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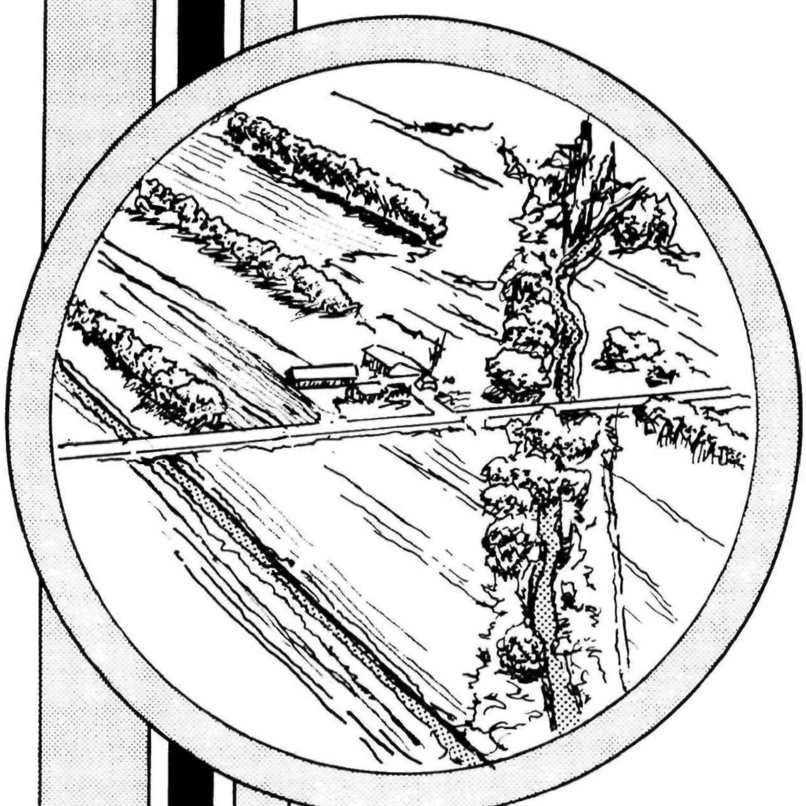
Agricultural Land Use Water Interaction: Problem Abatement, Project Monitoring, and Monitoring Strategies



Review Notice

The apendix referenced in the text is not included as part of this publication. It is available in limited number from the Environmental Protection Agency's Water Planning Division on request.

AGRICULTURAL LAND USE WATER QUALITY INTERACTION: PROBLEM ABATEMENT, PROJECT MONITORING, AND MONITORING STRATEGIES

by

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Purchase Order W-5571-NASX

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Acknowledgments

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Section 1

Introduction

This report documents the work performed for the Water Planning Division's Rural NPS Section (U.S. EPA, Washington, D.C.) under Purchase Order W-5571-NASX. The project tasks are as follows:

- Attempt to generalize agriculturally related NPS pollution problems in various receiving waters and generally outline their potential remedies through modification of practices and introduction of new practices and practice combinations;
- discuss the requirements, performance, and limitations of project monitoring; and
- consider the process/strategy of selecting projects for detailed monitoring/evaluation (M/E) across the United States.

Figure 1 indicates the logic in performing these tasks and how they are interrelated and covered in each section of this report.

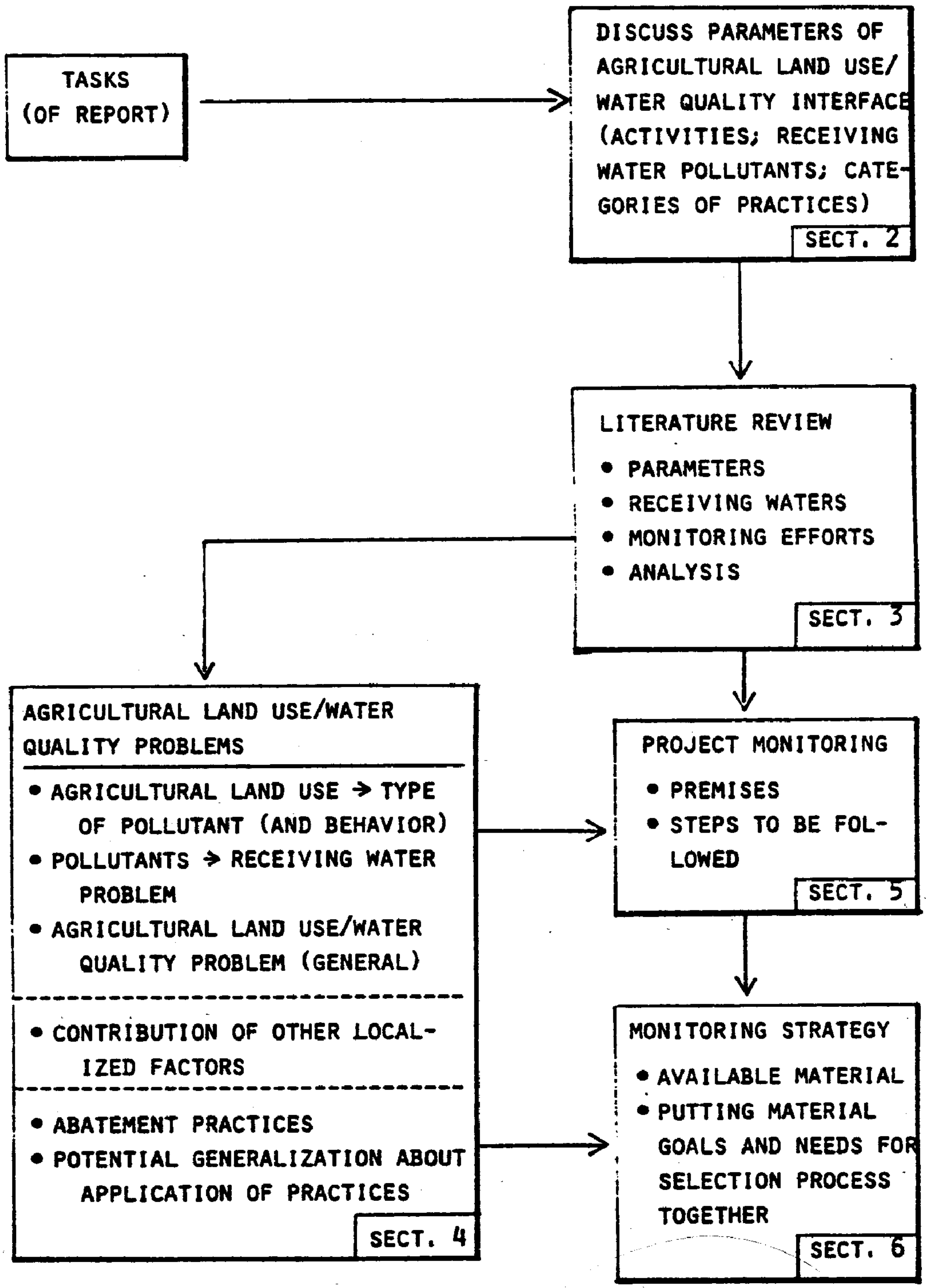
In our discussion we subscribe to the basic idea that existing water quality problems must be resolved and that the potential remedial actions must be geared to these particular problems. Since water quality degradation is the issue, only those agricultural areas and practices that appear to cause the problem should be modified, and the degree of modification or the introduction of new practices must be determined by the expected water quality improvements. This necessitates identifying the cause-effect relationships in a preliminary analysis for each project, and gearing the M/E efforts to the particular problem and its land/water setting.

The following main sources provided the necessary background material:

Studies:

- D.A. Haith and R.C. Loehr (eds.), "Effectiveness of Soil and Water Conservation Practices for Pollution Control," prepared by Cornell University for U.S. EPA, Athens, GA, October 1979 (EPA-600/3-79-106).
- Meta Systems Inc, "Costs and Water Quality Impacts of Reducing Agricultural Nonpoint Source Pollution," U.S. EPA, Athens, GA, August 1979 (EPA-600/5-79-009).
- International Joint Commission, Pollution in the Great Lakes Basin from Land Use Activities, Washington, D.C. 1980.

FIGURE 1. LOGIC OF THE REPORT



Journals:

- Journal of Environmental Quality
- Water Resources Research
- Journal of Soil and Water Conservation

EPA Documents:

- Water Pollution from Cropland (Vols. I and II)
- Animal Waste Utilization on Cropland and Pastureland
- Guidance Document for NPS Monitoring (NPS Task Force) (Draft of March 1980)

USDA Documents:

- RCA Reports, Resources Conservation Act

Various Meta Systems Documents

Section 2

Interrelationship of Agricultural Land Use Activities and Receiving Waters

Dominant Variables/Parameters

This section is the basis for the work in the next sections. Here we select the variables/parameters which are needed for a first-cut assessment of the water quality impacts due to agricultural land use activities (and their modifications), and which are needed as well to derive simple rules for project monitoring and M/E selection strategy.

This scheme entails the following steps:

1) choosing the basic agricultural land uses;
2) choosing the basic receiving waters;
3) describing the basic water quality problems and their indicators;
4) modifying the basic agricultural land uses for water quality improvement according to soil conditions, slope/length, climatic conditions, and drainage patterns.

We will work through these steps in some detail.

Step 1

There doesn't seem to be a unifying framework of land uses that we can draw on,* but on the basis of various reviews and discussions, we feel most comfortable with the following relatively crude classification.

Cropland**

- non-irrigated
- irrigated

Orchard/Vineyard

Grazing land (including range, improved range, pasture, and improved pasture)

Animal holding

Homestead

It is obvious that environmental problems created by a particular land use

*Various discussions with John Peterson, SCS (on detail to U.S. EPA), March 1980.

**In contrast to USGS classification, we do not include pastureland in cropland; we assume, however, that hayland is included, possibly as part of a rotation.

activity need to be evaluated in light of local dominant soil and physiographic conditions. Thus local land form might be more important than the land use activity itself, as Sonzogni et al. argue.* We, however, deal with different land use activities by assuming similar local conditions in any comparisons of environmental impacts.

Step 2

The following receiving waters are considered candidate types (very much in agreement with EPA's NURB project):

- lake/reservoir
- small stream
- river
- estuary
- oceanic bay (including Great Lakes Bays)
- groundwater

This is basically a sound classification, but it includes receiving water types that have a low priority under RCWA (as agreed upon by USDA and EPA), such as estuaries and coastal areas. It is obvious, however, that it is sometimes impossible not to trace impacts as far downstream as necessary, e.g., down to tidal estuaries. It might turn out to be useful in future refinements of the scheme to differentiate between nonstratified (shallow) and stratified lakes/reservoirs because the impacts of eutrophication are quite different, and it might also be helpful to separate reservoir and lakes in the future since reservoirs permit combinations of land and instream protection measures/management schemes that are different from those feasible in lakes.

Thus we select the following receiving water types for our current review:

- lake/reservoir
- small stream
- river
- bays (Great Lakes)
- groundwater

Step 3

The following water quality problems and their indicators are selected:

- sedimentation
- eutrophication
- salinity
- pesticides
- pathogens
- BOD/organic materials
- nitrates

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*Sonzogni, W.C. et al., "Pollution from Land Runoff," Environmental Science and Technology, Vol. 14, No. 2, February 1980.

We recognize that we are lumping together broad water quality impacts that are caused by a combination of various parameters and that are described by various parameters (such as eutrophication), and specific one-parameter problems (such as nitrate). We have chosen this representation because it is the most common. In any case, laying out the pathway of pollutants indicates very well how different parameters contribute to one "combined" problem and how, at the same time, they are representative of other "individual" problems (see Figure 2). Failure to recognize these interactions of various parameters that can be controlled on the land leads easily to incorrect investments in control strategies designed to improve water quality.*

Furthermore, we have not included at this point those secondary effects of the various water quality problems that must be anticipated. These can be seen either in terms of the anticipated use of the impacted receiving water or in general terms. For example, if the bacteria count is higher than permitted, swimming might not be allowed. If there are high incidents of eutrophication, the fish population changes as a result of the limited oxygen supply in the hypolimnion. The degree of diversity declines; valuable fish leave while trash fish survive; and total productivity may increase due to greater food supply. In the latter case, it can be argued that this change might provide a benefit to sport fishing, which implies that beneficial uses could be derived from a generally degraded receiving water if "sport fishing" is labeled the exclusive water use -- a highly unlikely prospect.

Step 4

In this step we select those practices/measures that effect water quality. In Figure 3 we have differentiated among five control strategies that lead to reduced edge-of-stream loadings and changing water quality:

1) Modification of land use activities without any additional structures and/or addition of non-structural conservation/control practices;
2) Management strategies;
3) On-site structures attached to/associated with ongoing land use activities;
4) Off-site structures capturing and/or modifying runoff and washoff;
5) Streambank and instream control measures.

Examples of the first control area are chisel plowing (instead of moldboard plowing); of the second area, timing and application of fertilizer and pesticides; of the third area, grassed waterways and terraces; of the fourth area, sedimentation basins, ponds, and grass strips; and of the fifth area, fencing against animals and copper sulfate applications against algal bloom.

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*A classic example is the switch from light-limited to phosphorus-limited eutrophication. Soil conservation methods might not prove very effective in controlling runoff/washoff of biologically available phosphorus. Thus reduction in soil loss might increase light penetration in the impoundment without substantial reduction in available nutrient supply.

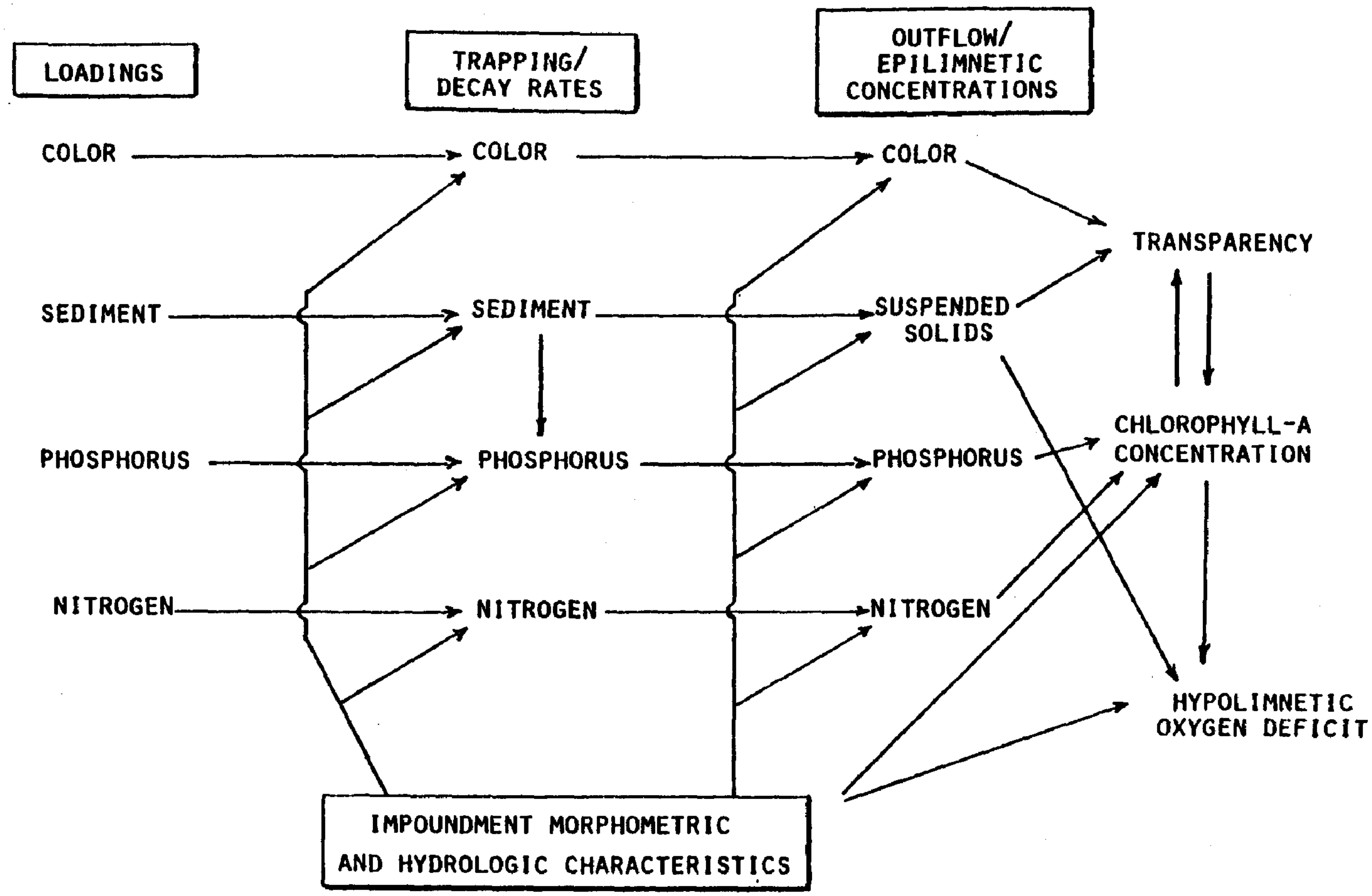
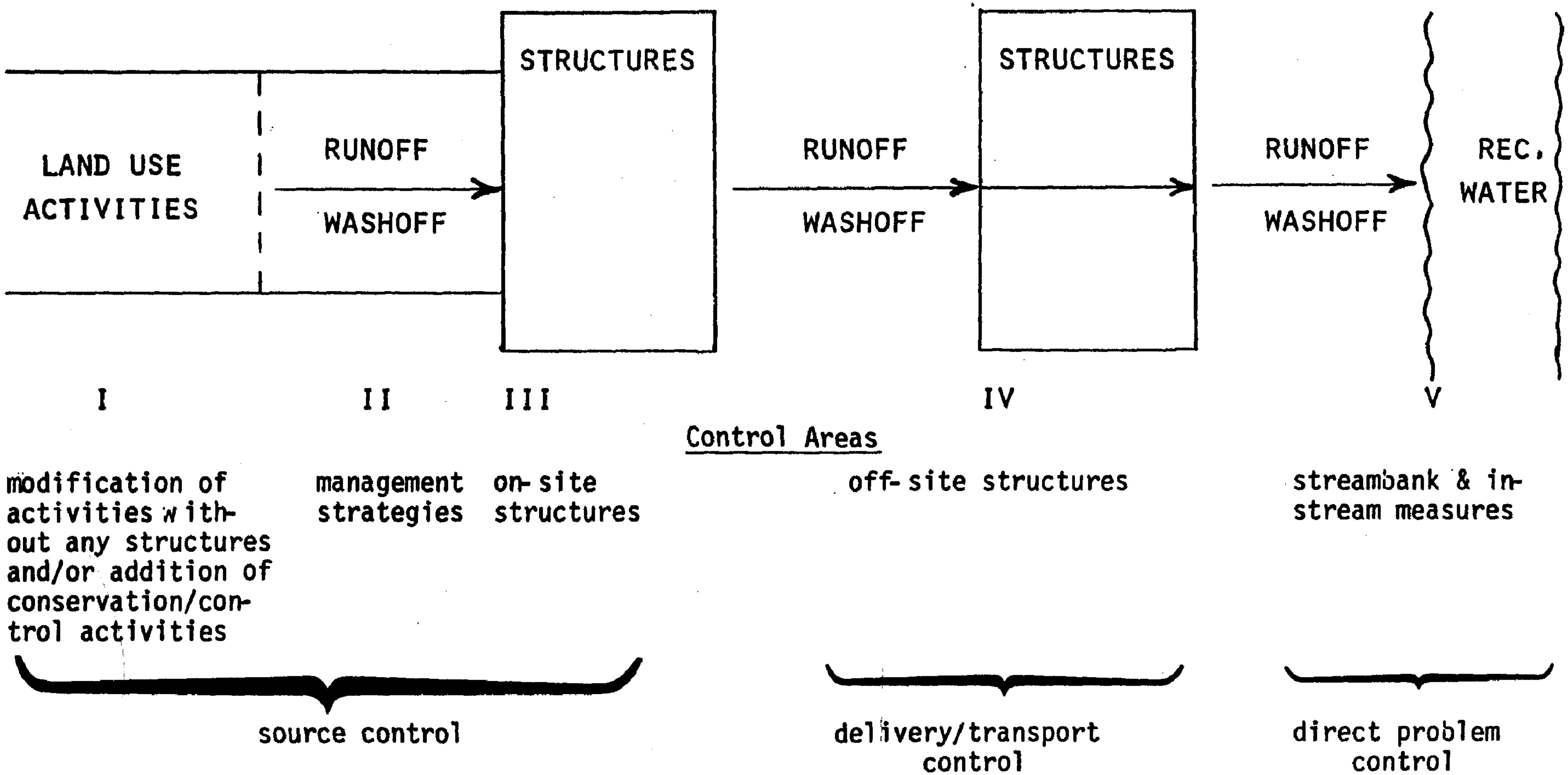


