# Ecological Perspective on Water Quality Goals

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ABSTRACT / The central assumption of nonpoint source pollution control efforts in agricultural watersheds is that traditional erosion control programs are sufficient to insure high quality water resources. We outline the inadequacies of that assumption, especially as they relate to the goal of attaining ecological integrity. The declining biotic integrity of our water resources over the past two decades is not exclusively due to water quality (physical/chemical) degradation. Improvement in many aspects of the quality of our water resources must be approached with a much broader perspective than improvement of physical/chemical conditions. Other deficiencies in nonpoint pollution control programs are discussed and a new approach to the problem is outlined.

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Increased societal concern for deteriorating water resources in the United States is clearly manifest in the passage of water pollution control legislation during the past decade. The Clean Water Act has set forth the objective of restoring and maintaining the "...chemical, physical, and biological integrity of the Nation's waters..." The Act further established a goal of eliminating the discharge of pollutants by 1985, and an interim goal of achieving, wherever attainable, water quality that provides for the protection and propagation of fish and provides for recreation in and on the water (commonly referred to as the "fishable/swimmable" goal). The major efforts and funding of water pollution control programs in the 1970s focused on point sources of pollution because it was relatively easy to control and regulate them. As the magnitude of the point source pollution problem was reduced, the relative contribution from nonpoint sources increased. Large scale efforts to curb nonpoint pollution are just beginning. However, before major expenditures are made, our experiences with several nonpoint pollution control projects prompts us to recommend an examination of water resource problems in the United States with respect to the current legislative framework.

The purpose of this paper is to examine the objectives and goals of the Clean Water Act and the ability of current programs to meet those objectives. We accomplish this through examining nonpoint pollution abatement programs in the United States and draw upon our experiences with an ongoing study, the Black Creek Project in Allen County, Indiana. We discuss the concept of biological integrity and outline briefly the fundamentals of stream biology to emphasize the need for a holistic approach to water resource management. Two alternatives are explored: (1) traditional soil and water conservation management, and (2) an innovative approach designed to restore biological integrity.

KEY WORDS Nonpoint source pollution, Water quality, Stream ecosystems, Flow regimes, Clean Water Act, Allen County, Indiana; Biotic integrity

## The Black Creek Project

In 1972 the Allen County, Indiana, Soil and Water Conservation District, with assistance from the USDA-Soil Conservation Service, Purdue University, and the University of Illinois, began investigating nonpoint source pollution in a 48.5 km$^2$ (12,000 acre) subwatershed of the Maumee River basin under a grant from the U.S. Environmental Protection Agency. This study, commonly called the Black Creek Project, was the first detailed look in the United States at the contributions of agriculture to the degradation of water quality and ultimately to a reduction of environmental quality. The Black Creek Project, although now providing information of use to Section 208 planners, actually predates the adoption of Public Law 92-500 which, in part, requires an analysis of the impact of nonpoint source pollution on water quality. It was funded under provisions of the 1969 Water Quality Act calling for special demonstration projects to improve the quality of water in the Great Lakes (Morrison 1977a).

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The Soil Conservation Service supplied technical assistance for implementing traditional soil and water conservation practices within the study watershed. Over a five year period, a sum of $519,000 was spent on cost-sharable practices and, although not 100 percent successful, the project was able to implement a great number of soil and water conservation practices. Researchers from Purdue University and the University of Illinois, representing agricultural engineering, agronomy, agricultural economics, rural sociology, and the biological sciences, investigated the impact of the project on various components of the system. Detailed results are reported by Morrison (1977b). The discussion that follows is an outgrowth of our experiences with the Black Creek Project and similar nonpoint pollution abatement programs in Indiana, Illinois, and Ohio.

## Biological Integrity and the Fishable/Swimmable Goal

Is the objective of chemical, physical, and biological integrity equivalent to the fishable/swimmable goal? Although these terms were not precisely defined in the Clean Water Act, it is clear that the two concepts are not equivalent. The interim goal is to achieve a level of *water quality* that is compatible with fishing and swimming in a waterway. Water quality is traditionally interpreted as the physical/chemical properties of water, a fact that greatly limits the scope of the goal. We believe other factors (discussed below) that may affect the actual attainment of fishable/swimmable conditions are not adequately addressed by existing pollution control and water resource management programs. For example, water quality standards for physical/chemical parameters have served as surrogates for the fishable/swimmable goal. States set water quality standards (WQS) based upon the criteria necessary to protect aquatic life and human health and, thus, compliance with WQS implies the attainment of fishable/swimmable waters. A comprehensive evaluation of both physical/chemical and biological data is a better determination of whether or not fishable/swimmable conditions are being achieved.

The concept of integrity mentioned in the Clean Water Act is, at best, elusive. A comprehensive symposium sponsored by the Office of Water and Hazardous Materials of USEPA (Ballentine and Guarraie 1975) did not produce a clear definition of integrity but several contributors strongly urged that the water resources of the nation be considered from a holistic (systems) perspective. Thus, unlike the fishable/swimmable goal, the integrity objective encompasses all factors affecting the ecosystem and can be defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region." A similar definition of ecological integrity was given by Cairns (1975). The summation of chemical, physical and biological integrity can be equated with ecological integrity. A system possessing integrity can withstand, and recover from, most perturbations imposed by natural environmental processes, as well as many major disruptions induced by man. A thoughtful discussion of these ecological concepts, including their measurement and management applications, was provided by Westman (1978).

