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SUMMARY OF THE BLACK CREEK PROJECT
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OVERVIEW OF THE BLACK CREEK PROJECT

By James B. Morrison [1]

The Black Creek Watershed is located in the Maumee River Basin, a highly productive agricultural area, geologically dominated by the former floor of glacial lake Maumee. The Maumee basin drains into the western end of Lake Erie through the gently flowing Maumee River.

Black Creek, located in north central Allen County, Indiana, is a tributary of the Maumee. The 12,000-acre Black Creek watershed was chosen to represent the Maumee Basin in a water quality study, because its physical and economic character so closely mirror that of the basin.

Like the Maumee Basin, Black Creek is largely an agricultural area. If you define the town of Harlan as "urban" then the watershed has about the same proportion of rural and urban areas as does the basin. It probably under represents the lake plain, and overrepresents upland areas, but in general, the watershed provides a satisfactory model for the basin which has been identified as the largest single contributor of silt to Lake Erie.

If you fly over the Black Creek watershed, you will be surprised to hear that it has an erosion problem. The basin appears to be flat. There are not obvious areas where soil loss would be expected to be great, but at the beginning of the Black Creek project, close inspection revealed many areas of potential water quality problems. Water had damaged roadsides, cattle had damaged ditch banks, the erosion from many small rills and gullies in fields produced tons of soil to be carried away toward the lake.

In 1972, a conference on the Maumee River was held by Rep. J. Edward Roush in Fort Wayne. The Maumee was at that time being considered for inclusion in the Wild and Scenic Rivers system. During the conference, speaker after speaker spoke to the question of pollution of the Maumee. They were in agreement that although problems of industrial and municipal pollution of the river remained, these were at least capable of solution by known and tested methods. The problem of agriculture, pollution from what would soon be known as nonpoint sources, was another question. Soil erosion, resulting from agriculture, may turn out to be the number one killer of rivers like the Maumee, the speakers concluded.

Those remarks, which kindled the interest of the Allen County Soil and Water Conservation District, were the conception of the Black Creek project. There seemed little doubt that soil erosion and the related fertilizers and pesticides which might be carried away with soil particles, could represent a water quality problem. There was, at the same time, a rather extensive body of experience and knowledge about controlling soil erosion. There was little understanding about how erosion control related to water quality.

Primarily, the stated purpose of the project was to determine if the traditional and well known techniques of soil erosion control could have a

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significant impact on water quality. Recklessly, we said we would apply those practices, find out how water quality improved, find out how much money was spent in getting the improvement, and finally predict how much loadings to Lake Erie could be reduced for certain expenditures in the Maumee Basin.

Much of the history of the Black Creek project has involved more realistically defining the goals.

Other authors in this report will speak in detail about the monitoring and modeling efforts, biological studies, application of technology, and tillage trials. This overview will concentrate on some of the changes in thinking that have accompanied nearly 10 years of work on Black Creek.

LAND TREATMENT PLANNING — Initial plans for conservation treatment of land in the Black Creek project were detailed. They involved many alternatives, many practices, and considerable effort. Unfortunately, often project administrators, and even new planners could not understand what was being planned and what kind of commitments had been made by the project and by the landowner. They were difficult to use in a voluntary program, they would have been impossible as a basis for determining compliance in a mandatory program. As the project continued the planning process was simplified, and an agreement form was developed that made it readily apparent what kind of work was to be accomplished each year, what the responsibility of the landowner was and what the responsibility of the project was.

LAND TREATMENT GOALS — The initial concept of the Black Creek project was "wall to wall" conservation. Apply as many different kinds of treatment as possible to every acre of land. Although this was not accomplished, the project and the landowners of the watershed managed to spend more than $750,000 on land treatment. At the end of the treatment phase, it was determined that the same water quality benefits could have been achieved by spending less than half of that amount —$325,000, concentrating the expenditure on critical areas, and limiting those practices involved to those which, in this particular area, had an obvious water quality impact — field borders, holding tanks. sediment basins, critical area planting, grassed waterways, livestock exclusion, pasture renovation, and terraces.

IMPORTANCE OF DITCH BANKS —At the beginning of the project, no one was certain how much of the erosion problem was represented by the condition of the ditch banks. However, everyone was certain that work had to be done there because the erosion problem was most visible there. Much money was spent on channel reconstruction, seeding, shaping, etc. This despite objections from the biological group that some of the work was doing more harm than good. Finally, it was done in the face of findings that less than 7 percent of the erosion could be attributed to ditch banks. Project personnel now say we would have spent less on the ditches if the work were to be done over. However, teams starting new projects continue to want to put initial effort on ditches for the same reasons outlined in Black Creek. Ditch bank erosion is visible, even if it is not too important.

COLLECTING AND ANALYZING DATA — As investigators sought to analyze the results of the Black Creek land treatment efforts, some significant changes in the thinking of most of them about data analysis occurred. Initially, most were convinced that an adequate picture of the impact of land treatment on water quality could be obtained by periodically collecting grab samples from the stream and its major tributaries. As the nature of the storm runoff events became more clear, the need for the collection of samples on a continuous basis during a storm and the value of automated samples became apparent. At the same time, the need for detailed analysis and predicting, such as could be provided only by a computerized model, became apparent. Other speakers will elaborate on these points.

Although this document concentrates on biological and physical aspects of the Black Creek project, it is important to recognize that there were collateral studies which provided useful information. Rather detailed studies of the sociology and economics of the Black Creek area led to some interesting conclusions. An interesting economic point was that it costs farmers much more to apply conservation practices when farm prices are good than it does when farm prices are less satisfactory.

As a part of the project, a computer network was established, controlling the collection of water samples and recording weather data on a 24-hour per day basis throughout the year.

Studies of the Black Creek ecology evolved from simple studies of the kinds and number of fish present to detailed investigations of the interrelationships within the stream-land-river system.

Details of these and other supporting studies are available in a series of reports on the project published by USEPA Region V.

MONITORING OF CHEMICAL ASPECTS OF WATER QUALITY IN BLACK CREEK

By Darrell Nelson [1]

Figure 1. is a graphical representation of the 5000 hectare Black Creek study area.

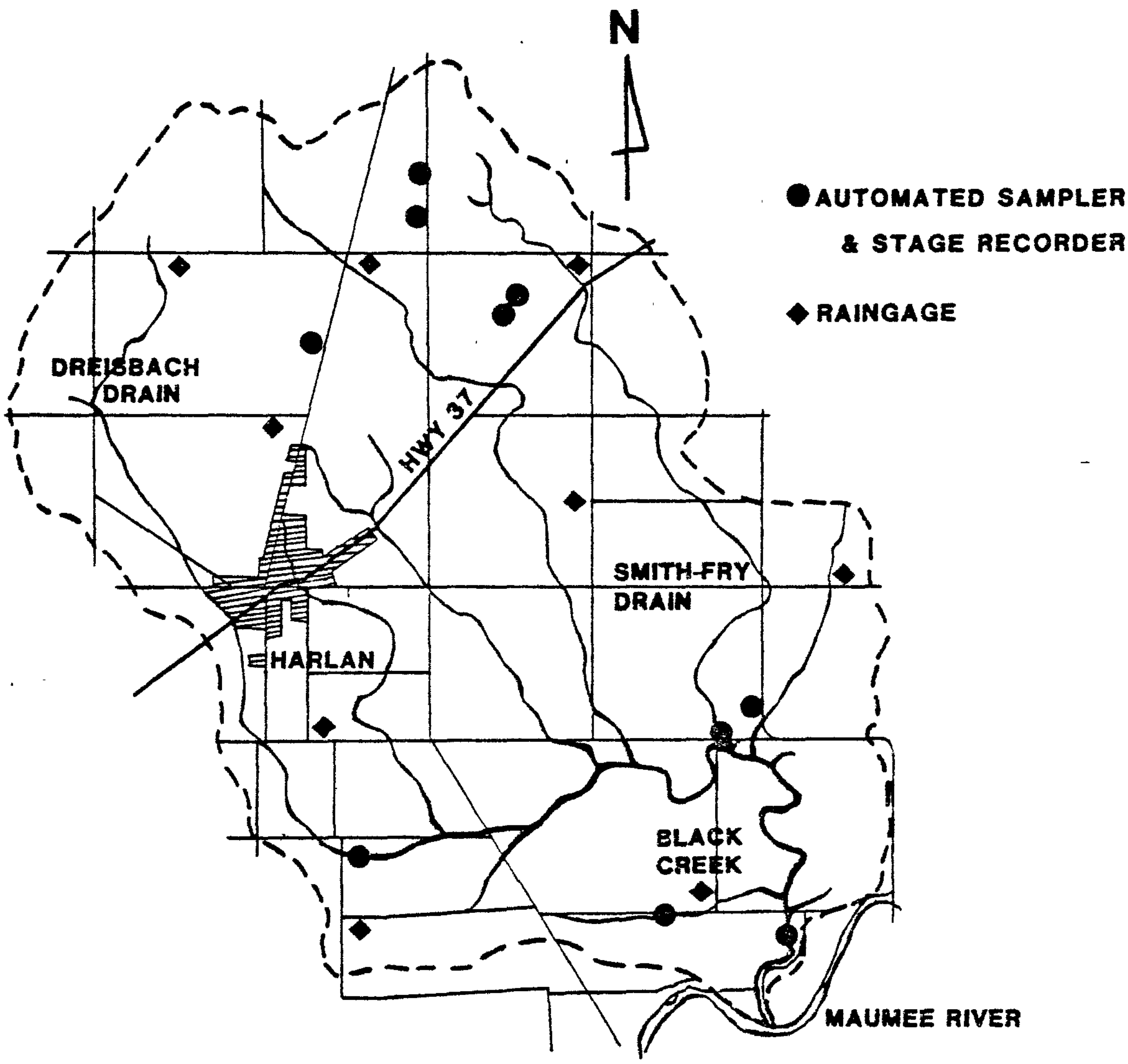

Figure 1. Black Creek Watershed

Table 1. provides information on soils and land use in the watershed. The drainage pattern in the area consists of one natural stream (Black Creek), running from east to west and discharging into the Maumee River, and a number

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of drainage ditches used as outlets for surface and tile drains. Grab sampling stations were established at numerous sites within the watershed to provide water quality data from the various soils and land uses on drains above the station. Automated samplers were installed at three locations (Stations 2,6, and 12) in the watershed (Figure 1) to provide data on loadings being discharged during storm events. Small subwatersheds were established and equipped with automated samplers to allow careful monitoring of the influence of selected best management practices on sediments and nutrients in drainage water. Samples were collected from each of the tile outlets in the watershed to provide information on the quality of subsurface drainage water and a tile system draining a 23 hectare field was continuously monitored by use of an automatic sampling system.

Table 1. Characteristics of the Black Creek Watershed and two intensively studied drainage areas within the watershed.

Characteristics	Black Creek Watershed	Smith-Fry Drain (Site 2)	Driesbach Drain (Site 6)
Drainage area, ha	4950	942	714
Soils:			
Lake plain & beach ridge	64%	71%	26&
Glacial till	36%	29%	74%
Land use:			
Row crops	58%	63%	40%
Small grain & pasture	31%	26%	44%
Woods	6%	8%	4%
Urban, roads, etc.	5%	3%	12%
Number of homes:	—	28	143

Flow was continuously monitored at all stations and water samples taken by grab or automatic methods. were analyzed for suspended solids, nutrients and other water quality parameters. Pesticides alkaline earth cations, and selected heavy metals were occasionally monitored in water samples to determine if unusual conditions existed in the watershed. All tile drainage samples were analyzed for suspended solids and nutrients. Whereas samples collected by the automatic sampler from the defined tile system were analyzed for pesticides and flow was continously monitored.

Meteorological conditions in the watershed were continously monitored. A complete hydrometerological station with automatic data acquisition and remote transmission capability was established at site 6 (Figure 1). The amount of rainfall was measured at seven other locations in the watershed and rainwater samples were collected for chemical analysis at two locations.

After collection, samples were transported to Purdue University where analyses were conducted. Data processing was also accomplished at Purdue to obtain loadings through multiplying measured flows by concentrations of solids or nutrients. Remotely collected meteorological data was stored in computer format until it was needed for correlation with measured flow data.

Results of Water Quality Analyses

Reconnaissance sampling early in the project revealed that no significant amounts of hexane — soluble pesticides where present in water, sediment, or fish tissue collected from the watershed. Specific pesticides evaluated included aldrin, dieldrin, DDT atrazine, trifluralin, and 2, 4, 5-T.

Table 2 provides information on the rainfall, runoff, and sediment lost from the two major subwatersheds in the Black Creek area form 1975 to 1978.

Table 2. Rainfall, runoff, and sediment and nutrient loss occurring in two drainage areas of the Black Creek watershed during the period 1975 to 1978.

Parameter	Site no	Year				
		1975	1976	1977	1978	Ave.
Rainfall, cm	2 & 6	108	66	96	77	86.8
Runoff, cm	2	29.1	12.4	18.5	18.5	19.6
	6	26.0	10.1	19.4	21.3	19.2
Sediment loss, kg/ha	2	2126	637	435	380	895
	6	3735	384	452	544	1279
Sediment P loss, kg/ha	2	5.24	0.98	1.67	0.65	2.14
	6	4.51	0.73	1.78	0.79	1.95
Sediment N loss, kg/ha	2	31.25	4.82	4.55	6.10	11.68
	6	28.98	2.86	4.71	6.91	10.87
Sol. inorg. P loss, kg/ha	2	0.14	0.06	0.14	0.21	0.14
	6	0.34	0.18	0.47	0.68	0.42
Sol. org. P loss, kg/ha	2	0.11	0.04	0.06	0.08	0.07
	6	0.13	0.04	0.10	0.35	0.16
NH_4^+-N loss, kg/ha	2	1.51	0.60	0.58	0.75	0.86
	6	1.82	0.85	1.30	3.06	1.76
NO_3^--N loss, kg/ha	2	19.01	5.55	15.42	8.27	12.06
	6	11.63	2.39	12.73	5.96	8.18

Precipitation was above normal during 1975, below normal in 1976, and near normal in 1977 and 1978. Runoff volumes increased with increasing rainfall, however, the percentage of precipitation appearing as runoff varied over the years (26% in 1975, 17% in 1976, and an average of 22% for the four year period). Sediment discharges from the watershed averaged 895 and 1279 kg/ha for station 2 and 6, respectively. However sediment losses in 1975 were from 4 to 8 times higher than average of the other three years. Adoption of best management practices in the watershed during 1975 and 1976 apparently resulted in decreased sediment losses during 1977 and 1978 as shown by low sediment discharges during these years even though rainfall occurred in near normal amounts.