FIGURE 2. PATHWAYS IN PREDICTING IMPOUNDMENT WATER QUALITY

FIGURE 3. CONTROL AREAS OF NONPOINT SOURCE POLLUTANTS



We feel that this differentiation of control options is useful for control of erosion as well as other pollutants for all land use activities. It provides a sense of the geographical separation of control options, a logical view of what type of practices/measures can be combined, and where and how their direct effects can be measured. It also indicates at a first glance which requirements are imposed on any monitoring attempts. Practices listed in the Conservation Manual* or the USDA/EPA publication on control of water pollution from cropland** can be put into these categories.

We recognize at this point that control strategies must be planned/designed in accordance with the natural/human-induced conditions of the areas to be controlled. Therefore, it is desirable to keep, say, a clayey soil, which has a relatively high enrichment ratio, out of the receiving water because of the potential inducement of biological activity, but it also becomes obvious that clayey soil is difficult to control by off-site structures that operate solely on physical control principles such as settling basins. Thus minimizing/preventing detachment might be the only reasonable control strategy. Based on the composition of the soils predominant in the areas to be controlled, a first selection of appropriate control mechanisms should be made.

We prefer to use the type of land use activity as our reference for control categories (like cropland) and not the general land-based problems (such as erosion and nutrient wash-off). This means that we have to develop practices for combinations of each land use activity and its land-based problem types which in turn are dependent upon the local soil and physiographic conditions. Clearly, there are overlaps; if erosion occurs from croplands, erosion control will always interface with fertilizer and pesticides that are applied.

We also prefer to define baseline conditions for each land use activity that constitutes (in a simplified sense) the most common practice:

- Continuous row crop (non-irrigated cropland), tilled up and down slope without any particular sophisticated fertilizer and pesticide application practice/management;
- Continuous row crop (irrigated cropland), furrow irrigated without any particular fertilizer and pesticide application practice/management;
- Draining from animal holding areas into the drainage of surrounding land;
- On orchards/vineyards, reducing the possible endangerment of the harvest by intensive chemical spraying with only minimal considerations of other aspects, such as erosion;
- Grazing range and pastureland without any advanced plan/management

*USDA, Soil Conservation Service, National Handbook of Conservation Practices Notice, Washington, D.C., 20013.

**USDA/EPA, Control of Water Pollution from Cropland, Vol. I, November 1975 (see Table 12, p. 63).

of these resources with regard to their carrying capacity;

- Homestead, relying on the surrounding land for absorption of waste/residuals.

We are aware of the oversimplification of these definitions of "baseline." But it is essential that we state some baseline conditions in order to make meaningful estimates of water quality impacts and their modifications.

Recognition of Water Quality Impacts

Having identified the various parameters and components of interest here, it is appropriate to make a brief statement about previous experiences in linking land-based activities to receiving waters and in identifying changes in water quality due to modifications of land-based activities. In a recent study based on the land data from the Black Creek Project,* Meta Systems analyzed long-term average impacts of various cropland activities on the water quality of a synthesized downstream impoundment.

Eleven selected farm practices (ranging from monoculture to rotation and structural measures) were analytically compared. Figure 4 shows the results as applied to one soil type, the lowland (silty clay; hydrologic class D). Various comparisons can be made, such as between practices on the basis of individual parameters or on an overall basis, or between individual parameters of one specific practice. Figure 5 depicts relative impacts; the highest net revenue is chosen as base case. The relative results can be used to identify the impact on individual uses. For example, a switch from the base case (CB-CH) to a C-B-W-H rotation would result in a decrease in each of the six water quality parameters, ranging from a decrease in impoundment sedimentation of almost 70 percent to a decrease in impoundment biomass of about 3 percent. This might also indicate that the water quality problem cannot be solved by control practices of categories 1 and 3, but only in combination with category 2 techniques such as reduced fertilizer application.

What is of major interest here is the attenuation effect of the receiving water.** Even in an impoundment, whose water quality is considered quite sensitive to input changes, significant edge-of-stream loadings are transferred to significant water quality changes only in a few instances. Since in the modeling exercise, a specific practice was implemented in the total watershed at one time, it becomes obvious what a difficult task the M/E

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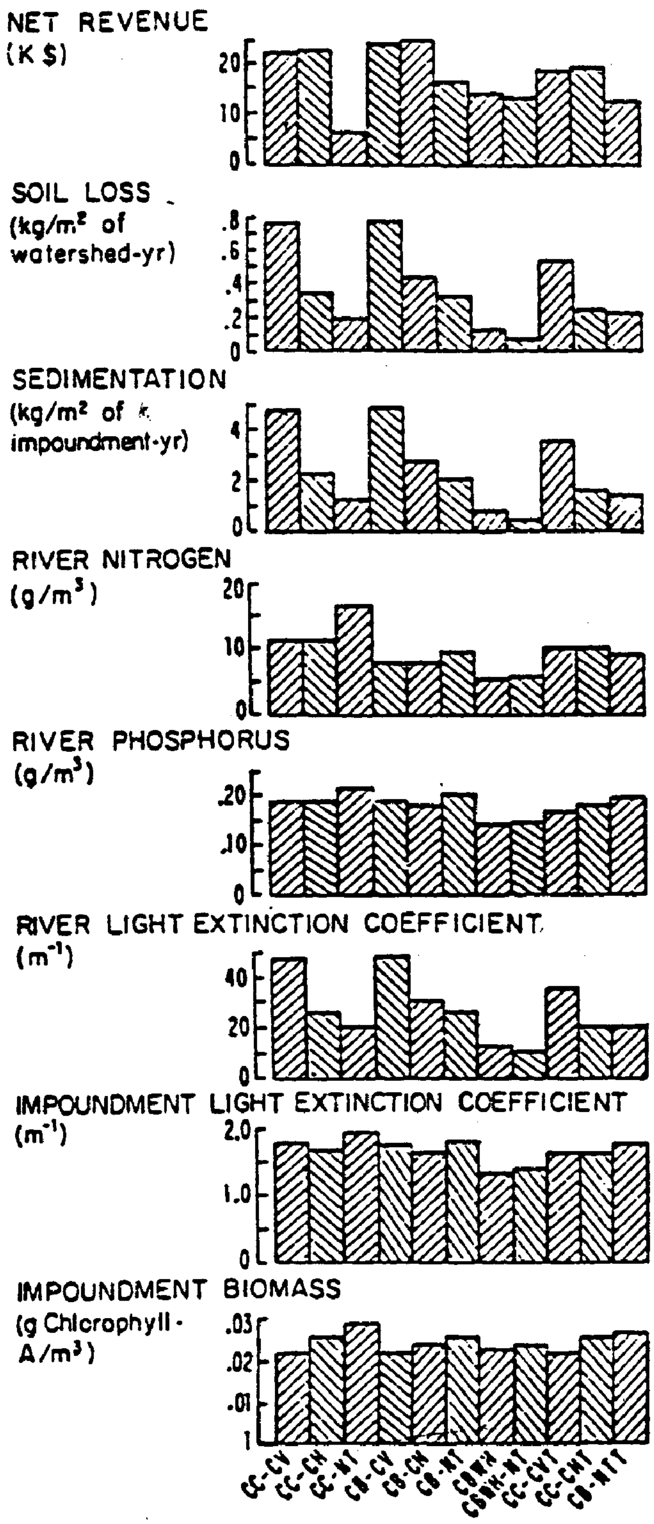
*Meta Systems, Costs and Water Quality Impacts of Reducing Agricultural Nonpoint Source Pollution, U.S. EPA, Athens, GA, EPA-600/5-79-009, August, 1979.

**For the overall configuration of watershed area, impoundment surface area, and impoundment mean depth values of 200 km^2, 5 km^2, and 4 m, respectively, have been selected as being typical of watershed/impoundment configurations in the midwestern data set used to develop the impoundment models. With a total flow rate of .25 m/yr from the watershed, the hypothetical impoundment has a surface overflow of 10 m/yr and a mean hydraulic residence time of .4 years.



Key:

CC-CV: Continuous corn, conventional tillage, without terracing

CC-CH: Continuous corn, chisel plowing, without terracing

CC-NT: Continuous corn, no-till planting, without terracing

CB-CV: Corn-soybeans, conventional tillage, without terracing

CB-CH: Corn-soybeans, chisel plowing, without terracing

CB-NT: Corn-soybeans, no-till planting, without terracing

CBWH: Corn-soybeans wheat-hay, conventional tillage for corn only, without terracing

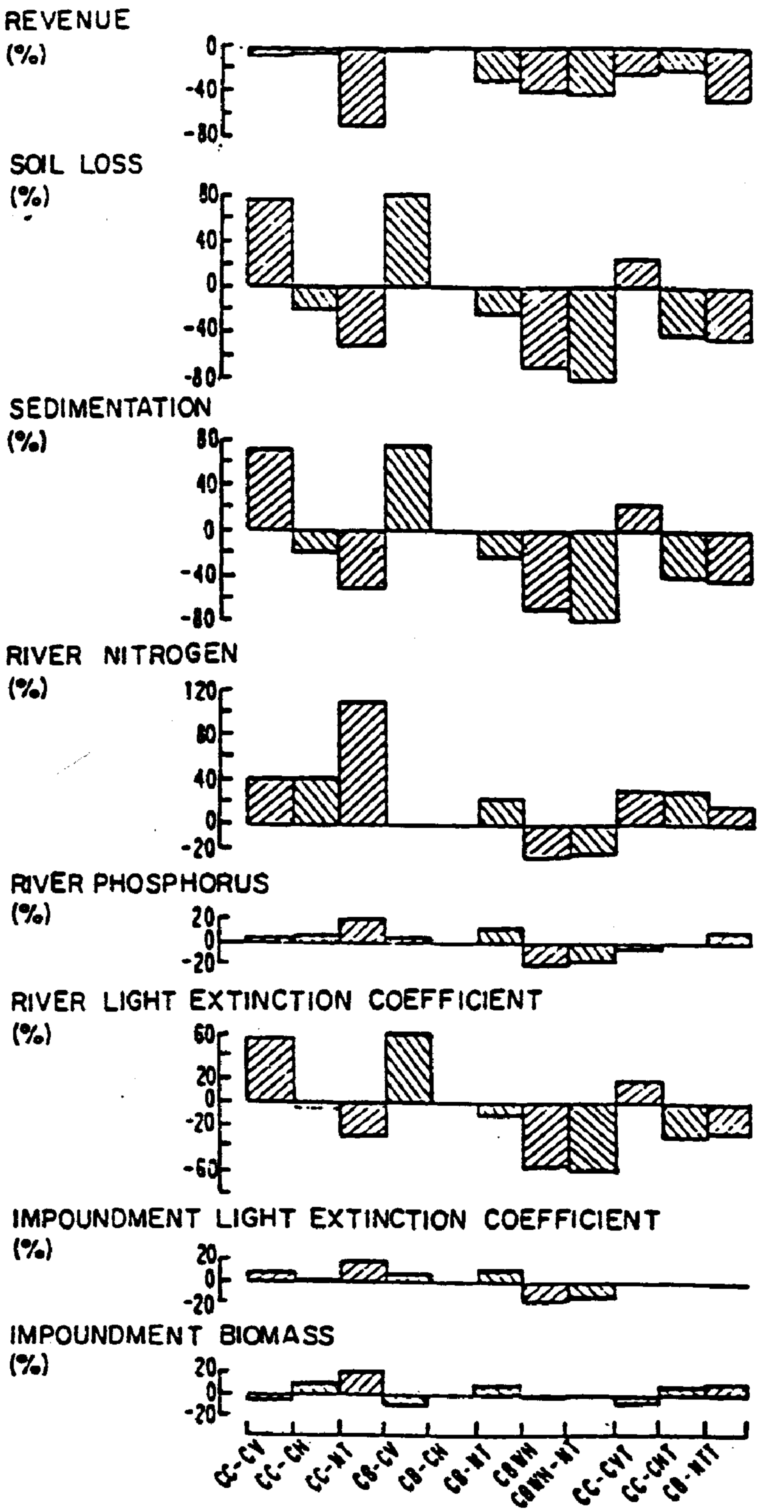
CBWH-NT: Corn-soybeans wheat-hay, no-till planting, without terracing

CC-CVT: Continuous corn, conventional tillage, with terracing (PTO terraces)

CC-CHT: Continuous corn, chisel plowing, with terracing

CB-NTT: Corn-soybeans, no-till planting, with terracing

FIGURE 4. COMPARISON OF PRACTICES -- LOWLAND



Key: See Figure 4.

FIGURE 5. PERCENT CHANGE OF HIGHEST REVENUE FACTOR -- LOWLAND

projects of RCWP face in delineating impacts from much smaller areas by water quality monitoring and evaluation techniques.

Wind Erosion

Wind erosion has indirect impacts on the quality of a region's water bodies. Soil particles (and their attached chemicals) are blown off a field and fall out onto water (with and without compositional changes in the air). The fallout has a definite impact, but given our current state of knowledge it is even more difficult than for the water-based erosion to establish a relationship between origin, transport (modification), and fallout location. If wind is the predominant transport mechanism, detailing the transport route over local and regional distances is extremely difficult. Also, measuring the composition of the fallout material is a very hard task. For example, it has to be decided whether and how dust particles should be isolated to give the quality of precipitation, the main source/force for fallout, which then implies the dust composition.

Factors similar to those in water-based erosion determine the erosion/erodibility of an area. The combination of these factors for a quantitative analysis has been attempted in the wind erosion equation, which is analogous to the Universal Soil Loss Equation.* The factors considered include wind erodibility, soil-ridge roughness, climate, median unsheltered travel distance across a field, and equivalent quantity of vegetative cover. Based on the identification of these factors, essential for wind erosion potential and controls, respectively, effective control means can be designed to curb wind erosion. Various practices that control water-based erosion are also effective in reducing wind erosion; but given the difficulty in relating control and impact, we can only emphasize the usefulness of these controls in areas hit by wind erosion without showing their positive impact. Therefore, we will not discuss wind erosion further in this report.

*See, for example, Skidmore, E.L., P.S. Fischer, and N.P. Woodruff, "Wind Erosion Equation: Computer Evaluation and Applications," Soil Service Amer. Proc., Vol. 34, 1970, pp. 331-335.

