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CHANGES IN CHANNEL PATTERN AND SINUOSITY OF THE KANSAS RIVER--CAUSE AND EFFECT RELATIONSHIP OR RANDOM PROCESS?

by

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Instructor in Charge

For the Department

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ABSTRACT

Changes in stream morphology can be deterministic (alterations of variables within the physical system by climatic or cultural influences and effects) or probabilistic (random processes). It may be difficult or impossible to isolate and identify specific cause and effect relationships.

Evaluation of changes in channel pattern and sinuosity of the Kansas River involves the selection of data of appropriate quantity and quality. Data for channel pattern and stream discharge, which constitute an empirically-derived functional relationship, best meet the requirements.

Stream discharge, through its association with precipitation, is investigated on a time scale of several decades. Annual discharge before these measurements were recorded is estimated indirectly from annual precipitation computed as a representative figure for the entire drainage basin.

Settlement and cultivation accelerated erosion and resulted in increased sediment loads supplied to the river. The significance of this change is discussed along with other possible factors. The channel lengths and gradients upstream and downstream from the study area are studied. An interpretation of the configuration and behavior of the river prior to 1850 is presented.

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Chapter 1

INTRODUCTION

In terms of a geologic time scale, man and his works have been an integral part of the landscape for only an instant. The degree of transformation and modification of the landscape in that instant is indeed striking. In areas of regional magnitude, the appearance of landscapes is very different. Cultural patterns have been superimposed on the physical matrix, in places all but effacing the natural patterns. Changes affecting the actual configuration of the land surface are difficult to assess. The acceleration, modification, or modulation of physical processes by cultural events are largely unknown quantities.

How can we evaluate these observed changes and identify their causes? Is it possible to isolate specific factors, to distinguish between the effects of natural and cultural influences?

The Kansas River affords an opportunity for the investigation of changes in its pattern (planimetric configuration) and sinuosity (ratio of channel to valley length). Is the shortening of the channel length during a span of several decades a result of changes in the regimen of the river, climatically - induced changes in the variables of water and sediment carried by the river, or has man altered the landscape sufficiently to effect the change? Are we perhaps dealing with random processes and events in which the scales of time and space involved are such as to prevent our understanding of them?

The purpose of this study is to examine the channel pattern and sinuosity of a portion of the Kansas River in the light of the questions that have been raised. This requires the documentation of the changes which the channel has undergone and an analysis of the variables affecting channel pattern.

The Kansas River from the vicinity of Wamego to Topeka (Figure 1) exhibits a variety of channel patterns, both in space and time (see Plate I). There are three distinct reaches in this area, each one of which is approximately 15 miles in length. Proceeding eastward (downstream) from the Riley-Wabaunsee County line, the river has formed the largest and best-developed meanders, which have changed very little over the past 100 years. The next reach downstream has experienced substantial change in the past 100 years and exhibits the highest irregularity of channel patterns. The easternmost portion is the straightest and crowds the southern limit of the floodplain. In reaches of the river exceeding ten miles in length the sinuosity ranges from near unity to 1.6. Comparison of maps dating from 1856 to recent aerial photographs reveals substantial channel shortening in particular reaches. This has resulted in relatively large decreases in sinuosity in these reaches and an overall decrease in sinuosity for the entire length of channel in the study area.

The mechanism of channel shortening has received little attention from fluvial geomorphologists. Channel patterns, sinuosity, and their relationships to other river and drainage basin variables have, however, been extensively discussed. Studies involving channel position changes have dealt with either the genesis or cause of meandering, the geometry of meanders, or the relationship between channel form and pattern to variables of the river system. Channel width and channel geometry have been related to discharge (Leopold and Maddock, 1953) and to quantity and size of sediment load (Leliavsky, 1955). Channel shape and pattern have been related to the percentage of silt and clay exposed in the channel cross section (Schumm, 1963b) and indirectly to bankfull discharge (Leopold and Wolman, 1957). Meander wavelength has been attributed to water discharge alone (Dury, 1954), to channel width (Leopold and Wolman, 1957), to channel gradient (Friedkin, 1945) and to mean annual discharge or to discharge of the month of maximum discharge (Carlston, 1965). Dury (1964) has made detailed studies of the former positions of streams in his papers dealing with his general theory of meandering valleys and underfit streams.

LOCATION MAP

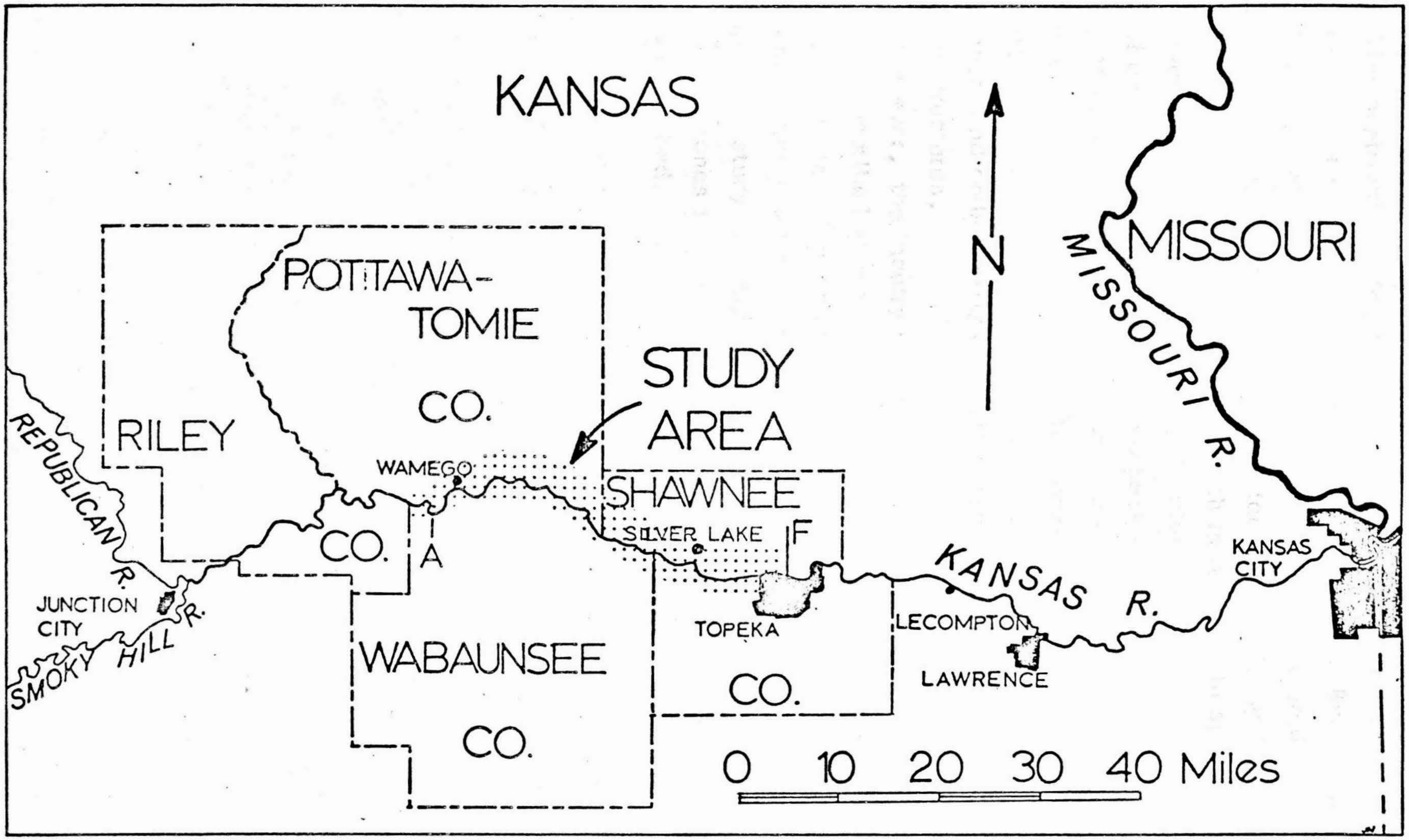


FIGURE 1.

The empirical relationships derived by the various authors cited in the preceding paragraph have relevance to this study. But the historical context in which the channel changes are to be considered imposes certain requirements: minimum conditions for the quantity and quality of the data must be met in order to sample both in time and in space. A realistic assessment of possible cultural influences requires that the period of observation be extended as far back as reliable information allows. It is believed that the time span considered (1856-1960) is appropriate. The period begins with the river in a "natural" condition, encompasses the period of settlement and cultivation of the area drained by the river, and ends shortly after the advent of major construction of hydraulic structures.

However, the inquiry cannot be limited to the particular section of the river described above. Since the morphology of alluvial rivers is primarily a function of upstream factors, the water and sediment supplied by the entire drainage basin must be considered. In addition, the relationship of the study area proper in the context of the upstream and downstream reaches is studied in order to assess the significance of the changes described.

Chapter 2

STREAM VARIABLES, MEASUREMENT AND TIME

2.1 Variables Affecting Stream Channels

The most important variables affecting natural stream channels include discharge, amount of sediment load, calibre of sediment load, width, depth, velocity, slope, and channel roughness (Leopold and Wolman, 1957, p. 72). There is complex interaction among these factors; some are essentially independent of the stream channel and depend on the nature of the drainage basin, others describe hydraulic processes. The complexity of the association among these factors is compounded by their dependency on external variables, by interdependency, or combinations of both. For example, a major flood may increase channel width, subsequently affecting velocity which in turn may result in a decrease in suspended sediment load or channel roughness.

2.2 Discharge and its Measurement

The functional nature of discharge has been extensively investigated. Leopold and Maddock (1953, p. 1) have derived empirical relationships for width, depth, velocity, and suspended sediment load, each as a function of discharge. Leopold and Wolman (1957, 1959) plotted channel slope in feet per foot (S) against bankfull discharge in cubic feet per second (Q) for various natural channels in Alaska, India, and the contiguous United States. The regression line described by the equation $S = 0.06\ Q^{-.44}$ separates, with only three exceptions, the braided streams from the meandering streams. The former lie above the line; the latter lie below the line. The authors define a meandering stream as one in which the ratio of thalweg length to valley length ≥ 1.5 (Ibid., 60). Carlston (1968, D47) derived the empirical equation,

$S \propto Q_m^{-0.52}$ (S = slope, Q_m = mean annual discharge in cfs.) as an average of five alluvial rivers in the U.S.

