Impact Targets versus Discharge Standards in Agricultural Pollution Management*

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in Agricultural Pollution Management

Abstract

When attempting to protect fish in streams, sediment or erosion targets are inefficient. Use of a habitat suitability target reveals lower cost abatement measures because it accounts for pesticides as well as soil particles. In Lake Michigan case studies, the lower cost measures involve more crop diversity and less use of no-till but affect more acres than the solutions based on sediment discharges or erosion rates.

Impact Targets versus Discharge Standards in Agricultural Pollution Management

Greater efficiency and greater attention to environmental impacts have become major themes of soil and water conservation programs (e.g., U.S. Department of Agriculture). These themes come together in the notion of "targeting" pollution abatement (Nichols). There are two sides to "targeting": 1) enhancing the cost-effectiveness of source abatement; and 2) directing abatement toward the most pressing pollution damages.

Cost-effectiveness has been a long-standing concern for soil and water conservation programs (e.g., Park and Shabman, Park and Sawyer, and Braden et al.). However, focusing on the most pressing problems has received relatively little professional attention. Clark, Haverkamp, and Chapman identified and quantified many of the problems, but did not address selective policies. Ribaudo identified high water use areas where erosion reductions could bring pollutant concentrations below specific thresholds, but did not study how different objectives could affect management choices.

Bringing together the two sides of targeting requires models that link sources to discharges, discharges to environmental quality indicators, and quality indicators to preferences. Heimlich and Ogg connected sources to potential environmental exposure in a field-level management optimization model, but did not account for transport of or synergies between pollutants. Crowder and Young modeled actual losses of pollutants to streams but for only a single field and without considering the joint impacts of multiple pollutants on water quality. Milon combined the first two components but considered only pollutant loads and concentrations rather than damage consequences of timber cutting for fishing economics in an Oregon watershed, but his four generalized management scenarios do not identify an optimal approach.

This paper characterizes the cost and management implications of different targets for agricultural pollutant abatement. This objective goes beyond Milon's work by investigating measures of actual environmental damages--impairment of fish habitat--in addition to erosion and pollutant load targets. The study stops short of incorporating preferences, but it yields new insight into how the choice of targets affects the efficient abatement choices and costs. The analysis employs a case study of anadramous fish habitat protection in agricultural watersheds in the Lake Michigan Basin.

The Model

Pollutant Delivery and Impacts

The model has been described in detail elsewhere (Braden, Herricks, and Larson and Larson, Herricks, and Braden). A brief overview will highlight its handling of pollutant discharge standards versus fish habitat impacts.

The model used here extends the Sediment Economics (SEDEC) model (Braden et al.; Bouzaher, Braden, and Johnson; and Johnson et al.). SEDEC optimizes a network of cropland sediment sources to achieve specified sediment loads at least cost. The extended model adds pesticide and water runoff components, and uses habitat suitability models (U.S. Fish and Wildlife Service) to transform sediment loads and pesticide concentrations into fishery impacts. Pesticide and sediment impacts simulations are not performed simultaneously due to differences in timing and mode of impact. Pesticide impacts are greatest during storm event losses resulting in acute greatest during storm event losses resulting in acute concentrations. The risk of large pesticide losses is especially high shortly after application. Although high concentrations of suspended sediments during storm events are undesirable, the accumulation of fine sediment particles in the stream bed is generally considered to be much more damaging to most fish species, especially if they occur during spawning periods or when eggs are incubating in the stream bed (McCabe and Sadretto). As a result of these differences, sediment and pesticide impacts are estimated by separate simulation models. Pesticide runoff and impact is simulated by a stochastic model of storm events occurring in the time period between the first pesticide application to thirty days after the last application. The simulation of sediment impacts is driven by a stochastic model which estimates seasonal sediment loads.

Both simulations first estimate the pollution discharge potential. This potential depends on the soils, slope, crop rotations, tillage practices, and conservation measures on each management unit within a watershed. In the sediment simulation erosion is computed from a seasonal and stochastic version of Wischmeier and Smith's Universal Soil Loss Equation (USLE). Sediment is routed to the stream with the sediment transport equation developed by Clarke and Waldo (see Braden et al.). Deposition of sediment is based on an assumed particle size profile and estimates of stream power developed from field measurements of stream conditions and current velocity.

The chemical simulation is limited to pesticides and disregards nutrients. Pesticide losses are determined from a modified version of Haith's approach. Surface water runoff is computed with the Soil

Conservation Service's curve number method adapted to crop growth phases following Knisel. Published partition coefficients are used to determine adsorbed and soluble fractions of the pesticides. Exponential decay of pesticides is assumed using published decay coefficients.

The combined effects on fish of sediment loads, pesticide concentrations, and chemical toxicities are captured in habitat suitability indices (HSI). HSI models are available for over 40 species. They combine individual habitat parameters, such as temperature, substrate conditions, flow regime and water quality, in a composite, unitless index ranging from zero to one. Zero represents unsuitable habitat; one represents ideal habitat.

The approach suggested by Herricks and Braga is used to incorporate the effects of toxic chemicals in HSI models. The chemical effects on habitat suitability capture both chronic and toxic exposures by relating concentrations associated with specific toxicological endpoints with different suitability values. The literature on pesticide toxicity refers almost exclusively to the soluble fractions, so the adsorbed chemicals are disregarded.