Section 3

Literature Review

The literature survey* covered 36 different articles reporting the findings of monitoring programs designed to answer a variety of questions (Table 1). These studies varied in pollution problems investigated, the aspects of the pollution phenomena addressed, the type and period of monitoring, and several other variables. Some general characteristics of the material surveyed are:

- The studies were conducted in 19 different states with the greatest concentration in states with large agricultural schools.
- The pollutants investigated included nutrients, pesticides, pathogenic bacteria, plutonium, oxygens and salt. Approximately 75 percent of the studies, however, were concerned primarily wih nutrients.
- Most studies listed no specific environmental problem related specifically to the monitoring site. Those water quality problems that were mentioned were usually theoretical -- such as a mention of eutrophication when nutrients are being investigated. Likewise, receiving waters were often unspecified, though our interpretation of the articles gives a distribution of 31 streams, 3 groundwater aquifers, 1 estuary, and 1 retention pond.
- The pollution sources addressed were predominantly cropland or cropland mixed with pasture, woodland, and/or residential areas.
- Abatement practices were investigated (to some degree) in 12 of these studies. Terraces, contour cultivation, grass-lined waterways, and various range and crop management techniques were addressed, but some of the other central techniques (such as sod-based rotation and filtration strips) were not.
- Monitoring techniques varied widely. Only 11 of the 36 tests used some automatic equipment; station locations ranged from natural streams to outlet culverts to runoff collection tanks; and test durations ranged from a month or 2 to 10 years (14 studies monitored for over 2 years, and an additional 14 monitored for 1 year or more).

Being reasonably representative, these studies suggest that the following needs should be recognized by the RCWA program. Care must be taken that the studies selected correlate well with pollution problems' specific data

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*The review was not intended to be exhaustive, but was undertaken to document some of the existing knowledge in this field.

TABLE 1. SUMMARY OF LITERATURE REVIEW

Article	Location	Pollution Problem			Pollution Source				Abatement Practice	Monitoring			
		Parameters	Receiving Water	Effects	Land Class(es)	Area (acres)	Soil Type(s)	% Slope		Time Period	Frequency of Sampling	Type of Sampler	Location of Sampler
1	CO	salt	stream		MX[2]	4,734				1 yr.	varies[3]	automatic	streams and canals
2	GA	N, CL	stream		CR[1]	3.2	grassed waterways, terraces, cover crops			3 yrs.	runoff events		watershed outlet
3	GA	herbicides, sediment	stream		CR[1]	3-6.7	grassed waterways, terraces, cover crops			3 yrs.	runoff events		watershed outlet
4	HI[4]	herbicide	estuary		pineapple MX[2]	2-6.2 ---		3-12% ---		sampler 3 mo.	used was faulty		in stream
5	ID	coliform, bacteria			CR-I	203,000	silt loam	0-12%		1 yr.	2-week intervals	grab	sub-surface drains
6	ID	coliform	stream		PAS, MX[2]	57,600				3 yrs.	weekly during grazing, else biweekly	grab	in stream (22 stations)
7	ID	coliform, BOD			MX	1000-1544				2 yrs.	2-week intervals	grab	outlet
8	IN	N,P			CR[1]	.021	silt-loam	8.2-12.4%	various tillage systems		simulated storm events	automatic and grab	outlet
9	IA	N, P, sulfate, sediment	stream		CR/T[1]	7.9-22.7		3-6%	drained and undrained terraces	3 yrs.	runoff events	grab	at outlet weir and collection tank

1. Multiple watersheds. See the abstract for more complete information.
2. Mixed watershed. See the abstract for more complete information.
3. Multiple sampling stations.
4. Two monitoring studies repeated in one article.

TABLE 1. (CONTINUED)

Article	Location	Pollution Problem: Parameters	Pollution Problem: Receiving Water	Pollution Problem: Effects	Pollution Source: Land Class(es)	Pollution Source: Area (acres)	Pollution Source: Soil Type(s)	Pollution Source: % Slope	Abatement Practice	Monitoring: Time Period	Monitoring: Frequency of Sampling	Monitoring: Type of Sampler	Monitoring: Location of Sampler
10	IA	P,N			CR(1)	74-128	loess		various terrace types	3,4 yrs	7.4 per run-off event		watershed outlet
11	IA	N,P, algal density	stream	eutroph.	CR, RS, MX(1,2)	40,000-3,600,000				14 mo.	weekly-summer monthly	grab	stream (16 stations)
12	IA	N	stream		CR(1)	74-150	loess silt-loam	2-18%	terracing, contour planting	3 yrs.	storm event	grab	outlet
13	KY	N,P	stream		MX(1)	494-200,000	varies	varies		2 yrs.	monthly	grab	in streams
14	LA	N,P,K	stream		CR, PAS(1)		silt-loam	5%	various tilling techniques	1-2 mo.	storm event	grab	tank
15	MI	N, chloride	groundwater		MX(2)	140,000				12 mo.	weekly plus some scattered	grab	in stream
16	MN	N,P, others			N PAS	.06		5%		5 yrs.	runoff event	grab	runoff captured in tank
17	NB	N,P	groundwater		CR(2,3)		loess		various management techniques	(soil samples only)			
18	NV	P,DO,N,BOD	stream		CR-I, PAS-I(1)	21.3-60.0			range management	1 "season"	at 12-hr. intervals during irr.	grab	stream gaging station

1. Multiple watersheds. See the abstract for more complete information.
2. Mixed watershed. See the abstract for more complete information.
3. Multiple sampling stations.

TABLE 1. (CONTINUED)

Article	Location	Pollution Problem: Parameters	Pollution Problem: Receiving Water	Pollution Problem: Effects	Pollution Source: Land Class(es)	Pollution Source: Area (acres)	Pollution Source: Soil Type(s)	Pollution Source: % Slope	Abatement Practice	Monitoring: Time Period	Monitoring: Frequency of Sampling	Monitoring: Type of Sampler	Monitoring: Location of Sampler
19	NV	DO,BOD,N,P	stream		CR-I[1] PAS-I	21.3-60			range management	(see study no. 18. They used the same data)			
20	NY	P	stream		MX[2]	81,500				20 mo.	from several per day to 2/month; varies with flow	grab and automatic	stream
21	NY	N,P	stream		crops[1]	.79	silt-loam	2-4%	various crop management techniques	1 yr.	storm event	automatic and grab	outlet and tank
22	OH	N,P,K			barnlot	0.4	silt-loam	13%		2½ yrs.	storm event	automatic	outlet
23	OH	N,P,K	stream		CR,WD[1]	43.5 and 303.7	silt-loam	12-18%		4 yrs.	every two weeks and during runoff events	grab	stream, at weirs
24	OH	N	groundwater		RS,MX[2]	304	silt-loam			5 yrs.	usually weekly	grab	springs
25	OH	P,N, others	stream		PAS[1]				range management	2 yrs.	weekly and runoff events	automatic	watershed outlet
26	OH	plutonium, cesium	retention ponds		CR,PAS[1]	5.4-8.9					(sediment samples were taken in ponds and nearby. No water samples were taken.)		
27	OH	N,P,sed., others	stream		CR, MX[1]	205-262[1]	clay, clay loam and sandy loam			32	runoff events	grab	watershed outlet

1. Multiple watersheds. See the abstract for more complete information.
2. Mixed watershed. See the abstract for more complete information.
3. Multiple sampling stations.

TABLE 1. (CONTINUED)

Article	Location	Pollution Problem: Parameters	Pollution Problem: Receiving Water	Pollution Problem: Effects	Pollution Source: Land Class(es)	Pollution Source: Area (acres)	Pollution Source: Soil Type(s)	Pollution Source: % Slope	Abatement Practice	Monitoring: Time Period	Monitoring: Frequency of Sampling	Monitoring: Type of Sampler	Monitoring: Location of Sampler
28	OK	N,P	stream		PAS[(1)]	19-27	silt-loams	2.7-3.5%	range management	10 yrs.	runoff events	automatic and grab	watershed outlets
29	OK	N,P,sed.	stream		CR,RG[(1)]		silt-loams		various crop and range management techniques	12 mo.	runoff events	automatic	watershed outlet
30	PA	antrazine (pesticide)			CR[(1)]	.01	silty clay loam	14%	pesticide application techniques	13 mo. (over 2 yrs.)	storm event	grab	runoff tank
31	PA	P	stream		CR,MX	1,900	loam, silty loam			33 mo.	3/wk-14 mo., weekly-19 mo.	grab	stream (1 station at weir)
32	SD	P,N,SS,COD	stream		CR[(1)]	8.8-18.7	loam and sandy clay loam		various crop rotations	2 yrs.	runoff events	grab and automatic	watershed outlet
33	TX	arsenic	stream		CR[(1)]	9.9	Houston black clay	≤3%	tillage techniques	3 yrs.	runoff events	automatic	watershed outlet
34	TX	N	stream		CR[(1)]	9.9	Houston black clay	≤3%		57 mo.	runoff events	automatic and grab	watershed outlet
35	WI	P, sed.	stream		CR,WD[(1)]	.0003 (20 plots)	Draway loam	4-6%	manure application practices	2 yrs.	simulated runoff events	grab	vacuum collection system
36	WI	N,P,K	stream		MX[(2)] (PAS, CR)	412,000	loess			2 yrs.	6-12 per yr.	grab	stream (30 stations

1. Multiple watersheds. See the abstract for more complete information.
2. Mixed watershed. See the abstract for more complete information.
3. Multiple sampling stations.

needs, and similar consideration must be given to see that all of the relevant pollution control and management practices are addressed. Also, some guidelines should be established to ensure that monitoring results from different monitoring programs are compatible in aggregate statistical analyses.

Section 4

Matrix Development
(Agricultural Land Use Activities/Water Quality Impacts)

This section serves primarily to develop a matrix that relates agricultural land use activities to water quality, and to indicate how water quality is affected by modification of the land use. The discussion is directed toward those land uses and receiving waters that were outlined in Section 2 and touches on effects of local conditions and controls for agricultural land use. Examples are presented for some control categories.

Pollutants Generated by Agricultural Land Use Activities

Precipitation and solar radiation are uncontrollable inputs to the agricultural production system, which is characterized by its soils and topography. For cropland, these inputs, together with controllable inputs such as seed, fertilizer, and pesticides, and input activities such as tilling and disking, result in crop production, but also in the negative impacts of agricultural runoff and percolation, erosion and sedimentation, and nutrient and pesticide washoff. We are not dealing with agricultural production here, but with the control of these negative impacts. Precipitation results in infiltration/percolation and runoff; precipitation, together with runoff, results in erosion and sediment transport; and runoff and percolation, as well as sediments, act as carriers for organic matter, chemical compounds, and pathogens -- depending upon many variables, such as topography, climate, and type and sophistication of land use activities. In Table 2 we have briefly summarized the pollutant generation of the various land use activities (at their baseline conditions) caused by the three transport mechanisms.

At this point we will briefly review the transport mechanisms and their pollutants, with particular emphasis on cropland.* First, we review runoff and percolation together, and then sediments' carrying capacity. Runoff occurs when the rate of precipitation exceeds the infiltration rate of the particular soil. Precipitation (characterized by its intensity, duration, and frequency) and, to a certain extent, the resulting runoff control the detachment process of soil particles -- together with other natural and man-induced conditions of land and soil. The detached particles are transported by the runoff as long as the water's volume and velocity are sufficient to carry them. They might be deposited on land at one point (with the heavier particles settling out first), or end up as sediment in the stream. The

*Although much of this material can be found in the literature, we present it here in a condensed form in order to provide a common background for our discussion.

TABLE 2. POTENTIAL GENERATION OF POLLUTANTS FROM VARIOUS (BASELINE) LAND USE ACTIVITIES

			Runoff							Percolation					Sediment/Soil*		
	Run-off	Perco-lation	Sed.	N	P	BOD	Pathogens	Pesticides	Salt	N	P	Pathogens	Pest.	Salt	N	P	Pest.
Cropland																	
• non-irrigated	X	X	X	X	X			X		X			(X)		(X)	X	X
• irrigated	X†	X	X	(X)	(X)			X	X	X			(X)	X	(X)	X	X
Pasture/Range	X	X	X	X		(X)	(X)	(X)							(X)	(X)	
Orchard/Vineyard	X	(X)	X	(X)				X					(X)		(X)	(X)	
Animal Holding	X	X	(X)	X	X	X	X			X	(X)	(X)		(X)		X	
Homestead	X	(X)	(X)			X	(X)			X	(X)	X					

*Implies also *erosion of* soils with high natural contents of nitrogen and phosphorus

†In case of irrigated agriculture, the runoff is not based on precipitation, but on irrigation water.

Note: (X) indicates lesser importance.

remaining sediments have higher concentrations of fine particles. In addition to sediments, soluble fractions of nutrients, pesticides, bacteria, and organic matter are removed from land. We concentrate here on nutrients and pesticides.

Pollutant Transport by Runoff/Percolation

Nutrients from Cropland. During rainfall, small surface depressions are filled with water prior to the beginning of overland flow (runoff). Surface-applied fertilizers can dissolve into this water. Nitrate, being very soluble, is leached to a large extent into the groundwater by infiltration -- the rate of which depends on the soil type (hydrologic group). When the water in depressions becomes part of the runoff (after infiltration capacity is exceeded), it transports a load of nutrients. The longer the time between application and overland flow, the greater the chance that moist soil has dissolved fertilizer and that light precipitation has leached the fertilizer (especially NO_3) into the ground, which means that there are fewer soluble components in the runoff. If, however, the infiltrated water moves laterally and again becomes surface flow (interflow), the nitrate will end up in surface water.* These facts explain why it is virtually impossible to generalize the relationship of nitrogen (N) concentration or loading with surface flow.

Phosphorus (P) is quickly immobilized, so soluble inorganic phosphorus in surface runoff usually represents only a small fraction of the total P lost to surface waters. Most evidence suggests that subsurface and groundwater movements of P are not a major source of stream pollution; the chance of P contributions to groundwater would be greatest on well-drained, coarse-textured (sandy) soils receiving large amounts of fertilizer and water, as well as on peat-soil, since these soils have little tendency to react with P. In general, soil solutions contain less than 0.1 mg of P per milliliter; thus leaching losses are extremely low even in well-drained soils.

In areas with seasonal snow cover, losses of soluble P may be appreciable in surface runoff during snowmelt, when soil/water contact is limited due to frozen soils and P may be leached from surface crop residues.

Pesticides from Cropland. Chemical and physical characteristics of pesticides, in combination with environmental factors, determine the potential losses through runoff and percolation/leaching -- with individual pesticides reacting more or less to specific environmental factors. The balance between dissolved pesticides and solid phase pesticides, often described by the adsorption partition coefficient, is the most important factor in allocating pesticide losses to the transport phenomena with which we are concerned.**

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*It is important to understand soil characteristics in terms of their hydrology and the geology. Poorly drained soils (hydrologic groups C and D) should produce larger loads of nitrate in runoff than well-drained soils. However, this is equalized if the leached nitrate becomes interflow.

**The Cornell study, citing Wauchope (1978) in order to put the usefulness of pesticide control by water and soil conservation practices (SWCPs) in

Various environmental factors influence the site of this equilibrium at various times. Potentially important parameters are organic matter content of soil, soil temperature, acidity, cation exchange, moisture content, and clay mineral content. Since water in the soil competes with pesticides for adsorption sites on soil particles, the fraction of the chemical adsorbed increases as the moisture level in the soil decreases. Precipitation on a dry soil will therefore desorb a portion of the pesticide, which will then move with the water in any runoff that occurs.

Thus pesticides might be moved by overland flow or leached down through the soil (dissolved in water or in soil solution), perhaps reappearing later in surface runoff (via interflow) or in groundwater. But, as explained above, the quantity of a pesticide actually moving in water from a treated area in any given runoff event depends on factors such as erosion and other runoff-related factors such as topography, intensity and duration of rainfall, soil erodibility, and land management and cropping practices, as well as on management factors, such as the amount of pesticides initially applied (i.e., antecedent soil moisture) and placement of pesticides. These factors are described in detail elsewhere.* Some of the important factors are:

- Characteristically, pesticide losses are highest in the first runoff occurring after application of the chemical, and the magnitude of the loss generally decreases as the time between application and runoff increases. The effect of elapsed time is particularly noticeable with short-lived pesticides and those that are not incorporated into the soil. Therefore, time management of pesticides must be determined by climatological and soil conditions.
- Due to the competition between water and pesticides for adsorption sites on soil particles, some pesticides will have greater losses in runoff if applied to wet rather than dry soil; this is particularly true for runoff events occurring shortly after application.

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perspective, states: "The small percentage of toxic material transported in runoff water and sediment limits the usefulness of SWCPs for reducing pesticide pollution in comparison with other control procedures. Wauchope (1978), in his extensive review of the literature on pesticide runoff losses, concluded that losses are generally 0.5 percent or less of the amount applied, with larger losses indicating the occurrence of a large runoff-producing rainfall event within one to two weeks after the pesticide application. Wauchope estimated losses for organochlorines to be about one percent of the applied material. He concluded that the major reason for the higher losses is the persistence of organochlorine insecticides in soil. Wauchope also noted that losses of herbicides applied as a wettable powder may be as high as five percent of the applied material, depending on weather conditions and the slope of the treated field." (p. 210) It is also obvious that the impacts of even the relatively small losses on runoff and sediment cannot be ignored and must be investigated on a case-by-case basis.

*Caro, J.H., "Pesticides in Agricultural Runoff," (chapter 5) in USDA/EPA, <u>op. cit.</u>, Vol. II, 1978.

- Placement of pesticides in soil generally means that there will be fewer pesticides lost in runoff than if they are left on the surface or sprayed on foliage.

- Persistence of pesticides in soils affects the temporal change of amounts lost in runoffs occurring at different intervals since application. However, many factors influence persistence, such as the sequence of overlapping loss processes* after application (implying rapidly changing loss potential in the initial period); weather; cultural practices; type, temperature, moisture level, and acidity of the soil; and interactions between chemicals when more than one pesticide is applied.

Pathogens, Organic Material, and Nutrients from Animal Holding. Runoff from areas having large animal populations can contribute significantly to water quality problems. Clearly, the actual impact depends on the waste production and its characteristics per animal, number of animals, and the management practices (which implies the magnitude of a slug discharge).

