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THE ECONOMIC IMPACT OF REMOTE SENSING DATA AS THE
SOURCE OF NONPOINT POLLUTION MONITORING AND CONTROL¹

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Summary

Nonpoint pollution of streams with sediment as a result of runoff from alternative uses of land has become a socially unacceptable product of economic activity as accessed by society currently. This report describes a research approach to economically achieve correction of the nonpoint pollution problem. The research approach integrates the economic model with those data which may be obtainable from remotely sensed sources.

The economic problem involves measurement of the direct benefits and costs associated with the changes in land management activities necessary to reduce the level of nonpoint pollution. These costs and benefits reflect changes in the net revenue of firms adopting the new management activities and the firms which incur alterations in the damage they received from either flooding or sediment deposition. In addition it is important to recognize the indirect economic impact on income and employment levels of those firms not directly affected by the change in management practices.

Remotely sensed data from ERTS-1 may provide some of the information required for the economic model which indicates efficient solutions to the nonpoint pollution problem. Three classes of data, i.e. soil categories, vegetative cover, and water turbidity, have the potential to be measured by ERTS-1 systems. There is substantial research which indicates the ability of ERTS-1 data to measure these classes of data under selected conditions. Certain limitations presently make it difficult to apply these techniques on a large scale, but if they are overcome remote sensing may provide a substantial amount of the data required to make efficient management decisions to reduce nonpoint pollution.

Introduction

Nonpoint pollution of streams with sediment as a result of runoff from alternative uses of land is a socially unacceptable product of economic activity in our present day society. The Federal Water Pollution Control Act Amendments of 1972 indicate that each state will need to develop a plan to control nonpoint pollution. This will include measures to reduce sediment levels in waterways. Correction of the sediment problem may contribute to a partial solution of the nutrient problem to the extent that nutrients are attached to the soil particles. Since society through its elected representatives has indicated a desire to correct this problem, it is important to achieve these corrections in an economically efficient manner in order to reduce the social cost and hence the tax burden on the citizen.

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This report describes a research approach to economically achieve correction of the nonpoint pollution problem. The research approach integrates the economic model with those data which may be obtainable through remotely sensed sources. The model requires information on both the benefits and the costs of alternative methods to correct the agricultural sources of the nonpoint pollution problem. This paper is divided into three sections. Section One describes the physical and economic system which must be understood to determine what benefits and costs should be measured to assess the economic consequences of achieving lower levels of nonpoint pollution. Section Two discusses the role of remotely sensed data in providing part of the information required to identify, measure, and monitor the problem. Section Three describes the economic subsystem and the remotely sensed data which have been selected to complete a detailed economic study.

The Physical and Economic System Interrelationships

The physical system is illustrated in Figure 1. The simplified physical system presented does not include detailed modeling of the hydrologic cycle, such as the relationship among precipitation, evaporation, transpiration, and percolation. These physical models have been presented in detail elsewhere and their inclusion here would add to the complexity of the illustration without adding to the clarity of presentation of the economic relationships. The simplified physical system suggests that precipitation falls on a variety of vegetative cover situations. This vegetative cover is managed in alternative ways, and it is located on a variety of soil types and slopes. As a result the subsequent runoff problem varies under different combinations of soil types, vegetative cover and management practices. Nearly every study undertaken to correct this sediment runoff problem involves some modification of vegetative cover or management practices to reduce soil losses and consequently sediment levels in the streams. These are the policy variables which can be adjusted most readily to achieve the desired reduction in sediment. (Another approach to control runoff, i.e. weather modification, will not be discussed here.)

Figure 2 describes the nonpoint pollution control system and the direct economic impacts. The correction of the problem of sediment runoff requires several steps and each of these steps involves certain costs. The first step involves determination of the exact relationship between the parameters of (1) vegetative cover, (2) soil type and slope, and (3) management practices and the sediment levels in waterways. This information may be obtained from sources which will be discussed in more detail in Section Two. The second step would involve interaction between agencies of government and private citizens to reach policy decisions about what changes in the policy variables should be encouraged to reduce sediment in streams. This might involve establishing subsidies or taxes to encourage adoption of the appropriate practices. For example, current Agricultural Stabilization and Conservation Service cost sharing policies encourage adoption. After the selection of these guidelines information would need to be disseminated to inform people about the most appropriate actions to correct the problem.