Monte Carlo simulation techniques are used with the simulation models to yield probability distributions of pollutant discharges and habitat impacts. This permits consideration of the uncertainty in estimating key model parameters as well as the random natural variability of weather events. Also included is the uncertainty and variability in the timing of farm management events. Excluded are yield and price variability. In each year simulated pesticide application and planting dates and the particular crop of a multi-year rotation are randomly selected for every independently managed farm field.

The probability distributions generated by the simulation models contain information about the probability of attaining suitability indices under a particular watershed management scenario. The index may be interpreted as a habitat quality level and the probability of attainment is a reliability level.

Economics

The economic analysis is conducted from the vantage point of a fully informed watershed planner. The watershed is subdivided according to farm and field boundaries. Fields are subdivided along lines of significant slope change. The resulting management units are characterized by area, soil types, slope, and hydrologic properties of the soils. They are embedded in a hydrologic model of surface runoff. The watershed is subdivided into catchments, which are independent in their surface runoff, and each catchment is depicted by a typical runoff path, called a transect.

Feasible crop rotations, tillage practices, and supporting conservation practices are specified for each management unit. A particular combination is assigned a specific annualized net return value from farm budgeting analysis, an erosion rate, and pesticide use rates. The use of pesticides needs to be correlated with yield assumptions. A conventional assumption is to use yield levels associated with "label rates" of pesticide application.

The pollutant losses from a catchment depend on the type and location of management practices being employed on all units at the time of a storm. A specific set of practices constitutes a management path. Each path has a particular level of net revenues for the catchment. There can be many management paths, depending on all feasible combination of practices on individual units. The simulation model develops probability distributions of results for each management path. Each probability distribution, then, is associated with a level of annualized net revenues. Economic outcomes are combined additively across catchments and habitat impacts are combined using weighting factors based on area and water yields. A dynamic programming optimization algorithm is used to select a management path from each catchment (hence, a set of practices on each management unit) such that certain targets on habitat quality and reliability are met with minimal loss in farming profits. The mathematical expression is (Braden, Larson, and Herricks):

$$\min_{x_{ij}} \sum_{j=1}^{J} \sum_{i=1}^{I^j} C_{ij} x_{ij} \tag{1a}$$

s.t.

$$\frac{\sum_{j=1}^{J} \sum_{i=1}^{I^j} PS_{ij} \, Q_{ij}^{50} \, x_{ij}}{\sum_{j=1}^{J} \sum_{i=1}^{I^j} Q_{ij}^{50} \, x_{ij}} \geq R \tag{1b}$$

$$\frac{\sum_{j=1}^{J} \sum_{i=1}^{I^j} PS_{ijg} \, a_j \, x_{ij}}{\sum_{j=1}^{J} \sum_{i=1}^{I^j} a_j \, x_{ij}} \geq R, \quad g = 1,\ldots,G \tag{1c}$$

$$\sum_{i=1}^{I^j} x_{ij} = 1, \qquad j = 1, \ldots, J \tag{1d}$$

$$x_{ij} = [0,1] \tag{1e}$$

where $j = 1, \ldots, J$ indicates transects; $i = 1, \ldots, I^j$ indicates the I^j management paths on transect j; $x_{ij} = 1$ if path ij is adopted and 0 otherwise; c_{ij} is the cost associated with path ij; Q^{50}_{ij} is the median daily runoff from path ij; a_j is the area contained within catchment j; PC_{ij} is the probability of pesticide concentrations exceeding a particular suitability level S^*; PS_{ijg} is the probability of sediment suitability exceeding S^*; and R is the target level of reliability. Constraints (1b) and (1c) are weighted average probabilities of exceeding the target suitability level for pesticides and sediment, respectively.

This formulation provides two types of insight. First, it identifies the watershed management measures that optimally achieve certain pollution goals according to economic criteria. As discussed by Braden et al., this is a benchmark for comparison of the feasible management alternatives and guides cost-effectiveness considerations.

Second, and most important, the problem allows assessment of alternative indicators of water quality targets. As the problem is written, the targets are the quality and reliability of a stream environment for specific fish species. However, the habitat suitability simulation can be bypassed to focus on probability distributions of pollutant loads. Or, the pollutant movement components could be disregarded to focus on the distributions of emissions. These alternatives are explored empirically below.

Two distinct environmental indicators should be good substitutes for policy purposes if they correlate closely (Nichols). In that case, the management prescriptions that are optimal for one indicator should be nearly optimal (although possibly second-best) for the other indicator. In the case of agricultural pollution and fish habitat, timing can cause critical differences between emissions, releases, and habitat suitability. The timing effects come through pesticide decay and the seasonal patterns of rainfall, erosivity, crop condition, and fish spawning requirements. These phenomena are not captured in the emission or release calculations, but enter into suitability. Their importance for management prescriptions and abatement costs is an empirical matter to which we now turn in a case study of sport fish protection in tributaries to Lake Michigan.

Impact Targets versus Discharge Standards: Case Study

Study Sites

Active sport fisheries have been successfully developed in Lake Michigan over the past two decades with substantial economic benefits for the near shore area. Chinook, coho, steelhead, and other salmonids are the most prized varieties.

The salmonid populations have been enhanced and sustained through extensive stocking. Natural spawning in tributary streams and rivers has been limited in many areas by nonpoint pollution from farmland, and by channelization that eliminates habitat while enhancing drainage. These factors not only compel continued stocking, they also reduce the range of seasonal salmon migrations. The migrations are highly valued by individuals and communities near the Lake, who seek to lengthen and enhance the fish runs.

The model was applied to two agricultural subwatersheds in Berrien County, Michigan, along Lake Michigan's southeastern shore. Corn, grains, and soybeans are the most common farm crops in the County, although orchards, vegetables, and vinyards also are present.