Note that this definition does not make specific mention of resource value in terms of man's use of water (beneficial uses). Instead, there is an implicit recognition that a functioning ecological system is the ultimate resource upon which man depends. As Woodwell (1975) has stated: "These are the resources that are used by all of the people on earth, all of the time." Only in the presence of a functioning biological system are other resources (for example, energy, minerals) useful to man. Some would argue that it is unrealistic to maintain ecosystem integrity as defined above. To these individuals, the beneficial uses of water are of greater and more immediate concern to the continued functioning of our society. Granted, it is unrealistic to adhere to the goal of fully natural ecosystems at the expense of beneficial resource use, but it is also unrealistic to assume that our environment can continue to absorb an accumulation of intrusions on the integrity of the biosphere (Woodwell 1975). A middle ground is required and was, we believe, the intent of the Congress when it enacted the Clean Water Act.

A compartmentalized model developed by Odum (1969) is useful in visualizing the middle ground we are seeking. It is a simple representation of the basic functional types of environments required by man (Fig. 1): 1) productive environments, for example, agriculture; 2) protective environments, for example, natural areas preserving ecological integrity; 3) a compromise between 1 and 2; and 4) urban-industrial environments. As will be discussed below, the compartment model is useful for addressing, in operational terms, strategies of innovative soil and water conservation management.

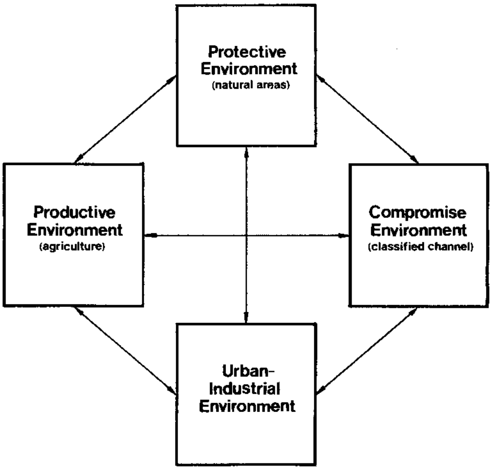

**Figure 1.** Compartment model of the basic kinds of environment required by man, partitioned according to ecosystem development and life-cycle resource criteria (modified from Odum 1969).

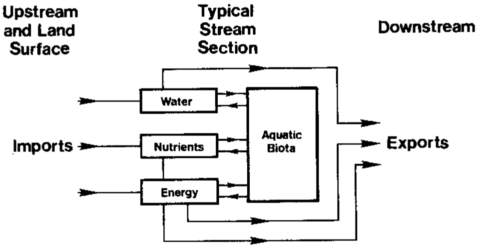

**Figure 2.** Generalized flow diagram for an aquatic ecosystem.

## Stream Ecosystems

An individual stream or section of a stream is not an isolated system. Streams and rivers are open ecosystems with dynamic imports and exports of nutrients, energy, and water (Fig. 2). Inputs to upstream (headwater) areas are ultimately carried to and affect downstream areas (Meade and Trimble 1974). But movements are not limited to transport from upstream to downstream areas. Many aquatic organisms, especially fishes, may depend upon migration among stream reaches for the completion of their life cycles. Thus, stream ecosystems must be considered in terms of extensive geographic areas and as dynamic, open ecosystems.

This ecological reality illustrates the weakness of using the interim fishable/swimmable goal as a terminal objective. Fishable, in this context, is often defined as making the stream useful to fishermen in capturing sport or commercial fish. However, since many small streams contain too little water to be used for swimming or to support a sport or commercial fishery, they are often discounted as not having any significance to the fishable and swimmable objective. We feel that it is inappropriate to measure the value of a stream reach based on this particular component of fishable and swimmable criteria. That quality must be more broadly defined than hook-and-line locally because the importance of headwater streams to downstream reaches (in terms of production of fishable benefits downstream) is underemphasized in that context. Although a headwater stream may never be fishable, it is an integral component of the watershed; its preservation is essential if downstream reaches are to be fishable and swimmable (Karr and Dudley 1978). The biological integrity mandate of the Clean Water Act depends on an overview of the entire water resource system at the watershed level rather than isolated consideration of local stream reaches.

The concept of the open ecosystem has two other implications. First, streams are subject to rapid and gross perturbations caused by land-use changes (urbanization, intensive agriculture). Secondly, properly managed land use in watersheds can effectively and rapidly lessen perturbations in stream systems.

A classification system developed by Horton (1945) and modified by Keuhne (1962) is commonly used by aquatic biologists to discuss the progressive increase in stream size. According to this system, the smallest streams in a watershed are first order. When two first-order streams join, they form a second order stream; when two second-order streams join, they form a third order stream. Ecological discussions of streams typically consider three size classes: the headwaters (1st to 3rd order), intermediate-sized rivers (4th to 6th order), and large rivers (7th and larger orders). While this classification system is generally useful, note that stream order effects may vary somewhat among watersheds. For example, differences in size of upstream watershed or watershed topography may affect the nature of the stream-order pattern.

Man alters streams by dredging new channels in poorly drained areas or by modifying existing natural channels.

These man-engineered watercourses must be considered streams even though they are clearly different from natural streams in many respects (for example, drainage and flow characteristics, chemical and physical conditions, bottom type). Important as these differences are, one basic ecological principle applies to both man-altered and natural streams; water, nutrients, and energy are exported to downstream areas. Thus, man's construction of drainage ditches is not separate from natural drainage patterns; rather, it is only an addition to or a modification of the natural stream network that profoundly affects water resources both locally and downstream.

We have been able to identify what we feel are four major classes of variables (Fig. 3) which, when modified by man's activities, play primary roles in determining the ecological integrity of running water (lotic) ecosystems (Karr and Dudley 1978). These are flow regime, water quality, habitat structure, and energy source.

