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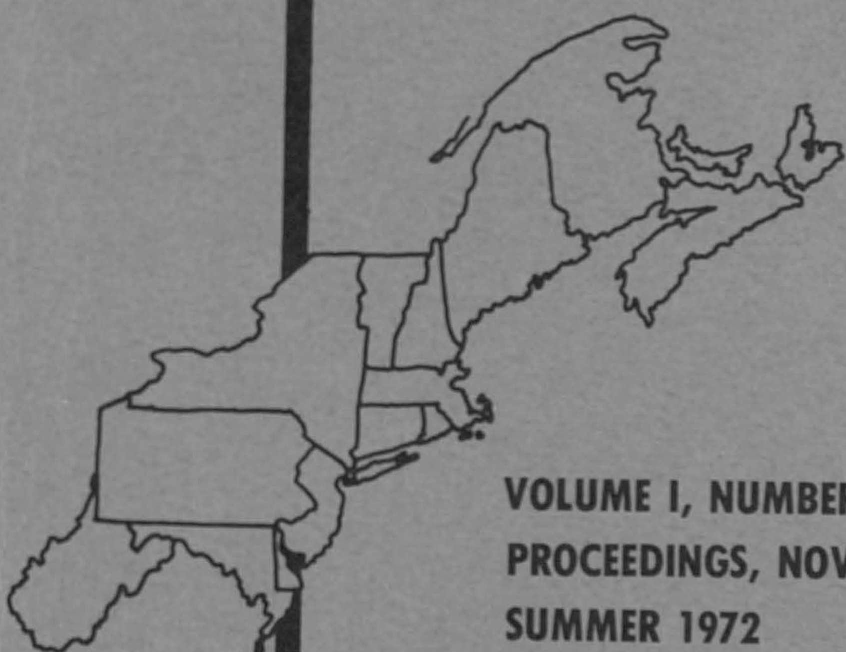

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CONTROLLING SEDIMENT AND NUTRIENT LOSSES FROM AGRICULTURAL LANDS

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Quality of the environment is measured and evaluated by some criteria, such as composition, and by performance [1]. However, quality, in terms of composition and/or performance, as a factor in environment has no meaning except as it relates to some use of the environment and scale of health, happiness and aspirations of man. For example, an environment is regarded as having a lower quality than 15 years ago because of an increase in the phosphorus contained in surface water and/or a change in the species of fish present in surface waters. In terms of performance, a particular environment (watershed) is not producing enough because the soil and phosphorus losses are twice the acceptable rate. Furthermore, the composition and performance of an environment are related. Measurement of the nitrogen and phosphorus content of water helps to determine if a given water resource can be used (perform) in a particular way.

It is this ability to measure the content and performance of an environment that enables one to determine if there is a possible conflict between waste constituents (content) and constituent requirements (performance) among uses of a particular resource. The conflicts between uses of a water resource are the result of three important and fundamental characteristics of the resource. These characteristics are: (1) the quality heterogeneity of water supplies; (2) the quality differentiation of demands by uses; and (3) the linkage between water uses.

The above characteristics can be explained by the ability of water to incorporate and transport, to some extent, everything it comes in contact with. Therefore, its every use whether natural, industrial or domestic has some effect on the constituent composition of a water supply. As a result, constituents and their levels will vary among water supplies. In turn, each user of a water supply desires different constituents in that supply or at least vary in their tolerance of a certain constituent. For example, dissolved oxygen is essential for a fish habitat but may be detrimental in cooling water because of increased corrosion associated with high oxygen levels [2]. This suggests that "water quality" has no absolute definition but that quality of a water supply can only be measured by content as it relates to the uses (performance) to which it is to be put.

Next-Use Concept and Pollutants

Viewed in an economic context, a water supply is regarded as an economic resource only when it exhibits the characteristic of scarcity and thereby needs to be allocated among competing ends. Realizing that water supplies and demands are quality differentiated, there is an increasing awareness that scarcity is a function of quality as well as physical quantity. Viewed in this manner, the waste constituents from one use may affect the quality of a water supply such that it increases the cost to or precludes the next use of that supply. This constitutes water pollution which is a problem of external diseconomies. This means the initial use of a water supply failed to consider the impact of its effluent so that additional costs must be borne by the next use to achieve the quality required for adequate performance by that use.

