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THE TREND OF SUSPENDED-SEDIMENT DISCHARGE OF THE BRANDYWINE CREEK AT WILMINGTON, DEL., 1947-1955

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OF THE BRANDYWINE CREEK AT WILMINGTON, DEL., 1947-1955

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ABSTRACT

This report presents an analysis and evaluation of the trend of the sediment yield for the Brandywine Creek at Wilmington, Del., for the period from December 1946 to September 1955. The interest in such an analysis and evaluation stems from the efforts of the Brandywine Valley Association and others to reduce erosion and improve land use in the watershed.

The data used for the analysis were taken from the continuous suspended-sediment and water-discharge records of the stream at Wilmington and the precipitation records at 8 standard and 1 recording rain gages. The analysis was made on the basis of 123 storm events for this period of record using only the water and sediment discharge attributed to direct runoff. These data represent 89 percent of the total sediment discharge and 19 percent of the total water discharge.

The sediment load for each of the storm runoff events was correlated with storm runoff, rainfall intensity, and season to remove the effect, if any, of the variation caused by these factors. The evaluation of the relative trend of sediment yield was made by two methods; first, the accumulative graph or double mass curve as a graphical method, and second, the rank correlation method which resulted in a

numerical coefficient and its significance. The graphical method of this evaluation shows an approximate 38 percent decrease in sediment yield for the period 1952 to 1955 from that for the period 1947 to 1951. The rank correlation coefficient was 0.152 for the same analysis showing a very high level (almost 99 percent) of confidence in the significance of a decreasing trend.

A parallel analysis to that above using "peakedness" instead of rainfall intensity as a measure of storm intensity was made because "peakedness" is easier to evaluate than rainfall intensity. The results of this analysis again indicates the probable decreasing trend of sediment yield as shown by the change in slope of the accumulative graph from 0.77 for the 1947 to 1951 period to 1.05 for the 1952 to 1955 period or 28 percent, and by the rank correlation coefficient of 0.114 with a 94 percent level of confidence of a decreasing trend.

Appendix A of this report shows a similar analysis by use of monthly sediment discharge and "direct" runoff as determined for an analyses of runoff patterns. The results indicate only a small decreasing trend, if any, in sediment yield. This is probably due to the fact that the correlations with rainfall and season for adjusting these data were rather poor - indicating bias by unknown parameters that cannot be evaluated.

Appendix B presents the methodology of using rank correlation to evaluate the trend of variate-values with respect to time with special reference to the trend of sediment yield from a watershed.

PERSPECTIVE

The Brandywine Valley Association, since its inception in 1946, has been active in bringing about reductions and removal of sources of pollution and in promoting better land use practices and soil conserving measures in the watershed. The association was formed, among other things, to coordinate and intensify the efforts of local soil conservation districts which were attacking, through the technical help of the Soil Conservation Service, the many water-associated problems of the watershed ranging from sheet erosion, to channel pollution, to sediment clogging of the port at Wilmington. In 1952 the Soil Conservation Service, working with the local people, developed recommendations for a comprehensive watershed treatment program aimed at controlling erosion, alleviating floods, improving over-all production of agricultural products, and increasing the recreational opportunities within the watershed.

The Geological Survey, in cooperation with the State of Delaware and the Brandywine Valley Association, has measured rainfall, runoff, and sediment within and from the watershed. The objective of this investigation was to study the suspended-sediment discharge record at Wilmington for the period December 1946 to September 1955 to ascertain the trend of sediment yield from the watershed during this period. In this connection the variations in sediment yield are correlated with some of the parameters likely to affect sediment yield for which data are readily available. These include precipitation, runoff, and season.

Sediment yield from a watershed is related to the many factors affecting erosion from the upland areas and to the ability of the channels to transport the material. The suspended-sediment concentration may then depend to a great extent on the season of the year, the source of runoff in the watershed, and the intensity and magnitude of the storm. Elements related to these factors may include vegetal cover, soil conditions, antecedent moisture, temperature, raindrop size and intensity, wind velocity during the storm, and the hydraulic characteristics of the stream channels. These parameters, although related to each other in varying degrees, exhibit a wide range of variation in a watershed of this size, and therefore, cannot all be evaluated in the absence of voluminous and detailed data. It is therefore apparent that the definition of the trend of sediment yield cannot be precise.

ACKNOWLEDGMENT

This report was prepared in the Water Resources Division of the United States Geological Survey as part of the investigations of water resource problems conducted by the Quality of Water Branch, S. K. Love, Chief. Outside the general supervision given by R. B. Vice, many of the concepts used for the report have grown out of personal conversations and contacts with other colleagues in the Geological Survey. Notable among these are B. R. Colby, R. G. Godfrey, and W. B. Langbein. The critical comments of W. H. Durum, and others, who kindly read the manuscript, have also been helpful. Unpublished records of sediment discharge data were furnished by J. K. Culbertson through N. H. Beamer, District Chemist, Pennsylvania.

THE WATERSHED

The Brandywine Creek basin above Wilmington, Del., (Henry Clay Bridge) has a drainage area of 314 square miles and is located mostly in southeastern Pennsylvania. The fan-shaped basin has an over-all length of about 45 miles and has more than 570 miles of channels which gives the basin a relatively high drainage density. Most of the major tributaries throughout the basin can be traced to their sources in perennially fed streams in shallow valleys of the upper reaches of the watershed.

The geology of the basin has been previously described (Wolman, 1955, p. 3) as follows:

> "After traversing a rolling upland of metamorphosed sediments and intrusive rocks, the stream successively crosses the North Valley Hills, the Chester Valley, and the South Valley Hills. The first of these is a northeast-striking anticline with a resistant quartzite core; the valley itself is composed of Ordovician limestone and dolomites. On the southern flank of the valley there is a belt of phyllite. The Brandywine then traverses an area underlain by schist. Above Chadds Ford the course of the stream through the schist is interrupted by a belt of gneiss, and about 4 miles above the city of Wilmington the stream encounters the Fall Zone in an area underlain by gabbro. The Coastal Plain sediments are not reached until the river nears its mouth."

The climate of the watershed is characterized by relatively mild winters and warm, frequently humid, summers. Less than 100 days in a normal winter have temperatures below freezing and an average of about 15 days are above 90°F. during the summer. The average growing season is from April 15 to October 20, the respective average dates of the

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Wolman, M. Gordon, 1955, The natural channel of Brandywine Creek Pennsylvania: U. S. Geol. Survey Professional Paper 271, p. 3.

last and first killing frost of the growing season. The average total precipitation (45 inches), of which approximately 3 inches is the melted equivalent of snow, is distributed rather evenly throughout the year. Normal warm season (April to September) precipitation is approximately 24 inches. The total annual runoff from the watershed at Chadds Ford, Pa., averages about 18 inches ranging in 39 years of record from about 10 to 30 inches. The average annual runoff for the period of this record is 20 inches as recorded at the gaging station at Wilmington, Del.

The watershed is largely rural in character although residential development is expanding at a rapid rate especially in the southeastern section of the watershed. The soils of the watershed are extremely variable ranging from the poor stoney soils in the mountains to rich alluvium along the streams. Most of the area, however, is mantled by soils that are deep and medium textured, of good fertility, and transmit air and water easily. About 35 percent of the area is crop land used primarily for growing corn, wheat, barley, and hay. About 18 percent is permanent pasture used mostly by dairy cattle. More than 45,000 acres, or 22 percent of the terrain, are forested with tulip poplar, white oak, and red oak as the dominant species. About 15 percent of the area is idle land, and homesteads, roads, etc., occupy the remaining 10 percent.

The suspended-sediment sampling station is located at Henry Clay Bridge in Wilmington, New Castle County, 0.2 miles upstream from the gaging station at Wilmington, and 4.4 miles upstream from the mouth. The channel in the vicinity of the sampling station, and for a distance upstream about 2.5 miles to Rockland, has a slope of 25 to 30 feet per mile. From Rockland upstream about 13 miles to near the confluence with the East and West Branches, the slope averages about 3.8 feet per mile. From this point toward the headwaters, the slope of the stream increases gradually in a general manner. Until the last few decades, numerous small dams in the channels were used to take advantage of the high base flow of the stream to develop power for the operation of grist mills, etc. Many of these dams have been washed out and the few remaining cannot be considered as sediment traps.

THE AVAILABLE DATA

Quantitative precipitation data were collected at 8 standard rain gages by the Geological Survey in addition to the Weather Bureau's regular rainfall station at Coatesville, Pa., from December 1946 to September 1955. Hourly precipitation data are also available at the Coatesville station for this same period. Figure 1 shows the name and location of these gages with respect to the drainage pattern of the watershed.

A continuous record of the gage height and flow of the stream at Wilmington are available for this period of record. Although the gage-height records are not published, the data were used to compute the water discharge and also to assist in computing the suspended-sediment discharge.

Depth integrated suspended-sediment samples were used to define a continuous graph of the stream concentration at Wilmington (data at other locations in the watershed were not obtained). Mean daily concentrations from this graph together with the mean daily water discharge

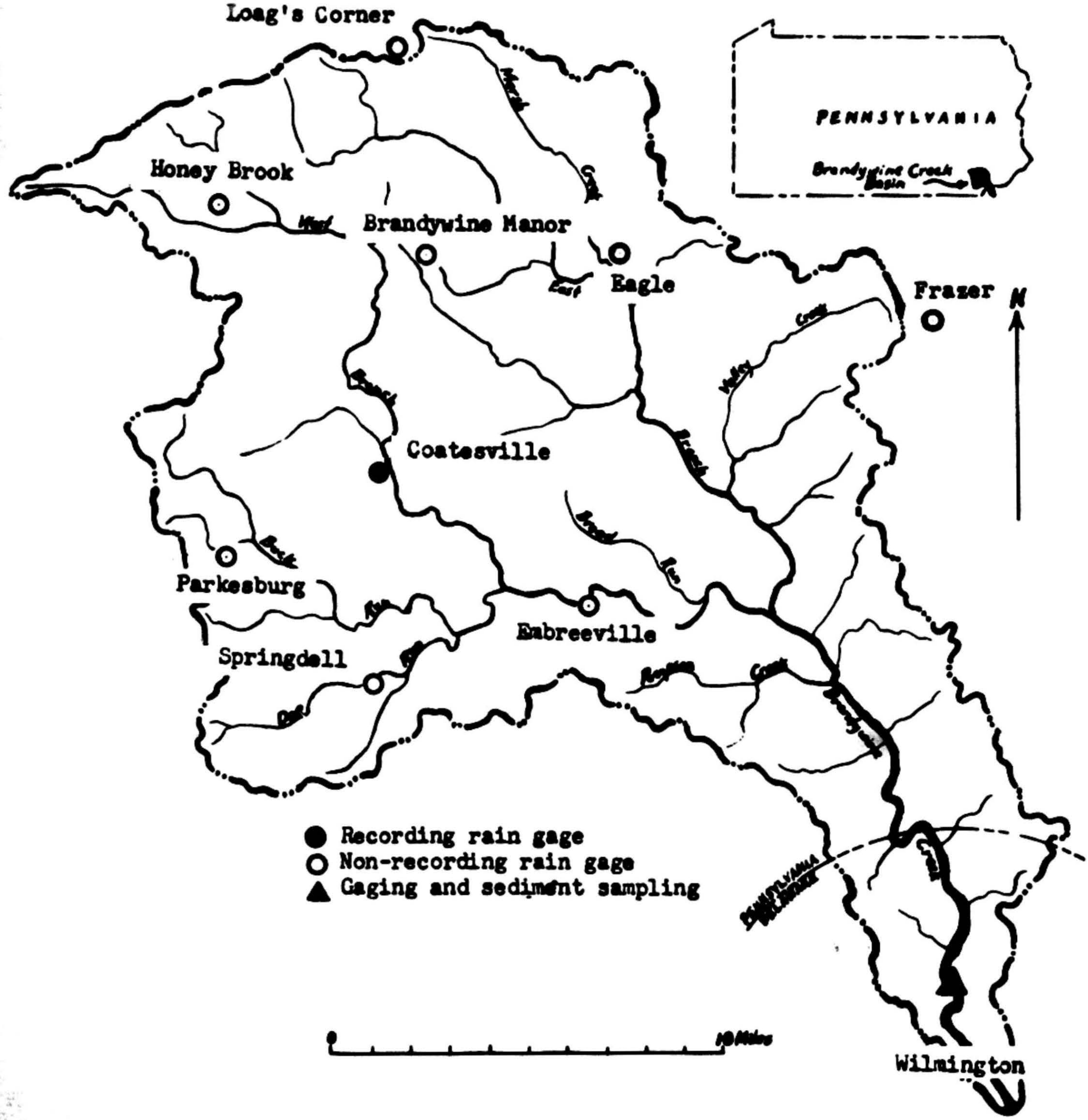

Figure 1.--Drainage pattern of the Brandywine Creek basin showing location of precipitation gages

made it possible to compute continuous or daily suspended-sediment discharges. The record is based on daily sampling at relatively steady flow, and usually, several samples per day when the stage and concentration are rapidly changing. The daily sediment concentration in parts per million and sediment load in tons, are published together with the mean daily water discharge in the annual series of Geological Survey publications entitled Quality of Surface Waters of the United States. Water-Supply Paper 1132 contains the Wilmington data for the period October 1946 to September 1948 (1947 and 1948 water years). The data for water years 1949, 1950, 1951, 1952, and 1953 are in W.S.P.'s 1162, 1186, 1197, 1250, and 1290, respectively, and the 1954 and 1955 data are in the process of publication.

Figure 2 shows duration curves summarizing these records by illustrating the percent of time that a given suspended sediment concentration or load equals or exceeds a given amount.

METHODS FOR ANALYSIS AND EVALUATION

As mentioned previously, the trend of sediment yield cannot be defined precisely in consideration of the many variables affecting sediment yield for which data are not available. The time-trend evaluation cannot be determined by simple averages of sediment yield data because, first, the average difference from year to year is small, and second, the apparent difference may be due to the effects of precipitation, water discharge, season of the year, or other factors in effect during the occurrence of the storm. The approach used in this evaluation consists of

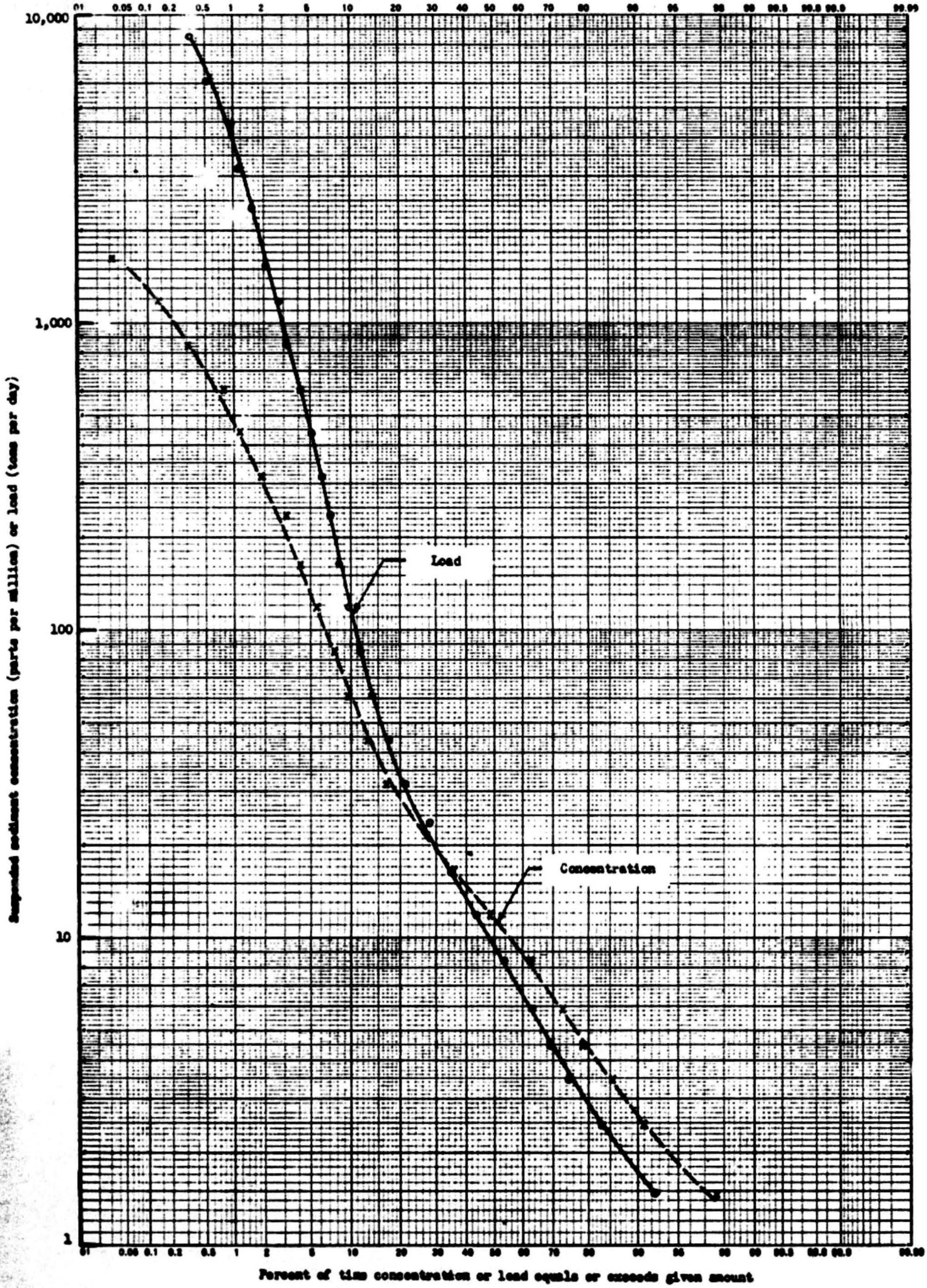

Figure 2.--Duration curves of suspended sediment concentration and load for Brandywine Creek at Wilmington, Del., September 1947 to September 1955

compiling the data in chronological order, adjusting the data to compensate for variations due to precipitation, water discharge and season, and defining the time trend, if any, by use of accumulative graph and rank correlation techniques.

Inspection of the sediment and water discharge data mentioned above in the Water-Supply Papers indicates that the base flow, although usually quite high, has a very low sediment concentration. The sediment yield on the days of this base flow may vary from 2 to about 20 tons per day whereas on days of moderate storm runoff sediment loads of several thousand tons per day occur. It therefore seems logical that only storm runoff be used in the analysis as it would be associated most directly with the watershed parameters affecting the yield of sediment. Since each storm event is an individualistic occurrence, each having different meteorologic, hydrologic, and watershed cover patterns, it is also logical that the data can be assembled on a storm event basis. (See note A)

COMPILING THE DATA

Direct storm runoff.--The method used to determine the quantity of direct storm runoff for each storm consists of subtracting the base flow occurring at the beginning of the storm from the storm runoff for each day during the storm period. This base flow was generally increased in nominal amounts each day during the storm runoff period in order to match the higher base flow occurring at the end of the storm runoff period.

Note A: Evaluation of sediment yield trend was attempted by use of monthly "direct runoff" as determined for an analyses of runoff patterns and the related sediment data. This analysis is inconclusive and probably invalid due to the inclusion of some base flow in the runoff and due to the fact that monthly data usually includes more than one storm. The report of these computations is shown as appendix A in this report.

The sediment yield for each storm was determined as the total load for each day of direct runoff for the storm event. That is, the insignificant quantity resulting from the base flow was not subtracted as far as the sediment is concerned. The tabulation below illustrates two examples of the data and the computations necessary for evaluating runoff and sediment yield for each storm.

Date	Mean discharge (cfs)	Estimated base flow (cfs)	Net runoff (cfs)		Sediment discharge (tons)	
April, 1951						
12	660	660	0		18	
13	2,200	680	1,520		4,340	
14	960	700	260	1,820	389	4,821
15	740	700	40		92	
16	690	690	0		27	
May, 1950						
17	386	386	0		11	
18	486	456	30		22	
19	1,730	530	1,200	1,530	1,180	1,347
20	894	594	300		145	
21	574	574	0		28	

Storms with a measured sediment yield of less than 100 tons were not considered in this tabulation. Several storms during the winter months were not used since their runoff was derived mostly from snowmelt. Such runoff events were thought to probably yield biased sediment loads with respect to precipitation data. Columns 1 and 2 of table 1 show the data in chronological order with the date of the runoff at Wilmington. The tabulation was checked and reviewed with a view toward the elimination of possible bias, especially with respect to the determination of the base flow. The sediment records were carefully reviewed to determine if the methods of computation for days of poor concentration definition were consistent during the 1947 to 1955 period of record.

Seasonal, annual, and period of record totals for the storms are shown in table 2 together with the total flow for these increments. The percentage of storm runoff to total flow has also been tabulated. During the period of record, the weighted annual mean sediment concentration of the storm runoff ranges from 227 to 690 ppm. The July to September season resulted in a maximum average storm runoff of 675 ppm whereas a minimum of 446 ppm occurred for the January to March season. For the total flow, the July to September season resulted in a maximum weighted average sediment concentration of 170 ppm whereas the minimum was April to June with 81 ppm. The percentage of storm runoff to total flow for the same increments has been tabulated and shows that 89 percent of the total sediment for the period of record is represented by the 123 storm runoff events whereas only 19 percent of the water discharge is represented. During the October to December season, a maximum of 96 percent of the total sediment and 25 percent of the total water discharge is represented by the storm runoff.

