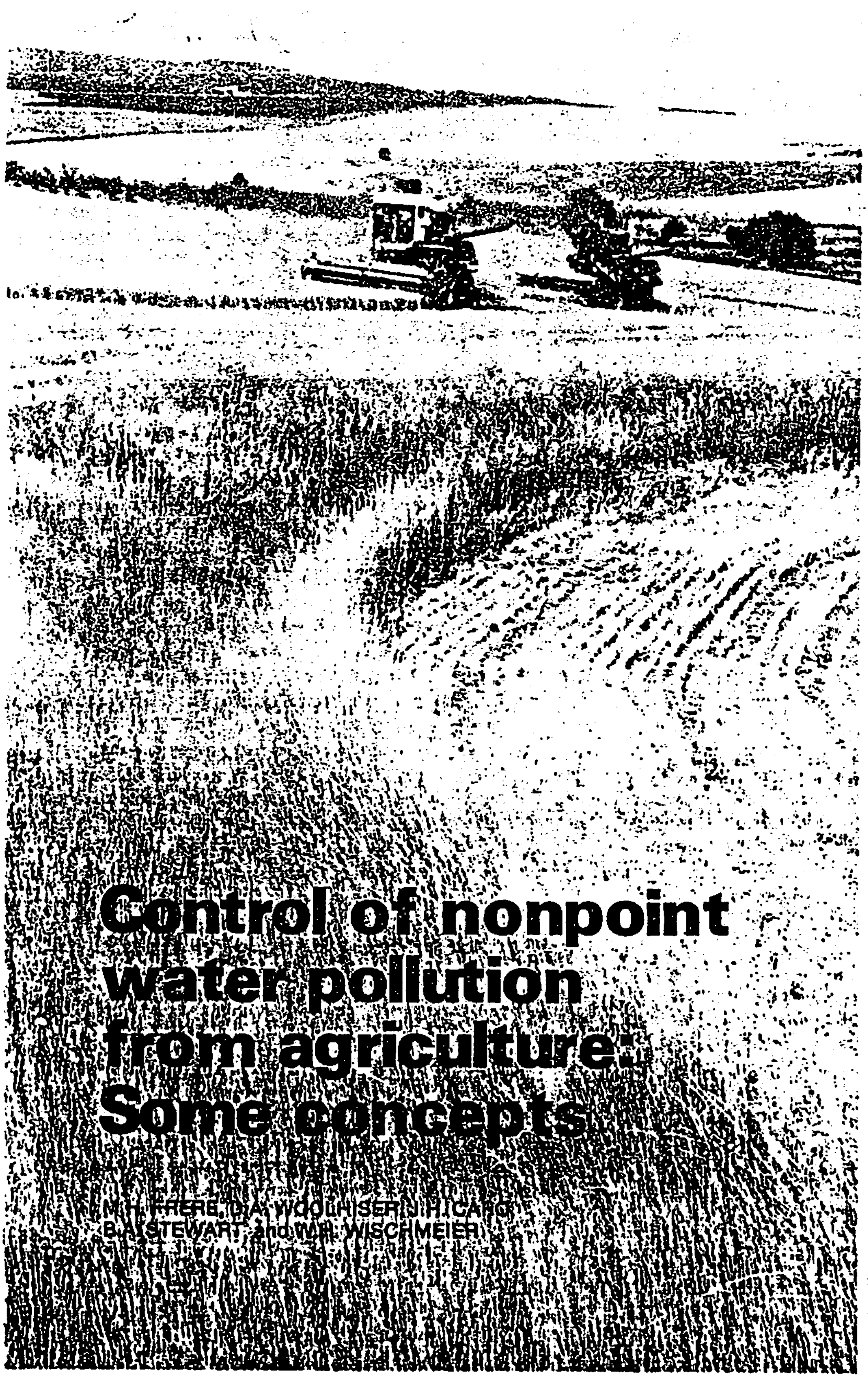

Control of nonpoint water pollution from agriculture: Some concepts

M. H. FRERE, D. A. WOOLHISER, J. H. CARO, B. A. STEWART, and W. H. WISCHMEIER

Photo by R. L. Kent

THE Federal Water Pollution Control Act Amendments of 1972 require the control of nonpoint as well as point sources of pollution (8). Initially, most pollution control efforts were directed at point sources. Now attention is being given to nonpoint sources, such as runoff from farmland.

