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EVALUATION OF SEDIMENT AND PHOSPHORUS MANAGEMENT PRACTICES IN THE WHITE CLAY LAKE WATERSHED[1]

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ABSTRACT: To evaluate the effects of management practices for protection of water quality in White Clay Lake (Wisconsin), surface and lake waters were monitored for a six-year period before and during structural and management changes for nonpoint pollution source control. The incremental nature of implementing controls combined with the annual variations in sediment and nutrient transport confounded obvious changes in water quality. So, several models were linked together to define loadings from specific land uses and to assess the effects of management changes and animal waste control measures designed to reduce sediment and phosphorus losses. The importance of including the thaw and snowmelt factor in the determination of erosion index for the Universal Soil Loss Equation was demonstrated. Model predictions of average annual phosphorus loading showed a 54 percent reduction following the installation of manure storage facilities and barnyard runoff controls, and a 22 percent reduction through changes in cropland management. The model also predicted a 29 percent reduction in sediment loading. The value of a peripheral wetland for retention of sediment and phosphorus was quantified. Changes in lake water quality attributable to the watershed work were not observed, but maintenance of existing good water quality as a result of this project is anticipated.

(KEY TERMS: lake protection; nonpoint source; phosphorus; agricultural runoff; watershed management; livestock waste management; sediment transport.)

INTRODUCTION

One of the most vexing problems in the management of nonpoint sources of pollution (NPS) is defining the cause and effect relationship between source controls and water quality improvement. The White Clay Lake Project, in which implementation of nonpoint source controls in a small agricultural watershed in Wisconsin was combined with a six-year watershed and in-lake monitoring program, provided an excellent opportunity to do so. Initial monitoring results established that although the condition of White Clay Lake itself was generally good, nutrients and sediments were being transported to it at rates which ultimately posed a threat to the lake's water quality. Management strategies were designed and implemented to reduce transport to the lake; in-lake monitoring was done throughout the project period to assess the trophic status of the lake. Because of the limited time span of the project, major changes in lake water quality were neither expected nor observed.

Water quality was monitored in the East Branch subwatershed of White Clay Lake before and during the implementation of structural and management changes for nonpoint source control. The year-to-year variability in precipitation, snowmelt, and runoff masked any obvious trends in water quality, so an evaluative tool was developed to estimate the long-term average changes which occurred as a result of nonpoint pollution control efforts. Several models were linked together to define loadings from specific land uses and to assess the effects of management changes and animal waste control measures designed to reduce sediment and phosphorus losses. Predicted values were compared to those observed in the monitored watershed. The models were then used to estimate long-term reductions in sediment and phosphorus loading attributable to changes in management practices.

METHODS AND MATERIALS

Streamflow from the East Branch subwatershed was monitored using a 5:1 broad-crested triangular wier (U.S. Dept. of Agriculture, 1962) and a Friez, Model FW-1 stage recorder. Water samples were collected at 1/2- to 3-hour time intervals during runoff events with an Instrumentation Specialties Company, Model 1392 sampler. The landowner maintained the monitoring equipment and collected grab samples weekly. Samples were stabilized by adding phenyl mercuric acetate prior to freezer storage and analysis. Total residue, ammonia-N (distillation, titration), nitrate-N (DeVardas alloy), organic-N (Kjeldahl, titration), reactive-P (unfiltered, ascorbic acid), total-P (persulfate, ascorbic acid), and specific conductance were measured (Amer. Pub. Health Assoc., 1971; 1976).

Annual loadings were calculated by determining the water volume represented by each sample and summing the incremental products of water volume and component concentrations for the year period. The occasional lapses in data were

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filled in by interpolation and estimation using data from a station in the adjacent South Branch subwatershed. Precipitation was measured in a standard 20 cm recording, weighing bucket, rain gage located near the outlet of the East Branch subwatershed. These measurements were supplemented by records from the Shawano NOAA weather station located about 17 km west of White Clay Lake.

Field surveys, interviews with farmers, reviews of conservation farm plans and air photos were used to develop detailed land use and management information for the period 1974 through 1979. A 1.2-m contour interval topographic map was used to delineate watershed boundaries, channel networks, and slope directions. A base map was developed from 1966 air photos showing field boundaries. A field was considered to be any contiguous piece of land managed as a unit and observed to have the same cropping pattern from 1973 to 1979. Subfields were defined based on soil units from advance sheets of the Shawano County Soil Survey (U.S. Dept. of Agriculture, 1982). Records of cropping systems, other land uses, direction of plowing, residue management and tillage and conservation practices were compiled annually.

Animal numbers were determined for each farm from town assessor records and farmer interviews. Total animal units (AU) were calculated using one milk cow to be equal to 1.4 AU; each heifer, 0.8; each calf, 0.25 AU; sows and gilts, 0.30 AU; and feeder pigs, 0.025 AU each. Total phosphorus (P) production rates of 0.034 kg and 0.068 kg per AU per day of dairy stock and swine, respectively, were used based on values developed by the Midwest Plan Service (1975).

