Modeling Erosion and Deposition in the Lyman Lakes and the Spring Creek Watershed

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Senior Comprehensive Exercise

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ABSTRACT

The Lyman Lakes act as a sediment basin for the Spring Creek watershed. A quantitative analysis was made of the relationship between erosion in the watershed and deposition in the lakes. The volume and weight of the sediment in the lakes was calculated by drilling through the ice on the lake and taking sample cores. The Universal Soil Loss Equation (USLE) was applied to the surrounding land in order to calculate the weight of sediment being transported throughout the immediate watershed. This weight was multiplied by a sediment delivery ratio to determine the amount of transported material that is eventually deposited in the lake. The results show that all the sediment in the lakes could have come from an area of approximately 255 ha (630 acres) near the lakes. The error inherent in the USLE and the many simplifying assumptions made for this study make the results highly inexact, but they may be used as general guidelines for planning within the watershed.

Keywords: soil loss, sediment deposition, Lyman Lakes

INTRODUCTION

The Lyman Lakes are two small ponds located on the Carleton College campus. They were created in 1916 by excavating an area and damming Spring Creek. The lakes act as a sediment basin for the creek. Fast-moving water slows as it empties into Upper Lyman Lake and drops much of its sediment. The water flows over a dam into Lower Lyman Lake. The lower lake is larger and has two man-made islands. Water flows from here over a second dam and eventually reaches the Cannon River.

The watershed extends to the south and east of the lakes. In the immediate vicinity of the lakes are the trees and grass of the Cowling Arboretum, athletic fields, and the Northfield Golf Course. Most of the remaining watershed is agricultural land. Some residential areas of Northfield may be within the watershed, but this is difficult to determine because water runoff is controlled by streets and sewers in many areas.

The Lyman Lakes were last dredged in 1961. Since then enough sediment has accumulated that the lakes are less than one meter deep in many areas. Carleton is currently investigating alternatives for managing the lakes including dredging and implementing better soil conservation practices in the watershed.

This study was an effort to quantify and better understand the relationship between erosion of the surrounding farmland and sedimentation in the lakes. The volume and weight of sediment in the lakes was measured directly. Mathematical models of soil erosion and transport were then applied to determine the area required to produce a sediment yield that would bring the lakes to their present condition.

EQUATIONS

Many mathematical models for predicting soil loss due to water erosion have been proposed for areas with different climates and topography. In the United States the most common and widely accepted is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1962) which states:

$$A = (2.24)RKSLCP$$

where:

A = the annual soil loss, metric tons/ha,

R = the rainfall erosivity factor,

K = the soil erodibility factor,

L = the slope length factor,

S = the slope gradient factor,

C = the cropping management factor, and

P = the erosion control practice factor.

The factor 2.24 converts the results from tons/acre/year to metric tons/ha/year. Technical guides generally still use English units, but the literature has been changing to SI units during the last ten years.

The USLE was designed to predict average annual soil losses due to rill and interrill erosion. Although the equation was first developed for land in the eastern two-thirds of the United States, thousands of plot years have been devoted to gathering data for parameters for other areas. The results may be used to determine changes in erosion rates caused by different land uses and conservation practices.

The rainfall erosivity factor, R, is a measure of the detaching power of raindrops and the contribution of rain to runoff. The erosivity is a product of two rainstorm characteristics, kinetic energy and intensity. Weischmeier and Smith (1958) developed an equation to determine the kinetic energy of a storm based on rain drop size distribution and rain drop terminal velocity reports:

$$E = 1.213 + 0.890 \log I$$

where:

E = the kinetic energy, Kg m/m mm, and

I = rainfall intensity, mm per hour.

Further analyses showed that soil losses due to a storm are proportional to EI, the kinetic energy multiplied by the rainfall intensity (Wischmeier, 1959). The R factor is determined by the recurrence intervals for storms with various E values.

The soil erodibility factor, K, is the erosion rate per unit of erosion index for a specific soil in cultivated continuous fallow on a 9 percent slope 22.13 meters long (SCS, 1975). In other words, the K factor is the inherent erodibility of a soil relative to other soils. The most accurate way to determine the erodibility factor for a soil is through expensive and time consuming direct measurement on a test plot. Mathematical models have also been developed based on factors which affect the infiltration rate, permeability, and total water capacity and factors that resist the dispersion, splashing, abrasion and transporting forces of rainfall and runoff. Theoretically, clay content should be the best indicator of erodibility because clay combines with organic matter to create stable aggregates and clods (Morgan, 1979). However, Wischmeier, et al. (1971) propose a nomograph for determining erodibility based on five different parameters; percent silt (.002 - .05 mm) and very fine sand (.10 -2.0), organic matter content, structure, and permeability. They found that the product of percent silt and percent sand and silt can account for 85 percent of the variance in erodibility. Special consideration is also given to distinctive soils such as fragipan soils.