Table 2 provides data on amounts of sediment - bound N and P discharged from subwatersheds in the Black Creek area during 1975 through 1978. The quantities of sediment - bound nutrients lost from the watershed decreased markedly after 1975 generally in proportion to reductions in sediment losses. Application of best management practices in the watershed was, at least in part, responsible for the reductions in amounts of sediment - bound nutrients observed during the course of the study.

Table 3 provides data on the amounts of soluble inorganic P and soluble organic P discharge from the two subwatersheds during a four-year period. The amounts of soluble organic P discharged were generally low. however, the amounts lost from the watershed did not decrease during the

Table 3. Proportions of total P and N leaving the Black Creek watershed transported as various nutrient forms.

Form of nutrient transported	Site no.		Site no.	
	2	6	2	6
	% of total P lost*		% of total N lost*	
Sol. inorg. P	6.0	16.6	—	—
Sol. org. P	3.0	6.3	—	—
Sediment P	91.1	77.1	—	—
NH_4^+-N	—	—	3.3	7.7
NO_3^--N	—	—	46.2	35.9
Sol. org. N	—	—	5.8	8.7
Sediment N	—	—	44.7	47.7

*Average for four years (1975-1978).

period of study. In fact, it appeared that soluble inorganic P discharge increased during 1978. One explanation for this finding may be that untreated household wastewater was discharged into the ditches near Harlan during the time an interceptor sewer was being constructed. Study had previously shown the septic tank effluents were a major source of the soluble P measured at Station 6.

Table 3 provides information on amounts of NH_4^+-N and NO_3^--N discharged from two subwatersheds in the study are during 1975 through 1978. The amounts of NO_3^--N in drainage water appeared to be related to amounts of rainfall in the watershed, i.e. losses of NO_3^--N were highest in 1975 and 1977, the two years with highest rainfall. However, the weighted mean NO_3^--N concentrations in drainage water appeared to increase somewhat during the course of the project. Losses of NO_3^--N were relatively high (average of 12 and 8 kg N/ha for stations 2 and 6, respectively) and likely reflect the fact that much of the watershed is tile drained and soils are maintained in high state of fertility by applications of manure and inorganic N fertilizers. Losses of NH_4^+-N were low throughout the study except for station 6 during 1978. the relatively high N loss obtained at station 6 likely resulted from septic tank effluents originating in Harlan during construction of the interceptor sewer line. Calculations suggested that 14% of the N added to soils by natural N fixation as through manure or fertilizer applications appeared as NH_4^+ + NO_3^- in drainage water (Table 4).

Table 4. Calculated average losses and inputs of inorganic N for the Black Creek watershed.

	Ave. inorg. N* loss or gain
Inorg. N losses:	kg x 10^{-3}
Measured total loss	58.8
From precipitation runoff	10.1
From septic discharge	
From applied or fixed N	41.4**
Inorg. N inputs:	
Applied and fixed N	286.8***
Infiltrated precipitation	34.9
Total inputs	321.7
% of total N inputs lost in drainage	17.5%
% of applied and fixed N lost in drainage	13.7%

*Average of four years (1975 - 1978)

**Calculated as the difference between total inorganic N loss and that derived from precipitation runoff and septic discharge.

***Based on farmer information on fertilizer and manure applied and average values for N fixation by legumes.

This finding suggests that improvements may be made in managing N additions to soil to minimize the amounts which are present in drainage water.

Analyses of water samples suggests that adoption of best management practices by farmers has not led to a reduction in the discharge of soluble forms of N and P from the watershed. In fact, there is a suggestion that losses of soluble N and P increased slightly as the conservation practices were implemented. In future projects some attention should be given to adaption of best management practices which minimize the transport of soluble nutrients from soil to water.

Table 5 presents the average proportions of total rainfall, runoff, and sediment transport which occurred in calendar quarters during the 1975-1978 measurement period. Rainfall was nearly equally distributed throughout the quarters which

Table 5. Average proportions of rainfall, runoff, and sediment and nutrient losses in the Black Creek watershed during calendar quarters.

Parameter	Site no.	Calendar quarter*			
		1	2	3	4
		% of yearly total**			
Rainfall	2 & 6	20.8	33.6	26.8	18.7
Runoff	2	46.9	34.1	3.8	15.2
	6	47.6	30.8	4.1	17.5
Sediment loss	2	34.2	54.1	2.6	9.2
	6	25.4	65.7	2.2	6.7
Sediment N loss	2	22.7	67.2	1.6	8.5
	6	23.4	64.3	2.9	9.4
Sediment P loss	2	32.1	60.3	2.8	4.8
	6	28.4	46.0	4.6	21.1
Sol. inorg. P loss	2	52.9	25.4	3.6	18.1
	6	59.3	16.4	5.0	19.3
NH_4^+-N loss	2	50.6	35.6	2.3	11.5
	6	67.1	15.9	1.7	15.4
NO_3^--N loss	2	44.2	36.6	2.6	16.7
	6	42.7	31.6	2.9	22.7

*1, Jan.-Mar.; 2, Apr.-June; 3, July-Sept.; 4, Oct.-Dec.
**Average of four years (1975-1978)

the 2nd quarter (April - June) having the highest proportion and the 4th quarter the lowest proportion. Most of the runoff in the watershed occurred during the first two quarters with the 1st quarter contributing during the second quarter (SS-65% of total) and very low during the last two quarters of the year.

A high proportion of soluble inorganic P was transported during the 1st quarter of the year likely due to snowmelt runoff carrying soluble P leached from plant material on the soil surface. A substantial proportion of the sediment bound P lost from the watershed was transported during the 2nd quater in relation to the proportion of sediment which was transported during the 2nd quater. A significant percentage of sediment-bound P was transported during low flow conditions. This suggests that high P solids originating from septic tanks are a source of sediment - bound P during low flow conditions in ditches.

More than 50% of NH_4^+-N lost from the watershed was transported during the 1st quarter indicating that snow melt may be a major contributor of NH_4^+-N. Losses of NO_3^--N were concentrated during the first two quarters of the year when runoff and percolation of water were high. Nitrate in streams originates largely from N applied as fertilizers and manure the previous year or mineralized from organic matter after crop harvest in the fall. There were low N loses measured during the two quarters following fertilization during a particular calendar year. Losses of sediment - bound N were concentrated during the 2nd quarter as was found for sediment and sediment - bound P loses.

At station 2 (draining largely agricultural land) more that 90% of the total P lost from the subwatershed was transported as sediment - bound P (Table 6). However, at station 6 (receiving some septic effluent) a surprising proportion (23%) of total P was transported as soluble forms of P. These findings suggest that for agricultural land the reduction in sediment discharge can have a marked effect upon minimizing total P loadings coming from a watershed.

Table 6. Proportions of total P and N leaving the Black Creek watershed transported as various nutrient forms.

Form of nutrient transported	Site no.		Site no.	
	2	6	2	6
	% of total P lost*		% of total N lost*	
Sol. inorg. P	6.0	16.6	—	—
Sol. org. P	3.0	6.3	—	—
Sediment P	91.1	77.1	—	—
NH_4^+-N	—	—	3.3	7.7
NO_3^--N	—	—	46.2	35.9
Sol. org. N	—	—	5.8	8.7
Sediment N	—	—	44.7	47.7

*Average for four years (1975-1978).

For urban areas or farmland impacted by septic tank effluents attention should also be directed toward reducing the amounts of soluble P lost from the area.

About one - half of the total N discharged from the Black Creek watershed is as sediment - bound N and one - half is as NO_3^- (Table 6). This finding suggests that in any land areas best management practices must be directed at minimizing runoff and leaching of NO_3^- as well as reducing sediment losses. Furthermore, modeling N discharge from agricultural watersheds will be difficult because of the requirement to describe:(i) sediment - bound N transport, (ii) leaching of NO_3^--N to tile drains, and (iii) movement of NO_3^- in surface runoff water.

Flow in ditches in the Black Creek watershed originates primarily from rain storms (event related), however, base flow and snow melt significantly contribute to total annual flow at certain times during the year. Sediment originates primarily from one to three large rainstorms (producing 2.5 cm of runoff) which occur each year. A relatively low proportion of transported sediment originates for the numerous small storms which occur during the year. However, many of the small storms occur when the soil surface is covered by vegetation and the erosion potential is low.

Sediment - bound P transported to drainage ditches in the watershed originates primarily from large rainfall events (Table 7) as was found for sediment. Rainfall events of all sizes as well as snow melt are major contributors to the soluble inorganic P leaving the watershed. This finding likely originates from the equilibrium which is established between P sorbed on soil particles and inorganic P in solution whenever rainfall or snow melt comes into contact with soil. This equlibrium is largely independent of sediment: waters rates and the soluble inorganic P loads are a function of volume of water originating in the various flow producing events. However, snow melt runoff is apparently enriched in inorganic P leached from plant residues on the surface of the soil.

Sediment - bound N in drainage water originates primarily from the large rainfall events responsible for most of the sediment transport. Various sized rainfall events and snow runoff transport NO_3^--N in about the proportion in which they contribute to the total flow. This finding suggests that NO_3^--N concentration in water present in ditches as a result of different events is similar and the amount transported is largely a foundation of the volume of water originating form the various flow producing events.

Water flowing from the watershed originates largely form surface runoff, however, subsurface and tile discharges into the ditches are responsible for about 30% of total flow. Almost all of the sediment transported in the watershed originates from soil erosion and transport of soil particles in runoff water. Tile drainage water contained low concentrations of suspended soils.

Sediment - bound P originated primarily from surface runoff at both sampling stations, however, at station 6 a surprising proportion, 20% of sediment - bound P, was drained from septic tank effluents. Septic tanks effluents were the source of a significant proportion (>30%) of soluble inorganic P leaving the watershed, but surface runoff accounted for greater than 55% of soluble inorganic P in runoff. Surface runoff was the primary source for soluble organic P in drainage water although septic tank effluent contributed a significant proportion in samples taken at station 6.

Table 7. Proportions of water flow, and sediment and nutrient losses from the Black Creek watershed associated with different flow producing situations.

Parameter	Site no.	Type of flow*			
		BF	SE	LE	SM
		% of total transported**			
Water flow (Runoff)	2	20	25	44	11
	6	16	24	47	13
Sediment loss	2	4	13	79	4
	4	9	81	6	
Sol. inorg. P loss	2	10	30	40	20
	6	14	27	34	25
NO_3^--N loss	2	13	30	44	13
	6	9	22	54	15
Sediment N loss	2	4	14	78	4
	6	2	13	76	9

*BF, base flow; SE, small rainfall events resulting in less than 2.5 cm of runoff; LE, large rainfall events resulting in more than 2.5 cm of runoff SM, snow melt runoff.

**Average of four years (1975-1978).

Ammonium N in drainage water originated largely in surface runoff, however, both septic effluent and tile drainage water was a source for some NH_4^+-N. Subsurface flow from tile drainage and surface runoff were equal as sources for NO_3^--N transported out of the watershed. Best management practices for minimizing NO_3^--N additions to surface water must be designed to control both runoff and leaching losses of NO_3^--N. Sediment - bound N originated primarily in surface runoff. Solids present in septic tanks effluents were relatively low in total N and the septic tank contributions were masked by the large amounts of sediment - bound N present in surface runoff from cropland.

Algae bioassay studies conducted to evaluate the availability of P in suspended stream sediments of the Black Creek watershed established that about 20% of the total P and 30% of the inorganic P present would ultimately become available. Therefore, sediment P is the major source of algae available P leaving the watershed (see Table 6) and best management practices should be directed at reducing sediment loss from the watershed if downstream effects are to be minimized.

IMPACT OF CROP SEQUENCE AND TILLAGE ON SOIL LOSS

By Jerry V. Mannering and Don Griffith[1]

My purpose is to review some of our results from the Black Creek study regarding conservation tillage. Conservation tillage is certainly recognized as an effective BMP in the Black Creek Project. I will review with you some of the findings regarding conservation tillage from the Black Creek study and also include other information not only from other studies in Indiana, but surrounding states as well regarding the impact of conservation tillage, primarily on erosion control.

One thing that you need to realize when you discuss conservation tillage is that soils are different and different soils respond differently to various forms of conservation tillage. The north part of the watershed represents the more sloping area where runoff and erosion is more of a problem. The central section area is a transition area of the old beach ridges that has higher sand content in the surface soils, but also suffers from inadequate drainage. The south section is representative of the high clay, poorly drained soils within the watershed. There are good reasons why farmers have not flocked to a tillage system that leaves a large amount of residue on the surface in this particular watershed and the reason is primarily because in much of the watershed people have been fighting excessive water all their lives, and a system that leaves a heavy mulch on the surface on poorly drained land aggrevates the wetness problem.

What we tried to do in the Black Creek study was to look at conservation tillage on a range of soils that would well represent the makeup of the watershed. For example, we had a study located on a Haskins loam soil, a nearly level soil that was influenced by sand cover from the old ridge. We tested conservation tillage on a Nappanee clay loam, an almost level soil and a Hoytville silty clay, another almost level soil with less than 1% slope. A fourth test was located on a more sloping rolling area of Morley clay loam on a 4-4.1% representing the upper third of the watershed. Erosion under equivalent rainfall would be 3, 4, or 5 times as much under the same conditions on the rolling part of the watershed compared to the other 3 nearly level areas. The more level areas as have been fighting excess water all of their lives. The reason the Black Creek watershed contains several drainage channels is that farmers needed them to get rid of excess water so that they could make this an economic farming operation. They cannot compete on this kind of land without an effective subsurface drainage system and they need adequate outlets. We need to understand some of the drainage needs of this area when we look at the overall impact of agriculture on water quality.

In the Black Creek tillage tests discussed in this report we were comparing the influence of fall tillage on the erosion that occurs that subsequent spring. We compared 4 treatments; 1). we did nothing to the plots after harvesting (no-till), 2). we had a light fall discing, 3). a fall chiseling around 8-9 inches deep, and 4). a fall moldboard plowing approximately 8-9 inches deep. With the moldboard plowing you invert most of the residues, which has an influence on soil erosion, and on water quality. The chisel plow

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on the other hand, depending on the amount of residues from which you start does leave appreciable amounts of trash on the surface. It also leaves the surface in a quite roughened condition. In some cases on some soils moldboard plowing also leaves the surface rough. But with chisel tillage you have the additional effects of the residue as well. The light disking treatment, as we used it, only slightly reduced the amount of residue cover on the surface. Most conservationists agree that if we can keep a sufficient amount of residue on the surface we can do a tremendous job in reducing soil erosion.