These sources are not discrete and identifiable, like sewer outfalls. The source of the water carrying pollutants is precipitation. Because precipitation is not controllable, the input to a water body is erratic (Figure 1). The best way of controlling pollution from these sources is not a treatment plant, but management of the land.

One difficulty in dealing with nonpoint pollution is the number of management units involved. In 1974 there were about 2.8 million farms in the United States with a land area exceeding 1 billion acres (*10*). In addition, farms are often located in more than one watershed. This makes it nearly impossible to monitor all agricultural runoff and greatly complicates the design of effective control programs.

Water Quality Standards

"How much is too much?" is an important but elusive question in the nation's pollution control effort. The performance of any control program cannot be judged adequate unless there are standards for comparison.

The concept of water quality involves many components. Many uses of water are mutually exclusive. The suitability of a water course as fish habitat; for recreation; and for use by municipalities, industries, and agriculture is affected by water temperature, bacterial content, suspended solids, biochemical oxygen demand (BOD), dissolved oxygen concentrations, and the concentration of numerous other chemical constituents. Since natural variations in these quantities are substantial and we cannot declare that the quality of any one natural stream is better than another (except with respect to a particular use), we can-

M. H. Frere is a soil scientist with the Agricultural Research Service, U. S. Department of Agriculture, Chickasha, Oklahoma 73018; D. A. Woolhiser is a hydraulic engineer with ARS, USDA, Fort Collins, Colorado; J. H. Caro is a chemist with ARS, USDA, Beltsville, Maryland; B. A. Stewart is a soil scientist with ARS, USDA, Bushland, Texas; and W. H. Wischmeier was a statistician, now retired, with ARS, USDA, Lafayette, Indiana.

Reprinted from the Journal of Soil and Water Conservation
November-December 1977, Volume 32, Number 6

not define a universally optimum water quality, nor use a single standard.

Two types of standards have been used in combating pollution from point sources. One form, the "stream standard," places restrictions on the quality of the stream and prohibits users from discharging anything that lowers the quality of the stream water below the given set of standards. The other form, referred to as the "effluent standard," specifies the quantities or concentrations, or both, of materials and heat that may be discharged into the stream. In some cases the treatment level (for example, 85 percent BOD removal) is specified.

Standards for drinking water (*11*) have been established, but it is not reasonable to apply these standards to water in all lakes, streams, and reservoirs. Water for recreation, wildlife, agriculture, and most industry need not be as pure as drinking water. Standards for agricultural use of water are mainly concerned with salts (*12*). As the water becomes more saline, fewer crops can be irrigated with it. Salt content is also important in industrial uses of water because it can cause such problems as boiler scale.

Since sediment has been recognized as a problem for many years, some standards (similar to the effluent form) have been established for erosion on croplands (*4*). But these standards (typically an allowable soil loss of 3 to 5 tons per acre per year) are based on the loss of a soil resource, not on the downstream environmental impact.

Before 1972, the federal government required states to set standards for interstate waters. The 1972 amendments require standards for navigable waters. Setting a standard for any particular body of water implies that society bears a substantial loss if the concentration of the constituent in question exceeds the standard.

Because adequate information is not available to define the concentration-loss relation quantitatively, standards are frequently subjective. For example, Oklahoma's standard for nutrients reads in part: "The total phosphorus concentration and nitrogen/phosphorus ratio shall be limited to prevent eutrophication problems" (*5*). Unfortunately, sufficient scientific evidence is not yet available to establish more objective standards for many parameters. This lack of numerical standards for some parameters will make it difficult to design effective control programs because the amount of control needed is unknown.