Therefore, the uses of a water supply must be considered in defining pollution and establishing water quality levels. Under the Next-Use Concept, degradation or pollution occurs when the effluent of an initial use adversely affects the next use to which the resource, i.e., water, may be put in meeting the needs of man [3]. If a conflict occurs between uses, an analysis reflecting both the costs and benefits of alternative levels of quality and methods of control should be undertaken. However, if the initial use has no adverse effect on the next uses, then there is no pollution and no need for establishing levels of water quality.

The next-use concept means that quality of a water supply will vary from area to area and from time to time depending on the uses of that supply. It can also be used in minimizing the costs of obtaining given quality levels, by expressing quality criteria (requirements) of uses in physical terms and regarding them as proxies for societal goals [4]; thereby, treating them as constraints upon a cost minimization objective.

Pollutants from Agricultural Runoff and Their Control

The major purpose of agriculture is to manage part of the environment in producing the food and fiber demanded by mankind [5]. Therefore, agricultural production and environmental research is not new. In the past, however, this research has concentrated on efforts to increase production and has largely ignored the effects of production on the environment. An example of this is a study by Duley [6] in 1926 which was concerned with runoff water as a means of depleting soil nutrients. Compare this with recent studies by Weidner, et. al. [7] and Timmons, et. al. [8], which are concerned with nutrients from agricultural runoff as a factor in stream pollution.

The increased concern over the effect of agricultural production on the environment has resulted in society asking agriculture, as well as other segments, to reassess their goals and to incorporate into them their role in quality management. Thus, it appears that in the future agriculture will not only have to increase production but in doing so will be required to maintain minimum quality characteristics. Therefore, agriculture must move toward management systems that will maintain both high production and environmental quality [9].

While agriculture's potential in polluting our surface waters is recognized, little is known about agriculture's contribution to the water quality problem. This ignorance and potential of agriculture's role in water quality management arises primarily from the combination of: (1) agricultural production being scattered over most of the nation and (2) the rapid adoption of modern technologies with their residues and fall-outs. Although some information is becoming available concerning agriculture's contribution to environmental quality, the important and difficult task remaining is that of relating its contribution to soil, climate, crop rotations, land practices, chemical and fertilizer use, and animal waste disposal practices [10].

However, when the sources of waste constituents entering surface watercourses are enumerated, agriculture is, with increased frequency, being listed as a major contributor. Sources of potential pollutants from agricultural production are [11]:

1. Sediment from erosion
2. Plant nutrients
3. Livestock manure
4. Pesticides
5. Waste from processing plants
6. Air pollution, primarily odors and dusts.

Assuming a concern for achieving specified quality levels for constituents from agricultural runoff, any of the first four waste constituents above could have served as the focal point of the thesis [12]. However, sediment and phosphorus were the constituents selected for intensive study. These are likely candidates because of the magnitude of sediment as a pollutant, the increased emphasis on phosphorus as a likely key nutrient in limiting growth of aquatic plant life and the diffuse source of such pollutants from agricultural runoff as compared to point sources (i.e., processing plants, feedlots, etc.). Furthermore, what appears to be important in the influence of sediments on water quality, in addition to the physical damages, involves the phosphorus', as well as nitrogen and pesticides, adherence to the sediment and its relationship with the phosphorus in solution [13, 14].

To regard sediment and phosphorus from agricultural lands as pollutants requires a means of transporting these elements to the point of use and in amounts sufficient to adversely affect other uses. Since runoff from agricultural land is capable of moving constituents (in this case sediment and phosphorus) over time and space, the question which arises is: "How would different levels and mixes of agricultural inputs and practices affect important environmental variables of concern to society?" Strategic then to analyzing agriculture's role in water quality management is: (1) the identification and measurement of agricultural pollutants associated with various agricultural practices; (2) the identification of next uses and their water quality criteria and (3) the specification of the physical linkage system. Only with this type of information can agriculture's contribution to changes in particular elements affecting water quality be determined and evaluated in a relevant manner.

Having designated sediment and phosphorus as the pollutants of prime concern in agricultural runoff, the rest of this paper is devoted to the presentation of the model and the results.