The concentration of nutrients and organic material found in manures of animal holding areas depends upon the time of year and the age of the manure. The quality of the runoff will be a function of the physical and biochemical changes that occur. There is less decomposition in the winter than in the summer, so that a large concentration of pollutants could accumulate. But there are other influences as well. Decomposition depends not only on temperature, but also on moisture content; also, the longer the manure remains wet, the better the chances of biological degradation of the pollutional compounds. In dry climates, when manure dries out rapidly, the pollutional constituents of the manure remain essentially constant. When the manures are wetted again by precipitation, the quality of runoff is essentially the same as it would have been if the material had been discharged at the time it was first deposited on the ground. The concentration of the various pollutants in the runoff is highest during the initial phase of rainfall; it decreases as runoff continues.

The results of several studies describing the magnitude and variability of constituents in runoff have been summarized in Table 3. The variability of runoff is illustrated by the BOD range of values, which varies from 500 mg/ℓ to 12,000 mg/ℓ. Solids and nitrogen concentration show even wider variations. The variable nature of the runoff indicates the significant slug effect that these discharges could have on a receiving water.

Salt from Irrigated Croplands. In areas with irrigated cropland, seepage/percolation and return flows from irrigated lands carry soluble salts into receiving ditches and thus into receiving water. This can result in substantially increased salt concentrations over natural levels, so that a continuous increase of salt concentrations must be expected in the downstream direction of a river that provides the irrigation water for a region.

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*These are volatilization, sorption, leaching, and eventually chemical and biological degradation (see A.E. Hiltbold, "Persistence of Pesticides in Soil," in Pesticides in Soil and Water, (W.D. Guenzi, ed.), Soil Sci. Soc. Amer., Inc. Madison, Wis., 1974, pp. 205-222.

TABLE 3. FEEDLOT RUNOFF CHARACTERISTICS

Animal	*Range of Values for Constituents, mg/l*							*Reference*
	Suspended Solids	*Ortho-phosphate PO_4*	*Organic Nitrogen*	*Ammonia Nitrogen*	*Nitrate Nitrogen*	*BOD*	*COD*	
Cattle	3,400-13,400	--	--	--	--	500-3,300	--	Owens and Griffin, 1968
Cattle	--	--	6-800	2-770	0-1,270	1,000-12,000	2,400-38,000	Wells *et al.*,1970
Cattle	1,000-7,000[a]					300-6,000		Norton and Hansen, 1969
Cattle	--	--	--	--	--	1,500-9,000	4,000-15,000	Loehr, 1969b
Cattle	1,400-12,000	15-80	--	1-139	0.1-11	--	2,500-15,000	Miner *et al.*,1966
Cattle	--	20-30	600-630	270-410	--	5,000-11,000	16,000-40,000	Loehr, 1969a
Cattle	1,500-12,000	--	--	16-140	--	--	3,000-11,000	Miner, 1967
Cattle	1,400-12,000	66-1,460[b]	265-3,400	--	--	800-7,500	--	Townshend *et al.*, 1970

[a]Volatile solids.
[b]Total phosphorus as PO_4.

Source: Porcella, D.B. and A. B. Bishop, Comprehensive Management of Phosphorus Water Pollution, Ann Arbor Science Publishers, Ann Arbor, 1977.

The groundwater is also very much impacted. For example, measurements at Boise River indicate that the specific conductivity, a measure of the salt content, is higher during the fall and winter months than during the irrigation season. This is judged to be due to lower river flows during this period than during the irrigation season, making groundwater contributions relatively higher. This implies that the groundwater's salt concentration must have reached a significant level that impairs beneficial uses such as drinking water supply.

Transport by Sediment

Nutrients. The second major transport mechanism is sediment. Soil particles act as carriers of nutrients and pesticides, especially phosphorus and organic nitrogen and those pesticides with a high adsorption partition coefficient. The finer soil particles, being transported the longest distance, have a higher capacity per unit of sediment to adsorb phosphorus and nitrogen; also, organic matter tends to be associated with the fine particles. This means that the transported sediment is richer in phosphorus and nitrogen than the original soil, a phenomenon known as "enrichment." Predicting the receiving water impacts of sediment-bound pollutants is complicated by their relatively low bio-availability, compared with soluble pollutants (see below).

The ratio of the particle fraction in the sediment to that in the original soil is called the "enrichment ratio" (ER). The enrichment ratio for clay (ER_c) is usually greater than 1. Although not much is known about organic matter enrichment (ER_{om}), one can speculate that the transport of organic matter is much the same as that of clay due to its characteristic low density.

According to the recent Cornell study,* one can generalize that the enrichment ratio for clay or organic matter increases with an increase of soil detachment due to raindrop splash relative to that due to overland flow. These enrichment ratios will also increase as transport energy decreases. The obvious shortcoming of the enrichment ratio concept is that it does not indicate the actual amount of clay in the sediment load. A low ER_c for sediment originating from a clayey soil may very well mean a much greater amount of clay in the sediment than a high ER_c from a sandy soil. A high ER_c for a small sediment load may mean less clay than a low ER_c for a big sediment load. In general, enrichment ratios of 2 to 6 are cited for first estimates.

Pesticides. Sediment-bound pesticides adsorb preferentially on smaller soil particles (like nutrients) because of these particles's high surface area per unit weight. Since the small particles are transported greater distances than coarser material in runoff, these pesticides might reach the receiving water. Rill and sheet erosion, which primarily involve surface soil, tend to favor movement of the most strongly adsorbed pesticides. Higher pesticide concentrations in eroded material do not necessarily mean that

*Haith, D.A. and R.C. Loehr (eds.), "Effectiveness of Soil and Water Conservation Practices for Pollution Control," prepared by Cornell University for U.S. EPA, Athens, GA, October 1979 (EPA-600/3-79-106).

gross losses will be greater in the sediment than in runoff water, since the amounts of water moved are so much greater.

Pollutant Impacts on Receiving Waters

A few general aspects of pollutant impacts on receiving water are:

- The impact of type and amount of pollutants on the receiving water quality is influenced by the type of receiving water.
- An individual pollutant's effect depends on its availability.
- Primary and secondary effects have to be distinguished -- e.g., nutrients might cause algal bloom (eutrophication), which might then lead to a significant depletion of oxygen in the hypolimnion of a lake.

In Table 4, we have summarized those pollutants from agricultural activities which could have an impact on receiving waters. If agricultural nonpoint pollutants were combined with point discharges of residential, commercial, and industrial activities, all entries of the matrix would have to be filled.

Below, we discuss briefly the impacts of the following pollutants; first in general, and then with reference to the various receiving waters:

- sediment (sand, clay, silt)
- phosphorus (total soluble and extractable particulate)
- nitrogen
- organic load (BOD)
- pesticides
- bacteria
- salt

Review of Individual Pollutants

Sediment and Nutrients. Once sediment reaches streams and lakes, it causes two major types of water quality problems -- those caused by the sediment itself and those created by pollutants adsorbed to sediment. The direct effects of sediment are benthic build-up impacting aquatic life and changing hydraulic profiles, and high turbidity (fish kills, reduction photosynthesis by aquatic plants, treatment costs of water supply). As one of the primary transport mechanisms for pollutants such as pesticides and nutrients, the interrelationship of sediment-attached nitrogen and phosphorus and dissolved chemicals in surface waters is not well understood. Generally, sediment found in surface waters resembles the soils from which it came, but it normally has higher silt, clay, and organic matter content, which we have called enrichment. Thus enrichment means that sediments delivered to surface waters have higher concentrations of nitrogen and phosphorus than do the original soils. However, because sediment-bound nutrients are isolated from the water column due to sedimentation, their potential impacts on receiving water productivity are not fully expressed.

Sediment also acts as a "scavenger" in the receiving water. Soluble phosphorus and other uncharged pollutants are removed from waters by attachment

TABLE 4. POTENTIAL IMPACT OF INDIVIDUAL POLLUTANTS FROM AGRICULTURAL ACTIVITIES ON RECEIVING WATERS

Impacted Receiving Water	Parameters							
	Sediment	P	N	BOD	Pesticides	Pathogens	Salt	Remarks
Lake/Reservoir	X	X	X	X	X	X	(X)	largely cumulative impact
Small Stream	X	(X)	X	X	X	X	X	largely transient impacts
River	(X)			(X)	(X)	(X)	(X)	largely transient impacts
Great Lakes (Bay)	(X)			(X)	(X)	(X)		
Groundwater			X	(X)	X	(X)?	X	slow transition; also cumulative

Note: (X) indicates the impact is not great.

to the sediment particles. Input of nutrients into receiving waters might cause a significant increase in biomass (algae). Various factors, such as temperature, available P and N, C, and light penetration, determine the degree of biomass development (eutrophication), which is generally measured in grams chlorophyll-a/m^3. The degree of biomass development is estimated by the "Trophic State" Index. While carbon may be limiting in special circumstances, eutrophication is generally limited by P, N, and/or light. Thus the degree of sedimentation in a receiving water might influence the availability of nutrients as well as the availability of light.

Preliminary data analysis should indicate whether P is more likely than N to limit primary production in lakes or reservoirs not subject to point source discharge. N/P requirements for algal growth generally range from 7 to 10. In many cases, P is more likely to be limiting to algal growth in impoundments not subjected to point sources (or any sewer influence). N becomes increasingly important as a limiting nutrient as portions of loads from point sources/sewerage increase. This arises because naturally occurring runoff is enriched in N, whereas culturally created pollution sources tend to be enriched in P relative to algal growth requirements.*

In discussing transport mechanisms, we have indicated that nitrate is not significantly adsorbed by sediment. This would tend to reduce the importance of sedimentation as an N removal/trapping mechanism in the receiving water as compared with its importance to the removal of P. Thus the amount of P attached to soil particles and suspended in runoff may indicate the potential amount available for receiving water pollution. However, this amount gives little indication of the amount of material immediately biologically available for aquatic plant growth. Estimating the "bio-availability" of particulate P is not yet done according to a unified theory; rather, various arbitrary measures are applied. Römkens and Nelson** consider the NH_4F/HCL extractable portion of the particulate P (Bray P) as the amount of particulate P that is available, and they assume that the remaining inorganic and organic particulate forms are unavailable to support algal growth in downstream impoundments. In their methodological study of the Black Creek area in Indiana, Meta Systems Inc*** concluded that extractable and total particulate P data from soils in the Black Creek area (collected by Sommers et al.)† generally support Taylor's suggestion

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*For example, the N/P ratio for rainfall in the Northeast averages about 62, while the N/P ratio for sanitary sewage ranges from 2 to 8.

**Römkens, M.J.M. and D.W. Nelson, "Phosphorus Relationships in Runoff from Fertilized Soils," Journal of Environmental Quality, Vol. 3, No. 1, 1974, pp. 10-13.

***Meta Systems Inc, op. cit.

†Sommers, L.E. et al., "Water Quality Monitoring in Black Creek Watershed," Environmental Impact on Land Use and Water Quality, (J. Lake and T. Morrison, eds.), 1975.

that about 10 percent of P in soils is available for aquatic plant growth.* Thus it is clear that "bio-availability" is an important assumption -- it is critical in evaluating the effects of erosion controls on eutrophication, given the current state of knowledge.**

Thus the water quality problems of sedimentation and eutrophication might be expected from sediments washed into receiving water. A secondary effect of eutrophication is that with an excessive amount of algal growth, bottom conditions of receiving waters deteriorate. Dissolved oxygen decreases (due to the organic loads from algae and sediment sinking to the bottom), and might cause a decrease in desirable fish species such as trout and an increase in trash fish, which survive better in marginal conditions (see discussion below).

Pesticides. When dissolved and sediment-bound pesticides enter a receiving water, they are distributed within the water in a manner and at a rate that depend primarily on whether the chemicals are initially dissolved in the water or adsorbed on particles of eroded soil suspended in the water. A dissolved pesticide will be diluted in the larger volume of water and will be subject to processes that dissipate it. In a flowing stream it will simply be transported away from the point of entry, later to undergo degradation or removal from the water. In a lake or impoundment, it may sorb or concentrate in algae and aquatic vegetation, or it may attach to suspended sediment and other particulates in the water such as bacterial flocs, diatoms, and general organic or inorganic fragmentary material. In either case, the pesticide is eventually deposited on the bottom of the lake unless it is chemically or biologically degraded before it reaches the bottom or is taken up by living organisms. Highly soluble pesticides that are only weakly adsorbed may be hydrolyzed or biologically degraded in solution at a rate that depends on the types and numbers of microorganisms in the water.

Pesticides entering the receiving water adsorbed on sediment will first distribute with the carrying sediment and then will equilibrate with the remainder of the aquatic system.*** Sediments entering water bodies will segregate on a particle-size basis: in a stream the fractionation will depend on stream velocity; in a relatively stagnant receiving water the particles will settle on the bed in decreasing order of particle size. The finer particles containing the highest concentrations of pesticides will be transported farthest down a stream; in a lake they will settle last and remain at the water-sediment interface. In large, thermally stratified lakes, density currents may control the movement and mixing of incoming sediments and settling may be very slow.

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*Taylor, A.W., "Phosphorus and Water Pollution," Journal of Soil and Water Conservation, Vol. 22, 1967, pp. 228-231.

**It becomes obvious that additional research is required. What happens to the fractions that are not biologically available? Not much is known; little more than guessing can be done about the rate at which it might become available.

***Conditions in the water body such as pH, salinity and temperature may affect the adsorption and desorption of the pesticide on the sediment.

The persistence of the pesticide in the receiving water will depend to a large extent on the specific type of pesticide. For example, an organophosphorus hydrolyzes rapidly in the aquatic environment, while organochlorines degrade very slowly but decompose at a quicker rate in anaerobic environments by microorganisms. This shows that it is difficult to generalize the relationship of pesticide input and receiving water type.

Biomagnification might be anticipated as a problem. There is as yet no extensive knowledge on this subject, although the Cornell study made a few statements about it. Biomagnification has generally not been a problem with most herbicides. Despite persistence and biomagnification occurring in invertebrates, (for example atrazine residues), in a study of pond fauna over a two-year period, no significant harmful effects were detected.* An exception to the general rule of herbicide nonaccumulation is trifluralin, which has been shown to magnify in aquatic food chains.

There are, however, problems with some herbicides and the organophosphate and carbamate insecticides, in spite of their generally low levels of biomagnification.** Adverse effects have occurred at levels below the established acutely "safe" level -- leptophos has been shown to produce delayed neutrotoxic effects on chickens. Recent evidence that DBCP, a pesticide ingredient previously thought to be safe, can cause sterility and possibly cancer in humans at long-term, low-level exposures has brought into question the adequacy of the entire procedure for testing pesticide safety.

Organic Material and Pathogens. Organic putrescible material in receiving waters is of no great concern in most agricultural land uses. In contrast to point source pollution of sewage and other putrescible matter, nonpoint source pollution generates only a relatively small input of putrescible matter, and this load originates primarily from some confined feedlots (not usually considered nonpoint source feedlots because of their size) and pasture areas quite intensively used by animals. The pollutional impact of these sources is measured in BOD (reflecting the oxygen needed to stabilize the receiving water) and coliform. In an overloaded receiving water the dissolved oxygen may become exhausted by the biochemical oxygen demand. In most situations washoff of organic material from feedlots will not result in exhaustion of DO, but when algae that feed off the feedlots' nutrients die, sink down, and decompose in the hypolimnion of lakes/reservoirs, the DO-household might be strained to its limit. This situation occurs in highly eutrophic lakes due to the thermal stratification in the summer and the resulting lack of import of additional DO into those layers.

The presence of coliform organisms (occurring in the intestinal tracts of warm-blooded species) is taken as an indication that pathogenic organisms may also be present; their absence is an indication that the water contains no disease-producing organisms. The coliform bacteria include the genera *Escherichia* and *Aerobacter*. However, the use of coliforms as indicator organisms is complicated by the fact that *Aerobacter* (and certain *Escherichia*) can

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*Haith and Loehr, op. cit., p. 225.

***Ibid.*

grow in soil. Thus the presence of coliforms does not always mean contamination with human or animal wastes. Apparently Escherichia coli (E. coli) are entirely of fecal origin. Since it is difficult to determine the presence of E. coli to the exclusion of the soil coliforms, the entire coliform group is used as an indicator of fecal pollution. Since tests have been developed to distinguish among total coliforms, fecal coliforms (FC), and fecal streptococci (FS), the use of the ratio of fecal coliforms to fecal streptococci has been suggested to show whether the suspected contamination derives from human or from animal wastes. It had been observed that the quantities of fecal coliforms and fecal streptococci that are discharged by human beings are significantly different from the quantities discharged by animals. Typical data on the ratio of FC to FS counts for human beings and various animals have been reported. In Table 5 the FC/FS ratio for domestic animals is less than 1.0, whereas the ratio for human beings is more than 4.0. If ratios are obtained in the range of 1 to 2, interpretation is uncertain.*

Use of the FC/FS ratio can be very helpful in establishing nonpoint source pollution in rural and other areas where septic tanks are used. In many situations where animal pollution is suspected on the basis of coliform test results, the actual pollution may in fact be caused by malfunctioning septic systems.

Review of Receiving Water Types

Depending on the type of receiving water into which the pollutant is discharged, pollutant effects on water chemistry and aquatic ecology will vary significantly. The water bodies discussed here -- small streams, rivers, lakes, impoundments, bays and groundwater -- each have hydraulic, ecological, and physical differences which affect the fate of pollutants. This discussion deals primarily with the mechanisms of pollutant transport and transformation of sediment and nutrients, and touches upon pesticides.

Small Streams/Rivers. In small streams/rivers** the fate of the entering

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*The following constraints are imposed on the interpretations (see D.D. Mara, Bacteriology for Sanitary Engineers, Churchill, Livingston (Edinburgh), 1974):

1) The sample pH should be between 4 and 9 to exclude any adverse effects of pH on either group of microorganisms.
2) At least two counts should be made on each sample.
3) To minimize errors due to differential death rates, samples should not be taken farther downstream than 24 hours of flow time from the suspected source of pollution.
4) Only the FC count obtained at 44°C is to be used to compute the ratio.