Since rainfall and the resulting runoff are erratic, a single numerical value for any given water quality parameter will not be adequate for nonpoint pollution sources. There is no practical way to guarantee that a standard will never be exceeded. Some frequency limitation to account for unusual hydrological events must be a part of the standards. The limitation might be X days a year or Y percent of the time or a return frequency of Z months.

Methods of Control

One of the most important concepts to be recognized in nonpoint pollution control is that some control programs are applicable to broad areas while others are limited to areas as small as individual farms or fields. An effective program will probably use a combination of incentives and/or disincentives to cause both large-scale and small-scale changes in farm management.

Broad-area Programs

Education is one method that could lead to control over a broad area. Many people in rural and urban areas are not convinced they pollute. An educational program to demonstrate or illustrate water quality problems and ways to handle them might be one of the least costly solutions. It circumvents the problem of specifying site-specific practices over a broad area. It also preserves rather than diminishes individual rights and choices.

While education is highly desirable, it is unlikely that this method alone will achieve adequate control. Extension Service and Soil Conservation Service personnel for years have encouraged practices to control soil erosion, but the number of acres requiring treatment remains large. Only 36 percent of the nation's cropland was considered adequately treated in 1967 (*9*), and some of these treated lands are not being maintained.

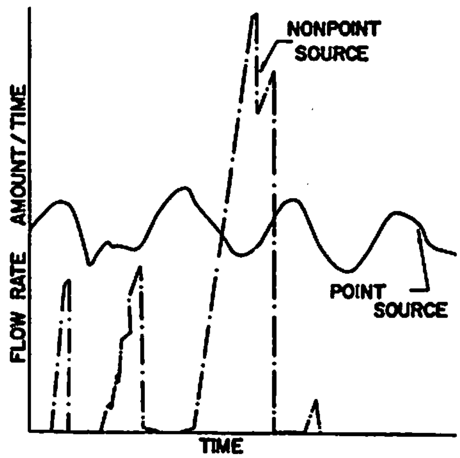

Figure 1. Temporal differences between point and nonpoint sources of pollution.

One problem with an educational approach is that of farm economics. An incentive program might help. In most cases instituting control practices will cost the land user money, either directly or indirectly through inconvenience, time, etc. Furthermore, most benefits from the improved water quality accrue to downstream users and the public at large. Therefore, a program with incentives to defray all or part of the land user's cost might result in sufficient control, and the benefits might pay for the incentive.

Incentives are not new in agriculture. They have been used for years to encourage the installation of conservation treatments. Nor would they be new in pollution control. Municipal and industrial waste treatment plants are subsidized through cost-sharing or tax write-offs. In the final analysis, an incentive program must be compared with all others in terms of its cost in accomplishing water quality goals.

Taxation of fertilizers, pesticides, and irrigation water has been suggested as a control tool that would encourage optimum use of these products over broad areas. But this approach is valid only if there is a direct relation between the amount of a pollutant and the extent the taxed input is used. There is probably a reasonable relation in some areas between salt in irrigation return flow and irrigation water used and possibly a relation in a few areas between nitrate in groundwater and nitrogen fertilizer. In all other cases the relation seems inadequate. The nutrients lost from a watershed in runoff seldom exceed a fraction of the fertilizer applied. Since some nutrients are lost from the soil even if fertilizer is not applied, major reductions in fertilizer may have only small effects on losses.

Taxes might also be applied to commodities to discourage the use of some and encourage the use of others. But this approach fails to recognize that even in small areas the same crop could produce pollutants from one field and none from another.

Permits or rights to use a material, like fertilizer, have been suggested as a means of achieving better control than with taxation (7), but permits or rights are subject to the same limitations as taxes. Some people contend that a tax per ton of soil loss, instead of a flat limit on soil loss, would achieve the same quality control with less economic impact (3).