There is a common dimension among these empirical relationships: discharge measurements represent conditions at one particular time or as an average over a short length of time. In relation to the scale of time required for a stream to acquire a graded condition, these are instantaneous measurements. At any given increment of time, adjustments among the interdependent variables in a stream regimen occur in response to changes both externally and internally. These adjustments in the geometry of the stream channel may result in considerable inconsistency in discharge figures. Discharge is computed from the stage-discharge relation, which is obtained from current-meter measurements and gage heights representing the river stage in feet above an arbitrary datum. The relation is based on the slope-area or contracted-opening measurements or upon a study of the conveyance characteristics of the stream. "Many of the streams in Kansas are affected by scour and fill which modifies the stage-discharge relation. For these streams the stage-discharge relation is adjusted by a shifting-control method based on frequent discharge measurements." (Kansas Water Resources Board, 1960, p. 47).

2.3 Inconsistency of "Instantaneous" Measurements

The inconsistency of "instantaneous" measurements is strikingly illustrated by the bankfull discharge values used by Leopold and Wolman (1957, Appendix F, p. 79) for the Kansas River. The discharge figures of 102,000 cfs at Wamego and 65,000 cfs at Lecompton were obtained by a field estimate of the bankfull stage applied to the rating curve. The figures represent conditions for each place at a particular point in time. The figures should be consistent with the relative locations at which they were obtained. Lecompton is 64 miles farther downstream and the river drains 3,180 additional square miles with an average discharge (for a similar period of record) of 2,092 cubic feet per second in excess of the average discharge at Wamego (U.S. Department of the Interior, 1966, pp. 81 and 95). The incompatible bankfull discharge figures indicate that conditions at the two places were not comparable and must be used with caution. The plotted discharge and channel slope figures place the Kansas River at Wamego and at Lecompton in the meandering class as defined by Leopold and Wolman (1957, Appendix F). For a limited reach upstream and downstream from Wamego, the channel may be characterized as meandering but figures given in Table 2 show that the sinuosity in this reach does not meet Leopold and Wolman's own minimum figure of 1.5. Lecompton is located on a section of the river in which the ratio of channel to valley length is nearly unity (see Figure 1); it is definitely non-meandering. This indicates that single, isolated measurements should not be used to derive functional relationships and calls attention to the time-dependency of variables in a river system.

2.4 Relevancy of Variables During Different Time Spans

Schumm and Lichty (1965, pp. 116, 117) discuss the status of variables during designated time spans and their relevancy in explaining fluvial phenomena. Their "modern time" is 1,000 years in duration (Table 1); "present time" is one year or less. During the span of modern time, channel morphology is a dependent variable. During present time, Schumm and Lichty believe that morphology is independent because it has been inherited from modern time. The observed discharge of water and sediment is indeterminate during modern time since the data for these characteristics do not exist. During present time these variables can be measured and are dependent. Schumm and Lichty point out that "It is during the brief span of present time that the possibility of an apparent reversal of cause and effect may occur, due to feedback from the dependent to the independent variables" (Ibid., 117). This may be the explanation for the incompatible discharge figures in Leopold and Wolman's article cited above. An exceptional flow may have modified the dimensions and shape of the channel which, in turn, could alter the flow characteristics.

The status of river variables during time spans of decreasing duration

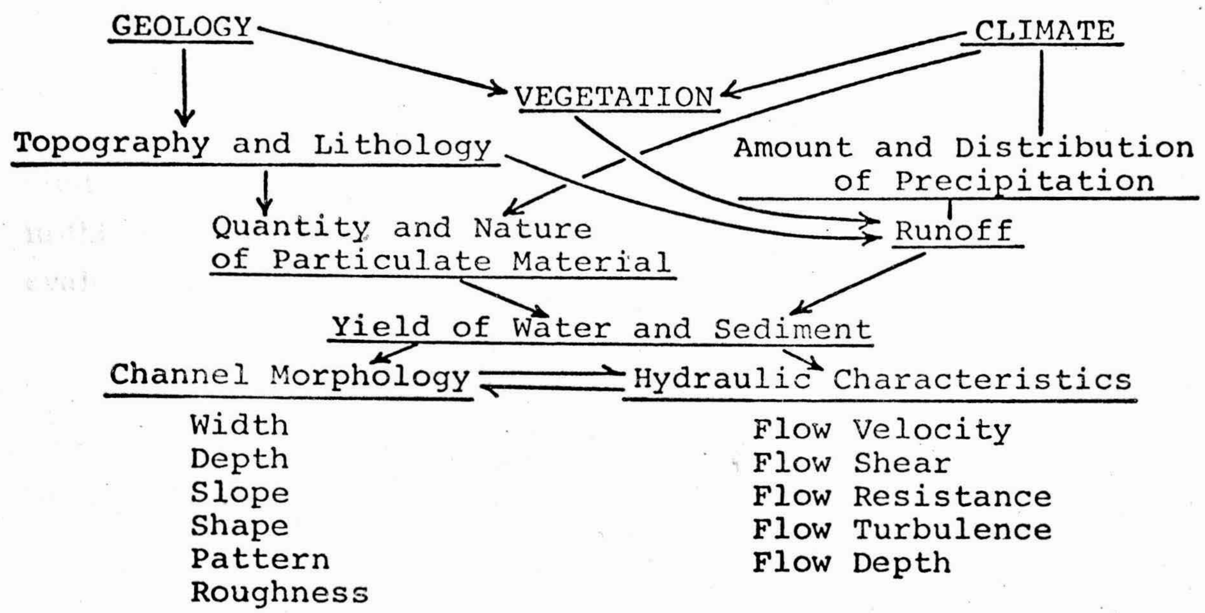
River Variables	Status of variables during designated time spans		
	Geologic	Modern	Present
1. Time	Independent	Not relevant	Not relevant
2. Geology (lithology and structure)	Independent	Independent	Independent
3. Climate	Independent	Independent	Independent
4. Vegetation (type and density)	Dependent	Independent	Independent
5. Relief	Dependent	Independent	Independent
6. Paleohydrology (long-term discharge of water and sediment)	Dependent	Independent	Independent
7. Valley dimension (width, depth, and slope)	Dependent	Independent	Independent
8. Mean discharge of water and sediment	Indeterminate	Independent	Independent
9. Channel morphology (width, depth, slope, shape, and pattern)	Indeterminate	Dependent	Independent
10. Observed discharge of water and sediment	Indeterminate	Indeterminate	Dependent
11. Observed flow characteristics (depth, velocity, turbulence, et cetera)	Indeterminate	Indeterminate	Dependent

(Schumm and Lichty, Ibid., p. 116, Table 1)

2.5 An Intermediate Time Span for the Present Study

Neither time span, one year or 1,000 years, is appropriate for an analysis of the relationship among river variables; records exist for only a small part of the former and a feedback phenomenon may be operative during the latter. Consequently, we must consider the relationships during an intermediate time span and so avoid both problems. Figure 2 is a synthesis of the inter-relationships among dependent and independent variables during an intermediate time span of approximately 100 years. The arrows point to the dependent members of the functional pairs.

Figure 2. Significant River and Drainage Basin Variables



2.6 Availability and Suitability of Data for the Kansas River

The relationship to be investigated with respect to the Kansas River must include variables which meet the requirements of suitability and availability. Data for channel pattern, from which sinuosity and slope can be derived, is readily available from maps and aerial photographs throughout historical time. The variables which are directly related to channel pattern are yield of sediment, yield of water, and various hydraulic characteristics. Measurements of the quantity and calibre of sediment load at Topeka have been taken since 1957, but the time period is much too short to extrapolate functional information in any meaningful fashion. Moreover, the recent data also reflect major changes resulting from the construction of hydraulic structures, most of which have been built since 1955 (Appendix 1). Data for hydraulic characteristics are equally unavailable and their relationships to channel pattern are complicated by feedback. Discharge is the only variable directly related to channel pattern which meets the criteria of availability and suitability. There are, however, difficulties in measurements and derivation of these data. Therefore, the following two chapters are devoted to extended discussion of the two variables used. In Chapter 3 attention is given to channel pattern and sinuosity and problems related to their measurement. Chapter 4 documents a method for the prediction of discharge from precipitation (in lieu of actual discharge data throughout the period covered in this study). Following these chapters it then becomes possible to evaluate the significance and possible causes of channel shortening.

Chapter 3

CHANNEL PATTERN AND SINUOSITY

3.1 Channel Length and Pattern

Channel pattern can be determined at various times since 1856 from maps and aerial photographs. Table 3 gives the lengths of common sections of the channel in designated years. The measurements were made with a Bruning linear planimeter, tracing the centerline of the channel as shown on the maps and aerial photographs. An experiment was conducted to measure any differences obtained by tracing the left bank, right bank, and centerline. Through a distance of 77 inches, the greatest variance was 0.1 inch. Around the sharper bends, the thalweg of the channel was approximated by tracing closer to the outside bank. This was done to smooth out the sharp curves and to eliminate errors resulting from abrupt turnings of the tracing wheel. The distances in Table 3 represents the average of at least three measurements of each section to ensure consistency and accuracy. The points A, B, C, D, E, and F are relatively stable positions of the channel and also separate rather distinct reaches of the river in terms of channel patterns. These points and the centerline of the channel in the years 1856, circa 1900, and 1942 are shown on Plate 1.

All maps generalize to some degree and the maps drawn from early surveys probably have greater generalization than recent maps, particularly with regard to small bends and curves in the channel. Tracings from the maps were prepared at scales common to the aerial photographs. Where evidence and reason dictated, slight alterations were made in the channel positions to match channel lines and meander scars on the air photos. All of the older maps were shown on a township and range square mile grid and the planimetry is believed to be quite accurate, but not precise. The differences shown in Table 3 are, in most cases, much larger than mapping inaccuracies.

YEAR	SOURCE	CENTERLINE OF CHANNEL										
		LENGTH, MILES			A - D		LENGTH		D - F		A - F	
		A-B	B-C	C-D	Miles	Sinuosity	D-E	E-F	Miles	Sinuosity	Miles	Sinuosity
1856	Surveyor General	4.50	14.40	12.80	31.70	1.485	17.60	7.05	24.65	1.413	56.35	1.452
1870	Kansas Pacific Railroad	4.80	14.55	12.75	32.10	1.504						
1873	Commercial Atlas						17.70	7.20	24.90	1.427	57.00	1.469
1898	Commercial Atlas						15.10	6.95	22.05	1.264	53.65	1.383
1902	Commercial Atlas	4.60	14.25	12.75	31.60	1.480						
1905	Commercial Atlas	4.60	14.25	7.25	26.10	1.222						
1921	Commercial Atlas						14.95	6.85	21.80	1.249	47.90	1.235
1942	Air Photos	4.67	14.02	7.57	26.26	1.230	11.17	6.91	18.08	1.036	44.34	1.143
1951	USGS Topo Maps	5.87	14.81	8.33	29.01	1.359	11.93	7.20	19.13	1.096	48.14	1.241
1959	Air photos	6.10	14.60	7.50	28.20	1.321	11.15	7.00	18.15	1.040	46.35	1.195
		FLOODPLAIN AXIS										
1951	USGS Topo Maps	3.26	11.35	6.85	21.35		10.55	6.90	17.45		38.80	
		VALLEY AXIS										
1951	USGS Topo Maps	3.26	12.65	6.89	22.80		10.38	6.33	16.71		39.51	

TABLE 2. CHANNEL LENGTHS AND SINUOSITIES

The planimeter can be read as fine as 0.1 inches and the shortest distance that can be measured at a scale of 1:42,240 (the smallest scale of any map measured) is 0.07 miles. In order to avoid measurements finer than the quality of the maps may allow, all distances except those from air photos and topographic maps were rounded to the nearest 0.05 miles.