Figure 3 is an interesting plot of the accumulated water vs. sediment discharge by 3-month increments from table 2 for both the storm runoff and the total runoff. The 3-month increments result in a somewhat smoother plot than would be expected for the storm runoff on an event basis or for the total runoff on a monthly basis. The units for this graph are such that the slope is the mean concentration. As indicated by some of the analyses above, the storm runoff results in a much smoother plotting than the total runoff. The graph of storm runoff can be

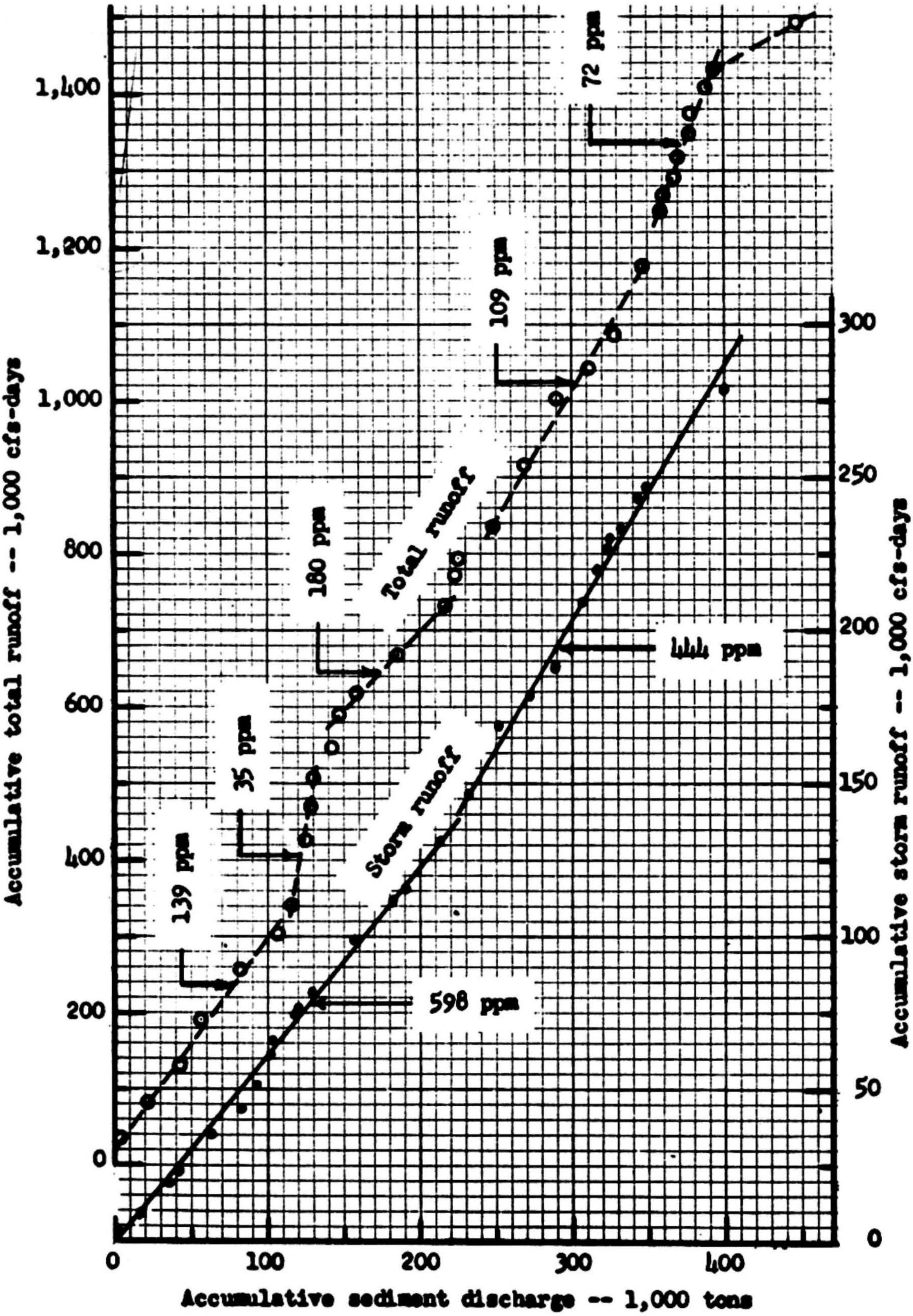

Figure 3.--Accumulative sediment vs. water discharge by 3-month increments for storm runoff and total runoff, Brandywine Creek at Wilmington, Del., January 1947-September 1955

divided into two intervals showing a mean concentration of 598 ppm from 1947 to 1951 and 444 ppm from 1952 to 1955. On the other hand, the mean concentration for the total runoff changes so drastically that a significant change in trend during this period of record cannot be determined. The mean concentration for continuous periods in excess of 9 months appears to range from 35 ppm to 180 ppm.

Precipitation.--Table 3 shows the total rainfall for each of the 8 gages (columns 1 to 8) located within the watershed for each of the selected storms (December 1946 to September 1955). The mean rainfall for each of these storms was then computed by the Theissen method using a weighting factor of 0.082 for the rain gage at Honeybrook, 0.050 for Loag's Corner, 0.126 for Brandywine Manor, 0.126 for Eagle, 0.104 for Parkesburg, 0.100 for Springdell, 0.343 for Ebersville, and 0.069 for Frazier. An evaluation of rainfall intensity for each storm was made on the basis of the hourly precipitation data available for the rain gage at Coatesville operated by the Weather Bureau. Column 10 of this table shows the total rainfall at Coatesville and may be compared with the weighted mean rainfall of the 8 standard rain gages in the watershed. Columns 11 and 12 show hours and quantity, respectively, of rainfall of 0.05 inch per hour or more for each storm. A weighted storm intensity measure (column 13) is then determined by dividing the weighted mean rainfall for the watershed by the total rainfall at Coatesville and multiplying by the ratio of the inches greater than 0.05 inch to the number of hours of the storm having more than 0.05 inch at Coatesville. This intensity measure is admittedly poor for some storms because the rainfall intensity at Coatesville may not be representative of the intensity for the whole watershed.

ANALYSES BY STORM RUNOFF EVENTS ADJUSTING FOR PRECIPITATION AND SEASONAL EFFECTS

Figure 4 shows a plot of the direct storm runoff and measured sediment as tabulated in table 1 with the runoff in cfs-days as the independent variable and tons of sediment discharge per storm as the dependent variable. A mean sediment transport curve ($Y = 0.0338 X^{1.46}$) was drawn on the basis of the average tons for several increments of water discharge. In table 1, the measured sediment (column 2) divided by the load shown on this transport curve (column 3) is tabulated (column 4) to indicate the departure of the plotted points from the rating. These departure ratios define the variation in sediment yield and will therefore be used in correlation with the measured parameters that may be the cause of the variation.

The mean concentration of each runoff event may be considered as a measure of variation for the sediment transport plotting. A fallacy of the use of this concept is indicated by the fact that concentration is a function of storm size, see figure 4, and that storm size is not distributed uniformly with time. The following tabulation of water and sediment discharge data for the first 10 storms used (see table 1) with corresponding decreasing departure ratios illustrates the somewhat random effect of concentrations:

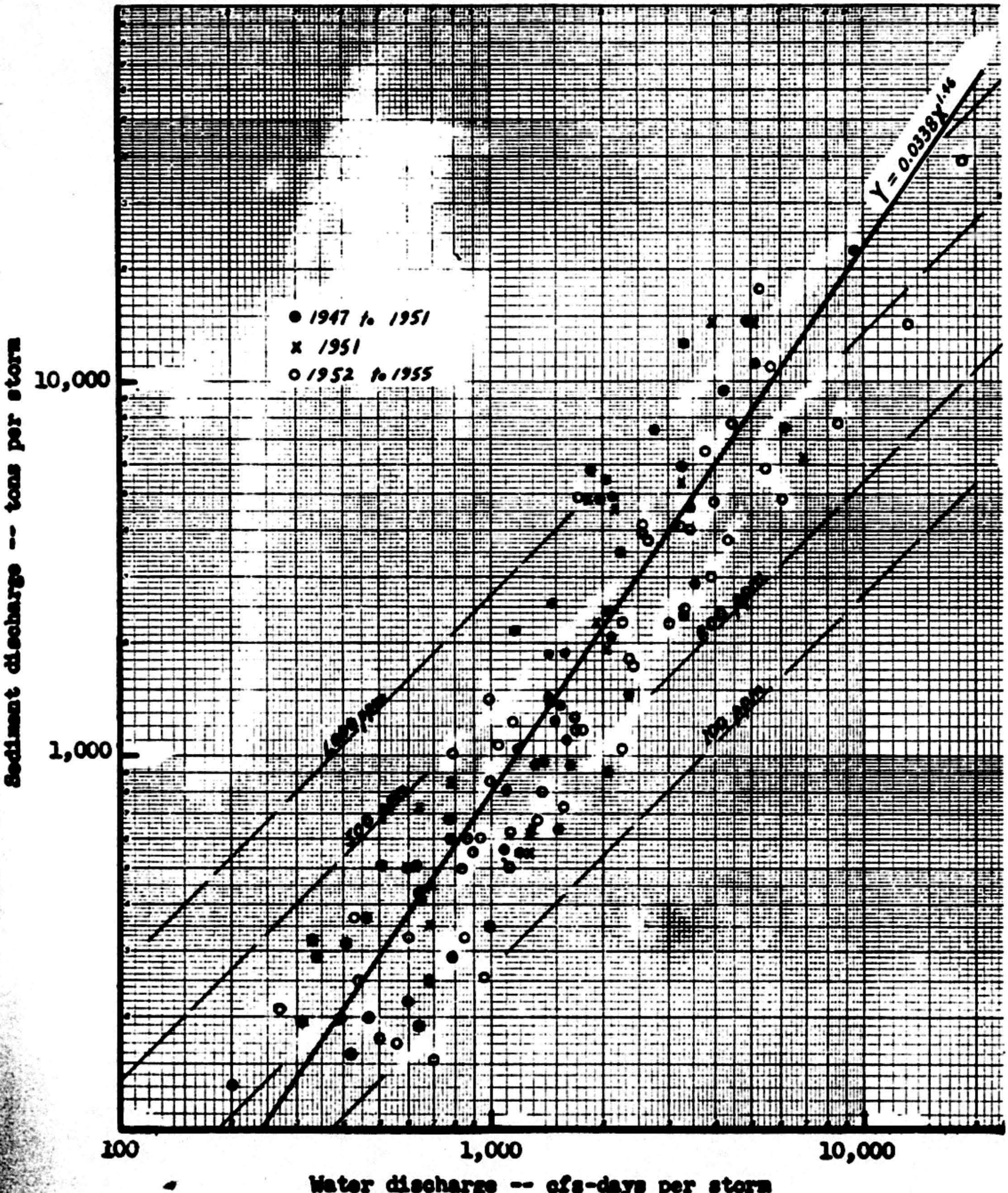

Figure 4.--Sediment transport curve with indicated mean concentration on a storm runoff event basis for Brandywine Creek at Wilmington, Del., December 1946-September 1955

Storm runoff (cfs)	Measured sediment (tons)	Computed sediment (tons)	Departure ratio	Concentration (ppm)
2,040	5,490	2,270	2.42	998
1,170	2,160	1,000	2.16	683
1,460	2,570	1,380	1.86	652
340	290	170	1.71	316
510	510	300	1.70	370
410	315	220	1.43	286
2,240	3,500	2,590	1.35	578
1,590	1,890	1,560	1.21	440
990	350	790	.44	131
1,530	640	1,480	.43	155

Close inspection of figure 4 indicates that more than one-half of the points for the first 4 years of record are to the left of the curve while for the last four years more than one-half of the points are to the right. This suggests a possible decrease in sediment discharge for a given water discharge with time. The trend accounts for some of the variation in the departure ratios and indicates that correction for this factor is necessary in order to improve the correlations with other parameters causing the total variation. Figure 5 shows the plot of the departure ratios with time and the approximate adjustment to be applied to these ratios for time trend. The time adjusted ratios are shown in column 5 of table 1.

Effect of rainfall quantity.--Because of the relative ease of evaluation, rainfall quantity for each storm is a logical choice for attempting to explain the scatter of the data for the water-sediment rating. Figure 6 shows the plot relating the time adjusted departure ratios to the areal mean rainfall for each storm (col. 9, table 3). The scatter of this plot indicates such poor correlation that no attempt was made to compute a regression, and analysis by use of this parameter was discontinued.

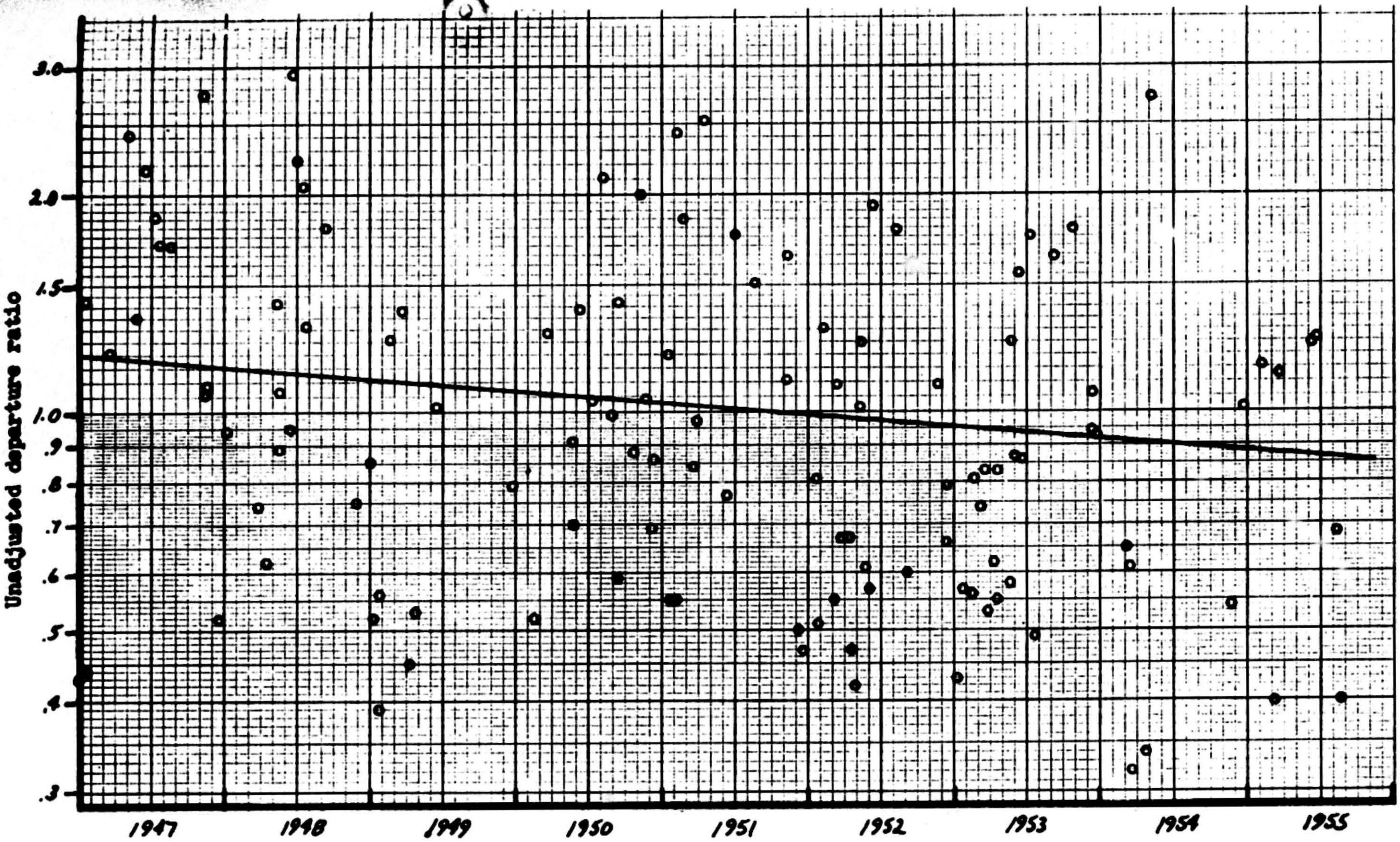

Figure 5.--Approximate trend in relationship of sediment discharge to water discharge (storm runoff event basis), Brandywine Creek at Wilmington, Del.

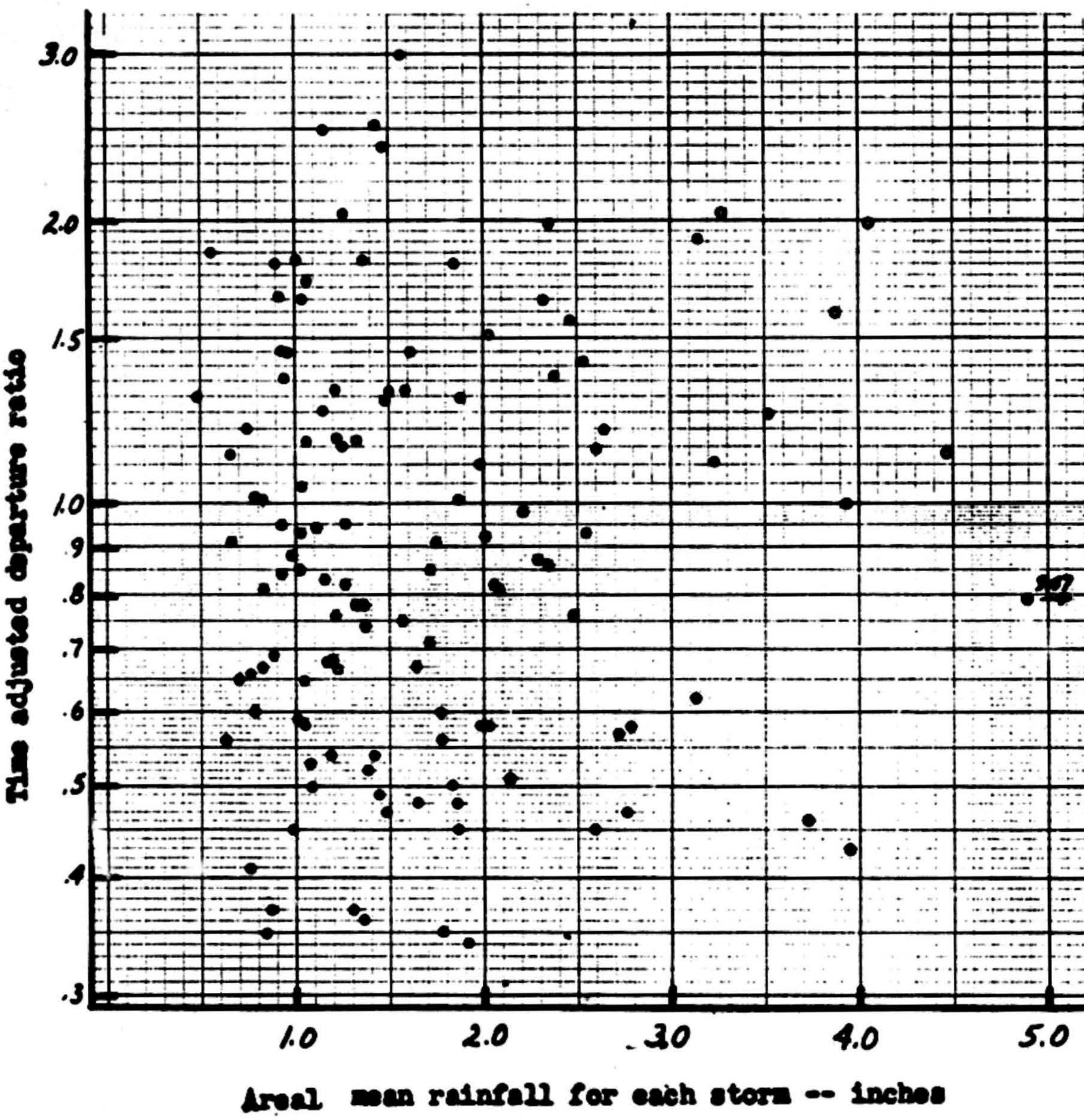

Figure 6.--Relationship between time adjusted departure ratios and areal mean rainfall for Brandywine Creek basin

Effect of rainfall intensity and of season.--The time adjusted ratios were then correlated with the rainfall intensity factors (col. 13, table 3) as shown by figure 7. A linear regression of the plot was computed and fits the equation, $Y_r = 2.59 X_r + 0.55$. The correlation coefficient of these data is 0.48 with limits between 0.34 and 0.62 at the 95 percent confidence level. Adjusted departure ratios for time and rainfall intensity are shown in column 6 of table 1.

After correcting for rainfall intensity, these ratios were then plotted against time of the year as shown by figure 8. The mean of the June and July ratios is 1.26 with limits from 1.04 to 1.47 at the 95 percent confidence level. The mean for the December and January ratios is 0.79 with limits from 0.64 to 0.93 at the 95 percent confidence level. The means of the ratios for the February to May period and the August to November period were found to be 0.98 and 1.02, respectively, and provide the basis for an approximate smooth adjustment curve for season of the year. The adjusted departure ratios for time, rainfall intensity, and season are shown in column 7 of table 1.

Since no additional parameters are available to explain the scatter of the data for the water-sediment rating, it is desirable to compute adjusted measured sediment loads on the basis of the adjusted ratios. However, before this step, the initial adjustment for time trend (fig. 4) was removed in order that the time trend element can be studied in the adjusted water-sediment transport curve. Comparison of the ratios in columns 7 and 8 with those in columns 4 and 5 of table 1 shows the effect of returning the time trend adjustment. The adjusted measured sediment discharge (col. 9) is plotted against water discharge (fig. 9) and

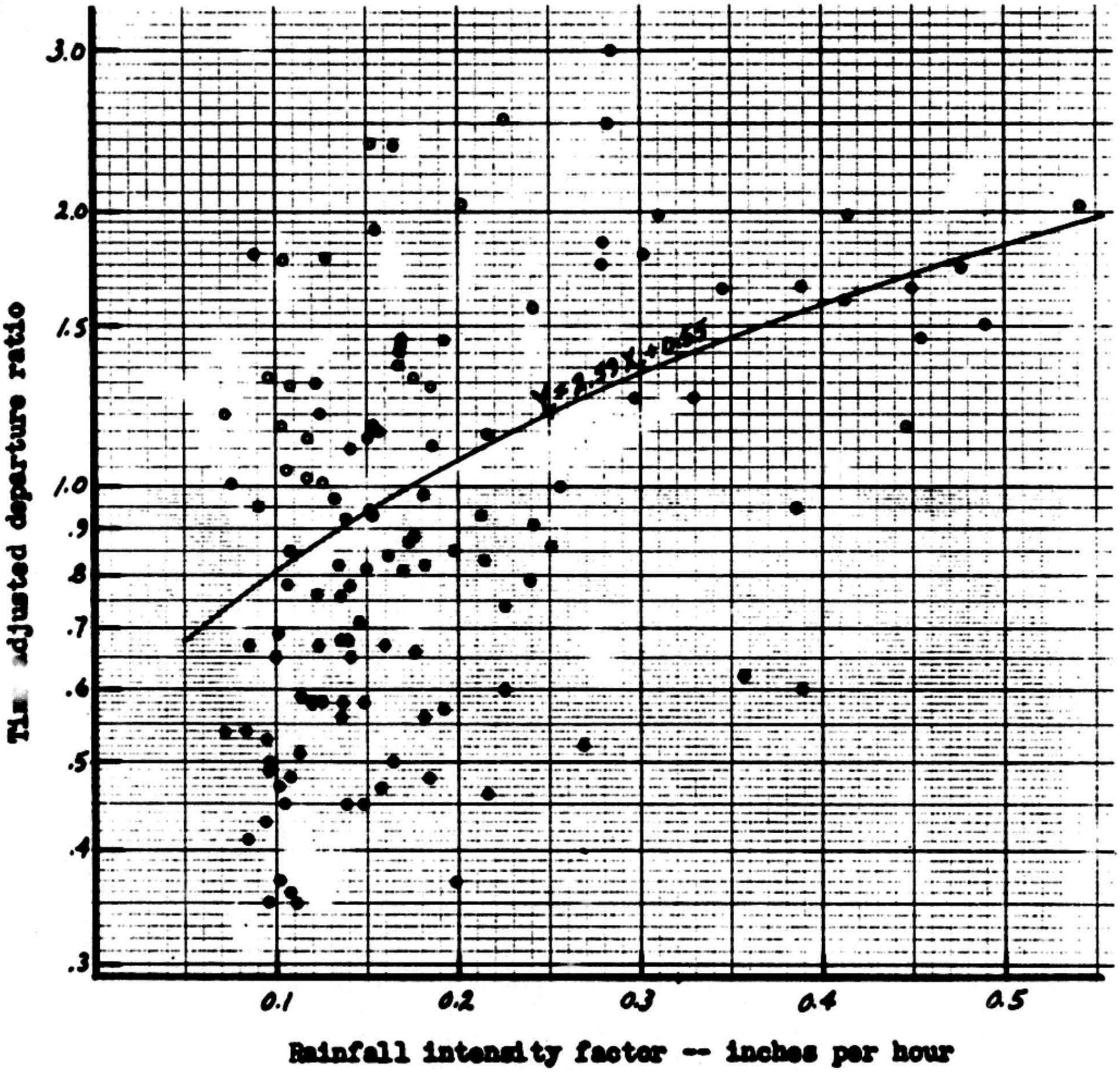

Figure 7.--Rainfall intensity factor adjustment to time adjusted departure ratios (storm runoff event basis) Brandywine Creek at Wilmington, Del.