Imposing legal penalties for exceeding standards, as is done for point sources, has also been considered. While use of this tool is possible, it is not practical because all runoff from each land holding would have to be monitored to document when and where a violation occurred. Many farming, ranching, and forestry operations occur on parts of several watersheds. Monitoring these to establish the source of each input to water courses draining several watersheds would be prohibitively expensive. In addition, water moving below the ground surface does not always follow the surface topography and may, in fact, come to the surface in springs or seeps on other lands.

One could wait, of course, until a lake, reservoir, or stream had a pollution problem, then try to trace the pollutant upstream to the location where it was entering the stream. However, inputs of pollutants, as we said, are often not continuous from nonpoint sources. Locating the exact source may be impossible. At the present time, mathematical models to predict where a pollutant came from are probably not defensible in court.

An alternative means of using legal action might be to require land users to follow a land use program designed specifically for their operation. Legal action would be taken against the land user for not following the certified plan, rather than for exceeding a runoff standard. This method provides a mechanism for handling those rare or unusual events, like a storm that has a chance of occurring once in a hundred years. The approach might also receive opposition as an infringement on civil rights.

The certifying agency could be a river basin district, a conservancy district, or a soil conservation district. Many practices that a plan might require could be monitored from the air. Preparing land use plans would be expensive and time-consuming, however. The development of mathemat-

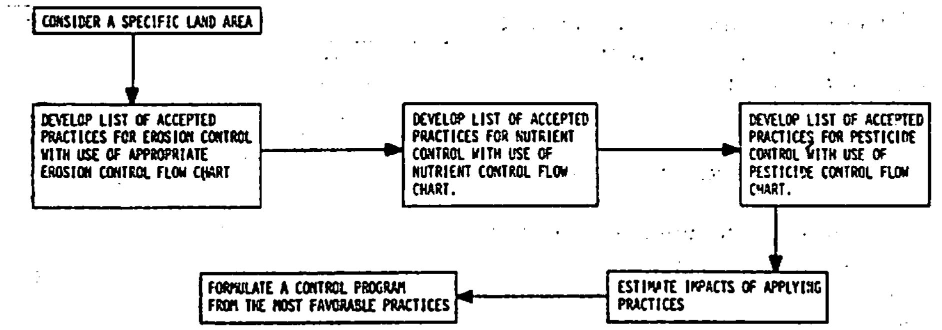

Figure 2. Master flow chart for developing programs to control nonpoint pollution from agriculture.

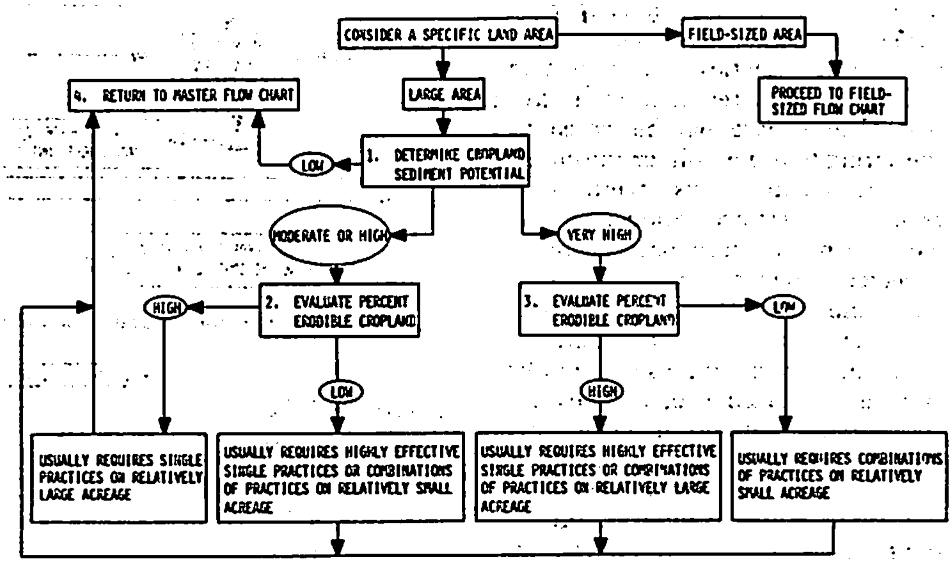

Figure 3. Flow chart for assessing soil erosion problems and controls over broad areas.