The Pipestone Creek study site drains to the St. Joseph River and on to Lake Michigan. The St. Joseph River system has been the focus of a joint effort by the states of Michigan and Indiana to extend the salmon runs. It has received large stockings of sport fish in recent years, and portions of the system are classified as trout streams. However, the segment of Pipestone Creek chosen for study has been channelized and the silty substrate is poor for spawning and fry development. The 93 hectare (ha) study site contains gently sloping farmland with silty and loamy soils.

The Galien River (East Branch) site is part of a smaller river system that also is classified for trout. The habitat conditions are good for salmonids with a meandering channel, cobble and gravel substrate, and pools interspersed with riffle segments. The study site contains 139 ha of gently sloping farmland with sandy and loamy soils.

Data

Catchments and transects were defined from U.S. Geological Survey topographic maps. Management units were identified from Soil Conservation Service (SCS) soil survey maps, plat maps, and Agricultural Stabilization and Conservation Service aerial photographs. Soils information, including productivity classifications, also came from SCS soil surveys. Rainfall distributions were based on a 57 year record for Eau Claire, Michigan, which is near both sites. Basic stream data were compiled through fieldwork.

Universal Soil Loss Equation coefficients and crop budgets, including pesticide application rate and assumptions about the timing of farming operations, were prepared jointly by Michigan Cooperative Extensive Service and SCS experts (Black). The crop-cover (C) factors for the USLE were disaggregated for crop growth phases, and variability was introduced following Thomas et al. Twelve possible cropping systems were considered, consisting of combinations of two rotations--Wheat-Corn (3)-Soybeans (WCCCS) and Alfalfa (3)-Corn (2) (AAACC), three tillage methods--moldboard plowing, till-planting, and no-till, and two mechanical practices--vertical plowing and contour plowing. These options are typical of the area, and the rotations make use of similar pesticides. Three pesticides were selected for study: Atrazine, Furadan, and Bladex. Atrazine and Bladex use does not vary with tillage practices while Furadan is used in fewer years when tillage is reduced. Assumed crop prices were \$60/ton for alfalfa hay, \$2.25/bu for corn, \$5.40/bu for soybeans, and \$2.30/bu for wheat.

Chemical toxicity data for salmonids were obtained from Mayer and Ellersieck. Physical suitability relationships were adapted from existing HSI models (e.g., Raleigh et al.).

Analysis

The SEDEC model was used to determine the economically optimal mangement practices for meeting sediment targets. The consequences for fish habitat suitability of the practices that optimally control sediment were determined using the extended model (without optimizing for suitability impacts). A similar approach was followed for erosion targets. The analysis also was performed in reverse--the optimal practices were determined with respect to suitability targets and the sedimentation and erosion consequences of those practices were traced. Finally, the subwatershed suitability target was applied to all individual catchments to assess the consequences of imposing uniformity throughout the stream reach.

While any suitability, sedimentation, or erosion levels could be selected for analysis, levels of 0.5, 0.7, and 0.9 were chosen here. These cover average to very good suitability conditions, on the assumption that poor conditions are not relevant environmental targets.

Results

The results are summarized as cost frontiers relating the minimum losses in farming profits associated with attaining particular environmental targets. The costs estimates are conservative in all cases: they do not reflect differences in farmer risks that may accompany different management systems; they assume that watershed management can be highly selective; and they assume all farmers would settle for the minimum compensation.

Figure 1 shows the cost curves for the two study sites assuming the extreme habitat suitability targets of 0.5 and 0.9 and allowing reliability to vary. The costs are per hectare for comparison, although the costs are borne unevenly across management units as a result of the optimization.

The curves are quite different for the two sites, and this is attributable to the different background conditions. The Galien site is already highly suitable and reliable for salmonids while Pipestone is not. Thus, the costs are greater for attaining high reliability levels at Pipestone.

The curves for the 0.5 suitability level extend to higher levels of reliability than do the 0.9 curves. This suggests that the practices that are best for usual weather circumstances (that dominate the suitability determination) are not the same as the best practices for extreme conditions (that dominate reliability). Furthermore, conservative farming practices alone cannot achieve high levels of suitability with high reliability. The dual extremes would require either land use changes more substantial than those considered here or supplementary measures within the stream channels.

The constraint on pesticide suitability turns out to be non-binding at low levels of reliability. The pesticide constraint does not become binding until rather high probabilities of exceeding the target suitability levels are reached, at which point the risk of excessive sediment accumulation is relatively low. (The reliability level at which pesticides become important varies inversely with the suitability level.) These findings are consistent with the consensus among fisheries biologists that deteriorated substrate conditions are most responsible for the general degradation of fish populations in midwestern streams (e.g, Smith, 1978).

Now for the comparison of targets. Figures 2 through 5 display the cost-suitability frontiers for the three alternative policies: 1) constraining the total sediment load in the watershed; 2) constraining the sediment load from each catchment; and 3) constraining the soil erosing on each LMU, and the frontier from targeting directly on suitability. The 0.5 and 0.9 levels of suitability are chosen to illustrate extremes.

The figures show that a sediment target reasonably approximates a habitat suitability target only over a limited range. The approximation grows worse as pesticides play a greater role in suitability determination, i.e., at higher levels of reliability where the pesticide suitability constraint is controlling. Since the critical pesticides are in solution, and since sediment runoff is not necessarily correlated with runoff volume or concentration, "targeting" sediment is a poor way to deal with pesticide effects.

