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Analysis of Channel Degradation and Bank Erosion in the Lower Kansas River

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FINAL REPORT FOR
ANALYSIS OF CHANNEL DEGRADATION AND BANK EROSION IN THE LOWER KANSAS RIVER

Prepared for

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by

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This report has been prepared to assist the Kansas City District in its evaluation of permit applications to authorize commercial sand and gravel dredging operations on the Kansas River. Various questions and issues have been raised in recent years regarding the relationship between long-term commercial dredging activities on the river, and an apparent increase in bed degradation and channel erosion occurring over the past several decades. The report identifies probable candidates for the apparent increased channel activity and examines their influence on the morphology of the Kansas River.

The scope of this report has been determined to be appropriate for inclusion within the Corps of Engineers' Missouri River Basin Sediment Series. The sediment series was established for the development of practical sediment engineering as related to a rational evaluation, regulation, and utilization of fluvial sediment phenomena. The series is a comprehensive, basin-wide compilation of studies of sediment problems identified in a program designed for flood control and allied purposes, as well as for continuity and perspective in the planning and design of individual projects. The series of reports includes investigations for the development of sediment transport theory and observations of pertinent phenomena. It is intended to develop applications of theory to practical problems, to develop empirical relationships, and to provide an aid to judgement.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES (continued)

Page

LIST OF FIGURES (continued)

LIST OF TABLES

LIST OF TABLES (continued)

EXECUTIVE SUMMARY

I. INTRODUCTION

Over the past few decades, severe bed degradation, channel widening, and bank erosion have occurred in the lower Kansas River. The approximately 52-mile reach between the confluence of the Kansas and Missouri Rivers and the Bowersock Dam at Lawrence, Kansas, shows the most noticeable activity, although additional problem areas occur in the upstream reaches. Several natural and man-induced factors may have influenced the morphology of the river and could be responsible for the apparent increase in channel activity during this time period. These factors include:

1. Changes in the stage-discharge relation on the Missouri River at Kansas City due to the Missouri River navigation channel and bank stabilization project. This project has been in progress since the early 1900's. It includes the Liberty Bend cutoff located approximately 14.5 miles downstream of the mouth of the Kansas River which was made in 1949.

2. Construction and operation of a number of reservoirs on tributaries of the Kansas River beginning in 1946.

3. Extraction of significant quantities of sand and gravel from the river channel, particularly in the reach from approximately 8 to 22 miles above the mouth.

4. Other activities, including construction of Bowersock Dam at Lawrence, the Johnson County weir, approximately 15 miles upstream of the mouth, and various other bank and channel protection measures throughout the river reach, including riprap revetments, levees, dikes, and jetties.

II. PURPOSE

The purpose of this project was to investigate the changes that have occurred in the lower Kansas River and to determine their probable causes. In conducting the study, the above factors were investigated to evaluate the amount of increased channel activity attributable to each, recognizing that natural alluvial channels are dynamic systems which will exhibit changes regardless of the influence of man's activities.

III. METHODOLOGY

The analysis procedure can be divided into four parts: (1) a geologic and physiographic description of the river system; (2) an initial qualitative geomorphic analysis; (3) a quantitative geomorphic analysis in which the results of the qualitative analysis are quantified and verified to the extent possible; and (4) the application of a continuity-based sediment-routing computer model.

The geologic and physiographic description of the system was developed from a review of pertinent literature and field observations. Two methods were used in performing the qualitative geomorphic analyses. The first method indentifies past changes in the river system due to natural and man-induced events and then extrapolates these observations to predict the response of the river to varying conditions based upon similarity to the observed changes. This method relies upon historical information contained in aerial photographs, previous reports, maps, stream gaging records, personal observation, and design or as-built plans for bridges, weirs, and other structures constructed near the river. A considerable amount of this type of information exists for the Kansas River. The second method utilizes the principles of geomorphology, hydraulics, erosion and sedimentation to identify the potential impacts due to various activities. By using a combination of these methods, it is possible to establish, within reasonable limits, the probable response of the system to a variety of scenarios. Although the exact magnitude of changes cannot be evaluated, the type and general direction of changes can be established, providing an excellent assessment of the factors which have created the current condition of the river.

The quantitative geomorphic analysis consisted of the following:

1. A hydraulic analysis of the Kansas River using the Corps of Engineers (COE) HEC-2 model with available cross sections and calibration data.

2. Calibration of sediment transport relations along the Kansas River.

3. An incipient-motion analysis using Shield's criteria.

4. Computation of average annual sediment loads based upon computed flow-duration curves and the transport relations from Number 2.

5. Analysis of reservoir-induced depth fluctuations on bank stability.

6. Analysis of the headcutting zone near RM 22 to RM 23.

The continuity model was applied to all but the lower 12 miles of the Kansas River. The hydraulics, and consequently the sediment transport rates, of the lower 12 miles of the river are a function of stage on the Missouri River as well as discharge on the Kansas River. Because of this, sediment transport rates within this reach are highly variable and difficult to accurately model. Furthermore, the qualitative geomorphic analysis indicates that this reach is relatively stable, although it has undergone historic cycles of aggradation during normal flows followed by degradation or scouring of the deposited material by flood discharges.

Five conditions were modeled. For four of these conditions, a synthesized hydrologic record supplied by the Corps of Engineers (COE) was used. Two variations of this record were used in the simulation. One variation was developed by applying the reservoir operating rules to the pre-reservoir flow portion of the record in order to obtain a synthesized 33-year daily-discharge record of regulated flows. The second variation of the synthesized flow record had the effects of the reservoirs removed from the post-reservoir flows in order to create a 33-year daily-discharge record of unregulated flows. The five conditions modeled were:

1. Model verification using the USGS recorded discharge record for 1964 to 1980 and the actual gravel extraction rates from state records. Agreement between computed and observed values of channel aggradation/degradation was very good.

2. No-reservoirs, no-dredging condition using the synthesized hydrology.

3. No-reservoir, with-dredging condition using the synthesized hydrology and the sand and gravel extraction quantities for the period 1940 to 1973.

4. With-reservoirs, no-dredging condition using the synthesized hydrology.

5. With-reservoirs, with-dredging condition using the synthesized hydrology and the sand and gravel extraction quantities for the period 1940 to 1973.

IV. RESULTS

The results of these analyses indicate the following conclusions:

1. Operation of the federal reservoirs has changed the flow duration characteristics of the Kansas River. This has resulted in reduction in the amount of bed material carried by the system (approximately 30 to 40 percent) on an annual basis. On a reach-by-reach basis, the reduction in bed-material transport due to operation of federal reservoirs varies. In

general, the aggradational tendency of some reaches increased while the degradational tendency in other reaches is somewhat dampened. This process helps offset the degradational impacts due to dredging in Reaches 2 and 11 (RM 147.5 to 121.5 and RM 24.0 to 15.1, respectively). The aggradation tendency in the Topeka area (Reach 5, RM 80.6 to 101.0) is reduced by the operation of the reservoirs. Although it still aggrades for the with-reservoir condition, the amount of aggradation is less, indicating a greater impact due to extraction of material through sand and gravel dredging. Changes in the flow duration have also had some impact on the sediment sizes being transported by the system. Incipient-motion analysis indicates that the maximum size that can be transported has been increased slightly for medium flows (those equaled or exceeded approximately 2 to 20 percent of the time). For higher flows, the maximum sizes that can be transported have been reduced by approximately 50 percent.

Rapid fluctuations in stage can decrease bank stability through its effect on pore water pressure within the banks. Operation of the federal reservoirs has not significantly changed the stage fluctuations in the Kansas River, and therefore this factor has little or no impact on the stability of the channel banks. Larger duration of two-thirds to three-quarters bankfull flows, on the other hand, may have increased the tendency for bank erosion, although this is probably compensated for by reduced bank erosion due to attentuation of high flows.

2. Sand and gravel dredging appears to be the primary cause of the bank erosion and channel widening in the lower 30 miles of the Kansas River. Significant quantities of material have been removed from the channel bed in this reach during the past 50 to 75 years. Between 1952 and 1976, approximately 49.3 million tons of material were dredged between Turner Bridge and Bonner Springs, which corresponds to an average thickness of approximately 15 feet within the main channel. Sediment continuity indicates a direct relationship between the dredging activity and channel degradation and bank erosion. As evidenced by the approximately 8 to 15 feet of degradation and 150 feet of channel widening between Turner Bridge and Bonner Springs, available data show areas within the lower Kansas River which have undergone the most severe degradation are the same locations where extensive dredging has taken place.

Sand and gravel dredging impacts tend to relatively localized, although removal of large quantities of material over a large area can result in lowering of the bed and an increase in the channel gradient at the upstream end of the dredge area. This increased gradient causes a local increase in the transport capacity and may produce a headcut that will translate through the system in an upstream direction, reducing the channel slope until a natural or man-made control is encountered. Available data indicate this this has, in fact, happened near RM 22.

Artifical deepening (and/or widening) of the channel due to dredging also creates a ponding effect which traps the coarse material and may induce further scour downstream of the dredge areas. This factor does not appear to be significant for this system, however.

3. Lowering of the base level of the Missouri River has had an insignificant impact on the degradation and bank erosion in the lower Kansas River since at least the early 1950's. Sufficient data are not available to evaluate this impact with any degree of certainty prior to that time. Historical thalweg profiles between the mouth and Turner Bridge indicate significant degradation between 1931 and 1951. It is thought that the majority of this occurred during the 1951 flood. Since 1951, the channel bed within this reach has actually aggraded. Additionally, the presence of the geologic control at RM 12.0, which was documented as early as 1956, and the Johnson County weir, constructed in 1967, will prevent further lowering of the Missouri River base level from translating upstream in the Kansas River.

4. Major man-made structures that affect the morphology of the Kansas River include Bowersock Dam and Johnson County weir. Both of these structures act to stabilize the channel by fixing the channel-bed elevations. Both structures produce some backwater effect at lower discharges, which results in trapping of the bed load and a portion of the suspended load. At higher discharges, the hydraulic conditions are such that the bed-material load is not significantly altered by the presence of the structures. Their primary impact is to fix the elevation of the channel bed, preventing further degradation.

   Other man-made structures which have a smaller impact are the bank protection measures which have been installed at numerous points throughout the system. These measures have limited the lateral migration potential of the river at specific locations and have slightly reduced the available supply of bank material. Due to their limited extent and the high percentage of unprotected bank, however, their overall impact on the degradation and bank erosion is minor.

In addition to the four factors discussed above, the impact of the 1951 flood on the morphology of the system should not be overlooked. This extremely large event dramatically altered the system, causing severe degradation and bank erosion. Based upon available information, the post-flood channel was straighter and the cross-sectional area much larger than was the case before the flood. Since that event (and partially as a result of changed flow regime due to the construction of the federal reservoirs), the channel has been steadily changing as it regains a quasi-equilibrium condition consistent with the present hydrologic regime. Many of the observed trends in the past three decades, including apparent accretion on the inside of the bends and formation of vegetated islands where unstable sand bars previously existed, can be attributed to this factor.

I. INTRODUCTION

Over the past few decades, severe bed degradation, channel widening and bank erosion have occurred in the lower Kansas River. The approximately 52-mile reach between the confluence of the Kansas and Missouri Rivers and the Bowersock Dam at Lawrence shows the most noticeable activity, although additional problem areas occur in the upstream reaches. Several natural and man-induced factors have influenced the morphology of the river and may be responsible for the apparent increase in channel activity during this time period. These factors include:

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1.1 Project Purpose

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A preponderance of data relating to the geomorphology and hydrology of the Kansas River system has been collected over the past several decades and numerous studies have been conducted to analyze various aspects of the present problem. In order to develop a full understanding of the causes for the increased channel activity, it is necessary to consider the integrated effect of all of the various factors, including natural causes. In this study, the primary objective was to analyze as many of the data and previous studies as possible to identify the factors contributing to the increased activity and to qualitatively assess and, to the extent possible, quantify the relative impact of each of the various factors.

1.2 Project Approach

In order to accomplish the objectives of the project, a three-level approach was taken. First, a qualitative analysis was performed, utilizing available data, observations from previous reconnaissance trips and studies, aerial photographs and observations of various persons familiar with the area to develop a clear understanding of the river system and the progression of changes that have occurred. Second, a quantitative geomorphic analysis was performed using available hydraulic, hydrologic, sediment, and channel geometry data along with engineering calculations to estimate the magnitude and rate of these changes. The engineering calculations were performed using a combination of available data and theoretical or empirical relationships applicable to sand-bed channels like the Kansas River. These calculations establish estimates of the total magnitude and rate of change that may occur due to the various activities and indicate the long-term equilibrium condition that the channel will attain. The third level of analysis consists of computer modeling of the system. This level is guided by and further verifies the previous two levels of study. For the Kansas River a sediment continuity based computer model was used. The calibrated model has the capability to simulate the various factors which influence the morphology of the river. By applying the continuity based model for various combinations of hydrology, sand and gravel mining extraction rates, backwater conditions from the Missouri River in the lower reach, and channel controls (i.e. weirs, jetties, etc.), the relative magnitudes of the impacts due to each of the various factors was assessed.

1.3 Description of Kansas River Basin

The Kansas River basin drains a large portion of northwestern Kansas and parts of eastern Colorado and southern Nebraska. A general watershed map of the basin is presented in Figure 1.1. Total drainage area of the basin is approximately 61,440 square miles. The Kansas River itself is formed by the confluence of the Republican and Smoky Hill Rivers near Junction City, Kansas. The river downstream of this point to its confluence with the Missouri River

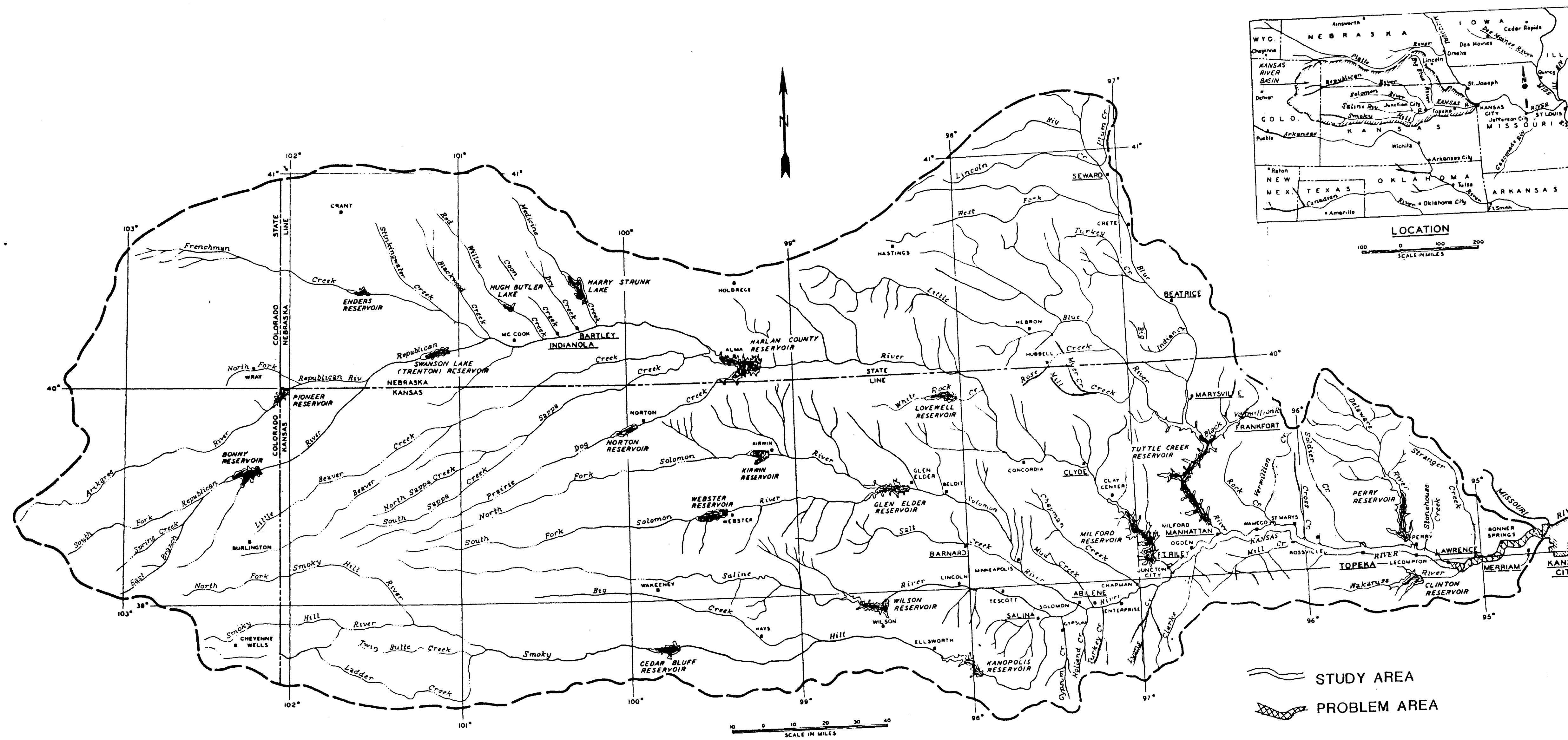


Figure 1.1. General watershed map for Kansas River (from Flood Plan Information Study, Kansas River, Kansas. U.S. Army Corps of Engineers, 1963).

is approximately 170 miles in length. The river valley in the reach below Junction City is characterized by a relatively high population density with intensive agricultural and industrial activity. Because of the potential for very large and devastating floods, flood protection works have been constructed near larger population centers, including the Topeka, Lawrence and Kansas City areas. In addition, many large reservoirs and numerous small agricultural reservoirs (13,000 to 15,000 according to Mundorff and Scott, 1964) have been constructed on the tributaries of the Kansas River over the past half century. Approximately 49,400 square miles (about 80 percent) of the total drainage area is controlled by reservoirs. Intensive sand and gravel mining has taken place in several areas, particularly in the reach from eight to 22 miles upstream of the mouth of the Kansas River and in the Topeka area. Other man-induced activities which have and will continue to have an impact on the system are the construction of channel control structures, including weirs, jetties, and bank protection measures. These factors will be addressed in considerable detail throughout the remainder of this report.

In general, the Kansas River is a moderately sized river with mean discharge varying from approximately 2,750 cfs at Fort Riley to 6,880 cfs at the USGS gaging station at Desoto. Active channel widths vary from approximately 400 feet near Manhattan, Kansas, to over 1,000 feet near Paxico, Kansas (Osterkamp and Hedman, 1981). The channel gradient ranges from 1.0 to 2.5 feet per mile throughout the reach. The channel bed is composed primarily of sand (D_{50} = 0.4 to 2.0 mm), while the banks are sandy and generally contain a higher percentage of silt and clay. There are, however, several areas where the channel bed is armored with coarser material (e.g. R.M. 9.7, 12.0, 21.5) or where the bedrock appears to be exposed (R.M. 101), providing some degree of vertical control for the channel bed. Additionally, numerous areas of the channel banks are composed of fine sand and silty material with little or no cohesion. These banks are extremely susceptible to erosion.

Most of the Kansas River watershed is utilized for agricultural purposes. Watershed sediment yields vary considerably from less than 200 tons/mi^2/year in areas with little land surface slope to 2,000 tons/mi^2/year in areas where the streams easily incise poorly consolidated glacial deposits (Osterkamp, Curtis and Crowther, 1982).

II. GEOLOGY AND PHYSIOGRAPHY OF THE BASIN

2.1 General

The Kansas River drainage system includes the Kansas River proper and the major tributary watersheds of the Smoky Hill, Republican, and Big Blue Rivers. As shown in Figure 1.1, the basin extends into Nebraska and Colorado. The elevations of the basin range from 700 to 1,000 ft (msl) in the eastern part of the drainage, to several thousand feet in the central basin, to over 4,000 feet in Colorado. Several physiographic provinces of Kansas are shown in Figure 2.1 and the characteristics of these topographic regions significantly affect the fluvial processes and sediment transport conditions of the Kansas River.

The High Plains include most of the upper watershed, making up about 1/3 of the entire drainage basin. The eastern limit and border with the Smoky Hills is defined by a prominent northeast trending limestone scarp. The plains are characterized by broad regular interfluves sloping 10 ft/mi to the east (Burns and McDonnell, 1982). The surficial materials consist of Pleistocene silt and aeolian deposits, which form a locally shifting mantle of silt. Only the Smoky Hill and Republican Rivers originate in this province and occupy valleys as wide as 15 miles cut in Cretaceous bedrock. Because much of the drainage is not integrated, erosion along stream channels is low and not considered significant as a sediment source to the Lower Kansas River (Osterkamp et al., 1981).

The Smoky Hills Province flanks the scarp of the High Plains on the east and includes major drainage areas of the Smoky Hill, Saline, Solomon and Republican Rivers. The boundary of this province with that of the Great Bend Prairie Province forms part of the southern boundary of the drainage basin. This area consists of a well-drained, dissected topography with irregular hills dominating the landscape. Surficial material is predominantly moderate- to coarse-textured, probably derived from the sandstone underlying much of the area. Sediment yield from this area is considered moderate (Osterkamp et al., 1981).

The Flint Hills Upland forms a belt in the center of the Lower Kansas basin. The Kansas River is the only through-flowing stream that crosses the Uplands. The section of river from Junction City to below the mouth of the Big Blue River is within this province. A series of prominent cuesta scarps and dip slopes developed on resistant cherty limestones of Permian age charac-

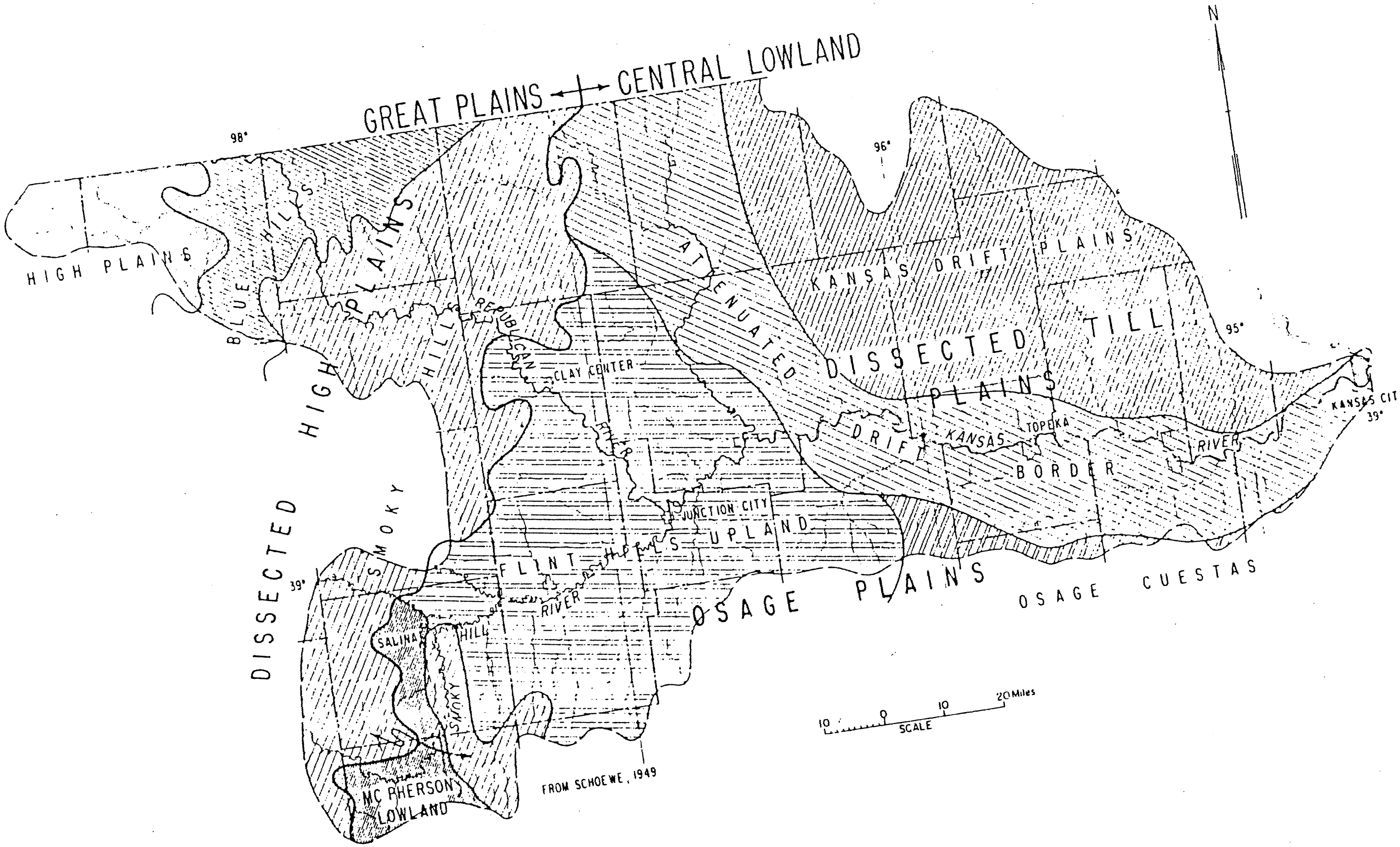


Figure 2.1. Map showing physiographic units of the lower Kansas River Basin (Mundorff & Scott, 1964).

terizes the region. The benches are formed on a smooth series of limestones that proceed west, forming a plain on an alluvial veneer and shale. Part of the area has outcroppings of fine-grained evaporites which are highly erosive, consequently parts of this province yield high rates of sedimentation.

The final province of importance is the Dissected Till Plains, which is quite different from the other regions. As shown on Figure 2.1 the Attenuated Drift Border, where most of the study section of river is located, and the Kansas Drift Plain comprise the lower-most drainage area of the Kansas River. The present Kansas River had its beginning during the Kansas glacial period and was an ice-marginal river. Tributaries draining the plain include Cross Creek, Soldier Creek and the Delaware River.

This province is characterized by the thick Kansas till overlying Cretaceous limestone and Permian and Pennsylvanian shales, limestones and sandstones. The drift border is characterized by major outcroppings of bedrock and local areas of drift. This region is well-drained, moderately fine-textured and has rounded hills and valleys. The Kansas Drift Plain is deeply dissected and is a major source of sediment to the Kansas River below Wamego (Mundorff and Scott, 1964).

2.2 Geology of the Lower Basin

The geologic outcrops in the lower Kansas River basin range in age from Pennsylvanian to the present, with Pleistocene deposits covering most of the area. The stratigraphy is described below in relation to its occurrence in the physiographic provinces.

Sedimentary rock, mainly limestone and shale of Pennsylvanian age, crop out only along and south of the Kansas River east of Wabaunsee County. This is the narrow upland section of the Drift Border bordering the Osage Cuestas province (Figure 2.1).

Permian rocks are also mainly limestones and shales and crop out predominantly in the divide areas of the glaciated area, the Dissected Till Plain. The limestones form the escarpment of the Flint Hills.

Cretaceous rocks crop out in the western part of the lower basin (High Plains Province) and are comprised of shale, clay, siltstone and sandstone. In the northwest portion of the High Plains there are also outcroppings of chalky limestone and chalk interbedded with shale.

Tertiary gravels overlay some of the Cretaceous rocks, but they are insignificant in extent.

The Quaternary glacial, glacial-fluvial and aeolian sediments mantle most of the basin, contributing much of the sediment load to the streams. Figure 2.2 summarizes the predominant Pleistocene deposits over the lower basin. As described in the legend, some deposits are discontinuous, e.g., aeolian and loess deposits are sometimes thin and locally distributed. There are glacial outwash deposits of gravel, sand, silt, clay and volcanic ash along the Kansas and Big Blue Rivers. Much of the area north of the Kansas River is composed of heterogeneous deposits of gravel, silt and sand (Mundorff and Scott, 1964).

A large concentration of gravel and till occur in the Turkey Creek area between Wamego and Topeka and prominent till boulders occur southeast of Wamego (Beck, 1959). Here, the till is very thin on the south side of the river and a concentration of boulders has remained subsequent to the removal of fines by erosion. On the north side of the river on the uplands, the till is very thick, e.g., around 80 feet, and is composed of clay, sand, gravel and a few large boulders. Another concentration of upland boulders is found southwest of Belvue (about 12 miles downstream from the Big Blue confluence).

A closer look at the Quaternary geology of the Lower Kansas River valley reveals three main deposits: Buck Creek and Newman Terraces and the alluvium of the inner river valley (Figure 2.3). The alluvium includes both fluvial deposits and thin, very fine dune sands forming the inner flood plain and extending to the first escarpment (Beck, 1959). The Newman Terrace is from the first to the second escarpment, and the Buck Creek terrace is from the second terrace to the valley wall. A third terrace, the Menokan Terrace, occurs locally above the Buck Creek Terrace. This terrace, which has a well sorted basal gravel, is not extensive.

The lithologies of the recent alluvium and Newman Terrace are quite similar. They grade upward from locally-derived basal flat limestone pebbles and boulders to brown-gray arkosic sand and gravel to fine and very fine sand, silt and clay. These deposits are highly variable, both horizontally and vertically, reflecting their fluvial origin, which characteristically produces lenticular and truncated sedimentary units. These two deposits also contain buried channel deposits of boulders, gravel and sandy material (Fader, 1974). Davis and Carlson (1952) reported significant deposits of coarse cobbles around 30-40 ft. below the river alluvium between Lawrence and Topeka.

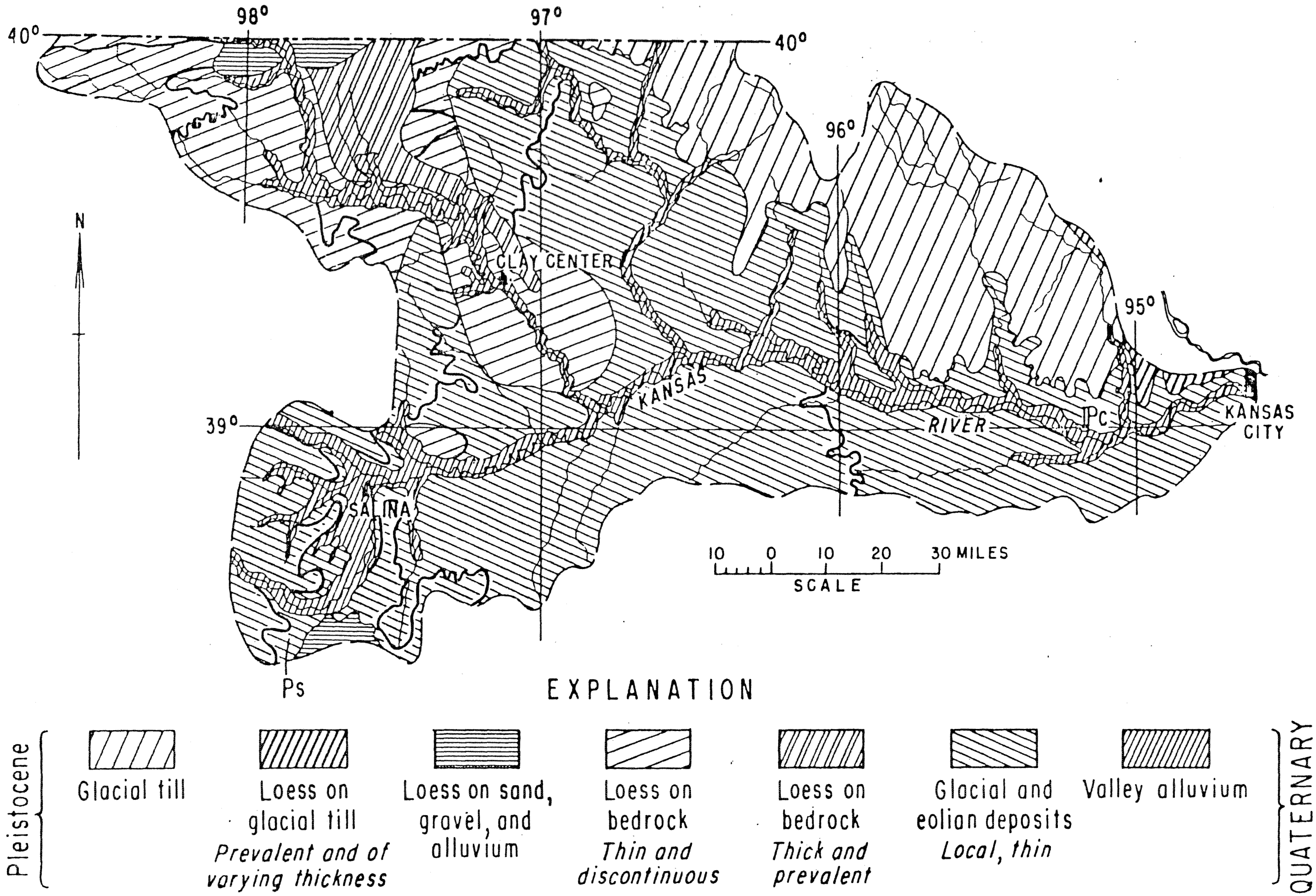


Figure 2.2. Map showing generalized surficial geology of the lower Kansas River Basin (Mundorff and Scott, 1964).

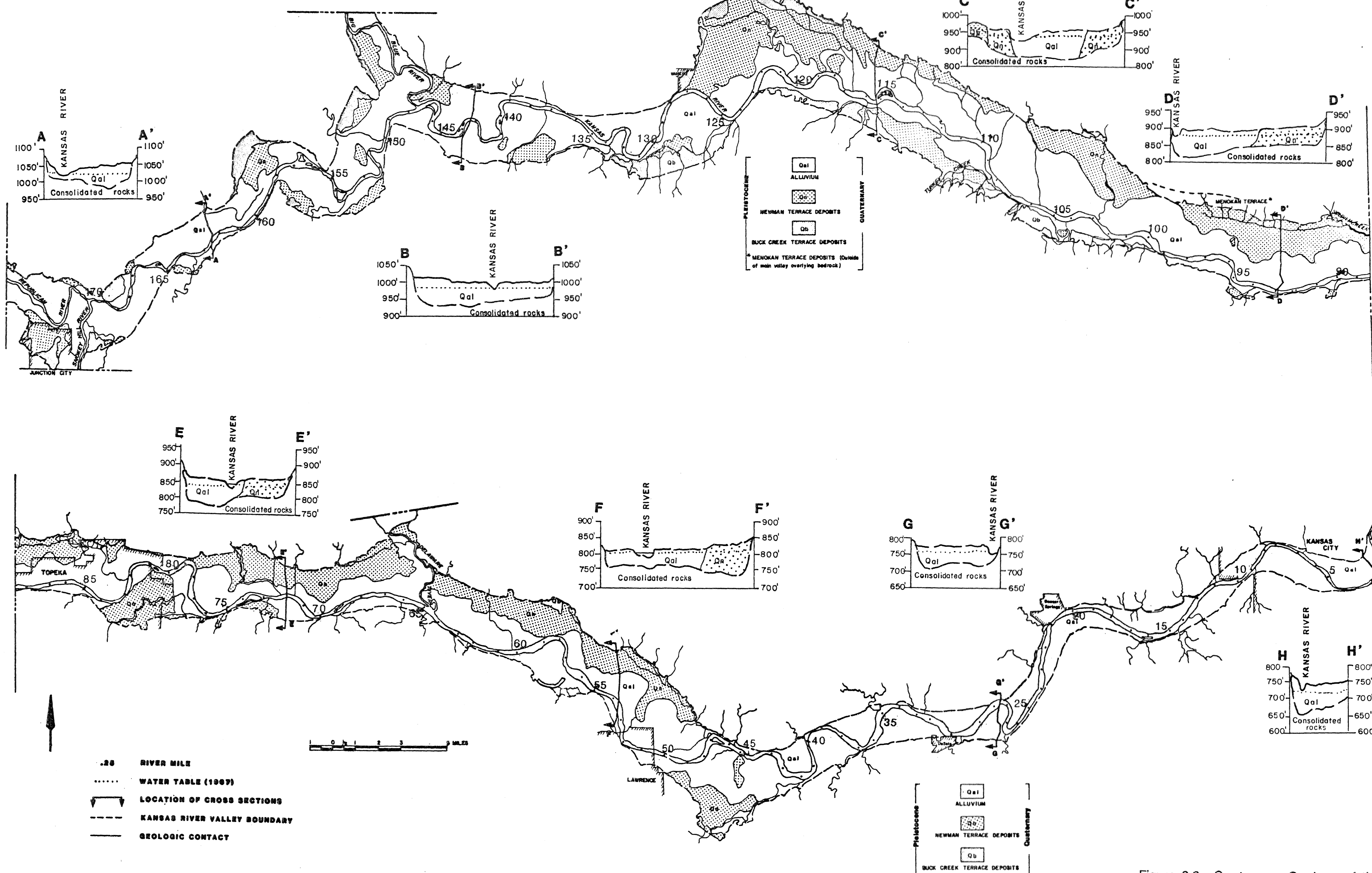


Figure 2.3. Quaternary Geology of the Kansas River Valley, Junction City

The Buck Creek terrace deposits grade upward from brownish-yellow sand, sandy silt, and fine gravel to reddish-brown silt. Alluvial fill material in many of the tributaries is mapped as sand and gravel from this terrace deposit. It is present mainly upstream of Lawrence where the river valley is wider (2+ miles) and more shallow than the downstream section. A brief description of the cut-and-fill development of the Lower Kansas River is provided below.

2.3. Fluvial History

The Kansas River evolved mainly during post-Tertiary time and eroded a total of at least 150 ft. into bedrock (Davis and Carlson, 1952). The maximum incision is shown in profile H-H[1] (Figure 2.3) at Kansas City. This may represent the response and adjustment of the Lower Kansas River to changes in base level of the Missouri during recent (late Pleistocene) times. The incised bedrock composed of shale, limestone, and sandstone has been instrumental in controlling vertical and lateral movement (discussed later).

The Kansas River had its beginning during the glacial advance of Kansan time (early Pleistocene). Following the incision of the bedrock surface at an elevation of 25 ft. above the Newman Terrace, the valley was filled by glacial outwash and alluvium to at least 60 ft. above the Newman Terrace. An example of these sediments is the Menokan Terrace, west of Topeka (Figure 2.3), which was preserved because it has a much higher bedrock surface. This suggests that the more resistant bedrock has acted as a control on the lateral movement of the river and has effectively resisted later erosion which formed the entrenched valley.

During Illinoian time (middle Pleistocene) the bedrock floor was again cut 50 ft. below its former level. The valley then aggraded about 30 ft. This terrace, Buck Creek Terrace, like earlier deposits, is only preserved in a few places in the valley, e.g., upstream of R.M. 100 (Figure 2.3).

Finally, during Wisconsin time, downcutting occurred to about 30-60 ft. below the present day flood plain. Following this, the lowest terrace, the Newman Terrace, was formed, which is about 15 ft. above the present day flood plain. This terrace is still aggrading today during short periods of exceptionally severe floods (Davis and Carlson, 1952).

The recent flood plain lies below this terrace and is characterized by point bar accretion slopes and abandoned meander loops of varying radii.

2.4 Degradation, Aggradation and Migration of the Lower Kansas River

The lower Kansas River has undergone lateral migration accompanied by degradation and aggradation throughout recent time. The total depth of erosion, over 150 ft., has resulted in an entrenched river valley system. As noted earlier, each downcutting episode was followed by aggradation of sediment on the incised valley floor.

The bedrock floor of the first major incision lies at least 40 ft. above the present day flood plain. It has since been incised and the resulting valley wall forms a bedrock control limiting the degree of lateral migration (Figure 2.3). Examples of obvious sections of river channel where this control is present are: Kansas City (R.M. 3.5), Bonner Springs (R.M. 20.5), and DeSoto (R.M. 29 and 31). A prominent straight reach between R.M. 24 and 26 appears to be controlled by the bedrock valley wall. Documented sites where escarpments are present and act both as lateral and possibly vertical controls are at R.M. 12-13, 28-29, and 39. At R.M. 12-13, a pivot point occurs as the channel flows against the bedrock bank and some channel armoring is occurring from eroded bank material.

In addition to bedrock control, coarse, well-cemented terrace material could act as a control to some extent. Although no specific sites have been documented, the most probable reaches where this could occur are along the upstream reaches above Lawrence where terrace deposits are present.

It is important to note that riprap dumped on the river banks along many sections supplements the role of the bedrock in controlling lateral migration. This is especially apparent along reaches bordered by the railroad, e.g. three-foot diameter riprap at R.M. 44. Jetties such as those at R.M. 13.5 and 27.3 also perform a similar function in protecting the river banks.

Two later entrenchments of the Lower Kansas River occurred to a depth below the present day flood plain. These two levels are illustrated in Figure 2.4, which compares the bedrock profile with the thalweg and water level (based on 1967 data). The higher bedrock surface (shown as peaks in the bedrock profile) is thought to be related to the Buck Creek Terrace. This surface is variable along the profile depending on where the recent river has migrated and incised this surface. This surface may act as a control against

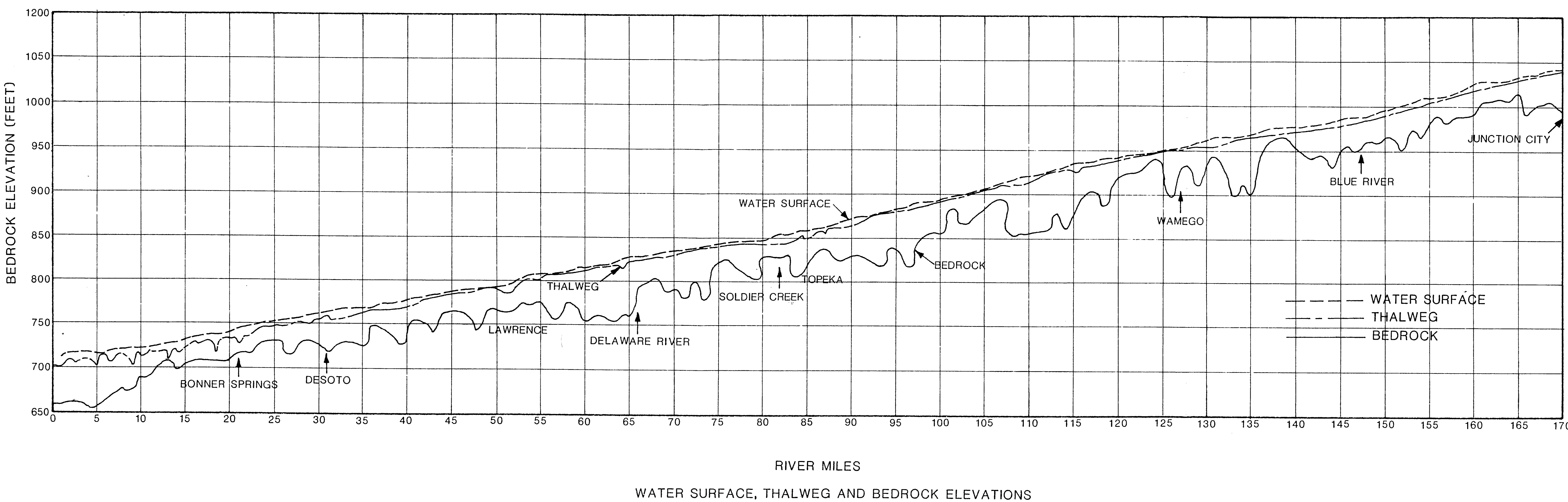


Figure 2.4 Bedrock, Thalweg and Water Surface Profiles for the Kansas River. (after Fader, 1974)

present day degradation, e.g., at R.M. 12-13, 101, and 132 (Figure 2.4). Other reaches of the channel may also have bedrock control, but are not shown on the profile due to both a scaling factor and the fact that the channel may have migrated laterally since the data were collected in 1967 and 1977.

The lower bedrock surface shown in Figure 2.4 is correlated with the last glacial downcutting. The alluvium has been aggrading since that time, forming a thick wedge of sediment. The modern channel flows over this wedge at Kansas City and at many sites upstream, e.g., R.M. 60-65, and R.M. 108-112.

Besides bedrock, armoring by cobbles and pebbles can act as vertical controls. Examples of documented reaches where armoring occurs are at R.M. 9.7, 12-13, 21.5 and 132. At these sites, it appears that the river may be flowing on paleo-channel material or old terraces, reflecting the past river which carried much coarser sediment than the present day river.

Gravel armoring was noted at R.M. 167 by the Corps of Engineers in 1956. This protective armoring is not noted today, probably because the channel has changed its course since 1956.

The well-armored gravel bars described above are the exception rather than commonplace on the Kansas River. The potential for gravel and pebble armoring is not considered high for most of the river. This is because there is a low percent of gravel and cobbles observed in the recent alluvium (Qal on Figure 2.3). Since the channel flows through this alluvium and is actively reworking it, very little armoring occurs.

Besides natural processes, man's activities have also influenced the aggradational/degradational nature of certain reaches. These activities include sand and gravel mining, construction of reservoirs on major tributaries, channelization for flood control and various channel structures to control lateral and vertical movement of the channel.

In summary, the lower Kansas River historically has actively degraded and aggraded in its channel and the valley reflects a series of entrenchments. Present day lateral migration is controlled by both the primary valley walls as well as higher bedrock surfaces of the past river valley. Multiple entrenchments have resulted in variable thicknesses of alluvium and in bedrock surfaces which can act as control against further degradation. As Figure 2.4 suggests, the depth to bedrock varies depending on where the present day channel has migrated across the past terraces and incised surfaces of the valley. At Junction City, the depth from the water surface to bedrock varies from 15

III. QUALITATIVE GEOMORPHIC ANALYSIS

This chapter presents a qualitative geomorphic analysis of the lower Kansas River including a discussion of the general condition of the river in its current state, the channel as it existed under natural conditions, and the possible impact of various factors on the morphology of the channel.

3.1 Methodology

Two methods are used in performing qualitative geomorphic analyses. The first identifies past changes in the river system due to natural and man-induced events and then extrapolates these observations to predict the response of the river to varying conditions based upon similarity to the observed changes. This method relies upon historical information contained in aerial photographs, previous reports, maps, stream gaging records, personal observation, and design or as-built plans for bridges, weirs and other structures constructed near the river. A considerable amount of this type of information exists for the study reach. The second method utilizes the principles of geomorphology, hydraulics, erosion and sedimentation to identify the potential impacts due to various activities. By using a combination of these methods, it is possible to establish, within reasonable limits, the probable response of the system to a variety of scenarios. Although the exact magnitude of changes cannot be evaluated, the type and general direction of changes can be established, providing an excellent assessment of the factors which have created the current condition of the river.

3.2 General Description of Existing River in the Study Reach

In order to more clearly analyze the system and to evaluate the probable impacts of the factors to be addressed in this report, the river was divided into a series of reaches. These reaches were selected based upon the hydraulic, sediment, geologic and man-made features which characterize the river. Activities such as gravel mining which are occurring in the river were also considered in selecting the reaches. Each reach is a length of river which has relatively similar characteristics. In many cases, the division between reaches was selected based upon either a geologic or hydraulic control which effectively separates the river upstream and downstream of that point. An example is the Bowersock Dam at Lawrence which prevents any degradation that occurs in the downstream reaches from progressing upstream. In addition, the flow is modular across the dam. Except at very high discharges (80,000 cfs and higher), flow across the dam is critical, indicating that conditions upstream of the weir are unaffected by downstream conditions.

Figure 3.1a and b is a thalweg profile of the river between the mouth at Kansas City (R.M. 0.0) and Junction City (R.M. 170). This figure shows the division of the qualitative reaches along with significant features occurring in or near the river. Figure 3.2a and b is a plot of the average bankfull top width. This plot was obtained from measurements taken from the 1983 aerial photography. Measurements of the active channel were generally from the edge of vegetation to edge of vegetation. Figure 3.3 is a plot of the median (D_{50}) bed material size from the 1983 bed material survey along the same reach. These figures will be used to aid in the discussion of the general characteristics of each of the qualitative reaches described in the following paragraphs.

Reach 1 contains the lower 12.2 miles of the river. Its primary hydraulic feature is the presence of backwater from the Missouri River. Depending upon the stage in the Missouri River and the discharge in the Kansas River, backwater effects extend from Turner Bridge at R.M. 9.6 to beyond the upstream end of the reach.

Because of the effects of the backwater, the flow tends to be very placid and deep. There are numerous bridge crossings throughout the reach. Revetment and flood walls have been constructed along both sides of the river from the mouth to R.M. 6.7 along the left (north) bank and to R.M. 9.6 along the right (south) bank. There is a gravel bar just upstream of the Turner Bridge at R.M. 9.6, indicating armoring of the channel bed (see Figure 3.4). Between R.M. 9.6 and R.M. 12.2 some bank erosion is evident. Bed material downstream of Turner Bridge is very fine silt and organic muck. This is underlain by sand at depths of two to six feet, indicating that deposition of fine material is occurring in this area.

Reach 2 contains the area between R.M. 12.2 and the Johnson County weir at R.M. 15.0. As discussed in Section 2.4, a rock outcrop occurs at R.M. 12.2 (see Figure 3.5a and b), which will serve as a geologic control, preventing further degradation of the channel in this area and acting as a lateral control to the north. At high stages on the Missouri River, backwater can affect the hydraulics in this reach. Gravel mining is occurring in this reach. Some bank erosion is taking place along both sides of the river within this reach. This can be seen somewhat in Figure 3.5b and is distinctly shown in Figure 3.6.

to 45 ft.; the depth is as shallow as 5 to 8 ft. at R.M. 124, while at Kansas City it is as deep as 65 ft.

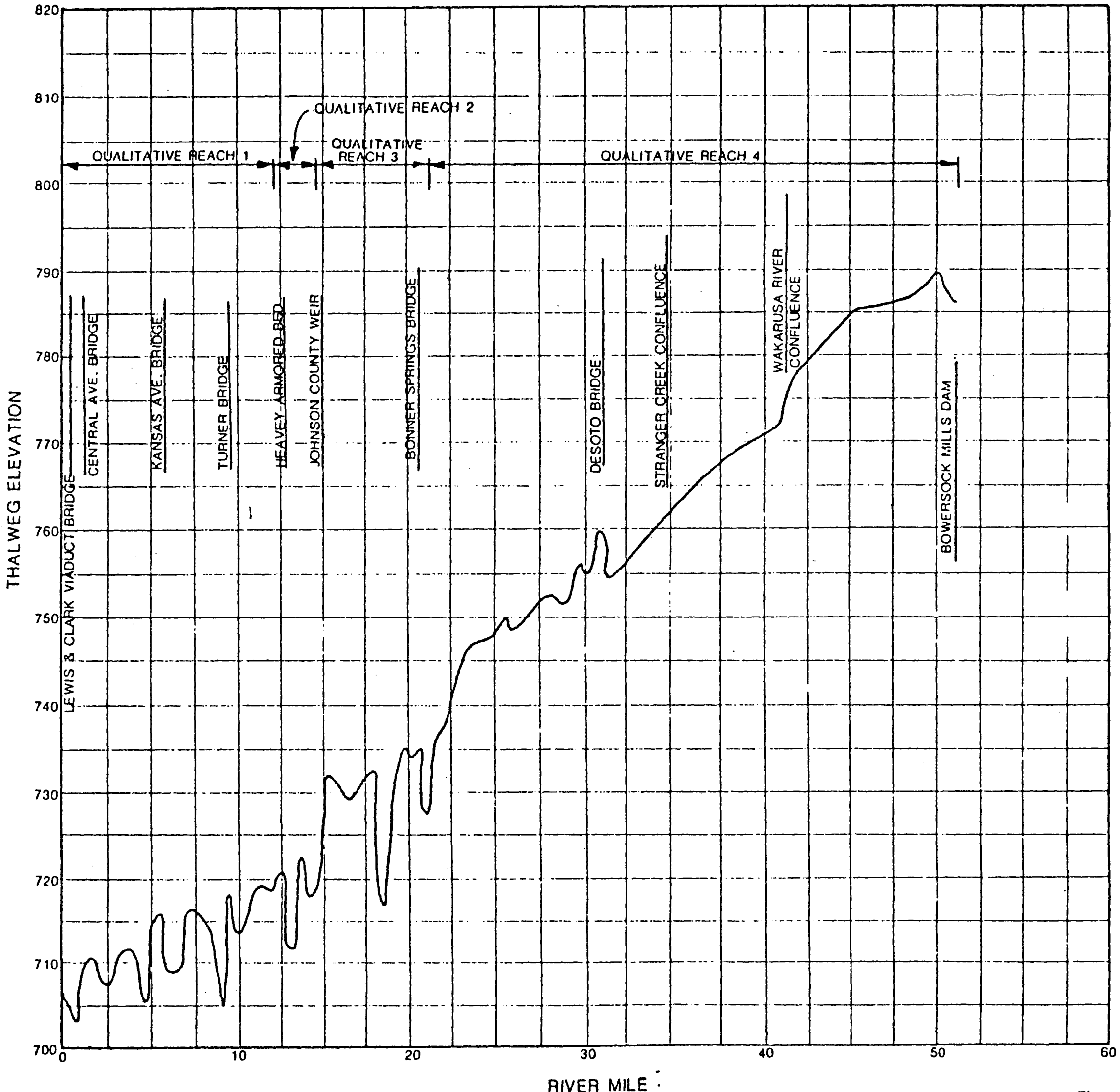


Figure 3.1a Thalweg profile and qualitative reach definition for the lower Kansas River. (from 1977 and 1983 data)

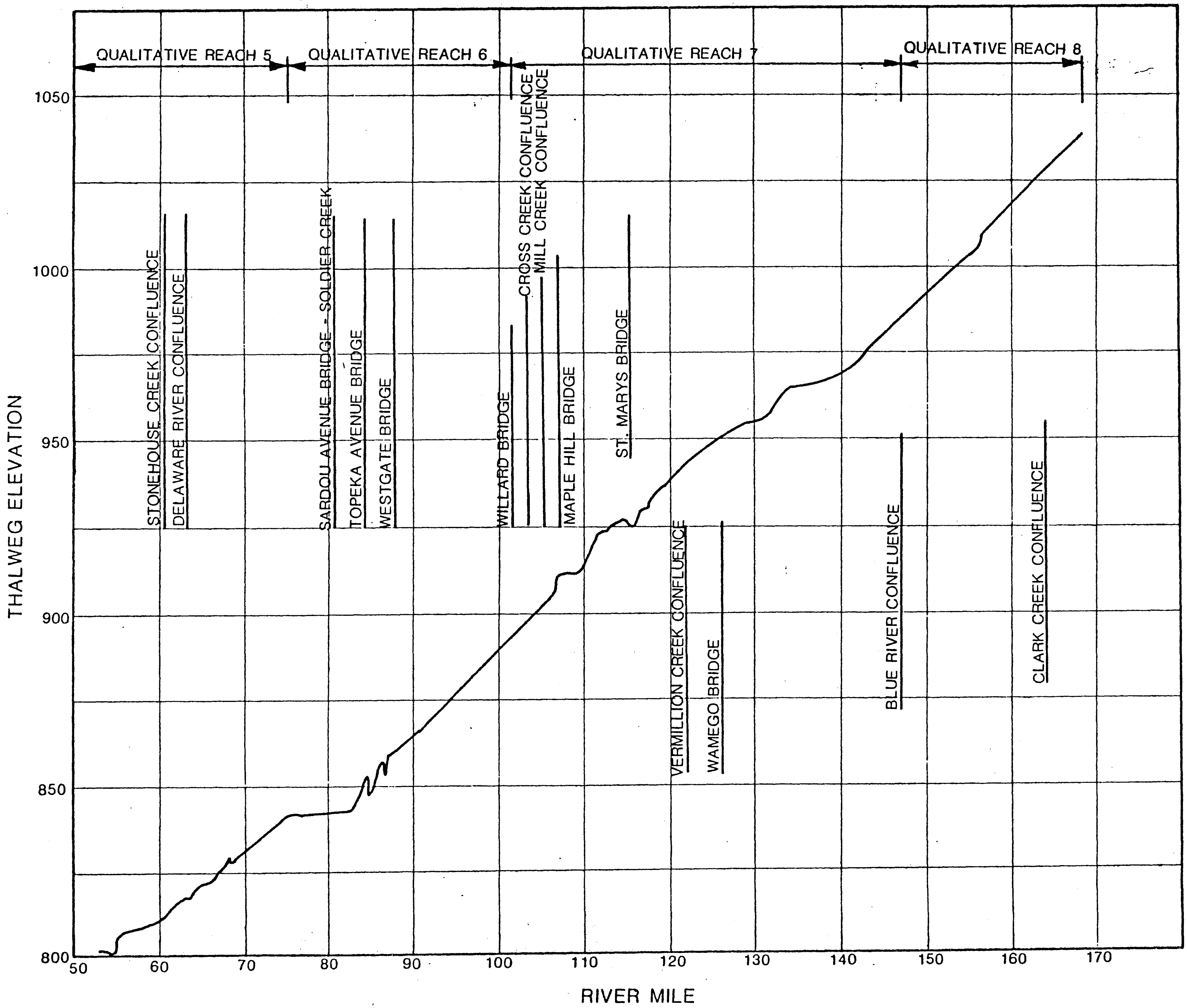


Figure 3.1b. Thalweg profile and qualitative reaches (from 1962, 1977 and 1983 data).

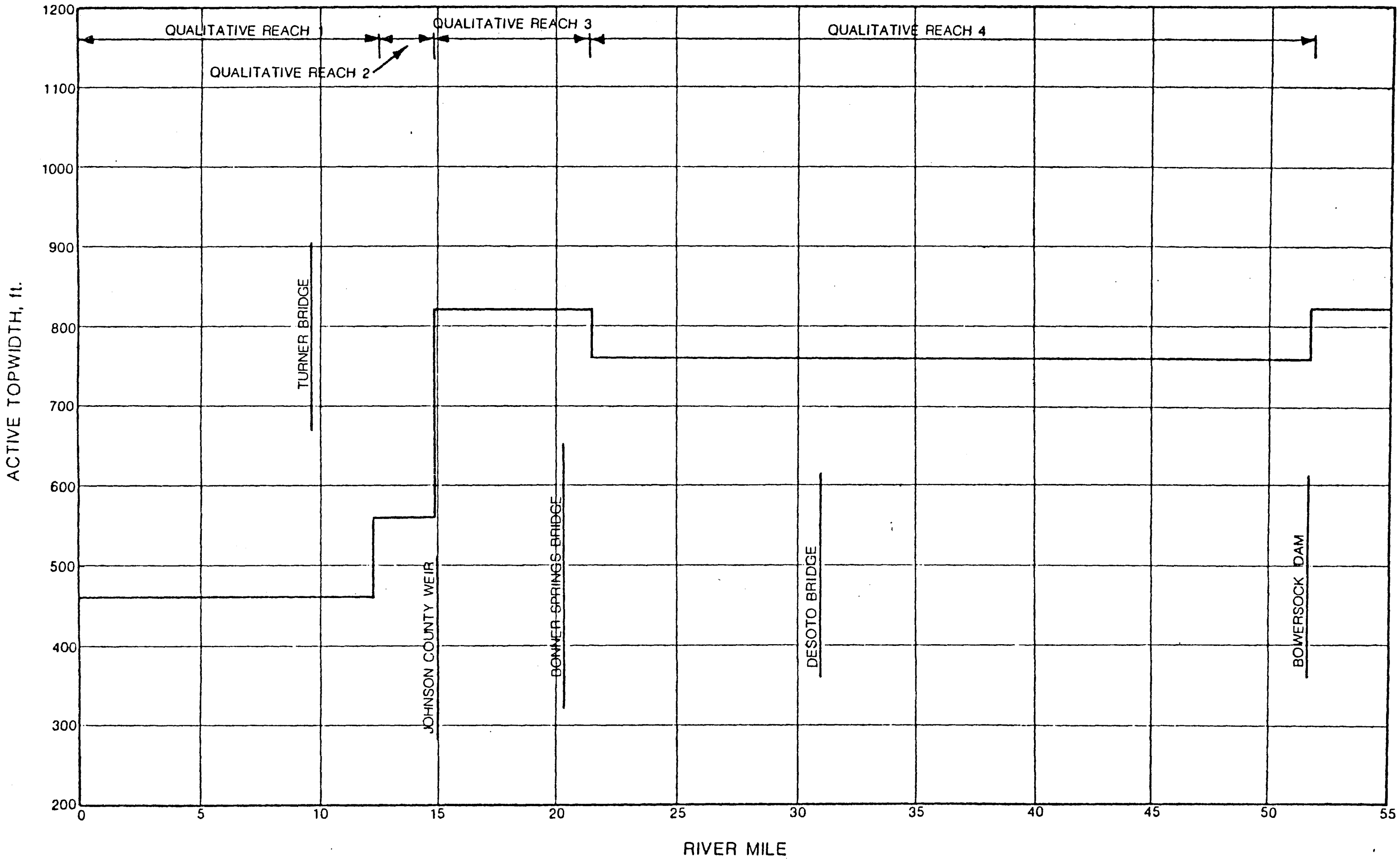


Figure 3.2a. Average active topwidth versus river mile (from 1983 aerial photography).

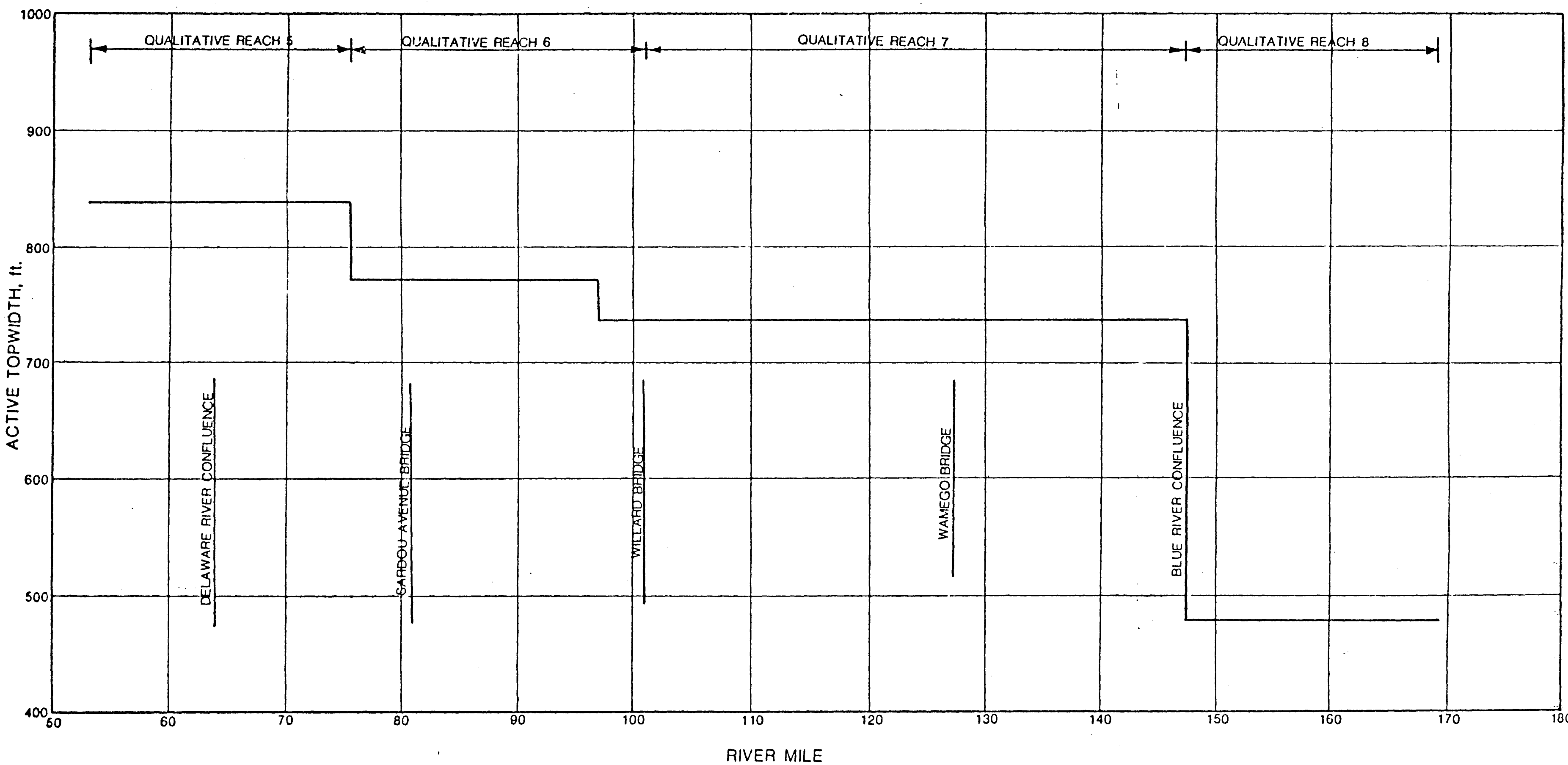


Figure 3.2b. Average active topwidth versus river mile (from 1983 aerial photography).

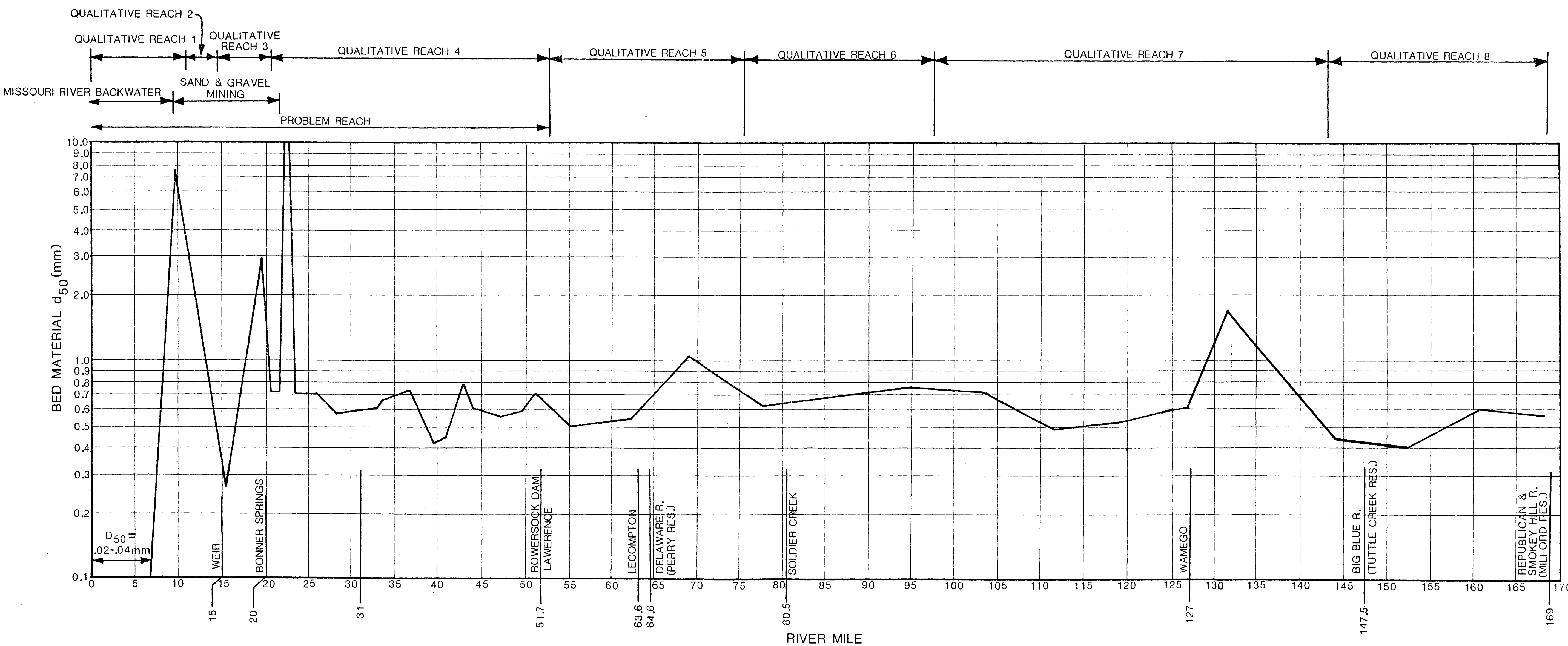


Figure 3.3 Bed material D_{50} and qualitative rea definition for the upper Kansas Rive (from 1983 Survey)

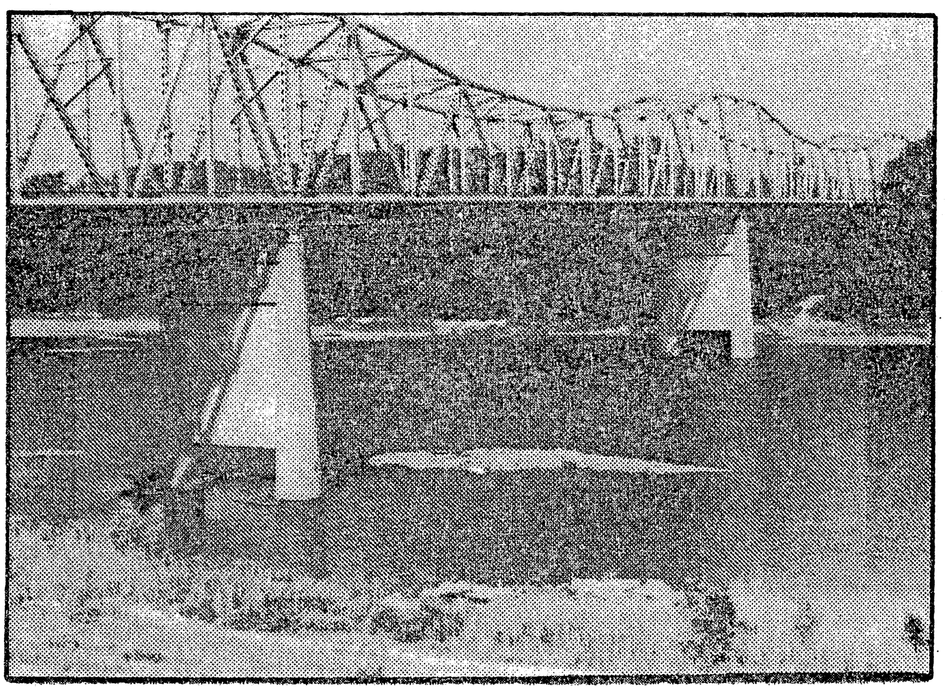


Figure 3.4. Turner Bridge (R.M. 9.6) looking towards left bank and slightly upstream.

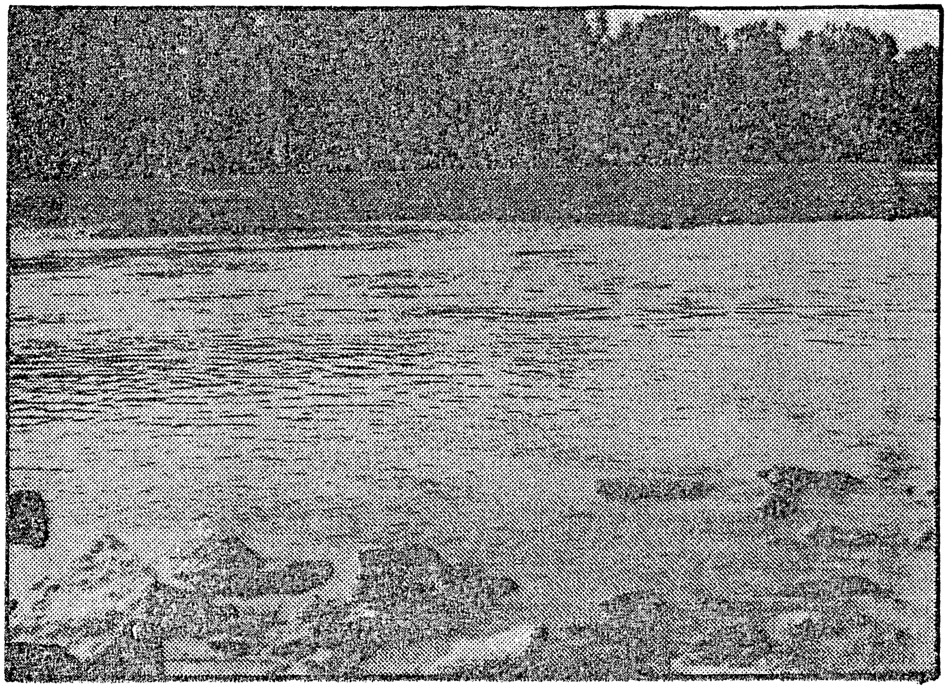


Figure 3.5a. Looking towards right bank at R.M. 12.2.

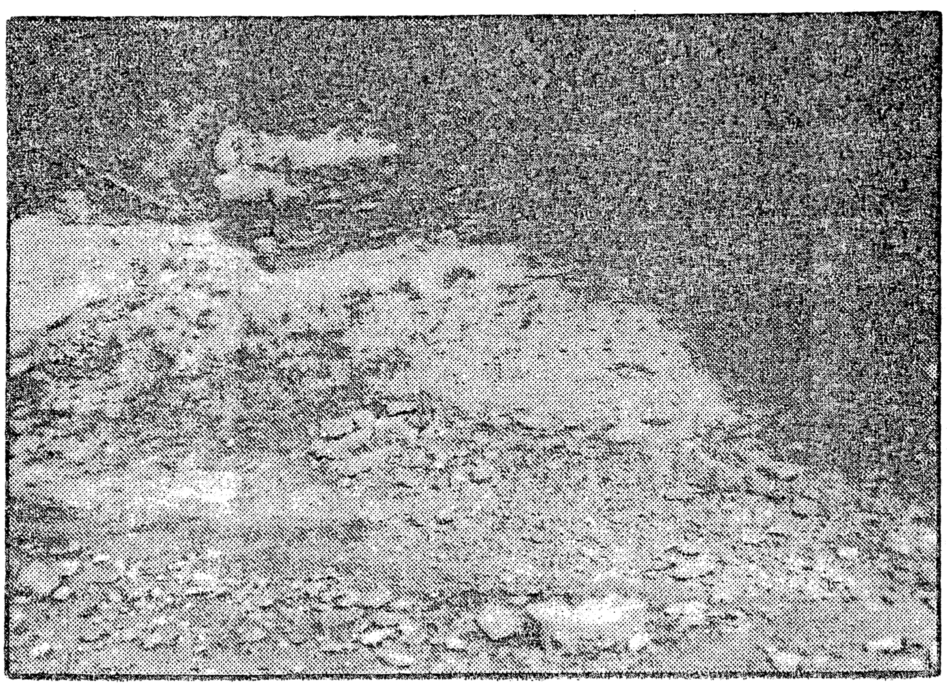


Figure 3.5b. Looking towards left bank at R.M. 12.2.

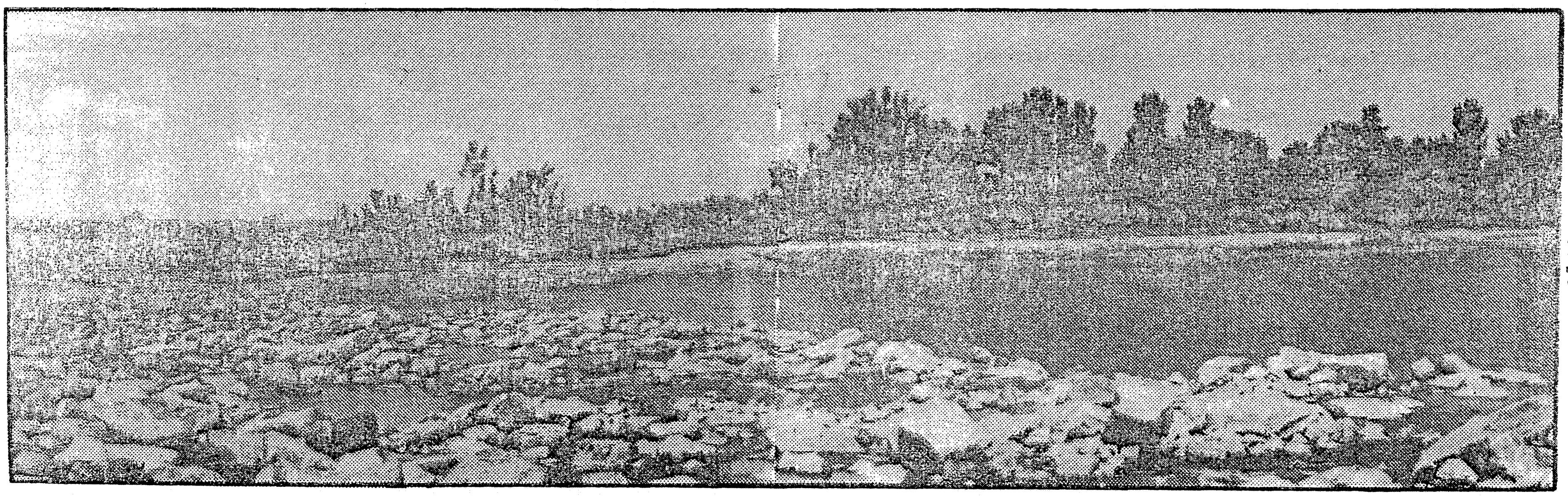


Figure 3.6. Left bank downstream of Johnson County weir (R.M. 15.0). Large rubble on the left and in the foreground is the downstream face of Johnson County weir.

Reach 3 extends from the Johnson County weir to R.M. 21.5. The weir was initially constructed in 1967 and consists of a rock jetty and weir constructed across the river to maintain water-surface elevations sufficiently high to insure proper operation of the Johnson County Water District No. 1 intake. The weir and jetty have seen numerous modifications since the initial construction. The jetty extends across the river to within approximately 25 feet of the intake structure and is constructed of rock riprap with a maximum size of five to six feet. The jetty forces the low-flow channel to the south bank adjacent to the intake structure. A differential of approximately nine to ten feet in the river bed elevation occurs across the weir; a rock chute channel carries the flow between the end of the jetty and the intake structure. This structure is an effective control for the channel bed. No further degradation of the channel will occur at this location. At low flows, the weir creates backwater for some distance upstream, resulting in deposition of fine sediment material. Considerable sand and gravel mining is occurring in the channel throughout this reach. Figure 3.7 is a photo of the river channel just upstream of the weir taken on August 31, 1983. The discharge on this date was approximately 1,100 cfs. This photo shows the placid flow in the backwater area for this relatively low discharge. Also note the dredge operation near the south bank just upstream of the I-435 bridge.

Reach 4 extends from R.M. 21.5 to Bowersock Dam at R.M. 51.7. Figure 3.8 shows the river looking upstream and toward the north bank from approximately R.M. 21.5. There is evidence of significant degradation in this area. The thalweg plot (Figure 3.1) indicates that the channel bed is quite low in this area compared to upstream and downstream reaches. Gravel bars armored with material having maximum size of approximately six inches occurs in this area (see Figure 3.9). Relatively high vertical banks occur along the north side of the channel. As will be discussed in later sections of the report, it appears that a headcut is progressing upstream through this area. Due to the size of the gravel material in the sand bars, this area will probably act as a channel control at least at low to moderate discharges, limiting the amount of additional degradation that may take place.

An important characteristic of Reach 4 is the presence of numerous areas of bank instability. Figures 3.10a-c and 3.11a and b show examples of the unstable banks which occur throughout the reach. At several locations bank protection measures have been installed, including revetments, riprap slope

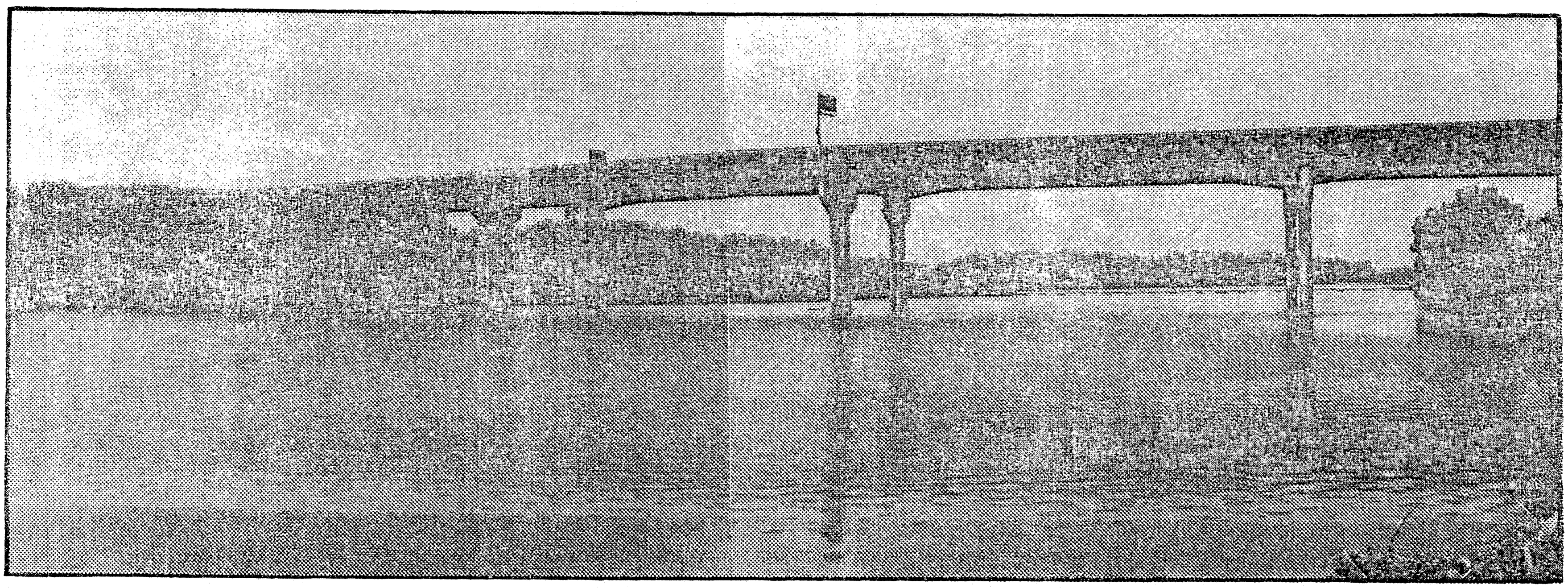


Figure 3.7. Looking upstream at R.M. 15 towards the I-435 bridge (Note: dredge in background).

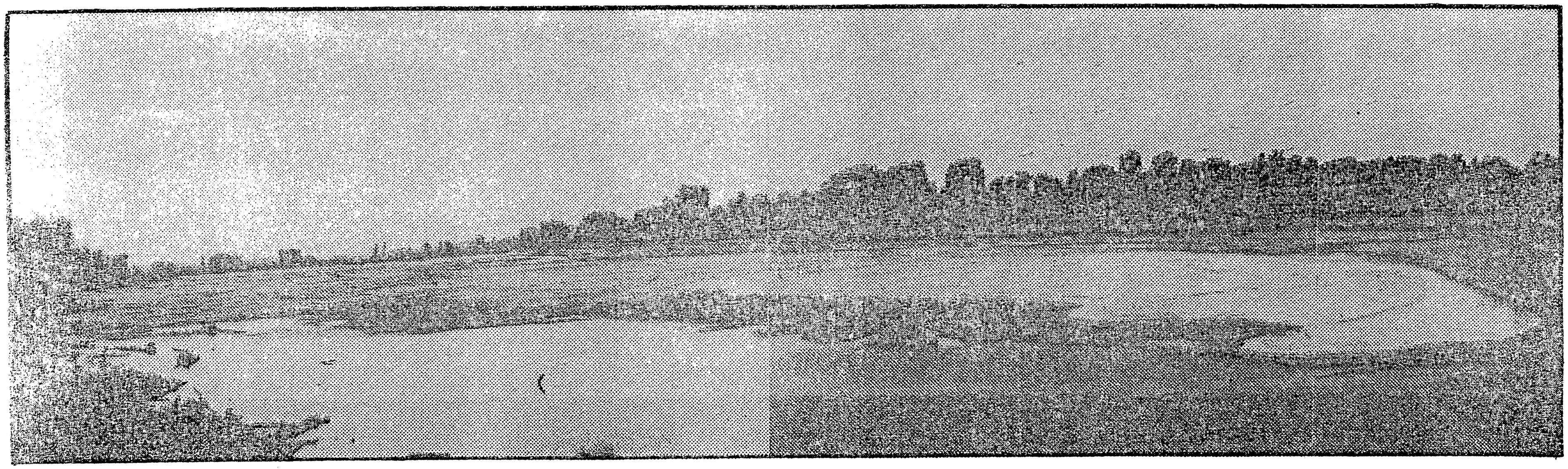


Figure 3.8. Looking upstream at R.M. 21.5.

