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I am submitting herewith a thesis written by Nancy A. Ward entitled "A Parametric Model of Suspended Solids Concentrations for Two Strip Mined Watersheds." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Engineering with a major in Environmental Engineering.

Bruce A. Tschantz, Major Professor

We have read this thesis
and recommend its acceptance:

Roger C. Minear

Donald E. Overton

Accepted for the Council:

L. Evans Roth
Vice Chancellor
Graduate Studies and Research

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A PARAMETRIC MODEL OF SUSPENDED SOLIDS CONCENTRATIONS FOR TWO STRIP MINED WATERSHEDS

A Thesis

Presented for the

Master of Engineering

Degree

The University of Tennessee

Nancy A. Ward

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ABSTRACT

The major problem analyzed in this study is the sediment production load at two strip mined watersheds in the New River Basin of Tennessee. The specific objective of this thesis is to begin the modeling process of the suspended solids portion of the total sediment load for storm events at the two strip mined watersheds and to make an initial comparison of suspended solids concentrations of the two strip mined watersheds, an urban watershed and a forested watershed. Regression equations of the form $SS = aQ^b$ are developed for the two strip mined watersheds, and the 90% confidence intervals are calculated. Concentrations at the peak flow value of the largest storm of record are compared for the two strip mined watersheds and the urban watershed, and average daily loads are compared for the strip mined watersheds, the urban watershed and the forested watershed for the day of the largest storm of record.

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CHAPTER I

INTRODUCTION

A. Sediment as a Pollutant

The relationship of sediment to water quality depends on the effect sediment has on the physical, chemical, and biological characteristics of water which determine its suitability for a particular use. When sediment interferes with this intended use, it becomes a pollutant. Sediment must be dealt with as both a physical and a chemical pollutant because not only is it a hindrance to irrigation, drainage, and the aquatic biota, but sediment is capable of transporting and depositing chemicals and elements through absorption on its active surface.

Grissinger and McDowell[1] defined the present day magnitude of the sediment production problem in a summary of statistics.

1. About four billion tons of sediment are produced annually in the United States.
2. Approximately one-fourth of this material is delivered to major streams.
3. Storage capacity of man-made reservoirs is reduced by about one million acre-feet of sediment each year.
4. The Mississippi River delivers between 300 and 500 million tons of sediment to the Gulf of Mexico each year.
5. The Potomac River transports about two and one-half million tons of sediment annually to the estuary of the Potomac. This is about one-twentieth of the gross erosion in the Potomac Watershed.
6. In amount, erosion produced sediment is at least 700 times that from sewage.

The annual cost of damage to society from sediment in streams is estimated to be $262 million in 1966[2] and approximately 500 million in a 1969 study.[1]

The major sources of sediment are from the natural and man-accelerated processes of erosion of soils and geological materials and the discharge of industrial, municipal, agricultural or individual refuse to water courses. With approximately 30% of the total sediment being classified as natural or geological in origin and less than 20% originating from industrial, municipal, and individual discharges, the majority of the erosion comes from land-disturbing activities associated with mining, construction, agriculture and silviculture.[1] Although mining activity is not the largest sediment producer in terms of total land disturbed and contributions of sediment on a nationwide basis,[3] mining does create local problems due to its high rate of erosion and this effect on water quality. One local problem under investigation is the impact of coal surface mining on drainage basin water quality in the New River Basin of the Cumberland Mountains of Tennessee.

B. New River Basin Study

The New River Basin is located in Anderson, Campbell, Morgan, and Scott counties in the Northern Cumberland Plateau region of East Tennessee. Surface mining in this region began in the early 1940's and continues to the present. Approximately 5% of the drainage area has been disturbed by mining activities through 1975.[4] The significance of a study in this area centers around the fact that approximately 70% of the coal mined in Tennessee comes from this region; little systematic information is available on the effect of coal surface mining on water quality in areas of Tennessee; the Tennessee Division of Water Quality needs water quality data for establishing meaningful water discharge standards

associated with coal surface mining in mountainous areas; and the U. S. Army Corps of Engineers needs information to develop a watershed erosion control plan as part of the major goal of establishing the Big South Fork National River and Recreational Area Project in Tennessee and Kentucky. The ultimate goal of the New River study is to identify, quantify and relate the stresses on society from the strip mining of coal in this region to the type and level of mining and reclamation practice so that meaningful state and federal standards can be implemented and so that cost effective mining techniques can be practiced.[4]

Six watersheds in the New River Basin are under study to establish bench mark water quality data in this region. The sediment production in this basin from surface mining activities is one aspect of this water quality investigation. The total sediment load within a stream can be evaluated in two components, the bedload contribution and the suspended material contribution. In the early portion of this watershed study the suspended material was monitored by measuring total and suspended solids in a weekly sampling routine. In monitoring this data at this early stage of the investigation, it was found that the higher suspended solids concentrations occurred during days of rainfall or following a rainfall day.[4] These results indicated the need to sample during storm events in addition to weekly sampling in order to determine if the major contributions to the sediment problem occurred during a storm event or from a longer base-flow condition.

C. Purpose of Thesis

The purpose of this thesis is to establish a framework for and to

begin the process of modeling the suspended solids concentrations with hydrologic variables to demonstrate the effects of strip mining on suspended solids concentrations in a stream during storm conditions. In using a parametric modeling technique and the data from storm events the approach is site specific and confined to within storm variations. This thesis reports on the initial modeling steps and the results that contribute to defining the water quality problem for the two strip mined watersheds, Bill's Branch and Green Branch. After establishing a model form that fits the data an attempt is made to compare these results for the two strip mined watersheds with results from an urban watershed and a forested watershed.

CHAPTER II

REVIEW OF LITERATURE

In developing an approach to analyze the strip mining sediment problem one must investigate several areas of past study. This chapter reviews two major aspects that are related to strip mining sedimentation. The first major aspect reviews several methods and models used to predict sediment production, and the second aspect summarizes the sediment related portions of past strip mining studies.

A. Sediment Production Models

The study of sedimentation requires the analysis of its primary source, erosion, and the primary cause of erosion, rainfall. Wind and other factors are erosive agents but rainfall is of major concern. The energy from a raindrop detaches the soil particles, and flow transports the particles. The splash of the raindrop also transports the particles, and the flow may also detach particles to be transported.

Classification divisions of erosion vary. The EPA classifies erosion in basically two forms, sheet erosion and channel erosion.[3] Sheet erosion is the uniform removal of a layer of soil, whereas channel erosion results from concentrations of surface water that detach and transport sediment in flowing streams or channels. Channel erosion is further subdivided into rill erosion, gully erosion, and streambank erosion. Rill and gully erosion are the results of temporary concentrations of surface runoff with gully erosion being more severe than rill erosion. Streambank erosion is the removal of soil from the sides of permanent streambeds

by the energy of moving water.[3] The severity of these different forms of erosion depends on the effectiveness of the raindrops and overland flow to detach and transport the soil particles.

The interrelationship between the raindrop splash and the overland flow as erosion and transport mechanisms is emphasized by Ellison's studies of raindrop erosion in 1944 and 1952.[5,6,7] Ellison's work indicated that the energy of the falling raindrop first tended to breakdown soil particles into finer particles that then infiltrated the soil. These particles eventually sealed the surface to infiltration and left a loose soil layer above the sealed zone. The raindrops and the resulting flow from lack of infiltration transported these loose particles. On sloped ground the raindrop splash tended to beat the soil down the slope, and the downslope splashes traveled greater distances than the upslope splashes. Ellison found that the amount of soil measured in a splash sampler was dependent on the rainfall intensity, drop size, and drop velocity. The effectiveness of the raindrops and flow was also dependent on the soil erodibility, land cover conditions, and the length and steepness of slopes.

Several predictive equations have been presented that use variations in climate, soils, vegetation and other watershed characteristics to estimate sediment yield. Two of the major forms of this type of equation are the Musgrave Equation and the Universal Soil Loss Equation.

Musgrave[8] reported in 1947 the following relationship:

$$E = IR(S)^{1.35}(L)^{.35}(P_{30})^{1.75}$$

where E is the soil loss per year in acre inches; I is an erodibility factor in inches; R is a dimensionless cover factor; S is the degree of slope

in percent; L is the length of slope in feet; and P_{30} is the maximum 30-minute rainfall amount. This equation resulted from the analysis of soil loss measurements for some 40,000 storms occuring on small plots in the United States.

In 1965 Wischmeier and Smith[9,10] presented a similar equation known as the "Universal Soil Loss Equation." This equation is

$$A = R\ K\ L\ S\ C\ P$$

where A is the computed soil loss per unit area; R is the local rainfall factor; K is the soil erodibility factor; L is the soil slope length; S is the steepness of the slope; C is the cropping management factor; and P is the erosion control practice factor. The soil erodibility factor, K has been reported by the Soil Conservation Service for most soil types. Wischmeier and Smith presented in 1971 a nomograph for computing K from five soil parameters.[3] The combined length-slope factor, LS, can be obtained from a chart with values based on a unit plot with a 9% slope and a length of 72.6 feet. Values not shown on the chart may be computed by solving the equation

$$LS = \sqrt{\lambda}\,(.0076 + .0053S + .0076\ S^2)$$

where λ is the length of the slope in feet; and S is the grade of the slope expressed in percent. In trying to determine the applicability of the LS factor for slopes greater than 5:1, Kirkpatrick, Seith, and Allen[11] reported in 1970 an error of 2.8% between observed and predicted sediment yield values for a slope of 5:1. On a 10:1 slope the error was 30%. The report concluded that this work was only a preliminary indication of possible inaccuracies of the LS factor that needed further quantitative analysis.

One of the differences between the factors in the Musgrave equation and the USLE is in the rainfall factor, R. Instead of measuring the amount of rainfall, the R factor in the soil loss equation is the product of the kinetic energy, E, of the rainfall and the maximum 30-minute rainfall intensity, I, for a given storm. This factor allows for the calculation of sediment yield from an individual storm or on an annual basis. Average annual R values for locations east of the Rocky Mountains in the United States can be estimated by interpolation on an isoerodent map of this region,[10] and the average yearly sediment yield can be calculated using this R value.

Following the establishment of the Universal Soil Loss Equation as a useful predictor of soil loss from farm practices, several variations of the equation have been presented to adjust the equation for land uses other than agriculture and to account for sediment that may have been trapped along the path from the source of the erosion to the point of measurement.

A sediment delivery ratio is one of the main factors added to the basic Universal Soil Loss Equation. The sediment delivery ratio is defined as the fraction of the total erosion delivered from the erosion source to the receptor water.[3] Some of the factors that influence this ratio are the size and density of the sediment sources, the texture of the eroded material, the characteristics of the sediment transport mechanism, the distance from the sediment sources to the receptor water, the slope of this distance, and the availability of deposition areas along this path.

In 1972 Williams and Berndt[12] reported the use of a modified USLE

with a delivery ratio to compute sediment yield. Delivery ratios were computed by dividing the measured sediment yield by the computed source erosion for an eight year period. These computed delivery ratios were related through step-wise multiple regression to watershed characteristics. The developed equation is $DR = .627\ SLP^{.403}$ where DR is the delivery ratio; and SLP is the percent slope of the main stem channel. This channel slope factor was computed by dividing the channel into an N number of equal length segments and channel slopes. SLP was then calculated using

$$SLP = \left[\frac{N}{\frac{1}{SLP_1} + \frac{1}{SLP_2} + \ldots + \frac{1}{SLP_N}} \right]^2$$

Williams and Berndt also subdivided the watershed and used weighted averages of the K, L, S, C, and P factors in the Universal Soil Loss Equation.