Total phosphorus loading from winter-spread manure and barnyards was estimated using a method initially described by Draper, *et al.* (1979), and modified to apply to Wisconsin by Moore, *et al.* (1979), and Moore (Moore, I.C., 1979, M.S. Thesis, Univ. of Wisconsin-Madison, Dept. of Soil Science). The method assumes that the amount of manure-derived P carried in runoff from each source can be represented as a set percentage of the total P excreted on an annual basis. The following runoff estimates are used based on northern climate research studies:

1. Four percent of the P excreted annually enters surface water runoff from barnyard sources.
2. Eight percent of the P in manure spread on frozen ground is carried away in runoff.
3. Three percent of the P excreted annually enters runoff from solid and semi-solid above ground manure storage facilities.

Only manure P that is deposited within a critical distance of 40 m to a channel is predicted to reach the channel because of phosphorus attenuation during overland flow. For manure P deposited within the critical distance attenuation is linear (i.e., is proportional to the flow distance divided by the critical distance). Barnyard phosphorus loadings were estimated as follows:

$$\begin{matrix}\text{Barnyard}\\ \text{manure P}\\ \text{delivered}\\ \text{to}\\ \text{channels}\end{matrix} = \sum_{b=1}^{n}\left[0.04 \cdot \begin{matrix}\text{Annual P}\\ \text{production}\\ \text{barnyard}\\ \text{(b)}\end{matrix} \cdot \left(1 - \frac{\begin{matrix}\text{Overland}\\ \text{flow}\\ \text{distance}\\ \text{barnyard}\\ \text{(b)}\end{matrix}}{\begin{matrix}\text{Critical}\\ \text{distance}\end{matrix}}\right)\right]$$

n = number of livestock concentrations located within the critical distance of a channel

Manure storage facilities were evaluated in a similar manner to barnyards, using appropriate flow distances and the runoff percentage for manure storage facilities. Winter-spread manure phosphorus was estimated as follows:

$$\begin{matrix}\text{Winter-}\\ \text{spread}\\ \text{manure P}\\ \text{delivered}\\ \text{to}\\ \text{channel}\end{matrix} = \sum_{f=1}^{m}\left(0.08 \cdot \begin{matrix}\text{Winter}\\ \text{P}\\ \text{production}\end{matrix} \cdot \begin{matrix}\text{Proportion}\\ \text{of cropland}\\ \text{in watershed}\\ \text{for livestock}\\ \text{concentrations}\\ \text{(f)}\end{matrix} \cdot \begin{matrix}\text{Proportion}\\ \text{of watershed}\\ \text{within}\\ \text{critical}\\ \text{distance}\end{matrix} \cdot \begin{matrix}\text{Average}\\ \text{attenuation}\end{matrix}\right)$$

m = number of livestock concentrations spreading manure within the watershed

A five-month winter production period and 50 percent average attenuation rate were used. Proportion of the watershed within the critical distance to a channel was based on average overland flow distance as determined from drainage density using the relationship described by Horton (1945).

$$\begin{matrix}\text{Average distance of}\\ \text{overland flow}\end{matrix} = \frac{1}{2}\left(\frac{1}{\text{drainage density}}\right)$$

Drainage density was determined by contour crenulation analysis (Moore, *et al.*, 1979).

Two modifications to the model were made by the authors. First, to reflect the importance of the snowmelt period and annual climatic fluctuations, the predicted animal waste loading was multiplied by the ratio of the individual year's thaw and snowmelt erosion index to the long-term average value. Second, to reflect the changes attributable to NPS management, barnyard controls were assumed to reduce barnyard loading by one-half.

The Universal Soil Loss Equation (USLE) was applied to each field in the watershed using a computer program developed by Miller, *et al.* (1979), which was modified to reflect refinements presented by Wischmeier and Smith (1978). Crop management (C) factors for this locality (curve 14) were derived from individual year crop values using Table 5 of

Wischmeier and Smith (1978). Values for the yearly erosion index (R) – the sum of rainfall and thaw and snowmelt indices – were calculated using watershed precipitation measurements. Thaw and snowmelt factors were determined by multiplying the December-March precipitation by 1.5 (Wischmeier and Smith, 1978). Total phosphorus loading from fields was estimated using an Environmental Protection Agency model modified to include a soluble P predictive component (B. A. Miller, 1979, M.S. thesis, Univ. of Wisconsin-Madison, Dept. of Civil and Env. Engr.).

Sediment associated phosphorus loads were estimated using the function:

$$Y(SEDP) = a \cdot Y(SY) \cdot C_S(PT) \cdot r_P$$

where:

$Y(SEDP)$ = total sediment associated phosphorus loading (kg/ha/yr),

a = dimensional constant (10 metric),

$Y(SY)$ = sediment yield (Mtons/ha/yr),

$C_S(PT)$ = total phosphorus concentration in soil (g P/100 g soil or %), and

r_P = phosphorus enrichment ratio.

The soluble reactive P predictive equation (Table 1) that was used estimates loadings from agricultural watersheds as a function of average annual precipitation, area, slope, soil type, land use, type of plowing, and residue management. The model was developed using techniques of statistical regression and data from Midwestern nutrient loading studies.