In this particular study we looked in turn at the effect of tillage on soil erosion, the effect of crop sequence effects on soil erosion because we tested the tillage treatments following both corn and soybeans and the interaction effects between the type of crop and the method of tillage. Tests were made using simulated rainfall because we wanted to control the amount and energy of rainfall that was occurring so we could get a relative comparison between treatments. The storm applied was an intense storm, about 2 1/2 inches per hour one day followed 24 hours later by another 2 1/2-inch storm. We measured the amount of runoff that occurred with a water stage recorder. Aliquot samples of runoff were taken every 5 minutes for determination of sediment load. Again, the period that we were testing, was the end of Wischmeier's crop stage 3 (rough fallow for the plow, disk, and chisel) and 4 (residue period for the no-till). Visual observations show that prior crop can have a significant effect on surface roughness, thus susceptibility to erosion. For example fall plowing high clay corn land leaves it much more rough and cloddy compared to fall plowed soybean land. Fall chiseled corn land is also rougher than fall plowed soybean land. Another important point to remember when evaluating the effect of tillage system on soil erosion is row direction. Any system that leaves marks or ridges such as chiseling will be much more effective across than up and down slope. A visual comparison of light disking following corn verses light discing following soybeans show the former to be cloddier and more resistant to erosion. By the time the simulated rain tests are made, the light disk treatment had weathered 4 or 5 months and the easily transported soil particles had been removed by natural runoff events. Therefore when tests were made in the spring percent cover following corn was as high on the disk treatment as the no-till treatment. The surface roughness was similar on no-till plots following both corn and beans, however, corn residues were much more plentiful than bean residues. We measured percent surface covered and the results are shown in table 1. for the Hoytville soil.

Table 1. Surface Cover - Hoytville Silty Clay

		%	
	Soybeans	Corn	Soybeans/corn
No-till	24	78	0.31
Disk	12	77	0.16
Chisel	9	57	0.16
Plow	1	4	0.25

On the Hoytville silty clay loam following both soybeans and corn we are setting increased residue protection from conservation tillage compared to fall moldboard plowing. Total amounts of residue cover are much higher following corn than beans on all conservation tillage systems. I don't believe that's news to any of you, but it does indicate why at least one of the major reasons why land following soybeans is more erosive than land following corn. Note that only 31%, and 16%, respectively, as much cover occurs after beans than after corn on the no-till, disk, and chisel treatments.

Effects of tillage on surface cover on the Morley clay loam is given in table 2.

Table 2. Surface Cover - Morley Clay Loam

	%		
	Soybeans	Corn	Soybeans/corn
No-till	26	69	0.38
Disk	17	70	0.24
Chisel	12	25	0.48
Plow	1	4	0.25

More residues are present following corn than following soybeans as expected. Residue cover following beans were 38%, 24% and 48% of the cover following corn for the no-till, disk and chisel treatments.

Soil losses on the Hoytville site are given in table 3.

Table 3. Soil Loss - Hoytville Silty Clay 0.8% Slope

	t/ha		
	Soybeans	Corn	Soybeans/corn
	7.8	1.1	7.1
Disk	6.9	.9	7.3
Chisel	9.3	1.7	5.6
Plow	5.3	4.3	1.2

Following soybeans soil loss from the no-till and the disk treatments are essentially the same, but soil losses from chisel are a little higher. Plowing has the lowest soil loss. On this level land the reason that soil loss from the chisel treatment is higher than on the plowing treatment soybean land is that the chisel created a furrow for water to flow from the plot. The plowed treatment left the surface irregular and roughened and we had more surface ponding. Following corn there was sufficient residue left on the surface of the chisel plot to interrupt the furrow. Following soybeans we didn't get a whole lot of control form conservation tillage. Following corn we did. Soil losses were similar from no-till and disk, but remember they had amount the same about of surface cover. Chisel although not as effective as the other forms of conservation tillage still gave fairly good control compared to plowing. The relationship of soil loss following soybeans to corn is quite striking seven times as much on the no-till and disk and 5 1/2 times on the chisel.

Table 4 contains soil loss data from the sloping Morley soil.

Table 4. Soil Loss - Morley Clay Loam 4.0% Slope

	t/ha		
	Soybeans	Corn	Soybeans/corn
No-till	13.4	2.4	5.6
Disk	12.4	2.5	5.0
Chisel	30.3	15.0	2.0
Plow	40.9	21.8	1.9

Results from our original base plot data would indicate erosion was at least 3 times more serious on the rolling (4%) land than it was on the nearly level land in the watershed. Positive influence from our conservation tillage in reducing soil loss following soybeans occurs on the Morley site. Soil losses form the no-till and disk treatments were less than half these from the chisel treatment where tillage furrows were up and down the slope. Still, soil loss was 25% less from chisel than plow treatments.

much more erosion control occurred from conservation tillage after corn where soil loss from no-till and disk were about 10-12% of those from plowing, and chisel losses were about 25% less than plowing. Again rows were up and down the slope. A ratio of soil loss following beans and following corn comparing the conservation tillage system shows over 5 times as much soil loss under the no-till and disk treatments and 2 times as much for the chisel and even on the plow treatment soil losses where he were almost 2 times as much following soybeans than following corn. The point here being that as we increase our soybean acreage we need to be much more careful about controlling soil erosion following that year of soybeans. Remember, its not the year you are growing soybeans, its the year after soybeans that is a problem. Although conservation tillage is effective in reducing soil loss, it loses much of its effect when you follow a crop like soybeans. In addition you need to be more concerned with row direction with systems such as chisel tillage if you are to do an effective job.

The Black Creek results are just one of many we have about the influence of conservation tillage in reducing soil loss. For example, tests conducted at Coshocton, Ohio under natural rainstorms show no-till to be especially effective in reducing soil loss. The data is given in table 5. These results were from a high intensity rainstorm. Even though the no-tilled corn land was on a slope of 21%, only a token amount of soil loss occurred. This study also demonstrated the value of contouring in reducing soil erosion. The results demonstrate there is no question of the effectiveness of surface residues such as you have in the no-till treatment in reducing soil erosion.

The conclusions from our and other tillage studies, are as follows: 1). tillage systems have a major effect on residue cover 2). prior crops significantly effect residue cover 3). there is an interaction between the tillage system and crop sequence and the amount of cover produced 4). an indirect relationship exists between surface cover and soil erosion 5). systems such as no-till or light disking that leave appreciable surface residue greatly reduce soil erosion-it is not only just a small percentage its a major reduction 6).

Table 5. Runoff and Soil Loss on Sloping - and Contour-Row Fields in Corn Watersheds (Coshacton, OH).*

Tillage system and row direction	% Slope	Runoff as % of rain	Soil loss t/A
Plow/clean till (sloping rows)	6.6	80	22.6
Plow/clean till (contour rows)	5.8	42	3.2
No-till (contour rows)	20.7	49	.03

* About 5.3 inches of rain fall within a 7-hour period.

chisel tillage is only effective if residues are plentiful or surface remains rough so its effect can vary from one soil type to another 7). row orientation is very important on a system like chisel tillage on sloping lands 8). soybean land is much more erosive than corn land primarily because of the residue but also because that soil tends to be looser.

I want to say just a few things about the acceptance of conservation tillage systems by farmers and the adaptability of these systems to Indiana. Don Griffith has provided leadership in this portion of the study. He has had replicated trials out the last few years in which has first objective was to determine which conservation tillage systems are adapted on the primary soil types in the watershed and the second objective was to have a high percentage of the farmers in the watershed using conservation tillage techniques. We haven't really succeeded in objective number 2. Some of the reasons why are discussed below. Most certainly there has been an effort to get more conservation tillage on the land through demonstrations and though research. We've had some successes and some failures. But, we have learned from these kind of studies and results.

Generally, we have found that on the better drained soils in the watershed, even no-till systems will work providing pests (primarily weeds) can be adequately controlled with chemicals. Table 6 contains yield results from the Morley clay loam soil, which is one of the more erosive soils in the watershed.

Table 6. Morley Clay Loam - 1976

		Yield (bu/ac)	
Tillage system	Harvest population	Corn	Soybeans
No-till	20,281	91.1	23.2
Chisel	18,812	89.5	21.7
Plow	17,609	88.2	24.3

Although yields are not particularly high, both conservation tillage systems were competitive with plowing for both corn and soybeans. We can conclude from these and other results that on these sloping, erosive lands conservation tillage is competitive with plowing. Additional results were obtained in 1979 and are given in table 7.

Table 7. Black Creek Tillage Trials - 1979 Morley - Blount Silt Loam

Previous crop	Tillage system	Harvest population	Yield bu/ac
Corn*	Plow	20,562	114
	Chisel	20,812	112
	No-till	18,375**	100
Soybeans	Plow	21,812	134
	Chisel	22,062	136
	No-till	20,562	134

* Lodging was severe in all continuous corn plates, approximately due to corn root worms damage.

** Reduced stands in no-till continous corn resulted from poor seed cover due to wet soils at planting.

Where we were following corn no-till was not competitive with plowing, probably because of reduced stands. When we were following soybeans, both no-till and chisel were competitive with plowing. Chisling was also competitive with plowing where corn followed corn. On the poorly drained soils we have not been getting the yields from conservation tillage that compare with the conventional systems.

Conclusions for these and other studies are as follows: 1). fall chisel can replace moldboard for continuous corn or corn after beans without limiting production where weeds can be controlled. 2). shallow tillage or no-till for continuous corn or corn after beans should not limit production on well or moderately well drained soils where perennial weeds are not a serious problem. 3). no-till sod planting should not limit production compared to moldboard where perennial weeds are not a serious problem. 4). shallow or no-till planting is likely to be more successful on poorly drained soils when corn follows soybeans or sod rather than corn. 5). perennial and herbicide resistant weeds are more likely to limit soybean than corn yields with no plow tillage. 6). shallow or no-till planting compared to deeper tillage is likely to lead to more serious disease problems such as phytophthora root rot for soybeans on poorly drained soils. 7). farmers are not likely to adopt conservation tillage unless success can be demonstrated in their area. 8). some form of conservation tillage that has been demonstrated to be adapted to soils in an area should be a high priority BMP. 9). where pests are easily controlled there should be little or no cost for the benefits gained in erosion control and water quality. 10). where perennial and resistant weeds are a problem added herbicide costs and/or reduced yields may reduce profit by $5-10/acre for corn. Costs-in terms of reduced yield or added chemicals, conservation tillage for soybeans conclusions are not yet fully developed.

We have put what we know about tillage in Indiana into an extension publication AY-210 "Adaptability of Various Tillage-Planting Systems to Indiana Soils." We've got a big job to do as far as selling conservation tillage in areas where it is highly adapted. I'm not concerned trying to get conservation tillage on all the land in the state of Indiana because we have lots of land where its a high risk situation. Poorly drained soils many times are not well adapted to systems that leave lots of trash on the surface. We're convinced that it certainly is tremendously effective in reducing soil erosion. It can be used in combination with other conservation practices to make soil erosion control more effective and even more complete, but we need to get more farmers interested and more farmers convinced that it will work on their situation.

ANSWERS

David B. Beasley [1]

Most hydrologic models attempt to model a physical system in which there is an input of rainfall or some other driving meteorological variable which interacts with the soil surface, crop cover, and subsurface soil layers to produce runoff, erosion, chemical washoff, subsurface drainage, etc. This concept is inherent to almost all watershed models that use a deterministic process. The general hydrologic and erosional relationships that must be addressed by a watershed model are presented in the Black Creek Final Report — Technical Volume (Lake, 1977).

Basically, large scale watershed models fit into two separate classification schemes. They are either long-term or event-oriented simulations. In addition, they either use distributed parameter or lumped parameter concepts. The time scale used in watershed models is somewhat dependent upon what the modeler or planner intends to do with the output data. A long-term simulation can give some insights into overall loadings, net surface effects, etc. An event-oriented simulation uses a much shorter time increment and attempts to describe, in detail, the storm-induced response of the hydrologic system and any modifications that may have been made or planned. For non-point source studies, the event-oriented simulations attempt to describe those situations in which the watershed is most active.

The difference between lumped parameter and distributed parameter modeling methods and concepts is much harder to define. One reason for this problem is the extent to which a particular model is either lumped or distributed can be quite variable. Some models exhibit both lumped and distributed properties. Essentially, a lumped parameter model attempts to describe the overall system response using aggregated or lumped representations of physical parameters. In most cases, the lumped parameter loses its physical significance in the process. Another characteristic of lumping is the inability of the model to provide spatial output. Once the system has been described, the output point is fixed. The distributed parameter model is, in effect, a system of small models (possibly lumped) which provide the ability to simulate processes in a spatial and temporal sense. Although much more physical significance can be maintained, an assumption of uniformity must be made within any of the small subdivisions. The distributed concept also allows for accessing output from any or all points within the modeled area. Two direct consequences of distributed parameter modeling are increased computer requirements and costs.

The ANSWERS (Areal Non-point Source Watershed Environment Response Simulation) program has been in use for nearly four years. In that time many improvements in the actual model, as well as the operational structure, have been made. ANSWERS is an event-oriented, distributed parameter watershed model. The original ANSWERS program (Beasley, 1977) was based on the

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distributed parameter watershed hydrology model developed by Huggins and Monke (1966). Channel flow, subsurface drainage, sediment detachment and transport (i.e., erosion and deposition), and land use and management interactions were also included.

Dr. Jack Burney, while a visiting professor at Purdue, rewrote ANSWERS into the basic form used today. The changes were, for all intents and purposes, transparent to the user and had very little effect on the output of the model. However, the size of the simulation and the computer time required to execute it were both reduced, resulting in a substantial savings in processing costs. Dr. Burney also added the concept of "shadow" channel elements. Essentially, this concept allowed for every element to be considered as an overland flow element with certain of these elements contributing their outflow directly to a companion or "shadow" channel element (which then routed the flow downstream).

The early versions of ANSWERS utilized the GASP-IV simulation language as the basis of the modeling structure. GASP-IV had many good features, such as the ability to simultaneously solve numerous differential equations in an implicit manner and the ability to easily take care to the scheduling of discrete occurrences within a continuous simulation. However, the processor time and space required by the many subroutines of GASP-IV led to its abandonment in favor of a smaller, somewhat faster system of explicit solution algorithms. The newer, FORTRAN-based version of ANSWERS is much more exportable, since all of the routines required to run the model are internal and written in FORTRAN, which almost every computer facility is capable of running.

The primary component relationships, although essentially intact from the original version of ANSWERS, have been modified to the extent needed to fit the newer model structure. In addition, several new components have been or are in the process of being added. These include: structural practices and their effects on erosion, sediment movement and runoff water; lateral groundwater movement (interflow); channel erosion; nitrogen and phosphorus yields; and several new statistical analyses of the watershed data file. Specific component relationships are described in detail in the Black Creek Final Report — Technical Volume (Lake, 1977).

