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Regional Analysis of the Effects of Land Use on Stream Water Quality, Methodology and Application in the Susquehana River Basin, Pennsylvania and New York

U.S. Geological Survey, Portland, Oregon

May 78

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U.S. GEOLOGICAL SURVEY
Water-Resources Investigations 78-12

Prepared in cooperation with the
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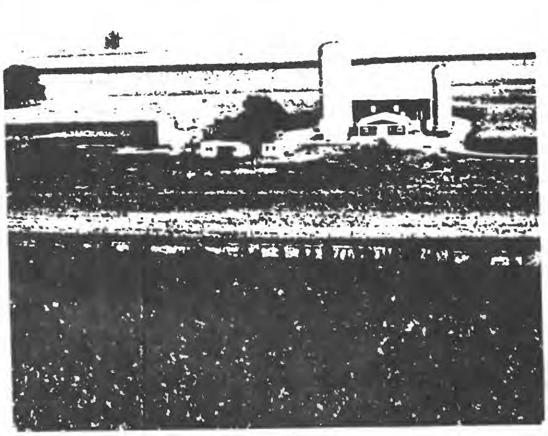
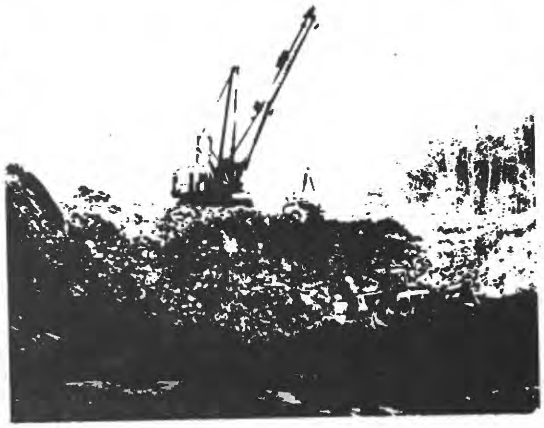

SUSQUEHANNA RIVER BASIN Water Resources Investigation 78-12

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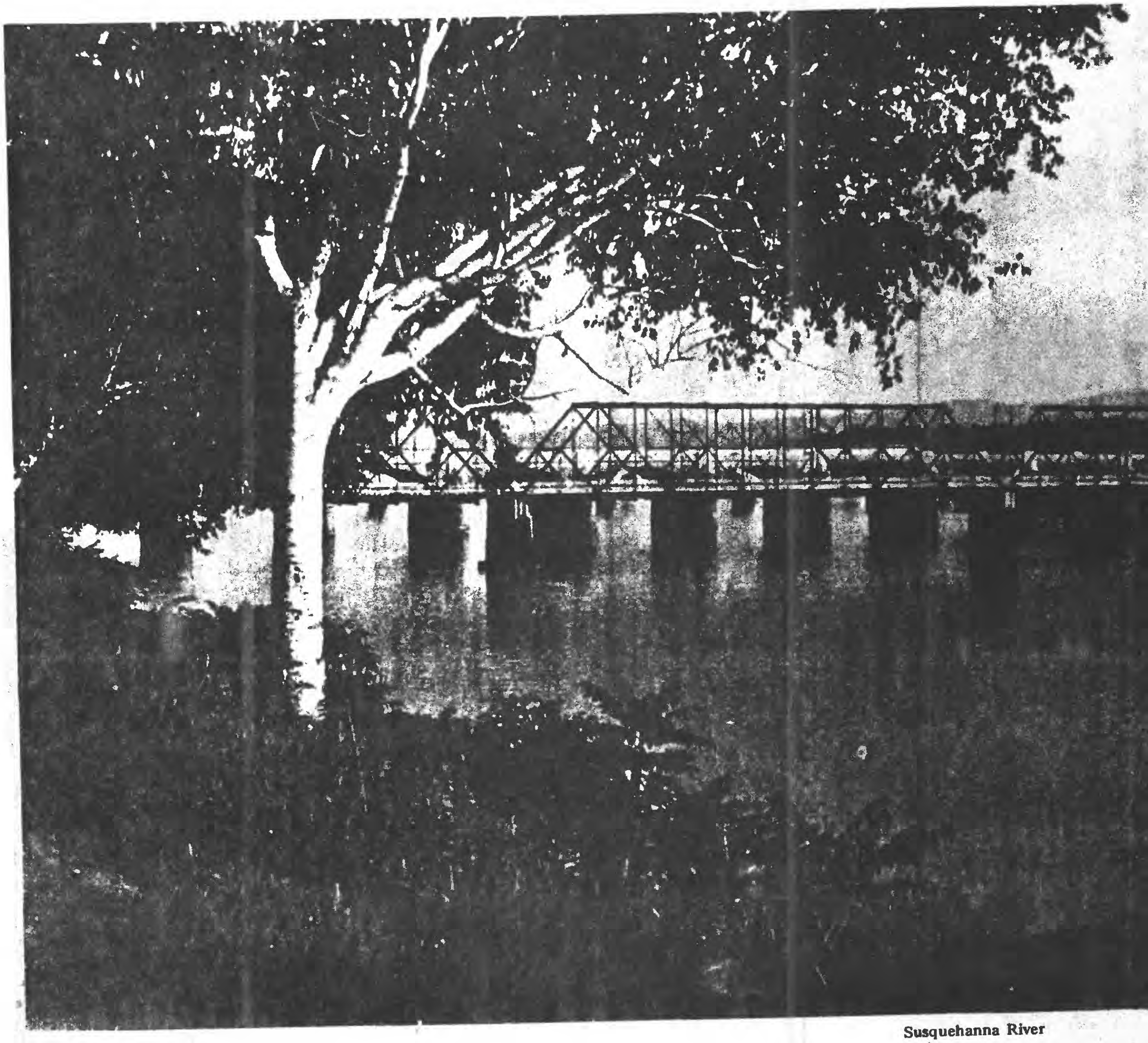
CONTENTS

ILLUSTRATIONS

TABLES

APPENDIXES



Susquehanna River

REGIONAL ANALYSIS OF THE EFFECTS OF LAND USE ON STREAM-WATER QUALITY, METHODOLOGY AND APPLICATION IN THE SUSQUEHANNA RIVER BASIN, PENNSYLVANIA AND NEW YORK

--

By David J. Lystrom, Frank A. Rinella, David A. Rickert, and Lisa Zimmermann

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ABSTRACT

This report presents a framework for compiling available data and for establishing statistical relationships between water quality and several regional factors of climate, physiography, and land use. The framework is applied to the Susquehanna River basin in Pennsylvania and New York. The Susquehanna River drains 27,510 mi^2 of diverse terrain and has a moderate climate.

A statistical approach is used in this study to assess the spatial variability of water quality among 80 subbasins of the Susquehanna River basin. Water quality, for purposes of this study, is defined by 17 characteristics of calculated annual yields or mean concentrations of suspended sediment, dissolved solids, and various chemical species of nitrogen and phosphorus. The water-quality characteristics are related experimentally to 57 basin characteristics which were compiled from available sources of data. The 57 basin characteristics were selected to account for nonpoint-sources of pollution or to describe processes which control the 17 water-quality characteristics. The six general categories of basin characteristics are (1) climate, (2) topography, (3) geology, (4) soils, (5) streamflow, and (6) land use.

Multiple-linear-regression equations were developed to relate water-quality characteristics (dependent variables) to basin characteristics (independent variables). Usable regression equations were developed for 14 of the 17 water-quality characteristics. These equations explain from 56 to 89 percent of the variation of the water-quality characteristics with standard errors of estimate ranging from 17 to 75 percent. The 14 regression equations can be used to estimate water quality at any stream site in the study region. These equations are also used to simulate generalized effects of specific basin characteristics on water quality. For example, simulated ranges of background water-quality characteristics can be generalized by mathematically removing the land-use variables from the regression equations. Comparison of

simulated ranges of background water quality to observed ranges gives a general indication of the effects of the land-use variables. For example, observed nitrate yields are as much as 20 times greater than simulated background yields. This increase is believed to be a result of animal wastes, the application of chemical fertilizers, and of increasing urbanization. Land-use variables affected by human activities and economic development had measurable impacts in all 14 of the usable regression functions.

It is concluded that this technique is a useful screening technique to assess the gross effects of land use and other basin variables on water quality in the Susquehanna River basin. On the basis of these results, it appears that similar regression-analysis techniques might be applicable to other regions.

INTRODUCTION

The concern over change in our environment which led to recent Federal legislation has also created an urgent need for practical methods to assess the relationship of water quality to land use. In response to the need, this report describes the application of regression techniques to describe the impact of land use on stream-water quality in the Susquehanna River basin, Pennsylvania and New York.

Background

The 2-year study summarized by this report was funded by the U.S. Environmental Protection Agency (EPA). The project objective was to develop a methodology for estimating the background water quality of rivers in the United States. Background water quality is needed as a basis for (1) assessing the level of culturally related nonpoint-source pollution, (2) developing realistic water-quality standards, and (3) formulating legislation concerning pollution abatement.

The project outline was formulated by a joint team from the U.S. Geological Survey and EPA. Four water-quality properties--suspended sediment, dissolved solids, nitrogen, and phosphorus--were selected for study because of wide concern about their impacts on stream water quality in rural areas undergoing rapid development. Suspended sediment, as an indicator of erosion and sedimentation, is considered by many to be the Nation's most critical nonpoint-source pollutant. Dissolved solids is of concern in heavily irrigated areas. Nitrogen and phosphorus from urban areas, agricultural fertilizer, animal feed lots, and irrigation return flow may stimulate eutrophication in streams and impoundments.

Specific objectives outlined for methodology development were:

1. Develop a methodology that is quickly and easily applicable for one large region, using existing data.

2. Provide a means to assess the general effects of land use on water quality and to estimate gross background streamflow quality.

3. Demonstrate the application of the methodology in layman's terms.

After the project outline was established, the authors began a survey of possible methodologies and study basins. Statistical and digital process-modeling techniques were quickly highlighted as the most promising methodologies. The statistical approach was chosen as the preferred method because the study required short-term results using existing data. The statistical approach was viewed as a first step, providing (1) initial answers on several key land-use and water-quality problems and (2) a basis for evaluating the need for more intensive assessments which might involve digital modeling and the collection of additional water-quality data.

Selection of the study basin involved consideration of available data on water quality, land use, and various characteristics of climate and terrain. Land-use and water-quality data were limited in many areas of the country. Through a screening process the Susquehanna River basin in Pennsylvania and New York was selected for the analysis.

Purpose and Scope

The purpose of this report is to (1) document the methods used to compile water-quality characteristics and the basin characteristics that affect water quality, and (2) demonstrate the feasibility of using multiple-regression analysis for regional water-quality assessment. The reported regression models are used to assess the generalized effects of land use on regional water quality. This approach may be useful in most areas of the United States for describing the extent of regional water pollution and for determining whether more detailed data and models are justified to evaluate the management alternatives needed to fulfill water-quality objectives.

Multiple-linear regressions are developed by standard statistical techniques. These regressions relate the spatial variations in water quality among 80 subbasins of the Susquehanna River basin to selected characteristics of climate, physiography, and land use. Water quality is represented here by yields and concentrations of suspended sediment, dissolved solids, and various species of nitrogen and phosphorus. The criteria for selecting and computing water-quality and basin characteristics are described in detail. Computed values of these characteristics are tabulated in the appendixes.

The regressions developed in this study generally represent the processes that affect regional water quality. The sensitivity of regression models to land use and natural basin characteristics is analyzed to minimize misuse. The accuracy, conceptual viability, and limitations of the regressions are discussed and examples are described to illustrate selected applications to management problems. In the examples, the culturally induced characteristics of land use are hypothetically removed from the regressions to provide indirect estimates of background water quality. By this approach, simulated ranges of background water quality are computed for subbasins throughout the study region. These results are used to define the relative effects of land-use variables on water quality and to estimate the expected ranges of water quality that would occur if land use approximated predevelopment conditions.

Planners and managers can also use the regression models to estimate water-quality characteristics for any subbasin of the Susquehanna River basin based on basin characteristics compiled from available data sources and information provided in the appendixes.

The regression models are tested by comparing observed water-quality characteristics to corresponding simulated results. The observed characteristics were computed from limited water-quality data collected during the 1976 and part of 1977 water years. These data were not used in determining the regression coefficients.

The approach used in this study is empirical and therefore direct applicability of the results is limited to the Susquehanna River basin and hydrologically similar adjacent areas. However, the general methodology is potentially applicable to any river basin or study region for which adequate data are available to define water quality and the appropriate basin characteristics.

BASIN SETTING

The Susquehanna River, which empties into the Chesapeake Bay, drains the largest basin along the east coast of the United States (area 27,510 mi^2), of which 76 percent is in Pennsylvania, 23 percent in New York, and about 1 percent in Maryland (Rudisill, 1976).

Physiography and Geology

The Susquehanna River basin spans four physiographic provinces (see fig. 1.): (1) the Appalachian Plateaus, (2) the Valley and Ridge, (3) the Blue Ridge, and (4) the Piedmont (Fenneman, 1928). The rocks of the Appalachian Plateaus province are nearly horizontal and are of Devonian, Mississippian, and Pennsylvanian age. They consist of alternating shale, siltstone, sandstone, limestone, and bituminous coal. The northeast part of the Appalachian Plateaus consists of flat-topped mountains and deeply incised stream valleys. The Valley and Ridge Province is underlain by folded and faulted rocks. The Valley and Ridge Province is characterized by a sequence of alternating shale, sandstone, and limestone of Paleozoic age which forms steep mountains and ridges separated by valleys. Only a small part of the Blue Ridge Province, which is underlain by crystalline rocks and contains deep, well-drained soils, lies within the Susquehanna River basin. The Piedmont Province consists of both uplands and lowlands, the former underlain by crystalline rocks and the latter by limestone, sandstone, and shale. The Piedmont generally has terrain that is gently rolling to hilly, and it has deep, well-developed soils.

Climate and Hydrology

The climate in the Susquehanna River basin is moderate. The length of the growing season ranges from 120 to 200 days and averages about 150 days. The growing season is shortest in parts of the Appalachian Plateaus and is longest near the mouth of the Susquehanna (Johnson, 1960; Kauffman, 1960).

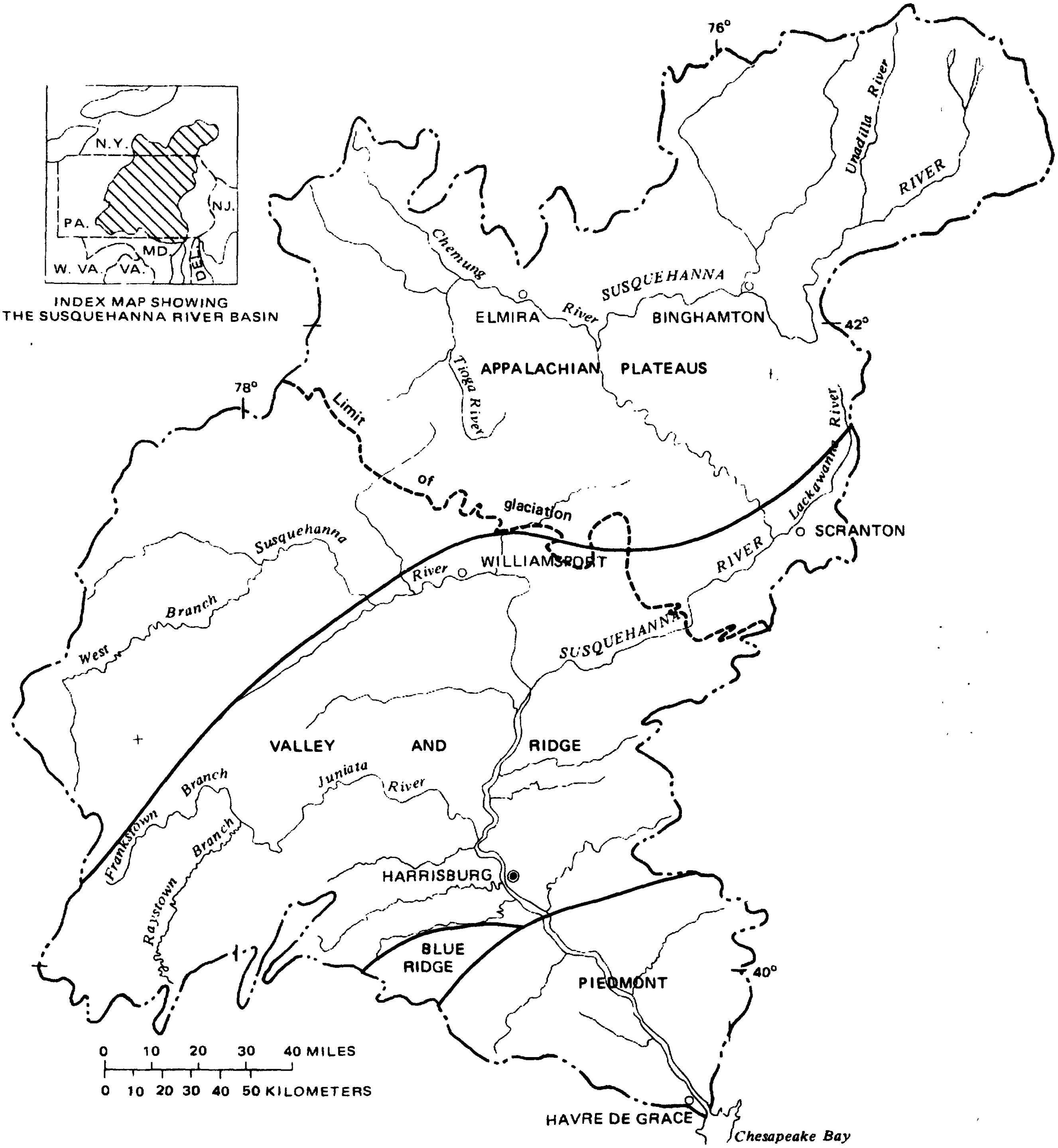

Figure 1.—Physiographic provinces of the Susquehanna River basin (Fenneman, 1928).

Average annual precipitation ranges from 32 inches in the northwestern part of the basin to 44 inches in the southern and east-central part, with a basin average of 40 inches.

About 50 percent of the precipitation over the Susquehanna River basin appears in the stream as runoff. The month-to-month variation in streamflow generally is more extreme than the variation in precipitation because of the large losses to evaporation and transpiration during the hot summer months and the impermeability of the soil during winter.

Streamflow is composed of water that reaches the stream by direct overland flow and by ground-water inflow which sustains base runoff. During baseflow periods the dissolved-solids concentration of the Susquehanna River is at a maximum because the chemical quality of the river water is affected by evaporation, ground-water inflow, and coal-mine drainage. As streamflow increases, the dissolved-solids concentration is lowered by dilution from direct runoff (Anderson, 1963).

Land Use

In the study region, climate, soils, and topography have influenced the use of the land for many decades. Where the soils are productive the flat-to-rolling countryside was commonly cleared for cultivation. Forests cover most of the land where the soils are poor or the slopes are too steep for cultivation.

Water quality in the Susquehanna River basin is greatly influenced by agriculture and the degree and type of urbanization and industrialization. In addition, streams receiving water from coal-mine fields are low in pH and high in iron, sulfate, and dissolved solids. Relatively little water is consumed by industry in the basin. About 60 percent of the Susquehanna River basin is covered by forest, 31 percent is used for agriculture, and 4 percent is urban (determined from Rudisill, 1976, p. 5, 13, 20, 31, 39, and 45).

APPROACH CONCEPTS

Water quality varies temporally and spatially within stream systems. These variations are a result of many complex processes which are controlled in large part by climate, physiography, and land use. Some of these controlling processes are well known; however, many are poorly known and some may still be unidentified.

The approach used in this study focused on establishing empirical relationships between water-quality characteristics and basin characteristics. The first step was to establish a conceptual framework for compiling available data. Water-quality and basin characteristics must be defined for a time period during which land-use and management techniques have remained relatively stable. Based on discussions with land-management and planning agencies in the basin, the 10-year interval from 1966 to 1975 was selected as the study period. Water-quality characteristics are defined by weighted or average annual concentrations, or average annual yields occurring during this period. Similarly, basin characteristics represent unique aspects of land-use, physical, and climatic conditions existing during the period. A simplified schematic diagram of the approach concepts is shown in figure 2.

The multiple-linear-regression approach (illustrated by the example in figure 2) is commonly used by hydrologists to define regional variations of streamflow as a function of basin characteristics. This method was applied extensively in 1969 and 1970 in a nationwide U.S. Geological Survey (USGS) program to provide a means for estimating streamflow characteristics of ungaged basins. (See Thomas and Benson, 1970; and Benson and Carter, 1973.) Similar studies have related water-quality characteristics to basin characteristics. (See for example Branson and Owen, 1970; Flaxman, 1972; Hindall, 1976; and Steele and Jennings, 1972.)

The multiple-regression approach provides a means of estimating water-quality characteristics at unsampled stream sites and of estimating the general effects of natural and cultural aspects of drainage basins on water quality. The principal advantage of this approach is that a multiple-regression model can be developed on the basis of available data and can be applied to a large region to define the general magnitude and possible causes of selected water-quality characteristics. From a regional vantage point, the approach provides information for reaching decisions on how to resolve certain water-pollution problems, and for determining where there is need for more sophisticated studies and the collection of more detailed data.

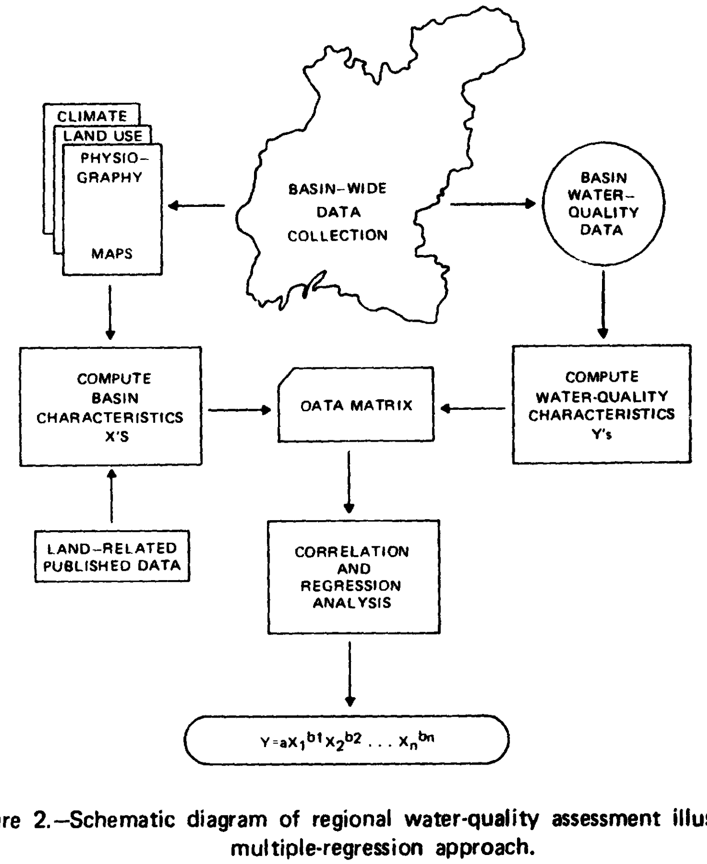

Figure 2.—Schematic diagram of regional water-quality assessment illustrating multiple-regression approach.

