VARIATIONS IN RUNOFF AND SEDIMENT YIELDS OF TWO ADJACENT WATERSHEDS AS INFLUENCED BY HYDROLOGIC AND PHYSICAL CHARACTERISTICS 1/

by

Andrew J. Bowie and Gerald C. Bolton 2/

ABSTRACT

Runoff, sediment, and supplemental information have been evaluated for two adjacent watersheds in the Pigeon Roost Creek basin in north Mississippi. Data for a 14-year period of record (water years 1958-1971) show the percent of runoff and sediment yield in tons per acre to be consistently in the ratio of 2 to 1. Weighted precipitation during the period varied only slightly, with maximum amounts alternating between the two watersheds. Intensive surveys were made of the land use, topography, soils, and geology of both watersheds. The results of these surveys show that differences in the geology and soils account for most of the difference in runoff from the two watersheds.

INTRODUCTION

Many hydrologic models have been developed during recent years in an attempt to describe the various flow processes. Many of the models have been designed to include several degrees of freedom that can be manipulated to produce a correct mathematical answer when applied to historical data. Often, however, the watershed parameters must vary between unreasonable limits for these models to fit observed data closely. This manipulation implies that a model is being used outside the range of conditions for which its basic assumptions are valid or that it is based on incorrect assumptions altogether. Unfortunately, because measurements of all the relevant parameters are either inadequate or nonexistent, very few actual field tests have been made to determine the range of applicability of most of these models.

1/ A contribution from the USDA Sedimentation Laboratory, Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service, U. S. Department of Agriculture, Oxford, Mississippi in cooperation with the Mississippi Agricultural Experiment Station and the University of Mississippi.

2/ Research Hydraulic Engineer and Mathematician, respectively, USDA Sedimentation Laboratory, Oxford, Mississippi.

Only intensive field study can determine the limitations that must be imposed or actual range of values assigned to various parameters. However, if the hydrologic studies conducted in a research watershed are to provide useful results, the findings must be quantitatively transferable to similar watersheds. To do this, the relationships of watershed physical characteristics and land use to water resource must be established. Only when these watershed characteristics are included in the relationships will it be possible to reconcile such diverse findings as to the difference in runoff and sediment yields of two adjacent watersheds, when for all apparent purposes the two watersheds are almost identical.

The purpose of this report is to examine two such watersheds and evaluate certain known parameters that influence runoff and sediment yields.

EXPERIMENTAL AREA AND INSTALLATIONS

The study area consists of two adjacent watersheds in the upper portion of the Pigeon Roost Creek basin in north Mississippi. These two watersheds are part of a 117-square-mile experimental watershed where erosion processes, sediment transport, and factors affecting stream channel equilibrium are being studied. The two watersheds are joined by a common boundary of approximately 1.0 mile and are shown in Figure 1 as numbers 4 and 5. Both watersheds were instrumented for measuring runoff and sediment in November 1956.

The standard instrumentation at each of the two gaging sites consists of a Stevens continuous water level recorder, type A-35, installed in a wooden shelter over a 24-inch corrugated iron pipe well. Footbridges constructed across the stream channels at selected cross sections are used to support a traversable streamflow sampler. The gaging stations are located in defined channels at the lower end of each watershed. (1) (2) [3/]

One of the primary considerations in instrumenting the watersheds for runoff and sediment yield investigations was to establish a rain gage network that would adequately describe precipitation events. The actual selection of rainfall gaging sites in the watersheds was determined to a large extent by accessibility to remote areas. Four recording rain gages were placed on Watersheds 4 and 5 between November 21 and December 26, 1956 (3).

The primary objectives of the studies conducted in the two watersheds are as follows:

1. To relate measured sediment yield to calculated gross erosion and to watershed characteristics and conditions.

2. To establish methods and procedures for predicting the effects

---

3/ Numbers in parentheses refer to appended references.

of conservation and flood control programs on sediment delivery and yields.

WATERSHED CHARACTERISTICS

Topography

The watersheds are located in the North Central Hills region of the East Gulf Coast physiographic section of the Coastal Plain Province. When the runoff and sediment yield studies were begun in 1956, the drainage area for Watershed 4 was established as 3.13 sq. miles and for Watershed 5 as 1.76 sq. miles. Later changes in instrumentation required relocation of the streamflow gaging stations and resulted in adjusted drainage areas of 2.47 sq. miles for Watershed 4 and 1.56 sq. miles for Watershed 5. The original boundaries of the watersheds are shown in Figure 2 as solid lines with the adjusted area as short dash lines. All data referred to in this report are relative, with adjustments made only for changes in the drainage area.

Both watersheds consist of rather narrow flat flood plains with natural channels and rolling severely dissected interfluvial areas. The major flood plain in Watershed 4 is approximately 2.0 miles long and 0.15 mile wide; that in Watershed 5 is 0.8 mile long and 0.08 mile wide. The channels have few straight reaches, and most have banks that scour easily. The average channel width-depth ratio ranges from 3:1 at Gaging Station 4 to 2:1 at Gaging Station 5. The average channel bed elevation at Gaging Station 4 is approximately 1.0 foot higher than the channel bed elevation at Gaging Station 5.

The compactness coefficient, which is the ratio of watershed perimeter to that of a circle of equal area, was determined by:

$$C = P/2\sqrt{\pi M}$$

where, C = compactness coefficient
P = perimeter of the watershed (miles)
M = watershed area (sq. miles)

The drainage density was determined by:

$$D = \Sigma L/A$$

where, D = drainage density (mi/mi^2)
ΣL = combined length of all stream channels (mi)
A = area of watershed (mi^2)

The mean slope for the watersheds was determined by:

$$S = d \cdot \Sigma c/A$$

where S = mean slope for the entire watershed
d = contour interval (ft.)
Σc = total length of all contours, combined (ft.)
A = watershed area (ft.^{2})

Similarly, the average slope of the main channel streams was computed by:

$$S_s = (\Sigma f/\Sigma w)\ 100$$

where S_s = average stream slope (ft./ft.)
f = elevation of slope line at the source, minus elevation at mouth
w = horizontal distance measured along the thalweg.