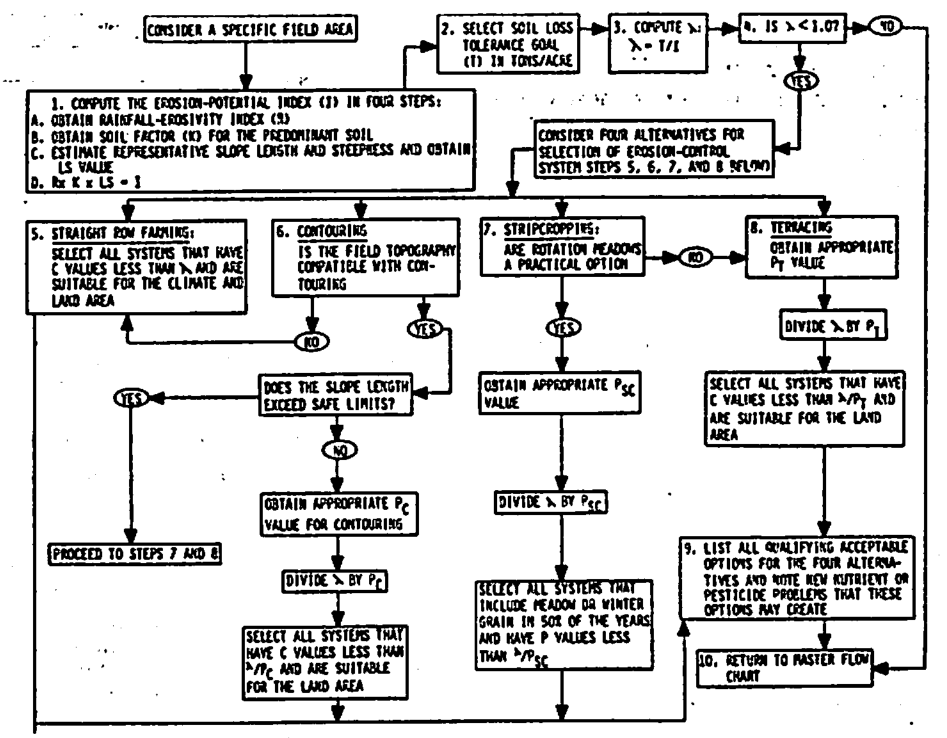

Figure 4. Flow chart for assessing erosion problems and selecting physically feasible control practices for field-size areas.

ical models is approaching the stage where they can decrease both the time and cost of planning (*1*).

Individual Fields

Many farm management practices that can be used for a certified plan to control water pollution are more or less site-specific. Their utility depends upon the particular farm or field where they are applied. Table 1 lists some control practices for erosion, nutrient, and pesticide pollution (*6*).

Use of these practices would be limited by crops, soils, climate, or economic conditions. For example, there may be no varieties of a crop being grown that are resistant to a given pest. The climate may be too cold in the spring to use no-till, or the climate may be too dry to use winter cover crops. The fertilizer application may have been too large because of unexpected drought. Sometimes weeds that cannot be controlled effectively with herbicides, like johnsongrass in corn, can prevent the use of no-plow systems. Replacing continuous row crops with rotations involving small grains or meadow can reduce income.

A field's topography further limits such practices as contouring, graded rows, terraces, grassed outlets, and contoured stripcropping. The common topographic requirement is one of relatively uniform slopes with few point rows. These hamper the use of large farm machinery. Other factors can also be important. For example, farming on the contour is most effective on slopes of 2 to 8 percent (*13*).

Some practices may control one source of pollution but create another. For example, terraces can control erosion, but the increased infiltration of water might create a nitrate leaching problem (*2*). Another example is the use of minimum tillage to reduce erosion. The increased use of fertilizer and pesticide that is usually necessary could pollute runoff.

