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GEOGRAPHIC DATA BASE AND WATERSHED MODELING FOR EVALUATION OF THE RURAL CLEAN WATER PROGRAM IN THE HIGHLAND SILVER LAKE WATERSHED

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INTRODUCTION

The Rural Clean Water Program (RCWP) was initiated in 1980. The Highland Silver Lake watershed near Highland, Illinois (in southwestern Illinois) was one of five areas selected for Comprehensive Monitoring and Evaluation (CM&E) projects nationwide. Field monitoring was started in December 1981. The project uses a multi-discipline team approach, with a team consisting of a local soil district conservationist, an economist from the U.S. Department of Agriculture, a water quality specialist from the Illinois Environmental Protection Agency (IEPA), and a hydrology and sediment specialist from the Illinois State Water Survey. The Soil Conservation Service provides technical coordination. The Southwestern Illinois Metropolitan and Regional Planning Commission (SIMAPC) serves as local and project coordinator.

The Highland Silver Lake watershed project has two objectives: 1) to determine the effectiveness of Best Management Practices (BMPs) in the areas with water quality problems, and 2) to project the possible impacts of future implementation of BMPs.

Early in the project the team recognized that field monitoring alone was not sufficient to evaluate the effectiveness of Best Management Practices applied in the watershed. The CM&E team recommended that a GIS (geographic information system) data base be developed and a watershed modeling approach be used to supplement the limited field data. In 1984, the Illinois State Water Survey was requested by the CM&E team to take additional responsibility for creating the geographic data base and conducting watershed modeling for the Highland Silver Lake RCWP project.

This report describes the creation of the geographic data base, the watershed modeling procedures, and the results of these efforts in predicting the impacts of implementing various Best Management Practices. It also discusses a gross erosion assessment of the watershed that was conducted.

Acknowledgments

This investigation, sponsored and financially supported by the State Rural Clean Water Committee and Agricultural Stabilization and Conservation Service, U.S. Department of Agriculture, was conducted under the general supervision and guidance of Richard G, Semonin, Chief; Richard J. Schicht, Assistant Chief; Michael L. Terstriep, Head, Surface Water Section; and Nani G. Bhowmik, Assistant Head, Surface Water Section; all of the Illinois State Water Survey. The guidance and assistance provided by the United States Department of Agriculture (USDA) and the Soil Conservation Service (SCS), under the direction of State Conservationist John J. Eckes and Assistant Conservationist Stephen Black, are gratefully acknowledged. Wayne Kinney and his staff at the SCS Edwardsville field office also provided valuable information and assistance. The Economic Research Service of USDA, the Illinois Environmental Protection Agency, and the Southwestern Illinois Metropolitan and Regional Planning Commission (SIMAPC) cooperated with the members of the Comprehensive Monitoring and Evaluation team.

Many Water Survey staff members contributed to this project. Amelia Greene and Lorna Morgan, under the direction of Robert Sinclair, digitized the map information. Kathleen Brown, Becky Howard, and Patricia Odencrantz typed the manuscript and camera-ready copy; John Brother, Jr., and Linda Riggin prepared the illustrations; and Gail Taylor edited the manuscript.

DATA BASE CREATION

Since the Best Management Practices were applied in varying types of areas throughout the watershed, the best way to describe the data was to use a geographic data base. Among many geographic information systems (GISs) available, ARC/INFO (ESRI, 1986) was selected for the Highland Silver Lake watershed. The main reason was the ability of this system to bring together a strong geographic analysis and modeling capability with a complete interactive system for entry, management, and computer display of spatial data. ARC/INFO provides all the modern GIS features efficiently integrated into a single system for the first time. These features include an easy-to-use command language, efficient digitizing and attribute entry, automatic editing, and automatic data base creation. A detailed description can be found elsewhere (ESRI, 1986).

Data Base Components

The watershed data base consists of five maps that show land use, soil types, stream network, slope, and subwatershed boundaries.

Land Use

Land-use information was obtained from USDA's aerial photographs and from land-ownership boundaries. These boundaries were digitized as polygons and their characteristics were represented by an attribute data file. The attribute data include the area in acres and the land use classification consisting of 16 different categories. Figure 1 shows major land use categories of the watershed.

Soil Types

The soil coverage was digitized from field sheets available from the local Soil Conservation District. The attribute data for each polygon consist of soil name, soil type number, soil erodibility factor, hydrologic soil group, and typical slope length for each particular soil in the Highland Silver Lake watershed. Figure 2 shows the major soil categories based on slope class.

Stream Network

The stream network is mapped from the U.S. Geological Survey's (USGS) 7.5-minute topographic maps. The stream networks were digitized as line data. The attribute data consist of stream junctions, stream river miles, stream condition, stream periodicity, stream order, stream slope, streamgaging stations, and lake sediment survey sites. The stream network for the Highland Silver Lake watershed is shown in figure 3.

Slope

Slope information is based on 2-foot contour maps developed specifically for the Highland Silver Lake watershed. A template was used to measure the slope in the contour maps, and equal-slope areas were delineated and digitized as polygons. The attribute data for each polygon

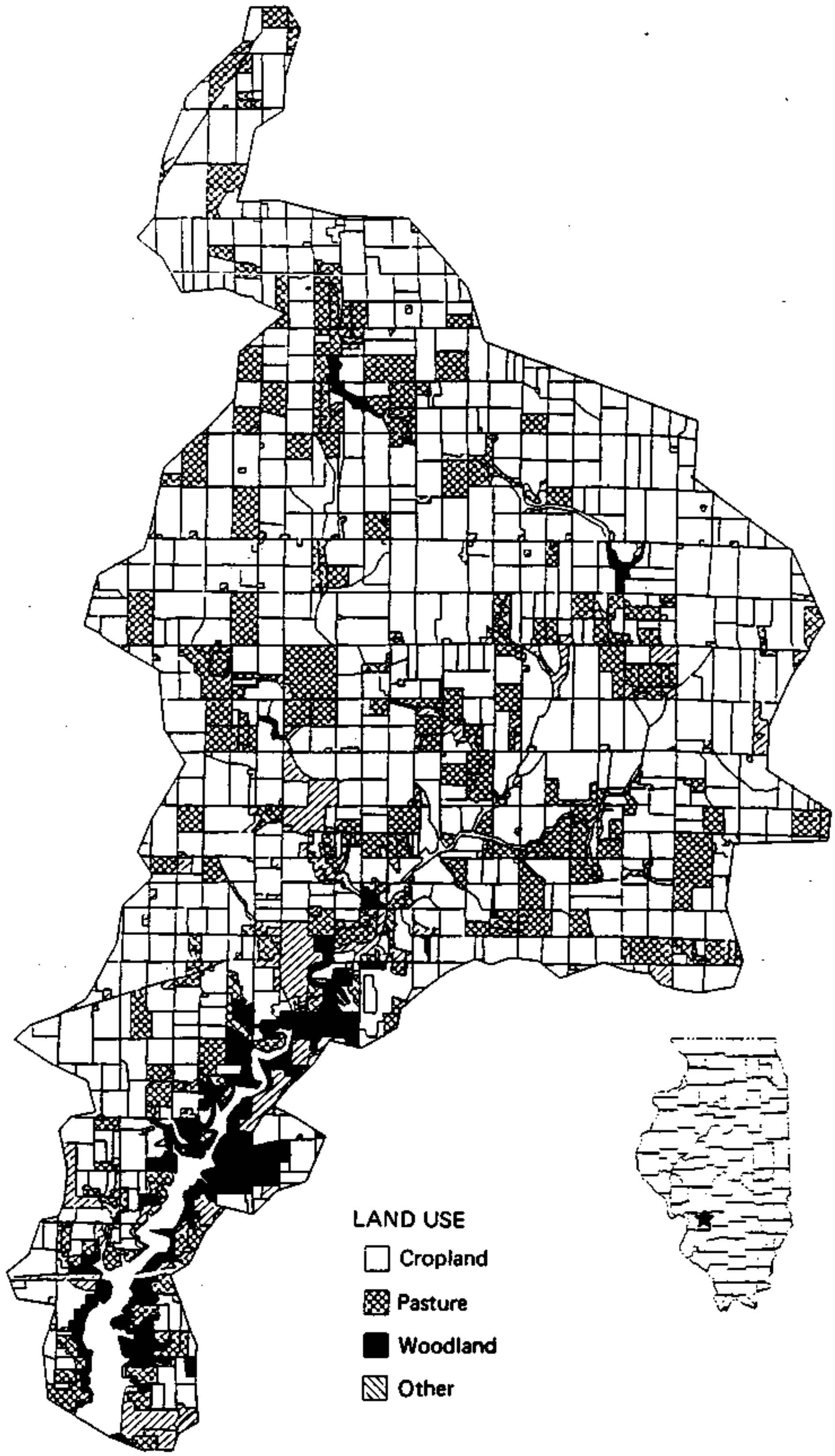

Figure 1. Land use map of Highland Silver Lake watershed

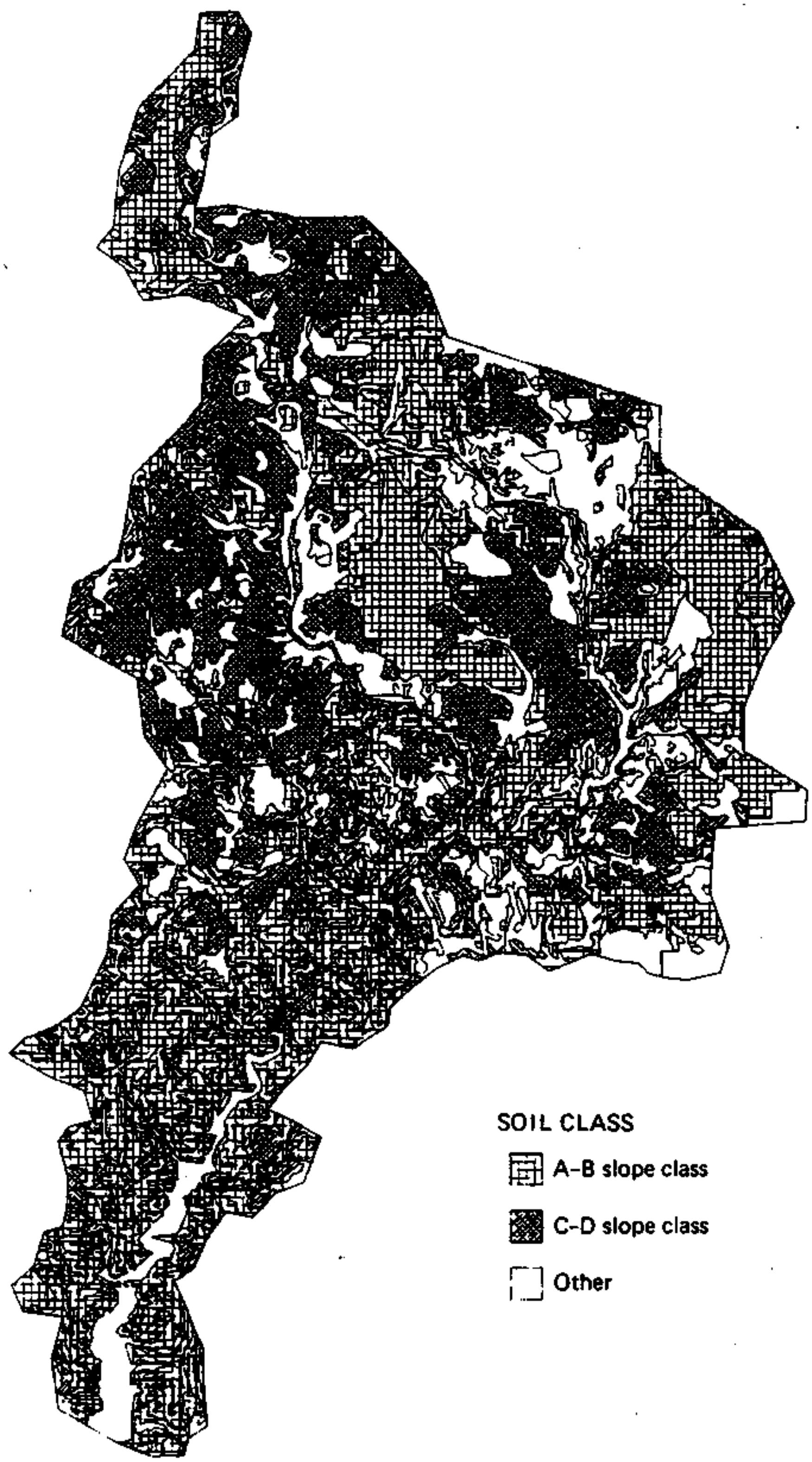

Figure 2. Soil map of Highland Silver Lake watershed

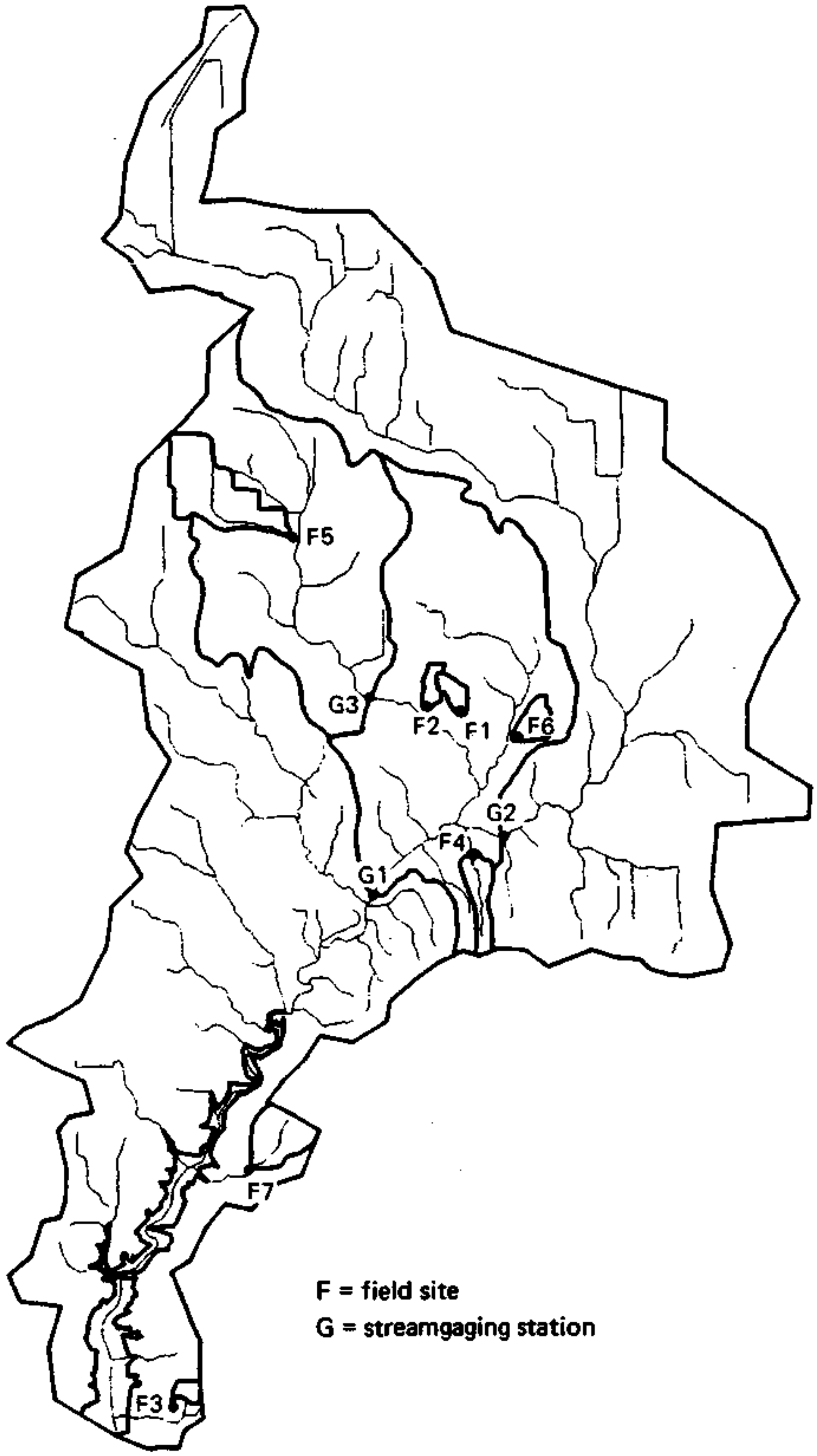

Figure S. Stream network, subwatershed boundaries, and field site and streamgaging station locations in the Highland Silver Lake watershed consist of the slope classification and area in acres. Figure 4 shows the slope delineation for the Highland Silver Lake watershed.