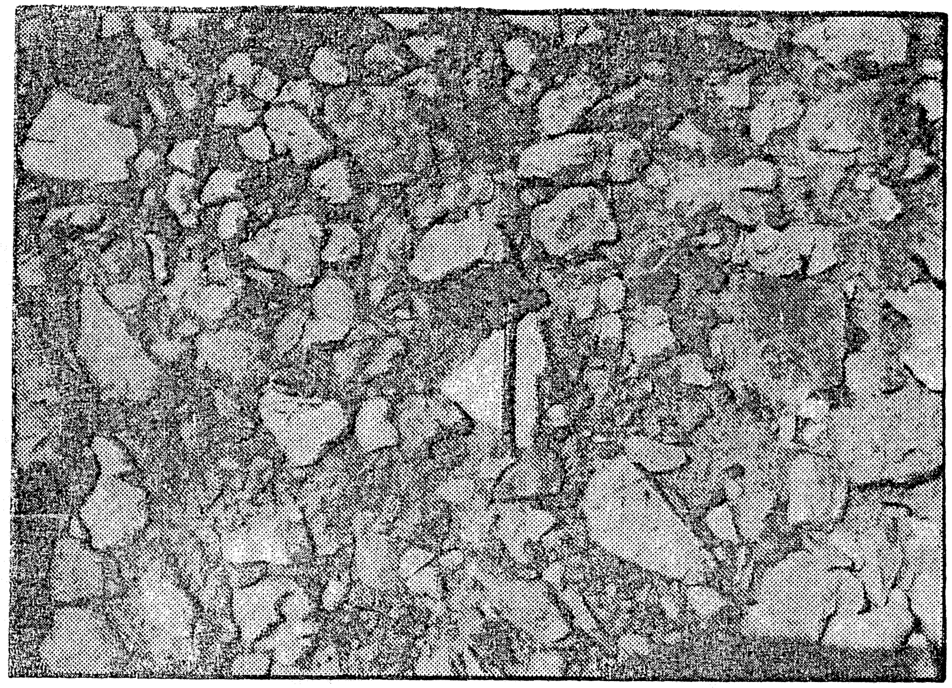


Figure 3.9. Armoring of the channel bed at R.M. 21.5.

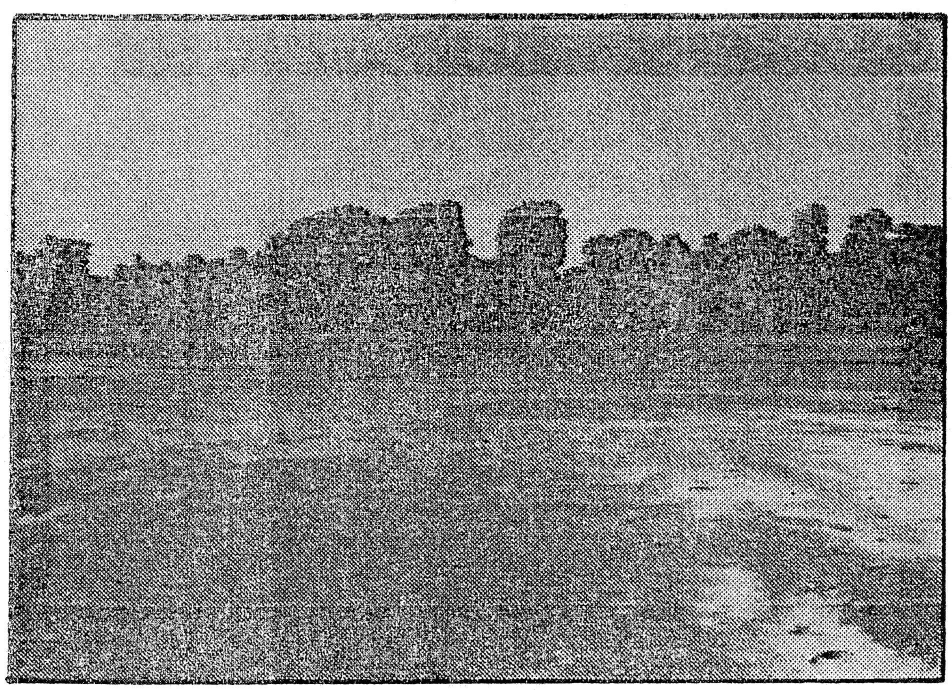


Figure 3.10a. Left bank at R.M. 22 (note confluence of Kaw Creek at left of photo).

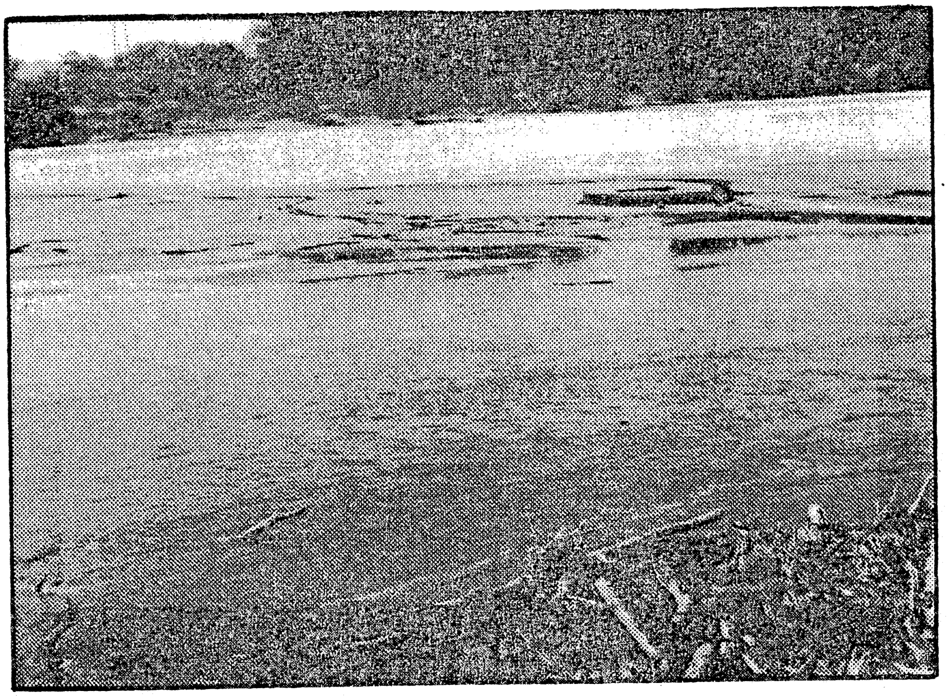


Figure 3.10b. Left(N) bank at R.M. 24.5.

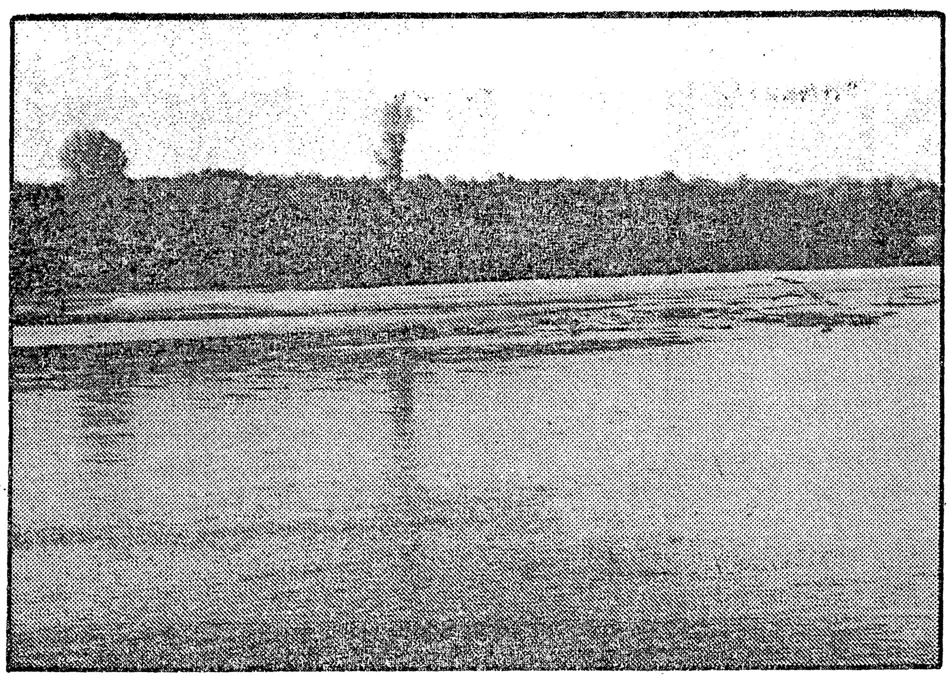


Figure 3.10c. Left(N) bank at R.M. 28.5

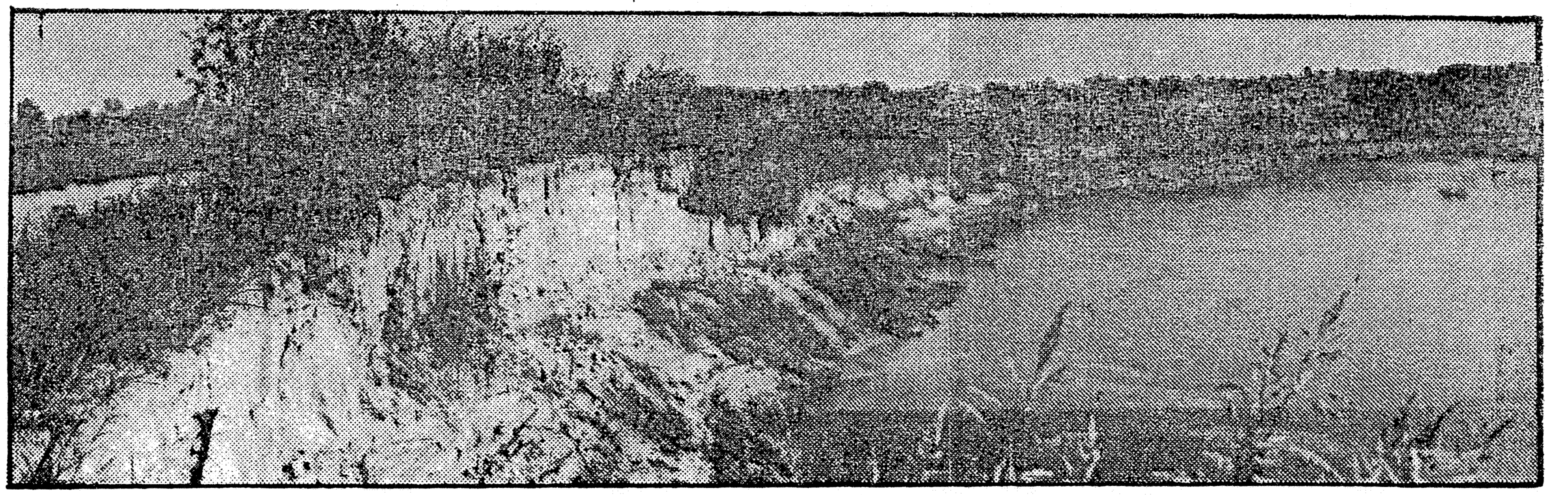


Figure 3.11a. Looking upstream at R.M. 41.

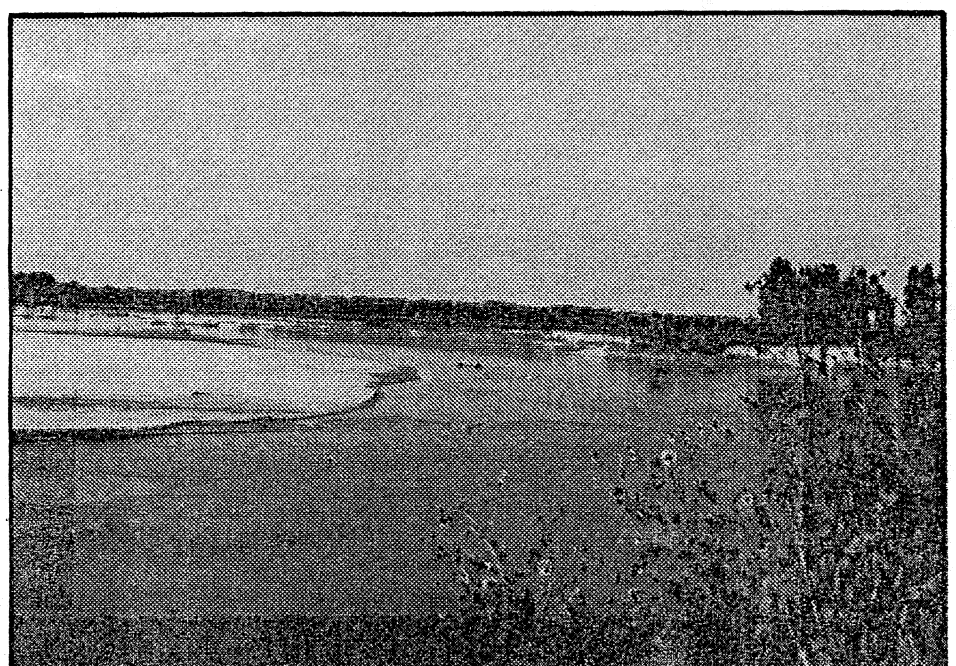


Figure 3.11b. Looking downstream at R.M. 41.

protection, hard points, jack fields, etc. in an attempt to stabilize specific channel bank areas.

Except for a limited area just downstream of the Bowersock Dam, very limited sand and gravel mining is taking place within this reach. There is evidence of degradation in the area immediately downstream of Bowersock Dam. As shown in Figure 3.12, the channel banks in this area are relatively high.

Reach 5 contains the area between Bowersock Dam (R.M. 51.7) and R.M. 76.0. The dam is an effective channel control. Like the Johnson County weir, it will prevent degradation that appears to be occurring in the downstream reaches from progressing upstream, and at low flows creates a backwater effect for some distance upstream. This is a relatively stable reach with very little bank instability and little evidence of bed degradation. Figure 3.13 is a photograph looking downstream from the Lecompton Bride (R.M. 63.5). The section of river shown in this picture is typical of the reach under consideration. The channel banks tend to be relatively low. The channel bed at this low flow (about 1,100 cfs) shows a regular pattern of alternate sand bars within the main channel area. The Delaware River, on which Perry Reservoir was constructed approximately eight miles upstream of the confluence, enters the reach at approximately R.M. 64.5.

Reach 6 extends from R.M. 76.0 to the Willard Bridge at R.M. 101.0. This reach encompasses the Topeka area where a series of flood protection works was constructed in the early 1900's, modified in 1938 and again after the 1951 flood. The existing works consist of levees along both sides of the river and provides protection for flows in excess of the 100-year flood. A photograph of the north levee and the river channel at approximately R.M. 86 is shown in Figure 3.14. These levees have had the effect of narrowing the channel in some places and have stabilized the channel banks.

In addition to the flood protection works, the City of Topeka has constructed two rock jetties across the channel at approximately R.M. 87 to control the low flow channel and insure an adequate supply of water to their water treatment plant. The west jetty (see Figure 3.15) was constructed in 1966 and extends from the west bank across the river to within approximately 70 feet of the sheet pile "dew drop" used to concentrate the flow for the west intake. In constructing this jetty, a section of an old cable and anchor jack field which ran roughly parallel to the channel was removed. The sand bar upstream of this jetty is caused by trapping of sand in the remains of the old

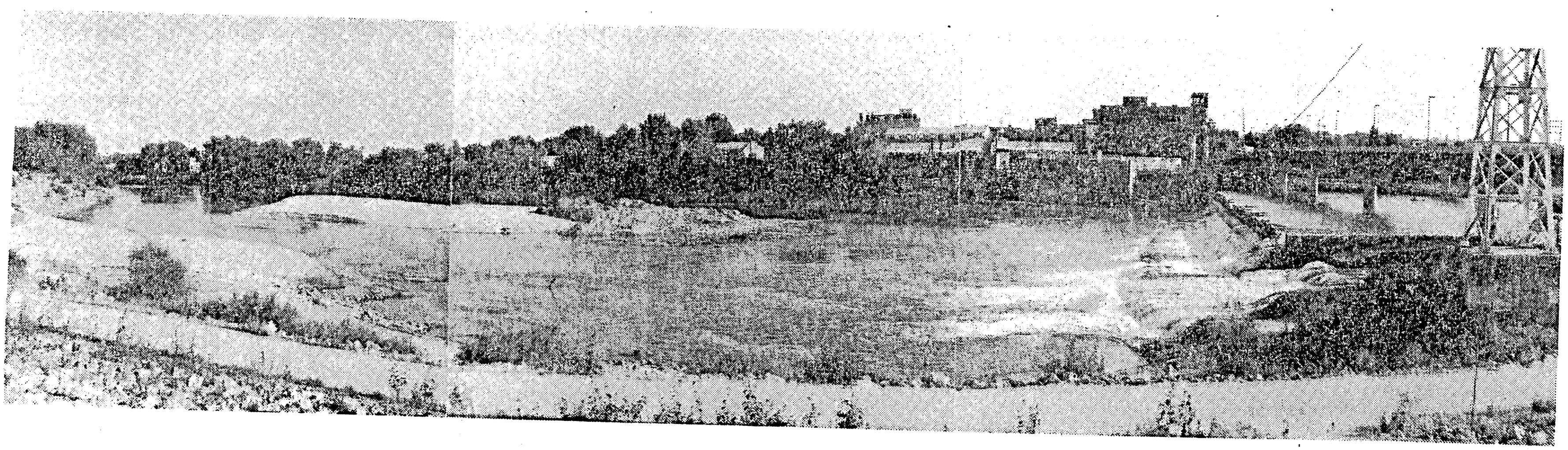


Figure 3.12. Bowersock Dam (R.M. 51.8).

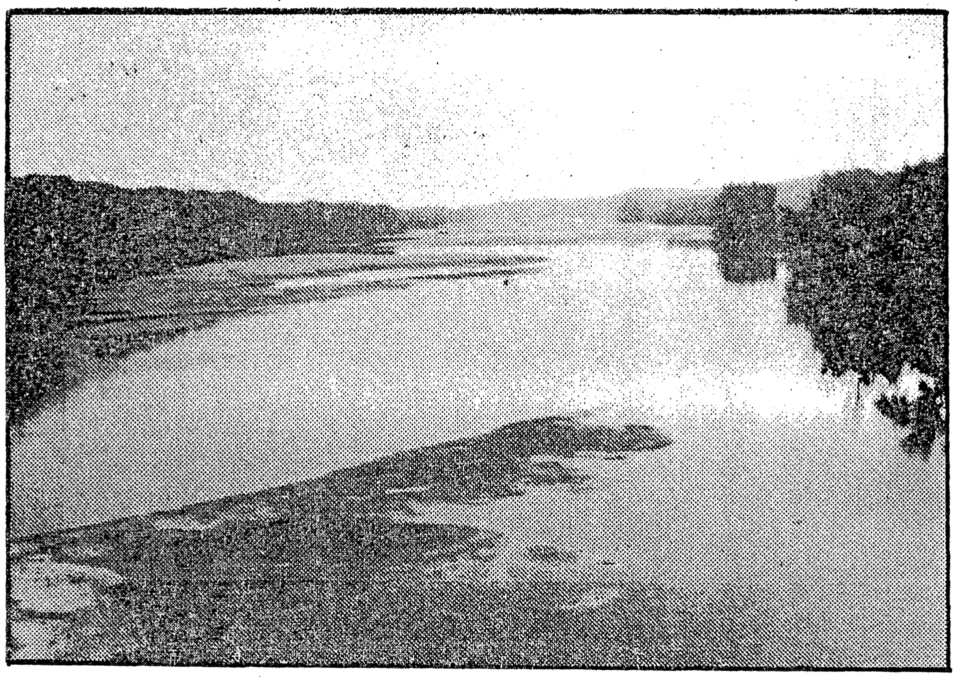


Figure 3.13. Looking downstream from the Lecompton Bridge (R.M. 63.5).

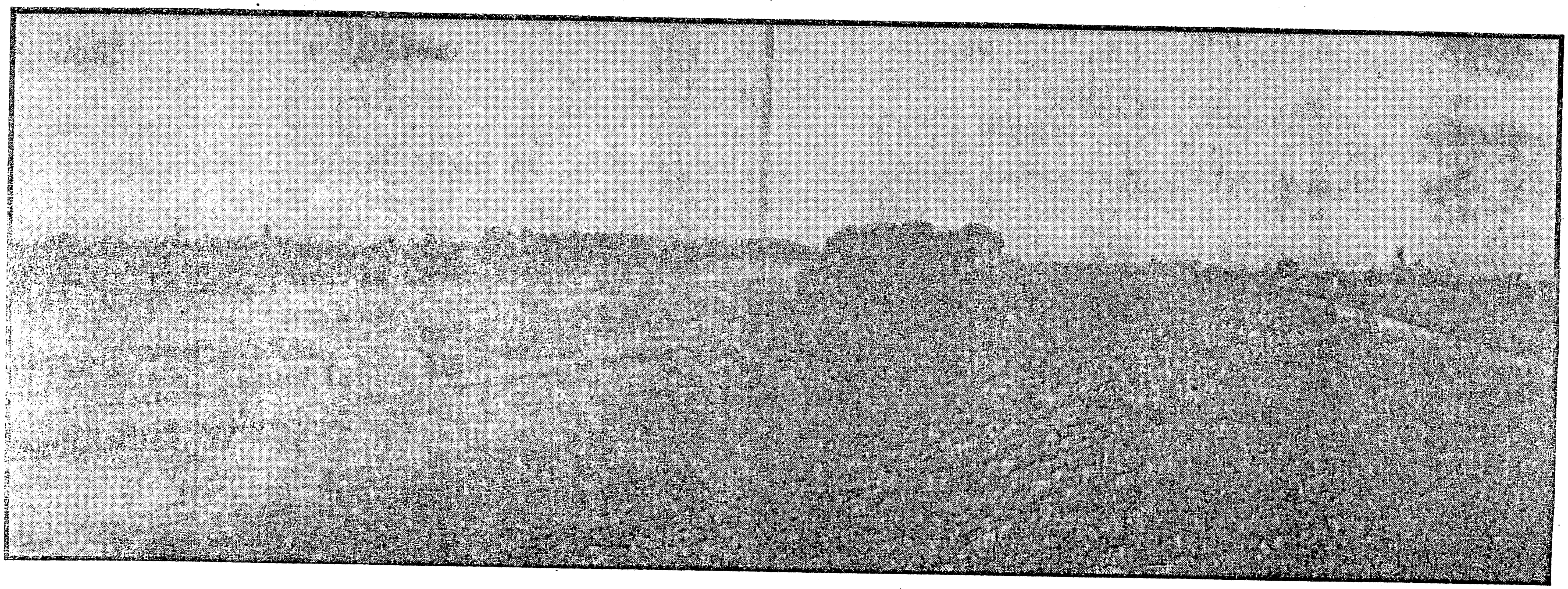


Figure 3.14. North levee looking upstream toward Westgate Bridge (≈R.M. 86).

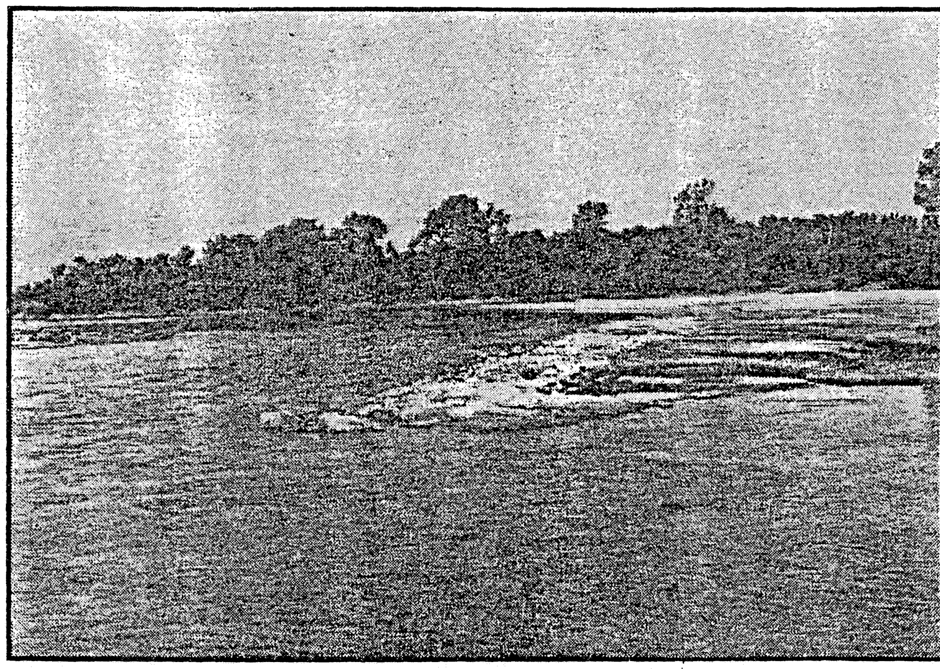


Figure 3.15. West jetty looking toward the north (approximately R.M. 86, discharge=2,400 cfs).

jack field. The existing east jetty is an extension of an old cable and anchor jetty constructed in the 1940's. The old portion was covered with rock to provide a haulway and a new 250-foot long section constructed to within approximately 100 feet of the east intake. Study of the flow patterns in the river evident from aerial photos indicates that these jetties are quite effective in controlling the low flow currents for operation of the intakes. The top elevations of the jetties are relatively low; inundation occurs when the discharge in the river is approximately 4,000 cfs. A proposed low weir at this location would act as a major channel control, preventing degradation immediately upstream of the structure.

A considerable amount of sand and gravel mining (on the order of 0.5 million tons per year since 1976), has taken place in the Topeka area. In addition, extensive flood control works have narrowed the channel. Degradation on the order of one to two feet has been documented near Topeka (Osterkamp 1981). With the exception of the Topeka area, the remainder of the reach appears to be relatively stable.

Reach 7 extends from the Willard Bridge at R.M. 101.0 to R.M. 148.0. A bedrock outcrop occurs at and just upstream of the Willard Bridge (see Figures 3.16a and b). A geologic cross section through the bridge indicates that the bedrock dips off sharply toward the north side of the channel. The existence of the rock over more than half of the active channel and the presence of relatively coarse gravel material, however, indicates that some vertical control of the channel exists at this location. As shown in Figures 3.17a and b, bank erosion is quite active in this reach. Bank protection measures have been installed at several locations. Figure 3.18 shows the river channel at R.M. 115 where a series of rock dikes has been installed along the south bank of the channel. There appears to be little evidence of bed degradation, however, since the 1951 flood. Stage records at Wamego (R.M. 126.9) indicate that approximately two feet of general degradation occurred during the 1951 flood but has exhibited little change since. The Big Blue River enters the Kansas River at the upstream end of the reach. Tuttle Creek Reservoir was constructed on this tributary (closure occurred in 1959) approximately ten miles upstream of the confluence. Approximately ten feet of degradation has occurred in the Big Blue River within one-half mile downstream of the dam. The impact of the dam appears to lessen downstream as no more than one to two feet of degradation is evident in the Kansas River at and immediately downstream of the confluence (see Appendix D).

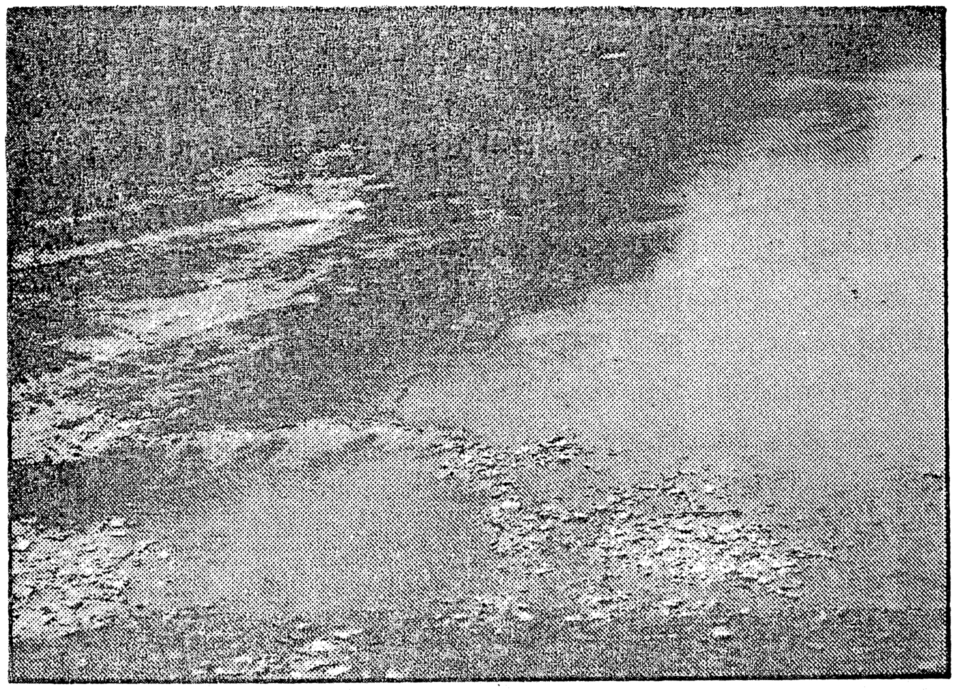


Figure 3.16a. Riffle and armor at R.M.101.

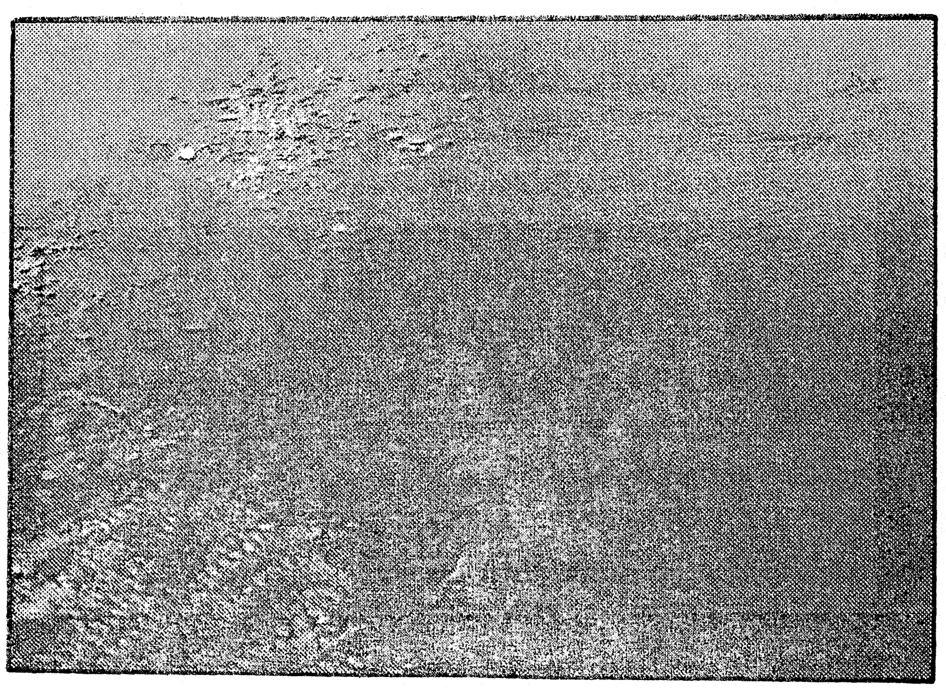


Figure 3.16b. Rock and gravel at R.M. 101.1

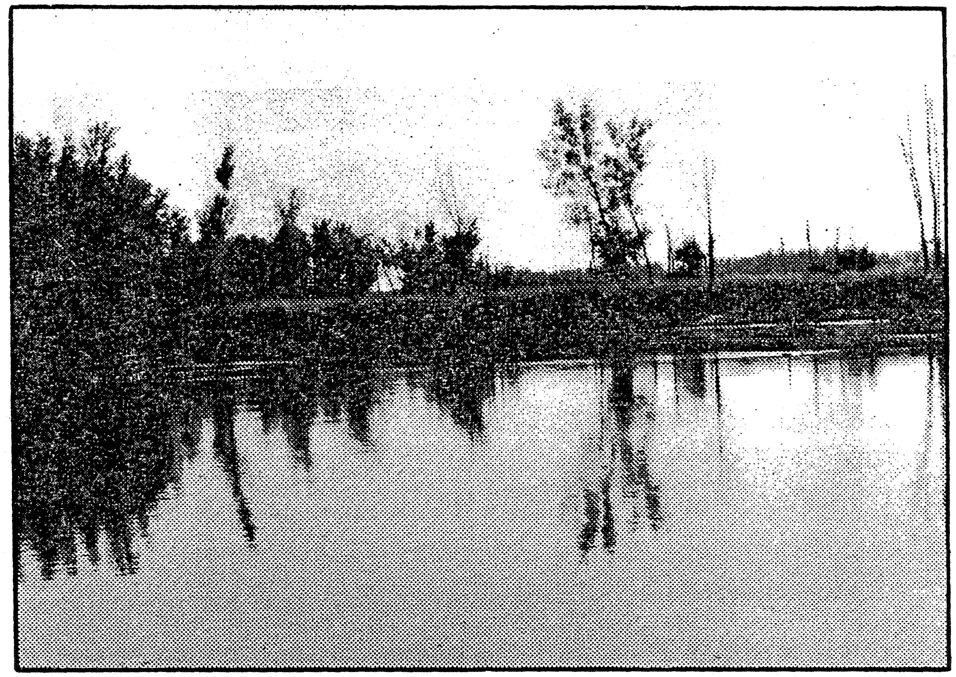


Figure 3.17a. South bank at R.M. 109.

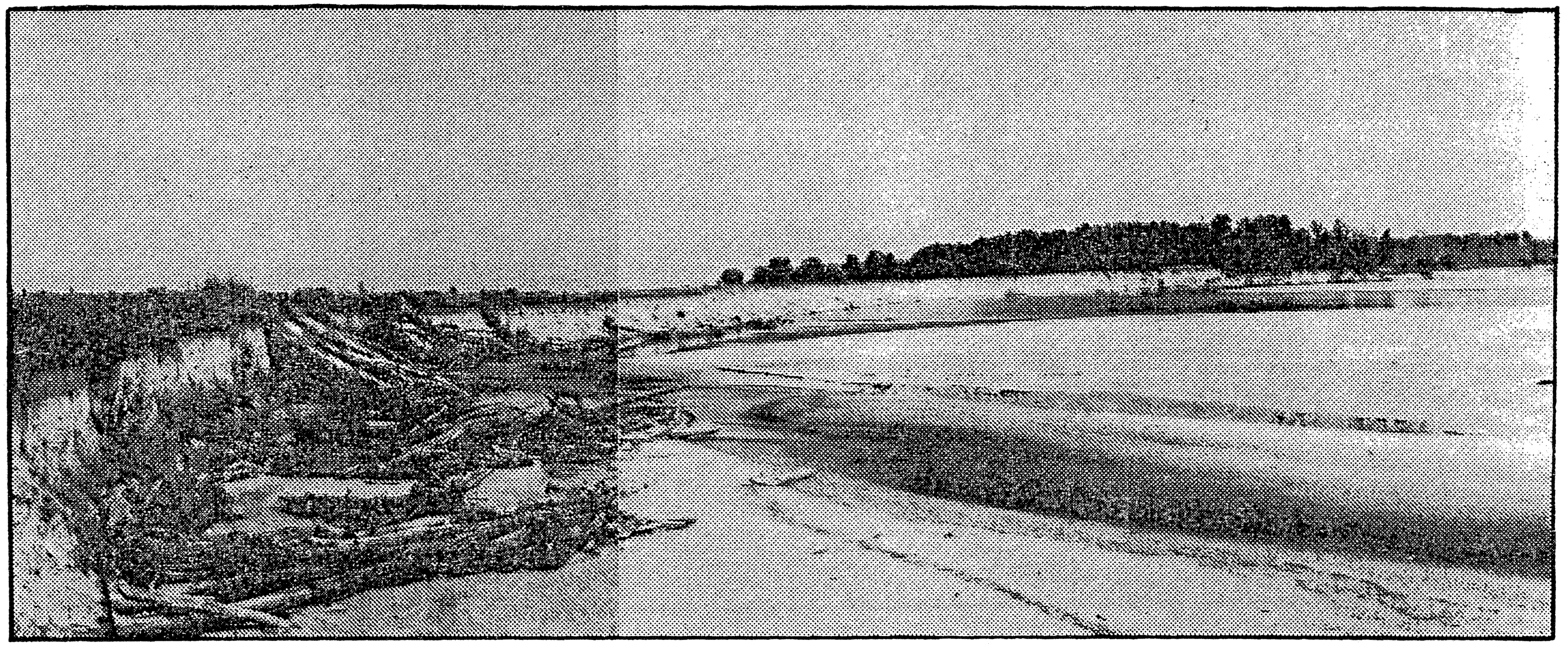


Figure 3.17b. North bank at R.M. 114.5 looking downstream.

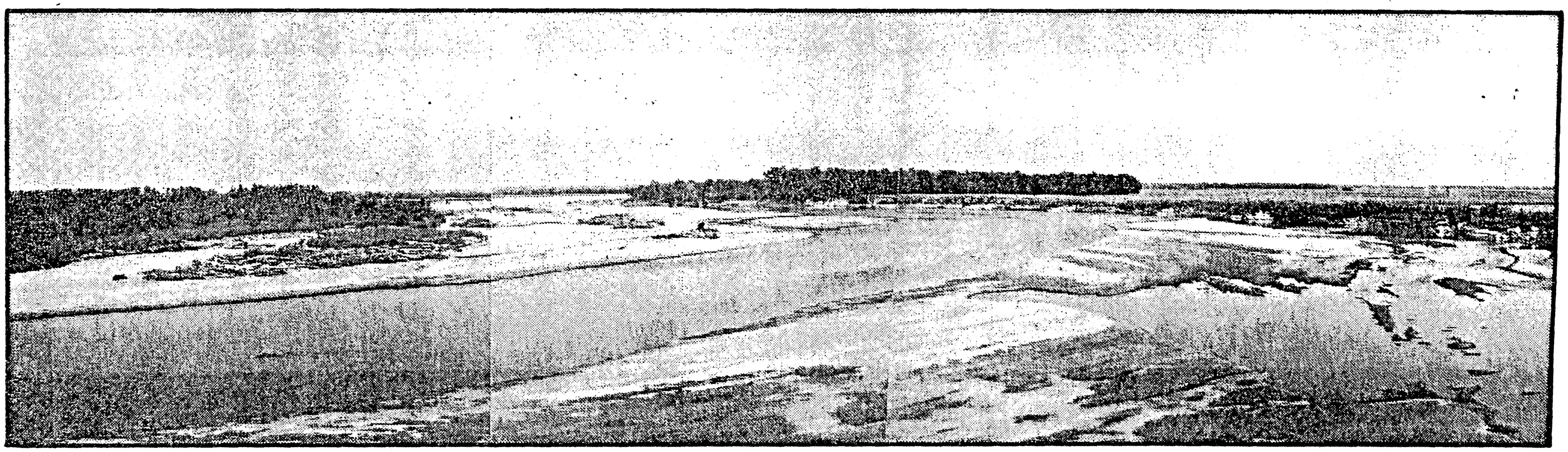


Figure 3.18. R.M. 115 looking downstream.

Reach 8 contains the remainder of the Kansas River from R.M. 148 to the confluence of the Smoky Hill and Republican Rivers at R.M. 170.4 near Junction City, Kansas. This upstream reach appears to be relatively stable. There are, however, some areas of active bank erosion. Milford Reservoir is located on the Republican River approximately eight miles upstream of the confluence with the Smoky Hill River. About six to seven feet of degradation has occurred in reach below the dam, but again tapers off to less than two feet at the confluence (see Appendix D).

3.3 Observed Trends in Channel Morphology

During recent history a significant amount of change has occurred in the Kansas River. Being an active alluvial stream, considerable change is certain to have occurred regardless of the activities of man. It is the purpose of this study to quantify, to the extent possible, the impact of the various activities of man during the past half to three-quarters of a century. In order to accomplish this, it is necessary to carefully study the documented changes that have occurred during the period of concern and to separate those changes which could reasonably have been expected to occur because of natural factors from those which were man-induced. Numerous studies have been conducted and considerable data collected by various agencies interested in the Kansas River. This section of the report is a compilation of data and observations from these previous studies, expanded to include data and observations obtained specifically for this study. By comparing conditions at various locations along the river at times which bracket a significant natural or man-induced event, it is possible to isolate changes or responses to the event. Along the Kansas, many activities or events have occurred simultaneously or during periods which cannot be isolated by available data. This makes analysis of cause and effect more difficult. Separation of the impacts of activities which occur simultaneously require the use of geomorphic principles to provide an estimate of an activity's relative significance in creating the impact. The following sections utilize the available data and observations to evaluate the observed geomorphic trends in the Kansas River which have occurred during the period of interest.

3.3.1 Temporal and Spatial Changes in Bed Material Size Distribution

Analysis of temporal and spatial changes in the sizes of material found in the channel bed can provide significant information regarding the condition of the river channel. For example, a general coarsening of the sizes may indicate that the channel bed is degrading with the removal of finer material. A trend showing a progression toward finer material may be indicative of general aggradation. In areas where the flow velocities are slowed (e.g. backwater from weirs or natural controls, dredge holes, etc.), the bed material would typically be expected to become finer. Additionally, removal of coarse material, which can not be carried by the flow under normal conditions, by sand and gravel dredging and redeposition of finer transported material will tend to cause the bed material to become finer.

In order to evaluate these possible trends along the reach, available bed material size distribution data were collected and analyzed. The primary data used for the analysis were derived from surveys conducted by the U.S. Army Corps of Engineers (hereinafter referred to as the COE), in 1956, 1962, and 1976, by Osterkamp and Hedman in 1979, and from a survey conducted by SLA and Van Doren-Hazard-Stallings (VHS) in September 1983, for this study. Gradation curves for the samples collected during these surveys (excluding Osterkamp and Hedman, 1979) are presented in Appendix A. To analyze possible trends in the bed material size, a plot of the median (D_{50}) size at each location was prepared. This plot is presented in Figure 3.19a and b. From the figures, it can be seen that the median bed material size varies from approximately 0.4 mm to 2.0 mm with the majority falling within the range from 0.5 mm to 0.8 mm. It is likely that the majority of this variation can be accounted for by the sampling technique. It is very difficult to obtain representative bed material samples for a large river. Considerable variation in bed material can take place in the distance of only a few yards. For the 1983 SLA survey, bed material was sampled by making a composite sample composed of four separate samples taken at roughly equal intervals across the channel. This process was benefited by the extreme low flows during the 1983 survey. Each separate sample was collected by digging a hole or trench approximately two feet deep. The trench walls were carefully inspected in order to evaluate variability of the bed material with depth. If no significant variability was noted, the sample was taken from the first 12 inches of bed material. If a large difference in bed material composition with depth was noted multiple

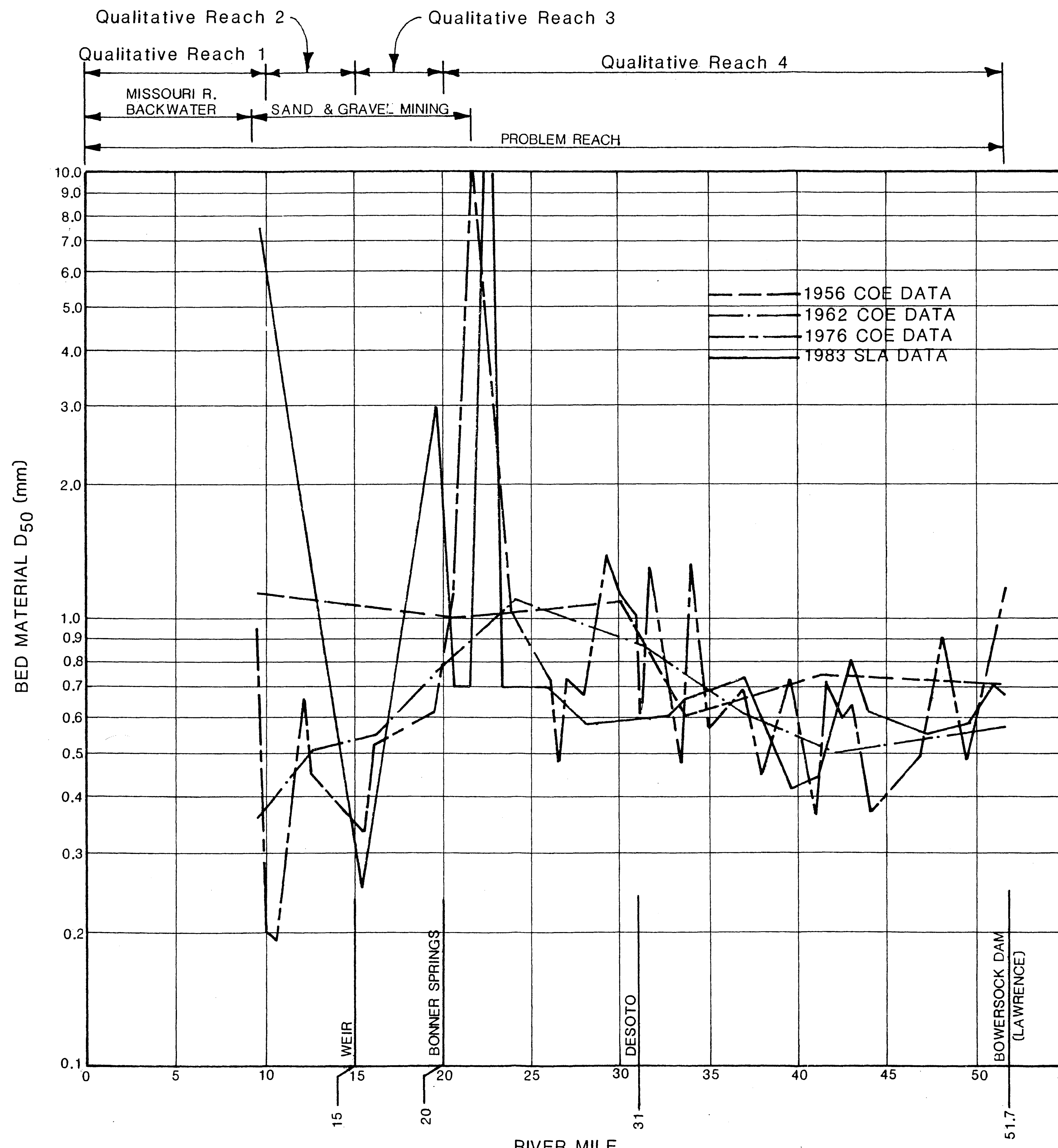


Figure 3.19a Historic D50 bed material size versus River Mile

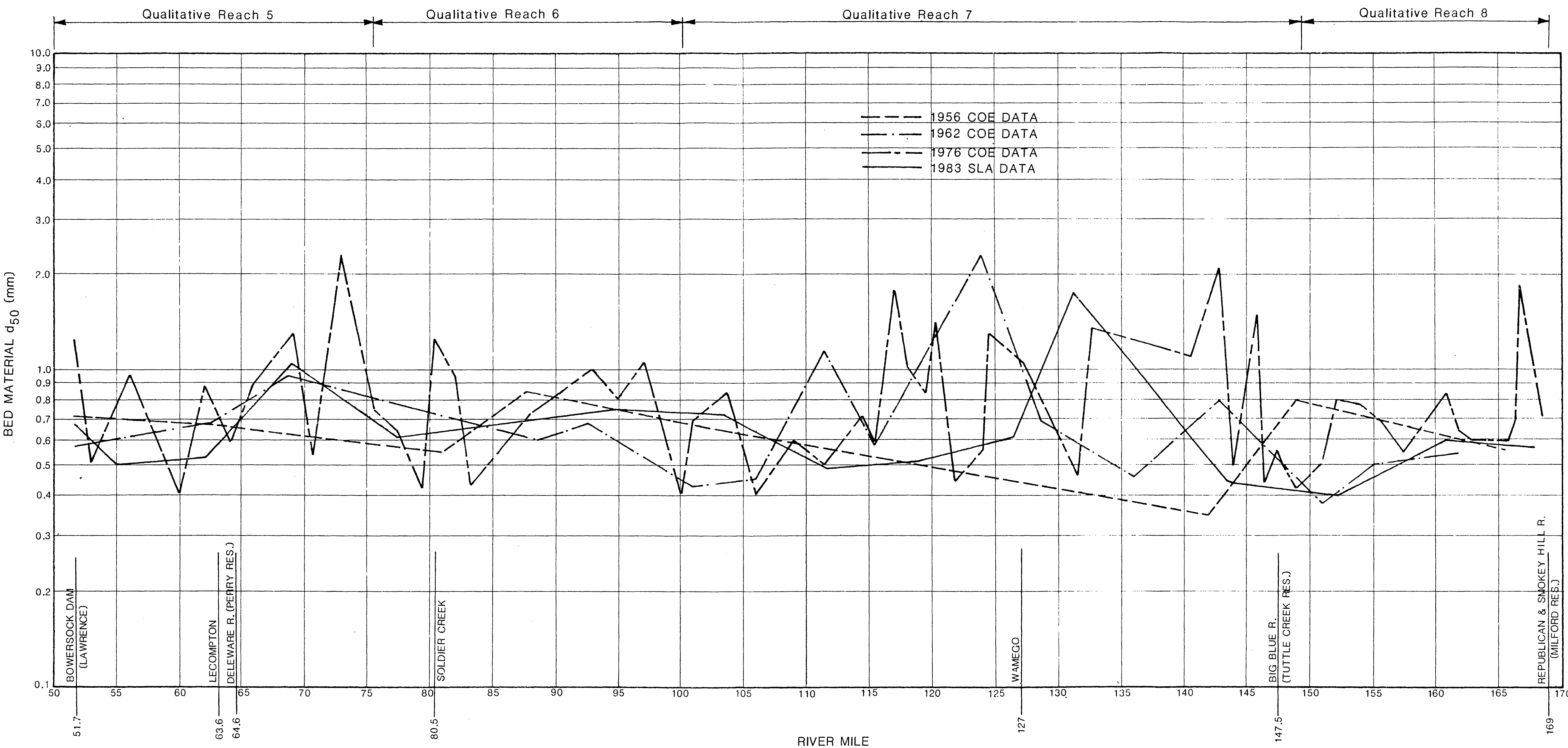


Figure 3.19b Historic D_{50} bed material size versus River Mile

samples from various depths were taken. The Kansas river bed material was found not to vary significantly to a depth of at least two feet. In areas that were armored, the armor layer was photographed with a scale. This allowed a rough determination of the armor layer size distribution from the photographs, using the pebble count method.

Additionally, bank samples were taken during the 1983 survey. These were generally a composite sample of the top two to three feet of bank material, however, if the bank was obviously stratified, multiple samples were collected and analyzed from the various bank strata. Bank sample gradations are included in Appendix A. Except for isolated areas where gravel bars or armoring of the channel occurs, there does not appear to be significant variation in the bed material size throughout the entire study reach.

Table 3.1 illustrates the change in median bed material size (D_{50}) from 1956-1983. With the exception of Reach 3 (R.M. 15-21.6) and Reach 4 (R.M. 21.6-51.7) no trend is apparent. The data for Reaches 3 and 4 indicate that the bed material has become finer with time. However, because of the limited number of data in these two reaches the observed trend is not statistically significant. The apparent reduction in D_{50} size in these two reaches may be the result of random sampling error. This apparent trend is corroborated by observations by dredgers in or near these reaches. Qualitatively, this apparent trend of the bed material becoming finer is an expected result of slowed velocities and consequent settling of fine material in the dredge pits.

3.3.2 Temporal and Spatial Changes in Suspended Sediments

Suspended sediment records from Wamego and Bonner Springs/Desoto were analyzed to identify trends in changes of size and quantity of suspended sediments that may be occurring over time. The analysis was limited to these two locations because the pre-1970 sediment data at other sites on the Kansas River are very sparse.

Osterkamp, et al., (1982), shows evidence that the suspended sediment at Wamego has become coarser with time. His analysis was based on both USGS and COE data. Figure 3.20 is a reprint from his report. The SLA analysis has shown the opposite to be true at Bonner Springs/Desoto. Data from the COE for 86 suspended sediment samples at Bonner Springs during the period June 1948 to July 1950 show an average size distribution of 39 percent clay, 47 percent silt, and 14 percent sand. From 1976-1978 the average size distribution of

Table 3.1. Average Median Bed Material Size.
(From COE, 1956, 1962 and 1976.
From SLA survey, 1983.)

Reach	River Mile	D_{50} (mm)			
		1956	1962	1976	1983
1	0.0- 12.5	1.2	0.44	0.50	*
2	12.5- 15.0	*	*	0.45	*
3	15.0- 21.6	1.0	0.70	0.66	0.45
4	21.6- 51.7	0.8	0.78	0.74	0.62
5	51.7- 76.0	0.68	0.83	0.95	0.69
6	76.0-101.0	0.68	0.64	0.80	0.68
7	101.0-148.0	0.50	0.88	0.90	0.60
8	148.0-169.0	0.68	0.47	0.72	0.50

*NOTE: These areas experience widely variable sizes in bed material within relatively small distances. Large armoring material occurs near R.M. 12.2 and fine organic muck occurs in the lower 7 miles. For this reason some samples in the lower 15 miles of the Kansas River were considered inappropriate for comparison purposes.

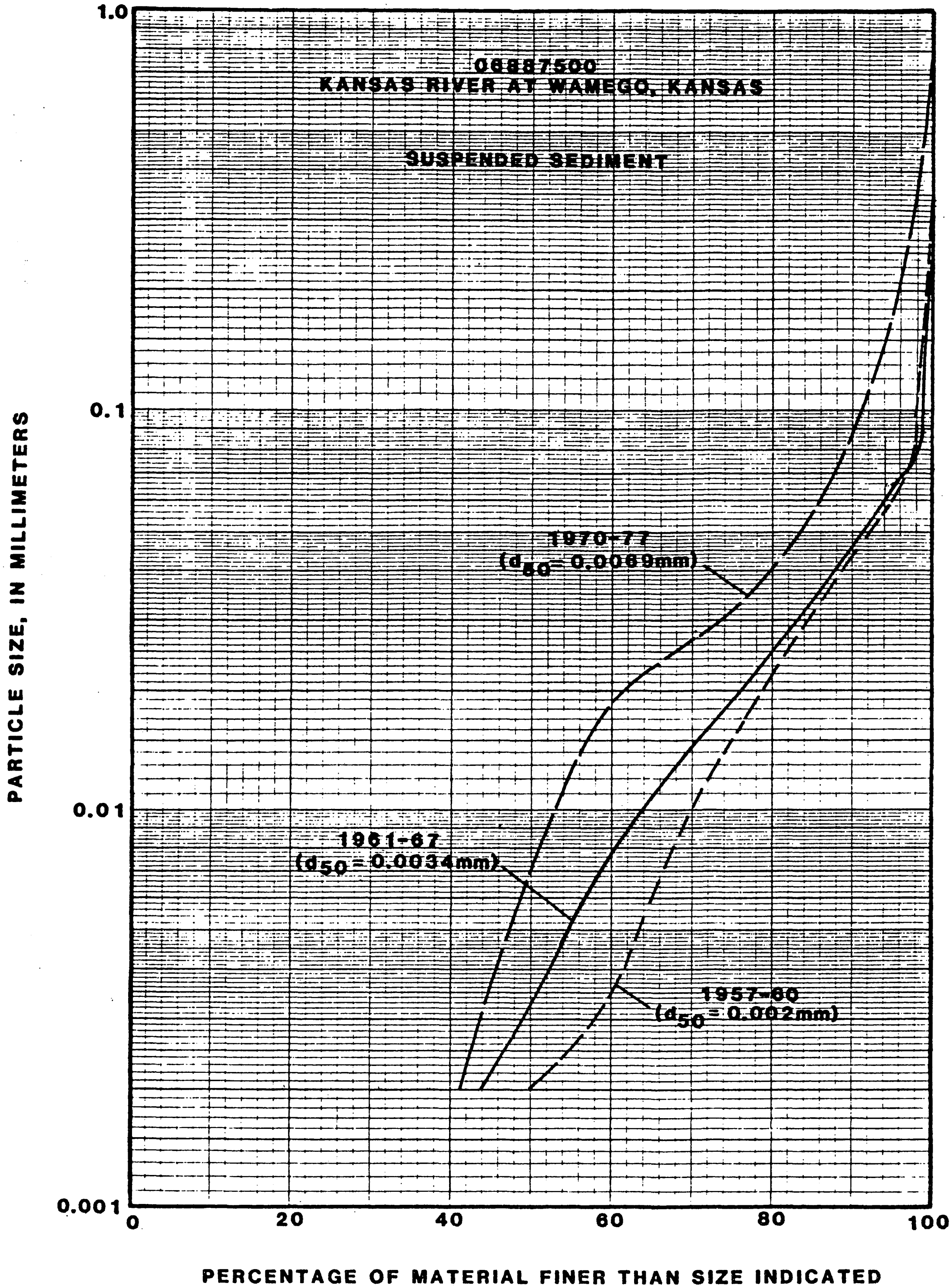


Figure 3.20. Suspended sediment size distributions at Wamego. (Osterkamp, 1982)

149 samples at Desoto was 59 percent clay, 35 percent silt and only six percent sand.

A possible explanation for the coarsening of the suspended sediment at Wamego relates to the trapping of sediment in Milford and Tuttle Creek reservoirs. The main source of the silt and clay components of Wamego's suspended sediment is the upstream watershed. Construction of the federal reservoirs has effectively cut off this supply, as well as the supply of sand from tributaries and the upstream watershed. However, the sand component of the suspended sediment load can be readily regained from material stored in the existing channel bed and to some extent, the banks. Since the channel bed is nearly all sand, the supply of sand available to make up the sediment deficit in the clear water released from the reservoirs is much greater than the available supply of silt and clay. This results in a higher percentage of the suspended load being composed of sand.

A different argument is needed to explain why the suspended sediment at Bonner Springs/Desoto may have become finer with time. A possible explanation is that the process of bank sloughing and erosion has been accelerated from 1948 to 1977 in the 10- to 15-mile reach above Desoto. The bank materials contain a higher percentage of silts and clays. Sloughing of bank material is, therefore, accompanied by a relative increase in the percentage of silts and clays available for suspension in the flow. Additionally, it should be noted that the reach between Bonner Springs and Desoto has been highly disturbed by dredging activities; and consequently, it is difficult to directly compare measurements made at the two stations.

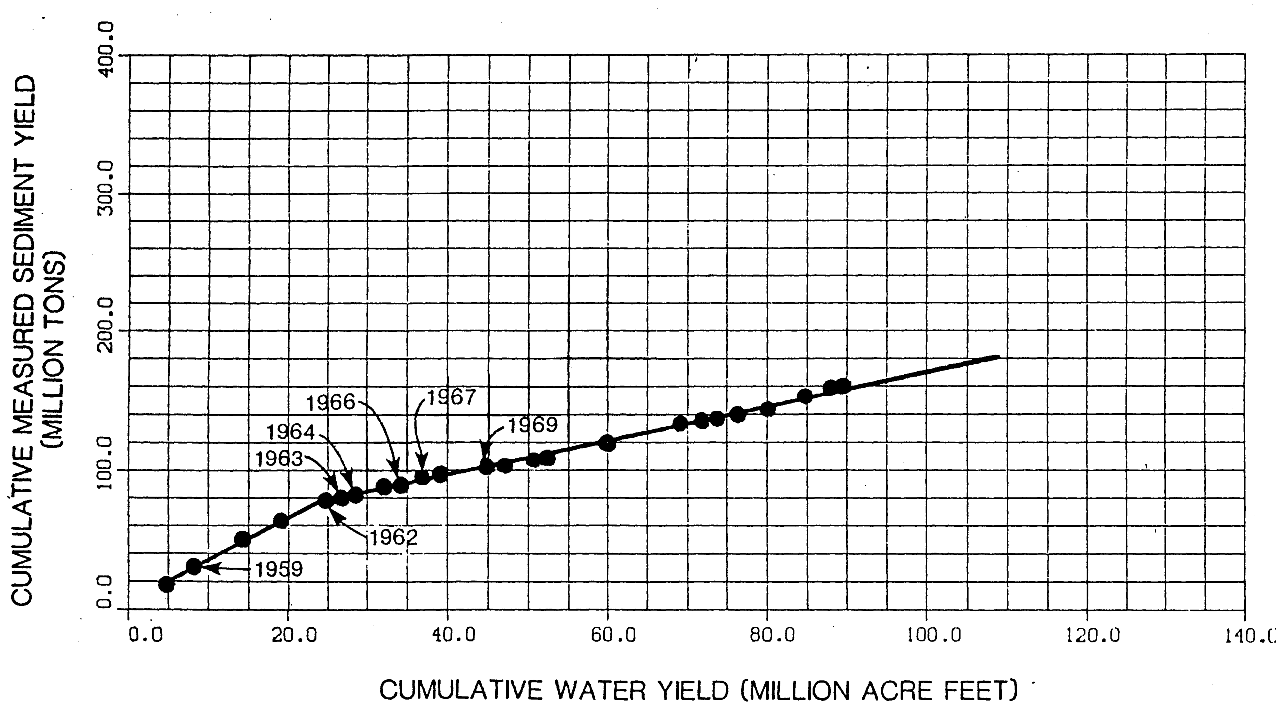
3.3.3 Annual Water and Sediment Yield

Continuous daily measurements of stage along with periodic measurements of discharge have been performed by the U.S. Geological Survey at several sites along the Kansas River since before 1920. Daily suspended sediment measurements were not made until 1958 and then only at Wamego and Bonner Springs/Desoto. Weekly to biweekly sediment measurements by the COE at various locations exist from 1948 to the present. Additional daily sediment data have been collected at several sites along the river by the COE since about 1976.

Double mass curves showing cumulative volumes of measured suspended sediment versus cumulative volume of water passing Wamego and Bonner Springs/ Desoto for the period 1958-1981 are presented in Figures 3.21 and 3.22. The data on which these figures are based (for the period prior to 1976) are taken from COE (1977) and appear in Table 3.2. The data for 1976-1981 was supplied by the COE. The break in the slope of the curve for Wamego corresponds roughly to the initiation of permanent storage in Tuttle Creek reservoir. Similarly, the two breaks in the Bonner Springs/Desoto curve correspond to the initiation of permanent storage at Tuttle Creek and Perry reservoirs. These figures indicate that the suspended sediment concentrations may have been reduced as a result of reservoir closure.

Although the plots seem to show significant trends, there are measurements for only five years prior to 1962. As a result, care must be taken in their interpretation, particularly when it is considered that closure of Tuttle Creek reservoir occurred in 1959; and therefore, nearly all the data prior to the break in the slope of the line are for the transition period between reservoir closure and reservoir operation. It seems reasonable to assume that suspended-sediment concentrations have decreased since initiation of permanent storage in the reservoirs; however, using only five years of pre-reservoir data to quantify the effects of the reservoir may create a considerable margin for error.

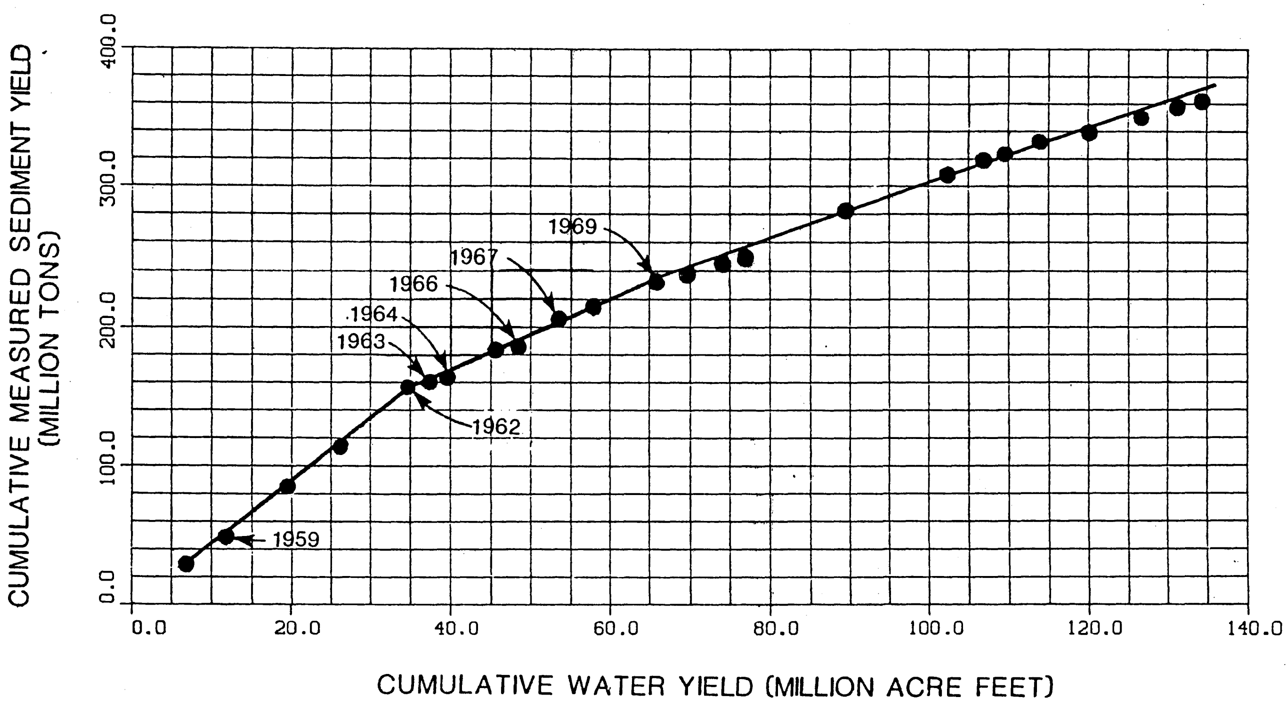
Figure 3.23 is a cumulative plot of water yield versus time for Bonner Springs/Desoto and for Wamego. The slope of the line represents average annual water yield. From the figure it is apparent that there is a break in the average slope of the line around 1940. It is uncertain whether this represents a general change in climatic conditions, since there are only approximately 20 years of record prior to 1940. Additionally, the 1930's were considered to be drought years in the Kansas River basin; and consequently, the slope of the line from 1920 to 1940 may not be representative of water yield prior to 1920. Because the average water yield has increased since about 1940, it can be concluded that the reduction in measured suspended load at Wamego and Bonner Springs (Figures 3.21 and 3.22) is not associated with a reduction in water yield at these stations.



RESERVOIR INFORMATION:

RESERVOIR	DATE OF CLOSURE	DATE OF INITIATION OF PERMANENT STORAGE
TUTTLE CREEK	1959	1963
MILFORD	1964	1967
PERRY	1966	1969

Figure 3.21. Cumulative water yield versus cumulative sediment yield at Wamego 1958-1981.



NOTE: See Reservoir Information - figure 3.21

Figure 3.22. Cumulative water yield versus cumulative sediment yield at Bonner Springs/Desoto.

Table 3.2. Water Yield and Total Measured Suspended Sediment Yield at Wamego and Bonner Springs/Desoto by Water Year.

Water Year	Water Yield (million ac-ft)		Total Measured Suspended Sediment Yield (million tons)	
	Wamego	Bonner Springs* /Desoto	Wamego	Bonner Springs* /Desoto
1958	4.74	6.76	17.36	29.30
1959	3.40	4.99	12.76	19.68
1960	6.25	7.69	19.78	36.16
1961	4.78	6.74	13.26	28.68
1962	5.67	8.50	14.58	42.83
1963	2.02	2.68	1.91	3.55
1964	1.59	2.28	1.73	3.78
1965	3.72	5.89	6.07	19.83
1966	2.05	2.83	1.06	2.94
1967	2.69	5.10	5.88	19.24
1968	2.20	4.42	1.73	8.30
1969	5.75	8.08	5.76	17.90
1970	2.24	3.58	1.10	6.02
1971	3.53	4.36	4.19	6.32
1972	1.82	2.77	1.22	3.81
1973	7.63	12.79	10.34	34.92
1974	8.95	12.35	14.59	25.79
1975	2.84	4.53	1.98	10.28
1976	1.89	2.72	1.6**	4.24
1977	2.60	4.26	2.6**	9.17
1978	3.77	6.26	4.19	7.03
1979	4.64	6.59	9.12	10.28
1980	3.37	4.60	5.99	8.18
1981	1.52	3.00	1.33	4.66

*USGS gage moved from Bonner Springs to Desoto in 1973.
**Graphically estimated by SLA

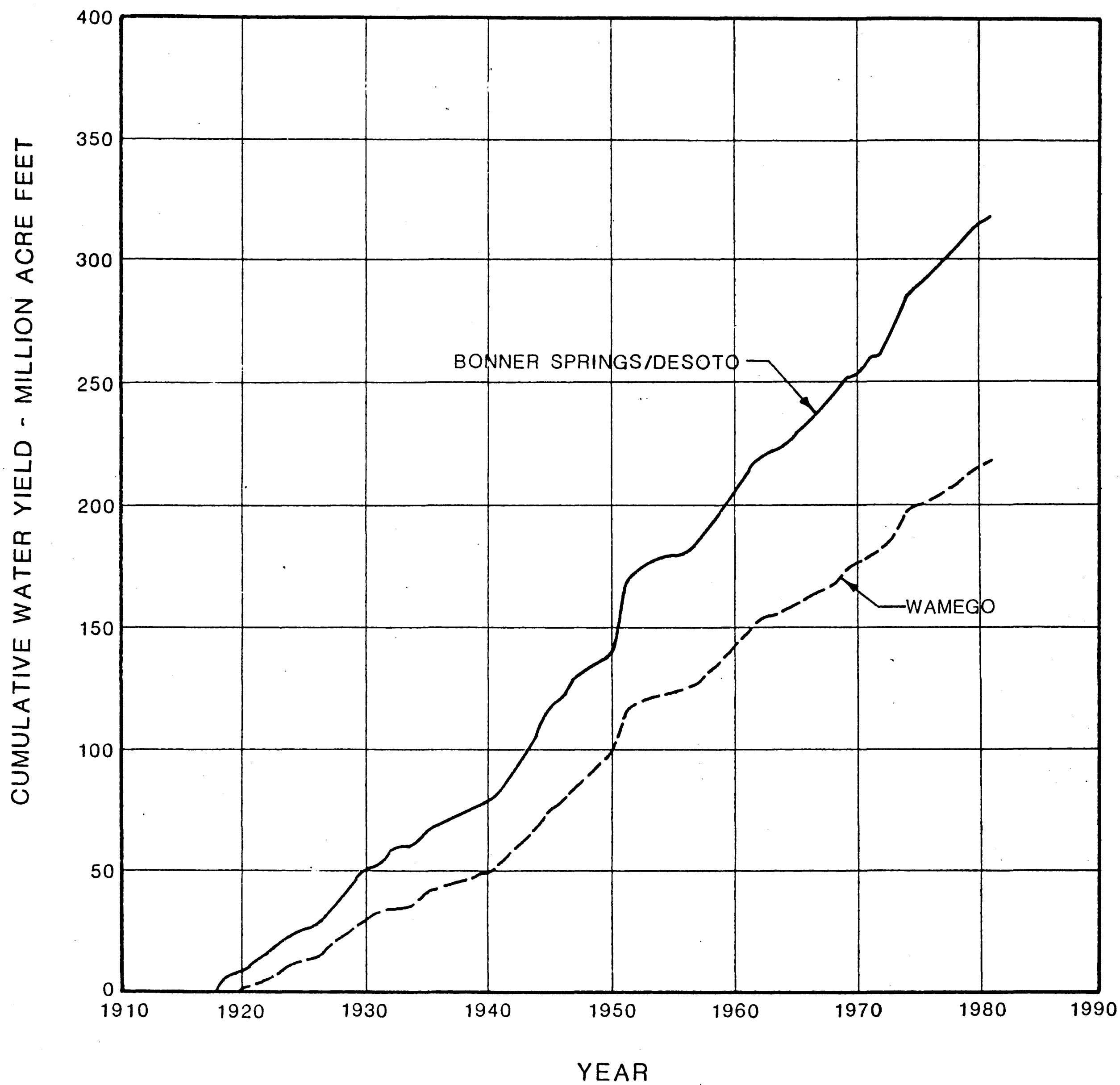


Figure 3.23. Cumulative water yield at Bonner Springs/Desoto.

3.3.4 Summary of Bank Erosion Inventory

Considerable data and a number of reports relating to channel migration of the Kansas River and related bank erosion are available. The figures in Appendix B were prepared utilizing the maps presented by Dort (1979). The 1983 channel was plotted on these figures from aerial photos taken on September 9, 1983.

Several interesting observations can be made by careful consideration of the figures. It appears that channel migration since approximately 1950 has proceeded at a much slower rate than prior to that date. This observation is in agreement with the COE (1982) and Dort (1979).

Several so called "natural" processes are in operation on the Kansas River which contribute at least in part to bank erosion. These include flood flows, the natural meander process, stability of bank material, climate, bank vegetation, and land cover changes.

It is probable that the Kansas River system is still showing signs of recovering or "healing" from the effects of the 1951 flood. Many references document the dramatic effects of this tremendous flood on river morphology. These effects included widening of the channel and the cutoff of meander loops. While there is no evidence to indicate that a general tendency for meander loops to reform is occurring on the Kansas River, the figures in Appendix B indicate that in the areas of active meander movement, between 1971 and 1983, the channel topwidth narrowed. The catastrophic nature of the 1951 flood should not be underemphasized. The peak of the flood (approximately 500,000 cfs) was the largest ever recorded. In addition, record durations for high discharges occurred. This is illustrated by Tables 3.3 and 3.4 taken from Jordan (1979), which show the high flow analysis for the Wamego and Bonner Springs/Desoto gauging stations. As can be seen from the tables, the average discharge for a consecutive 183-day period during the 1951 flood exceeded the highest daily average discharge for most years. In fact, the 183-day average discharge for 1951, if compared to the 1-day averages, would rank 23rd out of 58 values. The extremely high discharges for long duration resulted in a flood event with tremendous sediment transport capacity and consequent ability to alter the general morphology of the entire river system.

