FINAL REPORT

(for Contract Modification)

# CHANNEL MIGRATION STUDY

for the

Kansas River and Tributaries Bank Stabilization Study

submitted by

Dr. Wakefield Dort, Jr.

Geomorphology Laboratory
Department of Geology
The University of Kansas
Lawrence, Kansas 66045

June, 1981

for the

Kansas City District
U. S. Army Corps of Engineers

Contract No. DACW41-77-C-0114 Modified

Table of Contents

# INTRODUCTION

Intermittent migration of portions of the channels of the Kansas River and its major tributaries has led to localized damage to adjacent farmland. In certain areas, roads, powerlines, and houses have been endangered or, in some instances, lost. In response to appeals for assistance from landowners, the Congress, in 1973 and 1974, authorized the Kansas City District of the U.S. Army Corps of Engineers to undertake a study of bank stabilization problems along the Kansas River and those portions of its major tributaries downstream from large dams and reservoir impoundments.

In June, 1977, the Kansas City District of the Corps contracted with the Department of Geology of The University of Kansas for a project entitled "Channel Migration Study for the Kansas River and Tributaries Bank Stabilization Study". The main product of this Contract was an atlas of "Historic Channel Change Maps" which depict, in eleven colors, a record of changes in approximately 725 miles of river channel during the past 100 to 125 years. Data for this atlas were acquired from various published maps, such as county atlases, railroad plots, and several editions of U.S. Geological Survey quadrangles.

This Contract also resulted in production of channel-activity maps and maps outlining areas of valley floors that had been affected by active channel migration during (a) the period of historic record since about 1850 and (b) the time of formation of the present floodplain and low floodplain terraces through the past few thousand years. In addition, detailed plots of past channel activity and projections into the future were prepared for certain "Intensive Study Sites".

## CONTRACT MODIFICATION

After the requirements of the origional Contract had been satisified, the Department of Geology of The University of Kansas was awarded a Contract Modification which extended the scope of work of the original Contract and required additional products. This report is concerned only with the results of work accomplished under the Contract Modification. The order of presentation below follows that the subject matter of the Contract Modification document.

### Bibliography

A compilation of "Reference Lists of Publication, Maps, and Aerial Photographs of the Kansas River Basin" was prepared in 1977. This included 22 pages of references to published articles and books and an additional 43 pages of lists of maps and aerial photographs applicable to the project.

The scope of the first "Reference Lists" had been limited to material relating essentially to the specific area of study - the

Kansas River and its major tributaries downstream from the big dams and impounded resevoirs. Under the Contract Modification, the scope of the "Reference Lists" was expanded to include the entire drainage basin of the Kansas River, An area that includes the northern half of Kansas, approximately the southern third of Nebraska, and part of northeastern Colorado. The revised "Reference Lists", issued in July, 1979, included 38 pages of literature references and 52 pages of lists of maps and aerial photographs.

The July, 1979, edition of the "Reference Lists is attached as Appendix A of the Report. Since issuance of that edition, additional references have been discovered, and new maps have been issued. A third edition of the "Reference Lists" will be compiled and issued during the Winter of 1980-81 even though the life of the Contract Modification has terminated.

TERRACE ANALYSIS

Although the situation varies considerably from place to place, it can be generalized that the Kansas River occupies a valley that has a floor on the order of two miles wide and sides that rise precipitously to an upland 150 to 200 feet higher. The presence of terraces above the modern floodplain has long been recognized, but the ages of these terraces and the interpetation of the geomorphic history of the valley continues to be controversial.

Lohman and Frye (1940) believed that the Kansas River as seen today was established during the Kansan Glaciatian, considered at that time to have occured in the earlier half of Pleistocene time. The Menoken Terrace, represented by scattered remnants roughly 100 feet above the modern floodplain, has been called Kansan in age, although its precise relationship to the advancing or retreating Kansan ice sheet or to the following Yarmouth interglacial episode is unknown. The better-preserved Buck Creek Terrace lies approximately 30 feet above present floodplain. It has been considered to be of Illinoian age, meaning that it was presumed to be in some way related to the Illinoian Glaciation which occured in the later half of Pleistocene time (Davis and Carlson, 1952).

The extensive, well preserved, low-level Newman Terrace was identified by Davis and Carlson (1952) between Topeka and Lawrence and by Dufford (1958) from Lawrence to Bonner Springs. This surface lies only about 10 feet above the modern floodplain and is thought to be of Late Wisconsin (latest Pleistocene) or Early Recent time.

Recent revisions of Pleistocene chronology and terminology have raised the possibility that the Pleistocene Epoch began much earlier than was previously thought. This suggests a revision that might place the classical Kansan Glaciation in what is really the later half of Pleistocene time (as revised). This is however, of no importance to the present study. Both the Menoken and Buck Creek Terraces are so old and lie so high above the modern floodplain that their histories do not contribute significantly to an understanding of the recent history of Kansas River.

In contrast, the Newman Terrace surface is still being aggraded during severe floods. Nevertheless, the actual formation of the original floodplain surface, which has since been abondoned and dissected, occured so long ago that no remnants of original channels or floodplain scrolls remain visible either in the field or on aerial photographs. The Newman Terrace therefore is of significance to the present study only in that it is the lowest - and youngest - "fossil" valley floor to have formed prior to the present major cycle of erosion It thus sets an upper limit on the possible length of time during which the present river cycle has been active.

The presence of a terrace surface below the Newman Terrace, but above the present floodplain, was suggested by Davis and Carlson (1952). McCrae (1954) identified such a surface west of Lawrence. East of Lawrence, Dufford (1958) also recognized evidence of a pause in valley downcutting, but he thought that there actually was a complex of three surfaces - one 3 feet below the Newman Terrace, one just one foot lower, and a third for which the relationship was not clear. This sub-Newman surface or complex of surfaces was named the Holliday Terrace by McCrae (1954) and is now informally called the Holliday Terrace Complex.

Whereas all evidence of former channel activity on the Newman Terrace surface has been removed by subsequent smoothing and covering, mainly by overbank flood deposition, the Holliday surface or surfaces show well-preserved floodplain scrolls and segments of abandoned paleochannels. It was therefore considered that a careful study of these evidences of earlier channel forms and positions could yield data of importance to the present project. It was hoped that through such a study it would become apparent if there had or, conversely, had not been a marked change of channel size or of meander radius - both indicative of river discharge at some time in the past. In addition, comparisons of past meander shapes with those of the present might indicate something about changes in load quantity and size distribution.

Provision for a study of the Holliday Terrace Complex was an integral part of the Contract Modification which called for an investigation along the Kansas River by examination of aerial photographs accompanied by limited field checking. This analysis was to be extended up the major tributaries if possible. Ages of terraces were to be determined by radiocarbon dating of logs or bones included in the sub-terrace sediments if any could be found.

Study by Elks

The published literature includes a number of reports describing mathematical relationships between the discharge of modern streams and channel parameters such as channel width, meander wavelength, the radius of curvature of meanders, and channel sinuosity (the ratio of the length of a curved channel between two points to the straightline distance between those points). If specific relationships exist today, they should also have held in the past because the basic laws governing fluid flow in natural channels are considered to have been unchanging. This in turn means that if the critical parameters can be determined for prehistoric channels, termed paleo-channels, then the prehistoric discharge (or paleo-discharge) can be calculated.

In an attempt to use parameters of paleo-channels of the Kansas River as a basis for calculating paleo-discharge levels, John E. Elks investigated an area between Lecompton and Eudora (See Appendix B). Some data on especially well preserved remnants of paleo-channels were obtained from recently-published topographic maps. However, most of his information was derived from study of aerial photographs. In addition, to complete coverage of his study area on full-color photographs and from flights of black and white photography taken in several different years, he also used partial coverage of high-altitude infra-red imagery.

Remnants of the Newman Terrace were identified by their extensive preservation, their height above the river, and the absence of floodplain scrolls or other indications of past locations of channels. The Holliday Terrace surface (or complex of surfaces) was identified by its location on the channel side of erosion scarps that truncated portions of the Newman Terrace yet were truncated, in turn, by scrolls and scour lines that are closely associated with the present channel and that are on the present floodplain. It was not possible to separately identify the supposed three sub-surfaces of the Holliday Complex.

As accurately as possible, Elks measured the widths of paleo-channels on the Holliday surface and the radii of preserved meanders scars. He also attempted to measure wave lengths of these meanders. Unfortunately, only small segments of meanders have been preserved, not enough, in his judgement, for accurate determination of either meander radius or wave length. Even measurment of channel width was somewhat subjective where one side was bordered by a gently-sloping point bar. Nevertheless, Elks believed that computations based on widths of certain specific reaches of paleo-channels were sufficiently accurate that they provided as least approximate indications of the discharge of the river at the time the channels were formed.