TABLE 1. Soluble Reactive Phosphorus Loading (SRPL) Model 20: The Basic Equation.*

$$SRPL = Const + B_1X_1 + B_2X_2 + B_3X_3 + B_4X_4 + B_5X_5 + B_6X_6 + B_7X_7$$

SRPL = Soluble reactive phosphorus loading (kg/ha/yr)

Const = 0.2164

B_1 =	−0.0025	X_1 =	average annual precipitation (cm)
B_2 =	−0.0015	X_2 =	area (ha)
B_3 =	0.0093	X_3 =	slope (%)
B_4 =	−0.1616	X_4 =	1 if clay loam soil, else 9
B_5 =	0.1518	X_5 =	1 if corn,
=	0.0932	=	1 if oats,
=	0.2675	=	1 if hay,
=	0.1837	=	1 if pasture, else 0
B_6 =	−0.1700	X_6 =	1 if up and down plowing, else 0
B_7 =	−0.0949	X_7 =	1 if residue left or incorporated, else 0

*From B. A. Miller, 1979, M.S. thesis, Univ. of Wisconsin-Madison, Dept. of Civil and Env. Eng.

STUDY SITE DESCRIPTION AND LAND MANAGEMENT

The White Clay Lake Watershed is located in Shawano County in northeast Wisconsin (Figure 1). This 1,205-ha watershed is a gently rolling till plain of Late Wisconsin age which surrounds a 95-ha dimictic, mesotrophic marl-forming lake. Soils are primarily in the Onaway and Solona series (Typic and Aquic Eutroboralfs, respectively); maximum relief in the watershed is about 30 meters and slopes are generally less than 12 percent. About 70 percent of the 77 cm long-term average annual precipitation falls between May 1 and November 30 with the greatest amounts coming in June. December through March precipitation averages 15.6 cm.

Land use is primarily dairy agriculture consistent with a relatively short growing season (130 frost-free days) and slightly alkaline, youthful soils which favor production of legumes, particularly alfalfa. In the past 25 years, herd sizes in the watershed have increased, as has corn acreage, while land previously devoted to pasture has virtually all been converted to cropland.

East Branch Subwatershed

The present study focuses on land management and phosphorus and sediment loadings in a part of the watershed known as the East Branch subwatershed where a perennially flowing stream drains a land area of 328 ha. Land use for the years 1974 through 1979 is summarized in Table 2.

TABLE 2. Land Use Summary, East Branch Subwatershed, White Clay Lake, 1974-1979.*

Land Use	1974 (%)	1974 (%)	1976 (%)	1977 (%)	1978 (%)	1979 (%)
Corn**	8.2	16.6	17.5	20.0	18.0	8.6
Corn***	20.1	10.1	11.1	10.9	11.7	16.8
Oats	9.2	10.7	12.3	11.6	11.0	8.7
Hay	42.5	43.5	40.7	39.0	39.8	47.0
Animal Yard	2.3	1.4	1.7	1.8	2.0	2.0
Residences	3.0	3.0	3.0	3.0	3.2	3.2
Marsh	2.7	2.7	1.7	1.7	1.7	1.7
Wood	9.7	9.7	9.7	9.7	9.7	9.7
Other	2.3	2.3	2.3	2.3	2.3	2.3

*Total area = 328.0 ha.
**First and second year corn.
***Third year corn.

The ratio of corn to oats to hay was approximately 3:1:4 during most of the six years of study indicating CCCOHHHH to be an average crop rotation in the subwatershed. Farm plans developed to improve cropland management recommended rotations with fewer years of corn, generally, CCOHHH, CCOHHHH, or COHHHH. On less steep slopes, rotations were modified to include an additional year of corn, while on more sloping fields, an additional year of hay replaced a year of corn.