Subwatershed Boundaries

The locations of flume sites, streamgaging stations, and subwatershed boundaries are based on sub-watershed maps delineated from 7.5-minute USGS maps. The attribute data consist of the drainage area and the sub-watershed identification. Figure 3 shows the computer-generated sub-watershed boundaries.

GROSS EROSION ASSESSMENT

A gross erosion assessment of the Highland Silver Lake watershed was conducted. This assessment was based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978). The USLE is given as follows:

$$A = R\ K\ \underline{LS}\ C\ P$$

where R = rainfall factor

K = soil erodibility factor

LS = length and steepness of slope factor

C = cropping and management factor

P = conservation practice factor

A = computed average annual soil loss rate in tons per acre per year

By means of the USLE, the erosion rate was computed for each soil-coverage polygon. The ARC/INFO software performed the overlay and intersection of the basic coverages in order to define the parameters for the USLE. The factors of the USLE are determined as follows:

R -- The annual rainfall factor, which depicts the rainfall potential according to the rainfall patterns, was taken from the factors developed from U.S. weather data. The watershed is located within a single R-region with an assigned R value of 200.

K -- The soil erodibility factor is obtained directly from soil type. The K value for each soil was taken from tables developed by the Soil Conservation Service (1974).

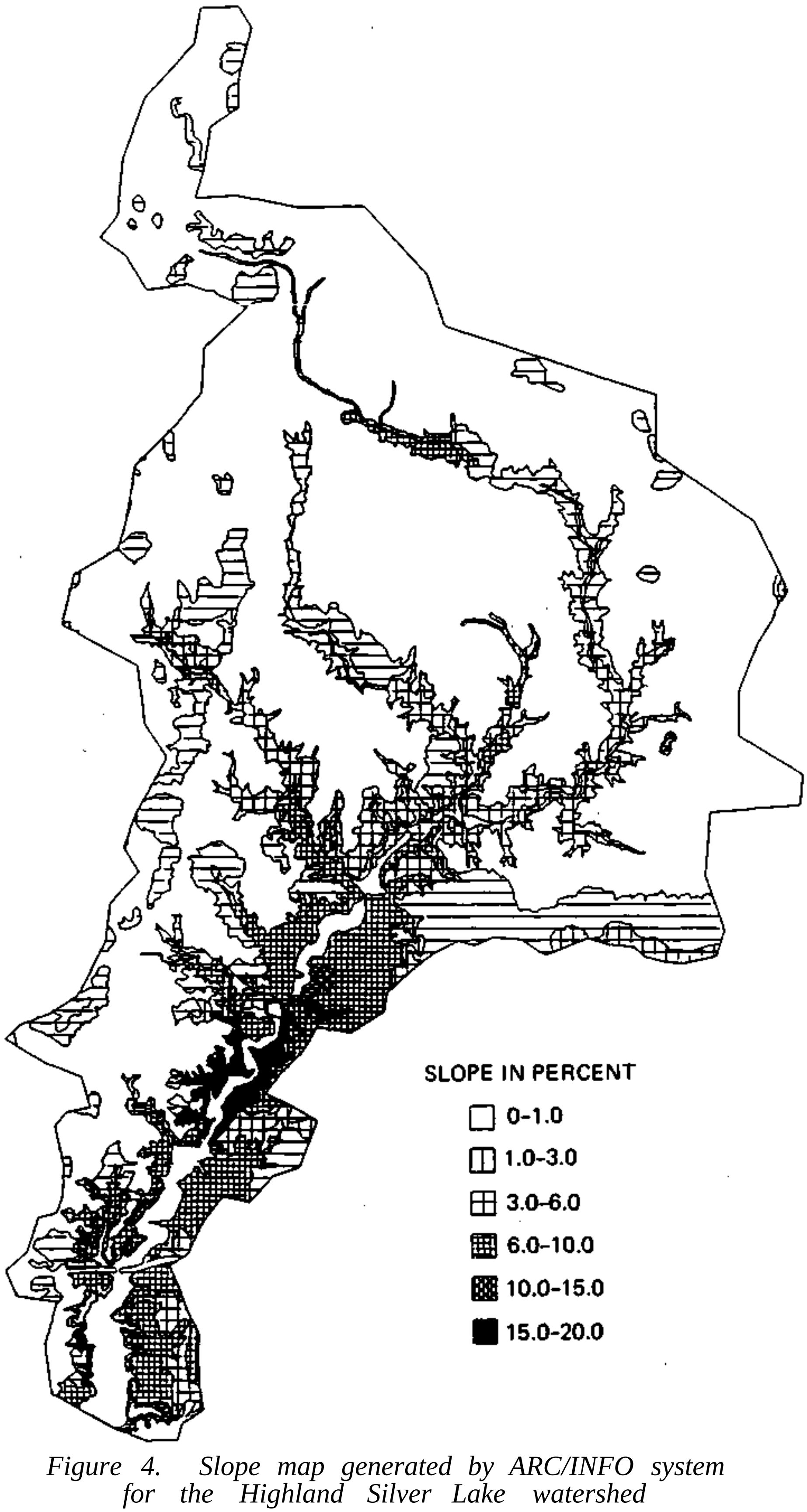

Figure 4. Slope map generated by ARC/INFO system for the Highland Silver Lake watershed

LS - - Slope length and steepness are determined by representative slope length and slope steepness values. The representative slope length was determined by the local District Soil Conservationist for each soil type in the watershed. The slope steepness value for each soil mapping unit was obtained through a coverage overlay of the soil and slope maps. Given slope length and steepness values, the LS values were determined by using a table developed by Wischmeier and Smith (1978).

C -- Cropping and management factors require the attribute data for soils and land use. To determine the C value for each soil-mapping unit, the soil and land use coverages were overlaid. Then the C value of each polygon of the overlaid coverage was determined by using a table which defines the C value as a function of crop rotation and tillage practices. An area-weighted average C value was then computed for each soil-mapping unit.

P - - The conservation practice factor is determined by the type of soil conservation practice and the slope of the land. Since the P values for different land uses are treated separately, the P values require slope, land use, and soil coverage overlays. The area-weighted average P value was determined for each soil-mapping unit.

Given the five types of input data for the USLE, the soil loss rate for each soil-mapping unit can be computed for various watershed conditions. To depict the impacts of watershed management strategies, four scenarios were developed: (1) the present condition, (2) the proposed treatment based on landowner/financial constraints, (3) the most likely condition, and (4) the best possible condition. The soil loss rates were computed for these four scenarios.

Results of Gross Erosion Assessment

The preliminary results are tabulated in table 1. Under the present condition the soil loss rate for the whole watershed was estimated as 2.9 tons per acre per year. The soil loss rates in sub-watersheds GS1, GS2, and GS3 are slightly less than this because most of the steeper land along the lake is not located in these sub-watersheds. The soil loss rates at

Table 1. Gross Erosion Rates at Field Sites and Streamgaging Stations
(Tons per acre per year)

	Scenarios			
Site*	Present condition	Proposed treatment	Most likely condition	Best possible condition
F1	2.7	1.5	1.9	1.2
F2	1.1	0.8	0.9	0.7
F3	11.9	3.3	3.6	2.2
F4	2.5	2.1	2.4	1.2
F5	2.6	2.0	2.2	1.9
F6	3.9	2.0	2.6	1.2
F7	6.6	3.1	4.5	1.2
G1	2.6	1.8	2.1	1.4
G2	2.5	1.8	2.1	1.4
G3	2.4	1.8	2.1	1.6
Whole watershed	2.9	1.9	2.2	1.4

*F = field site; G = streamgaging station the field sites vary from 1.1 to 11.9 tons per acre per year. If the proposed Best Management Practices were applied on the whole watershed, the average soil loss rate could be reduced to 1.9 tons per acre per year. The sub-watershed soil loss rates at the field sites could be reduced to 3.3 tons per acre per year or less. It was assumed that the most likely condition is that only about 75 percent of the landowners will adopt the BMPs. For this condition the average soil loss rate was computed as 2.2 tons per acre per year, slightly higher than for the proposed plan. The soil loss rates in the sub-watersheds also are slightly higher than for the proposed plan. Finally, under the best possible condition, with participation by 100 percent of landowners and with the best available technology, the average soil loss rate of the whole watershed could be reduced to 1.4 tons per acre per year. Under this condition, the sub-watershed soil loss rates at the field sites could be reduced to 2.2 tons per acre per year or less. Figure 5 illustrates the difference in gross erosion rates under present and best management conditions in the Highland Silver Lake watershed.

MODELING PROCEDURES

To simulate the changes in sediment and water quality parameters in the watershed due to the implemented and proposed BMPs, a distributed model was used. The AGNPS (Agricultural Nonpoint Source Pollution) model (Young et al., 1985) was selected because of its ability to reflect BMP changes.

The AGNPS model is a grid-cell-oriented, single-storm-event model. This model predicts runoff, eroded and transported sediment, and the nitrogen, phosphorus, and chemical oxygen demand concentrations carried by the runoff and sediment for every cell in the watershed. The watershed is divided into small square areas (cells) which are interconnected according to their drainage patterns (figure 6).

Model Components

The components of the AGNPS model pertain to three main areas: 1) hydrology; 2) erosion and sediment transport; and 3) nutrient generation and transport.

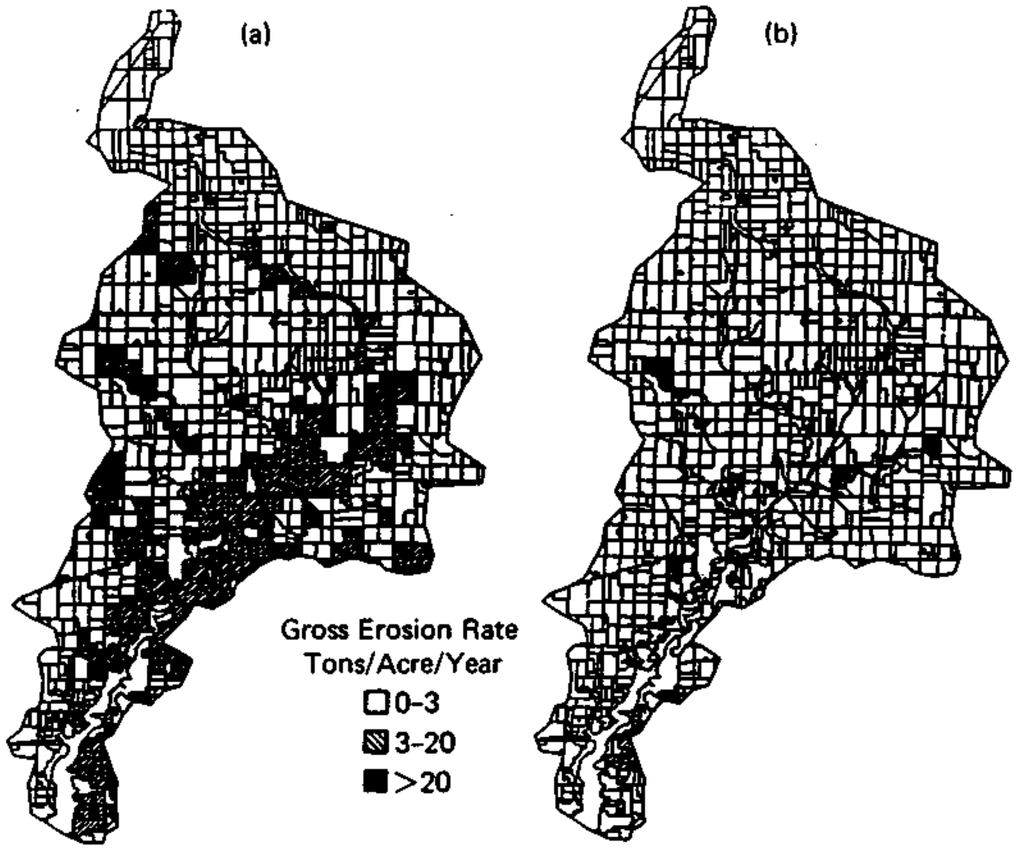

Figure 5. Gross erosion rates under a) present conditions and b) best management conditions in the Highland Silver Lake watershed

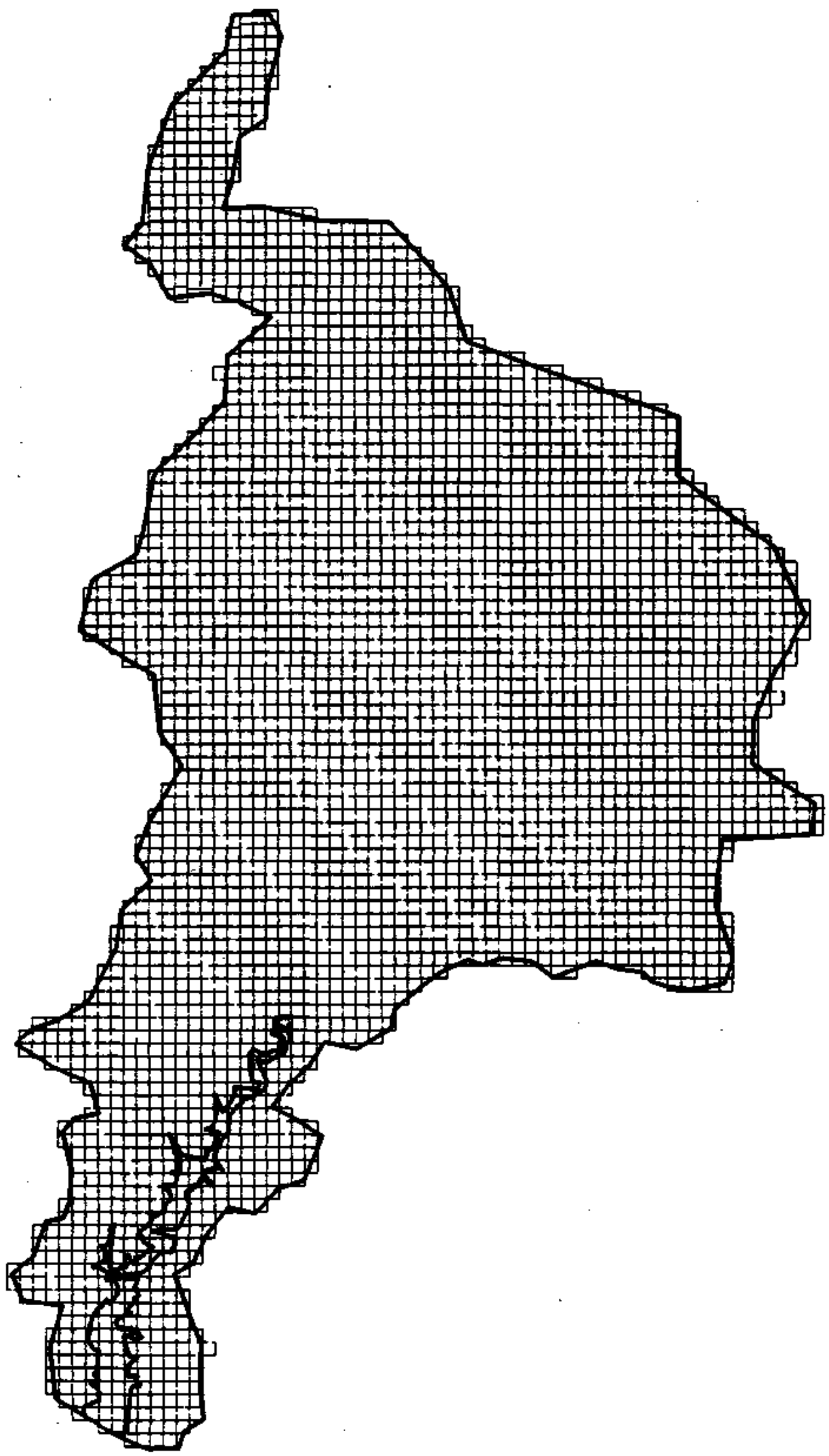

Figure 6. Grid-cell system for the AGNPS model of the Highland Silver Lake watershed

Hydrology

Runoff and peak discharge are determined for each cell. The runoff is computed by the curve number method developed by the Soil Conservation Service (1972).