Leopold and Maddock (1953) demontrated that the width (W) of a natural channel increases with mean annual discharge (Q) as a power function. The basic formula is stated as:

$$W = aQ^b$$

They found that for certain streams in the western and central United States, the value of the exponent "b" averaged 0.5, but the constant "a" varied, apparently with characteristics of the drainage basin. Based on data from 29 streams in humid reagions, Carlston (1965) determined that the equation read:

$$W = 7Q^{.46}$$

In contrast, Burn (1971), using data from streams scattered throughout Kansas, obtained the relationship:

$$W = 3.1Q^{.58}$$

Following the suggestion by Osterkamp (1977) that the exponent be kept at a constant 0.5, Elks used data from five gaging stations on the Kansas River to produce the equation:

$$W = 11Q^{.5}$$

Elks then applied this equation, derived solely from Kansas River data, to the information obtained from the paleo-channels near Lawrence. He found that these remnant segments readily separated into two groups. Meander scars located 1 to 3 miles east of Perry and also just northeast of North Lawrence appeared to have been formed by a river discharge equal to or slightly in excess of present discharge. In contrast, channel remnants 2 miles northwest of Lawrence and also 4 miles east of Lawrence have less width and higher sinuosity, relationships which he interpeted to mean that they had formed under conditions of discharge lower than that of the present. He suggested that there may also have been a lower bed load.

Elks had no means of obtaining absolute ages for channels of the two regimens. The best that he could say was that the smaller, more sinuous channels occur in positions well removed from the present course of the river and therefore may be presumed to be of some antiquity. This, in turn, suggested to him that an increase in mean annual discharge of the Kansas River occurred several hundred to a few thousand years ago.

## Other Studies

Study of the Holliday Terrace Complex was pursued further during the life of the Contract Modification. However, the several surfaces of the Holliday Complex, if, indeed, there are multiple valid subdivisions, are so nearly the same level that the slight differences in elevation cannot easily be distinguished on aerial photographs. Furthermore, both the group(?) of Holliday surfaces and the modern floodplain surface have relief, differences in elevation between the bottoms of relict paleo-channels or scour lines and the bordering "highs". As a consequence, it was soon discovered that completion of a reasonably reliable map of any subdivisions of the Holliday Terrace Complex will require prolonged field work involving accurate determination of elevations, perhaps to the nearest foot. Such a survey is beyond the scope of the present Contract and Contract Modification. (This job could, of course, be accomplished by photogrammetric methods using aerial photographs and an established grid of ground-truth elevations, but only at tremendous expense for an area as extensive as the floor of the Kansas River Valley from Kansas City to Junction City.)

In the absence of data in greater detail, the summary maps showing "Areas of Channel Migration" that were compiled under the original Contract do provide a fairly accurate indication of the extent of the Holliday Terrace Complex. It is the area that is shown by a pattern indicating occupation by active channels during "the last few thousand years".

It was also hoped that under the Contract Modification it would be possible to obtain knowledge of absolute or exact ages of some of the sediments and land surfaces being studied. The best source of such information would be from radiocarbon dating of wood or bone found contained in sediments underlying a specific channel floor, terrace surface, or other land form. Some logs have indeed been found protruding from cutbacks along the river and samples have been submitted for dating. Unfortunately, commercial radiocarbon laboratories operate with a tremendous backlog of orders. Dates on most of the samples sent in for the Kansas River Project have not yet been received.

One log from the Eudora Bend (Weaver's Bottom) yielded a radiocarbon age of 785 $\pm$ 130 years before the present. The sample came from the top of a clay layer that is present at extreme low-water stage and is covered by a thick section of silts that underlie an extensive surface that is probably modern floodplain (as opposed to Holliday Complex). If the date is valid, and there is at this point no reason to suppose otherwise, then the 12-foot thickness of overlying silts has been accumulated and the modern floodplain surface developed within about 800 years.

A log from a gravel pit located approximately one-half mile southeast of Bonner Springs yielded a radiocarbon age of 2395 $\pm$ 65 years before the present. The identity of the surface into which the pit has been excavated is not certain, but is probably related to the Holliday Terrace Complex. The sediments which enclosed the log, and which were at least approximately dated, were of course, deposited prior to the formation of the overlying terrace surface.

A reach of the river extending a few miles both upstream and downstrean from the Bonner Springs is characterized by extensive development of channel-side and mid-channel bars that are irregularly capped by coarse limestone gravel. Similiar bars are unknown along the rest of the mainstem Kansas River. Also noteworthy is the occurrence on these bars of numerous bones, many belonging to animals either extinct or at least not inhabitants of the area now. The total collection appears to represent a Late Pleistocene fauna, but the actual mode of occurrence of the bones in situ and, therefore, the signifance to interpretation of river activity is not at all clear. Christopher W. Holien has undertaken an investigation of this exceedingly interesting phonomenon, the subject of which is not related to the present Contract Modification and which will not be completed until the summer or fall of 1981.

Appendix C presents an abstract submitted by Johnson et al. for a meeting of the American Quaternary Association. This summarizes present thinking in regard to the probable age of "younger" alluvium in major valleys of eastern Kansas and adjacent areas.

MATERIALS ANALYSIS

One outstanding result of work accomplished under the primary Contract was the demonstration that through time the Kansas River has not acted as a single unit. Contrary to original simplistic expectations, the river can be subdivided into reaches of contrasting levels of activity. This holds true similarly for the timing of the activity. After the channel-migration maps had been compiled, it was seen that some reaches had been inactive during the late 1800s and early 1900s only to become highly active in the past 10-20 years. For other reaches the reverse was true, the activity being in the earlier part of the recorded history. There also are reaches which have been active throughout the past 100-125 years, and reaches that have remained stable throughout that period.

A reasonable expectation would be that a channel reach would be relatively active when it was migrating in a direction that led into easily eroded materials such as sand. In contrast, a reach would expectably be stable when it was migrating into material that eroded with great dificulty, such as clay beds. (The question of erosion into bedrock did not arise because the present channel of the Kansas River is in contact with bedrock at only a very few, very restricted localitites.)

In order to test this working hypothesis, the Contract Modification called for examination of the distribution of various kinds of materials exposed in the bed and banks of the Kansas River. This was to be accomplished by compilation of data that presumably had already been acquired by the U.S. Geological Survey and the Corps of Engineers. Minimal field examination was called for.

Unfortunately, the data obtainable from these sources turned out to be minimally used for the needs of this particular project. What is required is detailed information about absolute grain size, distribution of grain sizes, thickness of strata, continuity of strata, and levels of occurrence relative to various flow stages of the river. Furthermore, this information is needed for the entire lengths of both sides of the channel. Data obtained from the Survey and the Corps are very spotty and do not provide sufficient information to permit interpetations. A program of continuous mapping from a boat is needed for this purpose.

Study by Hoppie

A very detailed study of that portion of the Solomon River extending from Glen Elder Dam downstream to the confluence with the Smoky Hill River was undertaken by James R. Hoppie. (The resulting Master's thesis comprises Appendix D.)

Each of the major tributaries of the Kansas River follows a sinuous course down a broad, relatively straight valley floor that is underlain by a considerable thickness of alluvium - each is a so-called "alluvial river". The lower Solomon River was selected as a sample for which the problems and history of channel migration could be investigated in considerable detail for the Contract and Contract Modification.

Hoppie observed that within the area being studied the Solomon Valley could be subdivided into three segments of differing alignment or orientation. He then found that each segment had dominant, though different, meander shapes. He also recognized contrasts, from one segment to another, in gradient, various channel-shape parameters, and characteristics of the local geologic substrate. Ultimately, he concluded that the present-day geometry of the Solomon River is, to a considerable degree, determined by local geologic factors, and not, as held by current conventional geomorphic thought, by discharge, sediment load, or some other hydrodynamic condition.

A fundamental assumption in studies of fluvial geomorphology has been that stream systems are either in equilibrium or are working toward establishment of an equilibrium condition. It is believed that under "normal" conditions, discharge increases in the downstream direction and, as a direct consequence, various channel parameters and hydrodynamic processes also will show systametic changes along the length of the stream. The principle means of domonstrating these assumptions has been the use of bivariate or trivariate regression equations and the graphic plots from which these equations often have been devoloped. Hoppie's observations, however, showed that simple mathematical relationships among channel and stream parameters do not exist on the lower Solomon River. He found that vegetation and local surface or shallow subsurface geologic conditions frequently over-rode and altered or masked the expectable mathematical relationships so as to make the usually-accepted regression equations inaccurate and, indeed, misleading. Unsystematic changes were observed in stream gradient and velocity, channel cross section, channel stability, size and shape of meander loops, and distribution of sediment grain-sizes.

Although Hoppie's report is lengthy, it by no means answers all questions or solves all problems related to the lower Solomon River and it does not directly apply to other streams. Nevertheless, his work does serve to emphasize that natural streams may be comprised of segments that have dissimilar hydrodynamic and morphologic characteristics and that along-the-stream variations in parameters are not necessarily in the same direction or even at the same rate from one segment to another.

As noted previously, it would seem logical that contrasts in degree of local channel activity should correlate, at least in part, with contrasts in erosional resistance of geologic materials encountered in the bed and bank. Indeed, Schumm (1960; 1963; 1977, p 109) has gone so far as to state that channel shape "is closely related to the percentage of silt and clay in the sediments forming the perimeter of the channel".