Table 3.3. High Flow Analysis for Wamego. (Jordan, 1979)

STATION NUMBER 06887500

HIGHEST MEAN VALUE AND RANKING FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPTEMBER 30

DISCHARGE, IN CUBIC FEET PER SECOND

MEAN

KANSAS R AT WAMEGO, KS

YEAR	1	3	7	15	30	60	90	120	183
1920	16000.0 47	14800.0 45	12200.0 44	8620.0 46	6610.0 46	5470.0 41	4470.0 42	4070.0 41	3790.0 38
1921	20000.0 43	16200.0 42	14200.0 41	9270.0 43	8080.0 39	6380.0 37	5700.0 36	4810.0 36	3730.0 40
1922	24200.0 37	22400.0 35	16400.0 38	10100.0 40	7240.0 43	4600.0 46	4030.0 45	3920.0 43	3310.0 44
1923	46200.0 17	44500.0 16	41000.0 12	32600.0 13	24200.0 13	17600.0 12	13500.0 13	11000.0 18	8050.0 25
1924	20400.0 42	17900.0 41	15300.0 40	9700.0 42	6200.0 48	4400.0 49	3840.0 47	3460.0 48	3030.0 49
1925	23300.0 38	22300.0 36	15900.0 39	10900.0 39	7620.0 40	4720.0 45	4610.0 41	4040.0 42	3320.0 42
1926	28700.0 32	27000.0 31	22600.0 30	15900.0 34	10300.0 36	6170.0 39	4990.0 39	4190.0 40	3320.0 43
1927	41900.0 20	36500.0 22	31300.0 23	24700.0 19	19700.0 21	14100.0 24	13500.0 14	11900.0 13	10900.0 12
1928	27300.0 33	25300.0 32	23800.0 28	21600.0 26	17700.0 24	16100.0 16	12800.0 18	10500.0 19	7730.0 26
1929	35900.0 28	31700.0 27	23300.0 29	17900.0 30	14800.0 30	12800.0 28	11600.0 24	10000.0 24	8530.0 18
1930	50600.0 16	45300.0 15	31700.0 22	23700.0 22	15900.0 29	13800.0 26	10500.0 28	8750.0 28	6970.0 27
1931	15900.0 48	12500.0 49	7680.0 55	5890.0 54	4870.0 52	4150.0 52	3700.0 51	3390.0 50	3160.0 48
1932	20600.0 40	15400.0 43	11300.0 46	8620.0 47	7410.0 42	6060.0 40	5080.0 38	4810.0 37	4220.0 34
1933	16900.0 46	14600.0 46	10200.0 49	8760.0 45	7220.0 44	4430.0 47	3450.0 52	2870.0 52	2950.0 50
1934	11000.0 55	10600.0 55	8170.0 53	5490.0 55	3510.0 56	2330.0 56	1890.0 57	1760.0 57	1550.0 56
1935	140000.0 2	117000.0 2	77700.0 2	51300.0 2	35100.0 3	25600.0 4	18200.0 7	15400.0 7	10800.0 13
1936	14100.0 51	12100.0 52	8580.0 52	6790.0 51	5960.0 49	4380.0 50	3720.0 50	3710.0 45	2900.0 51
1937	15600.0 49	11100.0 54	8760.0 51	7270.0 50	5430.0 51	4420.0 48	3730.0 49	3260.0 51	3170.0 47
1938	26900.0 34	20400.0 39	16900.0 36	16400.0 33	14300.0 31	11700.0 30	9430.0 30	8000.0 31	5890.0 31
1939	24700.0 36	21200.0 37	19700.0 32	14900.0 35	10900.0 35	6730.0 35	5670.0 37	4770.0 38	4100.0 36
1940	7420.0 57	6590.0 57	4770.0 57	4020.0 57	3100.0 57	2250.0 57	2140.0 56	2140.0 54	1810.0 55
1941	112000.0 3	98400.0 3	64900.0 3	39600.0 9	24000.0 15	14500.0 20	11300.0 25	11300.0 14	8320.0 21
1942	69800.0 9	52500.0 12	40700.0 13	31200.0 14	24200.0 14	15300.0 18	12900.0 17	11200.0 16	10200.0 15
1943	88200.0 4	77600.0 4	64800.0 4	47500.0 4	28400.0 10	16700.0 13	12700.0 19	10500.0 20	8330.0 20
1944	75200.0 7	64000.0 9	48500.0 11	36100.0 12	26800.0 11	19500.0 11	16100.0 9	14700.0 9	13700.0 6
1945	78500.0 6	65100.0 8	56700.0 6	43900.0 6	30100.0 8	24700.0 5	22800.0 3	20700.0 3	15300.0 3
1946	38800.0 24	27600.0 30	19500.0 33	17900.0 31	12100.0 33	7160.0 34	7290.0 33	6450.0 32	5000.0 32
1947	71000.0 8	66300.0 6	54000.0 7	42300.0 8	34300.0 5	21000.0 8	18100.0 8	15300.0 8	11200.0 10
1948	56600.0 13	46300.0 13	36800.0 15	23900.0 21	20900.0 18	15000.0 19	11100.0 26	9020.0 27	9560.0 17
1949	53400.0 14	42500.0 17	35900.0 16	28200.0 17	25100.0 12	19800.0 10	15400.0 12	14600.0 10	13800.0 5
1950	83500.0 5	73000.0 5	51500.0 8	43100.0 7	30000.0 9	23700.0 7	18700.0 6	15700.0 6	12000.0 8
1951	393000.0 1	357000.0 1	270000.0 1	160000.0 1	124000.0 1	83000.0 1	61900.0 1	54900.0 1	39800.0 1
1952	36900.0 26	31300.0 28	24400.0 27	22100.0 25	16300.0 27	13500.0 27	11700.0 23	10400.0 22	8400.0 19
1953	18300.0 44	14800.0 44	9060.0 50	6210.0 52	4360.0 54	3190.0 54	2730.0 53	2580.0 53	2430.0 53
1954	26400.0 35	22900.0 33	17100.0 35	13000.0 37	10200.0 37	6450.0 36	6180.0 34	5400.0 35	3910.0 37
1955	11000.0 56	8400.0 56	6840.0 56	5160.0 56	4360.0 55	3000.0 55	2360.0 55	2030.0 55	1960.0 54
1956	17000.0 45	12400.0 50	8070.0 54	6160.0 53	4460.0 53	3220.0 53	2470.0 54	1980.0 56	1540.0 57
1957	45000.0 18	41700.0 19	34800.0 17	29700.0 15	22000.0 16	15700.0 17	13000.0 16	11100.0 17	8160.0 24
1958	51000.0 15	45500.0 14	33500.0 18	22500.0 23	18300.0 23	14300.0 22	13200.0 15	11300.0 15	10300.0 14
1959	38800.0 25	34600.0 24	28500.0 24	20400.0 28	16900.0 25	11300.0 31	10100.0 29	8640.0 29	6870.0 28
1960	67200.0 11	65800.0 7	61500.0 5	50700.0 3	34800.0 4	24200.0 6	20000.0 5	17900.0 5	13200.0 7
1961	68600.0 10	62400.0 10	49800.0 10	37400.0 10	30500.0 7	20600.0 9	15700.0 10	13000.0 12	11000.0 11
1962	35600.0 29	33500.0 25	28100.0 25	21300.0 27	16000.0 28	13900.0 25	11800.0 22	10300.0 23	9740.0 16
1963	12000.0 54	11700.0 53	11000.0 47	7670.0 49	5610.0 50	4230.0 51	3820.0 48	3500.0 47	3230.0 45
1964	12600.0 53	12300.0 51	11900.0 45	9920.0 41	7540.0 41	4800.0 43	3980.0 46	3440.0 49	2900.0 52
1965	40100.0 22	33300.0 26	26300.0 26	24300.0 20	20800.0 19	16200.0 14	12300.0 20	10500.0 21	8280.0 22
1966	14300.0 50	13800.0 47	13400.0 42	10900.0 38	8160.0 38	6190.0 38	4890.0 40	4190.0 39	3750.0 39
1967	41600.0 21	37900.0 20	33500.0 19	29400.0 16	21000.0 17	14100.0 23	10700.0 27	9560.0 26	6490.0 29
1968	34000.0 30	22600.0 34	13400.0 43	8830.0 44	6350.0 47	4800.0 44	4060.0 43	3590.0 46	3220.0 46
1969	36700.0 27	34800.0 23	32000.0 21	22500.0 24	20000.0 20	16100.0 15	15400.0 11	13900.0 11	11700.0 9
1970	33300.0 31	30200.0 29	21200.0 31	16900.0 32	14100.0 32	9700.0 32	7430.0 32	6060.0 33	4530.0 33
1971	38900.0 23	37700.0 21	32700.0 20	26100.0 18	19400.0 22	14400.0 21	12100.0 21	9650.0 25	8280.0 23
1972	13600.0 52	12700.0 48	10800.0 48	8420.0 48	6650.0 45	5070.0 42	4050.0 44	3910.0 44	3480.0 41
1973	43500.0 19	42000.0 18	38900.0 14	36200.0 11	33700.0 6	25900.0 3	22200.0 4	19500.0 4	15300.0 4
1974	61500.0 12	54300.0 11	50600.0 9	44400.0 5	42100.0 2	37500.0 2	30000.0 2	24700.0 2	19700.0 2
1975	23000.0 39	20900.0 38	19500.0 34	18400.0 29	16500.0 26	12600.0 29	9280.0 31	8430.0 30	6260.0 30
1976	20500.0 41	19500.0 40	16600.0 37	14600.0 36	11100.0 34	7640.0 33	6140.0 35	5480.0 34	4140.0 35

Table 3.4. High Flow Analysis for Desoto, Kansas. (Jordan, 1979)

STATION NUMBER 06892350

HIGHEST MEAN VALUE AND RANKING FOR THE FOLLOWING NUMBER OF CONSECUTIVE DAYS IN YEAR ENDING SEPTEMBER 30
DISCHARGE, IN CUBIC FEET PER SECOND
MEAN
KANSAS R AT DESOTO, KS

YEAR	1	3	7	15	30	60	90	120	183
1918	45700.0 35	34700.0 38	20200.0 43	14000.0 45	9860.0 47	5980.0 52	4710.0 53	4210.0 52	3450.0 54
1919	104000.0 11	74900.0 15	45000.0 22	28500.0 30	20700.0 32	16800.0 29	15700.0 22	15500.0 20	11400.0 22
1920	25100.0 49	18100.0 49	14000.0 49	11400.0 50	8660.0 50	6790.0 48	5620.0 47	5330.0 46	5050.0 43
1921	71400.0 22	58100.0 24	35200.0 31	20200.0 36	12400.0 41	11300.0 37	9650.0 35	8660.0 36	6780.0 38
1922	63200.0 26	47700.0 30	30300.0 36	17600.0 42	13000.0 40	9800.0 39	8500.0 39	8290.0 37	7060.0 36
1923	88600.0 16	74200.0 16	61600.0 15	44000.0 14	30000.0 17	21500.0 18	16300.0 20	13200.0 22	9660.0 26
1924	16000.0 54	15200.0 52	13500.0 51	9700.0 51	6990.0 52	5990.0 51	5270.0 49	4750.0 49	4180.0 52
1925	67800.0 24	65600.0 21	42300.0 24	24500.0 34	16900.0 36	10200.0 38	8330.0 40	7090.0 40	5920.0 39
1926	37300.0 40	31600.0 41	26400.0 39	17900.0 41	11600.0 44	6890.0 47	5360.0 48	4640.0 50	4400.0 49
1927	91500.0 15	79100.0 14	62900.0 13	42300.0 16	30400.0 16	20100.0 20	19800.0 15	16900.0 14	16600.0 8
1928	35600.0 43	33200.0 39	29400.0 37	23900.0 35	19000.0 33	17400.0 25	13900.0 26	11500.0 28	8860.0 30
1929	106000.0 10	91000.0 10	59700.0 16	33900.0 20	25600.0 20	22100.0 16	19000.0 17	16700.0 16	13200.0 17
1930	72200.0 21	62600.0 23	45200.0 21	32400.0 22	21200.0 31	17600.0 24	13600.0 28	10800.0 31	8770.0 31
1931	31300.0 46	24300.0 47	13500.0 52	7620.0 55	6860.0 53	6000.0 50	5030.0 50	5070.0 48	4890.0 44
1932	60200.0 29	53100.0 26	35200.0 32	30200.0 25	18600.0 34	12000.0 35	9390.0 36	8770.0 35	7380.0 35
1933	15900.0 55	12800.0 56	9630.0 55	8990.0 52	7790.0 51	4940.0 54	3990.0 54	3510.0 54	3790.0 53
1934	9940.0 59	9640.0 58	7500.0 58	5230.0 58	3330.0 59	2570.0 59	2160.0 59	1990.0 59	1800.0 58
1935	117000.0 7	98300.0 8	84500.0 4	70000.0 4	48000.0 6	33500.0 5	23900.0 7	19500.0 10	13800.0 15
1936	19900.0 50	17500.0 50	13700.0 50	11600.0 48	10200.0 45	7280.0 45	5740.0 46	5820.0 43	4440.0 47
1937	19100.0 51	17300.0 51	14100.0 47	11600.0 49	8840.0 49	6200.0 49	4810.0 52	4030.0 53	4240.0 51
1938	43400.0 37	35900.0 37	26500.0 38	19100.0 38	18500.0 35	15600.0 31	12400.0 32	10600.0 32	7720.0 32
1939	31100.0 47	27200.0 43	24600.0 40	19000.0 39	13500.0 39	8270.0 41	7160.0 42	6380.0 41	5350.0 42
1940	12100.0 58	9470.0 59	6930.0 59	5170.0 59	4330.0 58	3580.0 57	3010.0 57	3150.0 55	2640.0 57
1941	95200.0 14	86500.0 13	68800.0 10	44300.0 13	27800.0 19	17000.0 28	13600.0 29	13100.0 23	10000.0 24
1942	109000.0 9	90700.0 11	63600.0 12	50600.0 11	40700.0 12	24800.0 14	18800.0 18	15700.0 19	14100.0 14
1943	144000.0 2	133000.0 2	94800.0 2	78200.0 2	46300.0 7	27400.0 10	20500.0 13	16600.0 17	12700.0 19
1944	139000.0 3	125000.0 3	95700.0 3	75300.0 3	50800.0 3	33000.0 6	26700.0 5	23100.0 5	21000.0 5
1945	134000.0 4	119000.0 4	77000.0 9	59100.0 9	42700.0 9	38400.0 4	36200.0 3	31600.0 3	24100.0 4
1946	35900.0 42	23200.0 48	20000.0 45	19000.0 40	13600.0 38	8680.0 40	8720.0 38	8060.0 38	6800.0 37
1947	69000.0 23	67400.0 19	66100.0 11	52900.0 10	41900.0 10	26800.0 11	23900.0 8	20700.0 8	15200.0 12
1948	67400.0 25	52700.0 27	41400.0 26	27500.0 32	22200.0 27	17300.0 26	13000.0 30	11400.0 29	11900.0 21
1949	54200.0 32	48000.0 29	42700.0 23	34800.0 19	33300.0 14	26300.0 12	20900.0 11	18600.0 11	18900.0 6
1950	115000.0 8	105000.0 7	78900.0 8	60500.0 8	41900.0 11	32100.0 7	24800.0 6	21700.0 6	16200.0 9
1951	486000.0 1	436000.0 1	326000.0 1	205000.0 1	169000.0 1	108000.0 1	81800.0 1	71500.0 1	52700.0 1
1952	55800.0 31	47000.0 31	35700.0 29	30000.0 27	22100.0 28	19000.0 21	16300.0 21	14000.0 21	11200.0 23
1953	16100.0 53	14200.0 53	9080.0 56	6190.0 57	4740.0 57	3640.0 56	3130.0 56	3040.0 56	2850.0 55
1954	32600.0 45	26600.0 42	20800.0 41	16200.0 43	12300.0 42	7600.0 44	7360.0 41	6330.0 42	4610.0 46
1955	14400.0 57	13700.0 55	10100.0 53	7990.0 53	5340.0 55	3980.0 55	3210.0 55	2800.0 57	2840.0 56
1956	15500.0 56	11600.0 57	8210.0 57	6910.0 56	4900.0 56	3430.0 58	2670.0 58	2250.0 58	1760.0 59
1957	52600.0 33	41900.0 33	34300.0 33	31700.0 24	24300.0 21	18700.0 22	15100.0 24	12700.0 25	9410.0 28
1958	61400.0 27	55400.0 25	47000.0 20	38800.0 17	33100.0 15	22000.0 17	19700.0 16	16800.0 15	14600.0 13
1959	42800.0 38	40500.0 35	37000.0 28	27700.0 31	22700.0 26	15300.0 33	13900.0 25	12400.0 26	9830.0 25
1960	98900.0 13	92500.0 9	80000.0 7	63500.0 6	43300.0 8	29400.0 9	23800.0 9	21000.0 7	15700.0 10
1961	86200.0 17	71500.0 17	56300.0 17	42400.0 15	34200.0 13	25600.0 13	20700.0 12	18100.0 13	15200.0 11
1962	59400.0 30	44700.0 32	40700.0 27	30100.0 26	21700.0 29	18100.0 23	15200.0 23	13100.0 24	13700.0 16
1963	17100.0 52	13800.0 54	9730.0 54	7640.0 54	5950.0 54	5230.0 53	4850.0 51	4500.0 51	4270.0 50
1964	37100.0 41	24700.0 46	16700.0 46	14400.0 44	12300.0 43	7870.0 42	6440.0 43	5410.0 45	4430.0 48
1965	80500.0 19	68100.0 18	49300.0 18	35800.0 18	28900.0 18	22900.0 15	17100.0 19	16200.0 18	12300.0 20
1966	30200.0 48	25000.0 45	14000.0 48	11800.0 47	9280.0 48	7030.0 46	5980.0 45	5300.0 47	4740.0 45
1967	132000.0 5	106000.0 6	84000.0 5	69200.0 5	49500.0 4	29600.0 8	21600.0 10	18200.0 12	12900.0 18
1968	61300.0 28	50900.0 28	35600.0 30	32100.0 23	23800.0 23	14600.0 34	11000.0 34	9310.0 34	7640.0 33
1969	81800.0 18	63000.0 22	41600.0 25	29300.0 28	22900.0 25	20500.0 19	20100.0 14	19700.0 9	16700.0 7
1970	77300.0 20	67000.0 20	47300.0 19	33000.0 21	24100.0 22	15800.0 30	12200.0 33	9850.0 33	7640.0 34
1971	40500.0 39	38100.0 36	34300.0 34	28500.0 29	21400.0 30	15500.0 32	12800.0 31	10800.0 30	9600.0 27
1972	43800.0 36	32500.0 40	20200.0 44	13900.0 46	9900.0 46	7750.0 43	6240.0 44	5660.0 44	5630.0 41
1973	102000.0 12	87700.0 12	62600.0 14	50200.0 12	48800.0 5	41500.0 3	35400.0 4	31300.0 4	25300.0 3
1974	127000.0 6	110000.0 5	81100.0 6	63300.0 7	55600.0 2	47700.0 2	39100.0 2	32800.0 2	26500.0 2
1975	48100.0 34	41600.0 34	31600.0 35	25900.0 33	23000.0 24	17100.0 27	13700.0 27	12100.0 27	9300.0 29
1976	34500.0 44	26100.0 44	20500.0 42	19400.0 37	16400.0 37	11300.0 36	9030.0 37	7700.0 39	5870.0 40

Dort (1981) has pointed out the lack of complete and adequate bank material data along the Kansas River to allow analysis of the impact of this factor on bank erosion. In September of 1983, SLA conducted a bed and bank material survey along the Kansas River. The results of this survey are presented in Appendix A. Unfortunately, this survey was of a general nature and did not include comprehensive bank material sampling of active erosion sites. Some general remarks as to the effect of bank material composition and its relation to bank erosion along the Kansas River can be made, however. In many of the areas experiencing rapid or extreme bank erosion it was observed by the field crew that the bank was stratified with a fine silty layer (presumably deposited during flood events) overlying a layer of noncohesive sand. This was particularly apparent in reaches of the Kansas River downstream of Bowersock Dam (R.M. 51.3). It appears that at least in some instances (e.g. the reach around R.M. 41), that the natural meander process has caused the river to move into an area of easily transported noncohesive materials and consequently erosion in these areas has been extremely rapid. Erosion in these areas will probably continue until a natural or manmade control such as more resistant bank material or revetment is encountered.

No reliable data on long term climatic changes in the Kansas River drainage basin has been reported. As can be seen from Figure 3.23, the annual water yield has increased in recent years, which may be indicative of a climatic change. Increase in the water yield will generally contribute to an increase in bank instability for unstable areas due to an increase in sediment transporting capacity of the channel and higher shear stresses on the banks.

Riparian vegetation is generally considered to be a stabilizing influence on channel banks. The COE (1982) reports that as a percentage of the total bank length, the wooded bank length has increased from 61.3 percent in 1936 to 64.9 percent in 1978. This increase is probably statistically insignificant, and indicates that changes in riparian vegetation have not been an important factor with regard to bank erosion on the Kansas River.

Changes in sediment supply from the watershed due to changes in land use (i.e., urbanization, changes in farm acreage and/or farming practices, etc.) can have a dramatic impact on bank erosion characteristics. Dort (1981) reports that land use mapping has been adequate immediately adjacent to the main stem of the Kansas River but that data relating to changes in land use for the drainage basin of the Kansas River as a whole is sparse and inadequate to draw any conclusions relating to changes in sediment yield from the drainage basin.

Two bank erosion surveys have been conducted by the COE, one in 1956 and one in 1978. Both surveys, however, were necessarily of a qualitative nature, and consequently, use of this data is somewhat limited.

Testimony of land owners along the river indicates bank erosion along the Kansas River has increased in extent and severity since closure of Federal Reservoirs, however, it seems that no additional evidence exists to support this contention.

3.3.5 Aggradation, Degradation, and Channel Widening

Observations pertaining to aggradation, degradation, and channel widening include changes in stage discharge relations at gauges, historical cross section plots, and thalweg profiles.

3.3.5.1 Changes in Stage Discharge Relations at Gauges

USGS rating curves were analyzed for the Kansas River at Wamego, Topeka, Lecompton and Bonner Springs and for the Missouri River at the Kansas City. Figures 3.24 to 3.26 from Osterkamp, et al., (1982) show the changes in elevation with time corresponding to the ten percent and 25 percent flows (i.e. those flows that are equaled or exceeded 10 and 25 percent of the time). As explained by Osterkamp, changes in stage for the 25 percent flows are primarily related to aggradation or degradation of the channel bed. Changes in stage for the ten percent flow reflect both changes in channel bed elevation plus changes in channel width due to bank erosion. Figures 3.24 to 3.26 are complex because year-to-year variations in stage occur that partially mask long-term trends. Yearly variations are due to a number of factors including scour during periods of high flow and aggradation during periods of low flow.

The changes in stage elevation for the 25 percent flows were calculated for each station for the period 1950-1973. This period was selected because it begins with the completion of the first federal reservoir and ends the year the Bonner Springs gage was moved to Desoto. It includes the flood of 1951. The changes in stage elevation for this period are:

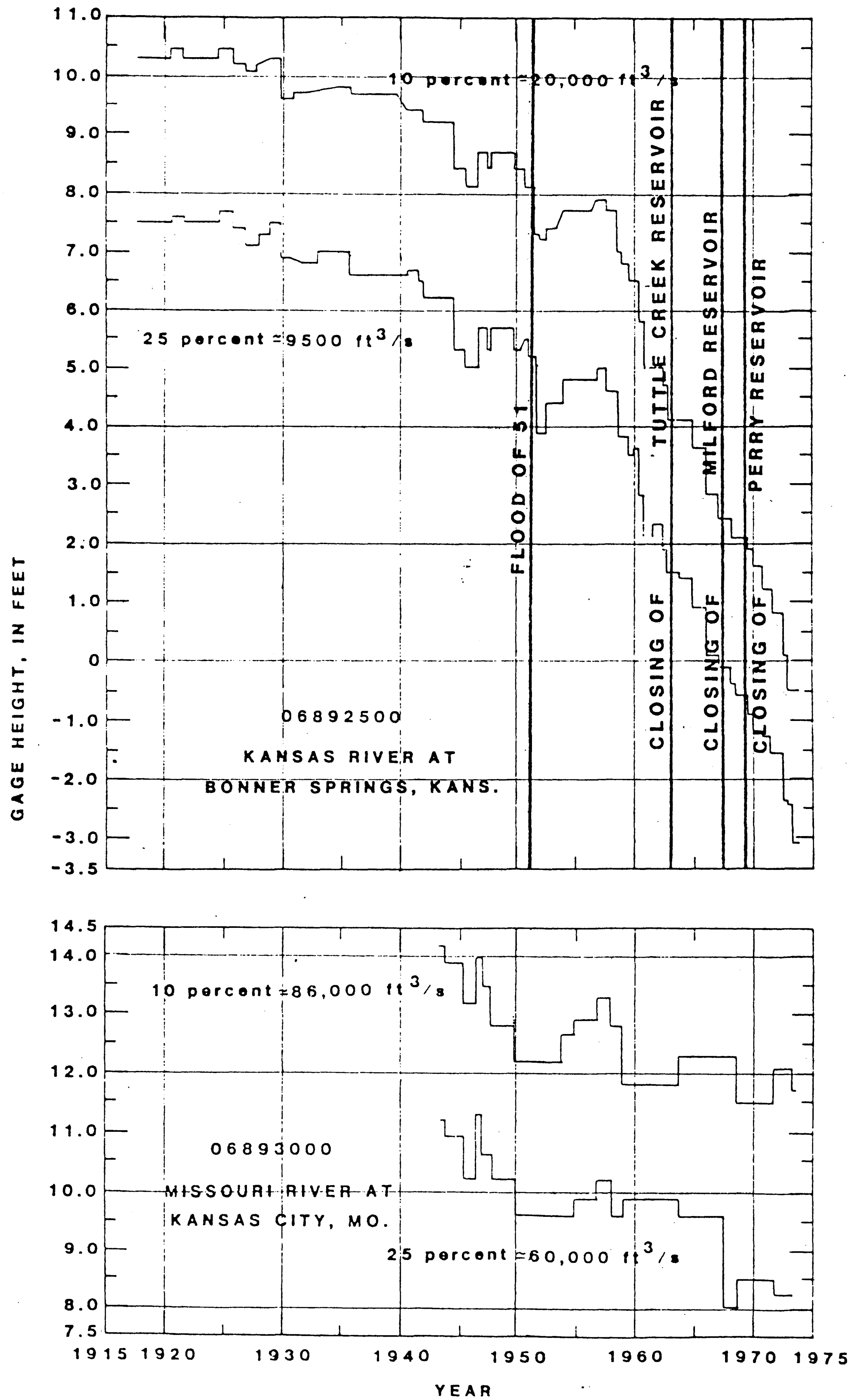


Figure 3.24. Stage versus time for the 10 and 25 percent flows at Bonner Springs and on the Missouri River at Kansas City. (from Osterkamp 1982)

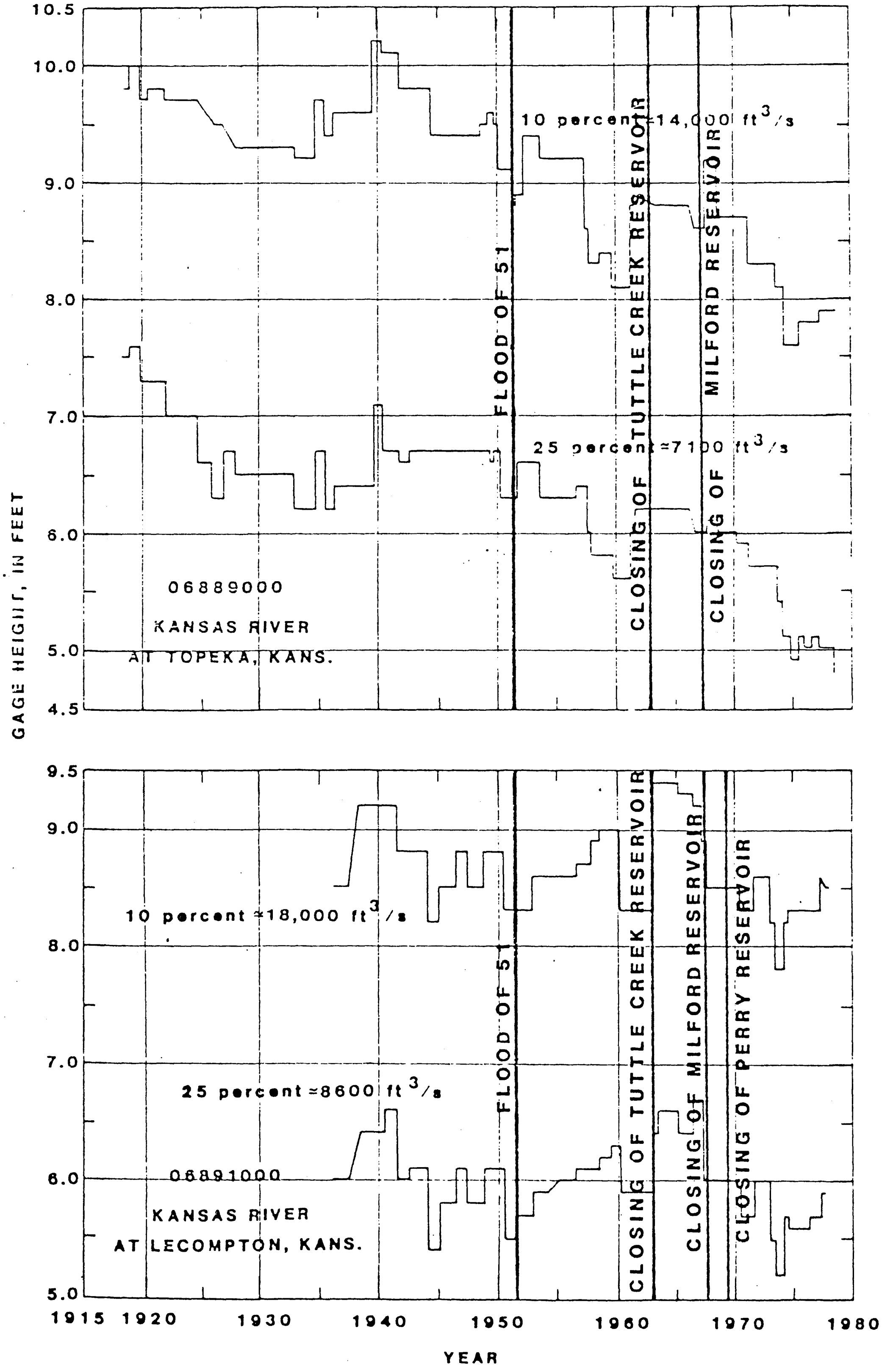


Figure 3.25. Stage versus time for the 10 and 25 percent flows at Topeka and at Lecompton. (from Osterkamp 1982)

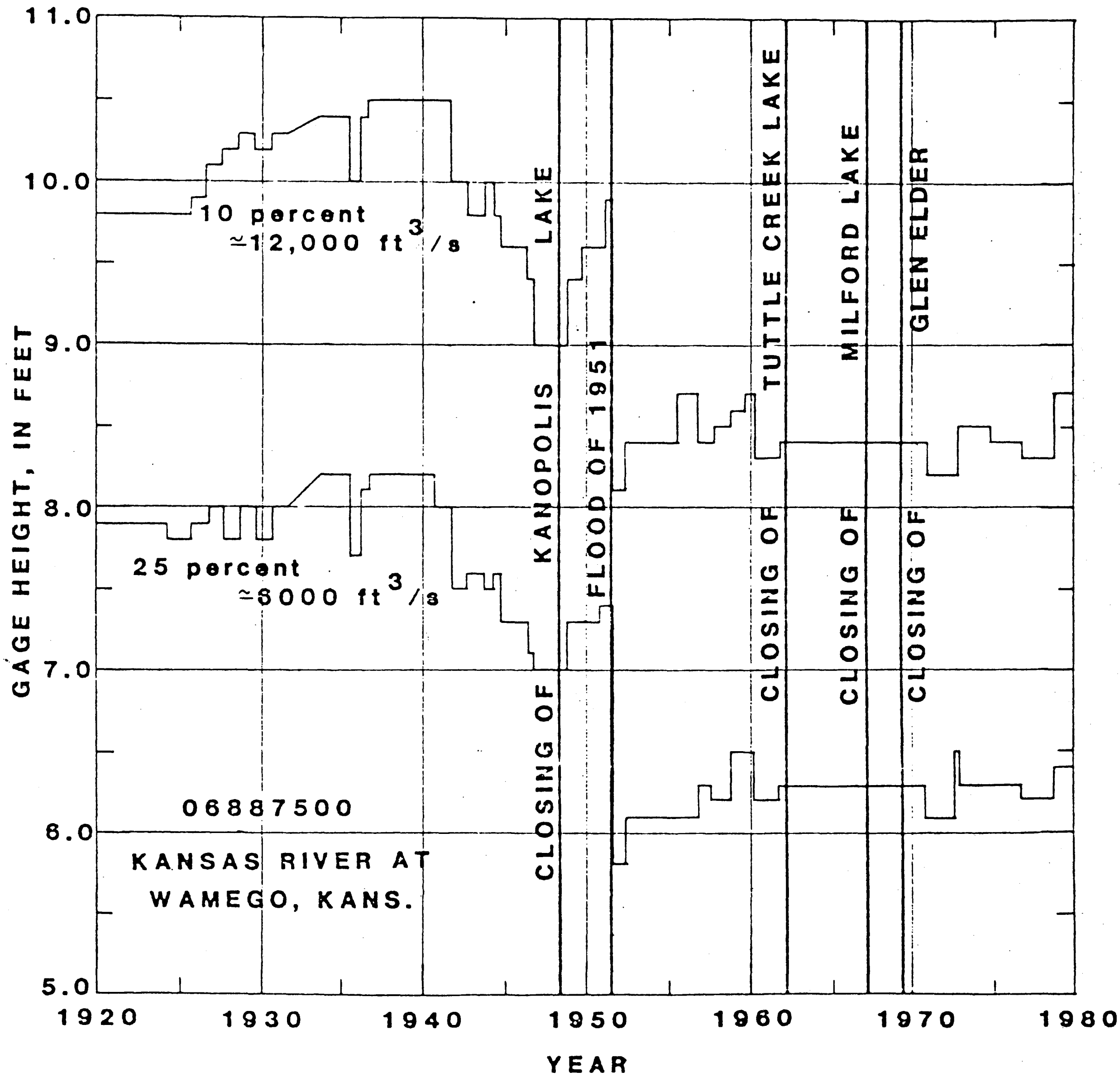


Figure 3.26. Stage versus time for the 10 and 25 percent discharge at Wamego. (from Osterkamp 1982)

Wamego	lowered 1.0 foot
Topeka	lowered 1.2 feet
Lecompton	lowered 0.6 foot
Bonner Springs	lowered 8.5 feet
Missouri River at Kansas City	lowered 2.0 feet

If the 25 percent flow stages are indicative of channel aggradation and degradation, these numbers indicate severe degradation in the area of Bonner Springs, relative to other locations on the Kansas River.

Some scattered data on stages of the Missouri River at the Kansas City gage prior to 1940 exist. This information is important, since before the construction of the Johnson County weir in 1967 base-level changes on the Missouri River may have impacted the reach above the weir. Table 3.5 gives the historical stages on the Missouri River prior to 1935 for the 25 percent and 10 percent flows. As can be seen from the table and Figure 3.24, the Missouri River experienced an increase in stage for the 25 and 10 percent flows prior to about 1935, at which point the stage corresponding to the 25 percent and 10 percent flows began decreasing. It was impossible to determine the gage datum for the early records from the available data. If it is surmised that the gage data are equivalent, then very little net change in the base level of the Missouri occurred between about 1900 and 1967.

3.3.5.2 Comparison of Historic Cross-Sections

A considerable number of historical cross sections were available for this study. These sections were provided by the COE and cover a broad range of years and river mileage. Table 3.6 lists the majority of the available cross sections where comparative data were available. Appendix C contains plots of these sections. All sections included in the table either had a significant period of time over which comparisons could be made and/or were at a location where a 1983 cross section had been surveyed. From the table, it can be seen that cross sections located between R.M. 9.5 and approximately R.M. 26 have experienced from about 4 to 20 feet of degradation and have become up to 180 feet wider.

Of some interest is the response of sections 13.68 and 21.00. These sections have shown no change and aggradation respectively for the period 1977 to 1983, yet are within the zone of most intensive dredging. At R.M. 13.68 it seems likely that dredgers may have removed material no faster than the river supplied it. This may have been due to the occurrence of bedrock limiting

Table 3.5. Historic Stages for the Missouri River at Kansas City.

Year	Stage (feet)	
	10% Occurrence Flow	25% Occurrence Flow
1935	15.0	11.8
1929	12.8	9.8
1905	12.8	10.4
1903	12.4	10.0
1883	≅10.6	≅9.0

Table 3.6. Kansas River Cross Sections - Changes With Time.

River Mile	Period	Δ Channel Bottom	Δ Channel Width
9.5	1962-77	No change in thalweg elevation, low flows channel shifted	Slight narrowing
13.68	1954-83	Main channel lowered 20 ft., little or no change from 1977 to 1983	Widened approx. 150 ft.
14.10	1956-77	Thalweg lowered 12 ft, main channel lowered 7 ft.	Slight narrowing of channel
17.07	1977-83	No change, low flow channel shifted	No change
17.55	1954-77	NA*	Widened approx. 150 ft.
21.00	1956-83	Little change for 1956-1962, thalweg lowered 13 ft. and main channel lowered approx. 8 ft. from 1962-1977, thalweg raised 4 ft. and main channel raised approx. 6 ft. for 1977-1983	Widened approx. 100 ft.
22.68	1977-83	Main channel lowered 3 ft., thalweg lowered 3 ft.	Left bank widened approx. 100 ft.
23.17	1954-77	NA*	Right bank widened approx. 180 ft.
23.70	1962-83	No change, low flow channel shifted to R. bank	Left bank widened approx. 150 ft.
24.85	1977-83	More pronounced low flow channel. Low flow channel shifted, thalweg eroded 4 ft.	Slight widening of channel
26.91	1977-83	Average channel lowered 1'-2', low flow channel shifted to L. bank	Slight widening at L. bank

Table 3.6 (continued)

River Mile	Period	Δ Channel Bottom	Δ Channel Width
28.96	1977-83	Thalweg lowered 4 ft., low flow channel shifted to L bank	Right bank widened approx. 25 ft.
31.04	1977-83	Thalweg lowered 7 ft. Main channel aggraded 3 ft.	No change
61.4	1977-79	Thalweg lowered ~2 ft. minimal net degradation of channel	Bank widened approximately 100 ft.
62.5	1962-79	Thalweg lowered ~3'. Net degradation ~2'	L. bank widened ~25 ft
63.8	1962-79	Net degradation ~2'	L bank widened ~15 ft
63.9	1962-79	Thalweg lowered ~5 ft. Main channel lowered 3 ft.	No change
68.2**	1962-79	Main channel lowered 3 ft. Thalweg, no change	Narrower by approx. 100 ft.
106.2**	1962-79	No change	Widened by approx. 125 ft.
115.4**	1962-79	No change in thalweg. More pronounced low flow channel.	Widened by approximately 70 ft.

*Not applicable - see note on cross section plot - Appendix C

**Comparative cross sections not at same location - see Appendix C dredging depths (see Figure 2.4) or due to physical limitations of the dredging equipment at this site.

It is not possible to tell if the aggradation that occurred at section 21.00 is the result of a flood event or is the natural response of the channel in this location due to a cessation of dredging. Additionally, it can be seen that the channel from approximately R.M. 26 to R.M. 68 has degraded two to three feet and has become slightly (approximately 25-50 feet) wider. Above approximately R.M. 68 only two locations (R.M. 106 and R.M. 115) had sufficient information to compare historical cross sections. At these locations the comparative sections were a few tenths of a mile apart. Because these comparative sections were not identically located they are most useful for the determination of large bed level changes. Examination of these sections shows that no significant aggradation or degradation has occurred at this location.

3.3.5.3 Changes in Thalweg Profiles

Figure 3.27 is a comparative plot of historic thalweg information for the reach between approximately R.M. 10 and R.M. 50. Above R.M. 50, sufficient historical thalweg and/or cross section information is not available to make a similar comparison.

Since the comparative thalweg elevations plotted in the figure are not at the same location, the plot is only valid for evaluating the general aggradation/degradation tendencies of the river. It does not have sufficient resolution to analyze local variations such as gravel pits. From the figure, it is apparent that between R.M. 10 and R.M. 25 the thalweg has degraded eight to ten feet since 1947. Additionally, examination of the 1977 and 1983 profiles reveals what appears to be a headcut at approximately R.M. 22-23.

Figure 3.28 is a plot of historic thalweg elevations for the lower ten miles of the Kansas River. In general it can be seen that this reach has degraded since the early 1900's, however it has aggraded since the 1951 flood. From 1968 to 1977 very little overall change in the thalweg profile has occurred.

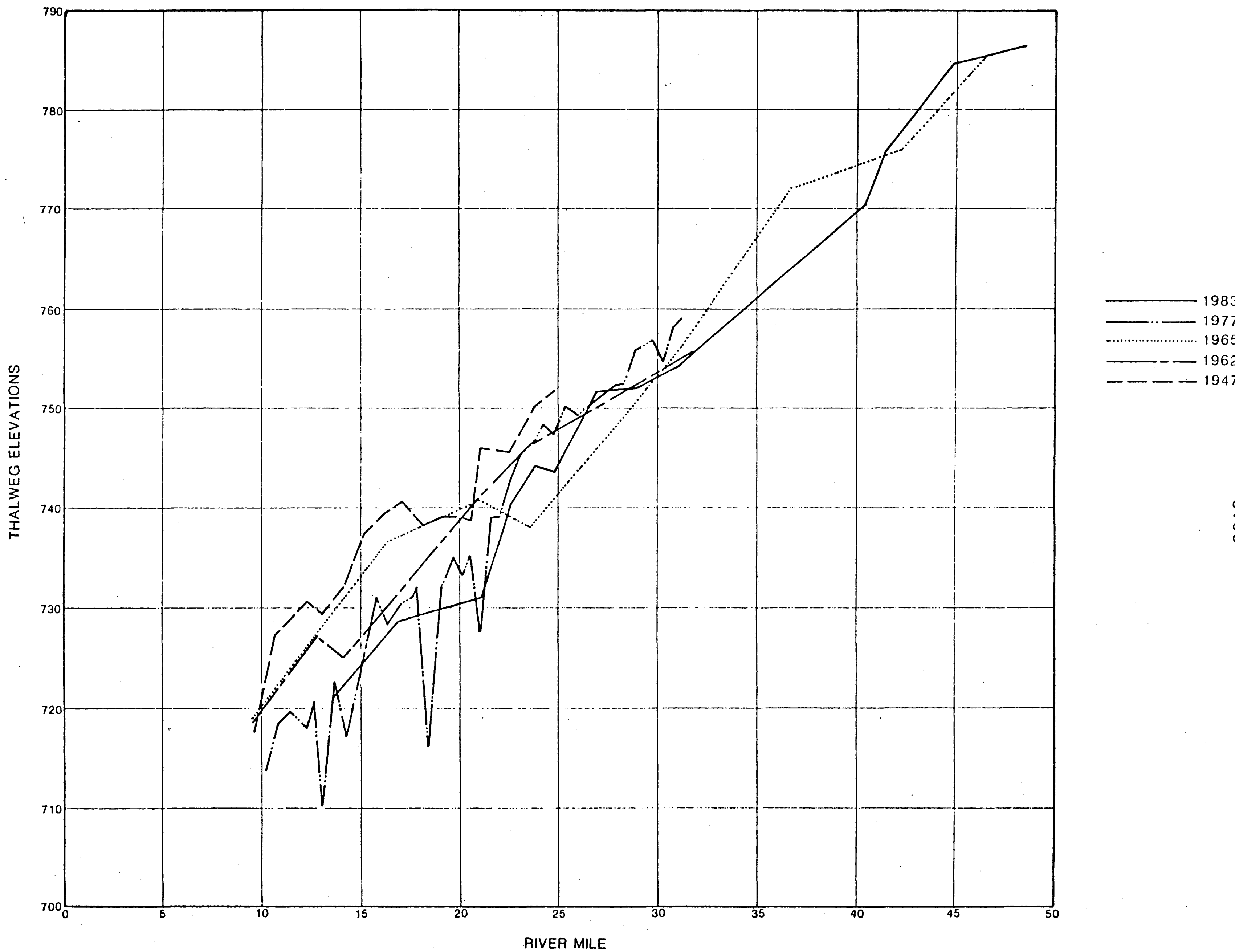


Figure 3.27. Historic thalweg profiles on the Kansas River R.M. 10 to R.M. 50.

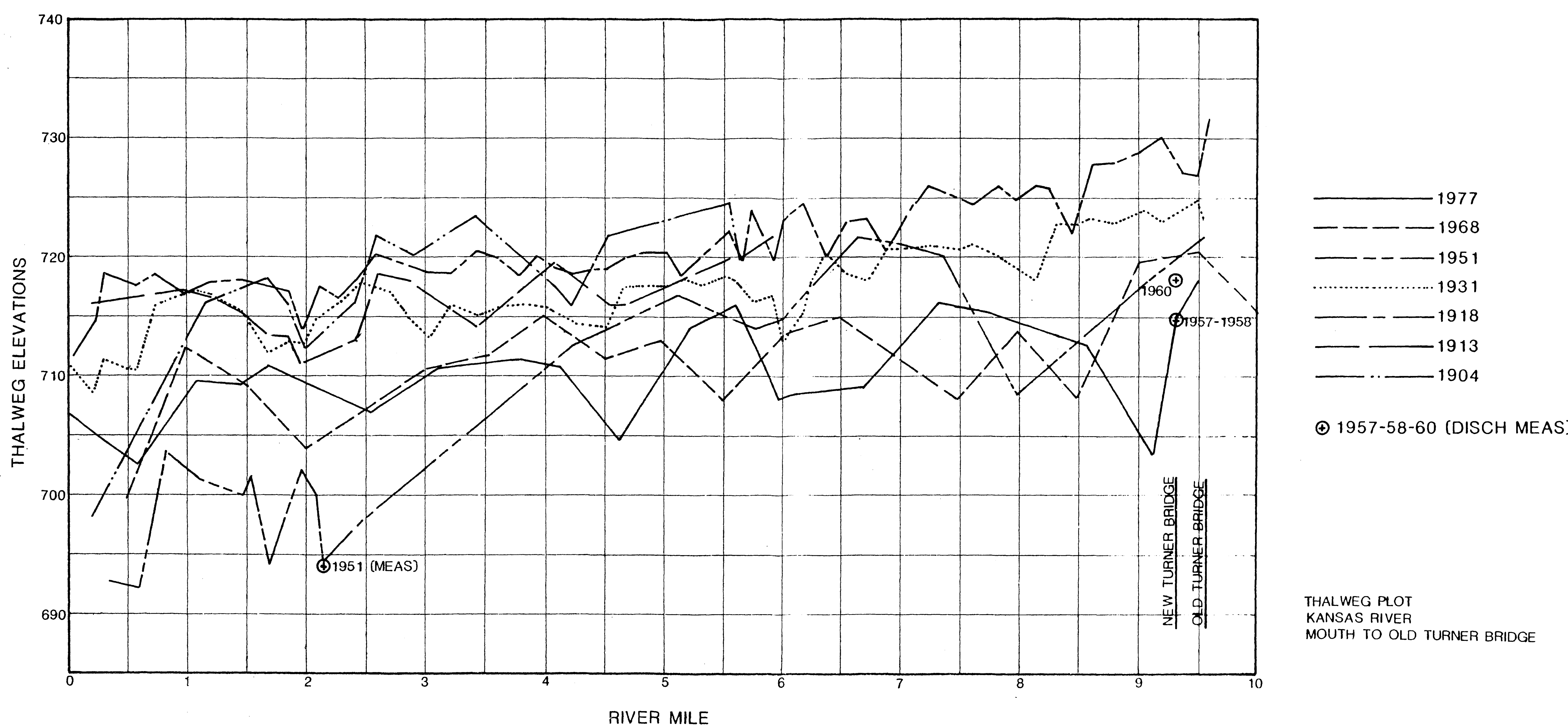


Figure 3.28 Historic thalweg profiles for the lower 10 M miles of the Kansas River.

3.3.6 Recent Island and Bar Formation

Careful inspection of the figures in Appendix B and the 1983 aerial photography reveals that the area of accretion of bottom land on the inside of bends and the formation of islands has probably exceeded the total area eroded since 1971. Table 3.7 lists the areas of accretion and islands that have formed since 1971. For the purposes of the table, permanent islands or bars were considered those which had distinct woody vegetation such as brush and small trees. Islands were considered those areas that had distinct sandy channels with no vegetation on all sides. Bars are those areas of accretion which are directly attached to the bank. As stated earlier, reaches which contain actively moving meander bends have been narrowing or at least remaining approximately constant in topwidth. This process of accretion and island formation supports the hypothesis that the river is still adjusting its plan form and cross-section geometry due to disequilibrium caused by the 1951 flood. Additionally, this process may be accelerated by the change in flow regimen caused by federal reservoirs.

By attenuating peak flows the amount of time that bars are inundated is reduced. This allows the establishment of permanent vegetation. Vegetation accelerates the formation of permanent islands or bars through two mechanisms:

1. Vegetation helps stabilize the bar or island against erosion from non-overtopping flows, and;

2. vegetation may slow the velocity of overtopping discharges sufficiently to cause the settling of sand and silt. This results in net growth of the island or bar.

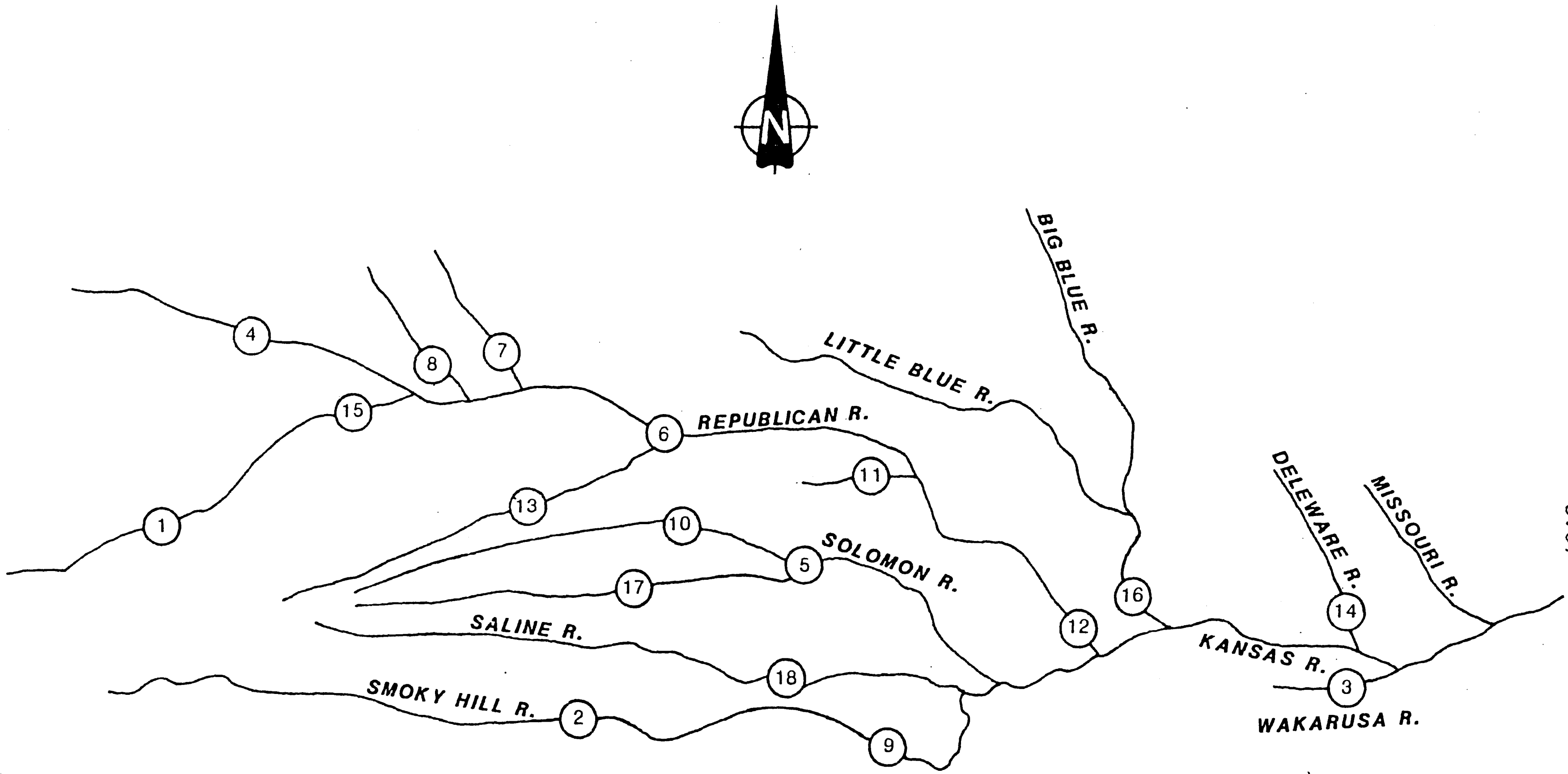
3.4 Effects of Federal Reservoirs

3.4.1 History of Reservoir Closure

Eighteen large Federal reservoirs have been constructed in the Kansas River basin since 1949. The primary purpose of these reservoirs is flood control. Figure 3.29 is a schematic showing their locations. Table 3.8 lists the capacities, completion dates and tributaries on which these reservoirs are located.

Table 3.7. Areas of Accretion or Island Formation For 1971-1983.

Location	Comments
RM14.9	Right Bank Accretion
RM16.0	Right Bank Accetion
RM23.2	Right Bank Accretion Due to Bank Protection Works
RM37.3	Island
RM41	Left Bank Accretion, Right Bank Erosion
RM44.9	Right Bank Accretion
RM46.2	Island
RM48	Left Bank Accretion, Right Bank Erosion
RM58.3	Island
RM69	Two Islands, Bank Erosion at Outside of Bend
RM70.5	Island
RM72.2	Left Bank Accretion
RM80.8	Island
RM90.6	Island
RM99.2	Right Bank Accretion Left Bank Erosion
RM108.5	Island
RM109.0	Right Bank Accretion Some Erosion Left Bank
RM109.5	Island
RM113-115	Meander Moving Downstream. Channel has Narrowed Resulted in Net Accretion
RM130.1	Left Bank Accretion
RM130.8-131.3	Meander Moving Downstream, Channel Narrowing
RM134	Two Small Islands
RM142	Left Bank Accretion
RM151	Meander Moving Downstream, Channel Topwidth Constant
RM153	Existing Island Enlarged, New Island Formed
RM155	Right Bank Accretion
RM156	Large Island, Right Bank Accretion
RM157	Right Bank Accretion
RM157.5	Island
RM159	Left Bank Accretion
RM159.5	Island
RM164.5	Island
RM166	Meander Moving Downstream, Topwidth of Channel Constant



NOTE: REFER TO TABLE 3.8 FOR RESERVOIR NAMES

0 20 40 MILES
SCALE

Figure 3.29. Location of Kansas River tributary reservoirs.

Table 3.8. Large Federal Impoundments of the Kansas River Basin (Data from COE)

	Reservoir	Date of Closure	Capacity* (ac-ft)	Tributary Located On
1.	Bonny	1950	170,000	Upper Republican
2.	Cedar Bluff	1950	377,000	Smoky Hill
3.	Clinton	1975	397,200	Wakarusa
4.	Enders	1950	75,000	Upper Republican
5.	Glen Elder (Waconda)	1967	964,000	Solomon
6.	Harlan County	1951	850,000	Upper Republican
7.	Harry Strunk	1949	89,000	Upper Republican
8.	Hugh Butler	1961	87,000	Upper Republican
9.	Kanopolis	1946	447,000	Smoky Hill
10.	Kirwin	1955	315,000	Solomon
11.	Lovewell	1957	92,000	Lower Republican
12.	Milford	1964	1,173,000	Lower Republican
13.	Norton	1964	135,000	Upper Republican
14.	Perry	1966	765,000	Delaware
15.	Swanson	1953	254,000	Upper Republican
16.	Tuttle Creek	1959	2,367,000	Big Blue
17.	Webster	1956	261,000	Solomon
18.	Wilson	1963	778,500	Saline

*Approximate capacity at top of flood control pool at closure.

3.4.2 Flow Duration

Construction of the Federal reservoirs has altered the flow characteristics of the Kansas River basin. The reservoirs have had the effect of reducing flood peaks and increasing the occurrence of intermediate flows.

The COE (1980) has prepared flow duration data for several stations along the Kansas River for the 40-year period 1935-1974. Curves prepared from this data for the stations for which adequate suspended sediment measurements were available are shown in Figures 3.30 through 3.33. Two curves were prepared for each station. These curves approximate the flow duration that would have occurred if no reservoirs had been built (natural conditions) and if the reservoirs had been in operation for the entire 40-year period (modified conditions). All curves are based on synthesized data considering the flows that actually did occur along with the reservoir operating strategies. Two operating schemes are documented in the COE report. One has downstream "target" low flows below which the river is not allowed to drop, while the other scheme has no such target low flow. The flow duration curves for the two operating schemes differ mainly at low discharges, i.e. those exceeded about 95 percent of the time or more. Conversation with COE personnel indicates that both operating schemes have been used at various times on the federal reservoirs. These curves illustrate the effect of the system of federal reservoirs on the flow characteristics of the Kansas River. In general terms, the operation of the lakes has reduced the peak flows (0 to 3 percent recurrence), increased the intermediate flows (3 to 25 percent recurrence), and decreased the moderate and low flows (25 to 100 percent recurrence). For the purpose of this report the no-target low flows were used exclusively.

3.4.3 Impacts on Maximum Daily Flows

Tables 3.9 through 3.12 illustrate the effect of the federal reservoirs on reducing the annual daily peak flows. The three columns in each table represent (1) the peak discharges that were actually recorded, (2) the synthetic peak discharges that would have occurred if no reservoirs had been built, and (3) the synthetic peak discharge with all the reservoirs in place. Referring to Table 3.10, for Desoto, it can be seen that discharges in excess of 100,000 cfs would have occurred ten times between 1935 and 1973 under natural conditions. Under the reservoir regulation conditions, the discharge would have exceeded 100,000 cfs only once during the same period. The peak

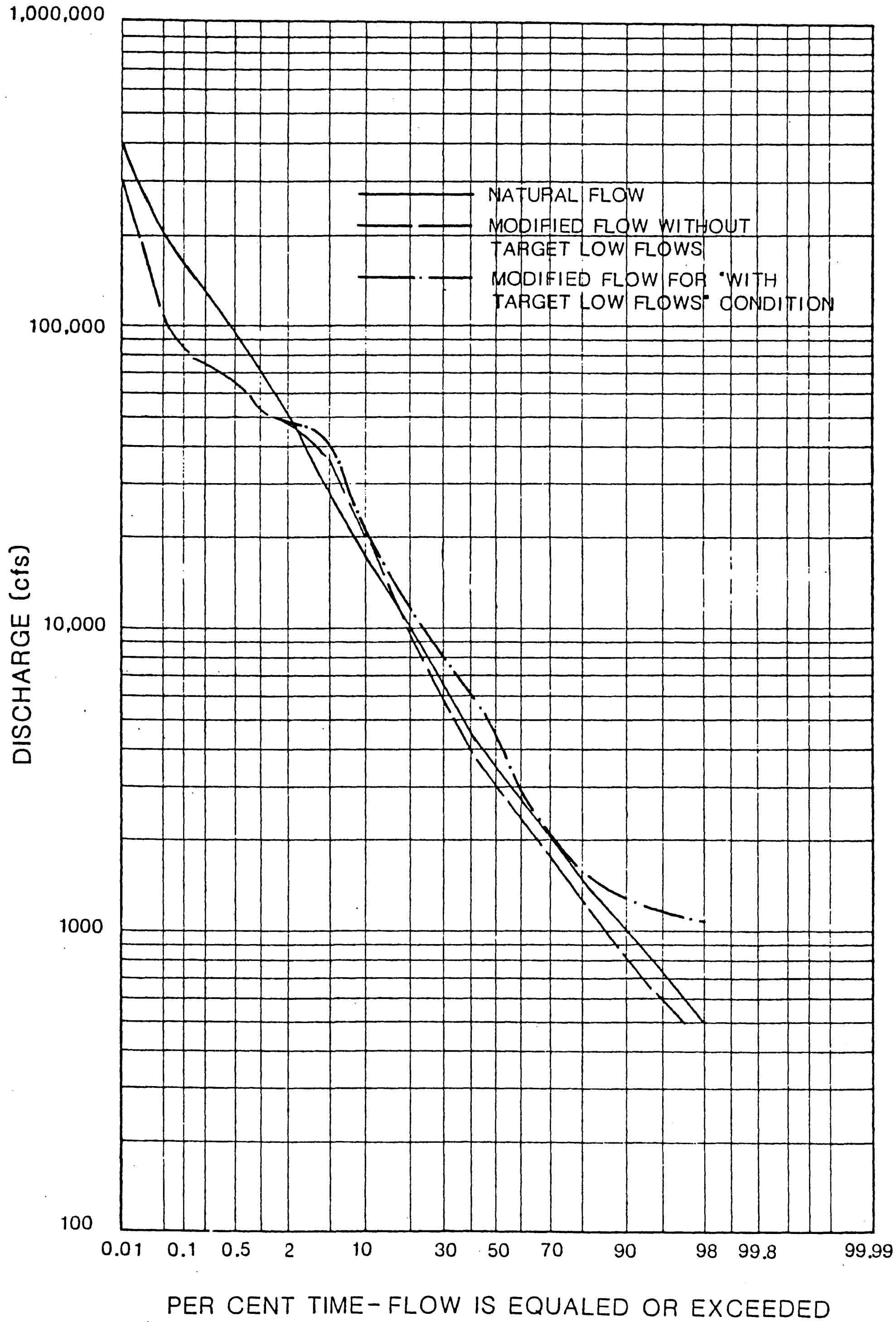


Figure 3.30. Flow duration curve at Bonner Springs/Desoto for synthesized hydrology.

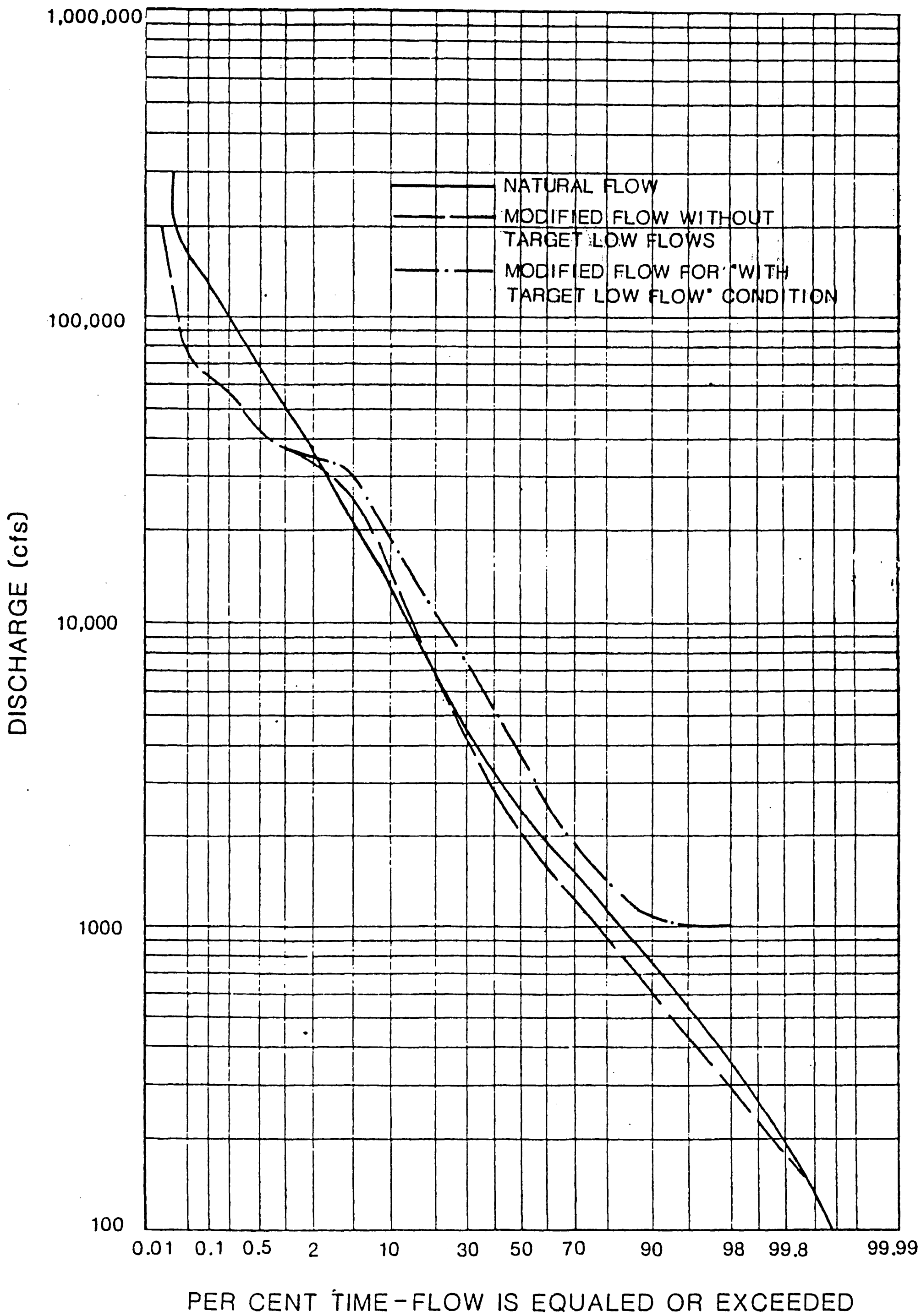


Figure 3.31. Flow duration curve at Lecompton for synthesized hydrology.

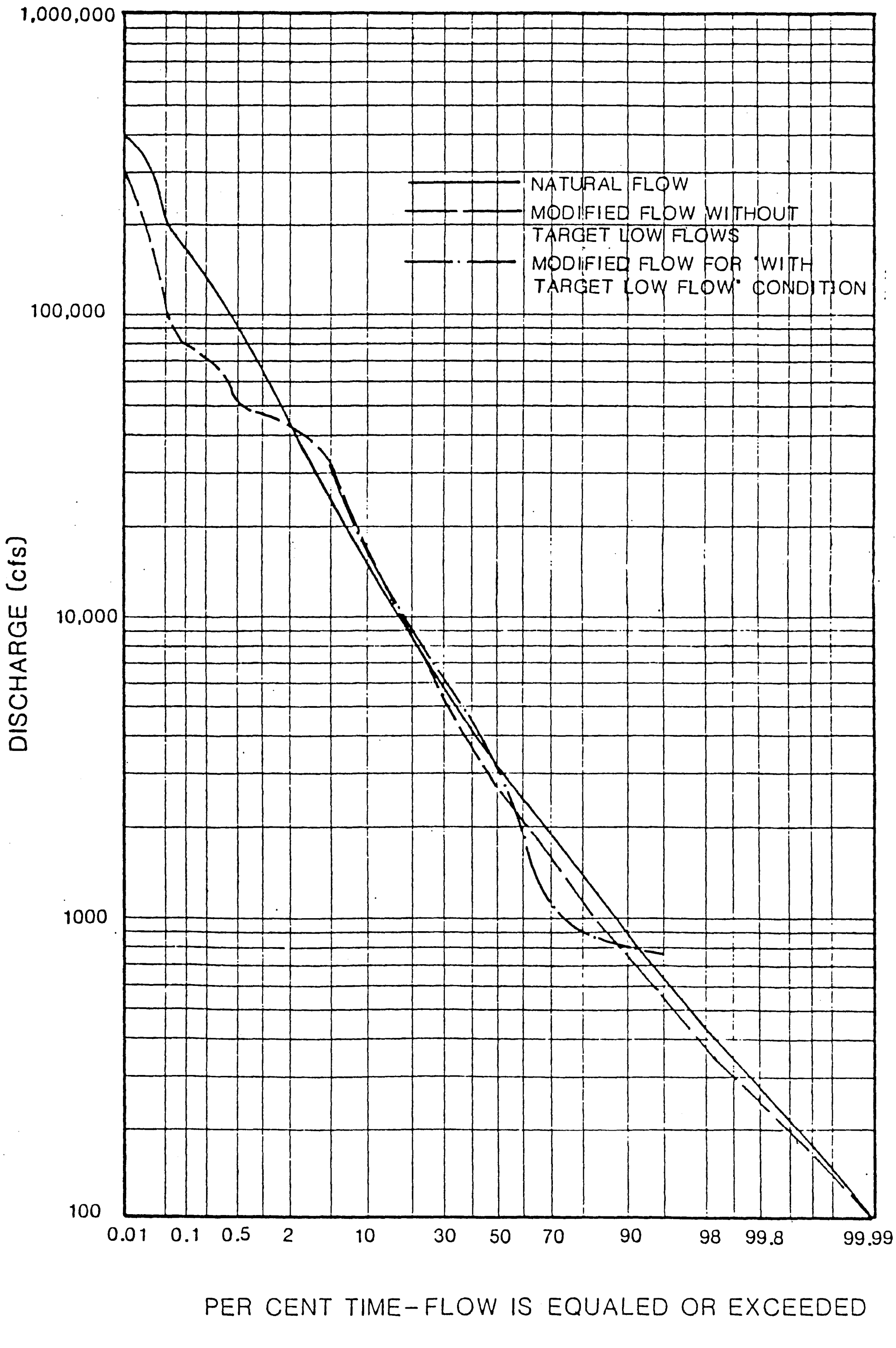


Figure 3.32. Flow duration curve at Wamego for synthesized hydrology.

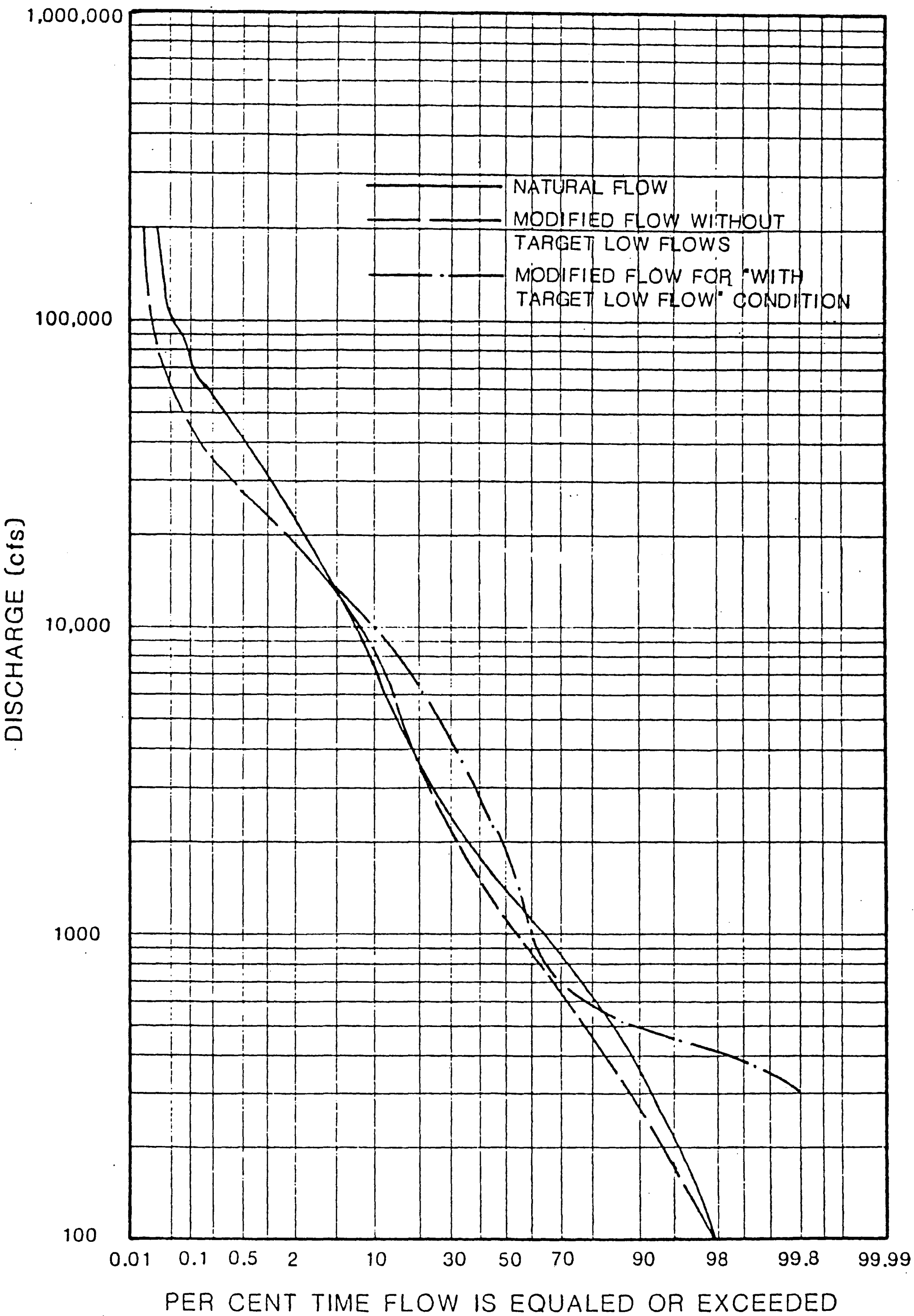


Figure 3.33. Flow duration curve at Fort Riley
for synthesized hydrology.

Table 3.9. Annual Maximum Mean Daily Discharges at Fort Riley.

Peak Discharges (cfs)

Calendar	Recorded	Natural Conditions (without reservoirs)	Modified Conditions (with reservoirs)
1935	-	124,990	32,270
1936	-	8,186	7,435
1937	-	10,505	11,784
1938	-	18,730	18,660
1939	-	13,379	10,954
1940	-	6,025	6,960
1941	-	46,734	40,624
1942	-	28,260	27,988
1943	-	42,899	19,701
1944	-	33,776	25,483
1945	-	37,841	27,965
1946	-	25,111	21,120
1947	-	53,227	22,020
1948	-	49,343	40,623
1949	-	26,130	20,243
1950	-	52,026	40,225
1951	-	277,742	231,874
1952	-	16,285	11,736
1953	-	15,347	14,325
1954	-	13,501	9,823
1955	-	9,372	4,345
1956	-	6,399	1,765
1957	-	47,570	19,766
1958	-	33,623	16,372
1959	-	17,206	15,322
1960	-	62,376	18,890
1961	-	44,319	26,453
1962	-	19,729	19,832
1963	-	9,605	11,572
1964	14,400	16,755	7,725
1965	25,600	27,635	22,134
1966	8,380	12,183	8,490
1967	25,500	30,684	27,054
1968	5,210	10,717	10,563
1969	15,300	20,183	19,240
1970	14,500	15,791	12,192
1971	31,900	39,980	30,892
1972	14,000	12,971	11,588
1973	56,600	94,399	54,449

Table 3.11. Annual Maximum Mean Daily Discharge at Lecompton.

Peak Discharges (cfs)

Calendar	Recorded	Natural Conditions (without reservoirs)	Modified Conditions (with reservoirs)
1935	-	148,050	46,051
1936	-	27,200	24,410
1937	17,800	17,800	19,604
1938	45,200	45,200	27,321
1939	30,100	30,100	26,911
1940	13,160	13,163	7,347
1941	101,000	101,091	63,708
1942	80,400	80,465	60,900
1943	141,000	140,988	78,922
1944	112,000	111,968	64,295
1945	127,000	126,986	92,628
1946	33,100	33,087	32,061
1947	77,200	77,293	46,292
1948	62,800	63,525	53,136
1949	52,300	53,300	46,590
1950	106,000	106,261	52,936
1951	472,000	469,945	348,298
1952	48,400	48,503	42,527
1953	16,900	17,144	15,570
1954	31,400	33,633	26,055
1955	12,600	14,693	10,900
1956	17,200	17,317	17,142
1957	43,900	65,364	37,716
1958	57,400	56,737	48,049
1959	42,200	42,455	35,110
1960	93,200	124,355	49,722
1961	70,600	80,464	49,168
1962	49,900	56,570	44,395
1963	15,500	16,926	15,902
1964	29,600	54,083	33,436
1965	70,600	73,700	51,230
1966	30,400	32,899	15,459
1967	94,500	109,375	61,555
1968	49,500	54,208	42,589
1969	58,700	64,229	46,071
1970	59,300	73,607	43,782
1971	38,600	62,050	40,873
1972	35,000	40,458	37,779
1973	129,000	201,503	86,343

Table 3.10. Annual Maximum Mean Daily Discharges at Wamego.

Peak Discharges (cfs)

Calendar	Recorded	Natural Conditions (without reservoirs)	Modified Conditions (with reservoirs)
1935	140,000	140,000	49,434
1936	14,100	14,100	13,002
1937	15,600	15,600	18,369
1938	26,900	26,900	25,378
1939	24,700	24,700	25,378
1940	7,420	7,420	7,522
1941	112,000	112,064	42,394
1942	44,000	45,020	39,433
1943	88,200	88,186	38,267
1944	75,200	75,143	38,585
1945	78,500	78,690	45,585
1946	38,800	38,775	33,143
1947	71,000	71,080	40,973
1948	56,600	57,801	44,921
1949	53,400	52,412	36,787
1950	83,500	83,962	39,453
1951	393,000	390,449	272,572
1952	36,900	37,007	35,992
1953	18,300	19,493	18,165
1954	26,400	27,305	24,724
1955	11,000	11,397	9,989
1956	17,000	17,122	17,103
1957	45,000	67,194	38,399
1958	51,000	51,115	39,351
1959	38,800	39,042	38,123
1960	67,200	125,910	34,631
1961	68,600	81,406	39,733
1962	35,600	49,154	47,382
1963	12,000	17,354	16,371
1964	12,600	39,564	31,564
1965	40,100	48,811	40,764
1966	14,300	11,533	10,918
1967	41,600	62,896	44,755
1968	15,000	28,035	25,847
1969	36,700	58,752	41,065
1970	33,300	41,735	28,610
1971	38,900	63,635	41,284
1972	13,600	28,165	26,662
1973	61,500	184,847	67,113

Table 3.12. Annual Maximum Mean Daily Discharges at Desoto.

		Peak Discharges (cfs)	
Calendar	Recorded	Natural Conditions (without reservoirs)	Modified Conditions (with reservoirs)
1935	117,000	117,000	64,544
1936	19,900	19,900	18,527
1937	19,100	19,100	17,728
1938	43,400	43,400	34,476
1939	31,100	31,100	24,730
1940	20,600	20,673	8,650
1941	109,000	109,000	67,399
1942	77,300	77,389	58,690
1943	144,000	143,991	58,181
1944	139,000	138,967	72,754
1945	134,000	133,987	81,616
1946	35,900	35,888	32,358
1947	69,000	69,173	46,906
1948	67,400	68,166	57,093
1949	54,200	55,140	55,537
1950	115,000	155,221	61,598
1951	486,000	484,012	347,156
1952	55,800	55,909	45,303
1953	16,100	16,404	14,685
1954	32,600	34,791	26,738
1955	14,400	15,181	13,650
1956	15,500	15,614	15,169
1957	52,600	58,779	42,432
1958	61,400	62,954	59,511
1959	42,800	43,063	40,771
1960	98,900	128,042	55,264
1961	86,200	88,746	67,713
1962	59,400	60,170	49,829
1963	17,100	16,321	15,285
1964	37,100	51,533	37,277
1965	80,500	81,755	60,607
1966	30,200	32,726	25,561
1967	132,000	147,034	80,670
1968	61,300	62,325	53,530
1969	81,800	87,261	64,744
1970	77,300	85.040	64,771
1971	40,500	63,594	42,836
1972	43,800	44,912	41,891
1973	102,000	188,355	85,698

flows prior to reservoir operation were probably a major cause of dramatic lateral migration and meander cutoff. Since reservoir closure these processes seem to have slowed (see Section 3.3.4).

The recorded peak discharges and the discharges under natural conditions are essentially the same until the mid to late 1950's. From the late 1950's to 1973, the recorded discharges fall predominantly between the natural and the modified condition. This period corresponds to the construction of the majority of the federal reservoirs. Discrepancies may be attributed to the fact that the reservoirs were not always operated in accordance with a single operating strategy.

3.4.4 Impact of Trapping of Sediment by Federal Reservoirs

The federal reservoirs have been highly efficient in trapping sediment. Reservoir surveys by the COE indicate that between 95 and 98 percent of the suspended sediment flowing into the reservoirs has been trapped. The 95 to 98 percent figures are based on the total tonnages of sediment of all size fractions flowing into and out of the reservoirs. The trap efficiency for the sand-sized particles is 100 percent since these large particles settle out faster than the smaller, lighter silt and clay-sized particles.

The COE has conducted reservoir surveys for at least five of the reservoirs. The results of these reservoir surveys are shown in Table 3.13. Estimates were made of the total sand trapped in Milford, Perry, and Tuttle Creek reservoirs since their closure. There were two components to this estimate of total sand load. The first component was the percentage of sand in the measured suspended load. This percentage of sand varied from 6 to 20 percent based on daily suspended sediment samples taken upstream of the reservoirs. The second component was that amount of sand which was being transported in the unmeasured zone, (i.e., the sand moving within a distance of approximately 0.3 feet above the channel bottom). This second component was estimated based upon the Meyer-Peter, Muller bed-load equation and the Einstein integration for the suspended load.

Because of the trapping of sand within the federal reservoirs, it would be expected that degradation immediately downstream of the reservoirs would occur due to clear water releases. The extent of this degradation is of some concern, since its progression into the mainstem of the Kansas River would cause degradation and bank erosion. The three reservoirs closest to the

Table 3.13. Reservoir Sediment Inflows (from COE reservoir surveys).

Reservoir	Period	Total Suspended Sediment Inflow (million tons)	Percent Sand	Total Sand* Inflow (million tons)	Average Annual Sand Inflow (million tons)
Tuttle Creek	1959-1973	71.2	6	5.98	0.43
Perry	1969-1979	22.0	4	1.23	0.11
Milford	1967-1979	16.5	16	3.70	0.28
Kanopolis	1946-1971	21.7	9	2.73	0.11
Harlan County	1951-1972	27.5	26	10.01	0.48

*Assuming ratio of total sand to measured sand = 1.4.

Kansas River that have been in operation for some time are Milford, Tuttle Creek, and Perry.

The COE reservoir surveys for these reservoirs give the amount of degradation that has occurred at selected cross sections in the outlet channels between the dams and the mainstem of the Kansas River. These reservoirs are located on tributaries of the Kansas River approximately 7 to 10 miles upstream of the mainstem. An estimate of the associated volume and weight of degradation is presented in Table 3.14.

An examination of the erosion downstream from these dams (see Appendix D) shows the same pattern in each case. Erosion immediately below the dams is severe (on the order of ten feet) but tapers off quickly to less than two feet at the mainstem of the Kansas River. Similarly, the outlet channel cross sections show considerable bank sloughing immediately downstream of the dams, which also tapers off quickly.

Referring to Figure 3.29, it can be seen that because of their proximity to the Kansas River, Milford, Perry and Tuttle Creek Reservoirs, are most likely to be associated with the problems of bank instability and channel erosion in the lower Kansas River. Since they are located a considerable distance upstream from Lawrence (start of the problem area of major interest), it appears extremely unlikely that the clear water releases from the reservoirs are a significant factor in causing the channel erosion in the lower Kansas River. It is possible that at least part of the degradation occurring immediately below R.M. 68 (see Section 3.3.5.2 and Table 3.6) may be associated with trapping of sediment by Perry Reservoir. An examination of the changes with time of the cross sections (Appendix D) and rating curves on the main stem of the upper Kansas River (Figures 3.24 to 3.26) supports these conclusions.

The trapping of fine, wash-load size sediment by the reservoirs has been blamed as a cause of increased bank erosion and instability. The process by which this may occur is as follows. Due to trapping of the majority of the wash load in the reservoirs, water released from the reservoirs will have a deficit of silt and clay material. As the river reworks the valley, the fine cohesive material found in the channel banks will be removed. New areas of deposition or accretion will be formed with material having a smaller percentage of cohesive material, leaving a more erodible bankline. Over a long period of time this process may result in a net increase in actively eroding

Table 3.14. Degradation on Tributaries Downstream of Reservoirs.

Reservoir	Period	Bulk Volume (ac-ft)	Weight* (million tons)	Annual Weight (million tons)
Tuttle Creek	1962-1973	1,853	4.04	0.37
Perry	1967-1979	540	1.18	0.10
Milford	1967-1980	919	2.00	0.15

*Assumes a unit weight of 100 lb/cf.

bankline. Referring to Section 3.3.6, it can be seen that a considerable amount of accretion of banks and island formation has occurred since reservoir closure. While it is true that this process is partially a consequence of the river "healing" from the 1951 flood, it can be surmised that these areas of accretion and island formation are composed of more easily erodible material than they would have been if no reservoirs had been in operation, indicating a potential for an increase in the amount of unstable bankline.

3.4.5 Qualitative Evaluation of the Impact of Federal Reservoirs on Observed River Changes

Operation of the federal reservoirs impacts the Kansas River through two mechanisms: changes in the natural discharge pattern or hydrologic changes, and trapping of incoming sediments resulting in essentially clear water release.

As discussed in the previous section, trapping of sediments by the reservoirs has had a severe effect on the tributaries immediately downstream of the reservoirs, but has had negligible effect on the mainstem of the Kansas River. Any effects due to trapping of bed load size material must proceed from the reservoirs and move downstream. With the exception of Clinton Reservoir (closed in 1979), the federal reservoirs are a considerable distance above Lawerence (R.M. 52). For these reasons the effect of trapping bed-load (sand size) material in the reservoirs has been insignificant in the lower 50 miles of the Kansas River, and has been slight and relatively localized in the upper portion of the Kansas River.

The trapping of fine sediment can result in increased bank erosion over a long period of time due to sorting and redeposition of bed material. This process has probably not been in effect long enough on the Kansas River to result in a general increase in bank erosion.

Hydrologic impacts affect the entire system. Essentially two major hydrologic impacts are the direct result of reservoir operation: (1) the attenuation of peak flows (the primary purpose of the reservoirs), and (2) increasing the occurrence of intermediate (approximately two-thirds to three-quarters bankfull) discharges.

As discussed in Section 3.3.4, lateral migration of the Kansas River has slowed dramatically in recent years. This is, to a large degree, attributable to the attenuation of peak flows by reservoir operation. High flows undoubtedly were a major cause of meander bend cutoffs and other dramatic shifts in channel alignment. Reducing the size of these flows appears to have had a stabilizing influence on the Kansas River.

Reducing the peak flows which transported large amounts of sediment, and increasing the intermediate discharges changes the flow regime, causing the river to adjust its plan form and cross-sectional geometry accordingly. Being a dynamic fluvial system, the Kansas River is attempting to adjust to a new equilibrium condition dictated by the regulated discharge pattern. This process is complicated by the fact that the 1951 flood tremendously altered the geomorphic characteristics of the system. In many reaches of the Kansas River, the present channel may be entrenched within the much larger channel created by the 1951 flood and is reworking the bed of that channel as if it were a flood plain. Sufficient cross-sectional evidence does not exist to test this hypothesis. The best historical cross-section data are in the reach that has had severe impacts from sand and gravel dredging. Net accretion of bottom land and formation of islands, as discussed in Section 3.3.6, does tend to support the view that the river is adjusting or "healing" from the effects of the 1951 flood.

The effects of Federal Reservoirs can be qualitatively summarized as follows:

1. Attenuation of peak flows has probably helped stabilize the system from the standpoint of lateral migration.

2. The trapping of sediments within the reservoirs has had an insignificant effect on the mainstem of the Kansas River, although degradation has occurred in the outlet channels immediately below the reservoirs. In time, this may progress into the mainstem. This will be addressed further in the following chapters.

3.5 Effects of Sand and Gravel Mining

Sand and gravel have been commercially dredged from the Kansas River bed since the early 1900's. Between Turner and Bonner Springs, Kansas (approximately river miles 9 through 20), there has been a concentration of sand and gravel mining since the late 1940's. The dredging operations employ floating, hydraulic suction devices which remove the sand and gravel from the river bottom. This material is pumped as a slurry mix onto the river banks for processing. The bulk of the sand and gravel is used in Kansas City in the construction industry as asphalt aggregate or as road base fill.

The primary area of dredging activity is in the reach between Turner Bridge (R.M. 9.6) and approximately R.M. 22. The next most intensive site of dredging activities is at Topeka (R.M. 83-87). Less important sites occur just downstream of Bowersock Dam, at Wamego, and at Manhattan.

Cross (1982) attempted to identify the historic positions of sand and gravel dredges within the reach between Turner and Desoto. As no accurate written records exist, a careful examination of available aerial photographs was made. Table 3.15 gives the results of Cross's study updated to reflect the 1983 aerial photography.

3.5.1 Annual Tonnages Removed

The total tonnage of sand and gravel removed from the Kansas River is listed in Table 3.16. These values are based on the scale weights of sand and gravel sold during that particular year. Since each company has stockpiles on the river banks, it is not possible to distinguish between the time the sand and gravel was dredged and the time that it was sold. Scale weights also do not reflect the amount of sand that was dredged from the river but was found to be unusable. The majority of this unusable material is returned to the river. Site inspection indicates the total quantities of unusable material to be relatively small.

Only limited data are available regarding the size distributions of the sand and gravel being dredged. The U.S. Department of the Interior, Bureau of Mines (1971) statedsthat percentage of gravel (sizes larger than 3/8 inch in diameter) sold from 1961 to 1968 ranged from 2.8 to 3.6 percent of the total quantity of dredged material. This is in agreement with comments made by a representative of Holliday Sand and Gravel Company (R.M. 15.5-16.5) during a reconnaissance site visit in September 1983. The 1971 study further stated that "most of the sand is coarser than 50 mesh (0.3 mm). The remaining material is predominantly finer than 100 mesh (0.15 mm); consequently, little sand is recovered in the size range 50 mesh to 100 mesh."

Table 3.15. Locations of Previous and Present Working Dredges, by River Mile, in the Lower Kansas River (Turner Bridge to Bonner Springs), 1954-1983. Data Obtained from Dredging Equipment and/or Storage Sites Evident on Aerial Photographs in the Years Indicated.

Year	1954	1970	1976	1979	1983
Dredge Locations (River Mile)	9.9				
	10.3				
	10.6				
	11.3	11.3			
	12.0	12.0			
		12.9	12.9	12.9[2]	12.5
		13.1			
	14.0[1]	14.0	14.0	14.0	14.4
	14.7[1]	14.7	14.7	14.7	15.6
			16.0	16.0	16.3
	18.4	18.4	18.4	18.4	
			19.3	19.3	19.1
		21.0	21.0	21.0	21.1
				21.7[1]	
Total Dredges	8	8	7	8	6

[1]newly established sites

[2]ceased operation in 1981

Note: 1954, 1970, 1976, 1979 data from Cross (1982).

Table 3.16. Gravel Mining Information.

