APPLICATION OF AN EROSION MODEL TO A DIVERSIFIED AGRICULTURAL WATERSHED

by

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ABSTRACT

Rural nonpoint sources of water pollution are becoming increasingly important in terms of cleaning up our nation's waters. However, the need for maintaining agricultural production to supply food for growing populations still exists. Agricultural runoff is the major nonpoint pollution source identified in the study area located in Marathon County, Wisconsin. Nutrient and sediment inputs from these lands have contributed to fish kills on the Eau Pleine Reservoir by causing algal blooms which contribute to low dissolved oxygen supplies.

A mathematical computer model (ERODE) developed by the USDA-ARS was applied to the Big Eau Pleine watershed. Basis of data collected for model application included land use, rainfall, topography, soils and farm management practices. ERODE uses a modified form of the USLE (Universal Soil Loss Equation) to calculate overland soil movement based on kinetic energy from precipitation and overland flow for individual storms. A spring R Value (USLE) representing soil detachment energy of snow melt was derived from simulated snow melt events.

The model was modified to handle varying land uses in the test watershed. Results indicate fair agreement between observed and simulated sediment yields. Improved

simulation was experienced for the spring season by decreasing the infiltration component for the derivation of the K factor (USLE).

The model shows potential as a planning tool for conservation considerations by attempting to fill the gap between soil movement on fields and sediment yield into the stream channel. It also provides a means of evaluating the impact of individual storms on soil loss and for identifying problem areas within the watershed.

The model's need for complete information on precipitation and sediment yield will limit its use to areas where this information exists.

ACKNOWLEDGMENTS

ACKNOWLEDGMENTS

My appreciation and thanks are expressed to my advisor, Dr. Byron Shaw, in making possible the development of this thesis. His constant dedication to the objectives of a clean environment in a realistic manner is also expressed in the philosophy of the remaining members of my committee. The giving of their time, effort and advice is a nonvisible yet invaluable and continuing contribution to the total cause of pollution control.

Sincere gratitude also needs to be expressed to the other members of the study project who have, at one time or another, occupied the graduate student office involved in the Big Eau Pleine study. Their continuous encouragement, taking many forms, always surfaced at the most needed moments.

Special thanks goes to Charles Onstad, Agricultural Engineer USDA/ARS, who supplied the necessary initial information on the model used as well as his personal time.

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> Then began the long battle between land & sea the former struggling to rise from beneath the ocean, the latter striving incessantly to recover its lost dominion ... Copious rains descended over the whole surface of the land, and flowing thence into the sea, carried down with them fine sand and silt and soluble material, and rolled along beneath their rills and floods the sand and pebbles they could not carry ... tending to restore the earth to its primitive uniform surface (Chamberlin, 1883).

INTRODUCTION

Soil erosion continues today in an accelerated form, much of it within agricultural or urbanized watersheds. Soil particles carry associated nutrients such as nitrogen and phosphorus whose levels at times become pollutants to aquatic ecosystems. Although being classified <u>nonpoint</u>, as compared to <u>point</u> sources of pollution, most of a watershed's sediment may come from a few relatively small areas that need special attention (USDA / EPA, 1975).

Initial soil loss equations (Li, 1973) including the well known USLE (Universal Soil Loss Equation) were geared toward maintaining productivity of the land. Thus certain allowable losses were tolerated so long as the rate of soil formation maintained that lost to erosion.

With increasing use of fertilizers and manures, the nutrients contained with and within eroding soil are surfacing as major problem-causers of excessive algal blooms along with sedimentation of lakes and reservoirs. A new emphasis is needed to determine the mechanics of erosion within a watershed and ultimately arrive at a method to localize the important sources of nutrients.

> Whether agriculture is responsible for nutrient losses in substantial amounts or not, the facts need be available to avoid unreasonable regulations, and to permit time for farmers to make any necessary adjustments in their operations if it can be shown that this will result in a substantial reduction in water pollution (Minshall et al., 1970).

Many modeling efforts are in progress today. One need only scan the literature available to obtain a notion of the amount and the direction of erosion studies to date. Novotny (1977) summarizes six models presently available which are classified into three flow types - continuous, semi-continuous, or event. All models described, with the exception of ACTMO (Agricultural Transport Model), do not have the inherent capability of localizing nutrient losses on some portion of the expressed relief within the watershed itself. All models simulate either sediment or nutrient loss at the watershed outlet to one degree or another, and at best describe a generalized source area, i.e., urban or agricultural.

The erosion submodel (Frere et al., 1975) used in this study is one of the three submodels of ACTMO (Figure 1). Its basis of calculation is a modified form of the USLE (Onstad & Foster, 1975; Onstad et al., 1976). Energy for soil detachment and transport is divided between rainfall and runoff in proportions specific to each individual watershed. Irregular slopes are also accounted for within the model according to the evaluation and subsequent al orithms presented by Foster & Wischmeier (1974). Throughout this paper the erosion model used will be referred to as ERODE to eliminate repetitive references to its combined name ACTMO which is composed of three specific submodels (Figure 1).

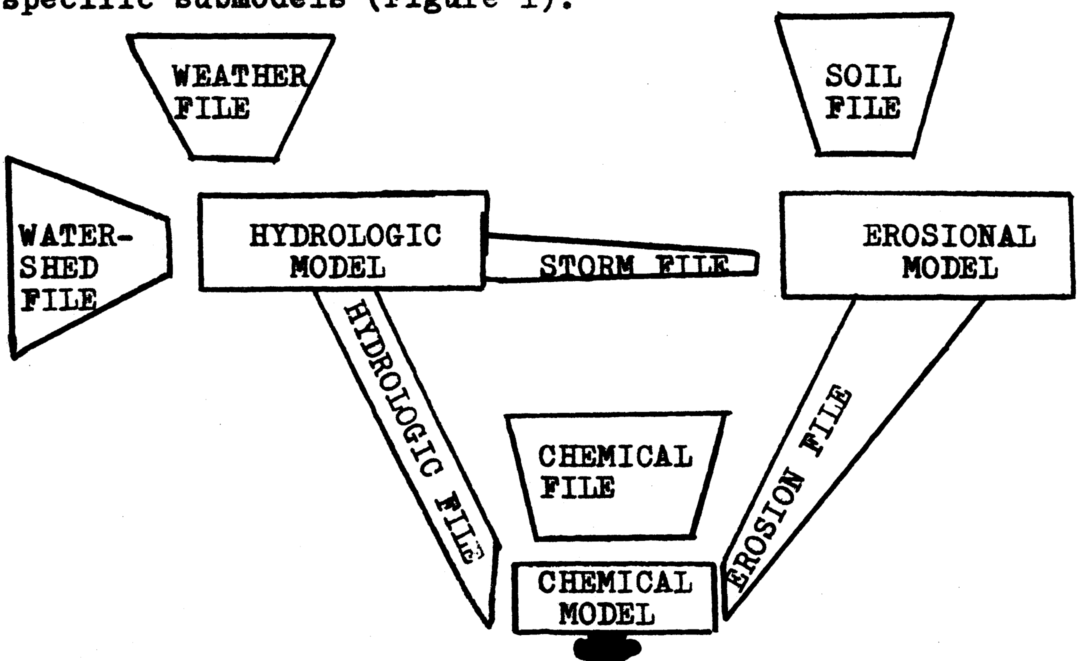


Figure 1. Flow diagram of the information transfer for the three submodels of ACTMO-Agricultural Chemical Transport Model (Frere et al., 1975).

Soil loss or suspended sediment yield on the Big Eau Pleine watershed is not large compared to other watersheds in Wisconsin, especially the driftless southwest region of the State (Hindall, 1976). However, it is believed that the nutrient input associated with these sediments is a major cause of algal blooms and subsequent fish kills experienced during many winters in the Big Eau Pleine Reservoir (Milwaukee Journal, 1974). If sediment yield can be successfully simulated at the reservoir inflow site while being localized on the soilscape itself, then appropriate and efficient methods to reduce this erosion can be determined. Hopefully, reduction in sediment yield would result in some reduction of associated nutrients.

The present study aims to adapt ERODE to a diversified agricultural watershed by the use of buffer zones or subzones which account for areas not in cultivation or rotation. If sediment yield can be successfully simulated then associated phosphorus inputs might also be predicted.

If sediment and phosphorus are correlated, the effects of soil conservation and farm management practices on water quality can be measured. Data on physical watershed parameters from Hamann Creek, a subbasin of the Big Eau Pleine (BEP) watershed, will be coupled with hydrologic information from the upper BEP watershed. Similarity between the Hamann Creek sub-basin and BEP basin are documented by a 100% sampling and 2% sampling respectively. Analysis methods used in this study will attempt to parallel those which can be practically utilized by agencies whose authority encompasses similar fields.

STUDY AREA

The general study area is located in the southwestern portion of Marathon County, Wisconsin. The legal description of the upper watershed outlet location is: on line between SEC. 13 T. 27 N., R. 3 E., and SEC. 18, T. 27 N., R. 4 E., Marathon County, on left bank 15 ft. upstream from bridge on State Hwy. 97, 1.0 mi N. of Stratford (Figure 4). The present watershed area is composed of a gently rolling landscape with dairying and associated crop production as its predominant land use and income producer. Several small farming communities exist which provide the services necessary to a dairying area including milk collection stations and cheese factories.

Early vegetation of the BEP (Big Eau Pleine) watershed consisted of a Northern Mesic Forest composed of Maple (Acer sp.), Hemlock (Tsuga sp.) and Yellow Birch (Betula lutea) species. Slight diversity was afforded by the infrequent inclusion of Pine Forests made up of White

Pine (Pinus strobus) and Red Pine (Pinus resinosa). Early farmers harvested good crops because of nutrients supplied from the original forest humus. When exhausted, the soil productivity declined tremendously (Hole, 1968).

Since 1950 the addition of fertilizers and lime to acid soils of the region raised yields of alfalfa-brome hay mixtures from 1.6 tons to 3.7 tons per acre (Love et al., 1960). This stimulated the dairy economy of the region.

The existant temperate climate in the watershed provides a growing season of approximately 120 days. Temperatures average $14^{o}F$ in January and $70^{o}F$ in July, with other than average temperatures being the more common. Average annual precipitation (water equivalent) is 32 inches. Snow amounts have averaged 52 inches. Average estimated ET (evapotranspiration) is calculated at 21 inches. This leaves approximately 11 inches of water going to overland flow or subsurface runoff to feed the well defined stream channels.

The bedrock geology of the area according to Hole (1976) is predominantly granite and undifferentiated ingeneous and metamorphic rocks. There are small areas consisting of gabbro and basalt. Depth to bedrock is generally not much greater than 5-8 feet throughout much of the watershed. Slow permeability of the soils limits extensive ground water recharge from rain events (groundwater supplies are therefore very limited (Hole, 1976). The watershed responds quickly to large rainfall events resulting in widely fluctuating storm flows.

Soils within the watershed are mainly silt loams with minimum relief which average two feet in thickness.

The greyish-yellow silt loams contain a loess cap which lies over acid sandy-loam to clay-loam glacial till. The Withee series (Typic Glossoboralf) along with its counterparts Fenwood (Typic Glossoboralf), Marathon (Typic Glossoboralf), and Rozellville (Typic Glossoboralf), lie primarily in the undulating upland. The Marshfield (Typic Glossoboralf) and wetter Mann (Typic Haplaquoll) silt loams occur in the nearly level plains (Hole et al., 1968; Marathon County, 1973).

The subsoil drainage is poor resulting in tight soils which limits production of field crops as water tends to pond (Hole et al., 1974). This emphasizes the need for quick excess water removal after spring thaw and precipitation events, incorporating the use of grassed waterways, surface drainage, and terracing. Very little contouring is evident in the region as a whole.

METHODS

Present computer modeling techniques analyzing the erosion process generally use basic relationships developed in early studies (Zingg, 1940). The relationships include the length and degree of slope and their effects on sediment yield and total runoff. Through time other causal factors have been added to the relationship to better explain each occurrence (Glymph, 1954). Factors involved included vegetation types and amounts, soil erodibility, cropping and management factors, overall size and shape of drainage basin, precipitation types and amounts, and runoff rates and volumes.

EROSION SUBMODEL

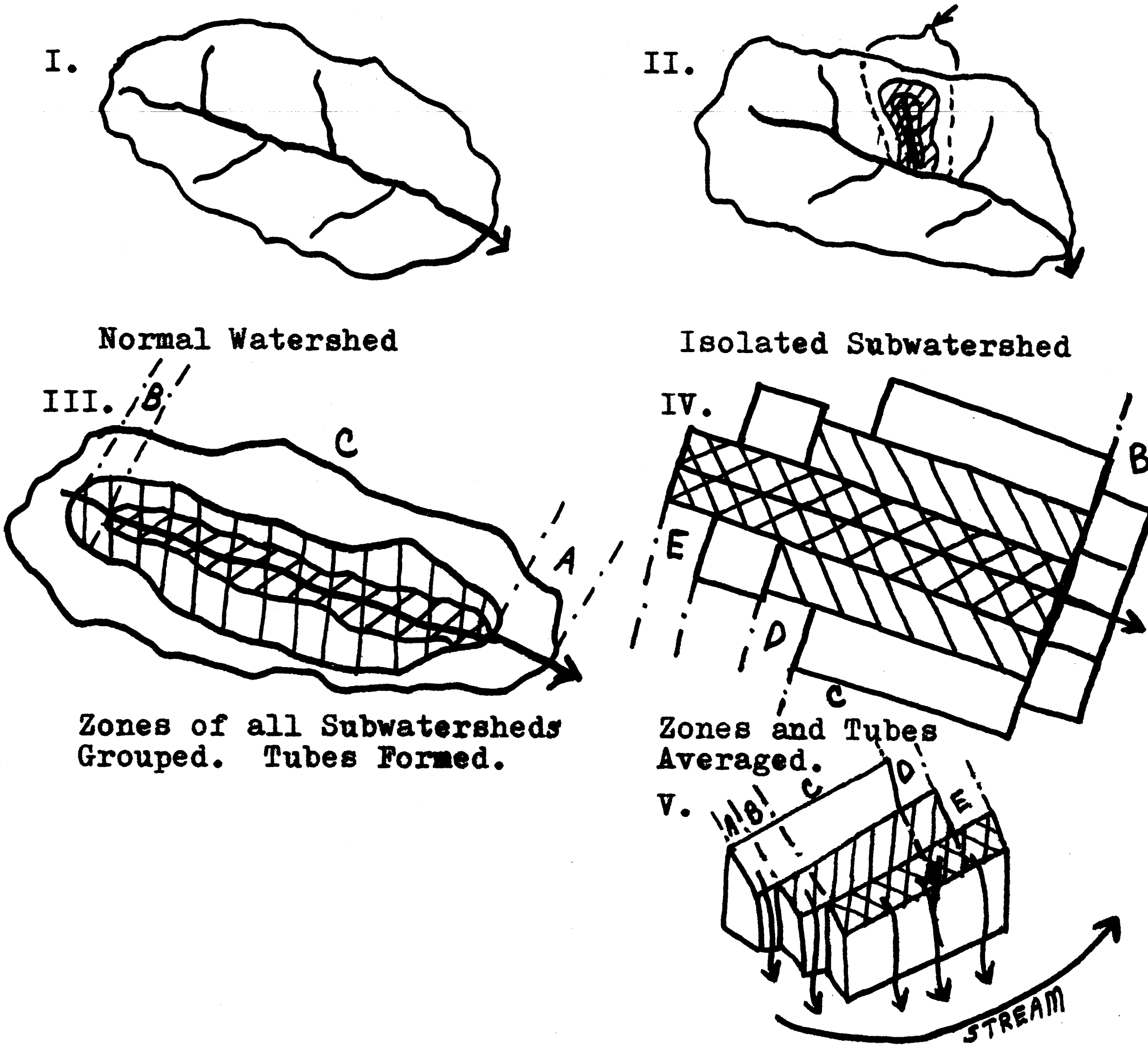
With the application of computers and modeling techniques the effect of concave and convex slopes, or their combination, have shown irregularities on previous sediment yield values based on averaging techniques (Foster and Wischmeier, 1974). In terms of detachment and transport capacity it is now known that any segment on the slope is affected by conditions of the upper segment or segments.

The ERODE model used in this study bases its calculations on this concept by dividing the watershed landscape into zones of uniform hydrologic response. A basic perspective of the grouping of soils involved (Table 1) is given in Figure 2. Further explanation of the derivation of parameters involved in the transformation is given by Frere et al. (1975) and Holtan et al. (1974). The percentage of zones which flow into subsequent zones define a tube. The individual areas within each zone formed by the intersection with the tube boundaries are termed compartments. These compartments and eventually their location within the watershed are the basic unit for sediment yield calculations based on the model's modified soil loss equation.

Table 1. Separation of soils into uniform hydrologic response zones by Land Capability Units (LCU) and slope.

Zone I (uplands)		LCU	Zone II (hillside)		LCU	Zone III (bottoms)		LCU
Rozellville	2-6%	II	Rozellville	6-12%	III	Fenwood	12-20%	IV
Fenwood	0-6%	II	Fenwood	6-12%	III	Marathon	12-20%	IV
Marathon	2-6%	II	Marathon	6-12%	III	Reitbrock	12-20%	IV
Withee*	0-6%	II	Reitbrock	6-12%	III	Mann*	0-2%	IV
Cassel	0-2%	II	Mosinee	6-12%	III	Mosinee	12-20%	IV
Mosinee	0-6%	II	Marshfield*			Rifle*	0-2%	IV

* = Predominant soils within zone



Combined Unit for a Subwatershed, with Zones and Tubes Averaged for Flow Routing.

Zone I (upland)

Zone II (hillside)

Zone III (bottom land)

—·— Tubes A, B, C, D, E

⟶ Channel

Figure 2. Subwatersheds modified to single computational unit by utilizing zone concept and tubes for routing flow to a stream channel.

The original Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1965) is:

$$A = R\ K\ L\ S\ C\ P \qquad (1)$$

where

A = estimated soil loss in tons per acre per year

R = rainfall and runoff factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cropping management factor

P = erosion control practice factor

The modified equation as presented by Foster et al. (1973) is:

$$A = (aR + bcQq_p^{1/3})\ K\ C\ P\ S\ L \qquad (2)$$

where

a, b = weighting parameters (a + b = 1)

c = equality coefficient

R = rainfall factor

Q = runoff volume in inches

q_p = runoff rate in inches per hour

K, C, P, S, L = USLE factors

In the preceding equation the initial "R" factor (USLE) is modified by the values observed for total volume of runoff (Q) and the peak runoff rate (q_p), as well as weighting parameters for each watershed. This modified "R" is the "R" value calculated and used within the erosion submodel employed in this study. This new "R" value is termed the effective "R" or "Reff" by this author. That portion of the equation ($aR + bc\ Qq_p^{1/3}$) is thus defined as the "Reff".

The weighting parameters directly reflect the relative amounts of erosion caused by rainfall and runoff under unit conditions, i.e., L, S, C, P = 1 (Frere et al., 1975). The equality coefficient, c, can be estimated from rainulator plot data for unit conditions. Here

$$c = (2A_u/K-R) \ / \ Qq_p^{1/3} \tag{3}$$

where

A_u = soil loss under unit conditions

The a, b (equation 2) and c (equation 3) parameters can be different for different watersheds, and are the values which are used to calibrate the ERODE model. Onstad et al., (1976) found "a" to be .05-0.5 and "c" to be 15-30 on the uniform singly cropped watersheds where initial simulations were run.

Simulation is optimized by minimizing the sum of the squared deviations expressed as

$$SD = \sum_{i=1}^{n} (\hat{Y}_i - Y_i)^2 \qquad (4)$$

where

$\hat{Y}_i$ = estimated sediment yield

Y_i = measured or observed yield

ERODE MODIFIED

The present study is the only known attempt to apply the erosion submodel on a diversified watershed. Previously the model had been applied on single cropped, uniformly treated watersheds of 1.5 and 82.8 acres (Onstad & Foster, 1975). These entire watersheds were uniformly tilled, and included in a crop rotation. The BEP watershed is a diversified watershed of 224 mi^2 having both cropped and noncropped areas. The cropped area includes corn, hay and oats on a rotational basis.