Regression Models

In this study the multiple-linear-regression technique is used to define spatial variations in water-quality characteristics as a function of the physical, climatic, and land-use aspects of stream drainages. The general form of a multiple-linear regression is

$$Y = a + b_1X_1 + b_2X_2 + \ldots b_nX_n \tag{1}$$

where Y is a water-quality characteristic (dependent variable), the X's are basin characteristics (independent variables), a is the regression constant, the b's are regression coefficients, and n is the number of basin characteristics. Nonlinear relationships between hydrologic variables have frequently been found to be linear if the variables are transformed to logarithms (Benson and Carter, 1973, p. 17). The general form of a log-transform regression is

$$\log Y = \log a + b_1 \log X_1 + b_2 \log X_2 + \ldots b_n \log X_n \tag{2}$$

An equivalent form of equation 2 is

$$Y = a\, X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n} \tag{3}$$

Because the logarithm of zero is undefined, a constant, such as 1.0, is added to all independent variables that could feasibly be zero. For example, the percent of agriculture (LU2) is zero for some basins used in this study. The method of computing the a and b constants is explained by Riggs (1968, p. 12-18). A system of statistical computer programs (STATPAC) was used to transform variables, compute regression coefficients, and perform other statistical tests (Sower and others, 1971).

Selection of Independent Variables

Selection of basin characteristics to be compiled for the analyses was based primarily on conceptual knowledge of the dominant sources and processes that affect water quality. Because implementation of the approach depends on availability of data, it was necessary in some cases to use a surrogate as an index of a variable that actually controls the particular process. For example, the percent of basin urbanized is a surrogate that can be used to define the effects of domestic sewage effluent on nutrient concentrations. Percent urbanization, however, is also a descriptor of overland urban runoff. It is important to recognize the limitations of surrogates to properly qualify assumptions about cause-and-effect relationships.

The process of selecting the most significant independent variables for each regression was complicated by the large number (57) of potential variables. Consequently, several trial-and-error regressions had to be computed for each water-quality parameter to derive the best equations. The final selection of a set of independent variables to form each regression equation was based on considerations and statistical criteria as follows:

1. Each independent variable must be statistically significant at the 95-percent level according to Students $\underline{t}$-test of significance (Draper and Smith, p. 305, 1966).

2. A combination of selected independent variables, as compared to other possible combinations, should (a) have the lowest standard error of estimate and (b) explain the greatest percent of variance of the dependent variable.

3. Combinations of cross-correlating independent variables (correlation coefficients greater than 0.6 or 0.7) should be minimized.

WATER-QUALITY CHARACTERISTICS

Available data were used to define one or more characteristics of sediment, dissolved solids, nitrogen, or phosphorus for 80 stream sites in the Susquehanna River basin. The sources of water-quality data used for this study were (1) the USGS WATSTORE water-quality computer file, (2) the USGS WATSTORE daily-values (streamflow) computer file, and (3) USGS annual publications "Water Resources Data" for Pennsylvania and New York, Part 2, 1966 to 1975. Figure 3 shows locations of the 80 stream-sampling sites and indicates which water-quality characteristics were computed for each site.

All water-quality data were transferred to magnetic tapes to facilitate computation of characteristics by use of computer programs written for this study. Although some additional data were available from other sources, these data were not used because there were differences in sampling procedures and laboratory-analysis techniques that might have caused inconsistencies among the data.

The methods of computing and selecting water-quality characteristics used for this study are based on: (1) the need for methods that are adaptable nationwide, (2) adaptability to the multiple-regression-analysis approach, and (3) availability of data. Several possible water-quality characteristics were excluded because of insufficient data. Two general criteria for including a water-quality characteristic in this study were: (1) a minimum of 20 sampling stations in the study region and (2) at least 10 samples collected at each station during 1 or more years within the study period.

The 17 water-quality characteristics considered in this study are as follows:

1. Suspended-sediment yield (SEDYLD): The average annual load per unit of contributing drainage area for the period of water years 1966 to 1975 (excluding 1972), in $(tons/mi^2)/yr$. Data for water year 1972 were excluded because of the extreme effect of tropical storm Agnes on sediment loads. The rationale for excluding 1972 is discussed under "Computation of suspended-sediment loads."

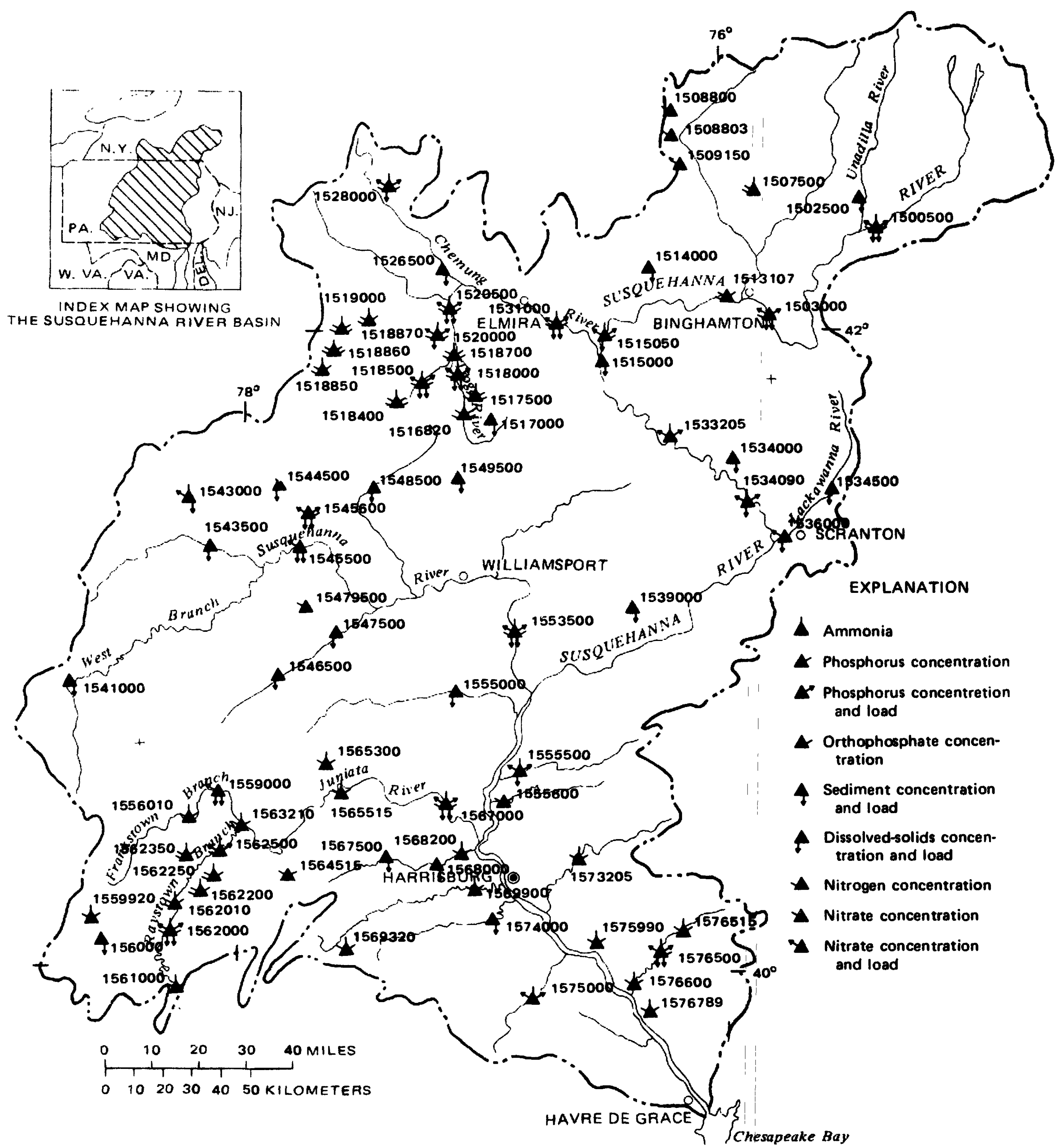

Figure 3.—Locations of stream-sampling sites in the Susquehanna River basin.

2. Suspended-sediment concentration (SEDCONC): The discharge-weighted average sediment concentration for the period of water years 1966 to 1975 (excluding 1972, see above), in mg/L.

3. Dissolved-solids yield (DSYLD): The average annual load of dissolved solids per unit of drainage area for the period of water years 1966 to 1975, in (tons/mi^2)/yr.

4. Dissolved-solids concentration (DSCONC): The discharge-weighted average annual dissolved-solids concentration for the period of water years 1966 to 1975, in mg/L.

5. Coefficient DSEXP of the transport curve relating dissolved-solids load, L_{ds}, in tons/day, to instantaneous discharge, Q, in ft^3/s. This relationship is defined by the equation log L_{ds} = log (DSCOEF) + (DSEXP) log Q. (See equation 13.)

6. Coefficient DSCOEF of equation 13 described above.

7. Nitrogen concentration (NAVE): The average total nitrogen concentration for each sampling site for the period of water years 1970 to 1975, in mg/L as N.

8. Standard deviation (NSD) about the average total nitrogen concentration (NAVE) for each sampling site for the period of water years 1970 to 1975, in mg/L as N.

9. Nitrate concentration (NO3AVE): The average total nitrate concentration for each sampling site for the period of water years 1970 to 1975, in mg/L as N.

10. Standard deviation (NO3SD) about the average total nitrate concentration (NO3AVE) for each sampling site for the period of water years 1970 to 1975, in mg/L as N.

11. Nitrate yield (NO3YLD): The average annual nitrate load per unit of drainage area for the period of water years 1966 to 1975, in (tons/mi^2)/yr as N.

12. Ammonia concentration (NH4AVE): The average total ammonia concentration for each sampling site for the period of water years 1970 to 1975, in mg/L as N.

13. Phosphorus concentration (PAVE): The average total phosphorus concentration for each sampling site for the period of water years 1970 to 1975, in mg/L as P.

14. Standard deviation (PSD) about the average total phosphorus concentration (PAVE) for each sampling site for the period of water years 1970 to 1975, in mg/L as P.

15. Phosphorus yield (PYLD): The average annual phosphorus load per unit of drainage area for the period of water years 1966 to 1975, in $(tons/mi^2)/yr$ as P.

16. Orthophosphate concentration (PO4AVE): The average total orthophosphate concentration for each sampling site for the period of water years 1970 to 1975, in mg/L as P.

17. Standard deviation (PO4SD) about the average total orthophosphate concentration (PO4AVE) for each sampling site for the period of water years 1970 to 1975, in mg/L as P.

Water-quality characteristics are tabulated in appendix 1 for 80 stream-sampling sites in the Susquehanna River basin. The following sections describe in detail the methods for computing each of the water-quality characteristics.

Suspended Sediment

Twenty-eight stream stations in the Susquehanna River basin have adequate data for computing average annual sediment loads for the study period (1966 to 1975 water years). Only one of these, Juniata River at Newport, Pa., has a complete record of daily loads. Twelve additional stations have published daily sediment loads for 1 or more years during the study period. The predominant source of available data is miscellaneous sediment concentrations in the U.S. Geological Survey's WATSTORE water-quality computer file.

Computation of Suspended-Sediment Loads

Average annual suspended-sediment loads are computed for the study period by the sediment-transport curve method. This method was shown by Miller (1951) to provide a useful method of computing annual sediment loads, and was also used for a previous stream-sediment appraisal in the Susquehanna River basin (Williams and Reed, 1972).

Sediment-transport curves are based on the relationship between sediment loads and discharges for each stream station. Daily sediment-load data were not available for most of the 28 stations; consequently, instantaneous loads were calculated for each instantaneous concentration and discharge by the equation

$$L_S = 0.0027\ C_S Q \tag{4}$$

where: L_S is the instantaneous sediment load in tons/day, C_S is the instantaneous sediment concentration in mg/L, Q is the instantaneous discharge in ft^3/s, and 0.0027 is a units conversion constant.

A computer program, REGPLOT, was developed for this study to plot instantaneous sediment loads (from eq. 4) versus instantaneous discharge as shown in figure 4. This program includes a least-squares curve-fitting routine for log-transformed linear and quadratic regression equations

$$\log L_s = \log a + b \log Q \quad \text{(linear)} \tag{5}$$

$$\log L_s = \log a + b \log Q + c (\log Q)^2 \quad \text{(quadratic)} \tag{6}$$

where L_s is instantaneous sediment load in tons/day; Q is instantaneous stream discharge in ft^3/s; and a, b, and c are regression coefficients. A transport curve for each stream station was defined by a single log-linear equation (eq. 5), or by a series of straight-line segments manually fitted to portions of a quadratic curve (eq. 6). The primary criterion for establishing a sediment-transport curve was a minimum of 10 data points that are reasonably well distributed over the range of daily discharges. Transport curves were

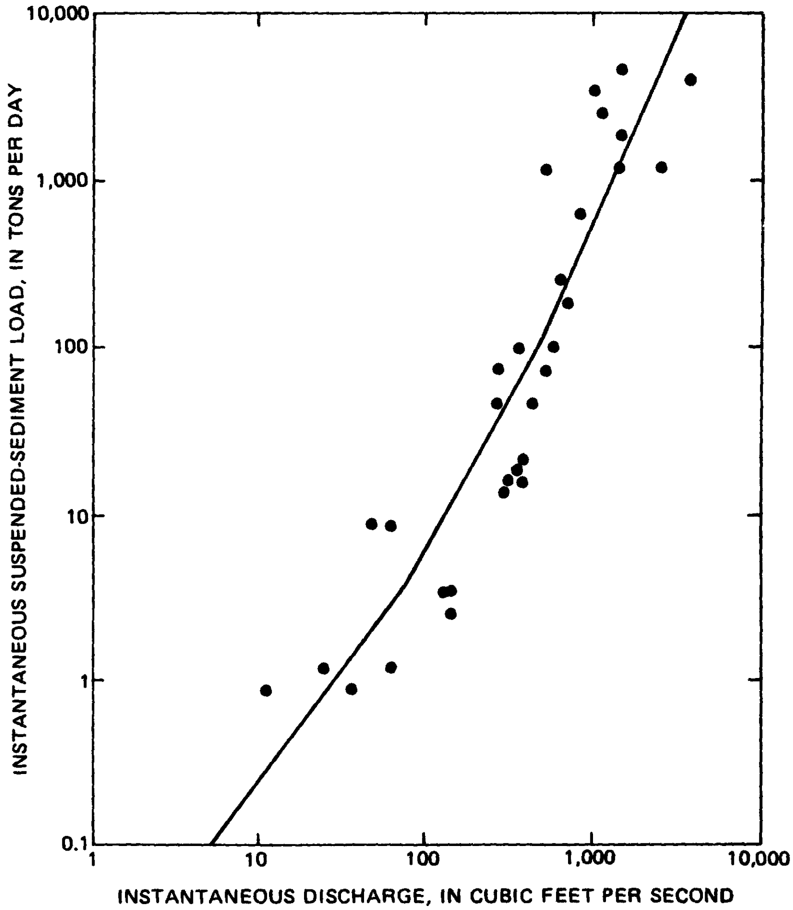

Figure 4.—Suspended-sediment load versus stream discharge for Crooked Creek at Tioga, Pa. (station 1518500).

not used if the range of daily discharges extended more than one-half of a log cycle higher than the plotted data points.

Once a sediment-transport curve has been defined for each station, the long-term mean annual sediment load is generated by computer from the curve by using records of daily discharge. A computer program, LOAD, is used to generate daily loads and to summarize monthly, annual, and 10-year average loads. This program utilizes a magnetic tape of daily discharges extracted from the U.S. Geological Survey's WATSTORE computer filing system. Definition of the sediment-transport curve is input on punched cards specifying log-linear regression coefficients (eq. 5) or a table listing the end points of each manually fitted straight-line segment of the quadratic curve (eq. 6).

Tropical storm Agnes, which occurred in June, 1972, produced floods having recurrence frequencies ranging from 2 to more than 100 years (Bailey and others, 1975, Table A-1). Because the extreme sediment loads occurring during this event are atypical of an average 10-year period, 9-year average annual loads, excluding 1972, were also computed. By comparison, the nine-year averages were as little as one-tenth the 10-year averages. Both 9- and 10-year average loads were related to several experimental sets of basin characteristics by regression analysis. (Refer to technique described in the section, "Multiple-regression analysis.") It was found that an acceptable regression model could be established for the 9-year average sediment load. However, none of the experimental regression models tested for the 10-year load was successful,(as indicated by low percentages of explained variation). Consequently, the 9-year load was selected for the study.

Accuracy of the Generated Sediment Loads

The scatter of data points about most of the sediment-transport curves was large; sometimes standard errors of estimate were as great as ± 100 percent. The accuracy of the generated annual loads and long-term averages is dependent on the assumptions that (1) transport curves represent the entire study period, and (2) the technique for fitting transport curves is unbiased. The first assumption is supported by experience indicating that the transport curves generally did not change greatly over the 10-year period. Bias in curve fitting can be tested by comparing annual loads computed by the transport-curve method with published annual loads. Annual suspended-sediment loads published in the annual USGS data reports are based on a systematic sampling program in which sediment concentrations are determined daily, and more frequently during periods of high flow. Figure 5 shows annual sediment loads, generated from transport curves, plotted against published annual loads for daily sediment stations. This plot represents 22 annual loads for 13 USGS stations. The least squares regression line in figure 5 very nearly coincides with the line of equal values, indicating that there is no appreciable bias in the curve-fitting technique. The standard error of estimate of the computed loads as compared with the published loads is about ± 31 percent. Broadly interpreted, this indicates that about two-thirds of the computed loads are within ± 31 percent of the published loads.

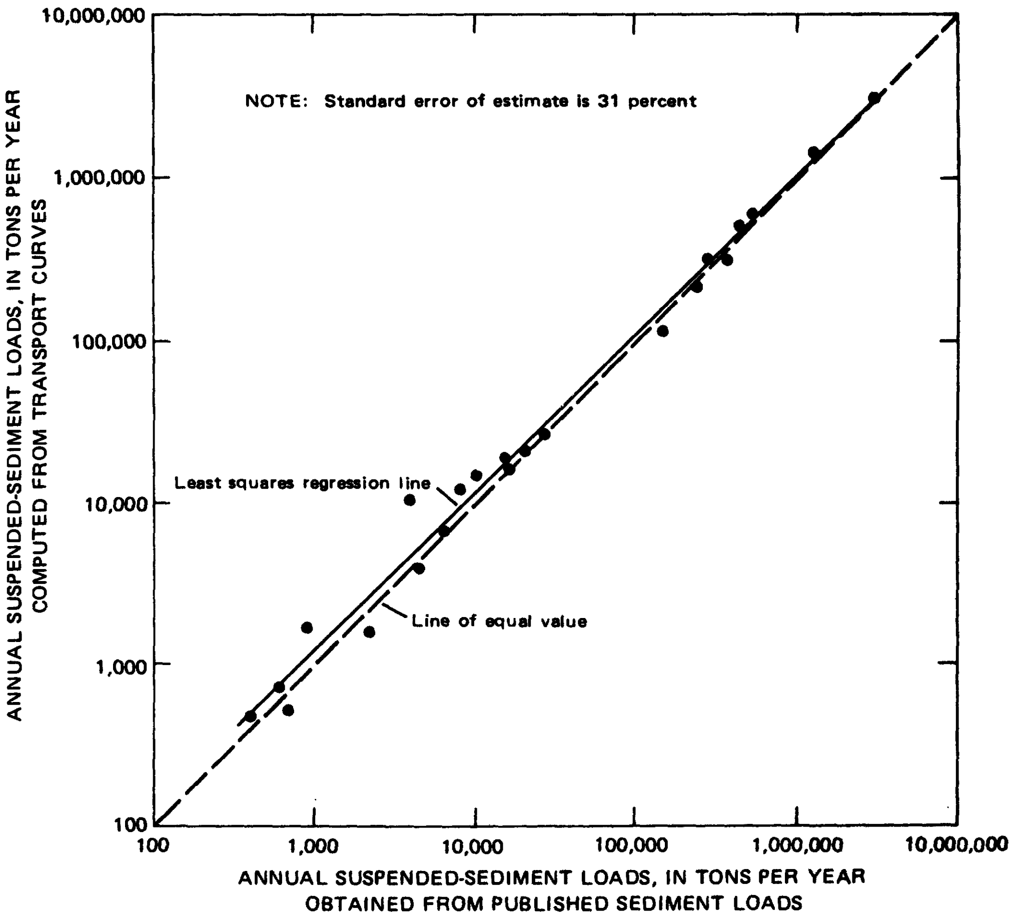

Figure 5.—Comparison of computed and published suspended-sediment loads for streams in the Susquehanna River basin.

Loads computed for miscellaneous sediment sampling sites have no comparable published data. However, the errors of estimate may be somewhat larger than those shown in figure 5 because these transport curves are based on fewer samples which, in some cases, did not define the entire range of streamflow.

Computation of Sediment Concentrations

Sediment concentrations vary substantially over time, with high concentrations resulting from flood runoff. It is therefore difficult to describe sediment-concentration variations adequately using a single characteristic. In this study the discharge-weighted average sediment concentration was selected as an index value. It is computed by program LOAD according to the equation

$$\text{SEDCONC} = \frac{\overline{L}_s}{0.986\overline{Q}} \tag{7}$$

where SEDCONC is the average annual discharge-weighted sediment concentration in mg/L; $\overline{L}_s$ is the average annual sediment load in tons/yr; $\overline{Q}$ is the average daily stream discharge, in ft^3/s; and 0.986 is a units conversion constant. Because of the method of computation, the accuracy of the average annual discharge-weighted sediment concentrations is limited to the accuracy of the computed average annual sediment loads.

Dissolved Solids

Available Data

Dissolved-solids loads and concentrations were computed for 26 stream stations in the Susquehanna River basin for the study period. Dissolved-solids concentrations and specific-conductance data were obtained from the USGS WATSTORE water-quality computer file. Dissolved-solids concentrations were determined by the residual on evaporation (DS_{roe}) method from unfiltered water samples. DS_{roe} concentration data were augmented with dissolved-solids estimates made by use of linear-regression relationships of DS_{roe} with sum of dissolved-solids constituents (DS_{sum}) and with specific conductance (COND).

Values for DS_{sum} in the Susquehanna River basin were consistently lower than those for DS_{roe}, and consequently could not be interchanged. Computer program REGPLOT was used to plot DS_{roe} concentrations versus DS_{sum} concentrations and to compute a least-squares-regression equation for each station having 10 or more paired analyses. The resulting equations were of the general form

$$DS_{roe} = a + b(DS_{sum}) \tag{8}$$

where a and b are regression coefficients determined for each station. These coefficients were computed and used to augment DS_{roe} data for six stations; the average standard error of estimate was 8 percent.