The equation can be expressed as follows:

$$R_o = \frac{(P - 0.25)}{(P + 0.8\ S)} \qquad (1)$$

where

R_o = direct runoff (in.)

P = rainfall (in.)

S - 1000/CN - 10 (where CN = curve number)

The curve number is a parameter that depends upon the land use, soil type, and hydrologic soil conditions of each cell.

The peak discharge is computed on the basis of a relationship used in the CREAMS Model (Smith and Williams, 1980). This relationship is given by the following equation:

$$Q_p = 8.5\ A^{0.7}\ S_c^{0.154}\ R_o^{(0.824A^{0.0166})}\ (L_c^2/43{,}560A)^{-0.187} \qquad (2)$$

where Q_p is the peak discharge in ft^3/sec; A is the drainage area in acres; S_c is the channel slope in ft/ft; R_o is the runoff volume in inches; and L_c is the channel length in feet. The effective runoff is computed for each cell in the watershed, with consideration given to the effect of impoundments in delaying and reducing the peak discharge. The peak discharge leaving the impoundment is added to the peak discharge for the remainder of the cell, with the runoff obtained from equation 2. Peak discharges from impoundments are computed according to the drainage area and outlet pipe diameter.

Erosion and Sediment Transport

Upland erosion is predicted by means of a modified version of the Universal Soil Loss Equation (USLE) for single storm events (Wischmeier and Smith, 1978), which can be expressed as follows:

$$E = EI \cdot K_s \cdot L_f \cdot S_f \cdot C_f \cdot P_f \cdot SSF \qquad (3)$$

where

E = soil loss in tons/acre

EI = rainfall energy-intensity

K_s = soil erodibility factor

L_f = slope-length factor

S_f = slope-steepness factor

C_f = crop and management factor

P_f = practice factor

SSF = slope shape adjustment factor

The sediment routing for each cell is computed on a particle-size basis from the upstream part of the watershed to its outlet. This routing is based on the equation described by Foster et al. (1981) and Lane (1982):

$$Q_s(out) = Q_s(in) + Q_s(lat)\ \Delta X/L_R - \int_0^x D(X)\ W\ dx \qquad (4)$$

where Q_s (out) is the sediment discharge at the channel downstream end of the cell; Q_s(in) is the sediment discharge at the channel upstream point; Q_s(lat) is the lateral sediment flow rate; AX is the downslope distance; L_R is the reach length; D(X) is the sediment deposition rate; and W is the channel width.

The lateral sediment flow rate, Q_S (lat), is computed from the eroded sediment value obtained from equation 3 divided by the overland flow duration. The overland flow duration is the ratio of the field slope length and overland flow velocity. The channel deposition rate, D(X), is given by:

$$D(X) = V_{ss}/q \cdot (q_s - g_s) \qquad (5)$$

where V_{SS} is the particle terminal fall velocity, q is the runoff rate per unit width, and q_S and g_S are the sediment flow rate and sediment transport capacity per unit width. The sediment transport capacity is computed from a modification of the Bagnold stream power equation (1966):

$$g_s = \eta \cdot K \, \tau \cdot V_c^2 / V_{ss} \tag{6}$$

where g_s is the effective sediment transport capacity, η is an effective transport factor, K is the transport capacity factor which is a function of the bed and suspended load transport efficiencies, τ is the mean shear stress at the bottom of the channel, V_c is the mean flow velocity computed from Manning's equation, and V_{ss} is the sediment particle fall velocity.

The sediment discharge equation for each particle size is given by the following equation:

$$Q_s(out) = \left[\frac{2 \cdot q(out)}{2 \cdot q(out) + \Delta x V_{ss}} \right] \left[Q_s(in) + Q_s(lat) - \frac{W \Delta x}{2} \left\{ \frac{V_{ss}}{q(in)} \cdot (q_s(in) - g_s(in)) - \frac{V_{ss}}{q(out)} \cdot g_s(out) \right\} \right] \tag{7}$$

where $Q_s(out)$ is the particle discharge at the outlet of the cell, q(out) is the discharge per unit width from the cell, ΔX is the channel length across the cell, V_{ss} is the sediment particle fall velocity, Q_s (in) is the sediment particle discharge entering the cell, Q_s (lat) is the lateral or upland sediment discharge, W is the average channel width, q(in) is the discharge per unit width entering the cell, $q_s(in)$ is the sediment particle discharge per unit width entering the cell, $g_s(in)$ is the sediment particle transport capacity at the upstream portion of the cell, and $g_s(out)$ is the sediment particle transport capacity at the outlet of the cell.

The sediment discharge within the cell is calculated according to the following time sequence: The first period is the time in which sediment eroded from the upland areas of the cell enters the channel. Therefore the duration of this period is controlled by the overland flow time. The second period follows when the upland erosion has stopped and the flow in the stream continues. During these two periods, the sediment discharge at the upstream part of the cell remains constant. This lasts for a time equal to the mean flow duration in the channel calculated at the upstream and outlet parts of the cell. The duration of this channelized flow is given by the following equation:

$$D = RO \cdot A/Q_p \quad (8)$$

where D is the duration, RO is the runoff volume, A is the drainage area in acres, and Q_p is the peak discharge.

Nutrient Generation and Transport

The methods used to predict nitrogen (N) and phosphorus (P) yields from the cells and watershed were developed by Frere et al. (1980). The contribution of soluble nitrogen and phosphorus that reaches the concentrated flow is assumed to remain. The basic equation to predict the soluble N concentration is:

$$\begin{aligned} RON = .892 \cdot [&(CZERON - CHECKN) \cdot EXP(-XKFN1 \cdot EFI) \\ &-(CZERON - CHECKN) \cdot EXP(-XKFN1 \cdot EFI \\ &-XKFN2 \cdot RO)] / COEFF + RN \cdot RO / EFRAIN \end{aligned} \quad (9)$$

where

RON = the soluble N in the runoff in lb/ac
CZERON = the available soluble N content in the soil in kg/ha
CHECKN = the available N due to the rainfall in kg/ha
XKFN1 = the rate constant for downward movement of N into the soil
EFI = the total infiltration for the storm in mm
XKFN2 = the rate constant as a porosity factor
RO = the total storm runoff in mm
EFRAIN = the effective rainfall in mm

The available N in the soil (CZERON) is calculated on the basis of organic matter N, fertilizer N, and soil porosity:

$$CZERON = (SOLN + FN(X) \cdot FA(X)) \cdot COEFF \quad (10)$$

where

SOLN = the soluble N in the surface centimeter of the original soil in kg/ha
FN(X) = the N fertilizer application in cell X in kg/ha
FA(X) = the fraction of this application remaining in the top centimeter of the soil
SOLN = 1 • CSN • POR
CSN = the concentration of N in the pore soil water of the surface centimeter of soil in ppm (because of the lack of field data, 5 ppm is considered the default value)

POR = the soil porosity

CHECKN = available N due to rainfall

The equation used to predict the soluble P in the runoff is similar to the equation for N except that the effects of rainfall are omitted. The detailed equation can be found in Young et al. (1985).

The chemical oxygen demand (COD) portion is based on the soluble COD. Various background concentrations of COD are provided in the model. The soluble COD is assumed to accumulate when it reaches the channel, without any allowable losses.

Model Verification

Before the model could be used for scenario runs, the model performance had to be verified on the basis of the field-observed data. The AGNPS model was tested by changing the rainfall events within a range of 0.7 to 5.9 inches for the 1984 condition. To verify these model outputs against the observed field data, the total suspended solid loads and runoff volumes were compared with field-observed data at the three streamgaging stations as shown in figures 7 through 9.

The results showed that the model outputs for runoff volumes and total suspended solid loads pass through the scatter points for the observed data. The discrepancies are mainly due to the seasonal variation in land use and ground coverages in the watershed and to the variations in antecedent soil moisture conditions before storm events. Because of the lack of detailed land management data for each event, the model can not be calibrated to reflect specific storm events but rather is used to depict the average condition within a year. For this purpose, the model outputs were reasonably close to the field-observed average conditions.

The second way the model was verified was to compare the model-predicted sediment deposition rate with the results of the lake sediment survey. The 1984 lake sediment survey showed that lake sedimentation was occurring at the rate of 0.9 tons per acre per year which is equivalent to 27,850 tons per year. The AGNPS model estimated the annual lake sedimentation rate to be in the range of 19,100 tons, which is lower than the field data indicated (see table 2). It is worthwhile to note that in the period 1981-1984, the rainfall was 14.5 percent higher than the long-

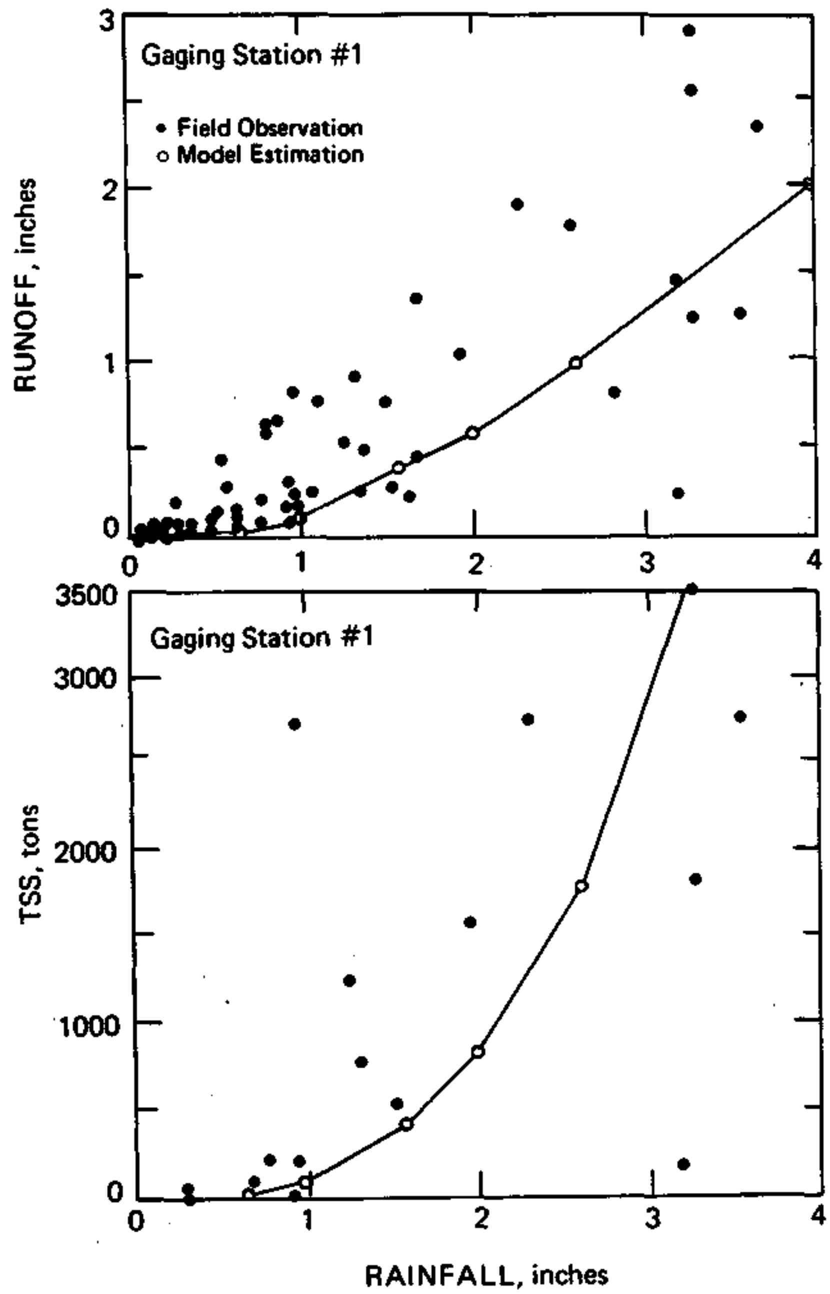

Figure 7. Observed and predicted runoff and total suspended solids at streamgaging station 1

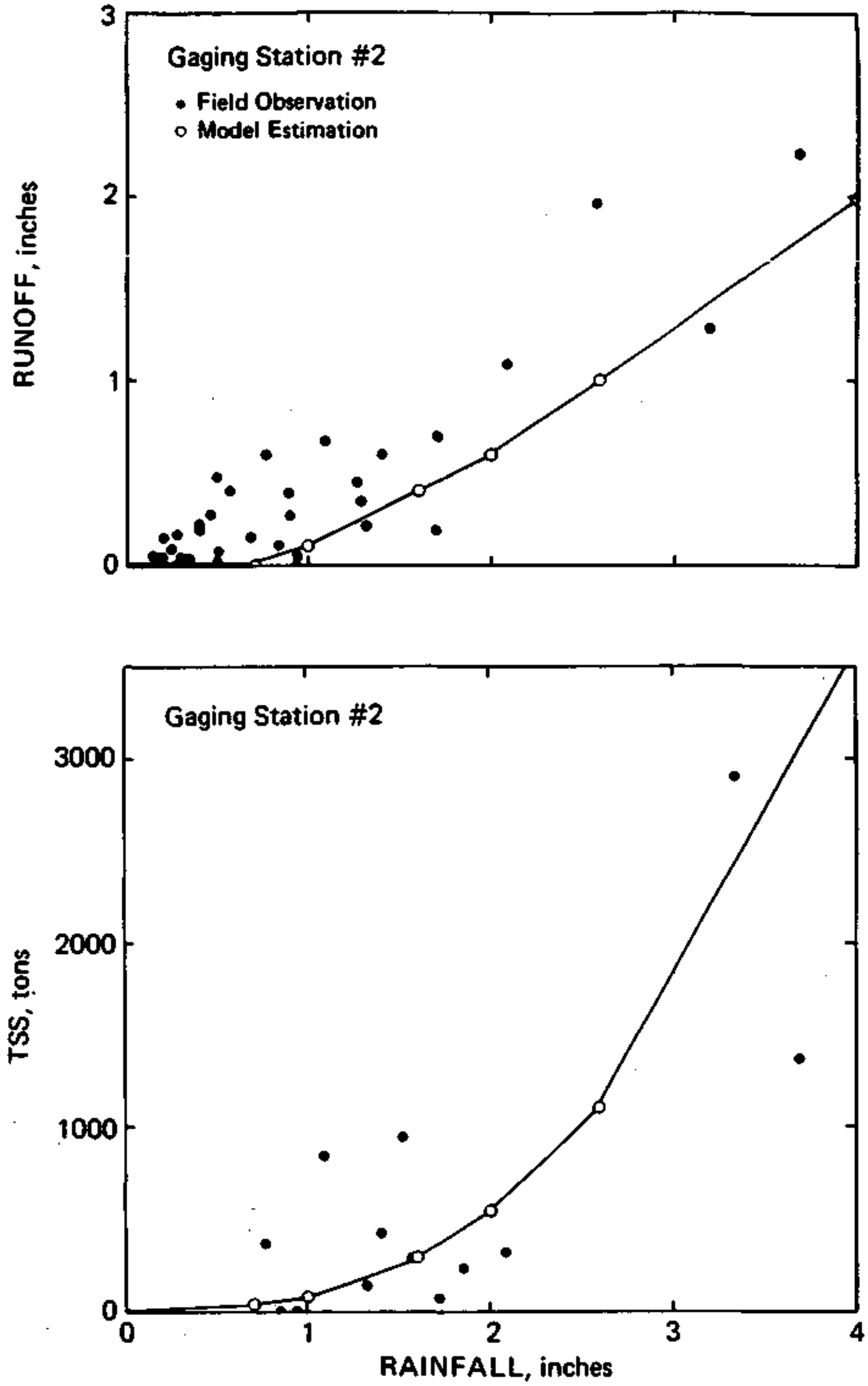

Figure 8. Observed and predicted runoff and total suspended solids at streamgaging station 2