The source material for Shawnee and Pottawatomie Counties was not always synchronous; the total length and sinuosity column, A-F, combines measurements from sources with proximate dates. The one exception is the 1905-1921 combination. Since the A-D distance at those dates differed by only 1.30 miles, the assumption is made that little change occurred between those dates and that the sinuosity represents conditions in 1921.

The 1905 Atlas of Pottawatomie County shows the channel positions before 1903 as well as in 1905. The shortening of the channel resulted from a double cut-off of a backward S-shaped curve during floods in 1903 and 1905. The only source that is not precisely dated is the Kansas Pacific Railroad map. The railroad was known by that name from 1868 to 1880, at which time it became a part of the Union Pacific Railroad (Curl, 1960, pp. 35-36).

3.2 Channel Sinuosity

Sinuosity is an index of the degree of meandering in a stream. Slightly different measures have been used to define it:

Leopold and Wolman	$\frac{\text{Thalweg Length}}{\text{Valley Length}}$
Brice	$\frac{\text{Channel Length}}{\text{Length of meander belt axis}}$
Schumm	$\frac{\text{Stream Length}}{\text{Valley Length}}$

(Morisawa, 1968, p. 81)

The sinuosities in Table 3 represent the ratio of the channel length to length of the axis of the modern floodplain. There is little difference between this latter measurement and the axis of the valley (Table 3). In the Kansas River valley the length of the modern floodplain axis is essentially the same as the length of the meander belt axis. In places, the width of the modern floodplain exceeds the meander belt axis but the difference is negligible in terms of the axis lengths. The variable width of the meander belt makes it an undesirable index.

Presumably, the length of the thalweg (the line connecting the deepest points in the channel) would be greater than the centerline of the channel. The thalweg can only be approximated from maps and the earlier maps have less detail, such as islands, which help in placing the thalweg. Determination of the thalweg in the field would not apply at earlier dates. From a consideration of consistency and variability, the channel and valley lengths are best represented by centerline distance and modern floodplain axis distance, respectively.

The statement was made above that discharge data are the only means available to explain changes in channel morphology. But the periods of greatest change in the channel lie between 1870 and 1920 and do not coincide with the period of discharge data (1917-1959). We are forced to look for other data which are closely associated with discharge, and for which cause and effect relationships during the period of greatest change can be examined indirectly. Precipitation is the only possible candidate. It is necessary, therefore, to engage in a lengthy discussion concerning the association between annual precipitation and discharge and to determine whether precipitation may be used as an acceptable estimator of discharge.

Chapter 4

PREDICTION OF DISCHARGE FROM PRECIPITATION

4.1 Appropriate Period of Observation

In order to pursue the investigation within the "natural condition" context, that is, prior to major dam construction, (Appendix 1) analysis of the association between annual discharge and precipitation should be restricted to the years between 1919 and 1947. At the same time, the record must be long enough for statistical significance. The period of observation was chosen as 1919 through 1952 even though reservoirs were completed in 1948, 1949, 1950, 1951, and 1952. If the assumption is made that most of the impoundment of water in a reservoir takes place in the year following its completion, the largest volume of water retained in any single year was 1952. The normal capacities of Cedar Bluff Reservoir, 185,000 acre-feet, and Bonny Reservoir, 41,000 acre-feet, constitute about five per cent of the total discharge in 1952. The increasing number of reservoirs, the difficulty in assessing evaporation losses from their surface, and the indeterminable effect of numerous farm ponds constructed since 1951 bias the discharge data for recent years.

The mean annual discharge at Topeka for 1919-1952 is 3,280,000 acre-feet, ranging from a low of 905,000 in 1934 to 17,380,000 in 1951. With increasing precipitation, discharge increases at an increasing rate, indicating that the relationship could best be described by a log or power function.

4.2 Appropriate Area of Observation

Since the discharge measured at Topeka represents the water collected by the entire drainage basin above Topeka, the precipitation must be representative of the same area. Two factors are exceptions to this statement. Large areas in the western part of the Kansas River drainage basin are non-contributing (U.S. Department of the Interior, Water Resources Data for Kansas, 1966, p. 84). Indeterminate amounts of water are lost to the atmosphere or to ground water and do not become integrated in surface flow.

The other factor may counterbalance this loss. It is estimated that as much as 300,000 acre-feet of water are annually lost by the Platte River to the Kansas system by southward seepage through buried sands and sandstones (Colby, 1956, p. 47). The configuration of the pre-Pleistocene surface and the presence of buried valleys in the headwater areas of the Little Blue and Big Blue Rivers may provide the means for the sub-surface movement of water from one basin to another (Reed, et al., 1965, p. 188, and personal communication with C. K. Bayne, U.S.G.S., Lawrence, Kansas). If this water is integrated with surface flow in the Kansas system, the effect of the non-contributing areas is minimized or nullified. Today there is considerable pump irrigation in this area, but the time period considered in this study predates the advent of wide-spread pumpage.

The Kansas River drainage basin above Topeka covers 56,710 square miles extending 440 miles E-W and 195 miles N-S (Figure 3). The major portion of the basin lies in the semi-arid plains region where rainfall amounts decrease and rainfall variability increases from east to west. Thus, precipitation, which is the most significant variable in accounting for variations in stream flow, has a counteractive effect in its variability of occurrence, intensity, and duration throughout the drainage basin. The use of an annual data base combines the wide monthly and seasonal variations. Difficulty arises in using data obtained at a point and applying it to an area in which the pattern may be highly variable. In a single year, a dry section may be immediately adjacent to a humid section (Colby, 1956, p. 33). Any single climatic station may record representative precipitation amounts for given years, but, in view of variability as a natural condition in a semi-arid mid-continent region, could not be expected to receive representative amounts every year.