The slope factor, L, is the erosion ratio of soil loss from the field slope length compared to that from a 22.13-meter slope on the same soil type and gradient. Slope length is the distance from the point of origin of overland flow to either the point where the slope decreases enough for deposition to begin or where runoff enters a defined channel (SCS, 1975). The slope-length factor is defined as:

$$L = \frac{x}{22.13}$$

where:

L = slope-length factor,

x = slope length, meters, and

m = an exponent ranging from 0.5 if slope $\geq$ 5 percent and 0.2 if slope < 1 percent (Wischmeier and Smith, 1978).

The slope-gradient factor, S, is the ratio of soil loss from the field gradient compared to that from a 9-percent slope. Erosion will be increased on steeper slopes because moving water will attain greater velocity and kinetic energy. Smith and Wischmeier (1957) give a parabolic description of the slope-gradient factor:

$$S = 0.065 + 0.045s + 0.0065s^2$$

where:

S = the slope gradient factor, and

s = the gradient, percent.

The slope-length factor and the slope-gradient factor are often multiplied together and considered as one number, the slope-effect factor, or LS. These equations were developed for uniform slopes and are good approximations for all slopes. They will usually overestimate soil loss from concave slopes and underestimate the loss from convex slopes (Mitchell and Bubenzer, 1980). For more exact work equations have been developed which consider individual portions of the slope which have different slope-effect factors. These equations are complex and impractical for general use.

The cropping-management or plant cover factor, C, is the ratio of soil loss from a field with a specified cropping and management system or plant cover to that from the fallow condition on which the factor K is evaluated (SCS, 1975). This factor includes the interrelated effects of crop sequence, productivity level, growing season length, cultural practices, residue management, rainfall distribution, and growth stage and vegatative cover at the time of the rain. Values for the cropping-management factor are generally measured from test plots rather than calculated. Farming practices which tend to reduce the cropping management factor are fall plowing instead of spring plowing, planting cover crops such as oats instead of row crops such as corn and soybeans, conservation tillage instead of conventional tillage, and leaving mulch or residue in the field after plowing. The C factor for forest and grass is generally 30 to 100 times less than that for farm crops.

The erosion control practice factor, P, is the ratio of soil loss with contouring, stripcropping, terracing or cross-slope farming compared to that with straight-row farming (SCS, 1975). Many other erosion control practices are already considered in the cropping-management factor.

The fraction of the eroded sediment which actually reaches a certain point in the watershed is the sediment delivery ratio. This ratio will be less for larger watersheds because they will have more places in which to trap and hold sediment as it moves through. Sediment delivery ratios today are based almost solely on empirical studies. Mathematical models require complex hydrology and sediment transport relationships which will probably be beyond our technological capabilities for several years (Mitchell and Bubenzer, 1980). Many studies have proposed ratios for various regions of the world with different land use, types and sizes of watersheds,and climatic conditions.

METHODS

The thickness of the sediment in the Lyman Lakes was determined by first drilling holes through the ice. Thickness was measured and sample cores were taken by forcing a 3-inch-diameter plastic pipe into the sediment. The sediment was a fairly homogenous black muck containing mostly silt, clays, and organic material. The top of the sediment was defined as the place where the pipe could rest on the bottom of the lake. The bottom of the sediment was defined as the place past which the pipe could no longer be easily forced downward. This corresponded to a layer of clay which was put down the last time the lakes were dredged presumably to prevent the lakes from leaking into the lower water table.

Data were collected from points that would be useful for drawing isopachs. Some areas on the east end of the upper lake near the mouth of Spring Creek were inaccessable due to thin ice throughout the winter. Data for this area were extrapolated from general relationships between water depth, the shape of the shoreline, and sediment thickness in other areas of the lake.

The data were plotted on maps (Figures 1 and 2) with isopachs indicating thickness of sediments. To determine the volume of the sediments areas of equal thickness were cut from the maps and weighed. The area and weight of these irregular shapes are directly proportional to the weight of a map of known area. Each area of the map was multiplied by the corresponding sediment thickness to determine the volume. Samples were weighed, dried, and weighed again to determine what percentage of the muck was water.

The USLE and an appropriate sediment delivery ratio was applied to the land surrounding the lakes in order to define an area that would have yielded enough sediment during the 24 years since the lakes' last dredging to bring them to their current condition. Field methods and values for variables were taken from the Soil Conservation Service Technical Guide (SCS, 1975). The rainfall erosivity factor, R, used for the area is 150, although Mitchell and Bubenzer (1980) suggest a slightly lower value. Soil types were identified in the Soil Survey of Rice County, Minnesota (SCS, 1975). The soil erodibility factors determined by the SCS ranged from 0.10 for the Salida series to 0.32 for the Klinger series.