Year	RM	Quantity (millon tons)	Source of Information
1926, 1927	unknown	1.5	COE (unpublished)
1927, 1928	"	1.0	"
1928, 1929	"	1.6	"
1929, 1930	"	1.9	"
1930, 1931	"	1.2	"
1939	9.5 to 22	0.5	COE (1977)
1940	"	0.1	"
1941	"	0.5	"
1942	"	0.7	"
1943	"	0.5	"
1944	"	0.4	"
1945	"	0.5	"
1946	"	0.8	"
1947	"	0.8	"
1948	"	0.8	"
1949	"	1.0	"
1950	"	1.3	"
1951	"	0.9	"
1952	"	1.1	"
1953	"	1.5	"
1954	"	1.8	"
1955	"	1.9	"
1956	"	1.8	"
1957	"	1.4	"
1958	"	1.7	"
1959	"	2.2	"
1960	"	1.7	"
1961	"	1.8	"
1962	"	2.3	"
1963	"	2.1	"
1964	"	2.2	"
1965	"	2.4	"
1966	"	1.4	"
1967	"	1.3	"
1968	"	2.0	"
1969	"	2.2	"
1970	"	2.3	"
1971	"	2.4	"
1972	"	2.7	"
1973	"	2.4	"
1974	"	2.8	"
1975	"	1.8	"
1976	"	2.1	"

Table 3.16. Gravel Mining Information (continued).

Year	RM	Quantity (millon tons)	Source of Information
1977	0 to 169	3.3	Burns & McDonnell (1982)
1978	0 to 169	4.0	"
1979	9.5 to 22	2.9	Cross (1982)
1980	"	2.1	"
1981	"	0.9	"
1978	81 to 86	0.49	Kansas State Dept. of Revenue
1979	"	0.54	"
1980	"	0.53	"
1981	"	0.40	"
1982	"	0.22	"
1983	"	0.30	"
1961	0 to 169	3.04	Hibpshman (1971)
1962	"	3.41	"
1963	"	3.35	"
1964	"	3.51	"
1965	"	3.63	"
1966	"	3.76	"
1967	"	3.52	"
1968	"	3.72	"
1979	143 to 150	0.18	Kansas State Dept. of Revenue
1980	"	0.14	"
1981	"	0.10	"
1982	"	0.07	"
1983	"	0.08	"
1979	123 to 129	0.05	"
1980	"	0.05	"
1981	"	0.03	"
1982	"	0.04	"
1983	"	0.03	"
1979	51 to 51.8	0.0	"
1980	"	0.02	"
1981	"	0.03	"
1982	"	0.04	"
1983	"	0.08	"

Table 3.16. Gravel Mining Information (continued).

Year	RM	Quantity (millon tons)	Source of Information
1979	9.5 to 22	1.79	"
1980	"	2.56	"
1981	"	2.17	"
1982	"	1.50	"
1983	"	2.71	"
1979	0 to 9.5	0.24	"
1980	"	0.34	"
1981	"	0.24	"
1982	"	0.17	"
1983	"	0.19	"

The dredging operations work within one stretch of river excavating a pit from 20 to 30 feet deep. The barge and pump then move on to a new site and the action of the river refills the dredge hole to some extent. A common complaint from the dredgers is that the material which refills the dredge hole is generally finer than the virgin material. It has been asserted that the reason the sediment which refills the dredge holes is finer is due to the construction of the upstream federal reservoirs. This argument seems erroneous. As discussed in Chapter II, much of the sand and gravel in the river channel and flood plain is reworked glacial material from interstream divides. As will be shown in the next chapter, the hydraulic conditions required to transport this material, even without the reservoirs, are generally insufficient to move gravel sizes. Coarse material currently being mined is obtained from ancient sand and gravel deposits which are coarser than the material presently being transported by the river.

3.5.2 Qualitative Evaluation of Impact of Sand and Gravel Dredging

Sand and gravel dredging appears to have had a striking local effect on the morphology in the Kansas River. The area of intensive gravel mining (Turner Bridge to Bonner Springs) has experienced the most dramatic changes as evidenced by the historical cross sections (Appendix C), historic thalweg profiles (Figure 3.27), stage-history relationships (Figures 3.24 to 3.26), and field observation. Both the COE (1977) and Smith (undated) agree that the gravel miners in this reach have been removing sand at a rate greater than it can be replenished by the river. This can only result in degradation of the reach in which the dredging is taking place and associated problems such as headcutting, downstream degradation and increased bank erosion. From the historic thalweg plot (Figure 3.27) it appears that a headcut has developed at about R.M. 22-23. Downstream effects due to the dredging between Turner Bridge and Bonner Springs have been insignificant. Examination of the historic thalweg profiles (Figure 3.28) for the reach below Turner Bridge, show the major impact on this reach seems to be due to the 1951 flood. The absence of impacts of dredging in this reach is primarily due to the fact that this reach is generally in a backwater condition due to stage on the Missouri River. Trapping of sand in the dredge pits has undoubtedly reduced the magnitude of deposition in the lower nine miles of the river; however, the reduction of peak flows by federal reservoirs has coincidently reduced the erosion that normally occurred at high flows in this reach.

Other areas of sand and gravel dredging show evidence of change, though none as dramatic as the Bonner Springs to Turner Bridge reach. For instance, Osterkamp (1982) reports about 1.5 feet of degradation for the Kansas River at Topeka and asserts that this is in part due to dredging and in part due to constriction of the channel by flood control works in this area.

Degradation has occurred immediately below Bowersock Dam; however, dredging activity here has been comparatively insignificant for about the last six years.

Available data indicate changes in the Kansas River at or near the dredge at Manhattan or Wamego have probably been relatively minor.

To summarize, the following observations pertaining to dredging can be made:

1. The reach of the Kansas River between Turner Bridge (R.M. 9.6) and Bonner Springs (R.M. 22) has experienced intense sand and gravel dredging since at least 1940. This reach has also experienced extreme degradation (8 to 10 feet or more), and channel widening (around 150 feet). Due to the absence of degradation and channel widening of such magnitude at any other location on the Kansas River, it can be concluded that sand and gravel dredging is the primary cause.

2. Effects of dredging downstream of Turner Bridge are damped out by the backwater effect of the Missouri River.

3. There is an apparent headcut just above Bonner Springs that can be associated with the degradation downstream of that area.

4. Some portion of the degradation at Topeka can probably be attributed to sand and gravel dredging.

5. No appreciable changes in channel morphology can be correlated with dredging activities at Manhattan and Wamego.

3.6 Impact of Lowering of Missouri River Stages

3.6.1 History of Stage Changes

Figure 3.24 (Osterkamp, 1981) shows the change in stage of the ten percent exceedence and 25 percent exceedence discharges on the Missouri River at the Kansas City gauge. As can be seen from the figure, there has been a steady decline totaling about two feet since 1940. This drop in stage is a result of general channel degradation which can probably be attributed to several factors, including shortening of the Missouri River channel by bend cutoffs including the Liberty and Jackass bend cutoffs, and construction of the Missouri River navigation channel past Kansas City. Prior to 1940, historical evidence indicates that the Missouri River may have been aggrading for the period approximately 1900 to 1940, as shown in Table 3.5.

3.6.2 Effects of Missouri River Stages on the Hydraulics of the Lower Kansas River

Stage on the Missouri River has a tremendous effect on the hydraulics, and consequently, on the sediment transport characteristics of approximately the lower ten miles of the Kansas River. The actual upstream limit of these effects and the actual reduction in velocities and increase in depths is discussed in Chapter IV. These lower ten miles are generally in a backwater condition due to the stage on the Missouri reducing the flow velocity in this reach and resulting in deposition of sediment greater than or equal in size to fine silt. These deposits are readily moved during infrequent periods of high discharge on the Kansas River combined with low stage on the Missouri River.

The variation in stage of the Missouri River for a given discharge on the Kansas River is shown by Figure 3.34. (Stage on the Missouri River at the confluence with the Kansas River was determined by adding 1.1 feet to the stage at the Kansas City gauge which represents the average slope of the Missouri River bed multiplied by the distance between the gauge and the confluence.) This figure was prepared from 1976-1977 data. The figure indicates that stage on the Missouri River can vary up to ten feet for low and intermediate discharges in the Kansas River. This has a dramatic effect on the hydraulics of the Kansas River. The significance of this effect is that hydraulic parameters (velocity, depth, topwidth, etc.) in the lower 10 miles of the Kansas River, are determined primarily by stage on the Missouri River, and secondarily, by discharge in the Kansas River. These effects are not transmitted upstream of the Johnson County weir, however, and may be dampened by the geologic control at R.M. 12.2.

Even though stage on the Missouri River has a dramatic impact on the hydraulics and sediment transport characteristics of the Kansas River, it appears that the change in stage for given discharges on the Missouri River

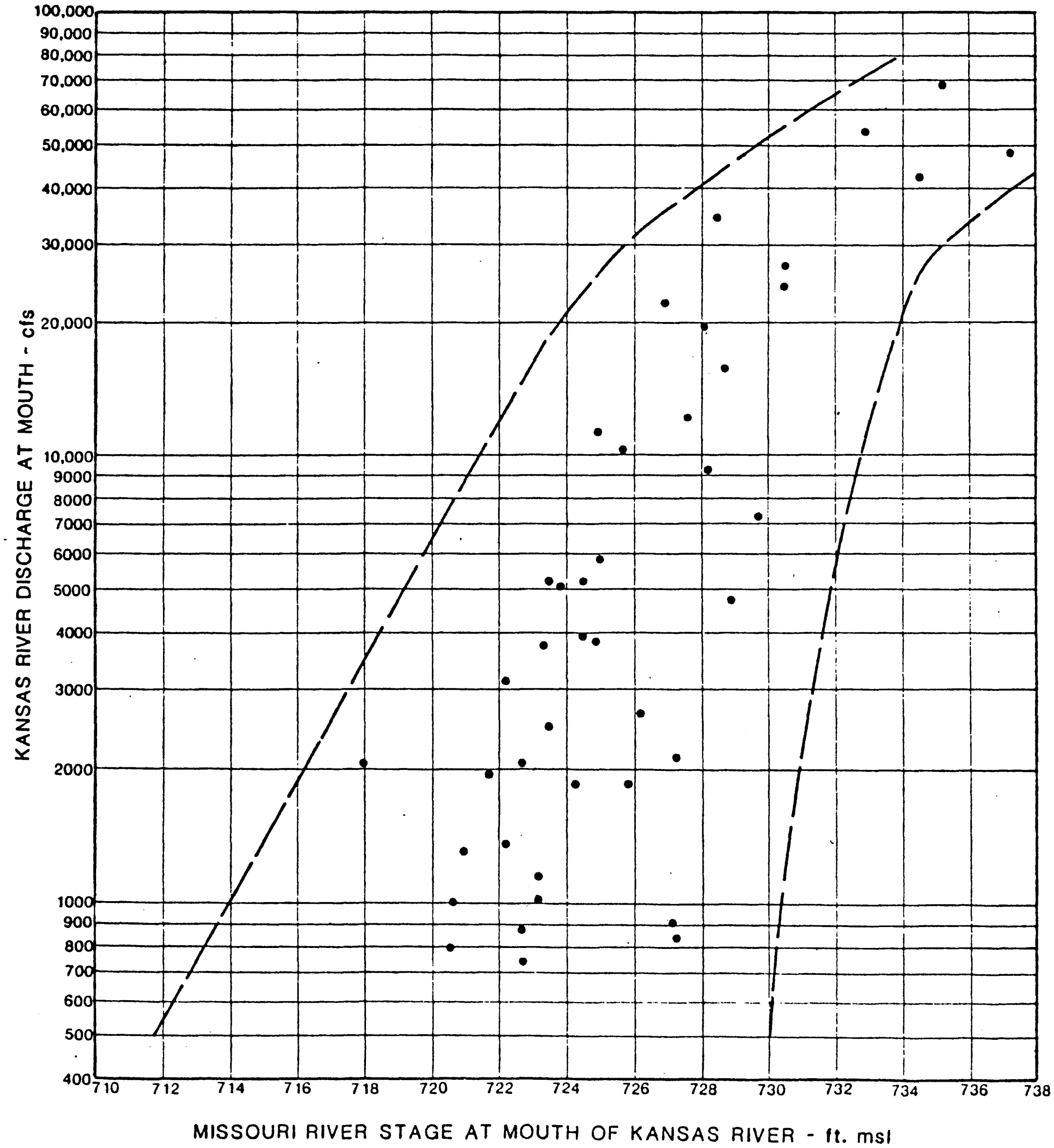


Figure 3.34. Stage on the Missouri River versus discharge in the Kansas River at the confluence.

has not been sufficient to induce any measurable geomorphic change on the lower Kansas River. This is discussed in detail in the next section.

3.6.3 Qualitative Evaluation of the Impacts of Lowering Missouri River Stages

Any effects, such as headcutting, due to lowering of the base level (and consequently, the stages) of the Missouri River would have to start at the mouth of the Kansas River and move upstream. Several observations support the conclusion that lowering of the base level of the Missouri River has had very little effect on the Kansas River. These observations are:

1. Examination of historic thalweg profiles in this reach (Figure 3.27) shows that the lower ten miles have aggraded since the 1951 flood. Overall, it appears that this reach has undergone cycles of aggradation and degradation in response to deposition at normal flows and scour of deposited fine sediments during large floods.

2. The geologic control at R.M. 12.2 may impair the upstream movement of effects due to lowering the Missouri River base level. The presence of this outcrop was reported by the Corps of Engineers (1956) and hence has not been recently uncovered. If any effects propagate beyond R.M. 12.2 they are stopped at R.M. 15 by the Johnson County weir. Prior to construction of the weir there may have been some upstream effects due to lowering of the Missouri River, but because of the hydraulic situation (i.e. the "backwater" condition of this reach at most discharges) and the presence of a control at R.M. 12.2 they were probably insignificant.

3. Field observation reveals no evidence to support the belief that the lower 10-mile portion of the Kansas River has experienced appreciable net degradation.

4. Historic data indicate that between 1900 and 1940 the Missouri River may have been aggrading. Because of this the net change in base level of the Missouri River prior to construction of the Johnson County weir may not have been significant enough to cause measurable impacts on the Kansas River.

3.7 Impacts of Man-made and Natural Controls

Two types of controls exist on the Kansas River, natural and man-made. Natural controls include bedrock outcroppings in the bed and/or banks and channel armoring. Armoring occurs when the river has sorted the bed material sufficiently to form a layer of gravel or cobbles that are not easily transported by the river. Man-made controls include dams, weirs, and bank revetment.

3.7.1 Natural Controls

On the Kansas River, several natural geologic features act as channel controls. In several places, the river may be laterally controlled by bedrock defining the fluvial valley (see Figure 2.4). In general these controls are insignificant. The major exception is at R.M. 12.2, where the bedrock along the north bank extends part way across the bottom of the channel, forming a vertical control as well. A geologic cross section of this control is not available. It appears that this control dips off to the south indicating that if the channel were to migrate south at this point this control would become ineffective. Examination of the figures in Appendix B indicates that historically this reach has been very stable laterally. The only other prominant geologic control exists just upstream of Willard Bridge at R.M. 101.1. Here, bedrock is exposed in the southern half of the channel and may act as a lateral control in that direction. A geological cross section indicates that the bedrock dips sharply to the north. Because of channel alignment due to the bridge abutments, this outcrop probably acts as a vertical control, although it is not as definitive as the control at R.M. 12.2. In the lower 50 miles of the Kansas River, bedrock outcrops that may act as lateral controls were also observed near Lawrence (approximately R.M. 51) and near Desoto (approximately R.M. 32). Other areas in which armoring may act as a control, at least for low and intermediate discharges, are R.M. 21-22, and R.M. 132. At R.M. 21-22, the armor layer is very thin and underlain by sand. This layer is probably ineffective as a channel control at all but low discharges. The thickness and effectiveness as a control of the armor layer at R.M. 132 is uncertain. Examination of the figures in Appendix B indicates that this area has acted as a pivot point about which the channel has laterally migrated. It is probable that the area is acting as a lateral control, and possibly as a vertical control.

3.7.2 Man-made Controls

Two significant manmade structures serve as major controls on the Kansas River. These are Bowersock Dam and the Johnson County weir. In addition, numerous bank and flood protection works have been installed. Table 3.17 (Corps of Engineers, 1982) lists the bank erosion measures along the Kansas River. These bank protection measures may act as lateral controls to some extent, but their overall impact on channel morphology is probably minor.

Table 3.17. Kansas River Existing Bank Protection Mouth to Junction City. (COE, 1982)

Kansas River Mile	Bank	Length, ft.	Stabilization Type	Sponsor/Owner	Year Installed
8.2	L	1,500	Riprap	Union Pacific R.R.	pre-1960
12.0	L	3,000	Riprap	Union Pacific R.R.	pre-1958
15.5	R	4,000	Riprap	Santa Fe RR.	pre-1954
17.0	L	5,000	Hardpoints	Local	
18.8	L	1,000	Hardpoints	Local	
18.8	L	5,500	Hardpoints	Local	
19.0	L	5,500	Riprap	Union Pacific RR.	pre-1954
21.5	R	2,000	Riprap	Local	pre-1954
23.4	R	2,500	Bus Bodies/Dikes	Local	
23.8	R	1,000	Kellner Jacks	Santa Fe RR.	
25.5	R	2,500	Riprap	Santa Fe RR.	pre-1954
27.5	L	6,000	Hardpoints	Local	pre-1954
29.0	R	5,000	Riprap	Local	1960
30.0	R	2,500	Kellner Jacks—Riprap	Santa Fe RR.	1954 to 1958
30.5	R	2,500	Riprap	Santa Fe RR.	pre-1954
31.4	R	300	Tires	Local	1979
31.5	L	1,000	Dikes	Corps, Sec. 14	1969
32.4	R	2,000	Dikes	Local	pre-1954
34.2	L	3,000	Riprap	Union Pacific RR.	pre-1954
39.0	L	1,500	Riprap	Union Pacific RR.	pre-1954
39.8	L	2,000	Riprap	Union Pacific RR.	pre-1954
40.2	R	3,000	Riprap	Local	pre-1958
42.8	R	2,500	Dikes	State Hwy. Dept.	1953 to 1954
43.1	L	1,500	Dikes	Corps, Sec. 14	1954 to 1960
43.7	L	2,500	Windrow Revetment/Toe Protection	Corps, Sec. 32	1979
44.1	L	2,000	Dikes	Union Pacific RR.	pre-1958
46.7	L	2,500	Riprap	Union Pacific RR.	pre-1954
48.0	R	2,000	Windrow Revetment/Debris	Local	
50.4	L	2,000	Riprap	Local	1956
52.0	L	2,200	Revetment	Corps	pre-1951
52.0	R	1,000	Riprap	Local	1934
52.7	R	1,500	Riprap	Local	1942
52.9	L	2,000	Riprap	Local	1944
54.2	L	1,000	Dikes	Local	pre-1953
55.0	R	2,000	Riprap	Santa Fe RR.	pre-1958
55.3	L	1,000	Riprap	Local	pre-1953
55.6	L	2,000	Dikes	Corps, Sec. 14	Late 1960's
55.6	L	1,500*	Dikes	KPL	Planned

Table 3.17 (continued)

Kansas River Mile	Bank	Length, ft.	Stabilization Type	Sponsor/Owner	Year Installed
56.5	Right	2,000	Riprap	Local	pre-1958
60.0	R	5,000	Riprap	Local	1948 and earlier
62.0	Left	3,000	Riprap	Local (part 1939)	pre-1958 (part 1939)
63.5	R	2,500	Kellner Jacks	Santa Fe RR.	pre-1958
66.3	L	1,000	Riprap	Local	pre-1960
68.9	R	1,500	Riprap	Local	pre-1960
71.7	L	2,000	Riprap	Local	1954
73.9	L	1,000	Riprap Local	Local	pre-1958
75.5	R	3,000	Riprap	Santa Fe RR.	pre-1958
77.2	R	2,000	Hardpoints	Local	pre-1958
78.1	L	6,000	Hardpoints	Local	1954
79.9	R	2,000	Riprap	Local	1942
81.0	L	6,500	Riprap	Corps and others	1960's and earlier
84.0	R	5,500	Riprap	Corps and others	1960's and earlier
85-87	L	15,000	Riprap/Hardpoints	Local	Many dates
87.0	R	1,000	Riprap	City of Topeka	
87.0	L	5,000	Dikes	Local	
87.7	R	1,500	Riprap	Local	pre-1960
88.8	R	1,000	Riprap	Rock Island RR.	pre-1960
90.0	L	2,000	Riprap	Kaw Valley Drainage District	1960
92.0	L	2,000	Carbodies/Hardpoints	Kaw Valley Drainage District	post-1960
92.5	R	4,000	Box Car/Riprap	Rock Island RR.	pre-1958
93.5	L	5,000	Hardpoints	Kaw Valley Drainage District	many dates post-1951
94.5	R	2,500	Box Car/Riprap	Rock Island RR.	pre-1958
95.0	L	8,500	Dikes	Kaw Valley Drainage District	Many dates post-1951

Table 3.17 (continued)

Kansas River Mile	Bank	Length, ft.	Stabilization Type	Sponsor/Owner	Year Installed
97.3	R		Riprap	Local	
98.5	R	1,500	Riprap	Rock Island RR.	pre-1960
99.3	R	1,000	Riprap	Rock Island RR.	pre-1954
99.2	L	500	Hardpoints	Tri-County Drainage District	1954 to 1960
100.0	L	3,000	Carbodies/Hardpoints	Tri-County Drainage District	1957
101.4	R	3,000	Hardpoints	Tri-County Drainage District	pre-1958
103.5	L	500	Hardpoints	Tri-County Drainage District	post-1950
106.9	L	500	Kellner Jacks	Tri-County Drainage District	
107.3	L	1,000*	Dikes	Tri-County Drainage District	Planned
109.0	L	1,000	Riprap	Local	pre-1969
110.7	L	500	Riprap	Local	
111.5	R	500	Hardpoints	County Hwy. Dept.	Co. Hwy. Dept
113.2	R	4,500	Dikes	Local	
114.8	R	2,000	Dikes	Local	
115.5	L	1,000	Dikes	Local	1954 to 1958
116.2	R	1,500	Riprap	Wabunsee Co.	1955
117.8	L	6,000	Riprap/Hardpoints	Local	No date
119.3	R	1,000	Riprap	Local	pre-1960
120.5	L	1,000	Hardpoints	Local	
121.5	L	3,000	Riprap	Union Pacific RR.	1958
127.5	L	3,500	Riprap	Union Pacific RR.	pre-1950
131.5	R	2,000	Dikes	Wabaunsee Co.	1978
132.5	L	8,000	Dikes	Local	
134.5	R	5,000	Riprap	Local	pre-1950
136.5	L	3,000	Riprap	Local	pre-1958
138-139	L	8,000	Riprap	Local	pre-1958
142.2	L	3,000	Dikes	Local	pre-1958
143.0	L	2,500	Riprap	Local	pre-1958
145.5	R	2,500	Riprap	Rock Island RR.	pre-1954
146.6	L	1,500	Hardpoints	Local	post-1960
149.0	L	3,500	Riprap	Corps and others	Several dates
156.0	L	4,500	Riprap	Union Pacific RR.	pre-1954
157.5	L	2,500	Riprap	Local	pre-1954
164.0	L	5,000	Riprap	Corps (Ft. Riley)	pre-1958
167.8	L	3,000	Riprap	Corps (Ft. Riley)	pre-1958
168.5	R	4,500	Riprap	Corps (Ft. Riley)	pre-1958
169.0	L	1,500	Riprap	Corps (Ft. Riley)	pre-1958
169.8	L	2,500	Riprap	Union Pacific RR.	post-1951
Subtotal	L	178,700 = 33.8 MILES			
Subtotal	R	99,800 = 18.9 MILES			
Total		278,500 = 52.7 MILES			

*Planned mileage not counted in totals.

These bank protection measures may be locally important but in many instances they probably have merely shifted the eroding area up or downstream and/or to the opposite side of the channel.

3.7.2.1 Johnson County Weir

The Johnson County Water District No. 1 intake is a permanent concrete structure built in 1964 on the right (south) bank of the Kansas River at R.M. 15.0. Within a few years after its construction, the intake began experiencing difficulties of operation due to low river stages brought about by channel degradation. In response to these problems a stone and rock jetty was constructed in order to concentrate the flow against the south bank and the intake structure. Later, the jetty was raised and extended to within about 25 feet of the intake and a rock-lined chute constructed to convey low flows. At present there exists about a nine to ten foot drop across the structure. The weir is composed of quarried rock and stone ranging from about one to six feet in diameter.

3.7.2.2 Bowersock Dam

One of the most important man-made controls in the Kansas River is Bowersock Dam, which is located at Lawrence, immediately downstream of the Massachusetts Avenue Bridge. The original dam, built in 1872, was a part masonry and part rock-filled timber crib structure. The initial construction was approximately 600 feet long and 7-1/2 feet high with a crest elevation of 806.5 feet msl. At the right abutment, an intake canal diverted water to seven hydraulic turbines that had a capacity of about 300 cfs each.

Floods in May and June, 1903 washed a channel around the north abutment. This washout was filled and the dam extended about 65 feet. In 1916, the concrete arch bridge for Massachusetts Avenue was built. At that time the north end of the dam was extended to a total length of 787 feet in order to place the north abutment of the dam in line with the north abutment of the bridge.

A plan set forth in 1924 proposed the creation of a uniform crest elevation at 808.0 feet msl, the addition of 4-foot high collapsible flashboards, and the addition of a second powerhouse at the left abutment. This plan was rejected, but a proposal was accepted in 1926 to add a gated sluiceway at the north end of the dam. This resulted in construction of a sluiceway with seven 8-foot by 10-foot gates with a discharge capacity of 3,000 to 4,000 cfs. At some point in time the crest elevation was raised to 808.0 feet msl and timber flashboards added to raise the upstream pool to 812.0 feet msl. Additional work, at an unknown date, consisted of driving a sheet pile wall across the downstream face of the dam and placing a concrete apron on the downstream side of the original structure. Presently, the City of Lawrence has a 50-year lease agreement with the current owner to operate and control the dam and adjacent structures, including the powerhouse.

3.7.2.3 Qualitative Evaluation of the Impacts Due to Natural and Man-made Controls

Natural and man-made controls have had a significant impact on the plan form and cross-sectional geometry of the Kansas River. In several places (R.M. 12.2, 101.1 and 132) natural controls have acted to limit lateral and vertical migration of the channel.

The Johnson County weir (R.M. 15) and Bowersock Dam (R.M. 51.8) are two man-made controls which have a pronounced effect upon the river. Both structures act as vertical grade controls and both have a region of fairly significant backwater extending a few miles upstream. Both of these structures severely limit the response of the fluvial system to outside influences by fixing the channel at the point of the structure.

Both man-made and natural controls have a stabilizing effect on the Kansas River by limiting degradation, and in some cases lateral migration and bank erosion. The effect of these controls on bank erosion is relatively local; however, they may influence the morphology of the entire system by acting as a barrier to headcuts propagating upstream.

3.8 Summary and Conclusions of Qualitative Geomorphic Analysis

The qualitative geomorphic analysis was broadly divided into two areas, (1) observed trends in channel morphology of the Kansas River, and (2) discussion of those trends with respect to operation of federal reservoirs, sand and gravel dredging, change in the base level of the Missouri River, and man-made and natural controls.

3.8.1 Observed Trends in Channel Morphology

The observed geomorphological trends can be summarized as follows:

1. For the period 1956-1983 the composition of the bed material in the Kansas River shows no significant trends in terms of changes in size. The data indicate a reduction in size of sediments in Reaches 3 and 4. Due to limited data, this apparent reduction is not statistically significant; and may be due to the relatively large variability inherent in bed material sampling.

2. Measured suspended sediment at Wamego seems to be coarsening while suspended sediment at Desoto is getting finer.

3. Evidence indicates measured suspended sediment load at Bonner Springs/Desoto was significantly reduced after reservoir closure.

4. The Kansas River has shown a decrease in lateral migration for the period of approximately 1950-1983 as compared to the period of approximately 1920-1950 (see Appendix B, or Dort [1979]).

5. Average annual water yield for the Kansas River appears to have increased after 1940. The approximately 20-year period of record prior to 1940 is too short to determine if this increase represents a general climatic change, however.

6. The 1951 flood considerably altered the channel morphology by significant amounts of degradation (see Figure 3.28 thalweg, and 3.24 to 3.26 rating curves), channel widening, and meander cutoffs (see Appendix D).

7. Stage discharge relations have shown a decline at all gauging stations (Fort Riley, Wamego, Topeka, Lecompton, and Bonner Springs/Desoto). Decline in the stage of the 25 percent occurrence discharge between 1950 and 1973 has been approximately 1-foot with the exception of Bonner Springs/Desoto, which experienced an 8.5-foot decline for that period.

8. Historic cross sections indicate 8 to 10 feet or more degradation and about 150 feet of channel widening has occurred in the reach from Turner Bridge (R.M. 9.6) to Bonner Springs (R.M. 22) since about 1956. From R.M. 22 to R.M. 68, about 2 to 3 feet of degradation has occurred with slight channel widening while above R.M. 68 little change has been documented in the cross-sectional geometry.

9. Examination of historic thalweg profiles corroborates the findings regarding channel degradation in 8. above and indicates the presence of a headcut at R.M. 22-23. Additionally, the lower 10 miles seem to have undergone cycles of deposition and erosion.

10. The number of permanent vegetated islands and bars has increased since 1971.

11. Three major geologic controls exist on the Kansas River, they are:

    a. At R.M. 12.2, a bedrock outcrop and channel armoring act as a vertical control (limiting degradation) and as a lateral control along the north side of the channel.

    b. At R.M. 101.1, a bedrock outcrop which dips to the north probably acts as a vertical control and as a lateral control to the south.

    c. At R.M. 132, channel armoring is present. This area may act as a vertical control and, while no outcrops of bedrock have been reported at this location, it seems to have been historically a lateral control (see Appendix B).

3.8.2 Impacts of Operation of Federal Reservoirs

The operation of federal reservoirs impacts the Kansas River through two mechanisms: trapping of incoming sediment and change in the flow regime of the river. Impacts associated primarily with trapping of sediment are:

1. Up to ten feet of degradation has occurred in tributaries immediately below the tributary reservoirs but tapers off to zero to two feet at their confluence with the Kansas River (see Appendix D). This degradation can be associated with the trapping of sand size and larger sediments and will eventually progress into and down the mainstem of the Kansas River. Some of the degradation below R.M. 68 on the mainstem may be due to the trapping of sediment by Perry Reservoir.

2. Trapping of fine sediment (silts and clays) may result in less stable banks over a long period of time (see Section 3.4.4) and may be causing the coarsening of suspended sediment at Wamego.

Impacts associated with changes in the flow regime are:

1. A reduction in peak flows. This probably results in:

    a. The reduction in lateral migration (see Appendix B).

    b. Acceleration of the formation of bars and permanent islands.

2. Bolstering the occurrence of intermediate (i.e. 2/3 to 3/4 bankfull discharge). The impacts due to this factor are discussed in Chapter IV.

3.8.3 Impacts Due to Sand and Gravel Dredging

Sand and gravel dredging can effect the morphology of a river in three major ways: (1) local degradation and channel widening, (2) downstream degradation and related impacts such as channel widening and bank erosion caused by the interception of the normal sediment load of the river, and (3) upstream degradation and related impacts due to headcutting. On the Kansas River, impacts due to sand and gravel dredging include:

1. The primary cause of eight to ten feet of channel degradation and 150 feet of channel widening between Bonner Springs (R.M. 22) and Turner Bridge (R.M. 9.6).

2. An apparent headcut at R.M. 22-23.

3. Some of the one to two feet of degradation at Topeka. (This degradation may be due, in part, to the channel constriction by the flood control works.)

No degradation or channel widening downstream of the intensive mining activity was conclusively linked to dredging on the Kansas River. This is primarily due to the fact that, downstream of the most intensive dredging (Turner Bridge to Bonner Springs), the Kansas River is generally in a backwater condition from the Missouri River.

3.8.4 Impact of Missouri River Base Level Changes

Impacts on the geomorphology of the Kansas River due to changes in base level of the Missouri must proceed upstream from the mouth of the Kansas River. These impacts have probably been insignificant for the following reasons:

1. The Johnson County weir was built in 1967; therefore any impacts due to base level changes in the Missouri above the weir are related only to Missouri River changes that occurred before 1967.

2. The presence of a geologic control at R.M. 12.2 was noted at least as far back as 1956. This control will effectively dampen the impact of lowering of Missouri River stages.

3. Examination of historic thalweg profiles (Figure 3.28) in the lower Kansas River shows no evidence of a general degradation corresponding to a lowering of the Missouri River. In fact there has been net aggradation since the 1951 flood.

3.8.5 Impacts due to Man-Made Structures

Two major man-made structures have a considerable impact on the Kansas River morphology. These are the Johnson County weir (R.M. 15) and Bowersock Dam (R.M. 51.8). The effect of these two structures has primarily been to dampen or stop impacts on channel morphology associated with other factors such as dredging, changes in flow regime, and changes in the base level of the Missouri River. More specifically:

1. Johnson County weir has acted to stop the upstream progression of impacts associated with changes in base level of the Missouri River and dredging below the weir. The structure acts as a vertical control fixing the channel bed elevation at the weir.

2. Bowersock Dam acts as a vertical control limiting degradation and blocking the upstream progression of any downstream changes in the channel.

Since both structures essentially fix the bed elevation of the channel at the structure, they tend to maintain the existing average slope of the channel above the structure.

In addition to the Johnson County weir and Bowersock Dam, there has been approximately 53 miles of bank protection and revetment installed on the Kansas River, primarily since 1945 (COE, 1982). While much of this protection has merely shifted the point of erosion upstream, downstream, and/or to the opposite bank, it represents about 15 percent of the total bank lines and, consequently, may have had a net effect of stabilizing the channel laterally.

3.8.6 Impacts Due to Tectonic Uplift

Schumm (1977) presents evidence that the Kansas Drift Plains are experiencing an uplift of 5 to 10 mm/year or approximately 20 to 30 inches per 100 years. As can be seen from Figure 2.1, tributaries draining this area include Soldier Creek, Delaware River, and Stranger Creek. This general uplift would cause a negligible increase in slope and resulting sediment loads on these tributaries for a period of many decades. Furthermore, the largest tributary which drains the Kansas Drift Plains, the Delaware River, is controlled by Perry Reservoir and any increase in sediment load due to geologic uplift would be trapped in the reservoir. For these reasons tectonic uplift of the Kansas Drift Plains is not considered an important geomorphic process on the Kansas River in an engineering time frame.

IV. QUANTITATIVE GEOMORPHIC ANALYSIS

4.1 Hydraulic Analysis

Hydraulic analysis for the Kansas River was performed using the COE HEC-2 backwater profile program. Hydraulic analysis of the system is necessary in order to define the sediment transport characteristics along the river. For this analysis, the system was broken into three parts:

1. The mouth to Johnson County weir (R.M. 15).
2. Johnson County weir to Bowersock Dam (R.M. 51.8).
3. Bowersock Dam to Fort Riley (R.M. 168.9).

Johnson County weir and Bowersock Dam act as hydraulic controls; hydraulic conditions up and downstream of the structures are independent because the flow over the structures passes through critical depth at all but relatively high discharges. Johnson County weir drowns out (ceases to act as a hydraulic control) at about 40,000 cfs. Bowersock Dam drowns out at about 80,000 cfs. Additionally, the hydraulics of the reach below Johnson County weir are primarily controlled by stage in the Missouri River rather than discharge in the Kansas River.

Cross sections used for the analysis were primarily from the 1977 cross-sectional survey for the lower 51 miles (below Bowersock Dam) supplemented by the 1983 cross sections where appropiate. Above Bowersock Dam, cross sections from the 1965 flood study (surveyed in 1962) were used. Some scattered sections from various surveys dating 1979-1983 existed in this upper reach and were used to check the adequacy of the 1962 sections wherever possible. It was found that very little change had occurred at these locations (see Appendix C). Therefore, wherever appropriate, these various sections were used to supplement the 1962 sections. Additionally, because of the relatively wide spacing of the upstream sections (about 4 to 5 miles), it was found necessary to interpolate sections in places. This was accomplished by a comparison of up and downstream sections and careful observations of available maps and aerial photography. Table 4.1 lists all the sections used and the date of their survey. Up-to-date bridge sections were not generally available. Where they were used, the normal bridge routine was used to model

Table 4.1. Cross Sections Used for Hydraulic Analysis.

Cross Section No. (Corresponds to R.M.)	Year Surveyed	Cross Section No. (Corresponds to R.M.)	Year Surveyed
0.04	1977	23.70	1977
0.30	1977	24.29	1977
0.69	1977	24.85	1977
1.09	1977	25.38	1977
1.68	1977	26.00	1977
2.51	1977	26.91	1977
3.10	1976	27.44	1977
3.73	1976	27.78	1977
4.12	1976	28.23	1977
4.69	1976	28.96	1977
5.20	1976	29.00	1983
5.59	1977	29.72	1977
5.95	1977	30.19	1977
6.13	1977	30.75	1977
6.68	1977	31.04	1977
7.32	1977	31.10	1983
7.72	1977	36.60	1962
8.57	1977	40.50	1983
9.12	1977	41.40	1983
9.51	1977	44.80	1983
9.82	1977	48.40	1983
10.26	1977	50.20	1976
10.77	1977	50.80	1976
11.49	1977	51.3	1976
12.20	1977	51.8	1983
12.58	1977	53.1	1962
13.00	1977	54.9	1962
13.68	1977	55.1	1978
14.19	1977	55.3	1978
14.83	1977	55.6	1978
15.00	1983	60.3	1962
15.91	1977	61.4	1979
16.36	1977	62.5	1979
17.06	1977	63.8	1979
17.55	1977	63.9	1979
17.94	1977	64.9	1979
18.46	1977	66.2	1979
19.08	1977	67.4	1979
19.74	1977	68.2	1962
20.17	1977	68.6	1979
20.56	1977	75.4	1962
21.00	1977	83.0	1982
21.64	1977	83.66	1982
22.04	1977	84.07	1982
22.68	1977	84.42	1982
23.17	1977	84.49	1982

Table 4.1. (Continued)

Cross Section No. (Corresponds to R.M.)	Year Surveyed
85.68	1982
86.06	1982
86.63	1983
86.72	1983
86.83	1983
86.95	1983
87.16	1983
87.68	1983
88.12	1983
88.70	1983
92.6	1962
97.1	1962
101.1	1962
106.1	1962
106.2	1979
106.8	1979
106.9	1979
107.0	1979
107.7	1979
109.0	-- *
110.5	-- *
111.6	1962
114.6	1979
115.4	1962
115.6	1979
116.7	-- *
117.7	1979
118.0	1979
118.6	1979
119.3	1962
123.8	1962
129.9	1962
131.6	1979
132.4	1979
133.8	1979
134.1	1979
135.4	1962
143.1	1962
151.1	1962
155.6	-- *
155.7	-- *
155.8	1962
162.1	1962
168.9	1962

*Interpolated

flow through the bridge. This was considered adequate because of the high bridge deck elevations encountered.

4.1.1 Calibration and Flow Resistance

A considerable amount of calibration information was available. This consisted of various water surface profile surveys and gauging station stage discharge relations. Water surface profile surveys ranged from 1,000 to 40,000 cfs with most between 1,000 and 2,000 cfs. It was found that in order to match the surveyed profiles and the stage at the gauging stations, a Manning's n of 0.030 for discharges below 20,000 cfs and 0.034 for discharges greater than 20,000 cfs was required. Generally, channel resistance decreases with discharge; however, if the bed form of the river is dunes and d_{50} of the bed material is greater than 0.3 mm, channel resistance will increase with an increase in depth (i.e., discharge) (Simons and Richardson, 1966). Stream power calculations and field observations indicate that this is probably the case on the Kansas River. Therefore, it is not unreasonable for the channel resistance of the Kansas River to increase with discharge. It should be noted that the resistance does not instantaneously jump from .030 to .034 at a discharge of 20,000 cfs. In reality the resistance gradually increases with discharge, however in light of the available data it was considered adequate for HEC-2 modeling purposes to use only two distinct values of channel resistance.

For the reach from Johnson County weir to Bowersock Dam, critical depth was assumed at the weir for discharges less than about 40,000 cfs. Above 40,000 cfs, the slope - area (normal depth) method was used to calculate the water surface elevation at the weir. At Bowersock Dam, the broad crested weir equation with a discharge coefficient of 3.3 was used to estimate the water surface elevation.

4.1.2 Hydraulic Modeling of the Lower Fifteen Miles

Because of the backwater effect of the Missouri River, somewhat more effort was required to define the hydraulic conditions in the lower reach of the Kansas River. In order to determine the extent of the backwater effect, HEC-2 runs were made starting at normal depth and at several reported stages on the Missouri River for a Kansas River discharge of 9,600 cfs. Results of this analysis are plotted in Figure 4.1. As shown by the figure, at high

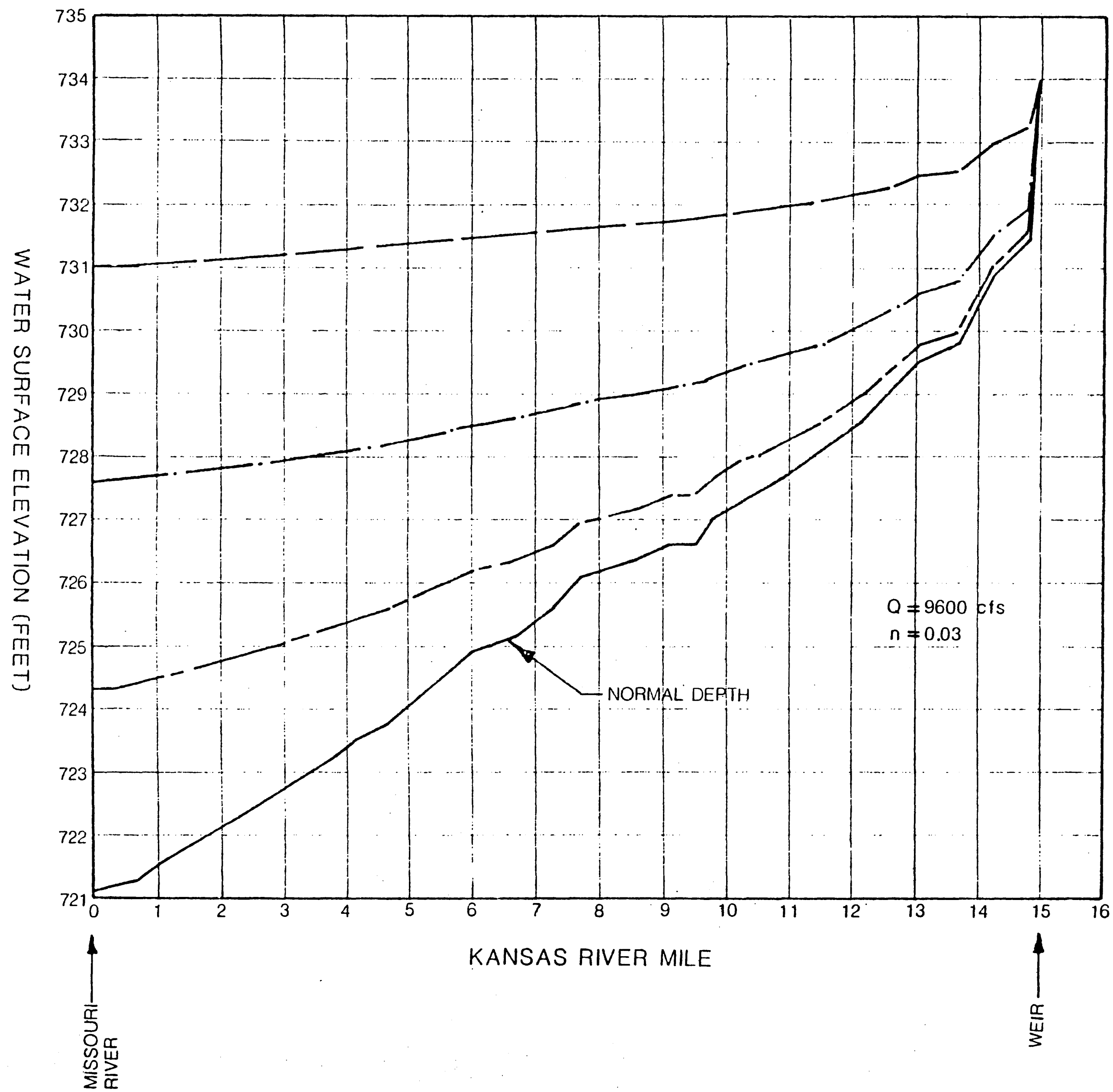


Figure 4.1. Water surface profiles at 9,600 cfs for different stages on the Missouri River.

stages on the Missouri River, backwater effects extend clear to Johnson County weir.

4.2 Refinement Of Reaches

For quantitative analysis and modeling purposes, the selection of reaches should be dictated by the following criteria:

1. Bed material size distribution should be relatively uniform within a given reach.
2. Tributaries should enter at the upstream end of reaches for proper distribution of sediment through the reach and to keep discharge as uniform as possible within a reach.
3. Reaches should terminate at controls. For sediment modeling purposes these controls will be isolated as independent stable reaches.
4. A given reach should have relatively uniform hydraulic and geomorphic conditions, i.e., velocity, depth, topwidth, and slope.
5. Areas of special interest, such as intense gravel mining, should be isolated as a separate reach taking into account the above four factors.

After careful consideration of these factors, the reaches shown in Figure 4.2 were selected. Also shown in the figure are the cross section numbers and the qualitative reaches.

4.3 Calibration of Sediment Transport Relations

Sediment transported by a river can be broadly categorized as either wash load or bed material load. Wash load in a sand bed stream such as the Kansas River is that portion of the sediment load which is composed of fine silts and clays which appear only in limited quantities in the channel bed and which do not settle easily. The source of wash load size particles is primarily the upstream watershed. The concentration of these particles varies greatly for any given discharge depending on watershed and climatic conditions. Bed material load is composed of those particles greater than wash load size. In the Kansas River, bed material load is composed almost exclusively of sand. Bed material load can be further subdivided into bed load and suspended bed material load. Bed load is that portion of the bed material load which moves in a thin layer adjacent to the river bed, while suspended bed material load is that portion of the bed material load moving in suspension.

Qualitative Reach	Section No. (Corresponds to River Miles)	Reach No.	Features
	0.04		
	0.30		Lewis and Clark Viaduct Bridge
	0.69		
	1.09		Central Avenue Bridge
	1.68		
	2.51		
	3.10		
	3.73		
	4.12		
	4.69		
	5.20		
	5.59		
	5.95	15	Kansas Avenue Bridge R.M. 5.9
	6.13		
1	6.68		
	7.32		
	7.72		
	8.57		
	9.12		
	9.51		Turner Bridge R.M. 9.4
	9.80		
	10.26		
	10.77		
	11.50		
	12.20	14	
	12.58		Rock Outcropping - Heavily Armored Bed
	13.00		
2	13.68	13	
	14.19		
	14.83		
	15.00	12	Johnson County Weir
	15.91		
	16.36		
	17.10		
	17.55		
	17.94		
3	18.46		
	19.08		
	19.74		
	20.17	11	Bonner Springs Bridge R.M. 20.2
	20.56		
	21.00		
	21.60		
	22.00		
4	22.70		
	23.17		

Figure 4.2. Schematic representation of the Kansas River with reach definitions.

Qualitative Reach	Section No. (Corresponds to River Miles)	Reach No.	Features
	23.70		
	24.30		
	24.85		
	25.38		
	26.00		
	26.90		
	27.44		
	28.23		
	28.96		
	29.00	10	
4	29.70		
	30.19		
	30.75		
	31.04		Desoto Bridge
	31.10		
	36.60		Stranger Creek Confluence R.M. 34.8
	40.50		
	41.40		
	44.80		Wakarusa River Confluence R.M. 41.6
	48.40		
	50.20	9	
	50.80		
	51.3		
	51.8	8	Bowersock Mills Dam
	53.1		
	54.9		
	55.1		
	55.3		
	55.6		
	60.3		
	61.4		
5	62.5	7	
	63.8		
	63.9		
	64.9		Delaware River Confluence R.M. 64.5
	66.2		
	67.4		
	68.2	6	
	68.6		
	75.4		Soldier Creek R.M. 80.6
	83.0		Sardou Avenue Bridge
	83.66		
6	84.07	5	
	84.42		Topeka Avenue Bridge

Figure 4.2 (continued). Schematic representation of the Kansas River with reach definitions.

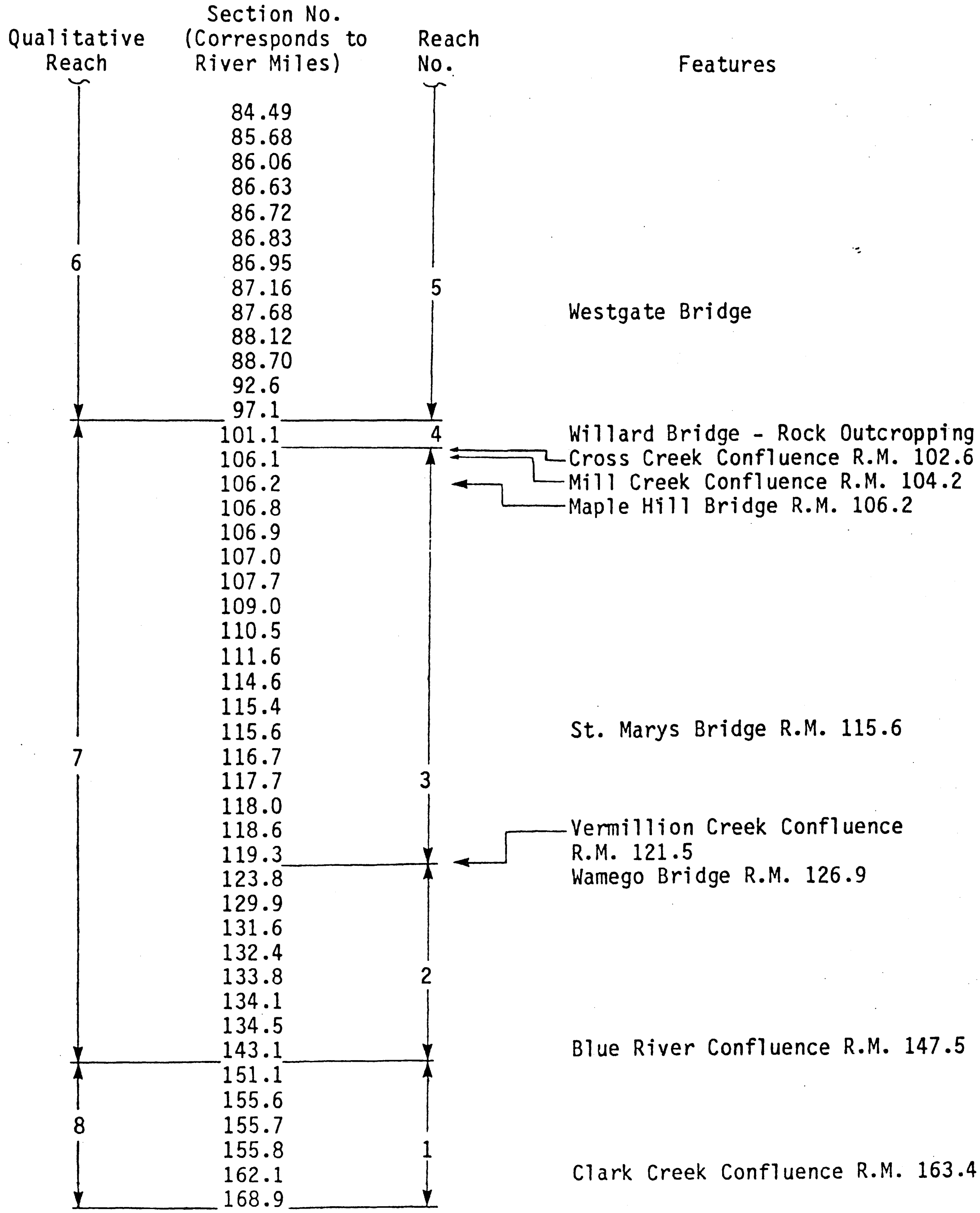


Figure 4.2 (continued). Schematic representation of the Kansas River with reach definitions.

Suspended sediment samplers measure both suspended bed material and wash load, but generally miss the lowest 0.3 feet of flow and, consequently, miss the bed load. The total material moving in this unmeasured zone is generally around 10 to 20 percent of the total bed material load for a sand bed stream. Considerable suspended sediment data for the Kansas River was available both from the COE and the United States Geologic Survey (USGS). The COE samples and those USGS samples for which gradation analysis had been performed were analyzed in order to determine percentages of clay, silt and sand. Unfortunately, no bed load measurements were available.

Wash load may have a considerable impact on channel geomorphology over a very long period of time, but its impact over a short time period is usually limited. Bed material load is an immediate dominant influence on the present Kansas River plan form and channel geometry. For this reason, the following discussion is limited to the bed material or sand load.

Bed material transport relations were developed at the following four locations along the Kansas River:

Fort Riley	River Mile 168.9
Wamego	River Mile 126.9
Lecompton	River Mile 63.8
Desoto	River Mile 31.0

At each station, suspended-sediment samples have been taken by a COE observer on a near daily basis since at least March 1978. These data, as published by the COE, report water discharge, total measured sediment concentrations (ppm), and measured sand concentrations (ppm). The corresponding annual total measured loads and annual total measured sand loads are also reported. These data correspond to the sediment moving in the measured zone only. They do not account for the sediment moving within 0.3 feet of the channel bottom (i.e., the unmeasured zone).

The USGS maintains suspended sediment sampling stations at three sites on the Kansas River - Wamego, Lecompton and Desoto. The USGS takes suspended sediment samples on a less frequent basis than does the COE. The USGS samples typically are depth integrated (DI) composites from several verticals across the stream. At each of these three stations, the USGS reports the size distribution of the suspended sediment samples from approximately two to ten times per year. The USGS does not compute annual sand loads from their data.

At the three common sampling stations (Wamego, Lecompton, and Desoto), data from both agencies was compared. At Lecompton and Desoto, the COE and the USGS data were in close agreement. At Wamego, however, the COE data consistently reported a much higher sand load. After discussion with COE officials, it was agreed that the COE data at Wamego would not be used since it indicated an unusually high sand load concentration compared to other stations. If mean annual bed material loads are calculated for all stations utilizing the COE data at Wamego, and a simple continuity check is made between stations, unreasonable values of channel aggradation and degradation as compared to historical data are indicated. Therefore, the sediment transport relations were based on COE data at Fort Riley, USGS data at Wamego, and both USGS and COE data at Lecompton and Desoto.

Both daily suspended sediment samples and annual sand loads were used to develop the sediment transport relations. A least-squares regression analysis was performed on the measured sand discharge versus river discharge data to obtain regression equations of the form:

$$Q_{sand} \text{ Measured} = aQ^b$$

These regression equations were then applied to the daily flow records to obtain annual measured sand loads. The regression equations were calibrated by adjusting the "a" coefficient so that the annual measured sand loads as predicted by the regression equations matched the observed measured annual sand loads.

These calibrated equations were then adjusted to include the unmeasured zone using a procedure involving the Meyer-Peter, Muller bed load equation and Einstein integration for suspended load resulting in a second set of regression equations of the form:

$$Q_{sand} \text{ Total} = aQ^b$$

This second set of equations was based on the previously calibrated regression formulas for measured sand load, plus the calculated sediment load in the unmeasured zone.

Because the Kansas River is a sand bed channel with very little armoring at and above the gauging stations for which these relations were developed, these relations reflect the bed material transport capacity of the river.

To further verify the calibration of the transport relations, a simple sediment continuity analysis was performed. This analysis consisted of estimating mean annual tributary bed material discharge based on information in Table 3.13, drainage areas, and physiography. The average annual bed material load at each station was then calculated using the derived sediment transport relations and a discretized approximation of the flow duration curves (Figures 3.30 to 3.33). Details of the calibration procedure are given in Appendix E.

Figure 4.3 is a schematic diagram of the Kansas River system. Knowing tributary inflows and transport capacity at the gauging stations, the average aggradation/degradation response of the system can be determined. The results of this initial analysis indicated that for the natural condition (no reservoirs or sand and gravel mining) the system degrades at a rate of about 1.5 feet every 10 years. Examination of stage-discharge records (Figures 3.24 to 3.26) historic cross sections, and thalweg data (Appendix C and Figures 3.27 and 3.28, respectively) lend little credence to this result. Therefore it was felt that adjustment of the transport relations was necessary. This adjustment was made based upon the following four premises:

1. From the historical data, it is probable that the Kansas River, before reservoir closure and in areas of no dredging, was relatively stable with respect to aggradation and degradation of the channel bed. Therefore, the assumption that in a pristine condition the Kansas River would be in equilibrium was made. This simplifies the modeling in that it establishes a baseline condition from which the relative effects of reservoir operation and dredging may be more clearly evaluated. In addition, as discussed in the next chapter, model verification was quite good using this assumption.

2. The transport relation at Wamego was the most representative of the natural transport capacity of all the derived relations due to its relative isolation from (distance from) reservoirs and dredging activities. Therefore, this relation was kept intact.

3. Since the Fort Riley transport relation was based upon the COE observer samples with no other data available for further verification, it was felt that the transport relation at this location could be adjusted the most.

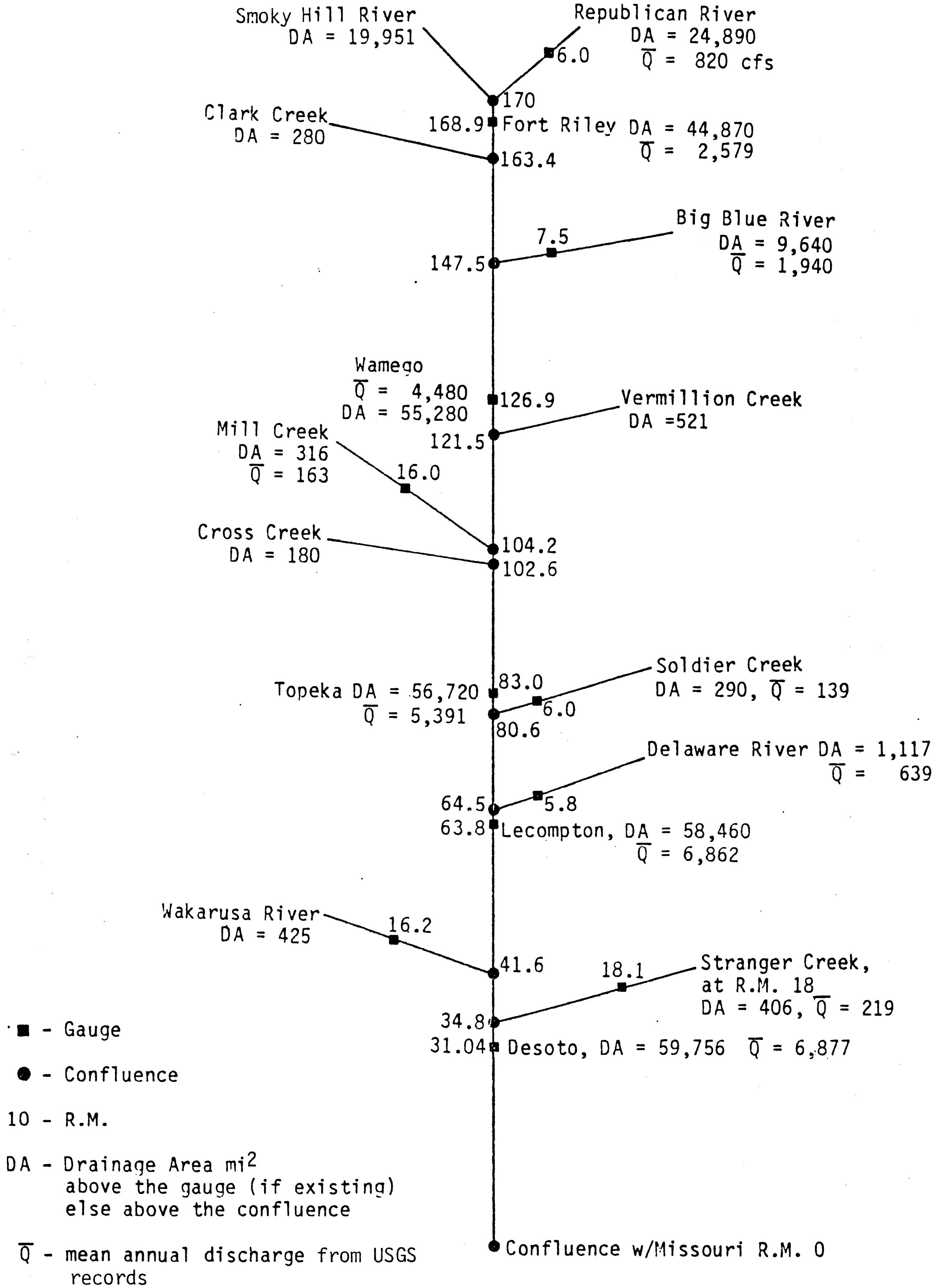


Figure 4.3. Schematic representation of the Kansas River.

4. Transport capacities of tributaries were estimated based upon measured inflows to existing reservoirs where appropriate, and upon the drainage area and inferences obtained from their drainage basin physiography.

It was found that in order to balance the system, i.e., to create an equilibrium natural condition, the initial estimated tributary inflows were increased, the transport capacity at Fort Riley was increased, the capacity at Wamego was left unchanged, the capacity at Lecompton was reduced, and the capacity at Desoto was reduced somewhat. This analysis was based upon 1935 to 1974 flow duration curves without reservoirs.

In order to determine the reasonableness of these corrections, a statistical analysis was performed on the coefficients of the original regression relations. It was found that within 95 percent confidence interval limits, the coefficients of the original regression relations could be adjusted up or down by a factor of 3 to 4, depending on the station. Within the 50 percent confidence interval the coefficients could still be adjusted up or down by a factor of about 1.5 for each station. Since the mean annual bed material load at a station is directly proportional to the coefficient of the transport relation, this means that there is a 50 percent chance that the actual bed material load moving past the gauging stations is over 1.5 times higher or over 1.5 times lower than the bed material load as predicted by the derived transport relations. Or there is a 5 percent chance that the actual bed material load is 3 to 4 times higher or 3 to 4 times lower than that predicted by the regression relations. No determination of the confidence limits of the derived exponent of the transport relations was made. If consideration of the exponent confidence limits is given, additional adjustment of the transport relationships can be supported.

This uncertainty is a consequence of the large amount of scatter in the collected data. Because of this high degree of uncertainty in the coefficients of the derived transport relations and the previously listed four factors, the adjustments to the derived transport relations in order to balance the system were considered reasonable.

The final adjusted transport relations are:

Fort Riley	$Q_s = 1.21 * 10^{-5} Q^{1.28}$ for $Q \leq 20{,}000$ cfs
	$Q_s = 4.58 * 10^{-7} Q^{1.61}$ for $Q > 20{,}000$ cfs
Wamego	$Q_s = 5.10 * 10^{-8} Q^{1.75}$ for $Q \leq 22{,}000$ cfs
	$Q_s = 1.26 * 10^{-9} Q^{2.12}$ for $Q > 22{,}000$ cfs
Lecompton	$Q_s = 3.86 * 10^{-9} Q^{1.97}$ for $Q \leq 38{,}000$ cfs
	$Q_s = 3.24 * 10^{-10} Q^{2.21}$ for $Q > 38{,}000$ cfs
Desoto	$Q_s = 4.35 * 10^{-8} Q^{1.74}$ for $Q \leq 28{,}000$ cfs
	$Q_s = 2.23 * 10^{-9} Q^{2.03}$ for $Q > 28{,}000$ cfs

where Q_s is total bed material transport in cfs, and Q is discharge in cfs.

Table 4.2 gives the adjusted tributary bed material loads for the natural condition. The effects of federal reservoirs and dredging on the aggradation/degradation characteristics of the river will be examined in the next chapter.

It should be noted that some modifications to the present data collection system might make the collected data more compatible with this form of analysis. The present data collection procedure is to take depth-integrated (DI) suspended sediment samples on a near daily basis at a single vertical in a cross section. An alternative program would involve taking less frequent composite DI samples, at several verticals in the cross section, along with measurements of bed load. Actual measurements, if possible, of bed load would provide additional calibration data for checking the bed load estimates.

4.4 Incipient Motion Analysis

The maximum size sediment particle that can be moved by a given discharge is referred to as the incipient size. Shields' parameter relates the incipient size to shear stress in the following manner:

$$D_s = \frac{\tau}{F_*(\gamma_s - \gamma)} \qquad (1)$$

Table 4.2. Estimated Average Annual Bed Material Loads for Kansas River Tributaries (Natural Conditions).

Tributary	Bed Material Load (million ft^3)*
Smoky Hill River	8.39
Republican River	3.91
Clark Creek	0.162
Big Blue River	5.40
Vermillion Creek	0.296
Mill Creek	0.221
Cross Creek	0.243
Soldier Creek	0.353
Delaware River	1.38
Wakarusa River	0.541
Stranger Creek	0.513

*Unbulked

where D_s is the incipient size, τ is shear stress, $F*$ is Shields' parameter, γ_s is the specific weight of the sediment particles (165.4 lbs/ft^3), γ is the specific weight of water. Shields' parameter ranges from approximately 0.030 to 0.060 and is generally assumed equal to 0.047 for sand bed streams. Shear stress can be calculated from:

$$\tau = \frac{1}{8} \rho \ f \ V^2 \tag{2}$$

where ρ is the density of water, f is the Darcy-Wiesbach friction factor, and V is average channel velocity. By Manning's equation, Equation 2, the wide channel approximation, and the fact that $\tau = \gamma RS$ where τ is bed shear stress, R is hydraulic radius, and S is energy slope; the following expression for f can be drived:

$$f = 8 \frac{\gamma}{\rho} \frac{n^2}{1.49^2} \frac{1}{D^{1/3}} \tag{3}$$

where n is the particle resistance only, and D is hydraulic depth. Manning's n for particle resistance only can be calculated from Strickler's relationship:

$$n = \frac{{D_{50}}^{1/6}}{31.3} \tag{4}$$

where D_{50} is the size of which 50 percent of the bed material is finer than in feet.

An incipient motion analysis based on Shield's criteria yields several important results. First, it can be used to evaluate the adequacy of a control in armored reaches. Additionally, when combined with the changes in flow duration, it can indicate the effect of federal reservoir operation on the amount of coarse material being transported by the system.

The most significant armored areas occur at R.M. 12.2 and R.M. 21-22. Figure 4.4 is a plot of incipient size versus discharge for these areas. As can be seen from the figure, a discharge of 350,000 cfs moves material approximately 40 mm in diameter in both these areas. From field observations it appears that at R.M. 12.2 the median size (D_{50}) of the bed armor layer is

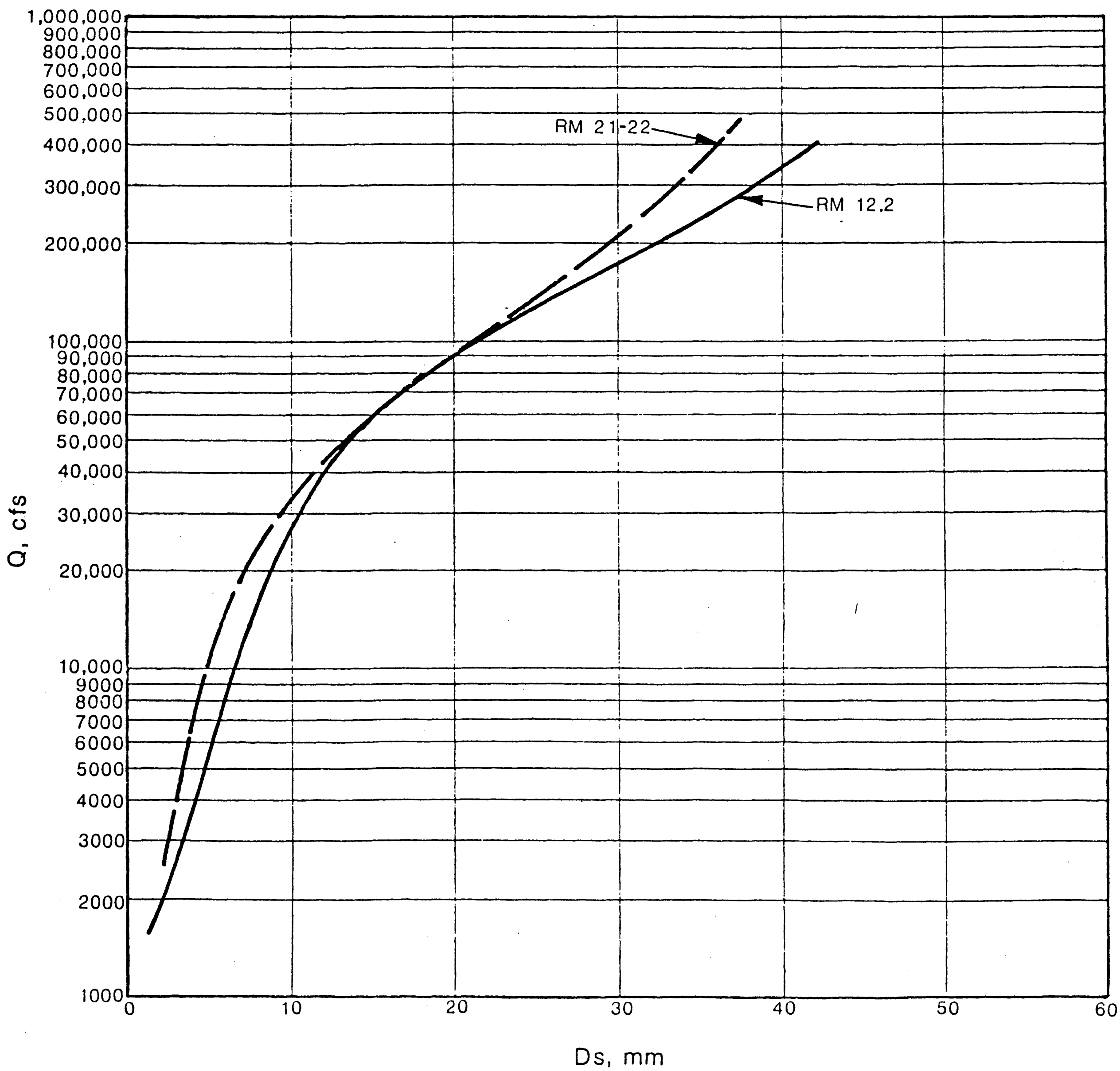


Figure 4.4. Incipient size (D_s) versus discharge (Q) for armored areas.

about 150 mm (6 inches), and at R.M. 21-22 it is about 76 mm (3 inches). Therefore, based on this analysis alone, it would be expected that the armor layer at both locations would be stable for even very large floods. This is probably true for the control at R.M. 12.2; however, at R.M. 21-22 the armor layer is relatively thin and is underlain by uniform medium sand. This layer will probably be undermined and disrupted by moderate (around 60,000 to 100,000 cfs) discharges. Some evidence of this undermining effect has been reported by COE personnel.

Figure 4.5 is a plot of the incipient size versus discharge for reaches 10 and 11. Reach 11 is an area of intensive dredging between the Johnson County weir and Bonner Springs. As can be seen from the figure, the incipient size in this reach for a given discharge is considerably smaller than in Reach 10 (which is fairly representative of the rest of the Kansas River). This is due to the effect on the hydraulics of Reach 11 caused by dredge pits and backwater from the Johnson County weir.

Reach 10 is the supply reach for Reach 11 and, consequently, to the sand dredges. The incipient motion analysis can be combined with the flow duration curve at Desoto (Figure 3.30) to determine the effect of federal reservoirs on the size of sediments which may be transported to the dredges. This is illustrated graphically by Figure 4.6. From the figure it can be seen that the bolstering of intermediate flows due to reservoir operation has increased the probability of occurrence of flows which can transport material from 1.5 to 4.5 mm in diameter. For example, the probability that flows which will move 2 mm-size material will occur has been increased from 10 percent or approximately 40 days per year to 13 percent or approximately 50 days per year. Sediments of 1.5 to 4.5 mm in diameter are considered coarse sand to very fine gravel and are relatively important to the dredgers.

The occurrence of large flows which can transport material larger than 4.5 mm has been reduced by the operation of federal reservoirs. For instance, the probability of flows that will transport 6 mm diameter material has been reduced from 0.7 percent to 0.15 percent or from approximately 2½ days per year to ½ day per year.

It can be concluded that the material being supplied to Reach 11 (area of intense dredging) probably contains a considerably less percentage of material greater than 4.5 mm (very fine gravel) and a somewhat higher percentage of material from 1.5 to 4.5 mm (coarse sand to very fine gravel), as a consequence of reservoir operation. In addition, as discussed later in this

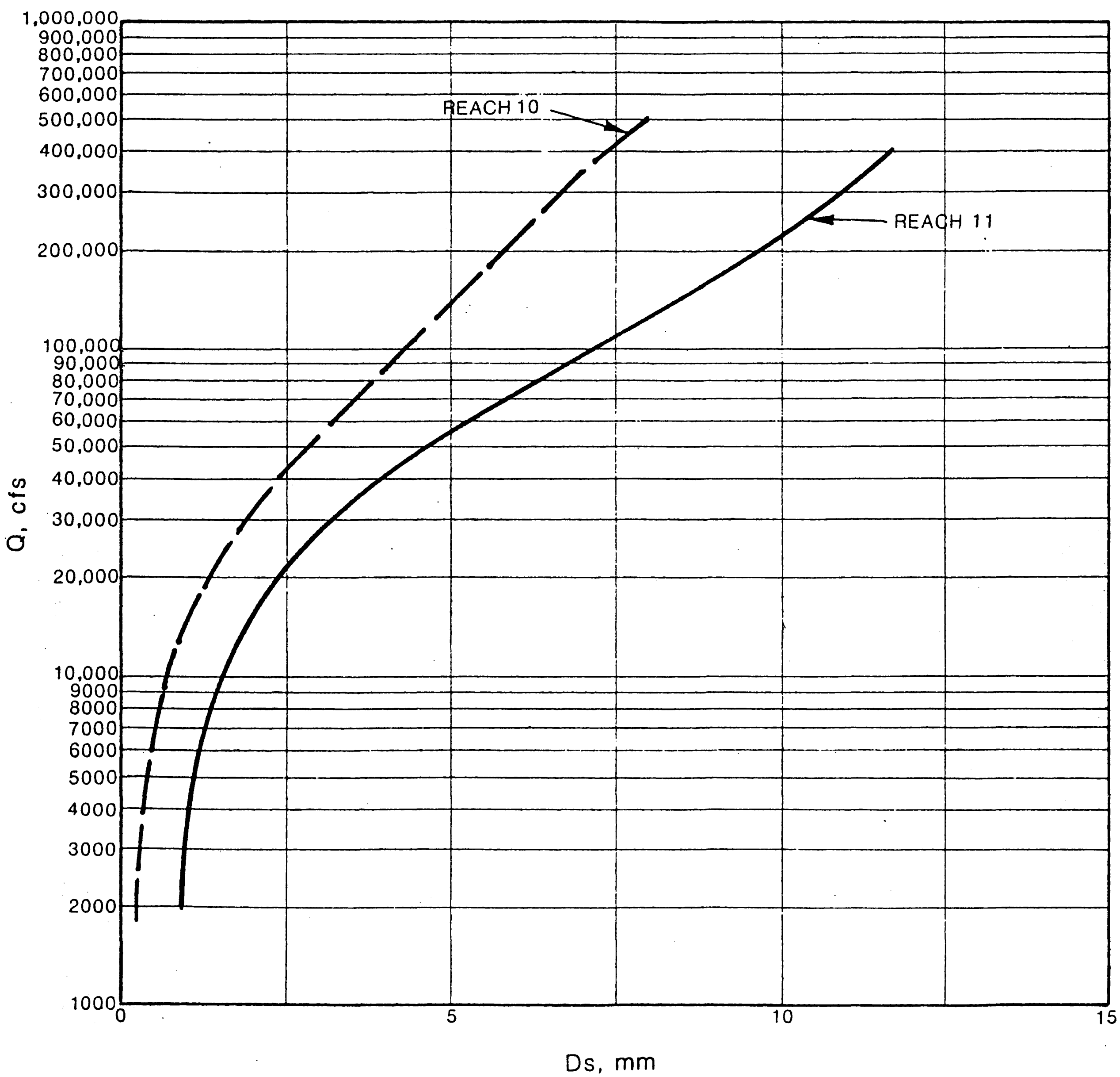


Figure 4.5. Incipient size (D_s) versus discharge (Q) for Reach 10 and Reach 11.

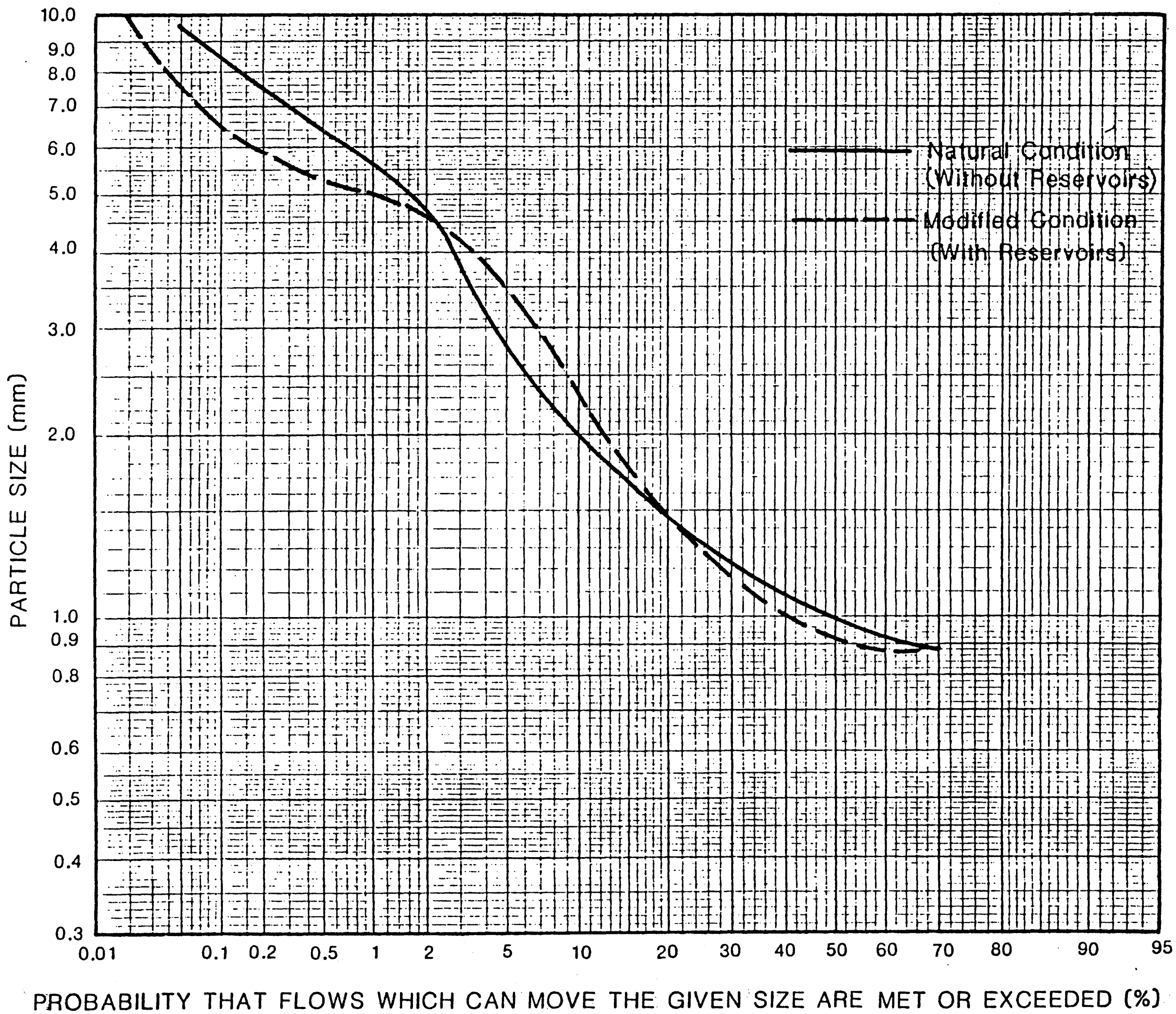


Figure 4.6. Particle size versus probability that flows which can move the given size are met or exceeded for Reach 10.

chapter, the reduction in peak flows has reduced the total quantity of bed material being supplied to Reach 11.

Since coarse material is very important to the dredgers, the reservoirs would appear to be having a detrimental effect on dredging operations. Referring to Appendix A, however, reveals that very little material coarser than 4.5 mm exists in the Kansas River bed. The historical bed gradation curves in Appendix A show little or no change in the composition of the bed material since 1956. Since the effects of the reservoirs would be to coarsen the bed material, it seems reasonable to assume that percentages of material greater than 4.5 mm in diameter in the bed were less than or equal to present percentages. Therefore, even though flows which could move this size material were more common prior to reservoir operation, there was very little material of this size for them to move. Material of this size presently being mined by the dredgers is coming from ancient in-stream deposits and is not, nor has it likely been, supplied by the river in historical times.

4.5 Impacts Due to Change in Flow Duration Caused by Federal Reservoirs

4.5.1 Annual Sediment Yield

The flow duration curves (Figures 3.30 to 3.33) when used in combination with the adjusted sediment transport equations, can be used to quantify the effect of the reservoirs on annual bed material yields. Table 4.3 lists average annual sand yields for four stations along the Kansas River for analyses with and without the federal reservoirs. Table 4.3 was developed by using incremental intervals of the flow duration curves. This table shows that operating the reservoirs reduces the average annual sand loads by approximately 20 to 40 percent over the natural (no reservoirs) condition.

4.5.2 Impacts on Bank Stability Due to Changes in Flow Regime

As can be seen from Table 4.3, the reduction in peak flows results in a net reduction in average transport capacity of the system. This could result in less bank erosion on the mainstem of the Kansas River since the average annual water yield is unaffected. On the other hand, 80 percent of the Kansas River watershed is controlled by reservoirs resulting in a large reduction in the supply of sediment to the system. Because of this reduction in supply degradation and bank erosion is happening on the tributaries below the reservoirs as discussed in Chapter III. It appears, however, that the tributaries

Table 4.3. Average Annual Sand Yields Based on Incremental Analysis of Synthesized 1935-1974 Flow Duration Curves.

Location	River Mile	Average Annual Sand Yields in Million Tons per Year: Natural Conditions (without reservoirs)	Average Annual Sand Yields in Million Tons per Year: Modified Conditions (with reservoirs)	Reduction (%)
Fort Riley	168.9	1.57	1.26	20
Wamego	126.9	2.11	1.21	43
Lecompton	63.8	2.36	1.37	42
Desoto	31.0	2.47	1.67	32

have made up their sediment deficits by the time they reach the Kansas River as, in general, very little degradation can be documented for the downstream portions of the tributaries near their confluences with the Kansas River and in the mainstem of the Kansas River downstream of the reservoirs. Eventually, degradation occurring on the tributaries as a result of the supply of sediment being cut off by federal reservoirs will progress downstream into the Kansas River. The length of time required for effects to occur on the Kansas River will be discussed in more detail in Chapter V.

