J., Warren C.E. & Hurley M.D. (1986) A hierarchical framework for stream habitat classification: viewing streams in a watershed context. *Environmental Management*, **10**, 199–214.
- Gordon S.I. & Simpson J.W. (1990) *The Big Darby Creek watershed project*. Final report presented to The Nature Conservancy, Ohio Chapter. 97 pp.
- Gregory S.V., Swanson F.J., McKee W.A. & Cummins K.W. (1991) An ecosystem perspective on riparian zones. *BioScience*, **41**, 540–51.
- Grumbine R.E. (1994) What is ecosystem management? *Conservation Biology*, **8**, 27–38.
- Gurtz M.E., Webber J.R. & Wallace J.B. (1980) Seston dynamics of southern Appalachian streams: effects of clear-cutting. *Canadian Journal of Fisheries and Aquatic Sciences*, **37**, 624–631.
- Hawkins C.J., Kerschner J.L., Bisson P.A., Bryant M.D., Decker L.M., Gregory S.V., McCoullough D.A., Overton C.K., Reeves G.H., Steedman R.J. & Young M.K. (1993) A hierarchical approach to classifying stream habitat features. *Fisheries*, **18**, 3–11.
- Hildrew A.G. & Giller P.S. (1994) Patchiness, species interactions and disturbance in the stream benthos. *Aquatic Ecology: Scale, Patterns and Process* (eds P. S. Giller, A. G. Hildrew and D. G. Raffaelli), pp. 21–61. Blackwell Scientific Publications, Cambridge MA.
- Horton R.E. (1945) Erosional development of streams and their drainage basins: hydrophysical approach to quantitative morphology. *Bulletin of the Geological Society of America*, **56**, 275–350.
- Hynes H.B.N. (1975) The stream and its valley. *Verhandlungen der Internationalen Vereinigung für Theoretische und Angewandte Limnologie*, **19**, 1–15.
- Karr J.R. (1991) Biological integrity: a long-neglected aspect of water resource management. *Ecological Applications*, **1**, 66–84.
- Kleiman R.E. & Erickson D.L. (1995) Landscape change in an agricultural watershed: the effect of parcelization on riparian forest cover. *Environment and Planning B: Planning and Design*, **23**, 25–36.
- Knisel W.G. (ed.) (1980) CREAMS: A field scale model for chemicals, runoff, and erosion from agricultural management systems. *United States Department of Agriculture, Conservation Research Report*, **20**, 642 p.
- Lammert M. (1995) *Assessing land use and habitat effects on fish and macroinvertebrate assemblages: stream biological integrity in an agricultural watershed*. MS thesis, The University of Michigan, 84 pp.
- Levin S. (1992) The problem of pattern and scale in ecology. *Ecology*, **73**, 1943–1967.
- Lindquist C. (1990) *A History of Lenawee County*. Windsor Publications, Chatsworth CA.
- Manson C., Bulkley J. & Allan J.D. (1994) *Surface Water Quality Management in the River Raisin Watershed: A Basin-wide Assessment of Current Policy and Possible Alternatives*. Monograph, School of Natural Resources and Environment, The University of Michigan, 46 pp.
- Michigan Department of Agriculture (1994) *Michigan Agricultural Statistics 1994*. Michigan Agricultural Statistics Service, Lansing MI.
- Michigan Department of Natural Resources (MDNR) (1991) *Qualitative biological and habitat survey protocols for wadable streams and rivers*. GLEAS procedure no. 51. Michigan DNR, Surface Water Quality Division, Great Lakes Environmental Assessment Section.
- Minshall G.W. (1978) Autotrophy in stream ecosystems. *BioScience*, **28**, 767–71.
- Naiman R.J. (1992) New perspectives for watershed management: balancing long-term sustainability with cumulative environmental change. *Watershed Management: Balancing Sustainability and Environmental Change* (ed. R. J. Naiman), pp. 3–11. Springer-Verlag, New York.
- Naiman R.J. & Décamps H. (eds) (1990) *The Ecology and Management of Aquatic–Terrestrial Ecotones*. UNESCO, Paris, and Parthenon Publishing Group, Carnforth, United Kingdom.
- Noss R.N. (1990) Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology*, **4**, 355–364.
- Osborne L.L. & Kovacic D.A. (1993) Riparian vegetated buffer strips in water-quality restoration and stream management. *Freshwater Biology*, **29**, 243–258.
- Roth N.E. (1994) *Land use, riparian vegetation, and stream ecosystem integrity in an agricultural watershed*. MS thesis, The University of Michigan, 126 pp.
- Roth N.E., Allan J.D. & Erickson D.E. (1996) Landscape influences on stream biotic integrity assessed at multiple spatial scales. *Landscape Ecology*, **11**, 141–156.
- Ryan R. (1995) *Perceptual river corridors: Understanding environmental preference in America's countryside*. MS thesis, The University of Michigan, 87 pp.
- Smith G.R., Taylor J.N. & Grimshaw T.W. (1981) Ecological survey of fishes in the Raisin River drainage, Michigan. *Michigan Academician*, **13**, 275–305.