The third step may be the most costly part of the correction process because it involves the direct cost to the firm and/or consumer which occurs where land uses and management practices are altered to reduce sediment runoff. The fourth step involves checking to determine the extent to which firms have adopted the recommended practices, and assessing the changes in sediment load that have occurred as a result of this adoption. The last step involves the cost of corrective action required to encourage further adoption of appropriate practices. It may include a feedback loop which results in modification of the original guidelines as a result of problems incurred in encouraging adoption. These steps include all the economic costs which must be determined to assess the total direct costs of alternative methods to control nonpoint pollution.

When these costs are incurred they result in direct economic impacts which must be assessed to determine social benefits. The first economic impact indicated in Figure 2 involves the changes in net revenue that occur for firms adopting policies which reduce nonpoint pollution. For example, if a firm switches land use in a field from corn production to grass, this results in lower revenue while reducing sediment runoff from the land. Other changes in management practices may result in increases in revenue to the firms. Both increasing and decreasing revenue must be accounted for to analyze the change in net benefits. In addition to changes that occur for the individual firm most directly involved in changing policy parameters, there are external effects of the policy action on downstream damage functions. The most closely related change occurs in the damage functions affecting human health, sedimentation, aquatic life, and aesthetic characteristics as the sediment level is reduced. The resulting reductions in the damage functions constitutes direct benefits of reduction in sediment load in streams. Another change occurs in the damage functions from flooding which are inadvertently modified by the policy actions taken to correct sediment runoff. For example, the shifting of land use from corn to grass reduces the sediment runoff, and also flattens and delays the peak volume of runoff which reduces flooding.

In contrast to the information presented in Figure 2, Figure 3 identifies the indirect economic impacts of the policy actions taken to reduce nonpoint pollution. The firms directly involved in

modification of revenues or damage functions are not the only ones which incur economic changes. There is an additional indirect impact upon the income and employment in other firms which provide inputs or use the outputs of the firms directly affected. For example, an indirect effect of shifting from corn production to grass production would be a change in fertilizer, machinery, pesticide, and herbicide purchases of the firm. This would change the net revenue of the firms producing these inputs. Similarly, the firm purchasing corn or grass could incur changes in their net revenue because changes might occur in the quantity and/or price of these products. The net change in social welfare involves a comparison of the change in the sum of direct and indirect costs to the direct and indirect benefits.

Feedback loops occur as indicated in Figure 3 which increases the complexity of the indirect impact system. Feedback loop a involves changes in the price and availability of inputs to firms directly involved in policy variable changes. Feedback loop b relates to the changes in employment and wages for firms affected by the externalities involved in sediment damage function reduction. Feedback loop c involves net revenue changes for firms involved in construction in the floodplains and other firms impacted by a reduction in the flood damage function. Generally the feedback loops are not measured due to the difficulty of developing a complete general equilibrium model of the economic system.

Agricultural Management Practices

Since a substantial portion of the direct cost of changing management practices to reduce soil loss occurs for the individual firm (illustrated as step three in Figure 2) it is appropriate to briefly consider the impact of these changes on sediment and cost. A number of studies have been completed which show the relationship of the vegetative cover and management practices to soil loss. Table 1 summarizes research on this relationship by Laflen and Moldenhauer [6]. Note that a vegetative cover of continuous grass-alfalfa sod gives soil loss levels of only a fraction of a ton per hectare. In contrast, corn-oats-meadow sequence will give soil losses of from two to three tons per hectare depending on slope gradient and length. Sediment losses from a corn-corn-soybean system is 5 to 6 times that from corn-oats-meadow. However, by changing management practices to leave two to six tons per hectare of residue on the land it is possible to substantially reduce soil loss.

Mulching or leaving residue on crop land is only one of the management practices that have been used to reduce soil loss. Other practices which have given very good results in decreasing sediment are ridge planting, till-planting, other minimum tillage or no-tillage practices and terracing. Some of these systems require fewer numbers of field operations which lower the cost per hectare.

For some practices, information is available on the effect of management practices on operating costs as well as on soil loss. Table 2 summarizes data from several studies of operation costs. For example, if wheel-track planting is used, costs are slightly less than for conventional methods' and a good reduction in soil loss is obtained. Costs for no-tillage systems are less than either conventional or wheel-track planting and soil loss is only a small percentage of that resulting from conventional practices (though even with conventional tillage soil loss is not high in this particular area.).