**We talk simultaneously about small streams and rivers under the assumption that they can be largely differentiated by their water flow velocity and volume (at average conditions), with small streams having larger velocity but much smaller volume and generally shallower beds.

TABLE 5. ESTIMATED PER CAPITA CONTRIBUTION OF INDICATOR MICROORGANISMS FROM HUMAN BEINGS AND SOME ANIMALS

Animal	Average indicator density/g of feces: Fecal coliform 10^6	Average indicator density/g of feces: Fecal streptococci 10^6	Average contribution/capita·24 h: Fecal coliform 10^6	Average contribution/capita·24 h: Fecal streptococci 10^6	Ratio FC/FS
Chicken	1.3	3.4	240	620	0.4
Cow	0.23	1.3	5,400	31,000	0.2
Duck	33.0	54.0	11,000	18,000	0.6
Human	13.0	3.0	2,000	450	4.4
Pig	3.3	84.0	8,900	230,000	0.04
Sheep	16.0	38.0	18,000	43,000	0.4
Turkey	0.29	2.8	130	1,300	0.1

Note: g × 0.0022 = lb.

Source: Mara, D.D., Bacteriology for Sanitary Engineers, Churchill, Livingston (Edinburgh), 1974.

Note: Doran, J.W. , and D.M. Linn* in a recent article, state that the FC/FS ratio for humans is 4.3; for cattle and other livestock and poultry it is .104 to .421; while for rabbits, birds, and mice it is 0.0008 to 0.043.

*"Bacteriological Quality of Runoff Water from Pasture Land," Applied Environmental Microbiology, Vol. 37, No. 5, 1979, pp. 385-391.

sediments cannot be determined without knowing the characteristics of the basin. Slope, water velocity, particle type and size all play an important role in sediment transport. At best, a few generalities can be made:

- As velocity increases, the distance of transport increases;
- Larger and more dense particles settle out first;
- Sedimentation occurs in pool areas;
- Turbulence will act to maintain particles in suspension.

The interaction between water velocity and sediment transport is complex. In general the rate of settling increases as the velocity decreases; if velocity increases, bank scour may also increase, and bed load may become suspended, causing an increase in the total solids being transported in the stream. Sedimentation might affect benthic life directly and impact aquatic life through turbidity, but sedimentation problems can also occur as a result of shifting substrates and thereby cause a loss of certain aquatic species. Sedimentation is thus dynamic, which means that constant shifting of deposited materials might occur.

A general idea of where sedimentation problems will occur in a stream can be determined from information on soil types and by locating pool areas where water velocities decrease.

Much of the transport of nutrients in streams is closely associated with sediment transport due to adsorption of phosphorus (and of some nitrogen) onto soil particles. Particulate phosphorus and nitrogen will disperse according to the mechanisms of particle dispersion. The dissolved fractions will be absorbed by aquatic vegetation, adsorbed onto suspended or bank sediments, or carried downstream. Factors affecting these processes are:

- water velocity and turbulence
- microorganisms and vegetation
- turbidity
- temperature
- particle size and type
- channel characteristics
- temperature

Assuming no additional inputs of nutrients, concentrations decrease as materials proceed downstream due to uptake by organisms and dilution or by dilution from unpolluted interflow.

The extent to which nutrients settling out affect the stream depends on the particular situation. During storm conditions with accompanying high flows, sediment material often becomes resuspended, essentially acting as a new input into the stream.

Very little is known about the impact of pesticide concentrations on receiving waters. Incidents of surface water contamination by the organochlorine insecticides are still occurring, and apparently several lakes in the Midwest have been closed to fishing because of accumulations of toxic materials.* It is not known whether this contamination is due to the continuing runoff and erosion of soils carrying these persistent pesticides. Some researchers have noted, however, that concentrations of organochlorine residues are high in areas of high sediment losses and turbidity of surface waters. Thus, for example, the presence of pesticide residues was established in the Mississippi River at New Orleans and in every major watershed in the State of Iowa.**

Lakes and Reservoirs

Determining the rate of sedimentation in lakes and reservoirs is difficult. Sampling inputs from diffuse sources and from output points gives a clue about the sediment balance, but does not indicate the location of sedimentation, which can only be found by instream investigations. However, it has been observed that due to the abrupt decrease in velocity, the initial point of entry is usually a major sedimentation point. Current pattern, eddies, and storm events exhibiting flushing effects further determine the other areas affected.

A few general trends in reservoir sedimentation have been observed:

- Reservoirs with greater drainage area/surface area ratios have shorter lifetimes;
- Sediment trapping efficiency increases with hydraulic detention time (volume/annual flow);
- Particles tend to be deposited in a gradation of particle sizes along the longitudinal axis of the reservoir. Coarser and heavier particles are dropped in the headwater and finer sediments are deposited toward the dam. This is affected by water level; temperature and dissolved minerals; mineral composition of the sediments, especially clay-sized fraction; volume relationship of reservoir storage capacity and influent water; configuration of basin; and amount of sediment previously deposited.

Eutrophication*** is a problem, particularly exacerbated by the environmental conditions of a lake/impoundment when high nutrient inputs occur.

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*Haith and Loehr, op. cit., p. 217.

**Richard, J., G. Junk, et al., "Analysis of Various Iowa Waters for Selected Pesticides: Atrazine, DDT and Dieldrin -- 1974," Pesticide Monitoring Journal, Vol. 9, No.3, pp. 117-223, cited in Haith and Loehr, op. cit.

***Traditional strategies for classifying lakes with respect to eutrophication have relied primarily upon subjective assessments of one or more types of water quality or biological characteristics. Recently, the increased availability of data has made it possible to develop more objective criteria for ranking and classifying lakes at a regional level on the basis of observed lake conditions or the factors governing them, such as nutrient loading, hydrology, and morphometry. Lack of an objective basis for specifying standards or criteria with regard to lake or impoundment water quality has arisen partially out of the fact that water quality concerns are related to beneficial

However, the dynamics of nutrients in lakes and reservoirs are not well understood. In an essentially closed lake system with a long hydraulic detention time, the nutrients entering remain in the system; they are either utilized by the vegetation, settle out, or remain in solution. Many reservoirs have short detention times and cannot be considered closed. In general, soluble nitrates and phosphates are readily available for plant growth. This is also true of ammonia, which can be utilized as a nitrogen source by many types of aquatic vegetation. In most receiving waters influenced by nonpoint sources, ammonia-N concentrations are at extremely low levels due to high rates of biological uptake, oxidation to nitrate, and/or adsorption to sediments. Nutrients associated with particulate matter tend to settle out and become part of the sediments, but a number of factors may affect this process. For example, turbulence will tend to keep particles suspended.

To what extent nutrients isolated in the sediment from the water column are available to aquatic life is not definitely known, especially, the extent of P-release under anoxic conditions. Phosphates tend to form very stable complexes with elements such as iron and aluminum. Some evidence suggests that sediment runoff from particular soils into reservoirs and lakes may actually reduce dissolved ortho-phosphate levels by forming complexes that precipitate due to the rapid equilibrium between water and sediments. However, these sediments could later supply phosphorus to aquatic organisms when the sediments are stirred up by turnover, turbulence, or even by bottom feeding fish such as carp and catfish. Bottom sediment in particular are easily resuspended due to a flushing effect of storm events in reservoirs. It should also be recognized that rivers characteristically carry higher concentrations of nutrients than do lakes. Thus by damming a river, these higher concentrations are retained in the system. The addition of nonpoint sources of nutrients to such a system could accentuate the buildup if flows are never high enough to flush the system.

Potentially long retention times might lead to long-term effects from persistent pesticides. The total elimination of aquatic life in those southern lakes that captured the pesticides from cotton field drainage is well known. But as in the case of streams/rivers, not much is known about the environmental impacts at different levels.

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use and do not always correspond with traditional trophic state criteria. While some states may have considered or be considering phosphorus standards, the nutrient in itself does not hinder water use. It is the indirect effects of the nutrient on such water quality aspects as transparency, odor, and dissolved oxygen that are of concern from a water use standpoint. Recent theoretical and empirical developments indicate that the effects of phosphorus supply on primary production and water quality vary with impoundment morphometric and hydrologic characteristics, and depend upon supplies of other nutrients. Thus it may not be advisable to establish universal phosphorus standards. Standards should be based on those water quality responses that are of direct concern to water use (See for example, W.W. Walker, "Use of Hypolimnetic Oxygen Depletion Rate as a Trophic State Index for Lakes," Water Resources Research, Vol. 15, No. 6, December 1979).

Bay Areas. The bay areas of the Great Lakes are considered, for our purposes, infinite sinks. Most likely, it will be impossible to detect significant differences of water quality parameters and water quality impacts due to changing agricultural practices in any reasonable length of time.

Groundwater.* Excessive nitrate and salt concentration in some agricultural land use areas are the most reported groundwater impacts due to parameters we are here concerned with. They are especially important for groundwater used as a drinking water source. There has also been some pollution of groundwater by pesticides due to leaching. The rate at which pesticides leach through the soil profile is influenced by many of the same factors influencing losses in runoff -- namely, adsorption/desorption characteristics of the pesticide, chemical reactions, solubility, rate of application, antecedent soil moisture, soil structure, and flow velocity. Such pesticides as 2,4-D, atrazine, cyanazine, dicamba, dimethoate, chloramben, dinoseb, monuron, and methoxychlor all exhibit a greater propensity for movement in the soil. However, under normal conditions, extensive leaching, and subsequent contamination of groundwater are unlikely** although some pesticides, such as atrazine, have been identified*** in groundwater during periods of application and in wet years. For example, in Iowa the pesticides atrazine, DDE, and dieldrin contaminated all water originating from shallow wells located in the alluvial plains of contaminated rivers.

It should be noted here that apparently the state of pesticide analysis under field conditions is not advanced enough to allow reliable monitoring of low-level concentrations in runoff and surface receiving waters and groundwater. This means that there is existing pollution that could produce little understood chronic and sublethal toxicity effects.

Agricultural Land Use and Water Quality Impact

On the basis of the above discussion, Table 6 shows, in simplified form, some agricultural land use/water quality impacts (as triggered by the "baseline" performance of these activities).

Other factors that influence the severity of water quality impacts should be mentioned. They are:

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*The quality and quality changes of groundwater are the most difficult to assess. This is true because, on the one hand data on groundwater quality are inadequate, and on the other hand, it is most problematic to take groundwater samples in situ and then extrapolate results at one geographic point to a larger volume of a system previously defined.

**Haith and Loehr, op. cit., p. 211.

***Leaching will be more of a problem in areas of pesticide disposal, areas with water tables not far beyond the root zone of crops, and in areas with sandy soils containing little organic matter or clay to bind pesticides as they percolate through the soil profile. Groundwater contamination by pesticides may also occur when solid-phase pesticides are washed down deep cracks which can appear when heavy rains follow periods of drought. Haith and Loehr, op. cit.

TABLE 6. AGRICULTURAL LAND USE/WATER QUALITY IMPACTS

Land Use Activity	Receiving Water: Lake/Reservoir large	Lake/Reservoir small	Small Stream	River	Bay	Groundwater	Problems
Cropland	X	X	X	(X)			Sedimentation
nonirrigated	X	X	(X)				Eutrophication (incl. hypol. DO-D)
	X	X	X	X	(X)	X?	Pesticide
	(X)	X	(X)			X	Nitrate
irrigated	X	X	X	(X)			Sedimentation
	X	X	X	(X)		X	Salinity
	X	X	(X)				Eutrophication (incl. hypol. DO-D)
	X	X	X	X	(X)	X?	Pesticide
	(X)	X	(X)			X	Nitrate
Orchard/Vineyards		(X)					Eutrophication
	X	X	X	X	(X)	X?	Pesticide
						X	Nitrate
Pastureland/Range		(X)					Eutrophication
		(X)	(X)				Pathogens
		(X)	(X)				BOD
	(X)	X	X				Sedimentation
Animal Holding	(X)	X	X	(X)			BOD
	(X)	X	X	(X)			Eutrophication
	(X)	X	X	(X)			Pathogens
		(X)	(X)			X	Nitrate
Homestead		(X)	(X)				BOD
		(X)	(X)				Pathogens
		(X)	(X)				Eutrophication

Note: (X) indicates the impacts are not great.
? indicates the situation is largely unknown.

- slope and length/topography
- use intensity
- climate/precipitation (region)
- soil type
- hydrologic group
- erodibility
- drainage density

The most obvious factors are slope/length and use intensity. In general, the steeper and longer the slopes, the worse the erosion condition that can be generated; the higher the use intensity, the greater the overall pollution potential. Several concerns relate to precipitation: intensity, duration, frequency, and snowfall and melting. If a field has not yet grown any protective cover and the more intensive a rain is, the higher will be the erosion; the closer a rain event follows the date of pesticide and fertilizer application, the more material applied will be washed off and/or percolated. These effects will be accentuated if the soil is highly erodible and the materials applied are largely sediment-bound. Clearly, seasonal and regional differences play a role here. High intensity rain is more detrimental on uncovered ground in the early planting season than on covered ground near harvesting time; rain characteristics vary significantly across the United States. Drainage density, i.e., the degree of development of runoff carrying channel capacity, affects the transport of material to the mainstream. The higher the density, the greater the potential of material transport to the receiving water.

It should be pointed out here that the water quality impact of the events described above depend at least on the time of year and type of receiving water. If there is a river or even a small stream under relatively high flow conditions, the impacts might be marginal. If there is a low flow season and the final receiving water is a reservoir, the impact could be quite significant. Again the land/water interplay is important.

Soils have various characteristics that are of interest: natural nitrogen and phosphorus content; organic matter content; distribution of sand, silt, and clay; structure; and permeability. These factors contribute to the erodibility of a soil, but they also influence a soil's general controllability (See the control categories outlined in Section 2), its overall eutrophication potential, its carrying/adsorption potential, and the leachate potential for nonadsorptive parameters. The hydrologic group indicates the drainage characteristics -- something closely linked to the soil type. This might have some influence on the release of pollutants to the surface receiving water. For example, it could be hypothesized that runoff carries much of the soluble nitrate fractions from poorly drained soils, while a much larger fraction infiltrates from a well-drained soil, resulting in possible nitrate contribution to surface water via interflow. Thus this phased input of nitrate could have some beneficial impact on the surface water quality of a stream since no heavy slug of nitrate enters the water at one instant. But in the case of a lake/reservoir as the ultimate receiving water, the phased input might play only a minor role if the input is delayed up to the cold season with its reduced biological activity and higher dilution rates.

This brief discussion indicates the inadequacy of a simple impact matrix (such as Table 6) that neglects the localized conditions, but it also makes us aware of the lack of knowledge in this field and it cautions us that certain standard agricultural practices are not simply transferrable across the nation without a detailed look at the specific problem.*

Considerations in Selecting Abatement Practices/Measures

Tables 7-15 list some of the practices/measures that have been suggested for the various agricultural land use activities. Most practices belong to category 1, but we realize (along the lines of our previous discussions) that certain pollutants, such as pesticides, can only be controlled through a combination of measures from different categories. The Cornell Study reviewed the measures suggested for non-irrigated cropland and classified their effectiveness as soil and water conservation measures for control of certain pollutant types (Table 16). Given our emphasis on water quality impacts, the usefulness of such a classification should be investigated. Our discussion had concluded that the degree of water quality impact caused by agricultural land use depends on the type and intensity of agricultural land use on localized factors, and, in particular, on the type and size of the receiving water. That means that every control measure should be tuned to the pollutant(s) and the resulting water quality problem. Thus the Cornell listing raises three questions:

1) Does the classification of land-based effectiveness provide us with an initial idea on which measures to select from?

2) Might a preselection based on land-based effectiveness lead to a wrong approach due to synergistic control effects for different parameters?

3) Do there exist any combinations of measures that are equally effective and possibly more desirable?

Before these questions can be answered, the development of technical preferences should be explained.

Technical evaluation (Figure 6) has to be performed in a "2-track" system. First, after the water quality problem has been described, the sources must be detected and their potential modifications through practices belonging to categories 1-5 must be analyzed. Second, the desirable water quality must be identified and the necessary reduction in pollutant input necessary to achieve the water quality goal computed (including possible instream measures). Third, the two tracks must be meshed in order to determine which practices/measures are capable of meeting the water quality goal. Finally, the feasibility of technically acceptable measures must be determined in socio-economic and institutional terms.

This approach to the technical evaluation process helps to answer the

*The discussion of these characteristics also provides a first insight into fundamentally different monitoring requirements for different land use/water quality interfaces in different parts of the United States.

TABLE 7. PRINCIPAL TYPES OF CROPLAND EROSION CONTROL PRACTICES AND THEIR HIGHLIGHTS*

Category	No.	Erosion Control Practice	Practice Highlights
1	E 1	No-till plant in prior-crop residues	Most effective in dormant grass or small grain; highly effective in crop residues; minimizes spring sediment surges and provides year-round control; reduces man, machine and fuel requirements; delays soil warming and drying; requires more pesticides and nitrogen; limits fertilizer- and pesticide-placement options; some climatic and soil restrictions.
1	E 2	Conservation tillage	Includes a variety of no-plow systems that retain some of the residues on the surface; more widely adaptable but somewhat less effective than E 1; advantages and disadvantages generally same as E 1 but to lesser degree.
1	E 3	Sod-based rotations	Good meadows lose virtually no soil and reduce erosion from succeeding crops; total soil loss greatly reduced but losses unequally distributed over rotation cycle; aid in control of some diseases and pests; more fertilizer-placement options; less realized income from hay years; greater potential transport of water soluble P; some climatic restrictions.
1	E 4	Meadowless rotations	Aid in disease and pest control; may provide more continuous soil protection than one-crop systems; much less effective than E 3.
1	E 5	Winter cover crops	Reduce winter erosion where corn stover has been removed and after low-residue crops; provide good base for slot-planting next crop; usually no advantage over heavy cover of chopped stalks or straw; may reduce leaching of nitrate; water use by winter cover may reduce yield of cash crop.
1	E 6	Improved soil fertility	Can substantially reduce erosion hazards as well as increase crop yields.
2	E 7	Timing of field operations	Fall plowing facilitates more timely planting in wet springs, but it greatly increases winter and early spring erosion hazards; optimum timing of spring operations can reduce erosion and increase yields.
1	E 8	Plow-plant systems	Rough, cloddy surface increases infiltration and reduces erosion; much less effective than E 1 and E 2 when long rain periods occur; seedling stands may be poor when moisture conditions are less than optimum. Mulch effect is lost by plowing.
1	E 9	Contouring	Can reduce average soil loss by 50% on moderate slopes, but less on steep slopes; loses effectiveness if rows break over; must be supported by terraces on long slopes; soil, climatic, and topographic limitations; not compatible with use of large farming equipment on many topographies. Does not affect fertilizer and pesticide rates.
1	E 10	Graded rows	Similar to contouring but less susceptible to row breakovers.