Comparison of the figures suggests that the range of reasonable approximation shrinks as the suitability target is raised. This is because the pesticide constraints bind at lower reliability levels when suitability targets are higher.

The sediment and erosion target curves in figures 2 through 5 are not smooth because some strategies (e.g., alfalfa rotations) used to control sediment also lower pesticides while others (e.g., no-till) can increase pesticide concentrations in runoff. Erosion and sedimentation targets take no account of the pesticide consequences and result in higher costs and greater or lesser reliability depending on the precise nature of the sediment control regime.

Management Implications

Optimal management scenarios for the HSI target are summarized in Table 1 and results for selected HSI suitability/reliability with alternative targets appear in Table 2. The selection of performance goals for Table 2 was limited by the fact that some or all of the alternative targets could not achieve reliability of 0.8 at Pipestone with either the 0.5 or the 0.9 HSI, nor at Galien with 0.9 HSI.

In the Baseline case, without habitat constraints, the WCCCS rotation and a combination of tillage practices are implemented at both sites. As indicated in Table 1, tightening the habitat constraint initially (the 0.5/.40 case) prompts greater use of no-till WCCCS. Requiring reliability of .80 causes a shift away from no-till WCCCS and toward the AACCA rotation. The greater availability of and concentration of pesticides with no-till accounts for this shift. Tightening the constraints also requires that changes be made in more of each watershed, involving more management units.

For each site, the mechanical practices change little or not at all with different constraints. This is because contour and vertical plowing perform very similarly on the long gentle slopes of the sites.

In comparing Tables 1 and 2, the erosion and sediment targets generally lead to more acreage in the WCCCS rotation and more no-till. (An exception to the no-till results appears in the Galien 0.5/.80 case, but more use of conservation tillage with the HSI/Reliability target accounts for this apparent anomaly.) These results are as expected and are more pronounced respectively for gross sediment, catchment sediment, and erosion--that is, as the target becomes further removed from fish habitat.

An unexpected result, at least for the sediment targets, is that less area and fewer management units are involved in the solutions, albeit at higher overall costs. An interesting implication is that if administrative costs increase with the area and number of farms involved in abatement actions, the ostensible efficiency gains of using suitability/reliability targets could be offset.

Conclusions

This study suggests that protecting fish habitat can be quite distinct from reducing agricultural pollution emissions or discharges, especially a single dimension such as sediment. Policies that address sediment or erosion effectively are less effective in protecting habitat, especially at high suitabililty and reliability levels. This is because soluable pesticides dominate extreme suitability and reliability conditions, and the correlation to sediment loads is not high.

This result is not surprising because fish respond to multiple qualities of the stream channel. Single dimensional policies will be effective only to the extent that the dimension chosen is highly correlated with overall suitability.

A specific policy concern has to do with no-till farming. No-till has been widely encouraged. At least in the cases studied here, this approach appears sound with respect to erosion and sedimentation. But, the consequences for fish, and perhaps other wildlife, may be perverse. This is because no-till sometimes involves greater use of pesticides, which are not as fully incorporated, while it also reduces runoff volume. Non-incorporation means that less water will move more chemicals. The results point toward the desirability of no-till systems that better control pesticide releases.

Another policy issue surrounds the apparent desirability of heterogenous cropping systems in a watershed. When suitability and reliability goals are high, tillage and mechanical practices are inadequate. Crop changes are needed (unless stream channel measures are undertaken), and the direction is toward greter diversity. Greater diversity reduces the probability of any one chemical exerting influence in a particular weather event. Some agricultural policies favor a few crops and may pose an additional impediment in some areas areas where high quality stream fisheries are sought.

Finally, the analysis suggests that less area and farms are affected by targeting on sediment than on suitability. Thus, the apparent disadvantages of sediment targets may be less pronounced when administrative costs are considered.

References

Beavis, B. and M. Walker. "Achieving Environmental Standards with Stochastic Discharges" J. Envir. Econ. Manag. 10(1983): 103-111.

Black, J., Department of Agricultural Economics, Michigan State University, East Lansing, personal communications, 1983.

Bouzaher, A., J. Braden, and G. Johnson. "A Dynamic Programming Approach to a Class of Nonpoint Source Pollution Control Problems." Manag. Sci. (forthcoming).

Braden, J., A. Bouzaher, G. Johnson, and D. Miltz. "Optimal Spatial Management of Agricultural Pollution." Amer. J. Agr. Econ. 71(1989): 404-413.

Crowder, B. and C. Young. "Soil Conservation Practices and Water Quality: Is Erosion Control the Answer?" Water Resour. Bull. 23(1987): 897-902.

Haith, D. "A Mathematical Model for Estimating Pesticide Losses in Runoff, J. Envir. Qual. 9(1980: 428-433.

Heimlich, R. and C. Ogg. "Evaluation of Soil-erosion and Pesticide-exposure Control Strategies" J. Envir. Econ. Manag. 9(1982): 279-288.

Johnson, G., D. White, A. Bouzaher, and J. Braden, "SEDEC User's Guide, Ver. 1.0." Univ. of Ill., Inst. Environ. Stud.,technical report, Urbana, draft, 1989.

Larson, R., E. Herricks, and J. Braden. Efficient Protection of Fisheries Habitat in Great Lakes Tributaries from Agricultural Pollutants. Ill.-Ind. Sea Grant Prog., Resear. Rep. No. 89-4, Urbana, Ill., 1989.