Sediment from surface erosion is a major transport vehicle for nutrients and pesticides. The larger and heavier sediment particles drop out first, leaving the finer particles in suspension. These have higher chemical adsorbing capacities than the coarser particles. Also, organic matter containing nutrients and adsorbed pesticides is lightweight and tends to be associated with the fine particles. Thus, the sediment that reaches water

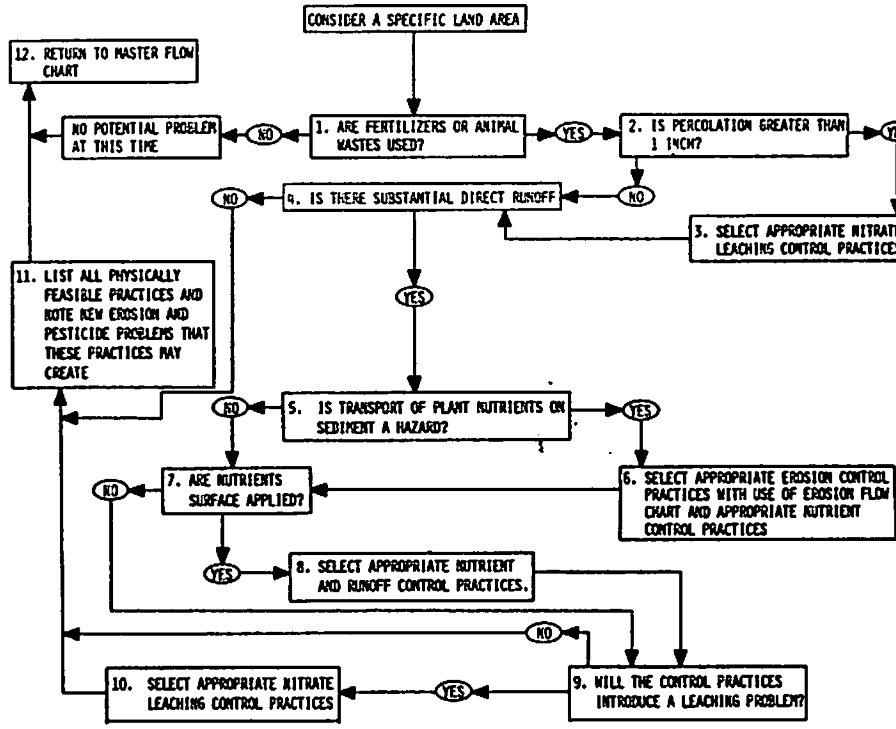

Figure 5. Flow chart for assessing nutrient pollution problems and controls.