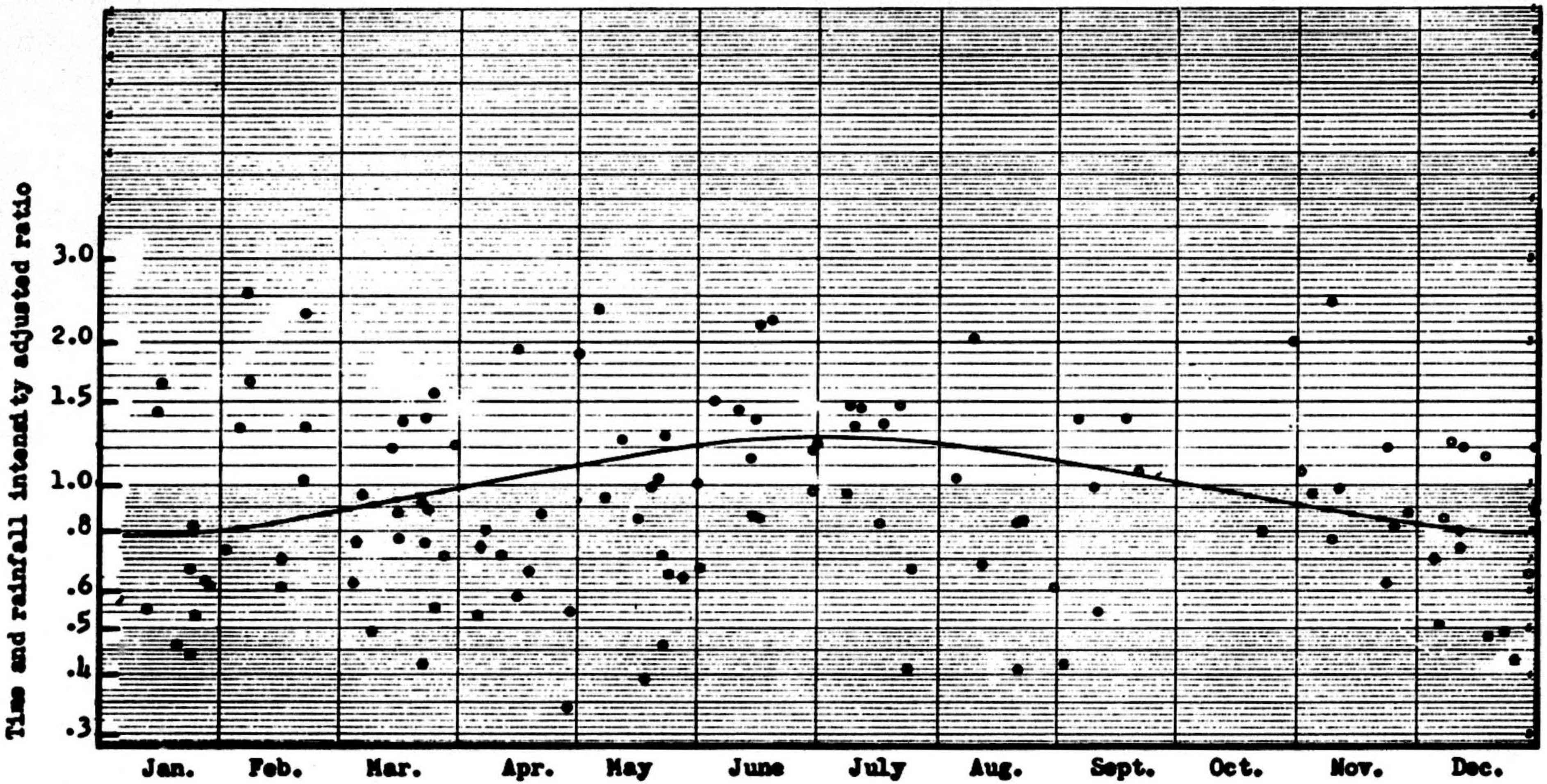

Figure 8.--Seasonal adjustment to time and rainfall intensity adjusted departure ratios (storm runoff event basis) Brandywine Creek at Wilmington, Del.

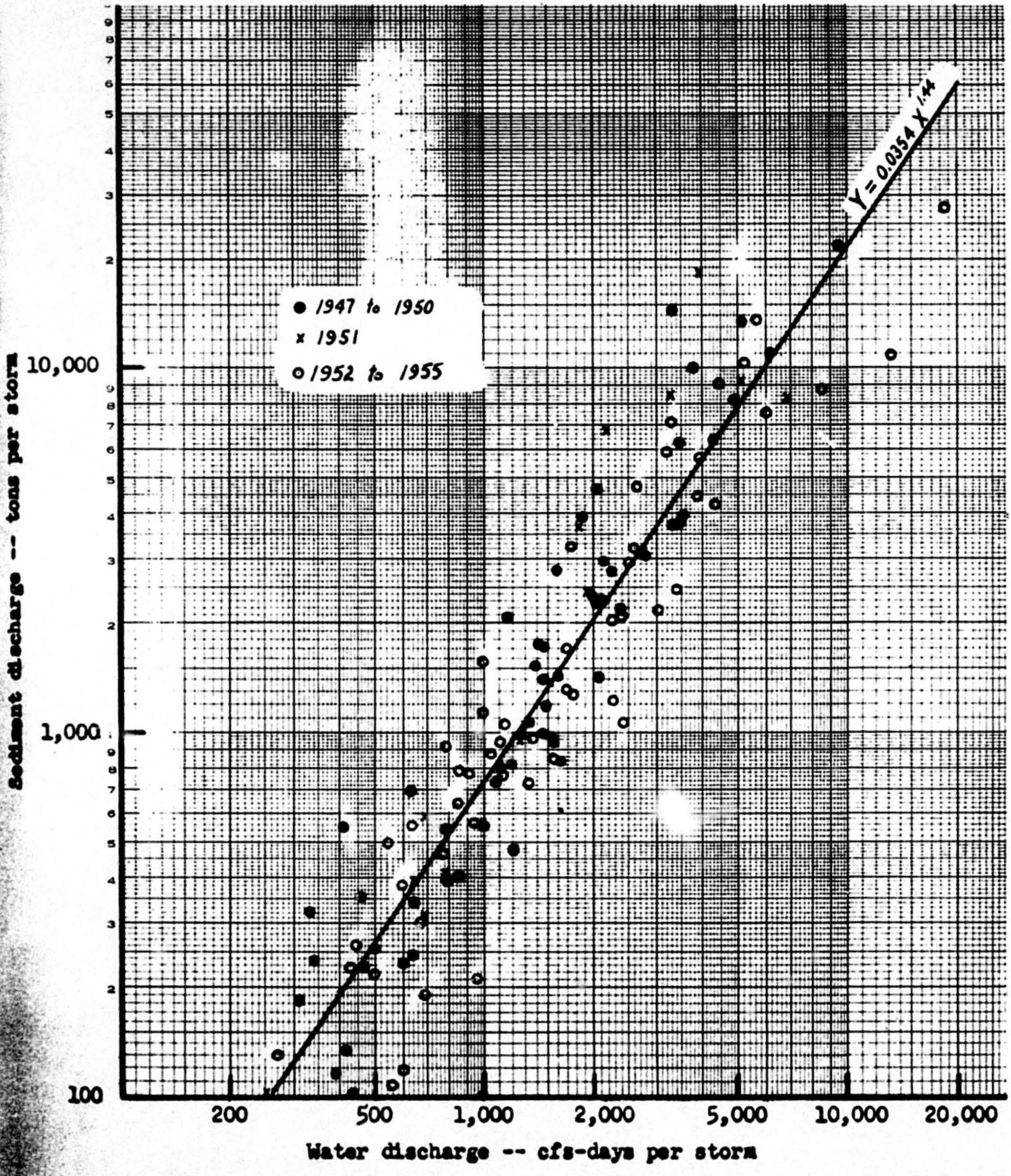

Figure 9.--Adjusted (rainfall intensity and season) sediment transport curve on a storm runoff basis for Brandywine Creek at Wilmington, Del., December 1946 to September 1955

and used to define the adjusted sediment transport curve in which $Y = 0.0354\ X^{1.44}$. This equation is nearly the same as that for the unadjusted equation ($Y = 0.0338\ X^{1.46}$) of figure 3 showing that the effect of the adjustment for rainfall intensity and season has only, in the main, the effect of reducing the scatter of the points.

Evaluation of sediment yield trend.--In an effort to evaluate the decreasing trend of sediment yield from the watershed, it is important that recognition be given the fact that decreasing sediment yield in a watershed of this size and complexity should be a gradual thing. Also, as indicated above only a few of the parameters affecting variation in sediment yield have been evaluated and, therefore, much variation in the water-sediment data remains in addition to the indicated variation caused by time. Logically then, only a relative trend of sediment yield with time may be indicated from the data. Most statistical analysis of this volume of data are cumbersome and time consuming, however, two methods will be used to evaluate the trend. They are, first, the double mass or accumulative graph method where a change in slope of the plotted accumulative measured versus computed sediment indicates a change in sediment yield with respect to the progression of storm events; and second, the rank correlation method which results in a numerical coefficient and its significance.

Figure 10 shows the plot of the accumulated adjusted measured sediment against accumulated adjusted computed sediment as determined from table 1, columns 9 and 10, and figure 9. The relatively flat sloping portion of this plot or high ratio of measured to computed load indicates

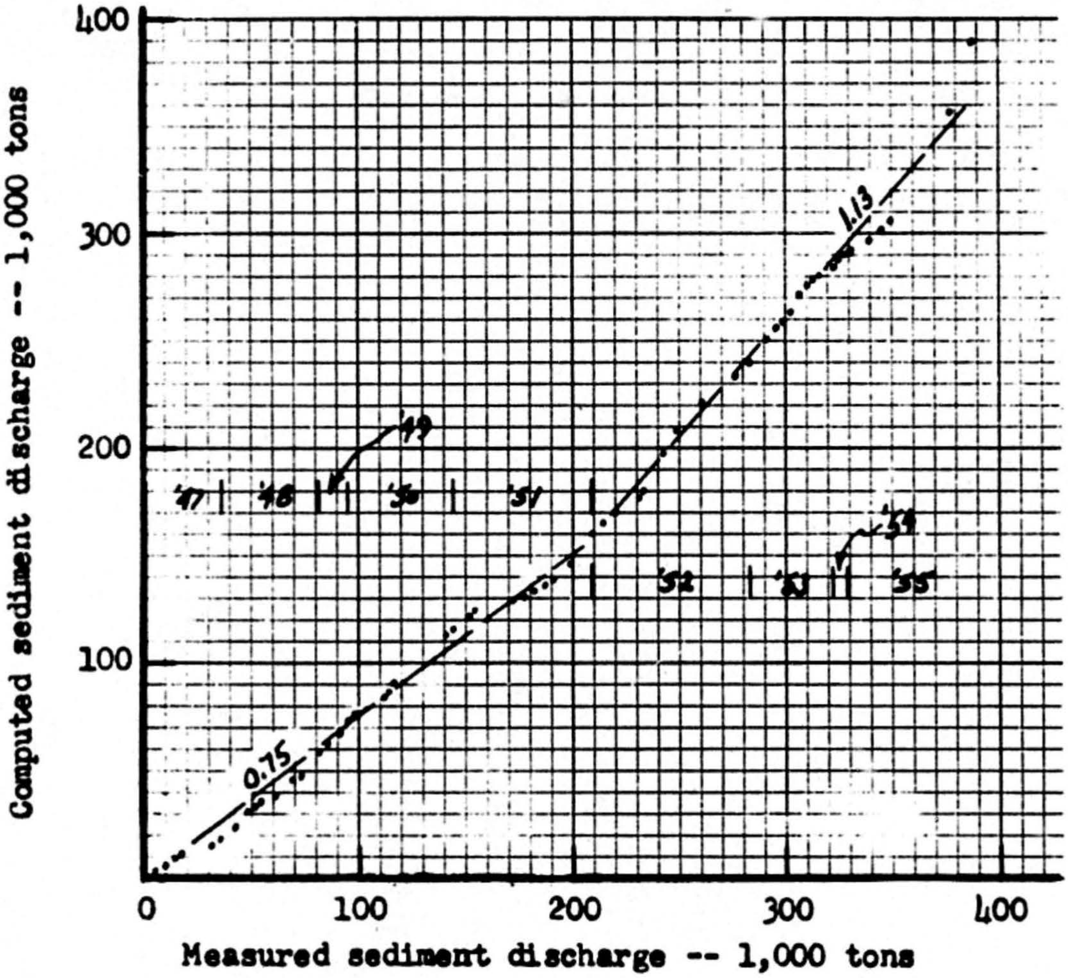

Figure 10.--Accumulative measured vs. computed sediment discharge adjusted for rainfall intensity and season, Brandywine Creek at Wilmington, Del.

that the data accumulated for this portion are from the higher sediment loads for a given water discharge on figure 9, that is, to the left of the computed rating. As points to the right of the rating are encountered or lower sediment loads for a given water discharge, then the slope of the accumulation graph is increased. For figure 10, the average slope of the accumulation for the period 1947 to 1951 is about 0.75 whereas the average slope for the period 1952 to 1955 is about 1.13. The somewhat poor fit of these slopes to the accumulative graph is caused by, first, the fact that data are not available to make adjustments for all factors that cause sediment yield variation from this watershed; and second, the trend of changing sediment yield should logically be a gradual thing and therefore perhaps a curve instead of straight lines would fit the accumulation more closely. The approximately 38 percent reduction in sediment yield indicated by the difference in slope of the accumulation is difficult to evaluate statistically for these same reasons. The statistical evaluation should define the range of percentage reduction for a given confidence level.

Appendix B illustrates and describes the method of using rank correlation on a statistical problem of this type. The analysis requires the use of the proper sediment data from the storm events to give a true picture of the evaluation of the trend. The departure ratios tabulated in column 11 of table 1 giving the relative position of the adjusted measured data with respect to the adjusted sediment transport curve is a good parameter. A perfect ranking of these ratios in decreasing order would indicate that each successive storm resulted in a lower sediment discharge for a given water discharge than the previous storm.

Computations for rank correlation coefficient using the unadjusted departure ratios (col. 4, table 1) and the adjusted departure ratios (column 11, table 1) show that τ = 0.152 and 0.138, respectively, for the 123 storms used for this period of record. Both of these coefficients show a very high level, about 98 percent, of confidence in the significance of a decreasing trend of sediment yield. As may be expected, the similarity of the two coefficients indicate that the adjustments made for rainfall intensity and season did not appreciably alter the ranking of sediment yield with time. The results of the rank correlation study of these data supplement the findings noted in the paragraph above which indicated a 38 percent reduction in sediment yield from the first to the last half of the record.

ANALYSIS BY STORM RUNOFF EVENTS ADJUSTING FOR PEAKEDNESS AND SEASONAL EFFECTS

Another parameter for consideration in attempting to explain the scatter of the plot of water versus sediment discharge is that of the peakedness of the runoff hydrograph at Wilmington. In theory a high peakedness factor should reflect the rainfall, the overland runoff, and the hydraulic characteristics that relate to high sediment yield from the watershed. Table 4 contains the runoff and sediment discharge as used for the rainfall intensity study outlined above and tabulated by table 1. A peakedness factor for most storms was computed (col. 4, table 4) as the ratio of peak runoff (col. 3) to the total runoff (col. 1) at Wilmington for each storm event. Factors for 6 runoff events cannot be computed either because hydrographs were not available or because some hydrographs contained 2 or more distinct peaks nearly equal in magnitude.

Effect of peakedness and season.--The procedure used for the rainfall intensity analysis is also used for the peakedness analysis in order that a comparison of the two parameters can be made. Therefore, reference is made to figures 2 and 3 and columns 3, 4, and 5 of table 1 for obtaining the time-adjusted ratios of the measured to computed sediment discharge. Figures 11 and 12 show the correlations of the peakedness and seasonal factors with the respective adjusted departure ratios. After removing the adjustment for time trend, the peakedness and season adjusted ratios are listed in column 7 of table 4. The adjusted measured sediment was then computed from these ratios, plotted on figure 13 and used for defining a new sediment transport curve (adjusted) by the equation $Y = 0.0156 X^{1.55}$. Although the mass of the data for the adjusted measured sediment has not been shifted appreciably from that of figure 4, the slope of 1.55 in comparison with 1.46 indicates that the peakedness factor may be somewhat biased with respect to storm size or runoff quantity.

Evaluation of sediment yield trend.--An evaluation of sediment yield trend for the data after peakedness and seasonal adjustment is conducted in the same manner as that for the data after rainfall intensity and seasonal adjustment using the accumulative graph and rank correlation methods. Figure 14 shows the plot of the accumulated adjusted measured sediment against accumulated computed sediment shown by the data in columns 8 and 9 of table 4. Again the probable decreasing trend of

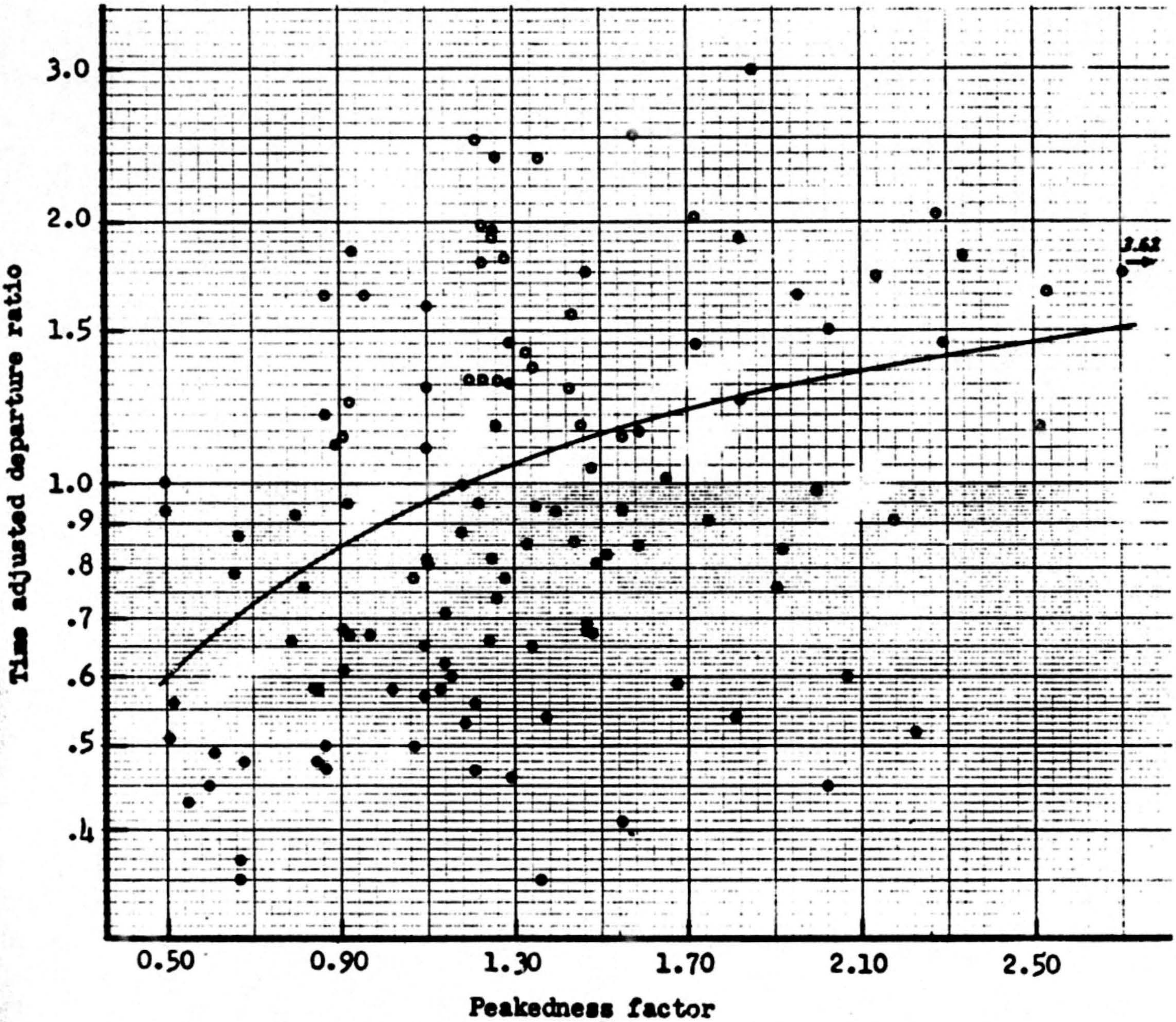

Figure 11.--Peakedness factor adjustment to time adjusted departure ratios (storm runoff event basis) Brandywine Creek at Wilmington, Del.

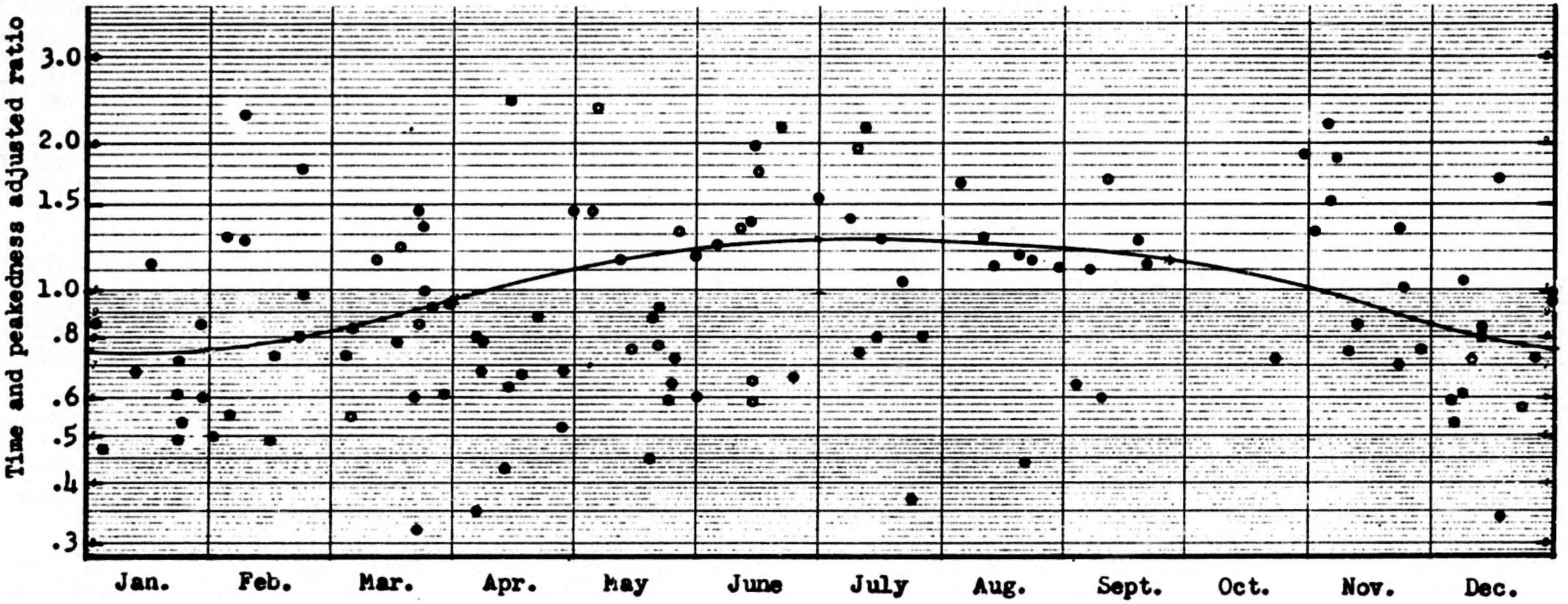

Figure 12.--Seasonal adjustment to time and peakedness adjusted departure ratios (storm runoff event basis) Brandywine Creek at Wilmington, Del.