The regression coefficients a and b in equation 8 did not vary appreciably among stations. Therefore, a regional model relating DS_{roe} to DS_{sum} was also computed based on 456 available analyses at 25 sampling sites in the study region. The resulting regional equation

$$DS_{roe} = 4.5 + 1.06\ DS_{sum} \tag{9}$$

has a standard error of 10 percent about the mean of DS_{roe}. This regional equation was used to augment DS_{roe} data for two stations, which had less than 10 dual data points available to define a station equation (eq. 8).

A similar procedure was used to augment DS_{roe} data based on available specific-conductance data. This method utilized the linear-regression equation

$$DS_{roe} = a + b(\mathrm{COND}) \tag{10}$$

where a and b are regression coefficients determined for each sampling station. These coefficients were computed and used to augment DS_{roe} data for 14 stations; the average standard error of estimate was 8 percent.

A regional equation was also computed by program REGPLOT for DS_{roe} versus COND based on 1,441 paired analyses at 27 stations. The regional equation is

$$DS_{roe} = 1.04 + 0.62\ (\mathrm{COND}); \tag{11}$$

it has a standard error of estimate of 14 percent. The regional equation (eq. 11) was used to augment DS_{roe} data for 10 stations.

The procedures and rationale for developing station and regional equations for DS_{roe} versus COND are described in detail by Lystrom and others (1978).

The data-augmentation procedures used in this study effectively increased the number of analyses for DS_{roe} from 719 to 1,547 and increased the number of usable stations from 19 to 26.

Computation of Dissolved-Solids Loads and Concentrations

Average annual dissolved-solids loads were computed by the same transport-curve method used for suspended-sediment loads. Unlike sediment concentrations, dissolved-solids concentrations in Susquehanna streams generally decrease with increased streamflow. Figure 6 is a typical example of the relationship of dissolved-solids concentrations to streamflow.

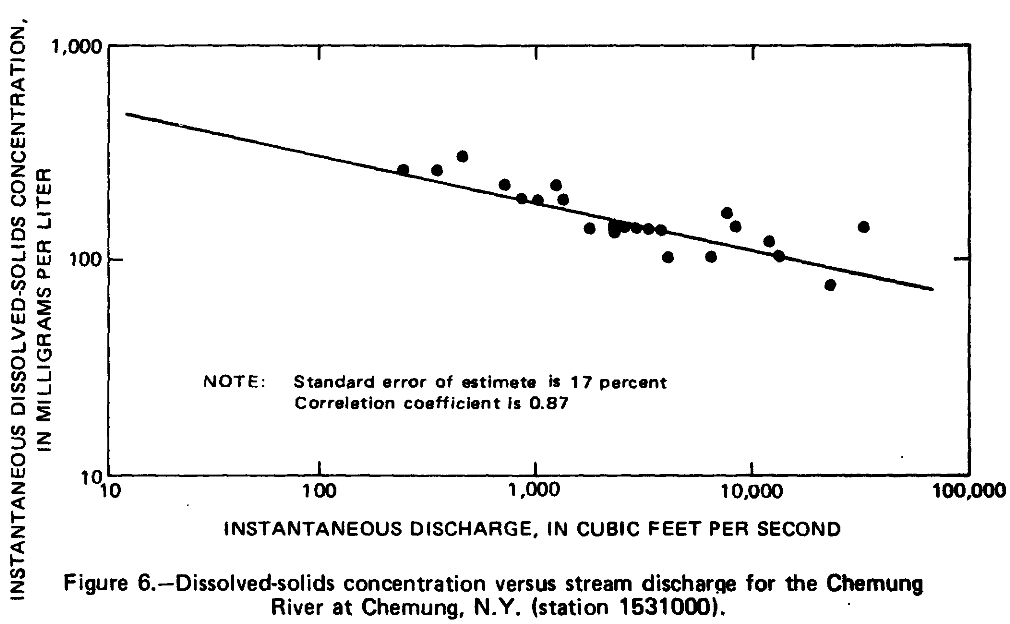

Figure 6.—Dissolved-solids concentration versus stream discharge for the Chemung River at Chemung, N.Y. (station 1531000).

For the purpose of plotting dissolved-solids transport curves, instantaneous dissolved-solids loads (L_{ds}), in tons/day, are computed by the equation

$$L_{ds} = 0.0027\ C_{ds} Q \qquad (12)$$

where C_{ds} is an instantaneous dissolved-solids concentration in mg/L; Q is the instantaneous discharge in ft^3/s; and 0.0027 is a units conversion constant. Program REGPLOT is used to plot transport curves and to compute log-linear regression equations of the form

$$\log L_{ds} = \log\ (\text{DSCOEF}) + (\text{DSEXP})\ \log Q \qquad (13)$$

where L_{ds} and Q are as explained for equation (12), and DSCOEF and DSEXP are regression coefficients for each station. The log-linear regressions provided a good fit for all dissolved-solids transport curves. A typical dissolved-solids transport curve is shown in figure 7. Average annual dissolved-solids loads and discharge-weighted average dissolved-solids concentrations are computed by program LOAD for the period of water years 1966 to 1975, as described for computation of sediment characteristics.

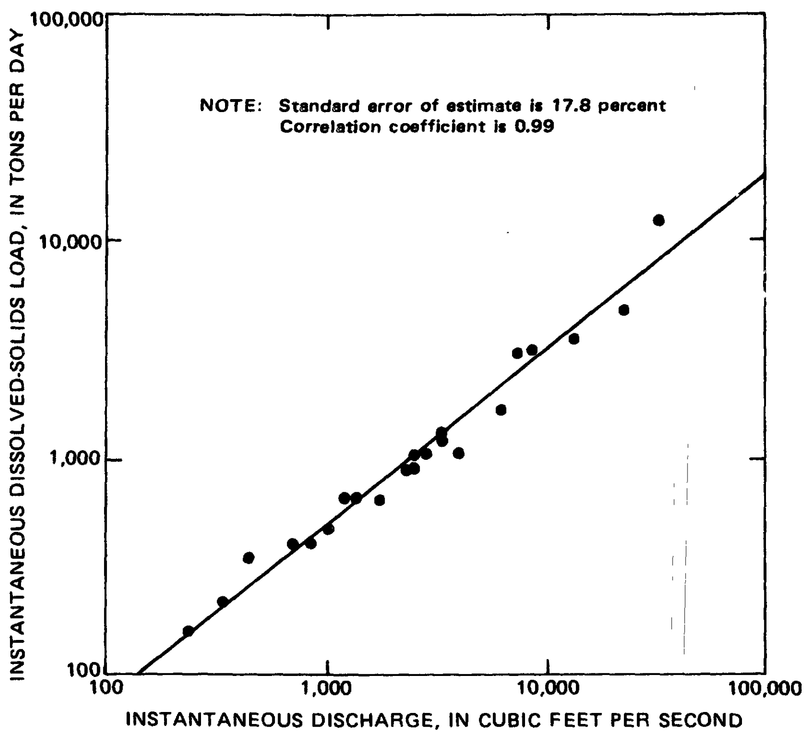

Figure 7.—Dissolved-solids load versus stream discharge for the Chemung River at Chemung, N.Y. (station 1531000).

For experimental purposes the regression coefficients in equation (13) (DSCOEF and DSEXP) were also included in this study as water-quality characteristics. (See appendix 1.) These coefficients define a unique dissolved-solids transport curve for each streamflow sampling station. Therefore, if each coefficient could be defined regionally as a function of basin characteristics, an estimated dissolved-solids transport curve (equation 13) could be used to generate daily dissolved-solids loads for any stream station, provided daily discharges were available.

Accuracy of Dissolved-Solids Loads and Concentrations

Data on dissolved-solids load, with which the computed annual dissolved-solids loads could be compared, are not available. The accuracy of generated annual loads, however, is considered on the basis of the general accuracy of transport curves (such as the one depicted in figure 7). The average standard error of estimate of daily loads for the 26 transport curves was 18 percent. The accuracy of the 10-year-average loads should be better than the standard error of the transport curves because of the compensating effect of summing daily loads to obtain annual loads. A similar assumption for annual sediment loads was verified in "Accuracy of the generated sediment loads." Because of the method of computation, the accuracies of the discharge-weighted average dissolved-solids concentrations are similar to the accuracies of generated dissolved-solids loads.

Nitrogen and Phosphorus

The same methods were used for compiling nitrogen and phosphorus information and, therefore, these two constituents are discussed together. The characteristics of nitrogen and phosphorus evaluated in this study were based on unfiltered samples. The characteristics evaluated were total nitrogen (N), nitrate (NO_3 as N), ammonia (NH_4 as N), phosphorus (P), and orthophosphate (PO_4 as P). Collectively, these constituents are referred to as nutrients.

Available Data

Only available nutrient data from water year 1970 to the end of the study period (water year 1975) were utilized because of uncertainties over methods used in the handling and analysis of water samples for nutrients prior to 1970.

Average concentrations based on a minimum of 10 seasonally spaced samples per station were computed for the five nutrient species. The number of stations representing each species is as follows:

Species	Number of stations
N	27
NO_3	58
NH_4	46
P	49
PO_4	20

Average annual loads were computed only for total nitrate and total phosphorus. Loads were not computed for the other three nutrient species because fewer than 20 of these nutrient-concentration stations have daily discharge data. For the purpose of defining the variability of nutrient concentrations the standard deviations about the mean concentrations were also included.

Computation of Average Nutrient Loads and Concentrations

Nutrient transport curves were found not to be useful for computing loads. The utility of nutrient-transport curves had been questioned initially when regression analysis of nutrient concentrations versus discharge resulted in very low correlation coefficients. Figures 8 and 9 are typical plots of nitrogen and phosphorus concentrations versus discharge. The mean of the correlation coefficients for all stations were 0.44 and 0.35 for N and P, respectively.

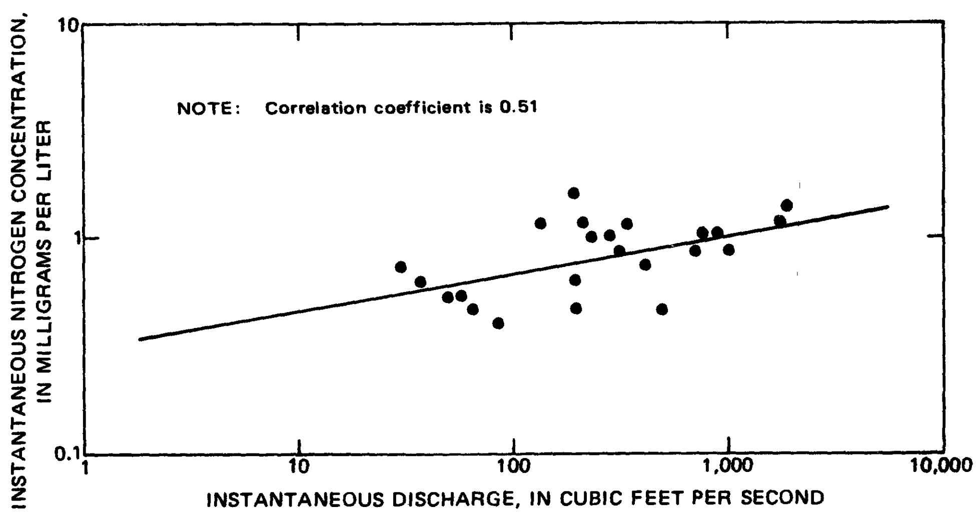

Figure 8.—Nitrogen concentration versus stream discharge for the Tioga River at Tioga, Pa. (station 1518000).

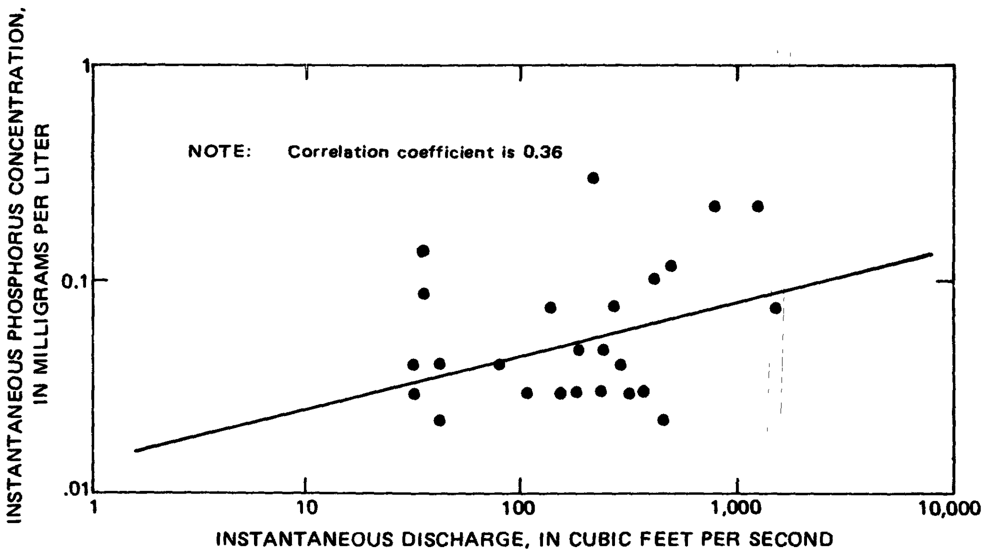

Figure 9.—Phosphorus concentration versus stream discharge for the Tioga River at Lambs Creek, Pa. (station 1516820).

To resolve the question of validity of the relationships between concentration and discharge for nutrient species, the analyses of variance (ANOVA) test (Mendenhall, 1971) was applied using computer program REGPLOT. The ANOVA test was used to determine whether the variation about the least-squares-regression curves relating concentration to discharge is significantly different from the variation about the mean concentrations. In this test, the variance about the regression curve, V_1, and the variance about the mean concentration, V_2, are computed for each station. The variances, V_1 and V_2, are explained by

$$V_1 = \frac{\sum_{1}^{N} (C_o - C_c)^2}{N - 2}, \text{ and} \tag{14}$$

$$V_2 = \frac{\sum_{1}^{N} (C_o - \overline{C}_o)^2}{N - 1}, \tag{15}$$

where N is the number of concentration-discharge observations, C_o is an observed concentration, C_c is the corresponding concentration computed by the regression curve, and $\overline{C}_o$ is the mean concentration. The ratios of variances, V_1/V_2, are then compared to standard F-distribution values for the 95th percentile of significance. The resulting number of significant differences are as follows:

Nutrient characteristic	Number of stations	Number of significant differences at 95-percent level
N	27	3
NO_3	36	2
NH_4	27	0
P	34	2
PO_4	20	0

According to the definition of the F-distribution at the 95th percentile, 5 percent of the variances would be significantly different if discharges and nutrient concentrations were drawn from random numbers. The results in the above table indicate that, on the average, there is no significant difference between the variation about the least-squares-regression curves and the variation about the mean concentrations. Because of this finding, it was decided for this study that nutrient parameters should be calculated from average nutrient concentrations rather than from nutrient transport curves. Consequently, average nutrient loads, L_n, in tons/year, were computed for each station by using the equation

$$L_n = 0.986\ \overline{C}_n \overline{Q} \tag{16}$$

where $\overline{C}_n$ is the average nutrient concentration is mg/L, $\overline{Q}$ is the 10-year mean daily discharge in ft^3/s, and 0.986 is the units conversion constant.

Accuracy of Nutrient Characteristics

The accuracy of average nutrient concentrations and loads is difficult to evaluate. Errors in these characteristics may be related to (1) discrete time sampling, (2) field sampling techniques, (3) sample storage, and (4) laboratory analysis. The relative effect of the last three error sources is generally minimal, although certain properties such as NH_4 concentrations are sometimes subject to considerable error. The effect of sampling at discrete time intervals (error type 1) is quite variable and is dependent on the distribution of sample coverage during critical periods or extreme events. Although accuracies of the nutrient characteristics cannot be evaluated directly, some inferences can be made from the standard errors of estimate, derived from the regional multiple-regression analysis, which are discussed later.

BASIN CHARACTERISTICS

A basin characteristic as used in this report is a numeric value defining some unique aspect of a drainage basin. The basin characteristics initially considered were those related to processes known to control sediment, dissolved solids, nitrogen, and phosphorus in streams. The characteristics compiled for this study were limited, however, to those for which data were available.

Two basic procedures are used in computing basin characteristics. First, a basin characteristic is averaged by area weighting within each drainage area to account for spatial variations. Area-weighted averages are computed by overlaying a grid of a known scale on a map depicting a specific characteristic such as basin slope. The values of the characteristic at grid intersections are summed and averaged. The grid-overlay method is used also to determine proportional areas for some characteristics, such as land use, by counting the grid intersections falling in each specific land-use category within a drainage basin. The proportion of each land use is, in this example, computed by dividing the number of grid intersections overlying a land use by the total number of intersections in the basin.

The second procedure for computing basin characteristics requires that time-variable characteristics, such as climate or streamflow, must represent a long-term average, or more specifically for this study the 10-year period (1966-75). However, if year-to-year changes of a characteristic are known to be small and the period of data available is short, the characteristic is computed for 1-year during the study period.

A total of 57 basin characteristics was compiled in this study. They are divided into six categories as follows: (1) climate, (2) topography, (3) geology, (4) soils, (5) streamflow, and (6) land use. Data sources and methods of computing each basin characteristic are discussed for each category in the following sections. Basin characteristics are tabulated in appendix 2 for 80 subbasins of the study region.

Climate

Five climatic characteristics were computed from isohyetal and isothermal maps using an area-weighting technique. The following are climatic characteristics and data sources used in this study:

1. Mean annual precipitation (PRECIP), in inches, from basin characteristics published in Page (1970) and Darmer (1970), and from isohyetal maps based on 1931-1960 precipitation data (Flippo, 1977, plate 2; and Dethier, 1966).

2. Twenty-four hour rainfall intensity having a 2.33-year recurrence interval (I24,2), in inches, measured from an isohyetal map by Reich, McGinnis, and Kerr (1970, fig. 8) with modifications made by the USGS office in Harrisburg, Pa. (H. Flippo, personal commun.).

3. Mean annual snow accumulation (SN), in inches, from basin characteristics published in Page (1970), a map prepared by U.S. Weather Bureau (1964) for Pennsylvania, and a map for New York by the U.S. National Oceanic and Atmospheric Administration (NOAA) (1972, p. 18).

4. Mean minimum January temperature (MINJAN), in degrees Fahrenheit, from Page (1970), Darmer (1970), a map for New York prepared by the NOAA (1972, p. 21), and a map for Pennsylvania prepared by the USGS office in Harrisburg based on 1931 to 1952 temperature records (H. Flippo, personal commun.).

5. Rainfall erosivity factor (R) according to the universal soil-loss equation (Wischmeier and Smith, 1965).

Topography

The following eight topographic characteristics are extracted from published sources or computed from maps as follows:

1. Total drainage area (AREA), in square miles, obtained from the latest USGS streamflow data reports or measured by counting grid intersections of a known scale overlain on 1:250,000-scale topographic maps.

2. Contributing drainage area (CONTDA), in square miles, is the total drainage area minus the area upstream from lakes and reservoirs, measured by the grid-overlay method using 1:24,000-scale topographic maps, or from Williams and Reed (1972).

3. Main channel slope (SLOPE), in feet per mile, determined from elevations at the 10- and 85-percentiles of the distance along the channel from the gaging station to the divide (Benson, 1962). Data sources are Darmer (1970), Page (1970), and 1:250,000-scale topographic maps.

4. Average basin slope (BSLOPE), in feet per thousand feet, based on the average of 25 or more slopes taken at points on an equal-spaced grid

pattern overlain on 1:250,000-scale topographic maps.

5. Percent of basin having slopes greater than 20 percent (SLGT20), based on 25 or more points from an equal-spaced grid pattern overlain on 1:250,000-scale topographic maps.

6. Area of lakes and ponds (STOR), in percent of drainage basin, determined from 1:24,000-scale topographic maps, Darmer (1970), and Page (1970).

7. Mean basin elevation (ELEV), in thousands of feet above mean sea level, was determined from 25 or more equal-spaced grid points on 1:250,000-scale topographic maps.

8. Drainage-density index (DDI), in miles per square mile, is the ratio of the total length of channels divided by the drainage area as determined from 1:24,000-scale topographic maps.

Geology

Nine geologic characteristics used in this study are based on generalized geologic maps of Pennsylvania (Socolow, 1960) and New York (Hollyday, 1969). Characteristics representing geologic units, listed as items 1-6 below, have been selected on the basis of (1) broad groups of formations caused by similar processes and thus having similar physical properties, and (2) specific rock types that could have regional effects on the water-quality characteristics under study. The proportion of a basin underlain by each geologic unit was determined using the grid-overlay method.

Selected ground-water characteristics, numbered 7-9 below, are included in addition to the geologic units. The ground-water characteristics are based on median ground-water values for each rock formation according to Seaber and Hollyday (1965, 1966), Seaber (1968), and Hollyday (1969). Area-weighted averages of ground-water characteristics were computed by the grid-overlay method. Geologic and ground-water characteristics used in this study are:

1. Undifferentiated sedimentary geologic units (SED), expressed as percent of drainage area.

2. Undifferentiated metamorphic and igneous geologic units (METIG), expressed as percent of drainage area.

3. Limestone and dolomite (LIMDOL) geologic units, expressed as percent of drainage area.

4. Coal formations (COAL), expressed as percent of drainage area.

5. Triassic sedimentary geologic unit (TRIAC), expressed as percent of drainage area.

6. Area glaciated (GLAC), in percent of drainage area (Fenneman, 1928).

7. Median dissolved-solids concentration of ground water (GEOTDS), in mg/L.

8. Median nitrogen concentration of ground water (GEON), in mg/L.

9. Median specific capacity of shallow wells (SPCAP), in (gal/min)/ft of drawdown.

Soils

Twenty-one area-weighted average soil characteristics were computed from generalized soil-association maps and associated soils data. The soil characteristics used in this study were tabulated and keypunched on computer cards for each soil series in the study region. Chemical and mechanical data defining the first 12 soil characteristics listed below were obtained from U.S. Soil Conservation Service (SCS) (1974a, 1974b), Cunningham and others (1972, 57 p.), Cunningham and others (1972, 805 p.), Ciolkosz and others (1972,1974), Peterson and others (1968, 1972), and Ranney and others (1970, 1972). Data for the remaining nine soil characteristics were obtained from SCS standard soil-interpretation forms (SCS-soils-5) for each soil series (U.S. SCS, 1971). A computer program (SOILS) was developed to compute a table of average soil characteristics for each soil association in the study region based on known percentages of the major soil series comprising each soil association. The 21 soil characteristics are tabulated in appendix 3 for the principal soil associations in the basin.

The next step in the procedure was to determine percentages of soil associations in each drainage basin. These percentages were measured by the grid-overlay method using generalized soil-association maps for Pennsylvania (U.S. SCS, 1972) and for New York (Arnold and others, 1970). Computer program SOILS was then used to compute area-weighted average soil characteristics for each basin based on the percentages of soil associations and the table of soil characteristics (appendix 3).