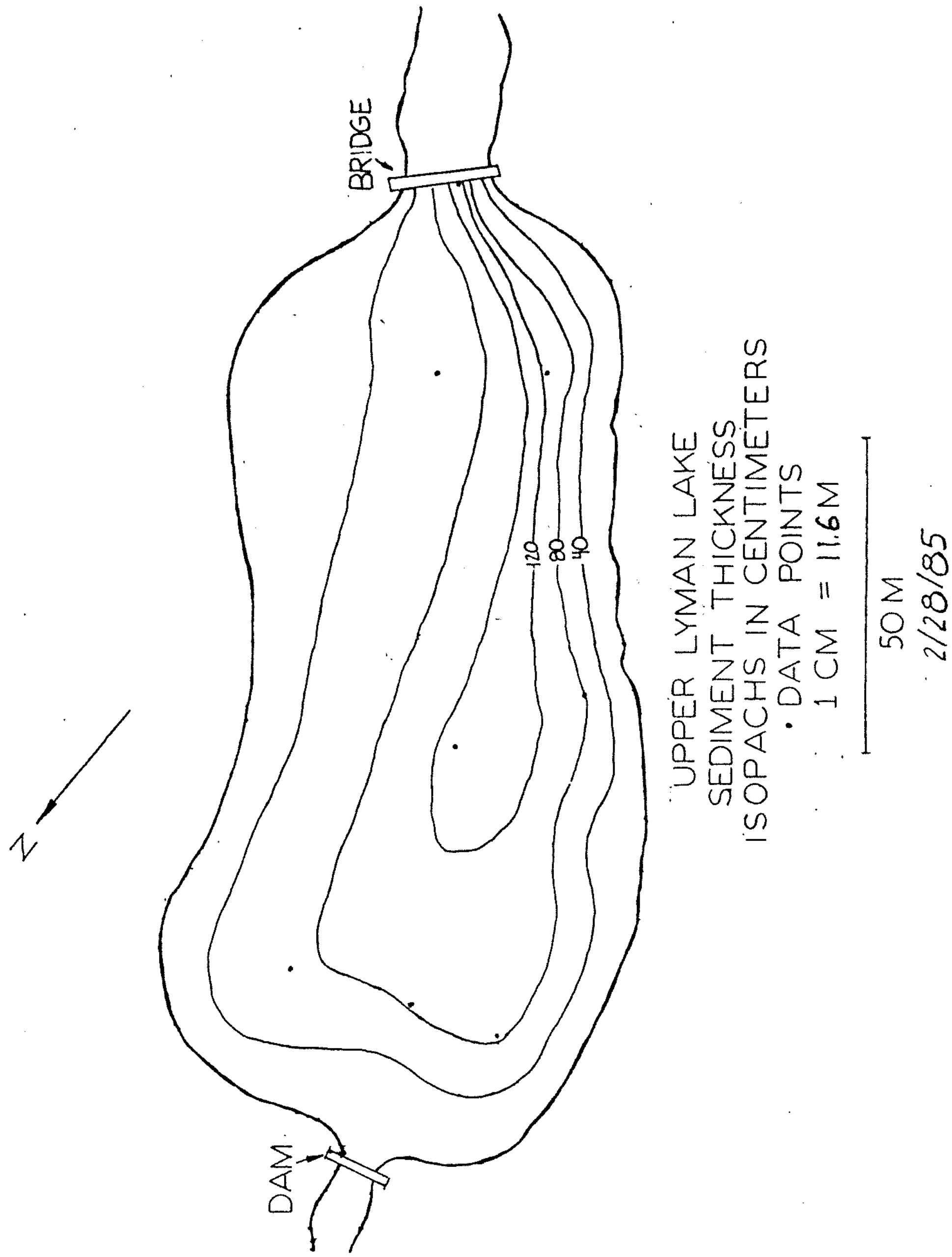

BRIDGE
DAM
N
120
80
40
UPPER LYMAN LAKE
SEDIMENT THICKNESS
ISOPACHS IN CENTIMETERS
· DATA POINTS
1 CM = 11.6M
50 M
2/28/85