A modification of ERODE was necessary to use it in this study. Sub-zones or buffer zones were adapted which represent the noncropped or permanent vegetative zones. This includes areas such as permanent pastures, wooded, idle, and farmyards. Figure 3 represents the final assemblage of the cropped and noncropped areas of the Big

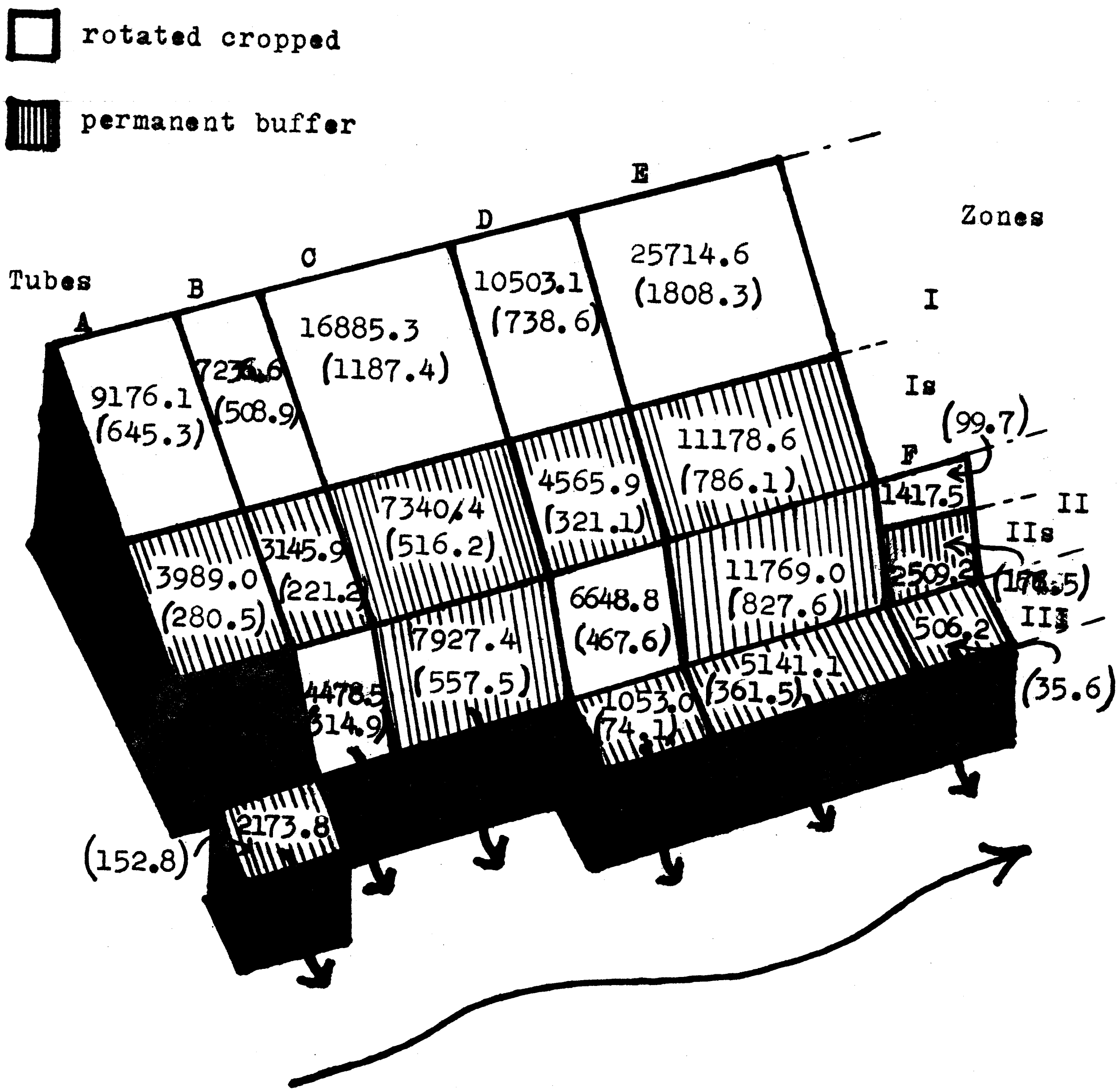


Figure 3. Computational unit of Big Eau Pleine Watershed. Values are compartment acres for BEP Watershed. Values in "()" are acres for Hamann Creek Basin.

Eau Pleine Watershed as used within the model. Explanation of the method used to arrive at the location of each compartment will be presented in the following section on the land use study.

SOILS & LAND USE STUDY

A complete (100%) soils inventory and land use analysis was carried out on the sub-basin of the BEP called Hamann Creek, an area of 25.75 mi^2, (Figure 4).

The soils were grouped into areas of similar hydrologic response based on land capability units (Table 1). These groups represent the corresponding hydrologic zones described in Figures 2 and 3. Zone I represents the nearly level upland portion of the landscape, Zone II the steeper hillsides, and Zone III the alluvial bottoms. Figure 5 shows the original zone location within the Hamann Creek watershed based on reductions of overlays from soil maps. A predominance of Zone I exists, indicating a watershed with minimum relief. Length of overland flow, a very important parameter in erosion and sediment yield calculations, was determined by using Horton's (1945) equation as presented in Chow (1964).

$$\bar{L}g = \frac{1}{2D\left[1-(\theta c/\theta g)\right]^{1/2}} \qquad (5)$$

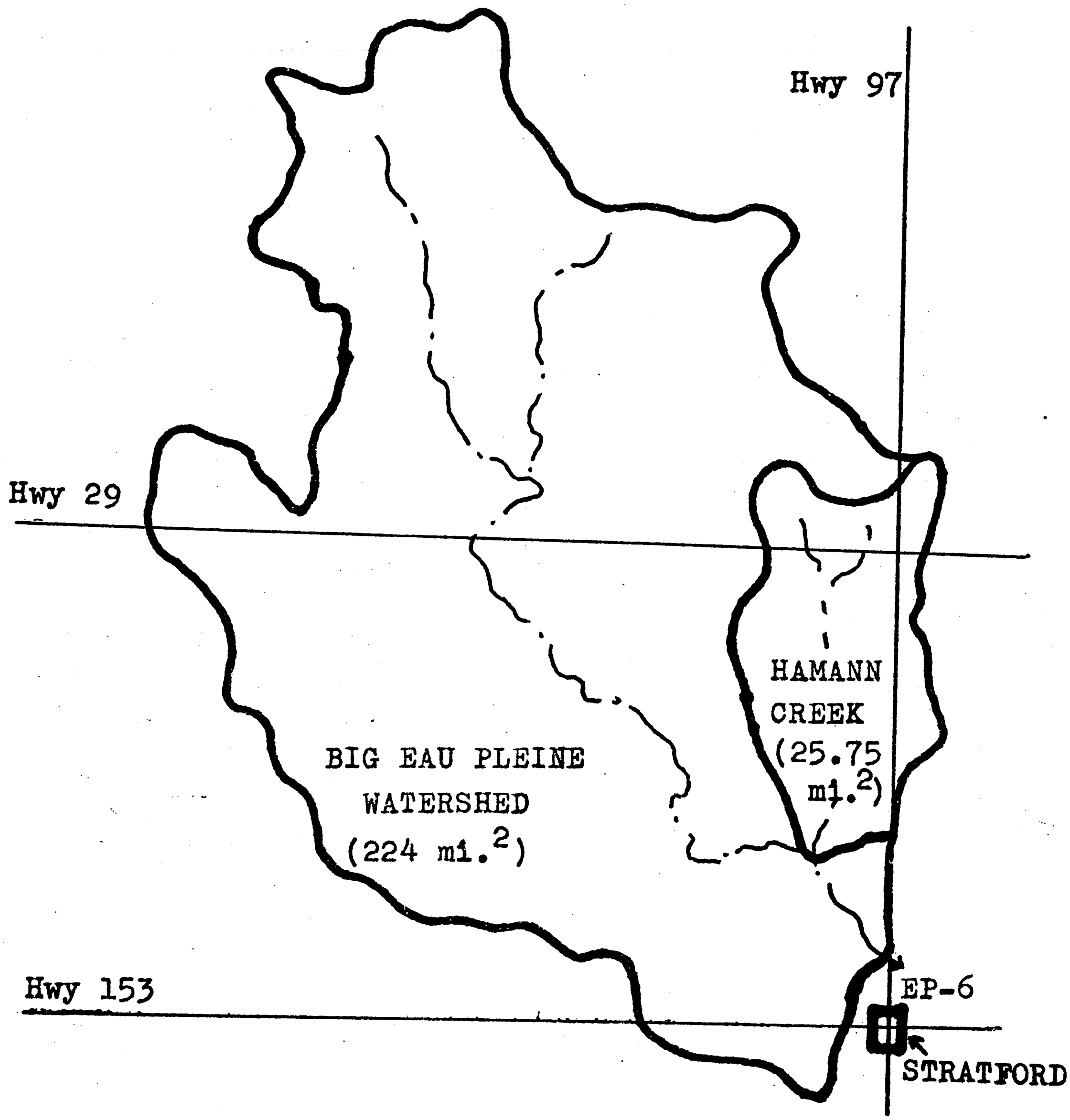


Figure 4. Upper Big Eau Pleine watershed and Hamann Creek sub-basin.

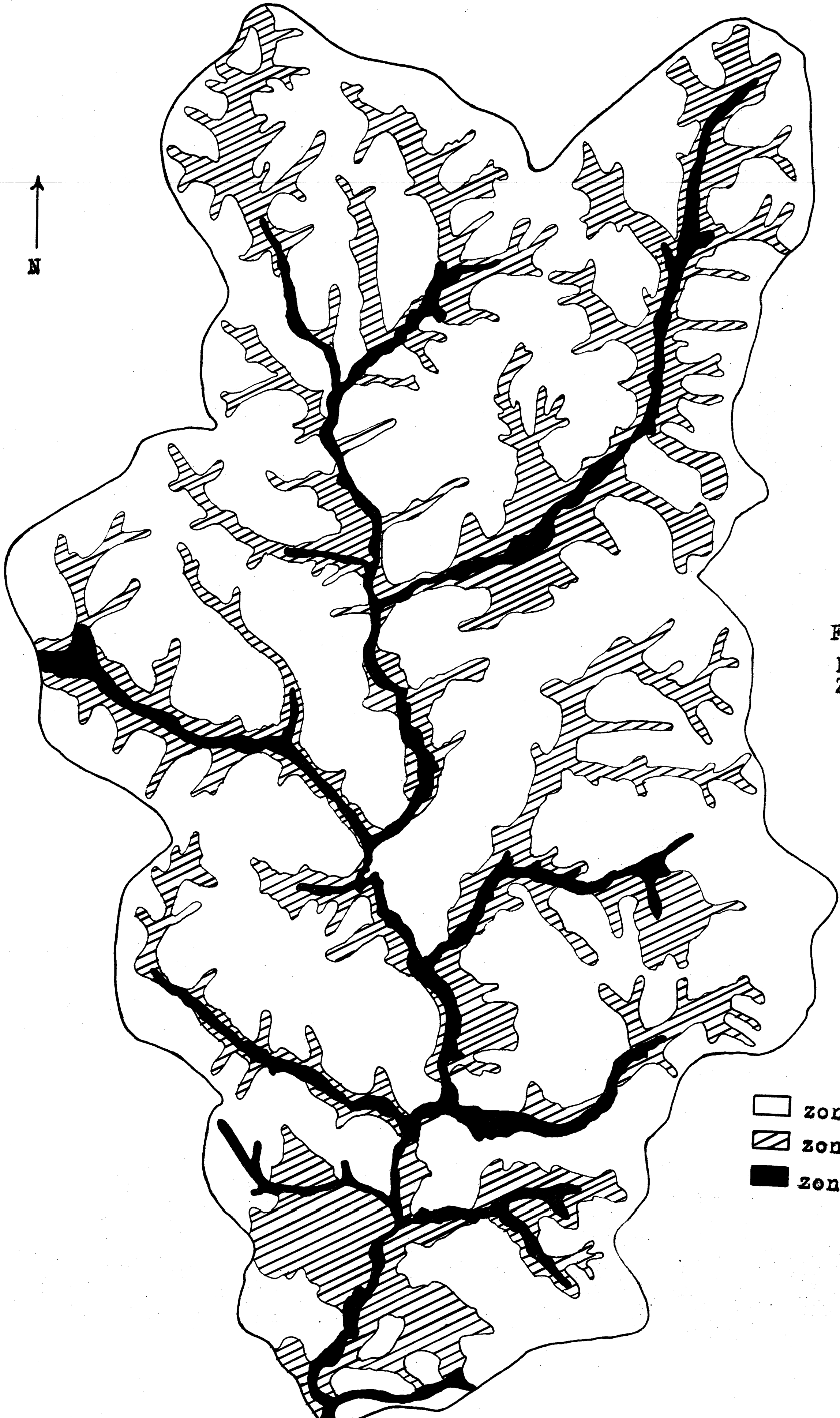


Fig. 5.
Hamann Creek
Zone Location

where

L_g = average length of overland flow.
D = drainage density of basin
Oc = channel slope
O_g = average ground slope in area

average length of overland flow was first determined from the stream channel boundary of Zone III, then from the stream channel to the upper boundary of Zone II, and correspondingly to the upper boundary of Zone I (the watershed divide). The difference between the upper boundaries is equal to the length of overland flow for that specific zone (see Table 2).

Table 2. Computer input file for the BEP watershed--based on data from Hamann Creek sub-basin.

Compart-ment/ tube	Zone & Sub-zone	Weight-ing Factor	% Slope	(Ft.) Slope length	(Ft.) Compartment Width	C Factor (USLE)
1/A	1	14498.	2.5	750.	532947.9	.160
2/A	*s1	3152.	2.5	530.	327698.1	.010
3/A	3	1142.	1.1	250.	378815.2	.020
4/B	1	11434.	2.5	750.	709965.7	.160
5/B	s1	7486.	2.5	530.	258557.4	.010
6/B	2	9629.	4.6	500.	390166.0	.160
7/C	1	26678.	2.5	750.	980698.1	.160
8/C	s1	5799.	2.5	530.	603297.8	.010
9/C	2	8522.	4.6	500.	547941.9	.010
10/D	1	16595.	2.5	750.	610019.9	.160
11/D	s1	3608.	2.5	530.	375265.3	.010
12/D	2	14295.	4.6	500.	459565.1	.160
13/D	3	553.	1.1	250.	183447.7	.020
14/E	1	40629.	2.5	750.	1493503.8	.160
15/E	s1	8831.	2.5	530.	918754.4	.010
16/E	2	12152.	4.6	500.	813473.3	.010
17/E	3	2699.	1.1	250.	895785.3	.015
18/F	2	3048.	4.6	180.	342102.8	.160
19/F	s2	2698.	4.6	320.	342162.8	.010
20/F	3	265.	1.1	250.	88130.6	.015

*s = subzone or buffer zone.

Land use studies involved used both individual farm visual surveys along with interpretation of vertical air photos and colored 35 mm slides taken from a light plane. Detailed information on exact acreages of each crop which made up each zone was needed to calculate an average "C" factor (USLE) for that compartment (see Table 3). For actual model calculations, all cropped land included in a rotation was grouped into one unit with notation as to proportions of each crop, i.e., acres of grain, corn, hay, etc. This was termed the erodible area. It was assumed that land use remained the same from one year to the next, i.e., on the average the number of acres of each crop did not change, but possibly their location within a zone did.

Table 2. Land use data including acreages of all crops for the Hamann Creek sub-basin. Results of 100% sampling.

ZONE	CORN	OATS	HAY	PAST.	FOREST	IDLE	RESID. & RDS.	TOTAL
I	1852.9	1938.0	4025.5	2435.2	255.9	304.5	239.9	11216.8
II	369.8	331.7	708.6	2009.4	267.2	26.3	381.5	3908.8
III	7.6	7.0	29.8	831.6	38.2	3.2	57.4	997.3
Sub Total	2230.3	2276.7	4763.9	5276.2	561.3	334.0	678.8	16121.6
% of Total	13.8	14.1	29.5	22.3	14.0	2.1	4.2	100.0

The nonerodible area or buffer zone included all other land uses within the basin which were permanently grassed or forested, as previously mentioned. The final result of this method of grouping land use into two categories appears in Figure 6.

Location of buffer compartments within each zone was determined by overlaying the zone location map (Figure 5) with the land use map for Hamann Creek sub-basin (Figure 6). The combined overlays are shown in Figure 7. This readily gave a visual perception to the general location of the two categories of land use within each zone.

In Zone I it was easily observed that the buffered area with permanent vegetation (buffered) was for the most part located nearer the stream channel than the erodible zone (cropped). This is expected as the more level uplands--being readily drained and generally fertile--would be chosen areas for early field location. The buffer zone, representing a calculated area of 30.3% (dot grid method) of Zone I, was appropriately placed in the lower portion of Zone I, creating a Zone "Is" or sub-zone.

It was immediately thought that Zone II would have its 63.9% of buffer area at the lower portion of its zone also. However, closer scrutiny revealed an area of

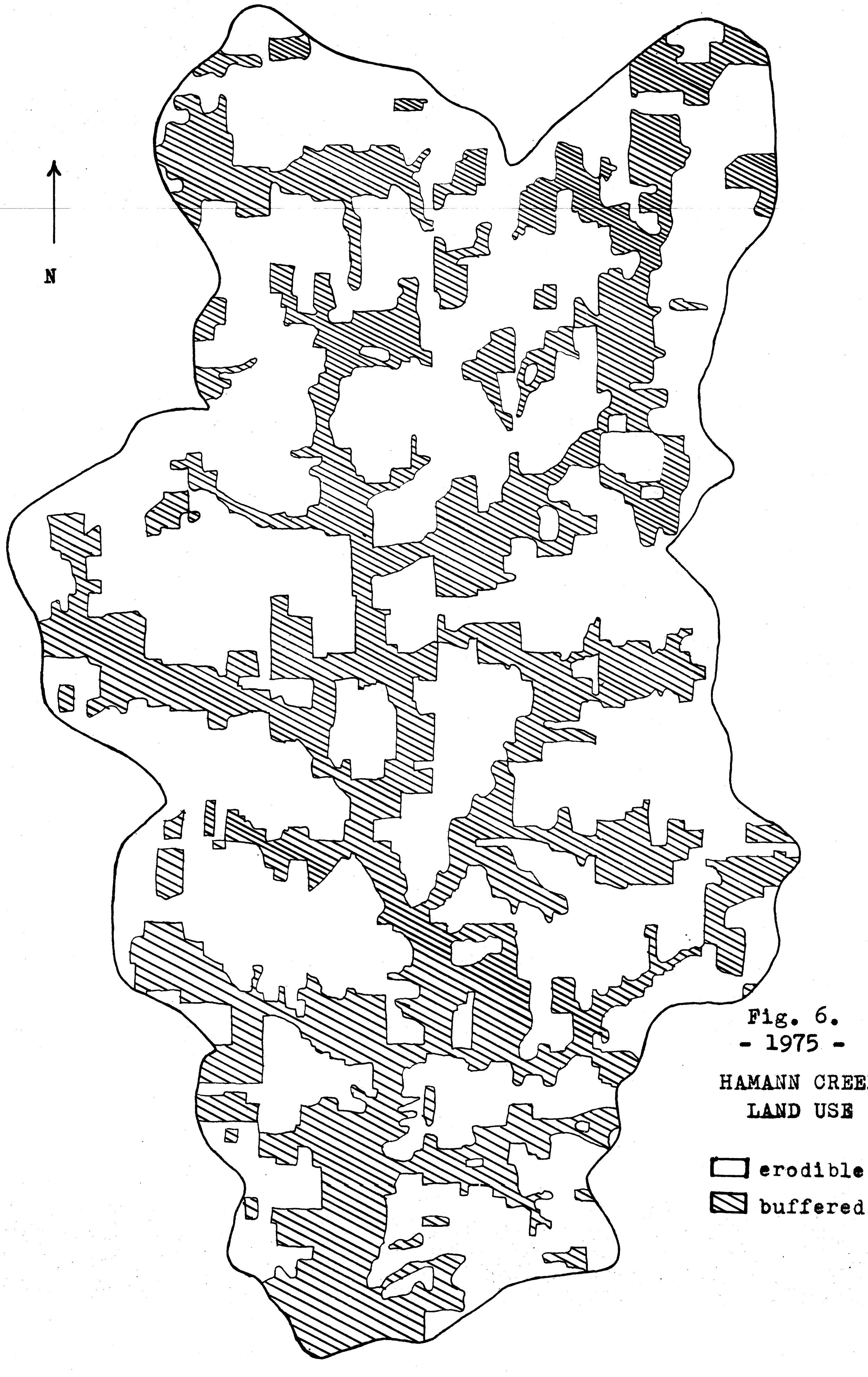
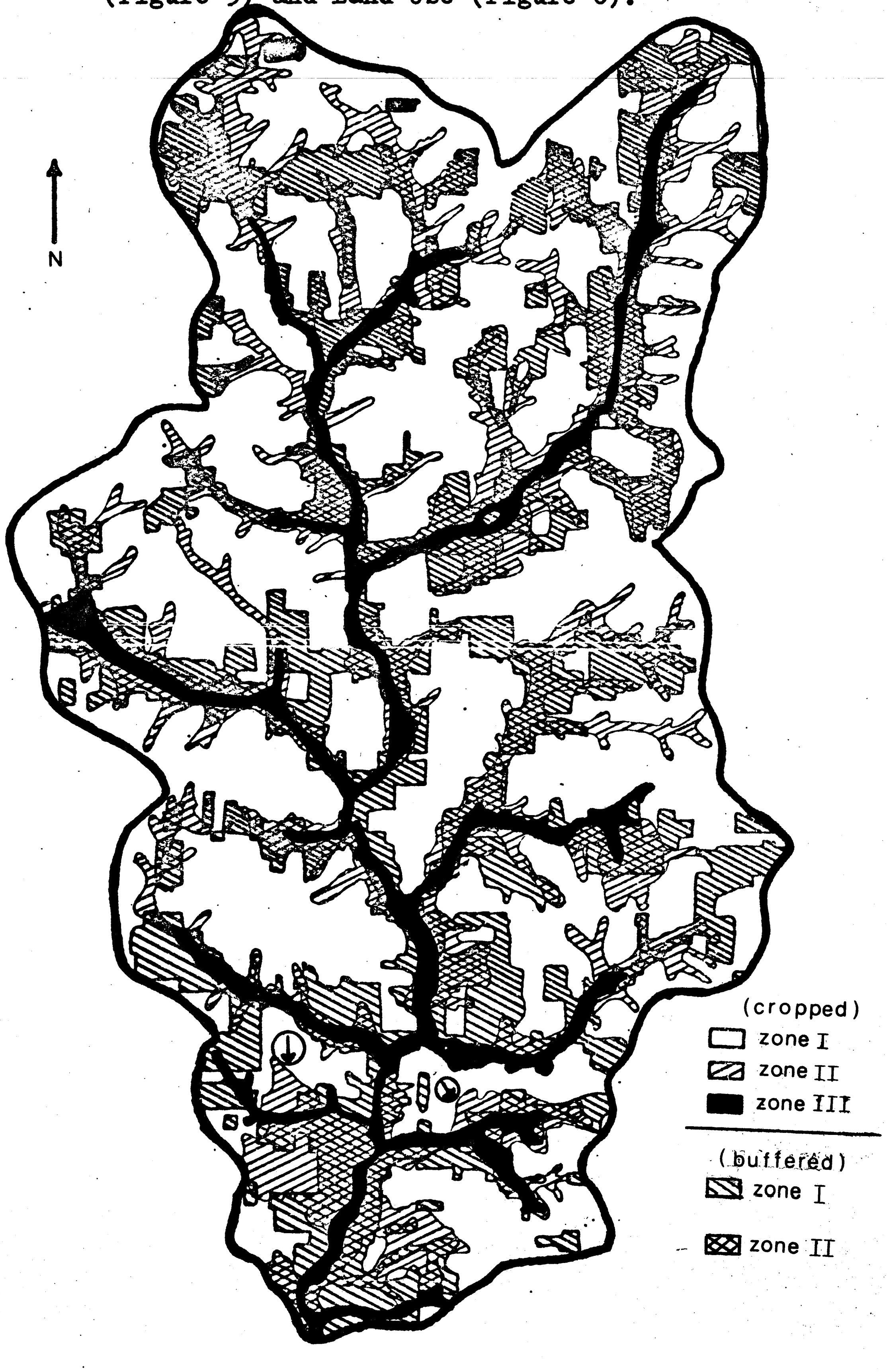