The MITRE Corporation[3] reported the use of the following sediment delivery ratio for construction sites: $Sd = D^{-.22}$ where Sd is the sediment delivery ratio, and D is the overland distance from the erosion site and the receptor water, in feet. The MITRE Corporation suggested that this function should be subjected to further testing. The use of this equation as a first approximation for other land uses such as mining and forestry activities was suggested because of the lack of systematically measured data to establish a ratio for these land uses.

Other studies reported by the Environmental Protection Agency[3] have defined the sediment delivery ratio in terms of the inverse of the drainage density and the texture of the soil. The inverse of the drainage density was defined as the ratio of the total channel-segment lengths to the basin area. Several drainage densities for different areas are

available from the U. S. Geological Survey and the Army Corps of Engineers.

As stated by EPA the USLE was established for use on small agricultural plots in areas east of the Rocky Mountains. Because similar factors had not been developed for agricultural use in the western United States and other land uses, the use of the USLE under these conditions has not been well defined.[3]

Other models besides the USLE have been used in the prediction of sediment yield for various land uses. Several regression models have been reported in the literature. Regression models use nonlinear least squares or linear least squares techniques to determine parameter values. The two most popular forms are the linear form, $Y = a + bx_1 + cx_2 + \ldots$ and the nonlinear form, $Y = ax_1^b x_2^c \ldots$ where Y is the dependent variable; x_1, x_2 ... are the independent variables; and a, b, c ... are the parameters.[13] In using these model forms for measuring sediment production as sediment yield the sediment yield is the dependent variable, and watershed characteristics, rainfall characteristics, runoff characteristics, and other variables that influence sediment production are the independent variables. Regression models are site specific because of the parameter values dependence on the data.[13]

Flaxman in 1972,[14] used a regression model to establish a sediment yield equation for several western states. Flaxman used four independent variables to predict the dependent variable, sediment yield. Independent variable x_1 was the average annual precipitation divided by the average annual temperature. This factor was intended to represent the natural response of vegetation to climate. Independent variable x_2 was the weighted average watershed slope as a percentage. Independent variable x_3

represented a soil factor and was the percent of soil particles coarser than one mm in the surface two inches of the soil profile, and independent variable x_4 was the measurement of soil aggregation. This value was determined through the measurement of pH and the amount of clay present, and by physical examination of the same two inch soil layer. The dependent variable Y was the measured volume of sediment divided by the years of accumulation and area of the watershed in square miles. Because the data showed skewedness, Flaxman used a logarithmic form. To eliminate the problems associated with negative logarithms, Flaxman found the factor of 100 to be the most significant constant to add to all the variables. The following equation resulted from a multiple regression analysis.

$$\log (Y + 100) = 6.21301 - 2.19133 \log (x_1 + 100) + .06034 \log (x_2 + 100) - .01644 \log (x_3 + 100) + .04250 \log (x_4 + 100)$$

The "t" values denoted a significant relationship for all the independent variables. Flaxman tried other independent variables that represented topography and soil characteristics, and rainfall and runoff variables, but these variables failed to add any significance to the model.

Betson reported in 1975 what he termed a first generation, regionalized, non-point source mineral water quality model.[15,16] The purpose in the development of this model was to provide a capability for simulating mineral quality constituent concentration or transport, under natural conditions, anywhere in the Tennessee Valley. Betson used the basic rating curve relationship and modified it by dividing the flow term by drainage area to make it applicable at various locations on a stream. Betson used the following equation $\text{Conc} = a \left(\frac{Q}{DA}\right)^b$ where Conc is the pollutant concentration in mg/l; Q is the mean daily streamflow in cfs;

DA is the drainage area in square miles; and a, b are the coefficients to determine the suspended sediment yield using this model. Betson related the coefficients through stepwise regression to watershed, soil, and rainfall characteristics. The model was calibrated using 19 watersheds, and separate equations for summer and winter conditions were developed. The regression equations and correlation coefficients are:

$$Wa = 52.7\ SL^{.308} K_{32}^{.132} DA^{.266} K^{2.17} RF^{-.211}$$

$$(r = .83)$$

$$Wb = 2.304\ RF^{1.59}$$

$$(r = .51)$$

$$Sa = 17.47\ K_{32}^{.369} DA^{.30} SL^{.401}$$

$$(r = .77)$$

$$Sb = 1.474\ RF^{2.53} DA^{.049} FF^{-.585} K_{32}^{-.115}$$

$$(r = .68)$$

where Wa, Wb, Sa, Sb are the seasonal winter and summer coefficients; SL is the watershed slope in the vicinity of the gage site - determined from a topographic map measured upstream 10% of the basin diameter from the gage site, ft/mile/10; K_{32} is the fraction of watershed area with soils with an erosion factor greater than .32; DA is the drainage area in square miles; K is the soil A-horizon erosibility factor; RF is the long term average watershed rainfall, inches/100; and FF is the fraction of the watershed area forested. All the terms in the seasonal regression equations contributed significantly at the 90% level as indicated by the Student's t-test. The "a" coefficient was modified by multiplying it by the mean seasonal flow raised to the "b" power in order to relate "a" to seasonal flows rather than unit discharge. Using the coefficients from

these equations, Betson generated daily sediment yield for each of the test watersheds. In comparing the observed and predicted values for each watershed, the model overpredicted for a small forested watershed and underpredicted the sediment yield for two agricultural watersheds.

In a study of urban land runoff Colston[17] used non-linear regression equations to relate pollutant concentrations to runoff characteristics. The monitored urban watershed was the Third Fork Creek Basin (1.67 $mi.^2$) in Durham, North Carolina. The independent variables used were rate of runoff (CSF), time from storm start (TFSS) in hours, time from last storm (TFLS) in hours, and time from last peak (TFLP) in hours. Two of the independent variables, TFLP and TFLS did not significantly contribute to the correlation coefficient and were eliminated for regression simplicity. The resulting equations only included CFS and TFSS as independent variables. The regression equation for suspended solids is

$$\text{Suspended solids} = 1.89\ CFS^{1.23}\ TFSS^{-.16}$$

$$(r^2 = .76)$$

where suspended solids are in pounds per minute; CFS is in cubic feet per second; and TFSS is in hours. Adjusting this equation for a concentration of suspended solids in milligrams per liter and a correction to flow at mid-depth resulted in the following equation

$$SS = 222\ CFS^{.23}\ TFSS^{-.16}$$

Colston calculated the annual suspended sediment yield for 1972 using this predictive equation, and adjustment for the vertical concentration distribution, and a baseflow term. The data for 1972 included 66 storm events, and the resulting annual suspended sediment yield was 6691 pounds/acre/year. In attempting to evaluate the effectiveness of the EPA Storm

Water Management Model in predicting the quality of runoff, Colston found wide variations in the computed and recorded values of the suspended solids concentrations. He concluded that the functions generating suspended solids concentrations need additional refinement.

B. Past Strip Mining Studies

This section reviews the past strip mining studies in the Appalachian region that reported sediment measurements. The major studies in Kentucky are in the Leatherwood Creek - Bear Branch area by Curtis in 1971[18,19] and from 1955 to 1959 in the Beaver Creek Basin by Collier and Musser.[20] A portion of the Indian Creek Basin study in Pennsylvania reported by Herricks and Shanholtz in 1975 dealt with the sediment in the stream.[21]

Willie R. Curtis reported results for Leatherwood Creek and Bear Branch in Breathitt County, Kentucky from 1967 to 1969. Suspended sediment samples were collected weekly at the gaging station weirs and bedload measurements were determined from material deposited behind the weir. Maximum suspended sediment concentrations during the three year study at three tributaries of Leatherwood Creek were 46,400; 26,900; and 9600 ppm as compared to 150 ppm for an adjacent unmined forested watershed. Curtis concluded that larger storms produced more sediment but the maximum concentrations depended more on activity and disturbance. The maximum concentrations occurred during active mining, and there was a decrease in concentrations one or two years after mining had ceased. Curtis formulated that, by knowing the sediment produced during the first 6 months after mining, it was possible to predict sediment yield for any 6 month period

or a total sediment yield. Curtis reported that the methods of mining, handling of overburden and reclamation practices were the major factors influencing sediment yield rather than the amount of disturbed land. No effects of individual storms were made in this study, however, Curtis reported in 1971 the evaluation of the effects of terracing on runoff and erosion through the use of storm data. Two types of spoil, shale and sandstone, were used in this study. The maximum rates for the terraced spoil were 32,000 ppm for the shale and 775 for the sandstone. For the control or unterraced spoil maximum values of 57,000 and 4,200 ppm were observed. The higher values for the shale spoil were expected because shale has a higher erosion potential than sandstone. These values were from 11 storm events between June 1969 and September 1970.

Another strip mining study in Kentucky was by Collier and Musser in the Beaver Creek Basin area from 1955 to 1959. The main objective of this study was the determination of the sediment yield from natural and strip mined drainage basins. Gaging stations in the Beaver Creek area were operated at Cane Branch, Helton Branch, and the West Fork Cane Branch. The Cane Branch watershed had 6.4% of the land disturbed by mining activity between 1955 and 1956 and an additional 4% of the area was disturbed between 1958 and 1959. Approximately 1% of the West Fork Cane Branch area was disturbed by coal prospecting areas and roads. Helton Branch was the unmined watershed with about 99% of this area being protected by a vegetative and litter cover.

Ten supplemental sites in the Cane Branch watershed were studied to better define the actual sources of sediment. The highest observed concentration of 12,000 ppm was sampled at a coal haul road sampling site.

Most drainage areas from portions of the spoil bank yielded concentrations greater than 400 ppm, whereas drainage areas with almost complete vegetal cover had concentrations less than 50 ppm.

Collier and Musser computed the annual sediment discharges and yields for Cane Branch and Helton Branch. The 1958 sediment yield results indicated that the yield for Cane Branch was 69 times the yield for Helton Branch.

In evaluating the storm concentrations, results also indicated that more sediment was transported in the Cane Branch area. The maximum observed concentration from storm runoff at Cane Branch was 75,000 ppm, at West Fork Cane Branch 2,780 ppm, and at Helton Branch 553 ppm. Most of the sediment was discharged during storm runoff, and the more intense storms yielded higher concentrations. The peak sediment concentration in Cane Branch occurred before the peak water discharge during all storms. In comparing the total sediment discharge for 70 storms that occurred from February 1956 to September 1959, Cane Branch's results indicated a variability between winter-type and summer-type storms. There was no seasonal variability indicated in the evaluation of 39 storms for Helton Branch during this same time period. This difference was attributed to the fact that unprotected strip mined areas of the Cane Branch were more sensitive to form, intensity and duration of precipitation, and to antecedent moisture conditions. Further evaluation indicated that changes in the water discharge - sediment discharge relationship for Cane Branch corresponded to changes in strip mining disturbance. In evaluating the particle-size distribution of the sediment at the different gaging stations, West Fork Cane Branch had the finest suspended sediment, and Cane Branch

had finer material than Helton Branch. Variations in size distributions at Cane Branch were dependent on the velocity and turbulence changes in storm runoff that affect the transport of different sized particles. Finer particles were observed after new mining activity had exposed fresh clay to erosion.