KANSAS BASIN, TRIBUTARIES and RESERVOIRS

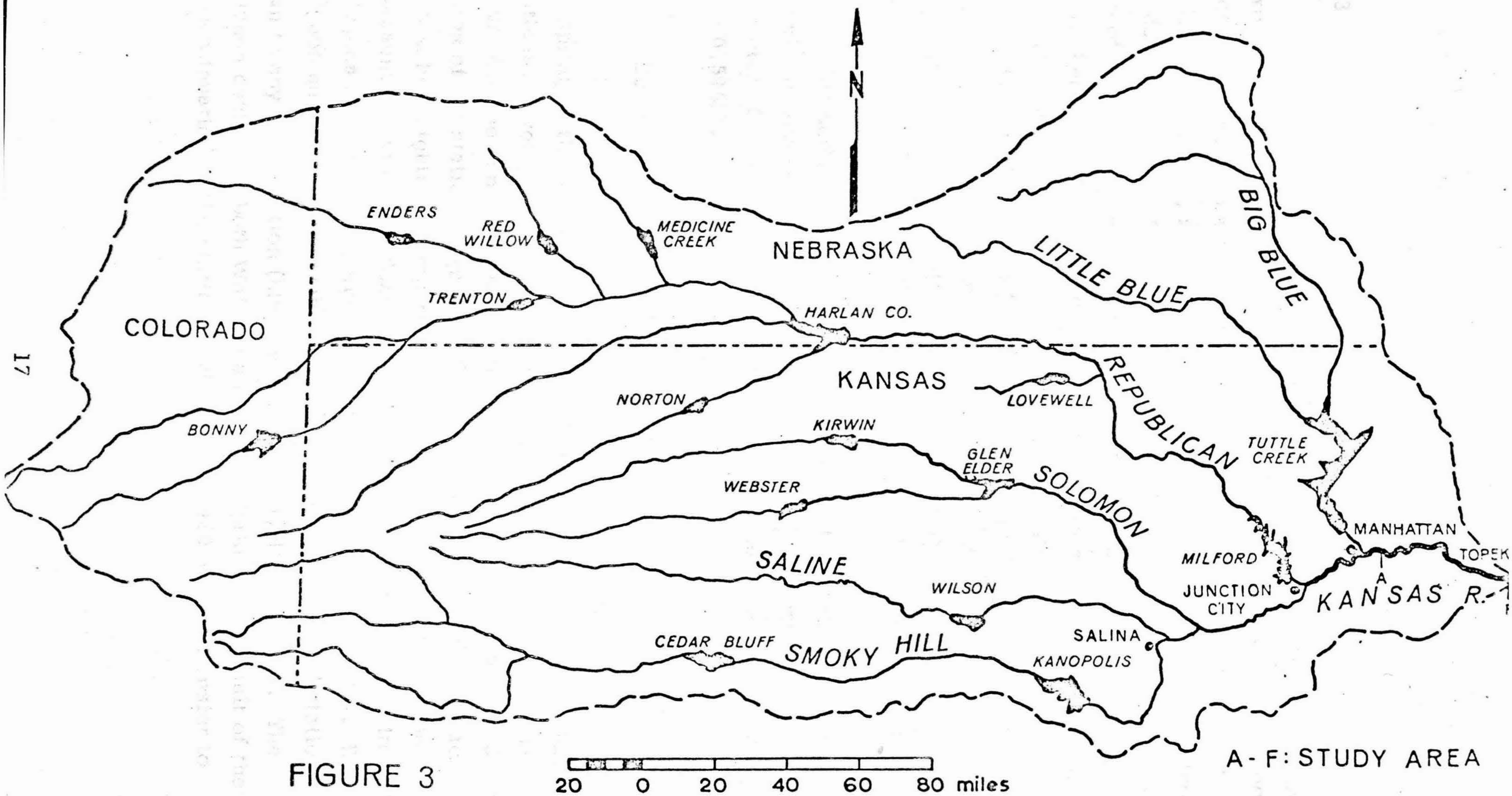


FIGURE 3

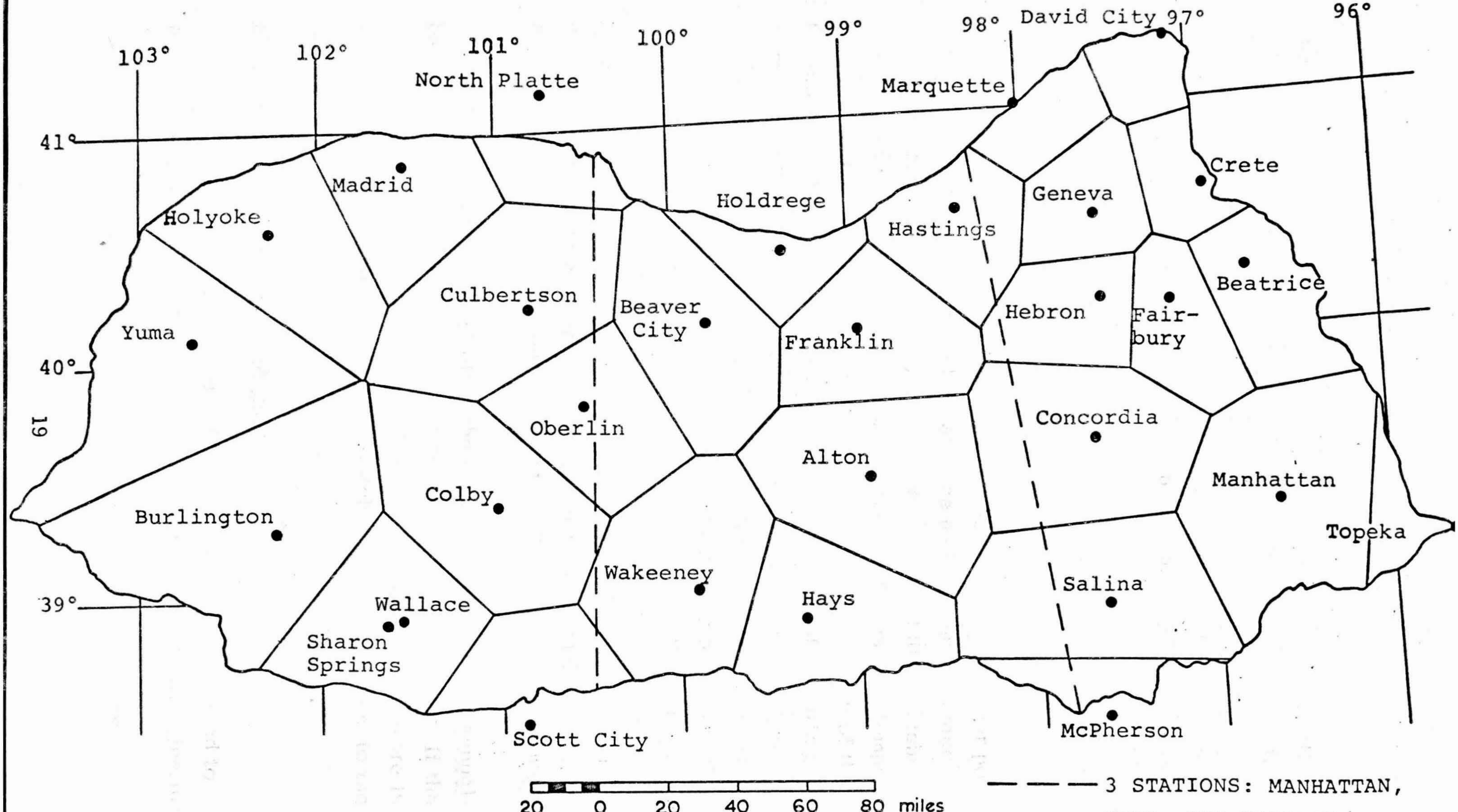
4.3 A Sample Using Three Climatic Stations

The logical solution is to arrive at annual precipitation figures derived from stations throughout the drainage basin, averaging out local eccentricities. Three stations were chosen: Manhattan, Hays, and Wallace, which lie, respectively, in the eastern, middle, and western thirds of the basin. Since the isohyets in the area trend N-S, the location of the stations in the southern part of the basin was not considered bias. Perpendiculars were drawn at the midpoints of lines connecting the three stations and the proportion of each station's area in relation to the basin was computed (dashed lines, Figure 4). The geometry and measurements were done on a map with a scale of 1:1,000,000. Each station's annual precipitation figure was multiplied by its respective areal coefficient and the three resulting figures for each year were summed to obtain a drainage basin precipitation figure.

The derived precipitation data were plotted against discharge volumes in acre-feet on a semi-log scale. A simple correlation analysis explained 60% of the variation in discharge by variations in precipitation ($r^2 = 0.5963$).

4.4 A Sample Using 29 Climatic Stations

The next step was to determine if a closer estimate of the annual precipitation throughout the entire basin could be obtained by using more stations. Twenty-nine stations with records dating from 1890 were chosen, Figure 4. The non-uniformity of the precipitation and the uneven distribution of the stations require that the precipitation recorded at each station be weighted in proportion to the area the station is assumed to represent. This can be done by the use of a Theissen network, irregular polygons formed by the perpendicular bisectors around stations. Each polygon encloses an area which is everywhere closer to that station than to any other station (Linsley and Franzini, 1964, p. 13). The polygon containing both Wallace and Sharon Springs is a result of the discontinuation of the station at Wallace in 1930 and its transfer to



THIESSEN NETWORK OF THE KANSAS RIVER DRAINAGE BASIN (ABOVE TOPEKA)

FIGURE 4

— — — 3 STATIONS: MANHATTAN, HAYS, AND WALLACE

——— 29 STATIONS

● DATA STATIONS

Sharon Springs. The two towns are nine miles apart, an insignificant difference in relation to the size of the polygon. The areal coefficients were calculated and a program was written to compute the basin precipitation data. A simple correlation analysis of the derived figures and the logs of the discharge data produced a coefficient of correlation of 0.8255 and a coefficient of determination of 0.6816, a significant improvement over the figures from three stations.

4.4.1 Other Possible Factors

At this point the problem was reviewed to evaluate other possible significant factors. These include average and maximum average temperatures, excessive precipitation, average relative humidity, sunshine percentage, average wind movement, mean number of days with temperature $\geq 90°F$ or $\leq 32°F$. The problems which arise from using many of these factors are: 1) incomplete records; 2) inconsistency of climatic stations in recording the same series of data; 3) evaluating the areal importance of data recorded at locations different than the 29 precipitation stations; and 4) standardizing data of varying magnitudes. My opinion is that the integration of yearly precipitation amounts over the entire basin compensates for much of the variation produced by the other factors listed above. All of these factors affect the amount of water which enters the drainage system and which is measured at Topeka but much of their effect has already been taken into account since precipitation is partly a function of several of the factors.

Variability of precipitation throughout the basin on an annual basis is probably greater than any of the factors listed above. If the most highly varying factor can be unified spatially, it seems there is little to be gained by unifying others which are closely related to the factor in question.

4.4.2 Effect of Settlement and Cultivation

Settlement and cultivation of the land would be expected to produce significant departures from the "natural" condition. Clearing the land, removing the protective vegetative and sod cover through cattle grazing and tillage very likely increases the percentage of precipitation that runs off. The time period between 1919-1952 is not relevant to distinctions of land settlement. By 1920, there was essentially as much land in Kansas and Nebraska rated as cropland as there was in 1950 (United States Bureau of the Census, 1950, p. 3 and 1920, p. 35). However, the large number of farm ponds constructed since the 1930's and, especially, after the 1951 flood may have produced significant changes in the runoff discharge at Topeka.

4.5 A Multiple Regression Model

It is possible to refine a simple correlation analysis to take into account certain exceptional conditions. Analysis of the most disparate plots on the scatter diagram (Figure 5) enables us to focus attention on years in which the annual discharge was substantially lower than the general trend for normal yields and to years in which the discharge was abnormally high. Many of the former cases followed dry years and the latter cases, wet years. If the soil moisture were at a maximum following an exceptionally wet year, less precipitation would infiltrate and a greater percentage would occur as runoff. The converse would apply following exceptionally dry years. These distinctions are difficult to describe numerically; they are "kinds of a thing" rather than "amounts of a thing." Nominative data can be introduced into a regression model by inserting dummy and interaction variables to designate particular conditions. Two dummy variables (R_2, R_3) and two interaction variables (R_2X, R_3X) were added to the regression model. The dummy variables adjust the Y-intercept of the regression lines for those observations which exceed one standard deviation (4.66) above or below the mean annual precipitation (22.59 inches). The interaction variables adjust differences in the slope of the regression lines. The regression model has three conditions defined by the amount of precipitation occurring in the preceding year:

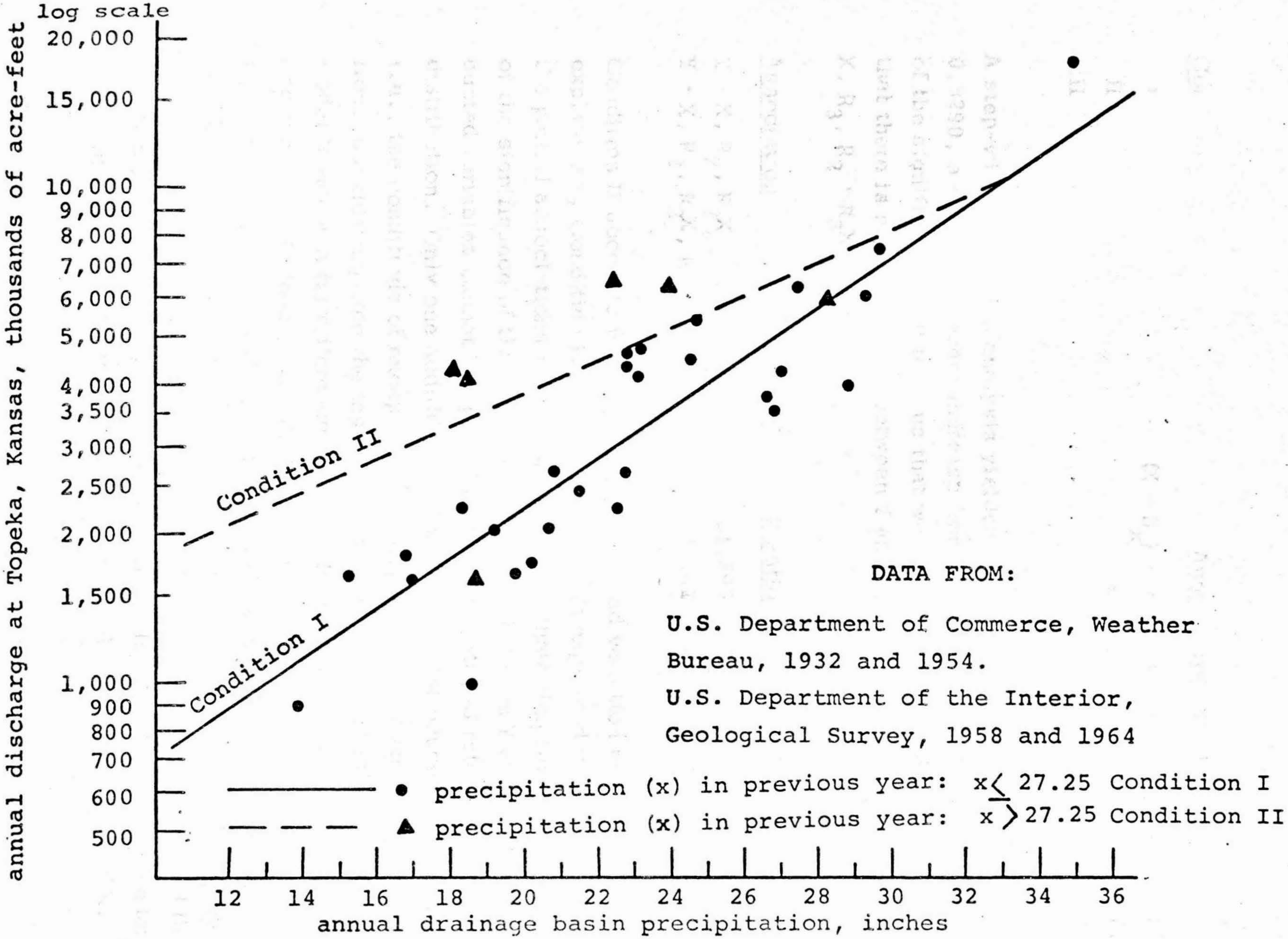


FIGURE 5. PRECIPITATION IN KANSAS R. BASIN vs. DISCHARGE AT TOPEKA 1919-1952

Condition	Annual Precipitation (x)	
I	$(X - S_x) < x < (X + S_x)$	$17.93 < x < 27.25$
II	$x > (X + S_x)$	$x > 27.25$
III	$x < (X - S_x)$	$x < 17.93$

A step-wise regression analysis yielded an R of 0.9105 and an R^2 of 0.8290, a quite significant increase from the simple correlations. Tests of the significance of R tells us that we must reject the null hypotheses that there is no association between Y and X, R_3, R_2, and between Y and X, R_3, $R_2 \cdot R_3X$, R_2X:

Association	R^2	F Ratio	F(P = .01)	Degrees of Freedom
$Y \cdot X, R_2, R_2X$	0.7965	51.595	4.51	30 and 3
$Y \cdot X, R_2, R_2X, R_3, R_3X$	0.8290	27.142	3.76	28 and 5

Condition II accounts for most of the explained variation beyond that explained by Condition I. The improvement in explained variation by the partial associations must be examined for their significance. Tests of the significance of the partial associations between Y and the introducted variables cannot be applied by the conventional referral to a _t_ distribution. Only one additional factor has been introduced conceptually, i.e., the conditions of exceptional departure from the average precipitation. But this required the insertion of two variables into the regression model to account for differences in the Y-intercepts and two variables to account for variations in the slopes of the regression lines. The significance of the partial relationship between the dummy and interaction variables and discharge (Y) can be determined by computing the coefficients of multiple correlation between discharge (Y) and precipitation (X) and the introduced variables (R_2, R_2X) adjusted for the loss of degrees of freedom and comparing this adjusted coefficient of correlation between Y and X.

If the relationship

$$\text{adjusted } R_{y\cdot x,\ R_2,\ R_2X} \geq R_{y\cdot x}$$

holds, we may infer a significant partial relationship between the introduced variables for Condition II and the discharge. The adjusted $R_{y\cdot x,\ R_2,\ R_2X} = 0.881$; $R_{y\cdot x} = 0.824$. Since $0.881 \geq 0.824$, there is a significant partial association between Y, X, and the introduced variables R_2 and R_2X. Analysis of the significance of the introduced variables defining Condition III yields:

$$\text{adjusted } R_{y\cdot x,\ R_2,\ R_2X,\ R_3,\ R_3X} = 0.867$$
$$R_{y\cdot x,\ R_2,\ R_2X} = 0.873$$
$$0.867 \not\geq 0.873$$

There is no significant partial association between discharge and R_3, R_3X when X, R_2 and R_2X are held constant. Thus, Condition III is not included in the equation nor in the scatter diagram. Figure 5 shows the regression lines described by the generalizing statement:

$$\log Y = 2.33934 + 0.05034\,X + 0.58090\,R_2 - 0.01741\,R_2X$$

The generalizing statement describes the association which explains 80% of the variation in discharge by variations in precipitation and the recognition of antecedent moisture conditions.

4.6 Precipitation Computed from 3 and from 29 Stations

Annual discharges for the years 1890-1918 can be estimated from annual drainage basin precipitation but lack of data prevents computation of precipitation from the 29-station network prior to 1890. Only three stations have recorded precipitation continuously since 1870. Fortunately, these stations - Manhattan, Hays, Wallace - are distributed in such a way that the east-west variation in precipitation can be largely accounted for. A simple correlation of the annual drainage basin precipitation from the three stations and from the 29 stations for the years

1890-1952 yielded a coefficient of correlation of 0.912 (Figure 6). The use of only three strategically-located stations agrees very closely with the figures obtained from a much finer Thiessen network.

4.7 Annual Discharge for the Years 1870-1918

Annual discharge for the years 1870-1918 can be estimated by insertion of annual precipitation figures (derived from the Thiessen networks) into the generalizing statement. Precipitation figures for 1870-1889 were obtained from a network of 3 stations; these for 1890-1918 from a network of 29 stations (Table 3). The estimated discharges for 1870-1889 are less reliable since they were computed from the equation which described the association between discharge and drainage basin precipitation using 29 stations. However, the individual annual figures are not important; any single value may be quite unreliable. Rather, the average annual discharge for the period 1870-1918 is the key to an analysis of any charge in the regimen of the river. The average figure, 3,818,000 acre-feet, is free of the unreliability of any single value since it is composed of values which would be scattered on either side of the regression lines similar to Figure 5.

4.8 Mean Annual Precipitation and Discharge

The close association between precipitation and discharge averaged over selected time periods reinforces the validity of the derived discharges:

Figure 7 is a semi-logarithmic plot of Table 4 with an eye-fitted regression line. We must remember that the average discharge for the period 1870-1918 was derived from the analysis of the association between precipitation and discharge during the period 1919-1952. The mean annual precipitation figures for these two periods are very similar, 22.88 and 22.29, respectively. From a consideration of the factors influencing precipitation, the conclusion is made that climatic and meteorological conditions were also very similar, both in general trend and in short-term fluctuations. Extremes occurred in both periods:

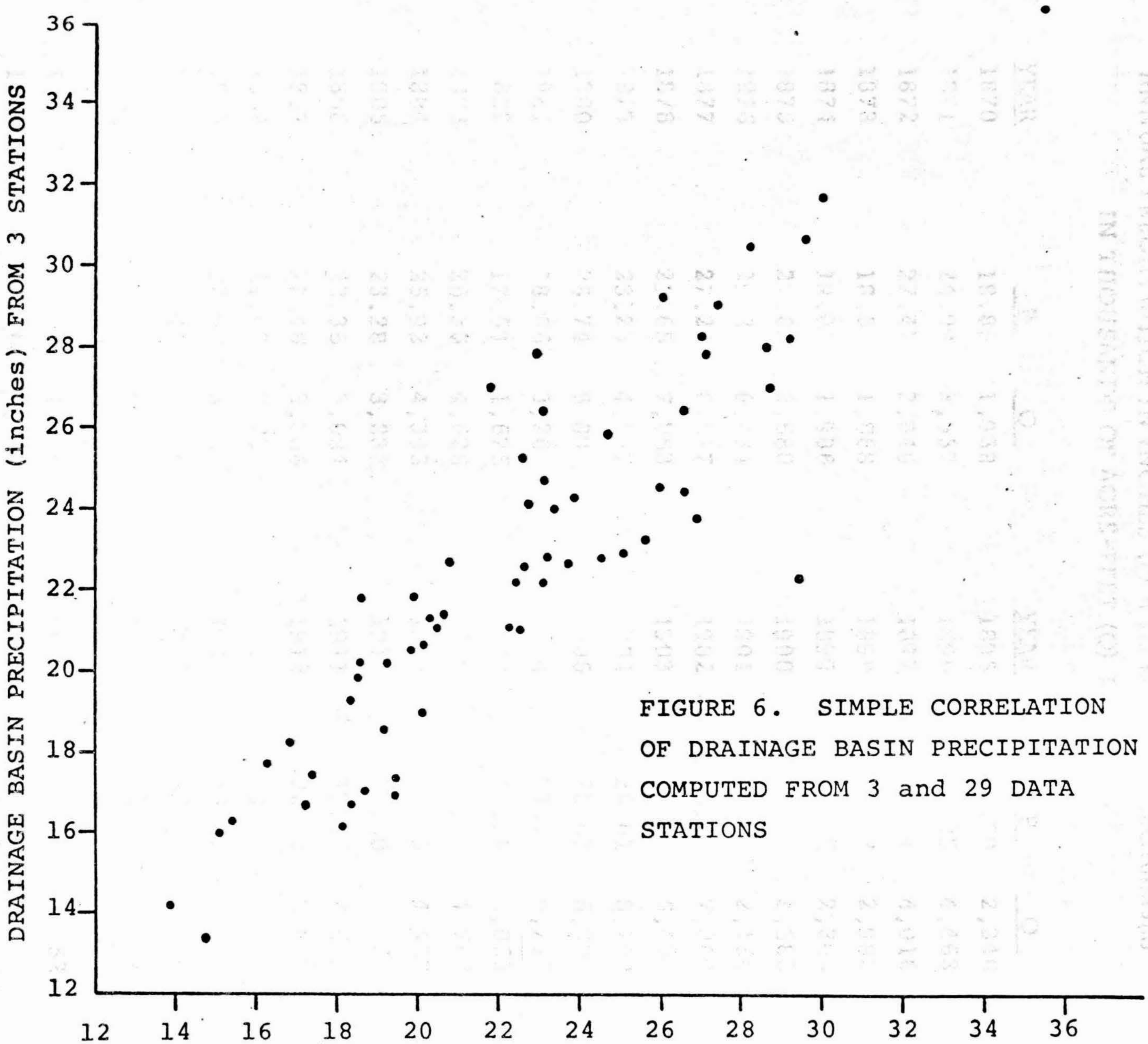


FIGURE 6. SIMPLE CORRELATION OF DRAINAGE BASIN PRECIPITATION COMPUTED FROM 3 and 29 DATA STATIONS

FIGURE 6. DRAINAGE BASIN PRECIPITATION (inches) FROM 29-STATION THIESSEN NETWORK

ANNUAL PRECIPITATION IN INCHES (P) AND DERIVED DISCHARGES IN THOUSANDS OF ACRE-FEET (Q) 1870-1918

YEAR	P	Q	YEAR	P	Q
1870	18.85	1,938	1895	20.50	2,346
1871	24.09	3,557	1896	26.05	4,463
1872	22.47	2,948	1897	25.14	4,016
1873	18.53	1,868	1898	22.57	2,982
1874	19.06	1,986	1899	20.35	2,306
1875	21.65	2,680	1900	22.27	2,880
1876	29.21	6,434	1901	19.80	2,164
1877	27.29	6,577	1902	30.01	7,060
1878	29.65	7,863	1903	27.00	6,434
1879	23.29	4,857	1904	25.61	5,790
1880	28.74	6,094	1905	28.61	6,002
1881	18.06	3,268	1906	23.11	4,792
1882	17.59	1,675	1907	19.35	2,055
1883	26.36	4,626	1908	26.62	4,767
1884	25.92	4,395	1909	26.00	4,437
1885	23.28	3,237	1910	16.20	1,426
1886	22.36	3,084	1911	19.37	2,059
1887	23.46	3,306	1912	22.76	3,049
1888	21.82	2,734	1913	20.12	2,245
1889	22.97	3,123	1914	19.07	1,988
1890	15.10	1,256	1915	35.59	13,470
1891	29.52	6,670	1916	18.53	3,387
1892	23.09	4,784	1917	18.50	1,861
1893	17.43	1,644	1918	23.32	3,252
1894	14.76	1,207			

Computed from Data in U.S. Department of Agriculture, Weather Bureau, 1933

Table 3

TABLE 4. MEAN ANNUAL PRECIPITATION AND DISCHARGE, SELECTED TIME PERIODS

TIME PERIOD	MEAN PRECIPITATION, INCHES	MEAN DISCHARGE, THOUSANDS OF ACRE-FEET
(A) 1870-1918	22.88	3818
(B) 1919-1952	22.29	3280
(C) 1919-1940	20.60	2705
(D) 1941-1951	26.07	6541
(E) 1952-1959	20.96	2818

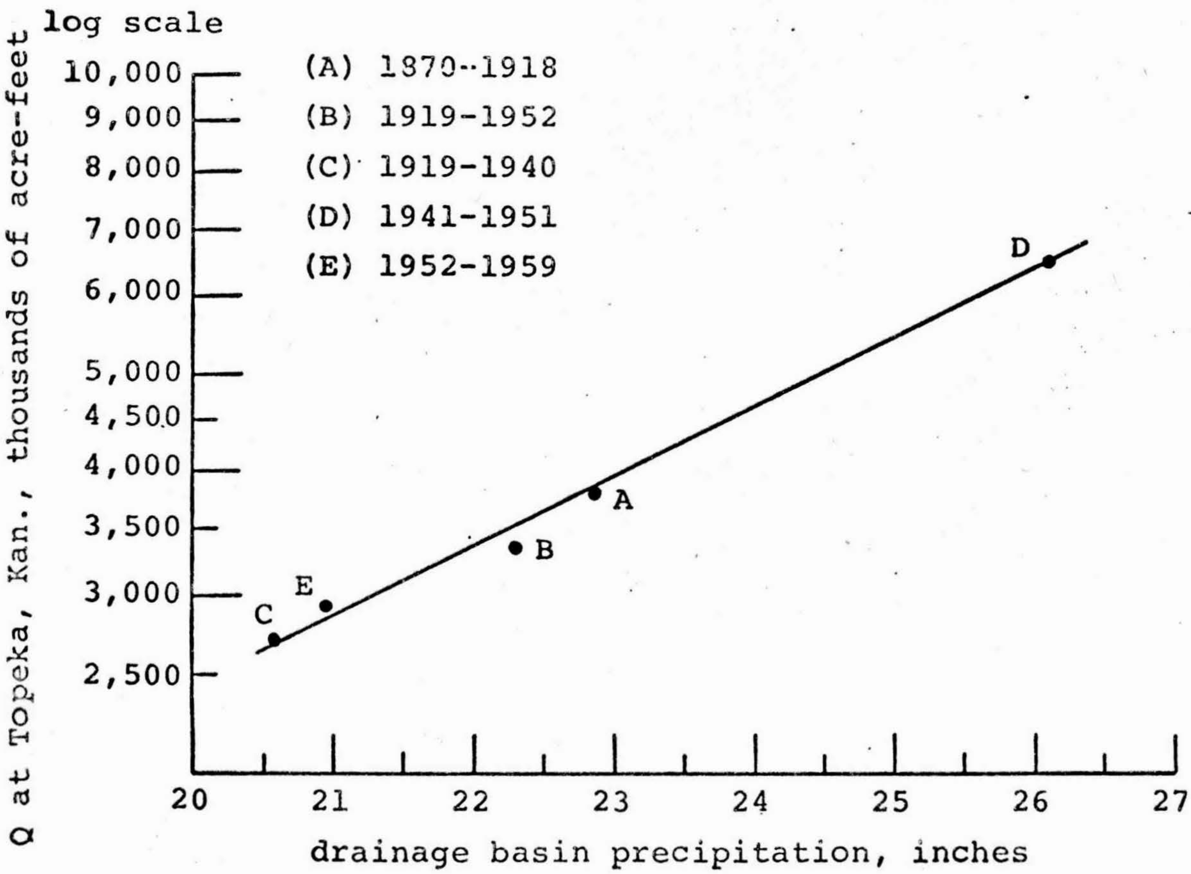


FIGURE 7. PRECIPITATION IN KANSAS R. BASIN vs. DISCHARGE AT TOPEKA, SELECTED TIME PERIODS

14.76 inches precipitation in 1894; 13.88 in 1934, 35.59 in 1915; and 34.88 in 1951. Extended droughts interrupted by years of above-average precipitation prevailed in both periods. The period 1910 until the early months of 1918, with the exception of 1915, was very dry. This drought was exceeded by the period 1930-1940, except for 1935 and 1938 (Kansas State Board of Agriculture, 1948, pp. 123-127).

The functional relationships shown in Figure 2, page 9 , do not include cultural effects and influences on the yield of water and sediment in a drainage basin. The following chapter discusses settlement and cultivation in connection with the shortening of the channel.

Chapter 5

SIGNIFICANCE AND CAUSES OF CHANNEL SHORTENING

5.1 Deterministic Interpretations

Many of the studies of cultural effects on physical processes have dealt with gullying and stream entrenchment in the Southwest U.S. (Dodge, 1902; Rich, 1911; Bryan, 1925; and Bryan, 1928). These writers tended to view the gullying as a result of changes in the vegetation cover brought about by man and his livestock. Later, attention was directed to climatic causes and the relationship to erosion-deposition. Tuan (1966) reviews these theories and investigates local conditions in which erosion-deposition took place. McLaughlin (1947) attributed the extensive widening of the Cimarron River in southwestern Kansas to overcultivation.

5.1.1 Cultivation and Soil Erosion

Some indication of the effects of continuous cultivation on runoff and soil erosion is provided by Table 5:

Losses from Erosion on a Shelley Silt Loam Soil at the Missouri Agricultural Experiment Station. The Slope was 3.7 per cent, the Plots 90 Feet Long and the Average Rainfall 40 Inches. (Average of Fourteen Years) [a]

Treatment	*Runoff, Per Cent of Rainfall*	*Tons of Soil Lost per Acre per Year*	*Relative Erosion, Bluegrass as 1*	*No. Yrs. to Erode 7 In. of Soil*
No crop, plowed 4 inches deep and cultivated regularly	30.7	41.64	122	24
Corn grown continuously	29.4	19.72	58	50
Wheat grown continuously	23.3	10.10	30	100
Rotation; corn, wheat & clover	13.8	2.78	8	368
Bluegrass sod continuously	12.0	0.34	1	3043

[a] **M. F. Miller and H. H. Krusekopf, *The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion,* Research Bulletin 177, Mo. Agr. Exp. Sta., 1932.**

Table 5

(from Buckman and Brady, 1968, p. 230)

Differences in soil types, slope, cultivation practices, and rainfall must be considered in an analysis of cultivation on the runoff characteristics in the Kansas River basin. Infiltration rates of rainfall are much higher in soils with a vegetal cover than in bare soils. Buckman and Brady (1968, p. 230) state that forests and grasses are the best natural soil protective agencies known.

5.1.2 Cultivation and Discharge

With increasing acreages being tilled and grazed during the period of settlement of the Plains, runoff percentages would increase. The mean annual discharge for the period 1870-1918, 3,818,000 acre-feet, would be an overestimation, applicable only to the last decade or two. Without additional data, estimates of runoff percentages in earlier years would be mere guesses. However, the peak stages and discharges listed in Kansas Streamflow Characteristics (Kansas Water Resources Board, Ibid., pp. 118-121) provide data of some significance. From 1869 to 1904, the maximum daily gage height exceeding flood stage (21.0 feet) is listed for those years in which flood stage was reached. From 1904-1956, several peak gage heights are given for each years. Since the data is more complete for the latter period, flood frequencies are computed from the annual flood series, in which only the maximum flood in any one year is considered. From 1869-1920, flood stage was reached at least once in each of 10 years, a flood frequency of 1 per 5.2 years. From 1921-1956, flood stage was reached in 14 years, a flood frequency of 1 per 2.5 years. If we examine the frequency of near-bankfull stage, selected as 18.00 to 20.99 feet, the situation is reversed. Near-bankfull stage was reached at least once in each of five years between 1905-1920 (not considering those years in which flood stage was reached). Near-bankfull stage occurred in only one year between 1921-1956. This seems to indicate that the flow was more regular in the earlier years, but fluctuated much more in the latter period. This view is consistent with a change from grassland to tilled land: In the former period, infiltration rates were relatively high and much surface drainage was supplied by subsequent slow movement of ground waters. Later, runoff percentages increased, resulting in large flows, followed by relatively smaller flows between periods of rainfall.