Fig. 6.
- 1975 -

HAMANN CREEK
LAND USE

Figure 7. Combined overlays of Hamann Creek Zone Location (Figure 5) and Land Use (Figure 6).



approximately 315 acres of erodible land of Zone II which bordered immediately on the defined stream channel. Examples of this situation are indicated by the circled arrows--lower portion Figure 7. This rotated cropland of Zone II, whose sediment is most easily delivered to the stream channel, is represented in the compartment located in the lower portion of Tube B of Zone II (Figure 3). All other areas of Zone II either buffer themselves or were followed by buffered areas of Zone III. Their calculated acreages are the values in parenthesis which appear within the compartments. No Zone II exists in Tube A, i.e., Zone I flows directly into Zone III.

Zone III located next to the stream channel, contains only 4.6% of erodible (cropped) land interspersed throughout its total area. These areas were not actually located and included for modeling purposes, because the net result would be the creation of many more tubes to account for these micro-erodible plots. Any change in routing of flow in the lower compartments requires a corresponding change in physical compartment size and location directly above the one added. This could be a never-ending process. Because of this, the decision was made to average the effect of this small amount of cropland within compartments wherethe majority of this land was located. The "C" factor within these compartments was increased accordingly to account for this situation. The determination of "C" values will be discussed in a later paragraph of this section.

At this point it is well to note the basic model which is shown in Figure 3 and relate the method by which land use and soils data were extrapolated for the entire basin. The values within the compartment represent acreage. The figures in "( )" (parentheses) are the acreages for Hamann Creek. The ones not in "( )" are for the entire Big Eau Pleine Watershed which were derived by multiplying the values in parentheses (Hamann Creek) by a factor of 14.22 as Hamann Creek is approximately 1/14th the size of the BEP above the Stratford bridge site.

The extrapolation mentioned above was necessary as abundant flow and sediment data exist at the site entitled EP-6, which is located approximately 1 mile north of Stratford (see EP-6, Figure 4). Extensive sediment loading and daily flow data are the basic requirements for implementing the ERODE model, along with land use and soils data. Only minimum flow and infrequent sediment data exist for the Hamann Creek sub-basin, It was therefore decided to use the information gathered at EP-6 by the USGS (1963-75) to calibrate the model.

A basic assumption here is that the soils and land use of the BEP Watershed are essentially the same as those for Hamann Creek. Information was compared with results obtained by Hansen (1977) wherein a 2% sampling of these two parameters was completed for the entire BEP Watershed. The land use summary appears in Table 4. It was felt that crop type and acreages corresponded close enough to allow the assumption to stand.

Table 4. Comparisons of land use types of Hamann Creek (100% sample) and those of the BEP (2% sample).

CORN	OATS	HAY	PAST.	FOREST	IDLE	RESID. & ROADS	TOTAL
(Hamann)							
13.8%	14.1%	29.5%	22.3%	14.0%	2.1%	4.2%	100%
(Big Eau Pleine)							
12.5%	14.0%	32.8%	14.9%	17.4%	(incl.)	8.4%*	100%

* includes some water bodies.

The comparison of soils between the two areas (Hamann and BEP) (Table 4) were also found to be acceptable. Though subsoils will vary, the average "K" factors (USLE) for the two areas were comparable; BEP = .39 (Hansen, 1977) and Hamann Creek = .43. As with the other physical parameters, the .43 value was used for the entire watershed, although actual values on smaller sites ranged from .28 to .43. The ERODE model does not make use of subsoil information as the erosion process is only concerned with the physical aspects of the surface soil as reflected in the "K" factor of the USLE. The "K" factor is the result of the effects of several parameters on erodibility of the soil surface. These are: textural type, % organic matter, soil structure, and permeability (Wischmeier et al., 1971). Indirect account is made for subsoil effect on permeability by

ERODE as follows: One of the input parameters for the model is complete information on total amount of surface runoff as well as peak runoff rate as determined by storm hydrographs. Permeability of the soils within the watershed will influence these runoff characteristics. This is the information included in the modified USLE equation presented in equation (2). Exact values of flow for the storms selected are given in Table 5. Application of this model on smaller watersheds may allow the use of separate "K" values for each zone or sub-zone.

The average land slope for Hamann Creek (2.9%) and of the BEP (3.1%) (Hansen, 1977) also suggested a strong similarity between the two basins rendering them compatible for extrapolation purposes.

The "C" factor of the USLE represents the cropping management factor. It concerns itself with the fraction of soil eroded from a field with a given crop cover and rotational scheme as compared with a fallow field.

Previous uses of the erosional submodel required only a single "C" value input. It was necessary to change these program statements within the model which would render it adaptable to "C" values for specific compartments. A listing of the original program with statement modifications is given in the Appendix (modified statements are underlined). Also, an averaged "C" value (CNEW) was added to the statement which calculates transport capacity (Appendix

Table 5. Input file for storm events including precipitation, flow and sediment yield for the Big Eau Pleine Watershed.

	Strm.	Date	Time	Year	Strm. "R"	Runoff Vol. (in.)	Peak Runoff Rate(cfs)	Sed. Yield (T/A)	"P" (USLE)	"K" (USLE)
summer calibrated	1	4/03	0330	1974	1.03	1.430	3200.	.0061	1.0	.43
	2	4/11	1000	1974	0.40	.764	1390.	.0032	1.0	.43
	3	6/09	0300	1974	6.36	.800	1700.	.0032	1.0	.43
	4	9/11	1600	1974	0.86	.006	0015.	.0000	1.0	.43
	5	4/27	1600	1975	1.43	1.020	3750.	.0049	1.0	.43
	6	6/17	0400	1975	2.30	.279	684.	.0009	1.0	.43
	7	8/28	0500	1975	9.27	.324	886.	.0011	1.0	.43
	8	9/10	1600	1975	4.36	.257	1140.	.0013	1.0	.43
spring	9	4/06	1200	1975	.001	2.260	1900.	.0078	1.0	.43
	10	3/02	1200	1974	.001	1.070	1400.	.0028	1.0	.43
	11	12/31	1200	1972	.001	.210	250.	.0006	1.0	.43
	12	4/06	1200	1971	.590	3.550	7200.	.0338	1.0	.43
	13	4/05	1200	1970	.001	1.560	2560.	.0084	1.0	.43
	14	4/04	1200	1969	4.06	3.110	4000.	.0257	1.0	.43
	15	3/06	1200	1968	.001	.397	600.	.0011	1.0	.43
	16	3/27	1200	1967	.001	4.680	11900.	.0428	1.0	.43
	17	4/25	1200	1965	15.1	.796	2320.	.0126	1.0	.43
summer predicted	18	8/25	1500	1972	.730	.312	876.	.0010	1.0	.43
	19	5/26	1500	1969	14.4	.470	2030.	.0063	1.0	.43
	20	6/21	0100	1968	.530	.408	1680.	.0026	1.0	.43
	21	6/30	2300	1967	5.47	.556	2830.	.0050	1.0	.43
	22	10/14	0700	1966	5.39	.130	754.	.0011	1.0	.43

Statement 17900). This change was necessary, for to ignore it would have permitted each compartment's transport capacity to be calculated using the "C" value of that compartment along with the entire slope length of that tube. This would result in error, thus the CNEW value is an average "C" which exists for the entire slope length to the point of calculation. In previous studies on singly cropped watersheds, only one "C" value was inputted, therefore the average "C" moving downslope with calculations, would always have been identical to the single inputted value.

The "C" values inputted for each compartment are listed in Table 2. In general, the "C" value inputted was calculated by the method which Williams & Berndt (1972) used for a watershed value. In this case "compartment" was substituted in place of watershed, for the computation

$$C = \frac{\sum_{i=1}^{n} C_i x DA_i}{DA} \tag{6}$$

where

C = cropping management factor for the watershed (in this case compartment)

C_i = the cropping management factor for crop "i"

DA_i = drainage area growing crop "i" with a particular management level.

n = the number of crops grown multiplied by the number of management levels in the watershed

Original values for C_i were based on information from Kruegar (1976) and Wischmeier & Smith (1965). Slightly larger "C" values located in Tubes A & D of Zone III reflect the 4.6% of cropland that exists within these two areas on the watershed as previously mentioned.

Since few effective conservation practices exist for a basin as a whole, the "P" value (USLE) was set at "1" (Table 5).

PRECIPITATION EVENTS/FLOW

The necessary input data for the Big Eau Pleine watershed for each storm event is listed in Table 5. Parameters include storm "R" values (USLE), runoff volume in inches, and the peak rate of runoff in cfs.

The inputted "R" was calculated from a defined storm event by the method for the EI (erosion index) calculation deriving storm energy (Wischmeier, 1958; Wischmeier and Smith, 1958). Here total rainfall energy is multiplied by the maximum 30-minute intensity. In this study the 30-minute intensity value was replaced by the 60-minute value and assumed equal to it. Few, if any, climitalogical stations record 30 min. values.

A storm was defined as a single event when it included all precipitation from the start of rainfall (including precipitation within an 8-hour time period) until precipitation ceased altogether or was interrupted by a period of time greater than 8 hours. Precipitation was assumed to be uniform throughout the entire watershed.

Precipitation values were taken from hourly readings (measured in 1/100ths.) at the Eau Pleine Dam which forms the reservoir (Figure 5). Two other stations (Medford and Marshfield) have hourly precipitation records (though incomplete) and were used as guides to have some insurance of uniform storm distribution. If total rainfall difference between two stations was greater than 0.5 inches (an arbitrary value), that storm event was not used.

In some instances discretion was used where total rainfall amounts were within the limits described above, but "R" values were quite different because of time distribution of the rainfall as in storm #8 (Table 5) where the calculated "R" for the Eau Pleine Dam station was 14.8 while the value for Medford was 4.36. Medford's value was chosen since no large increase in flow was registered at the EP-6 site. All attempts were made to choose isolated storms, i.e., those which did not represent a second peak on a hydrograph. A large basin such as the entire Eau Pleine has a hydrograph measured in days, not hours, and this tends to eliminate many storm possibilities.

Flow values used for input were chosen or calculated as follows: The peak flow rate was chosen by selecting the largest measured flow value for a single event. Many events have several measurements throughout one day as USGS sampling personnel tended to collect sediment samples and make flow measurements for entire storm periods to document hydrograph variation.

Total runoff volume in inches was determined by the method explained in Linsley et al. (1949). Figure 7 is a hypothetical hydrograph representing surface runoff determination. Line AC represents the extension of the recession existing prior to a point directly beneath the hydrograph. Line CB was drawn to a point B which represents an arbitrarily chosen point of initial recession. This method was selected over that suggested--which included selecting a value "N", representing days after a hydrograph peak, for a specific basin. The value "N" could vary as much as 50% for relatively flat basins like the BEP.

Values for flow volume and rate are listed in Table 5 for each event.

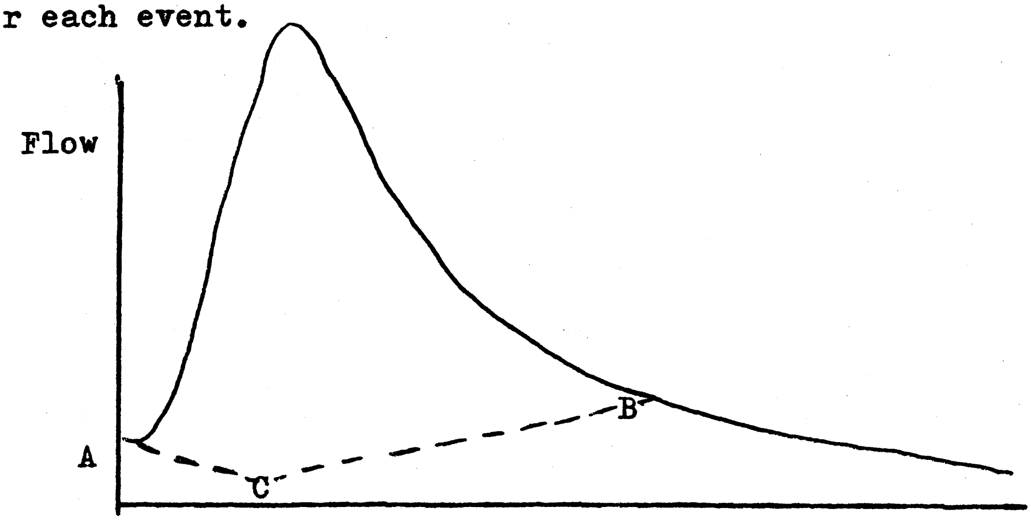


Figure 8. Arbitrary method for hydrograph separation.

Several methods to collect basic data on erosion rates are listed by Glymph (1954). Suspended sediment yield data used in this study was obtained by direct measurements and regression analysis. The information collected by the USGS at site EP-6 (Stratford Bridge) for over ten years was considered adequate for the purposes of this study. The sampling distribution as related to days on the hydrograph (time period), show that most sediment sampling was done at peak flow periods, decreasing as time from hydrograph increases - either negatively or positively (Figure 9).

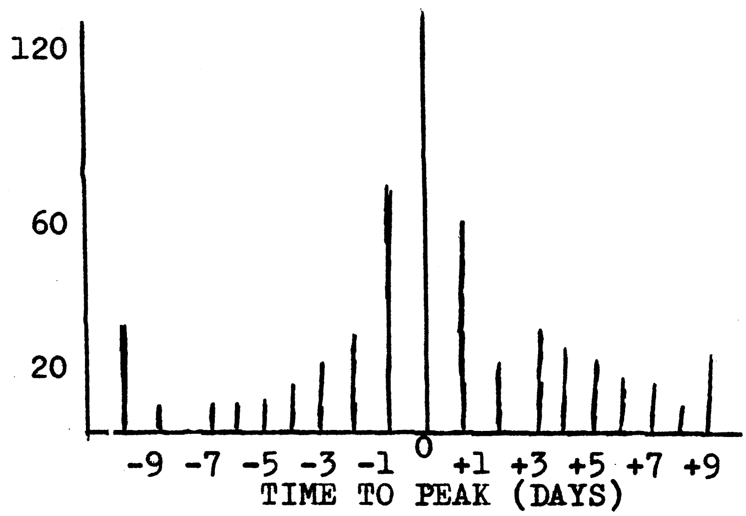


Figure 9. Sediment Sampling Frequency in Relationship to Stream Hydrograph. 0 = Peak Flow Day.

Sediment yield predictions require total observed yield values for each individual storm. Since only daily flow values and not daily sediment yield values are available for the EP-6 site, the missing yield values were filled in with those synthesized based on regression analysis. 389 sediment yield figures were correlated with average daily flow (cfs) covering a period of 11 years, 10/64 to 09/75 (Figure 10). The best result, after numerous attempts to arrive at a correlation coefficient, included a log (base e) transformation of both the dependent (sediment yield) and independent (flow) variables. Attempts using various flow ranges, seasonal separation, along with a multiple correlation with "time to peak" as a second independent variable, did not improve the relationship. To insure relevancy throughout the study, only storm events containing some actual observed (non-synthesized) data were used.

Since the USGS strives to choose sediment sampling stations at points of convergence within streams, it is felt that most of the total sediment being transferred by the stream is in suspension at this point (Hindall, 1977). That portion not measured (bedload) is offset by the lack of sediment source not measured (gully and stream bank erosion). Results of Mutchler and Bowie (1976) tend to support this assumption. ERODE assumes all sources of sediment to be sheet-rill erosion, as measured by the USLE.

PHOSPHORUS

Data for phosphorus was obtained from an ongoing study of the streams throughout the Big Eau Pleine watershed. This study is being carried out by the Environmental

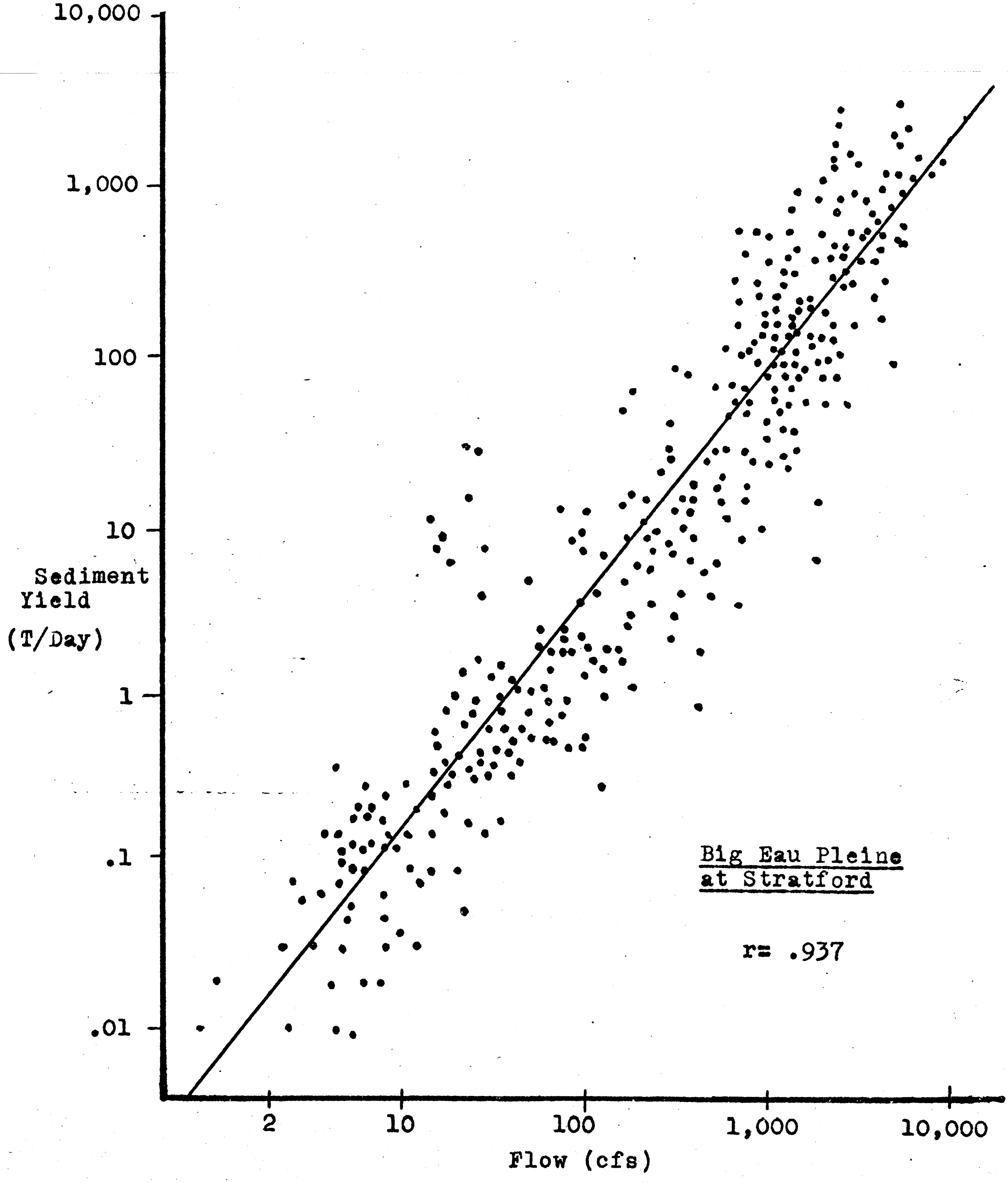


Figure 10. Correlation of sediment yield vs. ave. daily flow. of the Big Eau Pleine at Stratford (Log_e transformation.).