The calculated values for the above geomorphologic factors, plus relative erodibility, are listed in Table 1 for both watersheds. The only significant difference in the geomorphologic factors is the drainage density; Watershed 5 has 0.46 mile per square mile less drainage density than Watershed 4.

The percentages of each watershed having the various slope ranges are as follows:

Watershed	< 2%	2-12%	12-30%
4	11	41	48
5	5	67	28

Geology

Three major geological formations--Kosciusko, Tallahatta, and Meridian--are present in Watersheds 4 and 5 (4). All three formations are of the Claiborne group of Eocene age. Their texture is predominantly sands with local clay lenses. About 64 percent of the surface area of Watershed 4 is occupied by the Kosciusko formation, 29 percent by the Tallahatta formation, and 7 percent is valley alluvial material. In Watershed 5, 88 percent of the surface area is occupied by the Kosciusko formation, 10 percent by the Tallahatta formation, and only 2 percent is valley alluvial material.

The Meridian formation underlies the entire area of both watersheds and ranges in thickness from 180 to 200 feet. There are no surface outcrops of this formation within the watershed boundaries.

The Kosciusko formation is the youngest of the Claiborne group. This formation ranges in thickness from a few feet to 120 feet and outcrops at the higher elevations. There are some perched groundwater bodies within this formation. Generally, the Kosciusko has a low permeability because clay is more evenly disseminated throughout the formation.

The Tallahatta formation outcrops at the lower watershed elevations and lies between the Kosciusko and Meridian formations. Perched groundwater bodies of various depths and lateral extent occur throughout the formation. The clay lenses range from a few inches to several feet thick. The total thickness of the Tallahatta ranges from 120 to 150 feet.

Soils

The soils of the watersheds are composed of loess and coastal plain material. These soils have been classified by external and internal characteristics according to series and type (Table 2). The principal series include the upland soils--Cahaba, Providence, Lexington, Loring and Memphis, and the bottomland soil--Cascilla. The three principal soil types within the series are fine sandy loam, sandy loam, and silt loam.

Soil properties that influence runoff can be represented by a hydrologic parameter: the minimum rate of infiltration obtained for a bare soil after prolonged wetting. This parameter is the qualitative basis of the classification of soils into four major hydrologic soil groups (5). There are two hydrologic soil groups in Watersheds 4 and 5. The two groups are:

"B. Mostly sandy soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse texture. These soils have a moderate rate of water transmission."

"C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission."

The proportionate extent of the hydrologic groups is:

Watershed	Hydrologic Soils Group B Coaster Plain (Sandy) Material	Hydrologic Soils Group C Loess (Silty) Material
4	72 percent	28 percent
5	44 percent	56 percent

HYDROLOGIC DATA COMPARISONS

The locations of the four recording rain gages within the study area are shown in Figure 2. Precipitation for each of the watersheds was computed by the Thiessen-weighted method. Approximately 120 storms occur each year. High-intensity thunderstorms occur most frequently during the summer months. Winter storms characteristically have moderate rainfall intensities but relatively large total volumes. On the average, only 30 to 50 storm events each year produce runoff sufficient for hydrograph analysis.

Annual weighted precipitation during the period of record varied only slightly, with maximum amounts alternating between the two watersheds (Table 3). Figure 3 shows that Watershed 5 had 693.4 inches of total accumulated rainfall compared to 681.6 inches for Watershed 4.

Generally accepted methods and procedures were used to measure flow and to obtain sediment samples at each of the gaging stations; i.e., standard Geologic Survey procedures were used for velocity measurements, and the depth-integration method was used to collect samples of the water sediment mixture. Runoff for the study watersheds was determined from continuous water-stage information and current meter measurements. Stage-discharge relationships for the sand-bed streams were revised as needed to reflect changes in the stream cross section.

In all cases, flow data were obtained in a manner to give representative concentrations of the total sediment in transport. A comparison of the discharge weighted concentration is shown in Figure 4. The annual weighted concentration alternated between the watersheds, with higher concentrations for seven out of fourteen years for Watershed 5. Two years were computed with almost equal values. The maximum deviation from equal value was 1040 p.p.m.

Annual runoff and sediment yields, were consistently higher for Watershed 5 (Table 3). A comparison of the accumulated runoff and sediment yield is shown in Figures 5 and 6. As would be expected from the difference in annual yield, the accumulated yield is considerably higher for Watershed 5 than Watershed 4. The total accumulated runoff and sediment yield for Watershed 5 exceeded those for Watershed 4 by 84.2 inches, and approximately 25,000 tons, respectively.

RESULTS AND DISCUSSION

Table 3 shows the 14-year direct runoff yield for Watershed 5 was more than double that for Watershed 4. The average runoff for Watershed 5 is 22.3 percent compared to 10.6 percent for Watershed 4. The average measured sediment yields for the two areas are in the same ratio, with 6.70 tons per acre per year for Watershed 5 and 3.13 tons per acre per year for Watershed 4. This means that the stream sediment concentrations for both watersheds are very similar as indicated by Figure 4.