Roehl and Johnson[20] compared the estimated sheet erosion for Helton, Cane, and West Cane Fork Branches in another portion of the 1955 to 1959 Beaver Creek Study. A variation of the Musgrave equation that took into account the different sources of sediment yield was used to estimate sheet erosion for 1957, 1958, and 1959. Their results indicated that the change in land use was the major factor to increase the sheet erosion in Cane Branch. The sheet erosion for Helton Branch was definitely less even though the steeper and longer slopes would indicate a higher rate of erosion.

In 1975 Herricks and Shanholtz presented results from their study in the Indian Creek Basin in the Appalachian Plateau Province of Southwestern Pennsylvania. Through the use of flood hydrographs generated by the Stanford Watershed Model and computed water surface profiles, the particle tractive force was calculated. The tractive force was related to the particle diameter resulting in the following equation

$$d = \frac{T}{.06\ (Ss - Sw)}$$

where d is the particle diameter; T is the tractive force; Ss is the specific weight of the particle; and Sw is the specific weight of water. The largest diameter particle to be moved in the stream by a given storm flow was determined from this equation. Through this technique they

concluded that higher stream flows can alter the bottom and cause severe disruption of biological function.

CHAPTER III

PROCEDURES

Two thought processes were incorporated in arriving at the objectives and approaches of this study. Overton and Meadows[13] have outlined the general modeling process and the steps to be followed in parametric modeling of stormwater. Their flow charts of these processes are shown in Figures 1 and 2.

In reference to this thesis, the constraints of time, money, and manpower were within the time framework of a Master's thesis and the operation of a study financed by a grant (No. E-(40-1)-4946) from ERDA to analyze water quality within a strip mined region. The main result of these constraints on the objectives and approaches was the amount of available data generated prior to writing this thesis.

The phenomenon analyzed was the effect of the sediment production resulting from the erosion of soil exposed by strip mining in a watershed on the water quality. Rainfall and flow were continuously monitored but water quality samples were taken as grab samples. The analysis of suspended solids of the grab samples reflected the water quality effects. Experimental testing of these effects was through the use of a parametric modeling technique. The examination of the steps involved in parametric modeling pinpointed the objectives of this thesis. Because of the limited amount of data and the fact that the modeling process is in its initial stages of development, the objectives of this study were confined to the steps of model formulation, parameter optimization, feedback to refine the

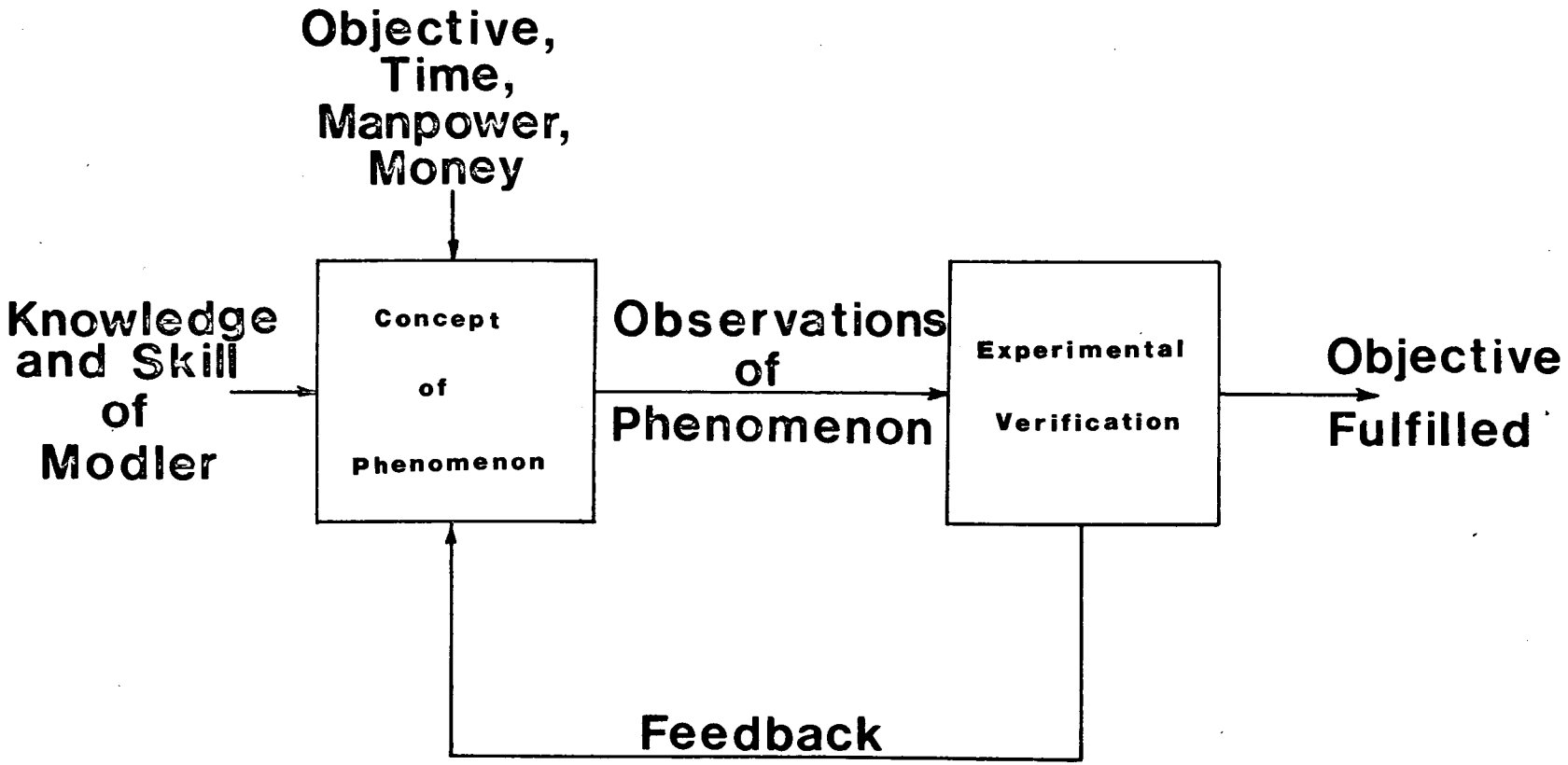


Figure 1. The Modeling Process (After Overton and Meadows, 1976).[13]

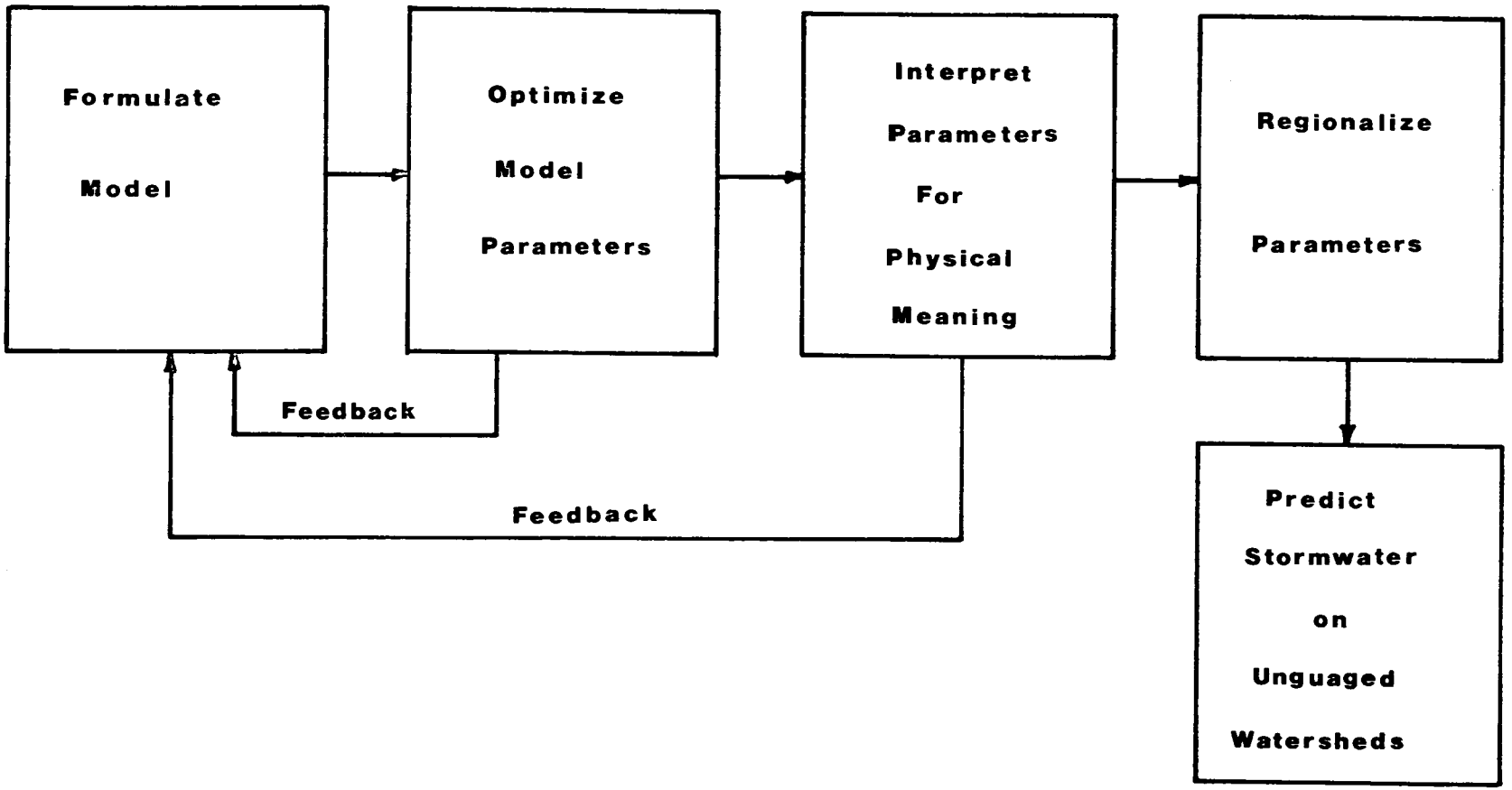


Figure 2. Steps in Parametric Modeling (After Overton and Meadows, 1976).[13]

model, and an initial evaluation of the effects of strip mining on water quality through a comparison with an urban watershed and a forested watershed model. These objectives were confined to only the two strip mined watersheds due to the time constraint of a Master's thesis, but investigation of these objectives in the future time framework of the ERDA project for the unstripped watersheds is possible. This section outlines the approaches and procedures followed in satisfying these objectives.

A. Data Collection

Four of the six watersheds monitored for the ERDA project were of primary concern in this thesis. Figure 3 locates these monitored areas on a topographic map of the New River Basin, and Table 1 presents the watershed characteristics. The strip mined areas for Bill's Branch and Green Branch are outlined along the contours in Figure 4. Only data from these two strip mined watersheds were used for the purpose of developing a parametric model for suspended solids, but the regression equations for Anderson Branch and Lowe Branch are presented.