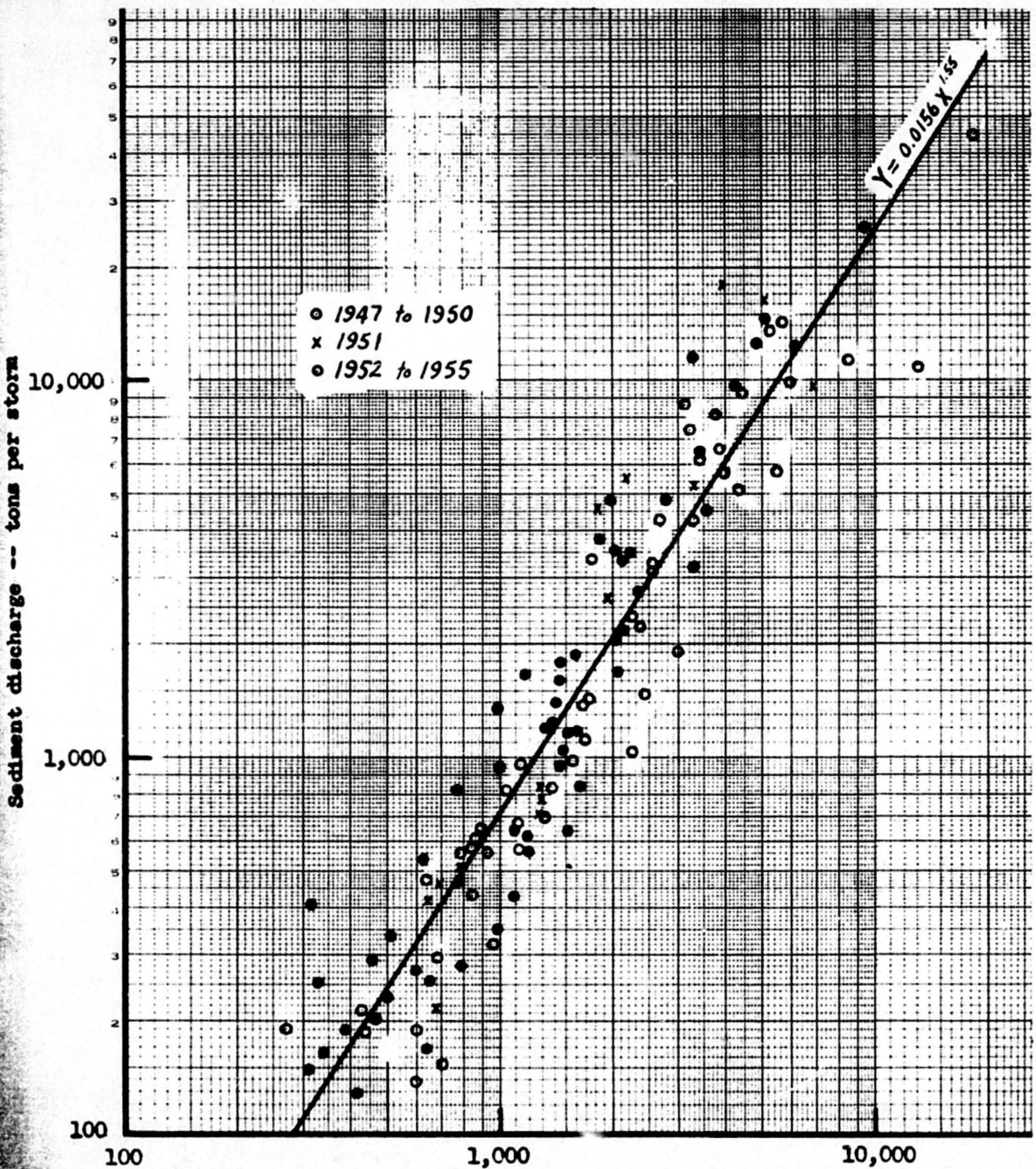

Figure 13.--Adjusted (peakedness and season) sediment transport curve on a storm runoff basis for Brandywine Creek at Wilmington, Del., December 1946 to September 1955

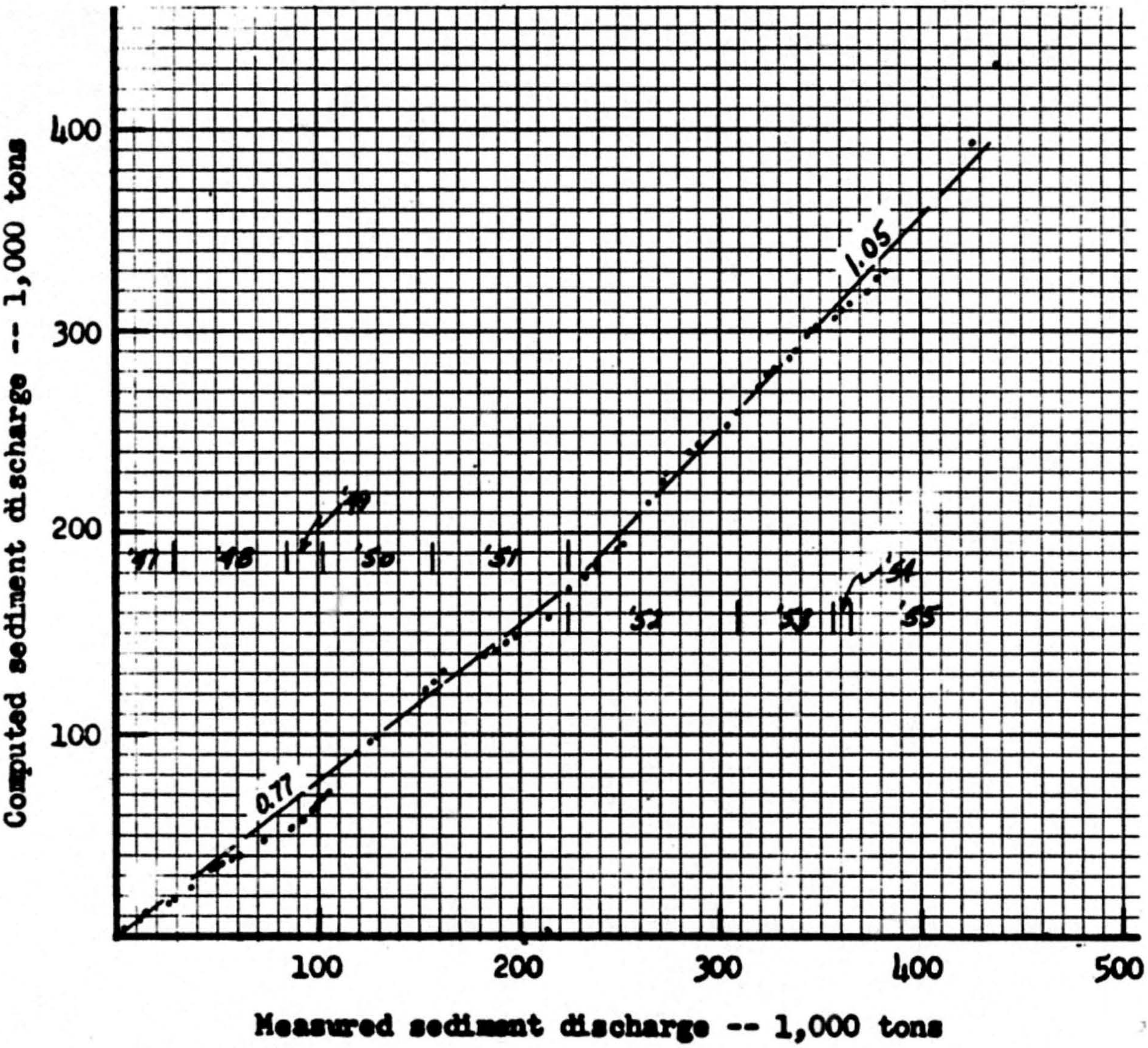

Figure 14.--Accumulative measured vs. computed sediment discharge adjusted for peakedness and season, Brandywine Creek at Wilmington, Del.

sediment yield of the watershed is indicated by the general change in slope of the accumulation from 0.77 for the 1947 to 1951 period to 1.05 for the 1952 to 1955 period.

Computation of a rank correlation coefficient for these data show $\tau = 0.114$, which has about a 94 percent level of confidence that a decreasing trend of sediment yield has occurred for this period of record. This coefficient supplements the finding indicated by the accumulative graph by giving the decreasing trend a level of significance.

The evaluation of the trend as determined after the peakedness and seasonal adjustment can be contrasted to the evaluation after rainfall intensity and seasonal adjustment in three ways: 1. The difference between the apparent 28 percent reduction for peakedness and 38 percent for rainfall intensity. 2. The plotting of the accumulative graph for the peakedness adjustment shows somewhat more deviation from the ideal smooth graph than for the accumulative graph of rainfall intensity adjustment. 3. The rank correlation coefficient for decreasing trend has a considerably lower level of significance for the peakedness than for the rainfall intensity adjustment. The deficiency of the peakedness adjustments, in part, may be due to the lack of data for 6 of the 123 storm events and in part to the possible bias of the peakedness factor with respect to storm size or runoff quantity.

CONCLUSIONS

1. The trend of sediment yield can best be measured by analysis of storm runoff occurring during the relatively short periods of high sediment concentration during each runoff event.

2. Storm runoff used in this study includes 89 percent of the total sediment discharge for the 1947 to 1955 period which was associated with 19 percent of the water discharge.

3. The departure ratio from a sediment rating curve of the sediment yield to storm runoff is a better measure of variation for studying the parameters causing differences in sediment yield than is the mean concentration of the individual storm runoff events.

4. Correction of the departure ratios for time trend before correlating with other parameters causing the variation of sediment yield decreased the scatter of these plots.

5. The correlation of rainfall quantity with these departure ratios is inconclusive indicating that at the Brandywine station rainfall quantity is not related to sediment yield for a given quantity of runoff.

6. A rainfall intensity factor can be related to the departure ratios and has a correlation coefficient of 0.48.

7. Variation in the departure ratios after adjusting for rainfall intensity correlates with season and shows averages of 1.26 for the June and July months and 0.79 for the December and January months.

8. Evaluation of the sediment yield trend with respect to time for the storm runoff after the adjustment of the data for rainfall intensity and season shows, on the basis of the accumulative graph, a reduction in sediment yield of about 38 percent when contrasting the 1947 to 1951 period with the 1952 to 1955 period.

9. The rank correlation coefficient of these adjusted departure ratios with time is +0.138 with nearly a 99 percent level of significance

that the departure ratios and consequently the sediment load decreased with time during this period (1947 to 1955) of record.

10. Adjustment of the departure ratios by correlation with a peakedness factor and season instead of rainfall intensity and season was used because the peakedness factor is much easier to evaluate than rainfall intensity. In the case of the Brandywine, the "peakedness" approach does not make evaluation of the sediment yield trend as decisive as does "intensity".

11. Evaluation after the peakedness and seasonal adjustments by the accumulative graph show a 28 percent reduction in sediment yield when contrasting the 1947 to 1951 period with the 1952 to 1953 period. Compare with 38 percent in conclusion number 8.

12. The rank correlation coefficient of the "peakedness" adjusted departure ratios is +0.114 with a 94 percent confidence level of significance that the sediment load decreased with time. Compare with +0.138 and 98 percent in conclusion number 9.

Table 1.--Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1946											
Dec. 21-23	1,530	640	1,480	0.43	0.36	0.43	0.54	0.65	960	1,380	0.70
1947											
Jan. 14-16	410	315	220	1.43	1.20	1.63	2.09	2.50	550	198	2.78
Jan. 20-22	990	350	790	.44	.37	.46	.58	.70	553	720	.77
Mar. 13-16	1,590	1,890	1,560	1.21	1.01	1.36	1.49	1.78	2,780	1,420	1.96
Apr. 30-2	2,040	5,490	2,270	2.42	2.04	1.89	1.73	2.06	4,680	2,080	2.25
May 19-23	2,240	3,500	2,590	1.35	1.14	1.03	.88	1.06	2,750	2,380	1.15
June 14-16	1,170	2,160	1,000	2.16	1.82	2.16	1.76	2.08	2,080	910	2.28
July 8-10	1,460	2,570	1,380	1.86	1.57	1.33	1.06	1.24	1,710	1,280	1.34
July 20	340	290	170	1.71	1.45	1.47	1.19	1.40	238	150	1.59
Aug. 17-19	510	510	300	1.70	1.45	.84	.73	.85	255	272	.94
Nov. 4-6	3,300	12,700	4,600	2.76	2.37	2.42	2.70	3.13	14,400	4,220	3.41
Nov. 8-10	2,050	2,420	2,290	1.06	.91	.77	.86	1.00	2,290	2,090	1.10
Nov. 11-13	1,410	1,420	1,310	1.08	.93	.98	1.13	1.32	1,730	1,200	1.44
Dec. 15-17	790	290	565	.52	.45	.48	.60	.69	390	510	.76
1948											
Jan. 1-4	3,460	4,600	4,900	.94	.81	.86	1.11	1.28	6,270	4,520	1.39
Mar. 27-29	470	200	270	.74	.65	.71	.73	.84	227	240	.95
Apr. 12-16	1,090	560	900	.62	.54	.71	.70	.81	729	820	.89
May 5-9	4,250	9,440	6,650	1.42	1.24	.94	.84	.96	6,390	6,200	1.03
May 13-15	1,480	1,250	1,400	.89	.78	.85	.73	.84	1,180	1,290	.92

Table 1.—Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1948											
May 17-18	780	600	560	1.07	.94	1.00	.85	.97	543	500	1.09
June 13-14	650	410	430	.95	.84	.86	.70	.80	344	390	.88
June 19-21	1,860	5,750	1,960	2.93	2.53	2.21	1.75	1.98	3,880	1,800	2.15
June 28-2	1,990	4,820	2,150	2.24	1.98	1.22	.97	1.10	2,360	1,990	1.19
July 14-16	2,120	4,920	2,400	2.05	1.80	1.35	1.08	1.23	2,950	2,220	1.33
July 24-25	600	500	380	1.32	1.17	.67	.54	.61	232	345	.65
Sept. 9-12	4,880	14,600	8,100	1.80	1.60	.99	.91	1.02	8,270	7,500	1.10
Nov. 27-30	1,390	960	1,280	.75	.67	.87	1.05	1.18	1,510	1,180	1.28
Dec. 29-2	6,190	7,500	8,800	.85	.76	.88	1.13	1.26	11,100	10,600	1.05
1949											
Jan. 5-8	3,300	2,380	4,570	.52	.47	.58	.74	.82	3,740	4,220	.89
Jan. 21-25	2,060	905	2,300	.39	.35	.44	.55	.61	1,400	2,100	.67
Jan. 26-29	3,560	2,860	5,100	.56	.50	.63	.70	.78	3,980	3,720	1.07
Feb. 22-24	630	510	405	1.26	1.13	1.32	1.55	1.71	690	370	1.86
Mar. 22-24	1,440	1,870	1,350	1.38	1.25	.89	.93	1.03	1,390	1,250	1.11
Apr. 6-7	640	190	420	.45	.41	.53	.53	.58	244	380	.64
May 23-25	1,200	550	1,040	.53	.48	.46	.39	.43	447	950	.47
July 13-15	1,450	1,400	1,370	1.02	.93	.83	.66	.72	990	1,260	.79
Dec. 27-29	1,320	950	1,200	.79	.74	.65	.82	.88	1,060	1,100	.96
1950											
Feb. 14-16	2,370	1,470	2,800	.52	.49	.61	.73	.78	2,180	2,590	.84
Mar. 21-25	5,110	11,200	8,750	1.28	1.20	1.38	1.45	1.54	13,500	8,080	1.67
May 18-20	1,530	1,360 50	1,490	.91	.86	.71	.60	.64	950	1,370	.69
May 24-25	420	160	230	.70	.66	.65	.55	.58	133	203	.66
June 4-6	310	194	140	1.38	1.30	1.50	1.23	1.29	181	130	1.39

Table 1.--Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1950											
July 10-12	1,190	1,050	1,020	1.03	0.98	0.96	0.76	0.80	820	940	0.87
Aug. 3-5	2,770	7,410	3,500	2.11	2.02	1.04	.84	.88	3,080	3,280	.94
Aug. 30-31	390	197	200	.99	.95	.61	.55	.58	116	181	.64
Sept. 10-12	1,630	950	1,620	.59	.57	.54	.50	.52	830	1,490	.56
Sept. 15-17	460	370	260	1.42	1.36	1.38	1.30	1.36	354	232	1.52
Oct. 23-24	1,100	810	920	.88	.85	.80	.84	.87	800	840	.95
Nov. 4-6	330	320	160	2.00	1.92	--	--	--	320	143	2.24
Nov. 25-27	9,510	22,500	21,600	1.04	1.00	.82	.97	1.01	21,800	20,000	1.09
Dec. 4-6	1,600	1,100	1,590	.69	.67	.70	.86	.89	1,420	1,440	.99
Dec. 8-10	2,120	2,060	2,400	.86	.83	.74	.92	.95	2,280	2,200	1.04
1951											
Jan. 14-17	3,290	5,400	4,510	1.20	1.17	1.43	1.82	1.87	8,430	4,200	2.00
Jan. 24-26	1,290	635	1,150	.55	.53	.67	.85	.88	1,010	1,050	.96
Feb. 1-3	1,290	630	1,150	.55	.54	.73	.90	.93	1,070	1,050	1.02
Feb. 7-9	3,920	14,400	5,930	2.43	2.38	2.52	3.01	3.10	18,400	5,440	3.39
Feb. 21-23	2,160	4,540	2,450	1.85	1.80	2.30	2.70	2.77	6,790	2,260	3.00
Mar. 19-22	2,040	1,920	2,280	.84	.82	.91	.96	.98	2,230	2,090	1.07
Mar. 30-31	690	450	465	.97	.95	1.21	1.24	1.27	590	421	1.40
Apr. 13-15	1,820	4,820	1,910	2.52	2.49	1.93	1.88	1.92	3,670	1,770	2.07
June 14-15	680	350	455	.77	.76	.85	.68	.69	314	413	.76
June 29-1	640	730	415	1.76	1.73	.97	.78	.79	328	380	.86
Aug. 20-21	780	850	560	1.52	1.51	.83	.72	.72	403	500	.81
Nov. 1-4	1,910	2,280	2,050	1.11	1.11	1.07	1.18	1.18	2,420	1,900	1.27
Nov. 7-9	5,050	14,200	8,600	1.65	1.65	.96	1.07	1.07	9,210	8,000	1.15
Dec. 5-7	1,260	550	1,110	.50	.50	.51	.62	.62	690	1,010	.68
Dec. 19-23	6,880	6,240	13,400	.47	.47	.49	.62	.62	8,310	12,400	.67

Table 1.--Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1952											
Jan. 22-25	840	500	620	0.81	0.81	0.82	1.04	1.03	640	560	1.14
Jan. 26-30	3,900	3,020	5,900	.51	.51	.61	.77	.76	4,480	5,400	.83
Feb. 4-6	3,270	5,900	4,490	1.31	1.32	1.31	1.62	1.60	7,190	4,150	1.73
Mar. 5-6	680	250	455	.55	.56	.62	.69	.68	309	414	.75
Mar. 11-14	4,450	7,750	7,100	1.09	1.10	1.20	1.29	1.27	9,020	6,570	1.37
Mar. 19-21	1,700	1,160	1,720	.67	.68	.75	.78	.77	1,320	1,600	.82
Apr. 5-8	1,730	1,190	1,780	.67	.68	.74	.74	.73	1,300	1,630	.80
Apr. 14-17	1,580	730	1,550	.47	.48	.58	.56	.55	850	1,400	.61
Apr. 25-2	8,580	7,680	18,500	.42	.43	.54	.49	.48	8,880	17,100	.52
May 11-13	1,150	1,230	980	1.25	1.28	1.25	1.09	1.07	1,050	890	1.18
May 20-21	440	250	245	1.02	1.04	1.27	1.08	1.06	260	220	1.18
May 25-28	5,450	5,880	9,600	.61	.58	.64	.53	.52	4,990	8,900	.56
May 30-3	3,000	2,250	3,980	.57	.58	.67	.55	.54	2,150	3,660	.59
July 8-11	5,290	17,600	9,100	1.93	1.98	1.46	1.15	1.12	10,200	8,420	1.21
Aug. 8-10	790	1,010	565	1.79	1.83	2.01	1.68	1.63	920	520	1.77
Sept. 1-4	2,410	1,740	2,900	.60	.62	.42	.38	.37	1,070	2,680	.40
Sept. 19-20	430	370	230	1.61	1.66	1.07	1.02	.98	225	210	1.07
Nov. 20-23	5,650	11,000	10,100	1.09	1.13	1.20	1.40	1.35	13,600	9,400	1.45
Dec. 5-7	1,120	625	940	.66	.69	.85	1.05	1.01	950	860	1.10
Dec. 11-12	4,000	4,760	6,050	.79	.82	.80	.99	.95	5,740	5,620	1.02

Table 1.--Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1953											
Jan. 9-12	6,050	4,860	11,200	0.43	0.45	0.55	0.70	0.67	7,510	10,300	0.73
Jan. 24-26	4,310	3,760	6,620	.57	.60	.53	.67	.64	4,230	6,300	.67
Feb. 15-16	1,130	505	950	.56	.59	.70	.84	.80	760	870	.87
Feb. 21-22	900	550	680	.81	.85	1.03	1.20	1.14	770	620	1.24
Mar. 4-5	1,680	1,260	1,700	.74	.78	.95	1.05	1.00	1,700	1,560	1.09
Mar. 13-17	3,420	4,000	4,820	.83	.87	.87	.82	.78	3,760	4,500	.84
Mar. 24-28	3,300	2,420	4,570	.53	.56	.55	.57	.54	2,470	4,220	.59
Apr. 7-8	1,380	800	1,280	.62	.65	.80	.80	.76	970	1,270	.76
Apr. 13-15	1,330	670	1,210	.55	.58	.66	.63	.60	730	1,110	.66
Apr. 16-19	930	600	720	.83	.88	.87	.82	.78	560	650	.86
May 18	600	220	380	.58	.60	.39	.33	.31	118	345	.34
May 26-28	2,580	3,990	3,200	1.25	1.32	--	--	--	3,200	2,930	1.09
May 30-3	2,260	2,260	2,610	.87	.92	1.01	.83	.78	2,040	2,400	.85
June 13-14	770	860	550	1.56	1.65	1.13	.91	.86	473	500	.95
June 23-24	600	328	380	.86	.91	--	--	--	380	345	1.10
July 9-11	270	210	120	1.75	1.85	1.45	1.16	1.08	130	107	1.21
July 23-24	560	170	345	.49	.52	.41	.33	.31	107	312	.34
Sept. 5-7	200	131	80	1.64	1.75	1.37	1.25	1.17	94	78	1.20
Oct. 29-31	990	1,400	780	1.79	1.91	2.00	2.15	2.00	1,560	720	2.17
Dec. 7-9	1,000	860	800	1.07	1.17	1.23	1.52	1.41	1,130	730	1.55
Dec. 10-12	860	600	640	.94	1.02	1.20	1.50	1.38	880	590	1.49
Dec. 13-17	3,220	4,110	4,420	.93	1.01	1.15	1.44	1.33	5,880	4,100	1.43

Table 1.--Storm runoff and sediment data with adjustments for rainfall intensity and season to reduce scatter in the water sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed sediment	Time adjusted ratio	Time and rainfall intensity adjusted ratio	Time, rainfall intensity, and season adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10	11
1954											
Mar. 1-5	2,360	1,830	2,800	0.65	0.71	0.76	0.85	0.78	2,180	2,570	0.85
Mar. 14-16	500	176	290	.61	.67	.77	.82	.75	217	263	.83
Mar. 20-22	700	154	480	.32	.35	.42	.44	.40	192	432	.45
Apr. 27-30	960	257	750	.34	.37	.34	.31	.28	210	690	.30
May 4-6	1,740	4,900	1,800	2.72	3.00	2.33	2.09	1.90	3,420	1,640	2.08
Nov. 21-23	850	325	630	.52	.58	.62	.73	.65	409	560	.70
Dec. 30-31	640	430	420	1.02	1.15	1.20	1.52	1.34	562	380	1.48
1955											
Feb. 6-9	3,780	6,520	5,600	1.16	1.32	1.65	2.02	1.79	10,000	5,180	1.93
Mar. 4-8	2,260	1,050	2,610	.40	.45	.49	.54	.47	1,230	2,400	.51
Mar. 22-24	2,670	3,780	3,330	1.13	1.29	1.56	1.61	1.42	4,730	3,080	1.54
June 8-11	1,050	1,070	860	1.24	1.42	1.43	1.16	1.01	870	790	1.10
June 12-13	2,560	4,020	3,180	1.26	1.45	1.37	1.10	.95	2,940	2,900	1.01
Aug. 11-16	18,360	38,630	57,000	.68	.79	.68	.57	.49	27,900	52,000	.53
Aug. 17-23	13,170	14,180	35,000	.40	.46	.41	.36	.31	10,900	32,500	.33

Table 2.--Comparison of storm and total runoff by seasons and years for Brandywine Creek at Wilmington, Del.