*Source: U.S. EPA/USDA, Pollution from Cropland, Vol. I, (Table 12).

TABLE 7. (CONT.)

Category	No.	Erosion Control Practice	Practice Highlights
1	E 11	Contour strip cropping	Rowcrop and hay in alternate 50- to 100-foot strips reduce soil loss to about 50% of that with the same rotation contoured only; fall seeded grain in lieu of meadow about half as effective; alternating corn and spring grain not effective; area must be suitable for across-slope farming and establishment of rotation meadows; favorable and unfavorable features similar to E 3 and E 9.
3	E 12	Terraces	Support contouring and agronomic practices by reducing effective slope length and runoff concentration; reduce erosion and conserve soil moisture; facilitate more intensive cropping; conventional gradient terraces often incompatible with use of large equipment, but new designs have alleviated this problem; substantial initial cost and some maintenance costs.
3	E 13	Grassed outlets	Facilitate drainage of graded rows and terrace channels with minimal erosion; involve establishment and maintenance costs and may interfere with use of large implements.
1	E 14	Ridge planting	Earlier warming and drying of row zone; reduces erosion by concentrating runoff flow in mulch-covered furrows; most effective when rows are across slope.
1	E 15	Contour listing	Minimizes row breakover; can reduce annual soil loss by 50%; loses effectiveness with post-emergence corn cultivation; disadvantages same as E 9.
1	E 16	Change in land use	Sometimes the only solution. Well managed permanent grass or woodland effective where other control practices are inadequate; lost acreage can be compensated for by more intensive use of less erodible land.
1	E 17	Other practices	Contour furrows,
3,4		"	Diversions
3		"	Subsurface drainage
3		"	Land forming
1,2		"	Closer row spacing

TABLE 8. PRACTICES FOR CONTROLLING DIRECT RUNOFF AND THEIR HIGHLIGHTS*

Category	No.	Runoff Control Practice	Practice Highlights
1	R 1	No-till plant in prior crop residues	Variable effect on direct runoff from substantial reductions to increases on soils subject to compaction.
1	R 2	Conservation tillage	Slight to substantial runoff reduction.
1	R 3	Sod-based rotations	Substantial runoff reduction in sod year; slight to moderate reduction in rowcrop year.
1	R 4	Meadowless rotations	None to slight runoff reduction.
1	R 5	Winter cover crop	Slight runoff increase to moderate reduction.
1	R 6	Improved soil fertility	Slight to substantial runoff reduction depending on existing fertility level.
2	R 7	Timing of field operations	Slight runoff reduction.
1	R 8	Plow plant systems	Moderate runoff reduction.
1	R 9	Contouring	Slight to moderate runoff reduction.
3	R 10	Graded rows	Slight to moderate runoff reduction.
1	R 11	Contour strip cropping	Moderate to substantial runoff reduction.
3	R 12	Terraces	Slight increase to substantial runoff reduction.
3	R 13	Grassed outlets	Slight runoff reduction.
1	R 14	Ridge planting	Slight to substantial runoff reduction.
1	R 15	Contour listing	Moderate to substantial runoff reduction.
1	R 16	Change in land use	Moderate to substantial runoff reduction.
3,4	R 17	Other practices	
		Contour furrows	Moderate to substantial reduction.
		Diversions	No runoff reduction.
		Drainage	Increase to substantial decrease in surface runoff.
		Landforming	Increase to slight runoff reduction.
4	R 18	Construction of ponds	None to substantial runoff reduction. Relatively expensive. Good pond sites must be available. May be considered as a treatment device.

*Erosion control practices with same number are identical.

Source: See Table 7.

TABLE 9. PRACTICES FOR THE CONTROL OF NUTRIENT LOSS FROM AGRICULTURAL APPLICATIONS AND THEIR HIGHLIGHTS

Category	No.	Nutrient Control Practice	Practice Highlights
2	N1	Eliminating excessive fertilization	May cut nitrate leaching appreciably, reduces fertilizer costs; has no effect on yield.
		Leaching Control	
2	N2	Timing nitrogen application	Reduces nitrate leaching; increases nitrogen use efficiency; ideal timing may be less convenient.
1	N3	Using crop rotations	Substantially reduces nutrient inputs; not compatible with many farm enterprises; reduces erosion and pesticide use.
1	N4	Using animal wastes for fertilizer	Economic gain for some farm enterprises; slow release of nutrients; spreading problems.
1	N5	Plowing-under green legume crops	Reduces use of nitrogen fertilizer; not always feasible.
1	N6	Using winter cover crops	Uses nitrate and reduces percolation; not applicable in some regions; reduces winter erosion.
1,2	N7	Controlling fertilizer release or transformation	May decrease nitrate leaching; usually not economically feasible; needs additional research and development.
		Control of Nutrients in Runoff	
1	N8	Incorporating surface applications	Decreases nutrients in runoff; no yield effects; not always possible; adds costs in some cases.
1	N9	Controlling surface applications	Useful when incorporation is not feasible.
1	N10	Using legumes in haylands and pastures	Replaces nitrogen fertilizer; limited applicability; difficult to manage.
		Control of Nutrient Loss by Erosion	
2	N11	Timing fertilizer plowdown	Reduces erosion and nutrient loss; may be less convenient.

Source: See Table 7.

TABLE 10. PRACTICES FOR THE CONTROL OF PESTICIDE LOSS FROM AGRICULTURAL APPLICATIONS AND THEIR HIGHLIGHTS

Category	No.	Pesticide Control Practice	Practice Highlights
		Broadly Applicable Practices	
2	P1	Using alternative pesticides	Applicable to all field crops; can lower aquatic residue levels; can hinder development of target species resistance.
1,2	P2	Optimizing pesticide placement with respect to loss	Applicable where effectiveness is maintained; may involve moderate cost.
1	P3	Using crop rotation	Universally applicable; can reduce pesticide loss significantly; some indirect cost if less profitable crop is planted.
1,2	P4	Using resistant crop varieties	Applicable to a number of crops; can sometimes eliminate need for insecticide and fungicide use; only slight usefulness for weed control.
2	P5	Optimizing crop planting time	Applicable to many crops; can reduce need for pesticides; moderate cost possibly involved.
2	P6	Optimizing pesticide formulation	Some commercially available alternatives; can reduce necessary rates of pesticide application.
1	P7	Using mechanical control methods	Applicable to weed control; will reduce need for chemicals substantially; not economically favorable.
2	P8	Reducing excessive treatment	Applicable to insect control; refined predictive techniques required.
2	P9	Optimizing time of day for pesticide application	Universally applicable; can reduce necessary rates of pesticide application.
		Practices Having Limited Applicability	
2	P10	Optimizing date of pesticide application	Applicable only when pest control is not adversely affected; little or no cost involved.
1,2	P11	Using integrated control programs	Effective pest control with reduction in amount of pesticide used; program development difficult.
1	P12	Using biological control methods	Very successful in a few cases; can reduce insecticide and herbicide use appreciably.

TABLE 10. (CONT.)

Category	No.	Pesticide Control Practice	Practice Highlights
2	P13	Using lower pesticide application rates	Can be used only where authorized; some monetary savings.
2	P14	Managing aerial applications	Can reduce contamination of non-target areas.
1	P15	Planting between rows in minimum tillage	Applicable only to row crops in non-plow based tillage; may reduce amounts of pesticides necessary.
1		Subsurface application	Reduces concentrations of pesticides in runoff.

Source: See Table 7.

TABLE 11. SOME SEDIMENT CONTROL PRACTICES FOR IRRIGATED AGRICULTURE (Estimated Sediment Loss Reduction for Selected Control Practices)

Control Category	Control Practice	Sediment Loss Reduction (%)*
2	Flow Cutback	30
3	Vegetative Buffer Strip	50
4	Sediment Pond	67
4	Mini-Basins	90
1	Sprinklers	100

*Baseline: Conventional Furrow Irrigation

Source: D.W. Fitzsimmons, et. al., Evaluation of Measuring for Controlling Sediment and Nutrient Losses from Irrigated Areas, EPA-600/2-78-138, July 1978.

TABLE 12. ANIMAL HOLDING CONTROL PRACTICES

Control Category	Control Practices
4	Diversion
4	Retention Points
1	Confinement
2	Proper Location
4	Evaporatiion Points
4	Land Disposal

TABLE 13. CONTROL PRACTICES/MEASURES (ORCHARD/VINEYARDS)

Control Category	Control Practices
1	Chiseling and Subsoiling
1	Drainage Land Grading
3	Drainage System Structure
3,4	Diversion
4	Ponding
2	Irrigation Water Management
2	Nutrient Management
2	Pesticide Management
4	Access Road Protection

TABLE 14. CONTROL PRACTICES/MEASURES (RANGE AND PASTURE)

Control Category	Control Practices
2	Range and Pasture Management and Use Plan
3	Spring Development
3	Ponding (including protection against losses)
4	Water Control Structures
5	Fencing
4	Stock Trails and Walkways

TABLE 15. CONTROL PRACTICES (HOMESTEAD)

Control Category	Control Practices
3	Septic System
2	Maintenance Schedule (Septic System)
3	Sizing (of Septic System)
3	Dry Wells (runoff from impervious area)
1	Alternative Waste Systems (compost toilets/ double plumbing for waste and grey water)

TABLE 16. EFFECTIVENESS OF SOIL AND WATER CONSERVATION PRACTICES IN CONTROLLING POLLUTANTS[1]

Control of SWCP	Strongly Adsorbed: Soil, Organic N, Organic P Paraquat	Strongly Adsorbed: Available Phosphorus	Moderately Adsorbed	Non-Adsorbed
Effective	no tillage conservation tillage ridge planting sod-based rotations cover crops[2]	sod-based rotations	ridge planting sod-based rotations	
Moderately Effective	graded rows contour listing terraces	graded rows terraces	contour listing no tillage	sod-based rotations
Slightly Effective	contour farming filter strips diversions	no tillage conservation tillage contour farming ridge planting contour listing cover crops diversions filter strips	conservation tillage contour farming terraces	contour farming ridge planting contour listing
Not Effective or Very Slightly Effective	grassed waterway[3] drainage	grassed waterway[3] drainage	graded rows cover crops diversions grassed waterway filter strips drainage	no tillage conservation tillage graded rows cover crops diversions terraces grassed waterway filter strips drainage

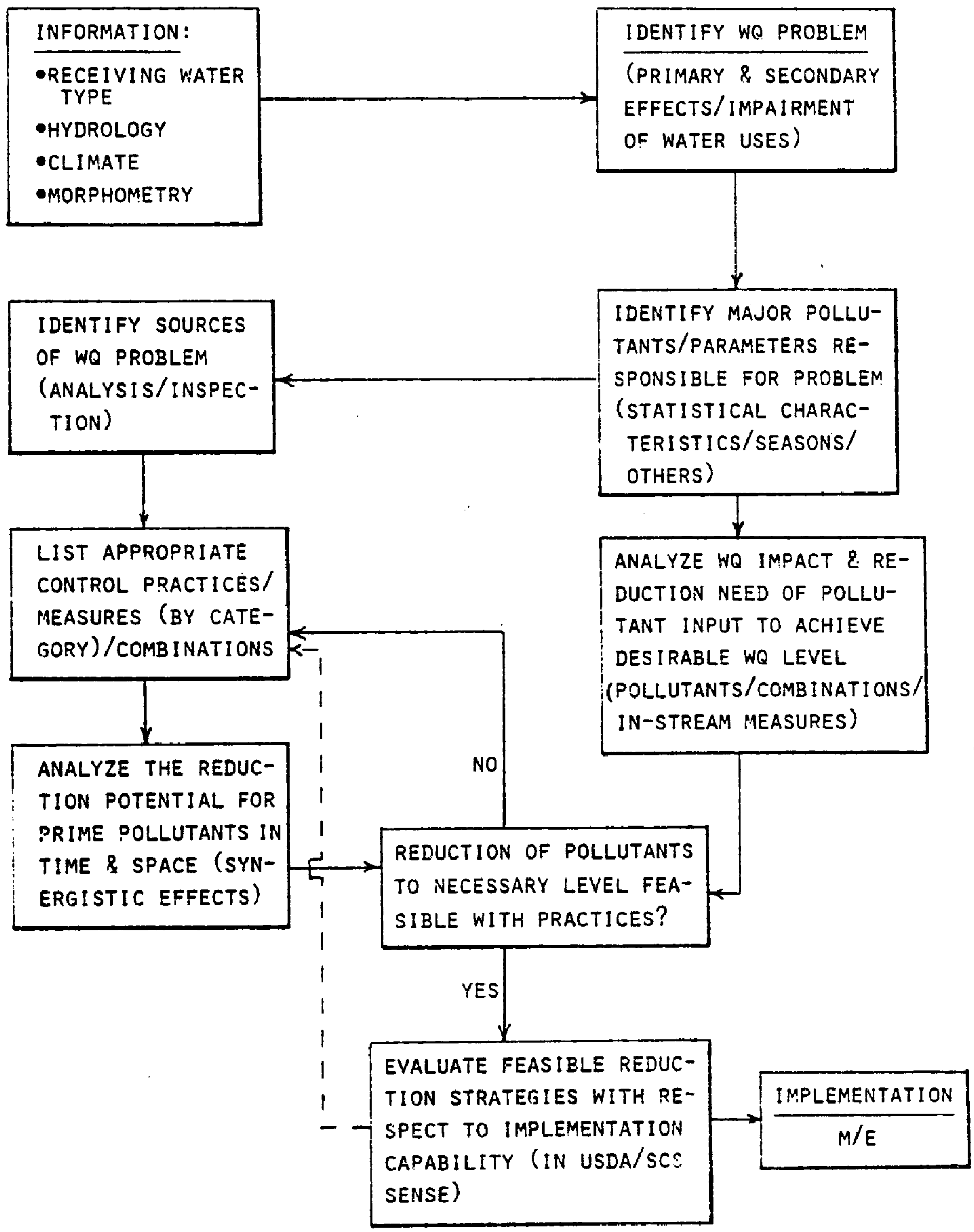
[1] These evaluations have been made for general situations. The site specific effectiveness of a particular practice as it fits into a total farming system might be different than indicated

[2] Not effective for pesticides.

[3] In combination with other practices, grassed waterways are effective.

Source: Haith, D.C. and R.C. Loehr (eds.), op cit.

FIGURE 6. TECHNICAL PROJECT EVALUATION



above questions about the usefulness of the Cornell listing of practices for water quality planning. Selection of those practices is only helpful if soil and water conservation practices (SWCP) are considered as remedial actions. For example, if erosion and sedimentation cause light-limited eutrophication in a lake, employing the "most effective" SWCP might result in worse eutrophic conditions because of the potential shift from light- to nutrient-limited eutrophication. Thus SWCPs must be tuned to the water quality problem, which means that "highly effective" SWCPs might not be highly effective water improvement measures. Combining different practices/measures from different control categories will produce in most cases a few equally effective load reduction measures; the ease of their implementation and M/E should determine the final choice.

It becomes obvious that quantifying the land use/water quality relationships is technically a difficult problem. Therefore, only the severest water quality problems and only those projects in which M/E of certain practices is desirable warrant this level of detail. This means that at this time the land use/water quality relationship cannot be quantified for all areas in all states.

Examples of Choosing Abatement Practices/Measures

For our example, we will assume that an agricultural land use affects a lake in all four water quality problem areas: sedimentation, eutrophication, pesticides, NO_3. Since we have discussed the interrelationship of sediment, eutrophication, and NO_3, we know that erosion control alone might only reduce the sedimentation problem without improving the other water quality parameters.

If eutrophication is P-limited, erosion control is helpful; if it is light-limited, there should be a reduction in the application rate in addition to some erosion control measures. NO_3 problems can most likely only be eliminated by reduced fertilizer application. Drainage characteristics notwithstanding, NO_3 might end up in the reservoir via interflow, a situation not helped by phasing input since pollutants accumulation is a problem in this receiving water type. Thus reducing runoff via SWCP does not help. Depending on the type of pesticide, SWCP might have some impact, but different management schemes would most likely mitigate the problem; i.e., reducing nutrient and pesticide application rates and timing their application must be added to erosion control practices in order to alleviate these combinations of problems. Parameters such as sand, silt, clay, distribution of soil/sediment, adsorption capacity, trapping of P and N in the reservoir, excessivity of N over P with respect to algae requirements, turbidity, snowmelt, potential enrichment of soil, and ratio of particulate P to dissolved P play an important role in designing the overall abatement strategy. Knowledge of pathways of pollutants is essential.

If there is a water quality problem of BOD, eutrophication, and bacteria in a small stream due to some type of animal holding, the remedy should be less complicated. Phasing the waste input over time into a receiving stream through a holding pond (and possible waste treatment) reduces its impact. This is definitely true for bacteria and BOD; if it is also true for nutrients, it must be assessed on a case-by-case basis. Controlled land application of manure might be the only possible way of controlling nutrient input.