A comparison of the watershed characteristics and hydrological data indicates that certain parameters and hydrological factors within the two watersheds are almost identical or with insignificant variances--namely precipitation, compactness coefficient, average slope of streams, land slope, slope length, and relative erodibility. It is not intended to imply that these variables do not affect runoff. On the contrary, there are many instances where one or a combination of the above parameters could become very influential in the response of a watershed to runoff. However, those parameters are not considered as contributing to the difference in runoff between the two study watersheds. Although Watershed 4 has a greater drainage density than Watershed 5, it is not considered a major contributing factor.

Cover conditions as influenced by land use patterns can play an important role in determining the long-term runoff potential of any watershed. Some of the difference in runoff in the study area can probably be attributed to differences in land use and cover; however, this difference is considered to be minor. The degree of cover on an annual basis has been fairly consistent, with each watershed averaging approximately 78 percent (Table 4). The most important change during the period of record was the reduction of cultivated land in Watershed 4 from 23 to 13 percent of the total area. The percentage of cultivated land in Watershed 5 remained fairly constant.

The watersheds do differ considerably in geology and soils. A relatively impermeable clay lense underlies the valley fill in Watershed 5 (4). A clay seal is also present beneath Watershed 4 but does not appear to be continuous. There is a smaller percentage of recent deposits or valley fill in Watershed 5, a higher percentage of the Kosciusko formation, and a smaller percentage of the exposed Tallahatta formation. Compared with the Tallahatta, the Kosciusko has a lower permeability due to a more even dissemination of clay throughout the formation.

The main channel bed in Watershed 4 is underlain with alluvium in the gage reach to a depth of approximately 20 feet. The water table has not been close to the surface within recent years, although there is evidence from water levels in the recorder gage well that it was within 1 or 2 feet of the surface of the stream during periods of high rainfall. The ground water table in Watershed 5 intersects the streambed of the main channel and major tributaries at several points in the channel reach. Consequently, the channel bed remains wet, even during periods of prolonged drouth, and responds rapidly to runoff.

The response of the channels to direct runoff is indicated in the double mass plot shown in Figure 5. A break in the trend occurs at the end of wet and dry years. The average weighted precipitation for the period of record for the study area is 49.1 inches. The break away from the equal value line occurs at the end of dry years and in the direction of the watershed with the wet channel. This implies that in dry years, the water levels drop, resulting in increased channel transmission losses in Watershed 4 relative to Watershed 5.

Loess soil cover in both watersheds ranges from 0 to about 10 feet deep. In many places the surface cover has been completely eroded because of poor farming and land management practices. When classified into the hydrologic soil groups, Watershed 4 has a higher percentage of the better drained Group B sandy materials and a lower percentage of the Group C fine texture silty material. The wider alluvial bottoms of Watershed 4 are surrounded by diversion ditches dug in deep sandy material. The alluvial bottoms of Watershed 5 are narrow and confined to the lower reaches and are not protected by diversions.

SUMMARY AND CONCLUSIONS

Analysis of the runoff data for a 14-year period for two adjacent watersheds in north Mississippi show the runoff and sediment yields to be consistently in the ratio of 2 to 1. The Thiessen-weighted precipitation during the period varied only slightly. A comparison of the watershed characteristics and hydrological data show the precipitation, compactness coefficient, average slope of streams, land slope, slope length, and relative erodibility of the two watersheds to be very similar. Although there is some difference in the drainage density, it is not considered a major contributing factor.

The land use pattern in both watersheds varied only slightly. The degree of cover on an annual basis was fairly consistent with, each watershed averaging approximately 78 percent cover. We believe that any change in land use was more than offset by the uniformity of ground cover.

An evaluation of the geology and soils factors, however, revealed considerable difference in the characteristics of each. Compared with Watershed 4, there is a smaller percentage of recent deposits or valley alluvium, a higher percentage of the less permeable Kosciusko formation, and a smaller percentage of the more permeable exposed Tallahatta formation in Watershed 5. The ground water table intersects the streambed of the main channel in Watershed 5, but remains several feet below the channel bed in Watershed 4. When classified into the hydrologic soil groups, Watershed 4 has a higher percentage of the better drained Group B sandy materials and a lower percentage of the Group C fine texture silty material.

The studies indicate that the geology and soils factors are the major contributors to the difference in runoff between the two watersheds. The degree to which each factor contributes to this difference, however, would be most difficult to ascertain.

REFERENCES

1. Miller, C. R. and A. J. Bowie. 1965. Sediment sampling: Instrumentation and Techniques. Transactions of the ASAE, Vol. 8, No. 2, pp. 267-274.

2. Bowie, A. J. and others. 1971. Direct Measurements and Computations of Total Sediment Discharge. Presented at the annual meeting ASAE, Pullman, Washington. Paper No. 71-259. To be published in Transactions of the ASAE.

3. Bowie, A. J. 1971. Agricultural Research Service Precipitation Facilities and Related Studies. ARS 41-176, Chapter 6, pp. 43-50.

4. Asmussen, L. E. and F. E. Dendy. 1963. A Report on Geological and Ground-Water Investigations in Pigeon Roost Creek Watershed, Marshall County, Mississippi. Southeastern Geolgoy, Vol. 5, No.1.

5. SCS National Engineering Handbook, Section 4. 1964. Hydrology, Part I - Watershed Planning. Chapter 7, pp. 7.1 - 7.5.

Table 1.--Geomorphologic Factors.

Watershed Number	Drainage Area (sq. mile)	Compactness Coefficient	Drainage Density (mi./mi.^{2}) 1/	Mean Slope (ft./ft.)	Mean Length of Slope (feet)	Relative Erodibility 2/ 3/	Relief Ratio (ft./ft.)	Average Slope of Streams (ft./ft.)
4	2.47	1.26	1.60	0.104	224	0.39	0.013	0.0046
5	1.56	1.36	1.14	0.090	224	0.37	0.009	0.0047

1/ Drainage density for each watershed computed only for main channel and primary tributaries.