Year	Jan. - Mar. Water (cfs-days)	Jan. - Mar. Sediment (tons)	Apr. - June Water (cfs-days)	Apr. - June Sediment (tons)	July - Sept. Water (cfs-days)	July - Sept. Sediment (tons)	Oct. - Dec. Water (cfs-days)	Oct. - Dec. Sediment (tons)	Total for year Water (cfs-days)	Total for year Sediment (tons)	Mean conc. (ppm)
					Totals of storm runoff used in analysis						
1947	2,990	2,550	6,410	12,920	2,310	3,370	7,450	16,830	19,160	35,670	690
1948	3,930	4,800	12,100	22,830	7,850	20,280	7,900	8,560	31,780	56,470	658
1949	10,990	8,520	2,610	1,380	1,450	1,400	1,320	950	16,370	12,260	227
1950	7,480	12,670	2,260	1,710	6,440	9,980	14,660	26,790	30,840	51,150	614
1951	14,680	27,970	3,140	6,050	780	850	15,100	23,270	33,700	58,140	639
1952	14,840	18,580	21,930	19,210	8,920	20,720	10,770	16,380	56,460	74,890	491
1953	20,800	17,350	10,450	9,780	1,030	510	6,070	6,980	38,350	34,620	334
1954	3,560	2,160	2,700	5,160	0	0	1,490	760	7,750	8,080	386
1955	8,710	11,340	3,610	5,090	31,530	52,800	--	--	43,850	69,190	584
Total	87,980	105,950	65,210	84,140	60,310	109,910	64,760	100,520	278,260	400,480	533
Mean conc.	446		478		675		575		533		
					Total flow for record						
1947	36,830	3,640	44,190	17,080	21,850	4,110	28,500	18,500	131,370	43,330	122
1948	58,500	13,200	67,600	25,610	44,380	23,820	40,050	8,940	210,530	71,570	125
1949	85,460	9,770	42,080	2,310	19,890	2,190	17,270	1,300	164,700	15,570	35
1950	41,290	13,800	41,240	3,110	29,040	10,760	47,480	27,360	159,050	55,030	128
1951	66,580	30,440	44,620	7,180	17,830	2,330	42,630	23,990	171,660	63,940	138
1952	80,040	19,660	85,220	20,530	39,880	21,650	40,940	16,860	246,080	78,700	118
1953	90,110	18,620	72,490	11,700	19,710	1,330	24,090	7,170	206,400	38,820	70
1954	28,600	2,650	28,580	6,020	10,670	320	16,040	1,070	83,890	10,060	44
1955	33,3[illegible]0	11,710	25,560	5,610	59,200	54,160	--	--	118,090	71,[illegible]80	224
Total	520,740	123,490	451,580	99,150	262,450	120,670	257,000	105,190	1,491,770	448,500	111
Mean conc.	87		81		170		152		111		
					Percent of storm runoff to total flow						
1947	8.1	70	15	76	11	82	26	91	15	82	
1948	6.7	36	18	89	18	85	20	96	15	79	
1949	13	87	6.2	60	7.3	64	7.7	73	9.9	79	
1950	18	92	5.5	55	22	93	31	98	19	93	
1951	22	92	7.0	84	4.4	36	35	97	20	91	
1952	18	94	26	94	22	96	26	97	23	95	
1953	23	93	14	84	5.2	38	25	97	19	89	
1954	12	82	9.4	86	0	0	9.3	71	9.2	80	
1955	26	97	14	91	53	98	--	--	37	97	
Mean	17	86	14	85	23	91	25	96	19	89	

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1946													
Dec. 21-23	1.65	1.40	1.77	1.18	1.72	1.74	1.82	1.74	1.67	1.71	14	1.55	0.108
1947													
Jan. 14-16	.65	.47	.79	.79	.57	.69	.84	.80	.75	.62	6	.36	.073
Jan. 20-22	.43	.90	.95	.86	.80	.91	.93	1.02	.87	.87	7	.72	.103
Mar. 13-16	.55	.65	.71	.84	.69	.82	1.01	.77	.83	1.06	9	.87	.076
Apr. 30-2	1.28	1.13	1.06	.87	1.00	1.39	1.59	1.17	1.27	1.10	6	1.05	.202
May 19-23	1.23	2.01	2.03	2.17	2.50	3.37	3.15	2.82	2.60	2.25	11	2.06	.216
June 14-16	1.98	1.45	1.62	1.93	1.59	1.25	.97	.82	1.36	1.81	12	1.67	.105
July 8-10	3.05	2.63	2.89	1.43	3.86	3.05	2.27	.78	2.46	3.27	10	3.20	.241
July 20	1.00	.87	1.00	.96	1.20	.99	.87	1.09	.97	.84	5	.73	.169
Aug. 17-19	.23	.42	.98	.52	.65	.64	1.57	.61	.94	1.19	2	1.15	.455
Nov. 4-6	2.20	2.45	3.19	3.88	1.74	1.25	1.92	3.19	2.38	1.97	13	1.78	.165
Nov. 8-10	1.34	1.54	1.58	1.93	1.44	1.89	1.95	1.69	1.75	1.59a	7	1.53	.241
Nov. 11-13	.68	1.02	.97	1.05	.88	1.18	1.06	1.07	1.01	1.09	6	.99	.153
Dec. 15-17	.73	.83	.87	1.13	.98	1.01	1.05	.98	.98	1.03	6	.94	.148
1948													
Jan. 1-4	1.95	1.80	1.78	1.83	1.91	2.15	2.37	2.25	2.09	1.89a	13	1.76	.150
Mar. 27-29	.66	.85	.97	.74	.38	.78	.66	.61	.70	.54	3	.33	.142
Apr. 12-16	2.05	1.67	1.58	1.58	1.24	1.30	1.27	1.25	1.43	1.52	11	.97	.083
May 5-9	3.65	3.59	3.67	3.46	3.48	3.36	3.51	3.45	3.52	2.51	11	2.33	.297
May 13-15	1.71	2.07	.30	1.42	1.00	1.51	1.64	1.37	1.37	1.18	9	1.09	.141

[a]Hourly precipitation at Coatesville unavailable and because of general nature of storm the duration and quantity is based on the hourly precipitation at Lancaster and Philadelphia (SW Airport).

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1948													
May 17-18	.67	.60	.77	.77	.93	1.27	1.51	1.34	1.11	1.00	6	.82	0.152
June 13-14	1.15	1.35	1.34	1.31	.95	.87	.39	1.67	.93	1.00	5	.87	0.162
June 19-21	1.20	1.37	1.16	.95	1.90	1.78	1.59	1.09	1.43	1.56	6	1.48	0.226
June 28-2	1.46	2.39	1.27	2.33	1.64	2.39	3.19	2.45	2.37	1.60	5	1.40	0.415
July 14-16	1.63	2.00	1.54	2.87	2.21	1.83	1.60	1.50	1.85	2.02	6	1.97	0.301
July 24-25	1.29	1.98	1.37	1.35	.55	.45	.79	2.20	1.07	.67	2	.56	0.447
Sept. 9-12	4.82	3.57	6.15	5.81	3.04	2.66	2.57	5.03	3.89	2.85	9	2.71	0.412
Nov. 27-30	1.74	1.47	1.49	1.50	1.48	1.55	1.79	1.79	1.64	1.55	15	1.22	0.086
Dec. 29-2	2.71	2.31	2.33	2.05	2.32	2.46	2.66	2.74	2.48	2.52	15	1.87	0.123
1949													
Jan. 5-8	2.25	1.86	1.50	.50	1.63	1.56	1.54	1.59	1.49	1.69	12	1.37	0.101
Jan. 21-25	1.49	1.44	1.52	1.60	1.76	1.85	2.02	1.93	1.78	1.76	14	1.32	0.096
Jan. 26-29	1.77	1.52	1.69	1.70	1.64	1.80	2.03	1.90	1.83	1.80	15	1.43	0.097
Feb. 22-24	.63	.65	.72	.71	.53	.68	.68	.64	.66	.72	3	.39	0.119
Mar. 22-24	.95	.70	1.05	1.19	1.10	1.22	1.29	1.15	1.15	1.06	3	.91	0.329
Apr. 6-7	.88	.63	.85	.73	.80	.71	.74	.76	.76	.80	8	.72	0.085
May 23-25	1.17	.96	2.63	1.85	1.76	1.75	1.86	2.20	1.86	2.65	9	2.36	0.184
July 13-15	3.51	2.97	3.12	2.45	2.58	2.45	2.20	2.07	2.55	2.75	11	2.53	0.213
Dec. 27-29	2.07	1.50	1.64	1.46	1.52	1.20	1.06	1.33	1.38	1.45	5	1.19	0.226
1950													
Feb. 14-16	1.30	1.60	2.08	1.59	1.13	1.00	1.34	1.78	1.45	1.44	6	.58	0.097
Mar. 21-25	2.29	2.86	3.21	2.04	2.55	2.60	2.82	2.45	2.65	2.45	19	2.20	0.125
May 18-20	1.38	1.62	1.90	1.99	1.79	1.51	1.95	1.85	2.35	2.20	9	2.11	0.251
May 24-25	.51	.88	1.09	1.06	.75	.77	.68	.37	.77	1.09	4	1.00	0.177
June 4-6	.50	.38	.54	.44	.49	.53	.45	.66	.49	.71	3	.53	0.122

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1950													
July 10-12	1.77	2.98	3.26	2.23	2.46	2.00	1.99	1.24	2.21	2.27	12	2.23	0.181
Aug. 3-5	.45	.80	2.63	2.72	3.24	3.71	4.38	4.66	3.28	3.22	6	3.19	0.542
Aug. 30-31	.99	.09	.75	.77	1.65	.27	1.77	2.55	1.26	1.99	3	1.83	0.386
Sept. 10-12	3.99	2.63	1.87	1.94	3.98	1.92	2.87	2.57	2.71	1.74	11	1.37	0.194
Sept. 15-17	.74	2.61	.64	.75	1.30	.43	1.00	.91	.95	1.69	5	1.49	0.168
Oct. 23-24	1.32	1.34	1.64	1.82	1.63	1.63	1.91	1.72	1.72	1.66	8	1.54	0.199
Nov. 4-6	.13	.21	.23	.42	.23	.25	.38	1.27	.34	.12	1	.08	--
Nov. 25-27	3.62	4.02	4.10	3.90	3.79	3.01	3.82	6.18	3.94	3.74	15	3.64	0.256
Dec. 4-6	1.42	1.15	1.31	1.52	.89	.86	1.18	1.60	1.22	1.10	7	1.01	0.160
Dec. 8-10	1.14	1.16	1.15	1.10	1.02	1.05	1.30	.98	1.16	1.24	5	1.15	0.215
1951													
Jan. 14-17	1.34	1.40	1.20	1.07	1.33	1.23	1.22	1.12	1.22	1.13	9	.86	0.103
Jan. 24-26	1.08	1.07	1.07	1.01	1.25	.97	1.10	1.06	1.08	1.15	10	1.00	0.096
Feb. 1-3	1.45	1.39	1.26	1.26	1.04	1.00	1.16	1.15	1.19	1.27	12	.92	0.072
Feb. 7-9	1.56	1.34	1.33	1.22	1.20	1.53	1.72	1.27	1.47	1.38	8	1.15	0.153
Feb. 21-23	.83	.91	1.19	.81	.81	1.00	.84	.87	.90	1.04	9	.93	0.089
Mar. 19-22	.96	1.20	1.45	1.27	1.11	1.21	1.38	1.16	1.27	1.38	9	1.32	0.135
Mar. 30-31	1.18	1.01	1.16	.92	.88	.89	.77	1.14	.93	1.04	5	.51	0.091
Apr. 13-15	1.34	1.65	1.44	1.40	1.45	1.30	.78	.68	1.15	1.50	4	1.47	0.282
June 14-15	.81	.99	1.28	1.31	1.39	.70	1.32	1.63	1.22	1.58	7	1.23	0.136
June 29-1	.98	1.59	1.17	1.32	.73	.78	1.15	.74	1.07	1.29	2	1.15	0.477
Aug. 20-21	1.36	.90	1.61	.97	3.47	2.50	2.64	.68	2.04	2.29	4	2.20	0.490
Nov. 1-4	3.08	3.19	3.62	3.11	2.94	3.02	3.41	2.90	3.24	3.04	14	2.45	0.187
Nov. 7-9	2.65	2.81	2.89	2.19	2.45	1.78	2.24	1.80	2.32	2.32	5	2.25	0.450
Dec. 5-7	.51	1.15	1.53	1.21	.02	1.17	1.37	.87	1.09	1.42	6	1.29	0.165
Dec. 19-23	2.45	2.33	2.85	2.69	2.34	2.66	3.05	2.71	2.76	2.74	16	2.52	0.158

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1952													
Jan. 22-25	.66	.63	1.10	.79	.91	.72	.85	.71	.83	.78	3	.48	0.170
Jan. 26-30	2.09	2.00	2.53	2.11	2.28	2.02	2.08	2.06	2.15	2.30	14	1.71	0.114
Feb. 4-6	1.14	1.27	1.83	1.34	1.19	1.21	1.73	1.51	1.50	1.45	8	1.36	0.176
Mar. 5-6	.48	.56	.79	.62	.47	.48	.71	.61	.63	.60	3	.42	0.136
Mar. 11-14	1.83	2.05	2.24	1.60	1.68	1.77	2.17	2.19	1.98	2.08	13	1.93	0.141
Mar. 19-21	.99	1.14	1.20	1.14	1.00	1.06	1.41	1.01	1.20	1.19	8	1.08	0.136
Apr. 5-8	1.49	.42	1.22	.96	1.24	.88	1.28	1.48	1.18	1.14	8	1.08	0.140
Apr. 14-17	2.18	1.73	2.05	1.93	1.58	1.57	1.34	1.41	1.65	1.93	10	1.26	0.108
Apr. 25-2	4.29	4.87	4.73	4.11	3.44	3.77	3.54	4.23	3.95	3.84	27	2.50	0.095
May 11-13	1.18	1.33	1.79	1.25	1.72	1.59	1.53	1.05	1.48	1.80	7	1.56	0.186
May 20-21	1.03	1.06	1.33	1.37	.86	.78	.95	.98	1.04	.80	7	.57	0.106
May 25-28	2.18	2.29	3.34	2.79	3.00	2.77	2.92	2.01	2.79	3.15	17	2.64	0.138
May 30-3	1.16	1.57	2.67	2.15	1.79	1.83	2.54	.14	2.03	2.27	13	1.75	0.120
July 8-11	2.58	4.66	6.18	3.40	3.10	5.06	3.72	4.48	4.07	4.70	12	4.30	0.310
Aug. 8-10	1.14	1.04	1.27	1.05	.70	.69	.86	1.96	1.01	1.66[a]	7	1.48	0.129
Sept. 1-4	3.55	3.46	3.92	2.82	3.35	2.81	2.80	3.50	3.14	3.20	8	2.92	0.358
Sept. 19-20	.20	.02	1.49	.80	1.06	1.39	.88	.83	.91	1.17	2	1.00	0.389
Nov. 20-23	4.25	4.51	5.38	4.48	4.47	3.77	4.38	4.27	4.46	4.69	26	4.13	0.151
Dec. 5-7	.99	1.01	1.18	.70	.97	.75	.87	.73	.89	1.00	5	.57	0.101
Dec. 11-12	1.71	1.66	2.42	1.89	1.58	1.95	2.22	2.56	2.06	2.00	9	1.58	0.181

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1953													
Jan. 9-12	2.54	2.51	3.25	2.64	2.04	2.05	2.63	2.84	2.59	2.47	18	1.80	0.105
Jan. 24-26	1.41	1.80	2.05	1.76	1.76	1.71	1.81	1.57	1.77	1.72	7	1.54	0.227
Feb. 15-16	.80	.88	1.29	.92	.81	.95	1.08	1.06	1.01	.90	8	.82	0.115
Feb. 21-22	.70	.65	1.06	.73	.65	.76	.79	.80	1.02	.77	6	.49	0.108
Mar. 4-5	1.01	1.13	1.58	1.32	1.21	1.32	1.36	1.50	1.33	1.41	10	1.24	0.107
Mar. 13-17	1.80	2.08	2.31	2.47	1.91	2.42	2.35	2.73	2.29	2.06	9	1.41	0.174
Mar. 24-28	1.83	2.03	2.16	2.00	1.30	1.53	1.65	2.02	1.77	1.54	9	1.42	0.181
Apr. 7-8	.87	1.10	1.35	1.15	.78	.78	.98	1.62	1.05	.93	8	.71	0.100
Apr. 13-15	1.09	.97	1.15	.95	1.02	1.17	1.03	.99	1.05	1.09	6	.78	0.125
Apr. 16-19	.52	.72	.90	.93	.77	1.08	1.19	1.15	.98	1.01	5	.91	0.177
May 18	1.02	.88	1.36	.90	.35	.35	.39	1.63	.78	.49	2	.49	0.390
May 26-28	1.50	1.69	1.77	1.76	.94	1.07	1.77	1.75	1.58	--	-	--	--
May 30-3	1.98	1.88	2.30	1.86	2.16	2.04	1.94	2.01	2.01	2.27	12	1.88	0.139
June 13-14	.87	.52	.91	.78	.89	1.34	1.15	1.53	1.04	1.29	3	1.29	0.346
June 23-24	1.33	1.42	2.41	.55	.82	.15	.03	.08	.67	.12	1	.06	--
July 9-11	.45	.41	.42	.26	.62	.45	.86	.16	.56	.57	2	.57	0.280
July 23-24	.90	.99	1.16	1.21	1.08	1.79	1.66	1.48	1.38	1.61	5	1.57	0.269
Sept. 5-7	2.48	1.18	.62	.74	2.34	1.60	.89	1.17	1.57	.87	5	.77	0.278
Oct. 29-31	2.96	3.17	3.04	3.30	2.73	3.28	3.09	4.09	3.15	3.49	18	3.08	0.155
Dec. 7-9	1.30	1.19	1.05	1.28	1.54	1.35	1.40	--	1.33	1.50	10	1.37	0.154
Dec. 10-12	1.15	1.00	.54	1.06	1.04	.74	.61	--	.79	1.04	6	.93	0.118
Dec. 13-17	1.55	1.62	2.14	1.90	1.77	1.79	1.91	--	1.86	2.00	13	1.77	0.126

Table 3.--Brandywine Creek basin precipitation (inches)
December 1946 to September 1955

Date of run-off at Wilmington	Honey-Brook	Loag's Corner	Brandy-wine Manor	Eagle	Parkes-burg	Spring-dell	Ebers-ville	Frazer	Weighted mean	Coatesville			
										Total	Hours >0.05	Quan-tity >0.05	Weighted intensity (in./hr.)
	1	2	3	4	5	6	7	8	9	10	11	12	13
1954													
Mar. 1-5	1.61	1.76	.74	1.55	2.34	2.03	1.83	1.85	1.71	2.01	11	1.90	0.147
Mar. 14-16	.80	.71	.35	.91	.86	.73	1.00	.89	.83	.90	5	.67	0.123
Mar. 20-22	.66	.83	.40	.95	.89	.90	1.02	.70	.85	.37[a]	6	.29	0.111
Apr. 27-30	1.10	.97	1.20	.97	1.30	1.47	1.45	1.59	1.30	1.32	6	1.21	0.199
May 4-6	.96	3.71	2.26	1.61	1.18	1.81	1.25	1.17	1.57	1.75	5	1.58	0.284
Nov. 21-23	1.83	2.10	1.97	1.63	1.77	1.98	2.26	1.86	1.99	1.61	12	1.45	0.149
Dec. 30-31	1.45	1.70	1.43	1.17	1.21	1.22	1.13	1.22	1.25	1.01	6	.76	0.157
1955													
Feb. 6-9	.96	1.15	1.27	1.30	1.39	1.22	1.14	1.32	1.21	1.30	11	1.15	0.097
Mar. 4-8	1.75	1.59	1.96	1.77	1.22	1.72	2.11	2.12	1.86	2.02	12	1.81	0.139
Mar. 22-24	1.58	1.78	2.12	1.80	1.87	1.67	1.96	1.90	1.88	1.88	14	1.51	0.108
June 8-11	2.22	2.39	2.66	2.44	2.51	2.46	2.63	2.56	2.53	2.80	14	2.62	0.169
June 12-13	1.26	1.25	2.15	2.88	2.20	1.49	1.02	1.13	1.61	2.11	8	2.02	0.193
Aug. 11-16	10.76	12.40	11.91	10.47	8.82	7.70	9.47	8.59	9.85	9.58	40	9.34	0.240
Aug. 17-23	3.77	5.06	5.75	4.61	4.84	4.38	3.72	4.44	4.39	5.57	19	5.21	0.216