Suspended solids samples were obtained at each gaging station as grab samples. The samples were taken during storm flow conditions at a designated location above the weir settling pond. To obtain a representative sample the samples were taken at mid-depth in turbulent stream flow areas. The lab analysis consisted of using tared Gooch crucibles with 934 AH Reeve Angel filters. One hundred milliliters of the grab samples with lower concentrations of solids were filtered and 50 ml samples filtered for samples with visible higher concentrations. The samples were dryed for at least two hours at $105^{o}C$ and were placed in a desiccator



Figure 3. Topographic Map of the New River Watershed, Tennessee. Study Basins Lettered in Figure Are Defined in Table 1 (After Minear and Tschantz, 1976).[4]

Table 1. Watershed Characteristics (After Bowers, 1977)[22]

Watershed	Area of Water-Shed* Acres	Average Slope (%)		Average Elevation (Ft.)		USG/TVA Sheet No.
		Watershed	Streambed	Watershed	Streambed	
Indian Fork (A)	2765	38.1	8.4	2341	1830	129 NW (FK. MIN)
Bill's Branch (D)	429	38.4	26.0	2407	2130	129 NW (FK. MIN)
Green Branch (F)	883	36.8	17.6	2287	1845	129 NW (FK. MIN)
Bowling Branch (E)	1888	32.5	7.4	1967	1580	128 SW (NORMA)
Anderson Creek (B)	518	34.1	18.4	1890	1630	128 SW (NORMA)
Lowe Branch (C)	589	31.9	12.6	1820	1540	128 SW (NORMA) (NEAREST NORMA)

*Above continuous gage station.

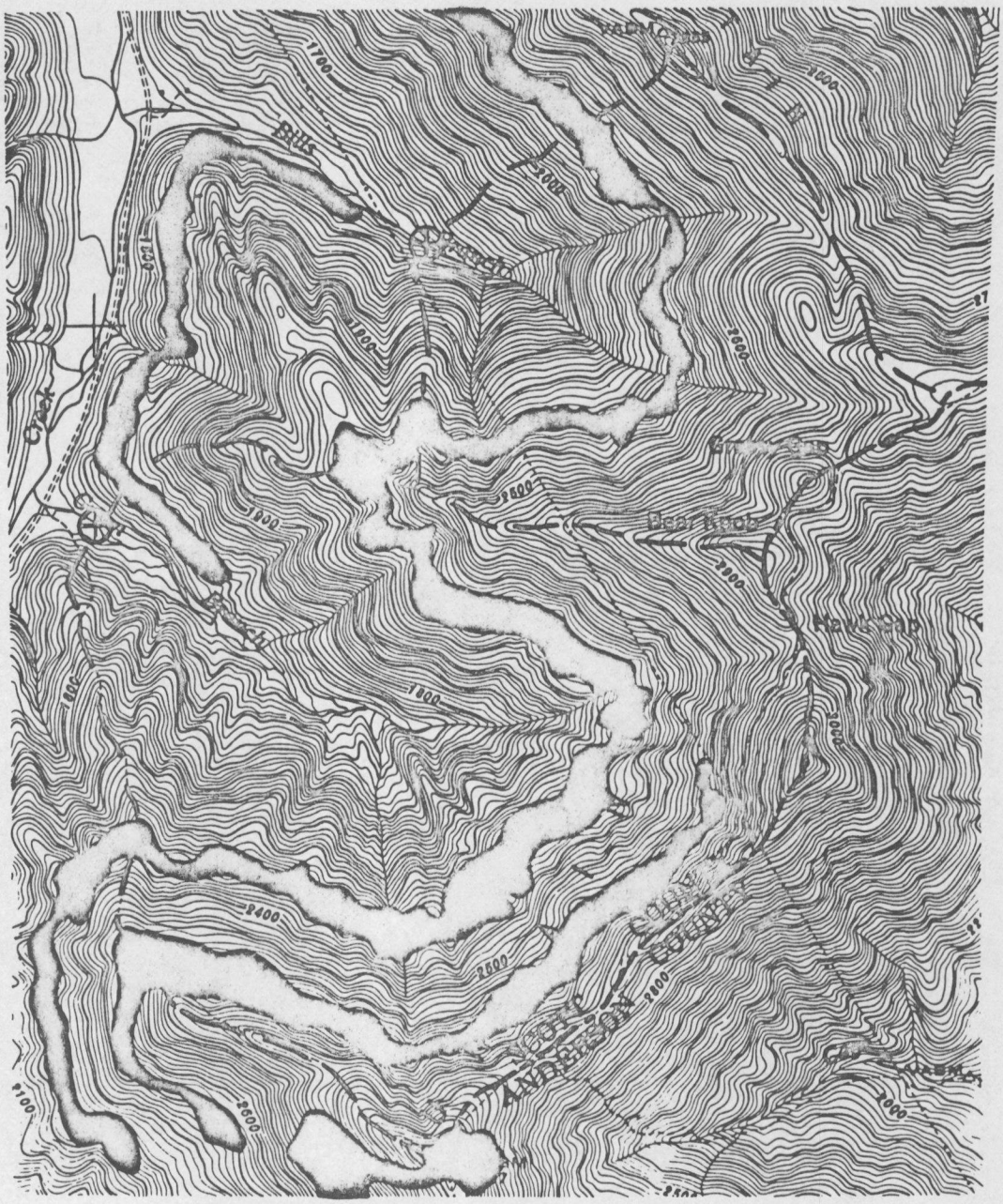


Figure 4. Strip Mined Areas at Bill's Branch and Green Branch (After Bowers, 1977).[22]

for one-half hour before final weighing. Samples were not replicated.

Continuous flow and rainfall data were monitored from the gages operated by the U. S. Geological Survey. Stage values were read from the staff marker when the continuous monitors were not functioning properly.

The suspended solids data used in this study were from three storm events at Bill's Branch and Green Branch during 1976. The storms analyzed occurred on March 5, May 28, and October 6. A total of 46 suspended solids samples (8 March, 14 May, 24 October) were obtained at Green Branch and 41 samples (10 March, 18 May, 13 October) at Bill's Branch. Since the samples respresented storm conditions rather than antecedent baseflow conditions, the flow values corresponding to the suspended solids samples were adjusted to storm flow by subtracting the baseflow component from the total flow. The technique used for separating baseflow is shown in Appendix A,[23] and the total flow, storm flow, and suspended solids sample values for each storm are listed in Appendix B.

B. Data Analysis for Regression Equations

The flow and suspended solids data were considered as instantaneous values rather than total storm loads since more flexibility in a regression model is gained due to a larger number of degrees of freedom. To provide a starting point in determining the model form and to offer a point of comparison with sediment production from an urban area, the model form $SS = a\ Q^b\ TFSS^c$ established by Colston for the 1.67 square mile Third Fork Creek Basin in Durham, North Carolina was chosen. Using the data from the three analyzed storms and the Colston equation format the a, b, and c parameter values were optimized using the nonlinear least

squares technique "The Method of Differential Correction" (DIFCOR).[13] In case, the problems associated with using a model form that would not fit the data and the sensitivity problems associated with locating an adequate initial guess of the parameters necessitated the use of the linear least squares technique, BMDO2R;[24] the data was log transformed and the resulting equation used was in the form

$$\ln(SS) = \ln(a) + b \ln(Q)$$

A suspended solids rating curve for each of the two strip mined watersheds was established by transforming the logarithmic regression equation back to the rating curve form $SS = aQ^b$. The 90% confidence bands for the regression equations were established to present the possible range of solids values around the mean response functions. To establish a point of comparison for urban and strip mined land uses, concentrations and the associated 90% confidence intervals were calculated for the same storm event using the rating curves. The peak flow value from the largest recorded storm event at Green's Branch (a two year storm)[22] was chosen as the point of comparison. The concentrations and confidence intervals at this peak flow value were calculated for Bill's Branch, Green Branch and Colston's watershed. An example of the technique for determining the confidence intervals for a mean response is outlined in Appendix A.[25]

C. Data Analysis for Betson's Model

Colston's model allows for a comparison of the suspended solids production from an urban area to that of the strip mined watersheds. A similar comparison is possible with forested watersheds using the

suspended solids rating curve for the Tennessee Valley established by Betson.

The a and b parameters in Betson's equation

$$CONC = a \left(\frac{Q}{DA}\right)^{b}$$

were determined for undisturbed, forested conditions at Bill's Branch and Green Branch. Concentrations for mining conditions at these branches were determined by subtracting the fraction stripped within the watershed from the fraction forested factor for undisturbed conditions. The fraction forested factor and other watershed characteristics were used in the summer equations for a and b reported by Betson. These summer equations were used to predict an average daily concentration for the day of the two-year storm, since the two-year storm occurred during the summer season on July 5, 1976. A sample calculation of the a, b, and CONC values is presented in Appendix A. The soil erodibility factors for the equations were defined by the Soil Conservation Service for the region.

An average daily concentration for Bill's and Green Branches under unmined conditions was generated using Betson's equation and the mean daily flow from the day of the two-year storm at Green Branch. A comparison was made with average daily concentrations for the two strip mined watersheds and Colston's urban watershed using the concentrations from the rating curves for the storm flow conditions for the day of the two-year storm. Because the concentrations predicted using Betson's model were based on the mean daily flow these concentrations represented total flow conditions. The regression equations used to generate concentrations

for Bill's and Green Branches and Colston's watershed were established for storm flow conditions so these concentrations represented storm flow concentrations. The assumption was made that base concentrations were negligible relative to storm concentrations. This assumption was based on data taken at baseflow conditions during the weekly sampling periods. The average daily concentration values for Betson's model and the regression equations are reported in the chapter of results.

CHAPTER IV

RESULTS

A. Regression Equation Results

In using Colston's rating curve form with independent variables of flow (Q) and time from start of storm (TFSS) For predicting suspended solids (SS) concentrations in mg/l, the following equation was developed for Green Branch:

$$SS = 93.19Q^{1.45}TFSS^{.14} \qquad r^2 = .78$$

The nonlinear least squares technique, DIFCOR was used to determine the optimized parameters. In trying to use this equation form and optimization technique to establish a relationship for Bill's Branch the DIFCOR program would not fit the data and optimize the parameters.

To relate the concentrations from Green Branch and Colston's model using the predictive equations for a storm event, the determination of the 90% confidence bands was the next step.

The confidence intervals using two independent variables are calculated in two separate planes. One plane is the confidence interval for the first independent variable and the second plane is the confidence interval for the second independent variable. This method assumes the independent variables are not interrelated. The independent variables Q and TFSS in Colston's equation are interrelated so this assumption presents a problem. The confidence intervals are also based on a linear form of the equation but the DIFCOR program established a nonlinear form. Because of these two problems, the inability of DIFCOR to fit the Bill's

Branch data, and TFSS not being a major contributor to a change in concentrations as evidenced by the low parameter values .14 (Green Branch) and -.16 (Colston) of TFSS, the parametric model form was reduced to $SS = a\ Q^b$ and the linear least squares regression technique in BMDO2R was used to fit the data. The data was log transformed and the regression program fitted the equation: $\ln SS = a + b \ln Q$.