2/ These are area-weighted mean values.

3/ Relative erodibility is the K factor (soil-erodibility factor) in the universal soil-loss prediction equation.

Table 2.--Classification and characteristics of soils-watersheds 4 and 5, Pigeon Roost Creek Basin

Series and Type (Slope Range)	Percent of Area		Internal Drainage	Permeability	Surface Runoff
	Watershed 4	Watershed 5			
Cahaba complex-fine sandy loam (12-30% slope)	48	28	Well	Moderate	Moderate
Providence silt loam (5-12% slope)	17	11	Moderate well	Moderate	Moderate
Lexington silt loam (2-12% slope)	5	5	Well	Moderate	Moderate
Calloway silt loam (2-5% slope)	0	0.7	Poorly drained	Slow	Slow
Grenada silt loam (5-8% slope)	0	2	Moderate well	Moderate to slow	Moderate
Loring silt loam (2-12% slope)	14	34	Moderate well	Moderate to Moderate slow	Moderate
Memphis silt loam (2-8% slope)	5	14	Well	Moderate	Moderate
Henry silt loam (0-2% slope)	0.3	0.3	Poorly drained	Slow	Slow to Very slow
Ochlockee sandy loam (0-2% slope)	0.7	0	Well drained	Moderate to rapid	Slow
Cascilla silt loam (0-2% slope)	5	5	Well drained	Moderate	Slow
Vicksburg silt loam (0-2% slope)	5	0	Well drained	Moderate	Slow

Table 3.--Summary of precipitation, runoff, and sediment yields for Watersheds 4 and 5, Pigeon Roost Creek Basin.

WATER YEAR	WEIGHTED RAINFALL (INCHES) 1/		RUNOFF (PERCENT)		SEDIMENT YIELD (T/A/Y)	
	Watershed 4	Watershed 5	Watershed 4	Watershed 5	Watershed 4	Watershed 5
1958	60.02	57.05	10.11	20.09	4.13	6.66
1959	42.14	42.19	6.55	16.16	2.43	5.31
1960	41.97	42.03	7.41	16.92	1.39	4.08
1961	48.81	48.72	8.48	19.44	2.41	5.87
1962	59.13	60.75	14.46	24.77	5.58	8.37
1963	35.00	36.18	3.66	9.45	1.08	2.38
1964	53.72	55.00	13.03	25.95	4.83	9.86
1965	49.73	53.77	18.74	33.62	5.50	10.35
1966	34.96	35.43	7.32	19.28	1.56	4.45
1967	45.34	47.80	8.67	20.25	2.46	6.99
1968	52.85	53.97	11.79	23.03	2.60	6.71
1969	60.13	60.25	16.81	31.68	4.99	10.51
1970	53.40	53.01	12.88	32.41	2.70	7.40
1971	44.40	47.22	8.63	19.23	2.13	4.85

1/ Computed by the Thiessen method.

Table 4.--Summary of land use.

WATERSHED 4 1/ Land use	1957 Contr. Acres	1957 None Contr. Acres	1957 Percent of Total Area C	1957 Percent of Total Area NC	1966 Contr. Acres	1966 None Contr. Acres	1966 Percent of Total Area C	1966 Percent of Total Area NC	1970 Contr. Acres	1970 None Contr. Acres	1970 Percent of Total Area C	1970 Percent of Total Area NC
Cultivation	386	83	19	4	189	59	12	4	138	61	9	4
Pasture	161	49	8	2	158	165	10	10	258	188	16	12
Idle	475	185	24	9	159	67	10	4	132	43	8	3
Forest	442	177	22	9	535	223	34	14	584	159	37	10
Gully	16	26	0.8	1.3	9	16	0.6	1	11	6	0.7	0.4
Total	1480	520	74	26	1050	530	66	34	1123	457	71	29

1/ Watershed area adjusted on January 1, 1965 from 2000 to 1580 acres.

WATERSHED 5	1957				1963				1970			
Cultivation	225	44	20	4	112	41	10	4	196	85	17	8
Pasture	282	101	25	9	171	182	15	16	177	139	16	12
Idle	210	33	19	3	224	125	20	11	166	65	15	6
Forest	209	5	18	0.4	238	22	21	2	253	38	22	3
Gully	10	11	0.9	1.0	5	10	0.4	0.9	6	5	0.5	0.4
Total	936	194	83	17	750	380	66	34	798	332	71	29

C - percent of total watershed area contributing.
NC - percent of total watershed area not contributing.