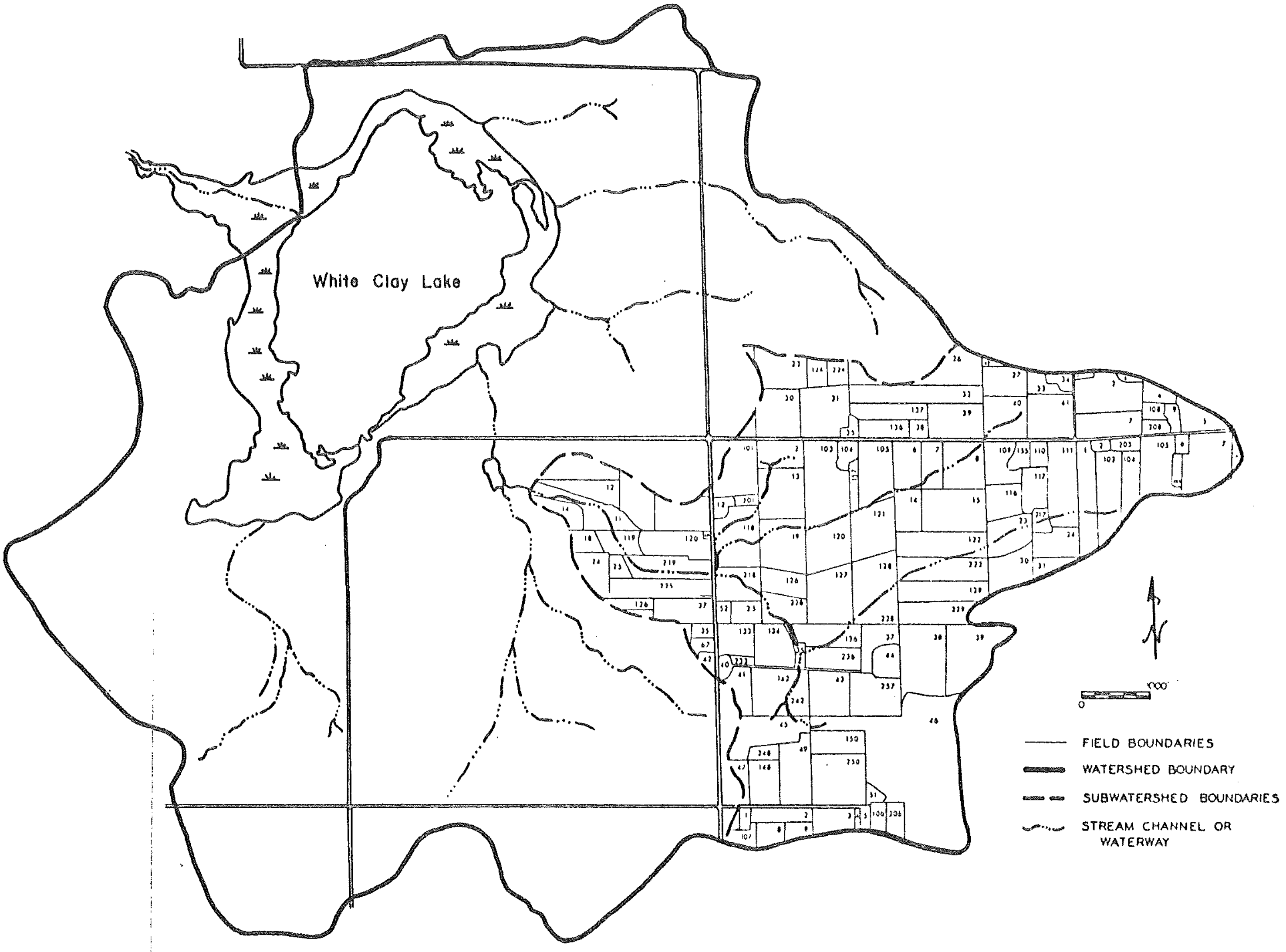

Figure 1. White Clay Lake Watershed, Shawano County, Wisconsin.

Fall plowing using a moldboard plow and incorporating residue, followed by spring disking, was common tillage practice in the watershed. Farmers were hesitant to use conservation tillage because of the fine-textured soils, and the morainal topography generally makes the use of contour strips difficult. Thus, most of the changes in cropland management during the project either involved changes in rotations or waterway improvements.

The Agricultural Stabilization and Conservation Service (ASCS) provided funds for installation of about 1600 m of tiled, grassed waterways in 1976. Contour strips were laid out in approximately 17 ha and several field boundaries were changed to avoid plowing up and down hill. In 1976, watershed farmers, on their own initiative, installed tile drains in some 23 ha to enhance production; 3.3 ha of wetlands were drained.

Location of the 10 livestock concentrations in the East Branch subwatershed is indicated in Figure 2. Associated with these barnyards were 558, 594, and 593 animal units in 1970, 1974, and 1978, respectively. As a result of the management effort, eight had manure storage facilities and six had barnyard runoff control measures installed by 1979. All but one farm had these practices installed by the summer of 1977. An additional impact in the subwatershed came from winter spreading of manure from four livestock concentrations located adjacent to it. Three of these had manure storage facilities installed by 1979.

RESULTS AND DISCUSSION

Monitoring Results

A summary of the water, residue, phosphorus, and nitrogen transport from the East Branch subwatershed for 1974 through 1979 is presented in Table 3. The year-to-year variability in this monitoring data is readily apparent. Observed climatic