Mayer, F. and M. Ellersieck. Manual of Acute Toxicity: Interpretation and Database for 410 Chemicals and 66 Species of Freshwater Animals. U.S.

Fish and Wildlife Serv., Resour. Pub. No. 160, Washington, D.C., 1984.

Milon, J. "Optimizing Nonpoint Source Control in Water Quality Regulation." Water Resour. Bull. 23(1987): 387-396.

Nichols, A. Targeting Economic Incentives for Environmental Protection. Cambridge, MA: MIT Press, 1984.

Park, W. and L. Shabman. "Distributional Constraints on Acceptance of Nonpoint Pollution Controls." Amer. J. Agric. Econom. 64(1982): 455-62.

Park, W. and D. Sawyer. "Targeting Soil Erosion Control Efforts in a Critical Watershed." U.S. Dep. Agr., Econ. Res. Serv., ERS Staff Rep. No. AGES850801, Washington, D.C., 1985.

Raleigh, R., T. Hickman, R. Solomon, and P. Nelson. Habitat Suitability Information: Rainbow Trout. U.S. Fish and Wildlife Serv., Rep. No. FWS/OBS-82/10.60, Washington, D.C., 1984.

Ribaudo, M. "Consideration of Offsite Impacts in Targeting Soil Conservation Programs." Land Econ. 62(1986): 402-411.

Thomas, A., W. Snider, and G. Langdale. "Stochastic Impacts on Farming: V. Risk Adjustment Through Conservation Planning." Amer. Soc. Agric. Engin. Trans. 31(1988): 1368-1373.

U.S. Department of Agriculture. The Second RCA Appraisal. Washington, D.C., 1989.

U.S. Fish and Wildlife Service. Habitat Evaluation Procedures (HEP). Div. Ecol. Sci, Rep. ESM 102, Washington, D.C., 1980.

U.S. Soil Conserv. Serv. Soil Survey of Berrien County, Michigan. U.S. Dep. Agric., Lansing, MI, 1980.

Wischmeier, W., and D. Smith. Predicting Rainfall Erosion Losses:

A Guide to Conservation Planning. U.S. Dep. Agric., Agric. Handbook 537, Washington, D.C., 1978.

Table 1. Optimal management summaries for selected salmonid suitability/reliability levels, Pipestone Creek and Galien River Sites.

Salmonid HSI/Reliability	Management Practices: Rotation (% ha WCCCS)	Management Practices: Tillage (% Mold-board/ % No-till)	Management Practices: Mechanical (% Vertical)	Extent of Management: Changes (% area)	Extent of Management: Changes (%units)	Extent of Management: Cost ($/ha)
			Pipestone Creek			
Baseline	100	67/ 6	93	---	---	0.00
0.5/.40	100	55/17	93	13	5	0.43
0.5/.80	91	27/28	93	33	11	2.30
0.9/.40	92	48/28	93	30	26	0.57
0.9/.80	72	18/31	93	71	80	11.03
			Galien River			
Baseline	100	42/22	87	---	---	0.00
0.5/.40	100	40/22	87	0	0	0.00
0.5/.80	82	26/26	84	41	17	1.60
0.9/.40	87	35/24	87	33	18	0.45
0.9/.80	64	24/17	84	65	73	8.77

Table 2. Comparison of watershed management for selected alternative pollution abatement targets and impacts, Pipestone Creek and Galien River Sites.

Impact HSI/Reliability	Target	Management Practices: Rotation	Management Practices: Tillage	Management Practices: Mechanical	Extent of Management: Changes		Cost
		(% ha WCCCS)	(% Mold-board/ % No-till)	(% Vertical)	(% area)	(%units)	($/ha)
				Pipestone Creek			
0.5/.40	Gross Sed.	100	55/17	93	5	2	0.43
	Catch. Sed.	100	53/19	93	7	3	0.50
	Unit Erosion	100	51/26	93	13	8	4.39
0.9/.40	Gross Sed.	92	51/26	93	21	15	2.51
	Catch. Sed.	93	53/31	93	24	19	7.87
	Unit Erosion	96	49/44	93	36	25	5.47
				Galien River			
0.5/.80	Gross Sed.	100	42/20	87	2	1	1.73
	Catch. Sed.	100	40/20	87	5	2	1.84
	Unit Erosion	100	35/28	87	12	21	2.63
0.9/.40	Gross Sed.	89	44/32	87	27	8	2.72
	Catch. Sed.	90	41/33	87	31	12	4.81
	Unit Erosion	94	33/41	87	37	33	6.02

Table 3. Summary Comparisons of Land Management for 50% Abatement, Long Creek Site

Delivery Model	Acres Changing Practices[a]: Rotation	Tillage	Structural	Acres in Rotation Including Cover Crops	LMUs Changing Practices[b]	Indices of Location of Management Changes[c]: Average Points per Transect	% of Total Points
	-------------(%)-------------			(%)	(No.)		
Clarke-Waldo	7.4	7.4	1.6	0	20	2.2	15.0
Fixed Coefficients	32.7	32.7	3.2	0.3	57	7.8	54.9
Single Coefficient	47.6	47.6	1.5	0	69	11.7	80.5
Walter-Black	21.0	21.1	2.1	0	40	6.9	34.0

[a] 1063.9 acres in study area. All changes in rotations were accompanied by tillage changes. Some tillage changes and most structural changes were not accompanied by rotation changes.

[b] 78 land management units (LMU) in study area.

[c] Indices based on assigning points to each LMU equal to the index ("i" in the text) of its location along a transect. Overall, 246 points are available. A low average point score means that management changes are concentrated close to the stream. A low percentage score reflects few management changes and proximity to the stream.