Task Force, located at the University of Wisconsin-Stevens Point. Sampling at the sites indicated in Figure 20 (p.74) was on a bi-weekly basis covering the period January 1974 to September 1976 for the purposes of this study.

An automatic sampler (ISCO) was located at the site marked EP-6 in Figure 4. Its purpose was to obtain sediment and phosphorus samples throughout the entire period of a hydrograph for the BEP watershed above this site. This would supplement the bi-weekly sampling.

Total and ortho-phosphorus were determined according to the methods described in Standard Methods, 13th Edition (1971) using persulfate digestion and stannous chloride methods.

RESULTS AND DISCUSSION

The original ERODE model was verified as functioning properly by matching the storm input and output data supplied with the program.

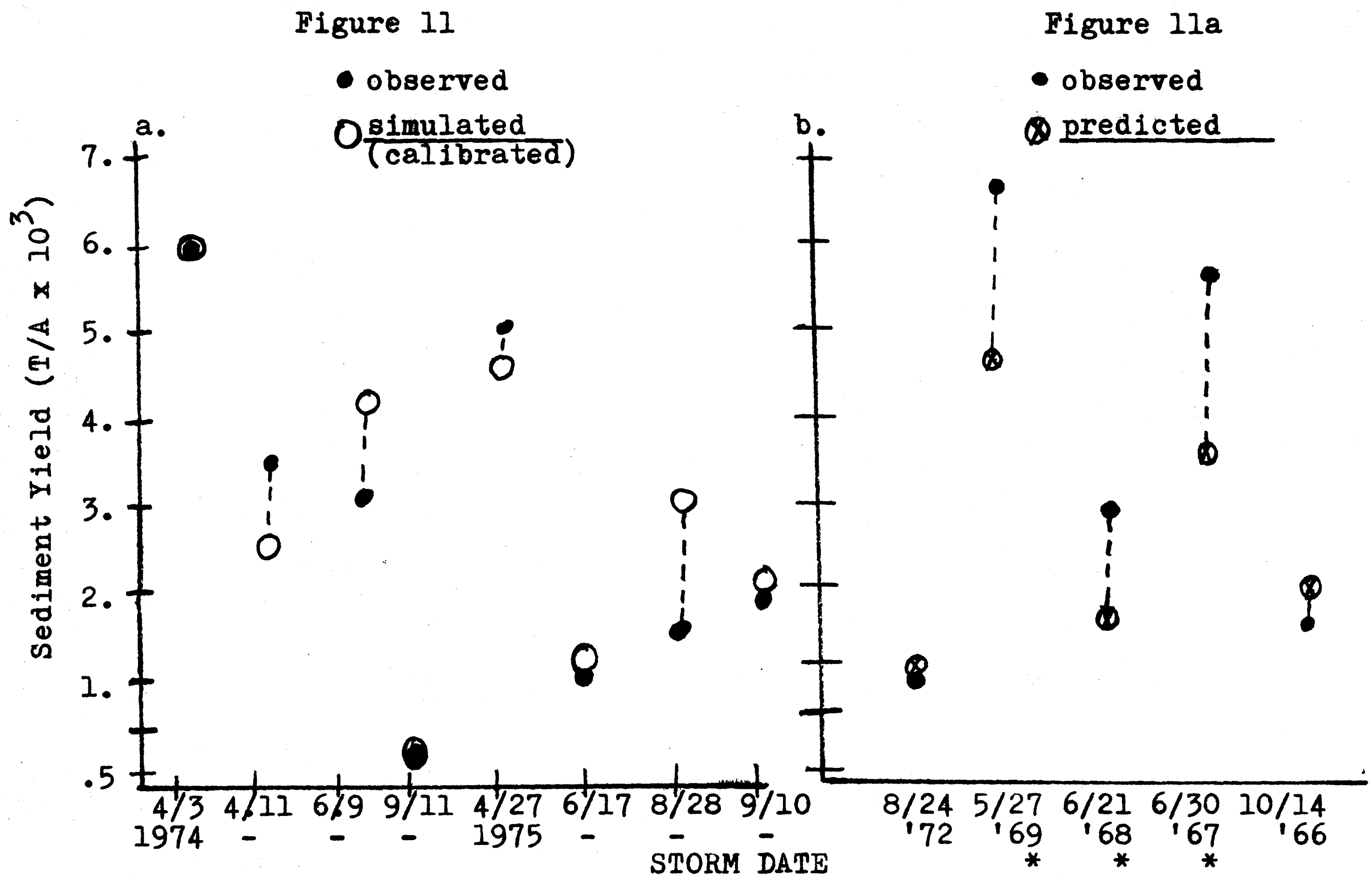
Computer simulation runs were made first on the IBM 1130 computer by card deck. Later, all information was transferred to the newly acquired Burroughs 6700 computer. Card decks became tape files and terminals were incorporated, greatly facilitating the numerous runs.

Model modification, involving program statement changes to adapt the buffer zone concept within the model, was also made easier with unlimited access to terminal use.

SIMULATION OF SEDIMENT YIELD

Sediment yield data used for calibration was initially limited to defined precipitation events for 1975, the year land use data was obtained. However, the lack of an abundant number of runoff events for this year, resulted in the storm events from 1974 being quickly included.

Figure 11 shows graphically the results obtained from calibration of the modified ERODE submodel complete with buffer zones. Calibration was actually accomplished using only the sediment yield data from 1975, as any further change in calibration parameters did not increase optimization, even after the 1974 data was introduced. Calibration parameters "a" and "c" from equation (2) were .007 and 1.0 respectively. This indicates that sediment yield is more closely associated with runoff energy than with rainfall energy on the watershed studied. Given the very minor slope gradient in general, the above conclusion would be logical, i.e., soil actually reaching the stream channel would be more dependent on overland flow characteristics rather than rainfall. This result would tend to uphold the validity of the original modification of the "R" (USLE) value within the model as presented by Foster et al. (1973). He suggests that total and peak runoff rates of overland



Figures 11 & 11a. Simulated and observed sediment yields for individual storm events of the Big Eau Pleine Watershed. No measured data were used for falling limb of hydrograph for predicted years '67, '68 and '69 during calibration. This resulted in many simulations being larger than observed values.

flow are better predictors of sediment yield than is rainfall amount and type; at least on an individual storm basis.

Overall simulation of sediment yield in this study can be termed <u>fair</u> for the 224 mi^2. diversified watershed. As can be seen (Figure 11) all but one simulated storm fell within a single unit of its observed value. Most simulated yields were greater than their observed value except for the two April storms 4/11/74 and 4/27/ 75. These lower "predictions" could be improved by a change (increase) in the K or C factor (USLE) for the spring period.

The event of 4/3/74, contrastingly, simulated very well. This is accounted for by the fact that all but one daily sediment value was derived from the regression equation, which calculates sediment yield based on flow data. Since the erosion energy within the model is weighted heavily toward overland flow characteristics, one would anticipate that prediction of the 4/3/74 event would be better than the other two April storms which contained several non-simulated sediment yield values.

Predicted sediment yields (Figure 11a)were also affected by the regression analysis method used to obtain "observed" yield values. Storms from years 1969, 1968 and 1967 were low on their predictions because the corresponding observed values were high due to synthesized data being necessarily used for the recession limb of the hydrograph resulting in overestimation of the yield for that storm. Overestimation results from a lack of measured data for the falling limb of the hydrograph.

This brings out the inherent problem in analyzing specific individual short-term events while data is based on long-term average values. Multiple regression using hydrograph position as a second independent variable along with average daily flow neither improved nor decreased the correlation coefficient to predict sediment.

It is believed other discrepancies between observed and predicted values would have been minimized if the watershed size were held to a smaller unit, thereby allowing a more detailed land use and soils study as well as providing some assurance of uniform precipitation distribution.

TUBE YIELD

Although sediment yield for the entire watershed is low for the events selected, there exist large differences between yields from individual tubes. The tubes comprise the pathway that overland flow and associated sediments must travel to reach the stream channel (Figures 3 and 11).

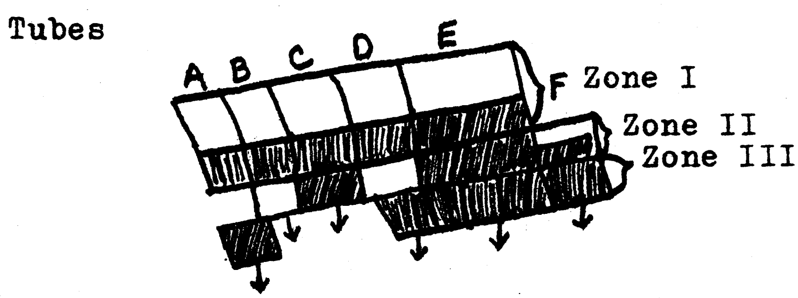


Figure 12. Tube location of major sediment yielding areas.

Table 6. Summary of sediment yield from each tube. (T/A X 10^{-3})

Tube (acres)	A (15337)	B (19848)	C (30515)	D (21397)	E (51372)	F (4433)
Storm						
4/03/74	4.1	13.3	6.6	3.1	5.5	0.4
4/11/74	1.6	5.4	2.7	1.3	2.2	0.2
6/09/74	2.7	8.6	4.2	2.0	3.3	0.3
9/11/74	0.1	0.4	0.2	0.1	0.1	0.0
4/27/75	3.1	10.3	5.1	2.4	4.2	0.4
6/17/75	0.8	2.5	1.2	0.6	0.9	0.1
8/28/75	1.9	6.0	2.8	1.3	2.1	0.3
9/10/75	1.2	3.6	1.7	0.8	1.3	0.2
Mean	1.9	6.3	3.1	1.5	2.5	0.2

Table 6 lists the sediment yield for individual tubes for the summer storms used to calibrate the model. Most are comparable with the exception of Tube B which consistently yielded higher sediment loads. Tube B was created from the land use and zone overlays previously described. It represents an area which exists within Hamann Creek. It was the only area found not to have a buffer zone (permanent vegetation) which is located directly below an erodible (cropped) area and adjacent to the stream channel as in Tube A. Deposition is minimized due to the steeper hillside area of Zone II.

A weakness in the original soil loss equation and directly reflected in the erosion submodel used in this study, is a lack of a factor to account for the increased depositional effect of a vegetative zone. A zone with vegetation will directly affect overland flow rates and amounts by providing a frictional force and maintaining a higher permeability as compared to cultivated cropland. This theory is upheld in studies by Saxton et al. (1971), Skidmore et al. (1975) and others. Piest et al. (1975) suggests a group of terms that will express the "conveyance" or "roughness" characteristics of the soil surface. The "C" factor (USLE) correctly gauges the effect of cover on soil loss rates but does not represent watershed conveyance. Conveyance is needed to represent depositional effects of soils having equal K and C values (USLE), to account for changes in infiltration and overland flow resulting from tillage and compaction due to grazing. For example, recently cultivated land will offer more resistance to flowing water than land with preformed rills, as will ungrazed compared with the grazed land.

The addition of a conveyance factor to the USLE and to the erosional model would strengthen its capability as a planning tool. With this, different widths of buffer strips could be inserted into the lower portion of Zone II in Tube B to gauge the effects of certain types of strips. Molchanov (1963) has found that a forest strip of 20 meters will act twice more effectively than a grassy strip of the same width in respect to controlling spring runoff. He states that the grassy strip does not differ much from fields with autumn plowing. The forest cover apparently traps more snow, reducing the frost effect, thereby increasing the infiltration possibilities. The snow within the forest will also thaw at a slower rate providing more time for the melt water to infiltrate. Other findings would have to be studied and applied on test plots to measure actual results. These results coupled with computer simulation would help choose the most optimum buffer width based on the existing characteristics of the watershed being studied. The critical time period of spring will possibly require the implementation of innovative conservation practices not common to the Big Eau Pleine area. The eventual localization of sediment yielding sources and buffer areas could help in locating priority treatment areas.

The computer model would serve as an invaluable planning and management tool by providing a functional method with which to study erosion problems. In this way errors in implementing an inefficient soil or water conservation device or practice would be limited to the computer terminal. Sensitivity of various parameters to differing conservation practices would also become evident. This aspect is not as easily discovered when the sole method of analysis requires actual application of a sediment controlling device in the field. Simulation of these practices within a certain range of accuracy certainly has its merits.

As in any computer model, its accuracy and validity can only be proven by numerous applications on various watersheds where sufficient data is available.

With ERODE a first step has been taken to adapt the model to a diversified watershed. Areas in permanent vegetation were separated from areas included in permanent rotation. The following step, which is not entirely necessary, would make the model more meaningful as a planning tool.

At present, compartments making up the cropped land contain areas of hay, grain, and row crops. It would be erroneous to assume that all these areas erode equally, yielding the same amount of sediment. The modification of separating these compartments into separate crop compartments would have to be implemented. Difficulty arises when portions of each compartment flow into portions of lower compartments automatically creating the necessary construction of more tubes. On a large diversified watershed this breakdown into smaller units could become virtually endless. If, however, this could be efficiently accomplished, the application of the chemical sub-model (Figure 1) would become practical. Without this second modification, use of the chemical model will be limited to singly cropped uniformally treated watersheds, which are the exception, not the general land use pattern.

The conveyance factor when developed, can be applied immediately to the ERODE model. This can be done even if the above micro-breakdown of the compartments is not instituted. Future use of this depositional factor will not only improve sediment prediction by computer means where the USLE is employed, but will directly affect the results of field analysis. Present means of calculating a sediment delivery ratio (SDR) for agricultural watersheds are not yet considered adequate (USDA/EPA, 1976). However, use of the SDR is nevertheless likely in water quality studies because of its acceptance within the SCS. Implementing the conveyance factor within the USLE will result in a more valuable sediment delivery ratio.

Sediment Delivery Ratio

Sediment Delivery Ratios (SDRs) are presently being developed and used singly or in conjunction with computer erosion models (Jacobs, 1972).

The SDR is defined as the percentage of gross erosion delivered to the watershed outlet. Several factors influence the ratio--two of which are the efficiency of the transport system and the nature of eroded sediments (Bubenzer & Mitchell, 1977).

The efficiency of the transport system is affected by the shape of the drainage basin and by rill and channel density. Unless these factors are uniform from watershed to watershed, the ratio of sediment yield to erosion may be expected to show considerable variation for equal size drainage areas, even within the same physiographic area (Glymph, 1954).

A need exists in further analyzing the concept of sediment delivery. The SDRs (as a function of watershed size) suggested by the SCS (Soil Conservation Service, 1971) should be re-evaluated and updated if this method is to be used in conjunction with water quality studies.

McCool, et al., (1976a) list preliminary results of an ARS and SCS study on a 27 mi^2 agricultural watershed in eastern Washington and adjacent Idaho. These results indicate delivery ratios higher than the .10-.40 values normally considered applicable to watersheds of that size.

Other studies cited by the USDA/EPA (1976) emphasize the need in considering factors other than watershed size when calculating SDRs. Here also the ratios computed were higher than those estimated from the SCS general curve for choosing delivery ratios.

One initial attempt to include other watershed characteristics other than size to arrive at a delivery ratio showed the complexity of doing so. Williams and Berndt (1972) derived a relationship using regression analysis between slope of the mainstream channel as a single unit and the sediment delivery ratio. However, when the channel was segmented and calculations completed, the ratio dropped from .55 to .28. This difference, as well as those cited previously, support the need for further studies where the sediment delivery ratio is concerned.

Within this study the ERODE model also tended to show a much higher SDR (ave. .67) than that suggested by the SCS (.06-.08). Part of the higher value is attributable to the model's use of the modified USLE. With the lack of input on the total influence of a buffer zone, the initial soil detached is being readily transported to the stream channel resulting in a higher delivery rate. Once the buffer zone is adequately portrayed within the model, this ratio will drop substantially. However, based on familiarization with the model and the study, the author believes the final value for the ratio will fall in the range of .40-.50 for the Big Eau Pleine Watershed.

Inclusion of a conveyance factor as discussed previously, will also tend to increase the delivery ratio as initial gross erosion estimates will be reduced, resulting in a less difference between the gross erosion and the sediment yield measured.

An excellent and important explanation of the dynamics involved with the SDR while proceeding down slope, is presented by Onstad et al., (1976). They identify a portion of the landscape in which no soil loss occurs. This concept parallels closely the "conveyance factor" idea presented by Piest et al. (1975) and perhaps could serve as a basis of its explanation.

The above two concepts can explain the apparent low SDRs suggested by the SCS. The following discussion will try to establish an explanation of the SCS's suggested low SDRs as compared to resultant higher rates actually measured.

Three factors are involved in any sediment delivery analysis:

1) the estimate of gross erosion
2) the sediment delivery ratio
3) the net sediment yield.

From studies where suspended sediment sampling have been going on for a long period of time the third factor (yield) is the <u>only</u> factor which is <u>known</u> to approximate its true value for a given watershed within statistically accepted error. The first factor (gross erosion) is a "calculated" value at best (USLE) and is not actually measured for a given watershed. It is instead based upon actual measurements of small tracts of land. The second factor (SDR) is also "calculated" based on information of the other two factors.

The discrepancy between the SDR's of SCS and others derived can be explained by considering the following three areas of possible error:

1) the lack of the SCS method to include other watershed characteristics besides size in initial calculations.

2) the trend to ignore the effects of a conveyance factor which should be included in the Universal Soil Loss Equation when this equation is used to determine gross erosion.

3) the inherent assumption when using the USLE to calculate gross erosion on a watershed basis that all areas are eroding equally. The study cited earlier by Onstad et al. (1976) suggests areas of zero soil loss on a landscape. Yet the 1-2% sampling for the CNI (Conservation Needs Inventory) in progress today ignores this basic fact. Hence, gross erosion estimates extrapolated for a watershed are extremely high, resulting in a low delivery ratio.

Total inclusion of the effects of the areas discussed above in actual gross erosion and delivery ratio calculations would undoubtedly result in an increased delivery ratio. The subsequent inclusion of a conveyance factor would also result in an increased delivery ratio by decreasing gross erosion estimates. The third area of possible error could be strengthened by limiting gross erosion calculations to areas above the 100% sediment delivery point as explained by Onstad et al. (1967). Other areas would be defined as areas of deposition. The reduction of the initial gross erosion estimate in this way would also result in an increased value for the sediment delivery ratio.

It must be emphasized here that the real error in working with sediment delivery ratios will possibly lie in its nonuniform application. The final seal of approval on use of the SDR should insure its uniform and consistent use on watersheds in all parts of the country. Only in this way will error be kept to a minimum and results approximate true values.

SPRING RUNOFF

Suspended sediment yield from spring runoff can be substantial in many northern areas of the United States and Canada (Bubenzer & Converse, 1975; Bubenzer & Mitchell, 1977; Hudson, 1971; Klausner et al., 1976; McCool et al., 1976a; Mutchler & Young, 1975; Skidmore et al., 1975; and Yoo & Molnau, 1976). Numerous measured sediment samples taken during this period of the year by the USGS (1964-75) at Stratford Bridge, have shown that even when actual suspended sediment concentrations are low the total volume of runoff is so great that sediment loading becomes significant.

Although not developed for this purpose, the attempt to simulate spring melt events using ERODE was successful. Figure 11 shows the initial simulation results.

Recalibration of the model was not done as optimization parameters were set to equal those derived from the summer storm events. Some error may be introduced by the assumption that energy for erosion during spring is proportionately the same as for summer between rainfall and runoff. With the virtual absence of rainfall for the spring events chosen, the above assumption would be in error to some degree. However, the error is minimized, in that summer calibration relied heavily on the runoff portion to achieve simulation.

The initial input value for "R" (USLE) should have been 0.0, however, internal computer manipulation prohibted use of zeros so the minute value of 0.001 was inputted to allow the program to run. See storm numbers 9-17 in Table 4 for Storm "R" values inputted. Values which exceed 0.001 (i.e., .59, 4.06 and 15.1) were melt periods combined with rainfall of these magnitudes, hence the values inputted.

The smaller yielding events (however still comparable with summer loadings) simulated best. Larger events showed poorer simulated values produced by ERODE, however, this could be due to the C and K factors of the USLE.

Though separate spring "C" values (USLE) were not calculated here, their overall increase would have a positive effect on improving spring simulation as did the "K" factor to be discussed.