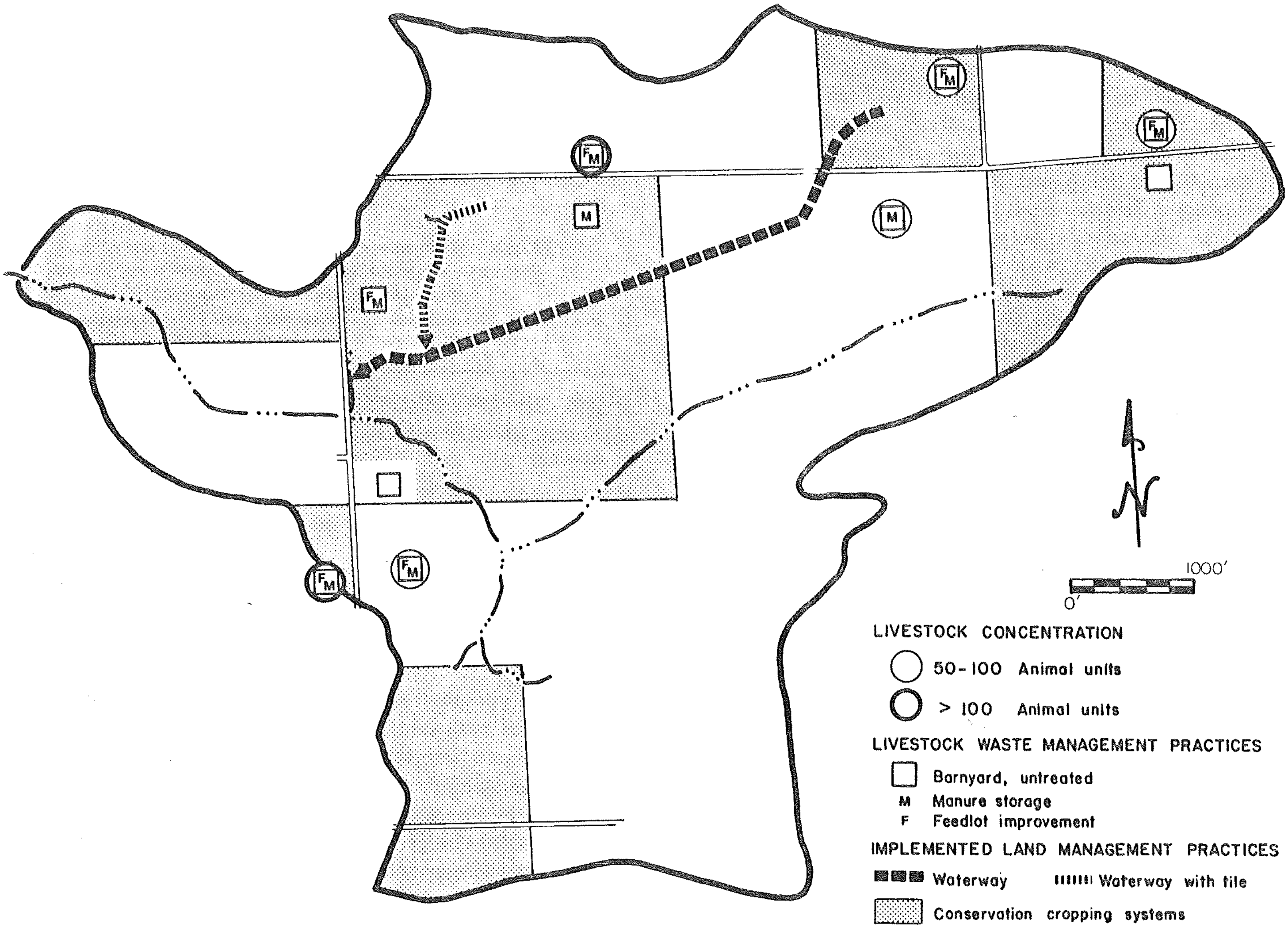

Figure 2. East Branch Subwatershed, White Clay Lake.

TABLE 3. Summary of Annual Water, Residue, Phosphorus, and Nitrogen Transport, East Branch Subwatershed.

Year	Water Volume (m^3)	Residue	Phosphorus	Nitrogen
			Total kg Mean (Range) – mg/L	
1974	405,000	227,400 563(10-6210)	214.6 0.53(0.02-6.1)	1660 4.10(1.8-15.5)
1975	616,000	184,000 299(60-1640)	166.9 0.27(0.01-3.47)	2221 3.61(1.55-26.8)
1976	682,000	197,300 289(29-827)	703.0 1.03(0.01-7.85)	2552 3.74(1.57-8.18)
1977	138,825	82,420 594(287-1100)	85.3 0.625(0.01-3.65)	785 5.65(1.51-16.3)
1978	238,096	143,273 602(180-1030)	50.8 0.213(0.02-5.75)	1666 7.00(2.6-18.3)
1979	1,209,815	587,934 405(257-1270)	293.2 0.241(0.02-1.45)	5984 4.94(1.47-8.34)

events provide some explanation, including a 50-year recurrence interval storm on June 9, 1974, a total snow loss of 36 cm between March 16 and 18, 1976, a very dry spring and growing season in 1977, and heavy snowfalls in the winter of 1978-79. Total rainfall, percent runoff, and rainfall intensity as indicated by snowmelt and thaw and rainfall erosion index (Wischmeier and Smith, 1978) provide some quantification of the climatic differences from year to year (Table 4). Note the relative significance of the thaw and snowmelt component of the erosion index (R) particularly for a low rainfall year like 1976 when it comprised 46 percent of the total index.

Some indication of the effect of watershed improvements may be obtained by comparing average loadings for the years 1974 through 1976 with the years 1977 through 1979 when installation of most practices was complete (Table 5). While total rainfall and the erosion index averaged 128 and 167 percent of the earlier period, total phosphorus loading was only 39 percent of the earlier period. The ratio of sediment load to the erosion index shows a 20 percent decrease, indicating less sediment output per erosion potential. Apparent inconsistencies in this analysis are noted as a decrease in water volume is associated with an increase in sediment load. Likewise, a 34 percent increase in sediment load is associated with a decrease in total phosphorus output. Because of overlying climatic variability and of difficulties in identifying nutrient and sediment sinks, attributing changes in material transport directly to watershed improvements was difficult.

Comparison of Monitored Loadings and Model Predictions

To better assess how the NPS management implemented in the East Branch subwatershed could change long-term average annual phosphorus and sediment transport, models were selected and calibrated against monitored data.