ANSWERS and the concepts behind it are receiving increasing national attention. Presently, several organizations are either using or preparing to use ANSWERS on their own planning projects. The most notable of these is the Honey Creek Watershed Project in Ohio where the U. S. Corps of Army Engineers, in cooperation with both USDA and USEPA are modeling the Honey Creek area in an effort to determine the possible benefits of concentrated application of conservation tillage practices.

Use of ANSWSERS in Planning

ANSWERS was designed to simulate the hydrology, erosion response, chemical yield, etc. of ungaged agricultural watersheds. Due to the use of a comprehensive descriptive data file and distributed parameters, the model has the ability to predict the consequences or benefits of land use and/or management changes. For these reasons, then, ANSWERS has applicability in either the planning or evaluation areas.

To date, the validation effort has been aimed at the use of ANSWERS as an evaluation tool. The success of this effort on several watersheds with varying land use, management, topography, climatic conditions has led to the conclusion that ANSWERS should have an equally successful record as an a priori planning tool.

Several examples of planning and/or evaluation programs using the ANSWERS program are available. One program, a Special ACP project in Allen County, Indiana, will be illustrated here to provide an insight into a methodology developed around the ANSWERS model for planning and evaluating water quality improvement programs.

Data gathered on soils, hydrologic and erosional response, nutrient yields, etc. as part of the Black Creek study were available and directly applicable. In addition, the personnel in the Allen County Soil Conservation Service (USDA-SCS) and Agricultural Stabilization and Conservation Service (USDA-ASCS) offices, along with the Allen County Soil and Water Conservation District (SWCD) were familiar with and interested in using ANSWERS as a part of the overall planning effort.

In order to best utilize very limited monetary and personnel resources, a planning methodology was developed which would simplify watershed selection and evaluation tasks. The planning methodology was divided into four phases:

1) Establishment of a "baseline condition",

2) Planning of structural, tillage, and management changes necessary for treating "critical areas",

3) Determination of water quality impacts caused by "critical area" treatment,

4) Apportioning cost sharing payments and credits on a cost effective, priority basis.

Marie Delarme Watershed Example

The Marie Delarme watershed in southeastern Allen County, Indiana has been identified as one of 14 watersheds in the county with potential water quality and erosion problems. This predominately agricultural area is 1203 acres (487 ha.) in size. Of this area, 1043 acres (422 ha.) is in row crops. The rest of the watershed is designated as pastureland, woodland, or homesites. The average slope in the watershed is 1.9 percent with local slopes ranging from 1 to 6 percent. Sixty percent of the watershed is mapped as poorly drained silty clay loam soils (Blount, Crosby, and Hoytville). The remainder of the soils are the moderately permeable silt loams (Haskins and Rensselaer).

The first phase in the planning methodology involved the setting of a "baseline condition". In order to eliminate year to year variations in predicted benefits, the initial or "baseline" conditions were simulated assuming that all of the tillable land (1043 acres) was planted to conventionally tilled corn. Antecedent soil moisture was assumed at field capacity and the storm used corresponded to a 1.5 hour event with a return interval of slightly more than 8 years. These conditions, when applied during an assumed crop growth stage of one month after planting, produce sediment yields at the outlet of the watershed which approximate the long-term average annual sediment and particulate phosphorus yields for this land use pattern.

Once the "baseline" had been simulated, a contour map which plotted local sediment yield or deposition was produced. This map depicted the "critical areas" or those areas where delivered sediment yield exceeded one ton per acre. With the map in hand, planners could determine which areas had the greatest problems. In addition, the map could be used for gross siting of proposed BMPs (Best Management Practices). The location and size of the "critical" areas can, in many instances, determine the particular BMPs which the planners suggest for bettering the runoff water quality.

After the planners had several alternative control strategies in mind, they simulated each combination of BMPs using the same storm as the "baseline condition". Although there is usually only one best solution, there may be several control strategies which reduce sediment or nutrients in the stream to acceptable levels.

The final phase of the planning methodology involves the actual selection of the most cost effective alternatives. Also, the setting of variable cost share rates, determined by comparing individual or systems of BMPs to overall watershed response can be performed. Cost effectiveness, as defined here, is a function of BMP cost divided by sediment yield reduction. Once the various BMPs have been evaluated for cost effectiveness, they can be ranked against each other and the watershed as a whole. Those practices which are more effective than the average could be encouraged with higher than average cost shares, while the less effective measures could still be encouraged, but to a lesser extent.

Some of the alternatives looked at in this particular example included:

1) Parallel Tiled Outlet (PTO) terraces were installed where local sediment yields generally exceeded one ton per acre,

2) Chisel plowing was instituted in all row cropped areas with local sediment yields in excess of one half ton per acre,

3) Various combinations of PTO terraces and chisel plowing.

Although there are many more structural and tillage-based BMPs than the two demonstrated, the comparisons were still quite valid. The most cost effective practices were, quite logically, the tillage-based BMPs. However, they did not reduce the sediment yield from the watershed to the extent that structural BMPs did. The most effective strategy used a mix of the two BMPs with structures in the areas with the highest yields. See Table 1 for sample results.

The evaluation criteria, whether cost effectiveness, percentage reduction, or actual reduction, is greatly influenced by the assumptions used in determining the "baseline condition". Also, rather small changes in the assumed input conditions (e.g., storm intensity or volume, soil moisture, surface conditions) can produce much larger changes in the output. Although the storm used in these simulations produced the average annual sediment yield in northeastern Indiana, it might not be applicable in other parts of the country.

The preceeding example described one methodology in which ANSWERS was used in both the planning and evaluation roles. The use of the sediment and nutrient yield information produced along with estimated costs for various treatment strategies can give the planner a very effective tool in working for cost effective solutions to nonpoint source pollution problems.

PRACTICAL USES OF THE ANSWERS MODEL IN BMP PLANNING: AN ALLEN COUNTY EXPERIENCE

by

Daniel McCain*

Other papers in this proceedings discuss the details of the work done in water quality management and ongoing research of planning at the national, regional or state level. The focus of my presentation will be practical local use of the ANSWERS computer model that is now setting priorities for conservation work as related to water quality in Allen County. At this time, we are past the 5 year EPA funded Black Creek (1972-1977) demonstrational project and well into our second year of applying ASCS Special ACP Water Quality money.

To be successful and get conservation on the land to improve water quality, we've had to involve people—not just agency personnel, but the people that do the farming. Ultimately, it is the farmers who carry out national objectives for conservation. To gain their cooperation, field people have to bring them together on some mutual basis. In the humid midwest (corn belt), that mutual interest centers on drainage basins.

In 1969, when I was assigned to work in Allen County, the emphasis of conservation work in the county—by both the Soil Conservation Service (SCS) and the Agricultural Stabilization and Conservation Service (ASCS)—was on drainage. More than a decade later, this emphasis has shifted dramatically. SCS and other agencies of the U.S. Department of Agriculture have undergone considerable change in how their appropriations are used, and their programs have also changed. In Allen County the difference has not been due entirely to the earlier Black Creek experience, but I'm certain that many local changes occurred as a result of national trends interacting with our staff, the soil and water conservation district supervisors, and farmers during the 1970's. We have found ourselves on the "cutting edge" with our local adaption of nationally conceived "non-point source" concerns.

After the work in Black Creek was complete, a search was made for other problem areas in the county. On a critical area map, targeted rural watersheds were located that had the worst water quality problems. The results was a list of 13 small watersheds (1,000 to 3,000 acres) we call the "Dirty Baker's Dozen." Using the ANSWERS model and ranking these watersheds according to gross soil loss per acre, the most important critical areas were pinpointed. In 1979 special funds were applied for and received through the Agriculture Conservation Program (ACP) for a water quality project. Most of the $75,000 in ACP funds received in 1979 has gone into one of the 13 target watersheds, a 1,645-acre area called the Brunson project. In 1980, two more critical watersheds were evaluated and the "Dirty Baker's Dozen" was reranked. This year $100,000 is spread into six (6) of the thirteen (13) watersheds.

A primary reason for this special ACP funding was an innovative approach to determine where planning is needed. When a group of people come to us for what they believe is simple-to-define technical assistance with drainage, they

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don't realize that we're going to try our best to develop their appreciation for water quality improvement, as well as solve their drainage problems. We are doubly fortunate in that the relationships that began emerging with Black Creek in 1972 and that exist among other locations decisionmaking groups reflects a strong commitment to attack problems head-on.

Groups we are now working with in the Special ACP Project approach are receptive. The ANSWERS model is a big reason why. Planning with ANSWERS involves the use of computer drawn maps such as the "erosion contours" map. This tool points out "hot-spots" or critical erosion areas identified by location within the watershed. A trained conservationist might wonder why these areas cannot be located through field work instead of using printouts from a computer model. We can, but that's not the point. A computer-drawn map of erosion contours in the watershed gives a focus for meetings with groups of farmers. Talking with them about the map helps them become more receptive to learning where and when erosion occurs because of slope and concentrated runoff.

In meetings with the group, we emphasized the proximity of erodible lands to the drainage outlets. When a conservation planner presents the group with a few conclusions from this fact, farmers can readily visualize where erosion is causing water quality problems. The total sediment yields computer by the model represent a net loss of topsoil through the "mouth" of the watershed.

A 20- by 40-inch blowup of the Universal Soil Loss Equation (USLE) sliderule calculator has been used before several groups. The calculator has not intimidated the groups: by using such visual aids, highly technical matters are comprehensible to farmers. Our partnership with the groups has to be educational-on both sides—to be effective. Taking the group on a field trip to see opportunities and to recognize potential benefits also help.

In conservation planning sessions with the groups we have tried not to put all our eggs in one basket, for example, with conservation tillage. Success with conservation tillage depends on many variables. It was not possible to persuade many farmers to convert to conservation tillage during the Black Creek era simply because of these variables. For example, climatic variability over a 4-year rotation might bring a wet spring, a dry spring, an early spring, and a late spring. Climate and other variables require the farmer to make daily decisions that can complicate his tillage plan.

Not that I'm negative about conservation tillage—in fact it's the one practice that can touch every acre—but I've seen what can happen when a farmer tries it without fully understanding it. It may require him to adapt his equipment and make other changes. Every spring day the farmer can face a different set of weather conditions, crop prices, operating expenses, and other things which he has no control but on which he must form decisions. Therefore, it is important to offer the farmer conservation alternatives that won't add to his burden of daily decisionmaking. Seen positively, however, conservation tillage is not a burden at all but an investment in wise management that pays off in savings in fuel, labor, time, water, and soil.

Even so, practices such as terraces serve as permanent "reminders" of conservation on the landscape. These practices can be very compatible with conservation tillage; most important, however, they signal a "commitment to conservation" and become symbols of the group's progress in understanding and dealing with erosion and sedimentation. And if nature provides a disastrous spring for tillage, at least part of the conservation system will function.

Permanent conservation practices require the farmer to make fewer decisions, although they won't necessarily be any easier to make than decisions about tillage. For example, if a farmer wants to construct terraces and waterways and needs financial help, he requests cost-sharing assistance from the ASCS office. SCS provides an engineering plan and gives him a cost estimate, and his thoughts come down to a one time "yes or no" decision. If he decides to go ahead with the practices, a contractor builds them and they become a permanent facility. The only questions remaining is whether the farmer will permanently maintain the practices.

In all, then, there are three ways we can tackle cropland erosion problems related to water quality. First, we encourage changes in TILLAGE and planting techniques. Second, we encourage CROP ROTATIONS that are compatible with the farmer's present tillage system. Or third, we suggest permanent land treatment practices such as TERRACES, which reduce slope length and increase temporary storage capacity for runoff. If the farmer selects any one of these changes—or some combination of them—improved water quality should be the result.

When we targeted critical areas in the Krunson project we had to go after the job from the top of the hill down. We didn't want to repeat an earlier experience in Black Creek; that is, overselling the group on what they were already prepared to request—outlet development. Also, in Black Creek more streambank protection than necessary may have been installed because of the farmers' concern about highly visible streambank erosion. Black Creek findings showed that only about 7 percent of the sediment load entering the Maumee River was caused by streambank erosion. However, the farmers noticed streambank erosion more than they noticed sheet and rill erosion on sloping cropland.

In planning with the groups and in orienting them to the kinds of practices needed, ASCS and SCS can provide farmers with cost sharing and technical help as far down the outlet as necessary to make a properly functioning project. In the Brunson project, individual terrace outlets were safely taken down the watershed through tile beside group grass waterways, and into a protected mutual open outlet. All these practices helped as part of a protective scheme for the critical areas.

It may also be necessary to study the channel far enough through the critical areas to find the unstable segments. In Black Creek, we were most successful with a practice we call "training," that is, putting rock riprap low on the channel banks in unstable soils and installing a 1 1/2- to 2-foot drop structure to lessen channel grade.

From the top of the watershed down, an opportunity and an obligation exists to explain technical alternatives to the farmers. The ANSWERS model is useful for these explanations because it graphically depicts the eroding areas. An overlay of the erosion contours map with an ownership map lets the farmer see whether he has an erosion problem that requires attention. But don't tell him, "Look, you dirty farmer, you're causing all these water quality problems and you're going to have to do something to clean them up." Instead, approach the group in a positive way by showing them the beneficial things that they can do—both as a group and as individuals—to improve water quality and reduce the sedimentation on their neighbors' lands downstream.

In some cases, the approach to land treatment in the Brunson project was turned 180 degrees from the previous approach in Black Creek, where outlets were usually developed first. In the Brunson project, we started at the top of the watershed by securing commitments from farmers for cropland treatment. Of the $75,000 allocated for the Dirty Baker's Dozen in 1979, ASCS approved $60,000 for cost sharing of group parallel tile outlet (PTO) basin terraces in the Brunson watershed. To make the terraces work, waterways were constructed and outlets developed to handle the metered tile flow from the terraces. Most of the job was completed in 1979. A second smaller group—SOUTHWEST BRUNSON—with some of the same farmers, completed additional terraces and a mutual waterway in the summer of 1980.

The ANSWERS model could prove even more valuable when used with the analysis of BMP's on farms and as a group. The hypothetical watershed (figure 1) and reduction estimates (table 1) illustrate a means of using the ANSWERS model in planning. Perhaps the time will come when the public will buy water quality improvement with "dollars spent for tons saved."