In an attempt to test Schumm's hypothesis insofar as it might relate to the Solomon River, Hoppie analyzed samples of sediment obtained from the bed and bank at 101 sites distributed throughout his area of study. He began this phase of the investigation with the intent of attempting to correlate areas of high channel activity with stretches of the river that had sandier sediment in the bed and banks. He found, however, that he could not satisfactorily identify anomalously sandier stretches. A wide range of grain sizes was present at almost every measured cross section. Furthermore, it seemed to him that the grain-size distribution at each point sampling site, especially on the channel floor, was greatly influenced by highly localized flow conditions that often were completely unrelated to major parameters of the stream. The alluvium in the banks was not so diverse, but showed no variations that could be matched with contrasts in channel instability.

There are marked differences between the Solomon River and its underlying geology and that of the mainstem Kansas River. Nevertheless, the results of Hoppie's study call for caution in blaming localized channel activity on an exposure of loose sand in the banks.

Eudora Bend Example

Centered on river-mile 41 on the mainstem Kansas River, just downstream from the town of Eudora, is the notorious "Eudora Bend", also known as "Weaver's Bottom". This is a reach that, active for the past sixty years, has recently undercut its outer bank at an especially high rate as compared with other active sites along the stream. Migration of the channel here has been watched closely throughout the life of the Contract and Contract Modification.

The area of maximium erosion and migration of the Eudora Bend does not coincide with any discernible zone or pocket of especially loose or sandy alluvium. Prominent layers of overbank deposits are continuous across this stretch and into adjoining areas that are much more stable. However, when considered in detail, the outside bank does show minor, local effects of variations in bank material that is being eroded. Small projections into the river are located where there are narrow, thick concentrations of clay and silt that are believed to be fills or plugs of former meanders that intersect the present channel at approximately right angles. Between these projections there are reentrants eroded in sediment that is composed mainly of silt and sand. A continuous clay-rich layer present at about the minimum flow level does cause development of a small bench at the base of the otherwise vertical bank. So, sandier sections are eroded faster that clay-rich sections, but the control is visible only on a very small scale.

## Study by Fleckenstein

The influence of vegetation on the erodability of a streambank is even more controversial that the role of sediment types exposed in the bed and banks. On the one hand, it would seem reasonable to expect that the presence of a tangled network of roots would strengthen or reinforce a mass of loose sediment, thereby inhibiting erosion. In addition, above-ground growth would impede the flow of the floodwaters, perhaps even causing deposition. In opposition to this conclusion are actual observations that exposed roots, as well as trees that have been undermined and so collapsed onto the river, cause intense local eddying and increased erosion.

In actuality, both effects occur, the balance between erosion and enhanced stability varying from place to place. Between river-miles 55 and 59 on the mainstem Kansas River, the channel has been unusually active during the past 100 years. Charles Fleckenstein examined the history of this channel migration and attempted to identify controlling factors. A copy of his report comprises Appendix E.

By compiling data from published maps and available aerial photographs, Fleckenstein was able to show that channel migration rates have undergone numerous localized variations. He attributed many of the point-to-point differences to contrast in bank materials - mainly clay versus sand. However, he also emphasized the influence of the presence or absence of forest vegetation along the banks, indicating that living tree roots have a marked positive effect on bank stabilization. Fleckenstein concluded that the major determinants of bank stability are stream discharge (level and duration), type of bank material being attacked, and the type and amount of vegetation along the banks.

He noted that when discharge was relatively low in the late 1930s, there was little channel migration, but that as discharge increased during the 1940s and the early 1950s, erosion was rapid wherever there were no bankside trees. In contrast, during the later 1950s landowners allowed trees to become established and the rate of channel migration slowed markedly, even though there was another increase in discharge.

## RUNOFF AND SEDIMENT LOAD

It is a nearly universal belief among fluvial geomorphologists that the activity level of a stream and various details of the size and shape of its channel are controlled, or at least strongly influenced, by the volumes of water and sediment being carried by that stream. It is further known that discharge and sediment load are, in turn, controlled, or strongly influenced, by conditions and events throughout the drainage basin, and that changes in basin conditions will soon effect changes in the channel downstream. For this reason, it was urged during the course of the main Contract that a study of changes in land use and climate be undertaken as part of this project.

The Land Inventory and Development Corporation of Laramie, Wyoming, was assigned the task of assembling data on changes in land use within the project area. It was initially expected that their report would provide all of the data needed for analysis of stream flow as influenced by changes within the drainage basin. However, study by the Land Inventory and Development Corporation was restricted by the terms of their contract with the Corps to a rather narrow band along the floodplains of the Kansas River and its major tributaries. No data were acquired outside of this band. Therefore, virtually no information was provided about the drainage basin _per se_; or no data were compiled about changes in the extent of cultivation or cultivation practices, grazing, development of farm ponds, and field terracing.

Discharge and sediment load will vary with the extent of various types of land use _throughout_ the drainage basin. They will also vary with the changes in climatic parameters. By the time it was understood that the report of the Land Inventory and Development Corporation would provide none of this necessary information, it was too late to undertake the gathering of these data on our own.

## Study by Ratzlaff

Approximately halfway between Topeka and Wamego there is a reach of the mainstem Kansas River that has been especially active during the past century, although rates of change have not been constant. Adjoining reaches both upstream and downstream have been much more stable. The combined stretch, extending upstream from river-mile 83 to mile 135, was studied by John R. Ratzlaff in an attempt to discover whether these variation in channel migration and stream morphology might be the result of specific changes in climate or land use within the drainage basin (a cause-and-effect relationship called "deterministic" by Ratzlaff) or whether they might be of a purely random nature (called "probabilistic"). His report is presented as Appendix F.

Data on channel shapes and positions were obtained from maps published at irregular intervals since 1856 and from aerial photographs made since 1942. These showed that maximium channel change occured between 1870 and 1920, mainly resulting in a channel shortening of about 18%. There was a concomitant decrease in sinuosity and, presumably, an increase in gradient, though the latter was not as clearly documented.

Variations in channel activity are often associated with variations in some aspect of discharge, which is, in turn, caused or influenced by variations in direct precipitation within the drainage basin or by changes in land use that would affect infiltration and runoff. Discharge data collected on the Kansas River prior to insertion into the system of reservoir controls are available only since 1917. However, precipitation data have been collected at three stations within the drainage basin since 1870 and for 29 stations after 1890. By noting precipitation-discharge relationships for the years following 1917, Ratzlaff was able to mathematically estimate discharge that probably accompanied precipitation amount recorded since 1870, thereby producing a discharge curve from 1870 to the present.

Ratzlaff concluded that from 1870 to the present, climatic and meteorological conditions were "very similiar, both in general trend and in short-term fluctuations". This would suggest that the 1870-1920 period of high channel activity was not the result of a climatic permutation. There was, however, also at about this time, a tremendous change in land use. Beginning in the mid-1800s, the grasslands of the Plains were either subject to greatly intensifying grazing pressures or were entirely destroyed by cultivation, as shown in the table below.

Acres of Farmland in Kansas

| | |
|---|---|
| 1860 | 2 million |
| 1870 | 5.5 |
| 1880 | 21.5 |
| 1890 | 30 |
| 1900 | 41.5 |
| 1950 | 48 |

With removal of the natural vegetation, infiltration decreases, runoff increases, and so does sediment yield.

Streamflow becomes more irregular; peak flows become higher, low flows become lower. Trunk streams would require steeper gradients in order to transport the increase quantities of sediment supplied from the drainage basin. These steeper gradients could best be provided by a decrease in channel sinuosity and consequent shortening of channel length - exactly what happened in the study reach.

After postulating that shortening of the channel distance between Wamego and Topeka could have been a consequence of the expansion of farming throughout the drainage basin, Ratzlaff noted that much of this shortening was accomplished through meander cutoff by the 1903 flood. However, he suggested that although flood erosion was the immediate cause of the change, conditions favoring or, indeed, necessitating that change (channel shortening) might represent a long-term adjustment to other controls (expanding cultivation).

Ratzlaff also looked farther into the past. Traces of former channels are visible as meander scrolls, scars, and ox-bows on both the floodplain and a low terrace. The complete pattern seems to record "a period of degradation, overall channel straightening, and southward shifting in the period prior to 1850", possibly for "several hundred years". If this interpretation is correct, channel change had been actively occurring along the Kansas River through the warming period of and since the warming stage of the Neoglaciation, and effects of changes in land use are merely additional impetus.

CAUSAL FACTORS

What might be termed the "payoff" part of the Contract Modification was to be an analysis of factors that appear to cause or control the bank erosion and channel migration observed along the Kansas River and its major tributaries.

A highly simplistic conclusion would be to repeat the well-known observation that meandering channels can be expected to migrate. It is a "normal" consequence of streamflow. Even if a channel is artificially straightened, it will soon begin to develop broad curves, then more sinuous meanders. This seems to always hold true *if* the channel is situated in easily erodable materials such as a thick accumulation of floodplain silts, a requirement that certainly holds for the stream being considered here.

In the instance of the Kansas River and its tributaries, however, this simplistic answer is inadequate. Taken as a unit, the Kansas River is not a meandering stream; there are many reaches in which the course is nearly straight. Furthermore, not all of the meanders are currently migrating. One sharp bend near DeSoto has not moved appreciably in more than 100 years.