Soil loss (Wischmeier and Smith, 1978) was calculated for each field and the entire subwatershed for the years 1974 through 1979, using the crops, cropping practices, and erosion index specific to each year. Predicted average annual soil loss during the six years of study was 2.78 Mg/ha, very near the soil loss values determined in the watershed using Cs-137 techniques (Mitchell, *et al.,* 1980; McHenry and Bubenzer, 1982) and significantly less than the 11.0 Mg/ha considered a tolerable loss for Onaway and Solona soils. Monitored sediment loss, estimated soil loss (keeping in mind the concerns of Wischmeier, 1976) and the calculated sediment delivery ratio are presented in Table 6. The six-year average delivery ratio of 0.26 is quite close to the 0.30 that might be predicted for a watershed of this size (Agriculture Research Service, 1975).

TABLE 5. Comparison of Monitored Loadings and Climatic Factors Before and After Implementation of Management Practices, East Branch Subwatershed.

	1974-1976	1977-1979
Average Annual Water Flow (m^3)	566,667	528,912
Average Annual Phosphorus Loading (kg)	361.5	143.1
Average Annual Sediment Loading (kg)	202,900	271,209
Average Annual Precipitation (cm)	57.3	73.2
Average Total Erosion Index	71.0	118.8
Sediment Loading Erosion Index	2,858	2,283

Total phosphorus (P) loading from cropland and animal waste was evaluated separately (Table 7). These individual contributions become important since specific control practices may be more effective on one source of P than another.

Soils in the watershed have an average total phosphorus content of 0.030 g/100 g of soil (I. C. Moore, 1979, M.S. thesis, Univ. of Wisconsin-Madison, Dept. of Soil Science). Using a literature-derived enrichment value of 2.4 (B. A. Miller, 1979, M.S. thesis, Univ. of Wisconsin-Madison, Dept. of Civil and Env. Engr.), the calculated soil loss and a delivery ratio of 0.26, sediment associated P loading was calculated. Annual total phosphorus loading from cropland was predicted to average 0.51 kg/ha, with 73 percent sediment-associated and 27 percent soluble during the six-year period.

Phosphorus runoff from winter-spread manure and barnyards was estimated using a method described by Moore (I. C.

TABLE 4. Climatic Indices, East Branch Subwatershed.

	1974	1975	1976	1977	1978	1979	Monitored Average	Long-Term Average
Total Precipitation (cm)	57.9	59.9	54.0	54.3	75.5	89.9	65.2	77.4
Runoff (percent)	21.1	31.0	38.0	7.7	9.5	39.2	24.2	– – –
Rainfall Erosion Index	90.0	73.8	20.8	16.9	135.0	183.0*	86.6	100.0**
Thaw and Snowmelt Erosion Index	5.1	5.6	17.6	9.0	4.9	7.5	8.3	9.1***
Total Erosion Index (R)	95.1	79.4	38.5	25.9	139.9	190.5	94.9	109.2

*Includes an estimated value of 20 for one 5.1-cm rainfall event for which intensity data were not available.

**Regional value from Wischmeier and Smith (1978).

***Calculated using long-term (20 year) December-March precipitation averages according to methods of Wischmeier and Smith (1978).

TABLE 6. Sediment Prediction and Delivery Ratio, East Branch Subwatershed.

	1974	1975	1976	1977	1978	1979	Average
Monitored Residue Transport (Mg)	227.4	184.0	197.3	82.4	143.3	587.9	237.1
Estimated Soil Loss (Mg)	1016.8	718.3	285.4	190.2	1154.6	2095.9	920.2
Sediment Delivery Ratio	0.22	0.26	0.69	0.43	0.12	0.28	– –*

*Average delivery ratio for six years = 237.1/910.2 = 0.26.

TABLE 7. Comparison of Monitored and Predicted Transport of Total Phosphorus, East Branch Subwatershed.

Phosphorus Source	1974 (kg)	1975 (kg)	1976 (kg)	1977 (kg)	1978 (kg)	1979 (kg)	Average (kg)
Cropland Sediment Associated P*	154.5	108.9	22.8	20.3	177.3	235.6	– – –
Cropland Soluble P	48.2	45.0	48.2	48.2	48.2	48.2	– – –
TOTAL P from Cropland	**202.7**	**153.9**	**71.0**	**68.5**	**225.5**	**283.8**	**167.5**
Barnyard P	40.2	42.1	131.9	56.7	29.8	41.4	57.0
Winter-Spread Manure P	13.2	14.6	46.1	9.5	4.0	2.5	15.0
TOTAL P from Animal Waste	**53.4**	**56.7**	**178.0**	**66.2**	**33.8**	**43.9**	**72.0**
TOTAL Predicted P Loading	**256.1**	**210.6**	**249.0**	**134.7**	**259.3**	**327.7**	**239.5**
TOTAL Monitored P Loading	**214.6**	**166.9**	**703.0**	**85.3**	**50.8**	**293.2**	**252.3**

*Sediment delivery ratio = 0.26.

Moore, M. S. thesis, Univ. of Wisconsin-Madison, Dept. of Soil Science). Within the East Branch subwatershed, a third of the land area was within the critical distance from a channel based on a channel density of 4.2 km/km. Five of the 10 livestock concentrations were within the 40 m critical distance from a channel. Runoff from above ground manure storage facilities was not considered to be significant because all facilities were built with long (>40 m) filter strips.

During the six years of study, phosphorus runoff from livestock waste was predicted to average 15.0 kg from winter-spread manure and 57.0 kg from barnyards. By this analysis, barnyard controls should be given greater attention than manure storage, especially if there is suitable land away from waterways available for manure spreading.