The operating costs per acre only measure part of the direct economic impact of these management practices. It is necessary to examine the changes in yield which results from different practices because this affects the revenue of the farm firms. The net revenue change to the farm firm takes into consideration both changes in costs and revenue.

Remotely Sensed Data for System Input Information

Remotely sensed data may be helpful to provide information inputs for three of the steps (1, 2, and 4) indicated in Figure 2, to correct the sediment pollution problem. These steps include the initial establishment of the relationship between sediment levels in streams and land management activities in the watershed. This is the micro physical relationship which must be measured in order to determine what the exact impact of changing management practices will be upon the sediment load in the stream or lake. The second step where remotely sensed data might be used involves the more macro description of land use in a watershed. Through identification of the crops being produced and the acreage devoted to each it is possible for policy makers to assess the magnitude of change which can occur when a specific management practice for a particular crop is introduced in the watershed. The fourth step where remotely sensed data might be helpful involves monitoring the changes that occur in the watershed to see if modifications need to be made in the incentive systems initially established to encourage adoption of the sediment reducing practices.

Remotely sensed data sources may provide information about three aspects of the problem which are important in controlling sediment levels in water. Previous research suggests vegetative cover and soil categories may be determined remotely under certain conditions. Furthermore, the sediment

levels in lakes have been measured with ERTS-1 data. Remotely sensed data may be particularly useful for two of these three aspects, i.e. vegetative cover and sediment in the water. The constantly changing nature of the sediment level in the water and the vegetative canopy suggest that these aspects of the problem need repeated up-dating of information. The soil type, in contrast, needs to be determined only once and no up-dating is required. Figure 4 illustrates the relationship between these types of information and the problem.

Remote Sensing of Vegetative Cover

The use of remotely sensed data for measuring the nature and extent of vegetative cover may be the most useful application for the nonpoint pollution problem. It is useful not only in determining the potential soil losses that may occur in a watershed, but it serves a second role in monitoring the adoption of practices to reduce nonpoint pollution. Several researchers have reported the use of ERTS-1 for assessment of vegetative cover.

Horton and Heilman [3] working in Southeastern South Dakota did digital analysis of August 15 ERTS-1 imagery in selected areas of bands 4, 5, 6 and 7. They found that it was possible to distinguish between corn and soybeans by using bands 6 and 7.

In Southwestern Michigan, Safir, et.al.[10] used an ERTS-1 frame collected on August 25. Major crops were reaching maturity at this point and forests had a dense canopy. They found the recognition process to be successful for each type of vegetation with a dense green canopy—in this case forests, corn and soybeans. Bare soil was also recognizable as a category but recognition of species was difficult in senescent vegetation. This points up one difficulty in remote sensing of vegetative cover. Since accuracy of classification depends on the stage of growth, optimum times for collecting data will vary from one species to the next.

Bauer and Cipra [1] point out in relation to their crop identification work in Northern Illinois, "One of the important advantages of computer processing of multispectral scanner data is that data from two or more dates can be included in the same analysis. . . In many cases the addition of temporal information in this manner can be expected to improve classification performance." In their study, Bauer & Cipra covered a 2000 sq. mi area and by using temporal and spatial data in addition to the spectral information were able to achieve improved results. They distinguished three classes: corn, soybeans, and other, and found the temporal analysis with August, September, and October data markedly improved recognition of "other".

Detection of field conditions which might be helpful in determining management practices seems to be more difficult. Johnson and Coleman [4], working in Imperial Valley, California, used sequential ERTS-1 imagery taken on August 26, October 1 and November 6, to identify several field conditions: growing crops, wet soil seeded crops, plowed soil, bare soil, and harvested stubble. Their results in large irrigated fields is more difficult to replicate when small irregular fields are encountered in other regions of the country. Care must be taken in recognizing the problems of using remotely sensed data in an operational mode on a large scale. However, there is potential for using it for vegetative cover identification on a large scale.