The extensive selection of soil characteristics is intended for experimental purposes because the characteristics that control the water-quality processes in the soil profile generally are not well known. The soil characteristics used in this study are as follows:

1. Clay content (CLAYA) of the A horizon, in percent by weight.

2. Silt content (SILTA) of the A horizon, in percent by weight.

3. Soil nitrogen (SOILNA) in the A horizon, in milliequivalents per 100 grams (meq/100 g).

4. Soil-nitrogen (SOILNG) concentration in the A, B, or C horizon, whichever is greatest, in meq/100 g.

5. Extractable-acidity (XACIDA) concentration in the A horizon, in meq/100 g.

6. Extractable-acidity (XACIDG) concentration in the A, B, or C horizon, whichever is greatest, in meq/100 g.

7. Extractable-cations (XCATA) concentration in the A horizon, in meq/100 g.

8. Extractable-cations (XCATG) in the A, B, or C horizon, whichever is greatest, in meq/100 g.

9. Cation-exchange capacity (CECA) of the A horizon, in meq/100 g.

10. Cation-exchange capacity (CECG) of the A, B, or C horizon, whichever is greatest, in meq/100 g.

11. pH (PHA) of the A horizon (in H_2O).

12. pH (PHL) of the A, B, or C horizon, whichever is lowest (in H_2O).

13. Soil erodibility (KA) of the A horizon according to the universal soil-loss equation (Wischmeier and Smith, 1965).

14. Permeability (PERMA) of the A horizon, in in/hr.

15. Permeability (PERML) of the least permeable soil horizon, in in/hr.

16. Hydrologic soil groups (HSG) according to SCS. Soil groups A, B, C, and D are arbitrarily equated to 1, 2, 3, and 4, respectively.

17. Available water capacity (WATCAP), computed as a depth-weighted average of the A, B, and C soil horizons, in inches of water per inch of soil.

18. Depth to bedrock (BDRK), in inches.

19. Proportion of soil (LT200A) in the A horizon that passes the No. 200 mesh sieve, in percent by weight.

20. Gravel content (GRAVA) in the A horizon, in percent by weight.

21. Stones greater than 3 inches (STONEA) in the A horizon, in percent by weight.

Streamflow

The six streamflow characteristics used in this study are based on the USGS WATSTORE computer file of mean daily flows and peak flows. Flood-frequency characteristics were computed by USGS computer program J407 which is based on Bulletin No. 17 of the Hydrology Committee of the U.S. Water Resources Council (1976). Streamflow characteristics used in this study are as follows:

1. Mean annual stream discharge (MAQ10) for the period of water years 1966 to 1975, in ft^3/s.

2. Mean annual discharge (MAQ9) for the period of water years 1966 to 1975, excluding 1972, in ft^3/s.

3. Largest peak discharge (PK10) for the period of water years 1966 to 1975, in ft^3/s.

4. Peak discharge having a recurrence interval of 2 years (P2), in ft^3/s, based on the period of record for each station.

5. Peak discharge having a recurrence interval of 25 years (P25), in ft^3/s, based on the period of discharge record for each station.

6. Ratio of the largest peak discharge during the study period to the peak discharge having a recurrence interval of 10 years based on the period of discharge record (PK10/P10).

Land Use

Characteristics of land use in this study are described using designated level I categories according to Anderson, Hardy, Roach, and Witmer (1976). Percentages of land uses in Pennsylvania were measured by the grid-overlay method using 1:250,000-scale land-use maps. These maps, based on 1974 aerial photography, are preliminary copies prepared by the U.S. Geological Survey's Land Information and Analysis office. Land-use percentages for basins in New York were computed by Cornell University using the Land Use and Natural Resource inventory (LUNR) of New York State (Crowder, 1974). Computations were made by digital computer from a data-storage system utilizing one-square-kilometer grid cells. LUNR data are based on 1967 and 1968 aerial photography.

In addition to defining land use by categories, a land-cover index (C-factor) was also used as a land-use characteristic. The C-factor is a ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled, continuous fallow as used in the universal soil-loss equation (Wischmeier and Smith, 1965). Area-weighted average C-factors were computed based on generalized values of C for agriculture, urban, forest, and extractive land uses (John Robb and others, oral and written commun., SCS, Harrisburg, Pa., 1976).

Level-I land-use categories and the C-factor used in this study are as follows:

1. Percent of drainage area urbanized (LU1).

2. Percent of drainage area under agriculture (LU2).

3. Percent of drainage area forested (LU4).

4. Percent of drainage area covered by water (LU5).

5. Percent of drainage area in a disturbed condition such as extractive, strip mines, construction (LU7).

6. Average basin C-factor according to the universal soil-loss equation (C).

Two additional characteristics of agricultural management were compiled to quantify chemical fertilizers and animal wastes applied to each basin. These characteristics are:

7. Tons of phosphorus applied per basin (AGP); includes estimates of chemical fertilizer and animal waste, in tons per year, as phosphorus.

8. Tons of nitrogen applied per basin (AGN); includes estimates of chemical fertilizer and animal waste, in tons per year, as nitrogen.

Characteristics of agricultural fertilizer are intended to be rough indicators of the combined effects of chemical fertilizer and animal wastes on the nutrient levels in streams. The annual nutrient application in each basin, expressed in tons of nitrogen (AGN) or phosphorus (AGP), was computed for each basin by the equation

$$\text{AGP or AGN} = Agr \sum_{i=1}^{n} (T_i)\ (P_i) \tag{17}$$

where: Agr is the area of agricultural land in the basin, in square miles; P_i is the fraction of county i in the basin; T_i is a loading density (see explanation below) for county i in tons per year of nitrogen or phosphorus per square mile of agricultural land; and n is the number of counties or parts of counties in the basin. The nutrient-loading density factor for each county, T_i, is based on the equation

$$T_i = \frac{Tc + Ta}{Acp} \tag{18}$$

where: Tc is the annual tonnage of chemical fertilizer for each county, expressed as nitrogen or phosphorus (U.S. Dept. of Agriculture, 1973 p. 208-211; New York State Dept. of Agriculture and Markets, 1969; U.S. Dept. of Commerce, 1972a, table 19); Ta is the annual tonnage of animal wastes for each county, expressed as nitrogen or phosphorus (see explanation below); Acp is the area of cropland and pasture for each county, in square miles (State Conservation Needs Inventory Committee, 1967, p. 35-36; U.S. Soil Conservation Service, 1967, p. 32-33).

The annual tonnages of nitrogen and phosphorus contributed by animal wastes *(Ta)* computed for each county by multiplying animal densities times average animal nutrient-production factors, are listed below (Omernik 1976, p. 13).

Animal	Total N (tons/animal)/yr	Total P (tons/animal)/yr
Cattle	6.34×10^{-2}	1.94×10^{-2}
Hogs	1.07×10^{-2}	3.56×10^{-3}
Sheep	1.11×10^{-2}	1.62×10^{-3}
Chickens		
Layers	4.63×10^{-4}	1.76×10^{-4}
Broilers	4.30×10^{-4}	9.92×10^{-5}

Animal densities were obtained from agricultural census (U.S. Dept. of Commerce, 1972b, 1972c, tables 8 - 11). Annual tonnages (T_i) of nitrogen and phosphorus estimated for chemical fertilizer plus animal wastes are tabulated for each county in the study area in appendix 4.

MULTIPLE-REGRESSION ANALYSIS

The linear-regression model (eq. 1) and the log-transform model (eq. 3) were initially tested for four water-quality characteristics (SEDYLD, DSYLD, NAVE, and PAVE). The linear model for PAVE was considered unsuccessful. Moreover, by comparison of the linear and log-transform models it was found for SEDYLD, DSYLD, and NAVE that the log-transform model provided lower standard errors (1 to 7 percent lower) and higher explained variance (6 to 18 percent). In addition, the residuals (differences between the observed and calculated values) were generally more randomly distributed for the three log-transform models. Therefore, the log-transform form of model was used to develop regressions for all the water-quality characteristics. The results of regression analyses for 17 water-quality characteristics are listed in table 1. To demonstrate this table, the regression model for sediment yield (SEDYLD) is

$$SEDYLD = (3.24 \times 10^{6})(PHA)^{-6.66}(LU2+1)^{0.288} \qquad (19)$$

The accuracy of an estimate computed by this equation is indicated by the standard error of estimate (table 1), which implies that approximately two-thirds of the sediment yields computed for the 28 stream sites used in this regression have an error within $\pm$ 40 percent when compared to measured yields. The percent of variation explained, shown in table 1, is calculated as the square of the multiple-correlation coefficient times 100 (Afifi and Azen, 1972, p. 117). One hundred percent of variation explained would indicate a perfect regression model with no error. Zero percent indicates that the variation about the regression model is equivalent to the variation about the mean of the water-quality characteristic, in which case, the model serves no purpose.

As previously explained, a value of one was added to several of the independent variables to avoid taking logarithms of zero. In some cases, a number

TABLE 1.--*Results of multiple-linear-regression analysis of logarithmic-transformed variables*

Water-quality characteristics[1] Y[3]	(Independent variables, X's[2,3]) Regression coefficients, b's[3]	Regression constant a[3]	Standard error of estimate in percent	Percentage of variation explained[4]	Number of stream stations
SEDYLD-Sediment yield in (tons/mi²)/yr	$(PHA)^{-6.66}$ $(LU2+1)^{.288}$	3.24×10^{6}	40	63	28
SEDCONC-Sediment concentration in mg/L	$(PHA)^{-6.47}$ $\left(\frac{MAQ9}{AREA}\right)^{-1.29}$ $(LU2+1)^{.255}$	2.92×10^{6}	40	72	28
DSYLD-Dissolved-solids yield in (tons/mi²)/yr	$(LU1+1)^{.438}$ $(LU2+1)^{.282}$ $\left(\frac{MAQ10}{AREA}\right)^{1.18}$ $(COAL+1)^{.124}$ $(XCATG)^{.333}$	8.43	24	82	26
DSCONC-Dissolved-solids concentration in mg/L	$(LU1+1)^{.382}$ $(LU2+1)^{.296}$ $(COAL+1)^{.106}$ $(XCATG)^{.272}$	1.13×10^{1}	17	89	26
DSEXP-[1]	No significant regression relationship established				48
DSCOEF-[1]	No significant regression relationship established				48
NAVE-average nitrogen concentration in mg/L	$(WATCAP)^{1.55}$ $\left(\frac{AGN}{AREA}+1\right)^{.684}$ $(SLOPE)^{.150}$ $(LU1+1)^{.378}$	7.02	17	77	27
NSD-Nitrogen standard deviation in mg/L	$(WATCAP)^{1.45}$ $(PRECIP)^{-2.65}$ $(LU5+1)^{-.464}$ $(LU1+1)^{.225}$	2.30×10^{5}	26	68	27
NO3AVE-Average nitrate concentration in mg/L	$\left(\frac{AGN}{AREA}+1\right)^{.730}$ $(WATCAP)^{1.82}$	1.94×10^{1}	50	76	58
NO3SD-Nitrate standard deviation in mg/L	$(WATCAP)^{3.29}$ $(LT200A)^{-4.89}$ $\left(\frac{AGN}{AREA}+1\right)^{.640}$ $(CLAYA)^{1.63}$	1.29×10^{9}	56	71	58
NO3YLD-Nitrate yield in (tons/mi²)/yr	$\left(\frac{AGN}{AREA}+1\right)^{.676}$ $(PRECIP)^{2.19}$ $(WATCAP)^{.913}$ $(LU1+1)^{.317}$	6.25×10^{-4}	31	89	24
NH4AVE-Average ammonia concentration in mg/L	No significant regression relationship established				46
PAVE-Average phosphorus concentration in mg/L	$(METIG+1)^{.592}$ $\left(\frac{AGP}{AREA}+1\right)^{.937}$ $(PHA)^{6.84}$ $(LT200A)^{-3.67}$	4.51×10^{-1}	75	58	49
PSD-Phosphorus standard deviation in mg/L	$(PAVE)^{1.02}$	8.14×10^{-1}	47	84	49
PYLD-Phosphorus yield in (tons/mi²)/yr	$(LU1+1)^{.583}$ $\left(\frac{AGP}{AREA}+1\right)^{.381}$	3.10×10^{-2}	36	68	20
PO4AVE-Average phosphate concentration in mg/L	$(WATCAP)^{-4.76}$ $(PERMA)^{1.16}$ $\left(\frac{AGP}{AREA}+1\right)^{1.24}$ $(LU1+1)^{.834}$	1.85×10^{-8}	44	74	20
PO4SD-Phosphate standard deviation in mg/L	$(XCATG)^{2.57}$ $(BSLOPE)^{-2.76}$ $(WATCAP)^{-2.82}$	2.98×10^{-2}	69	56	20

[1] Defined in section entitled "Water-quality characteristics".

[2] Defined in section entitled "Basin characteristics".

[3] According to equation 3: $Y = a\, X_1^{b_1} X_2^{b_2} \ldots X_n^{b_n}$.

[4] $R^2 \times 100$, where R is the multiple-correlation coefficient (Afifi and Azen, 1972, p. 115-117).

other than one was tested in an attempt to improve the linear fit of the model; however, no improvements were achieved in the standard error or the percent of variation explained.

Sensitivity of Independent Variables

From the standpoint of applying the regression models in table 1, it is useful to evaluate the relative effect (sensitivity) of each independent variable on a water-quality characteristic. The relative magnitudes of regression coefficients may not be proportional to the relative sensitivity of each independent variable because the coefficients are dependent on both the magnitude and variation of that independent variable. The relative sensitivity of each independent variable in a particular regression equation can, however, be approximated by comparing the regression weights of each independent variable. Regression weights are similar to coefficients except that they are computed by first standardizing the dependent and independent variables. Standardized variables are obtained by subtracting the mean and dividing by the standard deviation. These variables have a mean of zero and a standard deviation of one. On the basis of this approach, table 2 shows the computed regression weights for each independent variable. The observed range of each variable is also shown. Independent variables are listed from left to right in relative order of decreasing absolute values of regression weights. It is noteworthy that in five of the regression models the water-quality characteristics are most sensitive to the land-use related variables.

Validity of Regression Models

The acceptability of regression models should not be based entirely on statistical tests. The independent variables and regression coefficients of each equation also must be evaluated from the standpoint of conceptual knowledge of the water-quality processes. In this section, two basic questions are considered. (1) Is each of the independent variables related directly or indirectly to the water-quality characteristic? (2) Is the sign of each regression coefficient realistic in terms of intuitive understanding? In the first consideration, it is essential to know if any of the independent variables are surrogates that indirectly explain some other effect on water quality. For example, percent urbanization indirectly represents the effect of sewage effluent on the stream load of total nitrogen. In this case, percent urbanization is used as a surrogate. Second, the sign of a regression coefficient indicates a direct (positive sign) or inverse (negative sign) relationship between the dependent and independent variable. If the sign of a regression coefficient is contrary to intuitive understanding of the process involved, one of the following causes could be indicated:

1. The process involving the effect of an independent variable on a water-quality characteristic is not well understood.

2. The independent variable is a surrogate for another variable.

3. A large error occurred during compilation of a dependent or independent variable.

TABLE 2.--*Ranges of observed variables, and regression weights and selected correlation coefficients of independent variables*

Water-quality characteristic[1] minimum-maximum	Independent variables[2] minimum-maximum/regression weight[3]					Pairs of independent variables bivariate correlation coefficients of logarithms[4]		
SEDYLD 21.3-299.	PHA 4.9-6.3/-.71	LU2 0-81.0/.42						
SEDCONC 13.3-295.	PHA 4.9-6.3/-.61	MAQ9/AREA .94-1.8/-.37	LU2 0-81.0/.33			(LU2+1)v.$\left(\frac{MAQ9}{AREA}\right)$ -.52		
DSYLD 33.4-308.	LU1 0-13.9/.60	LU2 0-64.3/.48	MAQ10/AREA .98-1.99/.45	COAL 0-81.0/.35	XCATG 4.9-34.8/.30	(LU2+1)v.(COAL+1) -.62	(LU2+1)v.$\left(\frac{MAQ10}{AREA}\right)$ -.54	
DSCONC 29.0-282.	LU1 0-13.9/.58	LU2 0-64.3/.56	COAL 0-81.0/.33	XCATG 4.9-34.8/.27		(LU2+1)v.(COAL+1) -.62		
NAVE .40-1.59	WATCAP .06-.13/1.0	AGN/AREA .28-7.50/.92	SLOPE 1.8-289.0/.59	LU1 0-3.7/.58				
NSD .18-.98	WATCAP .06-.13/.72	PRECIP 33.6-42.5/-.43	LU5 0-4.4/-.42	LU1 0-3.7/.26		(PRECIP)v.(WATCAP) .51		
NO3AVE .15-7.45	AGN/AREA 0-41.5/.61	WATCAP .06-.16/.46						
NO3SD .07-4.14	WATCAP .06-.16/.83	LT200A 42.1-78.5/-.68	AGN/AREA 0-41.5/.55	CLAYA 10.4-21.8/.25		(LT200A)v.(WATCAP) .84	(CLAYA)v.(WATCAP) .58	(CLAYA)v.(LT200A) .50
NO3YLD .27-8.98	AGN/AREA 0-36.8/.63	PRECIP 33.6-46.0/.28	LU1 0-12.9/.25	WATCAP .07-.14/.24		(PRECIP)v.(WATCAP) .69		
PAVE .02-1.24	METIG 0-67.7/.63	AGP/AREA 0-13.2/.54	PHA 4.9-6.6/.50	LT200A 42.1-78.5/-.47		(LT200A)v.(METIG+1) .70	(LT200A)v.$\left(\frac{AGP}{AREA}+1\right)$ .57	(METIG+1)v.$\left(\frac{AGP}{AREA}+1\right)$ .56
PSD .01-1.18	PAVE .02-1.24/.92							
PYLD .03-.35	LU1 0-12.7/.80	AGP/AREA 0-11.8/.31				(LU1+1)v.$\left(\frac{AGP}{AREA}+1\right)$ .76		
PO4AVE .01-.20	WATCAP .06-.13/-1.30	PERMA .73-6.03/1.04	AGP/AREA 0-11.8/.75	LU1 0-12.7/.66		(PERMA) v.(WATCAP) .84	(LU1+1)v.$\left(\frac{AGP}{AREA}+1\right)$ .58	
PO4SD .01-.19	XCATG 7.3-18.4/.93	BSLOPE 60.-150./-.68	WATCAP .06-.13/-.65			(XCATG)v.(WATCAP) .72		

[1] Defined in section entitled "Water-quality characteristics".

[2] Defined in section entitled "Basin characteristics".

[3] Refer to documentation of U.S. Geological Survey computer program D0095 "General Regression (Step Backward) -- STATPAC" (written communication, Gary I. Selner, 1975).

[4] Only those correlation coefficients which exceed 0.5 are shown.

4. Significant cross-correlations between independent variables may cause the regression coefficients to be inaccurate.

5. The relation may be spurious. That is, the apparent significance of an independent variable may be due to chance.

These aspects were considered in the selection of independent variables and for each water-quality model and are discussed in the following sections.

Sediment Models

The suspended-sediment yield (SEDYLD) and concentration (SEDCONC) models both had a standard error of estimate of 40 percent (table 1). This level of error is not significantly larger than estimates of the errors in sediment loads and concentrations computed by the transport-curve method. (See "Accuracy of the generated sediment loads.") The percent of drainage area under agriculture (LU2) is significant in both sediment models. Agricultural land use is considered generally to be a major source of sediment. The 9-year mean-annual discharge (MAQ9/AREA) is inversely related to SEDCONC as shown by the negative sign of the regression coefficient in table 1. This indicates that discharge-weighted sediment concentrations are more dilute in areas of higher average flows. Variations in sediment yields, however, are apparently not affected significantly by the average flow level.

The inverse relationship with soil pH (PHA), as indicated by the negative sign of the regression coefficient shown in table 1, is difficult to explain. Soil pH may be explaining a closely related soil property or a land use. It should be noted that the range in soil pH is 4.9 to 6.3, indicating relatively acidic soils. Correlation coefficients between independent variables do not exceed 0.52. (See table 2.)

Dissolved-Solids Models

The regression models for dissolved-solids yields (DSYLD) and concentrations (DSCONC) explain 82 and 89 percent of the variation, respectively, and the standard errors of estimate are 24 and 17 percent, respectively. (See table 1.)

Four of the five independent variables found significant in the dissolved-solids yield (DSYLD) and concentration (DSCONC) models define realistic sources of dissolved constituents. These are (1) percent urban (LU1), (2) percent agriculture (LU2), (3) extractable cations in soil (XCATG), and (4) percent of basin overlying coal formations (COAL). The user of these models should recognize that LU1 may be a surrogate defining the effects of domestic-sewage effluents. Also, the characteristic, COAL, may represent the effect of acid-mine drainage, which is primarily a result of exposing coal formations to air and water. Therefore COAL may represent the effect of land use rather than geology. The 10-year mean-annual discharge, (MAQ10/AREA), relates to increased yields of dissolved solids in areas of high average flows; however, the effect of flow on concentrations is not indicated. Correlation coefficients between independent variables do not exceed 0.62. Regression models for DSEXP and DSCOEF did not appear to be meaningful. These models could only explain about 25 percent of the variation. The standard errors of estimate of the DSCOEF and DSEXP models were about 90 and 11 percent, respectively.

Nitrogen Models

Five of the six nitrogen models were successfully calibrated with realistic results. Standard errors of estimate ranged from 17 to 56 percent, and the percent of variation explained ranged from 68 to 89 percent. (See table 1.) A sixth model, the average ammonia concentration (NH4AVE), was considered to be of minimal value based on the small proportion of explained variation (about 27 percent). The difficulty in deriving a useful ammonia model may be due in part to the biochemical instability of ammonia and perhaps in part to laboratory analytical error.

Four independent variables found significant in various combinations in the NAVE, NO3AVE, and NO3YLD models describe possible sources of nitrogen. These independent variables are: (1) agricultural nitrogen (AGN), (2) percent urbanization (LU1), (3) mean annual precipitation (PRECIP), and (4) water capacity of soil (WATCAP). LU1 may be a surrogate defining the effects of domestic sewage effluents. Water capacity explains the ability of the soil to support vegetation, which indirectly relates to the occurrence of nitrogen in the soil. A fifth variable found in the total nitrogen model (NAVE), channel slope (SLOPE), indicates lower concentrations of nitrogen as a function of lower slopes. This may be the result of increased biological uptake of nitrogen occurring in the more sluggish streams which are characterized by lesser slopes. The cross correlations between independent variables in each of the three models were relatively small (less than 0.69).

It is difficult to explain the cause and effect of characteristics defining the standard deviation models for total nitrogen (NSD) and nitrate (NO3SD). As shown in table 1, the independent variables (AGN, LU1, PRECIP, and WATCAP) that define sources of NAVE and NO3AVE also explain the standard deviations, NSD and NO3SD. The significance of LU5 in the NSD model indicates that smaller variations in total nitrogen are associated with greater parts of the drainage area covered by water. A possible explanation is the biological uptake of nitrogen occurs more readily in lakes, ponds, and wide sluggish channnels than in rapidly flowing streams, therefore tending to dampen seasonal variations. There is no apparent explanation for the association of NO3SD to CLAYA (the percent of CLAY in the A soil horizon) and LT200A (the percent soil passing the No. 200 sieve). It is possible that CLAYA and LT200A may be surrogates for other regional parameters.