FIGURE 1

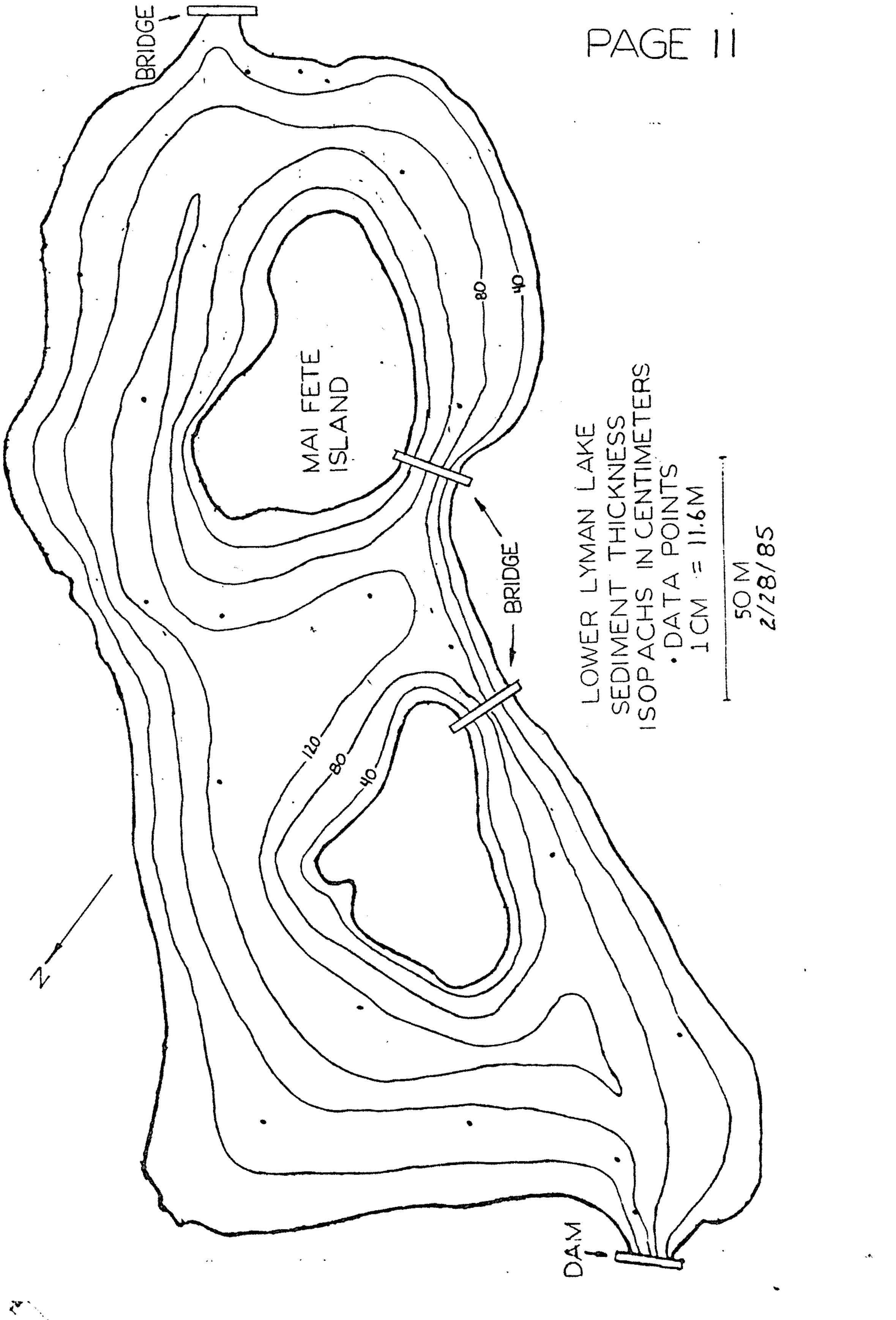

BRIDGE
MAI FETE ISLAND
80
40
BRIDGE
LOWER LYMAN LAKE
SEDIMENT THICKNESS
ISOPACHS IN CENTIMETERS
· DATA POINTS
1 CM = 11.6M
50 M
2/28/85
120
80
40
N
DAM

FIGURE 2

Lengths of slopes were paced off and slope-gradients were determined with a Brunton compass.

A sediment delivery ratio of 0.275 was applied to the calculated soil loss from 255 ha (630 acres) of land. This ratio is given by the SCS for "moderate" watersheds although no definition for moderate is given. This is a slightly lower value than that given by the American Society of Civil Engineers (1975) which does not make any adjustment for steepness of the watershed.

ASSUMPTIONS AND ERROR ANALYSIS

Without apology several simplifying assumptions were made for this study. For the USLE a crop rotation of corn-corn-soybeans was assumed for all farmland that was not permanent pastureland. This correlated well with the observed residue in the fields. Crop management and erosion control practices were considered to have been the same for the last 24 years as they are currently in each individual field. These practices include conventional tillage, spring plowing with residue left, and contour plowing on all except a few fields.

Erosion due to gullying was not included in the equations even though in a few places the gullies had reached the bedrock. It would have been impossible to determine how much has eroded from them in just the last 24 years. Also, some previously observed gullies have been filled in recently. Hillslope processes such as soil creep were not included. A significant amount of road and building construction has occurred in the watershed at various times. No account was made for this even though the ground exposed for construction and roads experiences dramatically increased soil losses and sediment delivery ratios (SCS, 1975).

The watershed could have been analyzed more exactly to better determine its sediment delivery ratio. The forest and grassland which surround the lake should act as an effective filter for sediment from agricultural land. Also, compensation could be made for smaller natural and man-made sediment traps such as the one which serves as a water hazard on the western most part of the Northfield golf course. As water slices to the right off one of the farm fields and flows into the small pond it undoubtedly deposits some of its sediment load. A qualitative check was made to determine that not much of the sediment settled out before the water left through a culvert which acts as an emergency drain for high water. Roads influence water runoff throughout the watershed, but culverts allow water to pass under them along all the major washes.