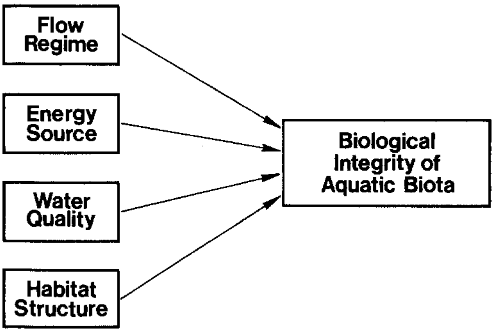

**Figure 3.** Primary variables affecting the structural and functional integrity of the biota of a headwater stream (modified from Karr and Dudley 1978).

### Flow Regime

Fluctuating water levels are an integral part of all stream ecosystems and aquatic organisms have evolved to compensate for changing flow regimes. Even areas decimated by catastrophic floods or droughts are often quickly recolonized (Larimore and Smith 1963, Horwitz 1978). But modifications of the land surface with changing land use typically result in flood peaks and low-flow periods that are more severe as well as more frequent. Late summer low-flow periods may be extended while hydrograph peaks following runoff events are often of shorter duration.

High water periods are determined by the frequency, occurrence, and type of rainfall event, the timing of those rainfall events, and such antecedent conditions as soil moisture, time since the last rain, and amount and type of soil cover. Flood events in natural watersheds tend to have a dampened hydrograph, while those in agricultural watersheds tend to have a sharp and extreme peak (Bormann and others 1969). Low flows in natural watersheds tend to be severe only in particularly dry years, while low-flow periods in modified watersheds, especially those with extensive drainage systems, are relatively more severe, especially during late summer and early fall periods when rainfall is at relatively lower levels in midwestern portions of the United States.

When such flow events prevent seasonal migrations of fish or interfere with egg or fry development, irreversible catastrophic changes may result. Under the extreme condition of dewatering, the biota may be lost entirely. Recognition of the significance of this problem has precipitated the formation of a special group within the Office of Biological Services of the U.S. Fish and Wildlife Service. This group, the Cooperative Instream Flow Service Group, is developing a detailed methodology for evaluating flow requirements of aquatic organisms. The primary objective is to develop criteria to assess the impact of altered stream-flow on habitat characteristics and the use of an area by aquatic organisms (Stalnaker and Arnette 1976). Efforts are underway to identify the hydraulic conditions necessary for a variety of organisms, including different age classes of the same species. For example, the distribution of walleye as a function of flow is given as a probability distribution that varies among the age classes and with the reproductive state of fish (Fig. 4). Fry are found in only the slowest water, while juveniles, and especially adults, utilize higher velocities. Finally, spawning fish require much higher flow rates. Modifications in a stream that destroy areas with "spawning" velocities may have a significant negative effect on walleye reproduction even though adult fish may not be directly affected. These efforts that examine the flow regimes and hydraulics of streams and their effects on ecological integrity will make major contributions to the management of running water resources.

### Water Quality

In recent years most efforts to reverse the degradation in the quality of water resources have focused on the physical and chemical properties of water. Temperature, dissolved oxygen, concentrations of soluble and insoluble organics and inorganics, heavy metals, and a wide variety of toxic substances are components of special interest.

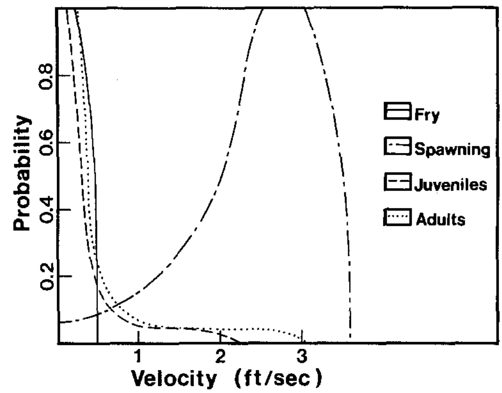

**Figure 4.** Probability of use curve for several age classes of walleye (*Stizostedion vitreum*) (adapted from unpublished material of the Cooperative Instream Flow Service Group, with permission of C. Stalnaker).

They may affect biological integrity by directly causing mortality or may shift the balance among species as a result of subtle effects such as reduced reproductive rates or changing competitive ability.

The importance of these factors on stream biota is widely known (Warren 1971, Hynes 1974). Water quality factors that are of special concern include light, temperature, dissolved oxygen, suspended solids, dissolved ions and other materials. These play critical roles in determining an area's suitability for aquatic organisms. In addition to the average conditions, extremes and their temporal patterns have important impacts on biota.

Each of these is of concern. In many watersheds, human activities may precipitate the degradation of ecological integrity because of the synergistic effects of several variables (see discussion of algal blooms below).

### Habitat Structure

The physical structure of the environment also plays a major role in determining the number and kinds of fishes and other organisms that can survive in a stream. Channel geometry in natural watersheds is typically meandering, with substrate diversities created by varying flow regimes length-wise and across the channel. The result is substrate sorting, the presence of pools and riffles, erosion and deposition areas, and ultimately a dynamic equilibrium between the flowing water and its substrate. In contrast, stream alterations, such as channelization, produce channels with little pool and riffle development and uniform substrates and depth. In addition, sedimentation increases as a result of a disequilibrium in a channel and/or because of erosion from the land surface. Finally, straight, open channels in the presence of abundant nutrients, sunlight, and high temperatures create ideal conditions for algal blooms. In years of below-normal rainfall in late spring or early summer, these algal blooms develop in late May and early June; in years with more substantial rainfall during the early summer, the algal blooms are curbed by the flushing action of channel flow.