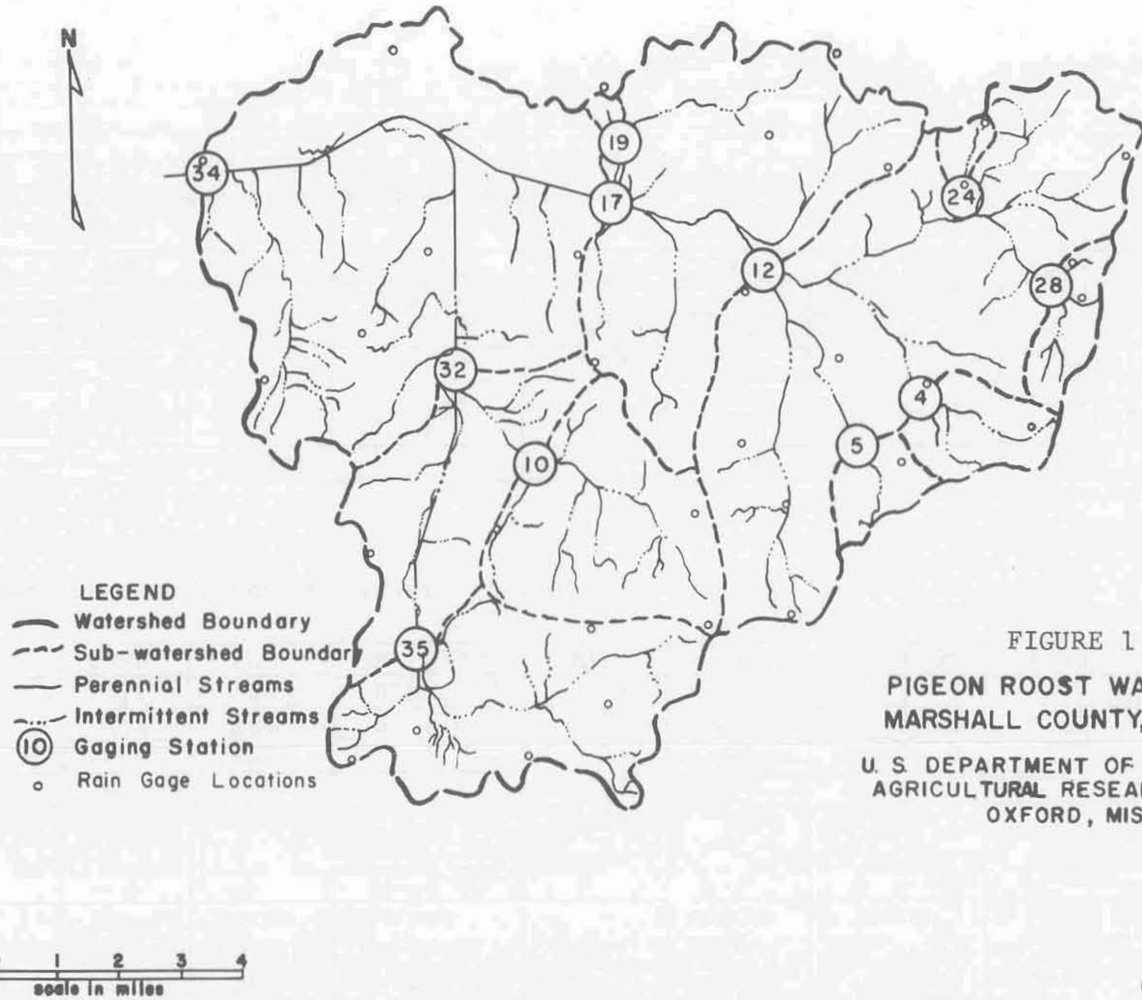

FIGURE 1

PIGEON ROOST WATERSHED
MARSHALL COUNTY, MISSISSIPPI

U. S. DEPARTMENT OF AGRICULTURE
AGRICULTURAL RESEARCH SERVICE
OXFORD, MISSISSIPPI

OCT. 1967

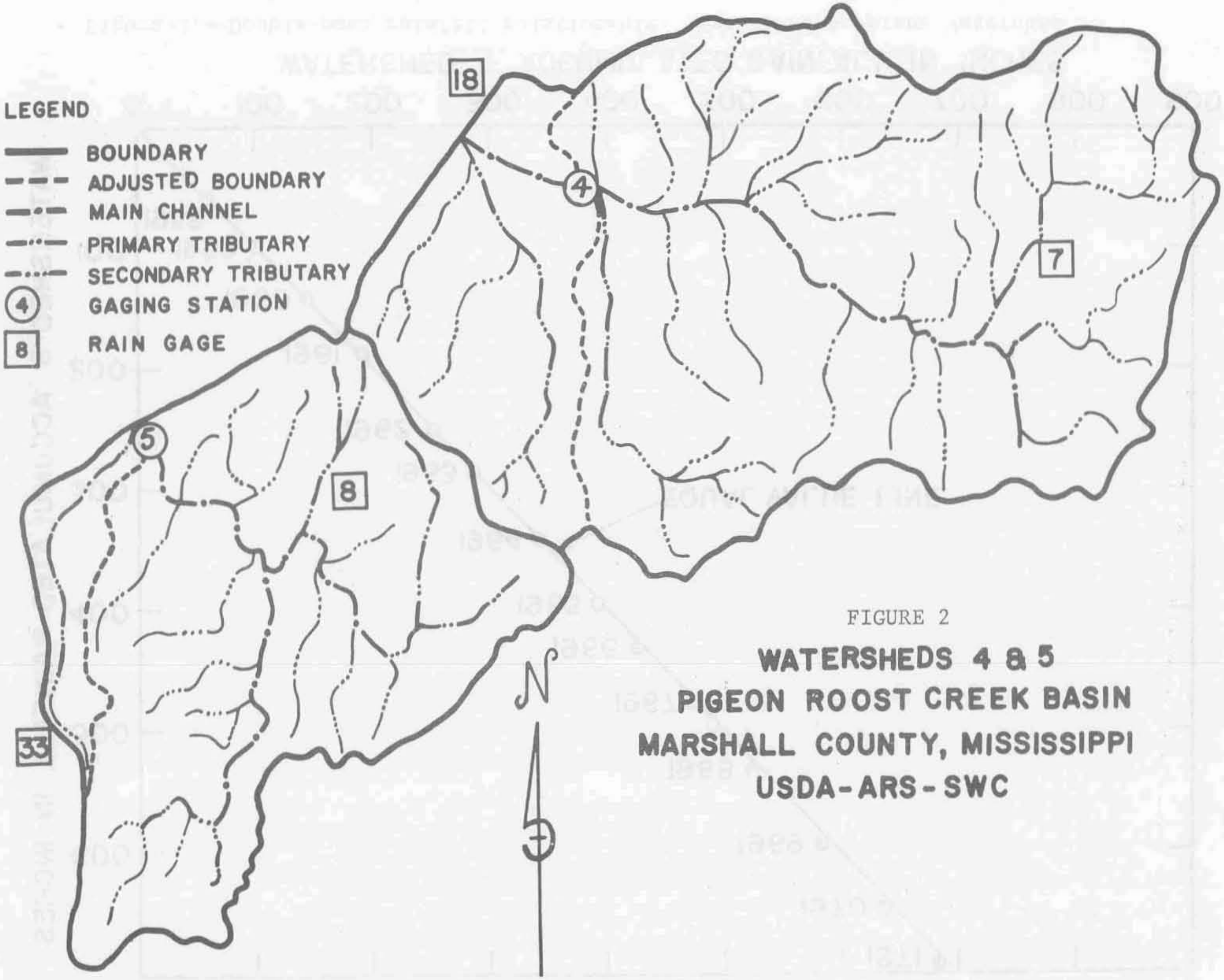