In addition to reducing the peak flows, the reservoirs have had the effect of bolstering the occurrence of the two-thirds to three-quarters bankfull (intermediate) discharges. Land owners along the river have contended that this has caused increased bank erosion. The probability of occurrence of discharges larger than approximately the five percent occurrence flow is reduced by reservoir operation. Therefore, by considering the weighted average sediment transport capacity of flows less than the five percent occurrence flow, some measure of the change in erosive power due to bolstering of these flows by reservoir operation can be determined. If the adjusted sediment transport relations (see Section 4.3) are used to calculate the average annual sand load carried by discharges less than or equal to the 5 percent occurrence flow (see Figures 3.30 to 3.33), then it can be shown (based upon the synthesized hydrology) that the sand load at Wamego carried by these discharges increases from 0.39 to 0.43 million tons per year or 9 percent for the natural and with reservoir conditions, respectively. The corresponding sand loads at Bonner Springs/Desoto increased from 0.54 to 0.60 million tons per year, or 11 percent, for the natural and with reservoirs, respectively. Because intermediate size flows remove material from the toe of the bank, they can cause relatively rapid bank erosion through the process of undermining, leading to bank sloughing. The increase in transport capacity at intermediate discharges probably does result in increased bank erosion due to these flows; however, this may be more than compensated for by a reduction in bank erosion associated with a reduction in peak flows.

Sustained flows of less than bankfull discharge can sometimes result in an increase in unstable banks because they may remove material from the toe of the bank, making it steeper. No data exists to document this process on the Kansas River.

4.5.3 Depth Fluctuation

A major cause of bank instability and consequent erosion is excessive pore pressure within the banks caused by a sudden lowering of stage within the river. Consequently, the magnitude of stage fluctuations on the Kansas River may be an important factor contributing to bank erosion. In order to evaluate the effects of federal reservoir operations on fluctuations in stage on the Kansas River, an analysis of the with-and without-reservoir hydrologic records was made. The daily discharges were converted to stage utilizing the historic stage-discharge relations at each station. Since a drop in stage for which the initial and final stages are both overbank flood levels would have no effect on bank stability, stages corresponding to more than bankfull discharges were excluded from the analysis. Additionally, fluctuations in stages which correspond to discharges too small to entirely fill the channel were considered insignificant with regard to bank stability and were excluded from the analysis. The mean discharge was considered a reasonable estimate of this lower limit. Thus, the results presented in Table 4.4 are for periods when the stage dropped, and the discharges on consecutive days were less than bankfull but more than the mean discharge at that station.

As can be seen from the table, the net effect of reservoir operation on fluctuations in stage is minimal. Therefore, no increase in bank stability can be attributed to this factor.

4.5.4 Summary of Impacts of Federal Reservoirs on Bank Stability

In summary, federal reservoirs have some beneficial and some detrimental effects on bank stability. Beneficial effects include the reduction in average transport capacity and, consequently, erosive power, and reduction in depth fluctuations. Detrimental effects are due to bolstering of the magnitude and duration of intermediate discharges and average transport capacity corresponding to those discharges, and trapping of sediments within the reservoirs. It is impossible to separate and quantify the relative effects of the first three factors without more data. Data acquisition to help resolve this issue would require the establishment of permanent range markers near problem areas. Cross sections or the bank line should be surveyed at these ranges

Table 4.4. Summary of Stage Drop Statistics on the Kansas River for Period of Record 1936-1973 (Synthesized Hydrology) for Less than Bankfull Discharges.

Site	Without Reservoirs				With Reservoirs			
	Average Drop (ft)	Standard Deviation (ft)	Maximum Drop (ft)	Number of Drops	Average Drop (ft)	Standard Deviation (ft)	Maximum Drop (ft)	Number of Drops
Fort Riley	0.6	0.5	3.8	2,343	0.7	0.8	5.2	2,061
Wamego	0.7	0.9	5.4	2,205	0.7	1.1	5.0	2,129
Topeka	0.9	1.2	7.1	2,221	0.8	1.3	7.2	2,276
Lecompton	0.8	1.5	5.7	1,997	0.7	1.5	6.0	2,076
Desoto	0.8	1.6	6.8	2,274	0.7	1.6	5.8	2,333

after each major flood event to determine the extent of bank erosion caused by high flows, and after each period of two-thirds to three-quarters bankfull release from the reservoirs, in order to determine the extent of erosion due to these flows.

Trapping of bed material within reservoirs causes downstream degradation. To date this has only occurred on tributaries, with the possible exception of downstream of Perry Reservoir as discussed in Chapter III. This issue will be addressed in detail in Chapter V.

4.6 Impacts Due to Gravel Dredging

From Table 4.3 it can be seen that the average annual sand load past Desoto is 2.47 million tons per year for the natural condition or 1.67 million tons per year for the with-reservoirs condition. From Table 3.16 it can be seen that sand and gravel dredgers between Bonner Springs and Turner Bridge have extracted an average of 1.97 million tons per year for the period 1952 - 1976. The aggradation/degradation of a reach is given by:

$$\Delta Z = (Sup - Cap - GM) \div (Length * Width) * BF \qquad (5)$$

where ΔZ is the net aggradation/degradation (ft), Sup is the sediment supply (ft^3), Cap is the transport capacity of the reach (ft^3), GM is the extraction of bed material by dredging (ft^3), Length is the length of the reach (ft), Width is the width of the reach (ft), and BF is the bulking factor (equal to 1.7 for a bed material porosity of 0.4). If the transport capacity of the reach between Bonner Springs and Turner Bridge is approximately the same as at Desoto, (i.e., the reach between Bonner Springs and Turner Bridge is in equilibrium so that sediment supply equals capacity) this results in a net sediment deficit of 1.97 million tons per year. This is equal to 40.50 million cubic feet of bulked sediment per year (assuming a porosity of 0.4). For a channel length of 12.5 miles and an average width of 1,000 feet, this results in approximately 15 feet of degradation, which is relatively close to what has been observed. Whether the reach between Bonner Springs and Turner Bridge is in equilibrium for both the reservoir and no reservoir conditions will be examined in detail in the next section.

The reduction in supply of bed material to the Bonner Springs to Turner Bridge area due to reservoir operation is a consequence of a general reduction in transport capacity throughout the system. If the capacity of this reach is reduced proportionately to the supply by the effects of the reservoirs, then the 15 feet of degradation is applicable to both the with reservoir and without reservoir conditions. Since the capacity of a reach does not necessarily change at the same rate as the supply changes due to the hydrologic effects of the reservoirs, some reaches may change from degrading or stable, to aggrading, even though total amounts of bed material moving through the system are 30 to 40 percent less than for the no reservoir condition. Because of this effect, net impacts due to dredging in some areas are less with the reservoirs than without. This will be shown to be the case in the next chapter for R.M. 22 to R.M. 15.

4.6.1 Impact of Dredged Areas on Local Hydraulics

The creation of a dredge hole has the potential to propagate changes in the river both upstream and downstream from the dredged area. In the downstream direction the effect is essentially a clear water release from the dredged area due to trapping of sediments. The clear water release can cause degradation and bank sloughing downstream of the dredge hole in the same manner as the clear water releases from the upstream reservoirs are causing erosion in the outlet channels immediately below the dams. In the upstream direction there exists a potential for a headcut to form due to the local increase in velocity as the water enters the dredged stretch of river. This headcut may advance upstream, resulting in severe degradation and bank sloughing.

The COE (1977) estimated that the average entrapment of sand for dredge pits between Turner Bridge and Desoto was approximately 70 to 80 percent. This figure only considers the suspended sand in the measured zone. If the sand in the unmeasured zone had also been determined, the trap efficiency would have been higher. Calculations using appropriate sediment transport relations indicate that the ratio of total sand transport to measured zone sand transport is approximately 2.00 and 1.20 for discharges of 5,000 and 20,000 cfs, respectively, near Desoto. Assuming that the COE's 70 to 80 percent entrapment figure is valid for the sand in the measured zone, and that 100 percent of the sand in the unmeasured zone is trapped in the dredge holes, the dredge hole's trap efficiency for the total sand transport is approximately 90 percent at 5,000 cfs and about 80 percent at 20,000 cfs.

Generally, as the flow decreases the trap efficiency of the dredge holes increases. Examination of historic thalweg profiles, cross sections, and other data (see Chapter 3) shows little evidence of downstream effects due to dredging. This is due to the fact that the Kansas River below the area of intensive dredging (i.e., below R.M. 9.5) is in a backwater condition from stages on the Missouri River. This causes the average sediment transport capacity to be very small. It is likely that this reach, prior to dredging activities and construction of federal reservoirs, underwent aggradation for the majority of flows and experienced considerable erosion of the deposited sediments during large floods. Presently dredgers intercept the majority of bed material load naturally supplied to the lower 10-mile reach of the Kansas River. Since this reach would normally aggrade due to its backwater condition, no adverse impacts such as severe net degradation are noted. Additionally, since major floods are now controlled by reservoirs, the erosive portion of the cycle of aggradation/degradation in the lower ten miles has been eliminated or severely reduced. Both of these factors tend to mask or compensate for any downstream effects due to dredging. These compensatory effects will be reduced as dredges move upstream and eventually a point will be reached where downstream effects due to trapping of bed material in dredge pits may become more pronounced.

A similar analysis was performed in order to determine the effect on local hydraulics and sediment transport due to the headcut at R.M. 22 to 23. Figure 4.7 is a definitive sketch of this headcut. The channel slopes shown in the figure were estimated from Figure 3.27. As can be seen from the figure, the area around the headcut can be broken into three zones. The upstream zone is a region that has been unimpacted by dredging and serves as the sediment supply to the downstream zones. The actual headcutting zone is considerably steeper than the other two zones. This results in an acceleration of the flow through this zone, resulting in higher velocities and sediment transport rates than upstream of the headcut. Because of the increased transport capacity, bed material is removed from this zone and the headcut progresses upstream. The third zone is relatively flat, deep and slow. This is a consequence of a general lowering of the base level through this zone due to dredging activities. This zone is an area of sediment deposition. The computed velocities and depths for discharges of 6,500, 15,000 and 40,000 cfs are:

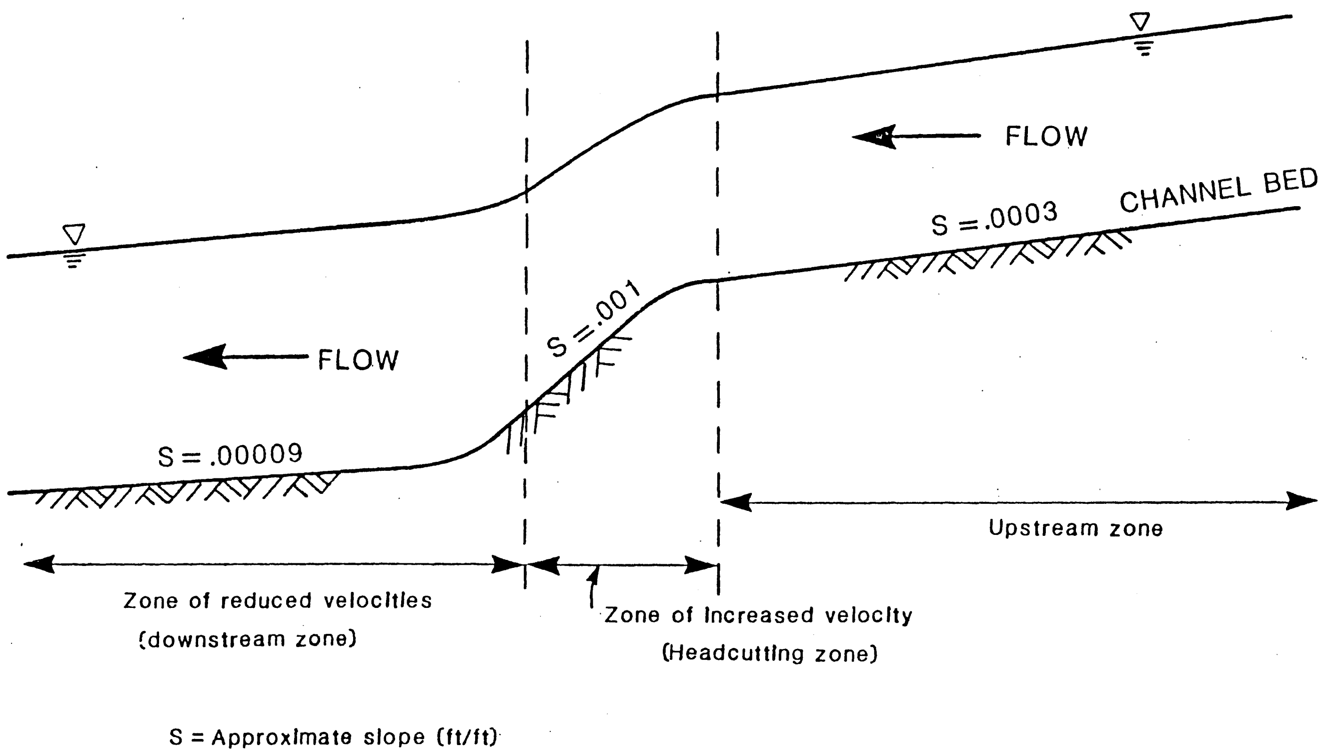


Figure 4.7. Definitive sketch of headcutting area.

Discharge (cfs)		Upstream Zone	Headcut Zone	Downstream Zone
6,500	velocity (fps)	2.1	3.0	1.5
	depth (ft)	3.9	2.7	5.5
15,000	velocity (fps)	2.9	4.2	2.1
	depth (ft)	6.3	4.4	9.1
40,000	velocity (fps)	4.4	6.3	3.0
	depth (ft)	11.4	8.0	16.4

These figures indicate about a 6-fold increase in transport capacity from the upstream zone to the headcut zone and about a 35-fold decrease in transport from the headcut to the downstream zone. This again illustrates the effective trapping nature of the dredge pits, and indicates that rapid erosion will take place in the vicinity of the headcut zone. A simple continuity calculation indicates that the headcut may move upstream as rapidly as 10 miles per year. This calculation does not take into account the fact that unless dredging operations proceed upstream maintaining the present channel depth, then the slope of the headcut zone will decrease as material is eroded at the upstream end of the headcut zone and deposited at the toe of the slope in the depositional zone. This reduction in slope results in a reduction of velocities through this reach and, consequently, the upstream rate of progression of the headcut slows. Based on experience gained by SLA working on other sand-bed channels, it is expected that the actual rate of progression of the headcut will not exceed one mile per year. It should be noted that the region labeled "headcutting zone" in Figure 4.7 will not progress per se upstream; rather, material will be eroded first in the vicinity of the break in slope separating the "headcutting zone" from the "upstream zone." This results in a reduction in the slope of the headcutting zone. It is the break in slope separating the headcutting zone from the upstream zone which actually progresses upstream. As the slope of the headcut reduces or tapers off, the headcut becomes less and less noticeable. It is impossible to determine analytically, but it seems likely that the present headcut is not severe enough and is far enough downstream that it would not endanger Bowersock Dam. However, as dredging operations progress upstream, the headcut will move upstream at roughly the same rate.

chapter, the reduction in peak flows has reduced the total quantity of bed material being supplied to Reach 11.

Since coarse material is very important to the dredgers, the reservoirs would appear to be having a detrimental effect on dredging operations. Referring to Appendix A, however, reveals that very little material coarser than 4.5 mm exists in the Kansas River bed. The historical bed gradation curves in Appendix A show little or no change in the composition of the bed material since 1956. Since the effects of the reservoirs would be to coarsen the bed material, it seems reasonable to assume that percentages of material greater than 4.5 mm in diameter in the bed were less than or equal to present percentages. Therefore, even though flows which could move this size material were more common prior to reservoir operation, there was very little material of this size for them to move. Material of this size presently being mined by the dredgers is coming from ancient in-stream deposits and is not, nor has it likely been, supplied by the river in historical times.

4.5 Impacts Due to Change in Flow Duration Caused by Federal Reservoirs

4.5.1 Annual Sediment Yield

The flow duration curves (Figures 3.30 to 3.33) when used in combination with the adjusted sediment transport equations, can be used to quantify the effect of the reservoirs on annual bed material yields. Table 4.3 lists average annual sand yields for four stations along the Kansas River for analyses with and without the federal reservoirs. Table 4.3 was developed by using incremental intervals of the flow duration curves. This table shows that operating the reservoirs reduces the average annual sand loads by approximately 20 to 40 percent over the natural (no reservoirs) condition.

4.5.2 Impacts on Bank Stability Due to Changes in Flow Regime

As can be seen from Table 4.3, the reduction in peak flows results in a net reduction in average transport capacity of the system. This could result in less bank erosion on the mainstem of the Kansas River since the average annual water yield is unaffected. On the other hand, 80 percent of the Kansas River watershed is controlled by reservoirs resulting in a large reduction in the supply of sediment to the system. Because of this reduction in supply degradation and bank erosion is happening on the tributaries below the reservoirs as discussed in Chapter III. It appears, however, that the tributaries

Table 4.3. Average Annual Sand Yields Based on Incremental Analysis of Synthesized 1935-1974 Flow Duration Curves.

Location	River Mile	Average Annual Sand Yields in Million Tons per Year: Natural Conditions (without reservoirs)	Average Annual Sand Yields in Million Tons per Year: Modified Conditions (with reservoirs)	Reduction (%)
Fort Riley	168.9	1.57	1.26	20
Wamego	126.9	2.11	1.21	43
Lecompton	63.8	2.36	1.37	42
Desoto	31.0	2.47	1.67	32

have made up their sediment deficits by the time they reach the Kansas River as, in general, very little degradation can be documented for the downstream portions of the tributaries near their confluences with the Kansas River and in the mainstem of the Kansas River downstream of the reservoirs. Eventually, degradation occurring on the tributaries as a result of the supply of sediment being cut off by federal reservoirs will progress downstream into the Kansas River. The length of time required for effects to occur on the Kansas River will be discussed in more detail in Chapter V.

In addition to reducing the peak flows, the reservoirs have had the effect of bolstering the occurrence of the two-thirds to three-quarters bankfull (intermediate) discharges. Land owners along the river have contended that this has caused increased bank erosion. The probability of occurrence of discharges larger than approximately the five percent occurrence flow is reduced by reservoir operation. Therefore, by considering the weighted average sediment transport capacity of flows less than the five percent occurrence flow, some measure of the change in erosive power due to bolstering of these flows by reservoir operation can be determined. If the adjusted sediment transport relations (see Section 4.3) are used to calculate the average annual sand load carried by discharges less than or equal to the 5 percent occurrence flow (see Figures 3.30 to 3.33), then it can be shown (based upon the synthesized hydrology) that the sand load at Wamego carried by these discharges increases from 0.39 to 0.43 million tons per year or 9 percent for the natural and with reservoir conditions, respectively. The corresponding sand loads at Bonner Springs/Desoto increased from 0.54 to 0.60 million tons per year, or 11 percent, for the natural and with reservoirs, respectively. Because intermediate size flows remove material from the toe of the bank, they can cause relatively rapid bank erosion through the process of undermining, leading to bank sloughing. The increase in transport capacity at intermediate discharges probably does result in increased bank erosion due to these flows; however, this may be more than compensated for by a reduction in bank erosion associated with a reduction in peak flows.

Sustained flows of less than bankfull discharge can sometimes result in an increase in unstable banks because they may remove material from the toe of the bank, making it steeper. No data exists to document this process on the Kansas River.

4.5.3 Depth Fluctuation

A major cause of bank instability and consequent erosion is excessive pore pressure within the banks caused by a sudden lowering of stage within the river. Consequently, the magnitude of stage fluctuations on the Kansas River may be an important factor contributing to bank erosion. In order to evaluate the effects of federal reservoir operations on fluctuations in stage on the Kansas River, an analysis of the with-and without-reservoir hydrologic records was made. The daily discharges were converted to stage utilizing the historic stage-discharge relations at each station. Since a drop in stage for which the initial and final stages are both overbank flood levels would have no effect on bank stability, stages corresponding to more than bankfull discharges were excluded from the analysis. Additionally, fluctuations in stages which correspond to discharges too small to entirely fill the channel were considered insignificant with regard to bank stability and were excluded from the analysis. The mean discharge was considered a reasonable estimate of this lower limit. Thus, the results presented in Table 4.4 are for periods when the stage dropped, and the discharges on consecutive days were less than bankfull but more than the mean discharge at that station.

As can be seen from the table, the net effect of reservoir operation on fluctuations in stage is minimal. Therefore, no increase in bank stability can be attributed to this factor.

4.5.4 Summary of Impacts of Federal Reservoirs on Bank Stability

In summary, federal reservoirs have some beneficial and some detrimental effects on bank stability. Beneficial effects include the reduction in average transport capacity and, consequently, erosive power, and reduction in depth fluctuations. Detrimental effects are due to bolstering of the magnitude and duration of intermediate discharges and average transport capacity corresponding to those discharges, and trapping of sediments within the reservoirs. It is impossible to separate and quantify the relative effects of the first three factors without more data. Data acquisition to help resolve this issue would require the establishment of permanent range markers near problem areas. Cross sections or the bank line should be surveyed at these ranges

Table 4.4. Summary of Stage Drop Statistics on the Kansas River for Period of Record 1936-1973 (Synthesized Hydrology) for Less than Bankfull Discharges.

Site	Without Reservoirs				With Reservoirs			
	Average Drop (ft)	Standard Deviation (ft)	Maximum Drop (ft)	Number of Drops	Average Drop (ft)	Standard Deviation (ft)	Maximum Drop (ft)	Number of Drops
Fort Riley	0.6	0.5	3.8	2,343	0.7	0.8	5.2	2,061
Wamego	0.7	0.9	5.4	2,205	0.7	1.1	5.0	2,129
Topeka	0.9	1.2	7.1	2,221	0.8	1.3	7.2	2,276
Lecompton	0.8	1.5	5.7	1,997	0.7	1.5	6.0	2,076
Desoto	0.8	1.6	6.8	2,274	0.7	1.6	5.8	2,333

after each major flood event to determine the extent of bank erosion caused by high flows, and after each period of two-thirds to three-quarters bankfull release from the reservoirs, in order to determine the extent of erosion due to these flows.

Trapping of bed material within reservoirs causes downstream degradation. To date this has only occurred on tributaries, with the possible exception of downstream of Perry Reservoir as discussed in Chapter III. This issue will be addressed in detail in Chapter V.

4.6 Impacts Due to Gravel Dredging

From Table 4.3 it can be seen that the average annual sand load past Desoto is 2.47 million tons per year for the natural condition or 1.67 million tons per year for the with-reservoirs condition. From Table 3.16 it can be seen that sand and gravel dredgers between Bonner Springs and Turner Bridge have extracted an average of 1.97 million tons per year for the period 1952 - 1976. The aggradation/degradation of a reach is given by:

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Generally, as the flow decreases the trap efficiency of the dredge holes increases. Examination of historic thalweg profiles, cross sections, and other data (see Chapter 3) shows little evidence of downstream effects due to dredging. This is due to the fact that the Kansas River below the area of intensive dredging (i.e., below R.M. 9.5) is in a backwater condition from stages on the Missouri River. This causes the average sediment transport capacity to be very small. It is likely that this reach, prior to dredging activities and construction of federal reservoirs, underwent aggradation for the majority of flows and experienced considerable erosion of the deposited sediments during large floods. Presently dredgers intercept the majority of bed material load naturally supplied to the lower 10-mile reach of the Kansas River. Since this reach would normally aggrade due to its backwater condition, no adverse impacts such as severe net degradation are noted. Additionally, since major floods are now controlled by reservoirs, the erosive portion of the cycle of aggradation/degradation in the lower ten miles has been eliminated or severely reduced. Both of these factors tend to mask or compensate for any downstream effects due to dredging. These compensatory effects will be reduced as dredges move upstream and eventually a point will be reached where downstream effects due to trapping of bed material in dredge pits may become more pronounced.

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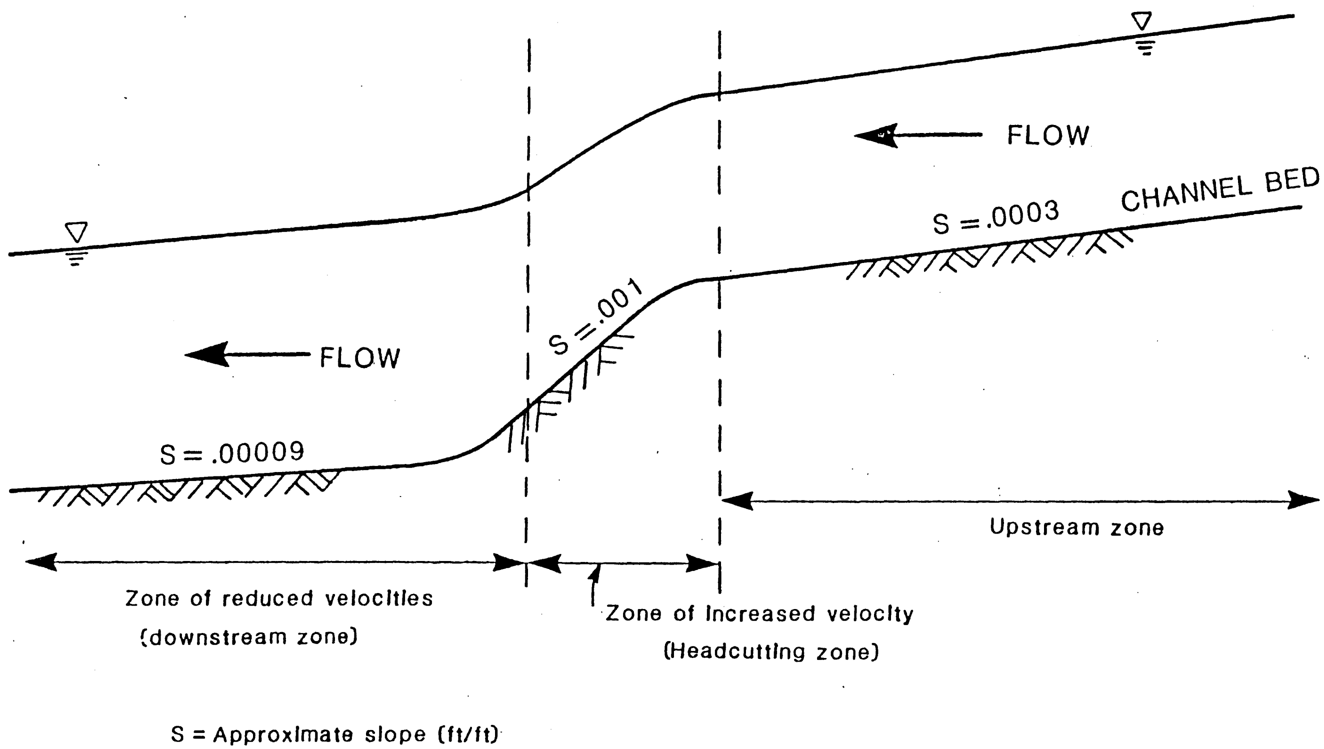

Figure 4.7. Definitive sketch of headcutting area.

Discharge (cfs)		Upstream Zone	Headcut Zone	Downstream Zone
6,500	velocity (fps)	2.1	3.0	1.5
	depth (ft)	3.9	2.7	5.5
15,000	velocity (fps)	2.9	4.2	2.1
	depth (ft)	6.3	4.4	9.1
40,000	velocity (fps)	4.4	6.3	3.0
	depth (ft)	11.4	8.0	16.4

These figures indicate about a 6-fold increase in transport capacity from the upstream zone to the headcut zone and about a 35-fold decrease in transport from the headcut to the downstream zone. This again illustrates the effective trapping nature of the dredge pits, and indicates that rapid erosion will take place in the vicinity of the headcut zone. A simple continuity calculation indicates that the headcut may move upstream as rapidly as 10 miles per year. This calculation does not take into account the fact that unless dredging operations proceed upstream maintaining the present channel depth, then the slope of the headcut zone will decrease as material is eroded at the upstream end of the headcut zone and deposited at the toe of the slope in the depositional zone. This reduction in slope results in a reduction of velocities through this reach and, consequently, the upstream rate of progression of the headcut slows. Based on experience gained by SLA working on other sand-bed channels, it is expected that the actual rate of progression of the headcut will not exceed one mile per year. It should be noted that the region labeled "headcutting zone" in Figure 4.7 will not progress per se upstream; rather, material will be eroded first in the vicinity of the break in slope separating the "headcutting zone" from the "upstream zone." This results in a reduction in the slope of the headcutting zone. It is the break in slope separating the headcutting zone from the upstream zone which actually progresses upstream. As the slope of the headcut reduces or tapers off, the headcut becomes less and less noticeable. It is impossible to determine analytically, but it seems likely that the present headcut is not severe enough and is far enough downstream that it would not endanger Bowersock Dam. However, as dredging operations progress upstream, the headcut will move upstream at roughly the same rate.

4.7 Impacts on the Kansas River Due to Base Level Changes on the Missouri River

As discussed in Chapter III, historical data shows no geomorphological changes which could be attributed to lowering of the base level of the Missouri River. For this reason, further quantification of the impacts due to this factor was not attempted.

4.8 Summary and Conclusions of Quantitative Geomorphic Analysis

The following are general conclusions of the quantitative geomorphic analysis:

1. Three distinct hydraulic controls exist on the Kansas River; they are:

   a. Bowersock Dam which drowns out (ceases to act as a control) at about 80,000 cfs.

   b. Johnson County weir which drowns out at about 40,000 cfs.

   c. Stage on the Missouri River which creates a backwater condition from the confluence to as far upstream as Johnson County weir for some conditions.

2. Sediment transport relationships based strictly upon observed data do not predict observed channel response accurately. Therefore, derived relationships were adjusted to reflect the historical channel response.

3. Armoring at R.M. 12.2 will resist very large floods and, consequently, can be considered a permanent vertical control. Armoring at R.M. 21-22 will not be stable for moderate to large flows.

4. The size distribution of material moving into the area of intense dredging has become finer. Specifically, the amount of material coarser than 4.5 mm in diameter has been curtailed.

4.8.1 Impacts Due to Federal Reservoirs

The impacts due to reservoir operation are as follows:

1. A reduction in peak flows results in a reduction in transport capacity of bed material throughout the system. This results in decreased bank erosion and a reduction in material (especially coarse sizes) being supplied to dredge pits.

2. An increase in the occurrence of intermediate discharges results in an increase in erosive duration (transport capacity) associated with these discharges and, consequently, an increase in bank erosion.

3. No significant effect on depth fluctuations occurs as a result of reservoir operation.

In addition to reducing the average transport capacity of the system, reservoirs have severely limited the supply of sediment. At present, impacts due to this factor are manifested only on tributaries. Eventually these impacts will be imposed on the Kansas River. This will be discussed in more detail in Chapter V.

4.8.2 Impacts Due to Sand and Gravel Dredging

Dredging activities between Turner Bridge and Bonner Springs have historically removed more material than the system can supply. This is partly a consequence of the operation of federal reservoirs, which have reduced the supply of bed material. This reduction in sediment supply is a consequence of a system-wide reduction in transport capacity. Referring to Equation 5 (Section 4.6), it can be seen that if the average transport capacity of a given reach is reduced more than the supply of sediment to that reach, then it may actually undergo aggradation as a result of reservoir operation. This is the case for R.M. 24 to R.M. 15 as is discussed in detail in the next chapter. In this location reservoir operation has mitigated the impact of dredging activities to some extent. The net impacts of dredging on the Kansas River have been degradation, channel widening, and the occurrence of a headcut at R.M. 22-23. The rate of upstream progression of this headcut should not exceed about 1 mile per year. Additionally, dredge pits act as sediment traps and have very high trap efficiencies for sand size materials. Because of the backwater effects of the Missouri River on the lower 10 miles of the Kansas River, and possibly also because of the attenuation of peak flows by reservoir operation, downstream effects due to trapping of sediments in the dredge pits have not been noticeable on the Kansas River. As dredgers move upstream away from the backwater reach, downstream degradation and bank erosion due to interception of the bed material load by dredgers should become more obvious.

The net impact associated with the present headcut is small. The headcut is actually just the transition region from the unimpacted river to the highly impacted dredging area. It is doubtful this headcut could endanger the Bowersock Dam. However, if dredging activity moves upstream, the headcut will also.

V. EROSION AND SEDIMENTATION MODELING

A continuity-based erosion and sedimentation model was developed, calibrated, and applied to the Kansas River. The primary purpose of the model was to refine and supplement the qualitative and quantitative geomorphic analyses. Specifically, the model was designed to help determine the relative impacts of sand and gravel dredging and operation of federal reservoirs on the river.

Because of the backwater effects of the Missouri River on the hydraulic conditions and sediment transport rates in the lower 12 miles of the Kansas River, the erosion and sedimentation response in this reach is dependent upon stage in the Missouri River as well as discharge in the Kansas River. Additionally, as discussed in Chapters III and IV and as evidenced by the historic thalweg profiles very little net geomorphic change has taken place in this reach. Although this reach has experienced considerable fluctuations in thalweg profile, the overall net change has been relatively small. Additionally, there has been very little change in channel alignment in the last 50 years (see page B.1). For these reasons, the lower 12 miles of the Kansas River were not modeled.

5.1 General Methodology

Prior to the execution of the model, the system is divided into reaches as described in Section 4.2. The model determines the net sediment deficit or surplus for each reach. The sediment balance is determined using the following relationship:

$$NSDS_i = SUP_i - CAP_i - DRE_i \qquad (5.1)$$

where $NSDS_i$ is the net sediment deficit or surplus of the ith reach, CAP_i is the bed-material transport capacity of the ith reach, SUP_i is the supply of bed material to the ith reach, and DRE_i is the amount of dredging of sand and gravel taking place within the ith reach. Bed-material transport capacities are determined from relationships of the form:

$$Q_s = a\ Q^b \qquad (5.2)$$

where Q_s is the bed-material transport capacity of the reach, Q is the river discharge, and a and b are regression coefficients. The bed-material supply is equal to the bed-material transport capacity of the adjacent upstream reach plus tributary-sediment inflows. Tributary-sediment inflows are calculated by relationships of the form of Equation 5.2. The relationships used for each reach and tributary and the methods used to develop them are described in the next section.

5.2 Modeling Data

Data input to the continuity model consists of sediment transport relations for the reaches, sediment transport relations for tributaries, maximum available volumes of sediment in the reaches of the Kansas River and its tributaries, daily discharges in the Kansas River and its tributaries, and the amount of sand and gravel dredging in the Kansas River.

5.2.1 Sediment Transport Relations for Reaches

The calibration and derivation of bed-material transport relations at Fort Riley, Wamego, Lecompton, and Desoto were discussed in Section 4.3. These four transport relations were assigned to the modeling reaches based upon:

1. the physical proximity of the given reach to the locations for which the transport relations were calibrated, and
2. similarity between the hydraulics of the reach and the hydraulic conditions at the calibration sites.

Table 5.1 lists the reaches and their assigned transport relations. In several instances hydraulic similarity was deemed more important than physical proximity for the assignment of transport relations to reaches. This explains why the Lecompton transport relation was used for Reaches 11 and 13. If average hydraulics for the reaches are compared to the hydraulics at the calibration sites, Reaches 11 and 13 are most similar to the Lecompton site. Velocities are slower and channel widths greater at Lecompton than at the other three calibration sites. Reaches 11 and 13 experience slow velocities and large widths and depths in relation to the other reaches because of the presence of numerous dredge pits. While it admittedly would have been more desirable to develop a separate transport relation for the dredged areas, there was no calibration data; furthermore, model verification (section 5.3) shows the Lecompton relation to reasonably model Reaches 11 and 13.

Table 5.1. Sediment Transport Relations for Reaches.

Reach No.	River Miles	Sediment Transport Relation
1	170.4 - 147.5	$Q_s = 1.21*10^{-5}\ Q^{1.28}$ for $Q \le 20{,}000$ cfs $Q_s = 4.58*10^{-7}\ Q^{1.61}$ for $Q \ge 20{,}000$ cfs
2	147.5 - 121.5	$Q_s = 5.10*10^{-8}\ Q^{1.75}$ for $Q \le 22{,}000$ cfs $Q_s = 1.26*10^{-9}\ Q^{2.12}$ for $Q \ge 22{,}000$ cfs
3	121.5 - 101.2	$Q_s = 5.10*10^{-8}\ Q^{1.75}$ for $Q \le 22{,}000$ cfs $Q_s = 1.26*10^{-9}\ Q^{2.12}$ for $Q \ge 22{,}000$ cfs
4	101.2 - 101.0	Grade Control
5	101.0 - 80.6	$Q_s = 3.86*10^{-9}\ Q^{1.97}$ for $Q \le 38{,}000$ cfs $Q_s = 3.24*10^{-10}\ Q^{2.21}$ for $Q \ge 38{,}000$ cfs
6	80.6 - 64.5	$Q_s = 3.86*10^{-9}\ Q^{1.97}$ for $Q \le 38{,}000$ cfs $Q_s = 3.24*10^{-10}\ Q^{2.21}$ for $Q \ge 38{,}000$ cfs
7	64.5 - 51.9	$Q_s = 3.86*10^{-9}\ Q^{1.97}$ for $Q \le 38{,}000$ cfs $Q_s = 3.24*10^{-10}\ Q^{2.21}$ for $Q \ge 38{,}000$ cfs
8	51.9 - 51.7	Grade Control
9	51.7 - 41.6	$Q_s = 4.35*10^{-8}\ Q^{1.74}$ for $Q \le 28{,}000$ cfs $Q_s = 2.23*10^{-9}\ Q^{2.03}$ for $Q \ge 28{,}000$ cfs
10	41.6 - 24.0	$Q_s = 4.35*10^{-8}\ Q^{1.74}$ for $Q \le 28{,}000$ cfs $Q_s = 2.23*10^{-9}\ Q^{2.03}$ for $Q \ge 28{,}000$ cfs
11	24.0 - 15.1	$Q_s = 3.86*10^{-9}\ Q^{1.97}$ for $Q \le 38{,}000$ cfs $Q_s = 3.24*10^{-10}\ Q^{2.21}$ for $Q \ge 38{,}000$ cfs
12	15.1 - 14.9	Grade Control
13	14.9 - 12.4	$Q_s = 3.86*10^{-9}\ Q^{1.97}$ for $Q \le 38{,}000$ cfs $Q_s = 3.24*10^{-10}\ Q^{2.21}$ for $Q \ge 38{,}000$ cfs
14	12.4 - 12.2	Grade Control

Note: Q_s = total bed-material transport capacity (cfs)

Q = river discharge (cfs)

5.2.2 Sediment Transport Relations for Tributaries

In general, adequate data for calibration of a sediment transport relation for each tributary of the Kansas River were not available. Since the bed material and bed slopes of the tributaries are similar to the mainstem of the Kansas River, sediment-transport relationships for the tributaries should resemble those of the mainstem. Referring to Section 4.3, the transport relations for the Kansas River at a given site are broken into two sets: one set for low flows and one set for high flows. For the tributary transport relations, the average exponent of the low-flow transport relations was used. The no-reservoir condition hydrology was used to calibrate the tranport relations on the tributaries, and the discreet daily flows were used. A coefficient was calibrated so that the mean annual tributary sediment load corresponded to those given in Table 4.2. The resulting transport relations for the tributaries are given in Table 5.2.

It should be noted that the tributary transport relations are rough estimates and at high flows may predict sediment loads that are somewhat erroneous. However, for long-term modeling it is more important to model mean annual or long-term loading than instantaneous or daily peak sediment loads. Furthermore, accurate determination of the no-reservoir (natural) condition transport relations is hampered by a lack of data on tributaries prior to reservoir construction.

The response of the mainstem for the model verification run was very close to that observed. Additionally, comparisons of eroded volumes of sediment in the tributaries below the dams agree favorably with the computed volumes (see section 5.3). For these reasons the tributary transport relations in Table 5.2 were considered adequate for this study.

5.2.3 Maximum Available Volume of Bed Material

Trapping of sediments by federal reservoirs can cause downstream degradation due to release of clear water. At present, this effect is only evident on the tributaries immediately below the dams. However, the effect will eventually progress downstream into the mainstem of the Kansas River. The exact nature and extent of this effect is impossible to predict because of the possible unknown presence of layers of armoring material in the alluvium and/or bedrock. For the purposes of modeling, it was assumed that the bedrock profile given in Figure 2.4 was representative and accurate, and that degrada-

Table 5.2. Tributary Sediment Transport Relations.

Tributary	Sediment Transport Relation
Smoky Hill River	$Q_s = 3.22 * 10^{-7} Q^{1.68}$
Republican River	$Q_s = 5.41 * 10^{-7} Q^{1.68}$
Clark Creek	$Q_s = 1.51 * 10^{-6} Q^{1.68}$
Big Blue River	$Q_s = 1.32 * 10^{-6} Q^{1.68}$
Vermillion Creek	$Q_s = 1.00 * 10^{-7} Q^{1.68}$
Mill Creek	$Q_s = 1.73 * 10^{-7} Q^{1.68}$
Cross Creek	$Q_s = 4.89 * 10^{-7} Q^{1.68}$
Soldier Creek	$Q_s = 4.58 * 10^{-7} Q^{1.68}$
Delaware River	$Q_s = 1.86 * 10^{-7} Q^{1.68}$
Wakarusa River	$Q_s = 1.27 * 10^{-7} Q^{1.68}$
Stranger Creek	$Q_s = 1.30 * 10^{-7} Q^{1.68}$

tion will eventually be controlled by this bedrock surface. Since the natural slope of the channel will not become adverse over an appreciable distance, the maximum volume of bed material which can be eroded can be calculated by constructing a hypothetical worst-case channel profile. The profile consists of horizontal segments drawn from a peak of the bedrock surface upstream until it intersects the bedrock surface. The volume of material between this hypothetical surface and the existing thalweg profile was calculated.

Dredging operations can create adverse channel bed slopes by removing material in the "valleys" between the peaks of the bedrock surface. For this reason, the calculated volume of available sediment in each reach was used as an upper limit to the amount of sediment that could be naturally removed by the river, but not as a limit to what could be removed by dredging. The limit is somewhat approximate, in that no consideration is given to available sediment in the river banks. Fortunately, the degradation limit for each reach was never approached for the 33-year model simulation, and consequently was not an important modeling parameter. At the end of the simulation for the reservoir conditions, however, all the tributary storage for the Delaware and the Big Blue Rivers had been exhausted. If the simulation had continued, tributary degradation would have progressed down the mainstem and the available bed material in each reach would become relatively important.

Volumes of bed material available in tributaries were determined by considering the hypothetical bed profile of the Kansas River at the confluence with the tributary in question, and using this elevation as the maximum scour depth of the tributary. Due to the lack of data, consideration of geologic controls was not made in calculating the available volume of bed material stored in the tributaries. However, the omission of this factor, which would most likely reduce the calculated sediment volumes, is offset to some degree by not considering material which would be available from the banks of the tributaries. Table 5.3 lists the estimated available bed-material volumes for the mainstem reaches and for tributaries. For the "no reservoir" condition and for uncontrolled tributaries, it was assumed that the available bed material in the tributaries was essentially unlimited. Additionally, for purposes of determining the available bed material, the Smoky Hill River was considered

Table 5.3. Available Bed Material in the Kansas River and Tributaries.

Reach/ Tributary	Available Bed Material (ft^3)
1	$1.48 * 10^9$
2	$1.47 * 10^9$
3	$1.48 * 10^9$
4	0
5	$2.48 * 10^9$
6	$1.20 * 10^9$
7	$5.81 * 10^7$
8	0
9	$9.82 * 10^8$
10	$1.58 * 10^9$
11	$4.38 * 10^8$
12	0
13	$1.16 * 10^8$
14	0
Republican River	$2.75 * 10^8$
Big Blue River	$2.76 * 10^8$
Delaware River	$7.58 * 10^7$

"uncontrolled" since reservoirs in the Smoky Hill drainage are all over 150 miles from its junction with the Kansas River.

5.2.4 Daily Discharges

Daily discharge data were available at Fort Riley, Wamego, Topeka, Lecompton, and Bonner Springs/Desoto from the USGS (actual recorded flows) and from the Corps of Engineers synthesized records. These latter discharges have the effects of the reservoirs removed in one case, and extended into the pre-reservoir period for the other case. In order to determine the daily discharges for the main stem reaches and for the tributaries, the following procedure was used.

For a given day the difference in discharge was calculated for two consecutive stations. If this difference was positive, that is, increasing in a downstream direction, the difference is distributed between incoming tributaries between the two stations in proportion to their drainage areas. The discharge for each reach was set equal to the discharge of the adjacent upstream reach plus tributary inflows. If the discharge from one station to the next downstream station for a given day decreased, tributary inflows between the two stations were set equal to zero and the discharge drop was assumed to be linear with distance between the two stations. For this case, the discharge for a given reach between the two stations was calculated as the discharge of the adjacent upstream reach minus the proportion of the discharge drop which would occur in that reach based upon the length of the reach. While this method of discharge calculation does not handle normal routing of flow events through the system, it was deemed adequate for this type of long-term modeling procedure based on past experience utilizing this procedure and considering the lack of discharge records on tributaries corresponding to the synthesized mainstem flow records.

Flows for the calendar year 1951 were excluded from the model input hydrology for the following reasons:

1. An initial model run indicated that the system's agrradation/degradation response for the year 1951 was as great as the response for the other 33 years of record combined. This considerably increases the difficulty of determining the relative impacts due to dredging and the operation of the reservoirs.

2. The calibrated transport relations are not applicable for the magnitude of discharges that occurred during the 1951 flood.

Therefore, the 1951 flood was excluded from all hydrologic input files used for the model runs.

Three separate hydrologic conditions were developed for model input. They are:

1. Actual recorded discharges from USGS gauge records for the period 1964-1980. This input was used for the calibration run. No flows prior to 1964 were used since the Fort Riley gauge was moved in 1963 to its present location, and since good calibration data are abundant for this period.

2. Synthesized hydrology from the COE based upon the recorded flows, adjusted to remove the effects of reservoir operation for the period 1940-1973.

3. Synthesized hydrology from the COE based upon the recorded flows, adjusted to include the effects of the reservoirs for the entire period of record, 1940-1973.

For Conditions 2 and 3, the 1940-1973 period of record was selected since very little sand- and gravel-mining information existed prior to 1940 and the synthesized flow records did not extend beyond 1973.

5.2.5 Sand- and Gravel-Mining Information

The primary source of sand- and gravel-dredging information was the Kansas State Department of Revenue. The limitations of this data were discussed in Section 3.5. For modeling purposes, the most important limitations are the lack of specific locations of dredges and quantities of sand removed at those locations, and the lack of detailed information pertaining to the upstream dredges at Topeka, Wamego, and Manhattan.

Locations of dredges and quantities removed at these locations were inferred from the information presented in Tables 3.15 and 3.16. In order to determine the historical quantities of material dredged in upstream reaches, the quantities for years for which records were available were carefully analyzed. Based upon this analysis, it was determined that prior to 1979, 11 percent of the total sand and gravel dredged from the Kansas River came from the reaches below Turner Bridge, 60 percent came from the reach between Turner Bridge and Bonner Springs, 20 percent came from the Topeka area, two percent came from the Wamego area, and seven percent came from the Manhattan area.

Within the reach between Tuner Bridge (R.M 9.6) and Bonner Springs (approximate R.M. 21), several model subreaches exist. In order to distribute the dredged material between these subreaches, the information presented in Table 3.15 was utilized assuming that the amount of material dredged within a subreach was proportional to the number of dredges operating within that subreach. In some instances (particularly prior to 1954), this resulted in a significant amount of the total dredged material being removed from reaches that were not modeled (i.e., below R.M. 12.2). Although specific data is not available to verify this assumption, it is qualitatively correct since historical evidence indicates dredging initiated in the immediate Kansas City area and has since moved upstream. This trend is continuing as indicated by recent applications for dredging permits near Desoto.

5.3 Model Verification

In order to check model calibration, a simulation was conducted using the USGS recorded discharges for the period 1964-1980. The river response from the simulation was compared with the actual bed aggradation or degradation represented by past cross sections (Appendix C and Table 3.5), thalweg profiles (Figure 3.28), and historical stage plots (see Figures 3.25, 3.26, and 3.27). The comparison is provided in Tables 5.4 and 5.5. Values given in Table 5.4 are unbulked. For converting the net aggradation/degradation values to an equivalent depth in feet in Table 5.5, a bulking factor of 1.7 was used (i.e., porosity of the bed material was assumed equal to 0.4). Based upon the close agreement between actual and simulated river response, it was concluded that the model calibration was adequate and the evaluation of different hydrologic and dredging conditions could proceed.

In order to further verify the reasonableness of the tributary bed material transport relations, quantities computed in the verification run were compared to quantities eroded from the tributaries below the dams determined from consideration of the cross sections given in Appendix D. These quantities are given in Table 5.6. From the table it can be seen that calculated transport rates from the model agree quite closely with calculated rates of degradation based upon the historic cross sections on all but the Republican River. There is a 60 percent difference between the average rate of degradation computed from the historical sections and the average transport capacity computed by the model for the Republican River. This indicates one of two things:

Table 5.4. Continuity Model Output for Verification Run.
(Using USGS recorded flows, 1964 - 1980)

Reach Information					
River Miles	Sediment Supply (MCF)	Sediment Capacity (MCF)	Dredged Quantities (MCF)	Net Agg/Deg (MCF)	Tributary Inflows (MCF)
					Smoky Hill R. = 100.2
					Republican R. = 46.7
					Clark Cr. = 2.1
170-147.5	149.0	197.9	0.0	- 48.8	
					Big Blue R. = 71.3
147.5-121.5	269.2	180.1	63.8	25.4	
					Vermillion Cr. = 5.1
121.5-101.2	185.2	203.1	0.0	- 17.8	
					Mill Cr. = 3.9
					Cross Cr. = 4.2
101.2-101.0	211.1	211.1	0.0	0.0	
101.0-80.6	211.1	147.0	143.1	- 79.0	
					Soldier Cr. = 5.1
80.6-64.5	152.1	156.5	0.0	- 4.4	
					Delaware R. = 20.2
64.5-51.9	176.7	201.2	0.0	- 24.5	
51.9-51.7	201.2	201.2	0.0	0.0	
51.7-41.6	201.2	222.3	0.2	- 21.3	
					Wakarusa R. = 9.7
					Stranger Cr. = 9.2
41.6-24.0	241.3	301.6	0.0	- 60.3	
24.0-15.1	301.6	282.2	277.2	-257.7	
15.1-14.9	282.2	282.2	0.0	0.0	
14.9-12.4	282.2	282.2	102.0	-102.0	
12.4-12.2	282.2	282.2	0.0	0.0	

NOTE: All values are unbulked volumes.

Table 5.5. Results of Sediment Continuity Model Verification.
(Using USGS recorded flows - 1964 to 1980)

Reach	River Miles	Net Aggradation/ Degradation (mcf)	Approximate Width (ft)	Approximate Length (ft)	Approximate Computed Aggradation/ Degradation[1] (ft)	Approximate Measured Aggradation/ Degradation[4] (ft)
1	170 -147.5	- 48.8[2]	600	118,800	- 1.2[2]	I[5]
2	147.5-121.5	+ 25.4	700	137,280	+ 0.4	I[5]
3	121.5-101.2	- 17.8	800	107,184	- 0.4	0
4	101.2-101.0	----	---	----	----	--[3]
5	101.0- 80.6	- 79.0	800	107,712	- 1.5	-1 to -2
6	80.6- 64.5	- 4.4	800	85,008	- 0.1	-1 to -2
7	64.5- 51.9	- 24.5	800	66,528	- 0.8	-1 to -2
8	51.9- 51.7	----	---	----	----	--[3]
9	51.7- 41.6	- 21.3	800	53,328	- 0.8	0 to -1
10	41.6- 24.0	- 60.3	800	92,928	- 1.4	-1 to -2
11	24.0- 15.1	-257.7	1000	46,992	- 9.3	-6 to -10
12	15.1- 14.9	----	---	----	----	--[3]
13	14.9- 12.4	-102.0	1000	13,200	-13.1	-10 to -15
14	12.4- 12.2	----	---	----	----	--[3]

[1] Assuming porosity of bed material = 0.40 (i.e., bulking factor = 1.7)

[2] A "-" indicates degradation, a "+" indicates aggradation

[3] Grade Control

[4] Based on Historic Cross Section, Thalweg Profiles, Rating Curves, and Reported Degradation

[5] "I" = insufficient information for accurate assessment of historical channel aggradation/degradation

Table 5.6. Degradation on Tributaries Downstream of Federal Reservoirs and Computed Transport Capacities.

Tributary	Period	Degradation* Bulk Volume (MCF)	Average Degradation Volume (MCF/Yr.)	Period	Computed** Degradation Bulk Volume (MCF)	Average Computed Degradation Volume (MCF/Yr.)
Republican River	1967 - 1980	40.0	2.86	1964 - 1980	79.4	4.67
Big Blue River	1962 - 1973	80.7	6.73	1964 - 1980	121.2	7.13
Delaware River	1967 - 1979	23.5	1.81	1964 - 1980	34.3	2.02

*Calculated from sections in Appendix D.

**From verification run, assuming bed material porosity = 0.4

1. The transport relation is somewhat high, or

2. some control such as armoring or bedrock has limited the amount of degradation (i.e., the system has become supply controlled).

Considerable bed material information on the Republican River was supplied by the COE primarily below Milford Dam. Examination of this information indicates that the Republican River immediately below Milford Dam is somewhat armored. At the Highway 77 bridge approximately 1 mile below the dam, the bed material d_{50} is approximately 8 mm and the d_{90} is 25 mm. Just above the confluence with the Kansas River the bed material d_{50} is approximately 0.8 mm and the d_{90} is about 4.0 mm. Above Milford Reservoir at Clay Center, bed material d_{50} is approximately 0.6 mm and the d_{90} is about 1.5 mm.

These numbers clearly indicate that as degradation proceeds downstream of Milford Dam on the Republican River, the bed material is getting considerably coarser. As this material becomes coarser, the transporting capacity of the tributary (and supply to the main stem) decreases.

In light of this information it was felt that the transport relation for the Republican River was a reasonable approximation of the transport capacity of the stream, particularly since the model verification was accurate.

There was insufficient data available to determine if armoring was occurring on the other controlled tributaries. All factors considered, the average annual tributary bed material loadings and transport relations were considered reasonable for the purposes of this study.

5.4 Model Results for Various Hydrologic and Dredging Conditions

Four different simulations were made for various hydrologic and dredging conditions. All four simulations used the COE synthesized hydrology with the 1951 flows removed. The different conditions considered were:

1. No federal reservoirs, no dredging.
2. No federal reservoirs, with dredging.
3. With federal reservoirs, no dredging.
4. With federal reservoirs, with dredging.

Model results for these conditions are given in Tables 5.7 through 5.10. Additionally, a summary of the information presented in Tables 5.7 through 5.10 with aggradation and degradation values converted to approximate depths in feet is provided in Table 5.11.

Table 5.7. Continuity Model Output for No Reservoir, No Dredging Condition for Synthesized Hydrology Without 1951 Flows.

Reach Information					
River Miles	Sediment Supply (MCF)	Sediment Capacity (MCF)	Dredged Quantities (MCF)	Net Agg/Deg (MCF)	Tributary Inflows (MCF)
					Smoky Hill R. = 285.4 Republican R. = 132.9 Clark Cr. = 5.5
170-147.5	423.8	511.5	0.0	- 87.7	
					Big Blue R. = 183.6
147.5-121.5	695.1	609.2	0.0	85.9	
					Vermillion Cr. = 10.1
121.5-101.2	619.3	664.1	0.0	- 44.8	
					Mill Cr. = 7.5 Cross Cr. = 8.3
101.2-101.0	679.9	679.9	0.0	0.0	
101.0-80.6	679.9	489.2	0.0	190.7	
					Soldier Cr. = 12.0
80.6-64.5	501.2	514.2	0.0	- 13.0	
					Delaware R. = 47.0
64.5-51.9	561.2	632.8	0.0	- 71.5	
51.9-51.7	632.8	632.8	0.0	0.0	
51.7-41.6	632.8	627.3	0.0	5.5	
					Wakarusa R. = 18.4 Stranger Cr. = 17.4
41.6-24.0	663.1	790.5	0.0	-127.4	
24.0-15.1	790.5	798.7	0.0	- 8.1	
15.1-14.9	798.7	798.7	0.0	0.0	
14.9-12.4	798.7	798.7	0.0	0.0	
12.4-12.2	798.7	798.7	0.0	0.0	

NOTE: All values are unbulked volumes.

Table 5.8. Continuity Model Output for No Reservoir, With Dredging Condition for Synthesized Hydrology with 1951 Flows Excluded, and the 1940 to 1973 Dredged Quantities.

Reach Information					
River Miles	Sediment Supply (MCF)	Sediment Capacity (MCF)	Dredged Quantities (MCF)	Net Agg/Deg (MCF)	Tributary Inflows (MCF)
					Smoky Hill R. = 285.4 Republican R. = 132.9 Clark Cr. = 5.5
170-147.5	437.8	511.5	0.0	- 87.7	
					Big Blue R. = 183.6
147.5-121.5	695.1	609.2	91.6	- 5.7	
					Vermillion Cr. = 10.1
121.5-101.2	619.3	664.1	0.0	- 44.8	
					Mill Cr. = 7.5 Cross Cr. = 8.3
101.2-101.0	679.9	679.9	0.0	0.0	
101.0-80.6	679.9	489.2	203.2	- 12.5	
					Soldier Cr. = 12.0
80.6-64.5	501.2	514.2	0.0	- 13.0	
					Delaware R. = 47.0
64.5-51.9	561.2	632.8	0.0	- 71.5	
51.9-51.7	632.8	632.8	0.0	0.0	
51.7-41.6	632.8	627.3	0.0	5.5	
					Wakarusa R. = 18.4 Stranger Cr. = 17.4
41.6-24.0	663.1	790.5	0.0	-127.4	
24.0-15.1	790.5	798.7	218.6	-226.7	
15.1-14.9	798.7	798.7	0.0	0.0	
14.9-12.4	798.7	798.7	98.5	- 98.5	
12.4-12.2	798.7	798.7	0.0	0.0	

NOTE: All values are unbulked volumes.

Table 5.9. Continuity Model Output for With Reservoir, No Dredging Condition for Synthesized Hydrology with 1951 Flows Excluded.

Reach Information					
River Miles	Sediment Supply (MCF)	Sediment Capacity (MCF)	Dredged Quantities (MCF)	Net Agg/Deg (MCF)	Tributary Inflows (MCF)
					Smoky Hill R. = 230.3
					Republican R. = 107.2
					Clark Cr. = 4.9
170-147.5	342.4	433.3	0.0	- 91.0	
					Big Blue R. = 162.2
147.5-121.5	595.5	422.4	0.0	173.1	
					Vermillion Cr. = 10.3
121.5-101.2	432.7	463.7	0.0	- 31.0	
					Mill Cr. = 7.7
					Cross Cr. = 8.4
101.2-101.0	479.8	479.8	0.0	0.0	
101.0-80.6	479.8	327.9	0.0	151.9	
					Soldier Cr. = 11.0
80.6-64.5	338.9	339.3	0.0	- 0.4	
					Delaware R. = 43.0
64.5-51.9	382.3	421.1	0.0	- 38.8	
51.9-51.7	421.1	421.1	0.0	0.0	
51.7-41.6	421.1	460.1	0.0	- 39.0	
					Wakarusa R. = 16.5
					Stranger Cr. = 15.7
41.6-24.0	492.3	581.6	0.0	- 89.3	
24.0-15.1	581.6	536.6	0.0	45.0	
15.1-14.9	536.6	536.6	0.0	0.0	
14.9-12.4	536.6	536.6	0.0	0.0	
12.4-12.2	536.6	536.6	0.0	0.0	

NOTE: All values are unbulked volumes.

Table 5.10. Continuity Model Output for With Reservoirs, With Dredging Condition for Synthesized Hydrology with 1951 Flows Excluded, and the 1940 to 1973 Dredged Quantities.

Reach Information					
River Miles	Sediment Supply (MCF)	Sediment Capacity (MCF)	Dredged Quantities (MCF)	Net Agg/Deg (MCF)	Tributary Inflows (MCF)
					Smoky Hill R. = 230.3
					Republican R. = 107.2
					Clark Cr. = 4.9
170-147.5	342.4	433.3	0.0	- 91.0	
					Big Blue R. = 162.2
147.5-121.5	595.5	422.4	91.6	81.5	
					Vermillion Cr. = 10.3
121.5-101.2	432.7	463.7	0.0	- 31.0	
					Mill Cr. = 7.7
					Cross Cr. = 8.4
101.2-101.0	479.8	479.8	0.0	0.0	
101.0-80.6	479.8	327.9	203.2	- 51.3	
					Soldier Cr. = 11.0
80.6-64.5	338.9	339.3	0.0	- 0.4	
					Delaware R. = 43.0
64.5-51.9	382.3	421.1	0.0	- 38.8	
51.9-51.7	421.1	421.1	0.0	0.0	
51.7-41.6	421.1	460.1	0.0	- 39.0	
					Wakarusa R. = 16.5
					Stranger Cr. = 15.7
41.6-24.0	492.3	581.6	0.0	- 89.3	
24.0-15.1	581.6	536.6	218.6	-173.5	
15.1-14.9	536.6	536.6	0.0	0.0	
14.9-12.4	536.6	536.6	98.5	- 98.5	
12.4-12.2	536.6	536.6	0.0	0.0	

NOTE: All values are unbulked volumes.

Table 5.11. Summary of Model Output for Various Hydrologic and Dredging Conditions for Synthesized Hydrology With 1951 Flows Excluded.

Reach No.	River Miles	Cumulative Net Aggradation/Degradation (ft)[1]						
		No Reservoirs No Dredging	No Reservoirs With Dredging		With Reservoirs No Dredging		With Reservoirs With Dredging	
			A[2]	Δ[3]	A[2]	Δ[3]	A[2]	Δ[3]
1	170.0-147.5	- 2.1	- 2.1	0.0	- 2.2	- 0.1	- 2.2	- 0.1
2	147.5-121.5	+ 1.5	- 0.1	- 1.6	+ 3.1	+ 1.6	+ 1.4	- 0.1
3	121.5-101.2	- 0.9	- 0.9	0.0	- 0.6	+ 0.3	- 0.6	+ 0.3
4	101.2-101.0	---	---	---	---	---	---	---[4]
5	101.0-80.6	+ 3.8	- 0.3	- 3.5	+ 3.0	- 0.8	- 1.0	- 4.8
6	80.6-64.5	- 0.3	- 0.3	0.0	0.0	+ 0.3	0.0	+ 0.3
7	64.5-51.9	- 2.3	- 2.3	0.0	- 1.2	+ 1.1	- 1.2	+ 1.1
8	51.9-51.7	---	---	---	---	---	---	---[4]
9	51.7-41.6	+ 0.2	+ 0.2	0.0	- 1.6	- 1.4	- 1.6	- 1.4
10	41.6-24.0	- 2.9	- 2.9	0.0	- 2.0	+ 0.9	- 2.0	+ 0.9
11	24.0-15.1	- 0.3	- 8.2	- 7.9	+ 1.6	+ 1.3	- 6.3	- 6.0
12	15.1-14.9	---	---	---	---	---	---	---[4]
13	14.9-12.4	0.0	-12.7	-12.7	0.0	0.0	-12.7	-12.7
14	12.4-12.2	---	---	---	---	---	---	---[4]

[1]Values based on average reach dimensions given in Table 5.5 and a porosity of 0.4
[2]Absolute value from volume in Tables 5.7 - 5.10
[3]Difference from no reservoirs, no dredging condition
[4]Grade Control

As discussed earlier, because of the extreme nature of the 1951 flood, discharges for this year were not considered in the model runs. From the tables, it can be seen that between the reservoir and no reservoir conditions, there is some difference in tributary loading on uncontrolled tributaries. This is due to the method used to assign flows to the tributaries. Quantities of sediment contributed by the uncontrolled tributaries are small enough that they have little overall effect on general aggradation/degradation in the mainstem of the Kansas River.

This information is most appropriately used for comparison between the different reservoir and dredging conditions to determine the relative impacts of the activities. The relative impacts of each alternative run as compared to the baseline (no reservoir, no dredging) condition are also shown in Table 5.11. Utilizing the tabulated information in this manner, the following observations were made:

1. Comparing the no reservoirs, no dredging condition with the no reservoirs, with dredging condition isolates the effects of dredging. As can be seen in all reaches in which dredging takes place, net degradation occurs. Reaches 2 and 5 are naturally aggrading; however, the rate of gravel extraction is approximately equal to the rate of aggradation, and the net degradation is very small (0.1 and 0.3 feet, respectively). Hence, current rates of dredging in these reaches probably have a stabilizing effect on channel morphology. Reaches 11 and 13 are approximately stable (0.3 feet degradation and 0.0 feet, respectively) for the no reservoir, no dredging condition. These reaches experience severe degradation for the no-reservoirs, with-dredging condition (8.2 and 12.7 feet, respectively).

2. Comparing the with reservoirs, no dredging condition to the no dredging, no reservoirs condition isolates the effects of the reservoirs, Effects of the reservoirs are due to the change in flow regime, primarily the attenuation of peak flows. In most instances this had the effect of reducing the average transport capacity of a reach more than the supply. This results in more aggradation, less degradation, or switching from degrading or stable to aggrading for a reach when compared to the no reservoirs, no dredging condition. This is particularly noticeable in Reaches 2, 7, 10 and 11, but is also true for Reaches 3 and 6, although the effect is less pronounced. In some cases the reduction in average sediment supply due to the change in hydraulic regime was greater than the reduction in capacity for a reach. This results in less aggradation, more degradation, or switching from aggrading or stable to degrading. This is particularly noticeable for Reaches 5 and 9, but is true also for Reach 1. In general, the system-wide response to reservoir operation is to either increase aggradation or decrease degradation.

3. Since the effects of the reservoirs are variable from reach to reach as discussed in 2. above, the combined effects of the reservoirs and dredging may be either additive or compensatory in nature. In Reaches 2

and 11 the impacts are somewhat compensating, while in Reach 5 the impacts are additive.

Figures 5.1 through 5.4 are time series plots of cumulative net aggradation/degradation for reaches below Bowersock Dam. These figures offer additional insight into the modeled system response. No dredging takes place in Reach 9 (R.M. 51.7 to 41.6) or Reach 10 (R.M. 41.6 to 24.0) for the period of simulation. These reaches, therefore, illustrate the impacts associated with changes in the hydrologic regime due to the reservoirs. As can be seen from comparing Figure 5.1 to Figure 5.2, the reservoirs can either induce aggradation or degradation in a given reach. Figure 5.3 illustrates graphically the effect of dredging on a reach. Figure 5.4 shows both with dredging conditions, with and without reservoirs, have the same response. This is due to the fact that trapping of sediments within dredge pits was not modeled. Trapping of sediments in the pits is a function of discharge and hydraulics. The model used constant sediment transport relations, which were a function of discharge alone. These transport relations were not adjusted to reflect changes in channel geometry and consequent changes in hydraulics due to dredging and/or large amount of aggradation/degradation. A model which would account for such changes was beyond the scope of this study and would be very difficult to implement given the existing data.

5.5 Allowable Dredging Rates and Locations

For the no dredging, with reservoirs condition, only Reaches 2, 5 and 11 aggrade. Only in these reaches will the effects of dredging (i.e., associated channel degradation and resulting bank erosion) be somewhat moderated. All other reaches are naturally degrading or stable, and any dredging activities within these reaches will result in immediate lowering of the channel bed by an amount dependent on the volume of material removed. Table 5.11 indicates that the rate of extraction due to dredging in Reaches 2 and 5 is about equal to the natural aggradation rate. This is not to say that dredging rates should not be allowed to increase in Reaches 2 and 5 or should be curtailed in the other reaches; rather, the allowable rate of dredging within a given reach is dependent upon the channel degradation and resulting bank erosion which can be tolerated at that location. Determination of "acceptable" impacts is dependent upon various environmental, socioeconomic, and political factors and is outside the scope of this report.

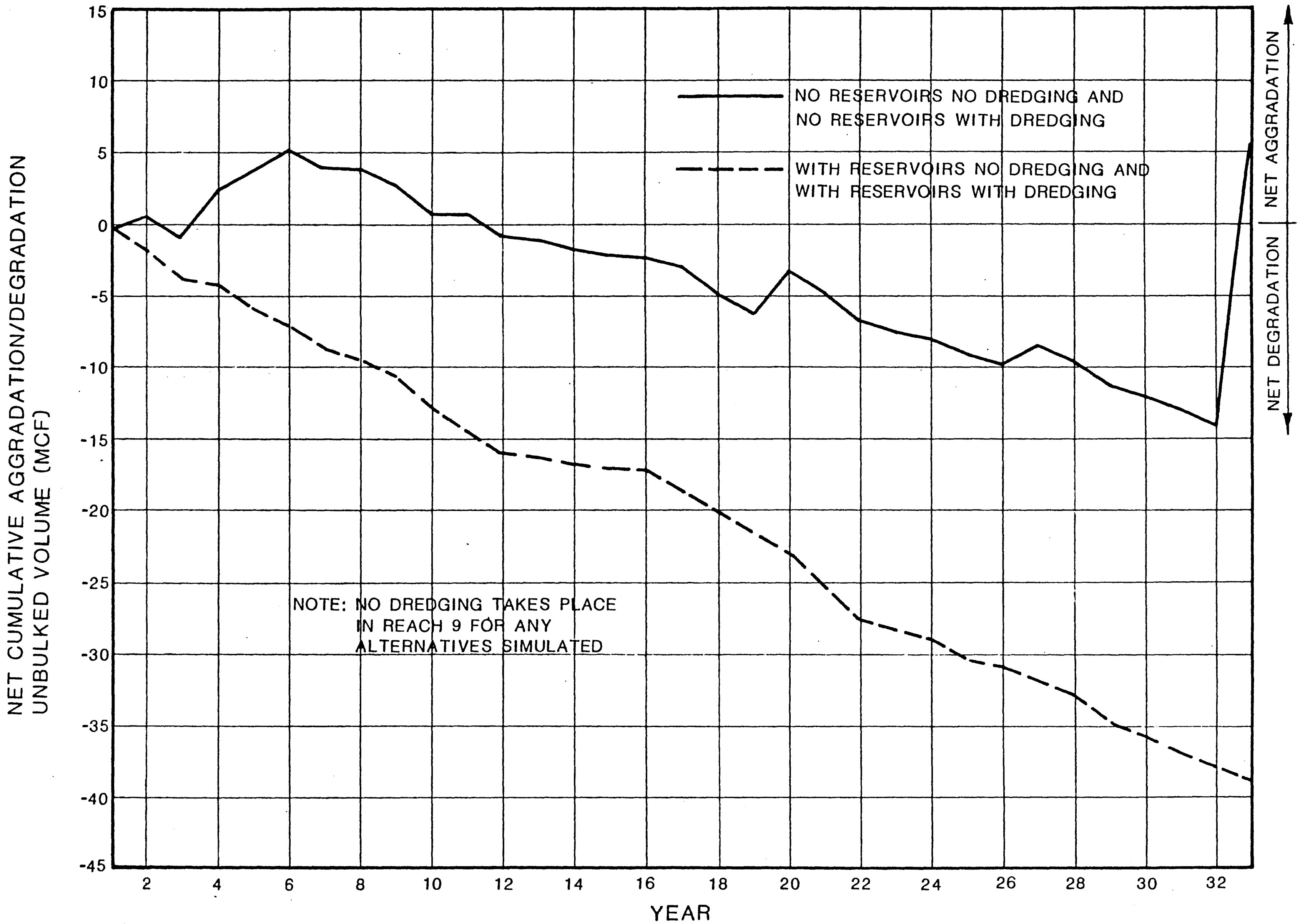

Figure 5.1. Net cumulative aggradation/degradation versus time for Reach 9 (R.M. 51.7-R.M. 41.6) for synthesized hydrology with 1951 flows excluded.

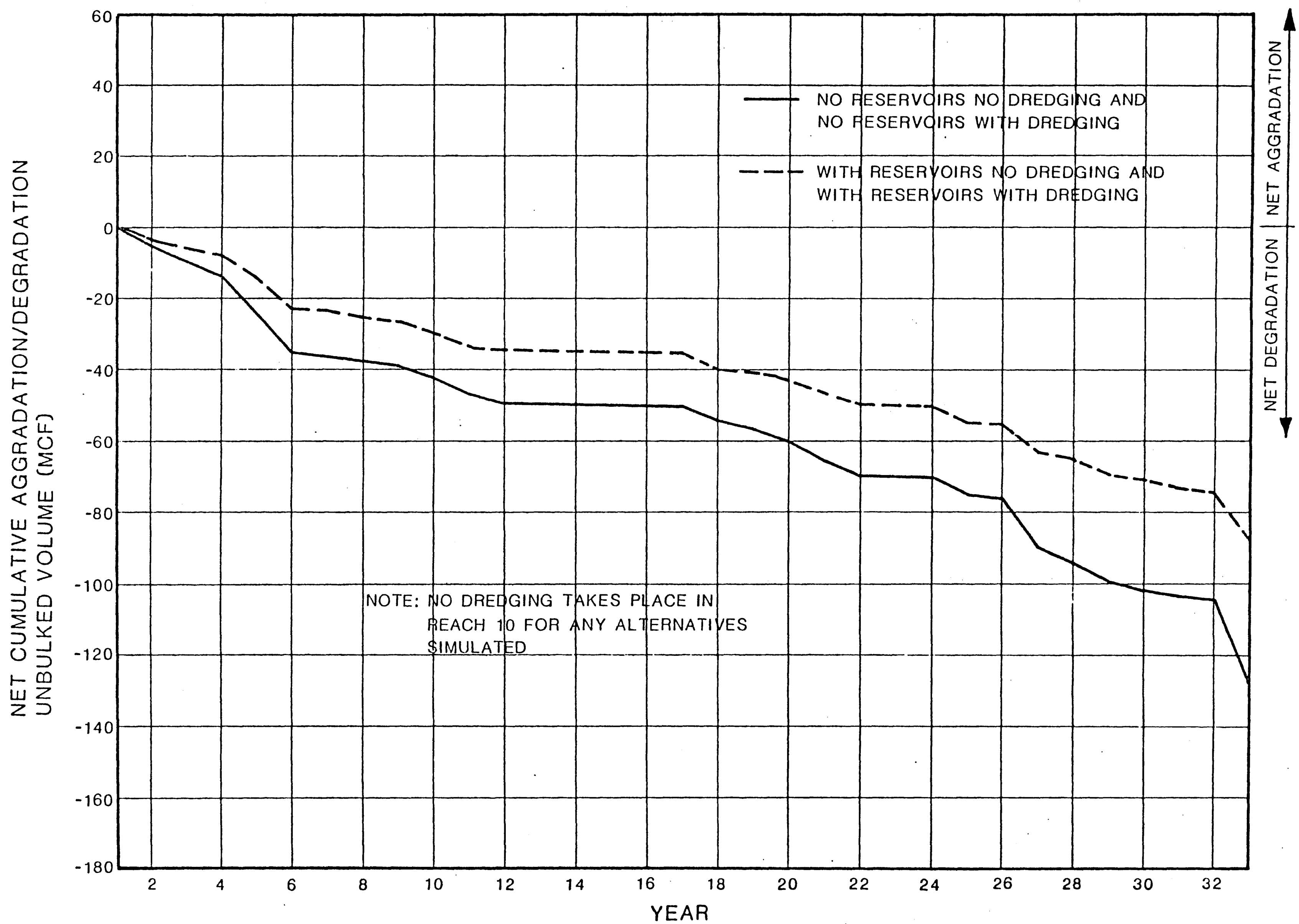

Figure 5.2. Net cumulative aggradation/degradation versus time for Reach 10 (R.M. 41.6-R.M. 24.0) for synthesized hydrology with 1951 flows excluded.

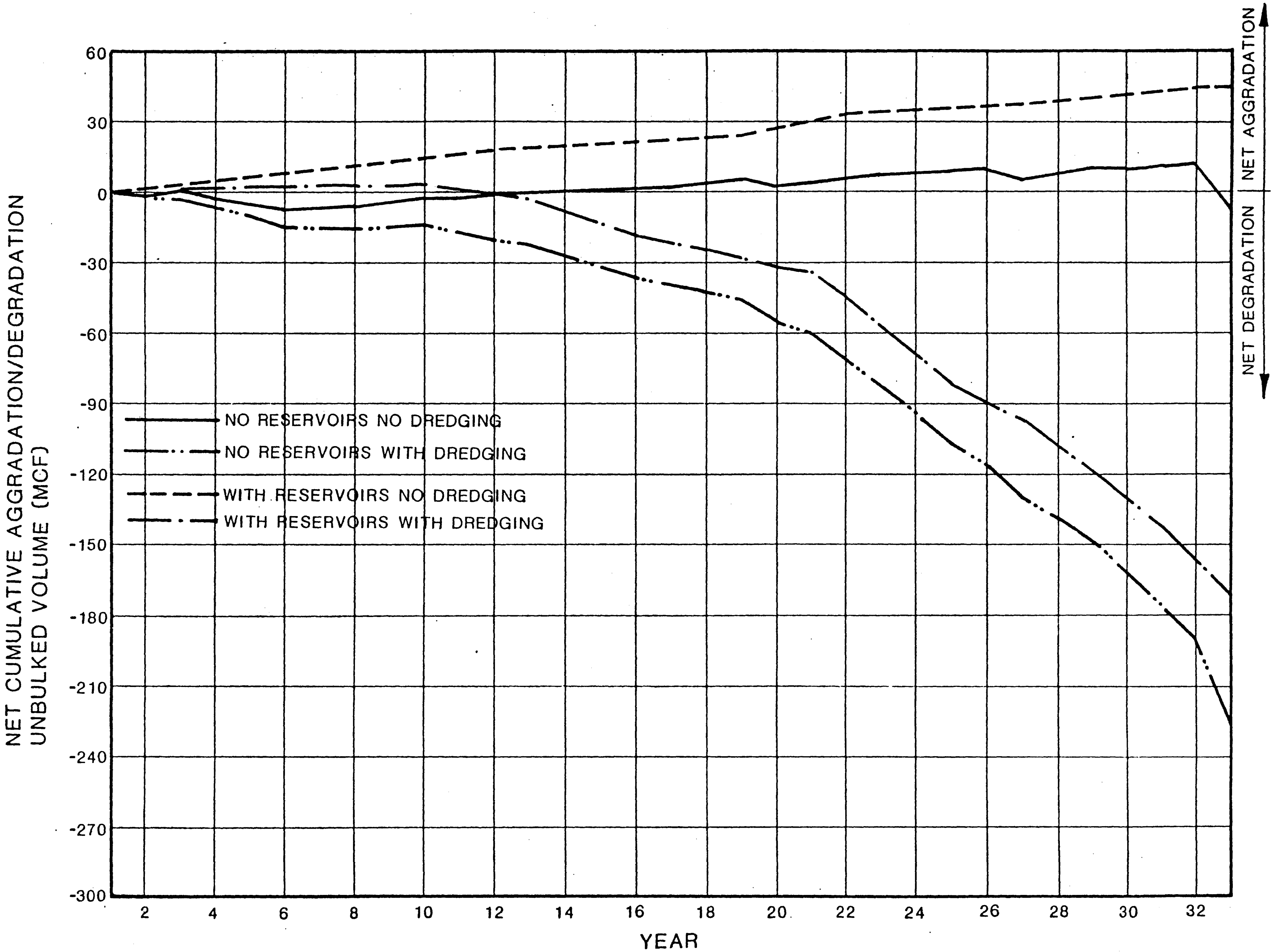

Figure 5.3. Net cumulative aggradation/degradation versus time for Reach 11 (R.M. 24.0-R.M. 15) for synthesized hydrology with 1951 flows excluded.

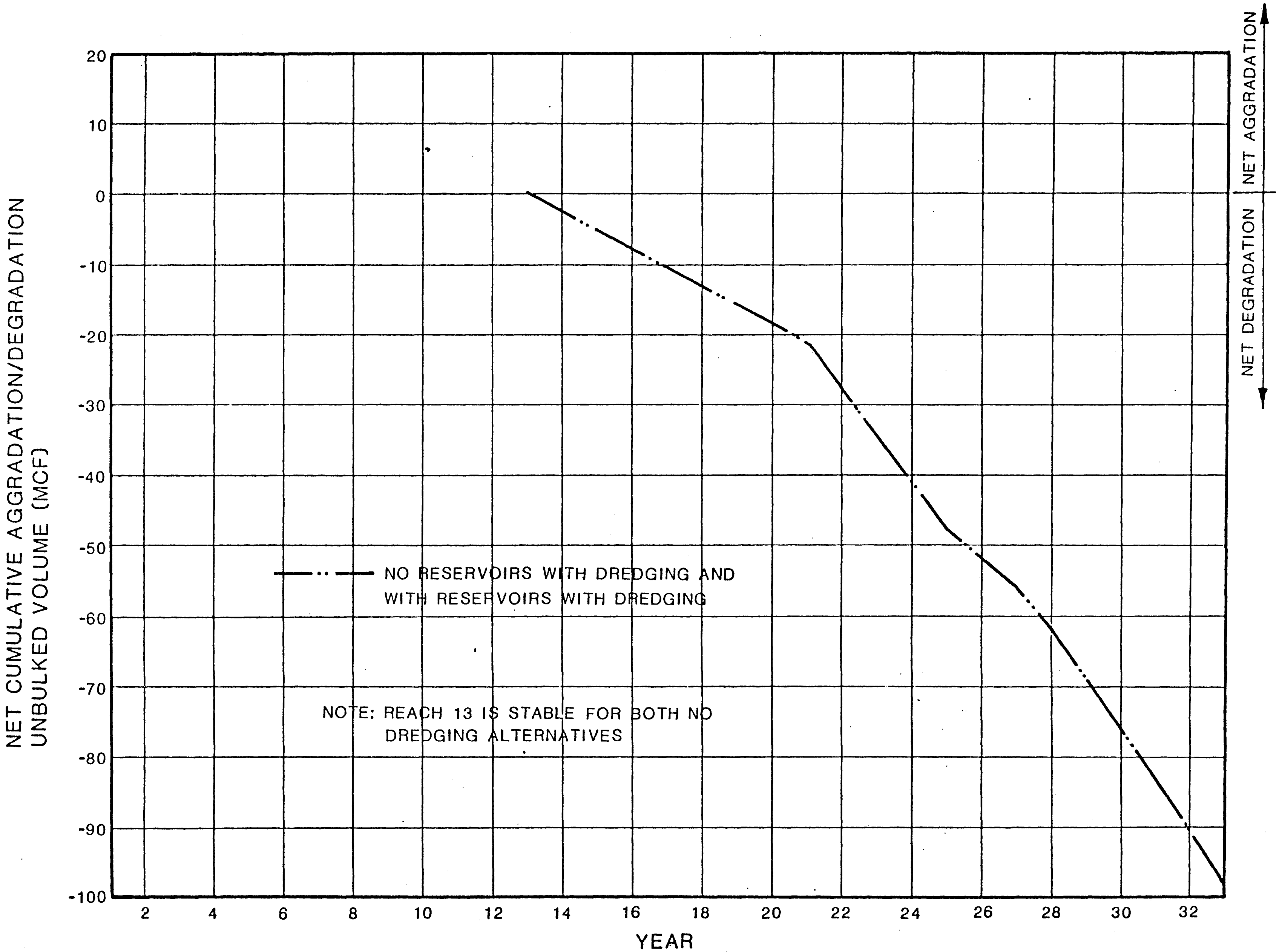

Figure 5.4. Net cumulative aggradation/degradation versus time for Reach 13 (R.M. 14.9-R.M. 12.4) for synthesized hydrology with 1951 flows excluded.