These and other complex interactions with the physical habitat of streams affect the biota of the stream. Bottom-dwelling invertebrates such as mollusks (Harman 1972) and insects (Allan 1975) seem to be especially affected by the diversity and sorting of bottom or substrate types in an area (sand, gravel, rocks, etc.). Substrate particle size determines the size of the interstitial spaces which, in turn, affects the type of bottom-dwelling community. Adequate interstitial space is essential for the movement and feeding of many aquatic invertebrates. Fishes, which use environments in a more three dimensional fashion, seem to respond to a complex of structural features including substrate type, depth, and current velocity (Gorman and Karr 1978). Further, many fishes and some invertebrates require places of concealment (cover) as feeding locales or as places to escape predation. General cover types include undercut banks, timber and brush snags, and aquatic vascular plants. Without essential habitat structure, many forms of aquatic life are eliminated from streams. If we measure habitat diversity as a mosaic of depth, current and substrate conditions, and fish species diversity (both using the Shannon's index; see Gorman and Karr 1978 for details), it is clear that more diverse habitats support a greater fish species diversity (Fig. 5). Thus, nonpoint control efforts that produce high water quality (physical/chemical conditions) may fail to produce a water resource with high biotic integrity if suitable physical habitats are absent.

Two recent research efforts illustrate the importance of considering habitat structure as a primary determinant of the quality of a water resource. In one case, we detected considerable movements by fish in a number of regions in a study watershed (Black Creek) in northeast Indiana. To study these movements, we marked fish with a procedure called cold branding. Silver brands with the shapes of various letters were supercooled with liquid nitrogen and touched to the sides of fish, duplicating the common hot branding used to mark livestck on open

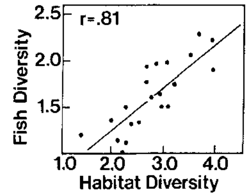

**Figure 5.** Relationship between habitat diversity and fish species diversity (from Gorman and Karr 1978).

ranges. We branded fish in three major habitat types. Three sampling stations were selected in the main channel of Black Creek in areas that had been subjected to major channel alterations early in the study. The second major habitat was on the Wann Drainage immediately east of the Black Creek watershed. Although there has been no recent channel modification work in this area, the stream reach had been modified approximately ten years earlier. The lack of disturbance over the years created a stream that had begun to meander in its channel base and in which dense vascular plant populations provided cover. As reported earlier by Gorman and Karr (1978), this section of stream contained a richer fauna than that found in similar reaches of the Black Creek watershed. The third study area was in the Black Creek watershed on the Wertz Drain where it traversed a woodlot and had an especially rich fauna (Gorman and Karr 1978).

Populations in higher quality habitat are relatively more secure (Table 1); they are able to survive locally over longer periods. Clearly, total emphasis on water quality in the physical/chemical sense will not overcome habitat structure deficiencies. Further, we have provided evidence in earlier reports that those areas with better quality habitat also have a beneficial effect on water quality (Karr and Gorman 1975; Karr and Schlosser 1977, 1978; Schlosser and Karr 1980).

In another study, one member of the group at the University of Illinois divided two sections of Jordan Creek in east-central Illinois with 1/4-inch mesh hardware cloth supported by steel posts. On one side of each section all cover features (logs, limbs) were removed from in or near the water. On the other side, a continuous series of similar objects was secured along the stream. In July and September, samples of the biomass of fish were 4.8 to 9.4 times as high in the areas with structurally complex habitats. Further, the larger fish, and especially the top predators, tended to select the structured habitat. In this case we know that water quality is the same in the structured and unstructured sides of the stream, yet the numbers of fish are markedly different. These improved habitat conditions seem to provide two things: habitat for small fish including a diversity of substrates for food organisms, and hiding places (cover) from which large fish can prey on smaller species. This emphasizes the importance of habitat structure as a determinant of biotic conditions in a stream.

## Energy Source

In stream ecosystems, the form and source of the energy and nutrients are especially important in determining ecosystem characteristics. The energy contained in the chemical bonds of organic matter is the basic energy source for animals, fungi, and many bacteria. The process of breaking the chemical bonds to release energy and simpler compounds is respiration. Production is the reverse process in which energy, in the form of solar

Table 1. Recapture rates, habitat diversity, and stream channel conditions at several sites where fish were marked by cold branding

| Stream | Channel and habitat conditions | Habitat diversity* | Number of fish marked | Fish recaptured (%) |
|---|---|---|---|---|
| Black Creek | Badly disturbed | 2.89 | 1,190 | 5 |
| Wann Creek | Disturbed, but recovering | 3.05 | 767 | 15 |
| Wertz Drain in Wertz Woods | Relatively natural | 3.31 | 958 | 37 |

*This is an index of complexity of stream habitat as a composite of substrate types (sand, pebble, rock, etc.), water depth, and current velocity using the information theoretical measure of diversity. Higher values indicate stream habitats of greater complexity. See Gorman and Karr (1978) for a detailed explanation of methods.

Table 2. General characteristics of running water ecosystems according to size of stream (modified from Cummins 1975)

| Stream size | Primary energy source | Production (trophic) state* | Light and temperature regimes | Trophic status of dominant | |
|---|---|---|---|---|---|
| | | | | Insects | Fish |
| Small headwater streams (stream order 1–3) | Coarse particulate organic matter (CPOM) from the terrestrial environment<br>Little primary production | Heterotrophic<br>$P/R < 1$ | Heavily shaded<br>Stable temperatures | Shredders<br>Collectors | Invertivores |
| Medium-sized streams (4–6) | Fine particulate organic matter (FPOM), mostly<br>Considerable primary production | Autotrophic<br>$P/R > 1$ | Little shading<br>Daily temperature variation high | Collectors<br>Scrapers (grazers) | Invertivores<br>Piscivores |
| Large rivers (7–12) | FPOM from upstream | Heterotrophic<br>$P/R < 1$ | Little shading<br>Stable temperatures | Planktonic collectors | Planktivores |