Remote Sensing of Turbidity

Measurements of turbidity levels in large water bodies have been achieved with ERTS-1 data. Turbidity measurements may not provide as much detail as required since it does not necessarily separate the organic from the inorganic particles in suspension. In addition, the size of soil particles in the inorganic portion of the turbidity level may not be identified by the remotely sensed data. These problems make the current application of ERTS-1 data on turbidity to the problem of nonpoint pollution rather difficult. However, some applications of ERTS-1 data to measuring the turbidity levels have been indicated in recent publications. Data from several ERTS-1 passes were used by Weisblatt, et.al. [12] to measure turbidity in Galveston and Trinity Bay, Texas. They found that MSS channels 5 and 6 yielded the most accurate measurements of turbidity in the 20 to 120 ppm range. Yarger, et.al., [13] working on two reservoirs in Kansas has achieved reliable prediction of suspended loads up to 900 ppm with ERTS-1 data from 23 cloud-free passes. In analysing their data they found that MSS band ratios were superior to absolute levels in measuring the sediment.

Remote Sensing of Soil Categories

Different soil categories exhibit spectral differences which are due to moisture content, texture, organic matter content and other chemical-physical properties. Research by Cipra [2] indicated four to six groupings of soil associations could be delineated on ERTS-1 imagery in Tippecanoe County, Indiana. In general band 7 gave more soils information than band 5. Data collected when the maximum percentage of soil is without cover and in a freshly tilled

state provides the best results in delineating these groups.

The soil category information available presently from ERTS-1 could be helpful when more detailed information on soil type was not available from other sources. Since the soil type does not change once it has been identified that information can be utilized to indicate potential acreage of different management practices, crop rotation, and crop species which could be utilized in a watershed.

Specific Economic Submodel

To determine the direct economic impact of alternative control practices it is necessary to specify the social value of land management practices. The direct costs of instituting the management practices are a function of the size of the operation, the prices of the factors of production and the volume of productive factors utilized. The changes in gross revenue to the firms adopting new management practices vary due to climatic conditions, soil type, yield, and the prices received for the product produced. Since certain management practices are restricted to particular soil associations and/or slopes their adoption is influenced by the number of acres with these characteristics in the watershed.

Under these conditions an economic model requires certain characteristics to appropriately describe the problem. It should be a multiple objective model which permits comparison of the changes in net revenue which occur when soil losses are reduced. This can be achieved in a linear programming framework with an objective function of net economic benefits and constraints which include the sediment loss and acreages of land suitable for different management practices. The stochastic nature of the problem is introduced through variable yields which affect both the economic value of individual management activities entering the objective function and the soil loss per hectare in the constraints.

Economic models with some of these characteristics have been developed and applied to similar problems by other researchers. Kaiser, et.al. [5] developed a linear programming model to analyze alternative plans for the management of range resources. Their objective function was to minimize the cost of management while achieving levels of environmental quality specified a priori as constraints in the model. Miller and Byers [7] developed a linear programming model with the net revenue of agricultural firms as the objective function. This model was used to develop trade-off functions between soil loss and net revenue for the firms located in the watershed. Narayanan and Swanson [9] applied a linear programming model to agricultural firms in a 1200 acre watershed to determine their response to alternative levels of runoff control. Work by these researchers indicate the feasibility of applying linear programming models to nonpoint pollution problems.

Economic research is underway at the Laboratory for Applications of Remote Sensing at Purdue University which incorporates the desirable physical and economic characteristics described above. Remotely sensed data is being utilized where appropriate to provide some of the data required for this research. The model includes the stochastic nature of the yield variability, as well as the usual nonstochastic parameters. The economic model is being applied to agricultural operations in Benton and Owen Counties in Indiana. Since these two counties have different soil types, vegetative cover, farm sizes, crop yields, and management practices, comparison of the two counties indicates changes that occur in activities in the optimum system design. It will permit assessment of the magnitude of change from current practices which will be necessary to achieve alternative levels of reduction in nonpoint pollution. The model is currently being run to provide insights into both of these issues.

TABLE I. ESTIMATED SOIL LOSSES FOR SELECTED CROPPING SYSTEMS AND SLOPE CHARACTERISTICS.^a

Cropping systems	Slope Length and Gradient			
	Three Percent Slope 120 m. Length	60 m. Length	Nine Percent Slope 60 m. Length	40 m. Length
Fallow	78.4	62.7	212.8	168.0
Corn-Corn-Soybean				
No surface residue	29.1	11.2	76.2	35.8
2.2-3.4 Metric Tons/Hectare Residue ^b	22.4	9.0	60.5	29.1
4.5-6.7 Metric Tons/Hectare Residue ^b	15.7	6.7	42.6	20.2
Corn-Oats-Meadow ^c	4.5	2.2	13.4	6.7
Continuous Grass-Alfalfa Sod	0.2	0.1	0.9	0.4

^a[6]

^bSurface residue covers 66% of the soil.