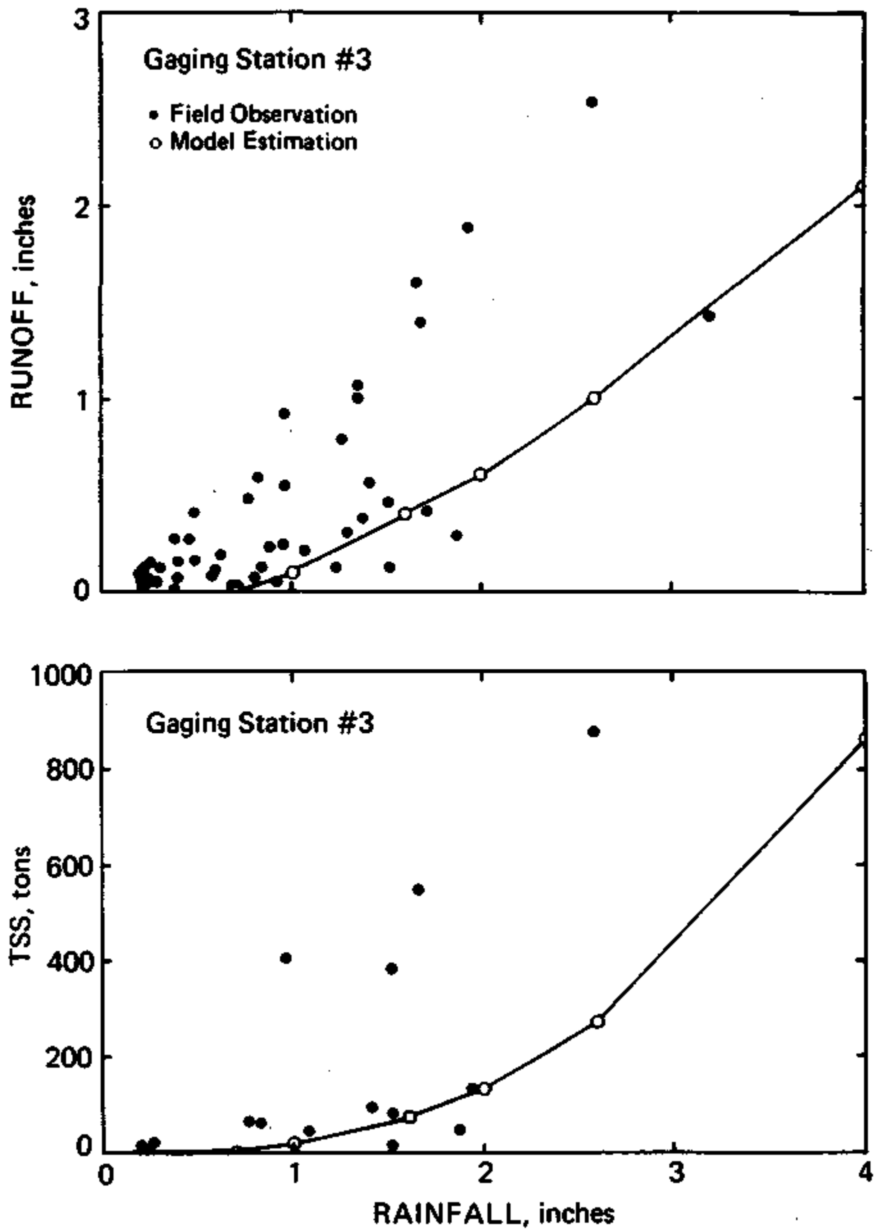

Figure 9. Observed and predicted runoff and total suspended solids at streamgaging station 3

term average. Consequently, the field measurement of the lake sedimentation rate indicated a rate higher than the long-term average.

Another way the model performance was verified was to compare the water quality loads predicted by the model with the field monitoring data on an annual average basis. The results of field observations at the spillway monitoring station, along with model results, are shown in table 2.

Table 2. Field-Observed and Model-Estimated
Water Quality Loadings at Spillway
(Tons per year)

	Observed	Estimated
Sedimentation rate	27,850	19,099
TSS	2,580	2,917
Total Kjeldahl nitrogen	145	510
Total phosphorus	20	106
Chemical oxygen demand, COD	1817	3414

As table 2 indicates, the total suspended sediment load predicted by the model is 2917 tons per year, which is relatively close to the field observation of an average of 2580 tons per year, made on the basis of 2 years and 10 months of data. The total nitrogen load, which consists of both soluble and sediment parts, is predicted as 510 tons. This is much higher than the field observation at the spillway station. The main reason for this discrepancy may be that there were not enough field samplings during major storm events. The annual total phosphorus load is estimated to be 106 tons, which again is much higher than the field observed data. This discrepancy may also be due to a lack of field samplings during major storm events. The COD is estimated to be 3414 tons per year, which is much higher then the field-observed value of 1817 tons.

In summary, the storm event verification indicated that the field-observation values are scattered around the annual average condition predicted by the model. This is mainly because the land use conditions and the antecedent soil moisture conditions at the time storms occurred deviated from the average conditions on which the model was based.

Detailed verification of each storm event is not possible at the present time because of the lack of detailed watershed data at the time the storm events occurred. However, the comparison of aggregated annual loadings and lake sedimentation indicated that the total suspended load at the spillway station was relatively close to the model prediction. The model estimation of the lake sedimentation rate is slightly lower than the rate determined in the lake sedimentation survey. The model estimations of the annual total nitrogen, phosphorus, and COD loadings are much higher than the field observations.

Model Input

For each cell, data on 21 input parameters are required to define the cell characteristics. The input parameters are:

1. Cell number
2. Receiving cell number
3. SCS curve number
4. Land slope in percent
5. Slope shape
6. Field slope length in feet
7. Channel slope in percent
8. Channel side slope in percent
9. Manning's roughness coefficient for the channel
10. Soil erodibility
11. Cropping and management
12. Conservation practices
13. Surface condition
14. Aspect
15. Soil texture number
16. Fertilization level
17. Fertilizer availability
18. Point sources
19. Gully source level in tons
20. Chemical oxygen demand
21. Impoundments

1. Cell number. Each cell in the watershed is identified by a sequential number.

2. Receiving cell number. This is the cell number of the cell to which most of a cell's runoff drains. Since all the cells (except boundary cells) are surrounded by eight neighboring cells, eight different drainage patterns are defined from which one is selected for determination of the receiving cell number.

3. SCS curve number. The soil conservation curve number is determined for each cell in order to obtain the direct runoff. Since this number is a function of the land use and hydrologic soil group, the land use and soil map coverages were intersected with the grid-cell map. Then a weighted average value for the cell was computed.

4. Land slope. The slope coverage was intersected with the grid cell map in order to obtain a weighted average value for the cell.

5. Slope shape. From field notes compiled by field technicians, a factor indicating the dominant shape of the slope was assigned for each cell. Three slope shapes were considered: uniform, convex, and concave. The slope shape adjustment factor (SSF), which is a function of slope shape, is incorporated in the modified Universal Soil Loss Equation (equation 3).

6. Field slope length. The field slope length for each cell was selected from typical slope lengths for the different soil types in the Highland Silver Lake watershed. This information was provided by the SCS field office. A weighted average value was computed from the intersection of the grid-cell and soil coverages.

7. Channel slope. Channel slopes for each cell were obtained from USGS 7.5-minute topographic maps. Thalweg elevations were obtained from data from cross-sectional surveys conducted in 1981 and 1984.

8. Channel side slope. The channel side slope values were based on data for 49 stream cross sections collected for the Highland Silver Lake project. For the stream segments where no cross-sectional survey was conducted, the best estimated value based on a 2-foot-contour topographic map was assigned to the stream.

9. Manning's roughness coefficient for the channel. The Manning's roughness coefficient was determined from the channel description provided by Young et al. (1985). For excavated or dredged channels the Manning's roughness coefficient was between 0.013 and 0.080. For natural streams, the range of Manning's roughness factors was 0.030 through 0.070. A detailed description of the determination of Manning's roughness coefficient can be found elsewhere (Chow, 1959).

10. Soil erodibilitv. The soil erodibility factor, K, derived from the Universal Soil Loss Equation (Wischmeier and Smith, 1978), is a quantitative value experimentally determined for a specific soil. Research results indicated that K is an average value for a given soil, and direct measurement of the factor requires soil loss measurements for a representative range of storm sizes and antecedent soil conditions. The K values for the Highland Silver Lake watershed soils were obtained from the

Soil Conservation Service (SCS) and the SCS computer data base, called S0IL-5(SCS).

11. Cropping and management. This parameter reflects the combined effects of crop cover and management, and is influenced by many significant interrelations. Crop sequence, crop residues on the field, crop growth, and the different months or seasons can also affect the magnitude of the C value. For the Highland Silver Lake watershed project, an annual average "C" value for crop rotation and residue management was provided by SCS.

12. Conservation practices. This parameter is also derived from the USLE (Wischmeier and Smith, 1978). Values for various conservation practices can be found in Young et al. (1985) and Wischmeier and Smith (1978). If the cell is predominantly water or marsh, a value of 0.0 was used. If the cell is predominantly urban or residential (worst case situation), a value of 1.0 was used. Agricultural conditions fall in between these two extreme conditions.

13. Surface condition. Surface condition is based on land use at the time of a storm. This parameter affects the time it takes overland runoff to channelize. The values range from 0.0 for a water body or marsh to 0.59 for permanent pasture or meadow. A detailed table is available in the model manual (Young et al., 1985).

14. Aspect. This parameter is reflected by a single digit which indicates the principal direction of drainage from the cell. This can be one of eight possible directions, proceeding clockwise from north (with a value of 1) to northwest (8). If there is no drainage from the cell a "0" was input.

15. Soil texture number. The major soil texture classifications and codes for the cells are as follows:

Texture	Input parameter code
Water	0
Sand	1
Silt	2
Clay	3
Peat	4

16. Fertilization level. This is the level of fertilization on the field. The levels are coded as follows:

Level	Assumed fertilization (pounds/acre) Nitrogen	Phosphorus	Code
No fertilization	0	0	0
Low fertilization	50	20	1
Average fertilization	100	40	2
High fertilization	200	80	3

17. Fertilizer availability. This parameter, which is a function of the tillage practice applied, indicates the percent of fertilizer left in the top half-inch of soil at the time of a storm. The worst case (with a value of 100 percent) would be if none of the fertilizer has been incorporated into the soil. The values range from 10 percent when a moldboard plow is used to 100 percent in the case of smooth tillage. The detailed values are available in the AGNPS manual (Young et al., 1985).

18. Point sources. A value was assigned to indicate the number of feedlots discharging within the cell boundaries.

19. Gully source level. This is the estimated gully erosion in tons occurring in the cell. This value was included in the total amount of sediment eroded in the cell.

20. Chemical oxygen demand (COD). A value was used to indicate the chemical oxygen demand within the cell in million grams per liter.

21. Impoundments. This parameter indicates the presence of impoundments in the terrace system. Information is needed on the area in acres draining into each impoundment and the diameter in inches of the outlet pipe of each impoundment.

Model Runs

The AGNPS model was run for seven different watershed conditions for the Highland Silver Lake watershed: 1) before-project condition (1981); 2) 1984 condition; 3) after-project condition (1990) with non-structural Best Management Practices (BMPs); 4) after-project condition (1990) with non-structural BMPs, grass waterways, and impoundments; 5) after-project condition (1990) with non-structural BMPS, grass waterways, impoundments, and animal waste management systems; 6) after-project condition (1990) with non-structural BMPs, grass waterways, impoundments, animal waste management systems, and fertilizer management; and 7) future condition with and without the project. Preparation of input data was based on the GIS data bases, information gathered by the District Soil Conservationist, and the field data collected by a project field technician. The full list of BMPs is included in the appendix.

The input data for the AGNPS model, as described previously, consist of 21 input parameters for each grid-cell. The following input parameters were determined by the project field technician for the 1984 condition: 1) slope shape, 2) cropping and management, 3) fertilization level, 4) fertilizer availability, and 5) impoundments.

The slope shape factors were determined from the field reconnaissance survey for each grid cell. The cropping factors were determined on the basis of existing crop rotation and tillage practices for each grid cell. The fertilizer application level was provided partially by the Cooperative Extension Service and partially by farm operators. The fertilizer availability factors were determined on the basis of the tillage practices used in the fields.

The rest of the parameters were determined from the attribute data for the Highland Silver Lake GIS data base as described in this report. Some of the data are physical descriptions of the watershed, which do not change as BMPs are implemented. However, some BMPs have an effect on some model parameters, as shown in table 3.

Before-Project Condition (1981)

This condition is identified as the condition prior to the start of the Highland Silver Lake RCWP project in 1981. In 1981, there were very few conservation management practices applied in the watershed. Most of the land was used to grow corn, soybeans, and wheat as dominant crops with less than 5 percent of the land in pasture or meadow. There were very few improved grass waterways, very little terracing, and very few contouring practices in the watershed.

There were 208 farms in the watershed. Of these, 135 farms were located in the critical areas, which are defined as those with greater than 2 percent slope for natric soils and greater than 5 percent slope for non-

Table 3. Best Management Practices That Have an Effect on Model Parameters

Model parameter	BMPs by which the parameter is affected
1. Cell number	None
2. Receiving cell number	None
3. Soil Conservation Service curve number	Terracing (BMP 4)
4. Land slope in percent	None
5. Slope shape	None
6. Field slope length in feet	Terracing (BMP 4)
7. Channel slope in percent	Grass waterway (BMP 7)
8. Channel side slope in percent	Grass waterway (BMP 7)
9. Manning's roughness coefficient for the channel	Grass waterway (BMP 7) Channel protection system (BMP 10)
10. Soil erodibility	None
11. Cropping and management	Permanent vegetative cover (BMP 1) Conservation tillage system (BMP 9) Tree planting (BMP 14) Permanent vegetative cover (BMP 11) Cropland protection system (BMP 8)
12. Conservation practices	Terracing (BMP 4)
13. Surface condition	None
14. Aspect	None
15. Soil texture number	None
16. Fertilization level	Fertilizer management (BMP 15)
17. Fertilizer availability	Fertilizer management (BMP 15)
18. Point sources	Animal waste management system (BMP 2)
19. Gully source level in tons	None
20. Chemical oxygen demand	None
21. Impoundments	Terracing (BMP 4) Diversion system (BMP 5) Sediment retention system (BMP 12)

natric soils. Average farm size was about 200 acres. There were 31 animal feedlots which contained 944 beef cattle, 1178 swine, and 760 dairy cows. The fertilizer usage was estimated as 63 pounds of nitrogen, 41 pounds of phosphorus, and 49 pounds of potassium per acre. There were no irrigation farms in the watershed.

The input data for this run were prepared on the basis of 1981 land use. Since the Soil Conservation Service keeps detailed information on land use for the contracted farm operators (those who have signed an agreement with USDA to apply BMPs on their land in return for government payment), the cropping factors were determined from this information. Outside the contracted areas, the cropping factors for the grid cells were determined on the basis of the field survey conducted by the field technician.

1984 Condition

This condition reflects the situation in 1984, which was the fourth year of the project. At this stage of the project 39 out of 208 farm operators in the watershed had signed contracts. Conservation tillage had been applied to about 4856 acres of land, filter strips had been applied to 1 feedlot, 40 sedimentation basins had been installed, and numerous other BMPs had been implemented. Since most of the input data for this run were collected through field surveys, some field judgments and information based on consultations with landowners were incorporated in the model.