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1946										
Dec. 21-23	1,530	640	--	--	--	--	--	640	1,370	0.47
1947										
Jan. 14-16	410	315	--	--	--	--	--	315	180	1.75
Jan. 20-22	990	350	--	--	--	--	--	350	700	.50
Mar. 13-16	1,590	1,890	--	--	--	--	--	1,890	1,450	1.30
Apr. 30-2	2,040	5,490	4,650	2.28	1.45	1.30	1.55	3,520	2,190	1.61
May 19-23	2,240	3,500	--	--	--	--	--	3,500	2,500	1.40
June 14-16	1,170	2,160	1,500	1.28	1.74	1.40	1.66	1,660	910	1.82
July 8-10	1,460	2,570	2,100	1.44	1.40	1.10	1.30	1,790	1,280	1.40
July 20	340	290	780	2.29	1.03	.82	.96	163	135	1.21
Aug. 17-19	510	510	880	1.72	1.18	.95	1.12	336	253	1.33
Nov. 4-6	3,300	12,700	4,500	1.36	2.19	2.20	2.55	11,700	4,540	2.68
Nov. 8-10	2,050	2,420	3,590	1.75	.74	.77	.89	2,040	2,200	.43
Nov. 11-13	1,410	1,420	1,980	1.40	.85	.89	1.07	1,400	1,210	1.16
Dec. 15-17	790	290	1,590	2.02	.34	.43	.50	282	500	.56
1948										
Jan. 1-4	3,460	4,600	3,800	1.10	.85	1.14	1.32	6,470	4,900	1.32
Mar. 27-29	470	200	630	1.34	.61	.65	.75	202	222	.91
Apr. 12-16	1,090	560	1,970	1.81	.43	.42	.48	432	820	.53
May 5-9	4,250	9,440	3,900	.92	1.45	1.28	1.47	9,780	6,700	1.46
May 13-15	1,480	1,250	1,900	1.28	.75	.65	.74	1,040	1,300	.80

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1948										
May 17-18	780	600	1,050	1.35	0.87	0.74	0.85	476	485	0.98
June 13-14	650	410	1,250	1.92	.65	.52	.59	254	365	.70
June 19-21	1,860	5,750	2,950	1.58	2.15	1.71	1.94	3,800	1,860	2.04
June 28-2	1,990	4,820	4 peaks	--	--	--	--	4,820	2,030	2.37
July 14-16	2,120	4,920	3,120	1.47	1.55	1.22	1.38	3,310	2,300	1.44
July 24-25	600	500	1,510	2.52	.80	.64	.72	274	324	.85
Sept. 9-12	4,880	14,600	5,350	1.10	1.68	1.40	1.57	12,700	8,230	1.54
Nov. 27-30	1,390	960	1,350	.97	.75	.87	.97	1,240	1,190	1.04
Dec. 29-2	6,190	7,500	5,060	.82	.95	1.27	1.41	12,400	11,900	1.04
1949										
Jan. 5-8	3,300	2,380	3,990	1.21	.47	.63	.70	3,200	4,500	0.71
Jan. 21-25	2,060	905	1,390	.67	.49	.66	.73	1,660	2,200	.76
Jan. 26-29	3,560	2,860	3,100	.87	.60	.80	.89	4,540	5,060	.90
Feb. 22-24	630	510	980	1.55	.98	1.21	1.34	540	350	1.54
Mar. 22-24	1,440	1,870	2,620	1.82	.99	1.07	1.18	1,590	1,250	1.27
Apr. 6-7	640	190	990	1.55	.35	.36	.40	168	355	.47
May 23-25	1,200	550	1,020	.85	.59	.49	.54	560	950	.59
July 13-15	1,450	1,400	2,240	1.55	.80	.63	.69	950	1,260	.75
Dec. 27-29	1,320	950	1,660	1.26	.72	.93	1.00	1,200	1,100	1.09
1950										
Feb. 14-16	2,370	1,470	1,450	.61	.73	.93	.99	2,770	2,700	1.03
Mar. 21-25	5,110	11,200	4,450	.87	1.45	1.58	1.68	14,700	8,900	1.65
May 18-20	1,530	1,360	2,200	1.44	.77	.74	.78	1,160	1,380	.84
May 24-25	420	160	520	1.24	.64	.53	.56	129	188	.69
June 4-6	310	194	400	1.29	1.24	1.01	1.06	149	117	1.27

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1950										
July 10-12	1,190	1,050	2,380	2.00	0.74	0.58	0.61	620	930	0.67
Aug. 3-5	2,770	7,410	4,760	1.72	1.65	1.32	1.38	4,830	3,420	1.41
Aug. 30-31	390	197	360	.92	1.11	.91	.95	190	167	1.14
Sept. 10-12	1,630	950	1,780	1.09	.60	.50	.52	840	1,520	.55
Sept. 15-17	460	370	620	1.35	1.27	1.07	1.12	291	214	1.36
Oct. 23-24	1,100	810	1,750	1.59	.72	.68	.71	650	830	.78
Nov. 4-6	330	320	600	1.82	1.52	1.53	1.59	254	130	1.95
Nov. 25-27	9,510	22,500	11,200	1.18	1.01	1.14	1.18	25,500	23,100	1.10
Dec. 4-6	1,600	1,100	2,370	1.48	.59	.71	.74	1,180	1,480	.80
Dec. 8-10	2,120	2,060	3,220	1.52	.72	.88	.91	2,180	2,300	.92
1951										
Jan. 14-17	3,290	5,400	4,140	1.26	1.13	1.52	1.16	5,230	4,490	1.16
Jan. 24-26	1,290	635	1,540	1.19	.53	.71	.73	840	1,050	.80
Feb. 1-3	1,290	630	1,770	1.37	.50	.66	.68	780	1,050	.74
Feb. 7-9	3,920	14,400	4,950	1.26	2.30	2.98	3.04	18,000	5,950	3.02
Feb. 21-23	2,160	4,540	2,650	1.23	1.77	2.20	2.25	5,520	2,350	2.35
Mar. 19-22	2,040	1,920	2,250	1.10	.85	.93	.95	2,170	2,190	.99
Mar. 30-31	690	450	840	1.22	.93	.98	1.00	465	400	1.16
Apr. 13-15	1,820	4,820	2,200	1.21	2.45	2.36	2.40	4,580	1,810	2.53
June 14-15	680	350	1,300	1.91	.59	.47	.48	218	390	.56
June 29-1	640	730	1,370	2.14	1.27	1.00	1.01	419	355	1.18
Aug. 20-21	780	850	1,580	2.03	1.14	.93	.93	512	485	1.05
Nov. 1-4	1,910	2,280	1,700	.89	1.31	1.29	1.29	2,640	1,950	1.35
Nov. 7-9	5,050	14,200	4,850	.96	1.87	1.89	1.89	16,200	8,800	1.84
Dec. 5-7	1,260	550	1,350	1.07	.53	.64	.64	710	1,010	.70
Dec. 19-23	6,880	6,240	6,000	.87	.57	.73	.72	9,650	14,000	.69

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1952										
Jan. 22-25	840	500	1,250	1.49	0.71	0.95	0.94	580	550	1.05
Jan. 26-30	3,900	3,020	2,000	.51	.85	1.13	1.12	6,610	5,900	1.12
Feb. 4-6	3,270	5,900	4,020	1.23	1.28	1.69	1.67	7,500	4,430	1.69
Mar. 5-6	680	250	820	1.21	.55	.65	.64	291	390	.75
Mar. 11-14	4,450	7,750	4,880	1.10	1.15	1.31	1.30	9,230	7,150	1.29
Mar. 19-21	1,700	1,160	2,500	1.47	.60	.66	.65	1,120	1,610	.70
Apr. 5-8	1,730	1,190	1,580	.91	.80	.81	.80	1,420	1,660	.86
Apr. 14-17	1,580	730	1,080	.68	.67	.64	.63	980	1,440	.68
Apr. 25-2	8,580	7,660	4,700	.55	.68	.62	.61	11,300	19,700	.57
May 11-13	1,150	1,230	1,650	1.43	1.15	.99	.97	970	890	1.09
May 20-21	440	250	650	1.48	.92	.78	.76	186	200	.93
May 25-28	5,450	5,880	4,600	.84	.72	.60	.59	5,660	9,820	.58
May 30-3	3,000	2,250	3,400	1.13	.60	.49	.48	1,910	3,900	.49
July 8-11	5,290	17,600	6,500	1.23	1.95	1.53	1.49	13,500	9,350	1.45
Aug. 8-10	790	1,010	1,850	2.34	1.29	1.03	1.00	560	496	1.13
Sept. 1-4	2,410	1,740	2,750	1.14	.64	.53	.51	1,460	2,800	.53
Sept. 19-20	430	370	1,090	2.53	1.13	.96	.93	214	192	1.11
Nov. 20-23	5,650	11,000	5,150	.91	1.33	1.49	1.43	14,400	10,300	1.40
Dec. 5-7	1,120	625	1,650	1.47	.61	.74	.71	670	860	.78
Dec. 11-12	4,000	4,760	5,000	1.25	.80	.99	.95	5,750	6,100	.94

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1953										
Jan. 9-12	6,050	4,860	3,600	0.60	0.68	0.92	0.88	9,850	11,500	0.86
Jan. 24-26	4,310	3,760	5,000	1.16	.61	.82	.78	5,160	6,900	.75
Feb. 15-16	1,130	505	1,900	1.68	.49	.63	.60	570	860	.66
Feb. 21-22	900	550	1,200	1.33	.80	1.00	.95	650	600	1.08
Mar. 4-5	1,680	1,260	1,800	1.07	.83	.87	.82	1,390	1,590	.87
Mar. 13-17	3,420	4,000	2,280	.67	1.22	1.36	1.29	6,210	4,800	1.29
Mar. 24-28	3,300	2,420	1,720	.52	.92	.99	.94	4,290	4,500	.95
Apr. 7-8	1,380	800	1,500	1.09	.68	.69	.65	830	1,170	.71
Apr. 13-15	1,330	670	1,300	1.02	.63	.61	.58	700	1,120	.62
Apr. 16-19	930	600	1,100	1.18	.88	.83	.78	560	640	.88
May 18	600	220	1,240	2.07	.45	.38	.36	137	323	.42
May 26-28	2,580	3,990	3,100	1.20	1.31	1.09	1.03	3,300	3,100	1.06
May 30-3	2,260	2,260	1,800	.80	1.17	.96	.90	2,350	2,520	.93
June 13-14	770	860	670	.87	1.99	1.58	1.49	820	478	1.71
June 23-24	600	328	1,310	2.18	.66	.53	.50	190	322	.59
July 9-11	270	210	250	.93	2.14	1.68	1.58	190	94	2.02
July 23-24	560	170	1,250	2.23	.37	.29	.27	93	292	.32
Sept. 5-7	200	131	725	3.62	1.10	1.00	.93	74	58	1.27
Oct. 29-31	990	1,400	1,240	1.25	1.90	1.85	1.72	1,340	700	1.91
Dec. 7-9	1,000	860	1,450	1.45	1.04	1.27	1.17	940	710	1.27
Dec. 10-12	860	600	1,420	1.65	.84	1.04	.96	610	570	1.07
Dec. 13-17	3,220	4,110	1,600	.50	1.69	2.11	1.95	8,610	4,350	1.98

Table 4.--Storm runoff and sediment data with adjustments for peakedness and season to reduce the scatter in the water-sediment relationship for Brandywine Creek at Wilmington, Del., 1947 to 1955

Date of runoff at Wilmington	Storm runoff (cfs-days)	Measured sediment (tons)	Peak runoff (cfs)	Peakedness factor	Time and peakedness adjusted ratio	Time, peakedness, and season adjusted ratio	Peakedness and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)
	1	2	3	4	5	6	7	8	9	10
1954										
Mar. 1-5	2,360	1,830	2,700	1.14	0.73	0.87	0.80	2,240	2,700	0.83
Mar. 14-16	500	176	460	.92	.78	.88	.80	232	244	.95
Mar. 20-22	700	154	950	1.36	.32	.35	.32	154	410	.38
Apr. 27-30	960	257	640	.67	.52	.47	.43	322	670	.48
May 4-6	1,740	4,900	3,230	1.85	2.36	2.07	1.87	3,360	1,700	1.97
Nov. 21-23	850	325	720	.85	.70	.78	.69	435	560	.78
Dec. 30-31	640	430	1,020	1.59	.98	1.29	1.14	479	356	1.35
1955										
Feb. 6-9	3,780	6,520	4,800	1.27	1.26	1.64	1.45	8,120	5,600	1.45
Mar. 4-6	2,260	1,050	--	--	--	--	--	1,050	2,510	.42
Mar. 22-24	2,670	3,780	2,940	1.10	1.35	1.47	1.29	4,260	3,270	1.30
June 8-11	1,050	1,070	1,400	1.33	1.33	1.08	.95	820	780	1.05
June 12-13	2,560	4,020	3,300	1.29	1.38	1.11	.98	3,120	3,070	1.02
Aug. 11-16	18,360	38,630	12,100	.66	1.12	.90	.78	44,500	64,000	.70
Aug. 17-23	13,170	14,180	17,050	1.29	.44	.36	.31	10,900	38,500	.28

Appendix A

The Trend of Suspended-Sediment Discharge by Use of Monthly Values of Direct Runoff of the Brandywine Creek at Wilmington, Del., 1947-1953

Water discharge and sediment data are shown in table 1a on a monthly basis. The direct runoff was determined by the Surface Water Branch and indicates only approximate monthly periods in order that a given storm will not be represented by data for two months. This direct runoff may consist of several storms for a given month and also represents a somewhat larger amount of flow than was previously determined for the storm runoff. Figure 1a illustrates the basic plot of these data and shows the sediment transport curve ($Y = 0.0307\ X^{1.61}$) from which the departure ratios (col. 4, table 1a) were computed. As in the body of the report, these departure ratios were plotted with time (fig. 2a) to determine the ratios for a minimum of scatter on plots correlating other parameters. The time plotting is inconclusive as a result of the small trend, if any, and the large standard error of the data during any single year.

Effect of rainfall intensity and season.--For these monthly data, a measure of rainfall intensity is given in column 10 of table 1a and was computed by $\frac{\Sigma (X)^2}{\Sigma X}$ where X is the daily rainfall at Coatesville. Figure 3a shows the plot relating the departure ratio (col. 4, table 1a) to this precipitation index. An approximate curve was sketched to these data on the basis of average departure ratios for several ranges of the precipitation index and used for adjusting the ratios (col. 5, table 1a) in consideration of this factor.

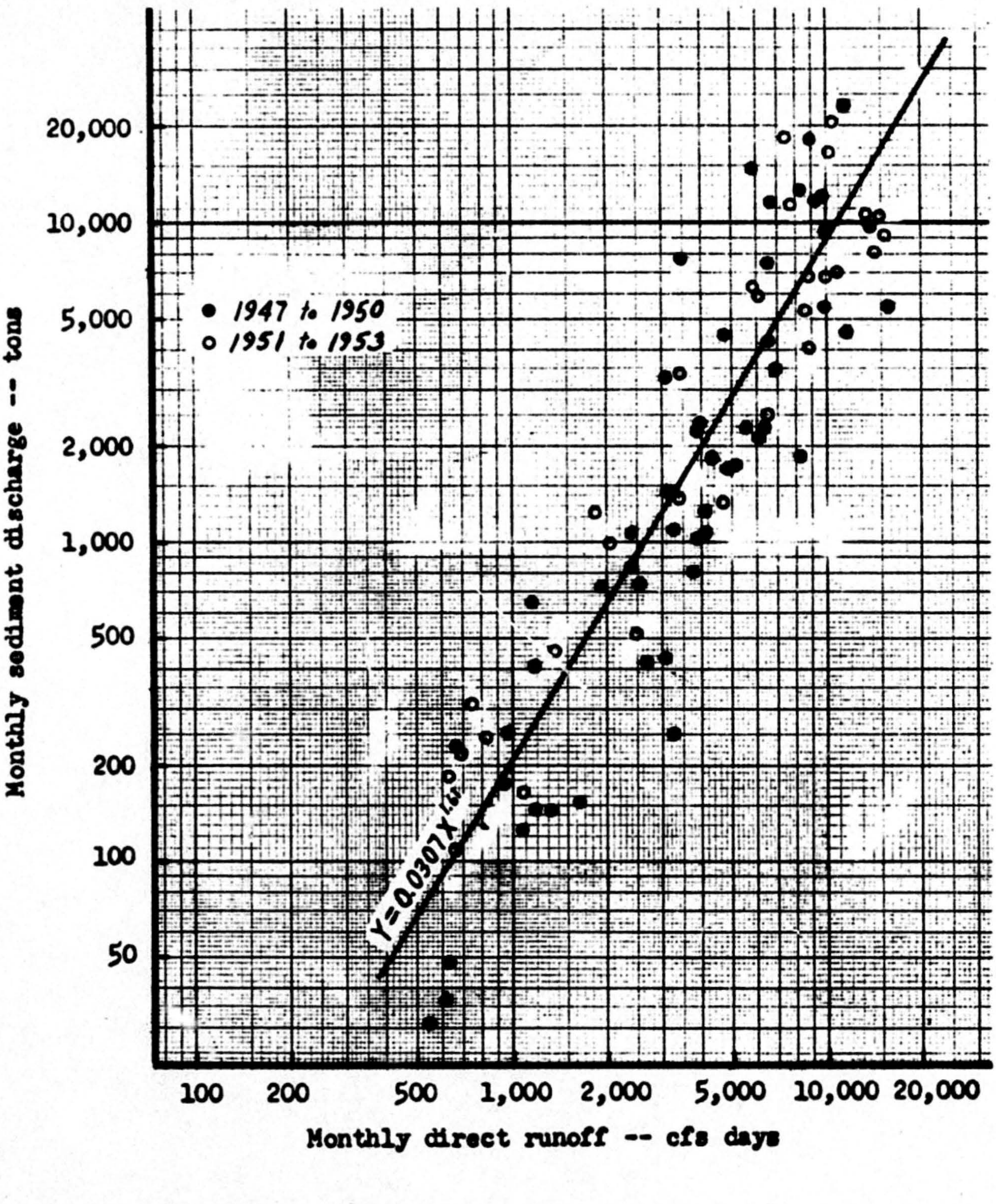

Figure 1a.--Sediment transport curve on a monthly direct runoff basis for Brandywine Creek at Wilmington, Del., January 1947 to September 1953

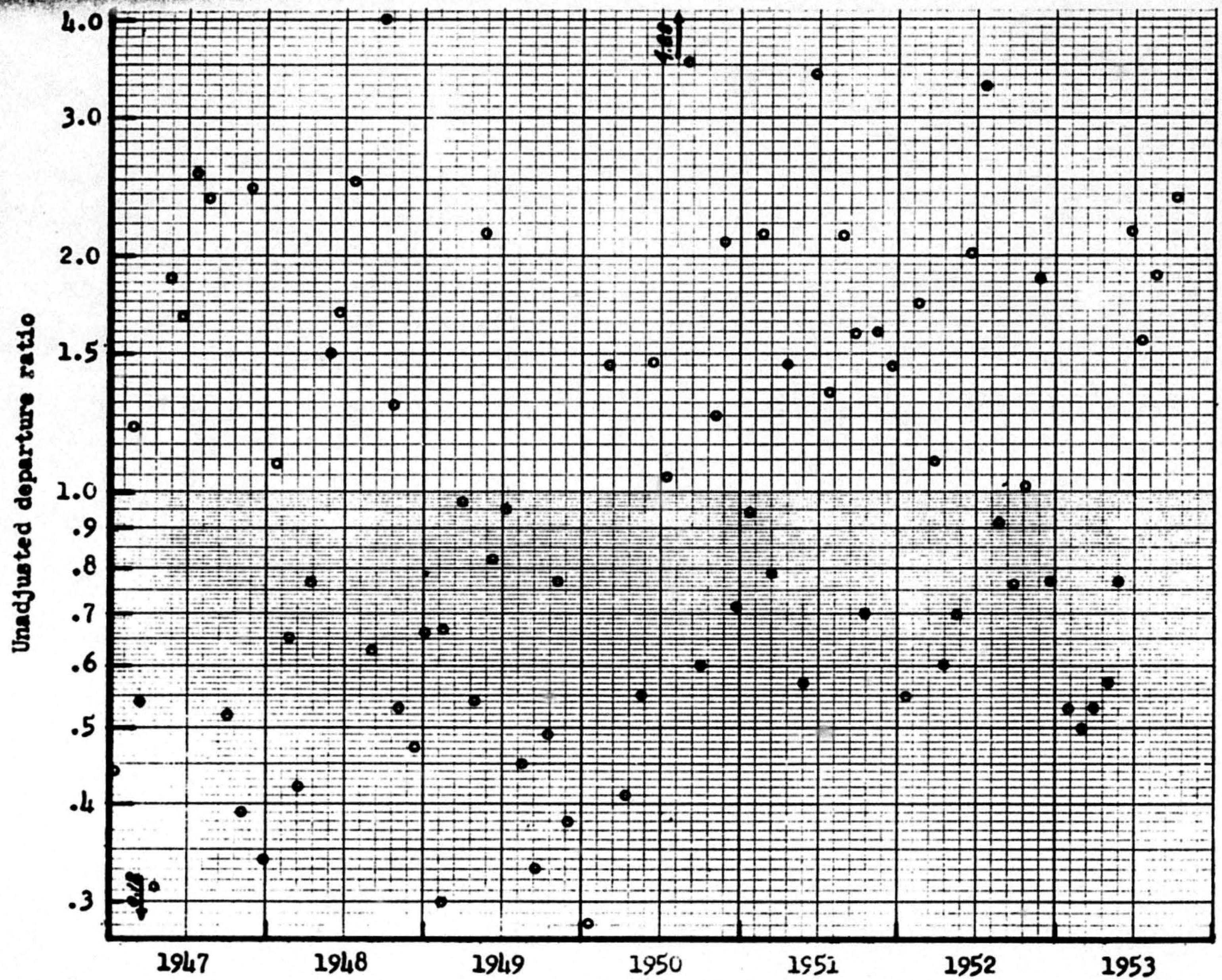

Figure 2a.--Test for determining approximate trend of sediment discharge to water discharge (unadjusted direct runoff), Brandywine Creek at Wilmington, Del.