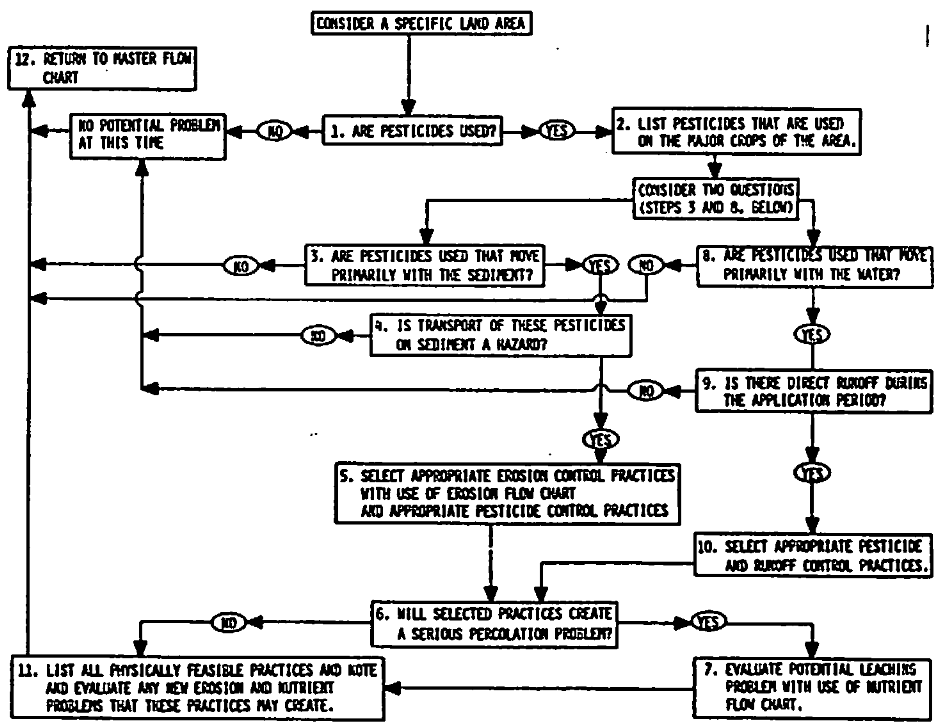

Figure 6. Flow chart for assessing pesticide pollution problems and controls.

Table 1. Some pollution control practices subject to possible crop, soil, climate, and economic limitations.

Control Practice for:		
Erosion	*Nutrients*	*Pesticides*
No-till planting	Eliminating excessive fertilization	Alternative pesticides
Conservation tillage	Timing nitrogen applications	Optimum placement
Sod-based rotations	Crop rotations	Crop rotations
Meadowless rotations	Animal wastes	Resistant varieties
Winter cover crops	Green legume crops	Controlled-release formulations
Improved soil fertility	Incorporating applications	Mechanical or biological control
Timing field operations	Slow-release fertilizer	Timing of applications
Plow-plant		

bodies is enriched in clays, organic matter, nutrients, and pesticides relative to the original soil matrix.

Enrichment is a factor that must be considered in evaluating the effectiveness of erosion control practices in reducing nutrient and pesticide pollution. Sediment loss could be reduced manyfold with only slight reduction in nutrient and chemical losses.

Our inability to predict accurately the transport of chemicals and sediment from a field to impacted water bodies poses one of the greatest problems in recommending site-specific control practices. Only part of the sediment from surface erosion on cropland reaches a stream or lake. The remainder is deposited on the flatter slopes of the field and other areas remote from the water body. In addition, channel erosion (gullies, streambank, etc.) often produces sediment that is completely and immediately available to the transport stream.

Even though the method to predict gross surface erosion (the universal soil loss equation) (*13*) is subject to sizeable error, it is far superior to the methods available for predicting the deposition of surface-eroded sediment during transport or for predicting the sediment from channel erosion. Therefore, the essential link between standards for the water body and the site of the controls (the cropland) is extremely tenuous. Application of standards necessary for a water body at the field exit rather than at the receiving body may result in overcontrol on the cropland and yet not control sediment in the receiving body.

Finally, elimination of soil loss from fields will not necessarily eliminate sediment in running waters. Clean, moving water can erode a stream channel's bottom and sides.

Use of Flow Charts

Many people with responsibilities for developing programs to control nonpoint-source pollution are not trained in the agricultural sciences. Therefore, we have developed a set of flow charts to help identify potential cropland pollution sources and select practices for pollution control (*6*). These charts have two important features. First, they help the user recognize possible pollution sources. Second, they help the user evaluate the consequences of any practice selected to control these sources.

The charts are not intended for use by pollution control officials in isolation, but as an agenda for a conference with local experts. Many questions posed in the charts require technical information that only those familiar with the subject and the area can answer. A workshop with people representing both agricultural and environmental interests is most appropriate.

Our discussion of the flow charts here is brief. For more detail consult the report "Control of Water Pollution from Cropland" (*6*).

Figure 2, the master flow chart, shows the general procedure to be followed. The scheme depends on answers to a set of sequential questions in four other complex flow charts.

One chart is for assessing erosion problems and controls over large areas. It requires information on cropland acreage and the land's erosion potential (Figure 3).