Phosphorus Models

The standard errors of estimate of the five phosphorus models ranged from 36 to 75 percent, and the percent of variation of the dependent variable explained ranged from 56 to 84 percent (table 1). These results indicate lower model accuracies than those for the nitrogen models.

The three primary phosphorus models (PAVE, PYLD, and PO4AVE) incorporate the effects of agricultural phosphorus (AGP) and urbanization (LU1), which define possible man-induced sources of phosphorus. LU1 may be a surrogate defining the effects of domestic-sewage effluents.

The association between metamorphic rocks-igneous rocks (METIG) and phosphorus concentrations is consistent with results found by Omernik (1976, p. 62-63) in the Eastern United States, where forested streams overlying metamorphic and igneous rocks were shown to have higher phosphorus concentrations than streams draining sedimentary rocks. The effect of the combination of water capacity (WATCAP) and permeability (PERMA) of soils on orthophosphate is difficult to define. The relationship of WATCAP to PO4AVE is inverse, whereas that of PERMA is direct. The cross-correlation between WATCAP and PERMA is high (0.84); therefore, the effect of these variables on PO4AVE should not be evaluated separately.

The remaining variables that affect phosphorus (PAVE) represent chemical processes rather than sources of phosphorus. The association of low soil pH (PHA) to decreased total phosphorus concentrations (PAVE) may be a result of increased anion-adsorption capacity as water passes through the soil column, which permits less phosphorus to reach the ground water (Barrow, 1970). The inverse relationship of PAVE to the percent of soil passing a No. 200 screen (LT200A) is similar. As the soil becomes finer, the surface area of soil particles increases, causing increased phosphorus adsorption in the soil horizon.

Accuracy of Regression Models

As mentioned earlier, the accuracy of a regression model is often judged on the basis of the standard error of estimate (SEE). (See table 1.) The apparent SEE of any regression model is comprised of both model error and sampling error. True model error is introduced by nonlinear relationships, incorrect choice of independent variables, or errors in the compilation of the dependent or independent variables. Sampling error involves temporal and spatial sampling errors that result from relatively short records and sparse distribution of stream-sampling sites.

The true error of a regression model is approached as the length of water-quality records and the number of subbasins used for calibration approach infinity. True error can be estimated indirectly for a particular regression model by a statistical procedure described by Moss (1976). This procedure is based on a Monte Carlo simulation of probable standard errors for a selected regression model by statistically representing a large number of stream sites and long periods of water-quality records. Estimates of true model error were made for two regression models defining suspended-sediment yield (SEDYLD) and dissolved-solids yield (DSYLD). Computations were made using computer programs (M. E. Moss, written commun., 1977) available on the USGS computer system. Results are shown below:

Model	Apparent standard error in percent (from table 1)	Simulated true model error in percent
SEDYLD	40	38
DSYLD	24	24

A comparison of the apparent standard error and the simulated true model error shows little difference for either model. This indicates that the apparent standard error is predominantly model error and is not significantly affected by temporal and spatial sampling errors. Consequently, development of more appropriate models and independent variables, and improvement of the accuracy of variables, are possible means of improving the standard errors of estimate.

Independent Testing of Regression Models

It is desirable to assess the usefulness of the regression models by comparing model results with observed water quality for several independent subbasins that were not used in model calibration. However, all available data for the study period were used for model calibration. Consequently, model testing is based on limited new data collected for 23 subbasins during water year 1976 and part of 1977. Ten of these subbasins were used (or, if not, their drainage areas are nearly equivalent to those used) for model calibration. The 13 additional basins were not used in deriving the models. Part of the nutrient data available for verification was collected by the Pennsylvania Department of Environmental Resources.

Table 3 is a tabulation of observed water-quality characteristics and corresponding characteristics simulated by eight of the 14 regression models given in table 1. Adequate data were not available to define sediment-transport curves, and consequently sediment models are not included in table 3. A comparison of observed versus simulated characteristics indicates generally that the dissolved-solids and nutrient models provide useful estimates of water quality.

To summarize table 3, the differences between the observed and simulated values were computed as a percentage of the observed, and then averaged for each water-quality characteristic. These average errors, except for the PO4AVE model, are less than or in close agreement with the standard errors of estimate of the regression models shown in table 1. The large average error of the PO4AVE model (95.8 percent) is due mostly to the fact that only four stations are represented and that one of these has a large difference between the observed and simulated values (table 3). The occasional large deviations between the observed and simulated values of some nutrient characteristics may be due to the uncertainties of the estimated agricultural phosphorus or nitrogen characteristics (AGP and AGN) for small basins.

Table 3.--*Testing of Regression Models*

Station number	Station name	Value status	Observed and simulated values of water-quality characteristics							
			DSYLD	DSCONC	NAVE	NO3AVE	NO3YLD	PAVE	PYLD	PO4AVE
1502770	Susquehanna R. nr Great Bend, Pa.	Observed	1/139.	1/87.6	1/0.92	1/0.57	0.90	1/0.07	0.11	0.02
		Simulated	128.	84.5	.88	.75	.88	.06	.08	.02
1509150	Gridley Cr. above East Virgil, NY.	Observed				1/.54				
		Simulated				.96				
1515050	Susquehanna R. at Sayre, Pa.	Observed	1/154.	1/96.2	1/1.14	.51	.82	1/.11	.18	1/.02
		Simulated	149.	94.3	.71	.62	.94	.06	.09	.03
1516350	Tioga R. nr Mansfield, Pa.	Observed				.41		.05		.01
		Simulated				.43		.05		.04
1518000	Tioga R. at Tioga, Pa.	Observed	1/112.	1/88.3						
		Simulated	133.	112.						
1518550	Crooked Cr. at Tioga, Pa.	Observed	1/73.5	1/74.8						
		Simulated	60.9	74.1						
1519500	Cowanesque R. at Cowanesque, Pa.	Observed	1/92.4	1/95.7						
		Simulated	74.3	91.0						
1520500	Tioga R. at Lindley, NY.	Observed	1/92.6	1/88.6						
		Simulated	84.2	92.1						
1531000	Chemung R. at Chemung, NY.	Observed	1/120.	1/113.	1.03	1/.59	.62	1/.08	.08	1/.03
		Simulated	91.6	98.4	.82	.58	.61	.07	.09	.04
1534300	Lackawanna R. nr Forest City, Pa.	Observed				.68	1.26	.06	.11	
		Simulated				.55	.82	.06	.10	
1545600	Young Woman's Cr. nr Renovo, Pa.	Observed	1/40.4	1/25.1				1/.02	.03	
		Simulated	45.5	28.4				.02	.03	
1553500	West Branch Susquehanna R. at Lewisburg, Pa.	Observed	1/160.	1/98.9	1/1.09			1/.03	.05	
		Simulated	136.	84.4	.82			.02	.07	
1555210	Middle Cr., Pa.	Observed				1.32		.10		
		Simulated				1.22		.12		
1555860	Beaverdam Branch Juniata R., Pa.	Observed				1.87		.62		
		Simulated				1.06		.14		
1556480	Little Juniata R. on Rt 220, Pa.	Observed				1.47		.83		
		Simulated				.87		.10		
1557550	South Bald Eagle Cr. on Rt 350, Pa.	Observed				.79		.11		
		Simulated				.48		.14		
1560510	Dunning Cr. off T-477 nr mouth, Pa.	Observed				1.76		.13		
		Simulated				1.10		.11		
1563500	Juniata R. at Mapleton Depot, Pa.	Observed	140.	111.						
		Simulated	172.	137.						
1564995	Honey Cr. at Reedsville, Pa.	Observed				.93		.08		
		Simulated				1.30		.11		
1565510	Kishacoquillas Cr. at Lewistown, Pa.	Observed				2.46		.15		
		Simulated				1.88		.13		
1566010	Tuscarora Cr. at Port Royal, Pa.	Observed				1.06		.07		
		Simulated				1.04		.18		
1571197	Mountain Cr. at Jct. to Yellow Breeches Cr., Pa.	Observed				1.08		.12		
		Simulated				.94		.51		
1571505	Yellow Breeches Cr., Pa.	Observed				1.95		.11		
		Simulated				2.21		.42		
	Average absolute error as percent of observed:		15.0	10.6	21.8	26.0	13.3	67.6	23.1	95.8

1/Station was used (or equivalent to station used) in calibration of regression model.

NOT REPRODUCIBLE

Although the data used for testing have a very limited range, table 3 is a reasonable representation of the accuracies of the models that may be expected if they are applied to previously unsampled streams.

APPLICATIONS OF REGRESSION MODELS

The multiple-regression models given in table 1 can be applied in a generalized manner or on a site-specific basis. Examples of these applications and their limitations are discussed in the following sections.

Generalized Applications

The multiple-regression models can be used to estimate background water-quality conditions by hypothetically removing the culturally induced effects of land use. In this approach, land-use variables such as percent urbanization (LU1) and percent agriculture (LU2) are set equal to zero. By doing so, the effects of these given land uses are removed mathematically from the model. By this method the equations in table 1 are used to estimate hypothetical ranges of minimum and maximum values for each water-quality characteristic. The estimated background ranges are compared to the observed ranges of water-quality characteristics in table 4. These comparisons suggest that the impact of land use on certain water-quality characteristics is considerable. For example, the maximum of the observed range of nitrate yields (NO3YLD) and phosphorus yields (PYLD) is greater than 10 times the estimated background range. The ranges shown in table 4 are for a selected set of stream stations that were used to calibrate each model. Actual ranges for all possible stream sites in the Susquehanna River basin may differ from those shown. Considering the broad areal coverage of the stream stations used for each model (fig. 3), it is reasonable to assume, however, that these ranges are representative of the study region.

Similar general applications of the regression models can be used to evaluate the generalized effects of any independent variable. However, consideration must be given to the limitations and cautionary aspects discussed under "Limitations of the regression models."

Specific Applications

Regression models can be used to estimate water-quality characteristics for specific stream sites in the study region. These estimates are based on regression models given in table 1 and coupled with estimates of the specified independent variables. Moreover, the independent variables can be hypothetically adjusted to evaluate the effects of changing land-use conditions. This procedure is similar to the approach described above.

Limitations of the Regression Models

Application of the regression models and interpretation of results is subject to a number of limitations. Each application should be evaluated on the basis of the following five considerations.

1. The regression models developed in this study are limited to conditions

TABLE 4.--*Observed ranges of water-quality yields and concentrations and background ranges simulated by regression models*

Water-quality characteristics[1]	Observed range		Simulated background range		Culturally affected variables[2] held constant at zero	Variables[3] assumed to be natural
	Minimum	Maximum	Minimum	Maximum		
SEDYLD-Sediment yield in (tons/mi^2)/yr	21.3	299.	16.2	83.0	LU2	PHA
SEDCONC-Sediment concentration in mg/L	13.3	295.	13.1	102.	LU2	PHA,$\frac{MAQ9}{AREA}$
DSYLD-Dissolved-solids yield in (tons/mi^2)/yr	33.4	308.	16.9	36.0	LU1,LU2,COAL	XCATG,$\frac{MAQ10}{AREA}$
DSYLD-Dissolved-solids yield in (tons/mi^2)/yr	33.4	308.	16.9	60.7	LU1,LU2	XCATG,$\frac{MAQ10}{AREA}$,COAL
DSCONC-Dissolved-solids concentration in mg/L	29.0	282.	17.4	29.6	LU1,LU2,COAL	XCATG
DSCONC-Dissolved-solids concentration in mg/L	29.0	282.	19.3	33.2	LU1,LU2	XCATG,COAL
NAVE-Average nitrogen concentration in mg/L	.40	1.59	.15	.46	$\frac{AGN}{AREA}$,LU1	SLOPE,WATCAP
NSD-Nitrogen standard deviation in mg/L	.18	.98	.25	.75	LU1,LU5	PRECIP,WATCAP
NO3AVE-Average nitrate concentration in mg/L	.15	7.45	.13	.69	$\frac{AGN}{AREA}$	WATCAP
NO3SD-Nitrate standard deviation in mg/L	.07	4.14	.06	.46	$\frac{AGN}{AREA}$	CLAYA,WATCAP,LT200A
NO3YLD-Nitrate yield in (tons/mi^2)/yr	.27	8.98	.12	.43	$\frac{AGN}{AREA}$,LU1	PRECIP,WATCAP
PAVE-Average phosphorus concentration in mg/L	.02	1.24	.01	.14	$\frac{AGP}{AREA}$	PHA,METIG,LT200A
PSD-Phosphorus standard deviation in mg/L	.01	1.18	[4].01	[4].11		
PYLD-Phosphorus yield in (tons/mi^2)/yr	.03	.35	.03	.03	LU1,$\frac{AGP}{AREA}$	
PO4AVE-Average phosphate concentration in mg/L	.01	.20	.00	.01	LU1,$\frac{AGP}{AREA}$	PERMA,WATCAP
PO4SD-Phosphate standard deviation in mg/L	.01	.19	.01	.13		XCATG,BSLOPE,WATCAP

[1]Defined in section entitled "Water-quality characteristics".

[2]Variables explained in section entitled "Basin characteristics". Includes only those variables affected significantly by man.

[3]Variables explained in section entitled "Basin characteristics".

[4]Based on simulated background range of PAVE.

in the Susquehanna River basin and in adjacent areas having similar physiographic and hydrologic properties.

2. The regression models can only define the effects of the independent variables found significant for each model. These models do not include basin characteristics that define the effects of major industrial point sources of pollution or localized nonpoint sources. Consequently, contributions by additional variables for each model should be considered by the user.

3. The estimates of background water quality discussed earlier in "Generalized applications," must be qualified as quasi-natural. The present water quality of the least developed streams may be affected substantially by air pollution, rainfall, and the after-effects of a previous land use. The first two qualifications pertain primarily to nutrients and the latter particularly to suspended sediment. Consequently, the estimates of quasi-natural water quality should not be equated to pristine conditions.

4. Interpretations of the causal effects of independent variables should be judged carefully. Variables that indirectly explain the effect of another variable can be misleading. These variables, referred to as surrogates, are discussed in the section entitled "Validity of regression models." Although the inclusion of surrogates may be useful, the user should be aware of their limitations before using these models in decisionmaking processes.

5. Expected errors in predicted water-quality characteristics are indicated by the standard errors of estimate listed in table 1. In cases where the regression models are used to evaluate specific effects of one or more independent variables, attention should be given to the cross-correlations between variables. If two independent variables in a regression model are highly correlated, the resulting regression coefficients for these variables may be improperly defined. Consequently, if either variable is held at a constant value while the other is hypothetically varied, the resulting computation of the water-quality characteristic may be significantly in error. Improper distribution of regression coefficients may occur, with cross-correlation coefficients as low as 0.5; however, significant errors may not occur unless correlation coefficients are 0.8 or larger. Correlation coefficients between independent variables that exceed 0.5 are listed in table 2. Cross-correlating independent variables will not have a large effect on the accuracy of the regression model unless the effect of one of these variables is evaluated in the manner just described.

DISCUSSION AND CONCLUSIONS

Multiple-regression analysis was found to be a useful technique for assessing regional variations in water-quality characteristics in the Susquehanna River basin. The method was specifically structured to define those basin characteristics that control nonpoint sources of pollution. The multiple-regression models developed in this study are applicable only to the Susquehanna River basin and hydrologically similar adjacent areas. The general approach, however, should be potentially applicable to other regions. In most regions, the most limiting factor is the availability of land-use and water-quality data. Land-use maps are becoming more widely available as a result of newly developed remote-sensing techniques. Deficiencies in water-quality data, however, can be overcome only by comprehensive data-network planning, sampling, and analysis.

Methods for compiling 17 water-quality characteristics and 57 basin characteristics from available data sources are described in detail. Selection of basin characteristics for each regression was based on statistical significance and from knowledge of the hydrologic processes involved. Eighteen of the 57 basin characteristics were selected for use in 14 successful regression models (table 1).

The 14 multiple-regression models, relating water quality to basin characteristics, explained from 56 to 89 percent of the variation of the water-quality characteristics, with standard errors of estimate ranging from 17 to 75 percent. The principal sources of error were coarseness in the model structure and errors inherent in the data and methods of data compilation. It is particularly important that the limitations described in this report be understood by the user to avoid misuse of the model results.

The regression models developed in this study can be used to make generalized conclusions about nonpoint sources of pollution. For example, regression models are used to estimate ranges of background water quality by mathematically removing the effect of land-use variables from each model. Comparison of ranges of observed water-quality characteristics to the estimated background ranges (table 4) shows that land use has a significant impact on 12 of the investigated water-quality characteristics. The greatest impact is indicated for nitrate yields where the maximum observed value is 20 times greater than the maximum estimated background value. This difference is indicated to be the result of chemical fertilizer, animal wastes, and urbanization. In view of this contrast, the standard error of estimate of the nitrate-yield model ($\pm$ 24 percent) is very good. By the same comparisons, the standard errors (ranging from 17 to 75 percent) of the 14 models range from acceptable to poor for making generalized estimates of background water quality. The models can also be used for estimating water quality at specific sites where water-quality data are lacking. The effect of individual land uses or other basin characteristics can be evaluated for a specific site in a manner similar to the generalized example.

The use of the regression models should be tempered by the limitations specified and by the scope of the general method used. It is particularly important to realize that the effects of land use explained by the regression models represent generalizations of the prevailing management practices during water years 1966 to 1975 for sediment and dissolved solids and during 1970 to 1975 for nitrogen and phosphorus. This methodology should be considered a "first-cut" approach for evaluating water quality on a regional basis. Based on this type of study, the need for more detailed data collection and areal investigations can be planned according to regional needs and problems.

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APPENDIXES

Station number	Station name	SEDYLD	SEDCONC	DSYLD	DSCONC	DSEXP	DSCOEF
1500500	SUSQUEHANNA R. AT UNADILLA, N.Y.	112.6	68.1	129.0	82.0	.875	.585
1502000	BUTTERNUT CR. AT MORRIS, N.Y.	--	--	89.7	53.7	.890	.256
1502500	UNADILLA R. AT ROCKDALE, N.Y.	110.4	69.9	--	--	--	--
1503000	SUSQUEHANNA R. AT CONKLIN, N.Y.	143.6	90.5	129.0	81.5	.834	.918
1507500	GENEGANTSLET CR. AT SMITHVILLE FLATS, N.Y.	--	--	--	--	.903	.172
1508800	FACTORY BROOK AT HOMER, N.Y.	--	--	--	--	.846	.737
1508803	W. BR. TIOUGHNIOGA R. AT HOMER, N.Y.	--	--	--	--	.800	1.367
1509150	GRIDLEY CR. ABOVE EAST VIRGIL, N.Y.	--	--	--	--	.710	.548
1513107	SUSQUEHANNA R. AT JOHNSON CITY, N.Y.	--	--	--	--	--	--
1514000	OWEGO CR. NEAR OWEGO, N.Y.	90.4	61.5	--	--	--	--
1515000	SUSQUEHANNA R. NEAR WAVERLY, N.Y.	195.2	119.0	--	--	--	--
1515050	SUSQUEHANNA R. AT SAYRE, PA.	--	--	138.0	86.4	.752	2.369
1516820	TIOGA R. AT LAMBS CR., PA.	--	--	--	--	.638	2.670
1517000	ELK RUN NEAR MAINESBURG, PA.	145.0	141.5	--	--	--	--
1517500	MILL CR. NEAR TIOGA, PA.	--	--	--	--	.869	.431
1518000	TIOGA R. AT TIOGA, PA.	96.0	80.8	134.0	105.0	.748	1.469
1518400	CROOKED CR. AT MIDDLEBURY CENTER, PA.	--	--	--	--	.842	.486
1518500	CROOKED CR. AT TIOGA, PA.	98.9	106.4	33.4	82.9	.880	.437
1518700	TIOGA R. AT TIOGA JUNCTION, PA.	--	--	--	--	.739	1.522
1518850	COWANESQUE R. AT WESTFIELD, PA.	--	--	--	--	.845	.358
1518860	MILL CREEK AT WESTFIELD, PA.	--	--	--	--	.759	.558
1518870	COWANESQUE R. AT COWANESQUE, PA.	--	--	--	--	.636	1.630
1519000	TROUPS CR. AT KNOXVILLE, PA.	--	--	--	--	.874	.468
1520000	COWANESQUE R. NEAR LAWRENCEVILLE, PA.	--	--	98.7	102.0	.700	1.848
1520500	TIOGA R. AT LINDLEY, N.Y.	237.0	237.9	98.1	93.8	.733	1.791
1526500	TIOGA R. NEAR ERWINS, N.Y.	299.4	294.9	--	--	--	--
1528000	FIVEMILE CR. NEAR KANONA, N.Y.	--	--	126.0	107.0	.823	.724
1531000	CHEMUNG R. AT CHEMUNG, N.Y.	217.9	214.7	137.0	129.0	.787	2.127
1533205	SUSQUEHANNA R. AT L.R. 65041, PA.	--	--	--	--	--	--
1534000	TUNKHANNOCK CR. NEAR TUNKHANNOCK, PA.	84.2	59.5	--	--	--	--
1534090	SUSQUEHANNA R. AT FALLS, PA.	--	--	123.0	88.3	.752	2.810
1534500	LACKAWANNA R. AT ARCHBALD, PA.	--	--	286.0	146.0	.671	2.529
1536000	LACKAWANNA R. AT OLD FORGE, PA.	--	--	181.0	136.0	.794	1.400
1539000	FISHING CR. NEAR BLOOMSBURG, PA.	214.0	121.9	--	--	--	--
1541000	W. BR. SUSQUEHANNA R. AT BOWER, PA.	90.5	51.4	--	--	--	--
1543000	DRIFTWOOD BR.SINNEMAHONING CR.STERLING RUN, PA.	71.5	40.4	--	--	--	--
1543500	SINNEMAHONING CR. AT SINNEMAHONING, PA.	--	--	110.0	64.4	.675	2.007
1544500	KETTLE CR. AT CROSS FORK, PA.	21.3	13.3	--	--	--	--
1545500	W. BR. SUSQUEHANNA R. AT RENOVO, PA.	55.8	32.5	275.0	157.0	.720	5.172
1545600	YOUNG WOMAN'S CR. NEAR RENOVO, PA.	76.9	49.5	46.7	29.0	.986	.084
1546500	SPRING CR. NEAR AXEMAN, PA.	--	--	277.0	282.0	.965	.898
1547500	BALD EAGLE CR. AT BLANCHARD, PA.	--	--	200.0	152.0	.776	1.708
1547950	BEECH CR. AT MONUMENT, PA.	--	--	--	--	.652	2.187
1548500	PINE CR. AT CEDAR RUN, PA.	--	--	81.9	56.1	.876	.377
1549500	BLOCKHOUSE CR. NEAR ENGLISH CENTER, PA.	276.7	169.7	--	--	--	--
1553500	W. BR. SUSQUEHANNA R. AT LEWISBURG, PA.	59.8	36.8	158.0	97.6	.706	4.513
1555000	PENNS CR. AT PENNS CREEK, PA.	--	--	138.0	92.4	.879	.552
1555500	E. MAHANTANGO CR. NEAR DALMATIA, PA.	--	--	147.0	98.8	.823	.796
1555600	WISCONISCO CR. AT MILLERSBURG, PA.	--	--	--	--	--	--
1556010	FRANKSTOWN BR. JUNIATA R. NEAR CLOVER CR., PA.	--	--	--	--	--	--
1559000	JUNIATA R. AT HUNTINGDON, PA.	65.6	52.2	222.0	164.0	.815	1.741
1559920	BOBS CR. AT REYNOLDSDALE, PA.	--	--	--	--	--	--
1560000	DUNNING CR. AT BELDEN, PA.	47.5	36.2	--	--	--	--
1561000	BRUSH CR. AT GAPSVILLE, PA.	--	--	--	--	--	--
1562000	RAYSTOWN BR. JUNIATA R. AT SAXTON, PA.	64.5	55.2	130.0	104.0	.760	1.543
1562010	SHOUP RUN AT SAXTON, PA.	--	--	--	--	.571	2.150
1562200	SHY BEAVER CR. NEAR ENTRIKEN, PA.	--	--	--	--	.764	.569
1562250	TATMAN RUN NEAR ENTRIKEN, PA.	--	--	--	--	.790	.246
1562350	COFFEE RUN NEAR ENTRIKEN, PA.	--	--	--	--	.718	.606
1562500	GREAT TROUGH CR. NEAR MARKLESBURG, PA.	--	--	--	--	.888	.216
1563000	RAYSTOWN BR. JUNIATA R. NEAR HUNTINGDON, PA.	--	--	--	--	.857	.904
1563210	RAYSTOWN BR. JUNIATA R. AT ARDENHEIM, PA.	--	--	--	--	1.025	.256
1564515	AUGHWICK CR. AT AUGHWICK MILLS, PA.	--	--	--	--	--	--
1565300	KISHACOQUILLAS CR. AT L.R. 44002, PA.	--	--	--	--	--	--
1565515	JACKS CR. AT LEWISTOWN, PA.	--	--	--	--	--	--
1567000	JUNIATA R. AT NEWPORT, PA.	65.6	54.8	161.0	124.0	.746	3.138
1567500	BIXLER RUN NEAR LOYSVILLE, PA.	67.4	59.3	--	--	--	--
1568000	SHERMAN CR. AT SHERMANS DALE, PA.	44.7	31.8	--	--	--	--
1568200	SHERMANS CR., PA.	--	--	--	--	--	--
1569320	MIDDLE SPRING CR., PA.	--	--	--	--	--	--
1569900	CONODOGUINET CR. PA.	--	--	--	--	--	--
1573205	QUITTAPAHILLA CR. AT SYNER, PA.	--	--	--	--	--	--
1574000	CONEWAGE CR. NEAR MANCHESTER, PA.	133.0	110.2	--	--	--	--
1575000	S. BR. CODORUS CR. NEAR YORK, PA.	--	--	--	--	--	--
1575990	CHICKIES CR., PA.	--	--	--	--	--	--
1576500	CONESTOGA R. AT LANCASTER, PA.	156.0	129.4	308.0	234.0	.941	.931
1576515	MILL CR. AT L.R. 36009, PA.	--	--	--	--	--	--
1576600	CONESTOGA CR. NEAR CONESTOGA, PA.	--	--	--	--	--	--
1576789	PEQUEA CR., PA.	--	--	--	--	--	--
1577500	MUDDY CR. AT CASTLE FIN, PA.	--	--	--	--	1.006	.167