Section 5

Project Monitoring

Background

In order to discuss monitoring the water quality impact of an individual project, several assumptions are made: the project area is larger than a single watershed;* the project is identified because of its water quality problems and not because of critical areas in the watershed (in the traditional SCS sense);** there is no uniformity in the river basin with respect to land use, topography, and soils; and there is no single ownership.

These assumptions lead to the following premises, which are necessary to the understanding of any project:

- The smaller the project area is with respect to the total basin/watershed, the more difficult it is to identify clearly any distinct impacts.
- The larger the volume of the receiving water is, the more difficult it is to trace impacts.
- If the receiving water is not a lake/reservoir (or possibly an estuary), it will be most difficult to measure and identify water quality impacts.
- The more individual practices are combined together in a so-called "Best Management Practice" (BMP), the less likely it is that the effectiveness of individual practices can be identified (since combinations of practices are very unique to a specific problem, the fewer practices are combined, the more useful are the results).
- The more diversified the ownership of the lands under investigation, the more difficult it is to monitor the agreed-upon practices.
- Even though severity of erosion and washoff is very much dependent upon precipitation events and their intensity, duration, and frequency, it is wrong to associate immediate agricultural pollution impact in every case solely with individual storm events; rather, impacts must be seen in terms of the hydrologic cycle and its interaction

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*One of the significant characteristics of the watersheds that are addressed in the literature review turned out to be their small size. There is apparently little experience in monitoring large area impacts.

**For example, the heavy erosion of an area far away from a stream will most likely influence the water quality less than the moderate erosion from a field near the stream.

with soil and groundwater (interflow) conditions.*

- Since each pollution problem is characterized by a unique setting, individual practices and combinations of practices must be analyzed in terms of individual pollutants and their behavior in the specific setting. (For example, classifying agricultural chemicals according to their expected dissolved and solid-phase forms can provide a basis for evaluation of a "baseline" effectiveness of a practice in reducing the load of agricultural chemicals on the stream, but only detailed consideration of soils' runoff/infiltration potential will permit identification of time-phased impacts.)
- If the runoff enters a receiving water characterized by relatively long detention times (e.g., impoundment), phased release of pollutants from the land (e.g., washoff vs. interflow) does not significantly reduce pollution potential, but phased release is helpful in mitigating impacts in a running stream.
- In general, all measurements of pollutant loads/concentrations that are chiefly induced by precipitation show a large variability. Experience has shown that a good initial working hypothesis is that runoff varies more between years than between land uses/practices, and that sediment discharges and particulate P and N vary more between land uses than years. However, the latter is only obvious for extreme differences such as cropland vs. pastureland, or row cropping vs. no-tillage, but is not necessarily true for marginal land use differences, as they might be created by the implementation of certain practices. This also implies that the increase of information due to extending a monitoring series over long years is only very marginal.
- The analytical techniques used up to now to analyze highly variable phenomena are not well developed. Using simple average values can be extremely misleading.
- In general, a network of monitoring stations must be installed to develop reasonable data sequences.
- In many cases, those parameters that are of concern for an evaluation of performance are not monitored (for example, monitoring only soluble phosphates instead of total phosphorus and soluble phosphates).
- Currently, existing water quality data can generally be used only to indicate water quality trends; they do not permit establishment of a historical land use/water quality relationship because available "characteristic" land use data are inadequate.

There are a few questions that should be addressed before the necessary steps for a reasonable monitoring program are laid out. First, how can instream concentrations be characterized? Because of the transient nature of the processes generating storm loadings and the resultant variabilities in concentration and flux, it may not be sufficient simply to consider average

*The surface runoff control by any practices does not necessarily reduce the total (runoff + percolation) losses of chemicals, so that due to interflow, there is a time lag between the precipitation event (the cause of this percolation) and the actual input to the stream.

concentration levels, for example, in relation to criteria or to the "control" land use impact. It seems more appropriate to consider the concentration history over a certain period, which includes both means and extremes of meteorologic conditions. This would provide a complete picture of water quality variations in time, which can serve as a basis for contrasting and evaluating the significance of variations during high-flow periods. Thus a hypothesis derived from these arguments is that in order to document precipitation-based problems effectively, we need to consider a range of flow conditions.

Frequency distribution is one way to characterize concentration levels. Such a distribution would be derived from monitoring data (or from simulation). It may be useful to summarize this distribution by fitting appropriate probability density functions. Time series behavior (serial dependence) and concentration/duration statistics should be considered, and the significance of using alternative time scales for sampling or averaging explored. Appropriate time scales might vary with component, water use, and type of water body, subject to data availability constraints. In general, little work has been done on this subject.

If it is desirable to estimate the impacts of concentration variations on specific water uses, it is necessary to map the concentration distribution onto a function that reflects relative degrees of use impairment or damage for each level of concentration. Such a function could be based upon water quality criteria or standards and might possibly be specific for each water quality component/water use combination. This would lead to two questions: (1) how to express environmental damage; and (2) how to specify water quality component/water use combination.

Clearly, the purpose of this report is not to answer these questions, but with regard to M/E, it should be made clear that for the estimation of relative degrees of use impairments or harm to aquatic life, for example, the averaging or sampling/monitoring used to derive the concentration frequency distribution must be consistent or made iteratively consistent with the characteristic response time of the damage to a change in concentration (i.e., the time it takes for any damage to be felt). This means that monitoring/analysis/evaluation should be performed continuously in order to improve the M/E program.

Since the value for historical water quality data has been constantly debated, some clarification would be useful at this point. Water quality data, measured at one location for a given time period, present the "lumped" impact of upstream land uses. Over time, they might indicate trends for certain parameters, and they can be analyzed in terms of average, median variance and range so that degree of variability of concentration and load can be established. Sometimes they have been related to external parameters, such as precipitation records and land use distribution. While the first type of analysis makes sense, the latter is of dubious value. In general, changing land use conditions and the variety of influencing factors (as expressed in our previous discussions) do not permit any conclusions about cause-effect relationships. Sometimes, those data might be useful in calibrating an analytical model designed to simulate land use/water quality interactions. But their value becomes highly questionable if no historical input data exist. Thus if there is a network of water quality monitoring stations, the correlation of the data from monitoring stations improves the state of knowledge and helps to identify critical areas. But again, it is inconceivable that water quality data alone can be interpreted so as to assess the effectiveness/performance of certain agricultural practices. The lack of historical data on the actual "land use/performance" and the high unreliability of the system do not permit respective conclusions from "lumpy" water quality measurements.

For example, EPA developed a very extensive data base on eutrophication of lakes/reservoirs in its National Eutrophication Survey. Using this data subset on midwestern impoundments to explain phosphorus retention phenomena was unsuccessful;* however, isolating those impoundments for which sediments samples taken by USDA and the Corps of Engineers were available made the phosphorus retention analysis much more conclusive. Thus EPA's results, that on the average 41 percent of total phosphorus export from 96 agricultural watersheds (of which 50 were in the cornbelt) is in ortho-phosphorus form, seem to be incorrect (as was also confirmed by some Black Creek data), which implies that monthly grab samples of lake tributaries most likely do not reflect the loadings of particulate P entering during storm events.
In summary, the sampling program and its derived conclusions did not prove adequate for the analysis and explanation of the actual driving forces of the system. Additional data on sedimentation indicate the importance of sediments, but even these data are inadequate to pin down critical areas and practices in the upstream watersheds. Only a network combining measurements of concentration and flow for the calculation of loads (and ultimately a receiving water budget) with downstream water quality impact data can permit determination of cause-effect relationships.

Setting Up the Monitoring Network

In setting up a basinwide monitoring program, five basic questions have to be answered:

1) What are the types of samples to be taken and measurements to be made (constituents, flow, etc.);
2) What are the locations of sampling stations;
3) What is the frequency and duration of sampling at the stations;
4) What are the methods to be used in sampling and measurement (i.e., equipment, etc.); and
5) How are the data to be processed and stored for later analysis?

Generally, these five characteristics of sampling programs cannot be considered independently, but it is not necessary to consider the same characteristics for each station; i.e., some stations might be designed to identify water quality and other trends in order to understand specific relationships. Thus some might be sampled at a lower or higher frequency for a few or many

*Meta Systems, op. cit.

constituents, respectively; high frequency sampling might be by automatic samplers, while low frequency sampling might be performed manually.*

The following steps should be followed in order to set up the most effective monitoring program:

1) Define the critical stretches of the receiving water;

2) Describe the apparent water quality problem in quantitative terms as much as possible (e.g., to label a problem "eutrophication" is inappropriate; rather, define some estimates of nutrient and sediment concentration, hypolimnetic DO conditions, and fish population);

3) State clearly which are the parameters that have to be controlled and in which season they are of concern (e.g., what is the limiting factor of the eutrophication; if P, should total particulate and dissolved P be monitored);

4) State clearly what the critical land areas are that determine water quality impact and describe those individual water quality parameters that are influenced by the critical areas (e.g., if an area is characterized by heavy gullies, the impacts of erosion and nutrient control might be different than the impacts of such control measures on a cropland without heavy gully formation);

5) Assess qualitatively the effects that various BMPs might have on runoff and edge-of-stream load (and on water quality);

6) Attempt an analysis (possibly with regional data) of the impacts of various practices and practice combinations on the pollutant loads, the load distribution, and on the receiving water's quality. On the basis of this analysis, identify the critical parameters to be monitored;**

7) Based on the problem's temporal and geographic characteristics, the parameters of concern, and the BMP's anticipated effects, lay out the monitoring network (including flow measurements). Since not all the areas are similar and not all areas are treated with the same practices, receiving water loads (i.e., flows and concentrations) must be measured at various points. (This is particularly important for lakes and reservoirs in order to derive a pollutant budget.);

8) Be prepared to monitor water quality and flow in creeks (draining to critical water quality stretches) during storm events occurring shortly after applications of fertilizer and pesticides (this generally requires automatic sampling equipment);

9) Determine the frequency of sampling in creeks/drains to the receiving water, and in the receiving water's critical stretch. Generally, due to the higher variability (i.e., more dynamic response to precipitation events), the frequency of monitoring has to be higher in the upstream parts of the

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*What individual(s) or institution(s) should do the sampling is frequently an important question.

**Haith and Loehr, op. cit., and Meta Systems Inc, op. cit. should provide some guidance on this type of analysis.

basin than in the downstream parts. Further, frequency depends on the information needed for characterizing a pollution problem in a receiving water. Simply stated, when the pollution problem is of a cumulative nature (like eutrophication in lakes/reservoirs), the critical area needs to be monitored relatively infrequently because changes do not occur rapidly. However, the drainage into the major receiving water has to be monitored on a regular basis in order to establish the input patterns. If a pollution problem is identified in a running stream, continuous/relatively high frequency monitoring is necessary in order to establish patterns. A nitrate problem (e.g., in certain seasons) is a typical example.*

10) Determine the appropriate length of time for a watershed to be monitored. This varies according to the nature of the pollution problem, the nature of the control or management strategy, and the length of monitoring chosen for other watersheds providing information to the program. Some pollution problems occur in a manner that requires long time periods in order to obtain a statistically significant number of observations. Examples are pesticides and fertilizer that may only be applied once during the course of a year and be absent from runoff waters after 3 or 4 runoff events. The eventual selection between different management and control strategies necessitates some understanding of the relative effectiveness of the different strategies, in terms of mean or median effectiveness and in deviation from this average. Longer periods of monitoring reduce the variance of an estimate at a single site. This leads to a tradeoff between parameter accuracy and monitoring duration. While long-term monitoring projects may be required for reduced variance, a greater diversity of projects is desirable so that the information will provide a more accurate estimate of the possible effectiveness of the management practices at some site that has not been monitored.** Generally, a combination of long- and short-term monitoring projects is superior to the exclusive use of either one.

11) Given the analytical framework for the analysis, the need for constant reassessment of the monitoring scheme, and the value of the generated data, process and store the data in such a way that they are easily accessible and transformable. All raw data should be retained. After initial collection, simple statistical manipulation can be performed, and simple relationships plotted. Thus questions such as the following can be addressed throughout the monitoring period:

- How do assumptions of flow in the model compare with actual flows? Do we encounter dry, wet, or average years/months?
- How do discharge and the concentrations and flux of all components monitored vary with season?
- At each station, what is the relationship of concentration to flow? (A typical pattern for nonpoint sources is a positive relationship between flow and the concentration of suspended-phase materials. Dissolved phase concentrations exhibit a variety of patterns.

*See U.S. EPA NPS Task Force, "Guidance Document on NPS Monitoring," 4th draft, Washington, D.C., March 1980.

**In an econometric analysis, this tradeoff is reduced bias vs. increased efficiency of the estimators.

Conductivity may decrease with flow due to dilution of base flow. Dissolved P is usually weakly or totally unrelated to flow. If a large negative relationship is apparent for any component, an upstream point source may be indicated.)

- Do concentration variations within storm events appear to follow any pattern with respect to flow or time?
- What is the flow-weighted average concentration of each component?
- Do there appear to be substantial differences in concentration and export (mass/watershed area-year) across stations? Could they be related to differences associated with land use activities?
- What is the total P loading?
- How does P discharge compare with loading? In case of reservoir/lakes, below the reservoir, what was the hydraulic detention time during the year? What is the measured phosphorus retention coefficient and how does it compare with that predicted on the basis of residence time?

The answers to these and similar questions help assess the appropriateness of the monitoring scheme. M/E is so expensive that the scheme has to be revised according to the information gained in order to make monitoring as cost-effective as possible.

12) Incorporate into the monitoring programs quality assurance.* Adequate steps must be taken to ensure that the data gathered are reliable. This includes proper sample collection and preservation methods. Calibration of field instruments, in particular, the dissolved oxygen meter, is critical. A quality assurance program should be set up to verify laboratory analyses, particularly for measurements that have not been made routinely in the past. Coded replications, spiking of extra samples, and analyses by independent laboratories are three typical means of verifying analyses. This type of activity should be emphasized in the early stages of the program and reduced, but not eliminated, as procedures become established.

An Example of a Monitoring Program

Ideally, an analytical framework of the land use/water quality interface serves two purposes: guiding the monitoring programs, and continuous analysis and evaluation. Using such an analytical framework, we present below an example of a monitoring program in which the analytical framework is oriented toward "long-term/average" conditions. Thus we explore how the framework's data needs and the respective monitoring program might be set up for a eutrophication problem in a drinking water reservoir that was identified as P-limited on the basis of analysis with regional data.**

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*For example, the NURP program provides some guidance. See U.S. EPA "Data Collection Quality Assurance for the Nationwide Urban Runoff Program." A similar document should be prepared for RCWP.

**Assuming a 3-year monitoring program revised periodically as data become available.

The methodology and associated data requirements can be organized in three general relationships or submodels (Figure 7):

1) land use/stream phosphorus relationships;

2) reservoir phosphorus balance; and

3) trophic state and associated water quality conditions.

By monitoring at selected locations, it should be feasible to identify the relative impacts of various land uses on stream P levels. Stations should be located so as to isolate areas within specific land use categories where possible. Both periodic and storm event sampling should be done. Staff gages should be installed and calibrated to permit flow measurements at each site.

Monitoring is also needed to establish the reservoir P balance, i.e., inflows and outflows expressed on an annual average basis. This will help to establish relationships among P loadings, nutrients available to support algal growth in the impoundment, and nutrients discharged to downstream stretches. Additional calibration of the phosphorus retention model is feasible with this type of information. Monitoring of flow and concentration at the inflow and outflow points is required. Since the data requirements are similar, stations at reservoir inflow points can be used both for estimating land use/stream P relationships and for estimating the reservoir P balance. The latter also requires outflow stations.

Monitoring within the impoundments will provide a means of assessing existing conditions and further calibrating the trophic index system. The latter describes relationships among phosphorus, chlorophyll-a, transparency, and oxygen depletion rate. This represents the linkage between the P mass balance and the reservoir water quality response. The program should also cover water quality aspects that may be indirectly related to trophic state, such as iron, manganese, and trace metals released from sediments during anaerobic periods. Impoundment monitoring also entails temperature profile data to determine the extent and period of vertical stratification.

Seven locations for watershed monitoring stations in the Sargent River system are listed in Table 17 (and shown in Figure 8) together with the recommendations for watershed and impoundment monitoring, including variables measured, spatial frequencies, temporal frequencies, and environmental conditions recorded. Station A, at the Almar Road drain, should permit some isolation of urban impact. Three of the stations (B, C, and D) are located on the lower ends of the three main branches of the river above the lake. Station E is below the confluence of three branches and above the lake. To complete the mass balance on the lake, Stations F and G are located on the eastern tributary and below the lake, respectively. Because they are critical to the input/output analysis of the reservoir, we suggest that stations E and G be given highest priority in terms of flow and quality monitoring activity.