*A stream is autotrophic if instream photosynthesis exceeds the respiratory requirement of organisms living in the area (that is, $P/R > 1$). It is heterotrophic if importation of organic material from upstream areas or the land surface is necessary (that is, $P/R < 1$).

radiation and simple compounds, is converted into complex organic compounds. Obviously, plants are the major producer organisms and high production rates are dependent upon abundant sunlight and essential nutrients. The fundamental energy relationship can be expressed by the production ($P$) to respiration ($R$) ratio: $P/R > 1$ when production exceeds respiration (autotrophy); $P/R < 1$ when respiration exceeds production (heterotrophy). In streams, this basic energy flow characteristic is sensitive to the organic loading from the terrestrial environment, the amount of sunlight and nutrients, the form or availability of nutrients (simple compounds vs. complex organic compounds), and a number of other factors such as turbidity.

Studies of the energetics of stream ecosystems (Cummins 1974) stress process-oriented attributes such as production, respiration, energy flow, nutrient cycling, and trophic dynamics. It is a fundamental postulate that many process-oriented attributes of running water ecosystems change as streams increase in size from headwaters to mouth.

The transition from small headwater areas to major rivers is referred to as the stream continuum. Structural and functional attributes of natural stream ecosystems change along this continuum (Table 2). These attributes serve as reference points for assessment of the status of the stream ecosystem in any location. If the ecosystem in a region differs from these expectations, the difference may be due to ecosystem degradation resulting from man's activities. At the very least, it suggests that more detailed study is required. The theoretical foundation for these "reference points" comes to a great extent from forested watersheds. As a result, it may be necessary to develop an alternate foundation for markedly different terrestrial environments in the dry nonforested regions of western North America (Minshall 1978).

Headwater streams in natural watersheds of eastern North America are usually heterotrophic. That is, they have production to respiration ratios ($P/R$) of less than 1.0 and are dependent on food produced outside the stream (allocthonous material). Dense tree canopies shade the headwaters so that instream production is minor, generally from small populations of moss or periphytic algae (algae attached to rocks or other substrates). One study in a New Hampshire watershed (deciduous forest) showed that 99 percent of the energy requirements for the biota of a headwater stream were of allocthonous origin (Fisher and Likens 1973). A very different watershed in Oregon (coniferous forest) demonstrated the same general pattern (Sedell and others 1973). In this situation the persistence of the biotic community depends on a regular input of food (organic matter) from external sources. The terrestrial environment supplies much of the energy input in the form of leaf litter shed in a predictable seasonal pattern (fall in temperate deciduous forest, dry season in tropical forest).

The particle size of organic matter entering a stream is just as importnt to stream ecosystem functioning as the amount, type, or timing of energy input. In undisturbed headwater areas, the terrestrial environment produces particulates of relatively large size (such as leaves, and twigs), referred to as coarse particulate organic matter (CPOM). Bacteria and fungi quickly colonize the CPOM and, as a result of their metabolic activity, speed the process of fragmentation into smaller particles—fine particulate organic matter (FPOM). (Any organic particle less than 1 millimeter in diameter is considered FPOM, regardless of its source.) The breakdown process of CPOM is accelerated by benthic invertebrates, primarily aquatic insects, which ingest and further fragment (or shred) the CPOM. Organisms with this functional capacity are called shredders. Shredders utilize some of the energy contained in the CPOM along with the rich growths of attached bacteria and fungi. But most of the CPOM is simply converted to FPOM and is available for use by another functional group of aquatic organisms called collectors.

Collectors either filter FPOM from the water or gather it from the sediments (Cummins 1973). Because of structural adaptations, most collector organisms utilize FPOM only within a narrow size range (Cummins 1974), thus illustrating the critical nature of particle size in stream ecosystems. The natural association of shredder and collector organisms in headwater streams results in a highly efficient utilization of energy (organic matter) input. Cummins (1975) has estimated that the biota process about 80 percent of the particulate organic matter (POM) and 50 percent of the dissolved organic matter (DOM) in natural first to third order streams.

Functional attributes are markedly different in undisturbed intermediate-sized rivers. The stream becomes autotrophic ($P/R > 1$) as the stream becomes less shaded and algae and vascular plants increase in abundance. CPOM inputs are reduced, resulting in decreased shredder abundance. Incoming allocthonous material is primarily FPOM from headwater areas and a variety of collector organisms is common. The autotrophic status of the stream accounts for the presence of a third functional group of aquatic macroinvertebrates. These are the scraper or grazer organisms that exploit periphytic algae and vascular plants. A few scrapers can always be found in natural headwater streams, but their abundance is severely limited by the low rate of primary production.

In large rivers (7th to 12th order), the stream again becomes heterotrophic primarily because of increased turbidities reducing light penetration and, therefore, the potential for photosynthesis (Cummins 1973). The primary production that does occur is generated by phytoplankton (free-floating algae). Free-floating collectors (zooplankton) are also present, utilizing the phytoplankton and suspended FPOM as food. Collectors also predominate in the sediments, as FPOM is the major energy source. Few scapers or shredders occur in a large river environment.

The fish fauna also reflects the energy sources available in a stream. However, fish can be more directly related to the value of the water resource (commercial or sport fish) in human terms. Cummins (1975) categorized the functional attributes of fish communities according to the food habits of the dominant fish. Predominant food habits are somewhat different for the three major ecological areas of an undisturbed river system. In headwater streams, fishes that feed upon macroinvertebrates (invertivores) dominate. Invertivores along with piscivores (fish that consume other fish) dominate intermediate-sized rivers. Finally, in large rivers, dominant members of the fish community are planktivores (fishes feeding upon both phytoplankton and zooplankton). Two additional categories are omnivores (consuming both plant and animal matter in approximately equal portions) and herbivores (consuming primarily plant materials). Omnivores and herbivores are rarely dominant in natural running water systems.