Figure Legends

Figure 1. Minimum costs of Achieving Selected Salmonid Habitat Suitabilities and Reliabilities, Pipestone Creek and Galien River Sites

Figure 2. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Pipestone Creek, HSI = 0.5

Figure 3. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Pipestone Creek, HSI = 0.9

Figure 4. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Galien River, HSI = 0.5

Figure 5. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Galien River, HSI = 0.9

FIGURE 1. Minimum Costs of Achieving Selected Salmonid Habitat Suitabilities and Reliabilities, Pipestone Creek and Galien River Sites.

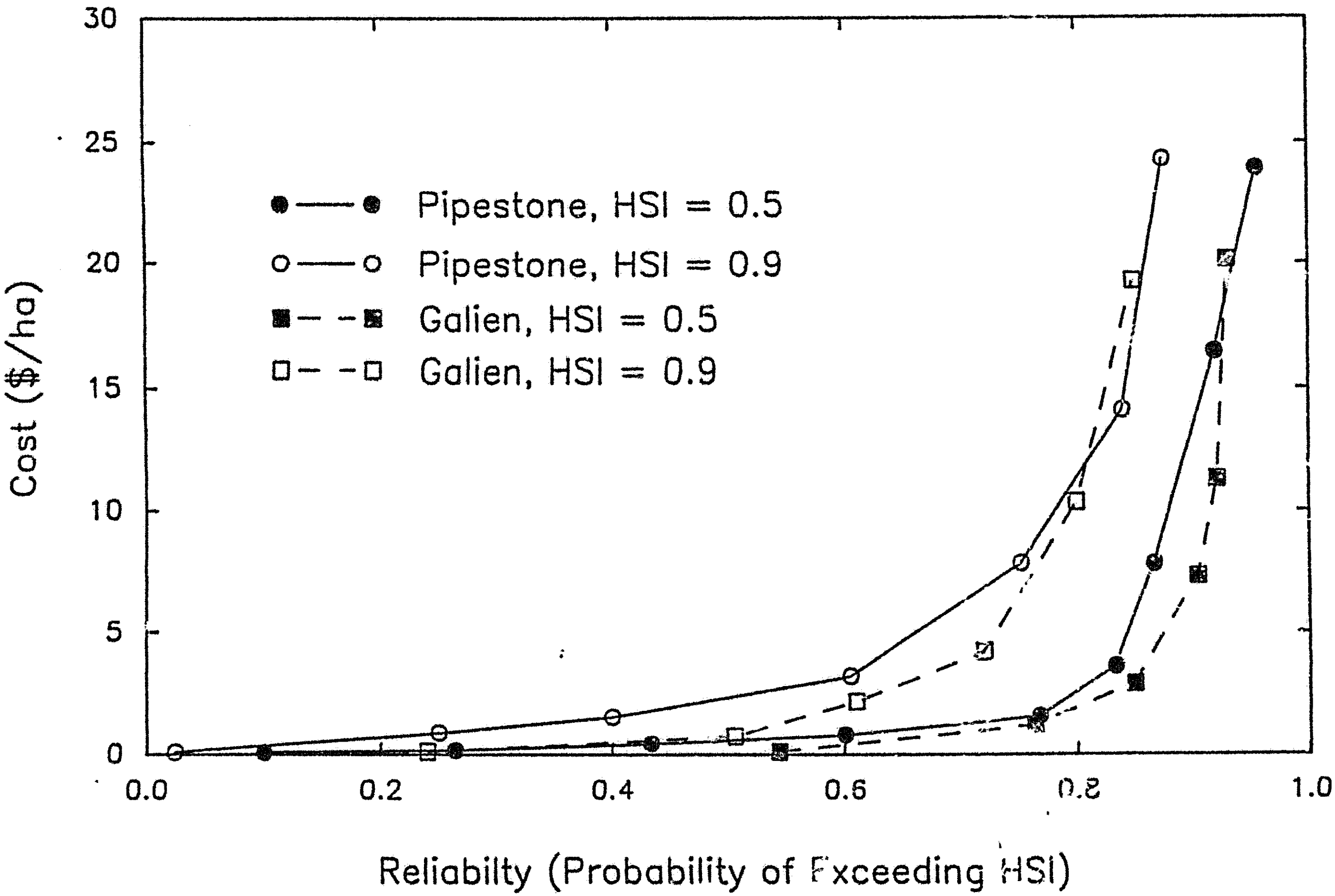

FIGURE 2. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Pipestone Creek, HSI = 0.5.