Table 1. Effect of BMPs in reducing sediment

Group	Individuals	Cells	Primary BMP Application	Level (Ave/Farm) Initially	with BMP's	% Reduction
A	All Plus	100	Outlet	1350	675	50%
	Samuels	20	Livestock exclus.	1500	700	53%
Sub Group B	Smith	17	None	2000	2000	0%
	Fry	13	None	0	1000	0%
Sub Group C	Sharp	6	Waterway	700	500	28%
	Jones	14	Terraces	1000	400	60%
	Green	8	Tillage	1200	600	50%
	Gray	10	Terraces	900	400	55%
	Johnson	12	None	1200	1200	0%
Sub Group D	Jones	14	Terraces	1000	400	60%
	Green	8	Tillage	1200	600	50%
Sub Group E	Gray	10	Terraces	900	400	55%
	Johnson	12	None	1200	1200	0%

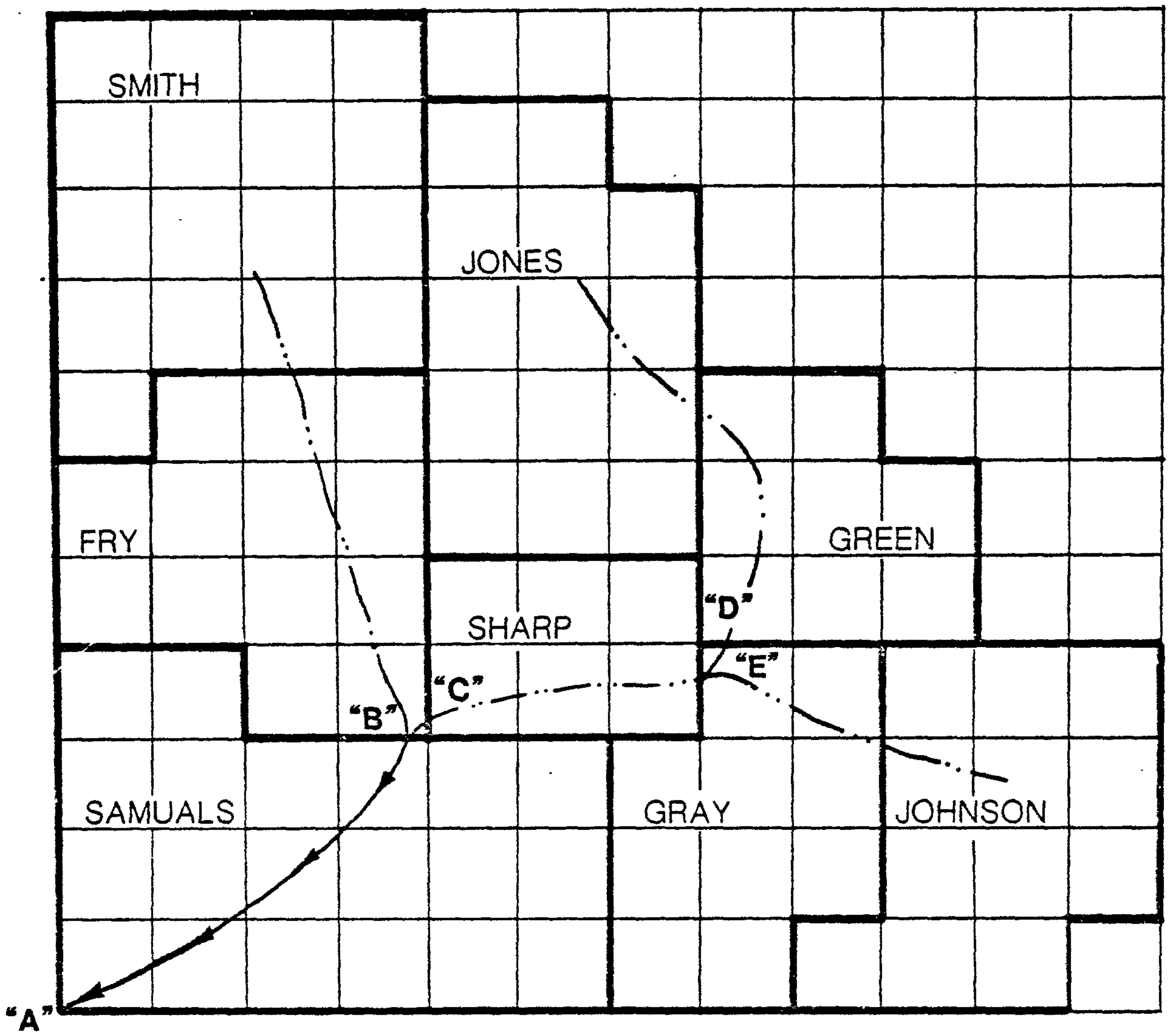

Figure 1. Hypothetical Watershed

BIOLOGICAL PERSPECTIVE ON WATER QUALITY GOALS

By James R. Karr and Daniel R. Dudley [1]

Increased societal concern for the state of the environment is clearly manifest in the proliferation of environmental legislation in the past decade. Early efforts directed towards pollution control focused on point sources of pollution because of the ease with which they could be controlled and regulated. As the magnitude of the point source problem reduced, the relative contribution of nonpoint sources expanded.

Concern for the degradation of water resource quality from nonpoint sources has been a matter of special concern since passage of the Water Quality Act Amendments of 1972 which called for the restoration and maintenance of "the chemical, physical, and biological integrity of the Nation's waters." In the following pages, we evaluate the progress made in attainment of that objective as a result of studies in the Black Creek watershed.

Black Creek: The Central Question

From its inception, the central question to be addressed by the nonpoint control program in the Black Creek watershed was: Are traditional erosion control programs sufficient to not only reduce erosion but also to improve the quality of our water resources? That is, is it possible to implement a voluntary program of erosion control in an agricultural watershed and thus control water resource problems resulting from nonpoint pollution from agricultural lands? It is now clear that the answer to that question is a distinct no!! That is not to say that some incremental improvement cannot be obtained with the traditional approach. Rather, attainment of the objective of PL 92-500 is not possible with that conventional approach. In the following pages, we outline the primary deficiencies of that approach as well as suggest an alternative conceptual model which will produce a more comprehensive solution to the nonpoint problem.

However, before we detail conclusions and results of the Black Creek studies, several concepts should be clearly outlined.

Fishable and Swimmable

The concept of "fishable and swimmable", first introduced in Public Law 92-500, is a desirable, but ambiguous 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

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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 for downstream reaches to be fishable and swimmable. The biological integrity mandate of Public Law 92-500 depends on an integrative view of the entire water resource system at the watershed level rather than its consideration for local reaches of the stream.

Water Quality vs. The Quality of a Water Resource

Planners, scientists, politicians and the general public commonly use the phrase "water quality". Almost invariably, the use of that phrase implies physical and chemical conditions of the water. These include such items as temperature, dissolved oxygen, nutrient levels, and concentration of suspended solids, heavy metals, and toxic chemicals. The assumption is generally made that improvement in "water quality" will result in optimization of the widest range of water uses by society (domestic, industrial, irrigation, agricultural, recreation, aesthetics).

In addition, it is assumed that there is nothing else that society need do (or can do) to improve the quality of water resources. As we will show below, both of these assumptions are false; their continued acceptance will result in progressive and continuing decay in water resources.

Loadings vs. Concentrations

Commonly, the sole point of focus of efforts to model nonpoint pollution is loadings (commonly annual loading, the total sediment or nutrient per unit area exiting a watershed). It is clear that major storm events play the primary role in determining annual sediment or nutrient loading. These major transitory events are especially important for consideration of effects on downstream areas, particularly receiving waters downstream--natural lakes or reservoirs. However, it is also important to note that the average conditions expressed in smaller runoff events, and even during base or low flow periods, play a major role in governing the characteristics of stream communities and, thus, the biological integrity of a water resource. More careful consideration must be given in all monitoring and modelling efforts to the relative merits of emphasizing concentration information throughout the year as opposed to the loading information which is determined by a few transitory events.

Both loading and concentration data during all flow conditions must be monitored and evaluated. The relative emphasis on the two will vary depending on the nature of the water resource problem under consideration.

Selection of Monitoring Sites

The selection of monitoring locations plays a major role in determining the reliability of water quality parameters and water quality conditions measured for a watershed. The selection of sample sites which are adjacent to bridges is often convenient and can be defended in many cases on those grounds alone. But, if there is some particular activity immediately upstream of that site which significantly increases or decreases suspended solids loads, conclusions about sediment and nutrient dynamics may be very misleading. For example, we had one sample site with unusually high suspended solids concentrations. We found that a couple ducks on a nearby farm pond regularly foraged in the stream channel and significantly increased suspened solids during much of the year. In addition, the selection of sample sites immediately upstream or downstream of wooded areas or meandering topography where the hydrology of sediment transport varies relative to straight reaches of the stream can affect the concentrations during many times of the year. The effects on loading estimates are obvious. Further, selection of sites in close proximity to downgrading channels or unstable banks (Dudley and Karr 1978) can profoundly affect the reliability of monitoring and modelling efforts. These and other potential impacts on water quality should be evaluated when sample sites are selected.

Biological Integrity Defined

We now return to our assessment of the central theme or hypothesis of the Black Creek study in the context of the biological integrity mandate of PL 92-500. The concept of integrity 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. However, careful reading of that document yields insight into the concept. The water resources of the nation must be considered from a holistic (systems) perspective. With this perspective, integrity of water can be defined as "The capability of supporting and maintaining a balanced, itegrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region." Such communities are able to withstand perturbations imposed by natural environmental processes. Further, they are even capable of withstanding many major disruptions induced by man and returning to their original state. A thoughtful discussion of these ecological concepts, including their measurement and management applications, was recently provided by Westman (1978).

Note that this definition does not make specific mention of resource value in terms of man's use of water. Instead, there is an implicit recognition that a functioning biological system is the ultimate resource on 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 (energy, minerals, etc.) of use 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 slavishly 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 PL 92-500.

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; e.g., agriculture, 2) protective environments; e.g., natural areas preserving biological integrity, 3) a compromise between 1 and 2, and 4)

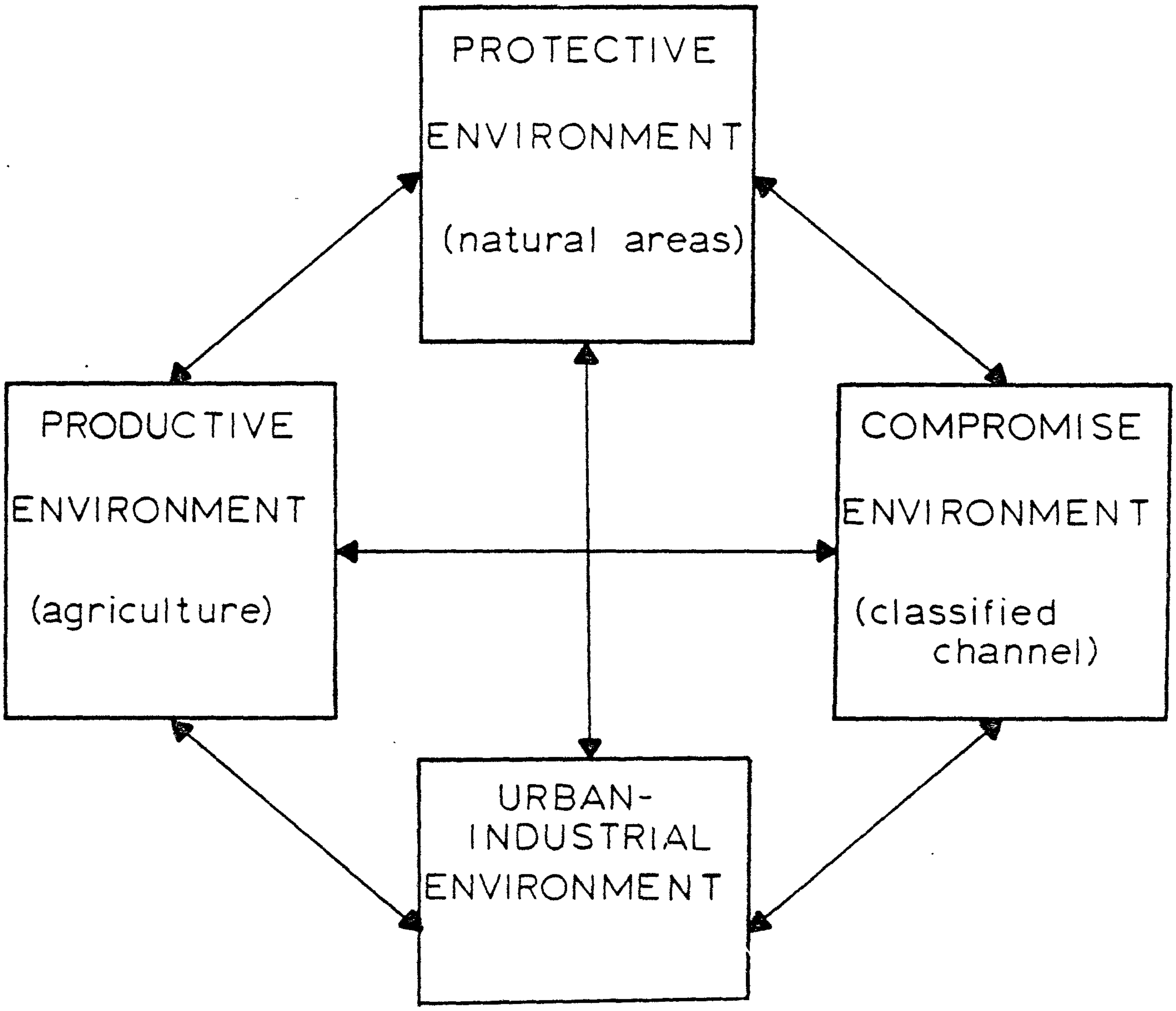

Figure 1. Compartment model of the basic kinds of environment required by mans partitioned according to ecosystem development and lifecycle resource criteria. (Modified from Odum 1969).

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.