^cResidue plowed under for corn.

TABLE II. COSTS AND REDUCTIONS IN SOIL LOSS, FOR DIFFERENT AGRICULTURAL MANAGEMENT PRACTICES.^a

	Conventional	Wheel-track Planting	Till Plant	No Tillage
Annual Cost of Machinery	\$23,200	\$23,200	\$22,500	\$22,000
Operating Costs \$/Hectare	407.20	404.34	401.94	399.67
Amount of Soil Loss Compared with Conventional Tillage (%)	100%	24.1% ^b 56.3% ^c 84.6% ^d	35.3% ^e	2.0% ^e 6.4% ^e

^a[8]

^bIn Fayette County, Wisconsin; cultivated.

^cIn Russell County, Indiana; cultivated.

^dIn Russell County, Indiana; no cultivation.

^eIn Bridgeport County, Nebraska.

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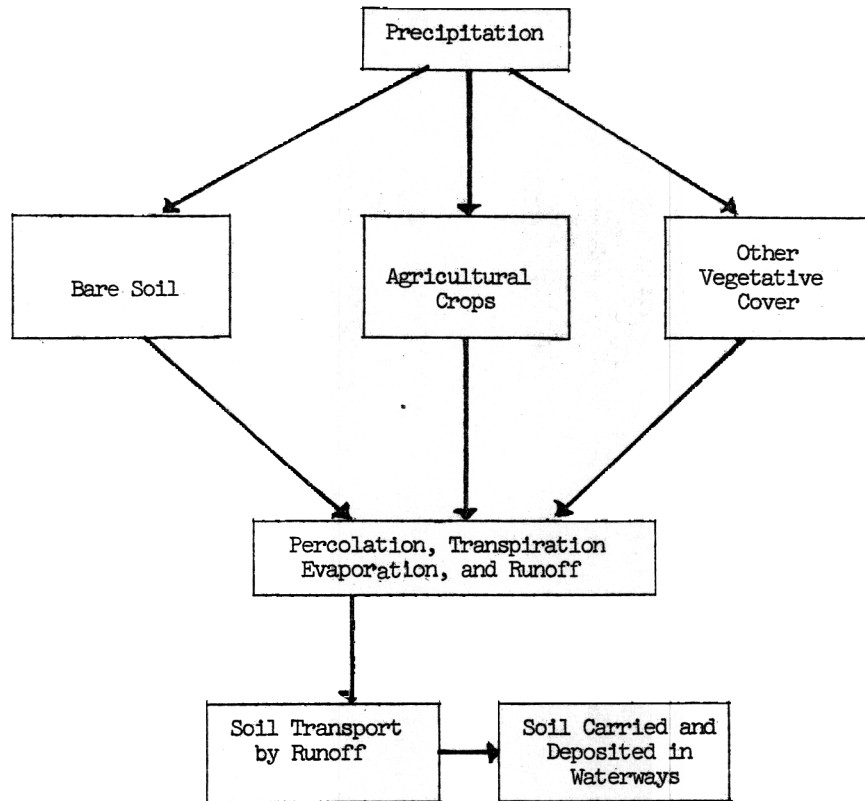
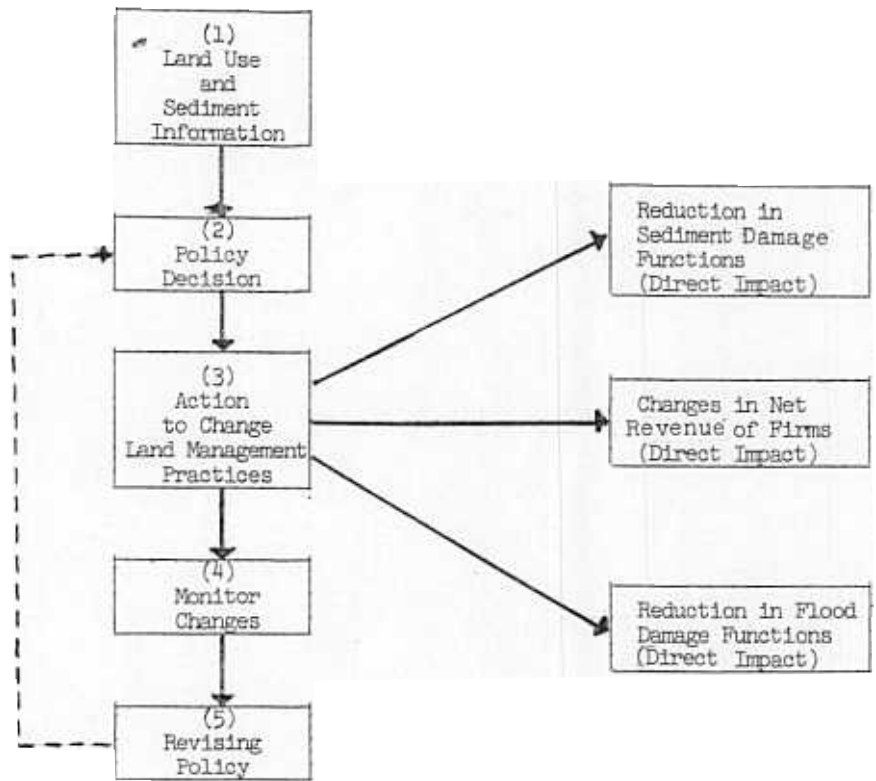
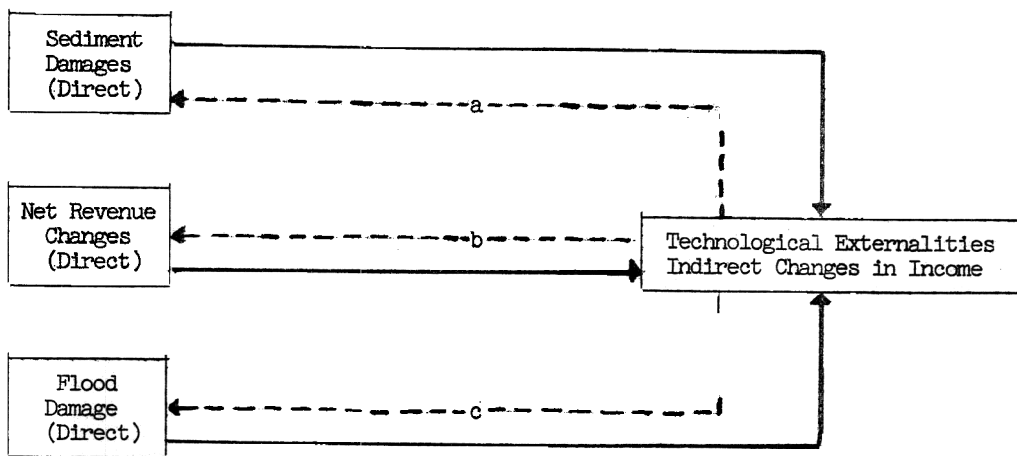