A comparison of monitored and predicted values for phosphorus loading from animal waste and cropland shows predicted values to be generally higher, and clearly different than monitored values in 1976 and 1978. Both years had unusual thaw and snowmelt periods, a factor which most USLE-based models do not account for adequately for this climate. The winter of 1975-1976 featured a heavy snowfall (44.7 cm water equivalent in December through March) with most snow melting during a short period in March. By comparison, in the winter of 1977-1978, there was only 11.9 cm of water equivalent in snowfall over the same months, following an extremely dry growing season. Thus, runoff in the spring of 1978 was minimal.

While the predictive capability of the model was variable from year to year, predicted average loadings and monitored average loadings during the six-year study period were 239.5 and 252.3 kg, respectively, suggesting that the model adequately predicts long-term average loadings.

Evaluation of Loading Changes Attributable to Nonpoint Source Management

The described models were used to evaluate changes in long-term average annual sediment and phosphorus loadings in the East Branch subwatershed during four periods of interest (Table 8). Each period corresponds to initiation or completion of a watershed improvement project. Period I corresponds to 1970, prior to any of the major watershed improvements. Period II corresponds to 1974 when initial ASCS-funded projects for animal waste storage had been installed. Land management practices for both periods were considered to be the same. Period III corresponds to 1978 when the initial U.S. Environmental Protection Agency (USEPA) and Wisconsin Department of Natural Resources (WDNR) funded projects were complete. Period IV corresponds to 1979 and beyond when all structural measures, conservation cropping systems, and land management practices identified in farm conservation plans were implemented. To evaluate the long-term efficacy of phosphorus and sediment management practices, the USLE erosion index factor (R) was set at 109 (Table 3) and cropland loading calculations were made for changes in crop cover and management (C) and conservation practices.

TABLE 8. Predicted Changes in Average Annual Sediment and Phosphorus Loading Attributed to Changes in Management.

	Management Period			
	I 1970	II 1971-1974	III 1975-1978	IV 1979+
SEDIMENT (Mg)	280.7	280.7	217.4	198.9
Percent Period I Loading	100	100	77	71
PHOSPHORUS (kg)				
Cropland Sediment Associated	160.7	160.7	126.7	118.4
Cropland Soluble	45.0	45.0	48.2	48.2
TOTAL Cropland P Runoff	**205.7**	**205.7**	**174.9**	**166.6**
Percent Period I Loading	100	100	85	81
Barnyard P Runoff	74.9	71.7	55.3	50.3
Winter-Spread Manure P Runoff	24.2	25.6	7.5	3.0
TOTAL Animal Waste P Runoff	**99.1**	**97.3**	**62.8**	**53.3**
Percent Period I Loading	100	98	63	54
TOTAL P Runoff	**304.8**	**303.0**	**237.7**	**219.9**
Percent of Period I Loading	100	99	78	72

Calculated average annual sediment loading declined by 29 percent in the East Branch subwatershed between Periods I and IV. This reduction is attributable to a combination of changed cropping rotations, installation of a grassed waterway, and barnyard controls including diversions and filter strips.

Predicted average annual phosphorus loadings from animal waste in the East Branch subwatershed also declined 54 percent from Period I to IV. Initial predictions of barnyard phosphorus loadings in Period I were three times that of winter-spread manure, indicating barnyards to be a source that deserves equal or greater attention than animal waste storage.

Predicted average annual phosphorus loadings from cropland also decreased from Period I to IV, mostly attributable to installation of grassed waterways and changes in rotations. While soluble phosphorus was predicted to increase slightly because of increased acreage of hay, there was an overall decrease because of larger reductions in sediment-associated phosphorus as soil loss was reduced. The 55 kg reduction in phosphorus loadings is comparable to the 46 kg from animal waste, but represents a much smaller percentage (22 percent) reduction of the initial loadings from cropland. However, since cropland runoff was 67 percent of the total runoff in Period I, this reduction is significant. As noted earlier, these reductions are due strictly to changes in rotations; conservation tillage practices which would further reduce sediment loss were not employed.

Implications for Lake Protection

The lake management plan was developed because nutrient data showing total phosphorus transports toward the lake in 1974 to be 0.66 g/m^2 of lake surface of which 0.38 g/m^2 came from surface water inputs (Peterson and Madison, 1978). The majority of the surface water inputs (0.34 g/m^2) were from the monitored East and South Branch subwatersheds.

Comparisons of ratios of vernal nitrogen and phosphorus concentrations (Table 9), using Scavia and Chapra's (1977) value of 12 as critical, shows the lake to be phosphorus limited for algal production. Using the lake's volume of 3.91 x 10^6 m^3 and a calculated phosphorus retention coefficient of 0.8, Vollenweider's (1975) model yields an acceptable total phosphorus (P) loading for the lake of 0.12 g/m^2-yr and an excessive loading level of 0.21 g/m^2-yr. Since the primary goal for White Clay Lake was to protect current water quality while maintaining its productive fishery, a 0.21 g/m^2-yr total phosphorus loading appears to be a reasonable objective for the phosphorus-limited lake.