Characteristics

NAVE	NSD	NO3AVE	NO3YLD	NO3SD	NH4AVE	PAVE	PSD	PYLD	PO4AVE	PO4SD
.99	.44	.56	.88	.21	.09	.04	.02	.06	.01	.01
--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--
.70	.18	.41	.65	.24	--	.04	.03	.06	--	--
.40	.22	.21	--	.17	.10	--	--	--	--	--
--	--	3.09	--	.58	--	--	--	--	--	--
--	--	1.48	--	.30	--	--	--	--	--	--
--	--	.57	--	.18	--	--	--	--	--	--
1.34	.36	.85	--	.37	--	.07	.09	--	--	--
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--	--	--	--	--	--	--	--	--	--	--
--	--	.59	.96	.28	.06	.09	.07	.15	.03	.03
.87	.46	.54	--	.30	.11	.07	.07	--	.04	.03
--	--	--	--	--	--	--	--	--	--	--
.72	.41	.41	--	.34	.06	.02	.02	--	.01	.01
.85	.32	.55	.70	.31	.10	.06	.07	.08	.03	.01
.82	.38	.47	--	.34	.10	.07	.10	--	.05	.10
.82	.42	.46	.45	.32	.07	.08	.05	.08	.05	.04
.89	.53	.57	--	.52	.10	.06	.08	--	.04	.06
.75	.30	.40	--	.31	.08	.07	.16	--	--	--
1.13	.35	.59	--	.30	.16	.10	.04	--	.07	.04
1.18	.41	.46	--	.29	.29	.07	.05	--	.03	.02
1.25	.66	.84	--	.58	.07	.03	.04	--	--	--
.90	.48	.56	.54	.38	.08	.05	.04	.05	.03	.03
.80	.39	.52	.54	.31	.08	.05	.03	.05	.03	.82
--	--	--	--	--	--	--	--	--	--	--
1.25	.88	.74	.87	.49	.12	.06	.04	.07	.03	.01
--	--	.72	.75	.22	.08	.12	.04	.12	.07	.04
--	--	.54	.75	.38	.20	.06	.08	.08	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	.71	1.04	.63	.42	.10	.11	.15	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	.65	.87	.67	--	--	--	--	--	--
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--	--	.37	.67	.21	.55	--	--	--	--	--
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--	--	.37	.65	.18	--	--	--	--	--	--
--	--	.17	.27	.11	--	.02	.02	.03	.01	.02
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--	--	.15	--	.07	--	--	--	--	--	--
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.78	.30	.51	.83	.18	.06	.04	.02	.06	.02	.01
--	--	--	--	--	--	--	--	--	--	--
--	--	2.58	3.83	1.49	.20	.08	.05	.12	--	--
--	--	1.62	--	.46	--	.10	.07	--	--	--
--	--	1.31	--	.89	.55	.65	.79	--	--	--
--	--	1.58	2.14	.62	--	--	--	--	--	--
--	--	1.75	--	1.32	.13	.08	.06	--	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	2.88	--	1.98	1.01	1.08	.93	--	--	--
1.54	.57	1.32	1.65	.72	.11	.07	.07	.09	.02	.02
.71	.88	.52	--	.75	.09	.04	.04	--	--	--
1.12	.98	.89	--	.99	.08	.03	.01	--	--	--
1.01	.63	.62	--	.42	.13	.03	.03	--	--	--
1.45	.53	.90	--	.31	.13	.04	.01	--	--	--
.67	.63	.34	.38	.23	.08	.03	.02	.03	--	--
1.59	.72	1.02	1.04	.43	.12	.06	.06	.06	.02	.01
1.43	.79	1.09	--	.77	.11	.04	.03	--	--	--
--	--	2.59	--	4.14	--	.29	.25	--	--	--
--	--	2.69	--	1.42	.22	.13	.10	--	--	--
--	--	1.78	--	1.27	.60	.11	.04	--	--	--
1.30	.37	.86	1.11	.47	.14	.11	.10	.14	.08	.12
--	--	--	--	--	--	--	--	--	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	2.34	--	2.36	.20	.18	.29	--	--	--
--	--	3.01	--	1.31	.58	1.24	1.18	--	--	--
--	--	4.62	--	3.15	2.20	.36	.30	--	--	--
--	--	5.72	--	2.81	.48	.38	.15	--	--	--
--	--	--	--	--	--	--	--	--	--	--
--	--	3.66	4.26	1.51	.23	.12	.05	.14	--	--
--	--	4.29	--	3.03	.28	.18	.13	--	--	--
--	--	6.83	8.98	2.16	.18	.27	.13	.35	.20	.19
--	--	4.12	--	3.72	.75	1.12	1.16	--	--	--
--	--	7.45	--	2.35	.34	.58	.43	--	--	--
--	--	7.34	--	1.37	.14	.25	.23	--	--	--
--	--	--	--	--	--	--	--	--	--	--

Station number	Climatic characteristics					Topographic characteristics					
	PRECIP	I24,2	P	SN	MINJAN	AREA	CONTDA	SLOPE	BSLOPE	SLGT20	STOR
1500500	39.7	2.45	96.5	60.0	15.0	982.0	907.0	2.8	110.0	4.00	1.34
1502000	38.7	2.50	94.4	80.0	13.9	59.7	--	27.8	90.0	1.00	.15
1502500	39.1	2.40	93.0	80.0	13.5	520.0	518.0	4.8	80.0	1.00	.10
1503000	39.4	2.57	102.6	60.0	14.8	2232.0	2160.0	3.6	120.0	1.00	.71
1507500	40.5	2.50	93.0	70.0	13.2	82.3	--	40.6	50.0	1.00	.54
1508800	36.0	2.50	88.1	80.0	17.0	15.8	--	26.0	130.0	5.00	--
1508803	36.0	2.50	88.1	80.0	17.0	71.5	--	9.8	130.0	5.00	--
1509150	36.0	2.40	90.7	80.0	17.0	10.4	--	26.3	110.0	1.00	--
1513107	41.0	2.50	94.4	80.0	14.0	3891.0	--	8.8	100.0	7.00	--
1514000	38.2	2.40	94.3	80.0	15.2	185.0	185.0	14.3	100.0	13.00	.0
1515000	41.0	2.46	93.7	70.0	13.0	4773.0	4500.0	1.5	100.0	6.00	.54
1515050	41.0	2.50	93.7	70.0	13.0	4690.0	4500.0	1.5	95.0	6.00	--
1516820	36.0	2.40	99.1	60.0	18.0	186.0	--	10.5	130.0	15.00	--
1517000	35.0	2.47	99.0	59.0	18.0	10.2	10.2	47.3	110.0	5.50	.12
1517500	34.0	2.40	76.5	52.5	18.0	76.8	--	33.3	110.0	1.00	--
1518000	35.0	2.60	99.8	57.0	18.0	282.0	282.0	44.0	130.0	7.00	.01
1518400	35.0	2.40	96.2	52.5	17.0	74.2	--	78.4	100.0	1.00	--
1518500	36.4	2.50	97.0	50.0	17.0	122.0	122.0	27.8	80.0	1.00	.0
1518700	34.0	2.40	97.4	52.5	18.0	466.0	--	19.7	100.0	5.00	--
1518850	34.0	2.30	94.5	49.0	16.0	53.0	--	35.0	110.0	5.00	--
1518860	35.0	2.30	94.0	53.0	16.0	13.0	--	62.5	130.0	9.00	--
1518870	35.0	2.30	94.0	54.0	16.7	91.0	--	44.4	100.0	5.00	--
1519000	34.0	2.30	93.0	50.0	16.0	66.5	--	90.9	80.0	1.00	--
1520000	36.5	2.40	97.0	52.0	15.9	298.0	280.1	20.1	100.0	5.00	.0
1520500	36.0	2.50	97.0	54.0	16.7	771.0	771.0	24.4	100.0	6.00	.0
1526500	35.8	2.40	97.0	55.0	16.7	1377.0	1320.0	17.1	120.0	10.00	.09
1528000	33.6	2.40	87.2	45.0	19.0	66.8	--	12.6	120.0	18.00	.03
1531000	34.2	2.44	94.7	53.0	17.0	2530.0	2450.0	7.2	100.0	4.00	.53
1533205	36.0	2.50	105.6	50.0	17.0	8410.0	--	.6	90.0	7.50	--
1534000	42.0	2.64	115.0	34.0	16.0	383.0	383.0	21.3	90.0	1.00	2.50
1534090	36.0	2.45	94.5	54.0	19.0	9440.0	--	3.9	100.0	5.80	--
1534500	44.5	2.55	113.8	62.5	16.0	108.0	--	38.9	110.0	4.70	--
1536000	42.5	3.10	120.7	41.0	18.0	332.0	--	21.9	120.0	5.30	1.67
1539000	43.0	2.60	135.5	36.5	18.0	274.0	274.0	39.6	120.0	19.00	.56
1541000	44.5	2.60	115.2	67.0	18.0	315.0	315.0	9.1	90.0	1.00	.01
1543000	45.0	2.37	106.9	53.0	18.0	272.0	272.0	26.5	130.0	7.00	.01
1543500	45.5	2.70	109.4	54.0	18.0	685.0	--	8.7	120.0	4.70	.01
1544500	43.0	2.46	123.0	53.0	18.0	136.0	134.5	37.4	170.0	33.00	.0
1545500	44.0	2.44	111.2	58.0	18.0	2975.0	2926.9	6.1	120.0	1.00	.02
1545600	40.3	2.48	104.3	52.5	18.0	46.2	45.9	99.5	90.0	5.00	.0
1546500	39.0	2.90	116.6	44.5	22.0	87.2	87.2	32.1	60.0	1.00	.0
1547500	39.2	2.25	114.7	38.0	21.0	339.0	339.0	12.2	110.0	1.00	.0
1547950	40.0	2.50	111.5	56.0	19.0	152.0	--	24.5	100.0	7.00	--
1548500	37.0	2.65	107.3	59.0	19.0	604.0	604.0	22.8	130.0	6.00	.0
1549500	37.8	2.60	104.7	57.4	19.0	37.7	36.1	54.8	160.0	4.00	.0
1553500	42.0	2.46	114.0	50.5	20.0	6847.0	6510.0	4.8	130.0	5.00	.02
1555000	39.0	2.65	118.4	46.0	22.0	301.0	301.0	18.9	120.0	4.00	.0
1555500	46.0	3.20	156.3	36.0	20.0	162.0	162.0	11.0	130.0	10.50	.0
1555600	45.0	3.25	150.5	35.0	22.0	105.0	--	10.2	95.0	1.00	--
1556010	42.0	2.50	120.0	56.0	22.0	249.0	--	10.2	140.0	13.00	--
1559000	42.0	2.55	118.7	38.0	19.0	816.0	816.0	9.0	100.0	1.00	.0
1559920	39.0	2.50	118.7	39.4	22.0	115.0	--	48.8	105.0	1.00	--
1560000	39.5	2.70	119.0	55.0	22.0	172.0	172.0	42.9	100.0	1.00	.0
1561000	36.0	2.70	126.5	53.0	22.0	36.8	--	26.2	130.0	9.00	.0
1562000	38.0	2.58	125.0	53.0	21.0	756.0	756.0	7.1	140.0	2.10	.01
1562010	38.0	2.60	125.0	50.0	22.0	21.8	--	190.7	110.0	5.00	--
1562200	38.0	2.60	124.0	50.0	22.0	10.5	--	58.8	210.0	33.00	--
1562250	38.0	2.50	124.5	44.0	22.0	7.5	--	288.6	130.0	10.00	--
1562350	38.0	2.40	124.0	38.0	22.0	4.7	--	14.4	160.0	11.00	--
1562500	37.5	2.50	123.0	46.0	22.0	84.6	--	15.4	110.0	1.00	.0
1563000	38.0	2.50	124.0	47.0	22.0	957.0	--	6.9	140.0	17.00	--
1563210	38.0	2.60	124.3	44.0	21.0	1940.0	--	1.8	130.0	8.00	--
1564515	39.0	2.60	130.4	42.0	22.0	292.0	--	12.6	110.0	12.00	--
1565300	39.0	2.50	120.4	40.0	22.0	146.0	--	21.2	100.0	1.00	--
1565515	38.0	2.40	123.0	44.0	22.0	60.7	--	11.1	110.0	5.00	--
1567000	42.5	2.62	130.8	50.5	23.0	3354.0	3354.0	7.6	150.0	16.00	.10
1567500	42.5	2.95	130.3	38.0	22.0	15.0	15.0	44.5	80.0	1.00	6.00
1568000	42.5	2.95	132.0	42.0	23.0	200.0	200.0	7.6	90.0	1.00	.0
1568200	42.0	3.00	142.8	42.0	22.0	208.0	--	7.6	90.0	1.00	.0
1569320	41.5	2.80	137.5	39.0	22.0	72.0	--	152.7	65.0	5.00	--
1569900	43.0	2.80	135.8	29.0	22.0	399.0	--	5.3	50.0	1.00	--
1573205	44.0	3.00	158.3	24.9	22.0	100.0	--	6.8	30.0	1.00	--
1574000	42.5	2.80	145.6	29.0	25.0	510.0	510.0	5.5	60.0	1.00	.21
1575000	43.5	2.80	151.0	31.0	24.0	117.0	74.0	16.2	110.0	1.00	.21
1575990	42.0	3.00	155.6	25.0	24.0	106.0	--	8.5	50.0	1.00	--
1576500	44.2	3.10	185.4	42.0	22.0	324.0	324.0	7.4	60.0	1.00	.01
1576515	42.5	3.30	165.6	24.0	24.0	20.0	--	50.0	40.0	1.00	--
1576600	43.0	3.20	162.1	24.0	24.0	418.0	--	6.1	40.0	1.00	--
1576789	42.0	3.30	167.5	25.0	24.0	134.0	--	9.2	90.0	1.00	--
1577500	44.2	3.40	151.4	33.5	24.0	133.0	130.8	17.6	80.0	.62	.0

ELEV	DDI	Geologic characteristics								
		GLAC	LIMDOL	COAL	SED	METIG	TRIAC	GEOTDS	GEON	SPCAP
1.110	1.179	100.0	.0	.0	100.0	.0	.0	197.66	.25	3.92
1.352	--	100.0	.0	.0	100.0	.0	.0	202.80	.24	3.58
1.109	2.340	100.0	.0	.0	100.0	.0	.0	197.07	.21	1.79
1.012	.915	100.0	.0	.0	100.0	.0	.0	195.85	.23	1.95
1.272	--	100.0	.0	.0	100.0	.0	.0	198.20	.17	.49
1.440	--	100.0	.0	.0	100.0	.0	.0	189.20	.18	2.53
1.440	--	100.0	.0	.0	100.0	.0	.0	201.40	.24	4.05
1.230	--	100.0	.0	.0	100.0	.0	.0	200.00	.14	.46
.998	--	100.0	.0	.0	100.0	.0	.0	195.53	.62	11.09
1.024	2.460	100.0	.0	.0	100.0	.0	.0	203.40	.28	6.28
.960	2.310	100.0	.0	.0	100.0	.0	.0	199.41	.26	3.12
.960	2.310	100.0	.0	.0	100.0	.0	.0	199.41	.26	3.12
1.825	--	100.0	.0	14.2	80.8	.0	.0	171.24	.86	2.04
1.750	1.220	100.0	.0	.0	100.0	.0	.0	--	--	.88
1.686	--	100.0	.0	.0	100.0	.0	.0	163.78	1.08	1.05
1.740	.476	100.0	.0	15.2	84.8	.0	.0	154.56	1.01	2.00
1.700	--	100.0	.0	.0	100.0	.0	.0	242.00	.46	.74
1.305	.566	100.0	.0	.0	100.0	.0	.0	179.20	.88	1.13
1.650	--	100.0	.0	.0	100.0	.0	.0	288.80	.16	.5[illegible]
1.630	--	100.0	.0	.0	100.0	.0	.0	123.06	1.34	1.91
1.780	--	100.0	.0	.0	100.0	.0	.0	164.00	.86	.79
1.800	--	100.0	.0	.0	100.0	.0	.0	180.00	.87	1.02
1.290	--	100.0	.0	.0	100.0	.0	.0	212.00	.21	.4[illegible]
1.278	.870	100.0	.0	.0	100.0	.0	.0	201.20	.51	.63
1.447	.970	100.0	.0	2.0	98.0	.0	.0	214.64	.57	.92
1.354	.860	100.0	.0	.0	100.0	.0	.0	231.92	.34	1.02
1.305	--	100.0	.0	.0	100.0	.0	.0	179.80	.14	2.[illegible]
1.120	.930	100.0	.0	1.0	99.0	.0	.0	207.53	.36	2.82
1.175	--	100.0	.0	.0	100.0	.0	.0	200.35	.28	3.96
1.370	1.160	100.0	.0	.0	100.0	.0	.0	--	--	.68
1.200	--	100.0	.0	1.0	99.0	.0	.0	181.43	.53	2.3[illegible]
1.500	--	100.0	.0	7.1	92.9	.0	.0	104.66	2.38	2.87
1.510	--	100.0	.0	28.0	72.0	.0	.0	131.32	.94	2.12
1.190	1.170	52.0	4.0	.0	96.0	.0	.0	211.43	.69	1.09
1.740	.710	.0	.0	100.0	.0	.0	.0	165.30	.50	2.60
1.760	1.330	.0	.0	57.0	43.0	.0	.0	138.90	.66	2.54
1.680	--	.0	.0	81.0	19.0	.0	.0	140.50	.52	2.96
1.760	1.950	.0	.0	15.0	85.0	.0	.0	119.50	1.30	2.56
1.770	.850	.0	.0	66.7	33.3	.0	.0	148.27	.72	2.7[illegible]
1.736	1.330	.0	.0	32.0	68.0	.0	.0	116.00	1.26	3.30
1.270	--	.0	78.0	.0	22.0	.0	.0	186.94	9.86	6.1[illegible]
1.000	--	.0	50.5	.0	49.5	.0	.0	197.43	5.04	2.93
1.736	--	.0	65.3	.0	34.7	.0	.0	187.82	5.57	4.37
1.900	.995	66.0	.0	4.0	96.0	.0	.0	133.02	1.21	1.79
1.350	.965	100.0	.0	.0	100.0	.0	.0	100.00	1.80	2.72
1.550	1.150	19.0	26.7	3.0	70.3	.0	.0	149.72	1.90	1.43
1.330	1.030	.0	56.0	.0	44.0	.0	.0	130.98	.32	.72
.860	.447	.0	.0	14.0	86.0	.0	.0	98.92	13.21	.93
.700	--	.0	.0	16.0	84.0	.0	.0	68.38	16.00	.78
1.712	--	.0	47.0	4.0	49.0	.0	.0	162.74	5.19	1.35
1.000	.860	.0	60.0	4.0	36.0	.0	.0	165.86	5.55	2.94
1.200	--	.0	73.3	1.0	25.7	.0	.0	241.28	7.50	.93
1.560	.669	.0	27.0	.0	73.0	.0	.0	146.41	6.32	1.37
1.550	--	.0	.0	.0	100.0	.0	.0	70.59	2.10	.46
1.470	.800	.0	36.0	4.0	60.0	.0	.0	158.27	6.42	1.41
1.500	--	.0	.0	74.0	26.0	.0	.0	112.20	.80	1.77
1.500	--	.0	33.0	.0	67.0	.0	.0	162.90	15.10	.63
1.250	--	.0	.0	41.0	59.0	.0	.0	87.39	1.15	1.16
1.000	--	.0	100.0	.0	.0	.0	.0	161.19	2.62	.46
1.350	--	.0	.0	.0	100.0	.0	.0	85.17	2.10	.49
1.360	--	.0	26.0	4.0	70.0	.0	.0	147.38	4.95	1.39
1.250	--	.0	44.0	4.0	52.0	.0	.0	153.81	4.91	1.84
1.193	--	.0	32.3	.0	67.7	.0	.0	146.78	3.22	.43
1.270	--	.0	36.0	.0	64.0	.0	.0	111.88	2.54	1.63
1.262	--	.0	86.0	.0	14.0	.0	.0	177.78	1.42	.75
1.470	.750	.0	55.4	5.9	38.6	.0	.0	157.74	4.23	1.25
.980	1.360	.0	100.0	.0	.0	.0	.0	230.50	3.39	1.60
1.180	1.230	.0	94.9	.0	5.1	.0	.0	224.85	3.92	1.67
1.180	--	.0	65.7	.0	34.3	.0	.0	177.67	4.95	1.14
.950	--	.0	56.0	.0	.0	44.0	.0	245.60	23.00	4.97
.500	--	.0	43.0	.0	57.0	.0	.0	232.78	16.63	2.92
.480	--	.0	89.0	.0	8.0	.0	3.0	330.84	23.77	5.22
.570	1.130	.0	5.0	.0	.0	9.0	86.0	215.84	18.93	.75
.700	1.368	.0	32.3	.0	.0	67.7	.0	160.05	12.50	.80
.500	--	.0	34.0	.0	28.0	.0	38.0	251.20	24.85	2.20
1.000	.800	.0	22.0	.0	31.0	3.0	44.0	266.03	28.97	1.11
.530	--	.0	66.0	.0	.0	34.0	.0	238.30	--	.90
.540	--	.0	58.0	.0	.0	11.0	31.0	271.20	16.68	2.39
.600	--	.0	41.0	.0	12.0	26.0	21.0	247.97	18.71	1.06
.600	1.760	.0	.0	.0	1.0	99.0	.0	105.30	4.44	.90