With increased runoff rates on land surfaces unprotected or only partially or seasonally protected by vegetation, erosion increased. Table 6 illustrates how rapidly the transformation of the landscape took place.

In 1930, the category previously designated as "improved"[1] farmland was changed to the equivalent term, "total cropland." Although the acreages are for the entire states, they are also representative of the Kansas River drainage basin. Within three decades after the Homestead Act of 1861, cropland acreage was 70 per cent of what it was in 1950. Total settlement of the land was essentially effected by 1920, surely one of the most rapid and complete exploitation of agricultural resources in the history of land development!

5.1.3 Discharge and Sediment Load Relationships

How would a stream respond to increases in discharge and/or load, two variables that influence, and may largely determine, channel geometry and morphology? The arrangement of main tributary streams to the Kansas River suggests that the master stream would respond quite rapidly. All but one of the trunk streams of the Kansas River basin are parallel to sub-parallel (Figure 3). The Smoky Hill, Saline, Solomon, Republican, and Big Blue Rivers converge within a short distance. Ninety-seven per cent of the Kansas River drainage above Topeka is integrated within a distance of 145 river miles, from Salina to Manhattan. This contrasts rather sharply with the usual system of drainage in which the master stream receives contributions at rather regular intervals. Relative changes of discharge and load produce changes in slope and sinuosity as summarized in Table 7.

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[1] "Improved land includes all land regularly tilled or mowed, land pastured and cropped in rotation, land lying fallow, land in gardens, orchards, vineyards, and nurseries and land occupied by farm buildings." (13th Census of the U.S., 1913, p. 25).

TABLE 6

ACRES IN FARMS

YEAR	KANSAS TOTAL	KANSAS IMPROVED	NEBRASKA TOTAL	NEBRASKA IMPROVED
1860	1,778,400	405,468	631,214	118,789
1870	5,656,879	1,971,000	2,073,781	647,031
1880	21,417,468	10,739,556	9,944,826	5,504,702
1890	30,214,456	22,303,301	21,593,444	15,247,705
1900	41,662,970	25,303,301	29,911,779	18,432,595
1910	43,384,799	29,904,067	38,622,021	24,302,577
1920	45,425,179	30,600,760	42,225,475	23,109,624
1930	46,975,647	31,415,703	44,708,565	25,499,594
1940	48,173,635	34,193,430	47,345,981	25,414,860
1950	48,611,366	29,439,625	47,466,828	23,776,470
TOTAL AREA	52,648,960 Acres		49,425,280 Acres	

(U.S. Dept. of Commerce. Bureau of the Census, 1922, 1932, 1952)

TABLE 7. SLOPE AND SINUOSITY ADJUSTMENTS TO DISCHARGE AND LOAD

Condition	GIVEN: Discharge	Load	RESULTANT: Slope	Sinuosity
1.	Constant	Increase	Increase	Decrease
2.	Constant	Decrease	Decrease	Increase
3.	Increase	Constant	Decrease	Increase
4.	Decrease	Constant	Increase	Decrease
5.	Increase	Decrease	Decrease	Increase
6.	Decrease	Increase	Increase	Decrease

Table 2 shows that the sinuosity decreased progressively from 1870 to 1900 to 1921 to 1942. Conditions 1, 4, and 6 are possible causes. On the basis of consistent precipitation, condition one best fits the decreasing sinuosity from 1870-1921. Both conditions four and six may have been operative in 1921-1942. Increased soil erosion accompanied decrease in rainfall during the drought of the 1930's.

Since 1940, there have been two short-term periods characterized by, respectively, abundant rainfall and drought. From 1941 through 1951, annual precipitation averaged 26.07 inches and discharge averaged 6,541,000 acre-feet, almost double the mean for the preceding 34 years. The increase in sinuosity from 1.209 to 1.253 is consistent with the model of channel length adjustment to average discharge (condition 3, Tabel 7). Precipitation from 1952 through 1959 averaged 20.96 inches, discharge 2,818,000 acre-feet. The first five years of this period were particularly dry. The channel was shortened 1.79 miles from 1952 to 1959.

It is important to emphasize that the consistency with which channel lengths and sinuosities fit the hypothetical relationships of Table 7 during these short-term periods may be mere coincidence. Additional factors were present. Harlan County, Kirwin, and Webster

Reservoirs were presumably filled between 1953 and 1959, in addition to replenishment of existing reservoirs. These, along with numerous farm ponds act as sediment traps. Waters released from reservoirs would be relatively free of sediment. Unloaded waters may degrade stream beds in the reach immediately downstream from the reservoirs or pick up bank material in order to equalize available and expended energy.

The programs initiated by the Soil Conservation service of the Department of Agriculture may be quite significant. Watershed planning programs and soil conservation programs including the construction of farm ponds, terraces, contour farming, crop residue management, proper range and pasture use, windbreaks, grassed waterways, drainage ditches, and conservation cropping systems may have significantly reduced erosion in the last 10-20 years. The first soil conservation district in Kansas was organized in 1938 following enactment of the Soil Conservation District Law (Kansas State Soil Conservation Committee, 1962, p. 4).

5.1.4 Gradient Steepening Through Deposition

Mackin (1948, p. 493) discusses the response of a graded stream to changes in control. He states: "A once-graded stream responds to an increase in load primarily by steepening its declivity below the point of influx,". Whether or not the Kansas River fits his concept of a once-graded stream is not known; the principle involved is the manner in which the steepening is accomplished. "The steepening is accomplished by deposition of part of the excess load in the channel at the point of influx with a consequent upbuilding of the channel at that point and the formation of a steepened part immediately below. Steepening of any segment permits increased transport of load through that segment to the next segment which is in turn the site of deposition and steepening. Thus the effect of an increase in load is registered by the downvalley movement of a wave of deposition, large or small depending on the rate and manner of addition of the load, and deposition must continue throughout the stream below the point of influx until the slope is everywhere adjusted to the transport of all the debris delivered to it." (Op. cit.).

The evidence cited in Table 2 suggests that the gradient of the Kansas River was increased through channel shortening rather than through the process articulated by Mackin. Whether or not the shortening was in response to a relative increase in load may still be open to question.

Further examination of the alterations involved in a gradient increase by deposition is in order. This process requires that the gradient of the stream from the point of influx along the segment through which the larger load is transported must everywhere be steepened. The gradient requirements, however, need not be increased in the same proportion throughout the downstream sections since the calibre of the load would be decreased through attrition, abrasion, and sorting. But does this segment extend clear to base level and if so, does this mean that the aggradation of the upstream portions be the primary contribution to the increased gradient requirement? This mechanism may operate in streams short distances from the coast but it seems improbable in streams hundreds of miles inland not subject to temporary base level controls.

The establishment of a steepened gradient by shortening the channel length seems much more plausible and easier to accomplish, particularly if the floodplain were deforested and cleared for agricultural activities.

5.1.5 Flood Velocity

Table 7 is a pragmatic model of the effects of changes in discharge and load. Other mechanisms and processes besides channel shortening may operate. The role of velocity in the transportation of load supplied to a stream is fairly well established. Mackin (1948, p. 470) quotes Rubey in attributing the capacity of a stream to move material to the "...third power of the bed velocity." Velocity is not entirely a function of slope. Leopold (1953, pp. 615-618) found that the mean flood velocity of tributaries of the upper Yellowstone River in Wyoming and Montana were essentially constant downstream despite marked decreases in gradient. This seems to suggest no functional relationship between velocity and slope and is completely incompatible with the hypothesis that the Kansas River shortened its course in order to transport an increased load supplied to it. The key to Leopold's analysis is the term, mean flood velocity. In order to establish a basis of comparability, he chose data corresponding to the flows during 5 to 50 year floods. (Ibid., 1953, p. 608). The velocity of flood flows in downstream sections would be expected to match those in upstream sections through a consideration of the mere mass of water involved. Flood waters are invariably swift and probably have little dependency on channel slope. The rating table for Wamego gives gage heights and their respective discharges. Solving for v in the formula Q = wdv (Q = discharge, w = width of channel, d = depth of channel, v = velocity) yields the following figures. The width of the channel is essentially constant with increasing depth. Gage height is similar, but not identical to depth.

TABLE 8

FLOW VELOCITIES

Gage Height (ft)	Width (ft)	Discharge (cfs)	Velocity (ft/sec)
4.3	750	1,870	0.56
5.0	750	3,040	0.81
6.0	750	5,140	1.14
9.0	750	14,000	2.07
14.0	750	36,500	3.48

(after U.S. Department of the Interior, Geological Survey, 1962, p. 73)

5.1.6 Channel Shortening by Floods

In 1900, the length of the channel in the study area was 53.6 miles. This was reduced by 9.3 miles by 1942. The double cut-off effected by the 1903 flood accounted for 5.6 miles, or 60 per cent of the reduction. This seems to imply that most of the changes in channel shape and pattern result from large flows of infrequent occurrence which overshadow normal flows in terms of geologic work accomplished. There is no doubt regarding the erosive and transporting capabilities of flood waters. What is commonly overlooked in comparisons of work done by forces of different magnitude is the frequency and length of time these forces are operative. Wolman and Miller (1960, pp. 57-63) concluded that by far the greatest part of the total sediment removed from the drainage basins during the period of record was carried by small to moderate flows and not by catastrophic floods. The floodplain and shape are controlled by moderate forces rather than the rare discharge of high magnitude (Wolman and Leopold, 1957, p. 66).

A consideration of the development and cut-off of a meander illustrates the work done by different processes. Development requires years of lateral erosion and accretion in which the loop is enlarged and lengthened while the meander neck is narrowed. A major flood may effect the cut-off before the two flanks of the meander erode into one another. But the meander is not abandoned immediately; it may remain an active channel for years. Additional time is required for the ends to fill up with silt and clay before the meander is finally isolated. The cut-off at the Silver Lake meander was present in 1856 but the meander wasn't abandoned until sometime between 1884 and 1898. Thus, floods may be the immediate cause of changes, but the conditions which necessitated changes in channel length and slope may be long-term adjustments to other controls.

5.2 Random Processes

The foregoing discussion has been confined to a deterministic interpretation of fluvial processes and their expression in geomorphology.

The assumption is that a change in channel morphology resulted from a change in the dynamic components of the physical system. Is this change entirely within the range of random processes? C. J. Mann (1970) summarizes recent work by several earth scientists concerning randomness in fluvial processes and geomorphology. These studies show that fluvial networks, meander development, stream profile gradient, and landscape development may be considered to be random phenomenon (Ibid., p. 96). Others believe that "the interpreted randomness is merely an accumulation of numerous deterministic events into a complex and undecipherable tangle which is not a result of the inherent randomness of the process." (Ibid., p. 97).