It is, therefore, clear that one must look elsewhere than in the expectable behavior of meanders in order to explain the activities of various reaches of the Kansas River. This also holds true for the major tributaries, although details differ. Because the Kansas River situation is so apparently complex, cause and effect relationships are not clear cut - as Ratzlaff discovered. We still do not have sufficient data to explain why certain events have happened or are happening in the Kansas system, but progress has been made toward this goal.

Study by Fleming

Alfred J. Fleming attempted to correlate channel migrations with variations in discharge. He devised a system of quantifying channel migration, measuring on aerial photographs the area over which a channel had migrated during a given interval of time. He called this the "activity area". Looking then at six "Severe Erosion Sites", he plotted activity areas against mean annual discharge and against peak discharge, both quantities having been recorded at nearby gaging stations by the U.S. Geological Survey. It was hoped that a direct and close relationship would thus be demonstrated, indicating that high rates of discharge resulted in correspondingly high rates of channel migration.

Fleming encountered a number of operational problems in implementing his study. Of primary concern was the method of measuring the "activity area". Since all of the sites involved a curved channel, the cross-sections were asymmetrical, having a steep cut-bank on one side and a gently-sloping point-bar slip-off slope on the other side. It was easy to delineate the cut-bank side of the channel, but no foolproof method was found to delineate the channel edge on the slip-off slope so that it would be at the same relative location at each site. This difficulty was compounded by the fact that different sets of photographs were taken at different stages of the river flow, each inundating to a different level on the point bar and thereby causing a variation in the width of the channel that may only be apparent rather than real.

There also was the problem of how to define the limits of the "activity area". Should it include all of the area that had been occupied by some portion of the channel at some time during a given interval, or should it be restricted to, for example, only the area traversed by the migrating right bank, or the left bank? Furthermore, what happens to the calculations if a channel migrates in one direction for a part of the time interval, then reverses its movement?

Finally, there were problems resulting from the fact that intervals between aerial photography flights were of differing duration both at a single site and from one site to another. These differences must, by some mathematical manipulation, be equalized. Fleming tried to convert irregular intervals into regular decades by computing percentages of total movement from one flight time to another.

Other systems could be devised. All, however, suffer from the fact that the rate of migration may well not be constant during the time between two successive photo flights.

Despite all of these difficulties, Fleming concluded that the channel of the Kansas River has been relatively stable during the period from the earliest aerial photographs in 1937 to at least 1942, and perhaps to 1951. The 1951 flood resulted directly in large-scale channel migration and appears to have been responsible for continuing activity for some time thereafter. It is possible that the river has not yet "recovered" from or adjusted to the effects of that flood.

Unfortunately, direct relationships between activity area and mean annual discharge, or between activity area and peak discharge, could not be demonstrated. There was, however, some suggestions that activity areas might be correlable with other discharge characteristics. In the future, with the acquisition of additional detailed flow data, it might be possible to demonstrate correlation with (a) the duration of high flow, (b) the time of year at which the high-flow event occurs, (c) the frequency of high-flow events, or some other discharge parameter. There have been statements from local landowners that bank erosion is most rapid when flow is at three-quarter bankfull stage. Fleming has so far been unable to document the validity of this assertion.

Local landowners frequently blame their channel-migration problems on the existance of the big dams and impounded reservoirs, arguing that sediment load settles out in the reservoirs, permitting the relatively sediment-free discharge to erode downstream areas. In his study, Fleming could detect no correlation between activity areas and times of closure of various big dams upstream. Appendix G is a copy of Fleming's report.

When examined in retrospect, it appears that although Fleming's comparisons of "activity areas" did indeed provide some interesting data, the quantitative significance might have been improved by a more precise definition of exactly what constitutes an "activity area". His conclusions are, perhaps, better thought of as a guide rather than an index. The details of channel-bank migration, hence activity, could be augmented by study of aerial photographs taken at times between those flights used by Fleming. However, if such photos exist, they have yet to be identified and located.

## Study by Jackson

Donald W. Jackson attempted to evaluate annual maximum discharge in relation to climate and land use, but the results of his study are inconclusive and the meaning of his report is unclear. He appears to believe that fluctations in stream discharge are the result of, or are very strongly influenced by, changes in land use within the drainage basin. A copy of his report constitutes Appendix H.

Study by Harrold

One frequently hears the simplistic assertion that impoundment of any reservoir results in entrapment of most of the sediment load that previously was carried past that point and that this removal, leaving the stream underloaded, causes erosion in downstream reaches. If this is correct, then an expectable consequence of dam contruction would be downstream channel degradation and bank collapse. In order to test this concept, Philip E. Harrold investigated changes that have occured in the Smoky Hill River downstream from Kanopolis Reservoir since that reservoir was impounded in 1948. His report is presented as Appendix I.

Harrold obtained measurements of present and recent gradients and sinuosities of the river from U.S. Geological Survey topographical maps. Information about older courses came from the Atlas of Historic Channel Changes that was compiled for this project and was published by the Corps of Engineers. Discharge records were provided by the U.S. Geological Survey. Channel-geometry and channel-material data were measured by Harrold at ten sampling stations between Kanopolis Dam and the confluence of the Smoky Hill with the Republican River.

Leopold, Wolman, and Miller (1964, p. 454) stated that a dam "tends to even out the duration curve, lowering the peak stages and increasing the base flow....In addition to creating changes in flow, dams with large storage capacity trap virtually 95 to 99% of the sediment that was previously passed through the reach in which the dam is located." Harrold accepted the correctness of those statements He also agreed that a stream leaving a reservoir is indeed underloaded and able to erode. However, he suggested that this erosion will be largely or even entirely confined to a rather short reach located directly downstream from the dam. Leopold, Wolman, and Miller published a plot (op. cit., Fig. 11-10) which showed that erosion occurred in the first ten miles below Kanopolis Dam after completion of that structure but prior to 1951. Harrold also found evidence of slight erosion in this reach from 1948 to the present. Farther downstream, however, the trend has been one of deposition in and aggradation of the channel.

Another effect of reservoir impoundment might be that the load transported by downstream reaches becomes selectively enriched in the finer fractions. Harrold speculated that geologic units cropping out along the Smoky Hill Valley east of Kanopolis Dam yield generally finer-grained detritus than do units to the west. As a consequence, the coarse sediment fraction that was deposited in the reservoir is not replaced in kind by downstream erosion and the over-all load becomes finer. Then, because channel walls lined with fine-grained sediment tend to be stable (Schumm, 1960), this selective decrease in average grain size along the lower Smoky Hill River should result in increased stability of the channel. This condition is what Harrold found to hold for this part of the river. There has been slight aggradation and almost no change in sinuosity. especially since 1933.

As with other studies of local areas or reaches, the conclusions formulated for the lower Smoky Hill River may not apply directly to other streams. However, Harrold's study strongly suggests that artificially underloaded streams return to equilibrium within a short distance below the point at which stress is applied to the system - if they are flowing in material that is easily eroded and entrained. Therefore, it is likely that bank instability, channel migration, and channel degradation of the mainstem Kansas River, and especially the downstream part of that stream, are not the direct consequence of sediment entrapment in upstream reservoirs. This aspect must, however, be subjected to much more detailed and careful analysis.

Study by Holien

Also making use of the Atlas of Historic Channel Change Maps published by the Corps of Engineers, Christopher W. Holien investigated changes in the sinuosity of the lower Saline River. He focussed on that part of the river situated downstream from Wilson Dam and Reservoir, arbitrarily dividing this reach into five segments according to the pagination of the atlas maps. Channel patterns were obtained for five points in time from 1886 to 1974.

Between 1886 and 1901, sinuosities of the five segments varied only slightly. The average was 2.3 for the entire reach. In contrast, sinuosities increased dramatically between 1901 and 1940. The range in a downstream direction was from 2.3 to 3.8, averaging 2.9. From 1940 to 1974, these sinuosities decreased, to a small degree over all, but rather markedly at the downstream end.

Unfortunately, Holien did not carry this study further to identify possible causes of the increased sinuosities. Furthermore, he did not examine records of channel changes upstream from the reservoir because the purview of the entire project terminated at the big dams, despite the fact that upstream data must be aquired before channel changes can be adequately interpreted for the downstream portion. Nevertheless, because of the dates involved, it can be stated categorically that these changes in the sinuosity of the lower Saline River were not the result of the addition of Wilson Reservoir to the system. This impoundment occurred between 1961 and 1964, well after the time of dramatic increase in sinuosity recorded in the downstream area. Appendix J presents Holien's report.

Study by Kopsick

A somewhat different kind of river investigation was undertaken by Paul R. Kopsick. He noticed that the radii of some of the prominent oxbow lakes and scars of abandoned meanders along the Kansas River appeared to be of almost equal size. When this observation was pursued, he discovered that many other meander scars had radii astonishingly similiar to those of the oxbow lakes. Between Kansas City and Junction City he identified more than 40 of these scars, all closely approximating the same size.