Development and Results of a Quality Management Model

Surface runoff from agricultural cropland is the primary transport agent of sediment entering surface waters. Therefore, planning for the control of sediment requires knowledge of the relations between those factors that cause loss of soil and those that help reduce such losses on cropland. Toward this end the "universal soil-loss equation" [15] was developed to provide specific guidelines needed to help select appropriate control practices for particular fields. In predicting these losses from individual fields, the equation takes into consideration rainfall, soil type, slope length and gradient, cropping practices and erosion-control practices. However, the estimation of sediment losses from a watershed is less reliable because the complex soils, land-use patterns and topography present problems in interpretation and factor evaluation that requires further research. By breaking the drainage area into a series of relatively homogenous land tracts, such as land capability classes by soil types, the erosion equation provides a methodical means of bringing the effects of rainfall, soils and land use into the computation of sediment losses. An additional problem is that the above are gross estimates of the quantity of soil moved from its original position. Since the prime interest concerns only that portion of sediment actually entering the watercourse, the initial sediment loss estimates must be adjusted for that portion deposited in sod waterways, fence rows, etc. To predict that portion delivered to the stream a delivery ratio of .25 developed by Seay [3] is used. Delivery ratios of .20 and .30 are also used to check its sensitivity.

The "universal soil-loss equation" and "delivery ratio" will give estimates of sediment being delivered to the watercourse under different cropping and land practices but nothing similar to this exists for predicting phosphorus losses in agricultural runoff. However, a review of the literature did point out three important characteristics of phosphorus losses from agricultural cropland:

1. A positive relationship between soil and phosphorus losses [7, 16].
2. Phosphorus is readily absorbed by soil particles [17].
3. Erosion is selective in removing phosphorus [18].

Considering the above properties of phosphorus, estimates of phosphorus losses were obtained by applying the level of phosphorus in the surface soil and an enrichment ratio1/ to the sediment losses predicted by the soil loss equation and the delivery ratio. In this manner assuming a given stream flow, estimates of both sediment and phosphorus contributions to the stream were obtained for various cropping, tillage and erosion-control practices.2/

For water use conflicts to result from the estimated sediment and phosphorus levels there must be a physical system linking the water uses. The physical linkage system of surface water pollution for the potential pollutants of sediment and phosphorus and the control methods is illustrated in Figure 1.

To operationalize the model of the physical system, several parts of the physical system are assumed to be constant. In the source section, rainfall, soil type, slope length, and slope gradient are assumed constant. In the stream carriage system, the delivery ratio, stream flow, and the transport of sediment and phosphorus are assumed constant. In the use section, quality and quantity levels are specified for the uses considered. These fixed factors relate primarily to relationships taken from the physical sciences and those which require simplifying assumptions. This leaves only soil conservation practices and water supply treatment as variables in the physical system, the justification being that both soil conservation practices and water supply treatment are important water quality management techniques.

In Table 1 the alternative methods allowed for controlling sediment and phosphorus losses by capability classes are presented. The question of which control methods and at what level depends on (1) the level of water quality desired; (2) the unit cost coefficients of alternative methods and (3) the technical coefficients of the alternative methods. A summary of the cost coefficients are presented in Table 2. Sediment and phosphorus coefficients were also estimated for each management system listed in Table 1 using the soil-loss equation and phosphorus enrichment ratio as explained above.

Upon developing the cost and technical coefficients for the alternative control methods, each of the techniques are regarded as an activity and linear programming is then the appropriate analytical tool to use.3/

1/ An enrichment ratio is the increase in the content of constituents in the eroded soil over that in the original surface soil.

2/ For a more detailed discussion of the development of sediment and phosphorus coefficients under alternative practices, see [5, Chapters 3 and 5].

3/ For a detailed presentation of the programming model, see [5, Chapter IV].