Leopold and Langbein (1963, pp. 184-192) see a principle of indeterminancy operating in landscape development. "By indeterminacy in the present context we refer to those situations in which the applicable physical laws may be satisfied by a large number of combinations of values of interdependent variables." (Ibid., p. 189). The physical laws governing forces and motions may be completely fulfilled by a variety of combinations of the interrelated factors. In the specific case of a stream receiving various rates of discharge and sediment, the preceding statement means that "...a number of interdependent hydraulic variables will change, including width, depth, velocity, slope, and hydraulic roughness. A particular change in discharge and sediment may be accommodated by several combinations of values of these dependent or adjustable factors." (Ibid., p. 189).

Langbein and Leopold (1966, H1) postulate that the planimetric geometry of the meander is a random walk phenomenon. Thus, the appearance, or shape, of a meander may be a random phenomenon, but this is quite different from the existence, abandonment, or absence of meanders. This last point can be articulated in other terms. At any instant of time, a given reach of an alluvial river displays meanders in various degrees of development. Some meanders may be just beginning to be developed, others may be in a mature stage, while some may have been cut-off in the recent past. If the river is in equilibrium or quasiequilibrium, the sinuosity remains fairly constant because new meanders are born and formed while older ones are cut-off and abandoned. But if the situation develops in which meanders are cut-off and the channel length shortened without a concomitant development of new meanders, the non-development suggests that an adjustment is being made to accommodate changes in the river system.

In the study area, only one meander has developed. Plate 1, T. 9S, R. 9E shows a gentle S-shaped curve in the 1942 channel. This curve is now a textbook example of a meander. The development of this curve does not coincide, either in time or place, with the major shortening of the channel. The argument can be made that man has, in the last several decades, increased his efforts to control the lateral movement of the river and prevent bank erosion from destroying his fields, thereby preventing meander development.

The substance of the controversy concerns the significance of the shortened reach within the context of the entire river. What has happened upstream and downstream? Inspection of the longitudinal profile provides comparisons from which substantive inferences can be made.

5.3 The Longitudinal Profile

The longitudinal profile of a stream has long been recognized and has been treated in a probabilistic model of stream length and elevation by Leopold and Langbein (1962). Their model agrees with empirical data, in that stream elevation declines exponentially with distance. An analysis of the entire length of the river will permit comparison of the upstream and downstream reaches with the central portion. Plate 2 shows the longitudinal profiles (1870 and 1960) of the Kansas River from the confluence with the Republican River to Kansas City, Kansas, 9.6 miles above the mouth. The elevations indexed by the circled numbers were obtained from 31 cross-valley profiles run by the Corps of Engineers, U. S. Army Engineer District (1965). Dashed lines connect common points of both profiles in order to show changes in channel length and gradient of the four reaches: 1) Republican River to Point A; 2) Point A to Point F (Study area proper); 3) Point F to Bowersock Mill dam at Lawrence; and 4) Mill dam to cross-valley profile #1 at mile 9.6. Since the floodplain displays no evidence of effective aggradation or degradation, the assumption is made that these points were essentially the same elevation in 1870 as in 1960.

TABLE 9. PARAMETERS OF THE LONGITUDINAL PROGILE, KANSAS R.

		Reach			
		1	2	3	4
Length (miles)	1870	38.9	57.0	40.5	39.7
	1960	35.3	47.7	36.0	41.9
Gradient (ft./mi.)	1870	1.876	1.737	1.679	1.889
	1960	2.068	2.075	1.888	1.789
Sinuosity	1870	1.376	1.469	1.374	1.247
	1960	1.249	1.195	1.221	1.316

(from U.S. Army Engineer District, Kansas City, Corps of Engineers)

The changes in the various reaches are, in the main, consistent with a progressively gentler gradient downstream. Reaches 1 and 2, the upstream portion, experienced the greatest channel shortening; reach 4, which was apparently oversteepened in 1870, increased its length slightly. The fit isn't perfect: Reach 2 is now oversteepened, particularly its downstream portion in which much of the channel shortening occurred. The irregular slope shown by the 1960 profile is, of course, greatly exaggerated. The undulations can be interpreted to be in support of Mackin's theory of adjustment to an increase in load discussed above (pp. 35-36). Slight undulations in slope most probably existed in 1870, also. The general configuration of the profile was probably much the same in 1870, especially in those reaches which have experienced little change. Lack of data prevents a valid comparison of the magnitude and location of the undulations in detail.

5.4 A Prehistoric Period

What was the nature of the channel pattern and behavior of the Kansas River during the period of decades or centuries prior to 1856? Historical documentation yields no information but meander scrolls and scars betray former channel positions. Indications of a slight incipient extrenchment provide a means to delineate the youngest meanders.

The modern floodplain shows several generations of meander scars, the youngest of which cut across, or are partially superimposed on, the older ones. The presence of an intermediate surface, recognized by Dufford (1958, pp. 28-29), on the floodplain provides a basis of comparability for connecting discontinuous channel segments of proximate ages. The meanders on the intermediate surface are truncated by mildly sinuous, slightly lower channel lines and meander scars. This slight topographic break, recognizable with stereo viewing but not on topographic maps, constituted delineation of the pre-1850 channel shown on Plate 1. Interpretation of the relative sequence of channel positions was also based on truncation of older by younger channel lines and relative freshness or obscureness of the scars. Stereo pairs of air photos taken in May, 1942 were viewed with a scanning stereoscope. The 1942 photos displayed optimum differences in soil types and textures in the identification of former channel positions. Attenuation of channel lines and meanders by cultural activities was also less than on photos taken in later years.

From the middle of T.10S, R.11E westward, the lack of old meander patterns suggests that the channel has been stable for a long time in this area. The two large meanders at, and downstream from, Wamego have migrated but have maintained stable forms for a considerable length of time. The discontinuous segments on Plate 1 corresponding to pre-1850 channel in the legend are placed at proximate dates on the basis of their cutting across older channel lines and being truncated by younger channels. The surface on which they occur is slightly lower than the intermediate surface between them and the Newman Terrace. The sequence suggested by the surface configuration and channel positions is a period of degradation, overall channel straightening and southward shifting in the period prior to 1850. The channel lines in Townships 11S, Ranges 13, 14, and 15E running sub-parallel to the present channel must be progressively younger from north to south.

The length of the pre-1850 channel was measured by connecting the segments with smooth curves (dotted lines, Plate 1). Westward from the middle of R.11E, the channel has been remarkably stable and inadequate evidence exists to differentiate the channel from its 1856 position. Therefore, the 1856 channel was assumed to be representative of the pre-1850 channel in that reach. The sinuosity of the pre-1850 river is 1.56, indicating that channel shortening has been a general process for several hundred years.

The slight renewal of downcutting could have occurred during the period 1550 A.D. to 1850 A.D., an interval comprising a portion of the Neoglaciation (Porter and Denton, 1967, pp. 204-205) or the Neo-Boreal (Bryson and Wendland, 1966, p. 280). This climatic change is well documented in Europe (Lamb, 1968) and in North America where glaciers formed as far south as New Mexico (Richmond, 1965) and "...the summer precipitation in northern New Mexico seems to have been two to three inches greater than the recent normal" (Ibid., Bryson and Wendland, p. 296).

Increased precipitation rates have been cited as a factor contributing to a phase of stream downcutting (Frye and Leonard, 1952, p. 15). For the Kansas River, a hypothetical sequence is a period of slight channel entrenchment in the waxing phase of the Neo-Boreal and adjustments of channel pattern and gradient to changes in discharge and load in the waning phase. In this context, the designation of the date 1850 to fix the beginning or end of the phase of climatic amelioration would be critical. If it marks the beginning of the phase, the channel shortening which occurred may have been climatically induced. The contemporaneous settlement and cultivation of the drainage basin may then be mere coincidence, unrelated to channel shortening. However, the channel length remained essentially unchanged from 1856 to 1870 (Table 2). Whether any significant conclusions can be drawn concerning the gradedness of the river during this short period of time is another unresolved and, perhaps, unresolvable question.

Chapter 6

CONCLUSIONS

The facts, interpretations, and rationalizations presented can be described in terms of the degree of certainty one can attach to them. The shortening of the channel is beyond question. The channel lengths in Table 2 are, of course, not absolute but the order of magnitude of the changes is convincingly shown.

The similarity of the precipitation for the period 1870-1918 and 1919-1952 also rates a high degree of certainty. The similarity of the nature of the discharge for these periods is lower on a scale of certainty but still quite reliable. We must acknowledge the possibility of smaller percentages of the precipitation occurring as discharge and smaller fluctuations between high and low flows in the earlier years. The functional relationship of bankfull discharge or the discharge of the month of maximum discharge, cited on page 2 can be added to the list of alternative explanations.

Man's role in the removal of the native vegetation and the resulting acceleration of soil erosion is common knowledge. How much soil has been eroded and what effect has this had on the behavior of streams and rivers, the receptacle for vast, but unknown, quantities of particulate matter? Thus, there is a wide gap between the existence of the fact on one hand, and the significance of the fact on the other. A consideration of the interrelated variables in Figure 3 and the number of possible combinations for which changes in discharge and sediment may be accommodated strongly suggest that a single cause and effect relationship would be difficult to isolate and identify. It seems reasonable and logical that a substantial increase in sediment supplied to a river would be manifested in some measureable form. The evidence for channel shortening as this manifestation is certainly not conclusive, but the mechanism does warrant due consideration in an analysis of channel morphology.

APPENDIX 1

RESERVOIR NAME	SUB-BASIN	COMPLETION	NORMAL CAPACITY ACRE FEET	FLOOD CONTROL CAPACITY
Kanopolis	Smoky Hill	1948	53,000	397,000
Medicine Creek	Republican	1949	39,000	52,000
Enders	Republican	1950	44,000	30,000
Cedar Bluff	Smoky Hill	1951	185,000	192,000
Bonny	Republican	1951	41,000	129,000
Harlan County	Republican	1952	350,000	500,000
Trenton	Republican	1953	120,000	134,000
Kirwin	N. Solomon	1956	95,000	219,000
Webster	Solomon	1957	72,000	200,000
Lovewell	Republican	1958	44,000	50,000
Red Willow	Republican	1961	38,000	50,000
Tuttle Creek	Big Blue	1962	1,634,000	1,933,000
Wilson	Saline	1966	266,000	510,000
Norton	Republican	1966	36,000	100,000
Milford	Republican	1969	380,000	700,000
Glen Elder	Solomon	1969	239,100	736,900

(Senate Document No. 122, Ibid., p. 45 and Personal Communication, M. M. Turner, Department of the Army, EE)

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