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). Major changes in the inputs to upstream (headwater) areas are ultimately carried to and affect downstream areas. Further, some aquatic life, especially fishes, may depend upon migration to upstream or downstream areas for the completion of their life cycles. The concept of the open ecosystem has two important management implications. First, streams are subject to rapid and gross perturbations caused by land-use changes (urbanization, intensive agriculture, etc.). Second, properly managed

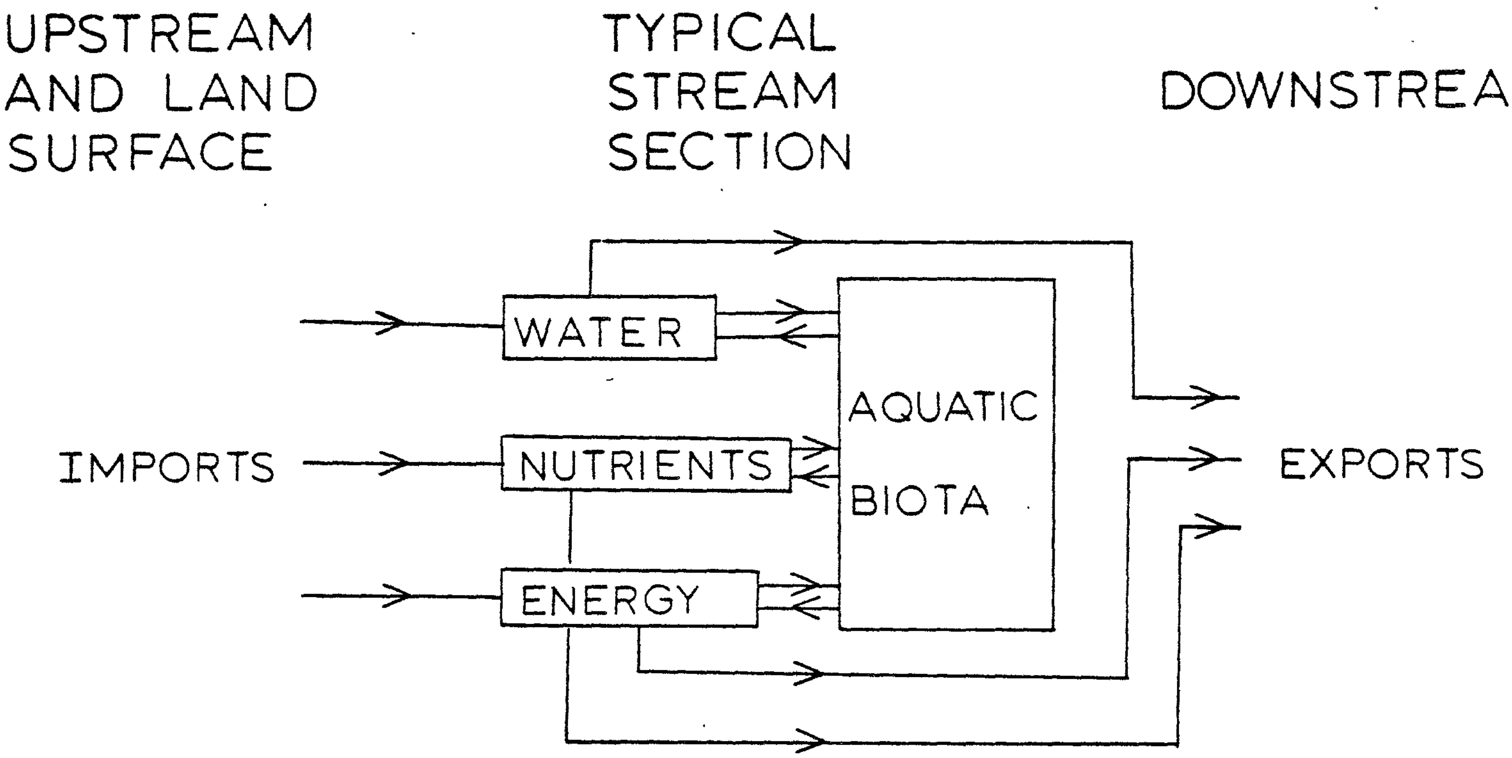

Figure 2. Generalized flow diagram for aquatic ecosystem.

land-use in watersheds can effectively and rapidly lessen perturbations in stream systems.

A classification system developed by Horton (1945) and modified by Kuehne (1962) is commonly used by aquatic bioligists 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; etc. Ecological discussions of streams typically consider three size classes: the headwaters (1st and 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 (i.e., drainage and flow characteristics, chemical and physical parameters, bottom type, etc.). 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 form natural drainage patterns; rather, it is only an addition to or a modification of the natural stream network that profoundly effects 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

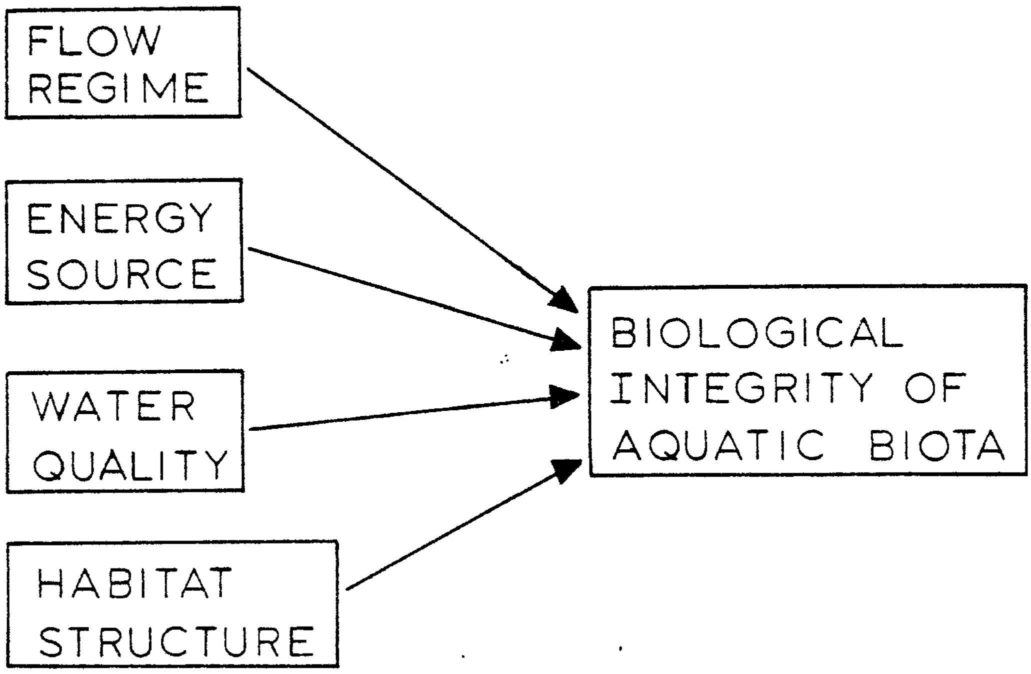

Figure 3. Primary veriables affecting the structural and functional aspects of the biota of a headwater stream. (Modified from Karr and Dudley 1978)

in determining the characteristics of the biota of running water (lotic) ecosystems (Karr and Dudley 1978). These are water quality, flow regime, habitat structure, and energy source.

Any project meant to address the mandates of PL 92-500 must address deficiencies in all of these to insure the optimization of water resource quality. Consideration of "water quality" characteristics alone, as has been the case in Black Creek and many other NPS efforts, cannot be expected to produce the water resource quality which seems to be the societal objective mandated by recent water resource legislation.

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. But modifications of the land surface with changing land use typically results 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 modified watersheds tend to have a sharp and extreme peak. Low flows in natural watersheds tend to be severe only in particularly dry years, while low flow periods in modified watersheds 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. Their primary objective is the development of criteria to allow assessment of the impact of altered stream-flow on habitat characteristics and the use of an area by aquatic organisms (Stalnaker and Arnett 1976). They seek to identify the hydraulic conditions necessary for a variety of groups of organisms, including different age classes of the same species when their requirements differ. For example, the probability distribution of walleye with respect to stream velocity varies among the age classes and with reproductive state of fish (Fig. 4).

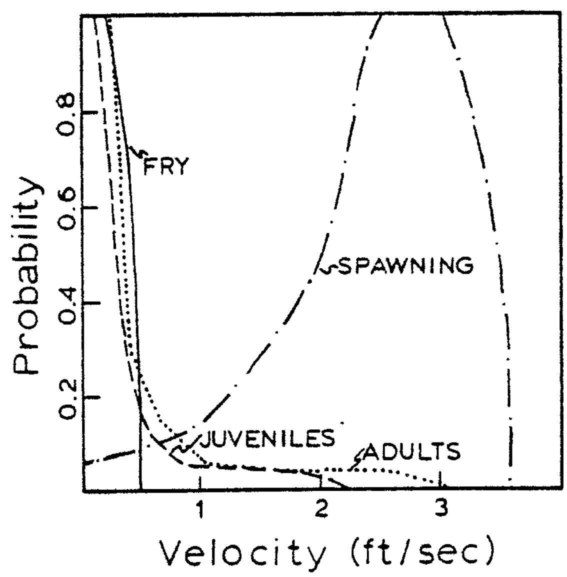

Figure 4. Probability of use curve for several age classes of Walleye. (Adapted from unpublished material of the Cooperative Instream Flow Service Group, with permission of C. Stalnaker.)

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 which destroy areas with "spawning" velocities may have a significant negative effect on walleye reproduction although adult fish may not be directly affected. These efforts to examine the flow regimes and hydraulics of streams and their effects on biological integrity will make major contributions to the management of running water resources.

Water Quality

In recent years most efforts to reverse the degradation in quality of water resources have focussed 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. 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 which 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 condition, extremes and their temporal pattern have important impacts on the biota.

Each of these are of concern individually. However, in many watersheds like Black Creek, human activities may precipitate problems of degradation of biotic interity because of the synergistic effect 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 typically includes a meandering topography, with substrate diversities created by varying flow regimes length-wise along the stream channel 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. Modified watersheds, on the other hand, tend to have very much reduced diversity in channel geometry; they are often straightened. Channel maintenance activities commonly create a uniform substrate and reduce depth diversity in the absence of pool and riffle topography. In addition, sedimentation increases due to a disequilibrium channel and/or because of erosion from the land surface.

Straight open channels in the presence of abundant nutrients, sunlight, and high temperatures creates ideal conditions for the choking algal blooms which are such an obvious component of Black Creek in late summer. In years of lower rainfall in late spring and 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 interations with the physical habitat of streams affect the biota of the stream. Bottom-dwelling invertebrates such as molluscs (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 amount of water and oxygen available to the bottom-dwelling community. Adequate interstital space is also essential for the movement and feeding of 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. However, as the variety of habitat conditions increases with the development of pools, riffles, meandering topography, and the sorting of substrate sizes, habitat complexity increases and supports a wider diversity of fishes (Fig. 5.).

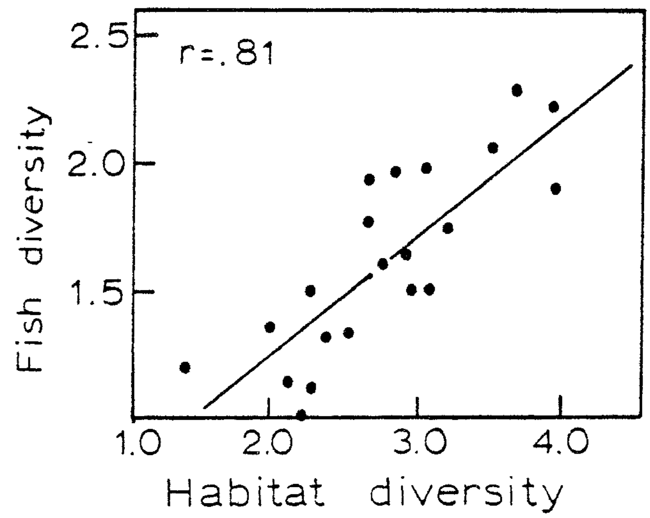

Figure 5. Relationship between habitat diversity and fish species diversity. (From Gorman and Karr 1978).

In addition to the general dependence of fish community structure on habitat characteristics, there is a more subtle significance to habitat structure. Early in our Black Creek efforts, we noted major seasonal migration in the watershed (Karr and Gorman 1975). In addition, we noted less easily explained movements which seemed to vary in magnitude among habitats within the watershed. This stimulated a study of the movements of fish in several stream reaches. Fish were marked with a procedure called cold branding. Silver brands in shape of various letters were supercooled with liquid nitrogen and touched to the sides of fish duplicating the common hot branding used to mark cattle and the livestock on open 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 (Stations 12, 26, and 29) early in the Black Creek study. The second major habitat was on the Wann Drainage immediately east of the Black Creek watershed (Station 13). Although there has been no recent channel modification work in this area, the stream reach had been modified perhaps ten years earlier. The lack of disturbance over the years created a stream which 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. Our final study area was a section of the Wertz Drain where it traversed the woodlot called Wertz Woods (Karr and Gorman 1975). This area has an especially rich fauna (Gorman and Karr 1978).

Populations in higher quality habitat are relatively more secure (Table 1);

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	Percent of 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

*Data for June 1975 using the information-theoretic measure of diversity for the composite of bottom, depth, and current velocity. See Gorman and Karr 1978 for more detailed explanation of methods.

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 of my (JRK) graduate students at the University of Illinois (P. Angermeier, pers. commun.) has divided two sections of Jordon Creek in east-central Illinois with 1/4" mesh hardware cloth supported by steel posts. On one side of each section all cover features (e.g., 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 was 4.8 to 9.4 times as high in the areas with structurally complex habitats.

Further, the large fish, and especially the top predators tended to select the structured habitat. In this case we know water quality is constant in the structure and unstructured sides of the stream, yet the numbers of the 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 again emphasizes the importance of habitat structure as a determinant of biotic conditions in a stream.

Note that, to a great extent, the hydraulics of flow regimes determines the physical structure of stream habitat, and, thus, the efforts of the Instream Flow Group will clarify the problems of stream management for both flow regime and habitat structure.

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 an simpler compounds is respiration. Production is the reverse process in which energy in the form of solar radiation and simple compounds are 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 repiration 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 to assess the status of the stream ecosystem in any location. If the ecosystem degradation resulting from these expectations, it 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 foundations for these "reference points" comes to a great extent from forrested watersheds. as a result, it may be necessary to develop an

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

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

alternate foundation for markedly different terrestrial environments in the dry nonforested regions of western North American (Minshall 1978).

Headwater streams in natural watersheds are usually heterotrophic. That is, they have production to reaspiration 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% of the energy requirements for the biota of a headwater stream was of allocthonous origin (Fisher and Likens 1973). A very different watershed in Oregon (coniferous forest) demonstrated the same general pattern (Sedell et al. 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 liter shed in 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 important 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, twigs, etc.), referred to as coarse paticulate organic matter (CPOM). Bacteria and fungi quickly colonize the CPOM and, as a result of their metabolic activity, speed the process of fragmentation into small 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 processes about 80% of the particulate organic matter (POM) and 50% of the dissolved organic matter (DOM) in natural first to third order streams.

Functional attributes are markedly different in undisturbed intermediatesized 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 are common. The autotrophic status of the stream account 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 and 12th order) the stream again becomes heterotrophic due primarily to increased turbidities reducing light penetration and, therefore, the potential for photosynthesis. 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 scrapers 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 in human terms of the water resource (commercial and sport fish). Cummins (1975) categorized the functional attributes of fish communities according to the food habits of the dominate fish. Predominate food habits are somewhat different for the three major ecological areas of an undisturbed river system. In headwater streams, fishes that feed upon macroinverrtebrates (invetivores) are dominant. Invertivores along with piscivores (fish that consume other fish) dominate intermediate-sized rivers. Finally, in large rivers dominate 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 plan materials). Omnivores and herbivores are rarely dominant in natural running water systems.