- Strahler A.N. (1964) Quantitative geomorphology of drainage basins and channel networks. *Handbook of Applied Hydrology* (ed. Ven te Chow), section 4-2, McGraw-Hill, New York.
- Strayer D. (1979) Some recent collections of mussels from Southeastern Michigan. *Malacological Review*, **12**, 93-5.
- Sweeney B.W. (1992) Streamside forests and the physical, chemical, and trophic characteristics of piedmont streams in Eastern North America. *Water Science and Technology*, **26**, 2653-2673.
- Turner M.G. (1989) Landscape ecology: the effect of pattern on process. *Annual Reviews of Ecology & Systematics*, **20**, 171-198.
- Vannote R.L., Minshall G.W., Cummins K.W., Sedell J.R. & Cushing C.E. (1980) The river continuum concept. *Canadian Journal of Fisheries and Aquatic Sciences*, **37**, 130-137.
- Webster J.R. & Benfield E.F. (1986) Vascular plant breakdown in freshwater ecosystems. *Annual Reviews of Ecology & Systematics*, **17**, 567-594.
- Young R.A., Onstad C.A., Bosch D.D. & Anderson W.P. (1987) AGNPS, Agricultural non-point-source pollution model. A watershed analysis tool. *United States Department of Agriculture, Conservation Research Report*, **35**, 80 p.

(Manuscript accepted 30 June 1996)