From measurments made on topographic maps at a scale of 1:24,000, Kopsick determined that the preferred ultimate radius of curvature of single loops in the present channel of the mainstem Kansas River is about 0.6 mile. He noted that accepted theoretical relationships would require that the size of meanders should increase with increasing discharge in a downstream direction. This renders especially remarkable the close similarity of loop sizes distributed all along the river. Both discharge and sediment load increase greatly from Junction City to Kansas City and corresponding increase in the dimension of all channel parameters would be expectable. This apparently does not hold for loop radius.

Kopsick also measured the radii of past meander loops preserved as scrolls on the floodplain and on the first (Holliday?) terrace. The fact that these also showed radii of about 0.6 mile indicated to him that there has apparently been very little change in the regime of the Kansas River for "a considerable period of time, presumably since the Wisconsin glaciation".

One portion of the Severe Erosion Site Study accomplished for the Corps of Enginneers project traced the evolution of a bend in the reach between river miles 129 and 135 near Wabaunsee. In 1885 this reach showed only a gentle bend, but by the 1970s a strongly recurved loop had developed, a loop with a radius of about 0.6 mile. This loop is now in the process of being cut off, although the presence of a minor "yazoo-type" of tributary may be injecting complications. However, here, as elsewhere along the river, it appears that meander loops develop and expand to a critical radius and then are cut off. There is little evidence of the sweeping or sideways shifting of meanders in a downvalley direction.

This particular investigation has raised some intriguing questions about behavior of streams in general and of the Kansas River in particular. Is there really a specific radius of curvature to which meander loops grow and then are destroyed by cut off? Is this favored radius the same for the entire river? Furthermore, has this radius remained constant through the past several thousand years, not influenced by variations in climate or land use - or impoundment of reservoirs? If answers to these questions can be demonstrated to be all affirmative, then there are profound implications applicable to problems of channel migration and bank stabilization. It should be possible to identify points of dangerous potential instablility along the present course of the river and to recognize the probable extent of future meander growth. Channel change might, at least in some areas, become predictable.

Kopsick's report is presented as Appendix K. Appendix L is a copy of an abstract that he submitted to The Geological Soceity of America.

## MISCELLANEOUS STUDIES

Despite the fact that the Scope of Work requirement for the initial Contract and for the Contract Modification were written with considerable care, the actual range of possible investigations that would contribute meaningfully to the over-all project is extremely wide. Two additions are mentioned here.

Study by Butler

A portion of a report by David R. Butler, included in its entirety as Appendix M, pertains to the Kansas River Project. He noted that a major flood event will result in the localized removal of existing forest vegetation along the banks. After a suitable interval, the bared ground will then be colonized by a new succession of trees. Examination of the species, the size, and the age of these new trees will provide a minimum date for the flood. The extent of new growth, plus the distribution of damaged older trees, will demonstrate the vertical and lateral reach of the floodwaters.

Butler studied the vegetation on a small part of Weaver's Bottom (also called the Eudora Bend) located just east of the town of Eudora. His transect included part of the floodplain, a narrow terrace, and the lower valleyside slope. Counting of annual growth-rings revealed that almost all of the trees on the low terrace were less than 28 years old. Furthermore, the trunks of the few trees of greater age were scarred. Butler suggested that high flow of the great 1951 flood had removed most of the vegetation from this terrace and that floating debris had damaged the few trees that remained standing. The level of highest scars would then provide an indication of the maximum rise of water level.

Study by Hall

In an effort to determine relative ages of seperate meander scars, Bruce Hall compared depths of soil development beneath each of three of these land forms. From a wide range of soil parameters, he chose depth of the $A_1$ horizon, percentage of clay-sized particles present, and percentage of organic matter as indicators of the length of time that had elapsed since each of the paleo-channels had been abandoned and soil formation had begun to affect the channel-bottom sediments.

Several soil samples were obtained from each of three meander-scar locations. Two of these sites were located just west of the town of Rossville on the northern side of the Kansas River; the third was ten miles farther east toward Topeka. The three selected soil parameters were determined for each sample. When the results were subjected to statistical evaluation, it was found that from one site to another there were no significant differences in clay content or depth of the $A_1$ horizon, but differences in content of organic matter did exist.

Hall interpreted these inconclusive results to mean that the three meander scars were of approximately the same age - meaning within a span of perhaps 50 years. Study of relevant sheets in the Atlas of Historic Channel Change Maps indicates that indeed the three meander scars could possibly have been occupied within a period of about 50 years, and two might have been active at the same time. This method of obtaining indications of relative or, perhaps, approximately absolute ages clearly merits further investigation with a much larger number of samples. A copy of Hall's report is presented as Appendix N.

## SUMMARY OF INTERPRETATIONS

The Plan of Study for the Kansas River Bank Stabilization Study, issued in February, 1978, stated that one of the over-all planning objectives was to "reduce the economic losses resulting from bank erosion and related problems in the study area". Planning tasks included (a) determination of the extent and severity of bank erosion, (b) investigation of causes of bank erosion, (c) assessment of economic and environmental impacts of bank erosion, and (d) estimation of the feasibility of alternative solutions to the erosion problem.

Although the Channel Migration Study, herein given its "final" report, was only a portion of the over-all project, it was, perhaps, the most important portion. All of the efforts of the Channel Migration Study were aimed at determining what has been happening along the river and to seek causes of those events, items (a) and (b) above. These matters of importance to geomorphologists.

In-house studies by Corps personnel have been concerned with the economic and environmental impacts of bank erosion. Evaluation of alternative structural and non-structural solutions to bank-erosion problems is an engineering concern and therefore also is being handled by Corps personnel; it is completely outside the scope of expertise of the geomorphologists.

Fundamental questions which the geomorphologists could and did investigate can be summarized by the query: Why is the channel of the Kansas River so mobile, so unstable? This is the key question. However, it might be more pertinent to ask first: Is it true that the Kansas River really is highly mobile?

A preliminary map that was included in the *Public Information Fact Sheet* of February, 1978, roughly separated the Kansas River into so-called "active" and "stable" reaches, plus a few miles of intermediate or "minor" activity. These subdivisions were based on a rather quick evaluation of historical records of the preceeding 100 to 125 years. This first, crude assessment of the activity level of channel migration along the mainstem Kansas River indicated that only about 35% of the channel could be characterized as highly active and an additional 18% as slightly active. The remainder of the river, almost half of its length from Junction City to Kansas City, appeared to have been stable during the 100-125-year period of record. This preliminary assemblage of data therefore indicated that the channel of the Kansas River *as a whole* could not be classified as an active channel in the sense that the ~~adjacent~~ adjective might be applied to, for example, the lower Mississippi River or the Rio Grande.

Completion of more precise compilation of channel changes along the Kansas River, resulting in publication of the *Historic Channel Change Maps* in 1979, emphasized this evaluation even more. If one arbitrarily defines important channel migration as consisting of lateral movement across a distance equal to or greater than the present width of the channel, then the lengths of channel reaches that have migrated actively since the 1850's aggregate to significantly less than half of the total length of the river. Of the 170 channel miles now present between Junction City and Kansas City, only about 20 miles (12% of the length) have shifted laterally through a distance greater than present channel width during the 40 years (since about 1936) of air-photo record. Approximately 50 miles (30%) migrated laterally during more than 100 years of apparently-reliable map records. Even more noteworthy is the observation that less than 10% of the channel length has been actively migrating since 1951. This suggests that the activity or mobility of the Kansas River as a whole has been and, perhaps, still is decreasing.

Although the project has been colloquially known as the "Kansas River Bank Stabilization Study", the actual study area included not only the mainstem Kansas River, but also major tributary streams up to the first Federal lake on each - Kanopolis Lake on the Smoky Hill, Wilson Lake on the Saline, Waconda Lake on the Solomon, Milford Lake on the Republican, Tuttle Creek Lake on the Big Blue, Perry Lake on the Delaware, and Clinton Lake on the Wakarusa.

The Saline and Solomon Rivers flow into the Smoky Hill and so, in a sense, become part of it. The name "Kansas River" has conventionally been applied to the stream that comes into being at the confluence of the

Smoky Hill and Republican Rivers about two miles northeast of Junction City. However, in terms of valley form and channel characteristics, the mainstem Kansas River does not begin in a geomorphic sense until the entry of the Big Blue River just east of Manhattan and 22 miles downstream from Junction City. This 22-mile reach is much more like the Smoky Hill and Republican than the lower Kansas. Further~~more~~more, this reach has been highly active throughout historic time. Indeed, if this reach were omitted from calculations, then the lengths or percentages of the Kansas River that have been active would be much smaller than those that were quoted above.

So - the Kansas River as a whole is not and has not been outstandingly active during historic time. It might then logically be asked why the bank stabilization study was undertaken. The answer is to note that the channel of the mainstem Kansas River has indeed been very active at a few specific localities and somewhat active at a few others. This activity has been annoying to a number of landowners; it has been outright ruinous to some. Channel migration has endangered roads, railroads, powerlines, dwellings, and other structures. Some roads and dwelling have been destroyed, and considerable areas of valuable agricultural land have been undermined and carried away. The purpose of and justification for the study is an attempt to understand the reasons for channel activity in those specific locations as a step toward mitigating the situation there, plus a search for fundamental principles that will permit prediction of probelms in other areas before they become extreme.