Our experience in modified and natural watersheds in Indiana, Illinois, and Iowa indicates major disturbances in these energy source (functional) dynamics. Many modified headwater areas seem to be more autotrophic than heterotrophic (Table 3) because of the abundance of sunlight and nutrients. Algal blooms alter the organic load and habitat characteristics of the stream. This, in turn, affects the aquatic invertebrate community, organic matter processing, and, thus, organic loadings downstream. In addition, there is some evidence that the trophic status of fishes shifts from piscivores to omnivores because of declining water quality, resource base,

Table 3. General characteristics of natural (Cummins 1974) and modified (Karr and Dudley 1978) headwater streams in eastern United States

| Parameter of interest | Natural | Modified |
|---|---|---|
| *Water quality* | | |
| Light and temperature | Heavily shaded<br>Stable temperatures | Open to sunlight<br>Very high summer temperature |
| Dissolved oxygen | Relatively stable | Highly variable |
| Suspended solids concentration | Low to very low | Highly variable |
| Dissolved ions | Generally low | High, especially for $P$ and $N$ |
| *Flow regime* | | |
| Flood events | Dampened hydrograph | Hydrograph peaks sharp and severe |
| Low flows | Moderately severe only in dry years | Moderately severe each year in late summer and early fall; extremely severe in dry years |
| *Habitat structure* | | |
| Pools and riffles<br>Meandering topography | Channel topography and substrate diversity in equilibrium with stream hydraulics | Reduced and/or destroyed by channel maintenance activities |
| Sedimentation | Minor except in a few unstable bank areas | Major problem with sediment source from land and from unstable banks; sedimentation decreases habitat diversity and directly abrades organisms |
| *Energetics* | | |
| Particulate organic matter size and source | Predominantly coarse particulate organic matter from forested terrestrial environment | Less coarse and more fine particulate organic matter from agricultural and domestic sewage |
| Production (trophic) state | Little primary production<br>Heterotrophic; $P/R < 1$ | Algal blooms common<br>Autotrophic; $P/R > 1$ |
| Trophic status of dominant | | |
| Insects | Shredders, collectors | Scrapers, collectors |
| Fishes | Invertivores | Invertivores but forced to select a broader range of food types |
| Migrant fishes | Top predators | Mostly filter feeders and/or omnivores |

and habitat conditions (Karr and Dudley 1978). As a result, populations of less desirable fishes increase while top predator populations, which act as a natural population check on other species, decline.

In summary, then, we suggest that the attainment of ecological integrity in our water resource systems demands a broad conceptual approach. Several key problems to be addrssed in agricultural watersheds are reiterated here:

1. *Allocthonous organic matter inputs:* FPOM input from sewage and stormwater runoff is substantial, as evidenced by high bacterial contamination (Dudley and Karr 1979). This change, along with the modification in form and content of CPOM discussed earlier, results in major structural and functional changes in the stream ecosystem.
2. *Nutrient availability:* Concentrations of simple nutrient forms ($PO_4$, $NO_3$, $NH_4$) do not limit algal populations. In addition, inputs of complex organic compounds associated with CPOM are not effectively processed.
3. *Sunlight availability:* A predominance of unshaded stream channels results in high solar energy input.

Coupled with available nutrients (#2 above), this results in buildup in algal populations (CPOM), which are either subject to slow decay in the headwaters or are washed downstream in large quantities during high flows. These algal blooms add to the organic load of the aquatic system and change the physical characteristics of the stream environment (reducing current velocities, covering natural substrates).

4. *Temperature and dissolved oxygen imbalance:* Seasonal and daily patterns of temperature and dissolved oxygen are exaggerated and poorly buffered from environmental influences (weather extremes, organic loading).
5. *Stream habitat characteristics:* The diversity and stability of high quality stream habitat are low (Gorman and Karr 1978). The ditching and drainage efforts prevalent in many agricultural watersheds perpetuate this problem.
6. *Seasonal low flows:* The loss of natural vegetation and installation of complex drainage networks results in rapid runoff instead of slow release of excess water. As a result, extreme low flows during dry periods, especially in late summer and early fall, place considerable stress on aquatic ecosystems.
7. *Changes in insect and fish communities:* These and other shifts in the four primary variables (individually and in the aggregate) cause major shifts in benthic insect faunas as well as the fish communities. In addition, because of the effect of these changes on the use of headwaters as spawning and nursery areas, the fish of downstream areas are also affected (Karr and Dudley 1978).

## Water Resource Management in Agricultural Watersheds

The central assumption of most agricultural nonpoint pollution control programs has been: traditional soil and water conservation practices are sufficient not only to reduce erosion and other nonpoint pollutants but also to improve the quality of the water resource. That is, it is possible to manage water resource problems resulting from agricultural land use through a voluntary soil and water conservation program. Numerous demonstration projects as well as the proposed Rural Clean Water Program are employing this basic assumption. We now examine the ability of existing programs (alternative A) to meet the goals and objectives of the Clean Water Act in contrast to the ability of management programs that incorporate the principles of stream ecosystems (alternative B).

### Alternative A. Traditional Soil and Water Conservation Management

The typical nonpoint pollution control program concentrates on a list of erosion control and animal waste control practices used by the Soil Conservation Service. This list is then reduced to a subset of Best Management Practices (BMPs) thought to have some value in improving water quality. The disadvantage of this approach is that a number of other activities that may result in improvements in the quality of the water resource are not considered. Further, the potential benefits of an integrated network of erosion control practices, coupled with practices that may only benefit water quality, may be greater than the benefits from erosion control practices alone.