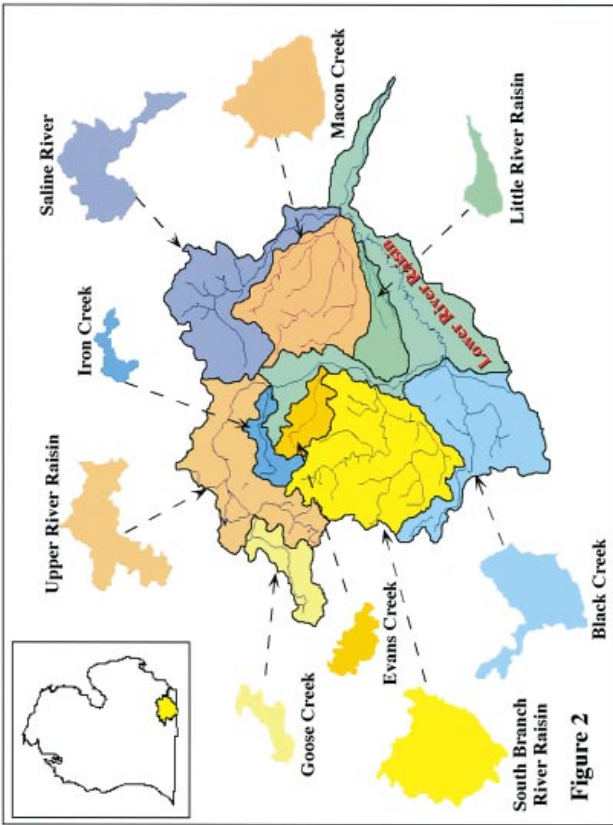


Figure 2

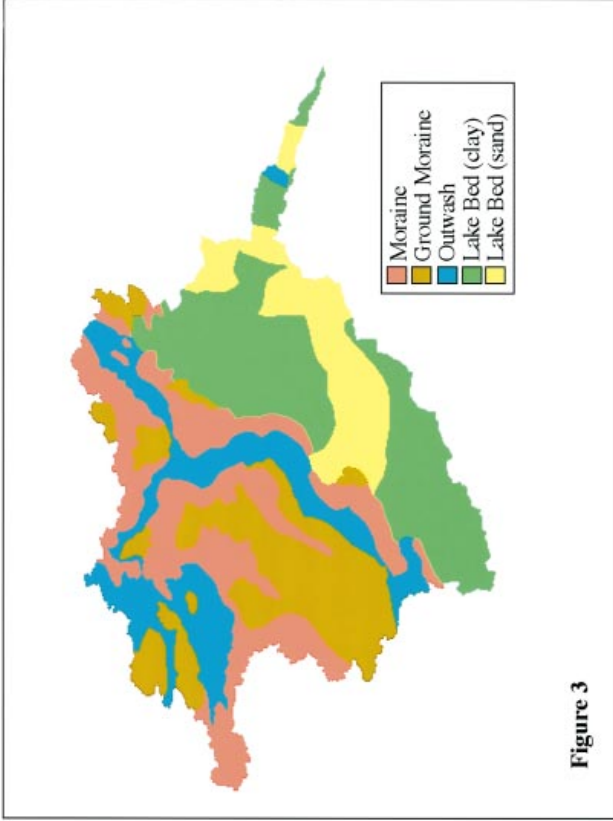


Figure 3

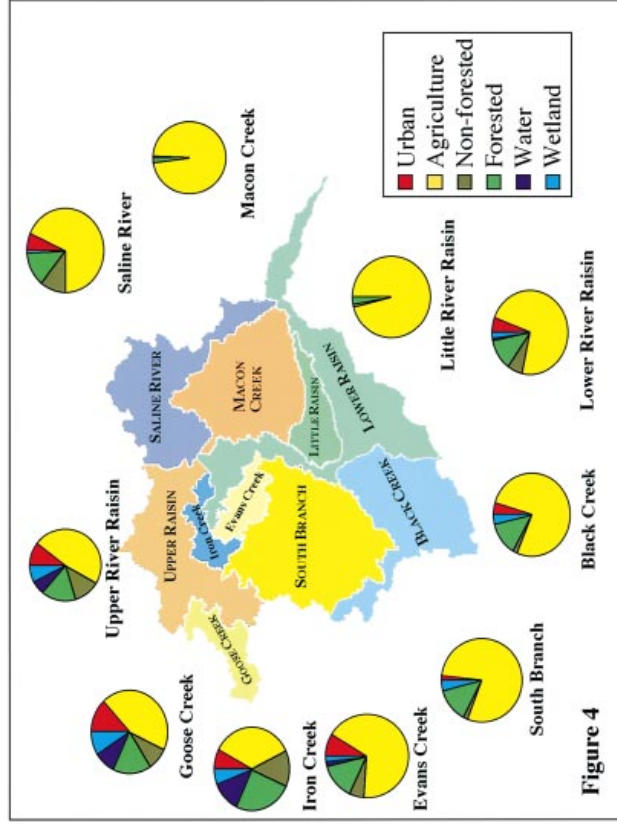


Figure 4

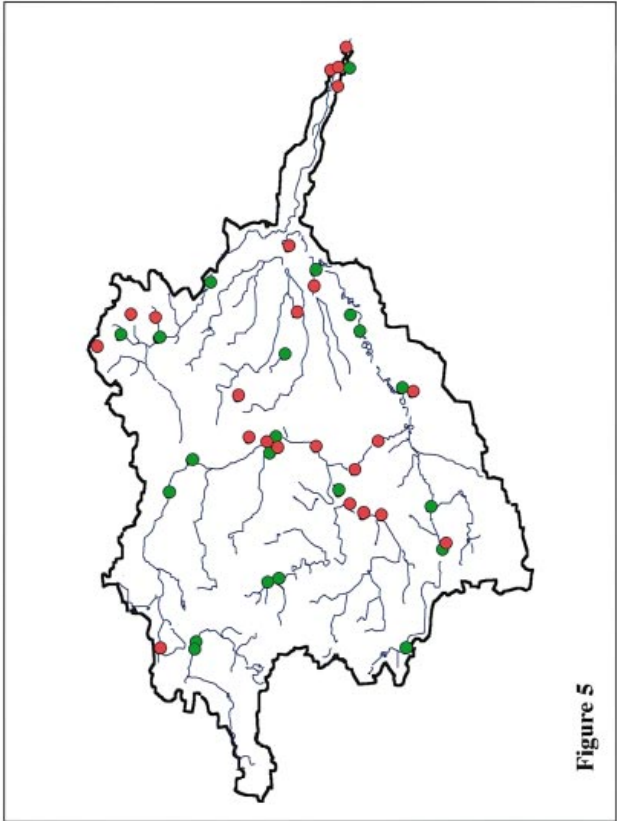


Figure 5

Fig. 2 Location of the River Raisin basin in south-eastern Michigan. Total catchment area is 2776 km². Individual, smaller catchments differ substantially in underlying geology and in land-use/cover.