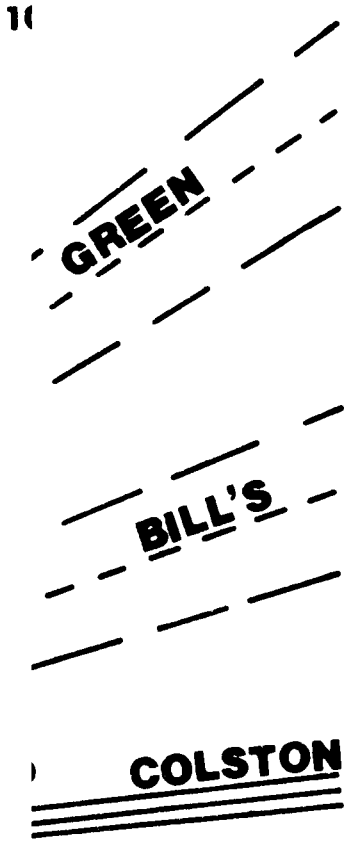
The results of this linear regression on the log transformed data for the two strip mined watersheds and the two unstripped watersheds are presented in Table 2 along with Colston's equation. The graph of the equations for Bill's and Green Branches and Colston's watersheds and the 90% confidence intervals is presented in Figure 5. The suspended solids concentrations and their range of values at the peak flow (Q_p = 167 cfs) for the two-year storm from Green Branch are located on this graph and summarized in Table 3. From the graph and the actual 90% confidence interval values, the conclusion is that at the peak flow value from the two-year storm event at Green Branch the suspended solids concentrations for the two strip mined watersheds were greater than the concentration of the urban watershed. Because of the overlap of the confidence intervals for flow less than 10 cfs, a conclusion of higher or lower concentrations within this region would not be valid.

B. Average Daily Load Results

In determining the variables to calculate Sa and Sb in Betson's model, the value of the soil erodibility factor, K_{32}, was not well defined. K_{32} is the fraction of the soil having an erodibility factor greater than .32, and the Soil Conservation Service reported the soils in this area

Table 2. Regression Equations

Branch	Land Use	Number of Observations	Regression Equation	r^2
Anderson	Unmined	14 (March 5) 12 (May 28)	$SS = 36.42\ Q^{.53}$	.13
	Disturbed	5 (Aug. 28) 14 (Oct. 6)	$SS = 1498.92\ Q^{.28}$	.11
Lowe	Unmined	12 (March 5) 10 (May 28) 3 (Aug. 28) 10 (Oct. 6) 35 Total	$SS = 15.17\ Q^{.24}$	.09
Bill's	Stripped	10 (March 5) 18 (May 28) 13 (Oct. 6) 41 Total	$SS = 211.79\ Q^{.77}$	.75
Green	Stripped	8 (March 5) 14 (May 28) 24 (Oct. 6) 46 Total	$SS = 103.23\ Q^{1.49}$	.79
Colston	Urban	415	$SS = 308.33\ Q^{23}TFSS^{-.16}$	.76



1000.0

Table 3. Confidence Intervals at Peak Flow (167 cfs) for July 5, 1976 Storm

Branch	Equation	Interval Range (mg/l)		
		Low	Mean	High
Green	$SS=103.23Q^{1.49}$	99,840	210,989	445,913
Bill's	$SS=211.79Q^{.77}$	5,474	11,083	22,437
Colston	$SS=308.33Q^{.23}$	886	1,001	1,130

to have an erodibility factor of .28. By definition the K_{32} factor for Bill's Branch and Green Branch should be zero. Using a value of zero in the calculation of Sa would have resulted in a zero value for Sa, therefore, a value close to zero (.001) was assumed to calculate Sa. All of the variables used to calculate Sa and Sb, and the resulting Sa and Sb values are presented in Table 4.

The mean daily flow for July 5, 1976 at Green Branch was 17 cfs and 12 cfs for Bill's Branch. Using the Sa and Sb values previously calculated, the drainage area of the basin and a mean daily flow, an average daily load in pounds per day was calculated. These values for the two watersheds for both forested and strip mined conditions, and average daily loads computed from the established equations for Green, Bill's and Colston's watershed are presented in Table 5.

The average daily loads for Bill's and Green Branches using the established equations are higher than the average daily loads for the urban watershed using Colston's equation. In comparing the loads from Betson's model for stripped conditions to the regression equation loads the values from Betson's model are significatly lower. The values for stripped conditions for Betson's model are only slightly higher than those calculated for forested or unstripped conditions. This slight difference and the lower value for Betson's model for stripped conditions could be attributed to the fact that Betson's model was developed for rural areas without significant point pollution sources such as mining, and just the change in the percent forested variable did not fully account for the

Table 4. Watershed Characteristics for Betson's Model

Branch	DA(mi^2)	SL(Ft/mi/10)	$\overline{RF}$(in/100)	FF(Fraction)	K_{32}(Fraction)	Sa	Sb
Green							
Stripped	1.38	194.30	.5	.76	.001	12.44	.461
Unmined	1.38	194.30	.5	1.0	.001	12.44	.389
Bill's							
Stripped	.672	202.75	.5	.90	.001	10.03	.588
Unmined	.672	202.75	.5	1.0	.001	10.03	.554

Table 5. Average Daily Loads Simulated for July 5, 1976 Storm

Branch	Equation	Land Use	Avg. Daily Load (lbs/day)
Green	$SS=103.23Q^{1.49}$	Stripped	10,955,750
Bill's	$SS=211.79Q^{.77}$	Stripped	904,565
Colston	$SS=308.33Q^{.23}TFSS^{-.16}$	Urban	122,386
Betson Green	$SS=12.44\left(\frac{Q}{1.38}\right)^{.389}$	Forested	3,038
	$SS=12.44\left(\frac{Q}{1.38}\right)^{.461}$	Stripped	3,629
Betson Bill's	$SS=10.03\left(\frac{Q}{.672}\right)^{.554}$	Forested	3,744
	$SS=10.03\left(\frac{Q}{.672}\right)$	Stripped	4,521

disturbance from mining. Further definition of the soil erodibility variable, K_{32} or the re-evaluation of the variables determining a and b to indicate a change from forested to mining conditions could better define mining contributions.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

A. Summary

In evaluating the results presented in the previous chapter this study has formulated a model of suspended solids concentrations for storm conditions at the two strip mined watersheds, Bill's and Green Branch. In optimizing the parameters and the feedback process the model form was reduced from $SS = a\ Q^b\ TFSS^c$ to $SS = a\ Q^b$. To determine the effects of strip mining on suspended solids concentration in a stream, average daily loads were calculated using the established rating curves for strip mined conditions, Colston's rating curve for urban conditions, and Betson's model for forested and for strip mined conditions. A comparison of expected concentrations at a peak flow from the two-year storm at Green Branch for strip mined and urban conditions using the established rating curves and Colston's equation also offered an evaluation of the effects of strip mining on water quality. The results of these two comparisons are:

1. The suspended solids concentrations for the two strip mined watersheds at the peak flow value from the two-year storm event at Green Branch are greater than the concentration of the urban watershed at this flow value.

2. The average daily loads generated from the established rating curves for the day of the two-year storm also indicate higher values for the two strip mined watersheds than for Colston's urban watershed.

3. The average daily load calculated for forested or unstripped

land use conditions for Bill's and Green Branches using Betson's model is lower than the value for the computed loads in the two strip mined and the urban watersheds.

B. Conclusions

The results of this study have satisfied the objectives of model formulation, parameter optimization, feedback to refine the model and an initial evaluation of the effects of strip mining on water quality through a comparison with an urban watershed (Colston's model) and a forested watershed (Betson's model). The conclusions from this modeling process are:

1. One must be cautious in using Betson's daily average model for watersheds with large nonpoint or point sources of pollution. Betson's model was developed for forested watersheds without these major sources of pollution, and the confidence one has in using Betson's equation for forested conditions is dependent on the reliability of the equations used to define the "a" and "b" parameters.

2. The model $SS = a\ Q^b$ should be used with discretion as a predictive equation based on the fit of the data defined by the r^2 values and the confidence intervals.

3. At this point in time the modeling process is in the feedback loop to refine the model. Refining the model may require changing the model form, changing the independent variables or gathering more data.

4. Following the steps in the parametric modeling process using the equation form $SS = a\ Q^b$ proved to be a successful approach to begin the parametric modeling of suspended solids. The success of this approach

rather than the success of the actual model form is the major contribution of this thesis toward modeling the suspended solids portion of the sediment load in strip mined watersheds.

C. Recommendations

1. More storm data should further define the relationship between flow and suspended solids with special emphasis on data at greater flows.

2. A comparison of the suspended solids data with an urban watershed of similar size and from the same physiographic province as the New River Basin should better define the comparison between stripped and urban conditions.

3. The relationship between suspended solids concentrations for storm conditions and other variables such as rainfall characteristics and soil characteristics needs investigation.

4. With more data and further evaluation of the factors affecting suspended solids production the steps for parametric modeling outlined in Figure 2 should be followed.

5. The suspended solids loads at Anderson and Lowe Branches should be analyzed to offer a comparison with unstripped conditions in the New River Basin.

6. More storm data may allow the development of a parametric model in terms of total storm load similar to the form of the Universal Soil Loss Equation. Storm data is needed for both the bedload component and the suspended load component of the total storm sediment load in order to make any comparisons with the total load predicted by the Universal Soil Loss Equation.

LIST OF REFERENCES

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1. Grissinger, E. H. and L. L. McDowell. "Sediment in Relation to Water Quality." Water Resources Bulletin, vol. 6, no.1 (January - February 1970), pp. 7 - 14.

2. "Erosion and Sediment Control: Surface Mining in the Eastern United States," Environmental Protection Agency Technology Transfer EPA - 625/3-76-006, October 1976.

3. McElroy, A. D., S. Y. Chiu, J. W. Nebgen, A. Aleti, and F. W. Bennett. "Loading Functions for Assessment of Water Pollution from Nonpoint Sources," Environmental Protection Technology Series EPA-600/2-76-151, May 1976.

4. Minear, Roger A. and B. A. Tschantz. "The Effect of Coal Surface Mining on the Water Quality of Mountain Drainage Basin Streams," Journal of the Water Pollution Control Federation, vol 48, no.11 (November 1976), pp. 2549 - 2569.

5. Ellison, W. D. "Studies of Raindrop Erosion," Agricultural Engineering (April 1944), pp. 131 - 136.

6. Ellison, W. D. "Studies of Raindrop Erosion," Agricultural Engineering (May 1944), pp. 181 - 182.

7. Ellison, W. D. "Raindrop Energy and Soil Erosion," Empire Journal of Experimental Agriculture, vol. 20, no. 78 (1952), pp. 31 - 97.

8. Musgrave, G. W. "The Quantitative Evaluation of Factors in Water Erosion, a First Approximation," Journal of Soil and Water Conservation, 2(1947), pp. 133 - 138.

9. Wischmeier, W. H. and D. D. Smith, "Predicting Rainfall - Erosion Losses from Cropland East of the Rocky Mountain," U. S. Dept. of Agriculture Handbook No. 282, Agricultural Research Service (1965), pp. 47.

10. Wischmeier, Walter H. "Rainfall Erosion Potential," Agricultural Engineering (April 1962) pp. 212 - 225.

11. Kirkpatrick, John C., R. T. Seith and O. R. Allen. "Pilot Plant Evaluation of Soil Losses from Disturbed Land," Third Symposium on Coal Mine Drainage Research (May 1970), pp. 24 - 41.

12. Williams, J. R., and H. D. Berndt. "Sediment Yield Computed with Universal Equation," Journal of the Hydraulics Division, ASCE, HY12 (December 1972), pp. 2087 - 2098.

13. Overton, D. E. and M. E. Meadows. Stormwater Modeling. New York: Academic Press, 1976.

14. Flaxman, E. M. "Predicting Sediment Yield in Western United States," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, HY12 (December 1972), pp. 2073 - 2085.