At present there are several applications pending approval for the establishment of dredging operations in the Desoto area (approximate R.M. 31). From Table 5.11 it can be seen that Reach 10 (R.M. 41.6 to R.M. 24.0) is in a degrading state. Consequently, there is no surplus of sediment within this reach; and therefore, dredging activities will result in additional degradation directly proportional to the quantity of material removed from the river.

VI. SUMMARY AND CONCLUSIONS

The purpose of this project was to determine the relative impacts of the operation of federal reservoirs, sand gravel dredging, changes in the base level of the Missouri River, and other man-made and natural factors on channel degradation and bank erosion in the lower Kansas River. These factors were assessed using a three-level analysis procedure which consisted of qualitative geomorphic, quantitative engineering, and computer modeling phases. The qualitative analysis was composed of two primary parts: documentation of observed geomorphic trends in the river, and determination, to the extent possible, of the relationship of those trends to the above factors using geomorphic concepts. In the quantitative engineering phase, principles of hydraulics and erosion and sedimentation were used to verify, refine and expand the results of the qualitative analysis. The computer modeling phase was then performed using a continuity-based sediment routing model which allowed further analysis of the relative impacts of the operation of the federal reservoirs and sand and gravel dredging.

The results of these analyses indicate the following general conclusions:

1. Operation of the federal reservoirs has changed the flow duration characteristics of the Kansas River. This has resulted in a reduction in the amount of bed material carried by the system of approximately 30 to 40 percent on an annual basis. As discussed in Chapter V, on a reach-by-reach basis the reduction in bed material transport capacity due to operation of federal reservoirs may or may not be as great as the reduction in supply of bed material to that reach. In general, the aggradational tendency of some reaches increased while the degradational tendency in other reaches is somewhat dampened. This process helps offset the degradational impacts due to dredging in Reaches 2 and 11 (R.M. 147.5 to 121.5 and R.M. 24.0 to 15.1, respectively). The aggradational tendency in the Topeka area (Reach 5, R.M. 80.6 to 101.0) is reduced by the operation of the reservoirs. Although it still aggrades for the with-reservoir condition, the amount of aggradation is less, indicating a greater impact due to extraction of material through dredging. Consequently, this reach aggrades less than it would without the reservoirs. Therefore, even though this reach still aggrades with the reservoirs, impacts due to dredging are more pronounced than they would be without reservoirs. Changes in the flow duration have also had some impact on the sediment sizes being transported by the system. Incipient motion analysis indicates that the maximum size that can be transported has been increased slightly for medium flows (those equaled or exceeded approximately 2 to 20 percent of the time) and reduced by approximately 50 percent for higher flows.

   Rapid fluctuations in stage can decrease bank stability through its effect on pore water pressure within the banks. Operation of the federal reservoirs has not significantly changed the stage fluctuations in the Kansas River, and therefore this factor has little or no impact on the stability of the channel banks. Larger duration of two-thirds to threequarter bankfull flows, on the other hand, may have increased the tendency for bank erosion, although this is probably compensated for by reduced bank erosion due to attentuation of high flows.

2. Sand and gravel dredging appears to be the primary cause of the bank erosion and channel widening in the lower 30 miles of the Kansas River. Significant quantities of material have been removed from the channel bed in this reach during the past 50 to 75 years. Between 1952 and 1976, for example, approximately 49.3 million tons of material were dredged between Turner Bridge and Desoto, which corresponds to an average thickness of approximately 15 feet within the main channel. Sediment continuity indicates a direct relationship between the dredging activity and channel degradation and bank erosion. As evidenced by the approximately 8 to 15 feet of degradation and 150 feet of channel widening between Turner Bridge and Bonner Springs, available data show areas within the lower Kansas River which have undergone the most severe degradation are the same locations where extensive dredging has taken place.

   Sand and gravel dredging impacts tend to be relatively localized, although removal of large quantities of material over a large area can result in lowering of the bed and an increase in the channel gradient at the upstream end of the dredge area. This increased gradient causes a local increase in the transport capacity and may produce a headcut that will translate through the system in an upstream direction, reducing the channel slope until a natural or man-made control is encountered. Available data indicate that this has, in fact, happened near RM 22.

   Artificial deepening (and/or widening) of the channel due to dredging also creates a ponding effect which traps the coarse material and may induce further scour downstream of the dredge areas. This factor does not appear to be significant for this system, however.

3. Lowering of the base level of the Missouri River has had an insignificant impact on the degradation and bank erosion in the lower Kansas River since at least the early 1950's. Sufficient data are not available to evaluate this impact with any degree of certainty prior to that time. Historical thalweg profiles between the mouth and Turner Bridge indicate significant degradation between 1931 and 1951. It is thought that the majority of this occurred during the 1951 flood. Since 1951, the channel bed has actually aggraded. Additionally, the presence of the geologic control at RM 12.0, which was first documented in 1956, and the Johnson County weir, constructed in 1967, will prevent further lowering of the Missouri River base level from translating upstream in the Kansas River.

4. Major man-made structures that affect the morphology of the Kansas River include Bowersock Dam and Johnson County Weir. Both of these structures act to stabilize the channel by fixing the channel bed elevations. Both structures produce some backwater effect at lower discharges, which results in trapping of the bed load and a portion of the suspended load. At higher discharges, the hydraulic conditions are such that the bed-material load is not significantly altered by the presence of the structures. Their primary impact is to fix the elevation of the channel bed, preventing further degradation.

Other man-made structures which have a smaller impact are the bank protection measures which have been installed at numerous points throughout the system (see Table 3.16). These measures have limited the lateral migration potential of the river at specific locations and have slightly reduced the available supply of bank material. Due to their limited extent and the high percentage of unprotected bank, however, their overall impact on the degradation and bank erosion is minor.

In addition to the four factors discussed above, the impact of the 1951 flood on the morphology of the system should not be overlooked. This extremely large event dramatically altered the system, causing severe degradation and bank erosion. The post-flood channel was probably straighter and the cross-sectional area much larger than was the case before the flood. Since that event (and partially as a result of changed flow regime due to the construction of the federal reservoirs), the channel has been steadily changing as it regains a quasi-equilibrium condition consistent with the present hydrologic regime. Many of the observed trends in the past three decades, including apparent accretion on the inside of the bends and formation of vegetated islands where unstable sand bars previously existed, can be attributed to this factor.

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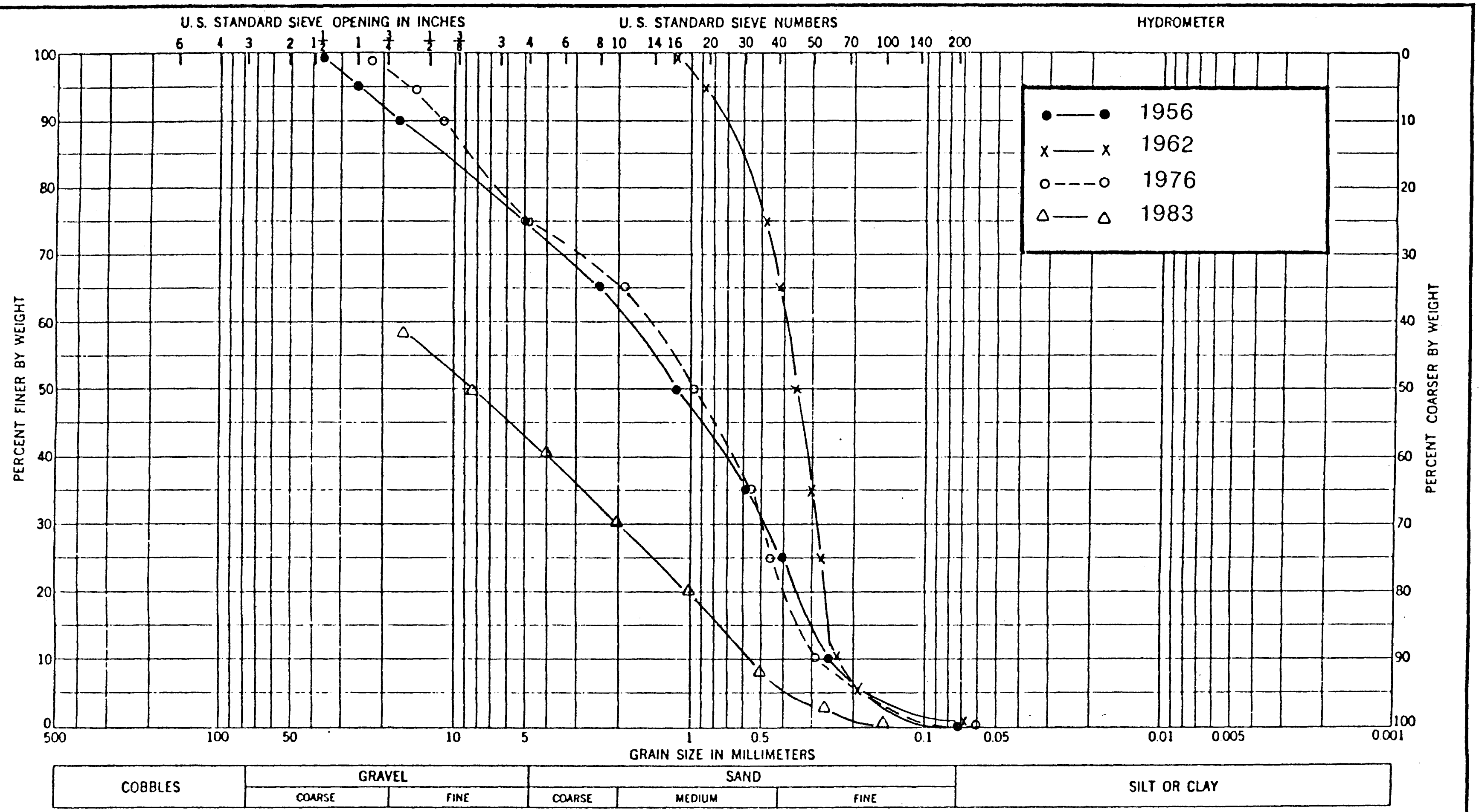
APPENDIX A

Sediment Sample Gradation Curves

Contents

A1

Historical Gradations



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

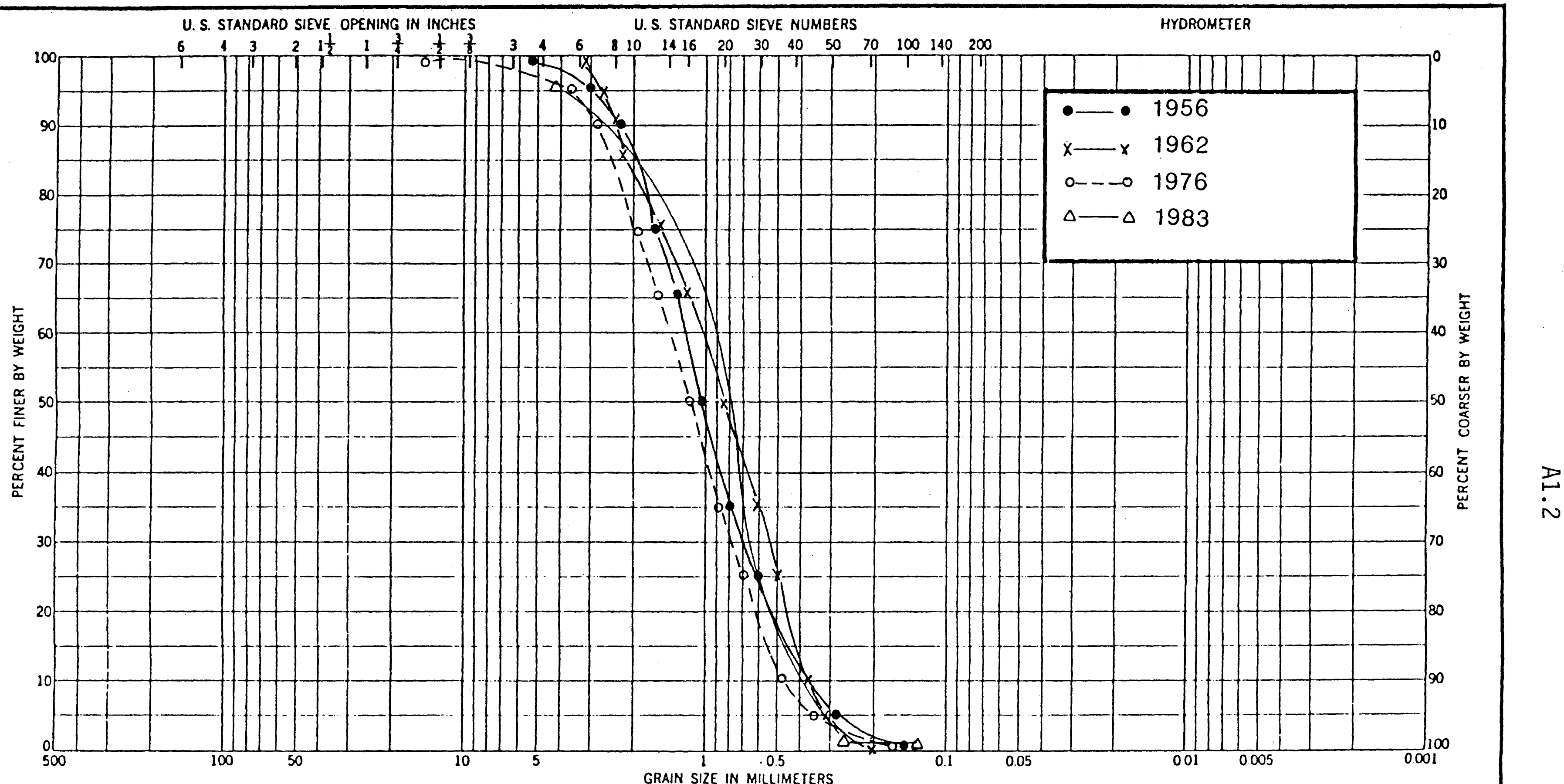
Area **RM 9.5-1956 & 1962,**

RM 9.7-1976, RM 9.7-1983

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

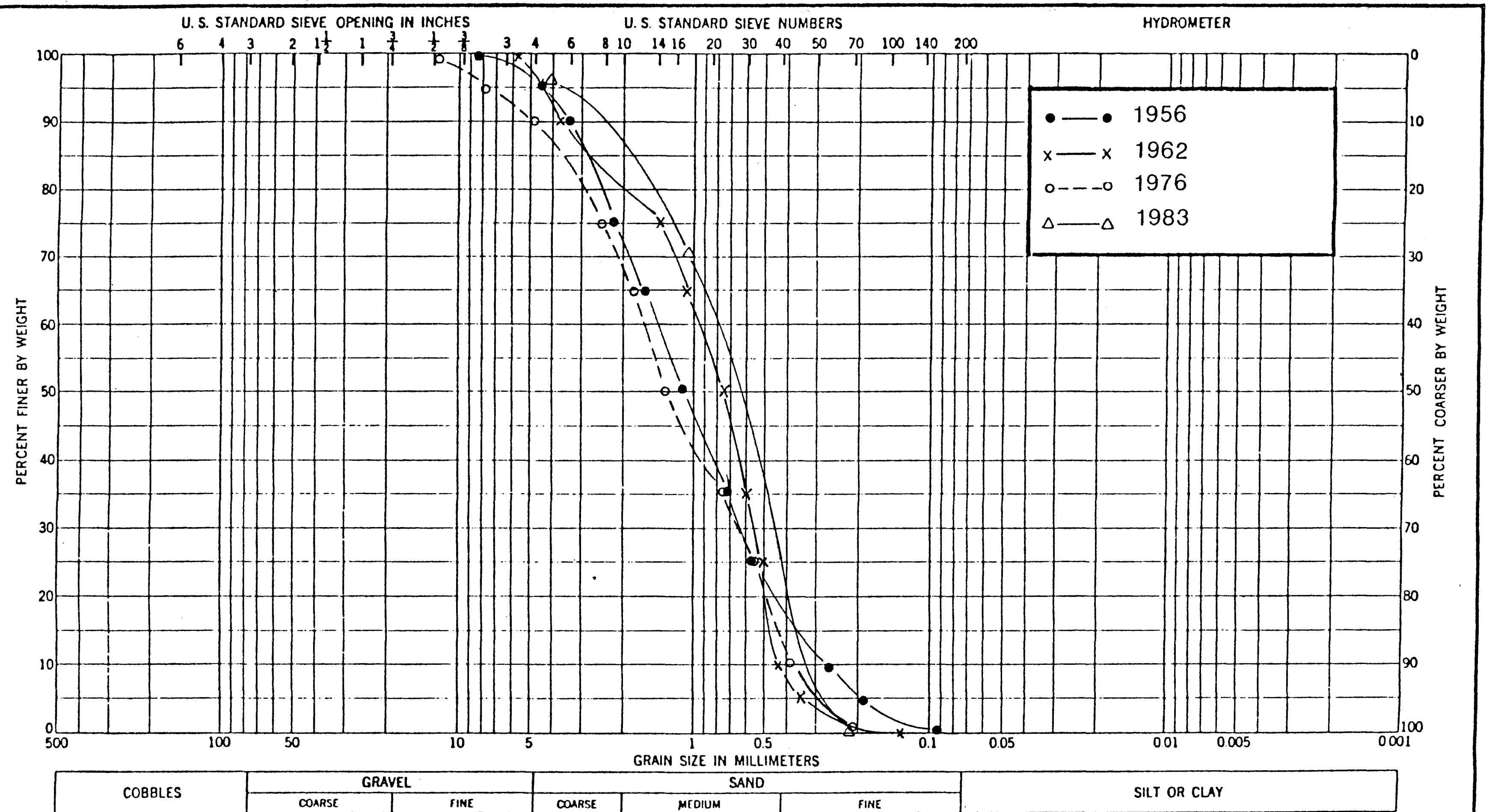
Area **RM 20.5-1956 & 1972**

Boring No.

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

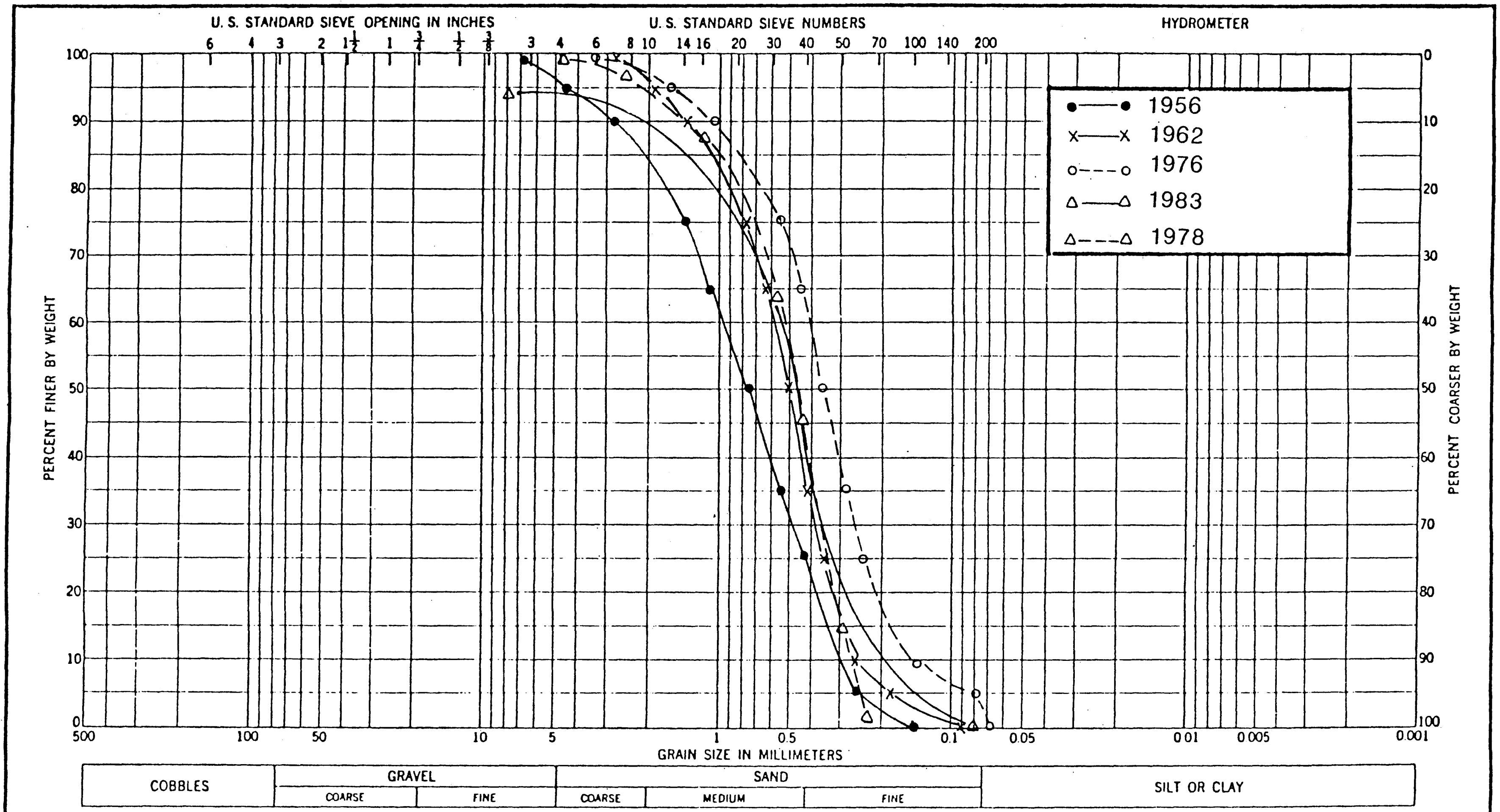
Project **KANSAS RIVER**
BED SAMPLES

Area **RM 30.0-1956 & 1976,**
RM 31.0-1962, RM 31.8-1983

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

Area **RM 41.0-1956, 1976 & 1983,**

RM 42.3-1962, RM 41.3-1978

Date

GRADATION CURVES

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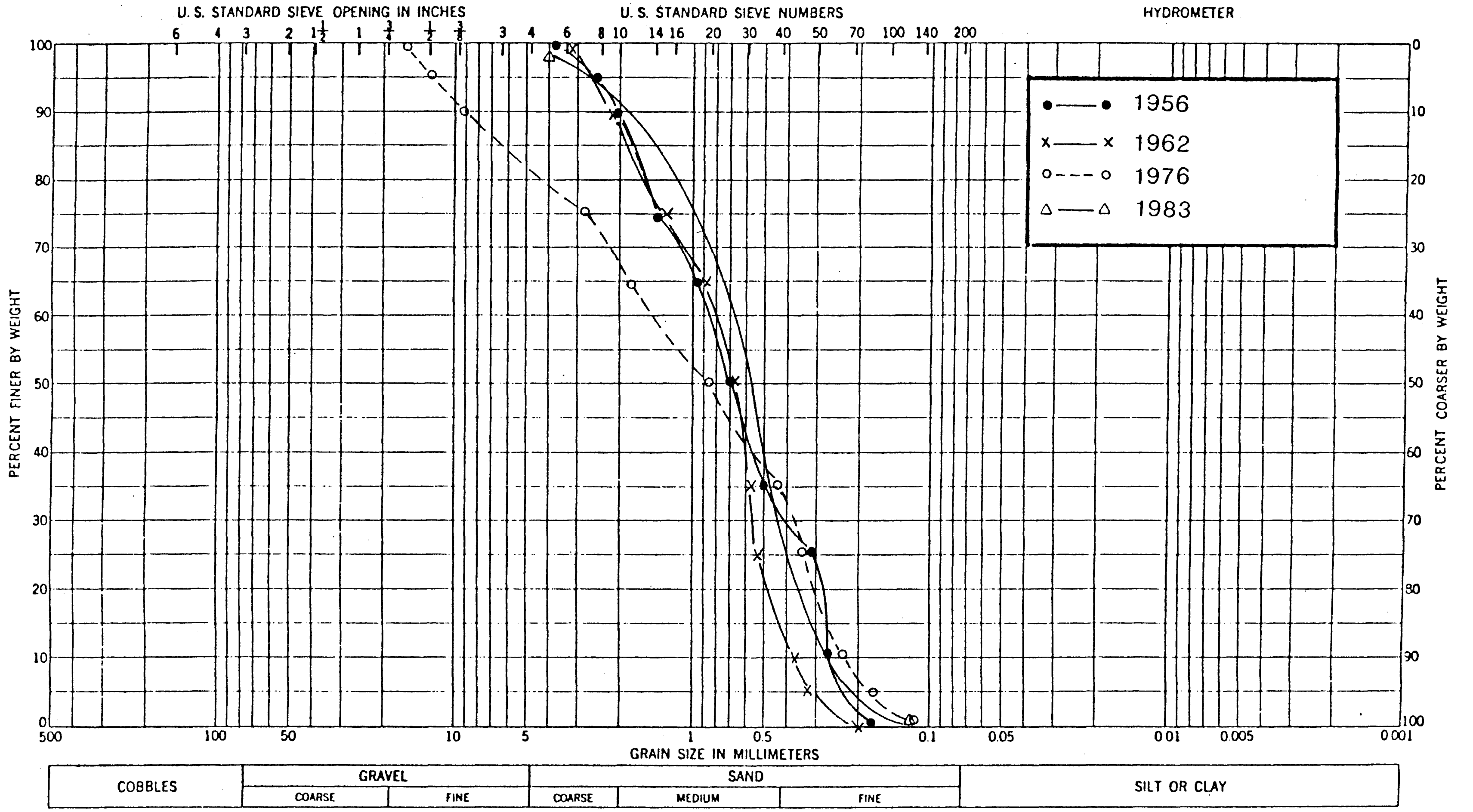


Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

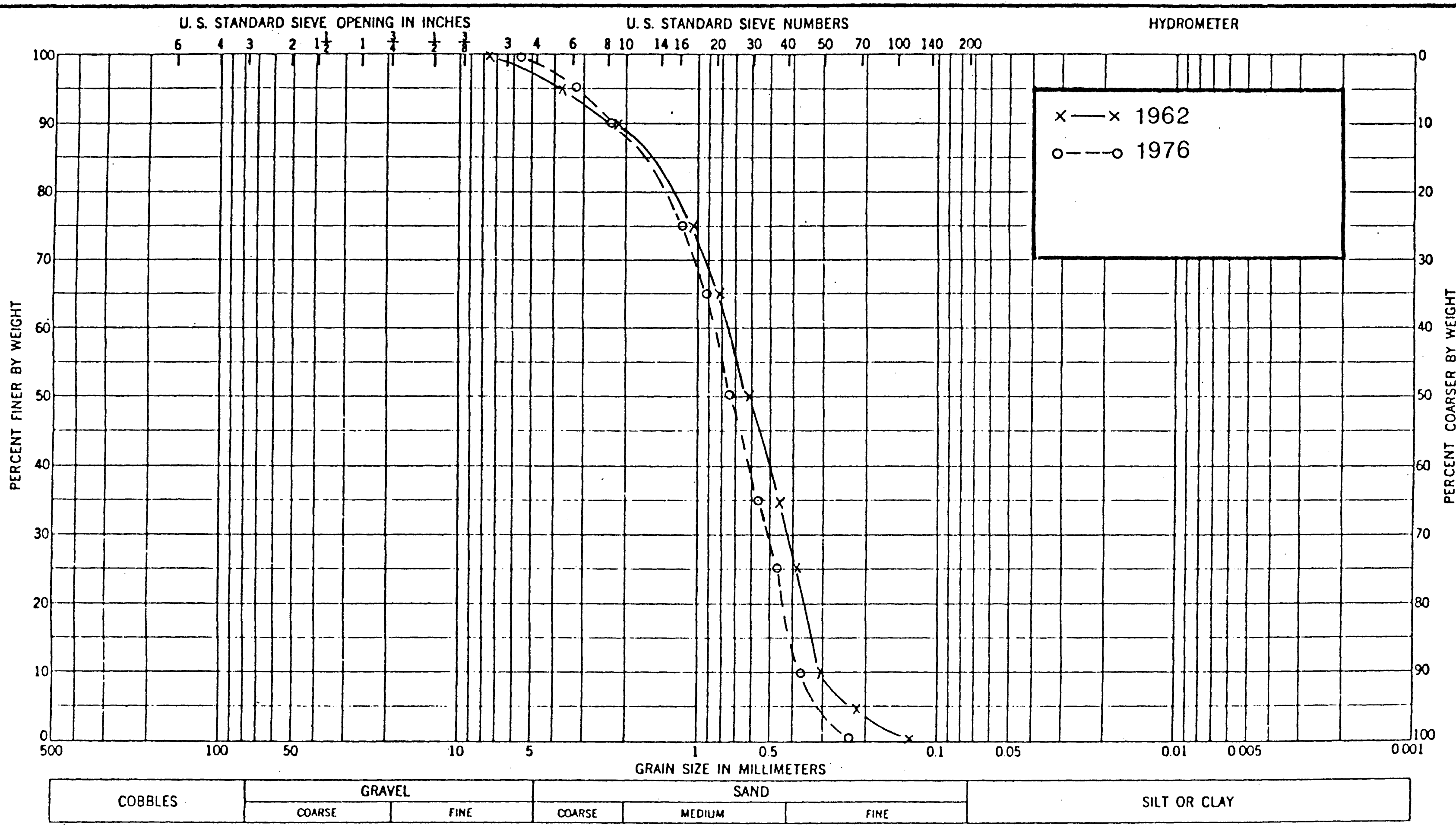
Area **RM 62.0-1956, 1972 & 1983**

RM 63.6-1962

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**
BED SAMPLES

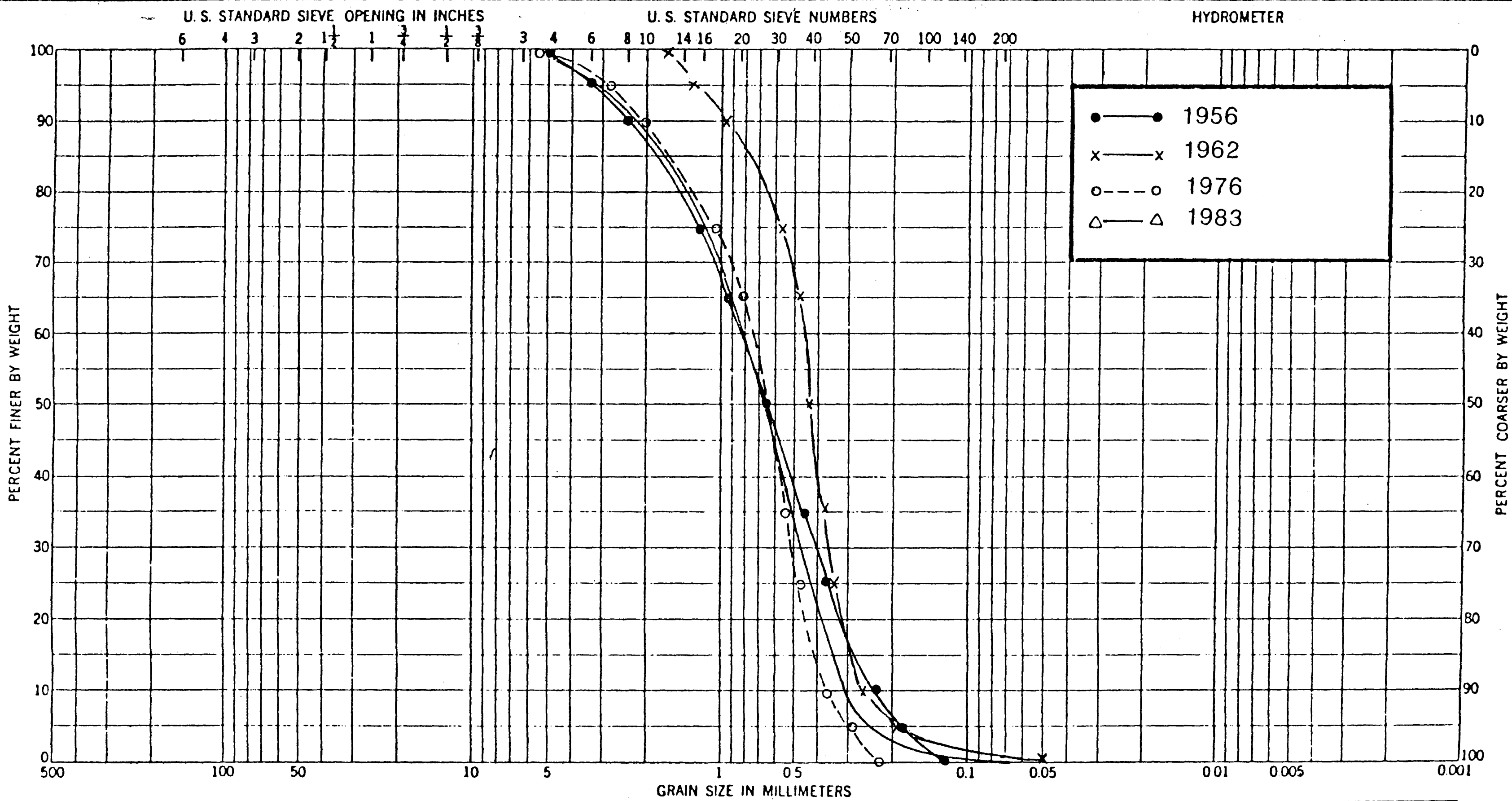
Area **RM 88.7-1976, RM 87.8-1962**

Boring No.