With the "K" factor (USLE) increased to .52 (original

.43) representing a reduction in soil permeability and deteriorated structure during this season of the year (Figure 12), the simulation improved considerably. Larger yielding events were more closely approximated without sacrificing the very good simulation of smaller yielding events. This latter discussion assumes a change in "K" to .52, however, if it can be shown that the value is closer to .65 the result would be greatly improved (Figure 13).

Future studies need to bring out the alleged concept that for reasons of existing frozen soil conditions, both permeability and initial soil erodibility are influenced during spring. Citings by Bubenzer & Mitchell (1977), Hewlett & Nutter (1969), Hudson (1971), Klausner et al. (1976) and Skidmore et al. (1975) reinforce the need for investigating this aspect of erosion analysis. A complete discussion concerning factors which influence soil erodibility is given by Wischmeier & Mannering (1969). First approximations of the soil erodibility using the nomograph (Figure 14) (Wischmeier & Johnson, 1971) can be refined if soil structure and permeability are known (Bubenzer & Mitchell, 1977). Since basic analysis on erodibility was limited to summer conditions, it would be reasonable to expect some change after freezing and semi-thawing have been introduced.

A new study area associated with "K" factor analysis,

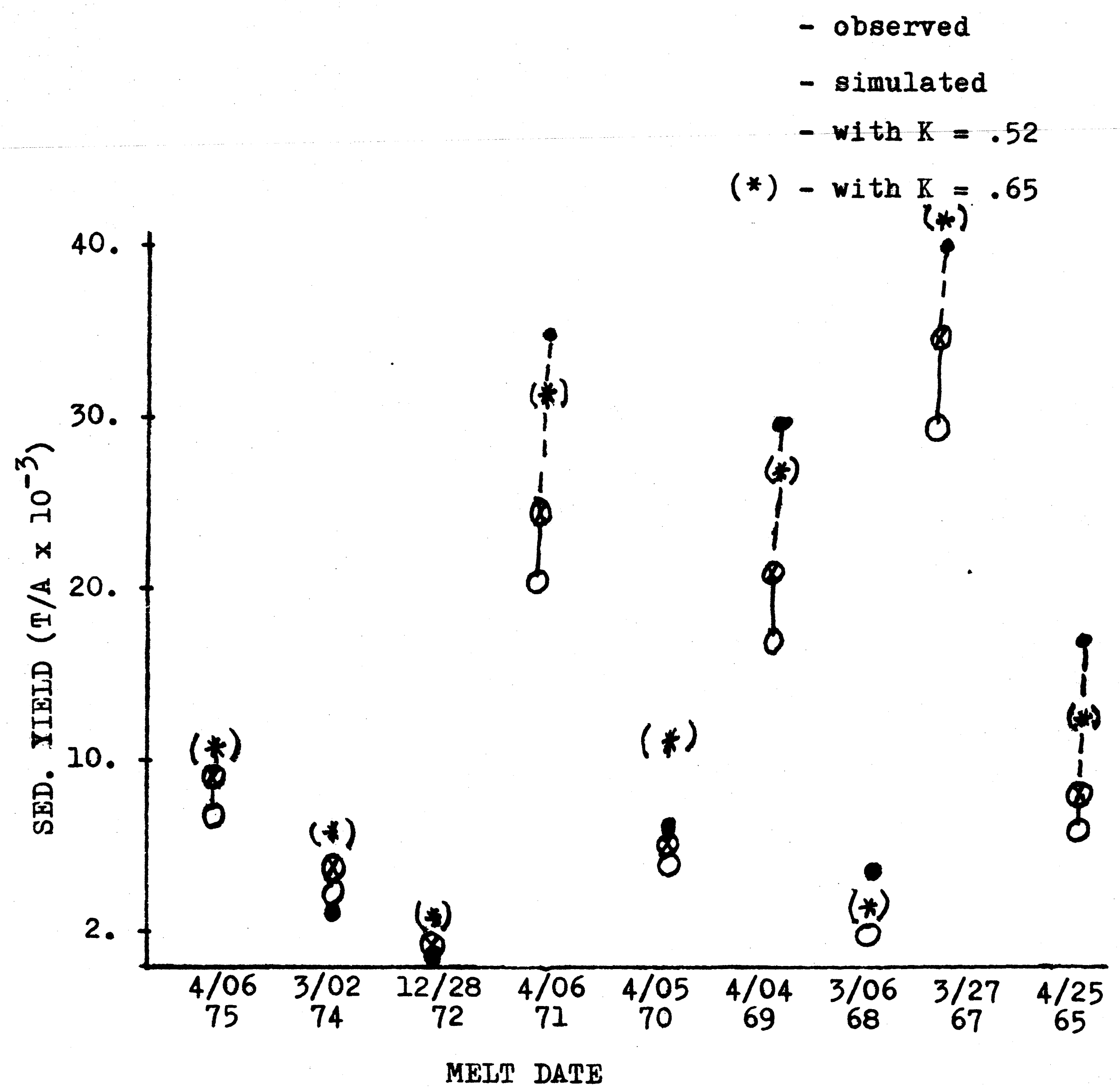


Figure 13. Sediment yield for selected spring runoff events during a ten-year period on the Big Eau Pleine Watershed.

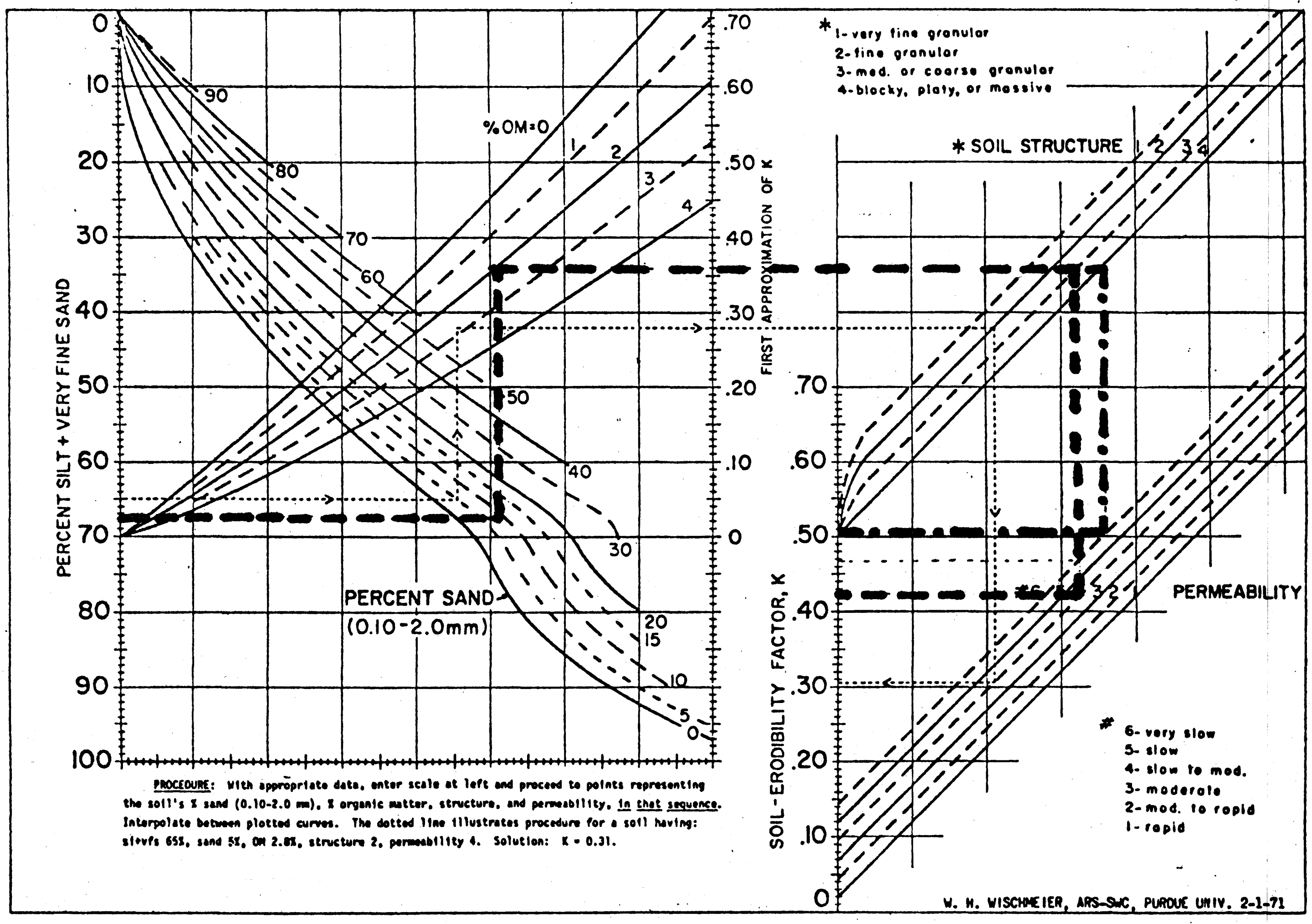


Figure 14. Soil Erodibility Nomograph - "K" (USLE) Determination based on soil information for the Big Eau Pleine Watershed. From EPA, Processes, Procedures, and Methods to control pollution resulting from all construction activity. EPA 43019.73-007

is needed to quantify the influence of winter spread manure on increased erodibility of suspended sediments (including manure) measured at the watershed outlet. Amount of manure and time of distribution coupled with snowfall time and amounts and frost depths, canact to positively or negatively affect erodibility during the spring (Klausner et al., 1976).

LONG TERM SEDIMENT YIELD

Up to this point, the emphasis has been on short-term (single storm) sediment yields. This method of analysis serves to bring out model parameter sensitivity and express effects on small areas or for short periods of time.

This portion of this thesis deals with the long-term sediment yield as determined from regression analysis for two Wisconsin watersheds. Annual distribution of sediment yield not only shows us what is happening for a specific period during the year, but can serve as a tool in determining the most logical direction that erosion studies should take in the future.

Annual Distribution of Sediment Yield

Average monthly distribution of suspended sediment yield was calculated for two streams; the Big Eau Pleine at Stratford and the Hay River at Wheeler. The legal

description of the Hay River sampling point is:
In SW 1/4 SEC. 25, T. 30 N., R. 13 W., Dunn County, on right bank 25 ft. downstream from Hwy. Bridge in Wheeler.

The Hay River Watershed (426 mi.^{2}) is almost twice the size of the upper BEP (224 mi.^{2}). Its sandy, loamy sand and silt loam soils (Hole, 1968) provide a better infiltration capacity for water. Increased forest and brushland cover (Frazier and Keifer, 1974) as compared with the BEP also tends to reduce the rates of flow as is evidenced by a complete lack of any flood prone area (Wisconsin Department of Administration, 1975), even though slopes are much greater.

A discharge rating curve was constructed for the Hay River (Figure 15) as was done for the BEP (Figure 10). A better relationship was obtained by separating the curve into two components. The breakpoint was made at flow equal to or greater than 700 cfs. Using average daily flow values (USGS, 1963-75) a daily sediment yield value in tons was obtained by employing the regression equations derived from correlating sediment yield (dependent variable) and average daily flow (independent variable). A log (base e) transformation resulted in a better correlation for the Hay River as it did for the BEP earlier. Computer use greatly reduced the amount of repetitive calculation time necessary to account for some 12 years (over 4,000 records) of base data.

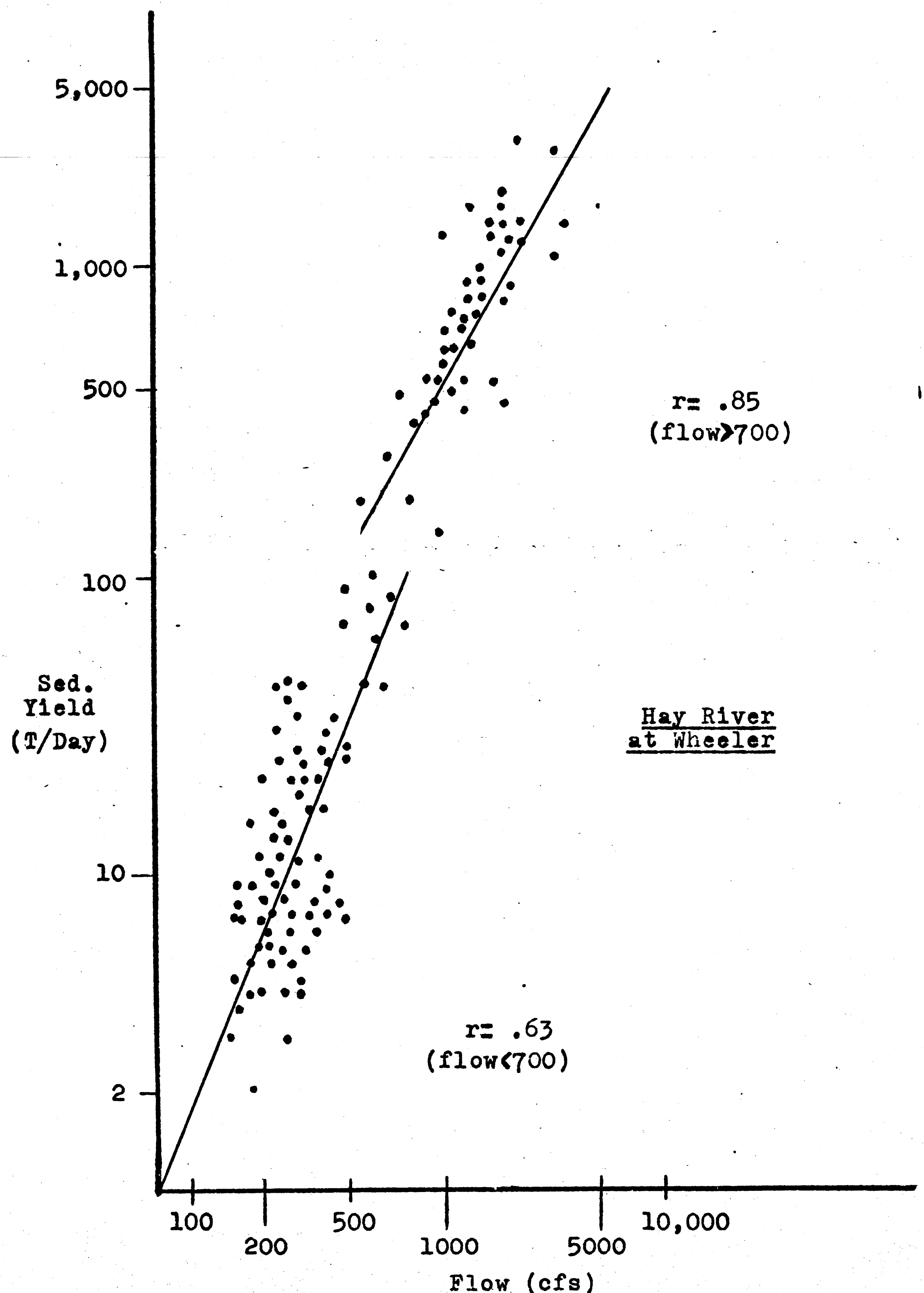


Figure I5. Discharge and suspended solids rating curve for Hay River at Wheeler, Wisconsin for the period 1964-75 ($\log_e$ transformation).

The result of totalling the calculated daily sediment values by months for the 12-year period is shown in Figure 16. Average monthly yield for this period is only slightly higher for the Hay River for most months as compared to the BEP, except for the month of April. Here total flow volume is much larger for the Hay River so even much diluted sediment (low concentration) will result in quite large loading amounts.

More important within the context of this thesis, is the annual distribution of total sediment load occurring for the two unrelated watersheds, where sediment data exists. The months of higher runoff (spring melt) correspondingly results in much higher sediment yields (Figure 16). The same trend is evident for both basins. The magnitude experienced shows the spring contribution as being at least equal to that experienced during the rest of the year.

Erosion is a result of some detachment energy; either rain, snow melt, or physical movement caused by freezing. Sediment yields on the other hand, must depend on a transport energy following a detachment phase which carries the sediment to the point of the watershed outlet. It is evident that this combination of erosion and transport energy exist in sufficient quantity that they result in the annual distribution of sediment yield which we see here.

Efforts to reduce this sediment yield by reducing the effect of the erosive energy during spring melt,

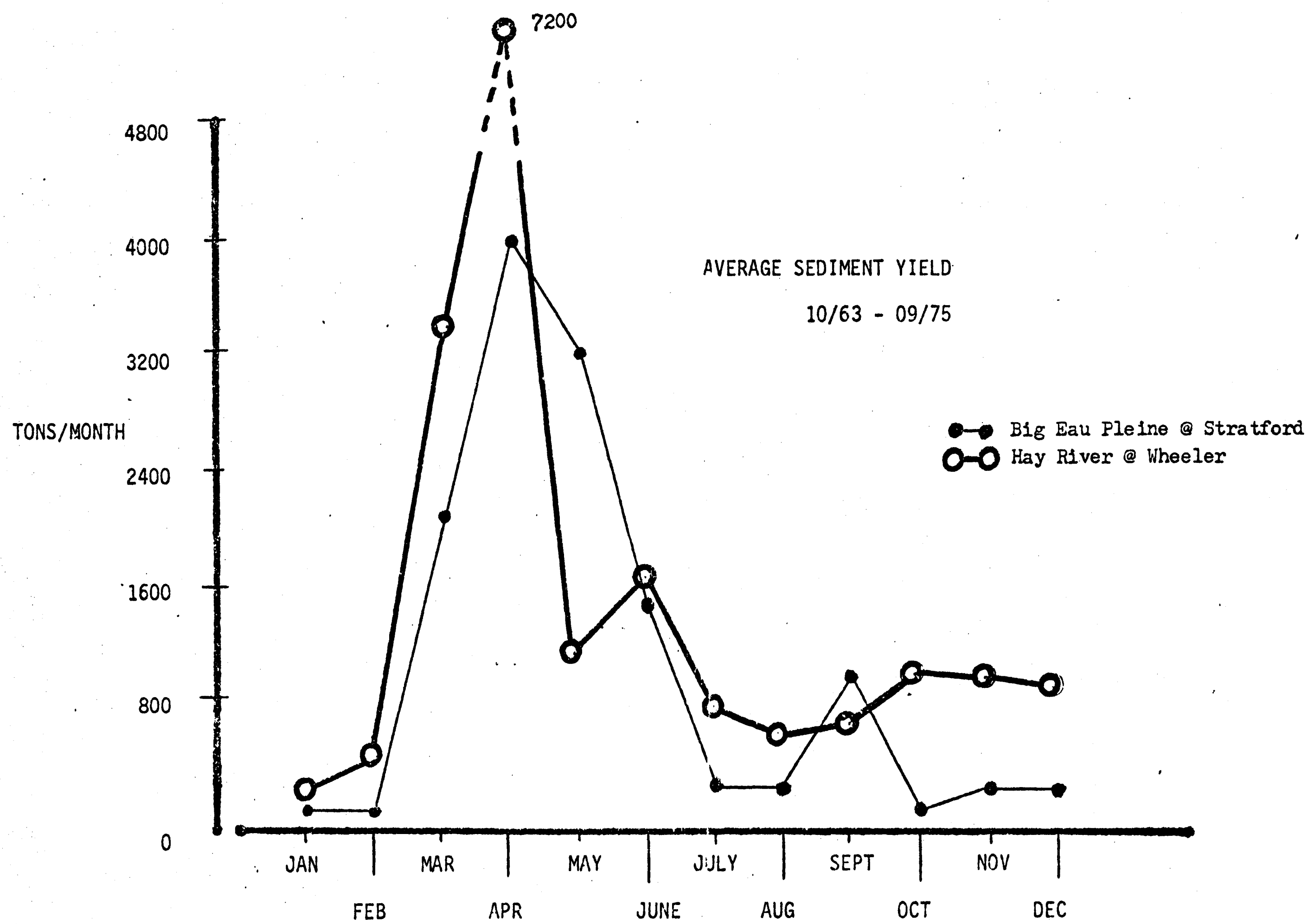


Figure 16, Yearly distribution of sediment yield for the Big Eau Pleine and Hay Rivers.

should be directed toward this time period when soil conditions are most vulnerable.

Annual Erosion Index

The present annual erosion index represents the monthly distribution of the "R" (USLE) value. This value is based solely on precipitation values where the maximum 30-minute intensity is multiplied by the total storm energy derived from previously calculated hourly rainfall amounts.

It is suggested that the annual erosion index distribution, which indirectly represents distribution of erosive energy availability, be modified to follow the trend suggested in Figure 17 (annual erosion). A very similar trend is also the result of studies by McCool et al. (1976b) for the Pacific Northwest region of the U.S. which receives abundant snowfall. This distribution of potential erosive energy would rightly include the energy from snowmelt which has been shown to account for a significant portion of total yearly erosion. Previous energy distribution analysis (Figure 17, annual erosion index) by the Soil Conservation Service, U.S. Department of Agriculture, has concentrated on rainfall events and has failed to consider spring melt effects in colder northern regions of the country. Perhaps this is due in part to the inevitable difficulty in assigning or determining an energy value for snow; at least one that would correspond with the "R" value for rain.