After-Project Condition (1990) with Non-Structural BMPs

This condition is based on the assumption that all the contracted areas will implement all the planned non-structural BMPs, which include permanent vegetative cover (BMP 1), cropland protection systems (BMP 8), conservation tillage systems (BMP 9), and permanent vegetative cover on critical areas (BMP 11). For the contracted areas, the input data for this run were based on the planned and implemented BMP data file compiled by Economic Research Service (ERS) and the Southwestern Illinois Metropolitan and Regional Planning Commission (SIMAPC). For non-contracted areas, no records were kept to identify changes in management practices. It was assumed that these areas would be kept the same as the 1984 field survey condition. It was recognized that this assumption might create some errors in the absolute model output values. However, any errors created by this assumption would not hinder evaluation of changes due to the RCWP program.

After-Project Condition (1990) with Non-Structural BMPs, Grass Waterways, and Impoundments

This condition reflects the incremental changes due to grass waterway practices and impoundments, which include terrace systems and diversion systems. For grass waterways, three parameters in the input file were changed: the main channel slope, side channel slope, and channel roughness. For impoundment structures the model requires data on drainage area and diameter of outlet pipe. These changes were made on the basis of the data file for non-structural BMPs. The basic data were derived from engineering files provided by the Soil Conservation Service (SCS), Madison County field office.

After-Project Condition (1990) with Non-structural BMPs, Grass Waterways, Impoundments, and Animal Waste Management Systems

This condition reflects the incremental changes due to the addition of nine animal waste management systems to the feedlots in the watershed, which is the number scheduled for installation. The AGNPS model has the option of simulating the feedlots. For animal waste management systems, the model requires data on drainage areas, SCS curve numbers, slope, surface condition, traveling time of runoff at the feedlot, roof areas, buffer areas, animal types and numbers, COD, phosphorus, and nitrogen. These data were compiled with the assistance of the SCS Madison County field office.

After-Project Condition (1990) with Non-Structural BMPs, Grass Waterways, Impoundments, Animal Waste Management Systems, and Fertilizer Management

This condition reflects the incremental changes due to fertilizer management systems. Fertilizer application data were obtained by contacting farm operators. The responses suggest that farm operators will shift from their current application rate to a low fertilization rate of 50 pounds of nitrogen and 20 pounds of phosphorus per acre. Use of this management practice was assumed only for the contracted areas.

Future Condition without the Project

The before-project condition (1981) was selected for the starting data set. For the future condition without the project, it is assumed that conservation tillage will be adopted at the same rate as in the region. Information obtained from the National Conservation Tillage Information Center, Fort Wayne, Indiana, indicated that by 1990 there will be about 13,600 acres of land in the watershed on which conservation tillage will be applied. Since conservation tillage can be applied only on cropland, the croplands are selected for further examination. The first step is to determine the number of acres of cropland on which conservation tillage has been applied. In order to follow the projected trend of the increase in conservation tillage in the region, a portion of the croplands needs to be adjusted so that its C values reflect conservation tillage.

Since the total projected acreage of conservation tillage in 1990 and the total acreage in the "before-project condition" are known, the increased number of acres of conservation tillage from 1981 to 1990 can be computed. Thus the adoption rate for conservation tillage can be defined. Because of the lack of information on the locations of this acreage, a random number generator was used to select a portion of cropland which will be converted to conservation tillage by 1990 to reflect the general trend. The end result of this process is that the total acreage of land to which conservation tillage has been applied will match the total acreage of the projected conservation tillage by the year 1990.

In 1981 there were 20,190 acres of cropland in the Highland Silver Lake watershed. In that year about 3130 acres had C values less than 0.15, which was a typical cropland C value for conservation tillage. Information obtained from the National Conservation Tillage Information Center indicated that by 1990 conservation tillage will be adopted for a total of 13,600 acres of cropland. This means that conservation tillage will be adopted for an additional 10,470 acres of cropland even without the project. In other words, conservation tillage will be adopted for about an additional 52 percent of the cropland. A random number of 0.52 or less was used to select the grid-cells for which the C values should be adjusted to a typical conservation value, defined as 0.15. The random selection process determined that 51 percent of the cells should be assigned a C value of 0.15. This percentage is almost the same as the projected 52 percent.

Future Condition with the Project

This condition is based on the regional trend of adopting conservation tillage, and on adoption of the land management practices recommended by the Rural Clean Water Program (RCWP). The precise locations of the RCWP land management practices are known. Therefore the first step was to use the data set for the after-project condition with non-structural BMPs, grass waterways, impoundments, animal waste management systems, and fertilizer management. This condition addresses only the contracted areas.

The second step was to retrieve the cropland acreages not in the contracted areas from the input data. A computer program was developed to examine the areas having "C" values that reflect the use of conservation tillage. No changes of C values were required for this category. The third step was to examine the rest of the lands which are not in conservation tillage. Within this category, for those lands not in the contracted areas, C values had to be applied to some selected acreages according to the predefined ratio. To achieve this, random numbers with values equal to or less than the pre-defined increase rate in conservation tillage were used to determine the adjustment of C values to the typical conservation tillage level, defined as 0.15. The end results of this operation were that the C values for 6920 acres on non-contracted lands were lowered to reflect the general trend.

Modeling Limitations

The input data and the model itself have many limitations. This section discusses the major ones. First, when the input data were compiled, contracts were still being accepted. A decision was made to use the end of 1985 as a cut-off date. At this time 95 contracts had been assigned; therefore the input data were based on 95 contracts. However, the most recent record shows that 16 additional contracts were assigned afterward. These additional contracts will have the effect of contributing toward further improvement of water quality. Some adjustment will need to be made to account for this.

Second, there are some discrepancies between the records sent for digitizing and those kept at the field office. As a result, some fields were not included in the data base. This affects total BMP acreages; however, the acreage is not significant.

Third, the modeling is based on the average condition of the watershed. Since there are no detailed input data available to simulate every storm event or all the conditions between 1984 and the end of 1990, conditions for an average year were used, and the C factors were determined from the annual average values. However, using average values to determine reductions in water quality loads due to the applied BMPs should result in fewer errors than using values for specific storm events.

Fourth, the available data from the Economic Research Service did not contain P values (conservation practice values). Therefore no change of P values was made for any conservation tillage practice (BMP 9). Thus the effects of this BMP may be underestimated.

Fifth, there is a lack of firm technical information on how to handle the effects of conservation tillage on the SCS curve number. Since the model manual did not contain guidelines for this adjustment, curve numbers were not adjusted to reflect the conservation tillage BMP. Therefore the reduction of runoff and peak discharge due to this BMP will be underestimated.

Sixth, the model considers gully erosion as a point source of sediment. Since there are no gully erosion data available, this input was assumed to be zero in the watershed. This may cause the total amount of the erosion from the watershed to be underestimated.

Seventh, in the incremental analysis the non-contracted areas were assumed to have no changes. However, for the with- and without-RCWP analyses, adjustments were made in the model to reflect the regional trend toward more conservation tillage. Additional "spin-off" effects on the non-contracted areas were not included in the model.

ANALYSES AND RESULTS

Four types of analyses were conducted and are discussed in this section: (1) an incremental analysis, (2) an analysis of the future condition with and without the project, (3) a critical-area analysis, and (4) a soil particle size analysis.

The incremental analysis is based on the concept of consecutively adding BMPs to the watershed to illustrate the incremental reduction of the hydrologic and water quality loadings in the watershed. The comparison of the future condition with and without the project is intended to define the net effects due to the RCWP project. Both these approaches analyze the changes due to the RCWP project, with the results expressed as percent reductions in hydrologic and water quality loadings.

The critical-area analysis is intended to compare the differences in the sources of pollutants in the critical and non-critical areas. The soil particle size analysis is intended to illustrate the variation in soil particle size due to the transport process.

Incremental Analysis

The base level of the model run is the 1981 "before" condition. To illustrate the incremental effects of BMPs, the following model runs were conducted. First, only the non-structural BMPs, which include most of the land management practices for reducing soil loss rates, were applied in the contracted areas. Second, grass waterways and impoundment structures were added to the non-structural practices. Third, animal waste management practices at the feedlots were added to the list of BMPs. Fourth, the fertilizer management practices were added to the list of BMPs. All the computer runs were conducted to reflect the effects of seven storms with rainfall amounts ranging from 0.7 to 5.9 inches. An annual value was computed on the basis of the frequency of the storm events.

Effects of Non-Structural BMPs

The effects of non-structural BMPs are determined from a comparison of the computer runs for the before-project condition and the non-structural BMP scenario as described previously. The results are tabulated in table 4. At all the field sites, the most significant reductions in hydrologic and water quality loadings are in sediment yield, nitrogen in sediment, and phosphorus in sediment as indicated in table 4 by percentages of reduction. Field sites 1, 3, 4, 6 and 7 have reductions in sediment

Table 4. Changes in Water Quality Loadings with Implementation of Non-structural BMPs
(In percentages)

Site*	Run-off	Peak disch.	N in sed.	Soluble N	N con-centr.	P in sed.	Soluble P	P con-centr.	COD	Sed. yield	N load	P load
F1	0	0	-15.3	0	0	-7.3	0	0	0	-26.2	0	0
F2	0	0	-2.2	0	0	-1.5	0	0	0	-2.8	0	0
F3	0	0	-37.7	0	0	-38.4	0	0	0	-53.5	0	0
F4	0	0	-25.5	0	0	-12.2	0	0	0	-33.6	0	0
F5	0	0	0	0	0	0	0	0	0	-0.1	0	0
F6	0	0	-20.4	0	0	-13.0	0	0	0	-30.2	0	0
F7	0	0	-11.2	0	0	-9.5	0	0	0	-27	0	0
G1	0	0	-21.8	0	0	-9.4	0	0	0	-14.3	0	0
G2	0	0	-3.4	0	0	-8.5	0	0	0	-10.5	0	0
G3	0	0	-3.8	0	0	-0.2	0	0	0	-5.4	0	0
SW	0	0	-4.9	0	0	-3.6	0	0	0	-7.2	0	0

*F - field site; G - streamgaging station; SW - spillway monitoring station

yield of more than 26 percent. The nitrogen and phosphorus in sediment show similar trends but with lower percentage reductions.

Field site 5 has less than 1 percent reduction in these three loadings, primarily because only a small fraction of the drainage area at field site 5 is in the contracted area. Consequently, no significant non-structural BMPs are applied on the watershed of field site 5. Field site 2 has few field-applied BMPs; therefore sediment yield, nitrogen, and phosphorus at this site showed significantly lower reductions than at the other field sites.

At the three streamgaging stations, the reductions in sediment yield, nitrogen in sediment, and phosphorus in sediment are smaller than at the field sites, and the variation among the streamgaging stations is smaller than that at the field sites. This may be attributed to the fact that the contracted areas are much more evenly distributed within the watersheds of the streamgaging stations. However, streamgaging station 3 shows much smaller reductions in sediment yield and phosphorus in sediment than streamgaging stations 1 and 2 and the spillway. Figure 10 shows the sediment yield reductions due to non-structural BMPs at the field sites and streamgaging stations.

There are no significant changes in runoff, peak discharge, soluble nitrogen, nitrogen concentration, soluble phosphorus, and COD (table 4). According to the model manual (Young et al., 1985), the runoff and peak discharge are related to the SCS curve numbers. The non-structural BMPs do not change the SCS curves; consequently, the runoff and peak discharge would not be affected. However, there is some evidence in the technical literature of relationships between conservation tillage and SCS curve number. Additional research is needed in this area.

Incremental Effects of Grass Waterways and Impoundments

A scenario was run with grass waterways and impoundment structures added to the BMP list. The results of this run were compared with those for non-structural BMPs. The effects of these incremental BMPs are expressed in table 5 in terms of percentage reductions in hydrologic and water quality loadings. The results indicate that significant reductions in peak discharge, sediment yield, and nitrogen in sediment occur at field sites 2, 3, 6 and 7. Smaller reductions in sediment yield and nitrogen in

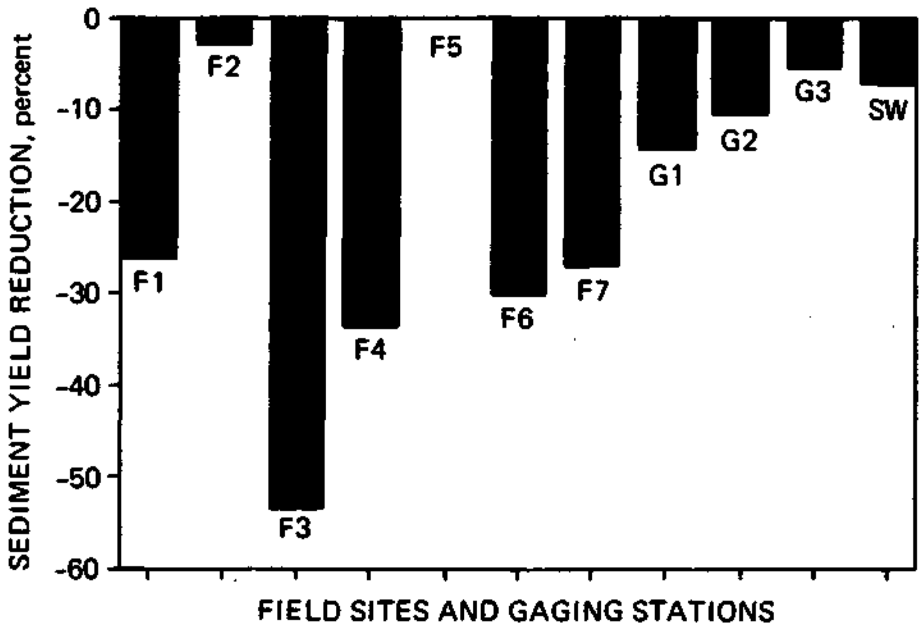

Figure 10. Changes in sediment yield with implementation of non-structural BMPs

Table 5. Incremental Changes in Water Quality Loading with Implementation of Grass Waterways and Impoundments (In percentages)

Site*	Run-off	Peak disch.	N in sed.	Soluble N	N con-centr.	P in sed.	Soluble P	P con-centr.	COD	Sed. yield	N load	P load
F1	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	-5.6	-2.1	0	0	-2.1	0	0	0	-2.7	0	0
F3	0	-2.7	-9.1	0	0	-9.4	0	0	0	-1.7	0	0
F4	0	0	-0.7	0	0	-1.3	0	0	0	-1.6	0	0
F5	0	0	0	0	0	0	0	0	0	0	0	0
F6	-1.8	-3.8	-1	-2.2	5.2	-1.4	-0.7	0	0	-1.4	-1.8	-3.4
F7	-0.5	-4.7	-3.1	-0.9	2.1	-3.1	-27	0	0.6	-4.6	-0.5	0
G1	0	0.1	-0.1	-2.1	0	-0.2	-0.1	0	0	-0.2	0	0
G2	0	0.5	-0.1	-0.9	-0.8	0	0	0	0.1	-0.5	-0.8	0
G3	0	0.1	0	0	0	0	0	0	0.4	1.2	0	0
SW	0	-0.2	0	-0.4	-1.7	0	-0.1	0	0	0.8	0	0

*F - field site; G - streamgaging station; SW - spillway monitoring station

sediment occur at the streamgaging stations. Figure 11 shows the percent reductions of sediment yield due to grass waterways and impoundment structures. There are few significant reductions in runoff, soluble nitrogen and phosphorus, and phosphorus concentration (table 5). The reduction of peak discharge may be attributed to the fact that impoundment structures have the capability to store runoff and consequently reduce the peak discharge. The reductions in sediment yield are mostly due to the increase of sediment deposition in the impoundment structures. This indirectly reduces the nitrogen and phosphorus in sediment.

Incremental Effects of Animal Waste Management Systems at Feedlots

As mentioned previously, animal waste management systems are scheduled for installation at nine feedlots in the watershed. A computer scenario run was conducted by adding nine animal waste management systems in the watershed. This BMP resulted in minor reductions in soluble nitrogen and soluble phosphorus, with greater reductions at field site 7, as shown in table 6. Figure 12 shows the reduction of nitrogen concentration due to animal waste management systems at the field sites and streamgaging stations. COD showed a slight increase (less than 2 percent) at field site 7, which has a feedlot located within its sub-watershed. Some changes show in peak discharge and sediment yield. Other hydrologic and water quality loadings show no significant changes.