In regard to the remainder of the study area, concern is essentially restricted to the Smoky Hill, Saline, and Solomon Rivers; included portions of other streams are too short for detailed consideration. Compilations of historic records show that the Saline River has a highly sinuous channel that has undergone lateral migration both rapidly and repeatedly. It remains active at many localities. The Solomon and Smoky Hill are roughly similar to each other, but present a marked contrast to the Saline. They are less sinuous, have been less active during historic time, and are less active now.

In order to evaluate progress and present conclusions of the Channel Migration Study, it seems best to refer to one of the first documents produced. In October, 1976, an Outline of Studies Required to Undertake a Comprehensive Bank Stabilization Study included a presentation of a hierarchy of pertinent questions. The so-called "Principal Questions" were listed as follows:

Are bank sloughing and channel migration being caused primarily by

I. natural responses to environmental change, such as
   - A. normal cyclical stream behavior?
   - B. a change in climate?
   - C. tilting of the land surface?

II. activities of the Corps of Engineers?

III. activities of other organizations or people, such as
   - A. sand and gravel extractors?
   - B. owners of land directly adjacent to the river?
   - C. owners of land elsewhere in the drainage basin?

IV. a combination of the above?

The following discussions will be presented in the order of these questions.

IA. Are bank sloughing and channel migration being caused primarily by normal cyclical stream behavior?

This question arose from the concept that a major portion of a mature stream could be expected to behave as a unit, that meanders would develop, enlarge, be cut off, and develop again across the entire floodplain all along the course and that those meanders would gradually "slide" or translate in a downvalley direction either while they are developing or after reaching a critical size or shape. According to this concept, every area along the banks would eventually be affected, and probably at a fairly predictable rate. However, this pattern does not hold for the Kansas River. Some reaches remained stable for many decades only to burst into movement recently; others have maintained their inactivity throughout much or all of the period of record. Some were active a century ago, but are now stable. Furthermore, downvalley translation of meanders seems to have been exceptional behavior on this stream.

It is, therefore, abundantly clear that the 170 miles of channel to which the name "Kansas River" has been applied by geographers and cartographers has not been responding as a unit to a simple cycle of stream activity - as had been simplistically envisioned when the study began.

The same statement holds true for what might be called the "geomorphic Kansas River", the 147 miles downstream from the entry of the Republican River. As was remarked on a prececeding page, one of the earliest results of this project was recognition that the Kansas River should be divided into several segments on the basis of contrasting levels of historic channel activity. This is also true of the tributary streams. For example, Hoppie (Appendix D) found that the portion of the Solomon River downstream from Waconda Lake is composed of three major, dissimilar segments that could, in turn, be separated into shorter reaches on the basis of differing channel characteristics.

When these various stream segments are examined at the level of detail permitted by the scope and duration of this project, no clearly cyclical behavior is apparent, At some localities a *sequence* of changes has been recorded, but no true *cycle* that involved return to some initial situation followed by a repetition of a sequence. It is, of course, possible that cycles on the mainstem Kansas River exist, but require considerably more than a century for initiation and completion. If this is correct, the same explanation might hold for the apparent lack of cycles on the Smoky Hill and Solomon Rivers. On the other hand, the extremely complex present sinuosity, as well as changes through the historic record, of the Saline River may contain cycles, but analysis has not been accomplished to that extent. Certainly, some chain-reaction events or sequences can be postulated for short, isolated reaches of each of the streams, but not for lengthy major segments. Furthermore, the initiator of even those localized events remains unknown.

IB. Are bank sloughing and channel migration being caused primarily by a change in climate?

Lines of equal amounts of mean annual precipitation, called isohyets, have a basic north-south orientation across Kansas. This is at right angles to the axes of the major streams. At the western end of the Kansas River Basin, expectable annual precipitation is only 14 inches; at the eastern end it is about 35 inches. Especially because of this great change in precipitation within a few hundred miles, fluctuations in precipitation from year to year, or over longer periods, might have considerable effect on the discharge of tributary streams and, through them, on the mainstem Kansas River.

Since 1920, annual precipitation at Salina has varied from 65% to 185% of the average. During that same period, annual discharge of the Kansas River near its mouth has varied by more than 1000%, and instantaneous discharge by more than 3000% (from only 160 cfs to an estimated 510,000 cfs). It has been clearly established that discharge bears a close, direct, power-function relationship to transport of sediment by a stream and, therefore, indirectly to erosion by that stream. It would then follow that in the downstream portions of a major system, such as that of the Kansas River, increased discharge, caused by increased precipitation in upstream areas, would produce increased erosion of channel banks.

Attempts to evaluate this possible influence on channel activity are handicapped by the relative brevity of meaningful climatic records in Kansas. In studying changes in the Kansas River between Topeka and Wamego, Ratzlaff (Appendix F) found that the greatest migrations of the channel occurred between 1870 and 1920, but discharge data for ~~the most~~ that part of the river did not begin until 1917. Furthermore, although precipitation records extend back to 1870, this is for only three stations in the entire Kansas River Basin. It was therefore impossible to compare factual climatic data with records of channel activity.

Working east of Lawrence, Elks (Appendix B) separated remnants of abandoned paleochannels into two groups on the basis of channel width and, less reliably, meander size. He believed that these formed under differing discharge regimes, the older group of smaller channels indicating distinctly less flow in the river. The lower discharge regime might be equated with a time of lesser precipitation, but Elks did not extend his interpretations that far.

Little specific evidence is yet available to tell when this lower regime occurred. The paleochannels are present on one or more surfaces of the Holliday Terrace Complex. The radiocarbon age of a log recovered from a gravel pit near Bonner Springs (some 25 miles downstream from the site of Elks' studies) was approximately 2400 years. The terrace surface at this locality, overlying and therefore younger than the sediments in which the log was buried, is probably also part of the Holliday

Complex. This rather tenuous line of reasoning thus suggests that the time of lower discharge occurred on the order of 2000-2200 years ago. Certainly it was too far back in time to have any direct effect on present behavior of the channel.

In summary, short-term variations in precipitation have been recorded and changes in climate are hypothesized for longer periods. All of these have affected discharge of the Kansas River and its tributaries. It is probable that each episode of higher discharge has caused accelerated bank erosion in some localities, and at a few spots this may have been the trigger to initiate a new sequence of local meander migration. However, there is nothing in the climatic record, as now known, to indicate a direct cause for the bank sloughing and channel migration now taking place.

IC. Are bank sloughing and channel migration being caused primarily by tilting of the land surface?

Depending on the geometrical relationships involved, tilting of a land surface may or may not affect the activity of streams flowing on that surface. If the axis of tilting ~~is~~ were parallel to the axis of a specific stream, effects of tilting ~~will~~ would probably be so slight as to be indiscernible. If the axis of tilting ~~is~~ were nearly at right angles to the axis of a stream, then effects ~~will~~ would be at a maximum, the direction of the effect being dependent on the relationship of tilt direction to direction of stream flow. Tilting which decreased the gradient of a stream ~~will~~ would cause a decrease in velocity, hence a decrease in general erosional activity, perhaps even a wave of deposition. In contrast, tilting which increased stream gradient ~~will~~ would cause an increase in velocity and, consequently, in erosion.

As noted in all textbooks of geology or geomorphology, Kansas is the epitome of a stable continental interior. Most discussions present the belief that the land surface of Kansas has not been raised (or lowered) since Tertiary time, tens of millions of years ago. Clearly, no such ancient movements would have direct effect on stream behavior today.

However, before completely dismissing this possible influence on modern streams, it should be noted that within the past few years some researchers have found evidence suggesting that there have been movements of the land surface in Kansas within the past few hundred thousand years, possibly even continuing to the present. Richard Rogers, a graduate student in Anthropology at The University of Kansas, believes that he has found field evidence of significant uplift of the land surface in central Kansas within the last 10,000 years. Evaluation of his evidence by a team from the professorial staff has so far been unable to prove him wrong. If this movement, which is contrary to all previous beliefs, actually has occurred, it would have had very considerable effect on the Kansas River and at least some of its tributaries, though whether events of the past 100 years could be blamed on it is questionable. The best that can be said at present is that there may have been some tilting which has caused an increase in erosional activity within the Kansas River system, but its short-term importance to present problems is probably minor.

II. Are bank sloughing and channel migration being caused primarily by activities of the Corps of Engineers?

This might be called THE most important question facing the study project. Certainly, it has been asked in one form or another by many farmers, other landowners, and even local politicians. The Corps of Engineers has been the most convenient "whipping boy" on whom to blame all problems encountered anywhere along the river.

The most-commonly heard statement is that the quiet waters of the big reservoirs trap most of the sediment load in each affected stream segment, the stream leaving each reservoir is then notably underloaded, and downvalley erosion (of the banks) inevitably occurs. There is, of course, an appealing logic to this statement. It would seem to comply with the most basic of principles of stream behavior. Any stream that is artifically deprived of the load it has been transporting will, as a direct consequence, be able to acquire a new load if suitable materials are available to it. However, no proof has been found during the present investigation that this is, indeed, a fundamental cause of, or even a strong influence on, present channel behavior along most reaches of the river system.