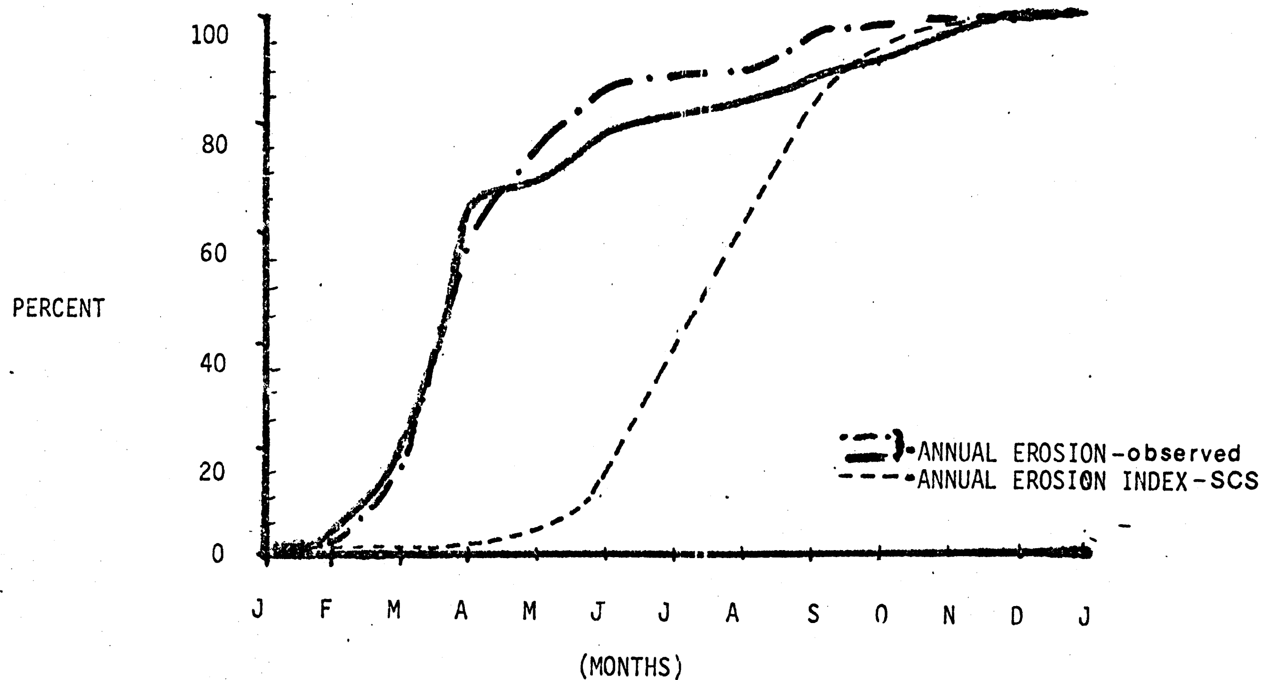


Figure 17. Distribution of annual erosion/index

Further studies, however, should emphasize the spring melt contribution and determine if a shift in emphasis for implementing soil conservation practices will be necessary in some colder northern regions of the country.

In agricultural watersheds the suspended sediment yield during any season of the year, but especially spring, might include organic particles from manure. The effects of their total amount and nutrient content on surface water quality is an ever-growing concern as streams and lakes become more eutrophic.

"R" FROM THE USLE

A falling raindrop under still air conditions possesses a velocity of approximately 30 ft./sec. This is equal to a soil detaching power of as much as 75 tons/acre/yr. The two primary efforts in soil conservation measures are to dissipate the velocity of rainfall and reduce the surface runoff (Shundar, 1972).

In this study, runoff and runoff combined with rainfall has been shown to be a major factor in sediment yield predictions. Flowing water generally has less energy than falling water, but it also has less work to do because often the soil has already been detached (Hewlett and Nutter, 1969).

In the case of spring melt waters, conditions for significant suspended sediment yield on an agricultural watershed would seem ideal. Freezing and semi-thawing of soil surfaces has taken place. Manure (organic suspended particles) spread during the winter on snow and frozen soil, would in many cases be easily detached. Visible documentation of floating ice portions on the lower landscape of the BEP showed that both soil detachment and transport were provided. The layer of soil on the surface of the ice was carried to the stream channel with little effort. Subsequent bombarding of ice sheets against soil inter-rill areas served to detach soil particles which were then picked up by the same flowing water which was transporting the ice.

Previous studies by William and Berndt (1972) support the importance of flowing water as correlated with sediment yield. They suggest that possibly the "R" factor should be replaced with a runoff factor for summer storms which concentrated in one season, thus indicating a general weakness of the USLE in sediment yield predictions when storm distribution is not uniform. The modification of the "R" value to include effects of overland flow by Foster's et al. (1973) (equation 2) did indeed result in better prediction of sediment yield on a watershed basis. The use of the modified equation incorporating runoff characteristics was carried a step farther within this study to eventually derive a spring "R" factor which is related solely to overland flow energy.

Effective "R"

As presented in this study, the erosional submodel (ERODE) combines overland flow characteristics with the calculated storm "R" value inputted, to arrive at a new "R" value within the model--termed here the R_{eff} (effective "R"). This R_{eff} value, weighted toward compartment size, is the modified "R" used in the USLE which is the basis of the model. Program statements were added to ERODE (see Appendix statements indicated by right-hand arrow, pages 97-103) to calculate and print out a weighted mean R_{eff} for a single storm. These values along with the corresponding storm "R" values inputted are shown in Table 7. Observed yield values are also given for each storm. This is the basic information necessary to establish the validity of using the R_{eff} as a basis to determine a spring "R" value of which calculations are presented later.

Figure 18 shows graphically the results of correlating sediment yield with the inputted storm "R". A very weak correlation exists (.17) between observed watershed sediment yield and storm "R" values. Thus, any attempt to use spring sediment yield to directly obtain a spring "R" value would be unsuccessful.

However, the correlation between watershed sediment yield and the "R_{eff}" used within the model is excellent

Table 7. Sediment yield and "R" values (USLE) for summer storms and spring melt events for 1974-75 for the Big Eau Pleine Watershed.

	Storm #		Observed Sed. Yield (T/mi^2)	Inputted Storm "R"	Effective "R" (from model)
Summer	1		3.90	1.03	.218
	2		2.05	0.04	.088
	3		2.05	6.36	.140
	4		0.06	0.86	.006
	5		3.14	1.43	.169
	6		0.58	2.30	.041
	7		0.71	9.27	.096
	8		0.83	4.36	.058
		Total	13.32	26.01	.816
		Mean	1.66	3.25	.102
Spring	9		4.99	.001	.281
	10		1.79	.001	.120
	11		0.38	.001	.013
	12		21.60	.590	.691
	13		5.38	.001	.214
	14		16.45	4.060	.523
	15		0.70	.001	.034
	16		27.39	.001	1.071
	17		8.06	15.10	.211
		Total	86.74	19.756	3.158
		Mean	9.64	2.195*	.351

* If no rainfall occurred during spring, this value = 0.0

(.93) (Figure 18). The R_{eff} weighted toward flow characteristics, would be expected to give better results because watershed sediment yield is closely associated with flow amount and rate, or with a melt event, as evidenced from the computer simulation technique used here.

Spring "R" ($\underline{R}_{spr}$)

The effects of snowmelt on sediment loss has been shown to be substantial. Studies by McCool et al. (1976a) and McCool et al. (1976b) have established initial USLE factors for the Pacific Northwest Region of the U.S. Included is a method derived to determine a spring "R" value which more correctly represents eroding energy of snow melt than would be calculated from energy and intensity data obtained from precipitation records of the area.

In this study a spring "R" value is calculated using the R_{eff} which is part of the modified USLE within the model. <u>In brief</u>, a ratio of the mean summer modified R (R_{eff}) to the mean inputted storm "R" is developed. This ratio is the basis for determining the hypothetical spring "R" (R_{spr}) based on the mean R_{eff} for the spring melt events studied. The hypothetical R_{spr} is that storm "R" value which would theoretically have to be inputted to match the observed sediment yield for spring (see "*" Table 7).

The ratio of the mean summer R_{eff} to the mean inputted

SOIL LOSS & ENERGY RELATIONSHIP

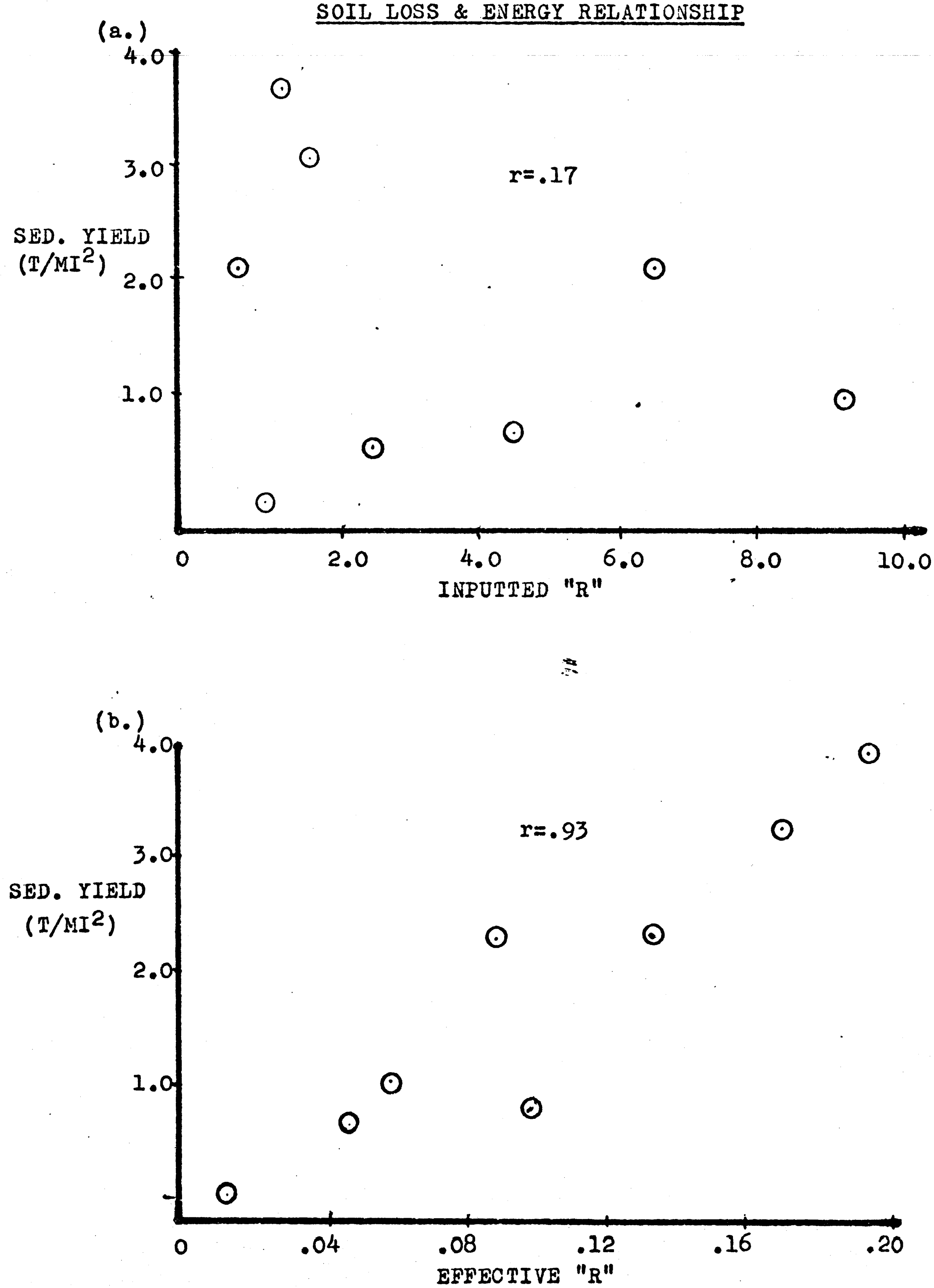


Figure 18. Sediment yield vs. "R" and R_{eff} respectively for summer storms, 1974-75 for the Big Eau Pleine Watershed.

R_{str} (Table 7) is 3.25/.102 = 31.87. Therefore

$$1\ R_{\substack{eff \\ (summer)}} = 31.87 \text{ storm "R" (or } R_{USLE}) \qquad (7)$$

Using this relationship the mean R_{eff} for spring .351 (Table 7) was multiplied by 31.87 to obtain an initial R_{spr} of 11.21. The mean yearly volume of spring runoff used in this study was 1.96 inches. The total mean yearly volume of spring runoff for the months April and May, based on twelve years of data, is 4.41 inches. Therefore, the above R_{spr} value to this point, represents only 1.96/4.41 of the total energy available during this season on the average. The total energy is then 4.41/1.96 times 11.21, or

$$4.41/1.96 \times 11.21 = 25.22 \qquad (8)$$

then

$$R_{spr} = 25.22$$

Subtracting out the mean inputted spring "R" value in Table 7, "*"), we get

$$25.22 - 2.195 = 23.03 \qquad (9)$$

The spring "R" value from the above mathematical manipulation now would be 23.03.

However, if we analyze the sediment yield per unit of energy represented by R_{eff} for the two seasons, we find that there is undoubtedly more sediment per unit energy delivered in the spring than the summer. This is shown by dividing the mean summer sediment yield 1.66 T/mi^2 by the mean summer energy used to deliver that sediment (R_{eff}) .102. So follows

$$1.66/.102 = 16.27 \tag{10}$$

Therefore, one energy unit in summer yields 16.27 units of sediment. The units at this point are not important. Hence, for summer

$$1\ R_{\underset{(summer)}{eff}} = 16.27 \text{ sed. units} \tag{11}$$

Deriving the same ratio for spring, we calculate from Table 7

$$9.64/.351 = 27.46 \tag{12}$$

Here one energy unit in spring yields 27.46 units of sediments. Therefore, for spring

$$1\ R_{\underset{(spring)}{eff}} = 27.46 \text{ sed. units} \tag{13}$$

Accordingly, a single unit of energy will yield 1.69 (27.46 divided by 16.27) more units of sediment in spring as compared to summer. Since the original storm "R" factor (USLE) is based on units of sediment delivered at that time, then to equate the two seasons above, each energy value for spring (R_{spr}) should be multiplied by an importance factor of 1.69. This would result in a mean total R_{spr} of

$$\underset{(equa.\ 9)}{23.03} \times 1.69 = 38.9 \tag{14}$$

The R_{spr} value, being equated unit for unit, with the summer value, would be 38.9.

The spring R value then (representing solely snow melt energy) would be added to the regional "R" value for the Big Eau Pleine watershed given by Wischmeier and Smith (1965), to obtain a new total "R" value (R_{tot}). This new value represents the total combined yearly energy available from rainfall and runoff for the BEP basin.

Here $$R_{USLE} + R_{spr} = R_{tot}$$

or $$125 + 38.9 = 163.9 \qquad (15)$$

or $$R_{tot} = \underline{164}$$

A summary of the above logic is given in Table 8.

The new erosion index distribution curve would be similar to the one shown in Figure 9 for the combined rainfall and snow melt. This curve would follow closely the curves for annual erosion in Figure 17. With the inclusion of the importance factor of 1.69 in the calculation of R_{tot}, the curve does not represent directly the erosion energy existing at these times of the year; but more correctly represents the effects of the existent potential hazard. The result is still expressed in a comparable "R" value, but becomes more meaningful when analysis of erosion control programs arise. For example, the most important potential erosion hazard no longer exists during July and August (upward trend of rainfall curve in Figure 19), but is now shifted to the period of March, April, and May.

Correspondingly, the emphasis for erosion control programs on the Big Eau Pleine should shift from the standard months of July and August to the spring months. Methods

Table 8. Summary of logic employed to calculate a new R_{spr} (spring "R") and subsequent new R_{tot} (total "R") for the BEP watershed.

(reference is made to Table 7)

1. An average R_{eff} from the model is derived for both the summer and spring seasons -.102 and .351 respectively.

2. The ratio between the measured summer storm "R" and the summer R_{eff} is 31.87.

3. This ratio is multiplied by the average spring R_{eff} from model runs and results in a theoretical R_{spr} (spring "R") of 11.21.

4. However, this value represents roughly only 1/2 (actually 1.96/4.41) the total runoff energy experienced for spring based on twelve years of data.

5. The total spring "R" is thusly corrected to 25.22 (11.21 x 1.96/4.41).

6. Necessarily subtracting out the associated R due to rainfall for the spring events used (2.195), results in a total spring "R" of 23.03 representing solely the snow melt contribution.

7. It was determined that a single energy unit for spring will erode more sediment (1.69 times more) than the same energy unit for summer. Therefore in terms of soil loss, a single R value for spring is 1.69 times more important when compared to the summer R value.

8. To adequately account for this difference the derived spring R is multiplied by 1.69 to obtain a new spring R of 38.9. Now "1" spring R equals "1" R from USLE.

9. Adding this spring R (38.9) to the SCS given R (125) for the BEP region, we obtain a new total R of 164. This value represents the average total effective energy available for erosion for a single year based on 12 years of data.

R_{eff} = the actual R value calculated and used by the model for each storm and melt event.

R_{spr} = the R value for spring being derived. Represents the total energy available from spring melt as compared with the summer energy from rainfall.

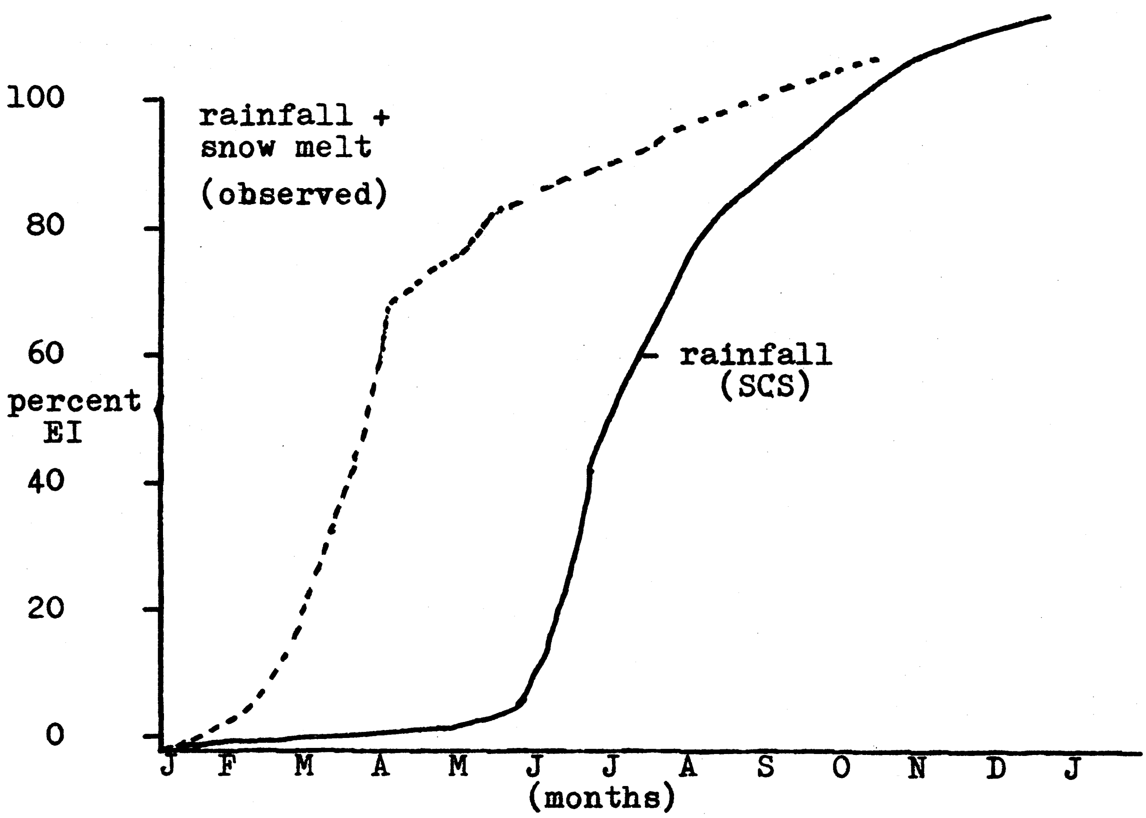


Figure 19. Annual erosion index (EI) distribution of rainfall + snow melt as compared with index for rainfall only.

for reducing soil loss during the spring period will certainly not coincide with those completely for the summer: For example, sedimentation ponds might be more effective in spring than the more logical methods of contouring and strip-cropping advocated in the summer.

A change in the "R" factor from 125 to 164 will also affect the soil conservation studies in another way. With the 2-3 tons allowable loss of soil presently for the watershed, an "R" factor of 125 would result in 15% of the watershed being over the allowed limit (Hansen, 1977). Implementing the factor of 164 would raise the area of the watershed exceeding the allowable limit to approximately 22%. Portions of the CNI (Conservation Needs Inventory) in progress today throughout the northern portion of the U.S. could be in error as much as 50% (slightly over for the BEP). This thought would have to be taken into consideration when present water quality improvement or maintenance plans (PL 92-500, Sec. 208) are developed. Present plans for the BEP region call for correlating water quality with the information gathered through the CNI (Baumann, 1977). The CNI data is based directly on calculations using the Universal Soil Loss Equation.