15. Betson, Roger P. and William M. McMaster. "Nonpoint Source Mineral Water Quality Model," Journal of the Water Pollution Control Federation, vol. 47, no. 10 (October 1975), pp. 2461 - 2473.

16. Betson, Roger P., "Urban Hydrology - A Systems Study in Knoxville, Tennessee," Tennessee Valley Authority, Division of Water Management, June 1976.

17. Colston, N. V., Jr., "Characterization and Treatment of Urban Land Runoff," Environmental Protection Technology Series EPA - 670/ 2-76-096, December 1974.

18. Curtis, Willie R. "Strip Mining, Erosion and Sedimentation," Transactions of the American Society of Agricultural Engineers, vol. 14, no. 3 (1971), pp. 434 - 436.

19. Curtis, Willie R. "Terraces Reduce Runoff and Erosion on Surface-mine Benches," Journal of Soil and Water Conservation, vol. 26, no. 5 (September - October 1971), pp. 198 - 199.

20. Collier, Charles R., J. J. Musser, J. W. Roehl and A. S. Johnson. "Influences of Strip Mining on the Hydrologic Environment of Parts of Beaver Creek Basin Kentucky, 1955 - 59," Geological Survey Professional Paper 427 - B, pp. B48 - B66.

21. Herricks, Edwin E., V. O. Shanholtz and D. N. Contractor. "Hydrologic and Water Qualtiy Modeling of Surface Water Discharges from Mining Operations," Department of Agricultural Engineering Research Division, Virginia Polytechnic Institute and State University (January 1975), pp. 1 - 44.

22. Bowers, M. H., "Stormwater Response of Small, Virgin and Strip Mined Watersheds Within the New River Basin," Master's Thesis, University of Tennessee, March 1977.

23. "Storm Hyrographs Using a Double-Triangle Method," Tennessee Valley Authority, Division of Water Control Planning, Hydraulic Data Branch, Hydrologic Research and Analysis Staff. Knoxville: 1973.

24. Dixon, W. S. ed., "Stepwise Regression," Biomedical Computer Programs (1973), pp. 305 - 319.

25. Walpole, R. E. and R. H. Myers. Probability and Statistics for Engineers and Scientists. New York: The Macmillan Company, 1972.

APPENDICES

APPENDIX A

SAMPLE CALCULATIONS

CALCULATION OF 90% CONFIDENCE LEVELS

Example: Green Branch Q = 167 cfs

Equation of the confidence interval for the mean response (Ref. 25)

$$\hat{y}_o - t_{\alpha/2} S \left[\frac{1}{n} + \frac{(x_o - \bar{x})^2}{S_{xx}} \right]^{1/2} < \mu_{y/x_o} < \hat{y}_o + t_{\alpha/2} S \left[\frac{1}{n} + \frac{(x_o - \bar{x})^2}{S_{xx}} \right]^{1/2}$$

From linear regression

$n = 46$

$S = .627$

$S_{xx} = 29.565$

$\bar{x} = 1.34182$

$\hat{y} = 4.637 + 1.4894x$, where $x = \ln Q$, $\hat{y} = \ln SS$

From statistical tables for the Student's t distribution

$t_{\alpha/2}$(44 degrees of freedom, $\alpha = .1$) = 1.6814

For Q = 167 $\hat{y} = 12.2596$

Calculating the confidence interval using these numbers results in the following range:

Low	High
11.5113	13,0079

These numbers are in terms of the log transformed data, therefore take the antilog of the numbers to give the actual SS range.

Low	Mean	High
99,840	210,989	445,913

CALCULATION OF BASEFLOW[23]

Example: Bill's Branch (May 28, 1976) storm

8:40 (5/28) storm begins flow = .334 cfs

13:00 (5/28) storm peak flow = 9.45 cfs

$$Q_{final} = .10(Q_{peak} - Q_{initial}) + Q_{initial}$$

$$Q_{final} = .10(9.45 - .334) + .334 = 1.25 \text{ cfs}$$

From the stage gage readings a flow of 1.25 cfs occurred at approximately 21:00 (5/28)

$$\frac{Q_{final} - Q_{initial}}{T_{final} - T_{initial}} = \text{slope of the line defining baseflow}$$

$$\frac{1.25 - .334}{21:00 - 8:40} = .074$$

At t - 9:00

$$\text{Baseflow} = \text{slope}\ (T_t - T_{initial}) + Q$$

Baseflow = .074(9:00 - 8:40) + .334 = .358 cfs

Storm flow = total flow - baseflow

Storm flow = .373 - .358 = .015 cfs

CALCULATIONS OF Sa, Sb and CONC FOR BETSON'S MODEL

Equations used:

$$Sa = 17.47 \times K_{32}^{.364} \times DA^{.30} \times SL^{.401} \quad (r = .77) \quad \text{(Ref. 16)}$$

$$Sb = 1.474 \times RF^{2.32} \times DA^{.049} \times FF^{-.585} \times K_{32}^{-.115} \quad (r = .68)$$

$$CONC = a \left(\frac{Q}{DA}\right)^{b}$$

Example: Green Branch (unstripped conditions)

$K_{32} = .001$

$DA = 883 \text{ acres} = 1.38 \text{ mi}^2$

$SL = (\frac{36.8}{100} \times 5280)/10 = 194.3 \text{ ft/mi/10}$

$RF = 50 \text{ (Ref. 4)}/100 = .5 \text{ in/100}$

$FF = 1.0$

$$Sa = 17.47(.001)^{.369}(1.38)^{.30}(194.3)^{.401} = 12.44$$

$$Sb = 1.474(.5)^{2.32}(1.38)^{.049}(1)^{-.535}(.001)^{-.115} = .389$$

$Q = 17 \text{ cfs}$

$DA = 1.38 \text{ mi}^2$

$$CONC = 12.44 \left(\frac{17}{1.38}\right)^{.389} = 33.04 \text{ mg/l}$$

LOAD = 33.04 (Q) conversion

LOAD = 33.04(17)(5.4) = 3038 lbs/day

APPENDIX B

STORM DATA

GREEN BRANCH: MARCH 5, 1976 STORM

Storm Began: 12:10 (3/5/76)

Total Rainfall: .61 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
16:00	4.08	2.97	486
16:30	5.01	3.89	960
17:00	5.01	3.88	1006
17:30	4.52	3.38	778
18:00	4.08	2.96	516
19:00	3.09	1.92	410
20:00	2.58	1.39	380
22:00	2.25	1.02	47

8 observations

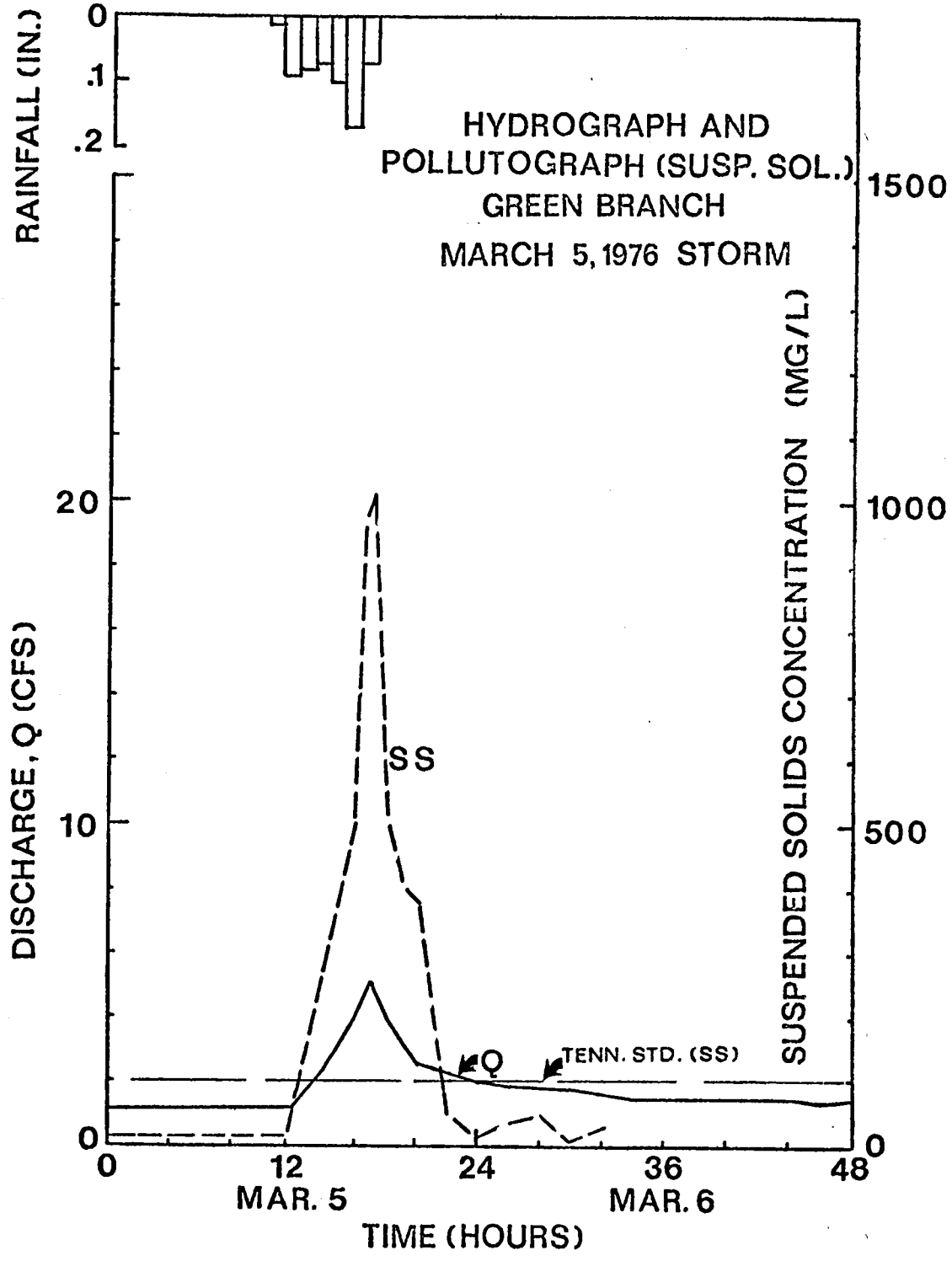


Figure A-1. Green Branch: March 5, 1976 Storm.