Incremental Effects of Fertilizer Management Practices

A scenario run was conducted by adjusting all the contracted cropland to a low fertilization level equivalent to 50 pounds of nitrogen and 20 pounds of phosphorus per acre. The incremental effects of the fertilizer management practices (table 7) indicated a 0.0 to 22 percent reduction in soluble nitrogen at the field sites and an 8.6 to 9.1 percent reduction at the streamgaging stations. Figure 13 shows the reduction of soluble nitrogen at the field sites and streamgaging stations. Nitrogen loads, nitrogen concentrations, and soluble phosphorus have similar trends to those for soluble nitrogen.

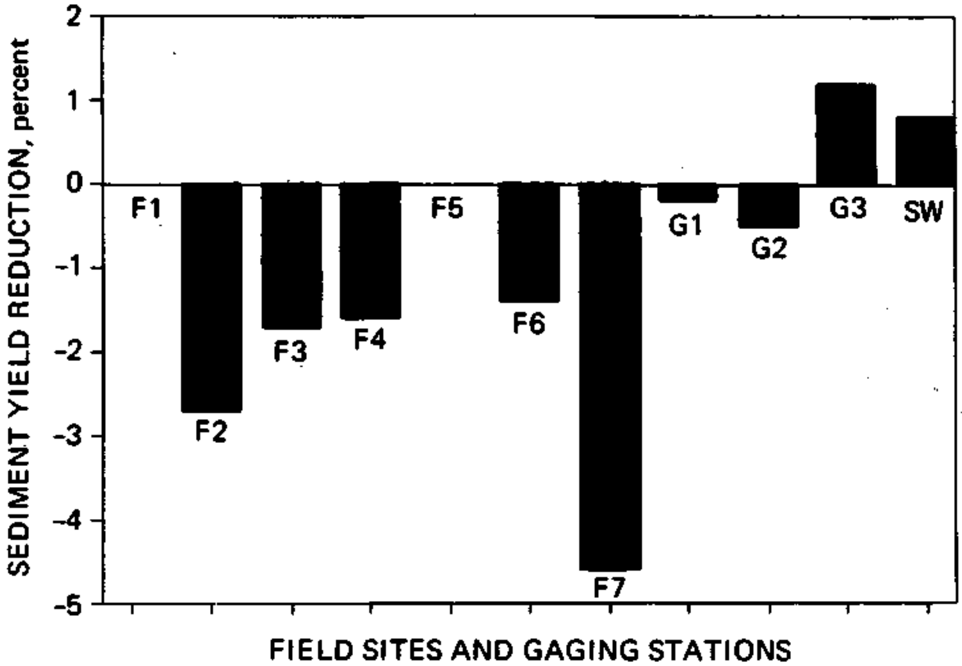

Figure 11. Incremental changes in sediment yield with implementation of grass waterways and impoundments

Table 6. Incremental Changes in Water Quality Loadings with Implementation of Animal Waste Management Systems
(In percentages)

Site*	Run-off	Peak disch.	N in sed.	Soluble N	N con-centr.	P in sed.	Soluble P	P con-centr.	COD	Sed. yield	N load	P load
F1	0	0	-1.5	0	0	-1.6	0	0	0	-2.1	0	0
F2	-0.5	-0.1	0	-0.4	1.6	0	-0.1	2.3	-0.3	-0.2	-0.9	0
F3	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	0	0	0	0	0	-7.1	0	0
F6	-1.8	0	-3.1	-1.2	5.3	-19.3	-0.2	3.2	0	-2.4	-1.4	0
F7	-0.6	-13.8	-0.1	-10.9	0	-0.1	-3.0	0	1.6	-1.5	-0.6	0
G1	0	-2.5	-1.4	-1.0	0	-1.1	-0.1	0	0.1	-9.3	0	0
G2	0	-2.5	-1.1	-3.1	-0.9	-1.1	-9.5	-2.4	0.4	-9.0	-0.9	-2.5
G3	0	-1.9	-3.1	0	0	-8.5	-0.3	0	0.4	-9.3	0	0
SW	0	-1.5	-0.6	-2.9	-0.2	-0.2	-0.1	0	0	-3.5	-0.2	0

*F - field site; G - streamgaging station; SW - spillway monitoring station

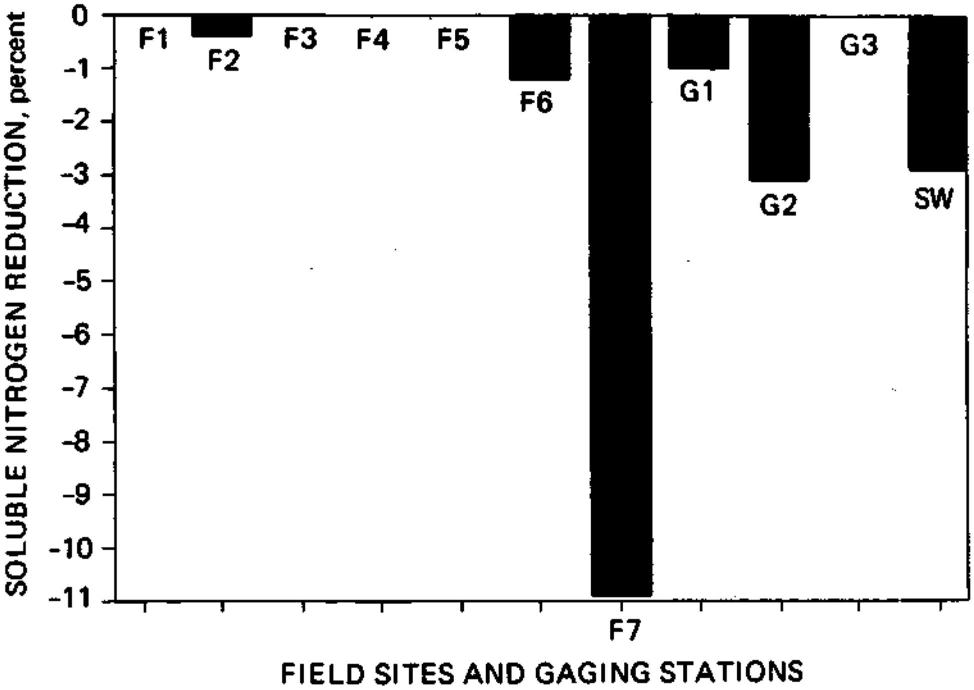

Figure 12. Incremental changes in soluble nitrogen with implementation of animal waste management systems

Table 7. Incremental Changes in Water Quality Loadings with Implementation of Fertilizer Management Practices
(In percentages)

Site*	Peak disch.	N in sed.	Soluble N	N con-centr.	P in sed.	Soluble P	P con-centr.	COD	Sed. yield	N load	P load
F1	0	0	-15.8	-14.8	0	-7.6	-12.3	0	0	-0.9	-0.4
F2	0	0	-1.7	-2.7	0	-1.6	0	0	0	0	0
F3	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	-7.8	-7.6	0	-7.4	-7.5	0	0	-3.4	-0.7
F5	0	0	-14.4	-14.8	0	-12	-14.4	0	0	-6.2	-5.6
F6	0	0	-22.5	-21.6	0	-22.1	-22.2	0	0	-6.1	-3.7
F7	0	0	-0.8	-1.2	0	-27	-4.6	0	0	-0.4	0
G1	0	0	-8.6	-8.6	0	-3.4	-0.4	0	0	-4.2	-0.4
G2	0	0	-9.0	-8.8	0	-4.5	-11.0	0	0	-4.0	-5.1
G3	0	0	-9.1	-10.7	0	-10.3	-13.2	0	0	-4.6	-7.6
SW	0	0	-9.1	-8.9	0	-4.9	-14.1	0	0	-3.6	-5.1

*F - field site; G - streamgaging station; SW - spillway monitoring station

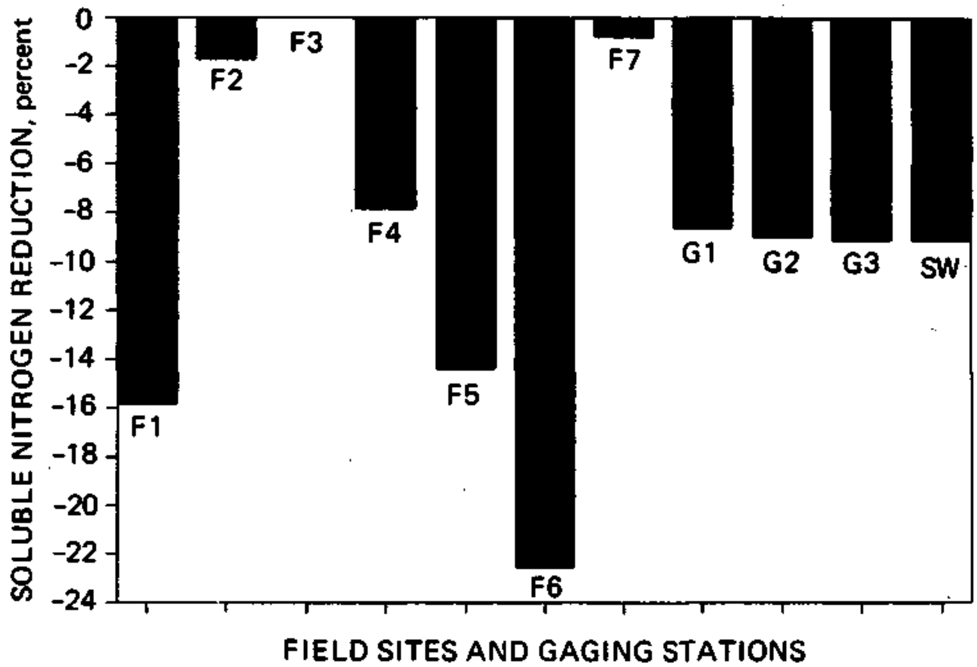

Figure 13. Incremental changes in soluble nitrogen with implementation of fertilizer management practices

Analysis of Future Condition with and without the Project

The purpose of comparing the scenario runs between the future condition without the RCWP and the future condition with the RCWP is to define the net effects of the RCWP program. The net changes attributable to the RCWP, in terms of percentage reductions of hydrologic and water quality loads, are presented in table 8. The most significant changes are in sediment yields, which show reductions of up to 54 percent as shown in table 8 and figure 14. Generally, the field sites have greater variation than the streamgaging stations. Most of the sediment yield reductions can be attributed to the soil loss reduction due to the applications of non-structural BMPs. Since the soluble nitrogen in sediment and the phosphorus in sediment are related to the sediment yield, the corresponding trends for these water quality loads are similar. Soluble nitrogen also shows quite significant reductions of up to 24.5 percent as shown in figure 15. The peak discharge also shows moderate reductions of up to 5.7 percent (table 8). Most of the peak discharge effects can be attributed to the impoundment structures.

Critical-Area Analysis

At the beginning of the RCWP project, the critical areas in the Highland Silver Lake watershed were defined as those with natric soils and slopes greater than 2 percent, and those with non-natric soils and slopes greater than 5 percent. On the basis of these criteria, a critical-area map of the watershed was generated (figure 16). It is recognized that these criteria are close to those defining main soil erosion sources. However, there is no objective evidence of the sources of water pollution. In order to provide insights into the characteristics of the critical areas, the watershed model was used to compare the erosion rates and water quality sources within the critical and non-critical areas.

According to the project critical-area criteria and the use of model grid-cell data, the critical areas are estimated to be 7050 acres out of 30,520 acres of total watershed area. The following erosion rates and hydrologic and water quality loads within the cells were computed:

1. Soil erosion rate
2. Sediment yield
3. Nitrogen in the sediment from the cell

Table 8. Net Changes in Water Quality Loadings with Implementation of RCWP Measures
(In percentages)

Site*	Run-off	Peak disch.	N in sed.	Soluble N	N con-centr.	P in sed.	Soluble P	P con-centr.	COD	Sed. yield	N load	P load
F1	0	0	-0.8	-15.8	-14.8	-1.2	-7.6	-12.3	0	-0.7	-0.9	-0.4
F2	-0.5	-5.7	-1.9	-2.0	-1.3	-1.9	-1.9	2.3	-0.3	-2.5	-0.9	0
F3	0	-2.7	-43.3	0	0	-44.2	0	0	0	-54.4	0	0
F4	0	0	-26.2	-5.0	-4.5	-13.0	-0.1	-0.8	22.8	-32	-2.4	-0.7
F5	0	0	1.0	-14.4	-14.8	8.1	-12	-14.4	0	2	-6.2	-5.6
F6	-1.8	-3.8	-22.4	-24.5	-17.5	-26.3	-22.8	-19.9	0	-29.9	-7.2	-3.7
F7	-0.6	-4.7	-14.1	-12.1	-1.2	-10.3	-30.7	-4.6	1.6	-28.5	-1.0	0
G1	0	-0.8	-22.4	-11.0	-8.6	-2.6	-4.9	-0.4	0.5	-13.0	-4.2	-0.4
G2	0	-0.7	-1.8	-11.9	-10.7	-7.0	-14.2	-13.5	0	-11.0	-4.8	-7.5
G3	0	0.1	-1.2	-9.2	-10.7	-6.5	-10.6	-13.2	0.4	-4.7	-4.6	-7.6
SW	0	-0.8	-5.3	-11.7	-9.1	-0.4	-5	-14.1	-0.7	-6.4	-3.9	-5.1