Except for a few newer developments on the edge of town, Northfield residential areas were not considered as part of the Spring Creek area. Water runoff here is dominated by impermeable streets and rooftops and sewer systems that generally run into the Cannon River. Soil loss from grass lawns should be minimal. The important type of sediment from these areas is coarse road sand combined with salt. Occurrence of coarse sand in the Lyman Lakes' sediments is mostly limited to a few areas around pipes which drain water from the roads on the Carleton campus.

The lakes are assumed to be perfect basins in which all of the sediment settles out. This is obviously not the case as shown by the murky water leaving the lower lake. Data concerning concentrations of particulate matter in water entering and leaving the lakes over an extended period of time were not readily available. An unpublished report (Schilling, 1984) calculates the residence time of the upper lake to be five days, which is not enough time for all of the fine material to settle out. Some clay does come out of suspension, as evidenced by the clay content of the sediments. A more detailed analysis of the trap efficiency of the Lyman Lakes could be very helpful in developing a more accurate sediment delivery ratio because they are of a known age and may be closely monitored.

The error inherent in the USLE is calculated to be about 107 percent for a particular year (Onstad, et al., 1979). Fortunately for this study, that error is reduced over extended periods of time. The error caused by an amatuer technician doing field work is estimated between 30 and 50 percent.

The net effect of all of these assumptions and possible errors will be considered insignificant. In spite of all the potential problems, the results of the study are still significant enough to useful.

RESULTS AND CONCLUSIONS

The Lyman Lakes contain 22,800 cubic meters (17,445 cubic yards) of muck. There are 15,150 metric tons (16,695 tons) of dry sediment contained in the muck. By dividing this figure by 24, the number of years since the last dredging, it is determined that the accumulation rate is 630 metric tons/yr (694 tons/yr). The sediment delivery ratio for the area is 27.5 percent (SCS, 1975), which means that 2,290 metric tons (2,524 tons) must have eroded from the surrounding land each year in order for that amount of sediment to reach the lakes.

The soil loss calculated for the surrounding land ranged from essentially zero for some grassland areas to over 67.2 metric tons/ha/yr (30 tons/acre/yr) for some steeper fields. The 1,555 ha (630 acres) area shown in Figure 3 produced enough sediment in the last 24 years to bring the lakes to their present state. Sediment from this area is also most likely to reach the lakes before settling out elsewhere.This does not mean that all of the sediment in the lakes came from this area.

If the USLE and an appropriate sediment delivery ratio were applied to the entire Spring Creek watershed, the predicted amount of sediment in the Lyman Lakes would be much greater than it actually is. There are two possible explanations for this poor relationship. The first is that there is something extraordinary about the watershed so that common sediment delivery ratios should not apply. The second is that the Lyman Lakes do not act as a very effective sediment trap. The latter conclusion is probably a large factor, but additional study of the watershed could be interesting and useful to determine if there is reason why the watershed seems unusual. In either case, the relatively small area outlined by this study should give encouragement that better soil conservation practices on any scale will have an impact on the Lyman Lakes area.