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

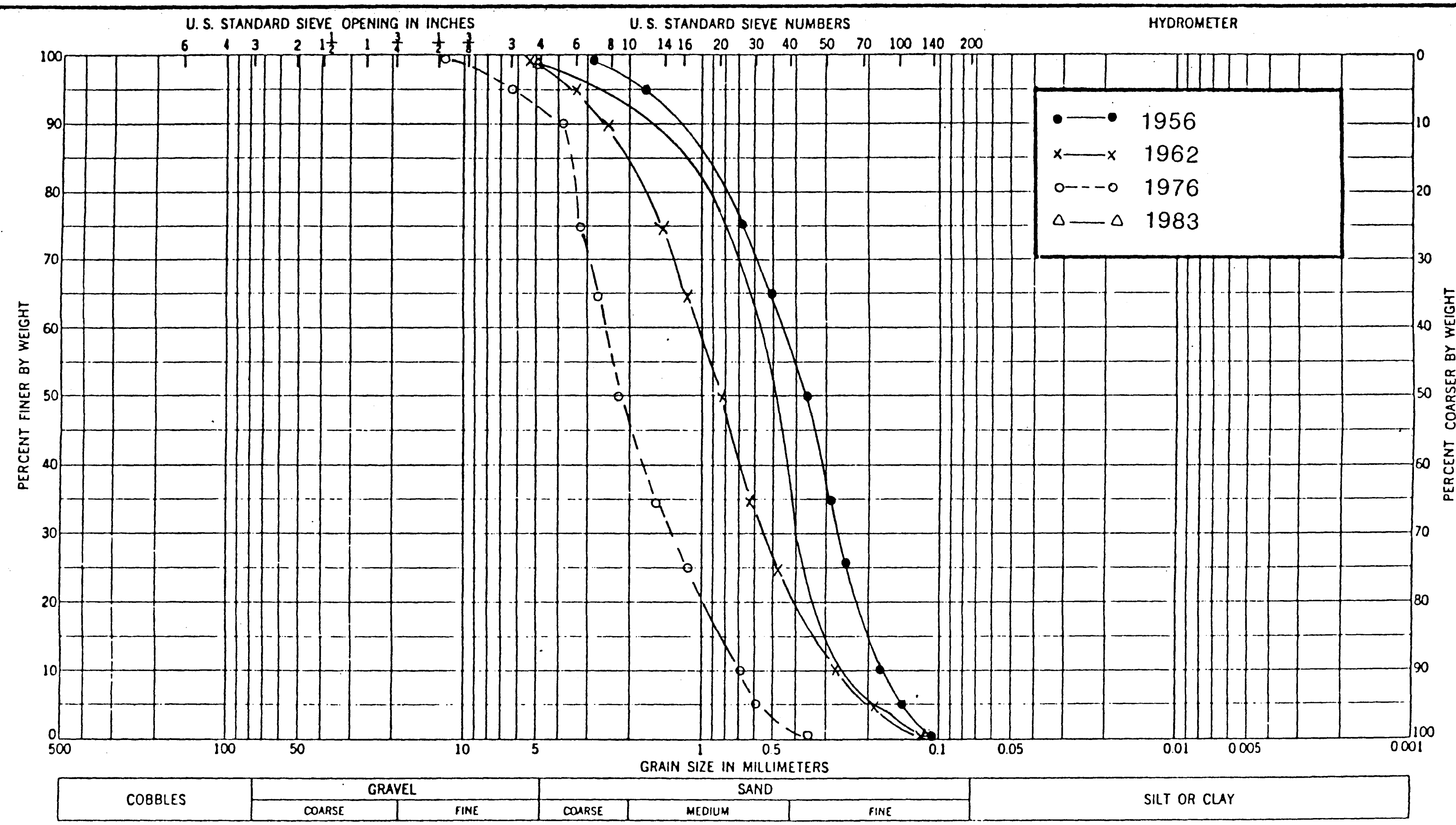
Project **KANSAS RIVER BED SAMPLES**

Area **RM 101.1-1962 & 1976, RM 103-1956 & 1983**

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

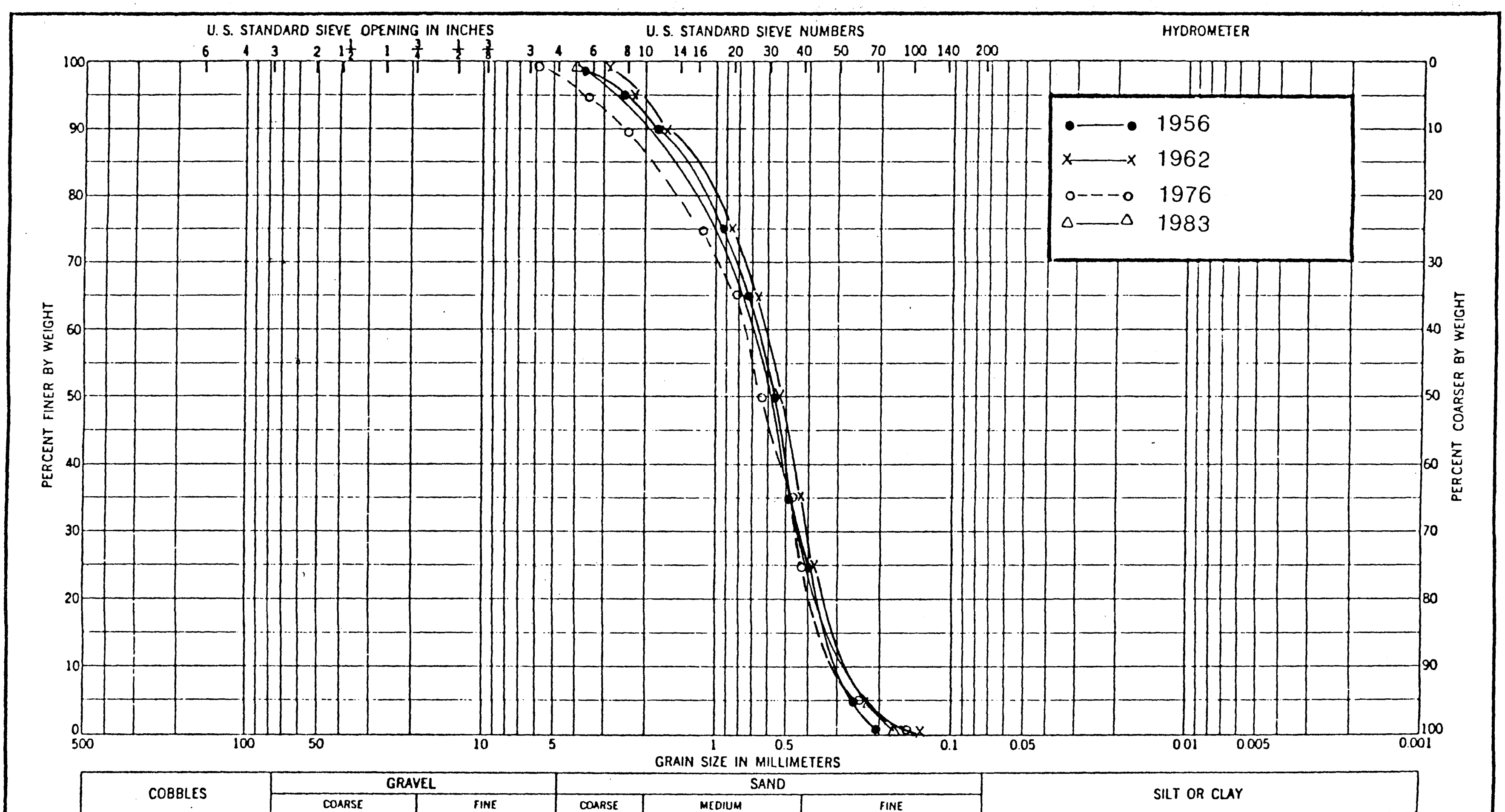
Area **RM 144-1983, RM 142-1956,**

RM 143.1-1962, RM 142.9-1976

Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BED SAMPLES

Area **RM 166-1956 & 1976,**

RM 162.1-1962, RM 168.5-1983

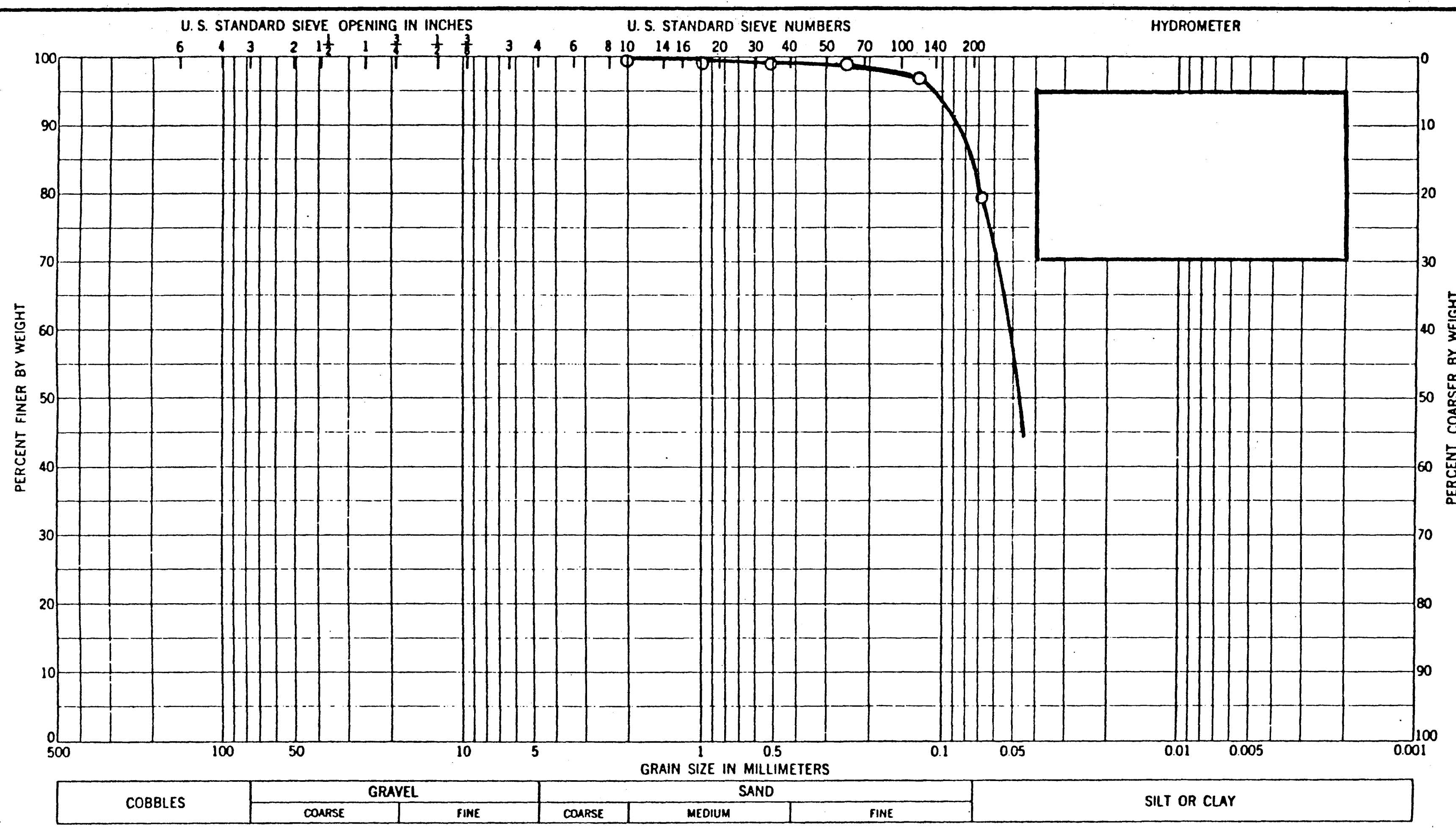
Date

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A2

1983 Bed Material Gradations



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

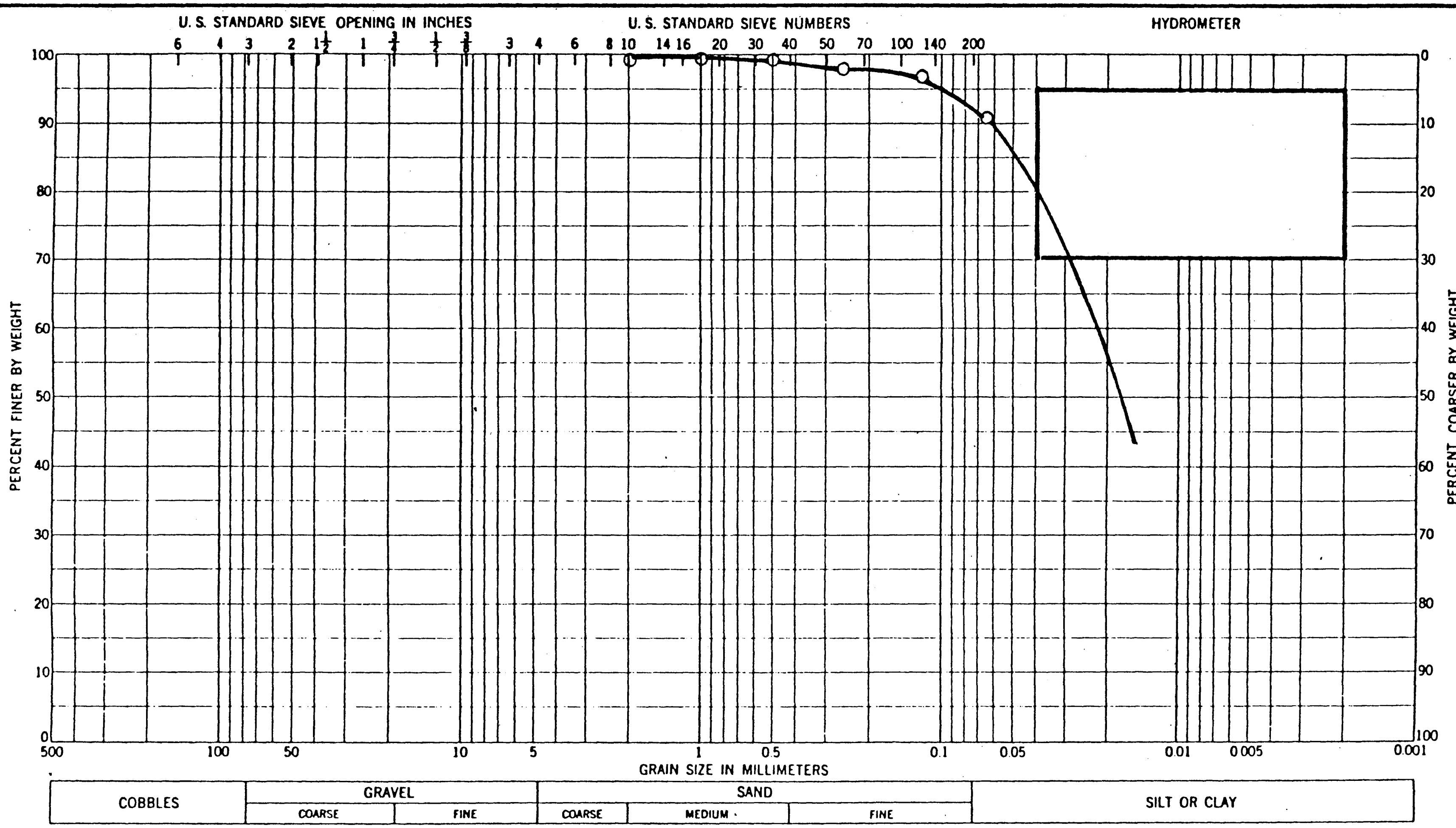
Area **BED SAMPLE**

Boring No. **RM 1.0**

Date **9/15/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

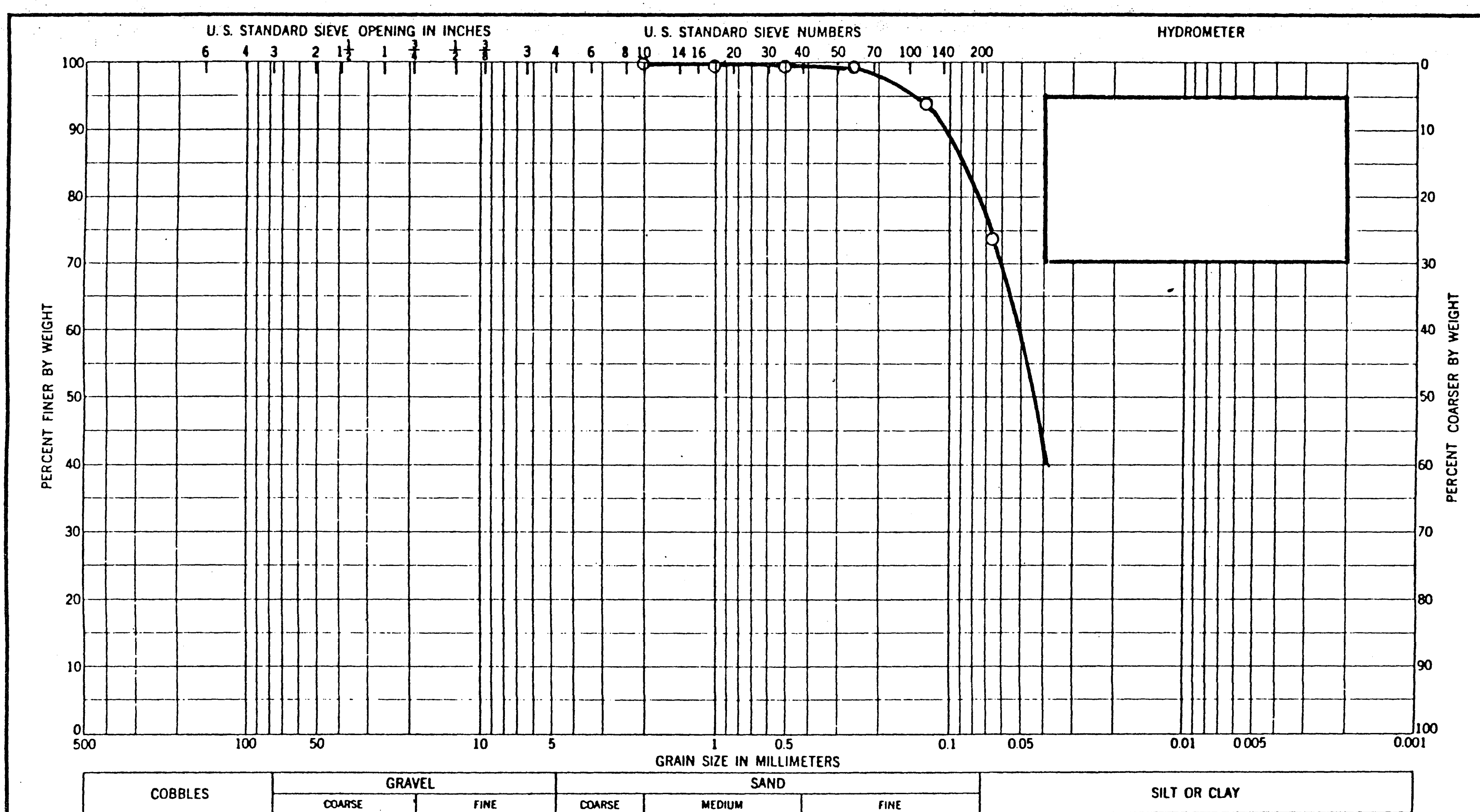
Area **BED SAMPLE**

Boring No. **RM 3.0**

Date **9/15/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

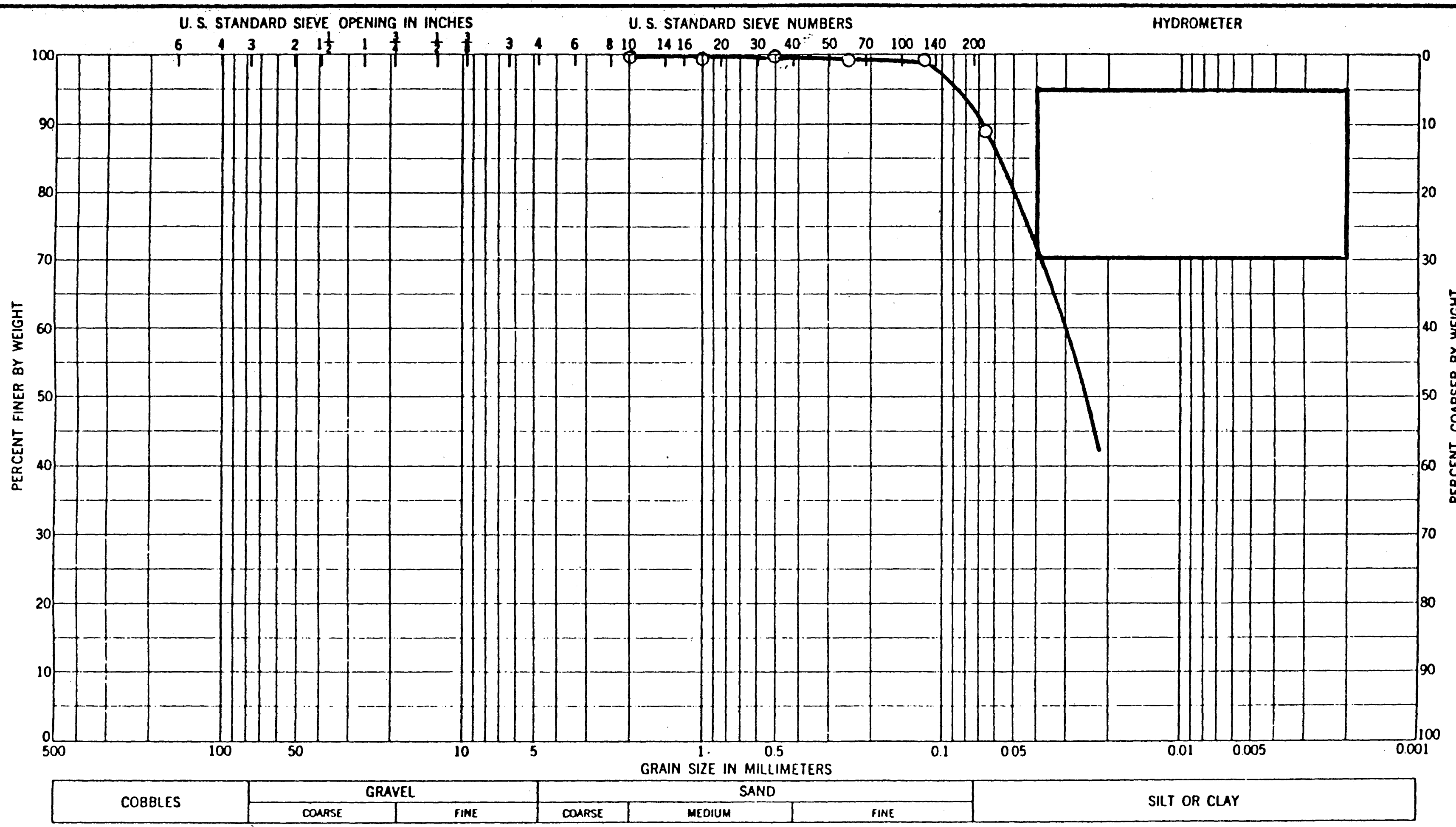
Area **BED SAMPLE**

Boring No. **RM 5.0**

Date **9/15/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.4

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project KS-COE-01

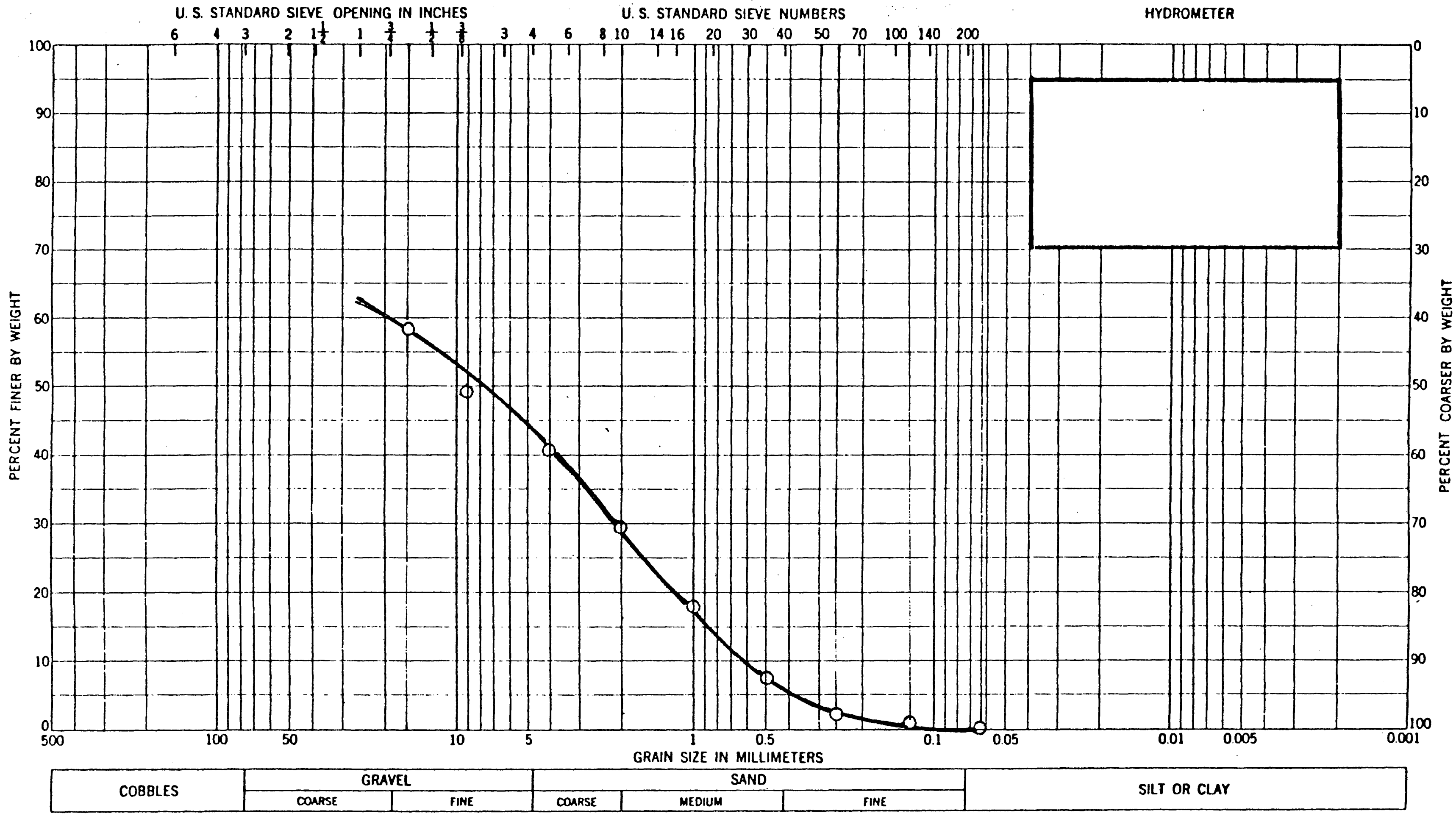
Area BED SAMPLE

Boring No. RM 7.0

Date 9/15/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

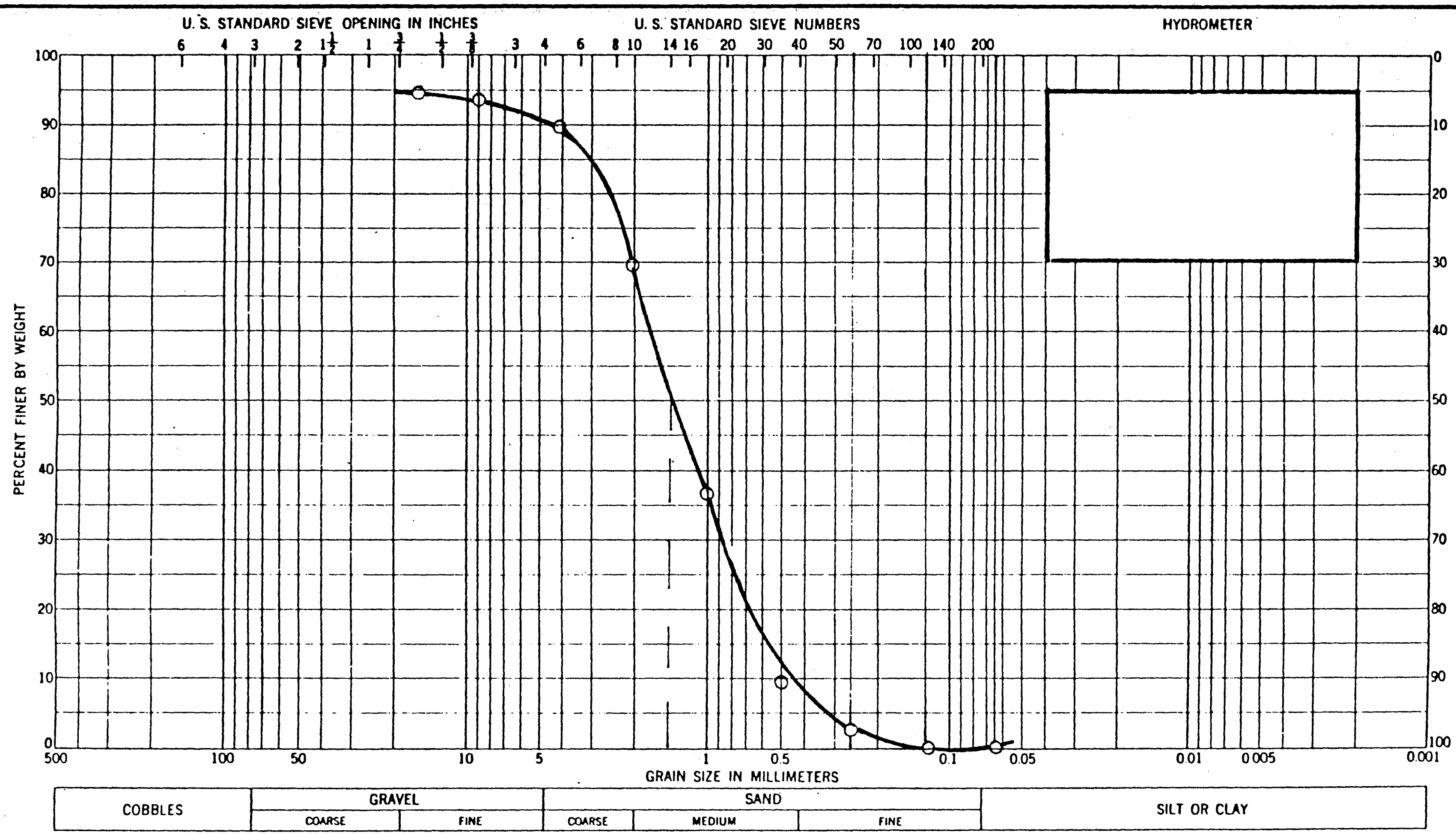
Area **BED SAMPLE**

Boring No. **RM 9.7**

Date **10/4/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.6

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

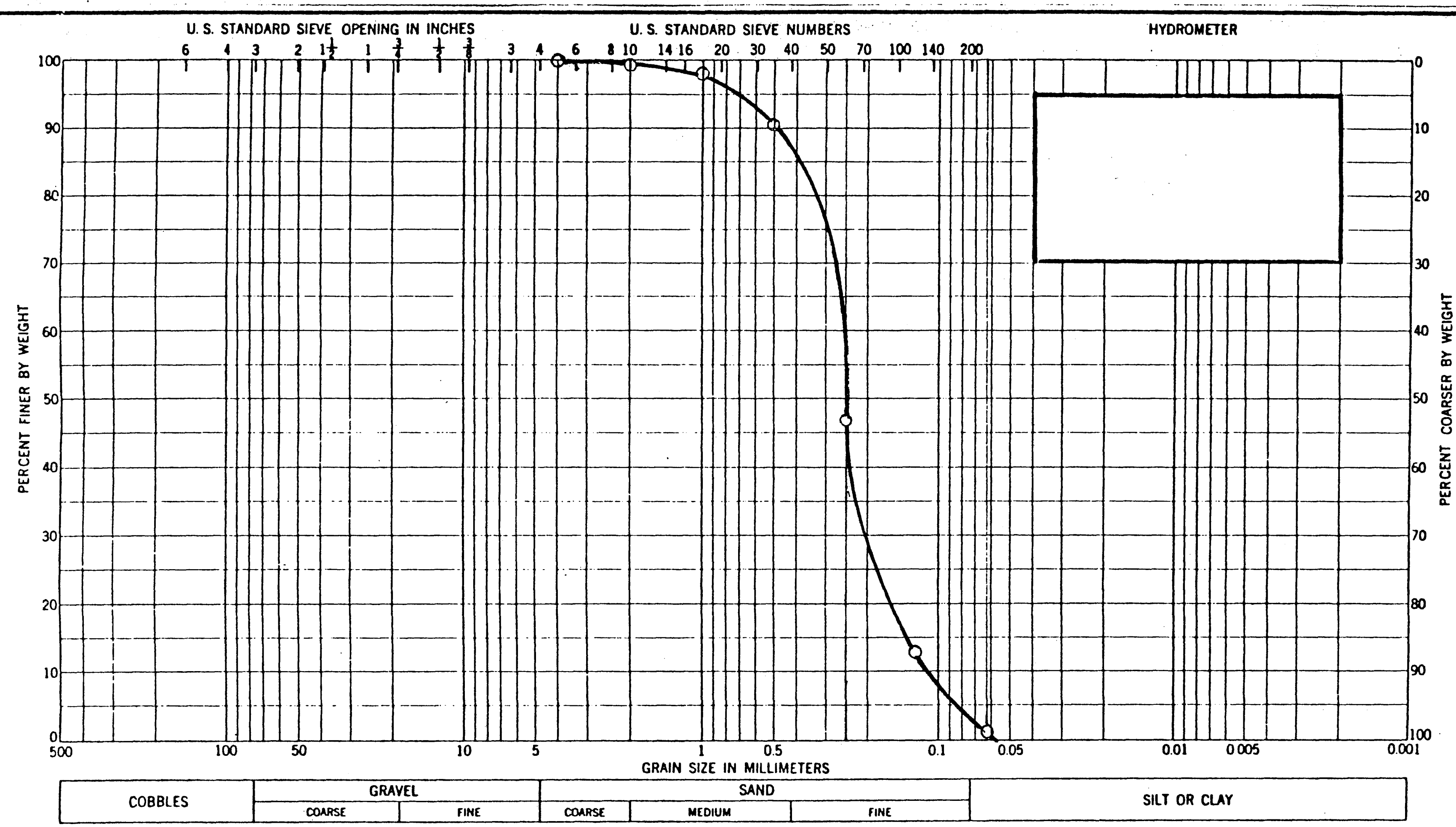
Area **SUBSURFACE BED SAMPLE**

Boring No. **RM 12.2**

Date **10/4/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.7

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

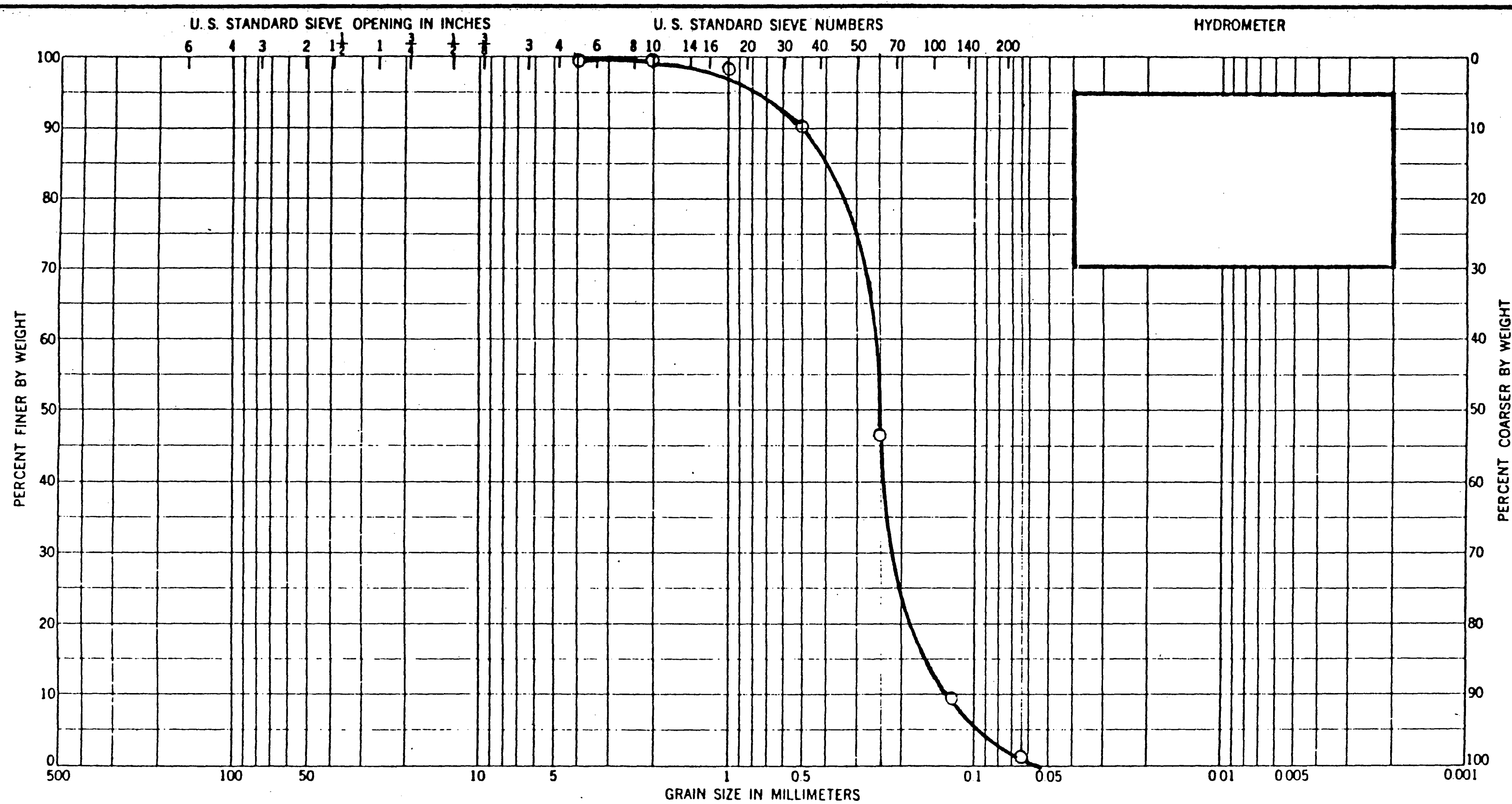
Area **SUBSURFACE BED SAMPLE**

Boring No. **RM 15.5**

Date **10/4/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

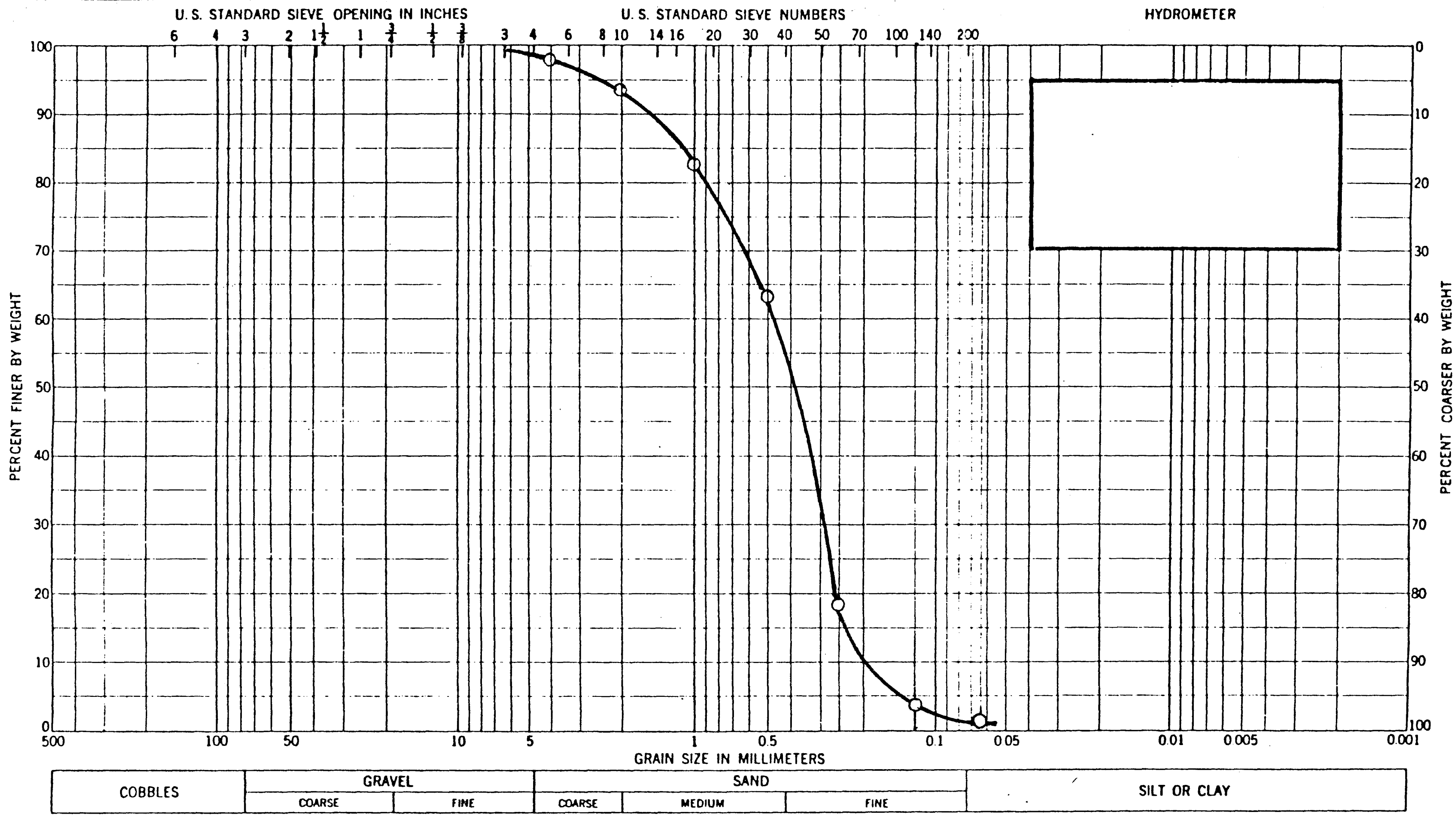
Area **SUBSURFACE BED SAMPLE**

Boring No. **RM 15.5**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

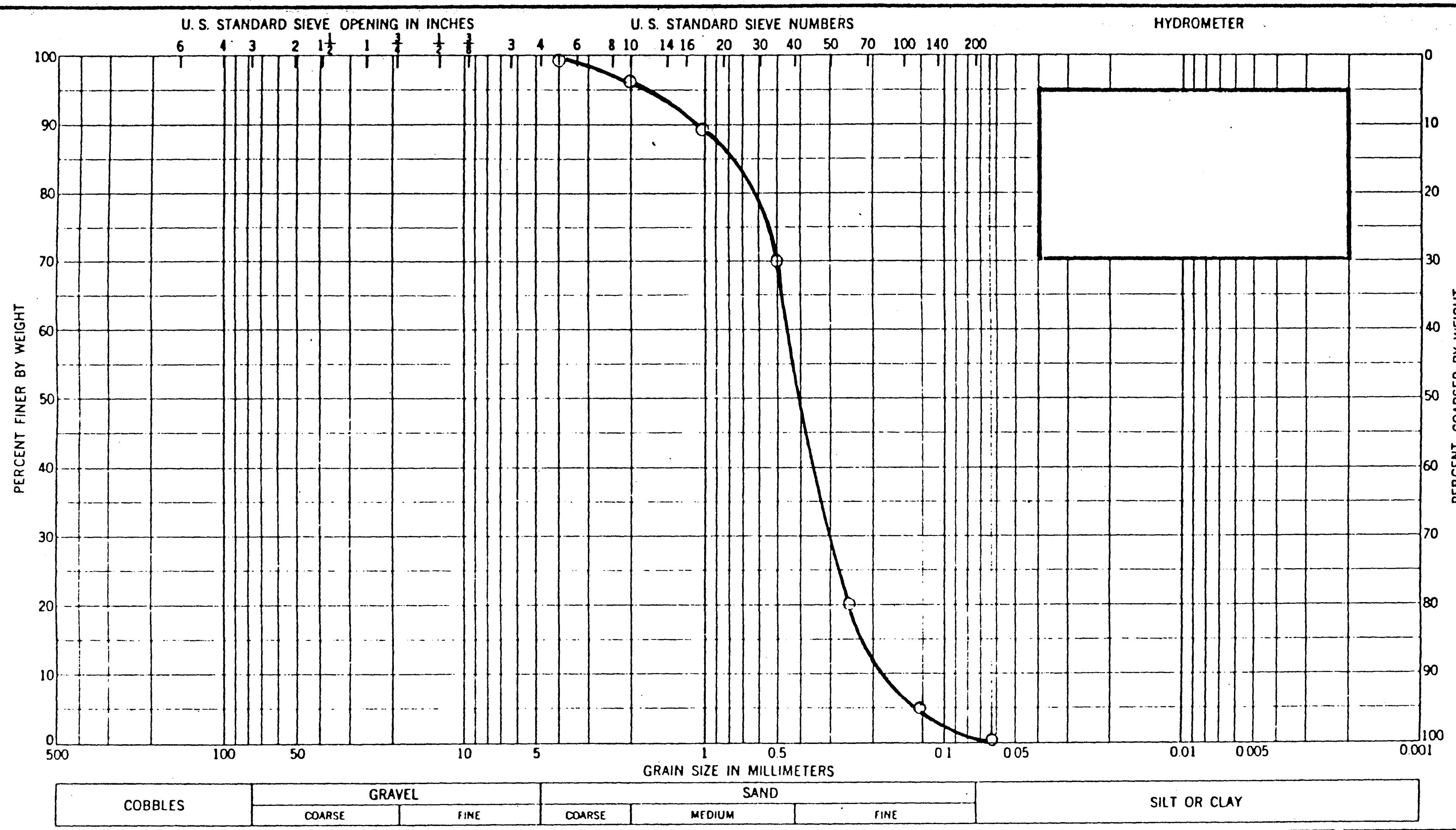
Area **SURFACE BED MATERIAL SAMPLE**

Boring No. **RM 16.2**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.10

Sample No	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project KS-COE-01

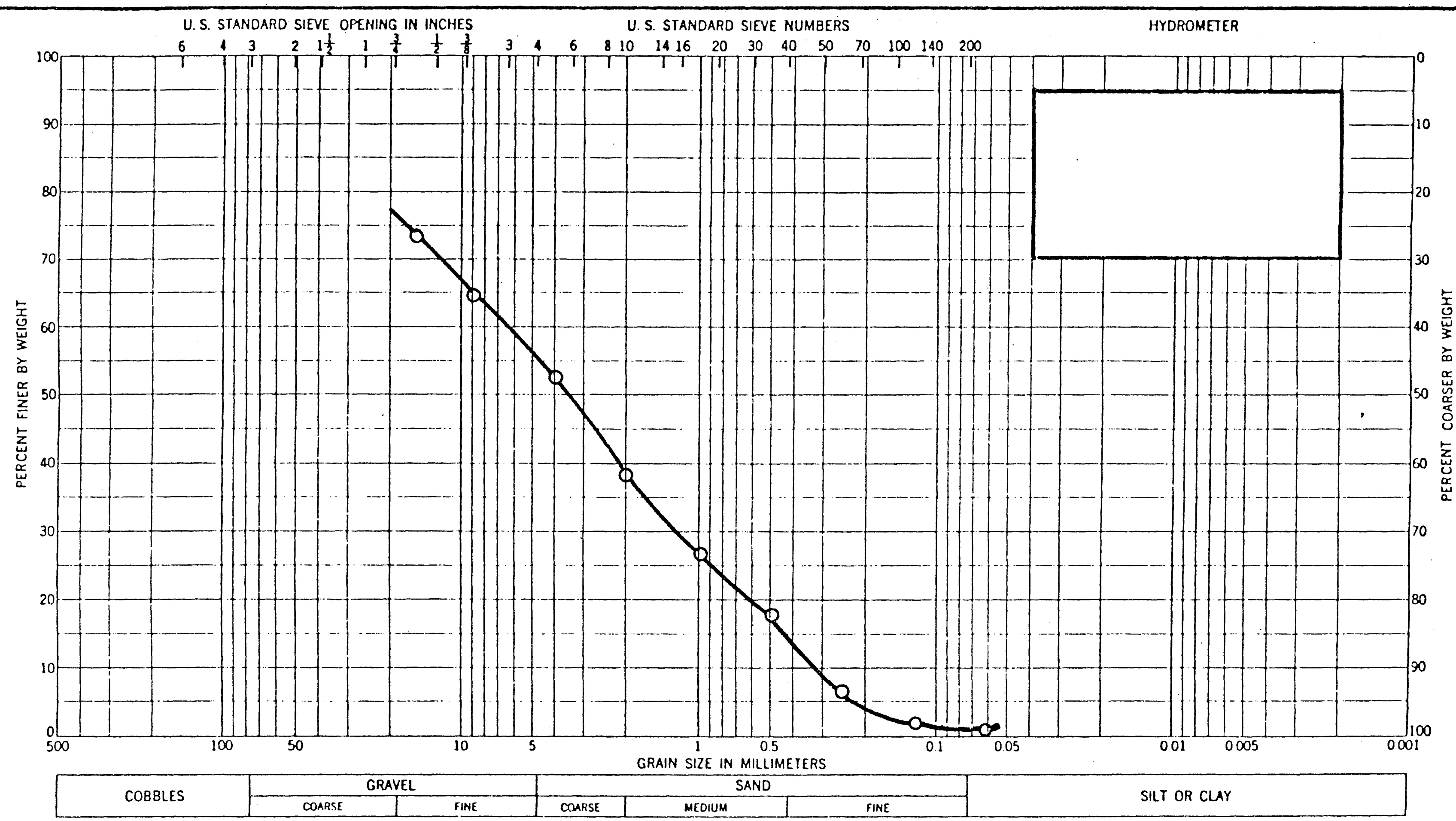
Area SUBSURFACE BED SAMPLE

Boring No. RM 16.2

Date 10/3/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

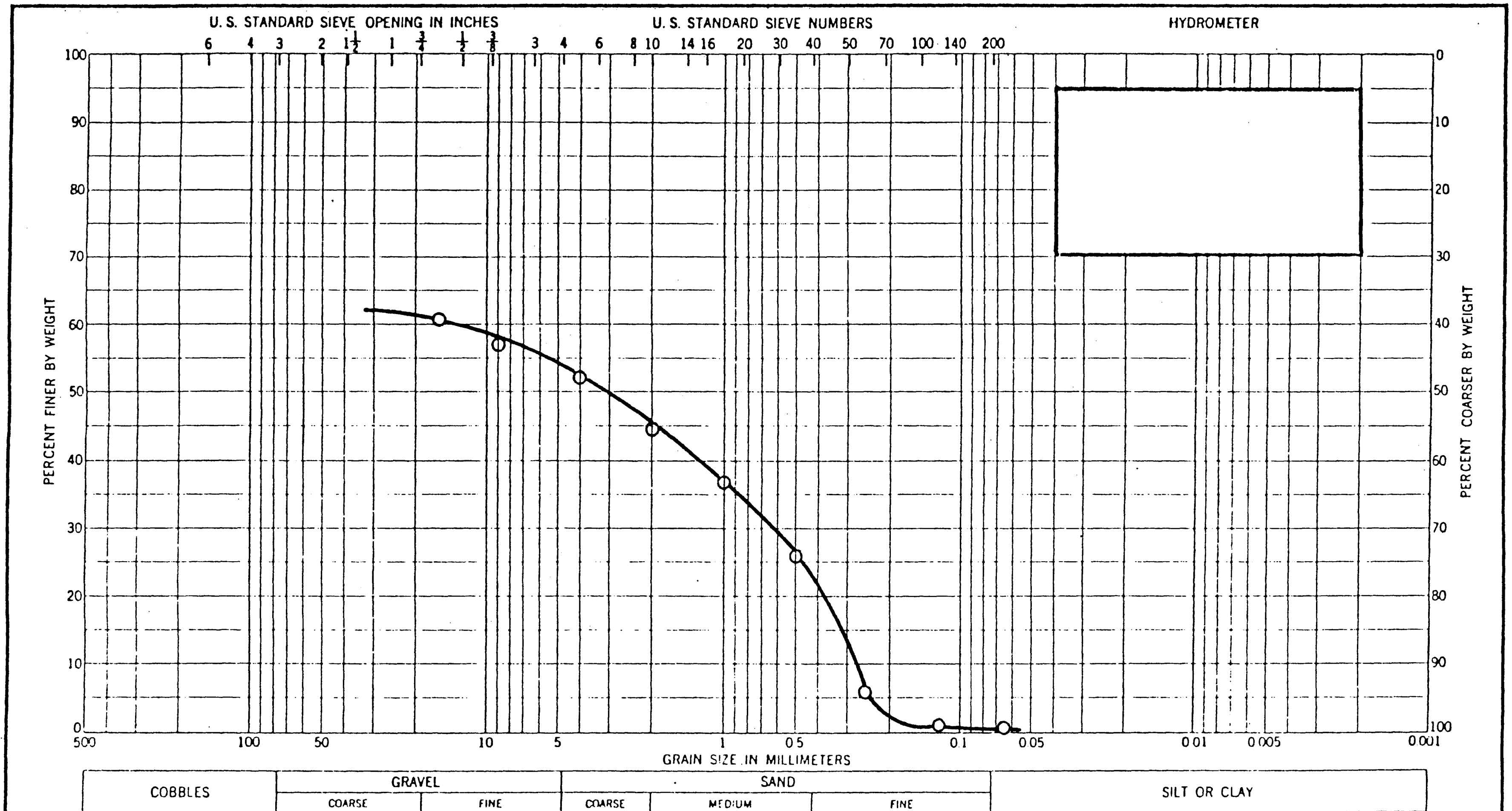
Project **KS-COE-01**

Area **SURFACE BED SAMPLE**

Boring No. **RM 19.5**

Date **10/3/83**

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

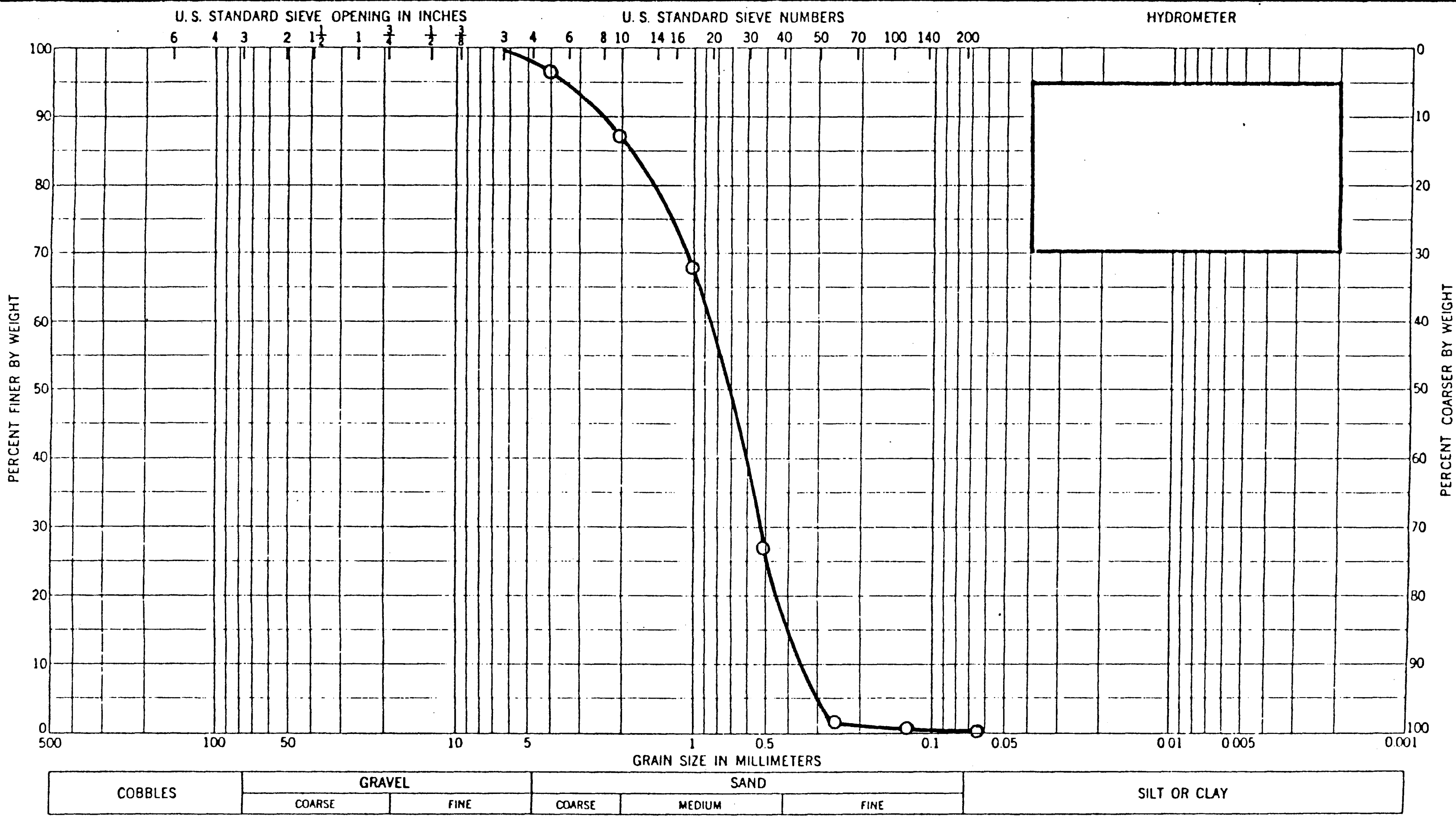
Area **SUBSURFACE BED SAMPLE**

Boring No. **RM 19.5**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

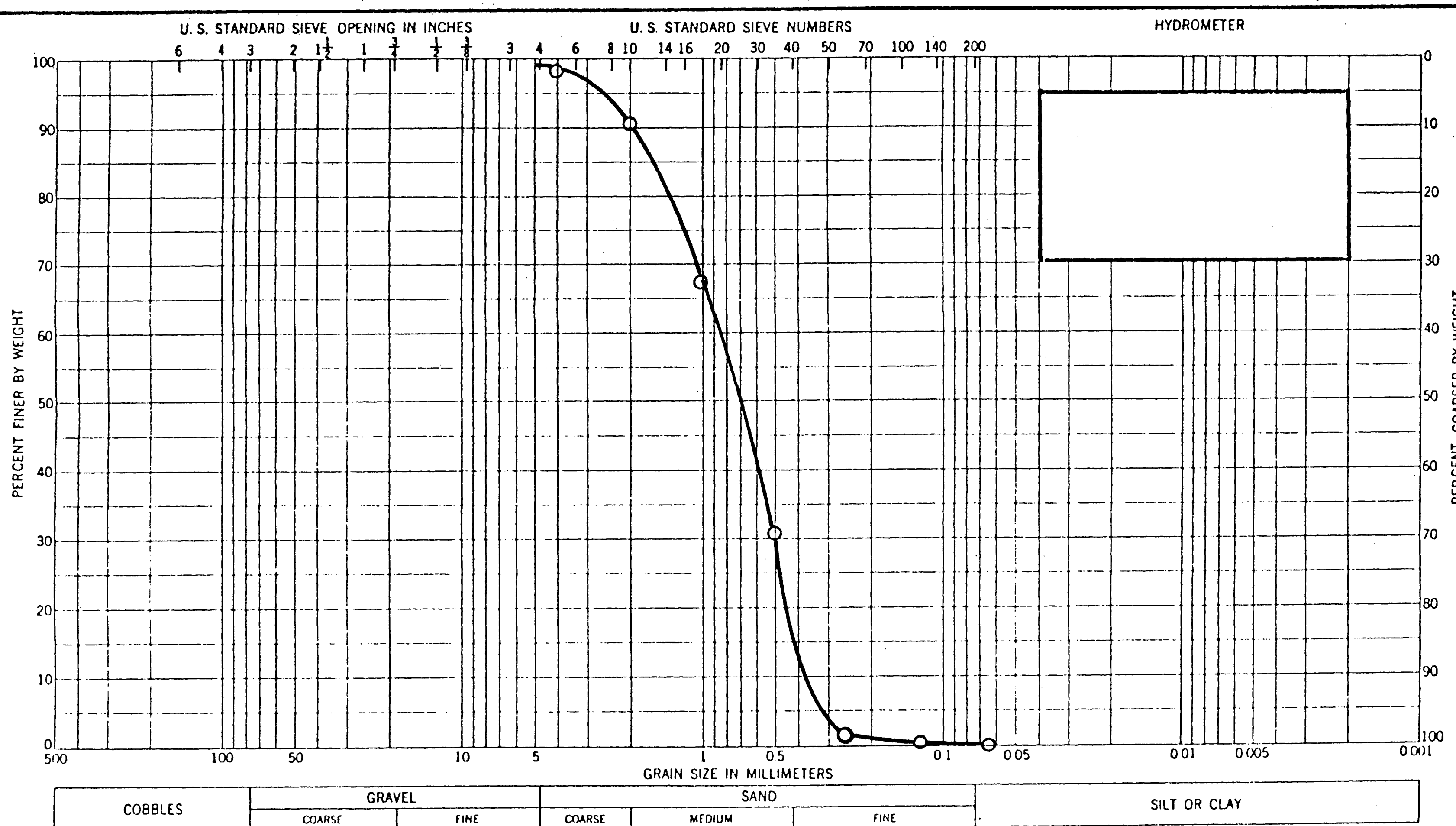
Area **BED SAMPLE**

Boring No. **RM 20.5**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

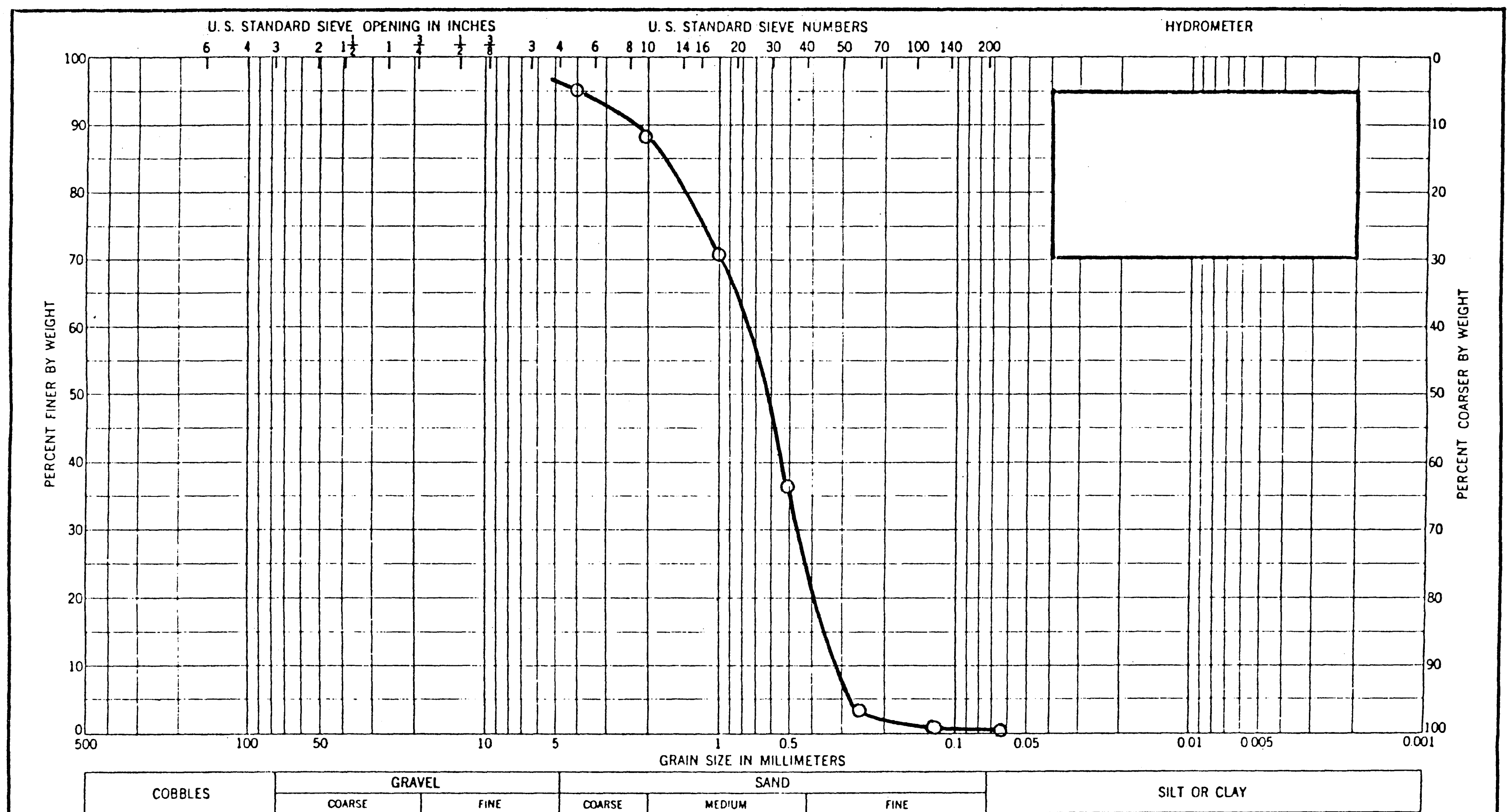
Area **BED SAMPLE**

Boring No. **RM 26**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

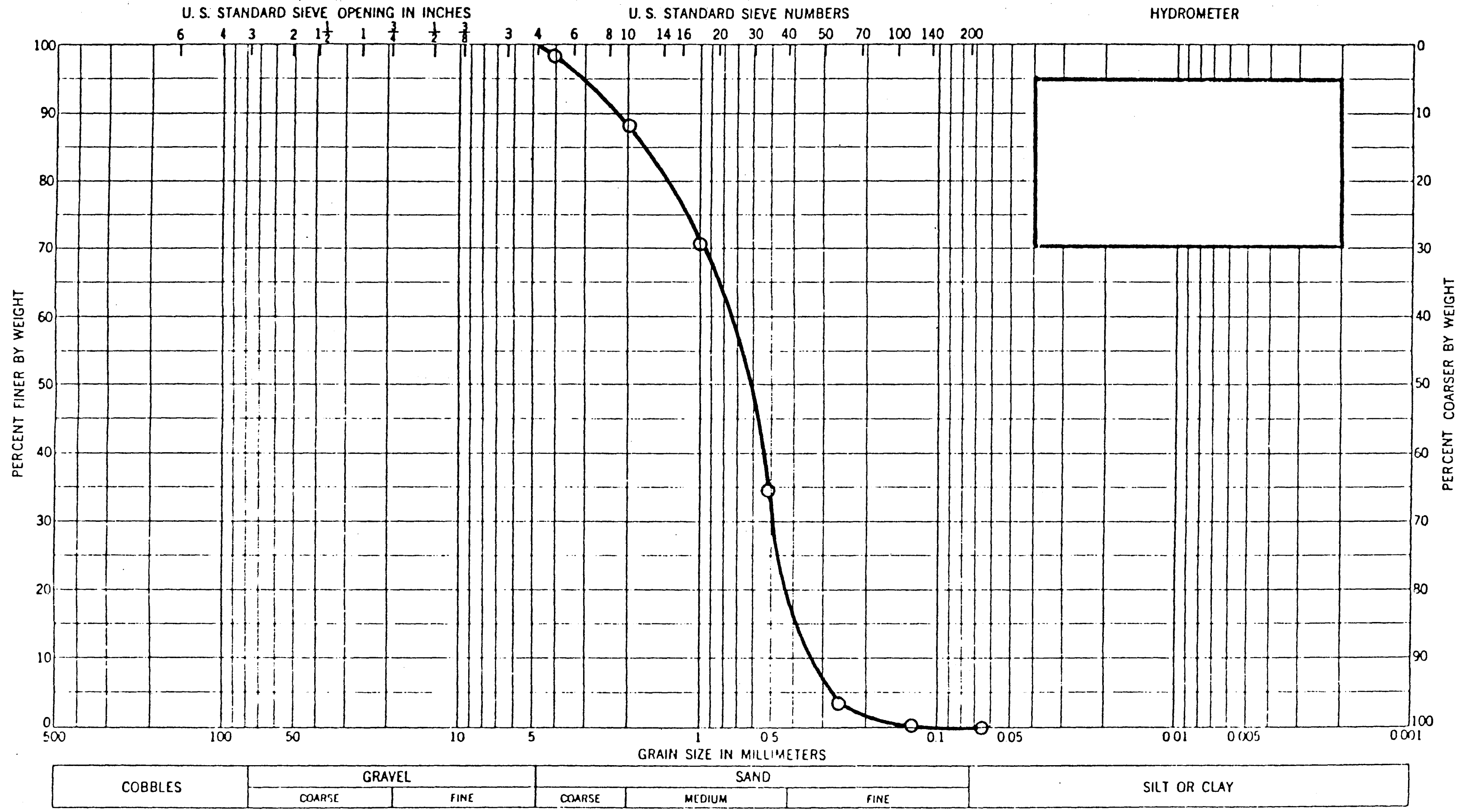
Area **BED SAMPLE**

Boring No. **RM 31.8**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.16

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project KS-COE-01

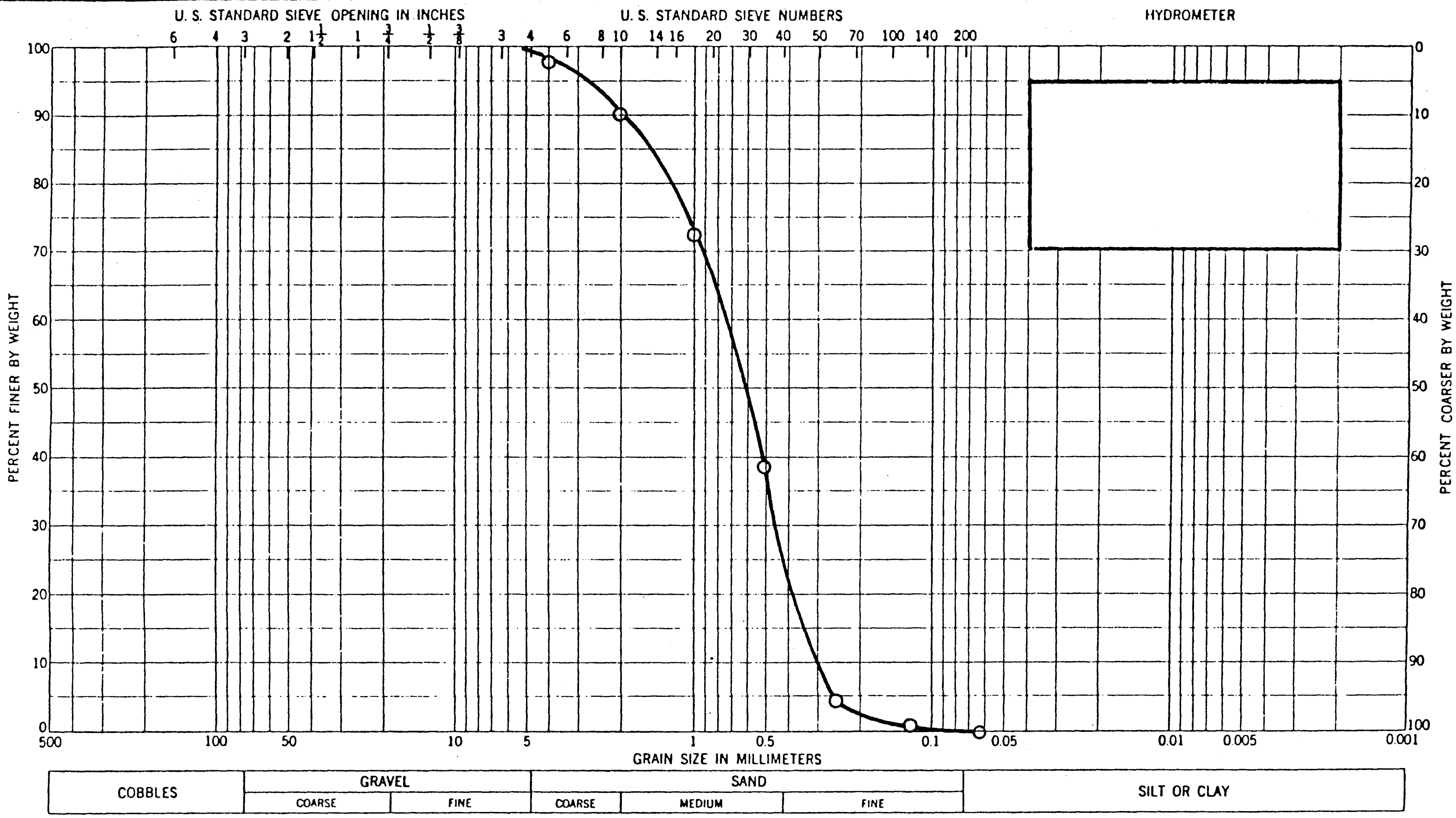
Area BED SAMPLE

Boring No. RM 28

Date 10/4/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.17

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

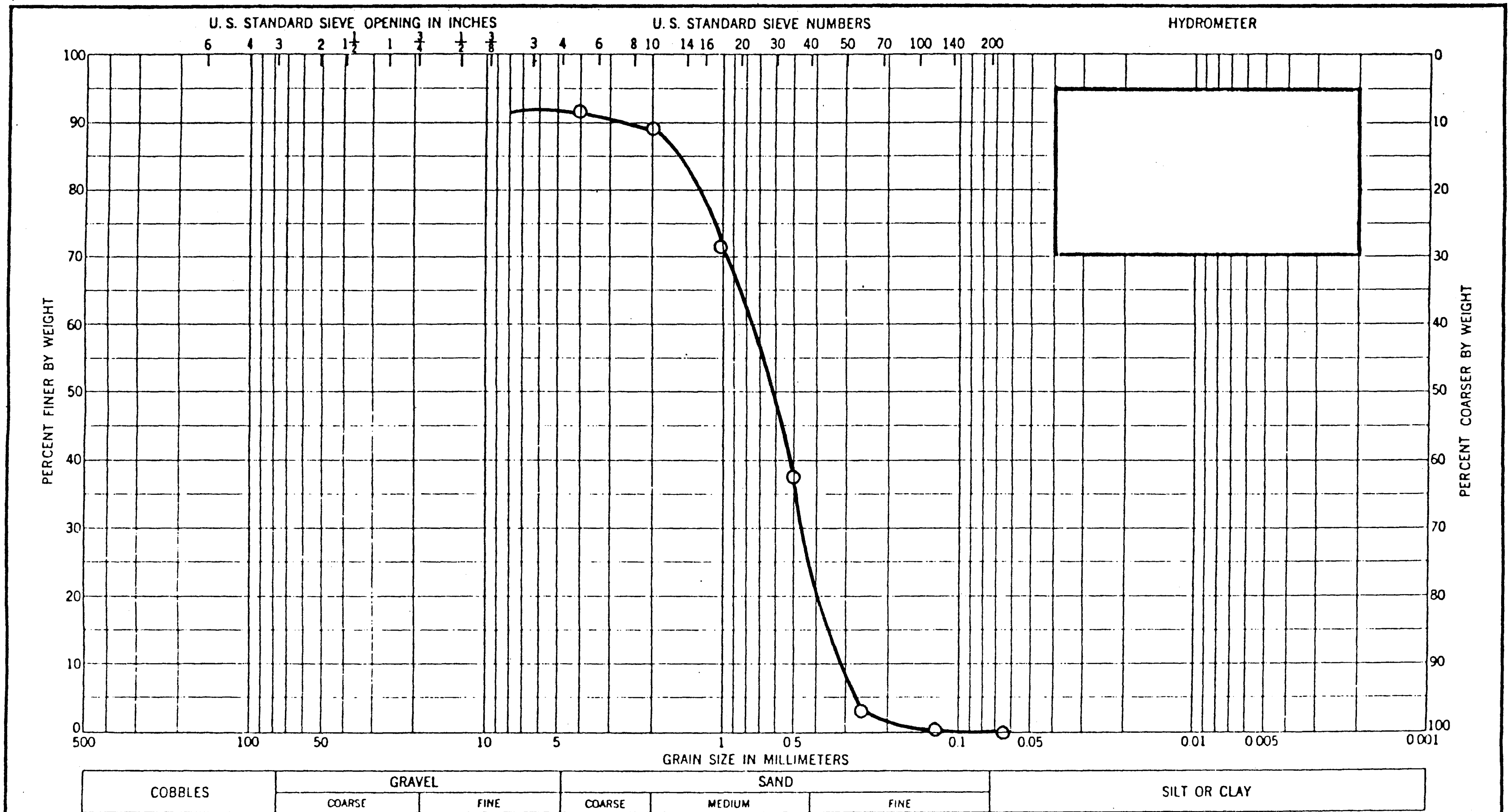
Area **BED SAMPLE**

Boring No. **RM 32.8**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

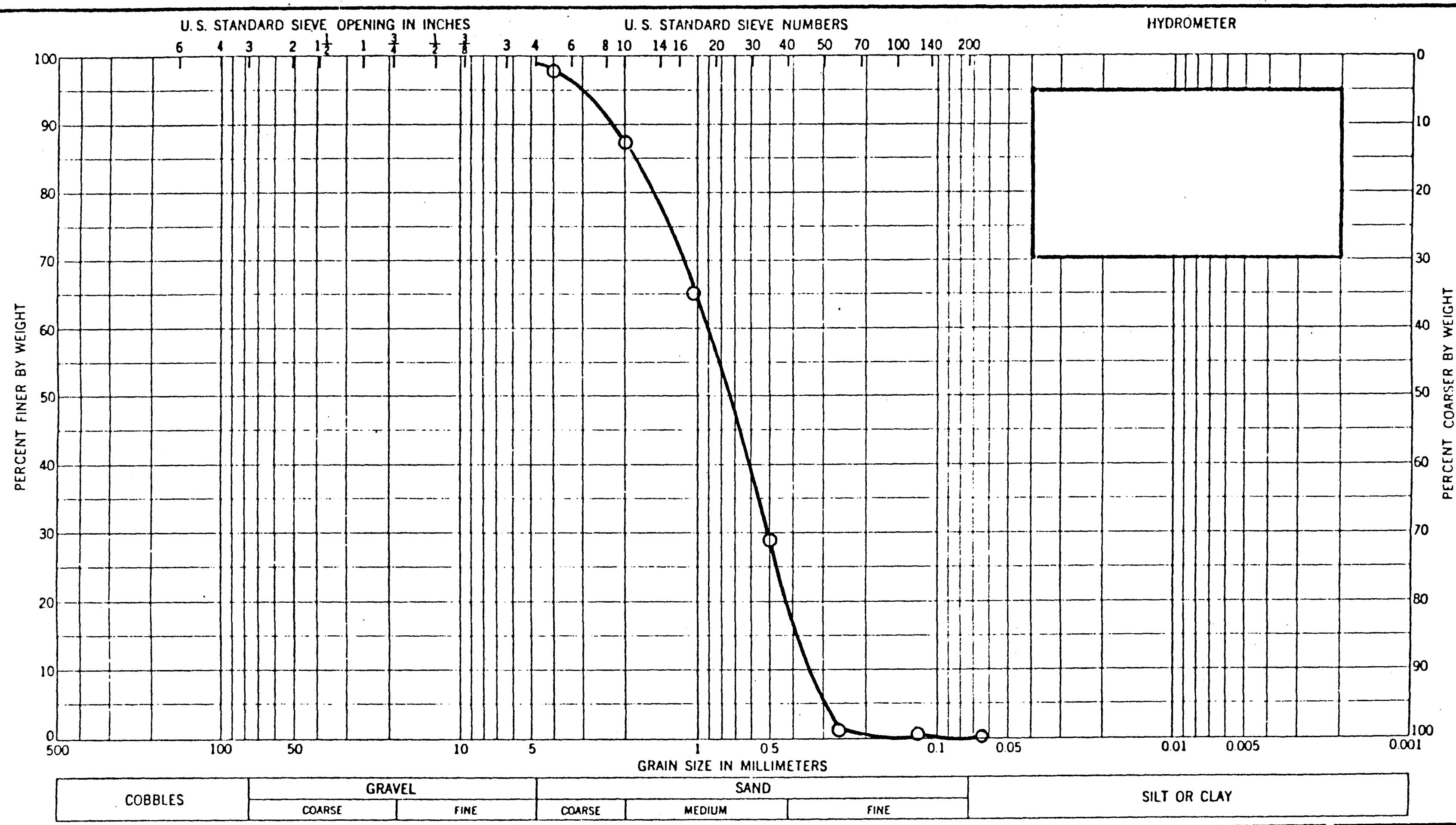
Area **BED SAMPLE**

Boring No. **RM 33.5**

Date **10/4/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

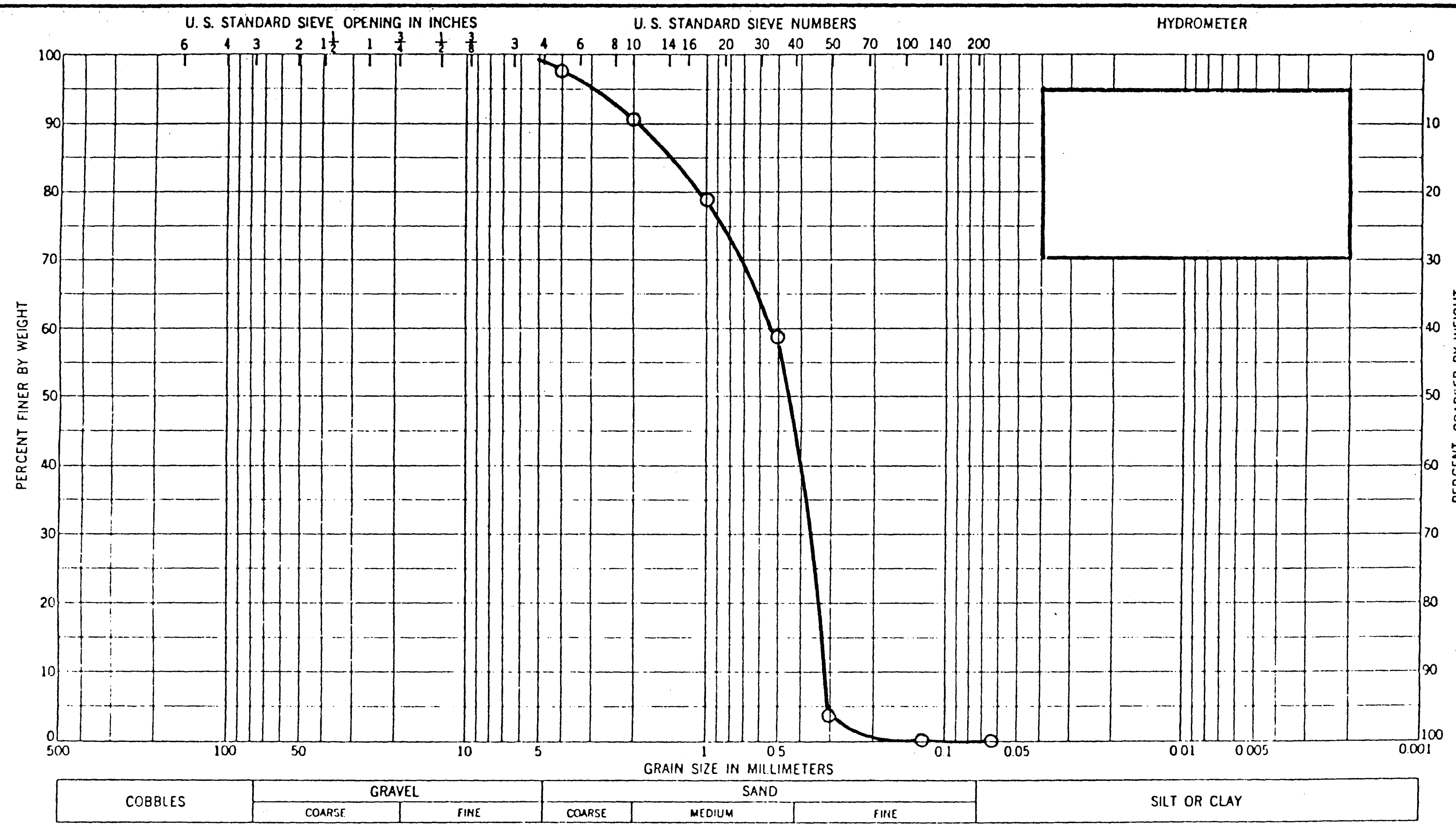
Area **BED SAMPLE**

Boring No. **RM 37**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.20

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

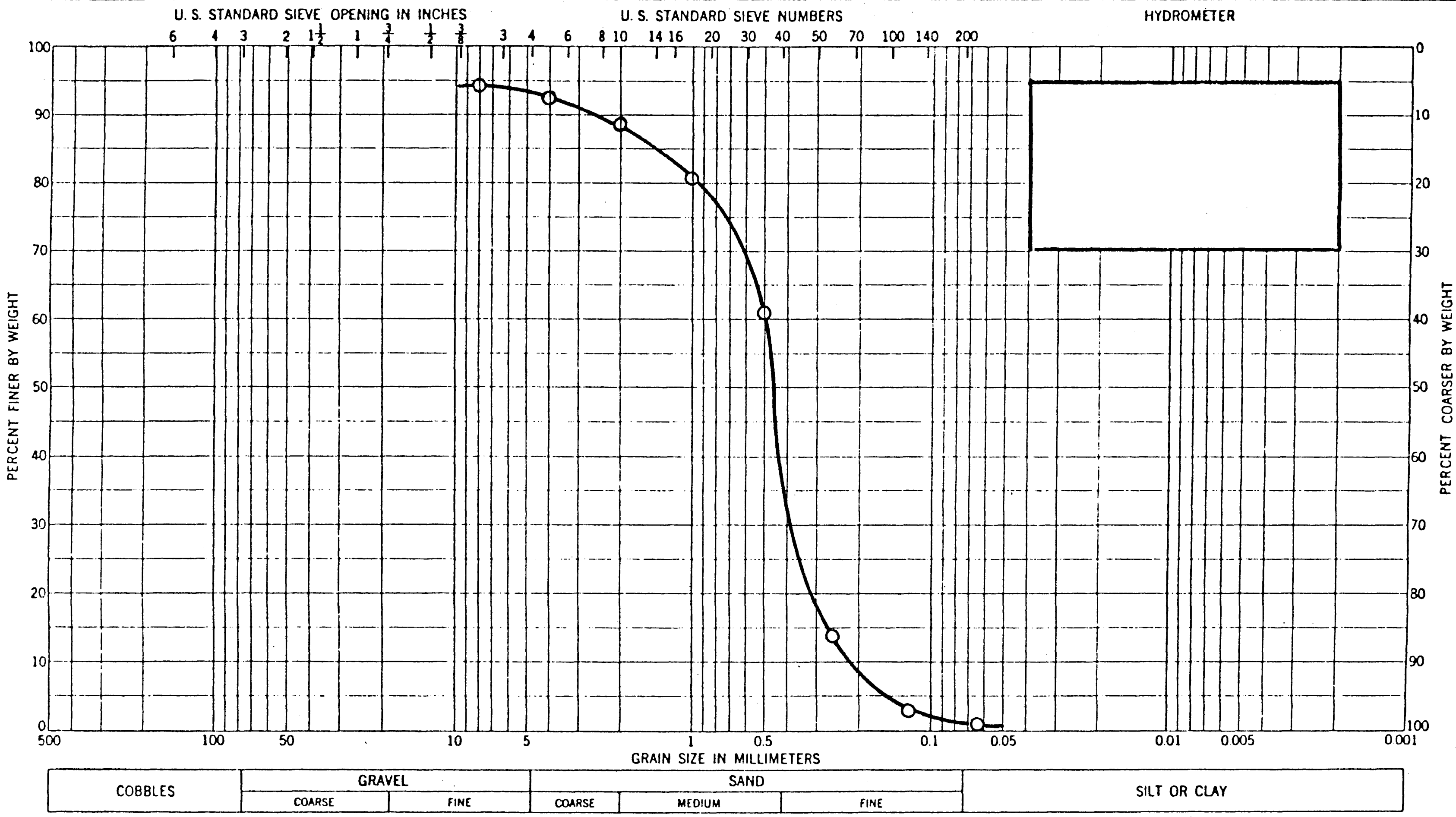
Area **BED SAMPLE**

Boring No. **RM 39.6**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.21

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

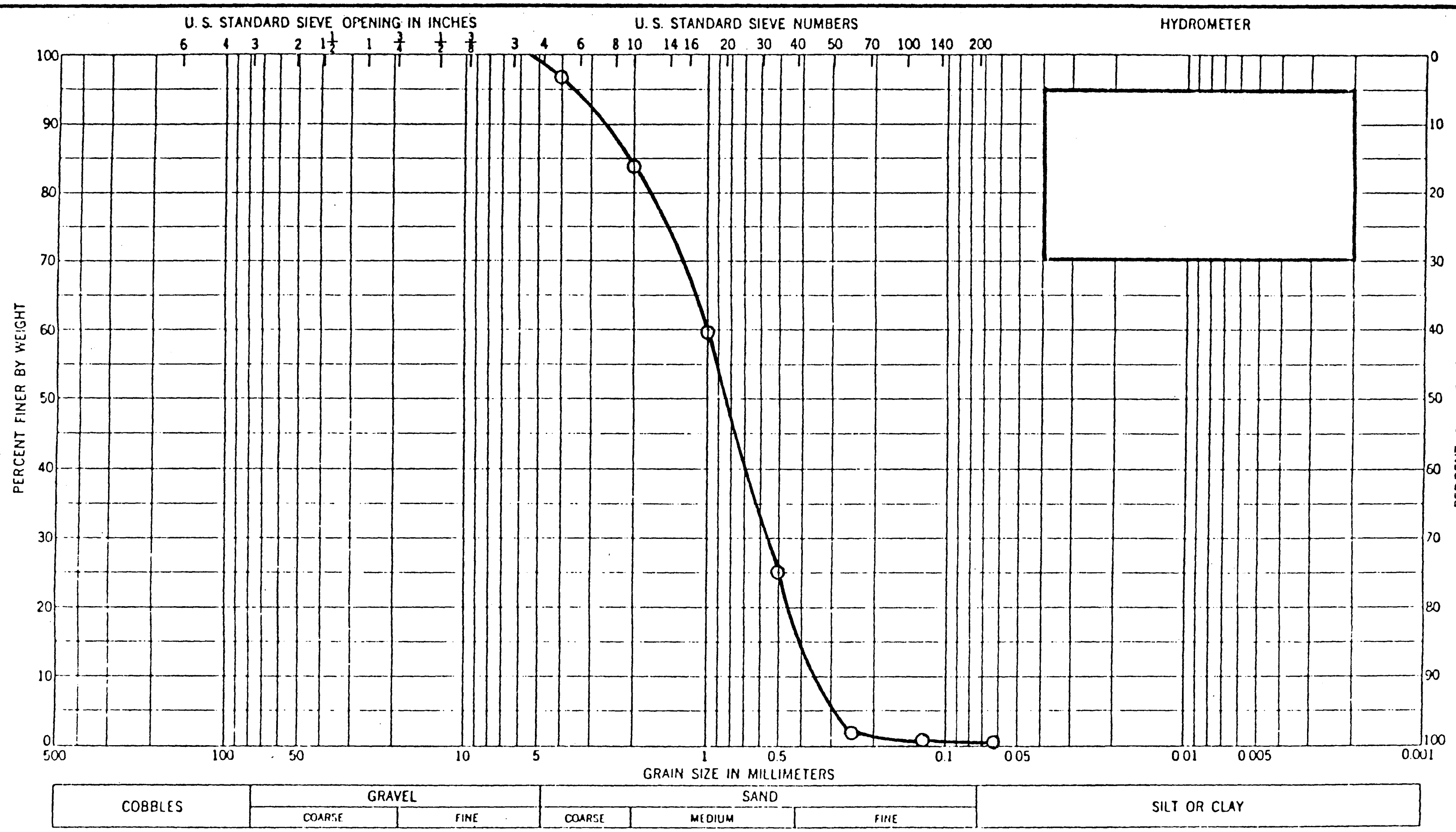
Area **BED SAMPLE**

Boring No. **RM 41**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

Area **BED SAMPLE**

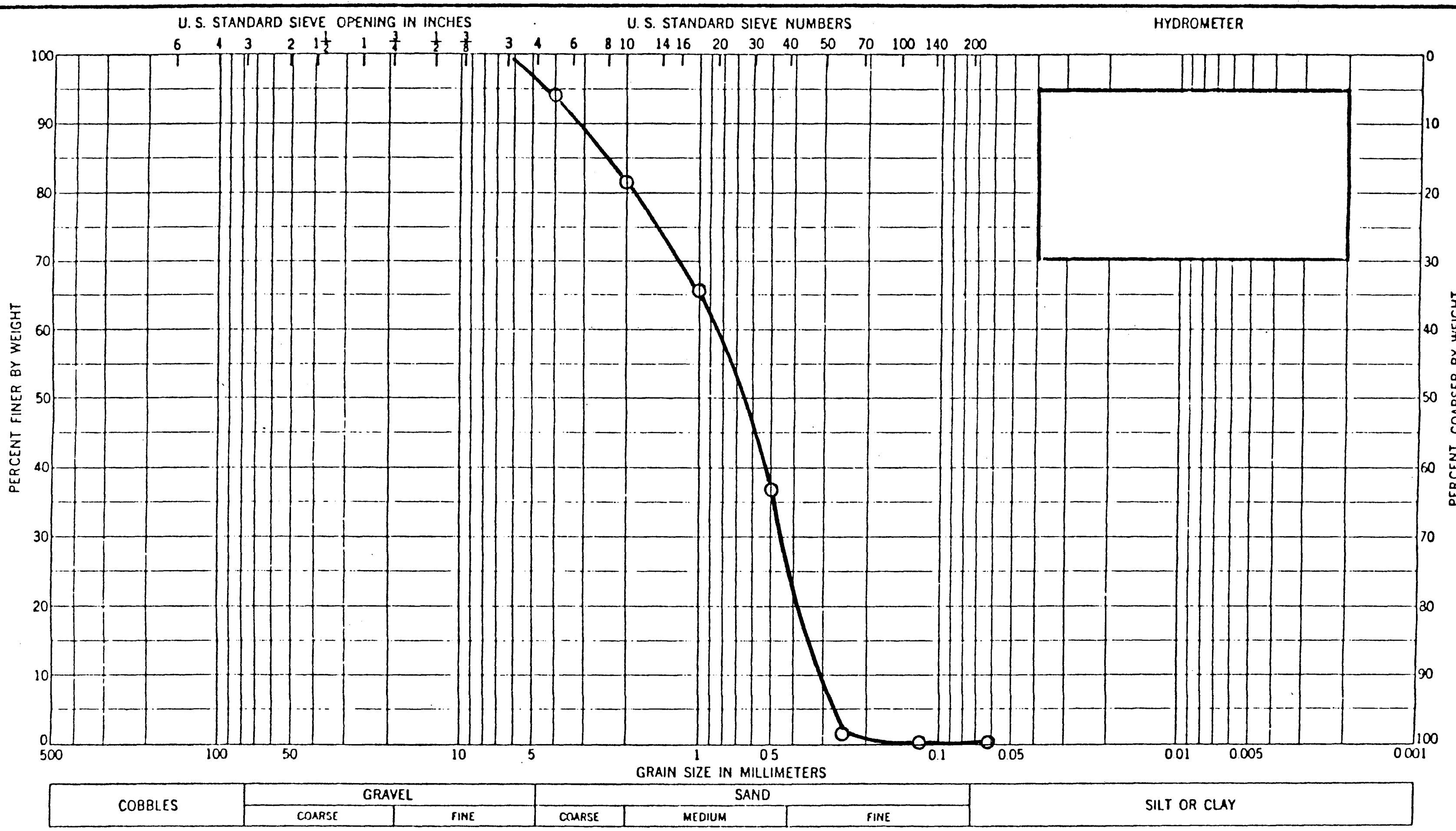
Boring No. **RM 43**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A2.22



A2.23

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

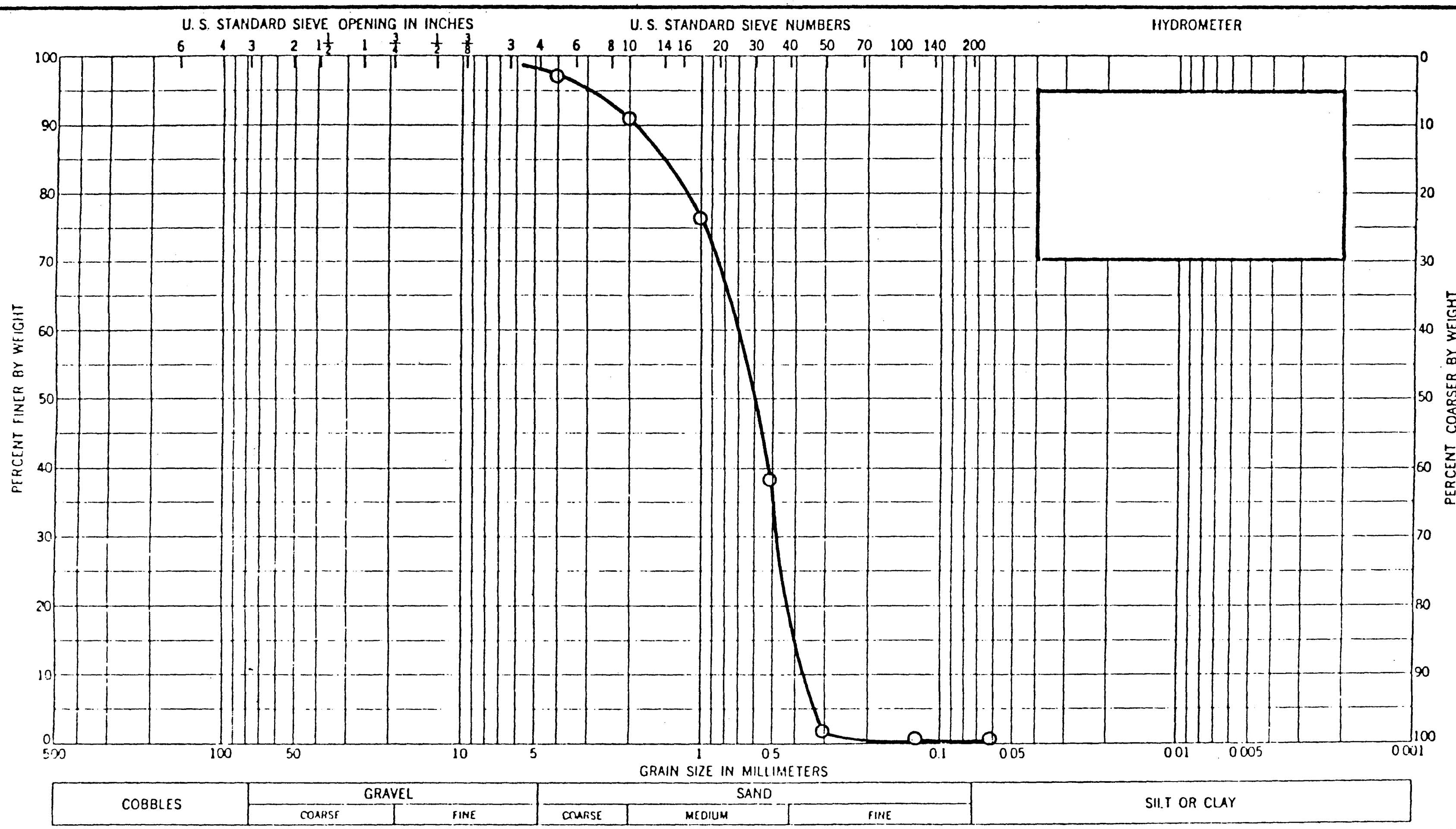
Area **BED SAMPLE**

Boring No. **RM 44**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

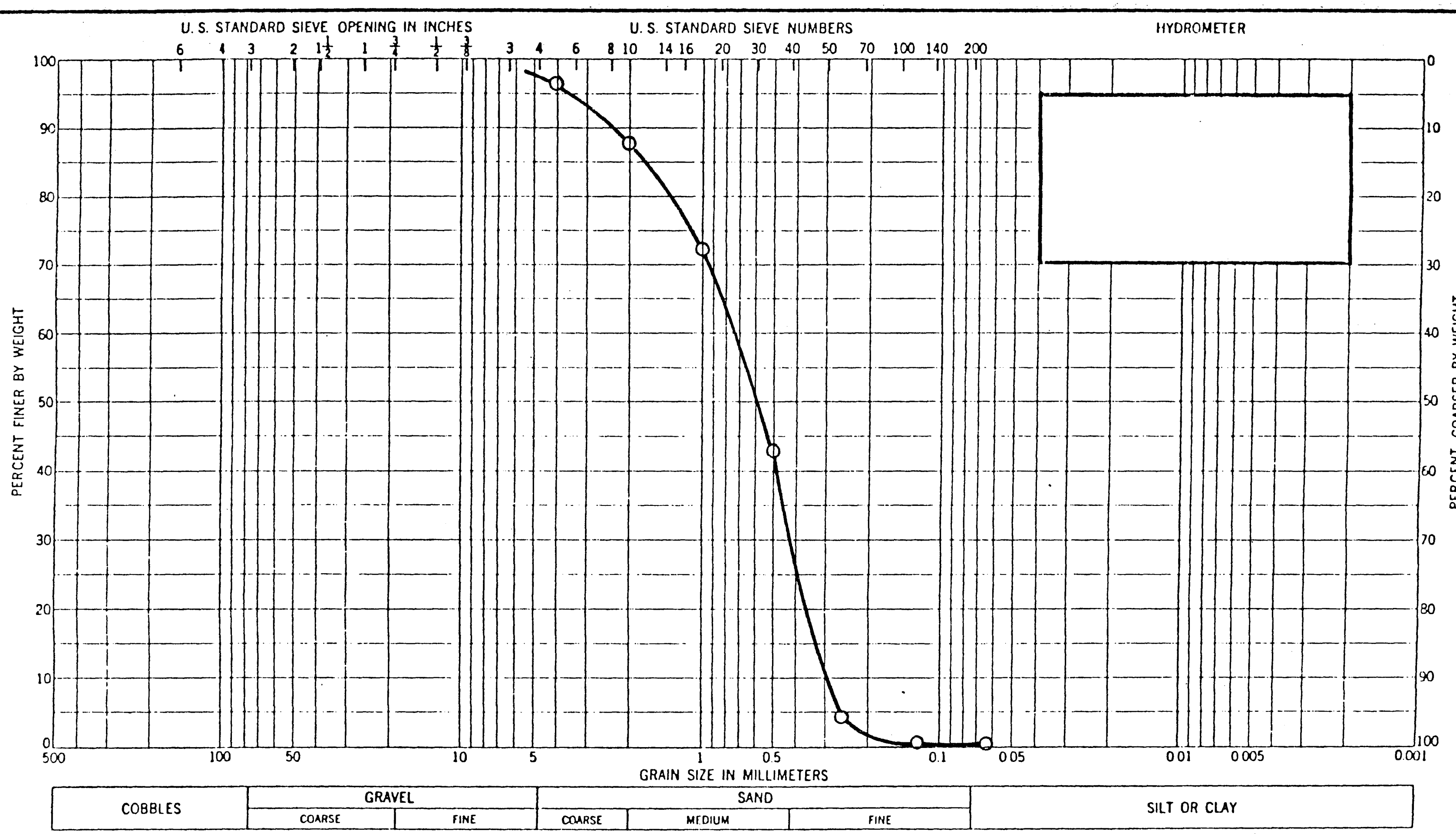
Area **BED SAMPLE**

Boring No. **RM 46.9**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

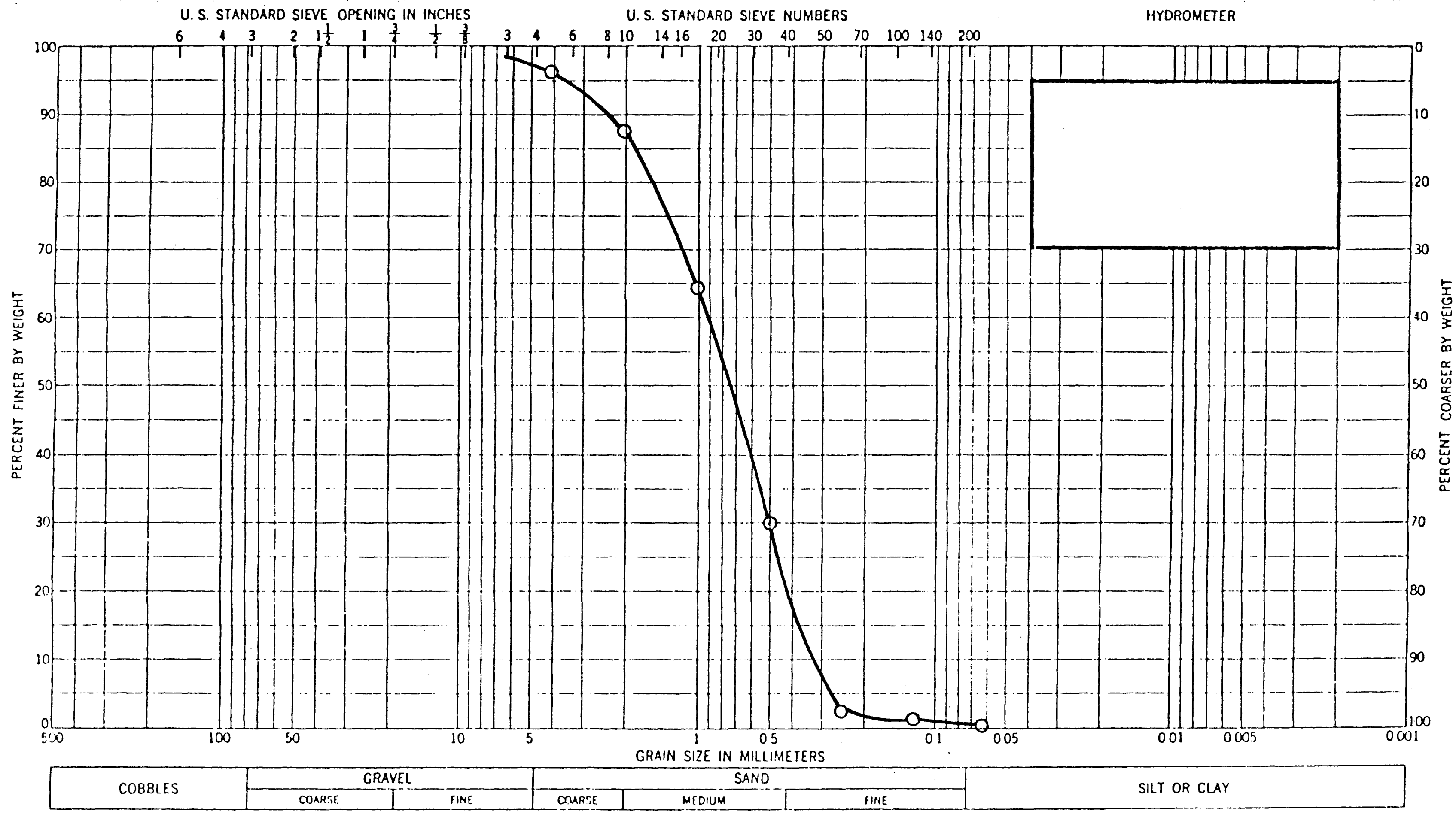
Area **BED SAMPLE**

Boring No. **RM 49.5**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.26

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

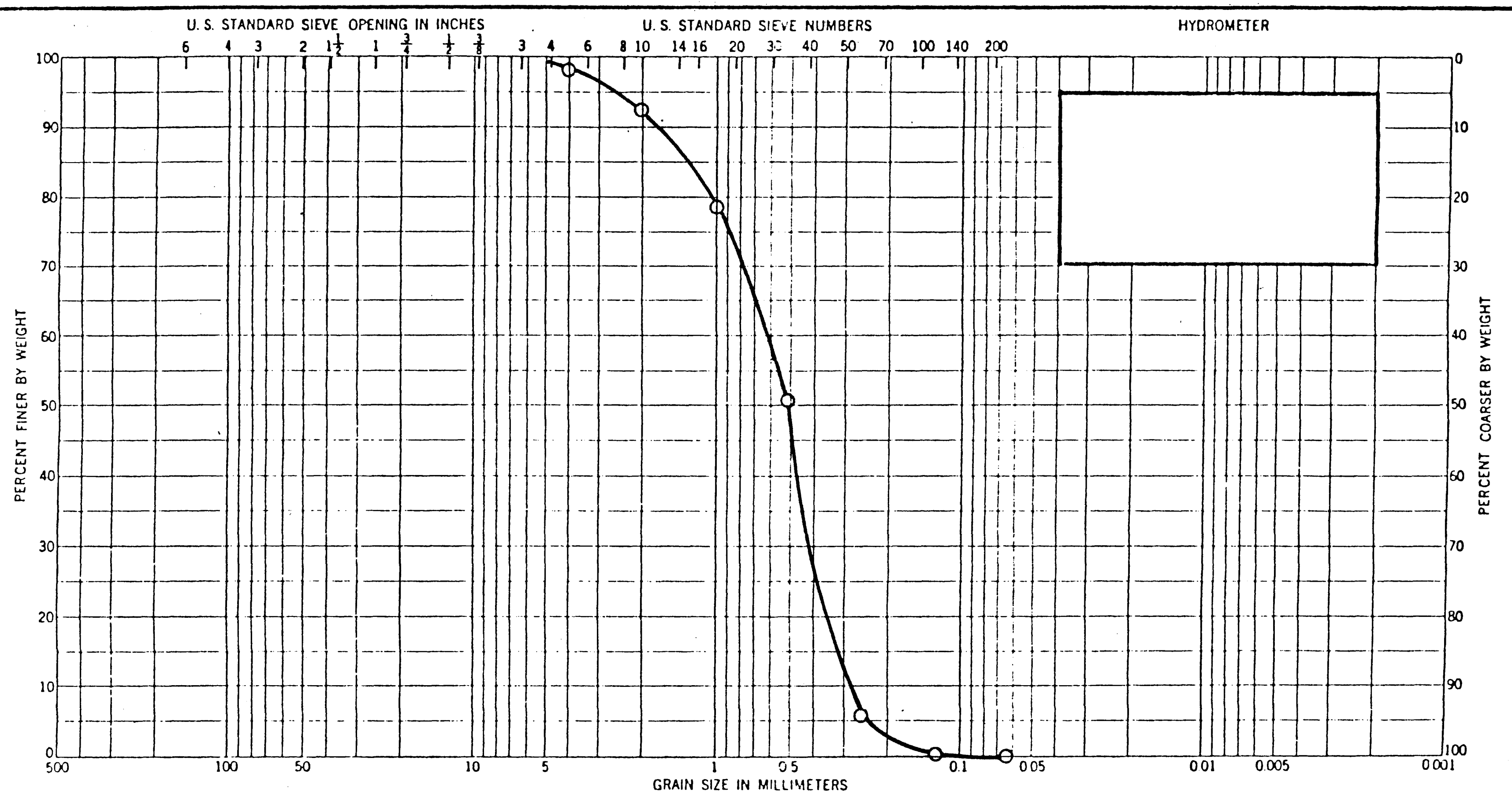
Area **BED SAMPLE**

Boring No. **RM 51**

Date **10/3/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

A2.27

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

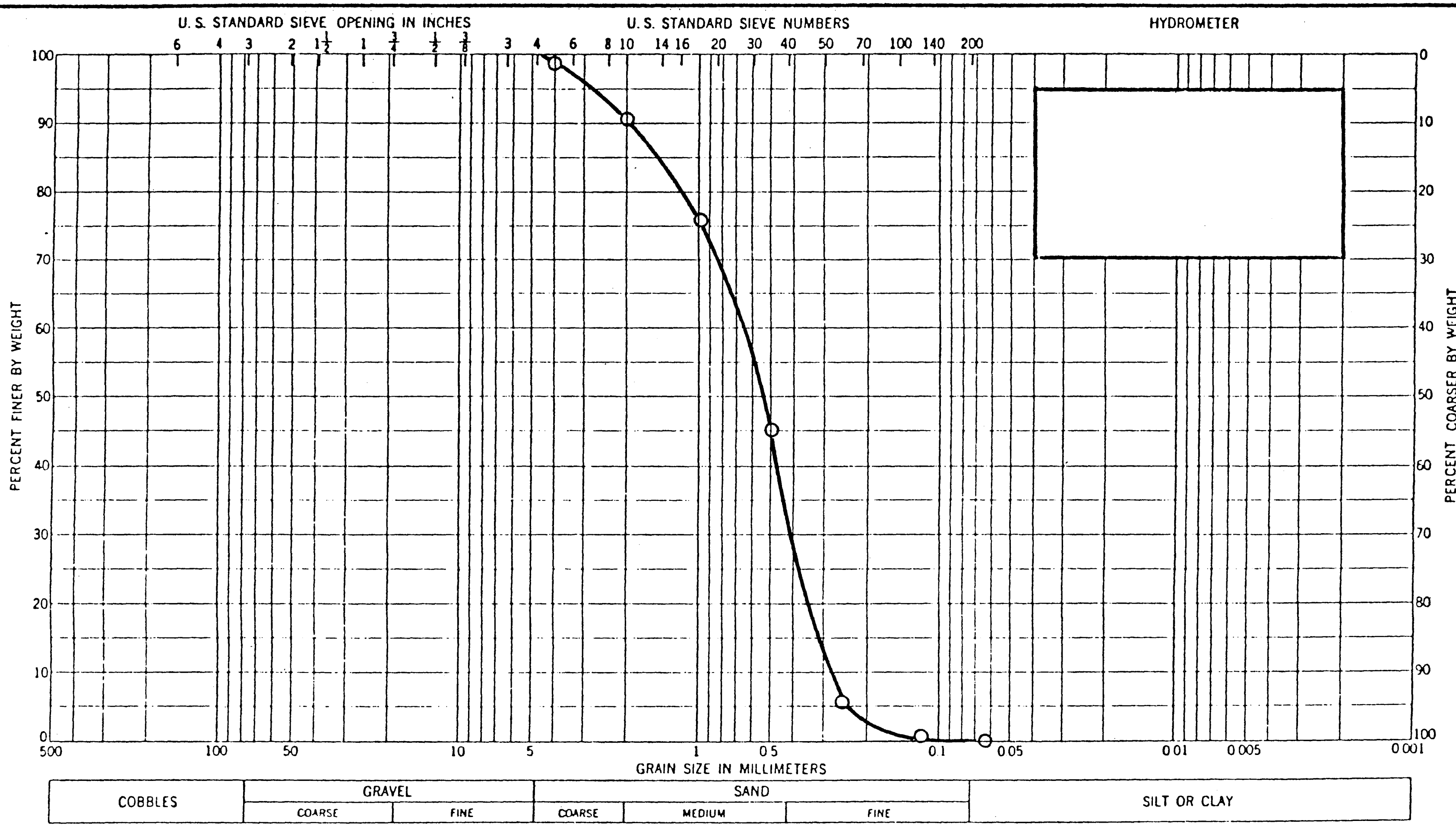
Area **BED SAMPLE**

Boring No. **RM 55**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

Area **BED SAMPLE**

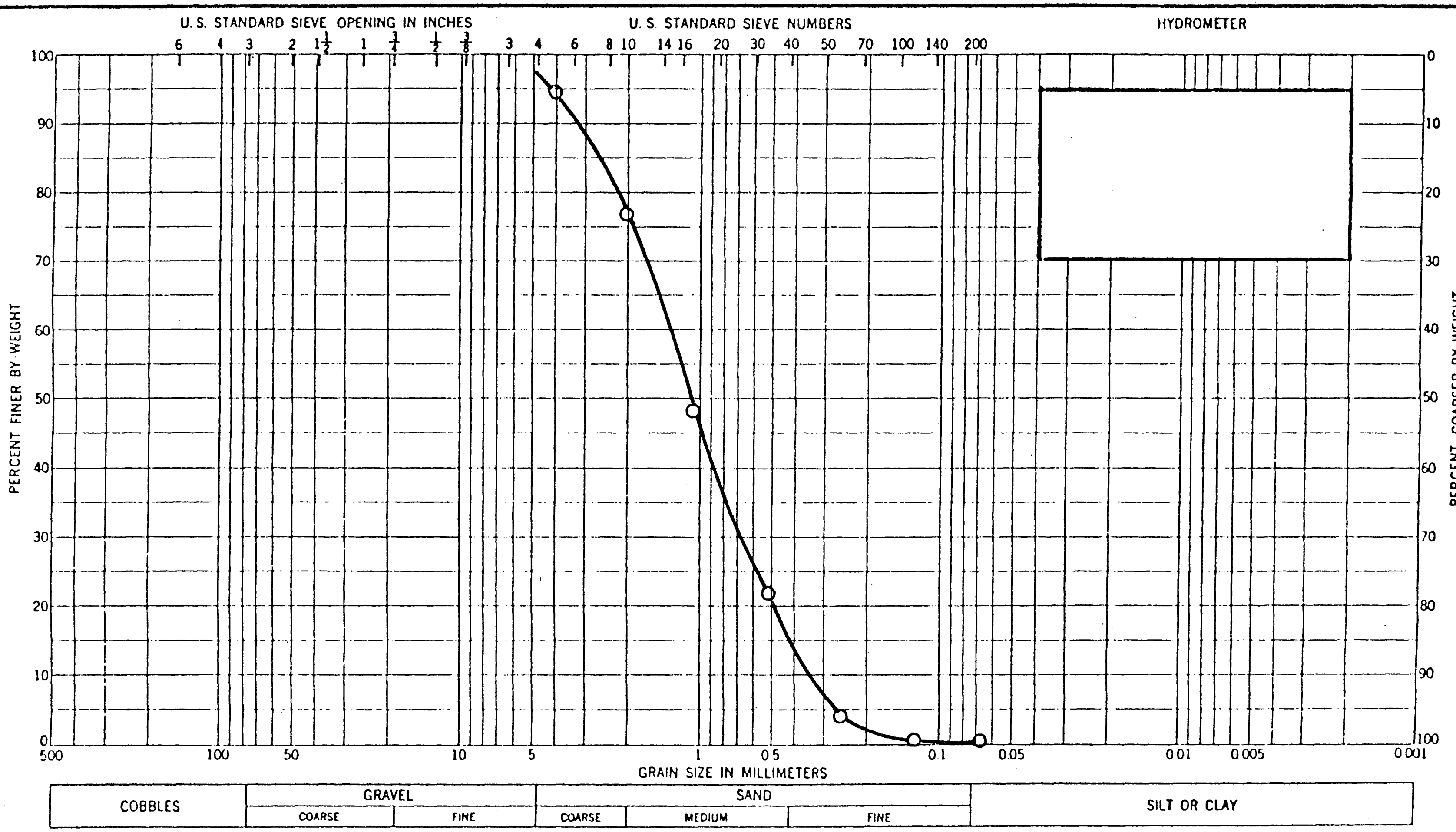
Boring No. **RM 62**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A2.28