FIGURE 2

WATERSHEDS 4 & 5
PIGEON ROOST CREEK BASIN
MARSHALL COUNTY, MISSISSIPPI
USDA-ARS-SWC

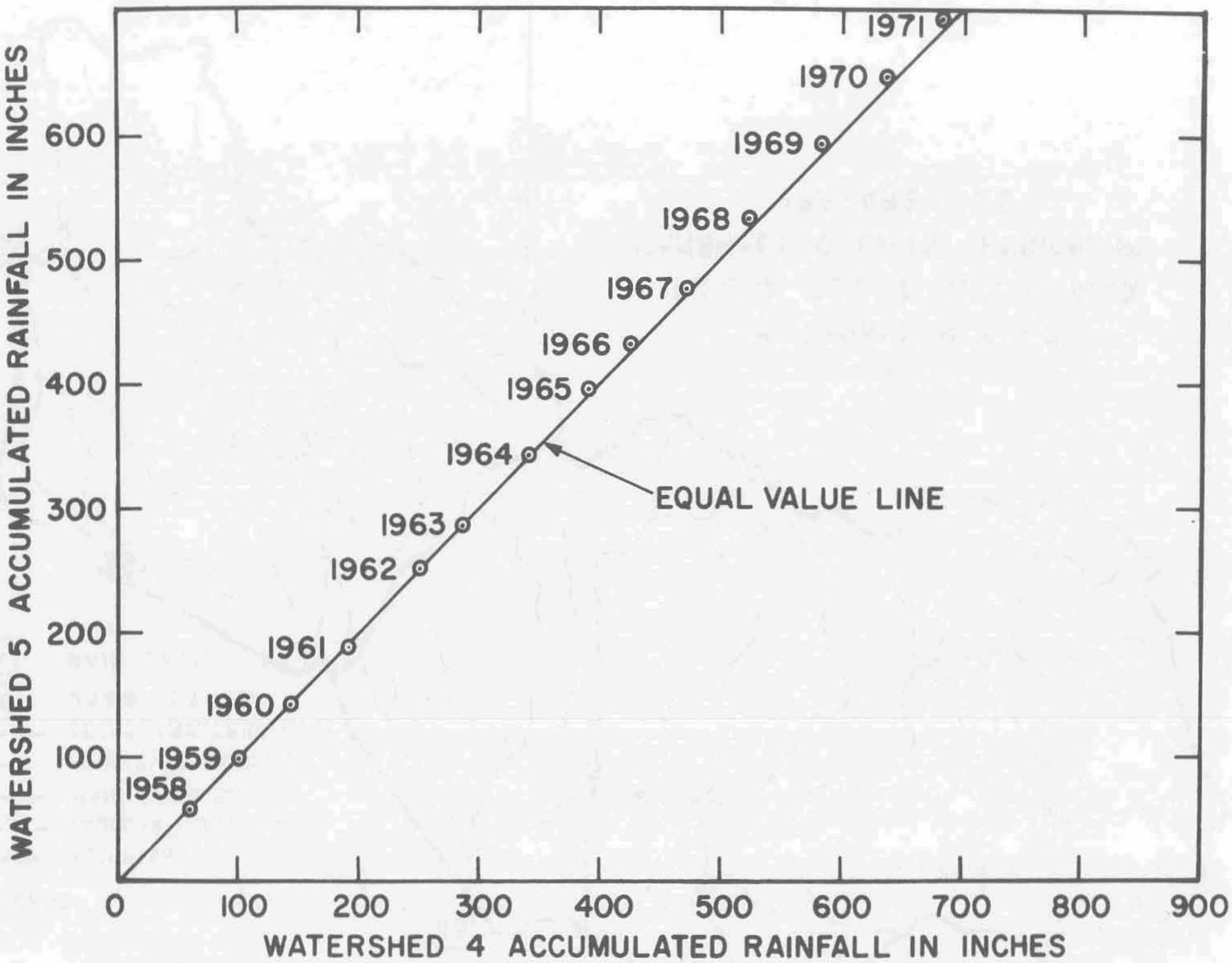

Figure 3.--Double-mass rainfall relationship: Watershed 4 versus Watershed 5.