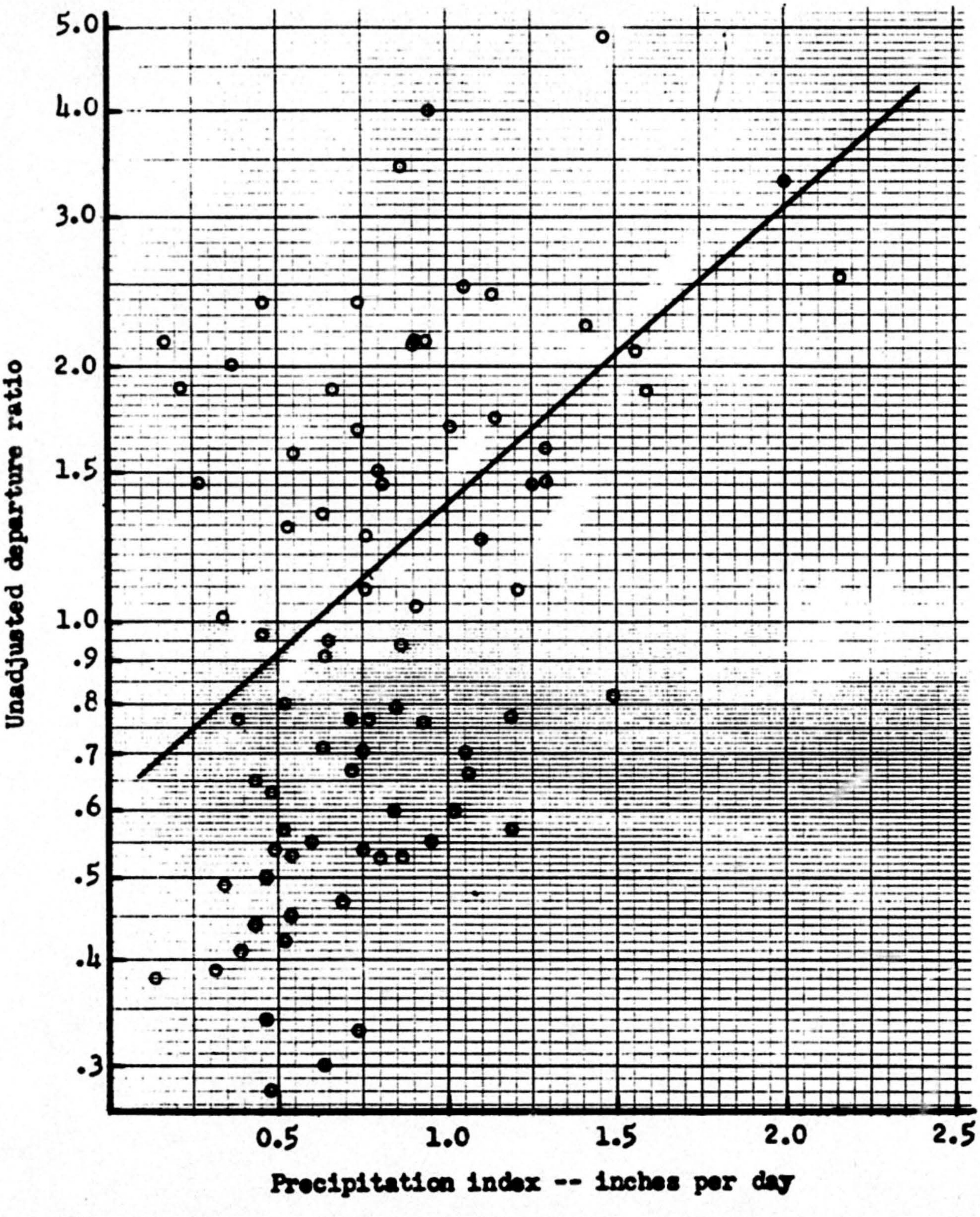

Figure 3a.--Rainfall intensity index adjustment to departure ratios (direct runoff basis) Brandywine Creek at Wilmington, Del.

The rainfall intensity adjusted ratios were then plotted against time of year as shown by figure 4a. An average curve fitting these points ranges from about 0.57 in late December and early January to about 1.57 in mid-July. On the basis of this, the adjusted departure ratios for rainfall intensity index and season are shown in column 6 of table 1a.

Evaluation of sediment yield trend.--Rainfall intensity and season are the only promising parameters for reducing the scatter of the sediment transport curve, and therefore, an evaluation of the sediment yield with time is in order. As in the report, the accumulative graph and rank correlation methods are used. The adjusted measured sediment (col. 7, table 1a) was computed from the rainfall intensity and season adjusted ratios and used for plotting the adjusted sediment transport curve of figure 5a. This curve ($Y = 0.0025 X^{1.62}$) has nearly the same slope as that of the unadjusted data but has shifted slightly to the right indicating a smaller sediment load for a given water discharge. The reason for this shift is not ascertained. The adjusted computed sediment as shown by this rating is tabulated (col. 8, table 1a) and is used to compute adjusted departure ratios.

The accumulative graph of figure 6a is a plot of the accumulated adjusted computed sediment (col. 8) against the accumulated adjusted measured sediment (col. 7). The plot is probably too irregular for an accurate evaluation of sediment yield trend. If only the first 1-1/2 years and the last 2-1/2 years of this record are considered, we might conclude that a considerable reduction in sediment yield is indicated by the 48 percent change in slope of the graph for these two periods. However, considering the graph as a whole, the large differences in trends for different periods

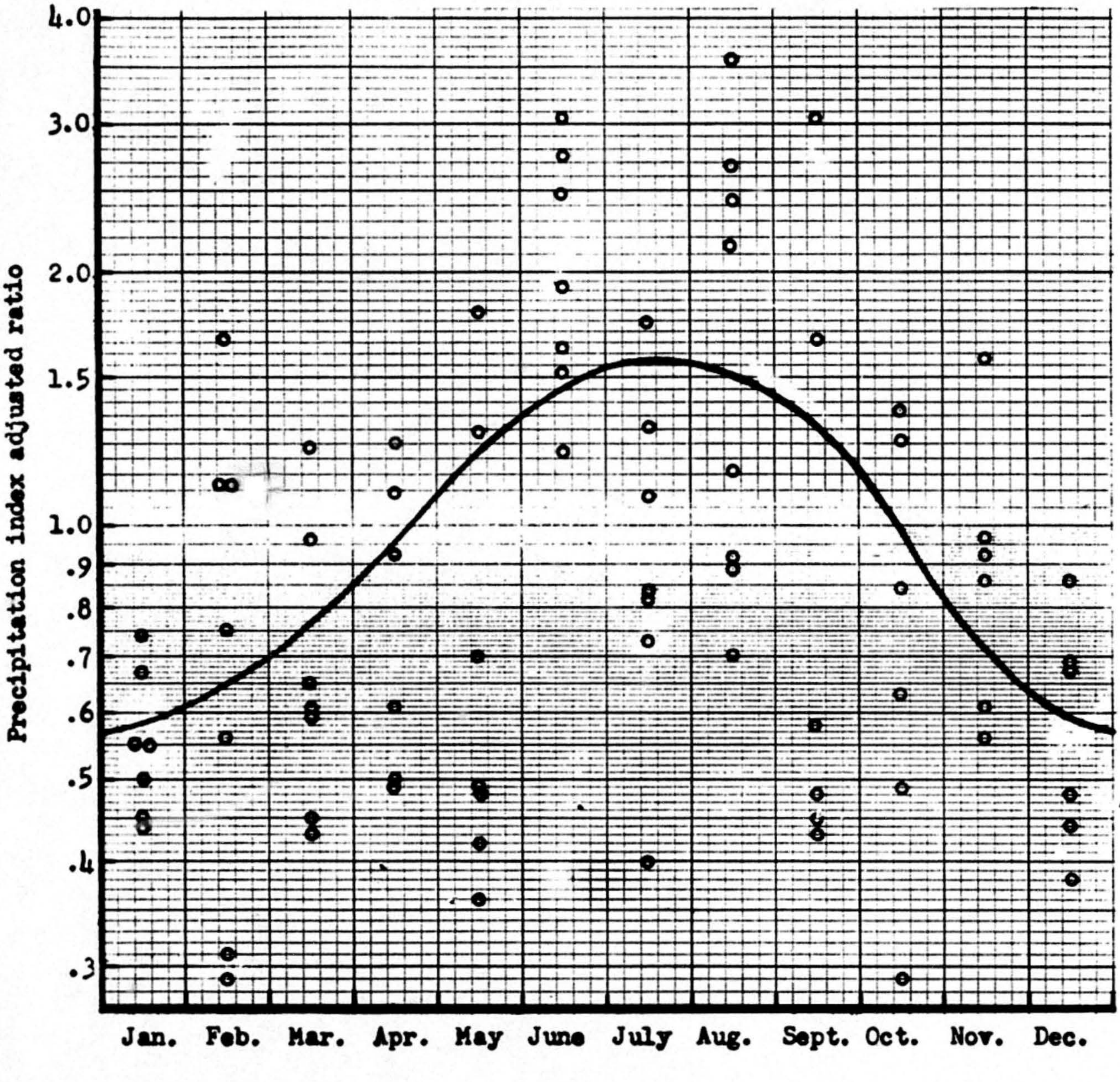

Figure 4a.--Seasonal adjustment to rainfall intensity adjusted departure ratios (direct runoff basis) Brandywine Creek at Wilmington, Del.

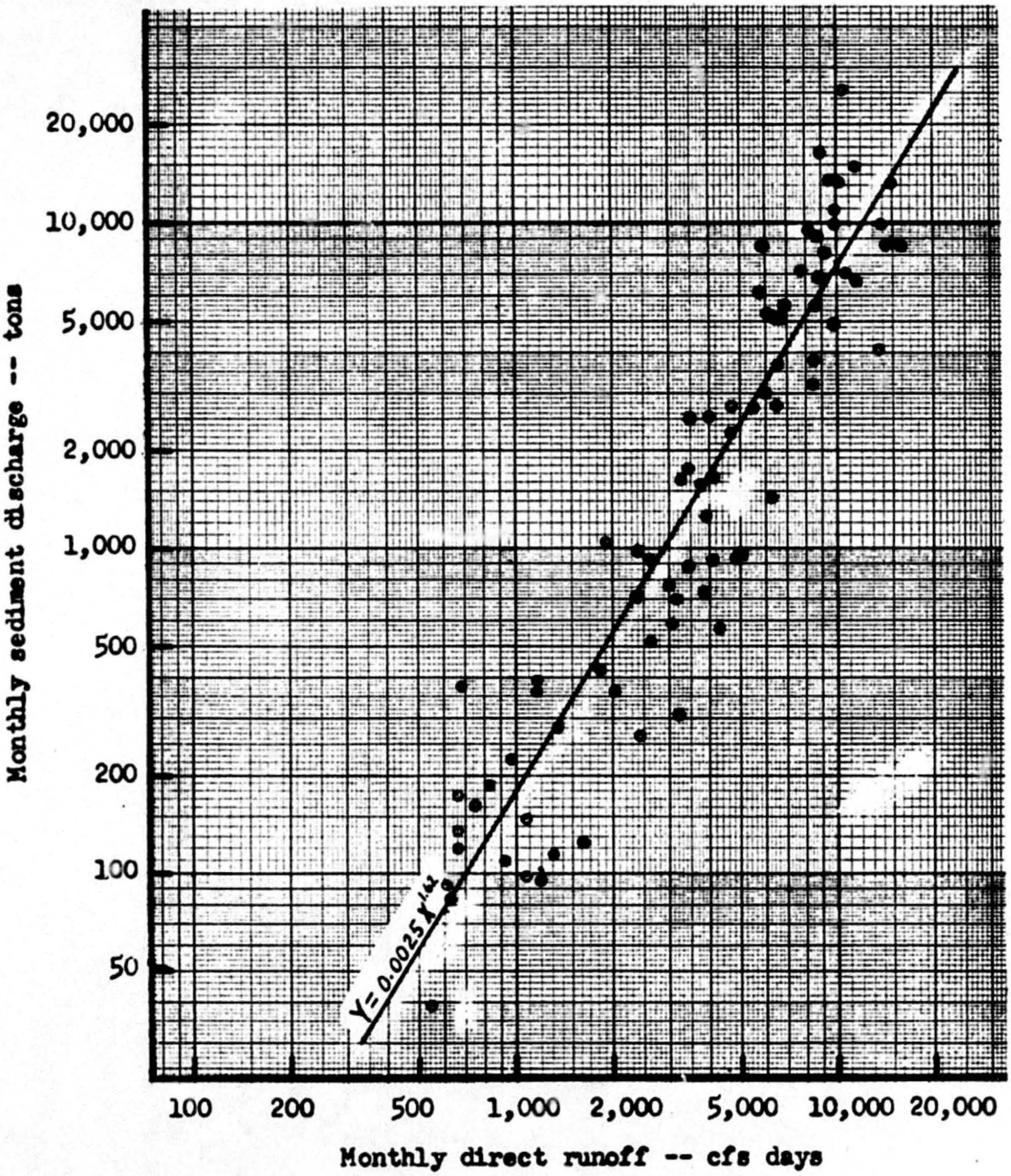

Figure 5a.--Adjusted (rainfall intensity and season) sediment transport curve on a monthly direct runoff basis for Brandywine Creek at Wilmington, Del., January 1947 to September 1953

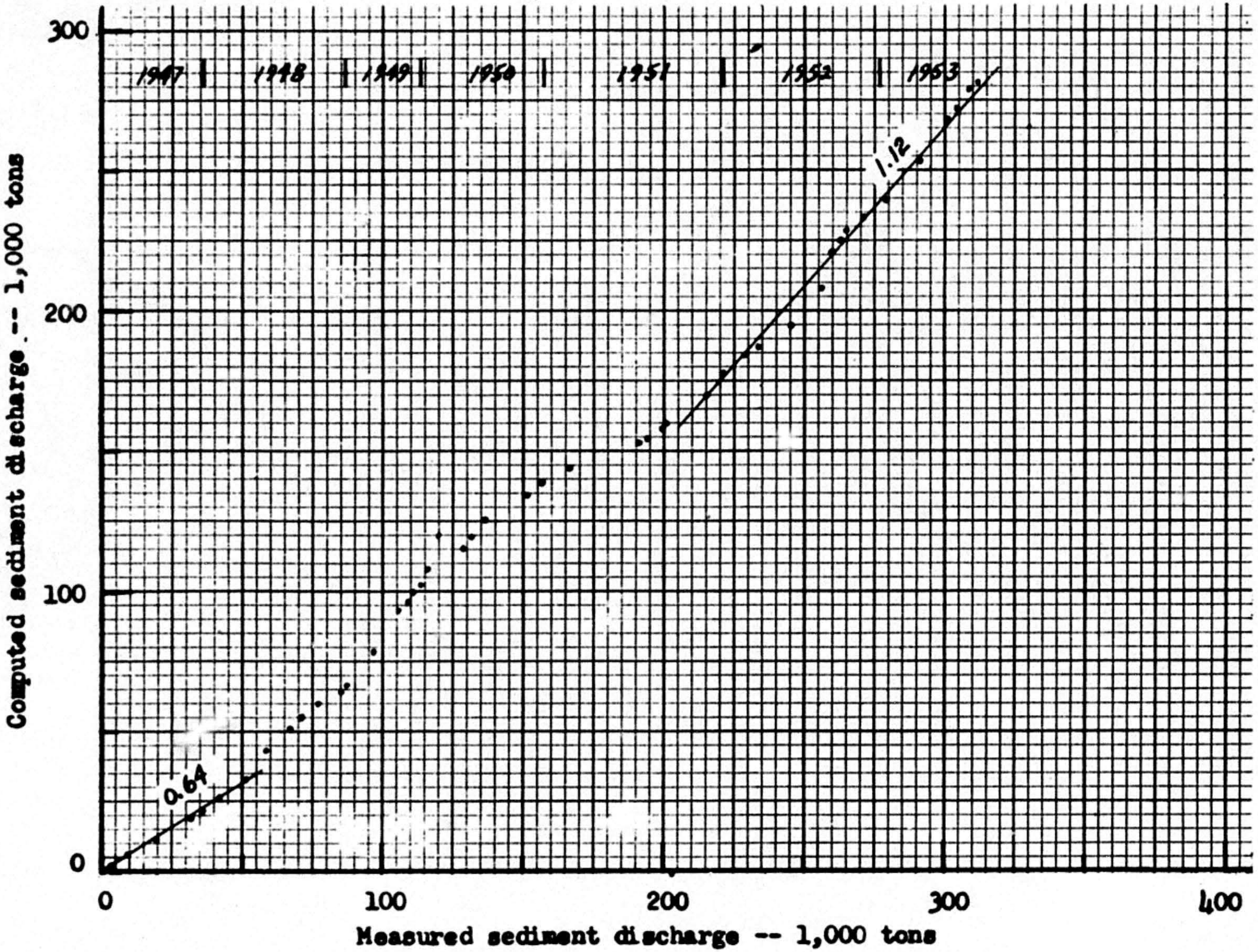

Figure 6a.--Accumulative measured vs. computed sediment discharge adjusted for rainfall intensity and season, Brandywine Creek at Wilmington, Del.

of time would tend to imply that these data are biased by some parameter that cannot be evaluated.

Computations for rank correlation coefficient (see appendix B) using the adjusted departure ratios of column 9, table 10, result in a coefficient τ = +0.015 which is so close to 0 that there is no significant decreasing trend of departure ratios or sediment yield with time. This computation supports the conclusions determined from the evaluation by the accumulative graph method.

Table 1a.--Direct runoff and sediment data on a monthly basis for Brandywine Creek at Wilmington, Del., 1947 to 1953

Month	Direct runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed	Rainfall intensity adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)	Precipitation intensity index (inches per day)
	1	2	3	4	5	6	7	8	9	10
1947 Jan.	3,790	803	1,810	0.44	0.50	0.86	1,560	1,500	1.04	0.427
Feb.	1,910	729	600	1.21	1.12	1.73	1,040	480	2.17	.761
Mar.	6,020	2,120	3,900	.54	.59	.77	3,000	3,150	.95	.491
Apr.	3,230	250	1,400	.18	.21	.22	308	1,150	.27	.400
May	8,340	12,400	6,600	1.88	1.79	1.46	9,640	5,450	1.77	.668
June	4,770	4,410	2,620	1.68	1.52	1.04	2,720	2,200	1.24	.741
July	3,070	3,280	1,290	2.54	.73	.46	590	1,040	.57	2.17
Aug.	1,180	646	272	2.38	2.15	1.42	390	218	1.79	.739
Sept.	1,200	146	279	.52	.45	.34	95	220	.43	.800
Oct.	546	31	79	.39	.49	.49	39	80	.49	.329
Nov.	8,920	18,000	7,400	2.43	1.58	2.20	16,300	6,050	2.70	1.13
Dec.	3,020	432	1,270	.34	.38	.64	770	1,030	.75	.471
1948 Jan.	6,540	4,830	4,420	1.09	.67	1.15	5,080	3,700	1.37	1.21
Feb.	9,810	5,500	8,500	.65	.75	1.17	9,950	7,200	1.38	.429
Mar.	11,600	4,650	11,200	.42	.45	.59	6,610	9,500	.70	.523
Apr.	2,560	742	960	.77	.92	.96	920	790	1.16	.383
May	9,230	11,700	7,800	1.50	1.28	1.05	8,190	6,500	1.26	.797
June	6,580	7,460	4,400	1.70	1.22	.84	3,700	4,600	.80	1.01
July	6,740	11,600	4,650	2.49	1.74	1.10	5,120	3,850	1.33	1.05
Aug.	4,040	1,260	2,000	.63	.70	.46	920	1,710	.54	.485
Sept.	5,890	14,800	3,700	4.00	3.03	2.29	8,480	3,100	2.74	.949
Oct.	977	259	200	1.29	1.37	1.37	224	160	1.40	.532
Nov.	1,090	126	240	.53	.56	.78	98	190	.61	.539
Dec.	4,180	1,040	2,230	.47	.44	.74	1,650	1,740	.95	.691

Table 1a.--Direct runoff and sediment data on a monthly basis for Brandywine Creek at Wilmington, Del., 1947 to 1953

Month	Direct runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed	Rainfall intensity adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment (tons)	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)	Precipitation intensity index (inches per day)
	1	2	3	4	5	6	7	8	9	10
1951 Jan.	8,800	6,790	7,200	0.94	0.74	1.27	9,150	6,000	1.52	0.861
Feb.	10,500	20,700	9,700	2.13	1.67	2.58	25,000	8,100	3.09	.896
Mar.	4,000	2,360	2,980	.79	.65	.85	2,530	1,640	1.54	.847
Apr.	6,090	5,850	4,000	1.46	1.25	1.31	5,240	3,300	1.59	.801
May	2,500	520	920	.57	.36	.29	267	730	.37	1.18
June	4,930	1,710	500	3.42	2.75	1.88	940	2,320	.40	.871
July	1,360	455	340	1.34	1.31	.83	282	280	1.00	.627
Aug.	1,840	1,240	560	2.22	1.16	.76	425	460	.92	1.41
Sept.	823	241	152	1.59	1.66	1.24	188	121	1.55	.554
Oct.	1,080	165	236	.70	.63	.63	149	190	.78	.746
Nov.	10,100	16,600	10,400	1.60	.92	1.28	13,300	7,700	1.73	1.29
Dec.	10,800	6,960	4,820	1.45	.86	1.46	7,030	8,400	.84	1.25
1952 Jan.	8,870	4,030	7,300	.55	.55	.94	6,860	6,050	1.13	.596
Feb.	5,760	6,180	3,550	1.74	1.12	1.73	6,140	3,000	2.05	1.14
Mar.	9,960	9,460	8,700	1.09	.96	1.25	10,900	7,400	1.47	.764
Apr.	14,800	10,100	16,800	.60	.50	.52	8,740	14,000	.62	.839
May	13,700	10,200	14,500	.70	.49	.40	4,080	12,400	.33	1.05
June	683	223	111	2.01	2.48	1.69	377	89	4.23	.368
July	7,450	18,000	5,450	3.30	1.08	.69	3,760	4,600	.82	2.00
Aug.	3,390	1,370	1,500	.91	.89	.58	870	1,230	.71	.635
Sept.	3,930	2,230	2,930	.76	.58	.43	1,260	1,600	.79	.927
Oct.	664	109	107	1.02	1.26	1.26	135	85	1.59	.337
Nov.	7,820	11,100	5,980	1.86	.86	1.20	7,180	5,000	1.43	1.59
Dec.	8,580	5,340	6,900	.77	.48	.81	5,590	5,700	.98	1.18

Table 1a.--Direct runoff and sediment data on a monthly basis for Brandywine Creek at Wilmington, Del., 1947 to 1953

	Month	Direct runoff (cfs-days)	Measured sediment (tons)	Computed sediment from rating (tons)	Ratio measured to computed	Rainfall intensity adjusted ratio	Rainfall intensity and season adjusted ratio	Adjusted measured sediment	Adjusted computed sediment from rating (tons)	Ratio measured to computed sediment (adjusted)	Precipitation intensity index (inches per day)
		1	2	3	4	5	6	7	8	9	10
1953	Jan.	15,000	9,050	17,000	0.53	0.45	0.77	13,100	14,100	0.93	0.800
	Feb.	4,710	1,300	2,600	.50	.56	.87	2,260	2,160	1.05	.466
	Mar.	14,200	8,070	15,300	.53	.43	.56	8,570	13,000	.66	.872
	Apr.	6,480	2,490	4,380	.57	.61	.64	2,800	3,700	.76	.516
	May	9,950	6,730	8,700	.77	.70	.57	4,960	7,400	.67	.718
	June	3,460	3,380	1,570	2.15	1.63	1.12	1,760	1,300	1.35	.935
	July	2,050	991	680	1.46	.84	.53	361	540	.67	1.29
	Aug.	631	184	98	1.88	2.58	1.76	173	77	2.25	.221
	Sept.	749	310	130	2.38	2.69	1.25	162	101	1.60	.462

Appendix B

Rank Correlation Methods 1/

When data are arranged in an order according to some quality which they all possess to a varying degree, they are said to be <u>ranked</u>. If each member of an arrangement has a <u>rank</u>, then the whole is called a <u>ranking</u>. Variate-values (quantities which vary from one member of a population to another) can always be replaced by a ranking according to their position on a scale. The ranking may be regarded as less accurate than the ordered relation of the members because it does not indicate how close the various members are on the scale. It may be said, however, that what the ranking loses in accuracy it gains in generality because it is invariant under stretching of the variate scale. Rank correlation methods are particularly useful when variate-values cannot be measured but have some sort of relative measure with respect to each other. An example is the hardness of a set of mineral specimens when the relative hardness is determined by the ability of one specimen to scratch another.