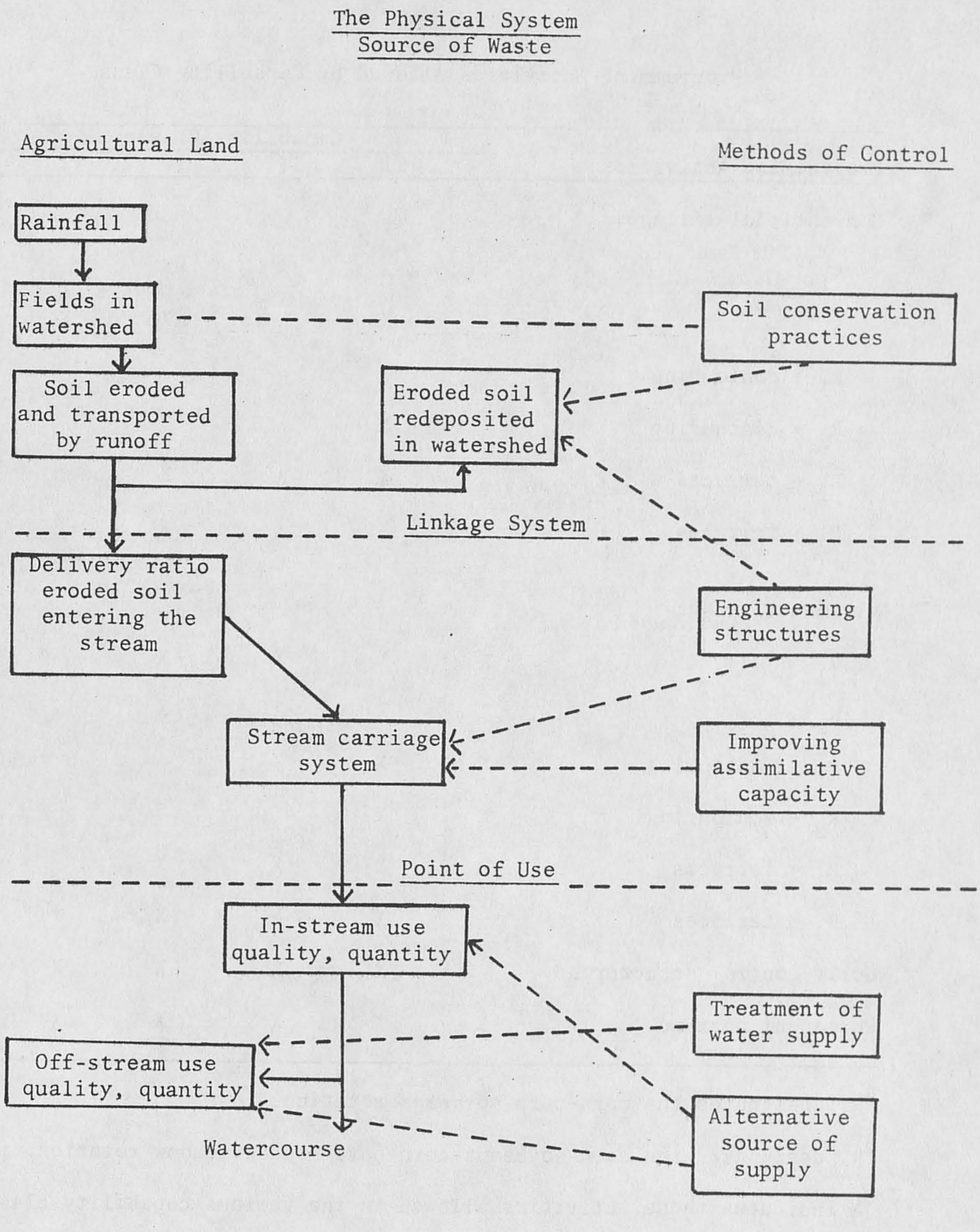

Figure 1.
Diagramatic Presentation of Physical Linkage System for Sediment and Phosphorus From Agricultural Lands

Table 1.
Programming Activities Allowed by Capability Class

Programming Activities	Capability Classes I	II	III	IV	VI	VII
Conventional tillage:						
R_1[a]	X[c]	X	X	X		
R_2[b]	X	X	X	X		
R_1 + contouring	X	X				
R_2 + contouring	X	X				
R_1 + terraces		X	X	X		
R_2 + terraces		X	X	X		
Minimum tillage:						
R_1[a]	X	X	X	X		
R_2[b]	X	X	X	X		
R_1 + contouring	X	X				
R_2 + contouring	X	X				
R_1 + terraces		X	X	X		
R_2 + terraces		X	X	X		
Gully control structures		X	X	X	X	X
Permanent pasture	X	X	X	X	X	X

[a]R_1 designates the corn-corn-soybeans rotation.