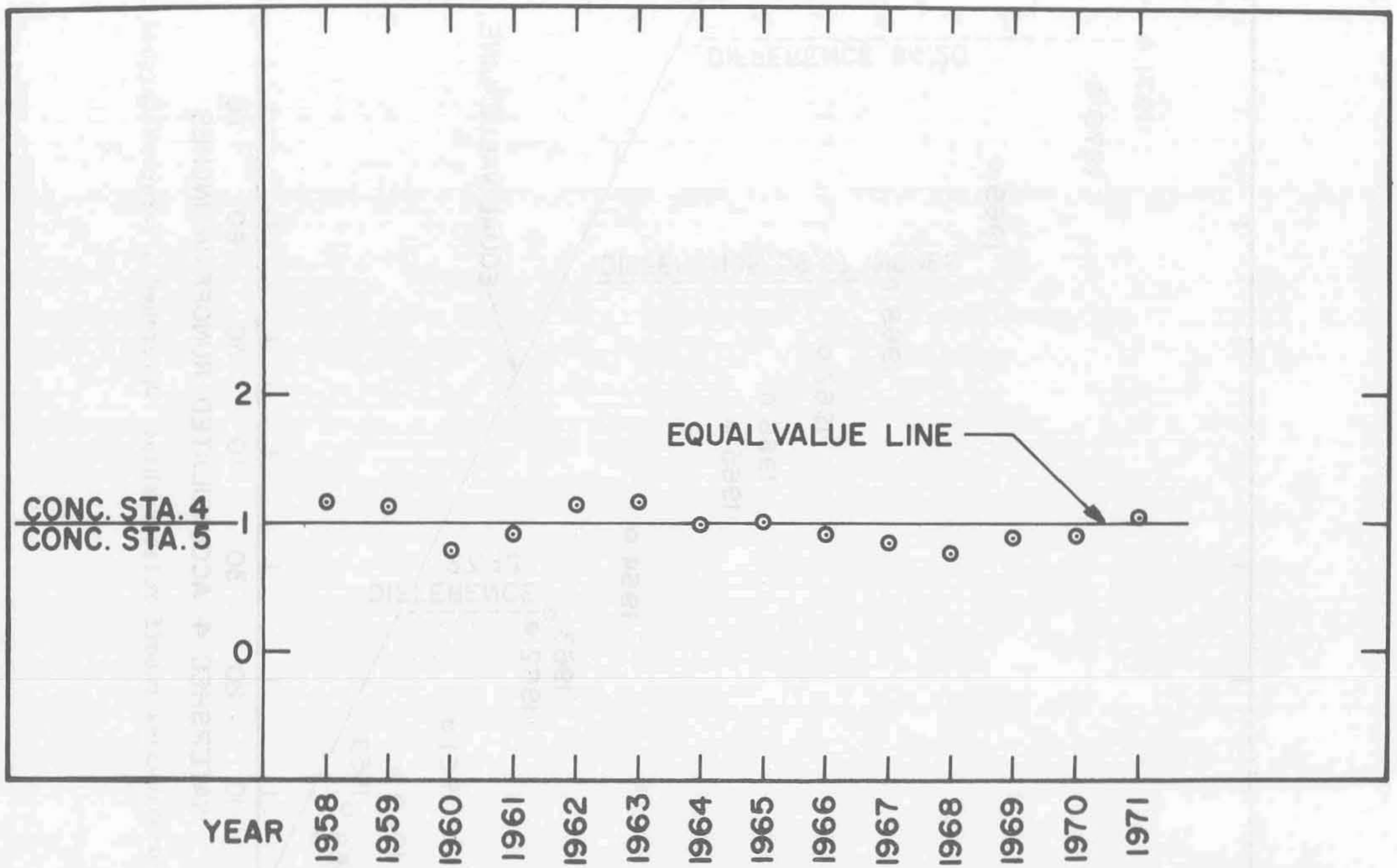

Figure 4.-- COMPARISON OF THE DISCHARGE WEIGHTED CONCENTRATION BETWEEN WATERSHED 4 AND WATERSHED 5

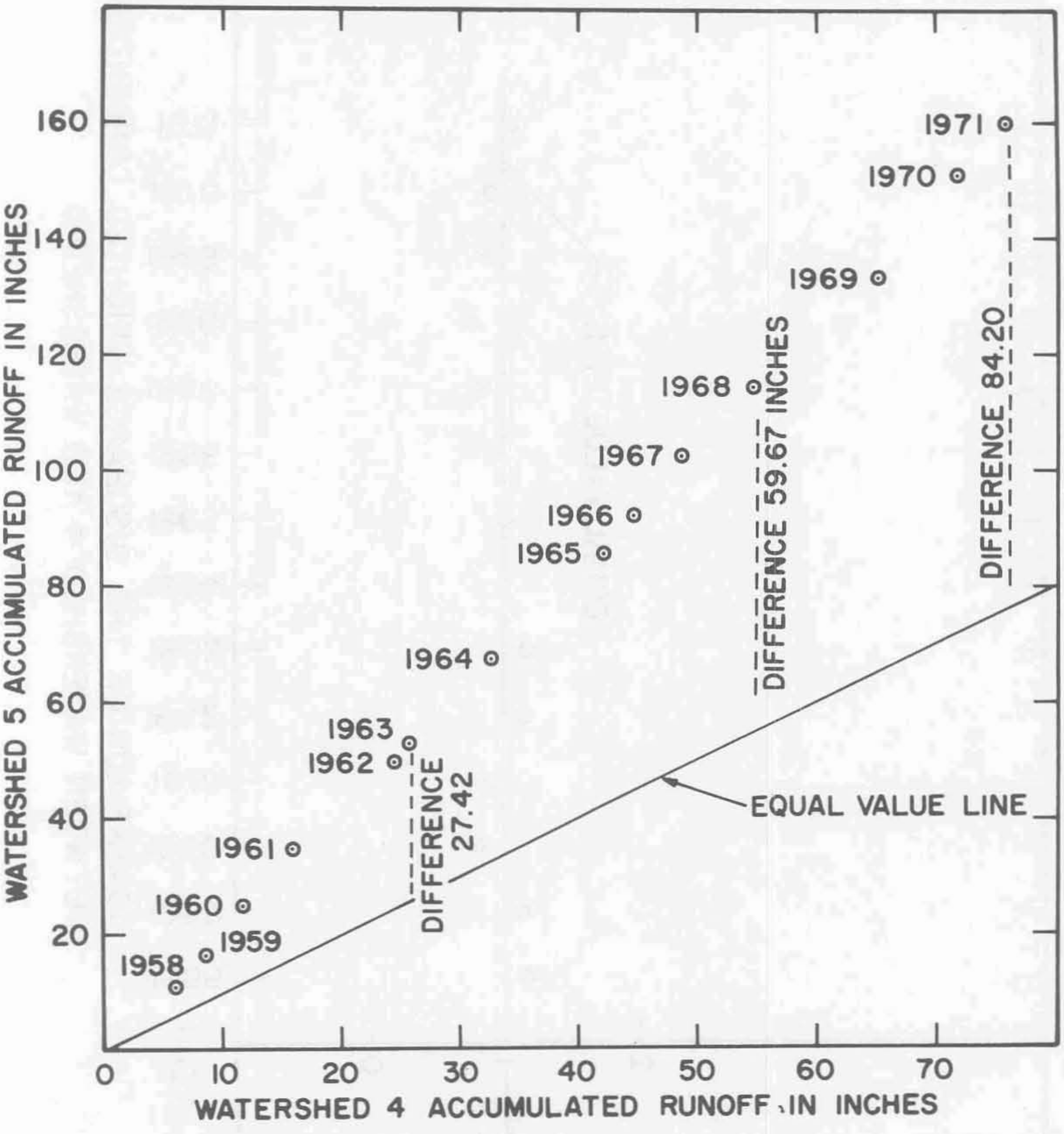