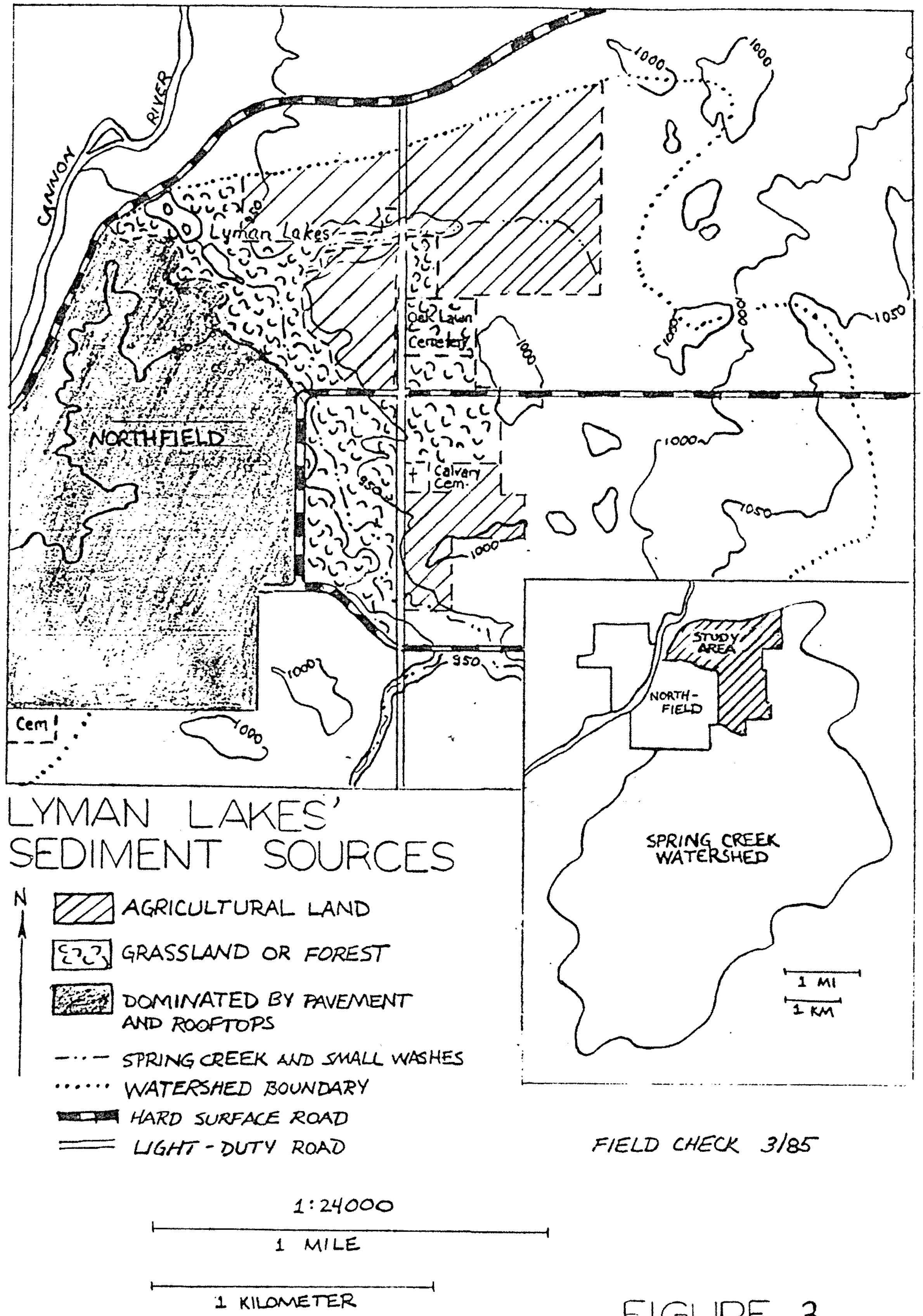

CANNON RIVER
Lyman Lakes
950
1000
1050
Oak Lawn Cemetery
NORTHFIELD
Calvary Cem.
Cem
STUDY AREA
NORTH-FIELD
SPRING CREEK WATERSHED
1 MI
1 KM
LYMAN LAKES' SEDIMENT SOURCES
N
AGRICULTURAL LAND
GRASSLAND OR FOREST
DOMINATED BY PAVEMENT AND ROOFTOPS
SPRING CREEK AND SMALL WASHES
WATERSHED BOUNDARY
HARD SURFACE ROAD
LIGHT - DUTY ROAD
FIELD CHECK 3/85
1:24000
1 MILE
1 KILOMETER