[b]R_2 designates the corn-soybeans-corn-oats-meadow-meadow rotation.

[c]X indicates those activities allowed in the various capability classes.

Table 2.
Opportunity Cost of Alternative Crop, Tillage and Land Practice Systems

Capability Class	Management System	Production Costs						
		Gross Revenue ($/ac)	Machine, and Labor ($/ac)	Seed, Chemical and Fertilizer ($/ac)	Land Charge ($/ac)	Terrace Cost ($/ac)	Net Return ($/ac)	Opportunity Cost ($/ac)
I	Conv. till.-R_1 a/	114.24	30.74	19.70	36.30	-	27.50	6.38
	Conv. till.-R_2 b/	90.21	28.50	13.37	36.30	-	12.04	21.84
	Conv. till. + contour-R_1	114.24	34.49	19.70	36.30	-	23.75	10.13
	Conv. till. + contour-R_2	90.21	32.39	13.37	36.30	-	8.15	25.73
	Min. till.-R_1	114.24	24.36	19.70	36.30	-	33.88	-
	Min. till.-R_2	90.21	24.35	15.58	36.30	-	13.98	19.90
	Min. till. + contour-R_1	114.24	26.87	19.70	36.30	-	31.37	2.51
	Min. till. + contour-R_2	90.21	27.50	15.58	36.30	-	10.83	23.05
	Perm. past.	57.40	-	18.67	36.30	-	2.43	31.45
II	Conv. till.-R_1	109.74	30.74	19.70	33.48	-	25.82	6.38
	Conv. till.-R_2	87.08	28.50	13.37	33.48	-	11.73	20.47
	Conv. till. + contour-R_1	109.74	34.49	19.70	33.48	-	22.07	10.13
	Conv. till. + contour-R_2	87.08	32.39	13.37	33.48	-	7.84	24.36
	Min. till.-R_1	109.74	24.36	19.70	33.48	-	32.20	-
	Min. till.-R_2	87.08	32.39	13.37	33.48	-	7.84	24.36
	Min. till. + contour-R_1	109.74	26.87	19.70	33.48	-	29.69	2.51
	Min. till. + contour-R_2	87.08	27.50	15.58	33.48	-	10.52	21.68
	Conv. till. + terrace-R_1	109.74	30.74	19.70	33.48	7.40	18.42	13.78
	Conv. till. + terrace-R_2	87.08	28.50	13.37	33.48	6.80	4.93	27.27
	Min. till. + terrace-R_1	109.74	24.36	19.70	33.48	7.67	24.53	7.67
	Min. till. + terrace-R_2	87.08	24.35	15.58	33.48	6.92	6.75	25.45
	Perm. past.	56.00	-	18.67	33.48	-	3.85	28.35

a/ R_1 designates the corn-corn-soybeans rotation.
b/ R_2 designates the corn-soybeans-corn-oats-meadow-meadow rotation.

Table 2 (continued)

Capability Class	Management System	Gross Revenue ($/ac)	Production Costs: Machine, and Labor ($/ac)	Seed, Chemical and Fertilizer ($/ac)	Land Charge ($/ac)	Terrace Cost ($/ac)	Net Return ($/ac)	Opportunity Cost ($/ac)
III	Conv. till.-R_1	96.38	34.49	19.70	24.80	-	17.39	7.62
	Conv. till.-R_2	76.38	32.39	13.37	24.80	-	5.82	19.19
	Min. till.-R_1	96.38	26.87	19.70	24.80	-	25.01	-
	Min. till.-R_2	76.38	27.50	15.58	24.80	-	8.50	16.51
	Conv. till. + terrace-R_1	96.38	30.74	19.70	24.80	12.11	5.28	19.73
	Conv. till. + terrace-R_2	76.38	24.36	19.70	24.80	13.11	14.41	10.60
	Min. till. + terrace-R_1	96.38	24.36	19.70	24.80	13.11	14.41	10.60
	Min. till. + terrace-R_2	76.38						
	Perm. past.	49.00	-	18.67	24.80	-	5.53	19.48
IV	Conv. till.-R_1	72.35	34.49	19.70	18.15	-	0.01	7.62
	Conv. till.-R_2	57.14	32.39	13.37	18.15	-	-6.77	14.40
	Min. till.-R_1	72.35	26.87	19.70	18.15	-	7.63	-
	Min. till.-R_2	57.14	27.50	15.58	18.15	-	-4.09	11.72
	Conv. till. + terrace-R_1	72.35	30.74	19.70	18.15	12.04	-8.28	15.91
	Conv. till. + terrace-R_2	57.14	28.50	13.37	18.15	10.44	-13.32	20.95
	Min. till. + terrace-R_1	72.35	24.36	19.70	18.15	13.85	-3.71	11.34
	Min. till. + terrace-R_2	57.14	24.35	15.58	18.15	11.31	-12.25	19.88
	Perm. past.	39.00	-	18.67[e]	18.15	-	2.18	5.45
VI	Perm. past.	30.00	-	18.67[e]	10.09	-	1.24	-
VII	Perm. past.	27.00	-	18.67[e]	6.05	-	2.28	-
	Gully							1,171.21