*F - field site; G - streamgaging station; SW - spillway monitoring station

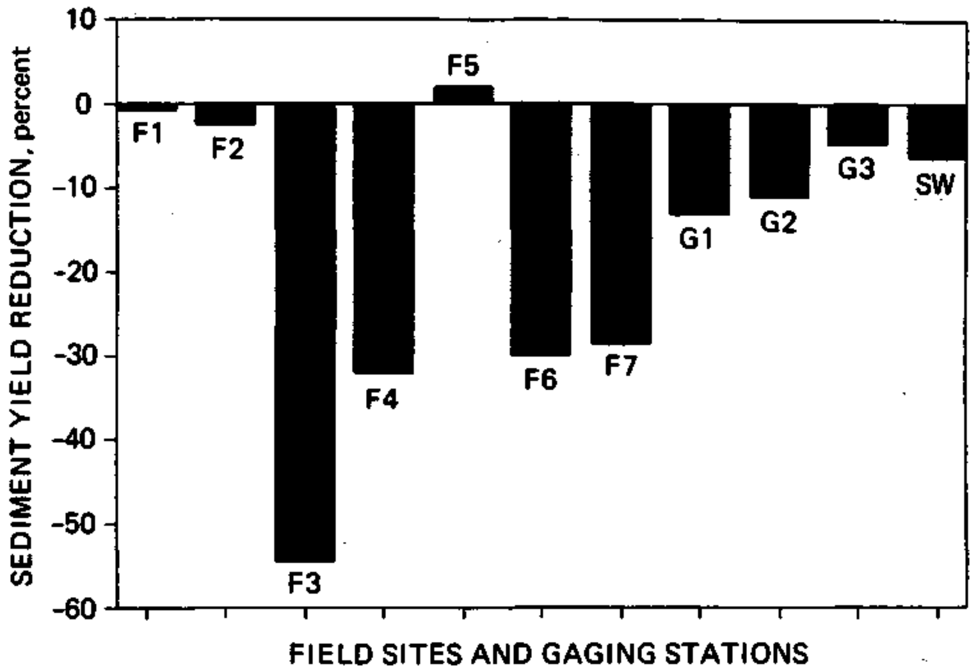

Figure 14. Net changes in sediment yield with implementation of RCWP measures

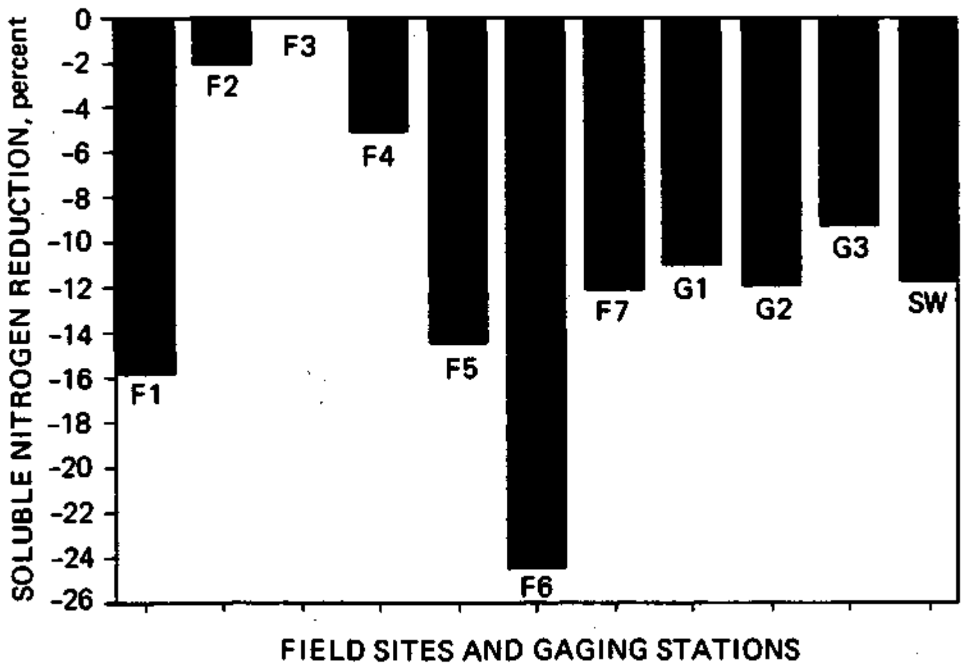

Figure 15. Net changes in soluble nitrogen with implementation of RCWP measures

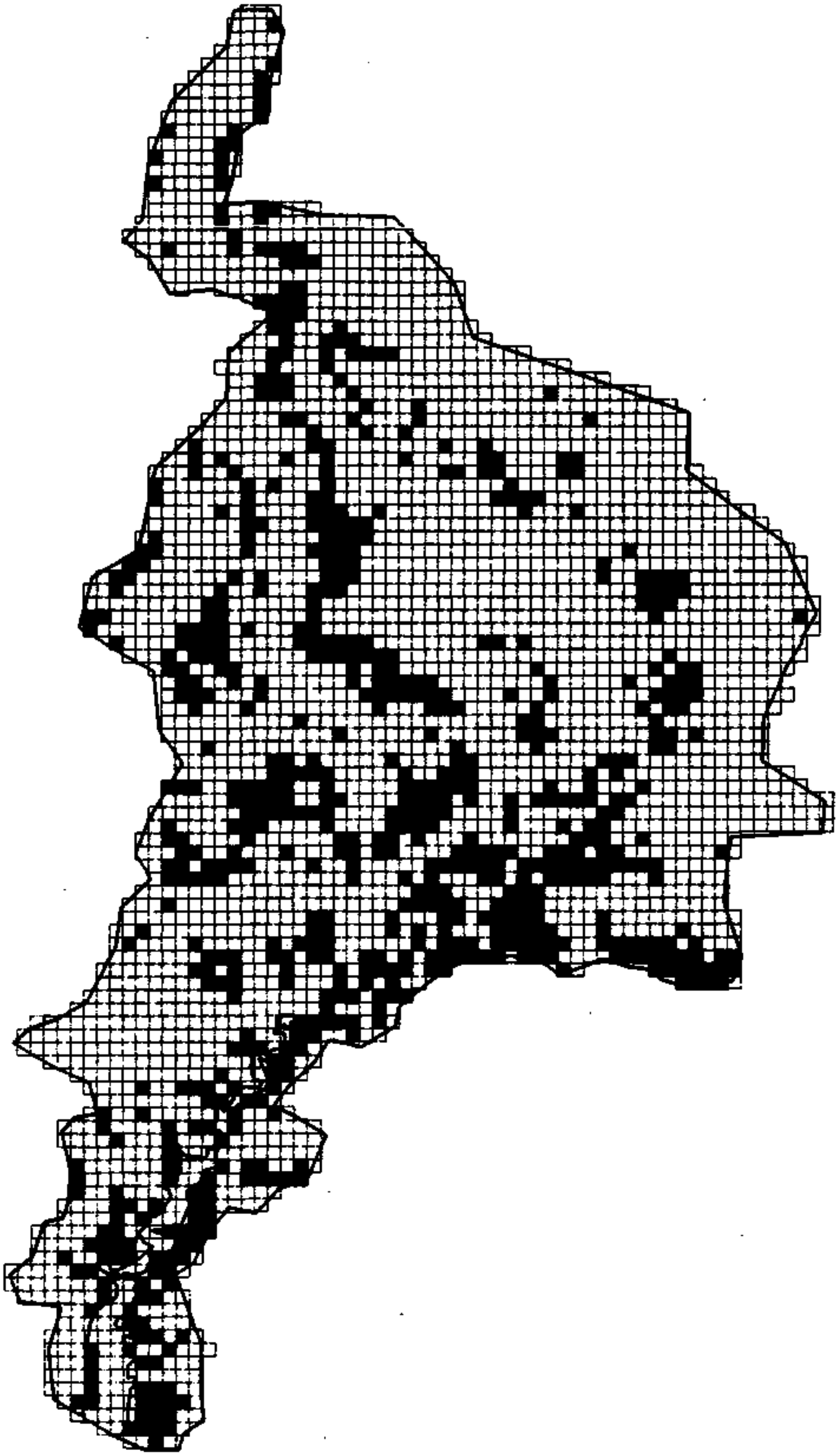

Figure 16. Critical-area distribution based on the project definition

4. Water-soluble nitrogen
5. Phosphorus in the sediment
6. Water-soluble phosphorus
7. COD generated within the cell

Table 9 shows the average values of these erosion and water quality parameters for the critical and non-critical areas. The results indicate that the non-critical areas have a soil erosion rate estimated as 1.2 tons per acre per year while the erosion rate in the critical areas is estimated as 2.1 tons per acre per year. However, it is worthwhile to note that within the critical areas, only 39.9 percent of the acreage has a soil erosion rate that is above the average rate for the whole watershed, and 15.7 percent of the acreage has a soil erosion rate more than twice the average soil erosion rate. This implies that very few cells within the critical areas generate large amounts of soil erosion and that most of the area within the critical areas is very similar to the rest of the watershed.

The results (table 9) indicate that in the non-critical areas the average sediment yield within the cells is 1.1 tons per acre while the critical areas contribute an average of 2.09 tons per acre or 90 percent more than the non-critical areas. However, only 41.8 percent of the critical-area acreage has a sediment yield above the watershed average sediment yield generated within the grid-cells, and only 16.5 percent of the acreage has a sediment yield more than twice the average sediment yield generated within the grid-cells. These results imply that few cells generate large amounts of sediment and that most of the cells in the critical areas are not distinctly different from the rest of the watershed. This trend is similar to that for the soil erosion rate.

In the non-critical areas there is an average of 3.4 pounds of nitrogen in the sediment per acre, and in the critical areas there is an average of 5.34 pounds per acre (table 9). The amount of nitrogen per acre in the critical areas is thus 57 percent higher than that in the non-critical areas. However, in terms of areal distribution, only 46.7 percent of the critical areas has amounts of nitrogen above the whole watershed average, and 15.2 percent of the area has amounts more than twice as high as the watershed average.

Table 9. Erosion and Water Quality Characteristics of Non-Critical and Critical Areas

	Erosion rate (t/ac)	Sediment yield within cell (t/ac)	N in sediment (lb/ac)	Soluble N (lb/ac)	P in sediment (lb/ac)	Soluble P (lb/ac)	COD (lb/ac)
Non-critical areas	1.2	1.1	3.4	4.5	1.7	0.97	60.3
Critical areas	2.1	2.09	5.34	3.42	2.67	0.72	53.0
Percentage of critical areas with rates/amounts above the average for the whole watershed							
	39.9	41.8	46.7	33.1	46.5	32.6	38.6
Percentage of critical areas with rates/amounts more than twice the average for the whole watershed							
	15.7	16.5	15.2	7.9	15.1	14.7	0

The non-critical areas produce 4.5 pounds of soluble nitrogen per acre while the critical areas generate 3.42 pounds per acre. This indicates that for the water-soluble nitrogen pollutant, the project critical-area definition does not define the right areas. In terms of areal distribution, only 33.1 percent of the critical areas generates amounts of soluble nitrogen greater than the average for the whole watershed, and 7.9 percent generates amounts greater than twice the whole watershed average. This also shows that for soluble nitrogen the project critical-area definition does not define the major soluble-nitrogen source areas.

The phosphorus in the sediment has a similar trend to that of the nitrogen in the sediment, while soluble phosphorus has a similar trend to that of soluble nitrogen (table 9).

The amount of COD generated in the critical areas is 53.0 pounds per acre, while in the non-critical areas 60.3 pounds per acre is generated. This indicates that as far as COD is concerned, the project critical-area definition does not define the major COD source areas. In terms of areal distribution, only 38.6 percent of the critical areas produces more COD than the average for the whole watershed, and none of the cells in the critical areas produce more than twice the watershed average.

Figure 16 shows that most of the cells in the critical areas are located along the main streams and tributaries. The total acreage, as indicated previously, is 7050 acres. The AGNPS model was used to select the 705 cells (7050 acres) that generate the most sediment. The computation of the sediment yield is based on the annualized sediment yield from seven selected storms. The results are plotted on figure 17. A comparison of figures 16 and 17 shows that the project critical-area distributions match the distribution of high sediment yield generated within the cells relatively well. This is mainly because the high sediment yield generated within the cells is related to the project definition of steep slope. The discrepancies between these two maps are due to the factors of land use, slope length, conservation practices, and sediment transport capability.

Figure 18 shows the 700 cells that generate the greatest amounts of clay. The results indicate that the high clay-load areas match quite well with the areas of high sediment yield generated within the cells. This may

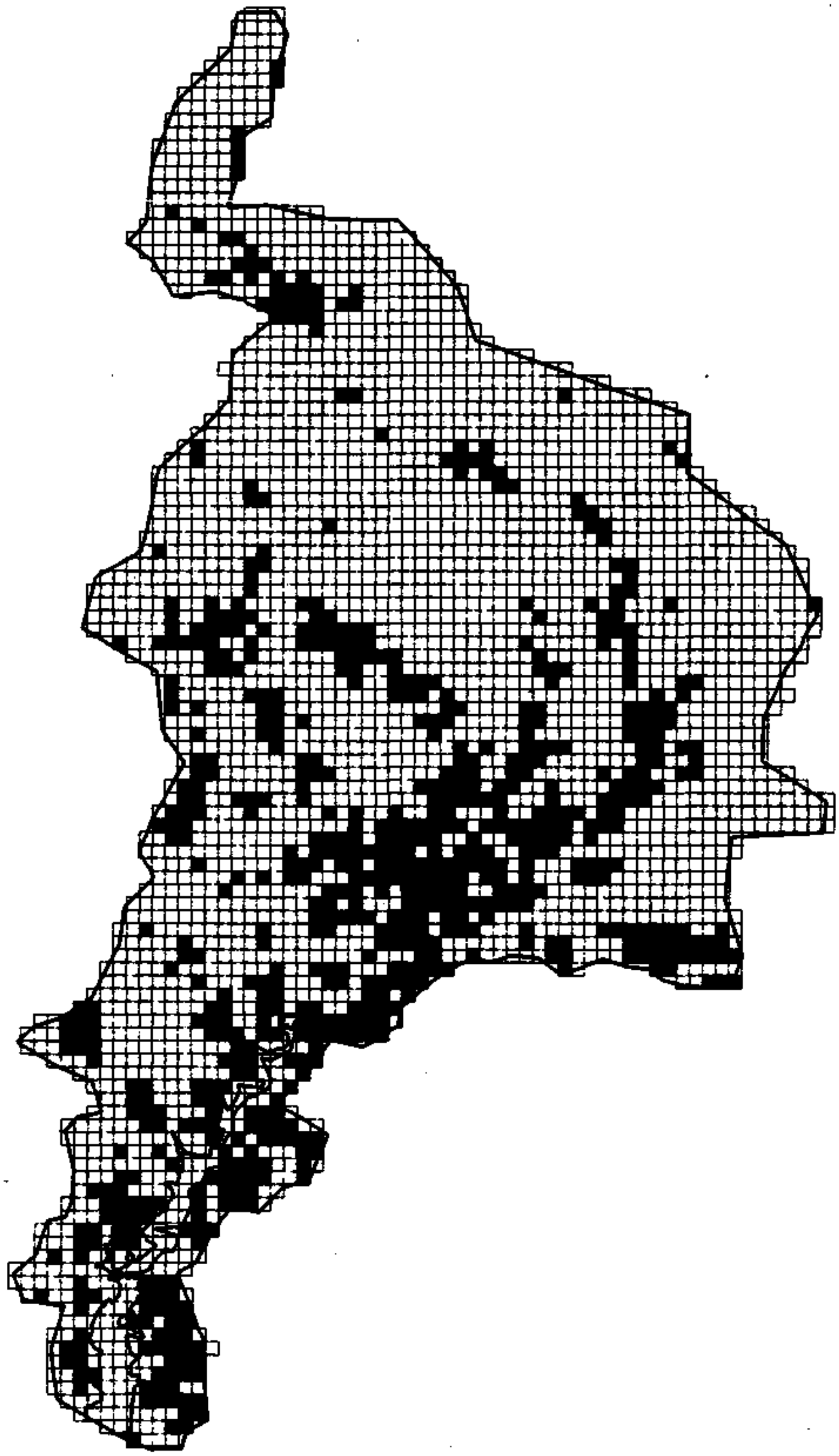

Figure 17. Areas that generate the most sediment, as determined by the AGNPS model

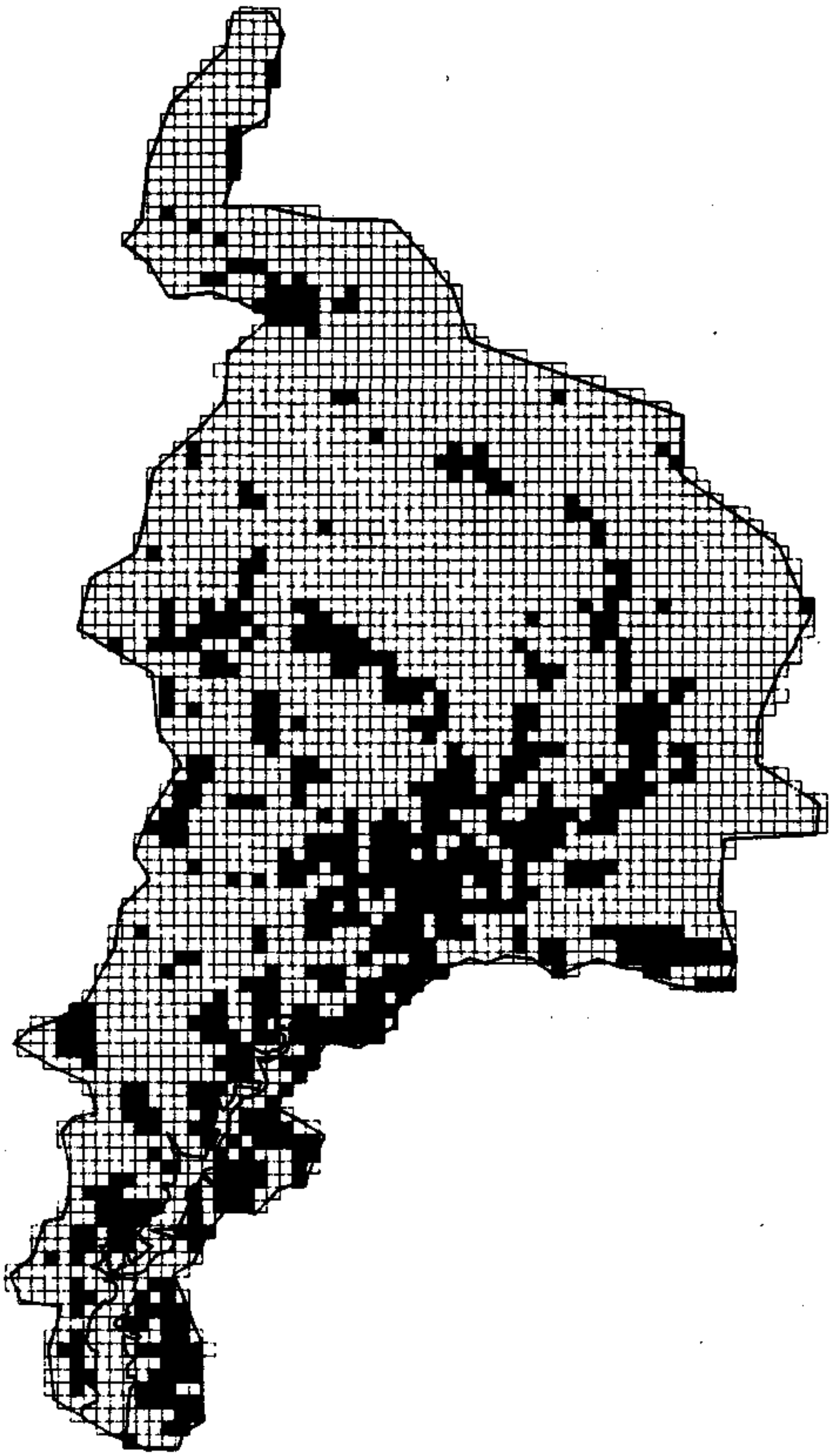

Figure 18. Areas that generate the highest amounts of clay, as determined by the AGNPS model

be attributed to the fact that most of the high sediment yields are dominated by clay.