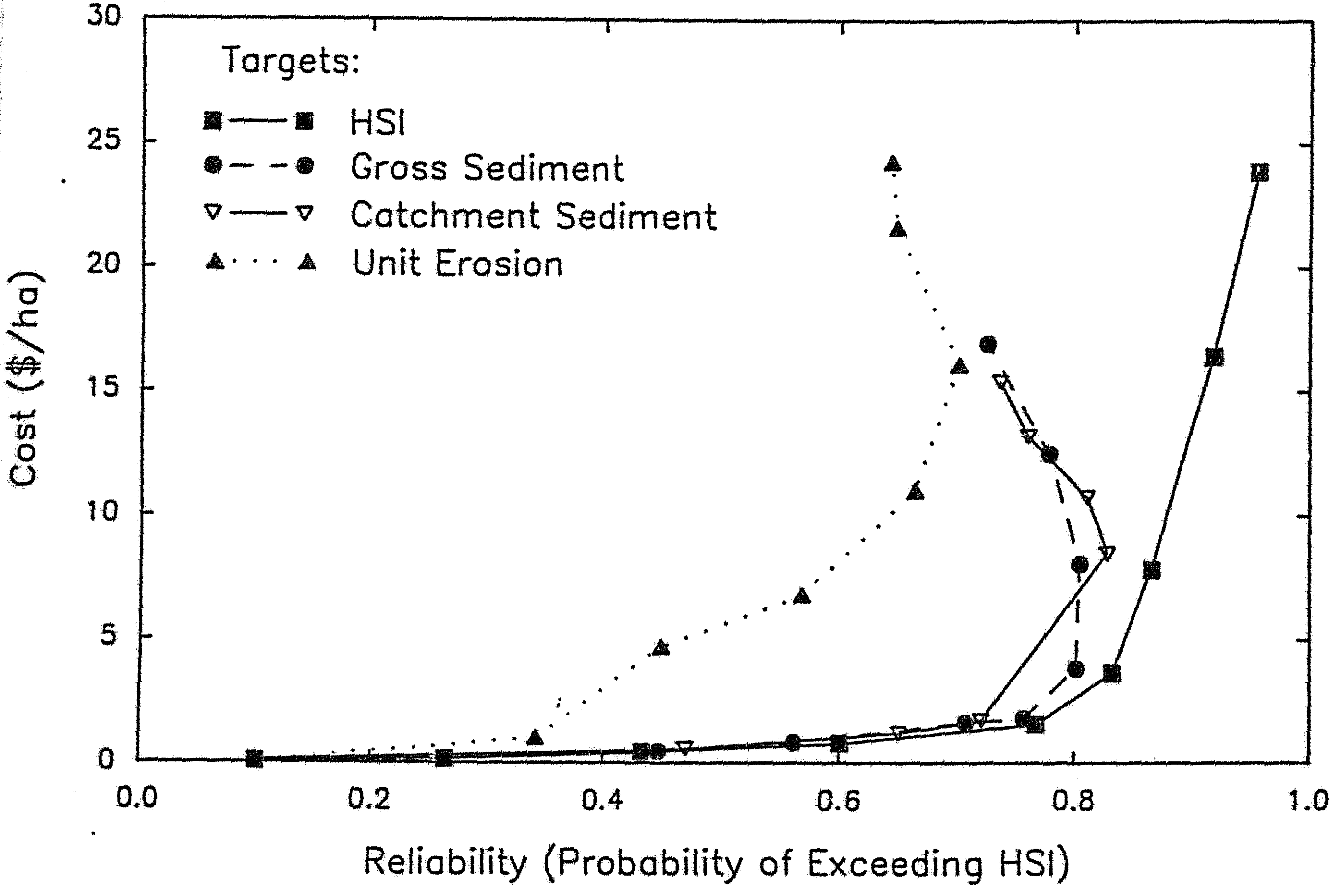

FIGURE 3. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Pipestone Creek, HSI = 0.9.