Several sediment and phosphorus constraints were used, with the three most stringent sediment and phosphorus constraints based on municipal use, a warm water fish habitat and contact recreation, respectively. Having specified the constraints the program was run initially to give solutions for various suspended sediment levels only and then with the phosphorus constraints added. These runs were made using three different delivery ratios and without "minimum tillage" activities in the final six runs. Solutions obtained in this manner made it possible to (1) derive total cost functions for the range of quality levels considered, (2) determine the impact of phosphorus constraints on total cost and at what level it becomes the constraining value, (3) observe the different activities which are present in the optimal solutions, and (4) observe the changes in the shadow price of the quality constraints (marginal cost) over the range of quality levels considered. Furthermore, the use of three different delivery ratios provides a sensitivity analysis of the program to changes in a physical parameter while the runs without "minimum tillage" indicate the impact of neglecting a modern technology.

Upon observing all of the computer results, some general comments are possible. Land capability classes 1 and 2 were always in continuous row crops with terracing observed in only one of the solutions. Neither contouring nor the C-S-C-O-M-M rotation entered any of the optimal solutions. The phosphorus constraints added very little to the total cost of the sediment constraints, from 0 to just under 7 percent depending on the delivery ratio. Finally, the most stringent sediment and phosphorus quality levels were obtainable in all solutions.

A summary of the results for sediment constraints only are presented in Table 3. The results are illustrated in Figure 2 for the sediment constraints with a .25 delivery ratio. Referring to Figure 2, the program starts by pasturing class IV land, then builds gully control structures and is terracing class III land when meeting the most stringent sediment constraint, which is 37.5 mg/l.

A summary of the programming for the combined sediment and phosphorus constraints are presented in Table 4. The programming results indicate the following: (1) that the costs per acre are high but not unreasonable; (2) the most stringent constraints were obtainable; and (3) that a large portion of the agricultural land would remain in continuous row crops. While the sediment and phosphorus constraints were obtainable the question which remains and needs to be analyzed is: "Are the benefits sufficient to justify any level of control on sediment and phosphorus from cropland runoff?" A study by Frankel [19] and a report by Kneese and Bower [20] indicate that municipal and industrial costs are surprisingly insensitive to intake water quality. This suggests the decision of which level of water quality will rest either on a large reuse of the water and/or on aesthetic and recreational benefits.

Table 3.
Linear Programming Results: Sediment Constraints with Three Delivery Ratios