Fig. 3 Quaternary geology of the River Raisin basin. The upper region of moraine and ground moraine is gently hilly, while the lower region of clays and sands is of very low relief. From Farrand & Bell (1982).

Fig. 4 Land use/cover in subcatchments within the River Raisin basin. Note the diversity of cover types in the upper basin and the dominance of agriculture in the lower basin.

Fig. 5 NPDES (National Pollution Discharge Elimination System) permit locations within the River Raisin. Green = publicly owned treatment works, red = small industries. See Manson *et al.* (1994) for a full listing.

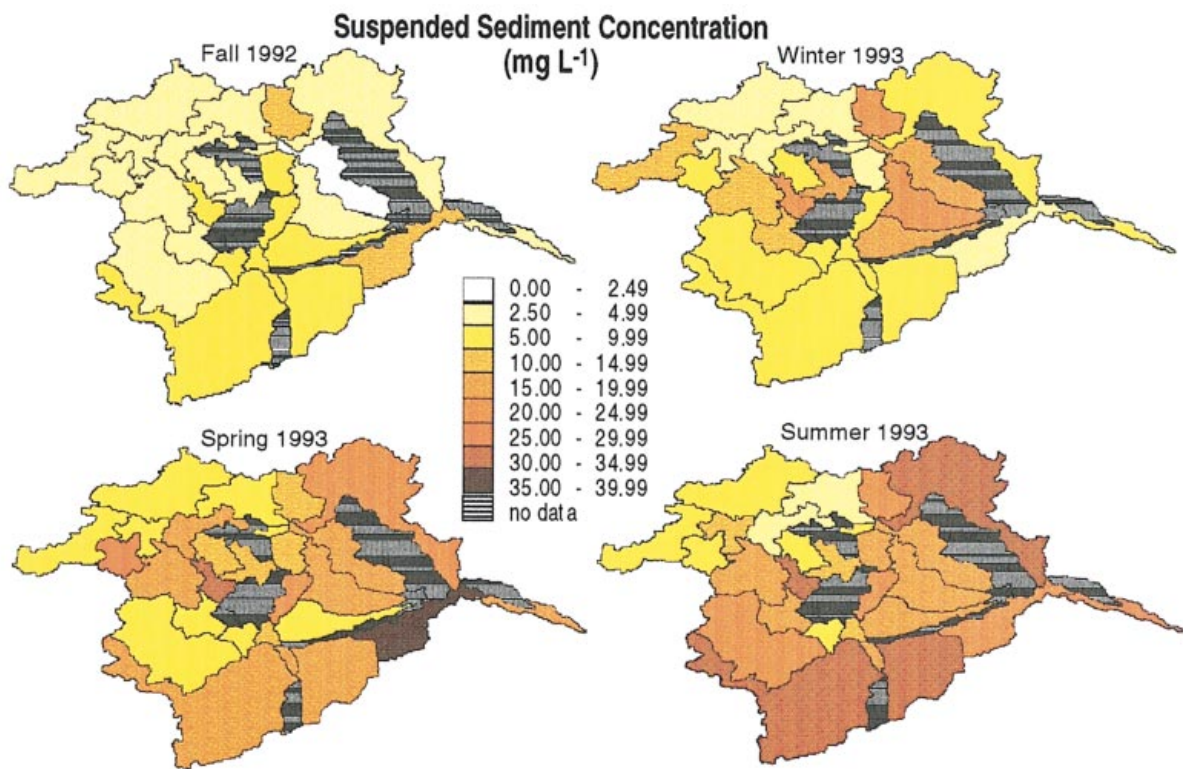


Fig. 7 Concentrations of total suspended sediments under lowflow conditions in four seasons, for the River Raisin basin in hydrologic year 1993. Darker red tones indicate higher values.