Station number	Soil characteristics									
	CLAYA	SILTA	SOILNA	SOILNG	XACIDA	XACIDG	XCATA	XCATG	CECA	CECG
1500500	12.7	39.6	.128	.268	13.59	18.27	3.52	7.29	17.11	24.38
1502000	11.3	33.9	.139	.208	17.08	23.19	3.65	8.82	20.74	31.46
1502500	13.3	40.4	.149	.391	14.74	20.29	4.87	9.75	19.59	28.00
1503000	13.4	42.6	.141	.290	13.82	18.47	4.24	8.44	18.04	24.92
1507500	13.7	45.1	.146	.216	12.80	18.24	4.35	8.61	17.15	23.93
1508800	14.5	44.9	.138	.200	12.09	15.76	5.11	10.04	17.20	22.96
1508803	13.2	43.1	.142	.202	13.33	17.35	4.25	8.50	17.58	23.45
1509150	14.0	45.6	.147	.212	13.98	18.31	4.35	8.89	18.33	24.54
1513107	13.9	45.7	.151	.300	13.30	18.07	4.64	8.88	17.93	24.69
1514000	13.4	45.4	.166	.217	13.40	16.82	5.94	9.96	19.33	24.37
1515000	13.9	45.6	.149	.277	13.27	18.05	4.67	8.87	17.94	24.49
1515050	13.9	45.6	.149	.277	13.27	18.05	4.67	8.87	17.94	24.49
1516820	16.1	46.4	.155	.386	13.49	17.78	4.57	8.19	17.92	22.73
1517000	18.2	45.6	.163	.521	14.20	17.02	4.42	7.11	18.61	21.42
1517500	17.8	45.9	.161	.482	13.98	17.00	4.45	7.37	18.43	21.55
1518000	16.6	45.5	.159	.447	13.95	18.29	4.53	7.82	18.27	23.05
1518400	15.6	47.5	.151	.290	12.94	16.93	4.60	8.65	17.53	22.17
1518500	16.6	46.2	.155	.389	13.37	16.80	4.47	7.88	17.84	21.61
1518700	16.3	45.2	.157	.434	13.71	18.08	4.50	7.82	18.00	22.82
1518850	17.3	44.6	.157	.358	14.49	17.81	4.41	7.77	18.91	22.91
1518860	15.5	46.0	.149	.206	13.61	17.72	4.53	8.81	18.15	23.36
1518870	16.2	45.4	.152	.301	13.64	17.31	4.45	8.20	18.10	22.51
1519000	14.7	43.4	.142	.199	14.73	18.87	4.65	9.99	19.38	25.66
1520000	15.3	44.0	.153	.321	14.44	19.77	4.56	8.65	18.71	25.32
1520500	15.9	45.0	.156	.395	14.09	19.01	4.56	8.22	18.38	24.10
1526500	15.0	45.8	.154	.322	13.26	18.17	4.50	8.03	17.59	23.45
1528000	10.4	46.6	.154	.215	14.27	19.00	4.25	7.39	18.51	25.28
1531000	13.3	41.7	.145	.275	12.90	17.34	4.31	7.80	17.10	22.89
1533205	14.2	45.1	.155	.323	13.48	18.21	4.72	8.54	18.13	24.37
1534000	17.1	46.5	.168	1.097	14.06	16.09	4.42	6.76	18.37	20.47
1534090	14.4	44.1	.150	.366	13.30	17.73	4.45	8.14	17.71	23.55
1534500	15.3	42.3	.154	.990	13.37	15.73	4.14	6.58	17.37	20.24
1536000	15.3	38.4	.149	.686	14.24	17.22	3,42	4.94	17.55	20.44
1539000	18.1	45.8	.176	.991	13.37	16.44	5.41	6.88	18.43	21.07
1541000	15.9	56.6	.176	.236	11.37	18.90	7.49	13.10	18.82	24.26
1543000	17.3	44.3	.122	.290	12.56	28.79	3.64	8.91	16.22	31.52
1543500	16.9	45.3	.125	.237	13.16	24.97	3.18	8.35	16.35	27.35
1544500	16.6	48.8	.142	.246	7.47	13.92	8.42	10.16	15.90	21.11
1545500	16.1	49.8	.146	.213	11.36	19.38	5.59	10.24	16.94	23.60
1545600	17.0	40.9	.120	.164	11.65	16.09	3.97	7.61	15.67	19.72
1546500	21.1	53.2	.145	.265	5.00	10.55	15.77	34.80	20.78	41.19
1547500	18.3	48.4	.148	.221	7.18	12.78	11.39	21.03	18.58	28.91
1547950	16.6	47.4	.138	.187	12.77	18.83	4.19	9.04	16.97	22.12
1548500	19.0	45.7	.161	.550	14.30	17.66	4.41	6.90	18.70	21.67
1549500	19.9	40.9	.168	.505	16.58	18.80	4.15	6.33	20.75	23.49
1553500	17.1	48.1	.151	.332	11.47	17.22	6.18	10.39	17.62	23.10
1555000	19.3	48.9	.136	.163	7.97	11.52	11.74	16.67	19.73	22.98
1555500	16.1	49.4	.144	.207	7.04	13.93	8.49	10.37	15.53	21.27
1555600	15.9	44.9	.130	.193	8.26	16.34	7.14	9.46	15.40	22.59
1556010	20.2	48.6	.169	.211	7.04	11.28	15.84	21.91	22.87	28.02
1559000	17.8	47.0	.147	.212	7.76	14.24	11.57	19.38	19.33	28.29
1559920	18.9	50.0	.170	.200	8.74	15.14	12.30	16.10	21.03	25.85
1560000	18.6	49.0	.170	.195	9.10	15.40	11.49	15.50	20.58	25.22
1561000	16.2	44.0	.138	.186	7.15	11.94	8.36	10.50	15.54	18.96
1562000	19.4	49.2	.161	.199	7.67	12.57	13.44	18.43	21.12	25.90
1562010	16.4	49.1	.153	.207	9.34	15.91	7.94	11.92	17.27	22.22
1562200	20.6	53.6	.172	.245	6.97	11.67	14.77	28.35	21.73	33.45
1562250	16.6	42.6	.154	.187	8.55	12.83	8.85	12.60	17.41	19.57
1562350	21.8	55.8	.170	.257	6.29	10.57	16.11	32.51	22.39	37.09
1562500	15.6	55.7	.170	.231	8.23	15.31	9.31	12.87	17.51	22.42
1563000	19.0	49.4	.162	.201	7.64	12.79	12.87	17.77	20.51	25.37
1563210	17.9	49.2	.148	.199	8.62	14.95	10.94	17.47	19.55	26.99
1564515	16.9	44.5	.147	.182	8.23	12.83	9.16	13.19	17.40	20.36
1565300	20.8	51.4	.170	.206	6.68	10.16	12.98	25.98	19.68	32.71
1565515	19.0	58.4	.324	.054	11.60	19.84	6.75	8.94	18.31	27.25
1567000	18.7	46.5	.161	.200	7.96	12.64	12.11	18.21	20.05	26.22
1567500	22.9	50.1	.246	.132	8.44	13.18	18.43	21.80	26.88	31.45
1568000	19.4	42.1	.169	.156	7.94	10.85	12.53	15.21	20.51	22.86
1568200	19.1	42.5	.168	.158	7.90	11.04	12.25	14.88	20.18	22.71
1569320	18.7	60.7	.119	.209	7.39	14.69	8.17	25.06	15.54	33.49
1569900	19.5	55.4	.167	.229	8.87	14.44	10.61	21.44	19.48	28.30
1573205	18.4	57.4	.143	.226	7.62	13.42	9.73	25.02	17.35	31.06
1574000	14.8	53.5	.144	.263	8.82	19.86	5.04	12.30	13.88	26.52
1575000	18.8	55.5	.128	.225	11.47	20.92	5.36	12.71	16.83	28.81
1575990	17.3	59.2	.118	.201	9.02	18.11	5.84	14.26	14.86	25.59
1576500	16.0	57.2	.106	.161	9.06	16.75	6.16	15.51	15.22	24.58
1576515	19.7	66.7	.095	.128	10.09	17.98	6.23	18.45	16.33	26.35
1576600	16.6	58.8	.104	.155	9.30	17.03	6.10	15.92	15.40	24.83
1576789	17.7	54.9	.099	.155	11.40	20.96	4.54	13.62	15.92	27.28
1577500	18.3	49.5	.144	.267	12.87	23.78	4.25	7.18	17.12	28.76

Soil characteristics

PHA	PHL	KA	PERMA	PERML	HSG	WATCAP	BDRK	LT200A	GRAVA	STONEA
5.2	4.5	.22	1.40	1.10	2.7	.099	44	50.7	32.0	7.2
5.1	4.1	.21	1.52	1.45	2.7	.109	37	50.6	33.8	8.5
5.3	4.5	.21	1.57	1.19	2.6	.095	47	50.4	32.9	7.6
5.3	4.7	.21	1.29	.98	2.7	.086	47	49.8	33.5	7.6
5.4	4.8	.21	.94	.70	2.8	.067	52	50.3	34.2	8.5
5.4	4.9	.24	1.03	.48	2.7	.098	52	51.2	31.6	6.2
5.1	4.5	.23	.88	.60	3.0	.076	50	51.1	34.1	8.1
5.3	4.8	.22	.82	.58	3.0	.071	50	50.1	35.9	8.7
5.5	4.9	.22	1.26	.91	2.7	.082	52	50.9	34.6	7.6
5.6	5.0	.21	1.29	1.19	2.6	.071	51	48.8	36.3	7.0
5.5	4.9	.21	1.23	.93	2.7	.078	51	50.1	34.7	7.7
5.5	4.9	.21	1.23	.93	2.7	.078	51	50.1	34.7	7.7
5.4	4.9	.23	.93	.68	2.9	.068	50	50.0	35.6	8.0
5.3	4.9	.24	1.00	.71	3.0	.076	46	50.6	35.7	7.8
5.3	4.9	.23	.95	.68	3.0	.074	47	50.6	35.7	7.9
5.3	4.9	.23	1.06	.80	2.9	.072	48	49.7	35.7	7.8
5.4	4.9	.23	.73	.51	3.0	.064	52	50.4	35.6	8.4
5.3	4.8	.23	.84	.59	3.0	.069	49	50.0	35.3	8.0
5.3	4.8	.22	1.04	.78	2.9	.070	48	49.2	35.3	7.7
5.3	4.8	.23	.96	.76	3.0	.078	45	50.0	37.0	7.9
5.3	4.8	.22	.78	.62	3.0	.069	49	49.9	36.8	8.3
5.3	4.8	.22	.84	.64	3.0	.071	47	49.6	36.1	8.1
5.3	4.6	.22	.74	.77	3.0	.085	44	52.1	36.7	7.5
5.3	4.8	.22	1.10	.94	2.9	.076	47	49.2	36.7	7.7
5.3	4.8	.22	1.09	.86	2.9	.073	48	49.4	36.1	7.8
5.2	4.7	.23	1.14	.85	2.8	.072	48	50.0	32.7	7.3
5.2	4.7	.19	1.54	1.12	2.5	.084	52	48.5	33.8	7.5
4.9	4.4	.20	1.13	.90	2.6	.071	44	46.3	31.8	7.0
5.4	4.8	.21	1.23	.96	2.7	.075	50	49.4	35.0	7.8
5.3	4.8	.24	1.07	.54	3.0	.079	51	53.6	30.4	7.4
5.3	4.7	.21	1.14	.86	2.7	.075	48	49.0	34.0	7.7
5.0	4.4	.22	1.08	.61	2.7	.076	47	49.5	28.7	6.9
4.4	4.1	.21	1.27	.82	2.6	.082	41	45.3	28.0	6.2
5.4	4.8	.24	2.15	1.68	2.7	.088	45	53.4	29.6	10.2
5.6	4.4	.31	1.28	.96	2.8	.115	42	72.1	13.9	3.8
5.3	4.4	.29	2.84	2.24	2.6	.106	52	61.5	11.9	4.8
5.0	4.3	.30	2.42	1.94	2.5	.105	49	62.9	11.9	4.4
6.1	5.0	.25	4.44	4.03	2.7	.107	45	53.3	27.4	6.6
5.3	4.4	.29	2.28	1.88	2.6	.108	45	64.5	15.0	4.4
5.3	4.5	.27	6.03	5.39	2.7	.098	45	53.4	24.5	7.4
6.4	5.3	.29	3.64	2.39	2.8	.142	44	72.0	12.0	5.6
6.1	4.9	.27	4.36	3.66	2.9	.113	40	56.8	25.6	8.0
5.1	4.3	.29	3.07	2.65	2.6	.105	45	63.1	15.7	4.9
5.3	4.8	.25	1.56	1.23	2.9	.090	45	53.9	31.3	6.8
5.1	4.7	.24	1.30	1.11	3.0	.098	35	49.6	38.6	7.3
5.4	4.6	.28	2.41	1.98	2.7	.103	44	59.3	23.1	5.8
6.0	4.9	.28	5.12	4.64	2.7	.114	42	57.6	25.5	7.1
6.1	4.9	.25	4.33	4.03	2.5	.103	44	54.7	25.6	9.9
5.9	4.8	.25	5.15	4.75	2.6	.104	45	52.8	26.7	6.8
6.3	5.2	.27	3.91	3.46	3.0	.104	37	55.3	28.8	7.0
6.0	4.9	.28	3.94	3.40	2.8	.111	41	58.1	22.2	6.2
6.1	5.1	.27	3.07	2.92	2.8	.102	40	54.2	28.6	6.7
6.0	5.0	.27	3.06	2.91	2.8	.098	38	52.4	29.8	7.3
6.1	4.8	.25	6.43	5.82	2.9	.098	41	47.1	34.1	9.1
6.3	5.2	.27	4.26	3.85	2.9	.107	40	55.0	29.3	7.1
5.8	4.7	.27	3.91	3.59	2.7	.103	41	57.0	24.9	6.6
6.3	5.1	.29	3.06	2.38	3.0	.116	34	59.6	28.2	9.1
6.0	4.7	.27	5.81	5.37	3.0	.087	34	42.1	40.7	11.6
6.4	5.2	.30	2.98	2.07	3.0	.127	37	65.7	23.2	8.1
6.1	4.7	.30	2.62	2.17	2.9	.115	43	64.7	21.5	5.4
6.3	5.1	.27	4.24	3.84	2.9	.106	39	54.2	30.2	7.5
5.9	4.9	.28	2.62	2.28	2.7	.112	41	58.4	23.0	5.9
5.9	4.7	.27	5.38	4.96	2.9	.094	36	45.9	36.2	9.9
6.3	5.1	.28	5.14	3.93	2.9	.126	43	63.0	25.1	7.8
5.7	4.9	.26	2.14	1.61	2.4	.107	50	51.9	43.0	10.6
6.1	5.0	.28	4.90	4.31	2.9	.105	40	53.2	30.2	8.3
6.2	5.6	.26	3.06	2.65	2.9	.103	42	54.6	33.6	5.0
6.1	5.1	.26	6.57	5.84	3.0	.097	41	48.7	35.0	8.1
6.1	5.1	.26	6.47	5.75	3.0	.097	41	48.7	34.9	8.1
6.0	4.7	.30	2.35	1.45	2.5	.148	47	71.3	19.0	4.6
6.6	5.1	.31	4.51	3.92	3.2	.118	37	57.3	35.7	10.8
6.0	4.6	.30	2.96	2.26	2.8	.130	37	62.1	23.9	7.9
5.5	4.5	.29	1.80	1.67	2.4	.123	48	62.3	21.1	3.1
5.3	4.5	.34	1.46	1.31	2.4	.145	51	70.0	13.0	2.2
5.6	4.4	.35	1.70	1.42	2.5	.132	46	65.0	13.5	2.3
5.5	4.4	.30	2.25	2.10	2.3	.130	46	63.2	18.3	4.2
5.5	4.5	.35	1.43	1.30	2.1	.157	48	78.5	7.7	1.2
5.5	4.4	.31	2.09	1.95	2.2	.135	47	65.9	16.1	3.6
5.2	4.3	.32	2.05	1.95	2.1	.135	47	70.1	10.9	2.2
5.1	4.5	.34	1.30	1.30	2.5	.136	54	64.6	15.3	2.4

APPENDIX 2.-- Basin characteristics--Continued

Station number	Land-use characteristics							
	LU1	LU2	LU4	LU5	LU7	C	AGP	AGN
1500500	1.5	29.7	67.0	1.6	.2	.018	1272	4011
1502000	1.9	16.4	81.2	.6	.0	.010	--	--
1502500	1.0	34.6	63.7	.5	.1	.019	--	--
1503000	1.8	30.7	62.8	4.4	.2	.021	2760	8908
1507500	.4	15.5	83.4	.7	.0	.009	42	132
1508800	.1	49.5	50.5	.0	.0	.041	45	139
1508803	.9	25.2	73.3	.1	.0	.022	103	321
1509150	2.2	61.2	36.5	.0	.0	.051	36	113
1513107	2.8	34.8	62.4	.8	.1	.031	5518	17580
1514000	.6	38.5	60.7	.2	.1	.023	--	--
1515000	2.5	33.1	62.9	1.3	.2	.021	--	--
1515050	2.5	33.1	62.9	1.3	.2	.021	6227	19752
1516820	2.0	36.0	60.1	.3	1.1	.037	250	744
1517000	.0	81.0	19.0	.0	.0	.056	31	93
1517500	.0	60.8	38.8	.3	.0	.043	176	540
1518000	1.3	42.4	54.9	.3	.8	.039	454	1348
1518400	.0	58.5	41.2	.0	.0	.041	165	490
1518500	.6	51.6	47.4	.0	.0	.037	239	711
1518700	1.0	44.8	53.2	.2	.6	.038	792	2354
1518850	.0	31.3	68.7	.0	.0	.023	91	257
1518860	3.7	44.4	51.9	.0	.0	.032	22	65
1518870	1.6	50.4	48.0	.2	.2	.038	226	650
1519000	.2	36.2	63.4	.1	.0	.026	93	288
1520000	.9	64.3	34.4	.2	.1	.046	736	2230
1520500	1.1	43.1	55.9	.1	.1	.031	1325	3926
1526500	1.7	39.0	58.5	.3	.1	.030	--	--
1528000	3.2	39.7	56.7	.1	.1	.031	104	321
1531000	2.2	38.3	58.1	.6	.1	.029	4068	12418
1533205	2.0	37.0	60.0	.9	.1	.028	12016	37401
1534000	3.7	43.0	51.7	1.2	.1	.032	--	--
1534090	1.7	36.3	61.0	.9	.1	.027	13322	41556
1534500	6.7	21.0	58.2	1.9	12.1	.142	--	--
1536000	12.9	16.7	54.6	1.0	14.4	.162	209	675
1539000	.5	35.2	63.7	.6	.0	.033	--	--
1541000	1.7	25.0	67.0	.0	6.3	.081	--	--
1543000	1.5	3.4	94.6	.0	.4	.008	43	93
1543500	1.3	4.5	91.9	.0	2.1	.026	--	--
1544500	.2	8.1	91.8	.0	.0	.009	--	--
1545500	1.5	12.3	82.8	.2	3.1	.041	1604	4284
1545600	.0	.0	100.0	.0	.0	.002	0	0
1546500	13.9	49.7	36.4	.0	.0	.036	--	--
1547500	6.3	36.0	56.6	.6	.2	.033	586	1527
1547950	.5	.5	95.9	.0	3.2	.034	2	6
1548500	.6	18.3	80.8	.0	.3	.021	--	--
1549500	2.1	31.3	66.7	.0	.0	.029	--	--
1553500	1.7	16.6	78.7	.5	2.2	.037	5332	14671
1555000	.8	33.1	66.0	.1	.0	.031	--	--
1555500	1.1	52.9	43.4	.0	2.4	.073	565	1620
1555600	2.3	36.3	59.7	.0	1.7	.051	257	730
1556010	7.5	24.2	67.0	.2	.9	.029	401	1214
1559000	4.6	31.1	63.3	.2	.5	.030	1466	4284
1559920	1.0	35.4	63.0	.0	.5	.032	185	545
1560000	1.0	43.0	56.0	.0	.2	.031	328	969
1561000	.0	23.6	76.3	.0	.0	.019	35	100
1562000	1.9	37.9	59.3	.2	.3	.032	1204	3509
1562010	1.2	2.4	89.4	.0	7.1	.075	2	6
1562200	2.5	10.0	87.5	.0	.0	.009	4	12
1562250	.0	23.3	76.7	.0	.0	.019	7	19
1562350	.0	31.6	68.4	.0	.0	.024	6	17
1562500	.3	23.9	72.9	.0	2.8	.047	83	224
1563000	1.6	33.2	63.1	.9	.7	.033	1328	3825
1563210	2.9	32.1	63.5	.6	.6	.031	3035	8784
1564515	1.2	26.6	72.1	.1	.0	.025	339	939
1565300	2.0	39.0	58.9	.0	.2	.037	428	1256
1565515	1.2	35.0	64.0	.0	.0	.032	157	460
1567000	1.9	30.8	65.9	.6	.4	.032	5532	15968
1567500	.0	55.2	44.8	.0	.0	.049	--	--
1568000	.1	33.0	66.8	.0	.0	.030	--	--
1568200	.1	34.2	65.6	.0	.1	.032	365	983
1569320	2.8	41.7	55.5	.0	.0	.036	178	527
1569900	4.9	64.8	30.1	.0	.4	.059	1508	4511
1573205	13.9	75.6	9.1	.5	.8	.073	771	2094
1574000	4.3	70.4	24.0	.6	.7	.067	2155	6482
1575000	6.3	66.2	25.2	2.0	.0	.057	457	1324
1575990	5.3	78.5	16.0	.0	.2	.069	1426	4478
1576500	12.7	64.2	22.1	.4	.4	.060	3810	11911
1576515	1.3	75.3	23.4	.0	.0	.064	223	706
1576600	14.2	69.8	15.8	.3	.3	.063	4640	14547
1576789	3.9	77.6	18.2	.0	.2	.068	1730	5465
1577500	10.0	61.0	29.0	.0	.0	.053	479	1387