GREEN BRANCH: MAY 28, 1976 STORM

Storm Began: 10:00 (5/28/76)

Total Rainfall: .96 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
10:30	2.41	1.05	202
11:00	7.85	6.36	494
11:30	11.0	9.38	2490
12:00	10.2	8.45	2246
12:30	7.22	5.34	1578
13:00	20.8	18.79	6108
13:30	22.6	20.46	5548
14:00	13.9	11.63	3880
14:30	10.6	8.2	2490
15:00	12.2	9.67	1574
15:30	9.89	7.23	1020
16:00	8.54	5.75	946
16:30	8.19	5.27	738
17:00	7.22	4.17	704

14 observations

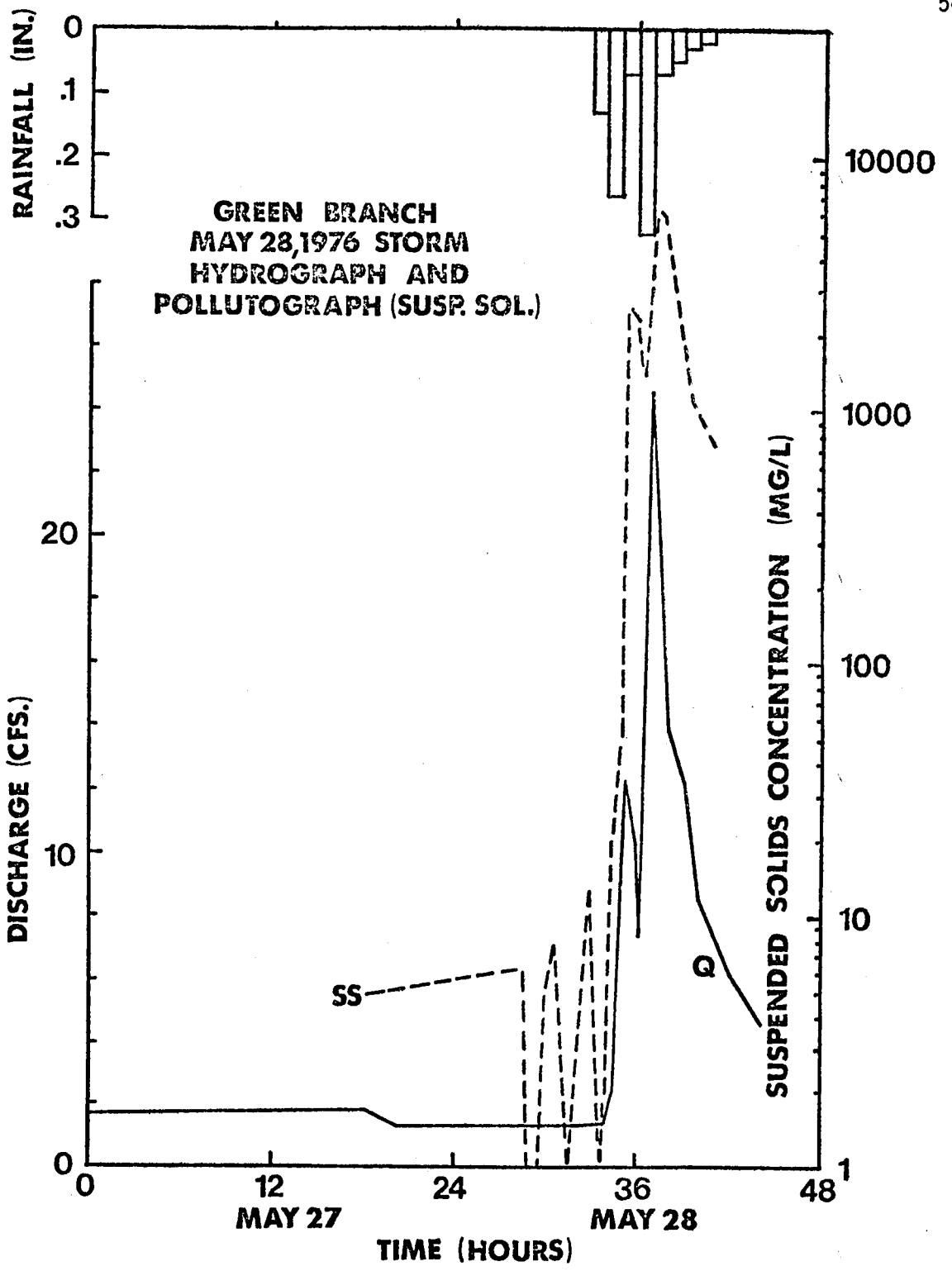


Figure A-2. Green Branch: May 28, 1976 Storm.

GREEN BRANCH: OCTOBER 6, 1976 STORM.

Storm Began: 7:10 (10/6/76)

Total Rainfall: .76 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
10:45	1.96	1.81	778
15:15	1.96	1.63	192
15:45	1.69	1.34	164
16:15	1.69	1.32	170
17:15	1.57	1.16	158
18:15	1.83	1.38	118
18:45	1.69	1.22	88
19:15	1.69	1.20	110
19:45	1.69	1.18	90
20:15	3.68	3.15	1498
20:45	9.55	9.00	2204
21:15	10.6	10.03	3344
21:45	9.23	8.64	3596
22:15	7.22	6.61	3168
22:45	6.09	5.46	2752
23:15	6.35	5.70	2368
23:45	7.53	6.86	2572
24:15	7.22	6.53	1882
1:15	5.27	4.54	1628
2:15	5.01	4.24	1656
3:15	4.29	3.48	1134
4:15	3.87	3.02	706
4:45	3.68	2.81	554
5:15	3.68	2.79	400

24 observations

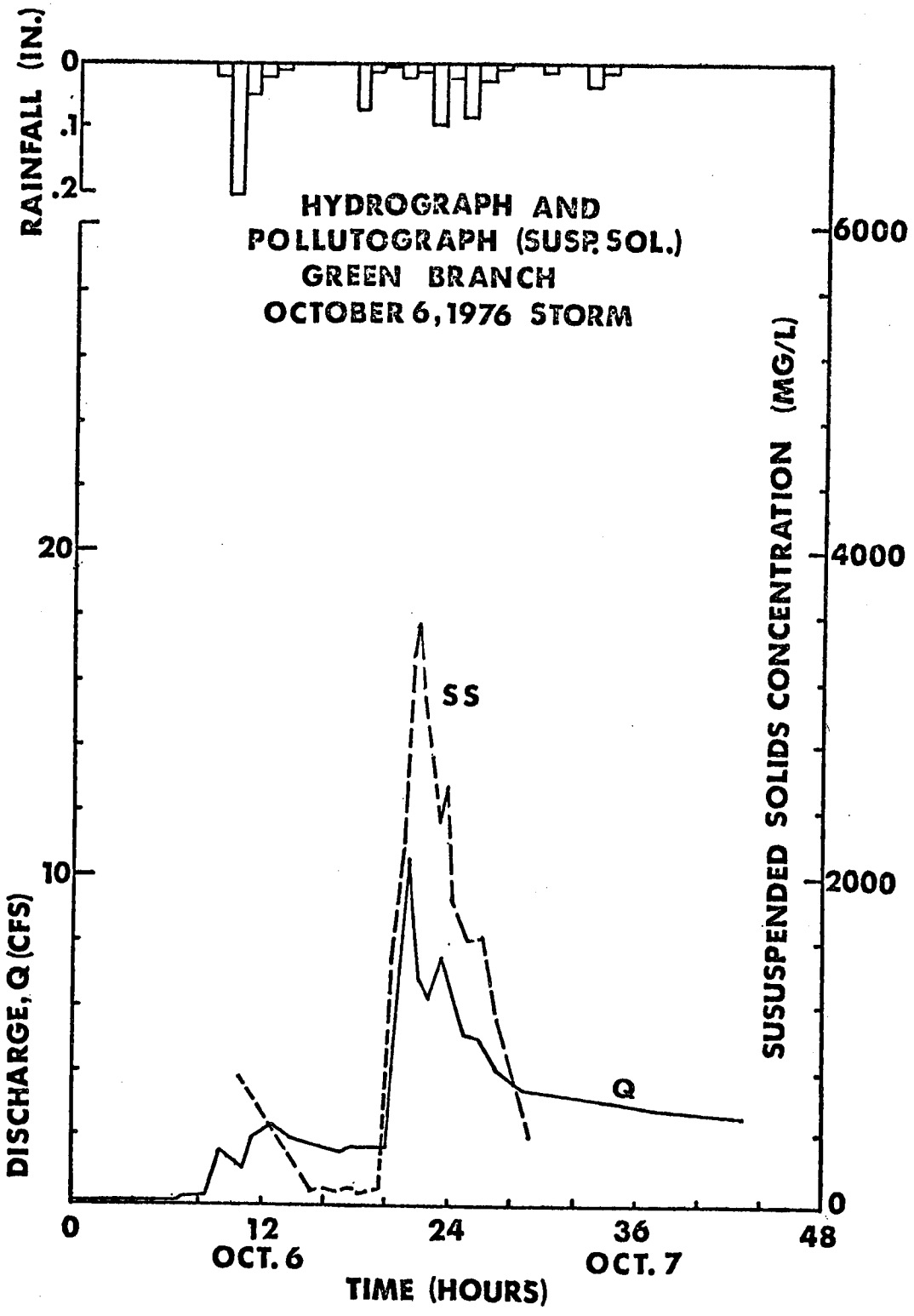


Figure A-3. Green Branch: October 6, 1976 Storm.

BILL'S BRANCH: MARCH 5, 1976 STORM

Storm Began: 10:50 (3/5/76)

Total Rainfall: .61 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
15:00	1.48	.763	100
15:30	1.64	.917	174
16:00	3.24	2.51	586
16:30	3.02	2.29	508
16:45	2.71	1.97	354
17:00	2.45	1.71	312
18:00	1.87	1.12	280
19:00	1.59	.827	296
21:00	1.30	.514	33
23:00	1.17	.361	15

10 observations

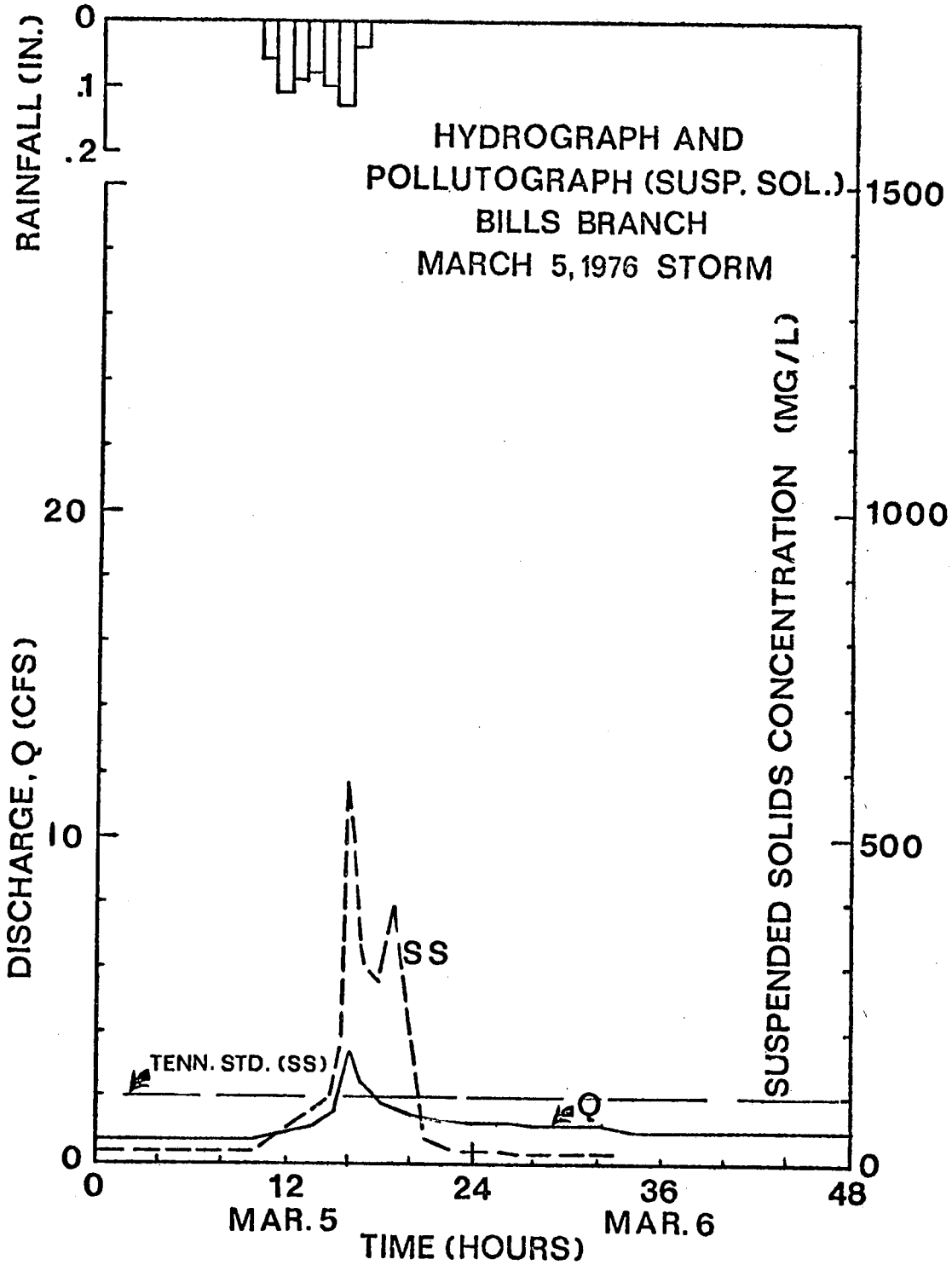


Figure A-4. Bill's Branch: March 5, 1976 Storm.