Another chart is used to evaluate erosion problems and select physically feasible control practices for field-size areas (Figure 4). Based on the universal soil loss equation, this chart requires data for factors relating to rainfall (R); soil erodibility (K); slope length and steepness (LS); crops (C); and such conservation practices as contouring (P_c), strip cropping (P_{sc}), and terracing (P_t).

The chart for assessing potential nutrient pollution requires information on the use of fertilizer or animal wastes, leaching, runoff, and erosion (Figure 5). Similar information is needed for the pesticide flow chart (Figure 6). A list of physically feasible control practices is developed in each chart. The practices are then evaluated to determine if any might cause additional problems.

The final list of physically feasible practices from each of the flow charts must be evaluated for social and economic impacts. Most college agricultural economics departments have computerized techniques to estimate the costs and returns to individual farmers for the various practices. The social and economic impacts of a control program at the area, regional, or national level are not easily estimated. Many interactions and secondary effects, both costs and benefits, must be considered for a useful evaluation.

Laws Require Pollution Control

Federal and state laws require that methods be developed for evaluating nonpoint-source pollution problems and for recommending control practices. Since the major responsibility for control lies with organizations covering large areas, such as river basins or states, the task is difficult at best.

Control methods can be classified into two groups: (1) methods applicable to broad areas, including education, incentives, taxation, and legal penalties, and (2) farming practices that are site-specific because of climate, topography, economics, etc.

Our set of flow charts should help users select farming practices to reduce nonpoint pollution and to evaluate their consequences.

REFERENCES CITED

1. Frere, M. H., C. A. Onstad, and H. N. Holtan. 1975. *ACTMO, an agricultural chemical transport model.* ARS-H-3. U. S. Dept. Agr., Washington, D. C.
2. Kreiter, C. W., and D. C. Jones. 1974. *Natural soil nitrate: The case of the nitrate contamination of ground water in Runnels County, Texas.* Proc., Second Nat. Ground Water Quality Symp. R. S. Kerr Environmental Res. Lab., Ada, Okla. pp. 179-188.
3. Miller, W. L., and J. R. Gill. 1976. *Equity considerations in controlling nonpoint pollution from agricultural sources.* Water Resources Bul. 12: 253-261.
4. Moldhenhauer, W. C., and C. A. Onstad. 1975. *Achieving specified soil loss levels.* J. Soil and Water Cons. 30(4): 166-168.
5. Oklahoma Water Resources Board. 1973. *Oklahoma's water quality standards.* Pub. 52. Oklahoma City, Okla.
6. Stewart, B. A., D. A. Woolhiser, W. H. Wischmeier, J. H. Caro, and M. H. Frere. 1975. *Control of water pollution from cropland.* Vol. I, *A Manual for Guideline Development* (ARS-H-5-1); vol. II, *An Overview* (ARS-H-5-2). U. S. Dept. Agr. and Environ. Protection Agency, Washington, D. C.
7. Taylor, C. R. 1975. *A regional market for rights to use fertilizer as a means of achieving water quality standards.* J. Environ. Econ. Manage. 2: 7-17.
8. U. S. Congress. 1972. *Federal Water Quality Pollution Control Act Amendments of 1972, Public Law 92-500.* Washington, D. C.
9. U. S. Department of Agriculture. 1971. *National inventory of soil and water conservation needs, 1967.* Stat. Bul. No. 461. Washington, D. C.
10. U. S. Department of Agriculture. 1974. *Agricultural statistics.* Washington, D. C. p. 421.
11. U. S. Public Health Service. 1962. *Drinking water standards of 1962.* Washington, D. C.
12. U. S. Salinity Laboratory. 1954 (reprinted 1969). *Diagnosis and improvement of saline and alkali soils.* Agr. Handbook 60. U. S. Dept. of Agr., Washington, D. C.
13. Wischmeier, W. H., and D. D. Smith. 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains.* Agr. Handbook 282. U. S. Dept. of Agr., Washington, D. C. □