Figure 5.--Double-mass runoff relationship: Watershed 4 versus Watershed 5.

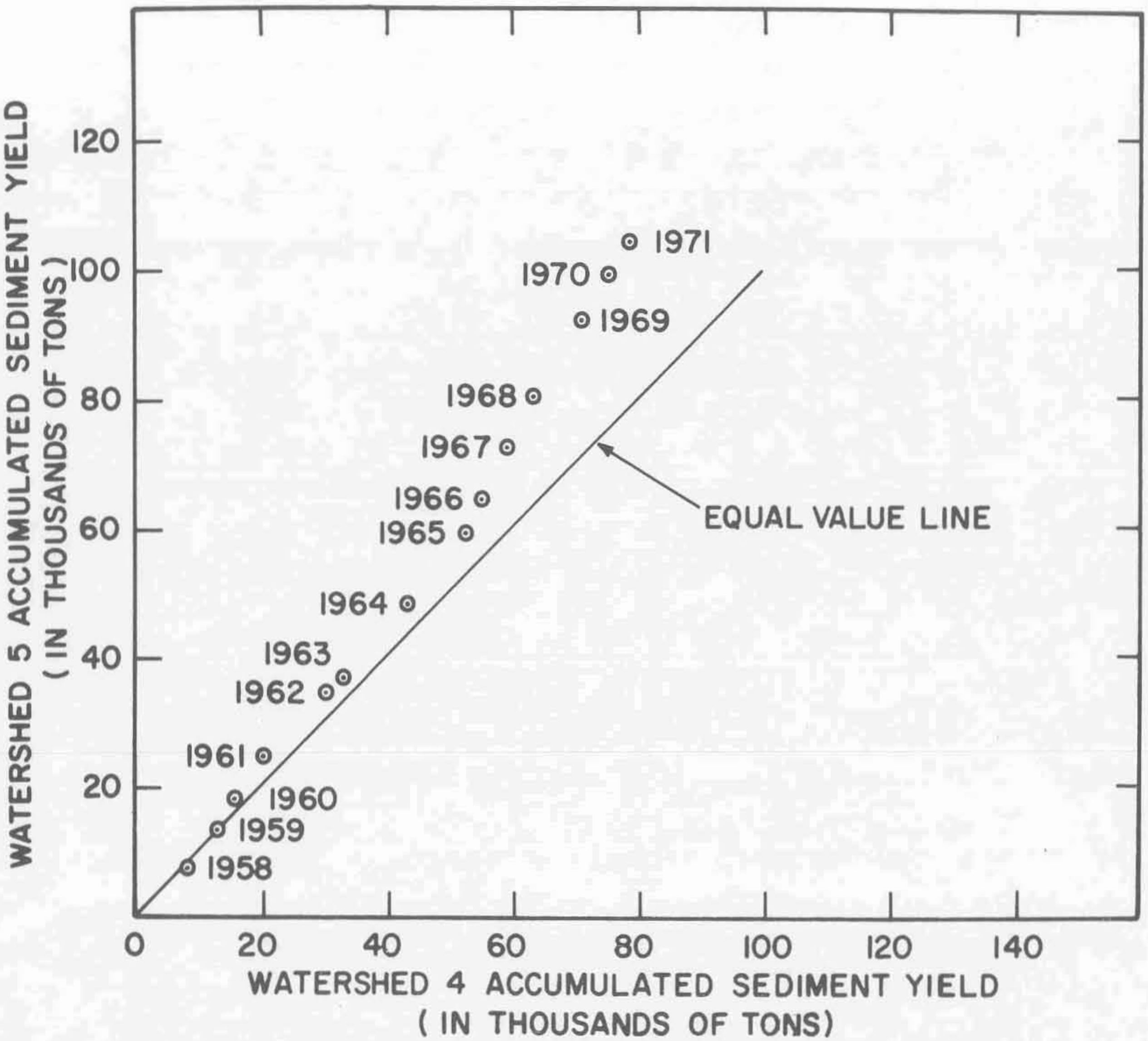

Figure 6.--Double-mass sediment transport relationship: Watershed 4 versus Watershed 5.