Watershed monitoring is scheduled on a monthly basis, but should be biweekly during spring runoff. A few storm events should also be monitored at each station in order to identify the extent of P concentration variations

FIGURE 7. CONTROL PATHWAYS TO BE STUDIED IN THE MONITORING PROGRAM

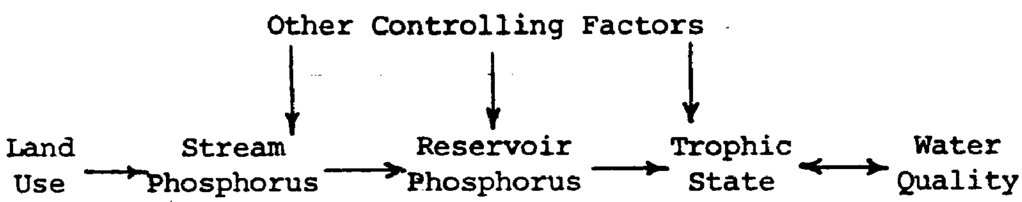

TABLE 17. RIVER WATERSHED AND RESERVOIR MONITORING PROGRAM

Watershed Station Locations*

A. Almar Road Drain
B. River, W. Branch
C. River, N. Branch
D. River, E. Branch
E. River, above lake
F. Eastern Tributary
G. Lake Discharge

Environmental Conditions Recorded

- precipitation (including previous 3 days)
- air temperature
- wind velocity direction (qualitative)
- sky cover (qualitative)
- odor (qualitative)
- reservoir level **
- reservoir discharge source** (spillway vs. regulator)
- reservoir flow regulator setting**

Water Variables Monitored

stage (flow)
total phosphorus
dissolved phosphorus
turbidity
dissolved color
conductivity

Monitoring Frequencies

a) watershed
spatial: 1 sample, mid-depth, mid-stream

temporal: monthly (except bi-weekly during spring runoff); 2 or 3 storm events per year

b) reservoir

Reservoir Variables Monitored	Spatial Frequencies: deepwater stas.	Spatial Frequencies: discharge stas.
temperature	profile†	grab
dissolved oxygen	profile†	"
total phosphorus	0-10 ft composite	"
dissolved phosphorus	"	"
ammonia nitrogen	"	"
organic nitrogen	"	"
nitrate nitrogen	"	"
nitrite nitrogen	"	"
pH	"	"
conductivity	"	"
dissolved color	"	"
turbidity	"	"
transparency	surface	-
chlorophyll-a	0-10 ft composite	-
iron	-	grab
manganese	-	"
trace metals	-	"

*Locations are identified in Figure 8.
**Lake discharge station only.
†Profiles at 5-ft intervals except 1-ft near thermocline (15-20 ft).

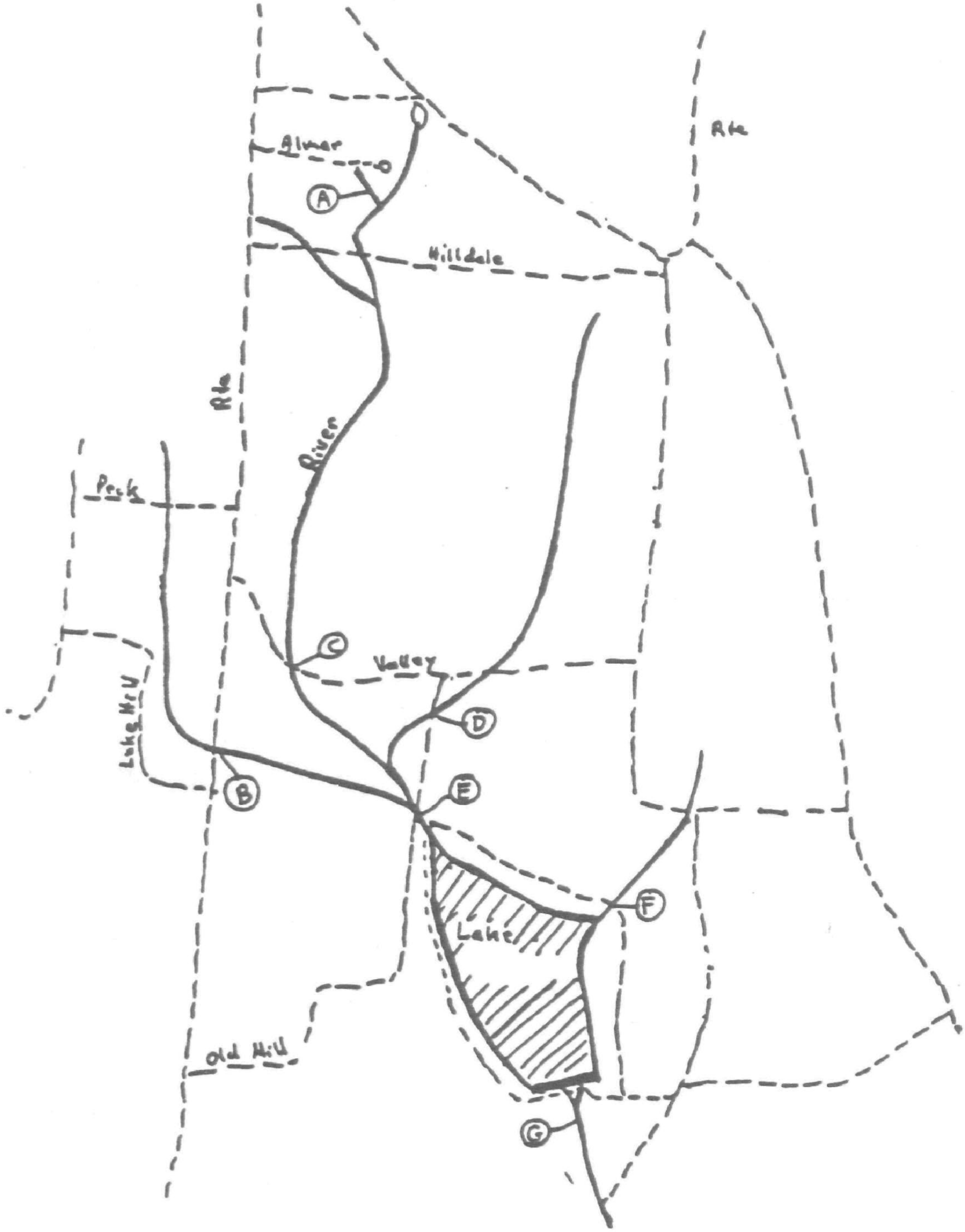

FIGURE 8. SUGGESTED MONITORING STATIONS IN THE WATERSHED

during these events and any relationships with flow. Measurements of total and dissolved P will provide a basis for assessing both the quantity and quality of nutrient sources in the watersheds. Dissolved P is considered a more readily available nutrient source for phytoplankton growth than suspended P. Turbidity, color, and conductivity will provide additional indications of the origins of the water (i.e., surface runoff vs. base flow) on seasonal and storm event bases.

Estimates of the annual hydrologic budget should be based on weekly stage data. Daily measurements would be preferable if convenient. If a continuous stage recorder and/or automatic sampler is available, installation at Station E just above the reservoir seems appropriate.

One deepwater and one discharge station should be established to monitor conditions in the reservoir during the stratified period. Discharge stations should be located to catch bottom-water releases. These are included to provide a means of detecting any nutrient, iron, manganese, and trace metal releases from bottom sediments that may occur if and when hypolimnetic oxygen levels become critical. Generally, one profile station should be established at the deepest location of the impoundment, but far enough removed from the dam to be representative of the open water.

A monthly monitoring frequency between April and October seems adequate. Sampling should be done under settled weather conditions. The program should include vertical oxygen and temperature profiles and surface composite samples of P species, N species, pH, conductivity, color, turbidity, and transparency. While algal growth in these reservoirs is probably limited, N species are included to provide a means of assessing any limiting effects of N. Chlorophyll-a is the basis of the trophic index and should be monitored or at least spot-checked if suitable laboratory arrangements can be made. If laboratory facilities are limited, N and chlorophyll-a analyses can be limited to one sample in late spring and one in late summer. N could be phased out altogether if the results indicate that it is insignificant as a limiting factor after one year of monitoring.

Copper sulfate or other algicide treatments will have influence on assessments of existing conditions using the trophic index system. If such treatments cannot be eliminated altogether, impoundment monitoring should be scheduled so that surveys do not follow immediately after treatment. In any event, treatment activities should be monitored and recorded for future reference in the data analysis.

Section 6

Monitoring Strategy

In Section 5 we outlined how to go about setting up monitoring projects for nonpoint source pollution abatement. In this section we present some criteria for selection of representative projects across the United States for M/E. This process should proceed in steps:

1) Determine the projects that exhibit agriculturally based water quality problems;

2) Characterize these projects according to the important M/E criteria;

3) Weight the M/E criteria for final choice of project.

For Step 1 the following sequence of actions might occur:

1) Local USDA (SCS; ASCS) and regional EPA sources designate significant pollution problems in each of the EPA regions with respect to location, pollutants, receiving waters, watershed characteristics (land use/ownership), and proximity to areas previously investigated in detail. This knowledge can be summarized for each region in a simple matrix (such as Table 6 in Section 4), where the entries would be the number of the particular land use/water quality problems in each region.

2) The land use/water quality combinations that cause the most significant deterioration of water quality are marked on the matrix.

3) If there is an obvious tradeoff between a "large number" of specific problems (land use/water quality combinations) and individual infrequent but severely impacting land use/water quality problems, the choice is made between the "large number" (possibly representing a typical problem) and the individual, most severe problem. If there is no obvious tradeoff, additional criteria are used, such as typical hydrology, ease of problem identification and isolation, and local capacity (basically the same decision-making process that has been used up to now).

For Step 2 the characterization of the projects chosen on the basis of criteria important for M/E project selection should proceed in two ways:

1) A determination should be made based on federal perspective whether or not a project is typical; and

2) On the basis of technical details, implementation potential, and institutional capabilities, a ranking should be made of the leftover projects.

For 1 under Step 2 above, we suggest the following tools:

Climatic regions (ultimately it is desirable to have at least one project in each of these regions);

Precipitation/runoff (permits distinction in dry and humid climates);

Livestock population (RCA project)

Crop intensity (RCA project)

(these indicate the overlap or isolation of problems of potentially great magnitude)

Soil erodibility and drainage maps

Other U.S. maps

(adding these maps permits evaluation of the seriousness of erosion problems or fertilizer drainage in areas under intensive investigation)

USGS, EPA maps on SS, P, N (these generally provide the background material necessary to put a project in perspective or to select a specfic project type).

For 2 under Step 2 above, there are some characteristics/criteria that were tested in our review of the current 13 projects and their suitability for M/E (Table 18). Not all of these characteristics/criteria carry the same weight (see below).

For Step 3 the ranking of the projects should be based on the characteristics/criteria of Table 18. All of these characteristics/criteria can be viewed as purely descriptive, but most of them lead to comparisons in the review process. Thus the weighting should not be static, but should reflect the information gained in conducting M/E projects. In this way, statements can be made about each characteristic/criterion, reflecting, more or less, the current state of knowledge.

1) In selecting projects across the United States, all areas should ideally be covered; however, for now it is desirable to focus on areas that have cold, as well as warm, seasons.

2) A general description of the water quality problem allows a first indication of the extent to which it can be quantitatively described.

3) It is necessary to isolate as much as possible individual, largely homogeneous land uses in order to draw any inferences for a potential project.

4) The choice of irrigated or unirrigated land use is largely a matter of agency preference.

5) Any point source or septic tank influence should be minimized because its impact cannot be easily isolated and abstracted from concentration/load estimates, especially in lake/reservoir receiving water systems.

6) Overall analysis and evaluation are facilitated if one specific pollution problem can be identified. Different problem types need different remedies in terms of practices/measures, but the more individual practices are eventually combined in a so-called "Best

TABLE 18. PROJECT CHARACTERISTICS

1. U.S. Location
   - North/South//East/West (i.e., separation into dry and humid areas and those impacted by snowfall)
2. Water Quality Problem (general)
3. Major Land Use (acres if available)
   - cropland (type of crop)
   - feedlots (covered under RCWP)
   - animal holdings (except feedlots)
   - range/pasture
   - mix (population centers and others)
4. Irrigation/Nonirrigation
5. Point Source Influence
   - point source
   - nonsewered/septic tanks
   - purely nonpoint source agricultural problem
6. Type of Pollution Problem (as defined by review of land)
   - erosion and associated nutrients
   - erosion and associated nutrients and pesticides
   - heavy pesticide use
7. Receiving Water (including hydrologic characteristics)
   - lake/reservoir
   - small stream
   - river
   - bay (Great Lakes)
   - groundwater
8. Drainage/Land Characteristics
   - flat, delta type
   - unclear drainage to critical water quality areas
   - clear-cut drainage
   - slope

9. Project Area (acres)/Watershed

10. Population in Project Area

11. Critical Area (acres
   - ratio of critical area to project area

12. Number of Farms (in critical land area)
   - large (> 200)
   - medium (100-200)
   - small (< 100)

   (these are not absolute limits, but reflect the 13 projects currently considered)

13. Number of Animal Facilities (in critical land area)

14. Water Use
   - drinking water supply
   - recreation (contact/noncontact)
   - fisheries and wildlife
   - agricultural and industrial water supply

15. Specific Water Quality Problems
   - coliform
   - pesticides
   - eutrophication (P-, N-, light-limited)
   - nitrate
   - sedimentation
   - salinity

16. Parameters Previously Monitored

17. Preliminary Analysis in Application (including pathway of pollutants)

18. Protective/Preventive Practices (suggested)

19. Suggested M/E plan in Project Application

20. Inclusion in 208 plan?

Management Practice" (BMP), the lesser the likelihood that the effectiveness of individual practices can be identified. Thus since combinations of practices are very unique to a specific problem, the fewer problems involved the better and, hence, the fewer practices combined, the more useful the results.

7) Given the current state-of-the-art of identifying and evaluating receiving water pollution phenomena, it must be emphasized that if the receiving water is not a lake/reservoir, it will be difficult to measure and identify water quality impacts. There is, however, at least one caveat to this suggestion: if this receiving water's pollution problem has been present for a long time, it cannot be cleared up quickly, because of the lake/reservoir's "memory" (e.g., nutrients in sediments). This makes it rather unlikely that any changes in water quality can be identified as a result of practice changes in a 5-10 year period.

8) In order to effectively perform M/E, there should be only one drainage area and clear-cut drainage patterns.

9 and 11) The smaller the project's critical area with respect to the total project basin/watershed, the more difficult it is to identify clearly any distinct impacts; also, the smaller the ratio of receiving water surface area to watershed area, the lesser the likelihood that changes due to isolated land practices can be extracted from water quality data. Furthermore, the type of analysis applied is somewhat influenced by this configuration; in impoundments with extremely short hydraulic residence times, seasonal variations of loadings may become of overriding importance.

10) Since permanent and temporary population may contribute to pollution (see 5 above), it is advisable to have as small a population as possible in the project area (including the impacted receiving water area).

12) The smaller the number of farms the better, since diversified ownership of the lands under investigation makes it more difficult to monitor the agreed-upon practices. This is especially true if measures other than structures have to be used.

13) Since a large number of animal holding facilities makes identification of the problem area difficult, it is desirable to have a relatively small, observable number of facilities in the area.

14) Definite water use characterization is important, since it implies standards for respective water quality parameters that would have been set by the state having jurisdiction over the problem area. Such standards would provide for clearly identifiable thresholds to be reached in the receiving water improvement.

15) Some of the specific water quality problems occur mostly in combination, such as eutrophication, sedimentation, and NO_3. This influences the set of practices to be applied (and monitored) and the monitoring requirements (space and time) in the receiving water. Since each pollution problem is characterized by a unique setting, individual practices and combinations of practices must be analyzed

in terms of individual pollutants and their behavior in the specific setting. The more interplay there is between problems, the more difficult analysis and monitoring become and thus the more careful their set-up must be.

16) Historical data can give some clue about past water quality trends, e.g., the time period a eutrophication problem has prevailed. But the data base is generally inadequate to draw any conclusions about the land use activities that caused the problem.

17-20) The more analysis performed prior to any monitoring exercise the better. The relative level of required analysis depends on the pollutant/practice/receiving water combination for each area (see 15).

On the basis of the above discussion, we feel that the following factors are most important in selecting M/E projects at this time:

- ease of identifying the water quality problem and its cause;
- eutrophication problems in lakes/reservoirs or in other relatively stagnant water bodies generated in a clearly identifiable upstream area, with focus on those eutrophication problems whose history is only relatively short;
- the potential for reducing the "reason for the water quality problem" to one land use type (e.g., cropland versus animal holding) and thus the avoidance of "mixed land uses";
- avoiding areas where uncontrollable septic tank influences are possible;
- given the interest in tradeoffs of point source vs. nonpoint source, isolation of a project in which correction of both problems can be monitored (it would be helpful to have historical data on the point source effluent);
- avoiding areas with more than one drainage pattern.

Finally, since the utilization of the data is important, we advise that their handling and storage be comparable to the EPA (STORET) and USGS systems. In this way the new data can be fit with other data sources to perform local and regional analysis of the type needed to initially assess the water quality problems of certain areas (See our discussion in Section 5).

Section 7

Conclusions

In this concluding section, we will reiterate five major points that have come out of this report.

1) Water quality considerations must be the driving force behind the selection of Best Management Practices. The "2-track" planning process (Figure 6) should ensure that the water quality problem is adequately identified and that appropriate practices/measures of the five control categories (Figure 3) are imposed.

2) Background water quality data are not essential in the selection of an M/E project. They are valuable in putting a water quality problem in perspective (e.g., in identifying the number of years a eutrophication problem has been present), but they do not alone lead to the identification of the reasons for past pollution problems.

3) Any design of a monitoring scheme, and the monitoring itself, must be preceded by analysis to determine the pathways of pollutants and to clarify which parameters have to be monitored at what frequency and what location.

4) The transferability of results from one project site (intensively monitored) to another is questionable because of currently limited knowledge. However, the transferability will improve as additional monitoring projects are carried out. The complexity of this issue is demonstrated by the length of time it took to develop regional estimators for hydrologic regions. It might, however, become possible to uncouple upstream land and drainage systems, and downstream receiving water systems on the basis of known receiving water behavior; but this can only be accomplished if it can be determined with certainty what the receiving water's response will be to changes in input. Thus, uncoupling might become feasible with lakes/reservoirs.

5) It is necessary to integrate firmly the land/water quality analysis with monitoring and evaluation of the water quality and the performance of the practices. This means that the monitoring system must be adjusted to the results of the monitoring and analysis, but it also means that the practices/measures must be adjusted as well. It is obvious that, in many cases, conventional measures do not meet established needs; they must be augmented by management measures in order to yield the desired water quality results.

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