This problem was specifically examined by Harrold for the Smoky Hill River below Kanopolis Reservoir (Appendix I). His study suggested that reservoir impoundment would indeed result in outflow of an underloaded stream that was therefore capable of renewed erosion of its channel. However, examination of present and past maps and aerial photographis indicated that this enhancement of erosion was limited to the first few miles below the dam. This finding is in agreement with the plot published by Leopold, Wolman, and Miller which showed that post-impoundment erosion on the Smoky Hill occurred only in a reach about ten miles long directly downstream from the dam. Similar findings have been reported from other streams.

Data on sediment load of the Kansas River and its tributaries are sparse and the record does not extend very far back in time. Therefore, it is not possible to run statistical analyses of long-term changes in sediment load or to evaluate the situation on the mainstem river on a strictly quantitative basis. The best that can be said at this time is that sediment-load reduction by upstream reservoirs is probably not an important factor influencing present problems of channel stabilization on the mainstem Kansas River or, indeed, on the lowermost reaches of the Smoky Hill, Saline, and Solomon Rivers.

Other frequently heard public statements suggest that present problems of bank sloughing and channel migration are directly related to Corps policies regarding control of discharge from the big reservoirs.

Many riparian landowners have invoked a two-thirds bankfull or three-quarters bankfull discharge as being most conducive to erosion, undermining of the banks, and collapse. They report that such relatively moderate flows result in greater damage than did the occasional pre-dam overbank floods. Supposedly, these statements are based on sporadic, though direct observations by the individuals involved, but acutal measurements have apparently never been made by them.

Landowner complaints of this sort have also been directed against the Corps at other localities, for example, on the Upper Missouri River and below Stockton Dam on the Sac River. Preliminary studies at the latter location suggest that maximum velocity of flow below the dam occurs at approximately two-thirds to three-quarters bankfull discharge and that the velocity then decreases before the peak of the hydrograph is reached at greater discharges. Measurements on other streams have shown that the rate of increase of velocity becomes less at higher discharges - velocity continues to increase with increasing discharge, but less rapidly. It may be that the exact interrelationships of velocity and discharge are stream specific. Anyway, this does suggest that there may be at least a grain of truth in the statements of the riparian landowners.

Nevertheless, other observations have shown that bank sloughing also occurs at relatively low-water stages. Some of this appears to be the result of failure of saturated bank materials shortly after flow level has declined. Other such events seem to be related to drying of alluvium with consequent cracking and creation of unstable blocks along steep exposed faces. It is possible to hypothesize a number of immediate causes of bank failure that work both separately and in concert at any particular location. Specific parts of the banks will be susceptible to failure under specific flow levels or changes in level. Control of discharge may well influence some of these processes, but others are probably only remotely influenced by discharge. Two aspects of this problem should be emphasized: (1) these processes of bank failure are active in all streams, with or without reservoirs, that have banks composed of alluvial sediments and (2) the Kansas River is in general, as described in a preceding section, a notably stable stream.

### IIIA. Are bank sloughing and channel migration being caused primarily by activities of sand and gravel extractors?

The removal by dredging of sand and gravel from the bed of the Kansas River is localized near major population centers - Kansas City, Lawrence, Topeka - where these materials constitute a valuable resource for various construction activities. Most of the extractive operations are concentrated along a 20-mile stretch extending from just above Bonner Springs downstream nearly to Kansas Cuty. In this same area it has been well documented that the bed of the river has been lowered several feet during the past few decades. The immediate, simplistic conclusion has been that removal of sediment from the channel floor has resulted in deposition of an equal quantity of load that was in transit from upstream. This deposition has, in turn, created an underloaded condition directly downstream and erosion from the bed has occurred in order to return the system to approximate equilibrium.

If the above scenario were correct, then the sand and gravel companies could be blamed for the channel degradation that is threatening bridge abutments, pipeline crossings, and other riparian structures, as well as the general stability of the channel sides. However, the correctness of this idea is far from certain and several studies are seeking definitive evidence.

It is conceivable that concerned scientists and engineers might eventually determine that extraction of sand and gravel in the general Bonner Springs-Edwardsville area is indeed causing some downcutting of the channel of the Kansas River in that reach, but such a conclusion would by no means relate to the entire river system. Any wave of degradation and accompanying channel instability that might have been initiated near Bonner Springs could not under any circumstances migrate upstream past the Bowersock Dam at Lawrence. Furthermore, it is likely that such a wave would become attenuated and insignificant before it traversed the intervening 30 miles unless downstream incision proceeded to greater depths than have at present been achieved.

Removal of relatively minor quantities of sand and gravel near Topeka could not reasonably cause channel instability for more than 60 miles to the location of the next extractive operations near Manhattan. Nor could the extractive operations at Manhattan and Junction City explain the high degree of channel instability between those two cities. Sand and gravel removal cannot be blamed for bank sloughing and channel migration along more than very short reaches of the river; this is not the cause of problems distributed throughout the entire system.

IIIB. Are bank sloughing and channel migration being caused primarily by activities of owners of land directly adjacent to the river?

The Kansas River and its major tributaries generally follow courses well out on their valley floors, thus well away from slopes leading to the uplands. Therefore, this question relates mainly to use of floodplain or terrace land close to the channel, plus anything done to the channel banks specifically.

Aside from limited areas of residential or industrial use, most riparian land along these streams is either in crops or woodland. Some parts of the valleyside slopes are used for pasture, but these seem to differ little from wooded slopes in showing almost no deleterious effects on any channel reach that happens to be against them at this particular moment in history. Indeed, some of the most stable portions of the river have flowed close to valley walls for many decades, and there seems to be some yet to be identified manner in which the channel becomes "caught" in such a position.

Apparently, a more critical aspect is the extent and maturity of riparian woodland. It has frequently been suggested that channel sides become more secure as the size of the vegetation increases Thus, it is believed that brush provides a little stability, young trees more, and a mature forest the maximum degree. Land-use data procured by comparison of aerial photographs dating from the 1930s to the present provide some justification for this belief. However, there is also some basis for arguing in support of a directly opposite effect. It would then be pointed out that a certain amount of localized bank erosion is inevitable. In a heavily forested area this would result in collapse into the river of a few large trees. The presence of these trees would then obstruct flow and create eddies which would, in turn, cause accelerated <u>local</u> erosion of the bank, perhaps leading to the undermining and collapse of more trees, the creation of more eddies, and so on. There would certainly be a major effect dependent on the kind of vegetation and the nature of the root systems.

It is probable that the presence or absence of trees is not the primary control of bank stability. However, if a given section of bank already has a tendency toward sloughing and migration for other reasons, then removal of forest cover may well trigger rapid erosion. Denuded areas that now have unstable banks probably were also unstable before the forest was cut, and stable reaches may remain stable whether the nanks are forested or clear-cut. Certainly, this was the conclusion of Fleckenstein (appendix E) regarding a reach of the Kansas River a short distance upstream from Lawrence. Nevertheless, it would appear to be prudent for landowners to encourage and preserve woodland strips along all river banks; most certainly this practice should be followed wherever the channel is curved and has a history of instability. Farmers who clear land in order to gain riparian acreage for crops may well lose all of that land - and more - because they have unwittingly caused acceleration of bank erosion and migration at that point.

During the past few decades, there have been many localized attempts by individual landowners, groups of landowners, or governmental agencies at various levels to mitigate problems related to bank sloughing and channel migration at numerous places along all of the streams involved in this project. So many structural and non-structural methods of bank stabilization, ranging from simple dumping of coarse trash to the careful emplacement of levees, jetties, and nets, have been tried under so many different situations that no general statement of efficacy can be made. Furthermore, accurate and detailed records of what has been tried and what then happened are extremely rare. Some of these applications have been distinctly unsound and consequences have varied from useless to downright disastrous, either right at the site or directly downstream. However, it is very unlikely that any such remedial work has had either a long-lived or far-reaching effect on the channel.

III. Are bank sloughing and channel migration being caused primarily by activities of owners of land elsewhere in the drainage basin?

The area being considered for this question is the entire drainage basin of the Kansas River, or alternatively, one of the major sub-basins. Activities of potential major impact would all come under the heading of land use - a change from forest or prairie to cropland, or a change in the type of crop grown or in details of its cultivation or harvesting. The link with the river system would be in the yield of water and sediment from the land.

Any variation in use of the land has the potential of either decreasing or increasing, seasonally or continuously, the quantities of water or sediment, or both, that enter local, fingertip tributaries. Whether or not these changes in headwater areas will, in turn, cause changes in the master stream will depend on the ability of intervening tributary reaches to absorb the effects - and on the presence or absence of artificial barriers, be they major reservoirs or small farmponds, that can effectively block downstream propagation.

The present study is concerned with events along the Kansas River and its main tributaries now or in the past few years. Major changes in land use within the drainage basin were accomplished many decades ago. It therefore seems safe to say that there is no immediate cause and effect relationship - that is, that migration of the channel now affecting the Eudora Bend, for example, is not a direct result of the changing from prairie to cropland in the late 1800s. However, one must question whether there is indeed some indirect linkage; whether, perhaps, a wave of channel instability has been gradually shifting downvalley through those intervening decades. Much basic research in much greater detail will be necessary before a definitive answer can be given. Nevertheless, it now appears that such an answer would be in the negative. None of the presently available data indicate the existence ofany wave effect at all. Hence, from the short-term point of view, present activities of landowners in the drainage basin are probably having no effect on the behavior of the Kansas River.