<u>Computation of τ</u>.--Some examples will be used to illustrate how to compute the coefficient and to indicate characteristics of the ranking method. The following is a ranking of the mean annual concentration of storm runoff for the Brandywine Creek at Wilmington, Del., for the

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1/ Kendall, M. G., 1948. Rank correlation methods: London, Charles Griffin and Company, Ltd.

years 1947 to 1954. We are interested in whether there is any relationship

Year	Mean storm concentration (ppm) (1)	Chronological rank (2)	Magnitude order (3)	Magnitude rank (4)	No. remaining > given rank (P) (5)	No. remaining < given rank (Q) (6)
1947	690	1	690	1	7	0
1948	658	2	658	2	6	0
1949	227	3	639	5	3	2
1950	614	4	614	4	3	1
1951	639	5	491	6	2	1
1952	491	6	386	8	0	2
1953	334	7	334	7	0	1
1954	386	8	227	3	0	0
					21	7

of changing concentration with time. A glance at the data (column 1) indicates some possible trend of decreasing concentration. Column 3 is a rearrangement of the data in decreasing order and is used to make the determination of the magnitude rank (column 4) easier. For example, the third magnitude order of 639 has the 5th rank chronologically. We can see that if columns 2 and 4 were in identical order, then the correlation would be perfect. Let such a coefficient = +1. If column 4 were in perfect reverse order of column 2, then the correlation coefficient should = -1.

The intensity of rank correlation is $\tau(\text{tau}) = \dfrac{P - Q}{\frac{1}{2}n(n-1)}$, where n is the number of pairs of comparisons, P is the number of positive scores, and Q is the number of negative scores. From two rankings of n, it is logical that 1/2n(n-1) is the maximum number of pairs of comparisons which can be made and equals the number of ways of choosing two things from n. A perfect ranking where τ = +1, then results in 1/2n(n-1) = P when Q = 0; and, an inverse perfect ranking where τ = -1, results in 1/2n(n-1) = Q when P = 0. In this example, 1/2n(n-1) = 28, P = 21 (scored by the number of entries remaining in column 4 greater than the given number of column 4), and Q = 7 (number remaining less than given number), then the correlation coefficient, $\tau = \frac{21 - 7}{28} = 0.50$. Since P + Q = 1/2n(n-1), and therefore Q = 1/2n(n-1) - P, Q may be computed directly, making column 6 in the above table unnecessary. Proof of the above relationships are demonstrated by Kendall, M. G., p. 17-24 of the above reference.

<u>Computation of ρ</u>.--Many statisticians prefer another coefficient of rank correlation denoted by ρ (rho) and named after C. Spearman. Data from the above table through the first four columns may be used to demonstrate the method of computation. The differences <u>d</u> between the two ranks (columns 4 and 2) are determined as 0, 0, -2, 0, -1, -2, 0, and +5 and should equal 0. These differences are then squared and summed, $\Sigma(d^2)$, 0, 0, 4, 0, 1, 4, 0, and 25 = 34. Spearman's ρ is then defined by the equation

$$\rho = 1 - \frac{6\,\Sigma(d^2)}{n^3 - n}$$

In this example,

$$\rho = 1 - \frac{6\,(34)}{8^3 - 8} = 1 - \frac{204}{504} = 0.596.$$

When the two rankings are identical all differences <u>d</u> are zero and it follows that $\rho = +1$. The proof that when one ranking is the reverse of the other, $\rho = -1$, is more complicated and will not be shown here.

The reader must not expect to find that the numerical values of τ and ρ to be the same for any given pair of rankings, except when there is complete agreement or disagreement. In addition to the above example where $\tau = 0.50$ and $\rho = 0.60$, the following illustrate the sort of differences between τ and ρ which arise in practice:

Example	A	B	C	D	E
τ	+0.11	+0.56	-0.24	+0.02	+0.67
ρ	+0.14	+0.64	-0.37	+0.03	+0.83

The coefficients have, in fact, scales as different as scales of Centigrade and Fahrenheit thermometers.

Tests of significance.--The important value of any correlation analysis is not to determine a numerical measure of the agreement between the rankings, but should determine to what degree can we conclude that there exists correlation in the population from which the sample was chosen. A relatively small correlation coefficient from a large number of samples is likely to be more significant than a large coefficient from a small number of samples.

Suppose that in a given population there is no relationship between the two quantities under consideration, then for a sample chosen at random, any order for the quality A is just as likely to appear with a given order for B as any other A-order. If we choose some arbitrary order for B (such as chronological ranking), then all the $n!$ possible rankings of the numbers 1 to n for A are equally probable. Each accordingly has the probability $1/n!$. To each of the possible arrangements of the A-ranking there will correspond a value of τ. The $n!$ number of these values may be classified according to the actual value of τ in a frequency-distribution that tends toward the normal curve, $f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{x^2}{2\sigma^2}}$

The parameter σ of the curve, which is equal to its standard deviation, is given by $\sigma^2 = \frac{1}{18} n(n-1)(2n+5)$.

With the simplicity of computing σ and with the distribution for the normal curve given in tables, it is relatively easy to test the significance of either τ or the quantity P-Q, one being a multiple of the other.

If there is no qualitative connection between samplings, a pair of rankings chosen at random will give some value of P-Q lying between the limits $\pm 1/2n(n-1)$. As indicated by the normal curve, most such values will cluster around the value zero. If the observed value of P-Q lies in the "tails" of the distribution of P-Q away from the mean value we shall reject the hypothesis that the two qualities in the rankings are independent. In the example given herein where $\tau = 0.50$, P-Q = 14, n = 8, and σ is computed to be 8.08, then the area under the normal curve corresponding to the deviate $\frac{14}{8.08} = 1.73$ is 0.0836 (total area under the curve is unity). This area 0.08+ is considered to be too great (0.05 is generally the upper limit) to say that the two rankings were independent of each other; i.e., the correlation as determined from the sample is insignificant. Theoretically, P-Q in the above computation should be corrected by -1; then the area included would be 0.1074 and insignificance of τ is even greater.

To avoid the need for continual reference to a table of the normal distribution and to simplify the determination of the level of significance for rank correlation coefficients of $\pm\tau$, figure 1b was constructed to show the lower limit of τ for a given number of samples or ranks and level of significance. In reference to the example used herein with 8 samples or ranks, τ would have to be at least 0.60 to be significant at the 0.05 level. Table 1b contains the values for the lower limit of $\pm\tau$ at several values of n at the 0.01, 0.02, 0.05, and 0.10 levels of significance from which figure 1b was drawn.

The standard deviation of the distribution of ρ is given by the simple form

$$\sigma^2 = \frac{1}{n-1} \quad .$$

The distribution of $\Sigma(d^2)$ as a frequency polygon fits closely the curve

$$f(t) = \frac{k}{\left(1 + \frac{t^2}{n-2}\right)^{\frac{1}{2}(n-1)}}$$

which may be rewritten in approximate form as

$$t = \rho\sqrt{\frac{n-2}{1-\rho^2}} \quad \text{or} \quad \rho = \frac{t}{\sqrt{t^2+n-2}}$$

and may be used to test the significance of ρ . Again tables are needed to show the areas under the curve for various values of t. To avoid the need for such a table and the need for computation, figure 2b was constructed to show the lower limit of $\pm\rho$ for a given number of samples or ranks and level of significance. The graph shows that ρ should be 0.71 for significance at the 0.05 level for the 8-rank example used herein. With t = 2.447 for 6 degrees of freedom (n-2) at the 0.05 level of significance, substitution in the above formula yields

$$\rho = \frac{2.447}{\sqrt{2.447^2 + 6}} = \frac{2.447}{\sqrt{11.99}} = 0.708 \quad .$$

which agrees with figure 2b and shows that ρ = 0.60 is probably insignificent, i.e., there is considerable chance that the two rankings are not independent of each other. Table 2b contains the values for the lower limit of ρ at several values of n at the 0.01, 0.02, 0.05, and 0.10 levels of significance from which figure 2b was drawn.

Additional example.--To further demonstrate the computational procedures of rank correlation, a computation involving some Brandywine Creek basin data (table 1 and page 37) will be used. Table 3b contains departure ratios (column 1) for 109 storms in chronological order (column 2). Column 3 contains the magnitude order ranging from 3.11 to 0.44. The magnitude rank of each ratio may then be determined by inspection as in column 4. The first magnitude rank, for example, is 108 because the magnitude order of 3.11 is ranked 108 in the list of ratios shown by column 1. The determination of positive scores (P) of column 5, or the number remaining in column 4 > the given rank, is relatively simple, yet considerable time is involved with this large number of items. Then, the total of column 5 is P = 3.375, $1/2n(n-1) = \frac{109}{2}(108) = 5,886$, Q = 5,886-3,375 = 2,511, and $\tau = \frac{3,375-2,511}{5,886} = 0.147$. Entering figure 1b at n = 109, it is noted that 0.147 is close to the 0.02 level of significance and indicates that there is only a small chance that the ranking of these ratios are independent of each other. In other words, the coefficient of 0.147 is great enough for a ranking of this number to indicate with very little reservation that the ratios occur naturally in decreasing magnitude with time. This cannot be said of the example used as the initial demonstration in this appendix where n = 8 and τ = 0.50.

Extra columns in table 3b are not shown for the computation of ρ. The method involves the determination of the difference d between each rank of column 2 and 4 and squaring. The sum of these squares, $\Sigma(d^2)$ = 168,930 and $\rho = 1 - \frac{6\Sigma(d^2)}{n^3 - n} = 1 - \frac{6(168,930)}{109^3 - 109} = 1 - 0.784 = 0.216$. On figure 2b, the coefficient ρ = 0.216 is close to the 0.02 level of significance for this ranking of 109 members. Then, as logically may be expected, ρ = 0.216 has the same significance as determined for τ = 0.147.

Table 1b.--Lower limit of τ (tau) for given number of samples and level of significance.

$$\tau = \frac{P - Q}{\frac{1}{2}n(n-1)}$$

n	Level of significance			
	0.01	0.02	0.05	0.10
5	--	--	0.900	0.770
6	.960	.893	.760	.654
7	.862	.786	.667	.571
8	.779	.707	.600	.511
9	.711	.647	.550	.467
10	.660	.600	.509	.432
11	.618	.562	.476	.404
12	.583	.530	.448	.379
13	.553	.503	.424	.359
15	.504	.457	.387	.327
17	.466	.423	.357	.301
20	.422	.383	.323	.273
25	.370	.337	.283	.239
30	.333	.301	.255	.215
35	.306	.277	.234	.197
40	.284	.258	.217	.183
50	.252	.228	.192	.162
60	.228	.207	.174	.147
70	.210	.191	.160	.135
80	.196	.178	.150	.126
100	.175	.158	.133	.112
125	.155	.141	.119	.098
150	.141	.128	.108	.092
200	.122	.111	.093	.078
300	.099	.090	.076	.064
500	.077	.070	.059	.049

Table 2b.--Lower limit of ρ (rho) for given degrees of freedom and level of significance.

$$\rho = 1 - \frac{6 \Sigma (d^2)}{n^3 - n} \quad ; \quad d.f. = n-2$$

d.f.	Level of significance			
	0.01	0.02	0.05	0.10
2	0.990	0.979	0.950	0.900
3	.958	.935	.879	.805
4	.918	.882	.811	.729
5	.874	.833	.754	.669
6	.834	.789	.707	.622
7	.797	.749	.666	.582
8	.765	.715	.632	.549
9	.734	.685	.602	.527
10	.708	.658	.575	.497
11	.683	.633	.553	.476
12	.661	.612	.533	.458
13	.641	.592	.513	.441
15	.605	.557	.483	.412
17	.575	.528	.455	.389
20	.537	.492	.423	.360
25	.487	.445	.381	.324
30	.448	.409	.349	.296
35	.418	.380	.324	.274
40	.393	.358	.304	.256
50	.354	.322	.273	.230
60	.325	.295	.250	.212
70	.302	.274	.232	.196
80	.283	.257	.217	.183
100	.254	.231	.195	.164
125	.228	.207	.174	.147
150	.208	.189	.159	.134
200	.181	.164	.139	.117
300	.148	.135	.113	.095
500	.115	.104	.088	.074

Table 3b.--Test by the rank correlation method for change in rate of sediment yield with time.

Ratio	Chronological rank	Magnitude order	Magnitude rank	No. remaining > given rank (P)
1	2	3	4	5
0.62	1	3.11	108	1
1.72	2	2.41	64	44
.61	3	2.41	61	46
1.35	4	2.31	60	46
1.98	5	2.01	12	93
1.11	6	1.98	5	99
1.44	7	1.78	53	52
1.31	8	1.72	2	100
1.01	9	1.61	66	42
1.02	10	1.59	35	68
1.03	11	1.54	68	40
2.01	12	1.50	23	78
1.49	13	1.49	13	87
1.43	14	1.47	38	64
.67	15	1.47	16	83
1.47	16	1.44	7	89
.87	17	1.44	105	3
.81	18	1.43	14	83
1.23	19	1.38	36	64
.70	20	1.35	4	87
1.14	21	1.34	24	74
.85	22	1.34	27	71
1.50	23	1.31	8	83
1.34	24	1.30	69	38
1.19	25	1.28	91	16
.83	26	1.27	43	56
1.34	27	1.25	56	44
1.06	28	1.23	19	72
.59	29	1.21	63	39
1.01	30	1.20	74	32
.67	31	1.19	25	66
.78	32	1.14	21	67
.54	33	1.12	107	1
.84	34	1.12	46	49
1.59	35	1.11	6	72
1.38	36	1.11	57	40
.57	37	1.08	72	32
1.47	38	1.06	28	60
.59	39	1.05	41	50
.57	40	1.05	97	9
1.05	41	1.05	101	5
.71	42	1.04	76	27
1.27	43	1.04	85	18
.71	44	1.03	11	61
.65	45	1.02	10	61
1.12	46	1.01	9	61
.54	47	1.01	30	53
1.01	48	1.01	48	41
.57	49	1.01	54	36
.50	50	1.01	88	15
.92	51	1.00	67	29
.84	52	.99	82	19
1.78	53	.99	103	3
1.01	54	.97	55	31
.97	55	.96	81	18

Ratio	Chronological order	Magnitude order	Magnitude rank	No. remaining > given rank (P)
1	2	3	4	5
1.25	56	.96	86	15
1.11	57	.94	89	13
.78	58	.93	62	25
.77	59	.92	51	28
2.31	60	.92	109	0
2.41	61	.91	90	11
.93	62	.87	93	9
1.21	63	.87	17	43
2.41	64	.87	99	4
.68	65	.86	96	5
1.61	66	.85	22	38
1.00	67	.85	102	2
1.54	68	.84	34	31
1.30	69	.84	52	21
.69	70	.83	95	4
.47	71	.83	26	33
1.08	72	.81	18	34
.79	73	.81	94	4
1.20	74	.79	73	13
.71	75	.78	32	28
1.04	76	.78	58	17
.72	77	.77	59	16
.64	78	.76	100	2
.67	79	.74	92	3
.50	80	.72	77	9
.96	81	.71	44	17
.99	82	.71	75	9
.46	83	.71	42	16
.44	84	.70	20	22
1.04	85	.69	70	10
.96	86	.68	65	10
.49	87	.67	15	20
1.01	88	.67	31	18
.94	89	.67	79	7
.91	90	.65	45	12
1.28	91	.64	78	7
.74	92	.63	104	1
.87	93	.62	1	16
.81	94	.61	3	15
.83	95	.60	106	0
.86	96	.59	29	13
1.05	97	.59	39	10
.59	98	.59	98	0
.87	99	.57	37	9
.76	100	.57	40	8
1.05	101	.57	49	6
.85	102	.54	33	7
.99	103	.54	47	6
.63	104	.50	80	3
1.44	105	.50	50	4
.60	106	.49	87	0
1.12	107	.47	71	2
3.11	108	.46	83	1
.92	109	.44	84	0
				P = 3,375

$\frac{1}{2}n(n-1) = \frac{109}{2}(108) = 5,886$

$Q = 5,886 - 3,375 = 2,511$

$\tau = \frac{P - Q}{\frac{1}{2}n(n-1)} = \frac{3,375 - 2,511}{5886} = \underline{0.147}$

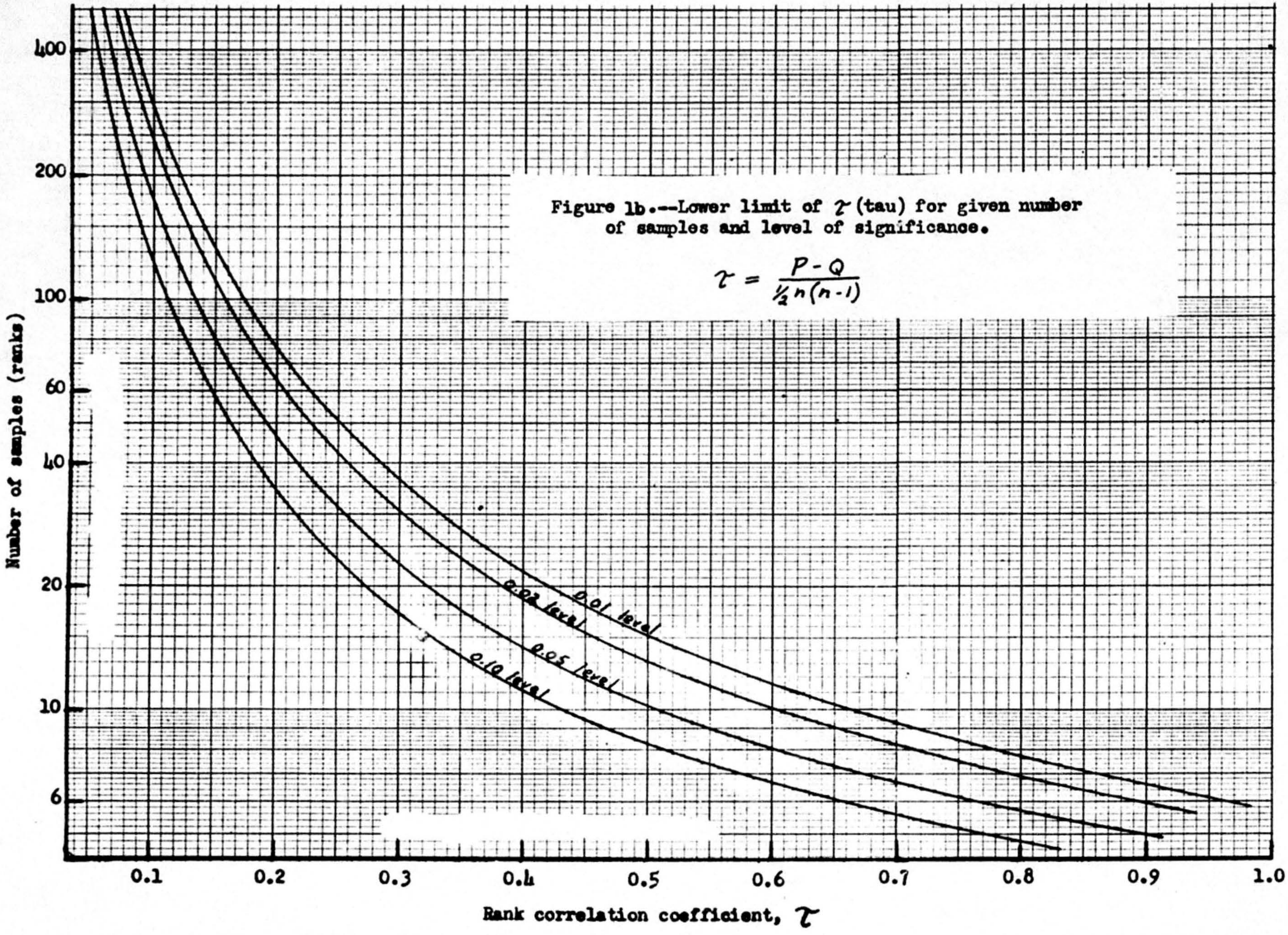

Figure 1b.--Lower limit of τ (tau) for given number of samples and level of significance.

$$\tau = \frac{P - Q}{\frac{1}{2} n(n-1)}$$

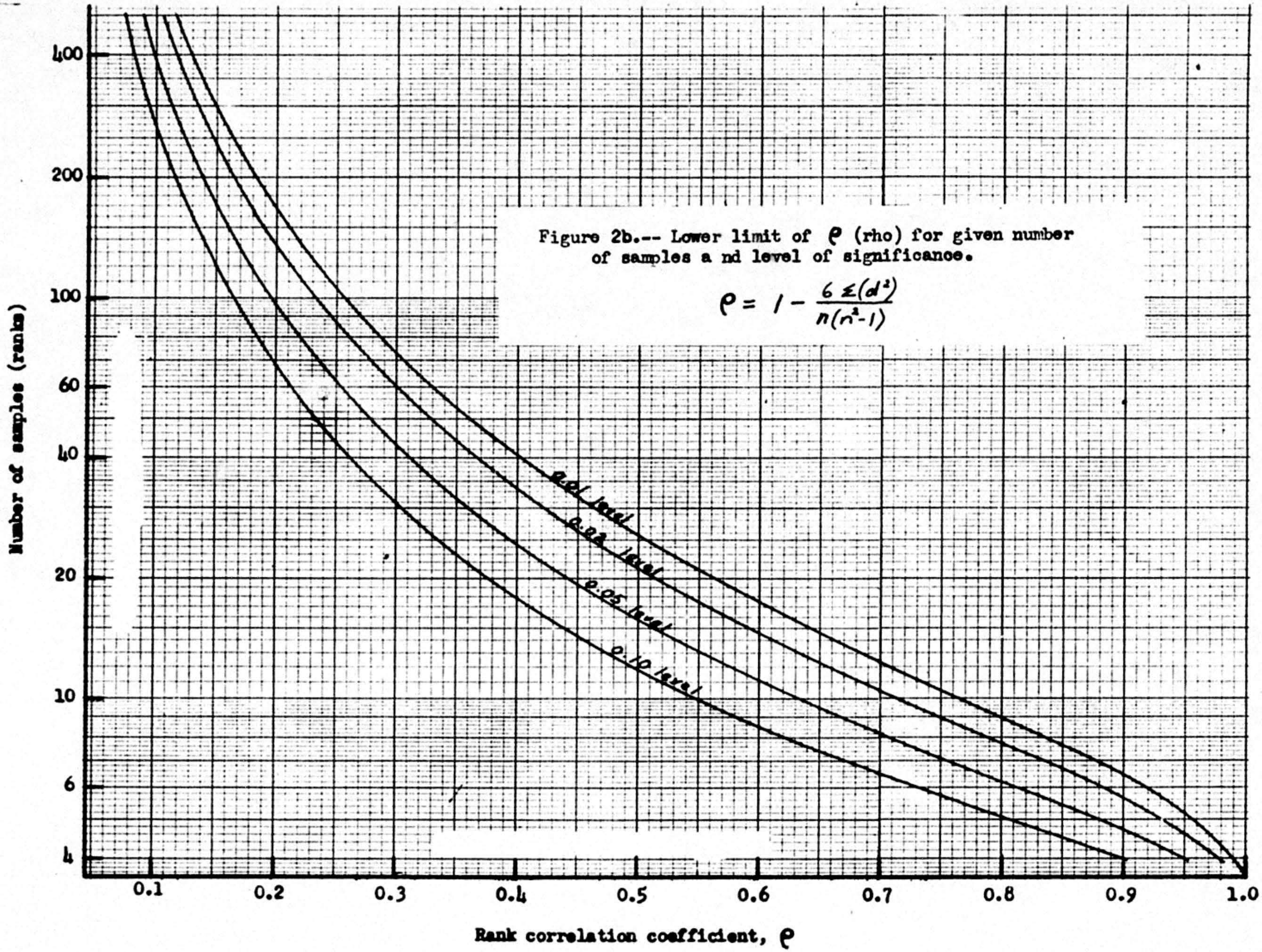

Figure 2b.-- Lower limit of ρ (rho) for given number of samples a nd level of significance.

$$\rho = 1 - \frac{6\,\Sigma(d^2)}{n(n^2-1)}$$