Station number	Streamflow characteristics					
	MAQ10	MAQ9	PK10	P2	P25	PK10/P10
1500500	1568.0	1520.0	12400	12500	23500	.62
1502000	101.0	--	2580	1910	3540	.87
1502500	849.0	830.0	9700	8562	16100	.72
1503000	3585.0	3477.0	32100	31100	55800	.68
1507500	--	--	--	2640	5150	--
1508800	--	--	--	--	--	--
1508803	--	--	--	--	--	--
1509150	--	--	--	--	--	--
1513107	--	--	--	--	--	--
1514000	285.0	276.0	14200	5910	14900	1.24
1515000	7758.0	7488.0	121000	64700	122300	1.18
1515050	7758.0	--	121000	64700	122300	1.18
1516820	--	--	--	--	--	--
1517000	11.3	10.6	3940	593	1860	2.92
1517500	--	--	--	--	--	--
1518000	364.0	340.0	59000	10400	35600	2.35
1518400	--	--	--	--	--	--
1518500	122.0	115.0	21000	3910	11400	2.49
1518700	--	--	--	--	--	--
1518850	--	--	--	--	--	--
1518860	--	--	--	--	--	--
1518870	--	--	--	--	--	--
1519000	--	--	--	--	--	--
1520000	292.0	282.0	40500	9980	28400	1.92
1520500	817.0	779.0	128000	21500	70200	2.56
1526500	1444.0	1359.0	190000	32000	89300	2.85
1528000	79.6	--	5110	1500	3480	1.86
1531000	2689.0	2522.0	189000	46500	113000	2.15
1533205	11920.0	--	--	--	--	--
1534000	569.0	550.0	21200	13000	33400	.82
1534090	14098.0	--	364000	123000	241400	1.82
1534500	214.7	--	--	--	--	--
1536000	449.0	--	--	--	--	--
1539000	510.0	488.0	30900	7540	23200	1.84
1541000	589.0	563.0	27500	7650	17600	1.99
1543000	500.0	488.0	32000	8460	27180	1.64
1543500	1187.0	--	60800	17600	52600	1.58
1544500	228.0	219.0	14300	3520	10800	1.82
1545500	5277.0	5102.0	181000	58300	135100	1.70
1545600	75.3	72.3	5370	753	3020	2.63
1546500	86.7	--	5410	642	2097	3.63
1547500	452.0	--	--	--	--	--
1547950	--	--	--	--	--	--
1548500	895.0	862.0	66000	11600	33800	2.67
1549500	62.9	59.7	6260	1880	5430	1.56
1553500	11264.0	10735.0	300000	110500	221000	1.66
1555000	455.0	427.0	34600	5130	16000	3.02
1555500	244.0	--	69900	4180	17085	6.29
1555600	--	--	--	--	--	--
1556010	--	--	--	--	--	--
1559000	1119.0	1040.0	57000	13900	39600	1.96
1559920	--	--	--	--	--	--
1560000	244.0	229.0	12000	3860	8320	1.79
1561000	--	--	--	--	--	--
1562000	958.0	896.0	40200	13200	34400	1.53
1562010	--	--	--	--	--	--
1562200	--	--	--	--	--	--
1562250	--	--	--	--	--	--
1562350	--	--	--	--	--	--
1562500	96.0	--	--	1670	4880	--
1563000	995.0	--	--	15200	24000	--
1563210	--	--	--	--	--	--
1564515	--	--	--	--	--	--
1565300	--	--	--	--	--	--
1565515	--	--	--	--	--	--
1567000	4405.0	4071.0	187000	45300	111000	2.18
1567500	19.9	17.3	5670	770	4315	2.16
1568000	311.0	285.0	27500	6590	20200	1.89
1568200	--	--	--	--	--	--
1569320	--	--	--	--	--	--
1569900	--	--	--	--	--	--
1573205	--	--	--	--	--	--
1574000	673.0	624.0	81700	15200	43900	2.59
1575000	138.0	108.0	26700	2308	9620	4.28
1575990	--	--	--	--	--	--
1576500	432.0	396.0	88300	6340	23400	5.66
1576515	--	--	--	--	--	--
1576600	--	--	--	--	--	--
1576789	--	--	--	--	--	--
1577500	--	--	--	4880	13400	--

APPENDIX 3.--Average soil characteristics of the principal

Soil associations	Soil characteristics 1/									
	CLAYA	SILTA	SOILNA	SOILNG	XACIDA	XACIDG	XCATA	XCATG	CECA	CECG
Pennsylvania 2/										
A1A	20.0	68.1	.110	.160	6.50	13.80	7.20	15.20	13.70	24.20
A1B	16.1	54.9	.148	.222	5.14	13.91	10.75	11.98	15.89	22.98
A1C	13.8	52.1	.167	.342	8.52	22.73	4.87	12.35	13.43	27.88
A1D	9.9	44.3	.098	.191	7.79	15.74	3.93	9.11	11.72	19.78
A1E	16.5	48.2	.140	.580	6.60	45.70	9.00	14.40	15.60	51.60
A2A	17.1	47.2	.178	.209	9.01	14.96	10.76	15.84	19.75	22.53
A2B	14.6	42.5	.110	.135	12.55	17.17	1.52	4.47	14.12	18.50
A2C	14.6	42.5	.110	.135	12.55	17.17	1.52	4.47	14.12	18.50
A2E	16.0	36.5	.122	.158	7.94	10.01	6.32	8.30	14.32	15.65
A2F	14.6	34.7	.100	.175	14.05	27.75	1.20	5.85	15.20	29.30
A2I	15.2	61.1	.194	.255	9.83	17.38	9.38	14.51	19.15	23.92
A2K	17.7	43.0	.113	.160	15.80	22.07	.83	6.30	16.67	23.03
A2L	16.5	52.5	.163	.222	12.79	20.47	5.93	12.22	18.68	24.91
A3A	17.8	59.2	.192	.222	9.77	17.67	8.82	14.07	18.58	23.02
B1A	19.7	66.7	.095	.128	10.09	17.98	6.23	18.45	16.33	26.35
B1B	20.7	67.2	.123	.243	6.53	11.87	9.83	34.53	16.37	39.37
B1C	25.0	61.6	.165	.288	4.48	7.64	19.67	43.63	24.15	46.79
B1D	19.0	61.1	.127	.147	8.40	15.82	7.45	12.47	15.85	20.65
B1E	18.9	67.9	.090	.110	9.60	17.00	6.90	18.20	16.50	24.90
B2A	27.3	49.3	.206	.211	6.37	8.64	29.41	33.82	35.75	37.32
B2C	3.9	19.7	.059	.214	5.72	26.72	1.37	5.82	7.06	29.05
B3A	19.2	58.4	.365		12.22	22.13	6.15	8.46	18.41	29.21
C1A	14.6	53.1	.115	.245	12.70	19.75	3.80	11.15	16.50	30.25
C2A	18.8	54.5	.137	.243	13.13	25.56	3.39	7.51	16.51	29.61
C2B	11.1	36.7	.092	.164	9.13	23.36	3.12	7.34	12.19	29.02
C2C	17.6	43.1	.153	.298	12.54	21.53	5.34	6.74	17.88	27.68
C2D	13.2	54.4	.123	.149	4.81	7.00	6.89	15.73	11.70	19.67
C2E	14.7	67.5	.113	.148	8.48	14.14	8.72	18.05	17.20	28.25
D1A	18.5	37.9	.157	.189	17.76	20.79	4.04	7.[illegible]	21.86	26.87
D1B	21.1	43.5	.177	.775	15.58	17.12	4.23	5.[illegible]	19.80	20.60
D1C	17.2	46.6	.180	1.957	14.57	14.95	4.32	5.48	18.65	18.85
D1D	16.0	49.3	.188	1.828	14.21	14.28	4.42	5.48	18.40	18.53
D2D	17.3	54.8	.176	.234	7.23	9.92	8.67	10.59	15.90	17.57
D2G	5.4	40.7	.117	.160	17.20	24.97	.93	2.93	18.13	25.53
D2I	14.7	48.1	.146	.211	12.51	16.90	4.66	9.18	17.16	22.42
E1A	11.8	40.5	.194	.608	13.18	27.19	6.55	8.38	18.26	33.25
E1C	16.6	49.2	.138	.740	10.76	17.75	6.02	7.58	15.31	22.16
E1D	18.1	59.0	.142	.242	17.32	17.38	7.84	8.26	23.34	28.36
E1E	10.1	33.3	.181	1.057	17.83	37.66	5.13	7.84	19.53	41.40
New York 3/										
045	2.1	29.0	--	--	--	--	--	--	--	--
049	10.8	46.8	.240	.240	9.90	9.90	11.40	11.40	21.30	21.30
050	10.4	41.3	.207	.265	9.69	18.40	7.98	9.02	17.67	26.55
052	13.9	63.5	--	--	--	--	---	--	--	--
062	8.9	30.7	.137	.247	7.57	22.73	3.53	5.90	11.10	26.43
065	9.9	33.5	.160	.300	9.40	30.30	3.20	5.70	12.60	33.90
066	10.8	46.8	.240	.240	9.90	9.90	11.40	11.40	21.30	21.30
067	15.6	28.8	.110	.120	4.40	6.70	7.50	7.90	11.80	12.00
076	11.5	49.3	.262	.345	14.64	17.07	8.66	12.94	23.30	26.59
133	16.3	46.0	.120	.176	6.80	9.20	6.90	12.40	13.70	17.60
137	16.6	48.7	--	--	--	--	--	--	--	--
150	13.8	55.3	--	--	--	--	--	--	--	--
200	17.7	49.2	.190	.270	12.20	13.90	16.80	23.80	29.00	37.70
230	8.6	50.5	.140	.200	17.25	20.75	2.90	6.55	20.15	26.85
232	13.8	68.1	.090	.090	5.10	12.10	3.40	7.00	8.40	19.10
239	18.3	53.2	.260	.451	19.84	25.16	8.46	19.48	28.30	38.17
247	16.2	49.2	.194	1.772	15.01	15.01	3.98	4.82	18.77	18.77
261	19.4	53.5	.245	.413	18.25	22.81	10.20	20.38	28.45	38.07
263	14.3	44.0	.140	.200	14.39	18.66	4.71	10.28	19.11	25.53
264	15.1	51.7	.151	.219	10.82	15.32	4.66	8.38	15.49	19.70
265	14.4	47.3	.147	.213	13.02	17.40	4.50	8.92	17.52	23.12
280	16.4	49.2	.163	1.427	10.82	11.70	6.50	8.48	17.16	18.18
281	17.9	47.9	.165	1.012	11.74	12.96	6.16	8.01	17.81	18.94
282	16.5	47.3	.221	.368	19.67	24.46	7.27	16.65	26.94	36.84
284	13.7	46.8	.153	.222	13.74	18.11	4.03	7.76	17.77	23.87
325	22.4	62.6	.030	.100	20.60	20.70	7.00	18.60	27.60	27.60
345	--	--	--	--	--	--	--	--	--	--
360	20.6	57.7	.160	.160	12.20	16.20	4.00	30.00	16.20	30.30
369	12.4	59.6	--	--	--	--	--	--	--	--
401	11.8	34.0	.140	.200	20.10	24.10	3.70	9.80	23.80	33.90
402	11.8	34.0	.140	.200	20.10	24.10	3.70	9.80	23.80	33.90
404	17.4	47.3	.161	.166	21.51	24.04	2.57	3.27	24.13	26.08
416	12.7	40.4	.201	.336	21.96	27.35	3.27	12.16	25.23	35.54
417	13.3	43.2	.148	.213	15.41	19.67	4.05	8.63	19.45	26.59
418	12.1	38.5	.149	.214	18.13	22.27	3.53	8.29	21.66	30.56
419	13.7	44.4	.147	.212	14.70	18.99	4.23	8.87	18.93	25.61
420	20.2	46.6	.170	.184	12.89	14.70	5.80	7.47	18.75	20.14
427	16.8	57.8	.157	.228	11.51	16.01	4.21	7.26	15.72	20.42
438	--	--	--	--	--	--	--	--	--	--

1/ Defined in section entitled "Basin characteristics".

2/ According to general soil association map of Pennsylvania (U.S. SCS, 1972).

3/ According to general soil association map of New York (Arnold and others, 1970).

Soil characteristics 1/

PHA	PHL	KA	PERMA	PERML	HSG	WATCAP	BDRK	LT200A	GRAVA	STONEA
6.2	4.5	.43	1.30	.40	3.0	.110	40	62.5	10.0	2.5
6.5	5.2	.24	3.26	3.06	2.6	.116	46	56.3	24.6	5.7
5.5	4.2	.30	1.97	1.82	2.5	.122	42	54.6	19.6	2.6
5.2	3.9	.23	3.30	3.30	2.4	.104	49	43.0	24.3	6.0
6.7	4.8	.32	1.30	.13	3.0	.120	60	62.5	10.0	5.0
6.0	4.7	.28	3.31	3.31	3.0	.083	28	41.5	43.0	12.1
4.8	4.4	.30	1.97	1.53	2.5	.107	48	56.2	22.5	6.2
4.8	4.4	.30	1.97	1.53	2.5	.107	48	56.2	22.5	6.2
5.9	4.6	.26	9.12	8.11	3.0	.092	42	42.9	37.7	10.8
4.6	4.0	.26	3.65	3.65	2.0	.095	45	56.2	16.2	4.5
5.9	4.5	.34	.59	.18	3.0	.122	41	74.6	15.8	4.0
4.5	4.2	.28	3.10	2.80	2.3	.100	48	62.5	10.0	4.2
5.3	4.4	.29	1.95	1.75	2.6	.107	43	70.2	11.9	3.3
5.9	4.6	.39	1.01	.17	3.0	.125	49	80.6	10.6	2.5
5.5	4.5	.35	1.43	1.30	2.1	.157	48	78.5	7.7	1.2
6.2	4.7	.32	2.63	1.30	2.7	.170	43	80.8	9.2	5.0
6.7	5.5	.31	2.75	1.25	3.0	.156	43	81.8	10.0	5.5
6.0	4.9	.29	1.30	.91	2.2	.122	60	55.0	37.5	2.5
5.7	4.4	.32	1.30	1.30	2.0	.170	48	77.5	7.5	0.0
6.8	6.3	.27	2.34	2.22	3.2	.105	37	62.5	23.5	1.9
5.1	4.2	.18	4.51	4.51	1.9	.098	53	39.4	4.7	2.5
5.6	4.9	.25	1.92	1.28	2.4	.109	52	48.3	49.2	7.7
5.1	4.7	.32	1.30	.85	2.5	.140	48	70.0	13.7	2.5
4.9	4.3	.32	1.30	1.30	2.4	.133	55	65.0	12.5	2.9
5.2	4.6	.25	2.67	2.67	2.0	.103	46	58.4	30.6	6.0
5.3	4.8	.36	1.30	1.30	2.6	.139	52	64.1	18.9	1.8
6.1	5.7	.22	1.72	1.55	2.0	.112	59	77.4	35.8	4.4
5.8	5.0	.36	1.30	.55	2.5	.125	50	71.4	30.8	5.0
5.0	4.5	.22	1.30	1.30	3.0	.107	30	48.2	41.8	7.5
5.1	4.8	.25	1.30	.94	3.0	.090	40	50.8	35.8	7.1
5.4	4.6	.25	1.30	.42	3.0	.088	55	57.5	23.7	6.7
5.4	4.7	.25	1.30	.22	3.0	.091	60	60.8	19.4	6.3
5.9	4.8	.25	3.15	3.06	2.2	.083	40	60.5	22.7	24.0
3.8	3.4	.19	1.30	.26	3.0	.097	60	46.7	14.2	6.7
5.4	4.9	.22	.64	.44	3.0	.059	54	50.4	35.5	8.6
5.4	4.8	.17	3.52	3.18	1.3	.068	54	41.3	34.6	5.4
5.5	5.0	.43	2.11	1.90	2.0	.126	49	65.5	14.7	.7
5.2	4.8	.43	1.22	.83	2.8	.156	50	68.0	8.0	1.0
5.1	4.9	.17	3.86	3.45	1.5	.083	50	37.5	35.2	4.0
6.2	6.2	.24	2.73	2.73	1.8	.086	60	44.3	10.1	.6
6.5	5.9	.17	3.30	3.30	1.0	.050	60	40.0	37.5	2.5
6.1	5.3	.17	3.30	3.17	1.0	.050	60	43.1	34.4	5.6
6.6	6.6	.17	1.30	1.30		.080	60	42.5	35.0	2.5
5.8	4.5	.17	2.63	2.43	1.3	.083	60	52.5	20.8	6.7
5.5	4.4	.17	2.01	1.91	1.6	.121	60	58.7	18.7	3.6
6.5	5.9	.17	2.05	2.05	1.6	.119	60	55.6	21.9	.9
7.0	5.3	.17	2.77	2.77	1.5	.094	60	46.8	29.5	5.5
5.7	5.3	.18	2.36	2.08	1.7	.064	60	42.9	36.9	3.3
5.6	5.3	.30	1.30	.13	2.0	.140	60	53.3	22.7	1.2
6.9	6.9	.32	1.30	.69	2.0	.139	60	64.4	12.8	
7.2	7.2	.30	1.30	.71	2.5	.120	37	55.0	17.5	1.2
5.6	5.3	.32	1.30	.34	3.0	.103	60	58.7	23.7	2.9
4.9	4.4	.18	1.30	.71	3.0	.115	51	52.5	33.7	7.5
5.3	4.9	.49	1.30	.15	3.0	.076	60	85.0	2.5	1.0
5.0	4.7	.22	1.30	.13	3.0	.056	60	49.0	36.0	7.5
5.4	4.7	.26	1.30	.22	3.0	.091	60	63.9	16.4	6.1
5.2	4.8	.22	1.30	.13	3.0	.055	60	48.7	36.3	7.5
5.3	4.6	.22	.68	.71	3.0	.082	46	52.5	36.2	7.5
5.5	5.2	.22	.57	.20	3.0	.040	60	48.7	35.0	9.4
5.4	4.9	.22	.72	.47	3.0	.063	53	50.0	35.6	8.8
5.6	4.6	.21	1.30	.41	3.0	.091	55	44.4	37.6	7.5
5.5	4.7	.21	1.30	.59	3.0	.092	49	44.1	39.9	7.5
5.0	4.5	.21	1.30	.49	3.0	.078	51	50.0	36.5	7.5
5.3	4.9	.21	.94	.47	3.0	.063	52	48.1	35.6	9.7
5.4	5.3	.25	1.30	.06	3.2	.050	60	69.2	20.8	6.7
--	--	.49	1.30	.13	3.0	.140	60	67.5	5.0	0.0
5.0	4.7	.49	1.10	.06	4.0	.160	60	75.0	5.0	0.0
4.9	4.9	.49	.40	.13	4.0	.124	60	80.0	2.5	0.0
4.9	4.0	.20	1.30	1.30	3.0	.130	30	52.5	37.5	7.5
4.9	4.0	.22	1.30	1.30	3.0	.121	30	50.9	37.5	9.1
4.3	4.2	.22	1.30	1.30	3.2	.099	23	45.0	43.8	7.5
4.8	4.1	.20	1.30	.88	3.0	.105	41	51.6	36.6	7.5
5.2	4.6	.21	.99	.71	3.0	.082	46	49.8	36.2	8.8
5.0	4.3	.20	1.30	.99	3.0	.104	39	49.6	36.8	8.9
5.3	4.7	.21	.89	.65	3.0	.077	48	50.1	36.0	8.7
5.3	4.8	.21	1.30	.86	3.0	.094	41	43.1	44.1	7.5
5.1	4.9	.30	.99	.36	3.4	.076	48	59.2	23.0	6.2
--	--	.28	1.30	.99	3.3	.123	28	58.6	17.5	1.8

APPENDIX 4.--Annual tonnages, by county, of commercial fertilizer and animal wastes expressed as nitrogen and phosphorus in $(tons/mi^2)/yr$

New York Counties

County	Phosphorus	Nitrogen	County	Phosphorus	Nitrogen
Allegany	3.2	10.1	Oneida	3.9	12.4
Broome	2.8	8.9	Onandaga	5.0	15.4
Cayuga	4.6	14.2	Ontario	4.2	13.0
Chemung	3.5	10.9	Otsego	4.2	13.6
Chenango	3.3	10.4	Schohorie	3.5	11.0
Cortland	5.7	17.8	Schuyler	2.8	9.0
Delaware	5.2	16.5	Steuben	3.9	12.1
Herkiner	3.7	11.9	Tioga	4.6	14.4
Livingston	4.1	12.5	Tompkins	3.8	12.0
Madison	5.1	15.9	Yates	4.0	12.0

Pennsylvania Counties

County	Phosphorus	Nitrogen	County	Phosphorus	Nitrogen
Adams	6.1	19.0	Lackawanna	3.9	12.5
Bedford	4.0	11.7	Lancaster	17.4	55.0
Berks	7.0	19.7	Lebanon	10.2	27.7
Blair	6.8	20.6	Luzerne	3.3	9.1
Bradford	3.7	10.7	Lycoming	5.2	14.0
Cambria	5.4	16.0	McKean	3.3	9.2
Cameron	5.6	10.5	Mifflin	7.6	22.3
Centre	4.8	12.5	Montour	4.5	13.3
Chester	5.6	17.3	Northumberland	6.0	18.0
Clearfield	3.6	9.8	Perry	5.1	13.5
Clinton	5.0	15.0	Potter	6.0	16.8
Columbia	5.6	15.3	Schuylkill	6.8	19.2
Cumberland	5.4	16.8	Snyder	6.6	19.5
Dauphin	6.5	18.9	Somerset	5.9	16.0
Elk	2.0	6.8	Sullivan	4.0	13.0
Franklin	6.8	18.9	Susquehanna	3.5	11.9
Fulton	4.1	11.4	Tioga	3.8	11.3
Huntingdon	4.1	11.1	Union	6.0	17.1
Indiana	3.8	10.1	Wayne	3.8	12.3
Jefferson	5.1	13.1	Wyoming	4.1	12.1
Juniata	7.0	21.0	York	5.9	17.1