Our results in Black Creek indicate major disturbances in these energy source (functional) dynamics. Many of the modified channel areas seem to be autotrophic rather than heterotrophic (Table 3) because of the abundance of sunlight and nutrients. The abundant algal blooms alter the organic load and habitat characteristics of the stream. Research in needed to determine what level of autotrophy can be tolerated without a distruption in biological integrity.

The trophic status of the aquatic invertebrate community has changed (Karr and Dudley 1978) in response to a variety of factors. The organic matter processing efficiency in the disturbed headwater system is modified thus increasing organic loading to downstream areas.

The trophic status of the migrant fishes has shifted from priscivore to omnivore because of declining water quality and stream habitat structure. This has increased the populations of the less desirable fish species and decreased the number of top predators that act as a natural population check on other species. (See Karr Dudley 1978 for more detailed documentation using the Maumee River watershed).

In summary, then, we find that the onslaught of human effects on the biotic integrity of the water resource system of Black Creek is affected by a diversity of factors and not just water quality in the physical-chemical sense. Briefly, several key points are reiterated here:

1. Allocthounous 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

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

	Natural	Modified
WATER QUALITY		
Light and temperature	Heavily shaded Stable temperatures	Open to sunlight 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	Damped 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 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

Table 3. (Continued)

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 Heterotrophic; P/R <1	Algal blooms common 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

changes in the stream ecosystem.

2. Nutrient availablility: 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: All 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, etc.).

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, etc.)

5. Stream habitat characteristics: The diversity and stability of high quality stream habitat is low (Gorman and Karr 1978). The ditching and drainage efforts prevalent in many agricultural watersheds prepetuates 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 4 primary variables (individually and in the aggregate) cause major shifts in the 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 larger downstream areas are also affected (Karr and Dudley 1978).

Clearly, more than just "water quality" conditions must be addressed if the "Fishable and swimmable" objectives of PL 92-500 are to be attained.

BMP's vs. Best Management Systems

In early development of the Black Creek study the list of conservation practices for improvement of water quality was limited to the erosion control practices used by the Soil Conservation Service. Slowly, this list was reduced to a subset thought to have some value in improving water quality. The disadvantage of this approach is that a number of other potential activities which may result in improvements in the quality of water resource are not considered. Further, the potential benefits of an integrated network of erosion control practices to reduce erosion, coupled with practices which may only benefit water quality, may be greater than the erosion, coupled, with practices alone. That possibility has not been adequately explored in earlier studies, including Black Creek. The time is right for more effective examination of careful application of an expanded list of BMPs into

Best Management Systems

The following questions must be routinely asked: What will be the effect of juxtapositon 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? We must more regularly examine the impact of nonpoint activities with and without varieties of management alternatives. What are the impacts of these on biological integrity? It is important that that 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 which may accrue from the presence of integrated biotic communities. After all this is the fundamental principle behind the effective action of primary sewage-treatment facilities. With this philosophy, we expect that the dollar cost to society may be lower per incremental improvement in the quality of our water resources.

Innovative Management to Restore Biological Integrity

We now address the specific measures that would improve biological integrity in streams and rivers of predominantly agricultural basins of the eastern United States. Our recommendations are designed specifically for the Black Creek watershed, but the applicability of these recommendations is broader.

The foundation of innovative management is Odum's compartmentalized model of environments required by man (Fig. 1). Man clearly needs productive environments (i.e., agriculture) and much of the Midwest needs to be devoted to agricultural production. However, protective environments that preserve biological integrity are also needed in all ecosystems to insure their continued functioning. If midwestern rivers, like the Maumee, are to be included in the national mandate for biological 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. Traditional soil and water conservation programs stress the productive environment as is demonstrated by the record of goals and accomplishments of the Black Creek project (Morrison 1977). Soil conservation practices 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 stream ecosystems.

At least two systems of land management (Fig. 6) might be applied to the Black Creek watershed in an effort to optimize production (agriculture) and protection (stream ecosystem integrity). The central feature of both alternatives is the designation of selected areas as type 3 environments where protective land use receives priority over the most productive uses. Farming need not be eliminated from these areas but alternative to the presently intensive agriculture must be found. Possible alternatives include rotation with limited row crops,conservation tillage systems, improved pasture management with the elimination of woodlot grazing, and permanent vegetative cover on erosive slopes. Under such management the average soil loss from cropland would be below the maximum tolerable loss for preserving the soil resource.

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 and the loss of cropland for filter strips.
Flow regime less extreme fluctuations in stream discharge	Augmenting 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 augmentating low flows
Habitat structure improvements in stream habitat for fish and other aquatic life	Stream renovation (18) practices instead of large scale streambank protection (channelization). Preserve natural habitat features (pools, riffles meandering, cover, substrate size sorting, etc.), to the maximum extent possible	The hydraulic improvements of channelization are only slightly greater than improvements under renovation practices (18). Agricultural production would not be affected by appreciably

Table 4. (Continued)

GOAL	RECOMMENDED PRACTICES	IMPACT ON PRODUCTION
		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 maintaining 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 (11)). An initial 'stocking' of the stream with CPOM and aquatic invertebrates may be considered.	Loss of some croplant adjacent to streams

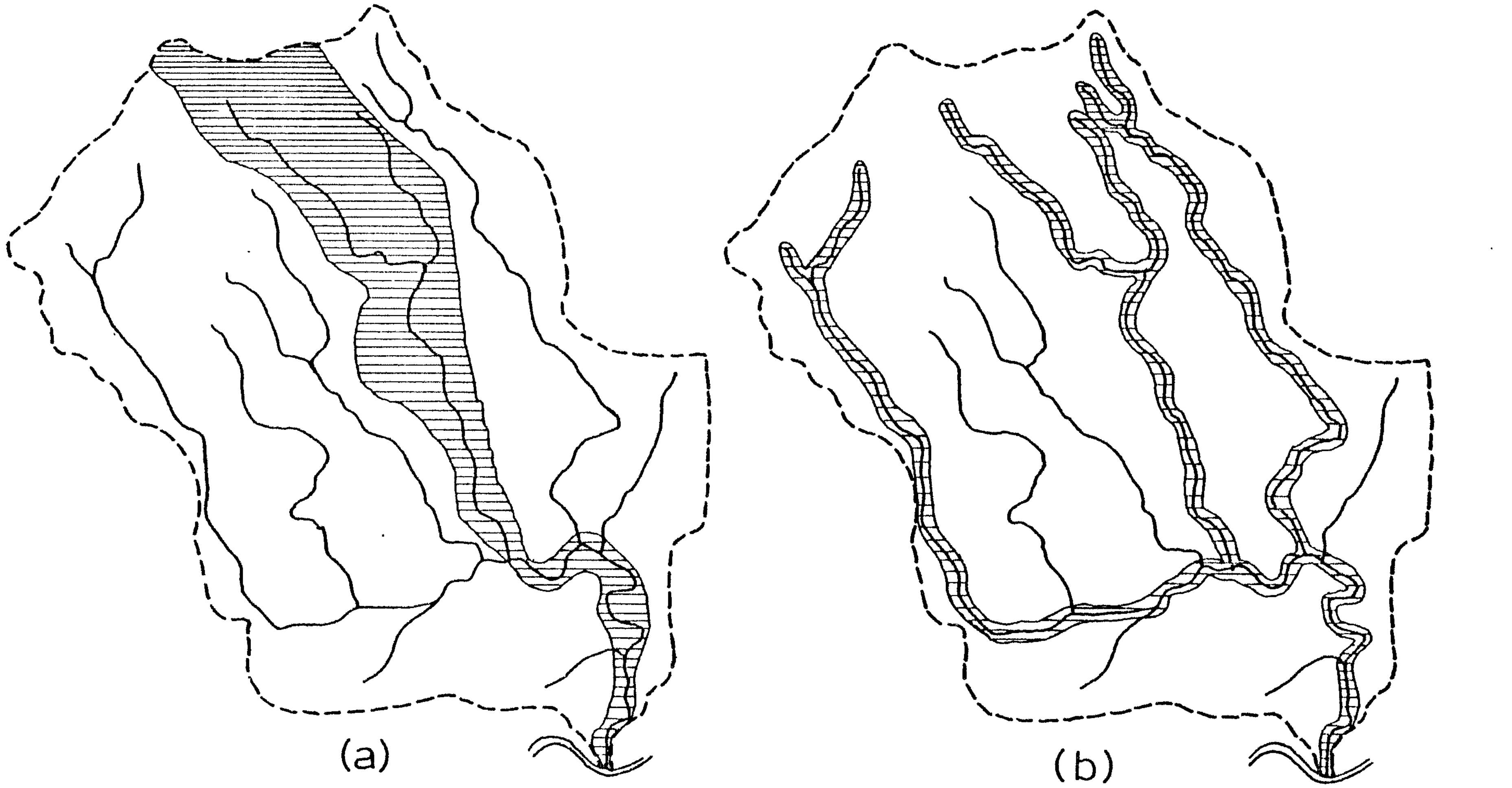

Figure 6. Black Creek watershed divided into type 1 (unshaded) and type 3 shaded) environments. Type 1 environments are productive and accomodate intensive agriculture. Type 3 environments represent a compromise between productive and protective qualities and function in preserve biological integrity. Conservation practices in type 1 environments address all four primary variables influencing biological integrity. See text and Table 4 for further explanation.

Fig. 6a is probably the best alternative for Black Creek because it will likely have less widespread effect on drainage than the other alternative (Fig. 6b). However, 6b might be the best choice in other watersheds. Clearly, 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.

The important concepts here is that the land and its associated biota play a primary role in regulating water quality. In type 3 environments the management strategy is to effect improvements in the four variables that influence biological integrity of Black Creek. 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 the areas designated as type 3 environments (Fig. 6). It is important to note that every watershed is unique and that the 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

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

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. Periodically federal agencies implement set-aside programs to take land out of production or to conserve soil resources. A system of classified streams should be developed to reduce local erosion and its effect on downstream water resources. Additional benefits form 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 landowner 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 are (or at lowest economic cost) will yield the greatest benefit to society. Under these circumstances, land holders might be eligible to collect extra ASCS or ACP benefits, to pay lower rates on crop insurance, or to lower interest rates in federal loan programs.

Many other incentive programs could and should be sought. These must protect the economic stake of the agricultural community and also produce the greatest benefit to society as a whole.

Institutional Approach to Implementation

Finally, our experience in the Black Creek project has yielded insight into some of the strengths and weaknesses of present institutional programs. Traditional soil and water conservation programs fail to manage water resources effectively because they have emphasized soil resources, drainage, production and, to a lesser extent, water quality. They do not manage the energy source, habitat characteristics, or flow regimes of streams with the "biological integrity" mandate in mind. Many have incorrectly assumed that if water pollution declines, habitat quality in a broad sense will be optimized. While traditional programs may have reduced pollution from cropland runoff, they have sacrificed natural energy source characteristics, flow regimes, and high quality steam habitat. How frequently, for example, have SCS planners asked, with biological integrity in mind, "How will implementation of this plan impact energy and nutrient supplies, flow regimes, and habitat quality in local and downstream areas?" Clearly, the result cannot always be to preserve the biota, but without consideration of the question, we will continue to degrade components of our biological environment.

A case could be made for confining soil and water conservation districts and the Soil Conservation Service (SCS) to their traditional roles of curbing soil erosion and its associated water pollution. After closely observing the activities of these agencies in the Black Creek project and elsewhere, we firmly believe that districts and the SCS should expand their roles. This belief is based on a cooperative relationship with farmers. We seriously doubt whether any other federal, state, or local agency could match the already existing cooperative relationships among districts, SCS and farmers.

Thus, the districts and SCS appear to be the best equipped agents for implementing water resource improvement plans in agricultural areas. However, an increased role by these agencies carries increased responsibilities to society. The only way to satisfactorily meet those responsibilities will be to expand the training base of SCS employees, or to seek more regular participation in development of plans by personnel familiar with the disciplines involved with the biological integrity of water resources. Planners and field technicians need to be trained in the ecological principles that are the basis of understanding and recognizing sensitive aquatic resources. Other existing agencies, such as Cooperative Extension Service and the special short-course facilities of many universities, could fill this educational gap.

Achieving clean water goals will depend on well-organized and well-conceived plans for control of non-point sources. For success in agricultural areas, district and SCS activities must be integrated with the stated goals for resource utilization throughout an area (i.e., a river basin). Rational decisions must be made with public input on such issues as the desired level and type of urbanization, agricultural production and water-resource value. Once these decisions are made and incorporated into the general framework of a 208 (or other) plan, district and SCS programs must center on implementing the needed practices in areas where the greatest overall benefits will accrue.

Typically, district and SCS contact is with people who voluntarily apply for soil and water conservation practices. Servicing this need has been and will continue to be useful in several respects, but effective soil and water resource management requires that action be taken quickly in the critical areas of a watershed. (Many would argue that this is an old policy. However, we emphasize that the method of identifying critical areas will differ with the expansion from soil resources to biological integrity.) Shifting district and SCS emphasis to these critical areas will require innovation, especially in educating the farming community and working cooperatively with landowners in critical areas, regardless of whether or not they voluntarily apply for assistance.

In conclusion, we believe a prerequisite for the effective management of land use and water resources is a basic understanding of biological integrity by those individuals and groups closely associated with the soil conservation movement. The history of soil and water conservation in this country reveals the strong emphasis on exclusively farm-oriented programs. The Black Creek project exemplifies the traditional approach, and its shortcomings in improving and maintaining biological integrity are the same as or similar to those of other traditional projects.

The soil conservation movement has always been dedicated to total resource conservation, but the demand for food and fiber has led to the emphasis on productive landscapes. However, man will successfully manage the earth's resources only if he modifies the environment in ways compatible with ecological principles. There is a clear need to conserve less productive landscapes that function to protect the environment, its resources, and its vital biological processes. Society, and especially the soil conservation movement as stewards of the land, has an obligation to establish and maintain such landscapes. The national goal of restoring "the physical, chemical and biological integrity" of water resources rests on our ability to percieve this basic ecological tenet and take innovative action in seeding solutions. take innovative action in seeding solutions.

Summary

The central assumption of the Black Creek study is that traditional erosion control programs are sufficient to insure high quality water resources in agricultural areas. We have tried to outline the inadequacies of that assumption, especially as they relate to the goal of attaining biotic integrity. The declining biotic integrity of our water resources over the past two decades is clearly not totally due to water quality (the effects of physical-chemical factors) degradation. Improvement in many of the aspects of the quality of our water resources in a much broader context than physical-chemical characteristics. Other deficiencies in nonpoint pollution control programs are discussed and a new approach to the problem is outlined.