TABLE 9. Concentrations and Ratios of Vernal Total Nitrogen and Total Phosphorus for White Clay Lake.

	1974	1975	1976	1977	1978	1979
Total P (mg/L)	0.04	0.02	0.015	0.06	0.03	0.02
Total N (mg/L)	1.41	1.13	1.00	1.03	0.86	1.31
Ratio N:P	35	57	67	17	29	66

However, monitored in-lake conditions are generally better than those predicted by Vollenweider's (1975) model, with an average summer secchi depth in 1974 of 2.6 m rather than the predicted 1.2 m. Average summer chlorophyll *a* values measured in 1977 through 1979 were 8.4 mg/m^3 rather than the 21.3 predicted for 1974. One explanation is the ability of calcite to adsorb phosphate and precipitate it from the photic zone, thus reducing the amount of phosphorus available for algae productivity in hard water lakes (Murphy, *et al.*, 1983).

Consideration of both the recommended Vollenweider P-loading limit and the acceptable water quality conditions measured in the lake at the current P-load rate, the lake should be able to maintain its current water quality status at loading rates of between 0.21 and 0.66 g/m^2-yr.

Although early analysis of nutrient and sediment transport from the watershed did not take into account the potential for attenuation in the lake's peripheral wetlands, the management plan specifically recommended preservation of the wetlands as a water quality buffer on the premise that significant retention of sediment and nutrients would occur. The value of the wetland fringe has been substantiated for this lake system. Cesium-137 data show that an average of 11 cm of sediment was deposited in the wetland area adjacent to the mouth of the East and South Branch stream since 1964 (Ritchie, *et al.*, 1983). This deposition rate is equivalent to about 10 kg sediment/m^2-yr. Johnston's (1983) soil profile work showed areal retention of sediment, phosphorus and nitrogen in a larger portion of the same wetland of 1.98 kg/m^2-yr, 2.6 g/m^2-yr and 12.8 g/m^2-yr, respectively.

Applying Johnston's values to the 2 ha of wetland at the mouth of the monitored subwatershed shows an annual retention of 40 Mg of sediment and 50 kg total phosphorus per year. Comparison of these values to annual movement of sediment and phosphorus from the East Branch subwatershed (Table 7) shows that the wetland plays an important role in the reduction of sediment and nutrient transport to the lake equivalent to 0.05 g P per m^2 of lake surface per year.

Livestock waste controls and improved cropland management in the watershed are predicted to reduce long-term average areal loading to the lake by 28 percent (0.09 g/m^2-yr). Thus, protection of the marsh fringe and nonpoint source controls are predicted to reduce surface water loading to 0.25 g/m^2-yr. While this loading is close to the desired 0.21 g/m^2-yr, contributions from ground water and precipitation yield a total areal loading to the lake of 0.52 g/m^2-yr. The inherent ability of the marl lake to tie up phosphorus, unquantified reductions in ground water phosphorus loading owing to replacement of a defective septic system at a resort bordering the lake, and the beneficial effects of the marsh bordering the entire lake, when combined with nonpoint controls seem to be adequate to maintain the lake's existing water quality and fishery.

SUMMARY AND CONCLUSIONS

The impact of implementation of a management plan for this agricultural watershed has been shown. The watershed work included changes in cropping practices and manure management, control of cropland and barnyard runoff and protection of littoral wetlands. Sediment and phosphorus transport changes were quantified using a set of models. Predicted long-term average annual loading from the East Branch subwatershed as a result of nonpoint source controls exhibits a 29 percent reduction in sediment and 28 percent reduction in total phosphorus output between 1970 (before) and 1979 (after). These reductions, coupled with a continued attenuation of sediment and phosphorus by the rezoned wetland areas, should significantly prolong the mesotrophic period of White Clay Lake's history.

Climatic variability and flushing of accumulated deposits are likely to mask any changes in sediment and nutrient loading attributable to progressive nonpoint source management in a small watershed. Thus, an evaluation strategy should use monitoring data to calibrate and verify a sediment and nutrient transport model which can then be used to estimate long-term changes in average loading and direct the cost effective investment of public monies.

The models used adequately predicted long-term average loading over the six-year period of the study. They were less successful in predicting loadings for a specific year, even with the thaw and snowmelt factor included. The thaw and snowmelt erosion factors should be incorporated routinely into soil loss calculations for small agricultural watersheds for this climatic regime.

Loading models can be used to develop a watershed management plan which can identify critical source areas and how to meet specific loading reduction goals cost-effectively. Savings might have been achieved by identifying farms which had adequate flat cropland for winter spreading of manure, rather than construction of more capital intensive storage facilities. Such nonstructural control practices, while lower in cost, are even more dependent on continued conscientious management.

The implementation of the management plan was done on a voluntary basis, and as such, all high priority sources would not necessarily be treated. Note, for instance, that the barnyard closest to the stream channel (Figure 2) was not treated, and that the adjacent land was not under conservation management, even though 90 percent cost-sharing was available.

The successful implementation of this watershed management project was the result of the cooperation and involvement of a variety of state and federal agencies whose activities were directed and coordinated by the lake rehabilitation district and personnel of the local SCS and ASCS offices. This local involvement will ensure that long-term project goals are met and that further efforts will be taken to reduce nonpoint source problems which impact lake water quality.

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