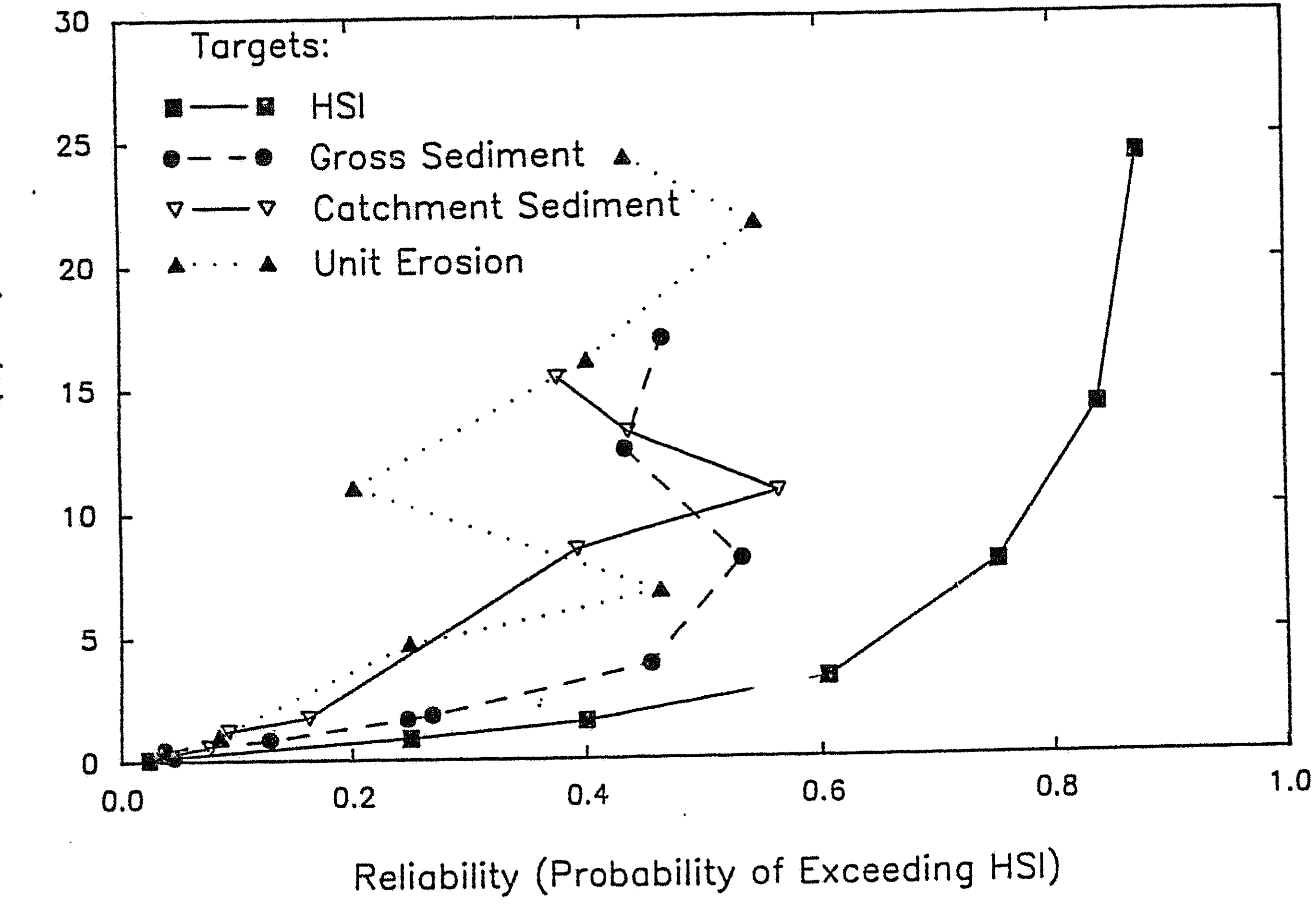

FIGURE 4. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Galien River, HSI = 0.5.

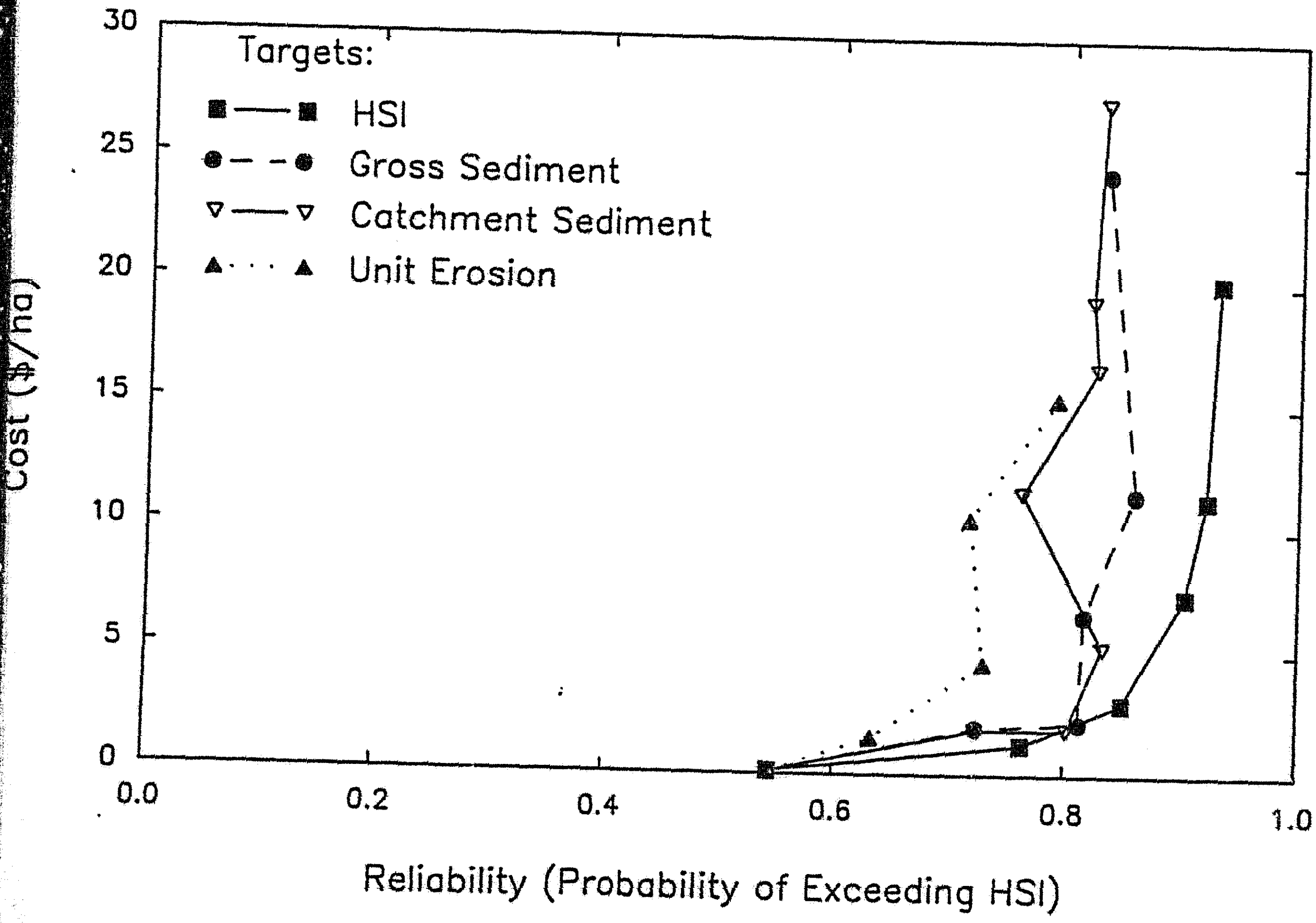

FIGURE 5. Costs of Salmonid Reliability with Selected Discharge Targets and Impacts, Galien River, HSI = 0.9.