SEDIMENT AND PHOSPHORUS

Phosphorus in the form of phosphate is one of the major elements required by assimilating plants which are used as food supplies for man and animal. Although some phosphorus is retained within the animal and human body to produce bones and muscles, a major part of phosphorus intake is excreted in feces and urine (Sawyer, 1965).

Total P (phosphorus) emmisions fromnonpoint sources have been estimated to be 0.73 million metric tons per year, or about 25% of the P made available in the form of fertilizer and livestock waste. The emissions many times are closely related to erosion (McElroy et al., 1975).

In a Vermont study it was estimated that the major source of phosphorus and nitrogen in northern climates comes from the surface runoff of manure-laden frozen soils. Studies by Midgley and Dunklee (1945) and Lee (1969) (as cited by Ryden, 1972), and Uttormark et al. (1974), conclude that P losses were affected more by the amount of snow and condition of frozen ground, than by degree of slope. This indicates that even on very gently sloping land one could expect that P sources from spread manure would eventually have a good chance of reaching the stream channel.

In this study attempts were made to derive a relationship between sediment yield and phosphorus forms. The entire upper Big Eau Pleine watershed (224 mi^2) was used as well as sub-basins of the Hamann Creek watershed (1-25 mi^2). Location of these sample sites can be found in Figure 20. It is not unanimously agreed that P

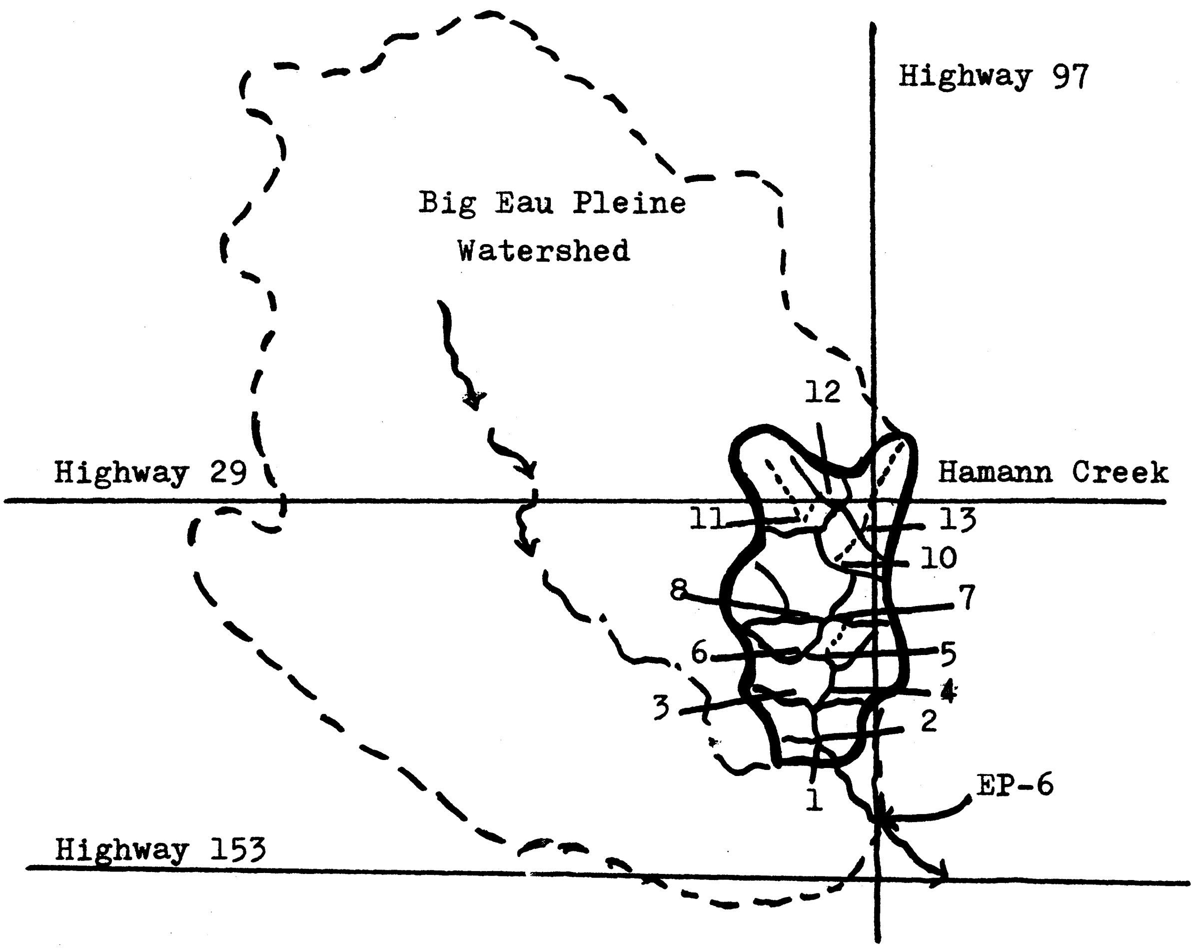


Figure 20. Location of the upper Big Eau Pleine basin and Hamann Creek sub-basin sampling site for phosphorus sediment and flow analysis.

concentrations are readily correlated with flows at all times, because of the dilutional effects of resulting run-off (Zanoi, 1970). Many watershed physical factors along with fertilizer management and cropping practices can affect the loads of P in surface runoff from agricultural lands (Ryden, 1972).

Sediment - Phosphorus Concentrations

Analysis of P within Hamann Creek was made difficult for three reasons: (1) Although both ortho-P and total P samples were taken bi-weekly for a period of over three years, corresponding flow measurements are minimal; (2) Suspended solids (SS) samples were infrequent at times, with few total volatile suspended solids data acquired; (3) Fate chose to place basin weather on a bi-weekly pattern also with the result that few data were gathered which would substantially represent varying time periods on the stream hydrograph.

For the EP-6 site at the point of the BEP watershed outlet, an automatic sampler was installed (spring of 1976) to collect samples throughout the period of a hydrograph. Once again fate chose to play a role and the sampler was inoperable during the single storm event which occurred during that dry year. Table 9 lists the results of the sampling period covering the general time period 1974-76. In most cases total P or ortho-P correlated as

Table 9. Results of sediment-phosphorus correlations for the Big Eau Pleine basin and Hamann Creek sub-basins.

site	area (mi^2)	SS vs. ortho-P	SS vs. total P	SS vs. particulate P	# records	ortho-P vs total P
HA-1	25.75	.17	.12	.03	38	.95
2	0.97	.48	.68	.51	16	.0
3	23.38	.57	.53	.37	24	.96
4	1.87	.87	.83	.41	18	.96
5	2.71	.13	.21	.29	19	.96
6	16.32	.51	.55	.45	26	.94
7	1.48	.76	.90	.91	4	.91
8	12.58	.57	.60	.52	25	.96
9	2.45	.14	.17	.20	26	.97
10	4.93	.24	.24	.20	24	.96
11	4.50	.55	.62	.56	26	.94
12	1.13	.96	1.00	1.00	3	.97
13	3.38	.30	.30	.30	18	.97
EP-6	224.0		.11		14	.76
(spring only)			.23		9	

--- values are correlation coeff. "r".

HA-1 = entire Hamann Creek sub-basin
HA's 3, 6, 8 = entire basins above those points
HA-9 includes HA-7 HA-10 includes HA-13 HA-11 includes HA-12

well as or better than the particulate P (total P minus ortho-P). In this study ortho-P represents the molybdate reactive P while total P minus ortho-P approximates particulate P absorbed on sediment particles. Results from sub-basin 11, 12 and 13 are somewhat biased in that for most periods of low flow their discharge was infrequent and at times nonexistent. This included spring periods as well as the dry summer of 1976.

Sub-basins of Hamann Creek (7 and 12) which did show better correlations were lacking in number of records and thus excluded any meaningful use of these results thereby obtained. Further sampling may prove, however, that these correlations will hold for a larger number of samples. If so, it could be deduced that a strong relationship exists between SS and P for high flows of Hamann Creek sub-basins; as the stronger correlations were found precisely in those sub-basins which maintained virtually no base flow for periods of no runoff. Any measurement within these basins could only have occurred during periods of high flow from rain or melt events, or a combination of both. The sub-basins involved are Ha's 2, 4, 7 and 12. These basins have a tendency to contain few recorded samples, yet maintain strong correlations between SS and P (See indicated sub-basins in Table 9).

In all cases the relationship between the ortho-P and total P concentrations remained strong. This could indicate two things: (1) analysis precision throughout the sampling period was consistent and (2) proportions of these two components did not vary considerably from year to year, or season to season.

A weaker relationship for the parameters discussed above is shown by the data for EP-6.(the entire BEP watershed). Limited data is the result of factors discussed earlier. A decrease in the correlation coefficient for the ortho-P vs. total P arises here. A possible explanation for this result could be the inclusion of other sources of P within the watershed aside from agricultural runoff, such as cheese factories and municipalities. Hamann Creek is virtually void of these two sources. An added attempt, using only the spring data for EP-6 showed only a minor improvement in the relationship between suspended solids and total P. However, it was felt that this correlation was too weak to attempt to construct a P - SS concentration curve.

Table 10 represents the result of an attempt to improve P and SS relationships by increasing the total number of records. Here areas of Hamann Creek sub-basins were grouped into larger units representing sub-basin tributaries and the mainstream channel.

A considerable improvement was obtained in the relationship of all parameters by employing the grouped basin technique. Correlation of SS to total P was better than

Table 10. Correlation coefficients of grouped sub-basins of Hamann Creek with regards to phosphorus and suspended solids.

	SS vs.: ortho-P	total P	particu-late P	# records
total Hamann	r = .59	.64	.54	276
Hamann sub-tribs.	r = .62	.67	.57	154
Hamann mainstream	r = .43	.42	.32	122

note: tribs. = HA's 4, 5, 7, 9, 10, 11, 12, 13
mainstream = HA's 1, 3, 6, 8

SS to ortho-P or Particulate P. In terms of future modeling considerations attempting to correlate SS with P, the result would indicate that smaller basins (from 1 mi^2 to 5 mi^2) would be more appropriate in providing more consistent results.

The larger sub-basins (from 12 mi^2 to 25 mi^2) when grouped together improved prior relationships between SS and P, but did not approximate the results obtained with the smaller sub-basins. The largest basin HA-1 (representing the entire Hamann Creek basin) shows results that were only slightly weaker than the grouped smaller sub-basins. Evidently increased sample size improved the correlation, however, simultaneous inclusion of larger sub-basin values (initially weaker) proved to negatively affect the relationship in the final outcome. Added records increased the range of values and did not improve the correlations as one would have anticipated.

Given the lack of sufficient flow data for the Hamann Creek site, any effort to derive a method for P loading calculation in this basin using the relationships obtained above, was not possible.

Using the combined data from Hamann Creek an interesting seasonal trend surfaced between the parameters SS and total P. Ratios of the average P and SS concentrations were calculated with the following result:

	spring (M, A, M)	summer (J, J, A, S)	winter (O, N, D, J, F)
SS (mg/l) / total P (mg/l)	75.6	122.0	155.7

The spring season shows that twice as much P is associated with the suspended sediment fraction of runoff than exists for the winter conditinn. The winter discharge would for the most part represent base flow. It was not determined if the increased SS:P ratio was attributable to a different fraction of mineral soil eroding or whether it was due to the organic portion of SS which could be derived from manure erosion.

Ratios of ortho-P to total P for the spring and summer were 1.65:1 and 1.73:1 respectively. These similar values suggest that possibly slightly more ortho-P is introduced in runoff waters during the spring, but this is at best speculative. Further studies would be necessary to prove or disprove this trend.

The above analysis shows that any meaningful results in terms of P and SS concentration relationships would be impossible thus it was decided to look at using loading of these two parameters.

Sediment - Phosphorus Loading

Loading not only depends on the concentration of an element but also on quantities of flows. Zanoni (1970) showed statistically that phosphate concentration could not be correlated with precipitation amount, whereas phosphate loading could. It is reasonable to assume that the same possibility might exist for phosphate and flow, given the difficulty shown in the previous section of this thesis.

Since daily flow values and sediment loading values now exist for the site EP-6, it was decided to use the limited P data available at this site in an attempt to develop correlative relationships between SS and P.

Concentrations of total P and ortho-P were converted to loading rates by the equation:

$$\underset{(mg/l)}{\text{concentration}} \times \underset{(cfs)}{\text{ave. daily flow}} \times 5.4 = \#/\text{day}$$

which converts concentration of a component into #/day of load.

The load value of phosphorus in #/day was then correlated with the corresponding loading value for suspended solids. The initial result is a correlation coefficient of r = .812 for the particulate (total P minus ortho-P) vs. SS and r = .927 for the total P vs. SS. The latter relationship is graphically illustrated in Figure 21. The more abundant lower values were quite scattered--even up to a P loading value of 1000#/day. The three circled values tending to disrupt the overall relationship all occurred during the month of December of the same year (1975). A high loading of soluble phosphorus could have occurred at this time from small precipitation events or melt periods in vulnerable areas of the watershed such as manure-laden fields or manure stacks and cheese factory waste disposal. It's also possible that these extremely high values could be the result of an almost instantaneous surge of feces loading directly from cattle in the water upstream. The actual source cannot be identified at this time.

The overall excellent correlation is, of course, due to the two values representing the largest loads for both the dependent and independent variables. However, tempting this result might appear to be, the decision was made to not use this relationship to obtain a meaningful comparison between P and SS for this study of the Big Eau Pleine Watershed. It's felt that a very good trend is expressed nevertheless, and encourages future studies.

It is believed that any relationship between these two parameters used in determining agricultural basin

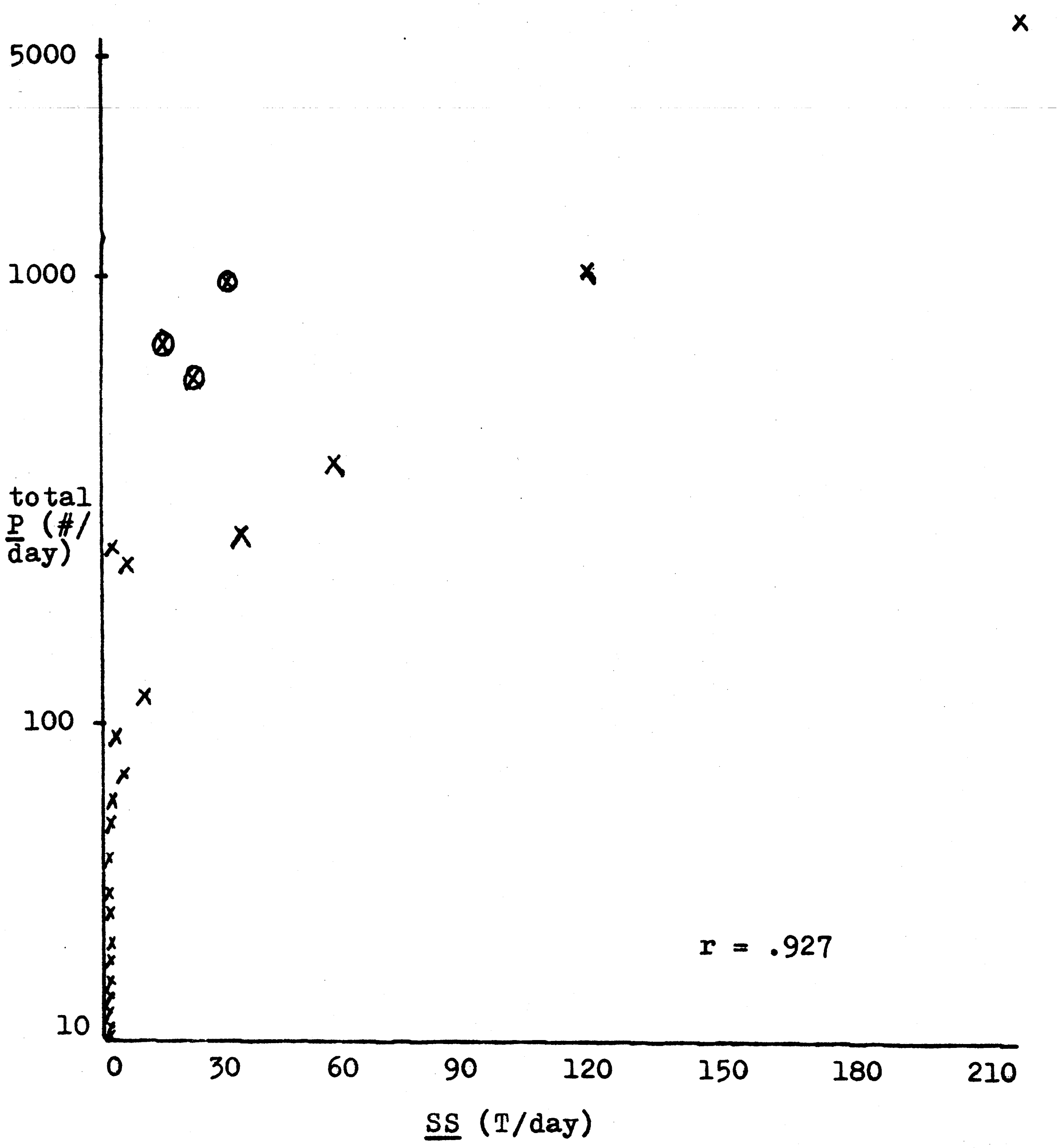


Figure 21. Graphical relationship between loading of total P and suspended solids (SS) as observed at the outlet of the upper Big Eau Pleine Watershed at the EP-6 site.

NOTE: The values circled which tend to disrupt the relationship occurred during December 1975 winter rains.

water quality on a long or short-term average will have to submit to the capabilities that loading rates appear to provide. It seems that regardless of the concentration of a nutrient, the flow characteristics will determine if those concentrations are or are not, harmful. Seasonal inputs of nutrients can similarly be tied to flow characteristics as well as nutrient concentrations. Perhaps a minimum nutrient concentration standard for P will be eventually determined for agricultural watersheds; however, this value will be directly determined from analysis of flow characteristics providing the necessary information on dilution that will make that standard possible.

In considering soil management and cropping practices, P management can be feasibly controlled by limiting soil loss. Massey et al. (1953--as cited by Ryden, 1972) show the effects of continuous cropping practices on losses of available P from steeper slopes. After two years of hay was introduced into the rotation the P loss was reduced by a factor of "4". Certainly it would not be possible to introduce two years of hay into the crop rotation of the BEP which already contains an average of 3 years. Economics would dictate the outcome. However, it might be possible to introduce 2 or 3 years of hay into certain, more easily eroded areas on the landscape by a change in rotation patterns throughout the remainder of cropped land. Any such suggestion must certainly be thoroughly studied and tested for results before it can become officially recommended.

SUMMARY

The main theme carried throughout the period of this study is one which tries to closely parallel the daily situation which would be encountered in erosion analysis by any agency or organization on any watershed. The methods and base data were used in a manner which does not limit this type of study to a single specific watershed. The problems encountered and the solutions presented hopefully reflect realistic conditions.

A summary of the study follows:

(1) The erosion sub-model of the ACTMO (Agricultural Chemical Transport Model) was modified by adding buffer zones to individual compartments, making its use applicable on larger, multi-cropped watersheds.

(2) Simulation of spring melt events was better than those for individual summer storm events due to the emphasis on flow energy instead of precipitation energy for the R value of the Universal Soil Loss Equation.

(3) Long-term sediment yields for two Wisconsin rivers (the Big Eau Pleine and Hay Rivers) show the suspended sediment yield substantial for the spring season. Frost effects and increased runoff volume from snow melt coupled with soil physical conditions and farming practices could

account for this.

(4) A spring R (R_{spr}) factor (USLE) as well as a new total R (R_{tot}) is derived for the Big Eau Pleine Watershed. The values are 38.9 and 164 respectively.

(5) Because of the uniform precipitation input requirement, the use of the erosion sub-model will have to be confined to one of two conditions:

a. entire watersheds of 1-10 mi^2

b. possibly partial watersheds of $1\text{-}10^2$ which represent portions of larger more complex watersheds.

(6) A possible loading rate of phosphate can be developed with increased information on flow amounts and characteristics.

Conclusions and Recommendations

Insufficient base data to apply computer models, especially on smaller watersheds will be an ongoing frustration within the field. Present precipitation data measurements are widely applicable to long-term average studies, but are basically inadequate for short-term storm event type studies where study basins are not directly adjacent to the gauging stations.

R value calculations can vary greatly as experienced in this study. If no "area type" weighting method exists within the model to account for this variation, much error can result. The original use of the R value requires maximum 30-minute intensity values for each single storm.

Most climatological stations record only daily or hourly values, thereby limiting the use of the Universal Soil Loss Equation as a basis for short-term erosion studies. Methods to derive a maximum 60-minute value should be given priority in future erosion studies if the use of the USLE will be continued. The USLE is a widely known and recognized equation, and it's likely that it will remain an important method in future erosion analysis.

The required daily flow data for this erosion submodel as well as others, will also continue to be a limiting factor in deciding where erosion studies will take place. Extrapolation of flow data from a small watershed to a larger basin is not without error. At times the use of hydrological models will facilitate the derivation of flow data, but it is generally believed that most models have not had sufficient testing to allow their arbitrary use in unknown watersheds for prediction purposes. In the case of the Eau Pleine watershed, a significant amount of nutrients and sediment are delivered in the spring, making computer simulation that much more difficult.