BILL'S BRANCH: MAY 28, 1976 STORM

Storm Began: 8:40 (5/28/76)

Total Rainfall: .95 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
8:45	.353	.013	18
9:00	.373	.015	3
9:15	.373	0.0*	13
9:30	.417	.022	20
9:45	.417	.003	31
10:00	.462	.03	9
10:30	.757	.288	61
10:45	1.06	.572	28
11:00	3.74	3.23	1248
11:15	4.10	3.58	1614
11:30	3.40	2.86	1226
12:00	2.54	1.96	874
12:30	2.22	1.60	632
13:00	9.45	8.80	1532
13:30	7.78	7.09	2330
14:00	4.98	4.25	1264
15:00	4.50	3.70	462
16:00	2.94	2.06	246
17:00	2.62	1.67	148

18 observations

*Data point not included.

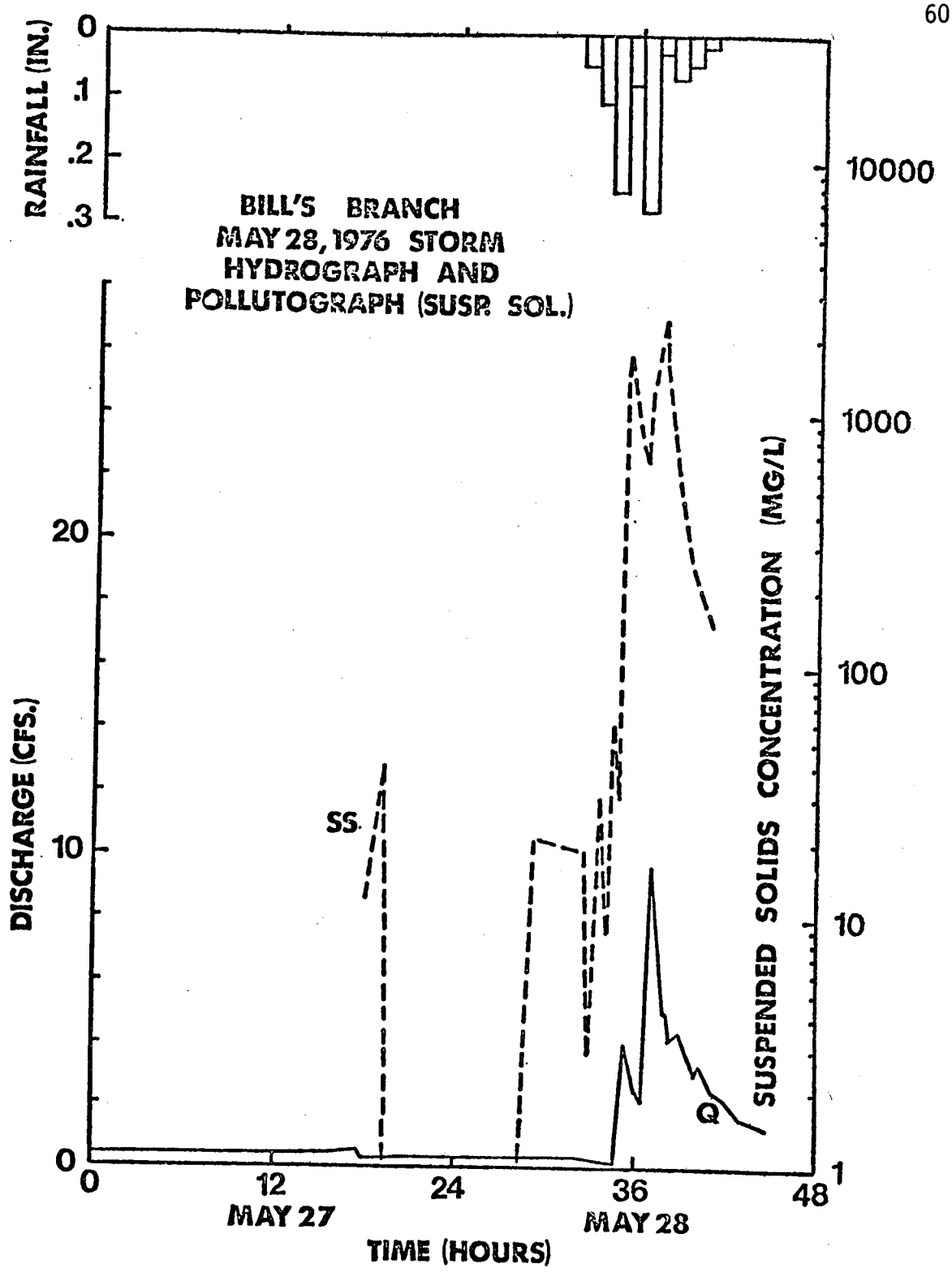


Figure A-5. Bill's Branch: May 28, 1976 Storm.

BILL'S BRANCH: OCTOBER 6, 1976 STORM

Storm Began: 7:15 (10/6/76)

Total Rainfall: .70 inches

Time	Total Flow (cfs)	Storm Flow (cfs)	Suspended Solids (mg/l)
12:00	.217	.130	42
15:45	.162	.075	26
19:30	.175	.088	12
20:00	.217	.130	46
20:45	.881	.794	142
21:00	2.00	1.91	614
21:15	2.54	2.45	658
22:15	1.17	1.08	206
23:15	1.75	1.66	182
23:45	2.71	2.62	360
1:45	.948	.861	116
5:45	.584	.497	30

13 observations

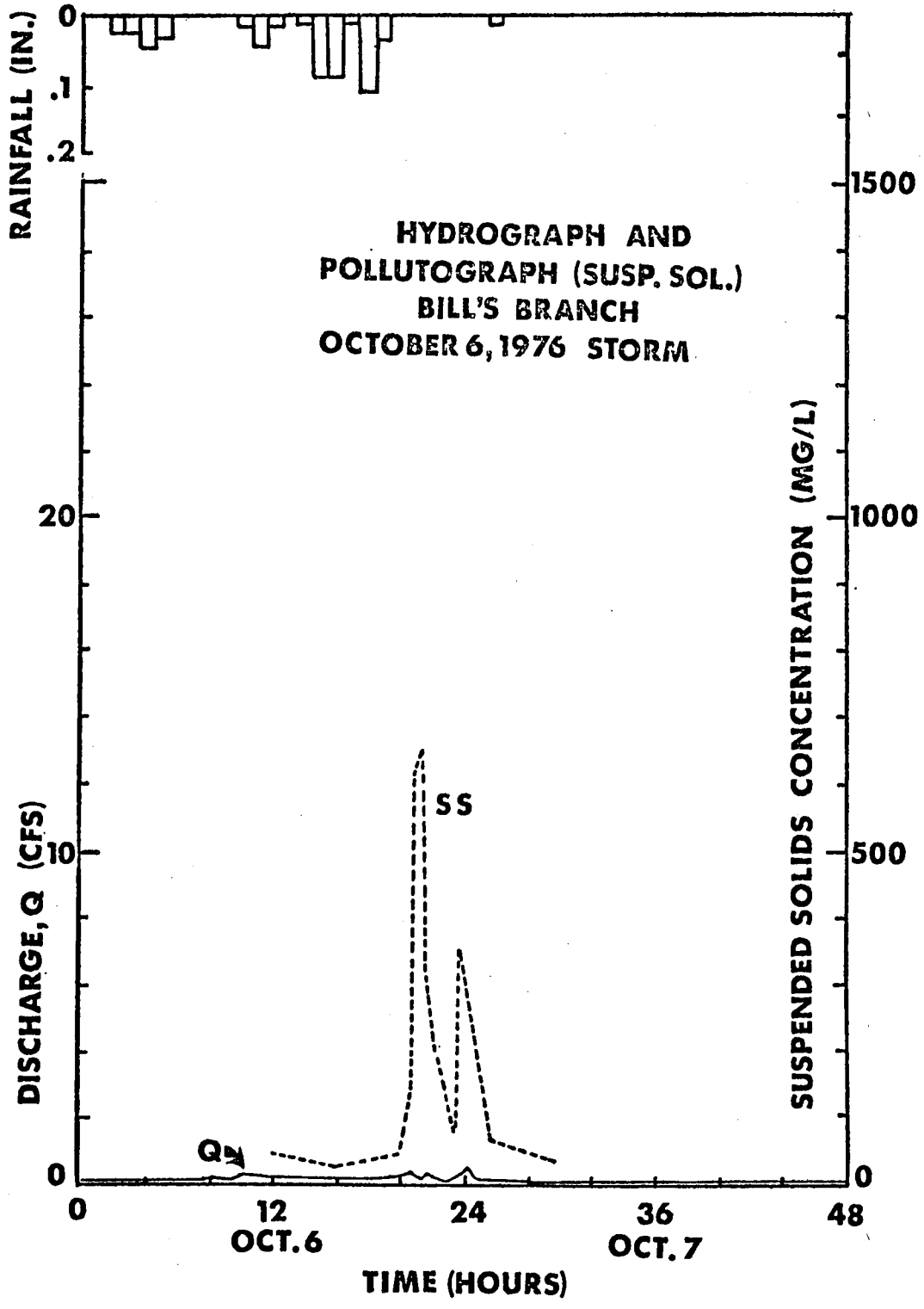


Figure A-6. Bill's Branch: October 6, 1976 Storm.

VITA

Nancy Ann Ward was born in Athens, Tennessee, on December 15, 1953. She attended elementary schools in Jackson, Mississippi, Starkville, Mississippi, and Nashville, Tennessee. In June 1971 she graduated from Hillsboro High School of Nashville and entered the University of Tennessee that fall. She received a Bachelor of Science degree in Civil Engineering with an emphasis in the area of soils and materials in March 1975. She entered graduate school at the University of Tennessee in March 1975 to begin study toward a Master's degree. After two quarters in Civil Engineering, she accepted a research assistantship in Environmental Engineering in January 1976. She received the Master of Engineering degree with a major in Environmental Engineering in March 1977.