Sediment Objectives (mg/l)	Value of Objective Function (Total Cost)	Value of Dual Activity for Objective Function (Marginal Cost)	Dollars Per Acre[a/]	Value of Objective Function (Total Cost)	Value of Dual Activity for Objective Function (Marginal Cost)	Dollars Per Acre	Value of Objective Function (Total Cost)	Value of Dual Activity for Objective Function (Marginal Cost)	Dollars Per Acre
	DR = .20			DR = .25			DR = .30		
	(000,000)	(000)		(000,000)	(000)		(000,000)	(000)	
10,000	-	0.30207	-	0.176	0.25078	.11	0.543	0.21437	.34
9,000	-	0.30207	-	0.427	0.25078	.27	0.757	0.21437	.47
8,000	0.264	0.56141	.16	0.678	0.25078	.42	1.241	0.56141	.78
7,000	0.566	0.56141	.35	1.082	0.56141	.68	1.803	0.56141	1.13
6,000	0.923	0.56141	.58	1.643	0.56141	1.03	2.364	0.56141	1.48
5,000	1.484	0.56141	.93	2.205	0.56141	1.38	3.159	1.03073	1.97
4,000	2.045	1.45365	1.28	2.903	1.20633	1.81	4.190	1.03073	2.62
3,000	2.607	1.45365	1.63	4.110	1.20633	2.57	5.220	1.03073	3.26
2,000	3.997	1.45365	2.50	5.316	1.20633	3.32	6.251	1.03073	3.91
1,000	5.451	1.45365	3.41	6.522	1.20633	4.08	7.282	1.03073	4.55
500	6.178	1.45365	3.86	7.125	1.20633	4.45	7.797	1.03073	4.87
250	6.541	1.45365	4.09	7.427	1.20633	4.64	8.055	1.03073	5.03
150	6.687	1.45365	4.18	7.548	1.20633	4.72	8.156	1.03073	5.10
75	6.796	1.45365	4.25	7.638	1.20633	4.77	8.235	1.03073	5.15
37.5	6.850	1.45365	4.28	7.638	1.20633	4.80	8.274	1.03073	5.17

a/ This calculation is based on 1.6 million acres of crop and pasture land which accounts for about 89% of the land in the Nishnabotna River Basin.