Similarly, figure 19 shows the 705 cells (7050 acres) that generate the greatest amounts of soluble phosphorus. A comparison of figures 16 and 19 shows that the distribution pattern of the cells generating the most soluble phosphorus does not match well with the project critical areas. This indicates that the areas of high sediment yield are not necessarily the areas of highest soluble phosphorus yield.

In summary, the project critical-area definition is close to the intended purposes in terms of soil erosion, sediment yield, nitrogen in sediment, and phosphorus in sediment, even though the critical-area distribution does not cover a high percentage of the areas with a greater-than-average soil erosion rate and sediment yield. In terms of soluble nitrogen and soluble phosphorus, the critical areas show lower loadings than the average for the non-critical areas. This indicates- that it is not possible to use one critical area criterion for all water quality pollutants. It is necessary to define the project-targeted pollutants and then to map the associated critical areas accordingly.

Soil Particle Size Analysis

To illustrate the particle size distributions at various sites in the watershed, the scenario for the before-project condition was run. Field site 1, streamgaging station 1, the main stream entry point to the lake, and the spillway station were selected to show the variation in the soil particle sizes within the watershed. The AGNPS model divides particles into five categories: clay, silt, small aggregate, large aggregate, and sand. Since the size of soil particles is strongly related to storm size, three storms with rainfalls ranging from 0.7 to 5.9 inches were selected to illustrate these changes. The results are presented in table 10.

The results indicate that at small field sites such as field site 1, small aggregates are the dominant components. The amounts of silt and clay are the next largest in the total sediment yield. However, for larger drainage areas, the silt and clay portions are dominant. When soil particles are deposited in the lake, almost all of the particles are clay-sized. This can be verified by the particle size analyses of the sediment cores collected during the lake sediment suryey. However, in terms of

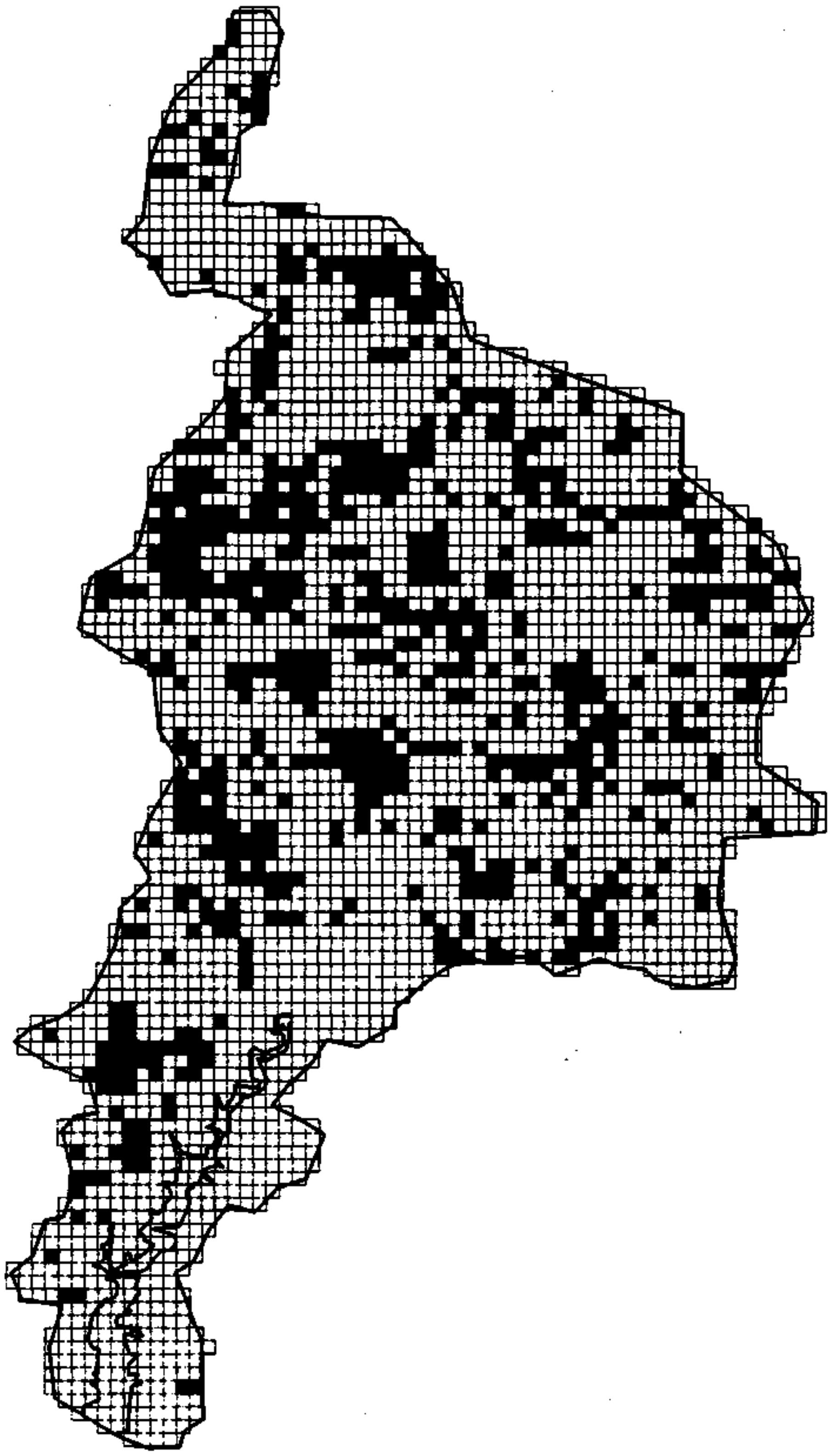

Figure 19. Areas that generate the greatest amounts of phosphorus, as determined by the AGNPS model

Table 10. Sediment Particle Size Distribution for Various Storms in the Watershed (In tons)

Site	Clay	Silt	Small aggreg.	Large aggreg.	Sand	Total sediment yield
Rainfall =0.7 inches						
F1	0.1	0	0.1	0.1	0	0.3
G1	29.7	8.3	6.6	4.1	1.3	50.0
IP	31.7	1.8	2.8	3.9	1.3	41.5
SW	1.5	0.5	0.6	2	0.6	5.2
Rainfall = 2.6 inches						
Fl						
Gl	446	441	889	26	7.7	1810
IP	598	284	208	21	6	1117
SW	315	8	3	10	3	339
Rainfall = 5.9 inches						
Fl	3.9	5.8	27	2.5	1	40
Gl	2514	3125	9393	99	20	151251
IP	3435	3013	2683	77	17	9225
SW	2928	76	46	20	6	3076

Note: F = field site; G = streamgaging station; IP = entry point of the main stem of Little Silver Creek; SW = spillway monitoring station instream sediment, analyses of 45 particle size samples from the main stream and the main tributaries of the watershed indicated that the particle sizes were quite varied, ranging from silt to very fine gravel. The data on the field particle size do not indicate any specific trend related to size of drainage area. Further research is needed to address this matter.

RECOMMENDATIONS

The following recommendations are drawn from the data base development for the Highland Silver Lake Comprehensive Monitoring and Evaluation Project:

1. Data Base

A. The experience gained during this project makes it apparent that a project data base should be developed early in the project. The data should be transmitted in a machine-readable format to all members of the CM&E team. The entire data base should be verified by the people collecting the data.

B. A geographic information data base is an efficient way to depict land use and the specification of BMPs. A geographic information system should be used to inventory all the data on soils, land use, slopes, contracted areas, critical areas, erosion inventory, and BMP status. The experience gained in the Highland Silver Lake project shows that this type of data base makes it feasible and economical to handle "map" information for nonpoint source pollution analysis.

C. Recording and documentation of BMPs should be considered as important as the receiving streamwater quality data for the RCWP project. To detect the changes due to applications of BMPs, physical, chemical, and economic data should be compiled, with manpower budgeted accordingly.

2. Modeling

The following recommendations are drawn from the experience gained in using the AGNPS model for evaluation of the Highland Silver Lake project.

A. A "distributed" model such as AGNPS is a useful tool for evaluation of an RCWP project. To precisely depict BMP application in a model requires field data, a geographic data base, and an understanding of the variations in the model parameters. This effort requires the cooperation of local conservationists and the project research team.

B. At the present time most distributed models are physical-based. Generally, very little parameter calibration is required. However, it is strongly recommended that the outputs of the models be verified against the field-observed data. This should be done before the model is used for prediction or scenario analysis.

C. Since the purpose of modeling in the evaluation of the RCWP is to detect the changes caused by applications of BMPs, it should be emphasized that the relative values are more relevant than the absolute values generated from the model runs. It is worthwhile to note that some components of the model may not perform as the watershed actually behaves, because of lack of field data or low resolution of the model.

D. It is recommended that the model be used in designing the monitoring system, locating critical areas, designing the data base, and determining cost-sharing levels. This effort will help to guide the project in the right direction.

CONCLUSIONS

The following conclusions can be drawn on the basis of the modeling efforts.

1. The results of the AGNPS-model incremental analysis indicate that non-structural BMPs can reduce the sediment yield by between 5.4 and 14.3 percent at the streamgaging station sites and by as much as 53 percent at the field sites. The nitrogen and phosphorus in sediment also showed significant reductions. However, the soluble nitrogen and phosphorus were not significantly reduced. Non-structural BMPs are not effective in reducing COD, runoff, or peak discharge.
2. The structural BMPs, which include grass waterways, sediment basins, and diversion structures, are not as effective as non-structural BMPs in reducing pollution loads. However, they are effective in reducing peak discharge.
3. The animal waste management systems are not effective in reducing COD in the Highland Silver Lake watershed. This can be attributed to the fact that there are few animal waste units in the watershed.

4. The fertilizer management BMPs are less effective than the non-structural BMPs in reducing the receiving-stream water-quality loading and concentration. To be effective, this BMP needs to be applied on most of the croplands.
5. The analysis of the future condition with and without the project indicated that the most significant reduction attributable to the RCWP is in sediment yield and the related nitrogen and phosphorus amounts in sediment. The nitrogen concentration and soluble nitrogen have been moderately reduced. The peak discharge reduction, which is mostly due to structural BMPs, is less significant.
6. The critical-area analysis indicated that the project critical-area definition serves the intended purpose of indicating the areas of highest soil erosion, sediment yield, and related nitrogen and phosphorus in sediment. For soluble nitrogen and phosphorus, the project critical-area definition does not define the high-pollution source areas. This indicates that it is not possible to use one critical-area definition for all nonpoint source pollutants. It is necessary to define the project-targeted pollutants and then to map them accordingly.
7. The particle size analysis indicated that except for very small field sites and extremely large storm events, silt and clay are the major sediment particles in the transport processes.

REFERENCES

Bagnold, R.A., 1966. An Approach to the Sediment Transport Problem from General Physics. U.S. Geological Survey, Professional Paper 422-J.

Chow, V.T., 1959. Open Channel Hydraulics. McGraw Hill Book Company, New York, N.Y.

Environmental System Research Institute, 1986. ARC/INFO Users Manual, Version 3.2, Redlands, California.

Foster, G.R., L.J. Lane, J.D. Mowlin, J.M. Laflen, and R.A. Young, 1981. Estimating Erosion and Sediment Yield on Field-Sized Areas. Trans. Am. Soc. of Agricultural Engineering, Vol. 24, No. 5, p. 1253-1262.

Frere, M.H., J.D. Ross, and L.J. Lane, 1980. The Nutrient Submodel. Chapter 4, p. 65-86, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems -- CREAMS, USDA Conservation Research Report 26, Vol I.

Lane, L.J., 1982. Development of a Procedure to Estimate Runoff and Sediment Transport in Ephemeral Streams. In Recent Developments with Explanation and Prediction of Erosion and Sediment Yield, Proceedings Exeter Symposium, IAHS Publication No. 137, p. 275-282.

Smith, R.E., and J.R. William, 1980. Simulation of the Surface Hydrology. Chapter 2, p. 15, A Field Scale Model for Chemicals, Runoff, and Erosion from Agricultural Management Systems -- CREAMS, USDA Conservation Research Report 26, Vol. I.

Soil Conservation Service, 1972. Hydrology, Section 4, SCS National Engineering Handbook. USDA, Washington, D.C.

Soil Conservation Service, 1974. Universal Soil Loss Equation. Resource Conservation Planning Technical Note-IL-4, Soil Conservation Service, Champaign, Illinois.

Wischmeier, W.H., and D.D. Smith, 1978. Predicting Rainfall Erosion Losses -- A Guide to Conservation Planning. U.S. Department of Agriculture, Agriculture Handbook 537, Washington, D.C.

Young, R.A., C.A. Onstad, D. Bosch, and W.P. Anderson, 1985. Agricultural Nonpoint Source Pollution Model, A Large Watershed Analysis Tool, A Guide to Model Users. Agricultural Research Service, U.S. Department of Agriculture, Morris, Minnesota.

APPENDIX: BEST MANAGEMENT PRACTICES

BMP 1 Permanent Vegetative Cover - Nonstructural

BMP 2 Animal Waste Management System - Structural
Facilities are provided for the storage and handling of livestock waste to prevent or abate pollution.

BMP 4 Terrace System - Structural
The installation of terrace systems can prevent or abate pollution by decreasing the slope length and steepness.

BMP 5 Diversion System - Structural
Diversions are installed where excess surface or subsurface water runoff contributes to water pollution problems.

BMP 7 Waterways - Structural
Waterways are installed to safely convey excess surface runoff across fields at non-erosive velocities.

BMP 8 Cropland Protective Cover - Nonstructural
This measure improves water quality by providing needed protection from severe erosion on cropland between crops.

BMP 9 Conservation Tillage System - Nonstructural
Use of reduced tillage operations in producing a crop, as well as residue management, are involved in this measure.

BMP 10 Stream Protection - Nonstructural
Streams may be protected from sediment and chemicals through installation of field border strips, protective fencing, livestock crossings, and livestock water facilities.

BMP 11 Permanent Vegetative Cover on Critical Areas - Nonstructural
This measure is used to stabilize sources of sediment such as gullies, banks, private roadsides, and field borders.

BMP 12 Sediment Retention, Erosion, or Water Control Structures - Structural
Structures may be built to control erosion and also to control sediment and chemical runoff to prevent water pollution.

BMP 14 Tree Planting - Nonstructural
Water quality may be improved by planting trees in critical areas.

BMP 15 Fertilizer Management - Nonstructural
Water quality may be improved through needed changes in fertilizer rate, time, and/or method of application to achieve the desired degree of control of nutrient movement in critical areas.

Note: BMP 3, BMP 6, and BMP 13 were not assigned to this project