Traditional soil and water conservation management does not effectively consider the principle of ecological integrity. The primary focus of the management agencies involved (Soil and Water Conservation Districts, Soil Conservation Service, Agricultural Extension Service, and Agricultural Crop Stabilization Service) is maintaining agricultural productivity through erosion control, land drainage, and the management of soil fertility (Carter 1977, Morrison 1977c). Thus, cropland is the unit being managed with benefits going to both cropland and, presumably, downstream waterways. Water resource benefits occur in downstream waterways because of reduced pollutant loading. Lakes and large rivers in highly agriculturalized areas would be expected to receive the greatest benefits from reduced pollutant loading. Traditional soil and water conservation programs are clearly needed in waters where sediment, nutrients, or toxics are a problem.

However, the major shortcoming of the BMP approach is the failure to consider the stream ecosystem between the cropland and the downstream waterway where the benefits of reduced pollutant loading show up. These stream ecosystems are headwaters and intermediate-sized rivers that have often been drastically disturbed by agricultural land-use practices. If reduced pollutant loading has any beneficial impact on these small streams and rivers, it is imperceptible due to major perturbations in flow regime, habitat structure, and energy dynamics. In summary, the effectiveness of BMPs in achieving water quality compatible with fishable/swimmable conditions has not been proven; and neither are BMPs geared towards reaching the objective of ecological integrity.

### Alternative B. Innovative Management to Restore Ecological Integrity

Soil conservation practices (BMPs) applied to the land have water quality benefits but they are only a part of a system of practices required for the sound management of water resources, including stream ecosystems. The time is right for careful application of an expanded list of BMPs into BEST MANAGEMENT SYSTEMS (Karr and Schlosser 1978). The following questions must be routinely asked: What will be the effect of the juxtaposition of several practices? How will they affect the widest range of water resource characteristics, not just how will they affect erosion control on the land, or water quality? What are the impacts of these on ecological integrity?

We must regularly examine the impact of nonpoint activities with and without varieties of management alternatives. It is important that the assessment include both local and downstream areas, as well as upstream areas. A further advantage of planning for integrated best management systems is that they may allow society to capitalize on the benefits to water quality that may accrue from the presence of integrated biotic communities. We may be able to capitalize on the ability of biota to serve as a natural treatment facility, rather than depending upon technological capabilities to improve water quality. Those technological capabilities often have higher societal costs than natural systems (Karr and Schlosser 1978).

The foundation of innovative management to restore ecological integrity is a conceptual model of an integrated land-use program based on Odum's model of environments required by man (Fig. 1). Man clearly needs productive (that is, agricultural) environments. However, protective environments that preserve biological integrity are also needed in all ecosystems to insure their continued functioning. If streams and rivers in highly agriculturalized areas are to be included in the national mandate for ecological integrity, then we believe it is necessary to incorporate the sound management of type 3 environments within those river ecosystems. The type 3 environment represents a compromise between productive and protective uses.

Many systems of land management might be applied to the Black Creek watershed in an effort to optimize production (agriculture) and protection (ecosystem integrity) through the designation of type 3 environments. Farming need not be eliminated from these areas; substitution of alternatives to continuous row crops such as rotation with limited row crops, conservation tillage systems, improved pasture management with the elimination of woodlot grazing, and permanent vegetation cover on erosive slopes and along stream banks are possibilities. All of these practices are commonly used to reduce on-site erosion. In the case outlined here their use will also be valuable as they affect sediment delivery rates to the stream channel and, in addition, help to stabilize stream channels (Karr and Schlosser 1978). Two extremes of distribution of protective environments are proposed in Fig. 6. A wide diversity of intermediate alternatives could be developed to satisfy local needs. An intensive research program is necessary before informed decisions can be made on optimum management programs. A key issue to address is the percentage of type 3 environment needed for a given level of ecological integrity in a river basin.

The important concept is that the land and its associated biota play a primary role in regulating the quality of a water resource. In type 3 environments the management strategy is to effect improvements in the four variables that influence ecological integrity while keeping the impacts on the productive components of the environments at a minimum. Some specific water quality benefits expected under such land use and vegetative cover management have been discussed by Karr and Schlosser (1978). Table 4 outlines a generalized management system that we believe would improve the biological integrity of headwater streams in agricultural areas. Practices aimed at improving water quality must be implemented in both type 1 and type 3 environments. The recommended practices for improving flow regime, habitat structure, and energy source are limited in application to areas designated as type 3 environments (Fig. 6). It is important to note that every watershed is unique and that practices and impacts can vary considerably among watersheds, as they do when planners select practices for erosion reduction. We realize land managed in this manner may not always be economically competitive in the current agricultural system. Potential mechanisms to solve this problem are now enumerated.

## Implementation Mechanisms

It is not the purpose of this paper to analyze incentive programs that might speed implementation of alternative B outlined above. However, we can make some general comments on incentives in hopes of stimulating detailed analysis of their costs and benefits.