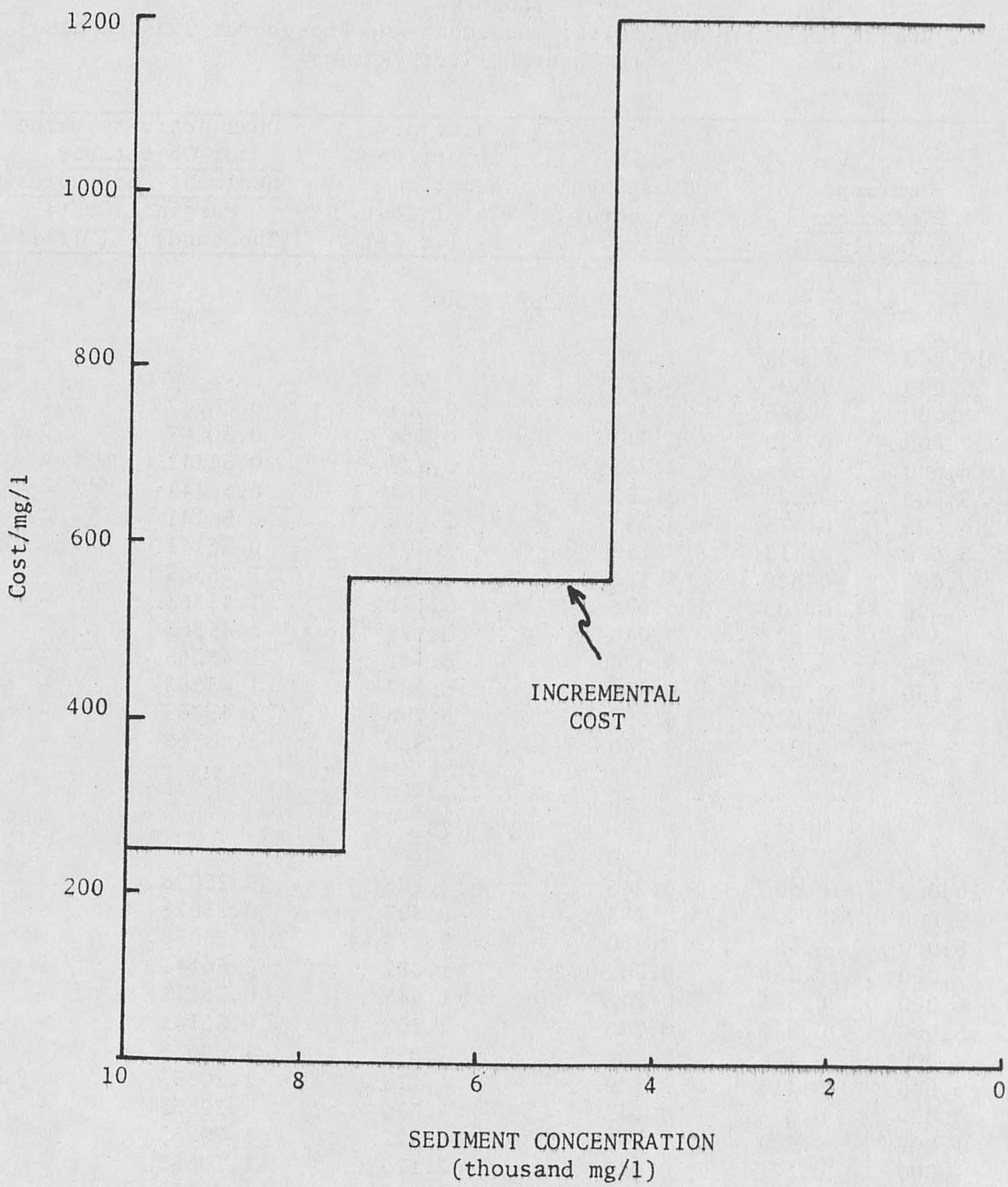

Figure 2.
Incremental Costs of Sediment Control

Table 4.
Linear Programming Results: Sediment and Phosphorus Constraints with Three Delivery Ratios

Objectives Sediment	Objectives Phosphorus (mg/l)	Limiting Phosphorus Values	Value of Objective Function (Total Cost Million $)	Dual Activity Value for Objectives (Marginal Cost): Sediment (Thousand)	Dual Activity Value for Objectives (Marginal Cost): Phosphorus (Million)
		DR = .20			
10,000	1.600	0.206	-	-	-
9,000	0.594	0.227	-	-	-
8,000	0.586	0.235	0.264	0.30207	-
7,000	0.580	0.243	0.566	0.30207	-
6,000	0.555	0.243	0.923	0.56141	-
5,000	0.522	0.222	1.484	0.56141	-
4,000	0.476	0.193	2.045	0.56141	-
3,000	0.413	0.155	2.607	0.56141	-
2,000	0.328	0.122	3.997	1.45365	-
1,000	0.209	0.076	5.451	1.45365	-
500	0.127	0.044	6.178	1.45365	-
250	0.075	0.024	6.541	1.45365	-
150	0.049	0.014	6.687	1.45365	-
75	0.029	0.005	6.796	1.45365	-
37.5	0.016	0.0003	6.850	1.45365	-
		DR = .25			
10,000	0.600	0.246	0.176	0.25078	-
9,000	0.594	0.253	0.427	0.25078	-
8,000	0.586	0.260	0.678	0.25078	-
7,000	0.580	0.262	1.082	0.56141	-
6,000	0.555	0.246	1.643	0.56141	-
5,000	0.522	0.226	2.205	0.56141	-
4,000	0.476	0.201	2.093	1.20633	-
3,000	0.413	0.179	4.110	1.20633	-
2,000	0.328	0.149	5.316	1.20633	-
1,000	0.209	0.108	6.522	1.20633	-
500	0.127	0.082	7.125	1.20633	-
250	0.075	0.067	7.427	1.20633	-
150	0.049	0.061	7.548	-	9.24956
75	0.029	0.059	7.638	-	8.16327
37.5	0.016	0.059	7.638	-	7.34683

(continued)

Table 4 (continued)

Objectives Sediment Phosphorus (mg/l)		Limiting Phosphorus Values	Value of Objective Function (Total Cost Million $)	Dual Activity Value for Objectives Sediment Phosphorus (Marginal Cost) (Thousand)	(Million)
			DR = .30		
10,000	0.600	0.167	0.543	0.21437	-
9,000	0.594	0.274	0.757	0.21437	-
8,000	0.586	0.271	1.241	0.56141	-
7,000	0.580	0.266	1.803	0.56141	-
6,000	0.555	0.250	2.364	0.56141	-
5,000	0.522	0.236	3.159	1.03073	-
4,000	0.476	0.220	4.190	1.03073	-
3,000	0.413	0.201	5.220	1.03073	-
2,000	0.328	0.173	6.251	1.03073	-
1,000	0.209	0.136	7.282	1.03073	-
500	0.127	0.115	7.979	1.03073	-
250	0.075	0.106	8.318	-	8.57258
150	0.049	0.104	8.583	-	7.70909
75	0.029	0.107	8.764	-	6.80359
37.5	0.016	0.112	8.863	-	6.12363

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