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Black Creek Implications: Present and Future

by
L.F. Huggins[1]

Previous speakers have presented findings of the Black Creek Project as they relate to specific subject areas. I will attempt to distill from these specific results some general project conclusions and to focus on their national implications.

WHAT IS WATER QUALITY?

It has been recognized for some time that agriculture, because of the large land mass involved, does contribute to problems associated with non-point source pollution. However, when any effort is made to devise control programs an immediate difficulty is encountered. We have never really come to grips with the difficult issue of defining what water quality standards we are trying to achieve, except as very broad goals delineated in PL 92-500.

Dr. James Karr's presentation emphasized the importance of considering streams such as Black Creek as breeding waters for the Maumee basin. For such streams, in addition to providing acceptable chemical concentrations, it is vital that habitat and stream structure be preserved. On the other hand, satisfactory lake conditions also require concern about total annual chemical yields from contributing catchments. These examples emphasize the necessity of viewing NPS pollution from a broad perspective rather than just localized conditions.

Another factor which complicates establishment of NPS water pollution standards is that, except for irrigated areas, the bulk of such pollution is storm induced. Thus, the critical low-flow, high concentration standards established for point source pollution are not relevant to NPS stream standards. While concentration levels cannot be ignored, habitat maintenance and annual yields into receiving lakes are usually more critical factors. Furthermore, the storm induced nature of this type pollution introduces a stochastic element that complicates issues.

It is also necessary to recognize that standards developed for different goals than water quality may be complementary to improved water quality, but should not be expected to suffice. Specifically, attainment of tolerable soil loss levels, developed in conjunction with the Universal Soil Loss Equation as a yardstick for preserving long-term productivity, does not assure that a satisfactory level of water quality will be achieved.

While the above discussion delineates some of the difficulties with developing meaningful NPS water quality standards, the necessity of progress in this area cannot be ignored. This discussion is meant to emphasize that it is essential for these standards to give due consideration to many diverse perspectives. Much of the valid criticism of current public assistance programs, whether they deal with water quality or other areas, results from selection of singular objectives undertaken with too narrow a perspective of

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society's overall needs.

MANAGEMENT BMPs

NPS pollution is insidious and difficult to control because, by definition, it is that pollution which arises from dispersed and poorly identifiable locations. Because agriculture is the dominate use of total land mass in most arable regions of the country, its contributions of chemicals and sediment to streams and lakes is often large, even when loadings per unit area may be low.

The importance of management-type BMPs, in contrast to more traditional structural measures originally designed for erosion control, to attaining improved water quality must be recognized. These measures, such a residue and tillage management, have the distinct advantage of directly protecting large areas. While it is certainly true that wide differences occur in the pollution contribution from individual areas, this ability to "treat" 100 percent of a field's surface does contribute to overall effectiveness. Furthermore, these BMPs can often be applied for very low capital costs.

The lack of increased utilization of management BMPs is a consequence of several practical difficulties rather than any lack of effectiveness. Difficulties with management BMPs include: 1) a lack of public visibility, 2) a lack of permanence (they can be abandoned quickly without any capital expense), and 3) public cost-sharing is difficult to administer because effective performance is often dependent upon a time-critical application which can only be verified for a brief interval. Despite these difficulties, the overall cost effectiveness of management BMPs requires that we develop innovative ways to overcome the problems and obtain more widespread application of them.

It is difficult to overemphasize the importance of maintaining a NPS control program that is built upon voluntary participation encouraged by publicly supported incentives. The success of any program will critically depend upon the positive cooperation of a large number of individuals. Furthermore, the effectiveness of almost all BMPs is strongly influenced by a landowner's management decisions. Maximum effectiveness will be achieved only if these individuals understand the purpose of <u>and</u> actively support the program which resulted in the BMP installation.

A voluntary NPS program, if properly conceived and administered, can be particularly effective with the agricultural community. Historically, this group has demonstrated a concern about their environment and a willingness to cooperate with their neighbors to improve general conditions. These attitudes and the publicly funded agencies established to provide technical and financial assistance to the agricultural community should be utilized to the maximum degree possible.

There are at least three general characteristics which are vital to the success of a voluntary NPS control program. Briefly, they must be 1) effective locally, 2) flexible, and 3) applied on a priority basis. Each point requires further elaboration.

First, recommended NPS control measures must be adapted to local conditions, i.e. they must be both effective and economically viable. No one knows more intimately the unique soil and topographic conditions of a land parcel than the person who annually tills the soil and harvests its crop. The credibility of the entire program is lost, and its shortcomings widely publicized, when inappropriate measures are recommended. This requirement suggests the need to provide field personnel with improved analytical tools that can be used to accurately show the farmer what benefits will be obtained from alternative BMPs and which management decisions are critical to its successful operation.

Secondly, any national program must recognize the need to preserve the maximum level of local flexibility. Conditions vary greatly from farm to farm as well as regionally. It is seldom true that one certain practice is greatly superior in all respects to certain other practices. Furthermore, successful farmers must base management decisions on numerous, non-related factors rather than a single consideration such as water quality improvement. Letting an individual choose between multiple BMPs of roughly equal effectiveness or with correspondingly different cost sharing permits other, personally important, factors to be considered and greatly improves the palitability of the entire program.

Finally, and perhaps most difficult to achieve because of political considerations and possible charges of favoritism, is the need to recognize that a given BMP will not be equally effective at improving water quality when it is applied to different locations. A cost-effective program requires the delineation of priority areas and incentives that are at least partially dependent upon water quality benefits expected from each individual situation. To assure that such a program can be fairly administered will require innovative new ideas from the public institutions and additional technical tools for helping local agencies objectively assess water quality benefits on a site-specific basis.

DETERMINING BMP EFFECTIVENESS

There is an abundance of evidence that national water quality goals will be attained only if due consideration is given to controlling NPS as well as point sources of pollution. Furthermore, after a much needed and rather massive effort at controlling point source discharges from waste water treatment plants, we are in a period of diminishing impact per dollar invested. Despite these considerations, only a token effort has been undertaken to control NPS pollution.

The neglect of NPS pollution control results from a combination of factors, but two of the most important ones are: 1) the difficulty of quantifying sources due to the complex nature of the diverse forms of such pollution and 2) the uncertain effectiveness of the general control approach, using BMPs, currently proposed. Solid evidence is critically needed concerning overall benefits that can reasonably be expected from a specific control program. To date, only a few projects such as Black Creek, the seven Model Implementation Projects and some thirteen "experimental" Rural Clean Water Projects have been funded to demonstrate what might be attainable on a national basis.

Monitoring = Truth?

One fundamental misconception concerning water quality held by the vast majority of persons, within both the scientific and informed lay communities, is that true conditions and control effectiveness can be determined only by field monitoring. The perception, though often not explicitly stated, is that bottles of water should be collected and subjected to sophisticated laboratory analyses to determine what is present so that quality conclusions can be drawn.

The primary problem of monitoring is not associated with the laboratory analysis of a collected sample, although there are still significant difficulties with certain chemical constituents. Rather, it is with determining the source of pollutants present in the sample, assessing the true significance of individual component levels (the standards issue raised above) and determining impacts of proposed treatments on pollutant yields. It must be concluded that many unknowns associated with NPS pollution cannot be effectively resolved by monitoring. Unfortunately, the pervasive misconceptions about monitoring have governed all publicly funded efforts to evaluate NPS control measures and have significantly slowed real progress toward development of programs with proven effectiveness.

Monitoring--Strengths and Weaknesses

No economically feasible monitoring program can be devised which is capable of establishing cause-effect relationships between NPS pollution and control measures on a watershed scale, even for a watershed as small as the 20 sq.mi. area of Black Creek. Especially on a short-term basis. This situation prevails because of the storm-induced nature of NPS pollution, seasonal variations in weather patterns and the uncontrolled nature of the many factors which profoundly influence levels of such pollution.

In view of the situation just described, of what utility are field monitoring efforts related to NPS pollution? They can, especially when directed toward biological community determinations and habitat evaluation, determine overall water quality conditions of a watershed. Furthermore, when restricted to field sized areas with a single land use, monitoring can quantify the benefits of individual control measures. Such information is vital to the development of the only viable alternative tool for assessing and controlling NPS pollution, simulation models.

In summary, monitoring programs are expensive. They are slow to produce meaningful results. They cannot establish cause-effect on a watershed scale. Finally, comprehensive monitoring of small, single practice areas is critical to the successful development of any methodology to assess NPS pollution and design control programs. Furthermore, the supply of such information is woefully short.

Simulation--Strengths and Weaknesses

There is certainly no shortage of models available which purport to simulate at least some phase of water pollution problems. The basic shortcomings of all currently available models can be summarized by criticizing them as incomplete and inaccurate. Models are incomplete because they do not account for all of the many factors involved in something as complex as NPS pollution. It is also a valid criticism that many models do not even accurately simulate the limited number of processes which they claim to include. The "bottom line" is that many of the currently "available" models are not very good.

All models are not created as equals! While this truth should be self-evident, the poor performance demonstrated by some crude models has seriously undermined the credibility of the entire simulation approach. It is certainly true that all models include approximations of the real processes they are trying to simulate. However, the adequacy of these approximations must be judged on the basis of the requirements for each particular application. Thus, a given model may be completely unsatisfactory for some applications, but quite satisfactory for another. While this complicates the selection task for the model user, it must be recognized that there is simply no such thing as a single best model.

The credibility of a modeling approach suffers unfairly relative to monitoring because shortcomings of any model are so obvious. Relationships used by a model are explicit and clearly documented in a manual or its computer program implementation. Thus, the omission or crude approximation of one or more component processes intuitively thought to be significant for a particular application raises doubt concerning the adequacy of that model. To varying degrees, such issues can be raised with all models.

In contrast, unwarrented faith is commonly granted numbers reported by monitoring studies. Seldom are these results published with sufficient information to permit a rigorous evaluation of the overall uncertainty in the values. Issues such as the timeliness of sample collection during changing flow conditions, physical conditions of the sampler intake, obstructions to normal stream flow conditions, etc. are almost never published (in the interest of brevity or a general lack of understanding concerning their impact on the result??). Even laboratory analyses of water samples are subject to serious discrepancies. For example, ask two independent laboratories to determine levels of sediment bound nutrients in identical samples. Better yet, attempt to split a single sediment laden sample and send both subsamples through the same laboratory. A comprehensive evaluation of the overall uncertainty associated with NPS physical/chemical water quality samples would show that errors in excess of 50 percent are not uncommon.

The advantages of simulation studies are: 1) they are inexpensive, at least in comparison with meaningful monitoring programs; 2) they produce results much more quickly than monitoring and 3) they can analyze hypothetical situations that can be used in a planning effort. This latter advantage can be especially significant to the success of a voluntary program as was illustrated earlier by Dan McCain. The opportunity to measure improvements relative to a common baseline rather than current conditions permits allowance for previous responsible stewardship. This avoids giving the greatest public reward to individuals that have been the worst environmental offenders prior to the announcement of the newest program to control such abuses. The inability of past government programs to proceed in this manner has encouraged poor citizenship and resulted in public disrespect for many programs.

If one's purpose is to determine water quality impacts of a specific pattern of applied BMPs, the advantage of simulating hypothetical conditions is also significant. By simulating storm patterns of particular or long-term significance, confounding factors as construction activities concurrent with a monitoring program and unusual weather patterns during the period of record can be eliminated.

CLASSES OF MODELS

The difficulty of selecting the most appropriate model for a given application was alluded to above. While space does not permit the development of a recommended procedure to follow in making such a selection, it is important to recognize the existence of two major model classes.

The first class of models should be called basin or regional scale models. These models are designed to analyze general or trend data over very large geographic regions that encompass several states. In their most comprehensive form, they will simulate macro-economic conditions as well as water quality phenomena. These models are designed to assess overall or average conditions and predict trends. Such models can assist with establishment of national water quality goals and program levels.

The second class of models might be called implementation scale models. This is meant to infer that they are designed to be used to assist planners and engineers with selection and locating of individual BMPs. Just as knowledge that the average depth of a stream might be two feet deep is of no value to a non-swimmer deciding whether to wade across, results from basin scale models are useless for implementation planning. Once an overall program scope has been established, an entirely different kind of model is required to assist with implementing the program.

An implementation model must be able to assess impacts of the unique combination of features present in the vicinity where individual BMPs might be located. To obtain the voluntary participation of local landowners, control measures that are effective and compatible with conditions on that parcel of land must be offered. Just because a given practice might result in a satisfactory average level of pollution control from an entire basin does not mean it will be effective everywhere in the region. Participation will be forthcoming when the landowner understands how suggested controls will work on his/her land and is convinced that its installation will thereby contribute to the overall societal goal of improving water quality. Thus an implementation scale model must be very site specific.

It is possible, though not always the best approach, to use an implementation scale model as a part of a basin-wide study. In order to be feasible, this approach generally requires applying the more detailed model on a statistically representative number of subwatersheds within the basin.

SUMMARY AND CONCLUSIONS

Some of the Black Creek experiences which have national policy implications for NPS control programs have been discussed. They can be summarized as follows:

The establishment of quantitative NPS pollution standards, while very difficult, is urgently needed. Such standards must reflect a broad range of considerations and should vary with different regions of the country.

While the effectiveness of individual BMPs will depend upon local conditions, there has generally been inadequate utilization of management-oriented practices in deference to structural measures. While management practices suffer from lack of public visibility and are difficult to administer, their relatively low capital costs and the effectiveness generally attainable due to the areal extent of treatment warrants much effort to overcome these problems and increase their utilization.

The effectiveness of any NPS control program is intimately dependent upon daily management decisions made by individual landowners. Therefore, a program based upon voluntary participation is not only politically desirable, but potentially much more effective than a regulatory approach. To be successful, voluntary programs must be designed to permit the use of measures which are locally adapted, offer the participant multiple alternatives and equitably distribute public and private costs.

Obtaining solid evidence concerning the effectiveness of NPS control measures is admittedly difficult. However, unwarranted reliance has been placed on monitoring programs. It is impossible to determine watershed scale cause-effect relationships by monitoring, especially within a time frame of 3 to 5 years.

Despite the many shortcomings of current simulation models, they clearly offer the best available technology for analyzing NPS pollution problems and planning control programs. However, the selection of a particular model is difficult because it must be dependent upon the types of pollution which are of prime importance.

Two fundamentally different classes of models are required for national program develop and for implementation planning. The ANSWERS model, discussed by David Beasley, is an example of an implementation scale simulation model.

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16. ABSTRACT

This is a progress report of the Black Creek sediment control project. This report discusses the details the work done in water quality management and ongoing research fo planning at the national, regional or state level. The Black Creek project exemplifies the traditional approach, and it shortcomings in improving and maintaining biological integrity are the same as or similar to those of other traditional projects.

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