Figure 1. The Physical System.



Flow —————→
 Feedback - - - - -→

Figure 2. Nonpoint Pollution Control System with Direct Economic Impact.



Flow —————→
 Feedback - - - - -→

Figure 3. Direct and Indirect Economic Impact

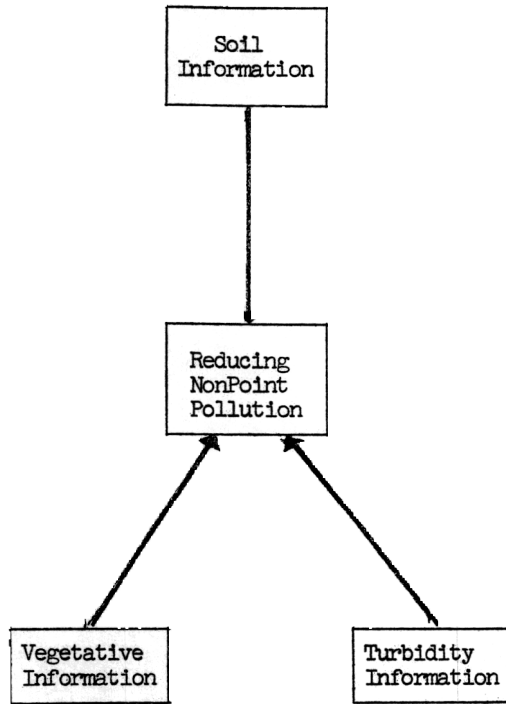


Figure 4. Physical Information to Assess Methods to Reduce NonPoint Pollution.