FIGURE 3

ACKNOWLEDGEMENTS

I would like to thank my helpful field assistants S. Baxter, A. Fidler, D. "L." Frankel, G. Carleton, and C. Choy for risking personal loss of body heat for this project. Bob Fitzsimons of the Rice County SCS, Faribault provided valuable guidance concerning field techniques. The Liquid Paper Corp. of Dallas, Texas also provided timely help. Finally, I thank Dennis Easley, the Carleton Geology Department faculty, and especially Ed Buchwald for giving me the opportunity to observe and take part in the environmental planning process.

```
10 REM             *** Universal Soil Loss Equation ***
20 REM Program to calculate soil loss from an area based on rainfall, soil
30 REM erosivity, slope length, slope gradient, cropping-management, and
40 REM erosion control practices.  Values and equations come from SCS (1975)
50 REM and Mitchell and Bubenzer (1980).
60 REM
65 WIDTH 80
70 PRINT "               ** UNIVERSAL SOIL LOSS EQUATION **"
75 PRINT "Enter soil loss factors for each field (See SCS Technical Guide, 1975).
80 PRINT "CAUTION: Results for slopes > 400 ft. or 24% are speculative."
82 PRINT "Do you want a paper copy? ";
83 OPT$ = INKEY$
84 IF OPT$<>"Y" AND OPT$<>"y" AND OPT$<>"N" AND OPT$<>"n" OR OPT$="" THEN GOTO 83
86 PRINT OPT$
88 IF OPT$ = "Y" THEN LET OPT$ = "y"
90 IF OPT$ = "y" THEN GOSUB 1010
100 PRINT:INPUT "Rainfall factor (R)";R: PRINT
120 IF OPT$ ="y" THEN GOSUB 1100
150 INPUT "Field name";F$
170 INPUT "Field size (acres)";SIZE
200 INPUT "Soil erosivity (K)";K
300 INPUT "Length of slope, in ft.";LENGTH
400 INPUT "% slope";SLOPE
410 IF SLOPE < 1 THEN LET M = .2
412 IF SLOPE >= 1 AND SLOPE <= 3 THEN LET M =.3
414 IF SLOPE > 3 AND SLOPE < 5 THEN LET M = .4
416 IF SLOPE >= 5 THEN LET M = .5
430 LET L = ((LENGTH/3.28)/22.13)^M
440 LET S = .065 + (.045 * SLOPE) + (.0065 * SLOPE^2)
500 INPUT "Cropping-management (C)";C
600 PRINT "Erosion control practices (Up and down or Contour)? ";
602 PRACTICE$ = INKEY$
610 IF PRACTICE$ <> "U" AND PRACTICE$ <> "u" AND PRACTICE$ <> "c" AND PRACTICE$ <> "C" OR
CTICE$ = "" THEN GOTO 602
620 PRINT PRACTICE$
630 IF PRACTICE$ = "U" OR PRACTICE$ = "u" OR SLOPE < 1.1 THEN LET P = 1:GOTO 800
640 IF SLOPE >= 1.1 AND SLOPE <= 2 THEN LET P = .6
642 IF SLOPE > 2 AND SLOPE <= 7 THEN LET P = .5
644 IF SLOPE > 7 AND SLOPE <= 12 THEN LET P = .6
646 IF SLOPE > 12 AND SLOPE <= 18 THEN LET P = .8
648 IF SLOPE > 18 THEN LET P = .9
800 LET A = R*K*L*S*C*P
805 IF A = 0 THEN PRINT "ERROR OR NO SOIL LOSS":PRINT:GOTO 150
810 PRINT "Field ";F$;"   A=";CINT(A);"tons/ac/yr, ";CINT(2.24*A);"met. tons/ha/yr"
820 PRINT "  Field total=";CINT(SIZE*A);"tons/yr, ";CINT(SIZE*2.24*A);"met. tons/yr"
850 IF OPT$ ="y" THEN GOSUB 1200
900 PRINT: GOTO 150
```

```
1105 WIDTH "LPT1:",1000 ** PRINTER COMMANDS **
1010 LPRINT "                    ** ANNUAL SOIL LOSS **":LPRINT "CAUTION: Results for slopes >
     400 ft. or 24% are speculative."
1020 RETURN
1100 LPRINT: LPRINT "Rainfall factor =";R: LPRINT
1105 WIDTH "LPT1:",132
1110 LPRINT CHR$(15) "Field   size   ero-     length          crop-    prac-  !
     SOIL LOSS              FIELD TOTAL"
1120 LPRINT " name   (ac)   sivity     (ft)   slope   mngmnt   tices  ! tons/ac, met. tons/ha
     tons     met. tons   "
1130 LPRINT "-----------------------------------------------------------!---------------------
     ---------------------------"
1140 RETURN
1200 LPRINT USING "\     \ ####    .###     ####     ##_%    .###     #.#    _! ####
     ####           ###        ####";F$,SIZE,K,LENGTH,SLOPE,C,P,CINT(A),CINT(2.24*A),CINT
1210 RETURN
```