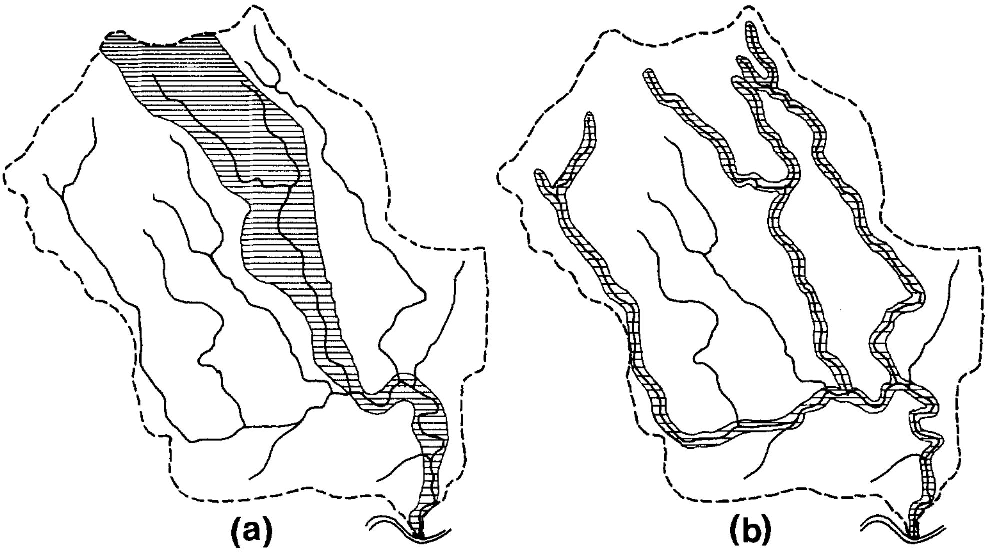

**Figure 6.** Black Creek watershed divided into type 1 (unshaded) and type 3 [shaded alternatives (a) and (b)] environments. Type 1 environments are productive and accommodate intensive agriculture. Type 3 environments represent a compromise between productive and protective qualities and function to preserve ecological integrity. Conservation practices in type 1 environments address water quality, while practices in type 3 environments address all four primary variables influencing ecological integrity. Alternatives (a) and (b) indicate two distributions of type 3 environments (classified streams) designed to improve water resources.

The objective of these and other incentives is to make less intensive farming on type 3 environments competitive with farming operations in type 1 environments while preserving some of the other environmental benefits of these areas. This can be accomplished by subsidies underwritten by society, the principal benefactor.

### Classified Streams

The principle involved in setting aside areas for protection is well established. Unique natural areas or historical sites have long been protected from further development to enhance their long-term value to society. Federal agencies periodically implement set-aside programs to take land out of production or to conserve soil resources. An analog, a system of classified streams, should be developed to reduce local erosion and its effect on downstream water resources. Additional benefits from such programs might derive from increased availability of local recreational resources (Karr and Schlosser 1978). Since headwaters play an especially important role in determining resource quality throughout watersheds (Karr and Dudley 1978), efforts to benefit soil and water resources might emphasize a classified headwater approach.

### Green Ticket

The basic outline of the "green ticket" program (Lake 1978) is to provide economic incentives to the farmer (or other land user) through governmental programs. These incentives must improve the profitability of a farm in exchange for installation and maintenance of needed conservation measures on the land. A sliding scale of incentives might exist to yield greater benefits to a farmer on areas identified as more critical. For example, areas that might be part of a larger classified headwater area might yield higher economic gain to the land owner than a patchwork of areas yielding lower benefit to society. We can even visualize groups of farmers exerting pressure on neighbors to develop a classified headwater program on their marginal land in the name of soil and water conservation benefit to society and economic benefit to them as individuals. Such programs should be encouraged on areas identified as locations where treatment of the smallest possible area (or at lowest economic cost) will yield the greatest benefit to society. Under these

Table 4. A generalized management system to improve the biological integrity of Black Creek and the anticipated impact on agricultural production within the watershed

| Goal | Recommended practices | Impact on production |
|---|---|---|
| Water quality: reduction in sediment and nutrients | Traditional practices, especially conservation tillage, terraces, grass waterways, filter strips along stream channels, animal waste management plans, and soil fertility testing and management plans. | Production reduced slightly by conservation tillage on some soils; loss of cropland used for filter strips. |
| Flow regime: less extreme fluctuations in stream discharge | Augmentation of low flows through storage and later release of storm runoff and/or pumping ground water during dry periods. Conservation practices listed under water quality help in reducing peak stream discharge. | Minimal impact on production through augmenting low flows. |
| Habitat structure: improvements in stream habitat for fish and other aquatic life | Stream renovation (Nunnally 1978) practices instead of large scale streambank protection (channelization). Maximum preservation of natural habitat features (pools, riffles, meandering, cover, substrate size sorting, etc.). | The hydraulic improvements of channelization are only slightly greater than improvements under renovation practices.<br>Agricultural production would not be affected by appreciably greater flood damages. In Black Creek, impaired tile drainage outlets are uncommon, meaning stream renovation would have little impact through the impairment of subsurface drainage. |
| Energy source: energy relationships capable of maitaining community structure and function | The management of a forested riparian environment that insures inputs of CPOM and a reduction in solar radiation. Additional water quality benefits such as improved temperature and dissolved oxygen and the trapping of sediment and nutrients are predicted under such management.<br>An initial stocking of the stream with CPOM and aquatic invertebrates may be considered. | Loss of some cropland adjacent to streams. |

circumstances, land holders might be eligible to collect extra Agricultural Crop Stabilization Service benefits, to pay lower rates on crop insurance, or to lower interest rates in federal loan programs. Further incentives could be integrated into local and state tax structures. Many other incentive programs could and should be sought. These must protect the economic state of the agricultural community and also produce the greatest benefit to society as a whole.

## Summary

To conclude, we believe the results of experimental nonpoint pollution control efforts like the Black Creek Project demonstrate the need for improvement in the institutional approaches being taken to meet the goals of the Clean Water Act. Special concern must be placed on the attainment of ecological integrity rather than the interim goal of fishable and swimmable. Restoring and maintaining the quality of the nation's water resources require a new approach that encompasses the four primary variables of flow regime, habitat structure, water quality, and energy dynamics.

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