An emphasis in hydrograph time period sampling is suggested to minimize the inherent problem encountered in obtaining single daily sediment loading and flow values. Much sampling is done in a random fashion and can result in limited useful data in terms of a hydrograph period. Therefore, an emphasis during the entire storm period or melt event with spot samples taken at low flow, would strengthen the sediment yield studies.

The addition of a conveyance factor to the USLE to account for watershed surface roughness and differing land uses appears to have its merits. Simulation, sediment delivery ratios, and overall erosion analysis on a watershed basis would be greatly enhanced with the addition of this depositional factor.

Another study of as much importance as the conveyance factor is the alleged variation of the "K" value (USLE) during different seasons of the year. Soil permeability can change drastically under the following conditions:

a. Summer situations where a single soil type has been allocated a specific single value for K. It seems reasonable to assume that varying land uses (i.e., cropland vs. permanent pasture) will eventually have different infiltration rates as a direct result of their use, thus affecting the K value. Perhaps the original K factor could be modified by employing a technique which would take into account the existing C factor.

b. Spring conditions in colder northern regions of the U.S. where frost penetration can modify the soil physical condition ranging from honeycomb (permeable) to cement-like (impermeable).

Studies investigating the effects of crop cover and soil moisture amounts could be undertaken to possibly develop K factor curves similar to the one shown in Figure 22. These curves would represent the probable decrease in K values during the spring time period from a maximum of 1 to some minimum value which would reflect soil permeability from a specific land use during the summer months.

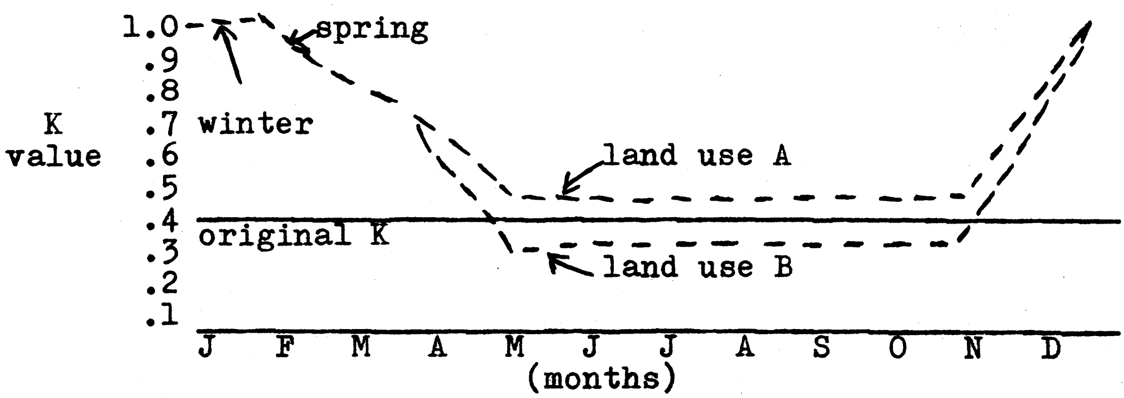


Figure 22. Hypothetical K factor curve based on seasonal land use and soil moisture effects for a single soil type.

The use of the Universal Soil Loss Equation on a short-term period would be greatly enhanced if the seasonal and land use effects can be accounted for by developing the relationship necessary to arrive at these values. Seasonal or monthly values of the K and R factors will aid greatly in determining the seasonal or monthly effects of suspended sediment yield and associated nutrients.

Water Quality Management

The new annual erosion index distribution (Figure 19) representing rainfall and snow melt energy, should serve to make future seasonal erosion studies more accurate. It follows that any water quality plan should be based on methods which mimic as closely as possible, the natural conditions which directly influence that quality. Adaptation of the seasonal or monthly R and K values as explained above would be directly in line with any quality plan having these objectives.

The voices answering the question of "How to control nonpoint sources" are beginning to be heard. Many ideas and suggestions are being expressed which include regional plans and individual farm efforts which might include taxation (Miller and Gill, 1976). Contrary to what has been the rule of thumb for many years in the past, the emphasis of the National Pollution Control Policy is now on keeping pollutants out of the water rather than considering the capacity of the same to assimilate wastes (Loehr, 1974). The role of some agency like the Soil Conservation Service in water quality maintenance and improvement of nonpoint sources appears to have surfaced as a necessity. In fact, Loehr states that many nonpoint sources will be difficult to control if control is defined as the ability to establish and enforce effluent standards for a given runoff event. However, if the control is approached by using appropriate management practices, many of the sources are controllable. In comparison this attitude could be paralleled with that taken by the SCS regarding the soil erosion problem. Soil conservation practices were based not on the amount of sediment reaching the stream, but instead on the amount being eroded from upland areas. The gap between the appropriate management practices and water quality can be bridged with the aid of computer analysis techniques.

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APPENDIX

APPENDIX

MODIFIED EROSION SUB-MODEL

Listing of erosion sub-model indicating changes implemented to apply it to the BIG EAU PlEINE watershed in Marathon County. Listed program includes all necessary statements to run said program using buffer zones.

1. Heavy underlining indicates changes made in program statements to allow several C values (USLE) to be inserted.

2. Heavy indicator arrows show program statements added or changed to allow calculation and printout of an effective R value (USLE). The R_{eff} is the R value that the model uses to calculate sediment yield from each event. It is a combined value representing both rainfall and runoff energy.

```
#FILE (10007)EP/EROD2 ON PACK
$SET SEQ 100+100
$SET LINEINFO
$RESET FREE
FILE  5(KIND=REMOTE)
FILE  3(KIND=REMOTE,MAXRECSIZE=22)
FILE  2(TITLE="EROD2/DATA",KIND=PACK,MAXRECSIZE=14,BLOCKSIZE=420)
       COMMON LOC(20),ICHAN(15),ITUBE(22),NTUBE(22),WGT(22),SSTP
      *(22),SWID(22),SLEN(22),RE(22),XNRE(22),GDET(22),NDEX(22),
      *DEP(22),YIELD(22),SUM(5),TOT(5),IVAR(4,22),VAR(7,22),C(22)
        INPUT=5
        A=43560.
        B=1./2000.
        D=A*8.521
        E=1./3.
        G=4./3.

C   NUM=NUMBER OF INCREMENTAL UNITS COMPRIZING THE WATERSHED
C   NCHAN=NUMBER OF CHANNEL SEGMENTS
C   QFAC=FACTOR TO CONVERT FLOW RATE IN CFS TO IN/HR
C   FKRAT=RILLIBILITY RATIO  OF ABOUT 1.0
C   ACRE=WATERSHED SIZE IN ACRES
C   LOC=IDENTIFICATION ARRAY
        READ(2,500)NUM,NCHAN,QFAC,FKRAT,ACRE,LOC
  500   FORMAT(2I3,E10.0,F5.0,F10.1,20A2)
C
C   ICHAN(I)=UNIT NUMBERS OF THE CHANNEL SEGMENTS
C
        READ(2,501)(ICHAN(I),I=1,NCHAN)
  501   FORMAT(15I3)
C
C   ITUBE(I)=STREAMTUBE DESIGNATION
C   NTUBE(I)=UNIT NUMBER OF STREAMTUBE =1 AT THE DIVIDE
C   WGT(I)=WEIGHTING FACTOR FOR PEAK FLOW RATES (AS*S**0.5)
C   SSTP(I)=UNIT SLOPE STEEPNESS
C   SLEN(I)=UNIT SLOPE LENGTH
C   SWID(I)=UNIT SLOPE WIDTH
C   C(I)=&C& FACTOR USLE
        DO 2 I=1,NUM
  2     READ(2,502)NDEX(I),ITUBE(I),NTUBE(I),WGT(I),SSTP(I),SLEN(I),
       *SWID(I),C(I)
   502  FORMAT(I3,A2,I2,F7.0,2F6.1,F9.1,F4.3)
        F=43200./A/ACRE
  605   FORMAT(/28X'SUM (TONS)'5F11.2)
  606   FORMAT(8X3I5,5X'AVE (T/AC)'5F11.4,F15.8)
        PRINT /,"ENTER TOTAL NUMBER OF STORMS"
C  --KEYBOARD INPUT--
C  NST=TOTAL NUMBER OF STORMS
C  INPUT=INPUT METHOD (1=KEYBOARD, 5=PAPER TAPE)
C       NOTE: INPUT IS SET TO 10 AFTER STORM PARAMETERS ARE READ
```

```
      READ/,NST
      PRINT /,'ENTER P1, P2, P3 AND COMPARISON NUMBER'
C  --KEYBOARD INPUT--
C  IPR2=PRINT OPTION FOR SUMMARY TABLE (SAME)
C  IPR3=PRINT OPTION FOR LAST 2 LINES OF SUMMARY TABLE (SAME)
C  NCOMP=COLUMN NO. FOR COMPARISON TO MEASURE YIELD (USUALLY =4)
C
      READ/,IPR1,IPR2,IPR3,NCOMP
 63   CONTINUE
C   STORM PARAMETERS
C   MONDA=MONTH AND DAY
C   ITIM=TIME OF DAY
C   IYR=YEAR
C   R='R' VALUE FROM USLE
C   Q=RUNOFF VOLUME (INCHES)
C   QPEAK=PEAK RUNOFF RATE (CFS)
C   Y=MEASURED SEDIMENT YIELD
C   P='P' FACTOR, USLE (=1.0 IN MOST CASES)
C   FK='K' FACTOR, ULSE
C      CL,SI,SA ARE THE PERCENTAGES OF CLAY, SILT & SAND RESPECTIVELY
      DO 60 J=1,NST
      READ(2,99)ISTRM,MONDA,ITIM,IYR,R,Q,QPEAK,Y,P,FK,CL,SI,SA
   99 FORMAT(2I5,2I4,2F6.3,F6.0,F6.4,2F6.2,3F4.2)
      IVAR(1,J)=MONDA
      IVAR(2,J)=ITIM
      IVAR(3,J)=IYR
      IVAR(4,J)=ISTRM
      VAR(1,J)=R
      VAR(2,J)=Q
      VAR(3,J)=QPEAK
      VAR(4,J)=Y
      VAR(6,J)=P
      VAR(7,J)=FK
60    CONTINUE
      INPUT=10
61     PRINT /,'DO YOU WISH TO TERMINATE RUN? (YES OR NO)'
10200 READ(5,10205) ISAT
10205 FORMAT(A6)
C   ISAT=OPTIMIZATION CONTROL (0=REPEAT, 1=FINISHED)
      IF(ISAT.EQ.'YES   ') GO TO 1000
 62   PRINT /,' ENTER RCON, JI, JO, AND QMULT'
C   --KEYBOARD INPUT--
C  RCON='A' IN EQUATION (2) OF ONSTAD ET A
C  JI=BEGINNING STORM NUMBER
C  JO=ENDING STORM NUMBER
C  QMULT=(NORMALLY 30.0), SEE EGUATION NO TWO
C
      READ/,RCON,JI,JO,QMULT
      IF(RCON)42,44,43
42     QCON=-RCON
       RCON=0
       GO TO 46
43     IF(RCON-1.0)44,45,45
44     QCON=1.0-RCON
       GO TO 46
45     QCON=0.
46     SVAR=0.
```

```
      DO 16 J=JI,JO
      DO 70 IT=1,5
70    TOT(IT)=0.
      EFECR=0.0 <----
      WTDMR=0.0 <----
      SWTDMR=0.0 <----
      SPERAC=0.0
      MONDA=IVAR(1,J)
      ITIM=IVAR(2,J)
      IYR=IVAR(3,J)
      ISTRM=IVAR(4,J)
      R=VAR(1,J)

      Q=VAR(2,J)
      QPEAK=VAR(3,J)
      Y=VAR(4,J)
      P=VAR(6,J)
      FK=VAR(7,J)
      IF(IPR1-1)65,64,64
64    WRITE(3,600)ISTRM,MONDA,ITIM,IYR,LOC
600   FORMAT(/  5X'CALCULATION TABLE'5X4I5,5X20A2)
      WRITE(3,608)R,Q,QPEAK,FK,P
608   FORMAT(/30X'R='F7.3'    Q='F7.3'    QP='F7.2'    K='F5.2'    F
     *F5.2)
      WRITE(3,601)
601   FORMAT(/ ' T UN   WGT   STP    WID    PLEN   TLEN       QP
     *,1X,'RE',9X,'INRE',9X,'TDA',10X,'DMR',5X,'GR/GI',3X,'GDETM',/,
     */0'3(5X'FT')3X,' IN/HR'2(7X'TONS')10X'AC'27X,'TON')     4X'O
603   FORMAT(/  9X'SUMMARY TABLE'5X3I5,5X20A2)
609   FORMAT(/30X'TUBE'10X'TOTAL    INTERRILL'5X'RILL'6X'YIELD'
     * '  DEPOSITION')
610   FORMAT(30XA2,6X5F11.2)
607   FORMAT(' ')
 65   QPK=QPEAK*QFAC*F
      FIT=R*RCON
      FTO=Q*QCON*QMULT
      JC=0
      DO 5 JJ=1,NCHAN
      JCI=JC+1
      JC=ICHAN(JJ)
      JCO=JC-1
      RE(JC)=0.
      XNRE(JC)=0.
      GDET(JC)=0.
      DEP(JC)=0.
      YIELD(JC)=0.
      TLEN=0.
      TDA=0.
      TGDET=0.
      QP=0.
```

```
15800        SWGTC=0.
15900 C      NEW WEIGHTED C VALUES ARE ADDED IN THE FOLLOWING LOOP BY TED K.
16000 C     PERAC=COMPARTMENT SIZE IN ACRES.      TDA=COMPARTMENT ACRES SUMMED.
16100 C     WGTC=WEIGHTED 'C' FACTOR.        SWGTC=SUM OF WEIGHTED 'C'FACTORS.
16200 C     CNEW=CALCULATED 'C' FACTOR USED IN 17900.
16300        DO 5 K=JC1,JCO
16400        T=0.43+0.3*SSTP(K)
16500        TT=0.043*SSTP(K)**2
16600        PERAC=SLEN(K)*SWID(K)/A
16700        PLEN=TLEN
16800        TDA=TDA+PERAC
16900        TLEN=TLEN+SLEN(K)
17000        QP=QP+QPK*WGT(K)
17100        FT=FTO*QP**E
17200        DMR=FT+FIT
17300        S=(T+TT)/6.613
17400        WGTC=C(K)*PERAC
17500        SWGTC=SWGTC+WGTC
17600        CNEW=SWGTC/TDA
17700        GDET(K)=DMR*FK*C(K)*P*S*SWID(K)*(TLEN**1.5-PLEN**1.5)/D
17800        TGDET=TGDET+GDET(K)
17900        GDETM=DMR*FK*CNEW*P*S*SWID(K)*TLEN**1.5/D
18000   900  FORMAT(F6.3)
18100        WTDMR=DMR*PERAC
18200        SWTDMR=SWTDMR+WTDMR
18300        SPERAC=SPERAC+PERAC
18400        EFECR=SWTDMR/SPERAC
18500        SDETM=GDETM
18600        IF(TGDET-GDETM)77,77,78
18700 77     GDETM=GDET(K)
18800        DEP(K)=0.
18900        GO TO 8
19000 78     DEP(K)=TGDET-GDETM
19100        TGDET=GDETM
19200 8      RGRGI=FKRAT*TT/T*(TLEN**2-PLEN**2)/(72.6*(TLEN-PLEN))*FT/FIT
19300        IF(RGRGI)75,76,76
19400 75     RGRGI=0.
19500 76     XNRE(K)=GDETM/(RGRGI+1.0)
19600        RE(K)=GDET(K)-XNRE(K)
19700        IF(RE(K))34,34,35
19800 34     XNRE(K)=GDET(K)
19900        RE(K)=0.
20000   35   WR=2.4*FKRAT**(-0.3)*(SSTP(K)/6.0)**0.3/12.0*SWID(K)
20100        SAR=WR*SLEN(K)
20200        RD=RE(K)/SAR*324.0
20300        YIELD(K)=GDET(K)-DEP(K)
20400        UL=GDET(K)/PERAC
20500        IF(IPR1-1)67,66,66
20600    66  WRITE(3,602)ITUBE(K),NTUBE(K),WGT(K),SSTP(K),SWID(K),SLEN(K),
20700       *TLEN,QP,RE(K),XNRE(K),TDA,DMR,RGRGI,SDETM,WR,RD,GDET(K),
20800       *DEP(K),UL,C(K)
20900   602  FORMAT( ' ',A2,I2,1X,F7.0,F4.1,F9.1,2F6.0,4E12.5,F9.4,E10.4,F9.2,/
21000       *' RILL WD(FT)='  E11.5,'  RILL DP(IN)=' E11.5,'  DET(TON)='  F8.2,
21100       *'  DEP(TON)=' F8.2,'  LOSS(T/AC)=' F6.4,  '     C='F5.3,/,T13,11('
21200       *-'),14X,11('-'),11X,8('-'),12X,8('-'),14X,5('-'),7X,5('-'))
```

```
   67 RE(JC)=RE(JC)+RE(K)
      XNRE(JC)=XNRE(JC)+XNRE(K)
      GDET(JC)=GDET(JC)+GDET(K)
      DEP(JC)=DEP(JC)+DEP(K)
      YIELD(JC)=YIELD(JC)+YIELD(K)
      IF(NTUBE(K+1)-NTUBE(K))3,5,5
    3 TLEN=0.
      TDA=0.
      TGDET=0.
      QP=0.
      SWGTC=0.
    5 CONTINUE
      JC=0
      IF(IPR2-1)69,68,68
   68 WRITE(3,603)MONDA,ITIM,IYR,LOC
      WRITE(3,608)R,Q,QPEAK,FK,P
      WRITE(3,609)
69    DO 25 JJ=1,NCHAN
      JCI=JC+1
      JC=ICHAN(JJ)
      JCO=JC-1
      DO 11 L=1,5
   11 SUM(L)=0.
      DO 14 K=JCI,JCO
      SUM(1)=SUM(1)+GDET(K)
      SUM(2)=SUM(2)+XNRE(K)
      SUM(3)=SUM(3)+RE(K)
      SUM(4)=SUM(4)+YIELD(K)
      SUM(5)=SUM(5)+DEP(K)
      IF(NTUBE(K+1)-NTUBE(K))13,14,14
   13 IF(IPR2-1)15,71,71
   71 WRITE(3,610)ITUBE(K),SUM
15    DO 12 L=1,5
      TOT(L)=TOT(L)+SUM(L)
   12 SUM(L)=0.
   14 CONTINUE
      IF(IPR2-1)25,72,72
   72 WRITE(3,607)
      WRITE(3,604)ITUBE(JC),JC,GDET(JC),XNRE(JC),RE(JC),YIELD(JC),
     *DEP(JC)
  604 FORMAT(30XA2,I3,3X5F11.2)
      WRITE(3,607)
25    CONTINUE
      IF(IPR2-1)74,73,73
73    WRITE(3,605)TOT
74    DO 30 L=1,5
30    SUM(L)=TOT(L)/ACRE
      YYY=(Y-SUM(NCOMP))**2/2.
      IF(IPR3-1)41,40,40
40    WRITE(3,606)MONDA,ITIM,IYR,SUM,YYY
41    SVAR=SVAR+YYY
```

```
C   CALCULATION OF PARTICLE SIZE DISTRIBUTION AND AMOUNTS ERODED.
C   TED KAMINSKI ADDED THIS TO THE ERODE MODEL FROM ORIGINAL
                                                BY ONSTAD
         SS=CL*200.+SI*40.+SA*0.5
         SSE=14.6+SS*0.84
         CR=CL/(SI+SA)
         CRE=0.021+CR*1.08
         CREEP=CRE+1.
         SAE=-(SSE-(CRE*200.+40.)/CREEP)/39.5
         SIE=(1.-CREEP*SAE)/CREEP
         CLE=1.-SAE-SIE
         WRITE(3,17)CL,SI,SA,SS,CR,CLE,SIE,SAE,SSE,CRE
      17 FORMAT(/17X'CL     SI     SA'5X'SS'5X'CR'5X'CLE  SIE    SAE    S
        *    CRE'/12X,2(2X,3F6.3,F8.3,F6.3))                            E
         TCLE=TOT(4)*CLE
         TSIE=TOT(4)*SIE
         TSAE=TOT(4)*SAE
         WRITE(3,9000)EFECR
    9000 FORMAT(/90X,'EFFECTIVE R ='F9.4)
         WRITE(3,18)TCLE,TSIE,TSAE
     18  FORMAT(,30X,' TONS OF CLAY ERODED='F9.2/30X, ' TONS OF SILT ER
        *='F9.2/30X, ' TONS OF SAND ERODED='F9.2//)
 16      CONTINUE                                                       DEI
         WRITE(3,103)SVAR,RCON,QCON,QMULT,JI,JO
 103     FORMAT(/' SUM OF VARIANCES ='F12.8,40X,3F7.4,2I4/)
         GO TO 61
    1000 CALL EXIT
         END
```