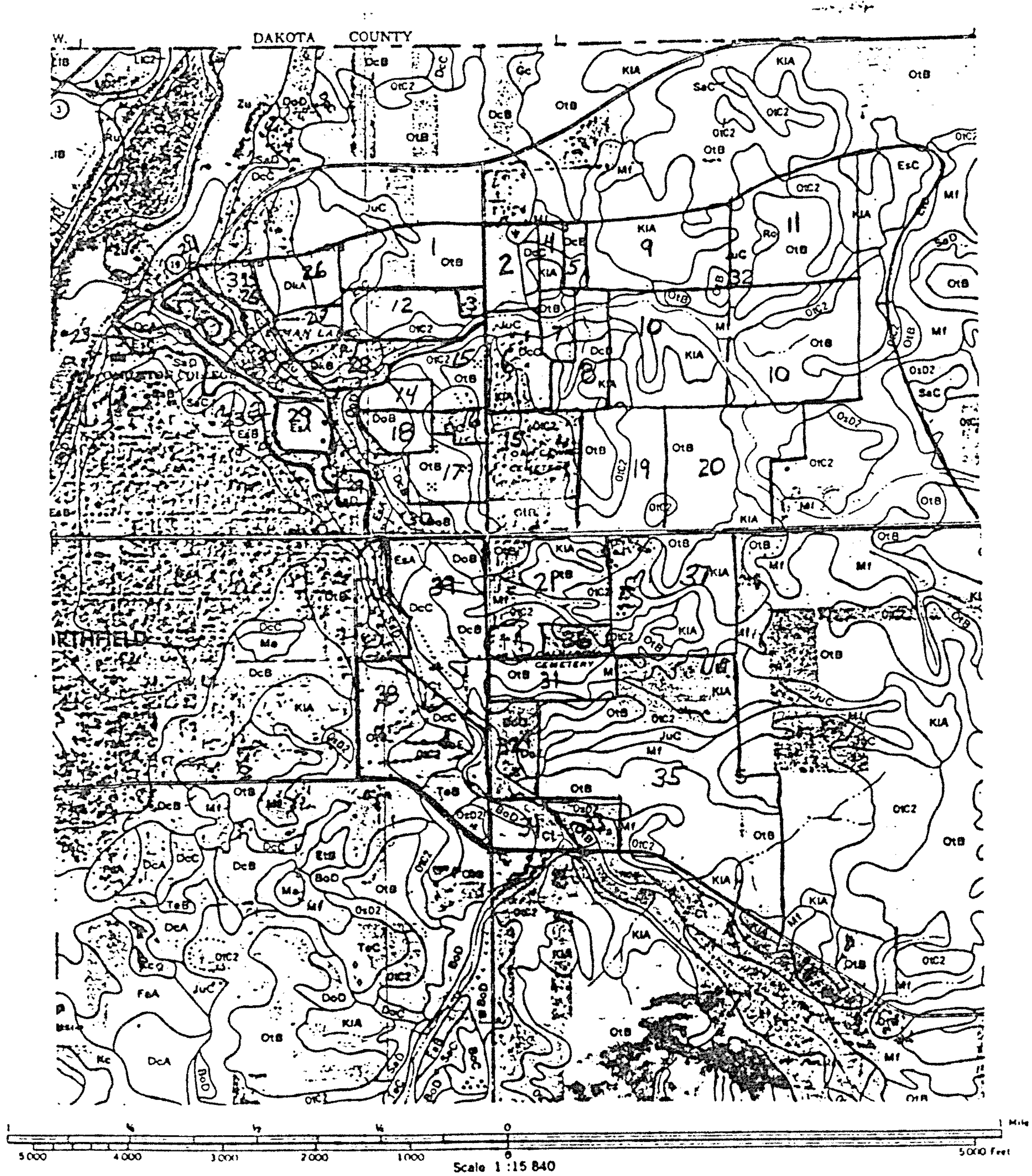
** ANNUAL SOIL LOSS **

CAUTION: Results for slopes > 400 ft. or 24% are speculative.

Rainfall factor = 150

Field name	size (ac)	ero-sivity	length (ft)	slope	crop-angent	prac-tices	SOIL LOSS tons/ac,	met. tons/ha	TOTAL tons	met. tons
1	20	.280	450	5%	.390	0.5	9	21	185	413
2	10	.280	210	5%	.390	0.5	6	14	63	141
3	3	.280	210	0%	.006	1.0	0	0	0	0
4	5	.200	210	5%	.390	0.5	5	10	23	50
5	5	.200	150	9%	.003	1.0	0	0	1	1
6	15	.280	450	12%	.003	1.0	0	1	7	16
7	7	.270	300	8%	.390	0.6	16	36	113	254
8	13	.270	150	2%	.390	1.0	4	8	46	104
9	40	.320	100	2%	.390	0.6	2	5	90	201
10	40	.280	100	2%	.390	1.0	3	7	131	292
11	40	.280	100	2%	.390	0.6	2	4	78	175
12	10	.280	200	11%	.390	0.6	22	49	220	492
13	10	.280	250	12%	.390	0.6	29	63	281	630
14	5	.280	400	5%	.390	0.5	9	19	43	97
15	29	.200	70	9%	.005	1.0	0	0	4	9
16	3	.280	50	25%	.003	1.0	1	2	3	6
17	15	.320	175	11%	.390	0.6	23	53	352	789
18	5	.280	100	2%	.390	0.6	2	4	10	22
19	25	.280	220	11%	.390	1.0	38	86	960	2150
20	45	.250	300	3%	.390	0.5	3	7	146	327
21	30	.280	300	9%	.003	1.0	0	1	8	17
22	4	.200	150	1%	.003	1.0	0	0	0	0
23	9	.100	150	26%	.005	1.0	1	1	5	12
24	3	.100	150	14%	.011	1.0	0	1	1	3
25	8	.200	250	7%	.011	1.0	0	1	3	8
26	12	.240	350	2%	.390	0.6	2	5	29	66
27	6	.200	300	7%	.003	1.0	0	0	1	2
28	10	.200	100	7%	.011	1.0	0	1	3	6
29	10	.200	300	0%	.003	1.0	0	0	0	0
30	20	.320	200	22%	.011	1.0	6	13	113	252
31	16	.280	200	8%	.390	1.0	23	51	366	820
32	10	.200	250	10%	.390	1.0	25	57	253	567
33	9	.280	300	2%	.390	0.6	3	6	22	49
34	8	.200	300	5%	.390	0.5	5	12	43	96
35	20	.280	400	5%	.390	0.5	9	19	174	390
36	6	.280	200	7%	.390	0.5	9	21	57	128
37	40	.320	200	7%	.003	1.0	0	0	7	15
38	35	.280	200	7%	.003	1.0	0	0	5	11
39	35	.200	200	10%	.003	1.0	0	0	6	14

APPENDIX
FIELD NUMBERS



N

ADAPTED FROM SCS, 1975

NOTE: FIELD NOS. 11, 19, 20, 33, 34, 35, 37, AND THE EAST HALF OF 10 DO NOT APPEAR ON FIGURE 3

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