IV. Are bank sloughing and channel migration being caused primarily by a combination of several responses and activities?

The answer to this question must be in the affirmative. It is a valuable generalization that natural processes rarely work alone. One may be dominant, or several may be of approximately equal importance, others will have lesser roles. Yet all will be acting simultaneously. Furthermore, of the many variables which may influence the mix of processes, some will be dependent and some independent. In sum, the natural world is often exceedingly complex, or at least appear to be complex, and human efforts to simplify studies by examining only a part of the whole often result in conclusions that bear little relationship to fact.

The preceding considerations of individual factors potentially responsible for present river behavior produced few positive conclusions. On the negative side, it is possible to rule out sand and gravel extraction as a cause of channel migration for other than very localized reaches near urban areas. It is also probable that even though there has been an irregular, though progressive change in climate since the Little Ice Age, this cannot be the direct control of bank stabilization problems occurring now. Additionally, despite suggestions by Rogers, there is no widely accepted evidence that the land surface has recently undergone tilting. And finally, map compilation has clearly shown that the river is not responding to a simple cycle of activity.

On the other hand, there are certain factors which cannot be ruled out even though it is not, at least at present, possible to build strong supporting arguments. For example, even though the aggregate records of channel behavior over the past century demonstrate the absence of a single or simple cycle of river activity, it is nevertheless possible that a cycle, or even several overlapping cycles, of greater complexity are in action. Certainly, there exist examples of discrete reaches which have undergone progressive change from nearly straight to highly sinuous, and Kopsick's (Appendix K) recognition of an apparently critical meander-loop size seems to provide an end point for such an increase in sinuousity. Unfortunately, the cause of the initial increase in curvature remains unknown and further investigation is called for. There are also indications that an increase in curvature of one segment may progressively influence the adjoining segment or segments downstream, or even upstream. However, this influence is not translated through great distances and, again, the initiating cause is unknown.

Similarly, the effects of the mere presence (<u>not</u> the management) of reservoirs cannot yet be fully evaluated, in part because this project did not include any examination of stream behavior upvalley from the impoundments. Thus there is no means of comparison of the uncontrolled flow with that below the dams. However, because these dams and reservoirs do intervene between the bulk of the drainage basin and the downstream channels being studied, it is believed that any activities of man over large areas of the basin are now having minimal effect on the stability of those downstream channels.

In a more-positive vein, it is clear that destruction of riparian woodland can be followed by very rapid erosion of the bank, with consequent acceleration of channel migration. Even though the deforestation may only be a final trigger, this recognition of the importance of preserving streamside vegetation is a significant product of the over-all project.

Of equal or even greater potential importance is the possibility that details of reservoir management may influence downvalley stream behavior. It has been suggested that the frequence, the duration, and the volume of discharge from the reservoirs, both singly and grouped, strongly influence downstream bank stability - at least in certain localities where, perhaps, other factors have already combined to create a potentially unstable situation vulnerable to a triggering mechanism. This aspect most certainly derserves further analysis.

It can also be mentioned in this section that the great 1951 Flood seems to have caused major disturbance of a quasi-equlibrium state of the river. Channel activity increased markedly with that event and has remained relatively high ever since. Apparently the river is still engaged in "recovering" so that another quasi-equlibrium can be established. This is not to suggest, however, that when that adjustment has been completed there will be no more channel migration.

It can be assumed that the river never will remain quiet.

Finally, the obvious must be acknowledged. From an engineer's point of view it would be highly desireable to conclude with a definite statement of cause for current problems of bank sloughing and channel migration along the Kansas River. This cannot be done. There are several causes, sometimes working together, sometimes separately. However, it can be said that these causes are not infinite in number, and they are not random. This project has led to considerable understanding of the situation. Future study, both sponsored and not, will produce additional details.

# Appendix

As a result of interim review of draft documents related to the Kansas River and Tributaries Bank Stabilization Study, the Omaha Office of the U. S. Army Corps of Engineers submitted a series of questions to the Kansas City District. Those questions, and some comments on them, are listed below.

1 - What changes have occurred in channel width? No system-wide changes in channel width have been recognized and it is believed that none have occurred within historic times. Plots from published maps and from aerial photographs reveal a few areas of highly localized changes, some narrowing and some widening, but these do not comprise a discernible trend.

2 - What changes have occurred in channel depth? No system-wide changes in channel depth have been recognized and it is believed that none have occurred within historic times. Changes in the Bonner Springs area have been reported from other sources, but this specific project discovered no new evidence.

3 - <u>To what extent has construction of Corps dams contributed to bank erosion?</u>

This question has been addressed in the Final Report. Available evidence indicates that <u>construction</u> of the dams, with resulting impoundment of large reservoirs, has had no discernible influence on most of the miles of channel investigated. Only in the first few miles below each of the big dams has erosion occurred as the released waters acquired a new sediment load, and even in these restricted reaches the effects have been minor. However, it is possible, though by no means clearly demonstrated as yet, that <u>operation</u> of the dams (the timing, duration, and volume of water released) may have had a direct and perhaps deleterious effect on bank stability, but it is probable that areas thus affected were already unstable as a consequence of other influences.

4 - <u>What has happened to the channel bed over a given period of time?</u>

The scope of work for this project did not include any study of the <u>bed</u> of the channel; therefore, no information has been acquired.

5 - What reaches are actively degrading or widening, and what reaches are stable?

Reaches that have undergone recent widening and reaches that are stable have been shown on maps produced for this project. These were delivered to the Corps as they were completed and are not an integral part of the Final Report. No reaches have been identified as affected by a trend toward channel widening.

6 - Provide a thalweg profile plus bank elevations.

These would be products of a major suveying effort. They are not part of the Scope of Work for this project.

7 - Is the meandering process resulting in a net loss in channel area or are there trade-offs taking place?

It would seem as though this question should ask if there was a net gain in channel area occurring as the outer bank of a channel bend is undermined and eaten back. Nevertheless, regardless of how the question is worded, the answer is "no". Compilation of channel changes for the last century does not indicate any trend toward either widening or narrowing. In very limited specific locations there may have been a net change, but that trend is itself subject to expectable modification in the near future.

8 - <u>Are there any natural or man-made controls in the river?</u>

The meaning of this question is unclear. There is the Bowersock Dam at Lawrence, the Johnson County Waterworks diversion near Bonner Springs, and many levees, especially in the urbanized areas. Natural controls of a sort exist wherever the channel is presently impinging against a valley wall.

9 - <u>Is channel armouring occurring?</u>

The Scope of Work of this project did not call for any study of the bed of the channel; therefore, no data on armouring have been gathered. With the exception of the stretch near Bonner Springs, gravel is notably scarce, but there could be armouring by mud balls at other locations.

10 - <u>What is happening in each of the channels below our projects regarding tailwater trends, channel capacities, etc.?</u>

No data were gathered that would apply to this question.

11 - <u>What is the bankfull discharge for each reach both for preproject and post-project conditions?</u>

Acquisition of such data is an engineering concern and was not included in the Scope of Work for the geomorphology study. No data were acquired.

12 - <u>Are there any differences in channel sinuosity throughout the Kansas River project?</u>

As discussed in the Final Report, the mainstem Kansas River and each of its tributaries can be subdivided into a number of reaches that show contrasting sinuosities. The Scope of Work did not call for a detailed examination of this aspect, but it will be investigated during the 1981-82 academic year as a private project funded by The University of Kansas.

13 - <u>Where have either natural or man-made cutoffs been made?</u>

These are shown on maps prepared earlier in the project and delivered to the Corps.

14 - <u>What is the influence of cut-offs on bank erosion?</u>

No direct influence has been detected, but this will be studied further as a private project.

15 - <u>To what extent has land-clearing influenced erosion rates?</u>

No quantitative data are available. The report by Fleckenstein (Appendix E) suggests that there has been localized increase in bank erosion where forest cover has been removed.

16 - <u>The influence of sand dredging on bed and bank stability should be documented.</u>

This aspect of river history has been assigned to another group for study.

*Channel Migration Study*

APPENDIXES

Reference Lists of Publications, Maps, and Aerial Photographs of the Kansas River Basin (Second Edition, July, 1979) ** Appx 2- Recon Rpt* — 90 pages

Air-Photo Interpretation of Floodplain Features: A Means of Determining Former Discharges of the Kansas River
by John E. Elks — 79 pages

An Episode of Late-Holocene Soil Development on Floodplains of the Central Plains (abstract)
by William C. Johnson, Wakefield Dort, Jr. and Curtis J. Sorenson — 1 page

Morphologic Responses of the Solomon River to Geologic Influences
by James R. Hoppie — 246 pages

Study of Kansas River Migration
by Charles Fleckenstein — 20 pages

Changes in Channel Pattern and Sinuosity of the Kansas River - Cause and Effect Relationship or Random Process?
by John R. Ratzlaff — 51 pages

Recent Channel Migrations of the Kansas River and some Possible Relationships to Discharge Variability
by Alfred J. Fleming — 35 pages