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

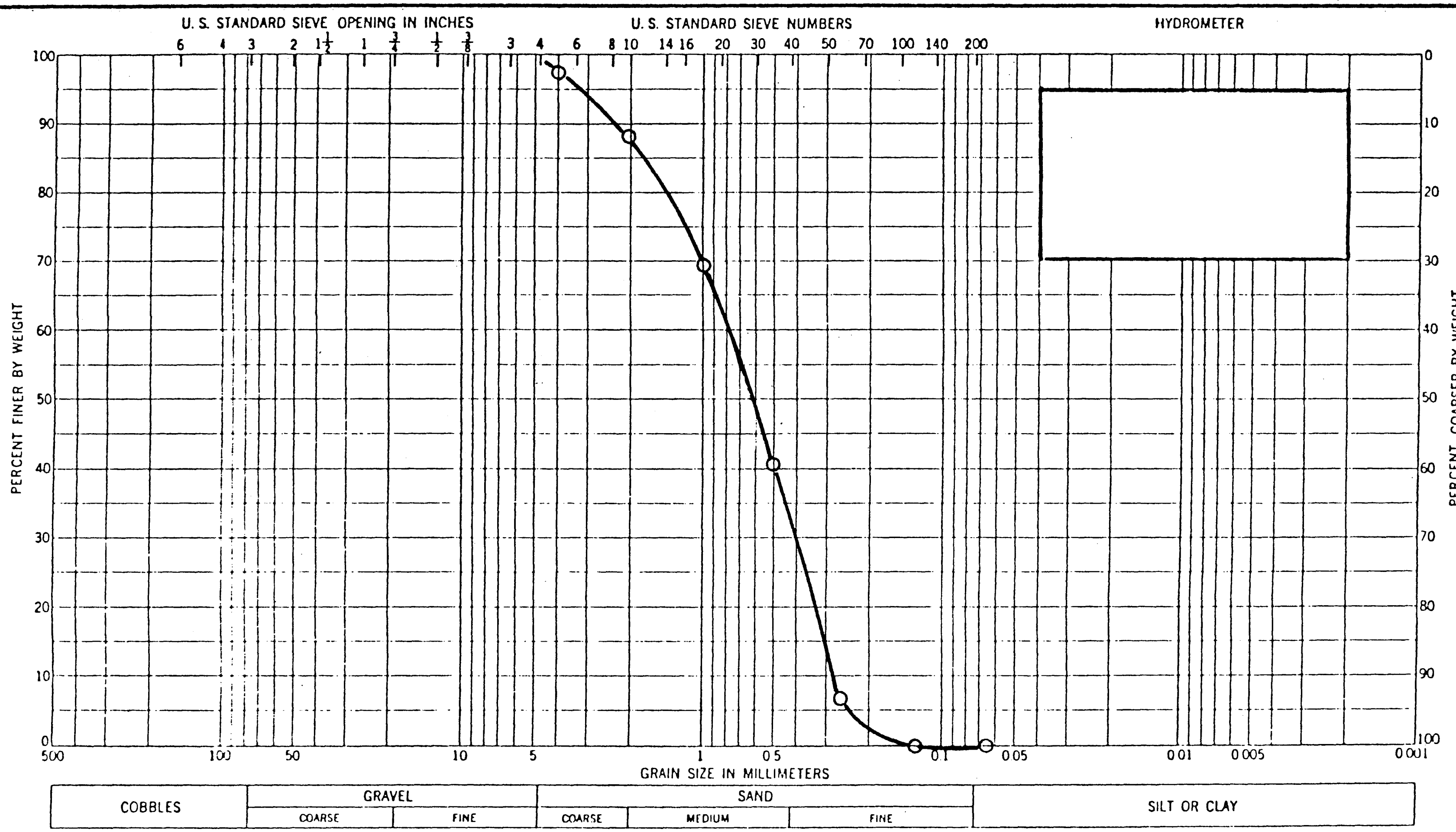
Area **BED SAMPLE**

Boring No. **RM 69.2**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.30

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project KS-COE-01

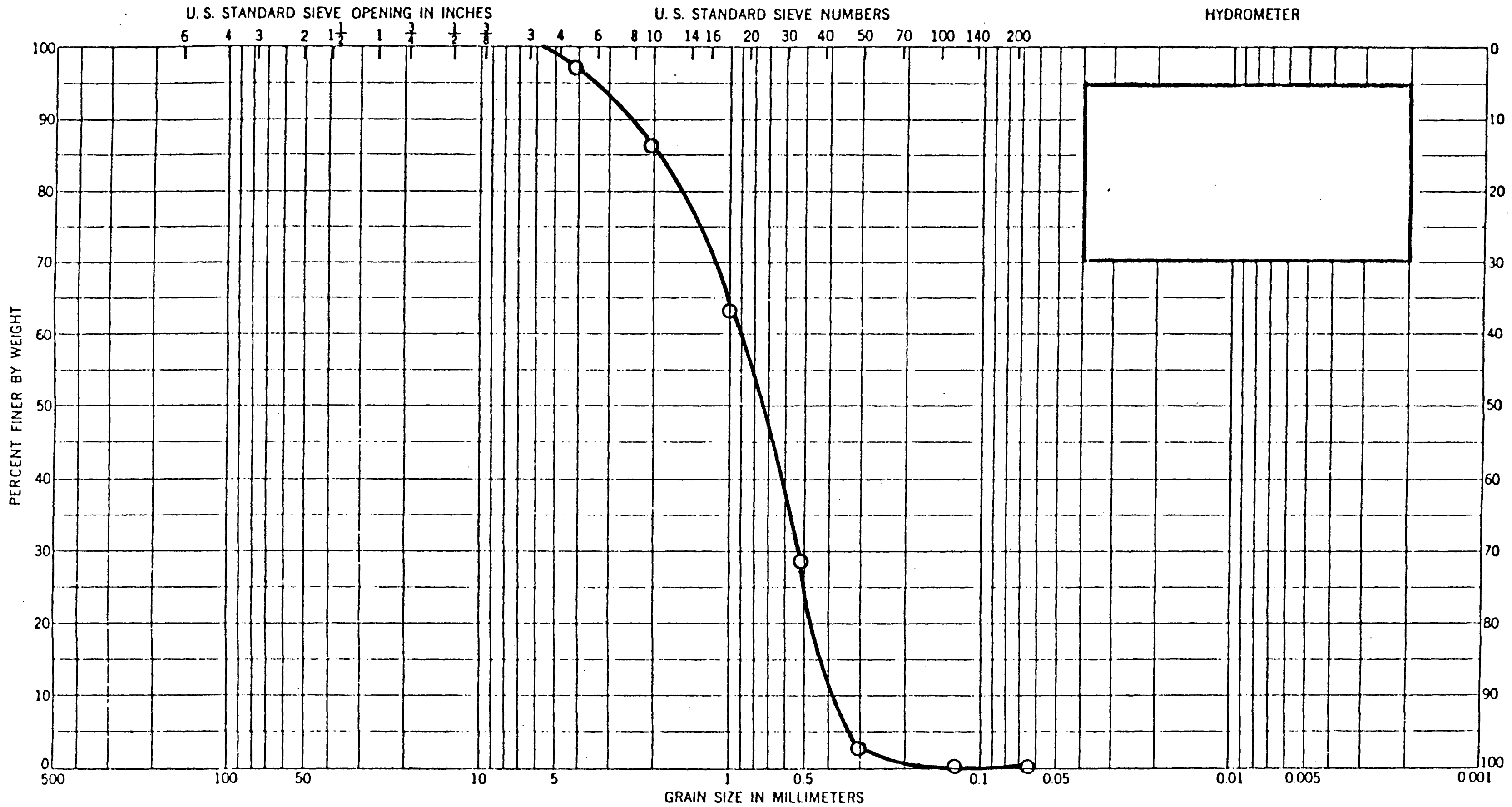
Area BED SAMPLE

Boring No. RM 77.5

Date 10/5/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



COBBLES	GRAVEL		SAND			SILT OR CLAY
	COARSE	FINE	COARSE	MEDIUM	FINE	

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

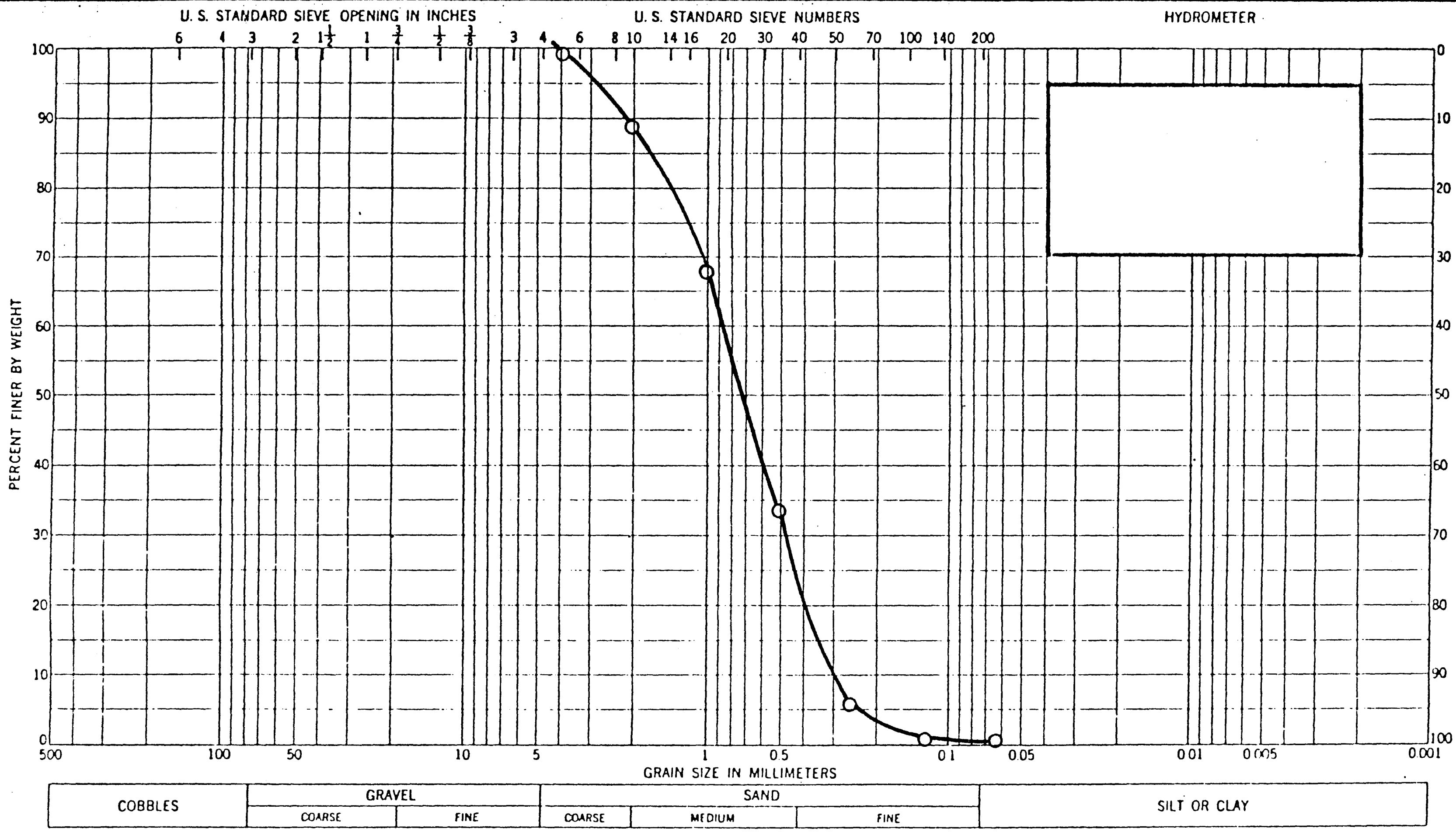
Area **BED SAMPLE**

Boring No. **RM 94.8**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

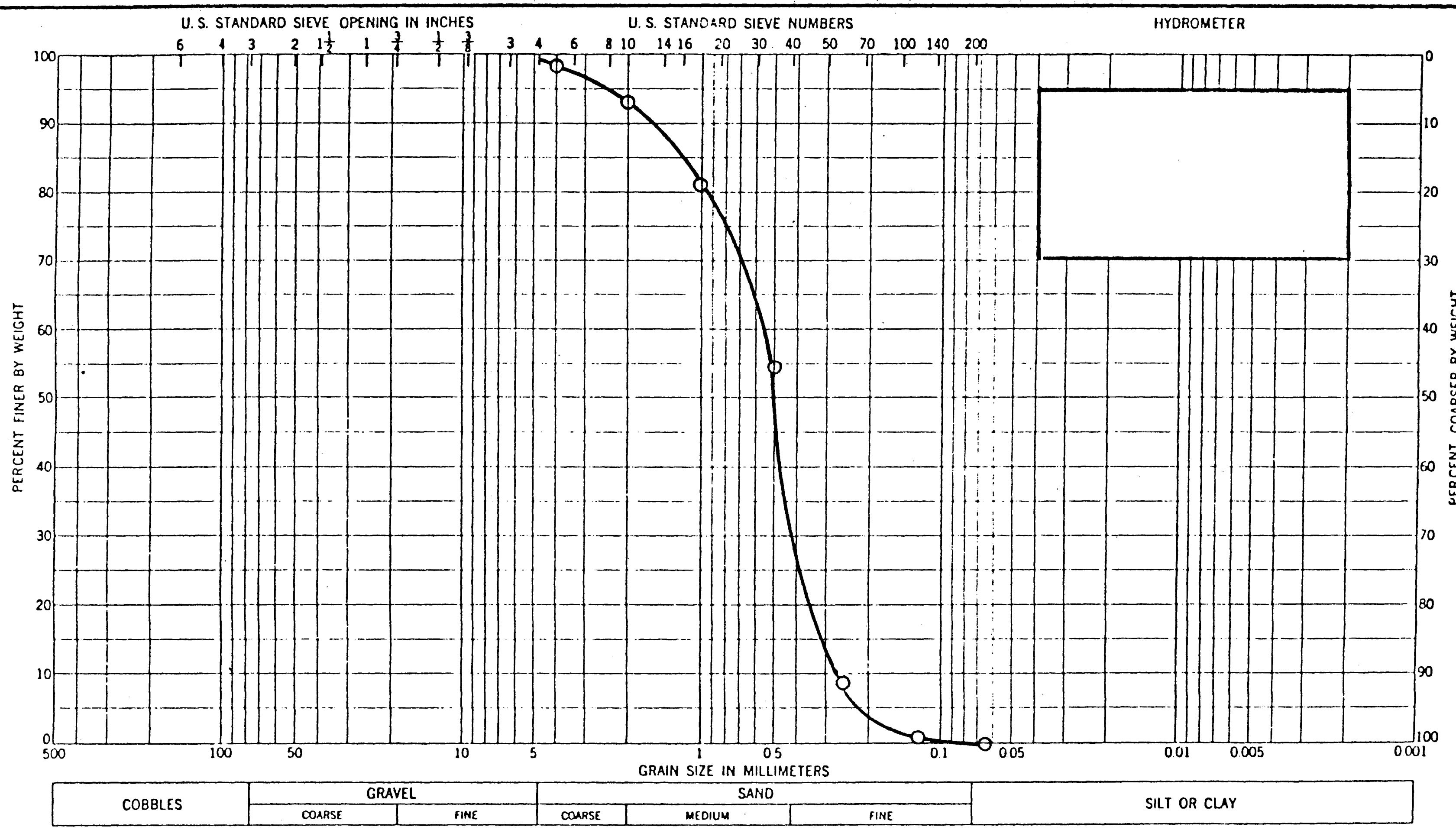
Area **BED SAMPLE**

Boring No. **RM 103.7**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.33

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

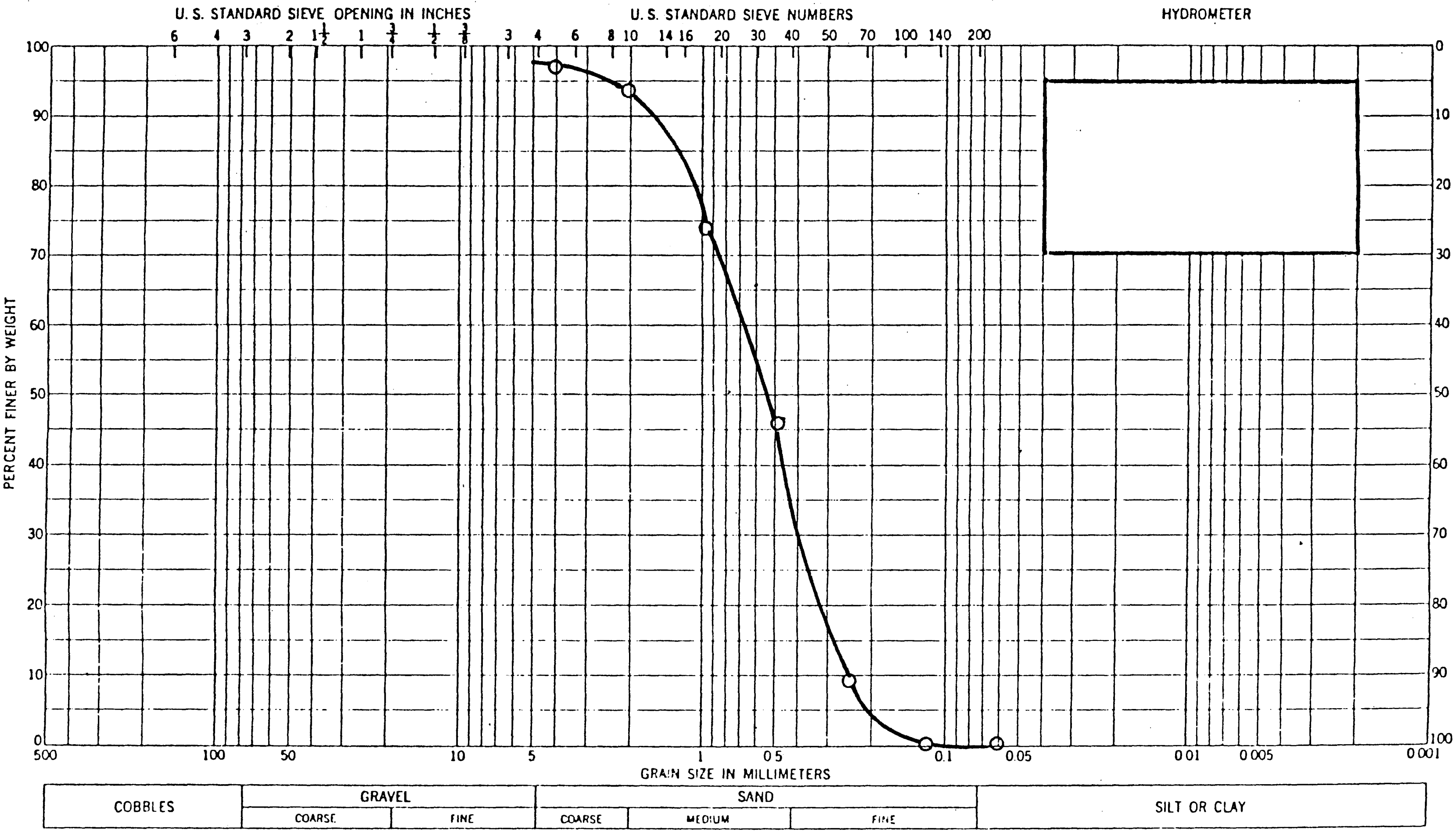
Area **BED SAMPLE**

Boring No. **RM 111.7**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.34

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

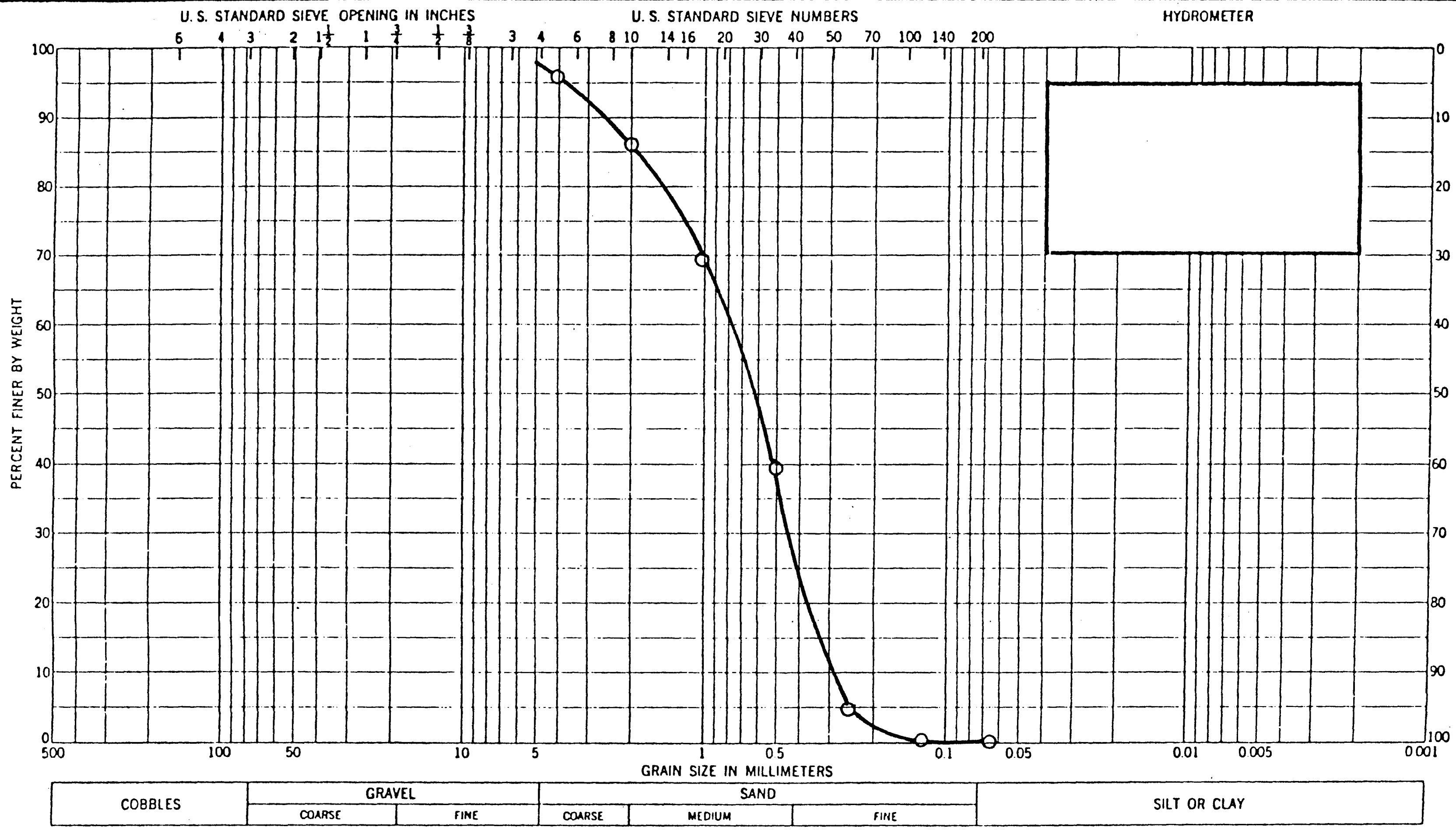
Area **BED SAMPLE**

Boring No. **RM 119**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

Area **BED SAMPLE**

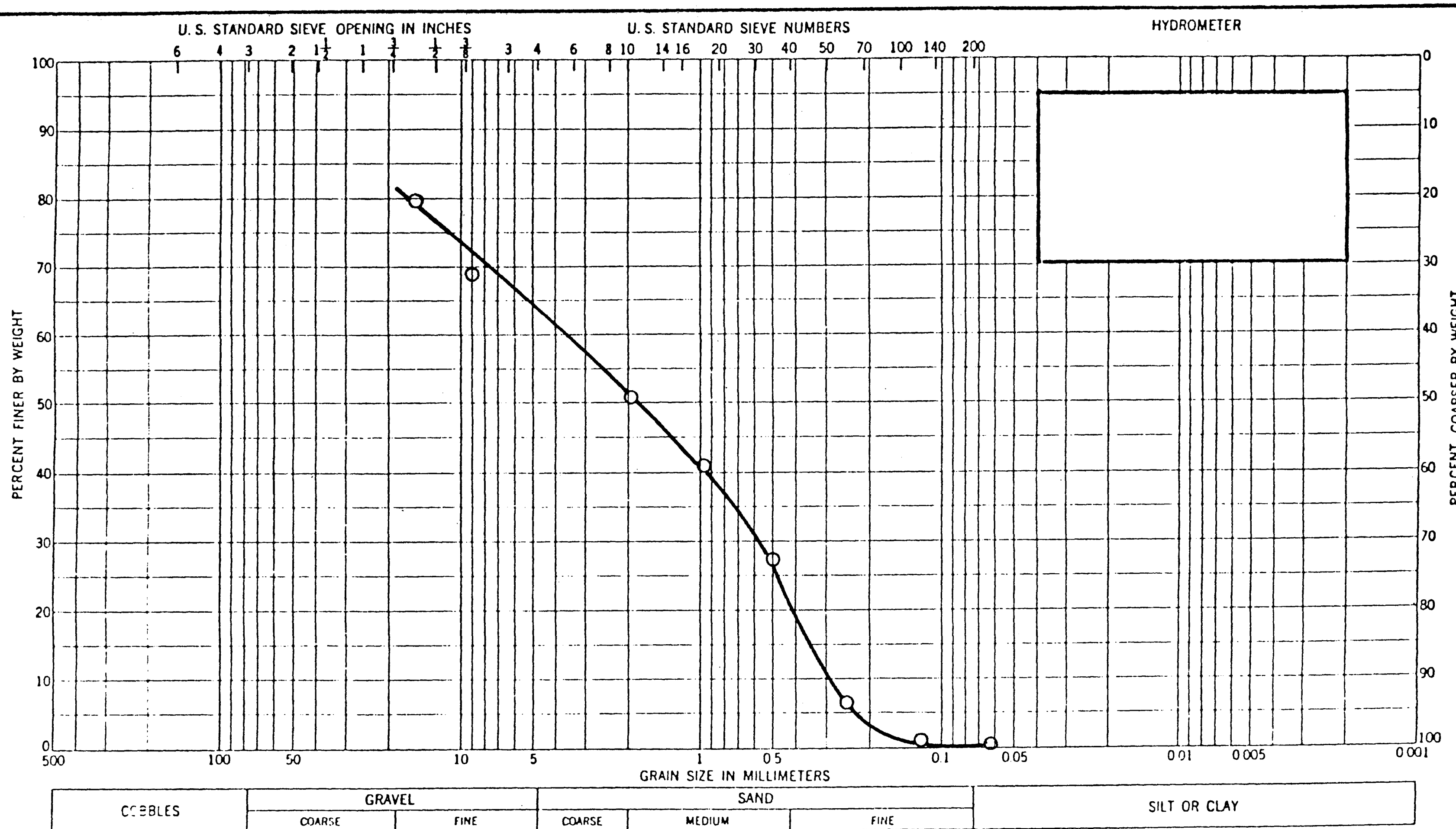
Boring No. **RM 127**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A2.35



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

Area **SUFACE BED SAMPLE**

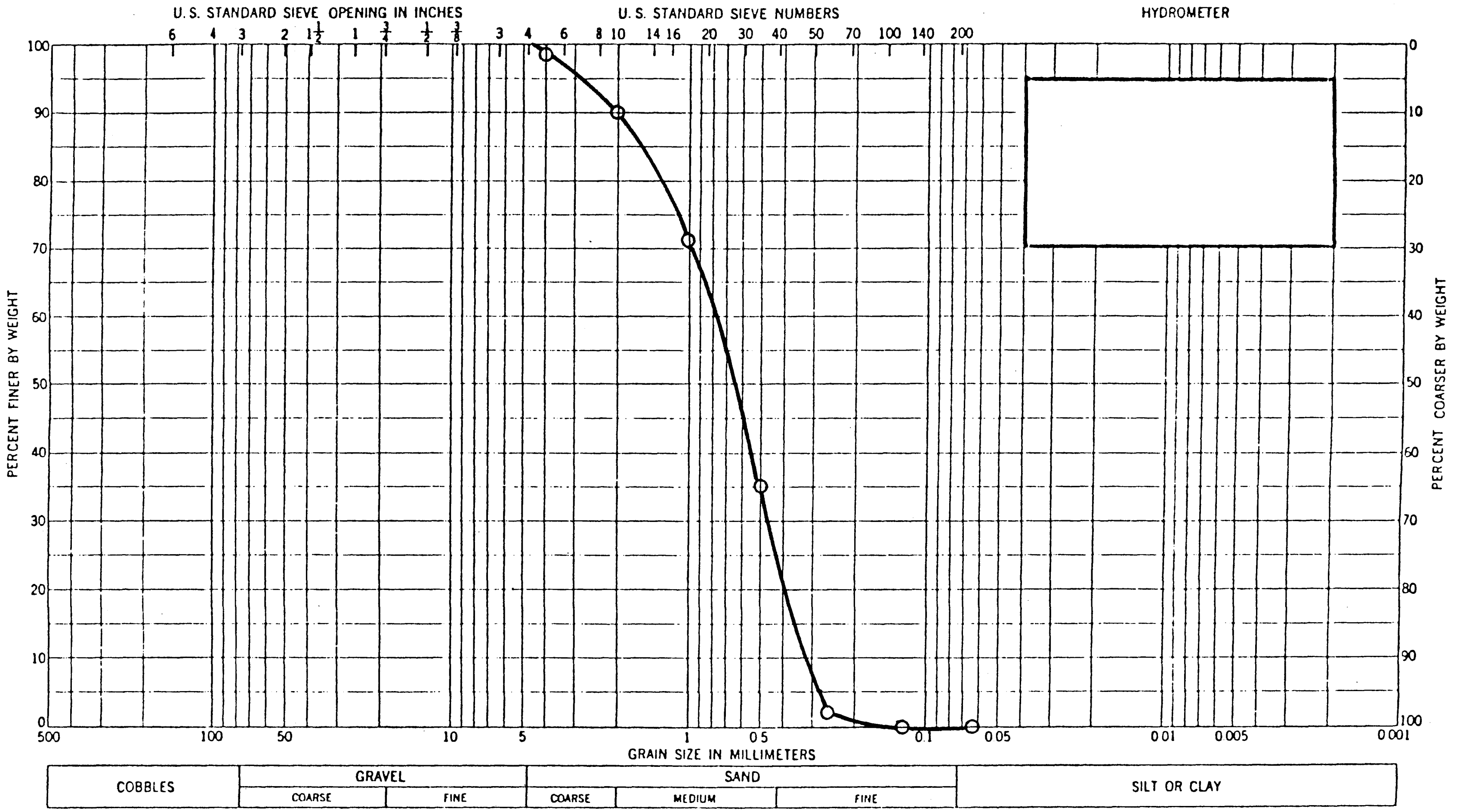
Boring No. **RM 131.7**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A2.36



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

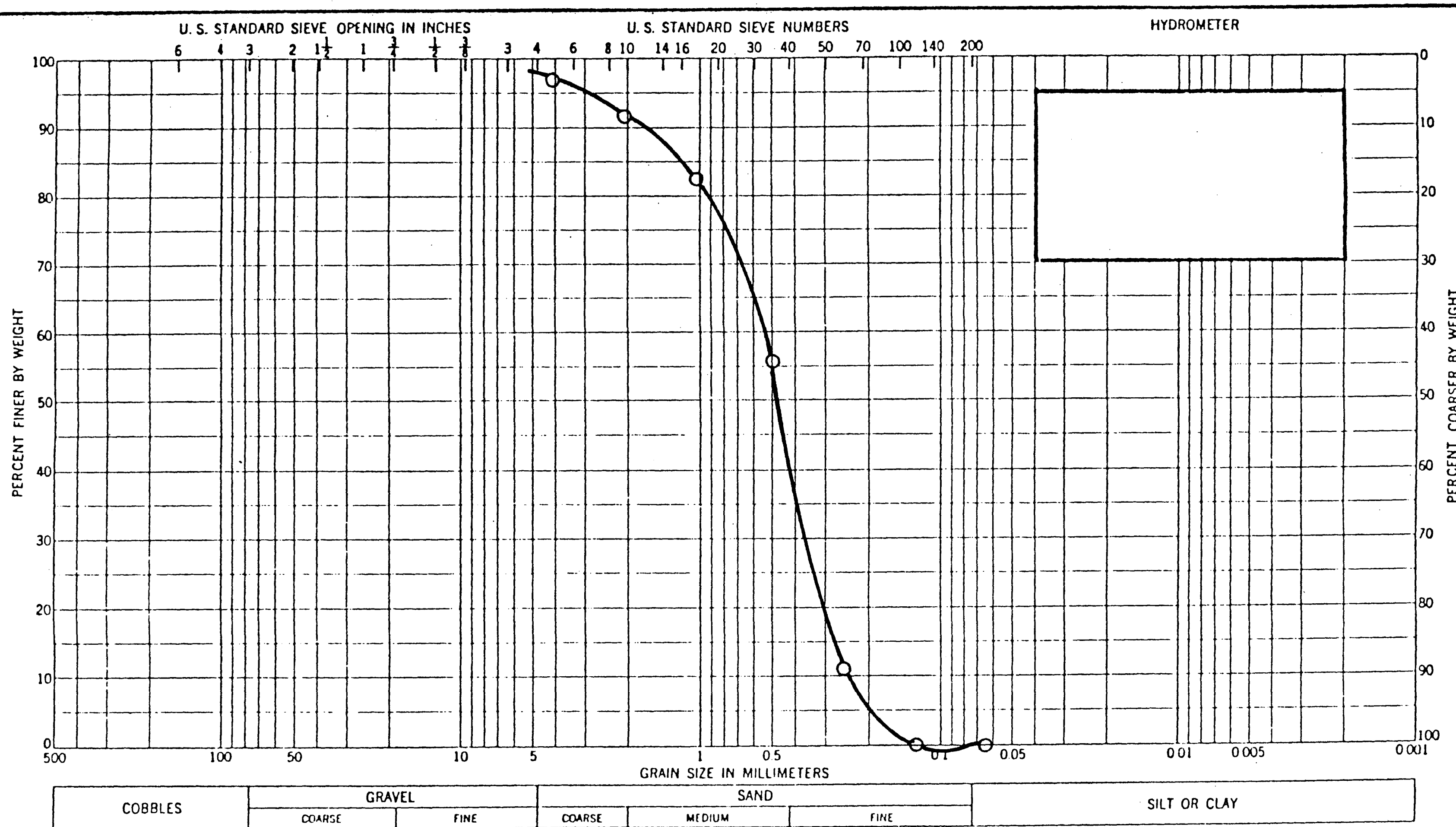
Area **SUBSURFACE BED SAMPLE**

Boring No. **RM131.7**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

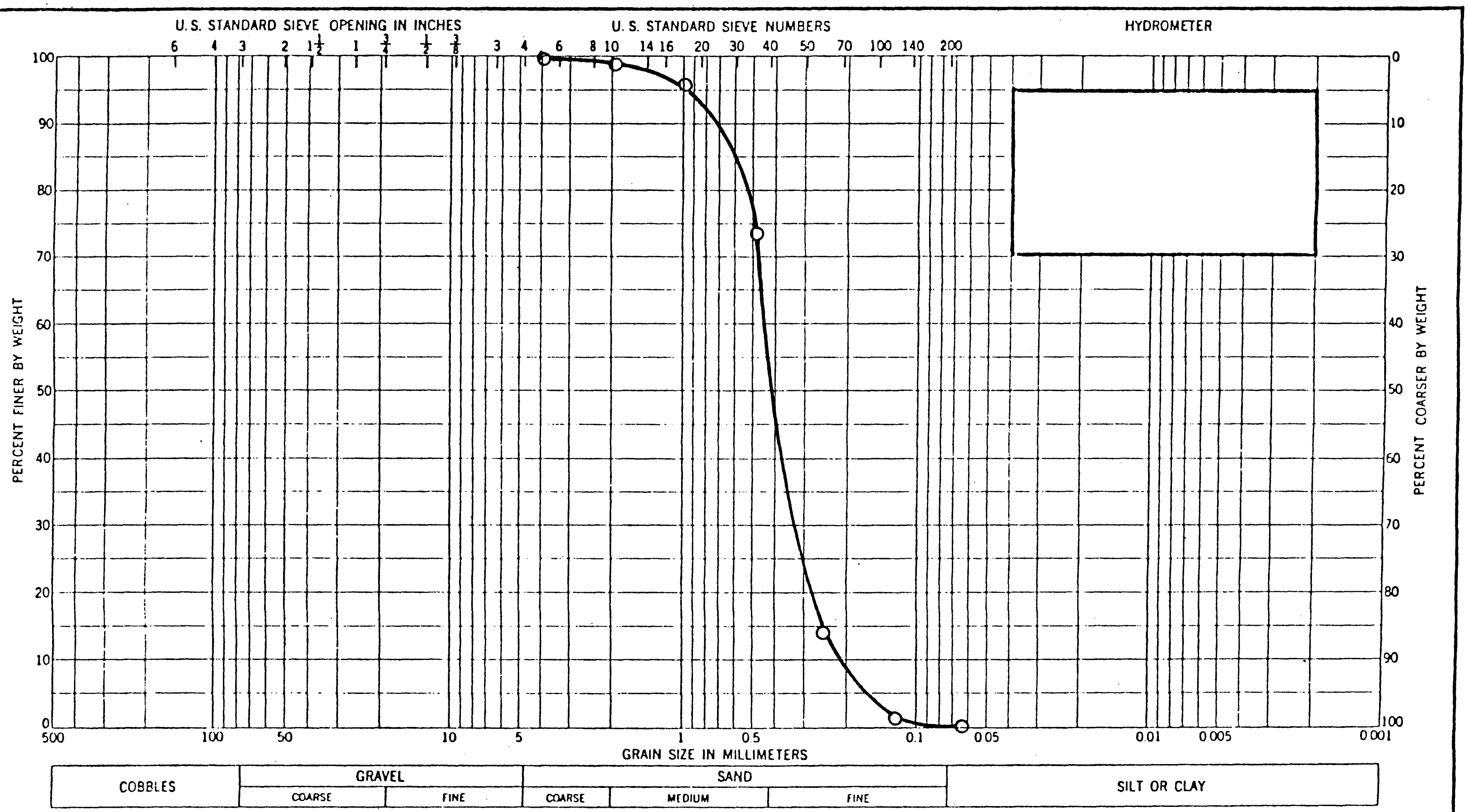
Area **BED SAMPLE**

Boring No. **RM 144**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

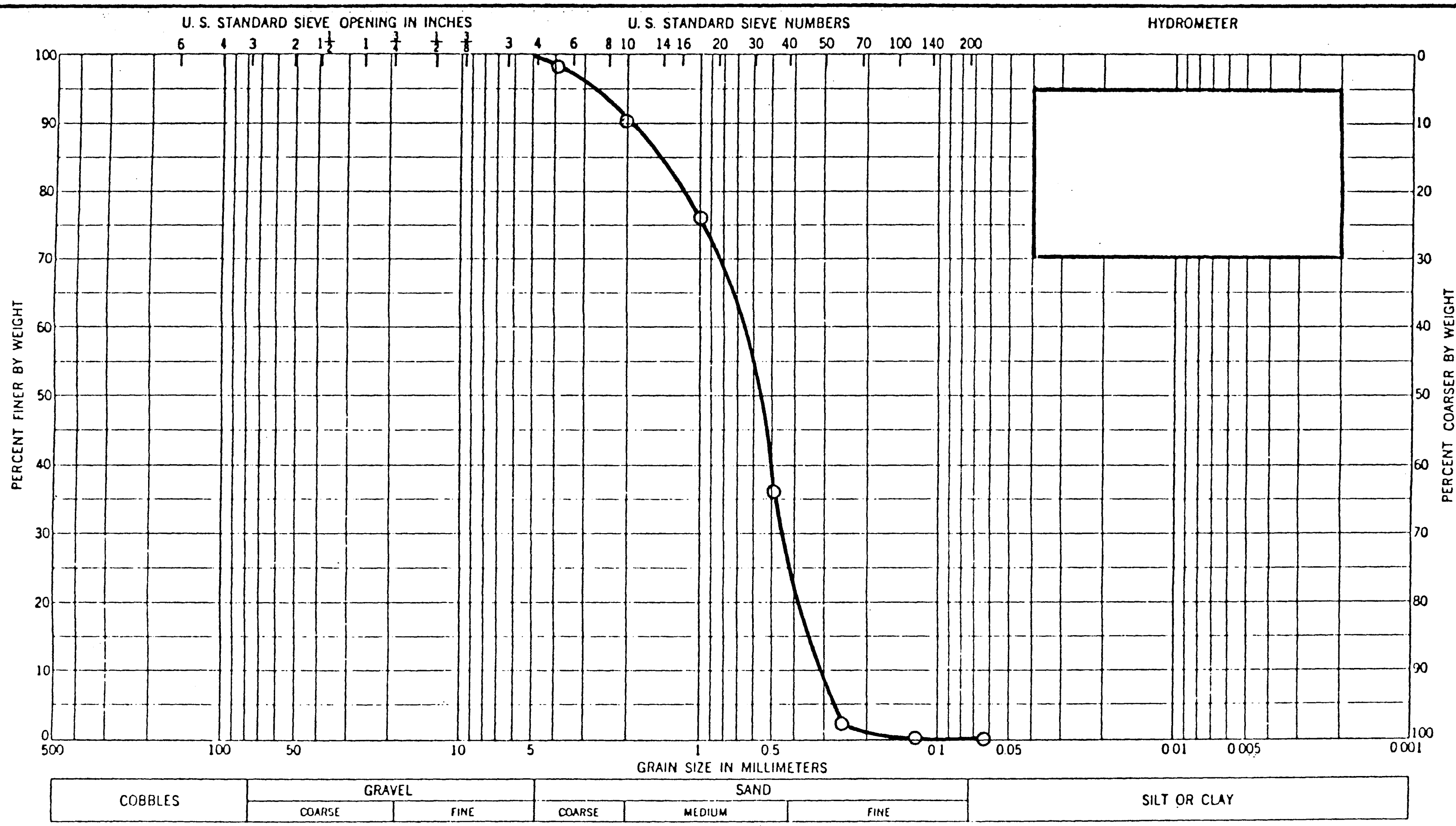
Area **BED SAMPLE**

Boring No. **RM 152.3**

Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A2.40

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

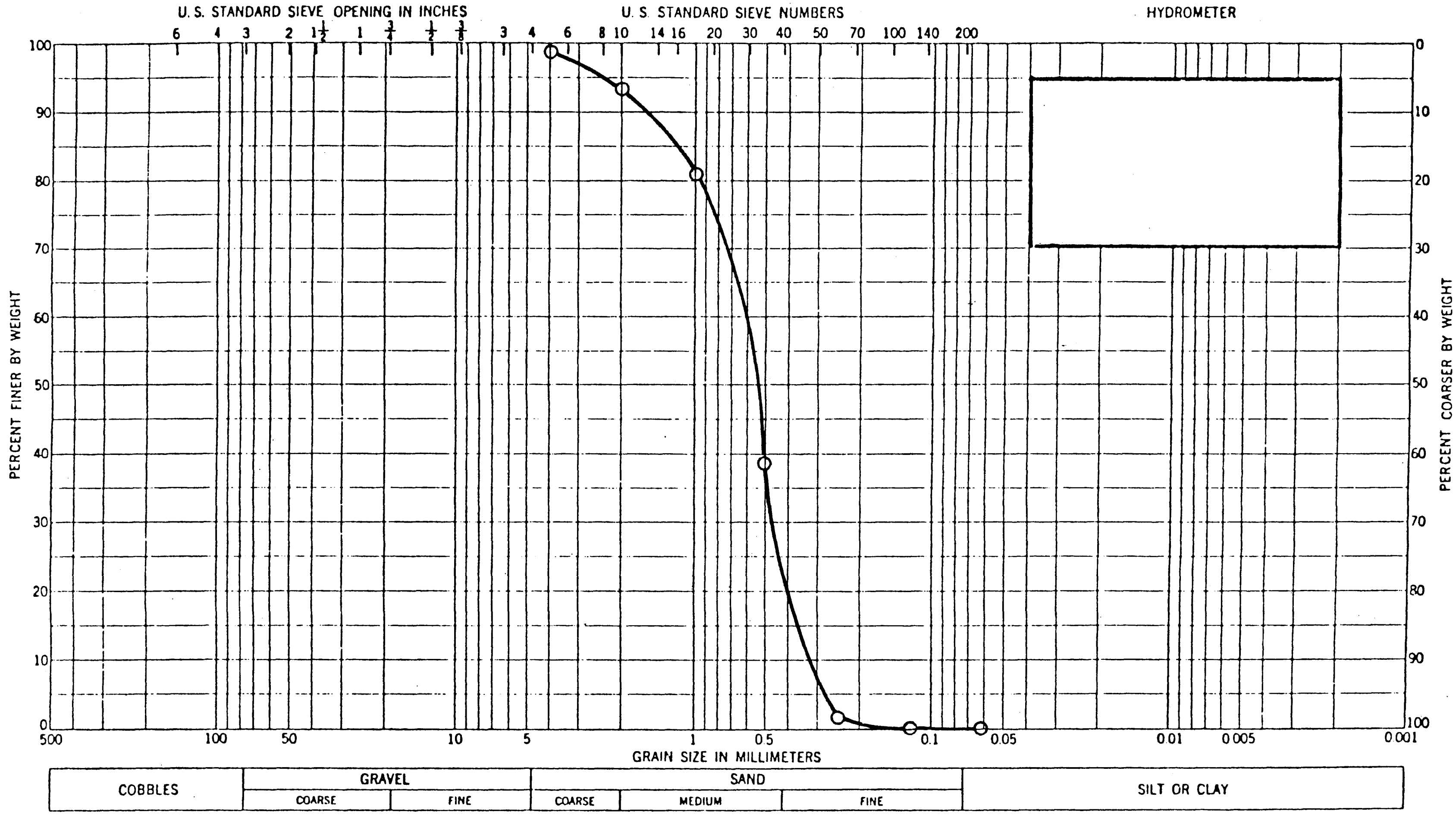
Area **BED SAMPLE**

Boring No. **RM 161 RM**

Date **10/6/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KS-COE-01**

Area **BED SAMPLE**

Boring No. **RM 168.5**

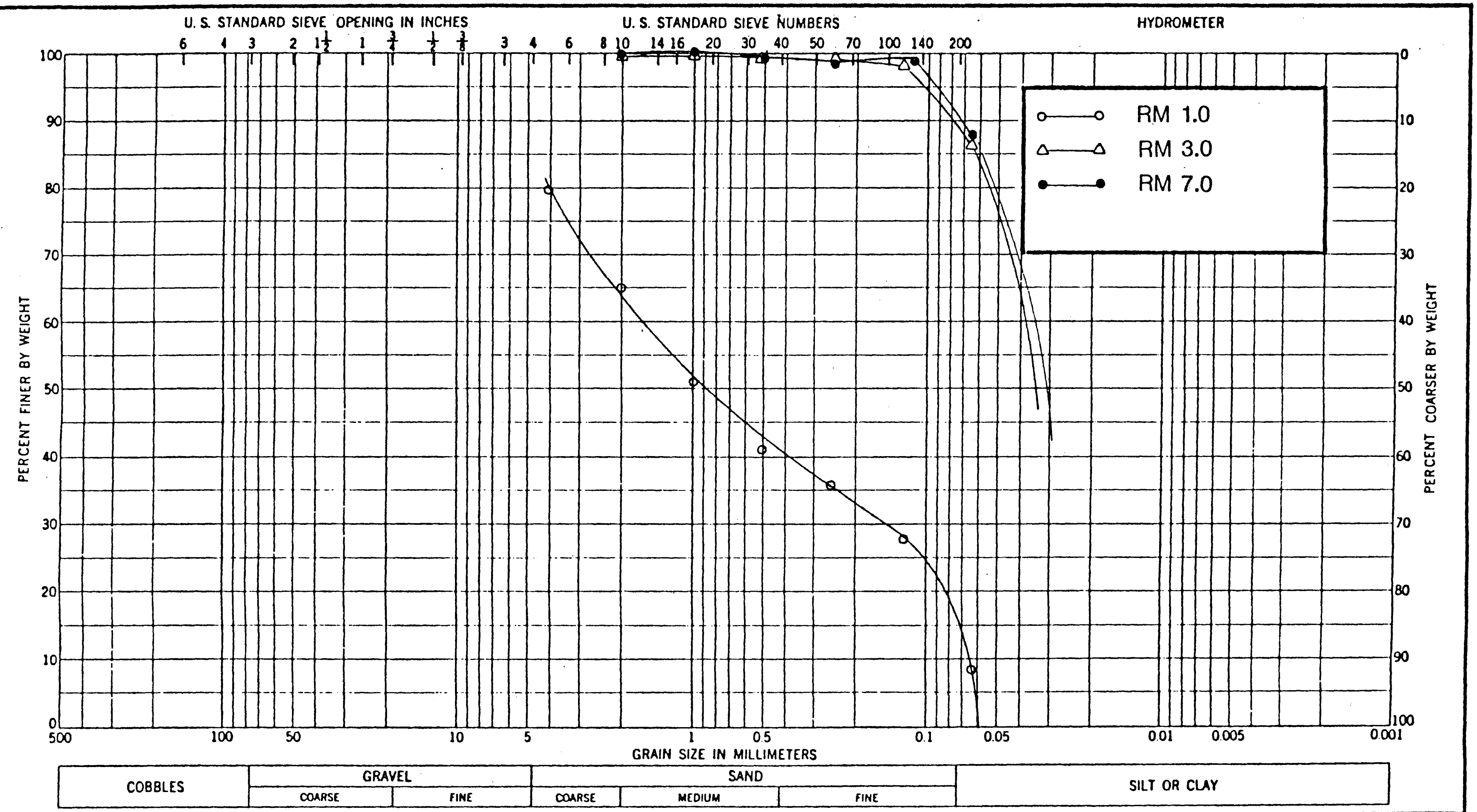
Date **10/5/83**

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A3

1983 Bank Material Gradation Curves



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

RM-1.0 (LEFT) 10/4/83

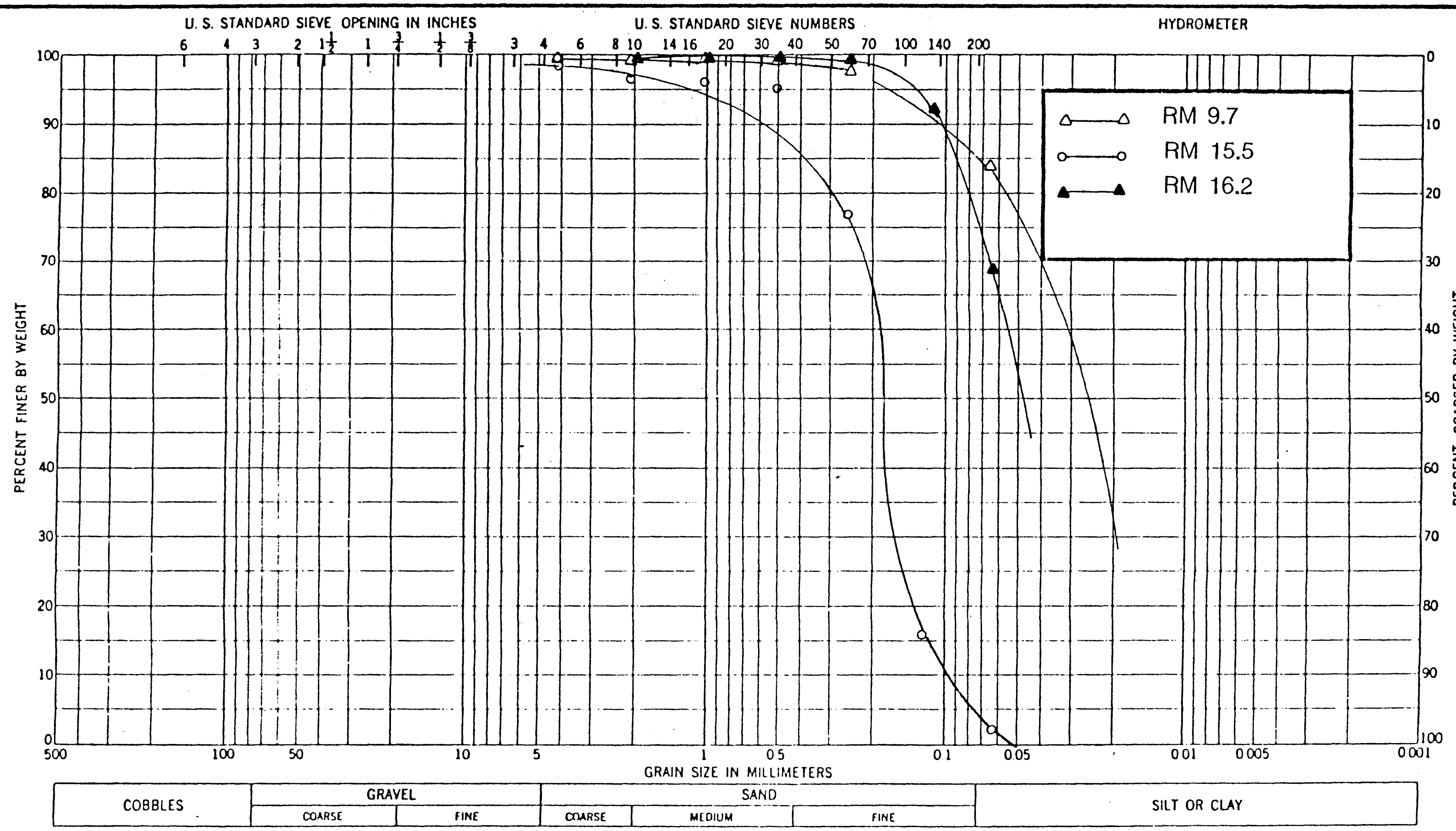
RM-3.0 (RIGHT) 9/15/83

RM-7.0 (LEFT) 9/15/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087

A3.1



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

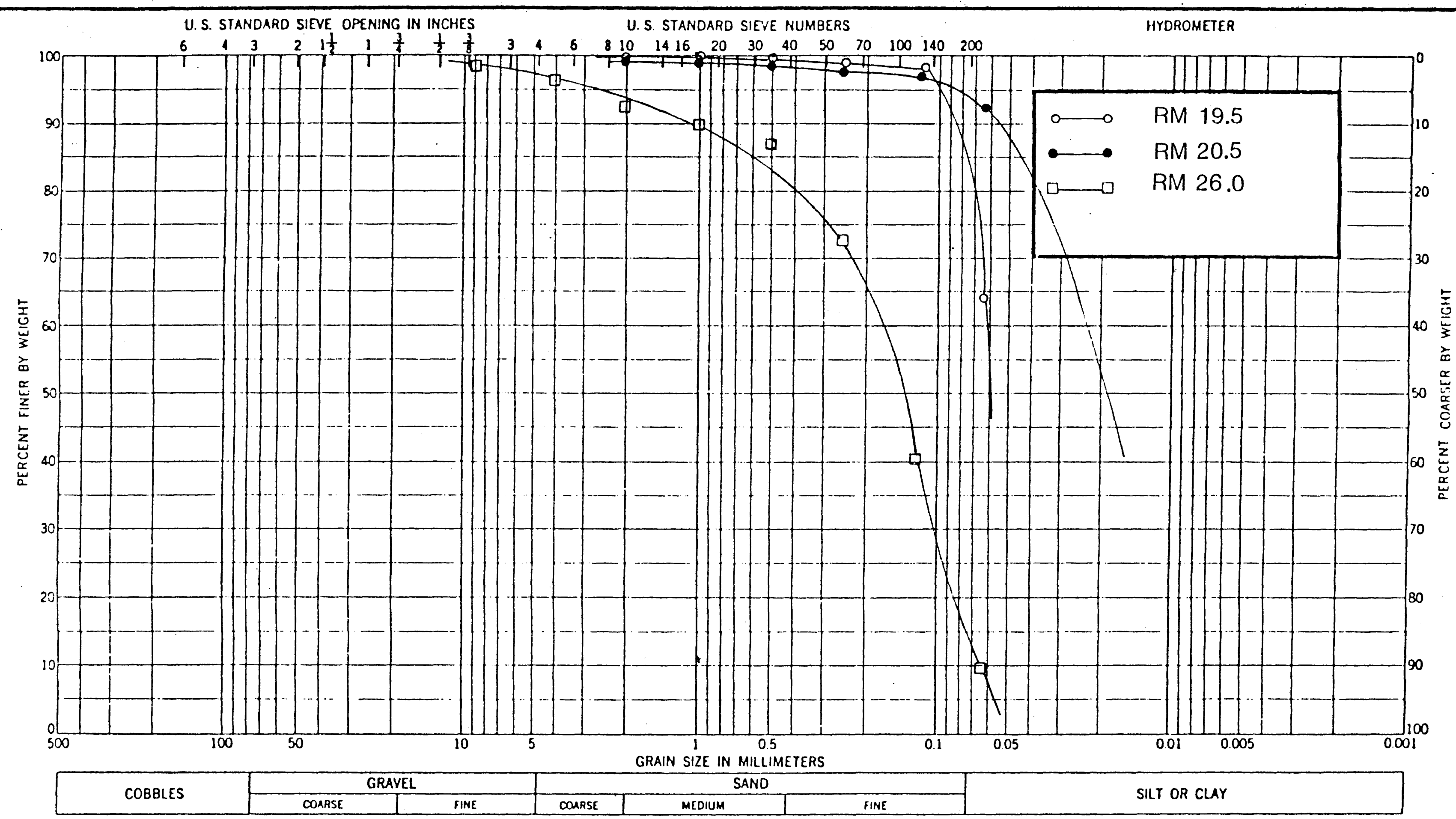
RM-9.7 (RIGHT) 9/15/83

RM-15.5 (LEFT) 10/5/83

RM-16.2 (RIGHT) 9/15/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

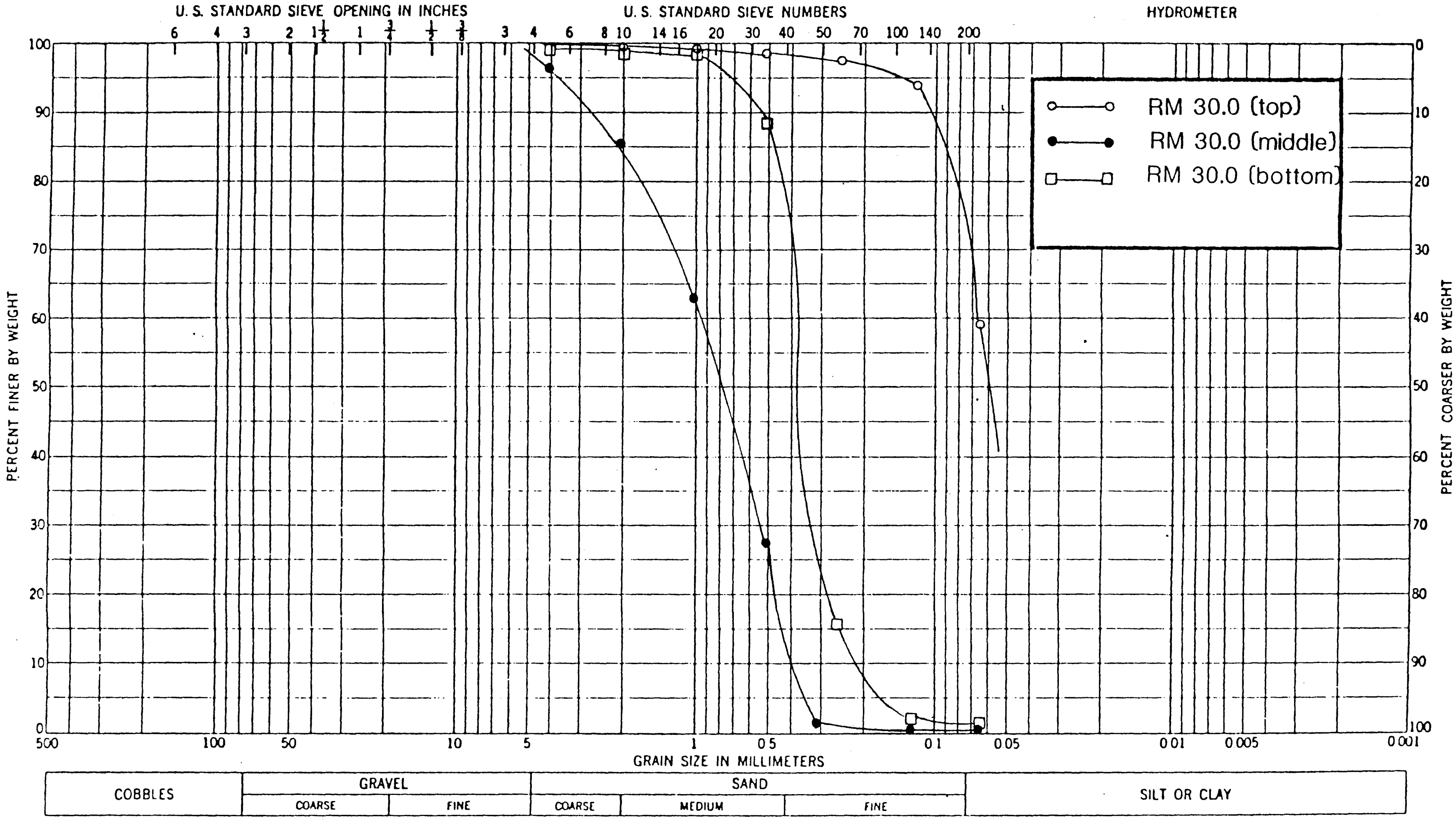
RM-19.5 (LEFT) 9/15/83

RM-20.5 (LEFT) 9/14/83

RM-26.0 (LEFT) 10/5/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A3.4

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project KANSAS RIVER

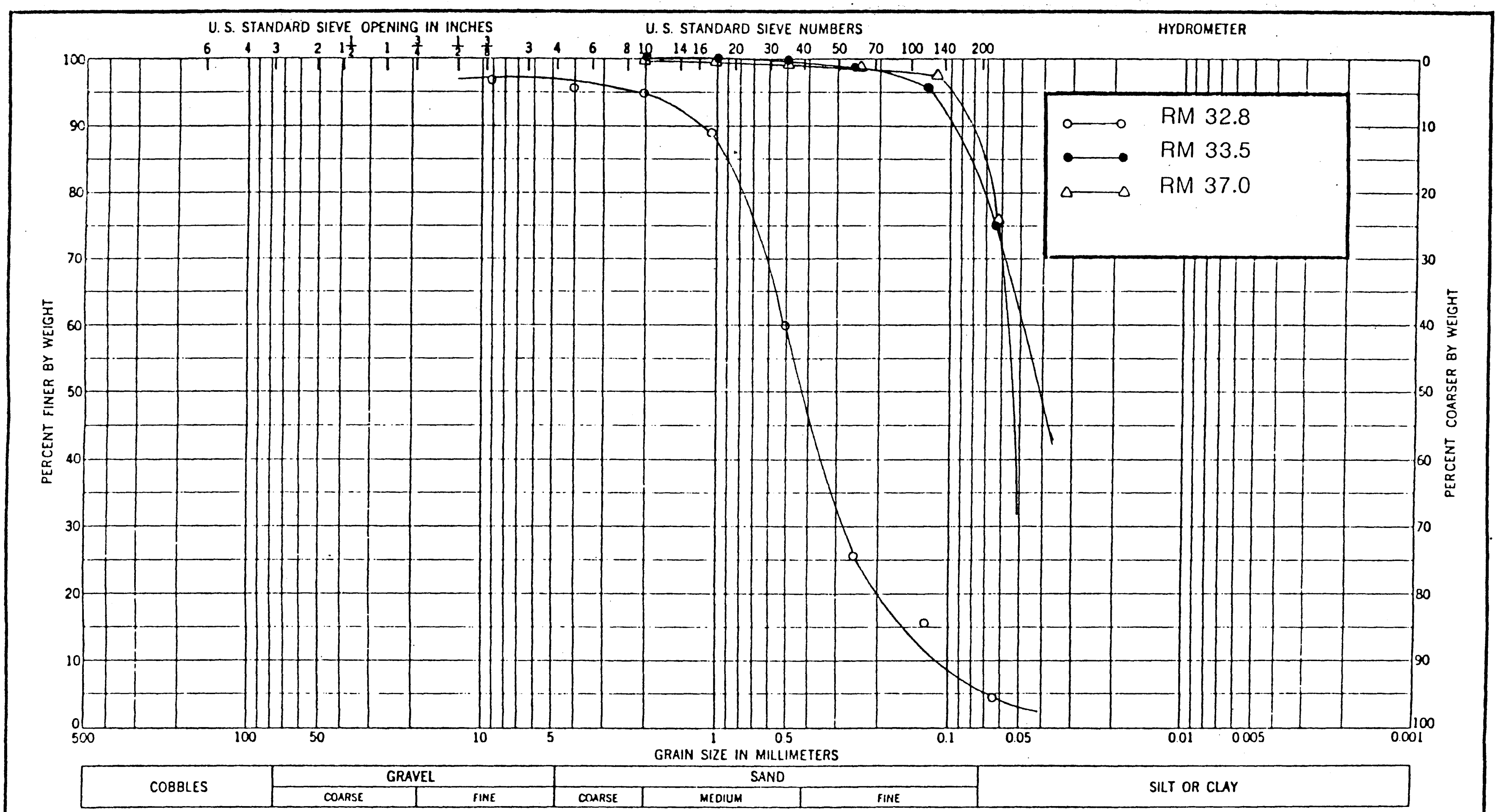
BANK SAMPLES

RM-30.0(TOP LEFT) 9/15/83

RM-30.0 (MIDDLE LEFT) 10/3/83

RM-30.0 (BOTTOM LEFT) 10/3/83

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLE

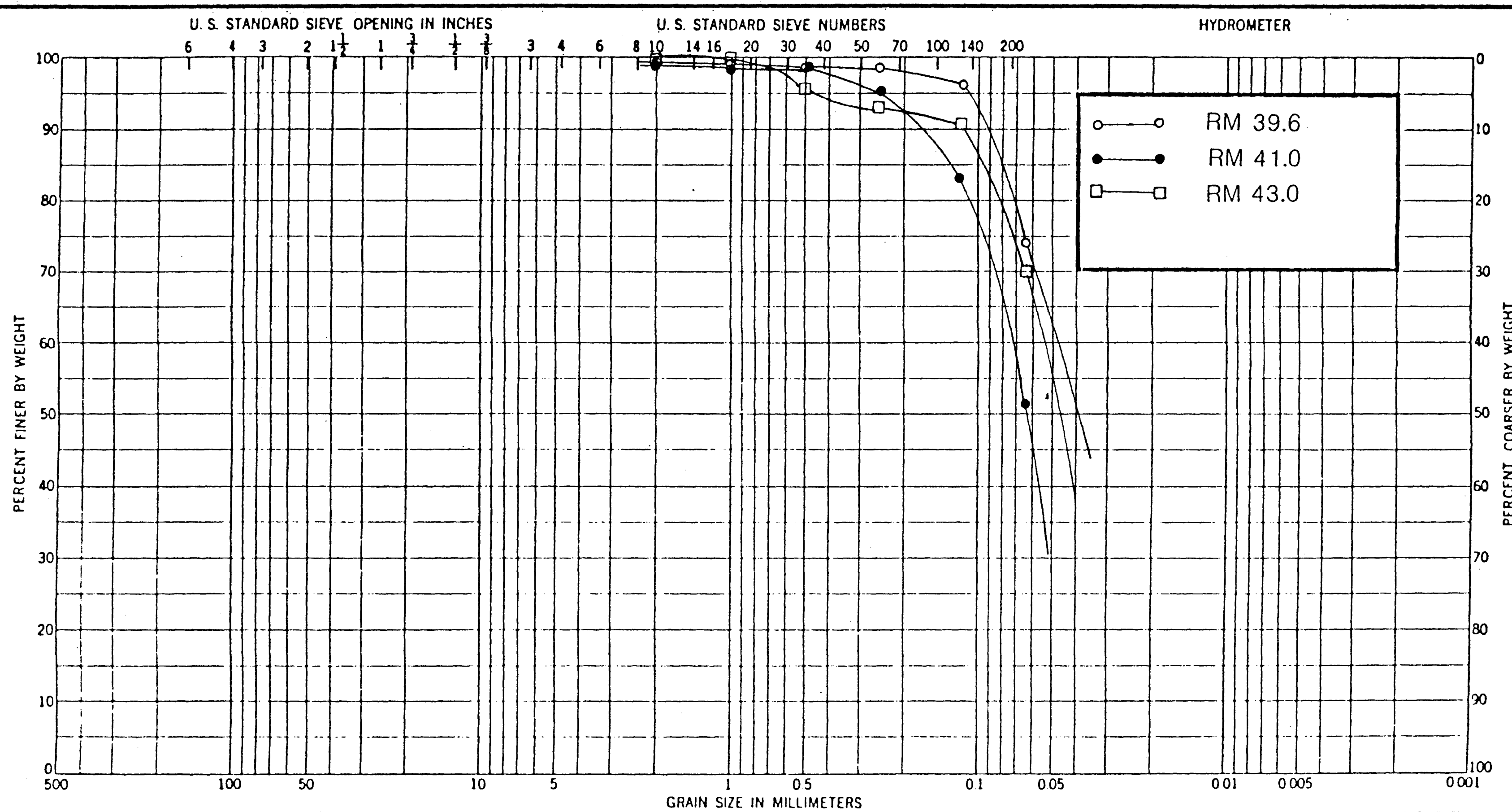
RM-32.8 (LEFT) 10/3/83

RM-33.5 (RIGHT) 9/15/83

RM-37.0 (LEFT) 9/14/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



A3.6

Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

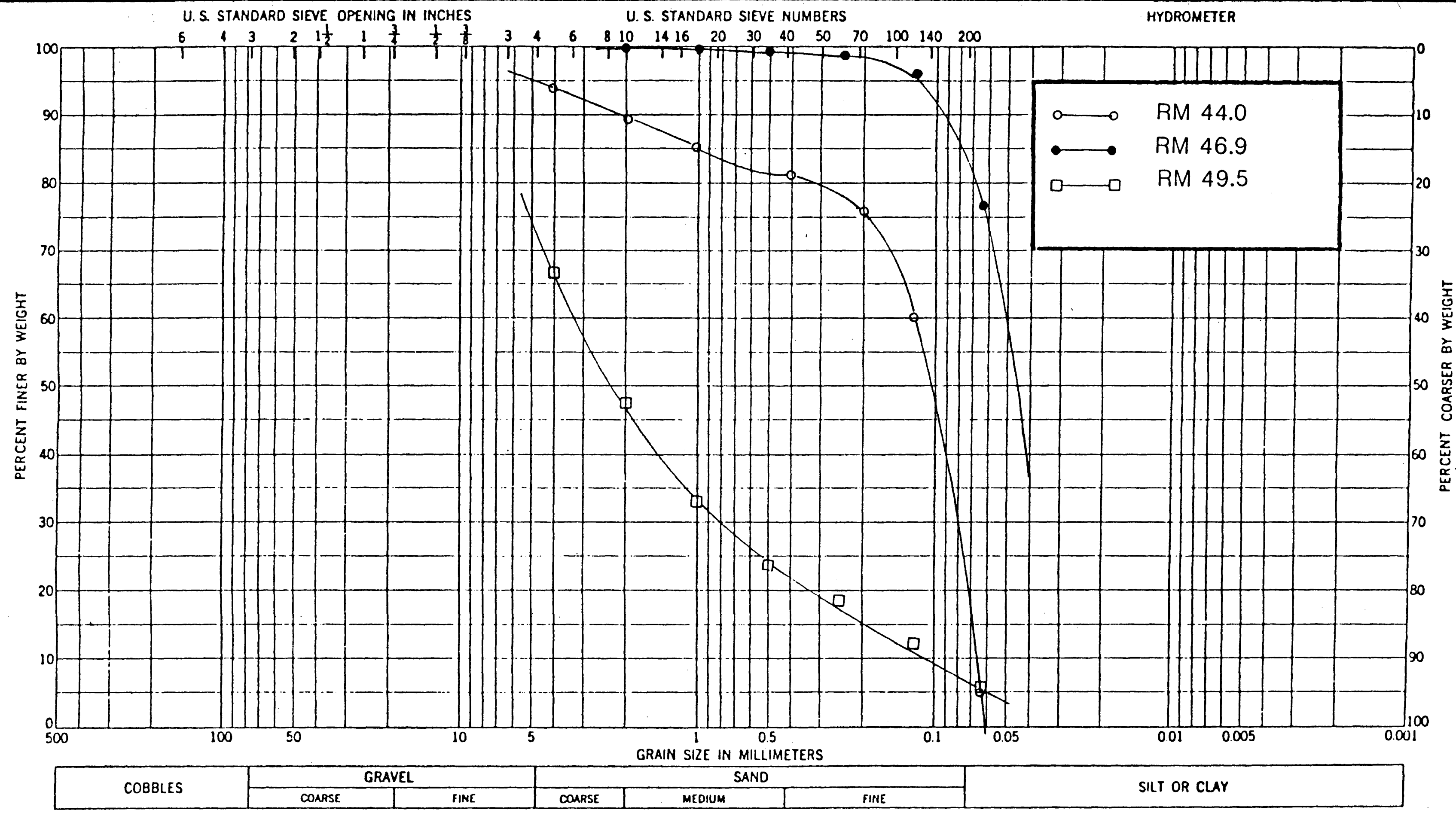
RM-39.6 (LEFT) 9/14/83

RM-41.0 (LEFT) 9/14/83

RM-42 3.0 (LEFT) 9/1483

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project **KANSAS RIVER**

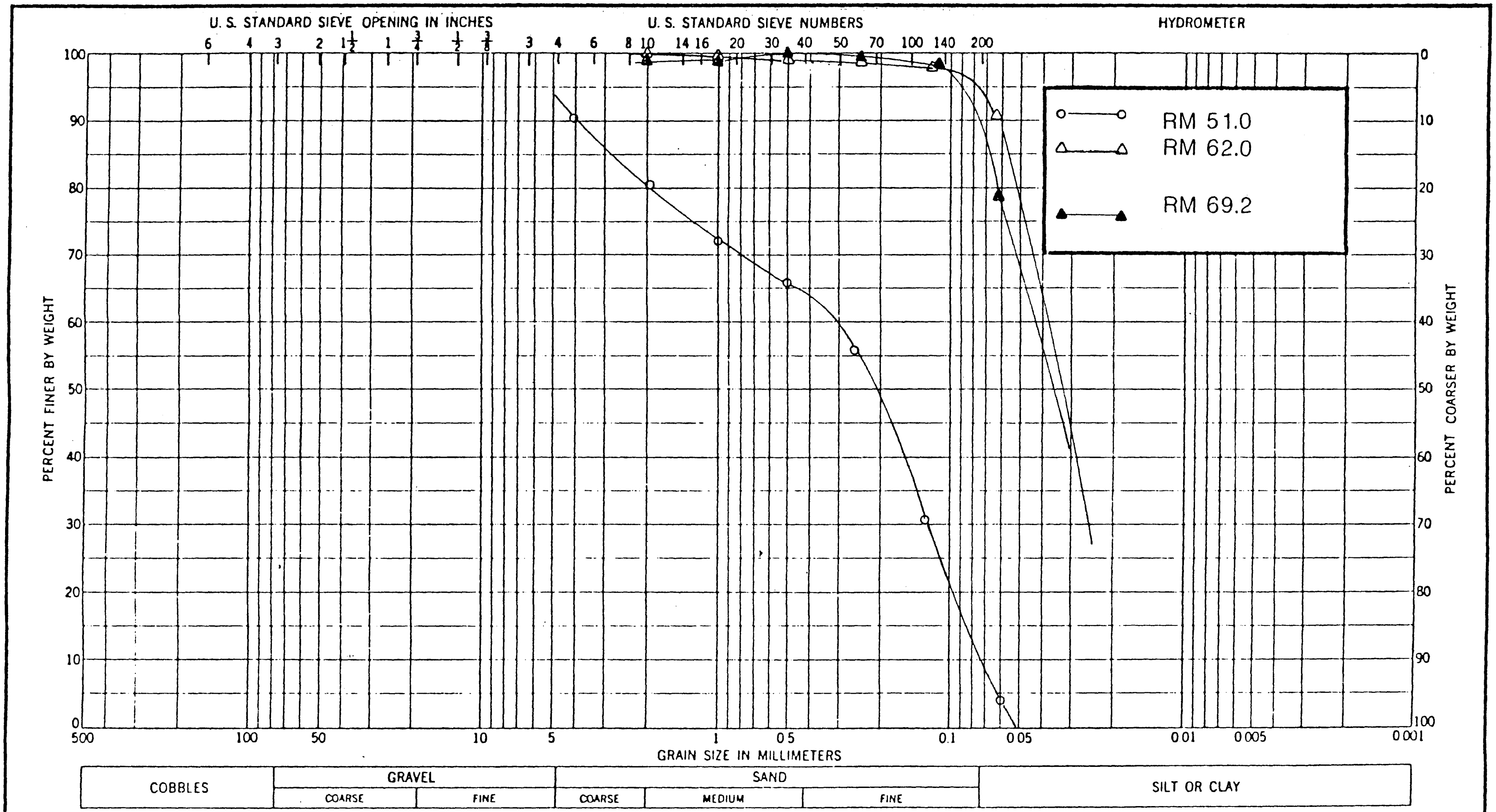
BANK SAMPLES

RM-44.0 (LEFT) 10/4/83

RM-46.0 9/14/83

RM-49.5 10/4/83

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

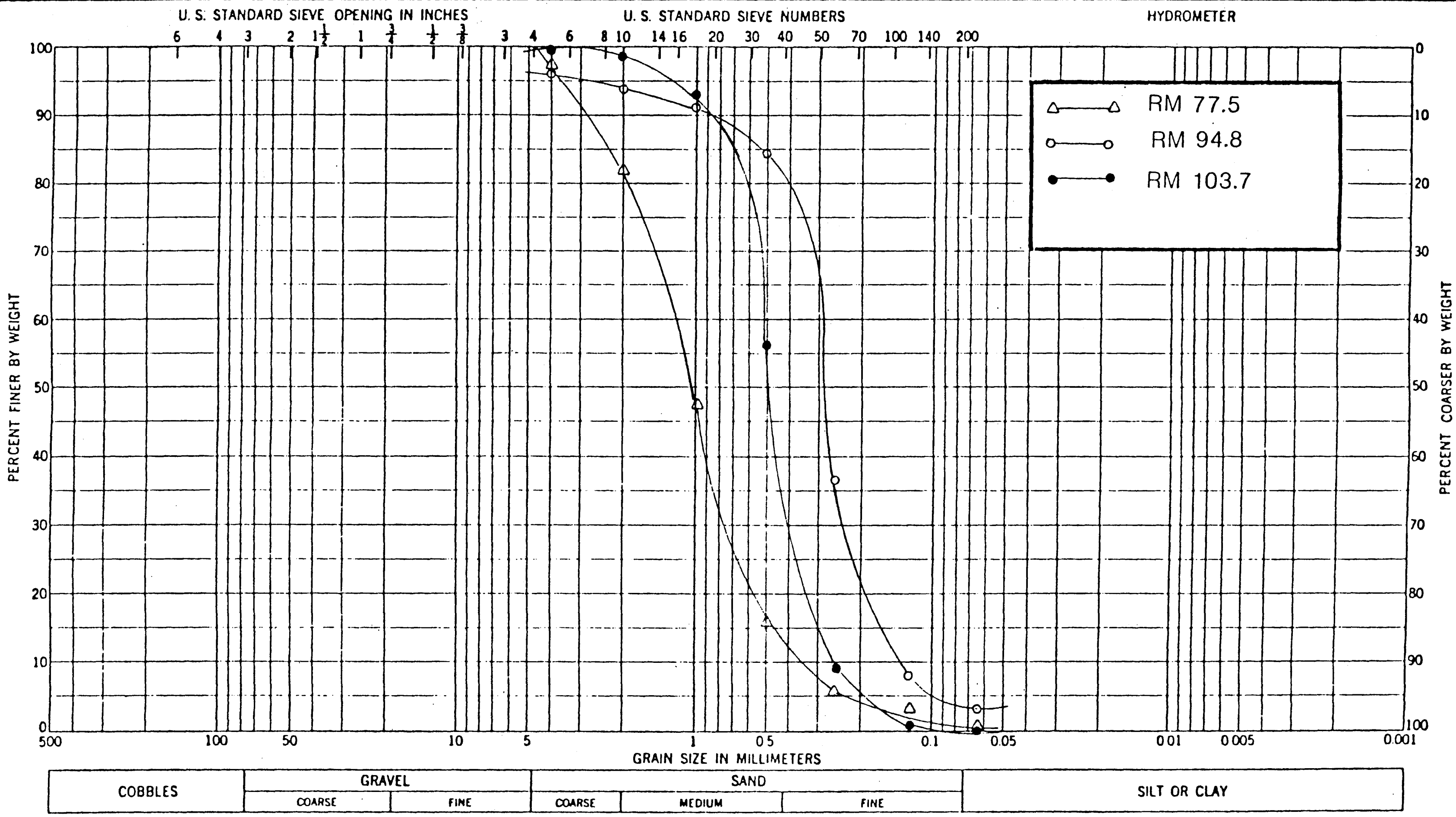
RM-51.0 (LEFT)

RM-62.0 (RIGHT) 9/14/83

RM-69.2 (RIGHT) 9/27/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project **KANSAS RIVER**

BANK SAMPLES

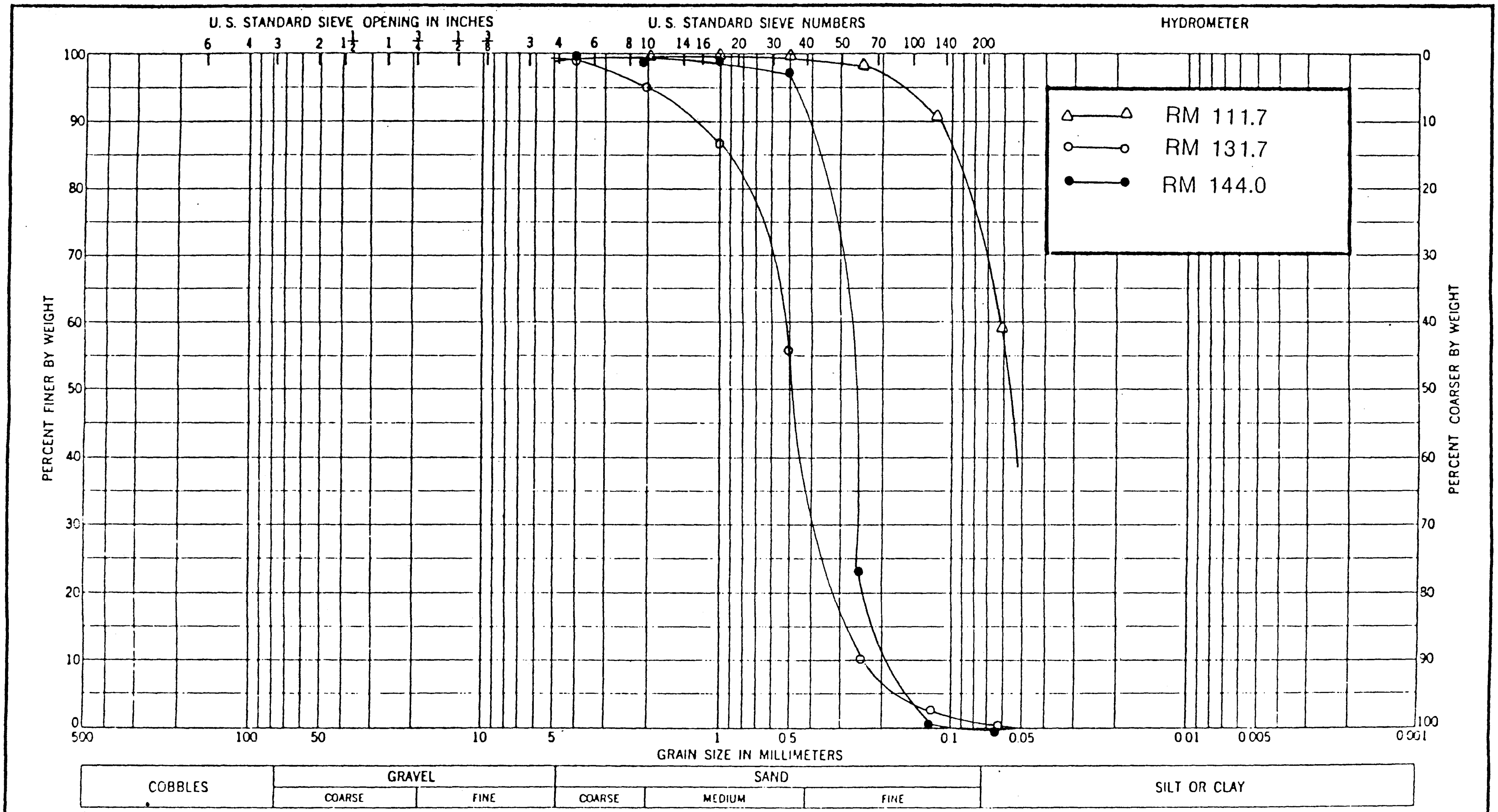
RM-77.5 (RIGHT) 10/5/83

RM-94.8 (LEFT) 10/6/83

RM-103.7 (LEFT) 10/6/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

Project KANSAS RIVER

BANK SAMPLES

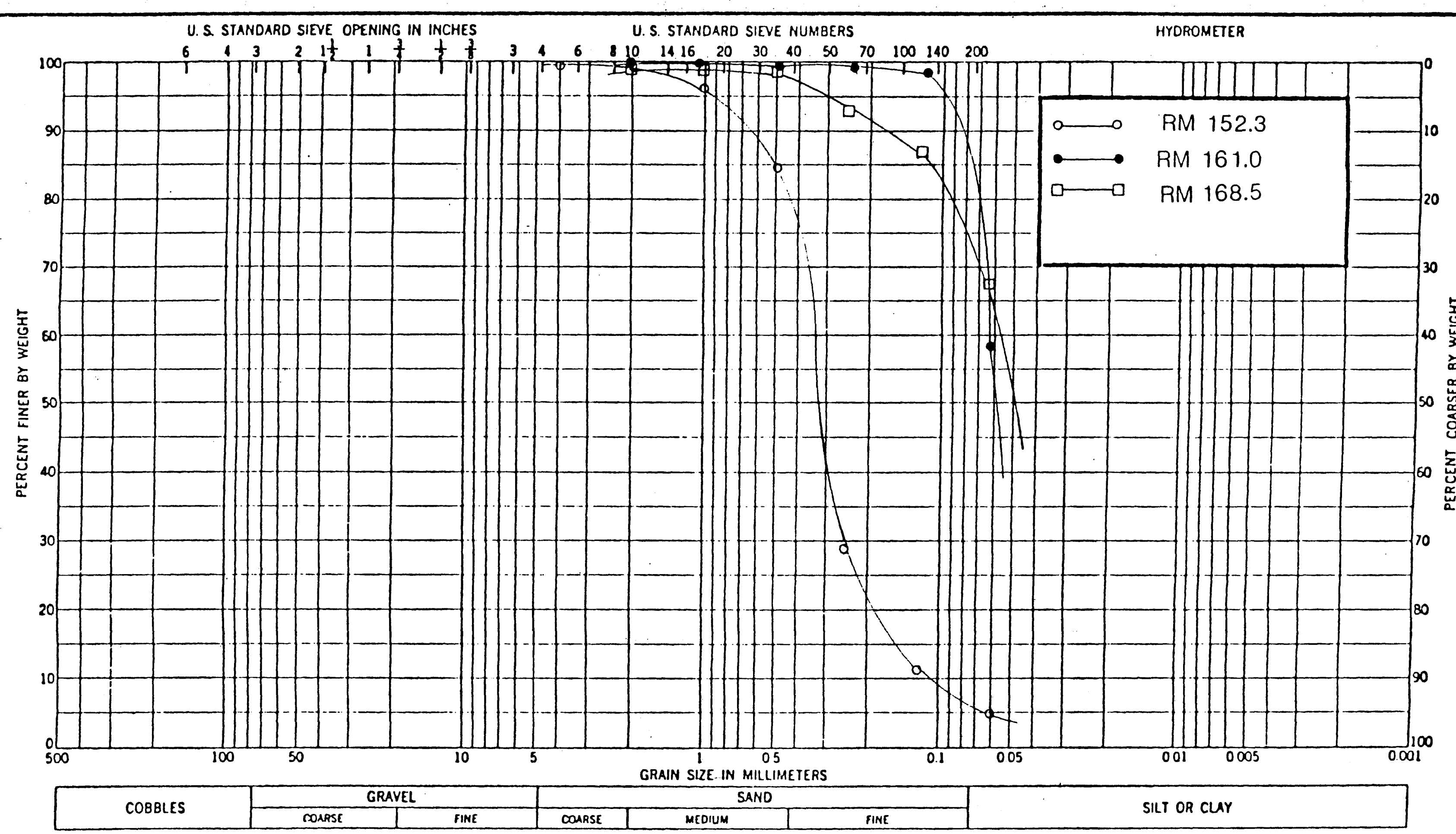
RM-111.7 (RIGHT) 9/27/83

RM-131.7 (LEFT) 10/6/83

RM-144.0 (LEFT) 10/6/83

GRADATION CURVES

ENG FORM 1 MAY 63 2087



Sample No.	Elev or Depth	Classification	Nat w %	LL	PL	PI

GRADATION CURVES

Project **KANSAS RIVER**

BANK SAMPLES

RM-152.3 (LEFT) 10/6/83

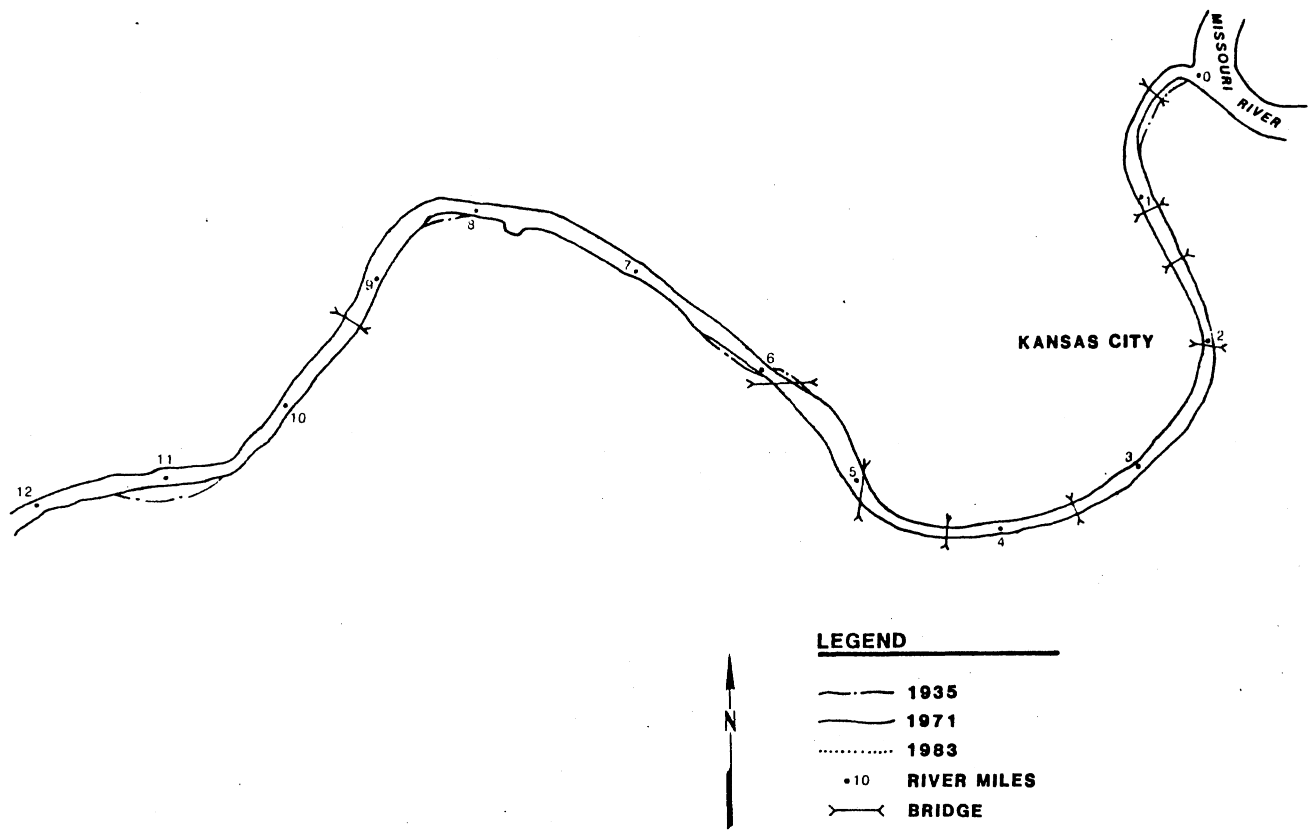
RM-161.0 (LEFT) 9/27/83

RM-168.5 (LEFT) 9/27/83

ENG FORM 1 MAY 63 2087

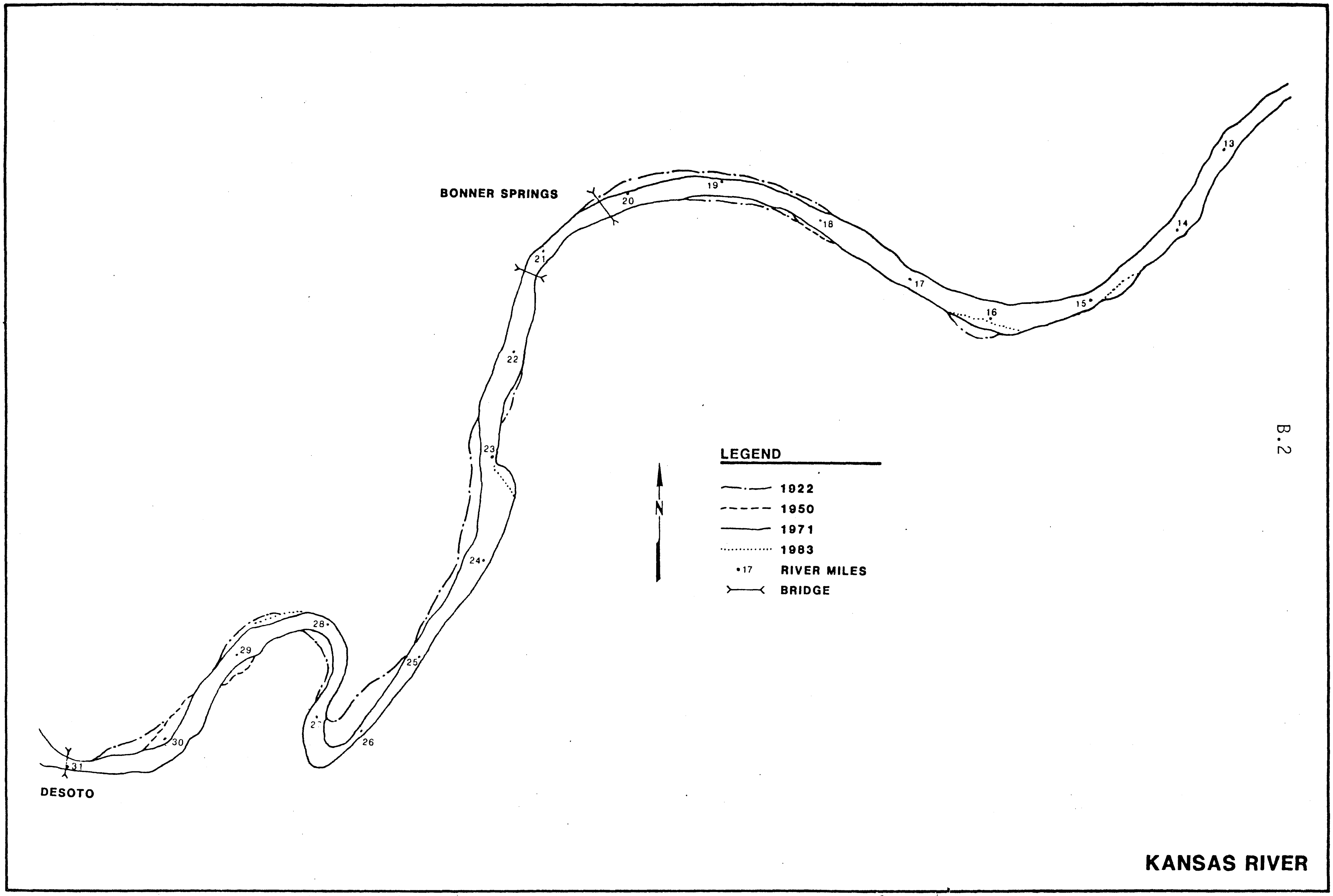
APPENDIX B

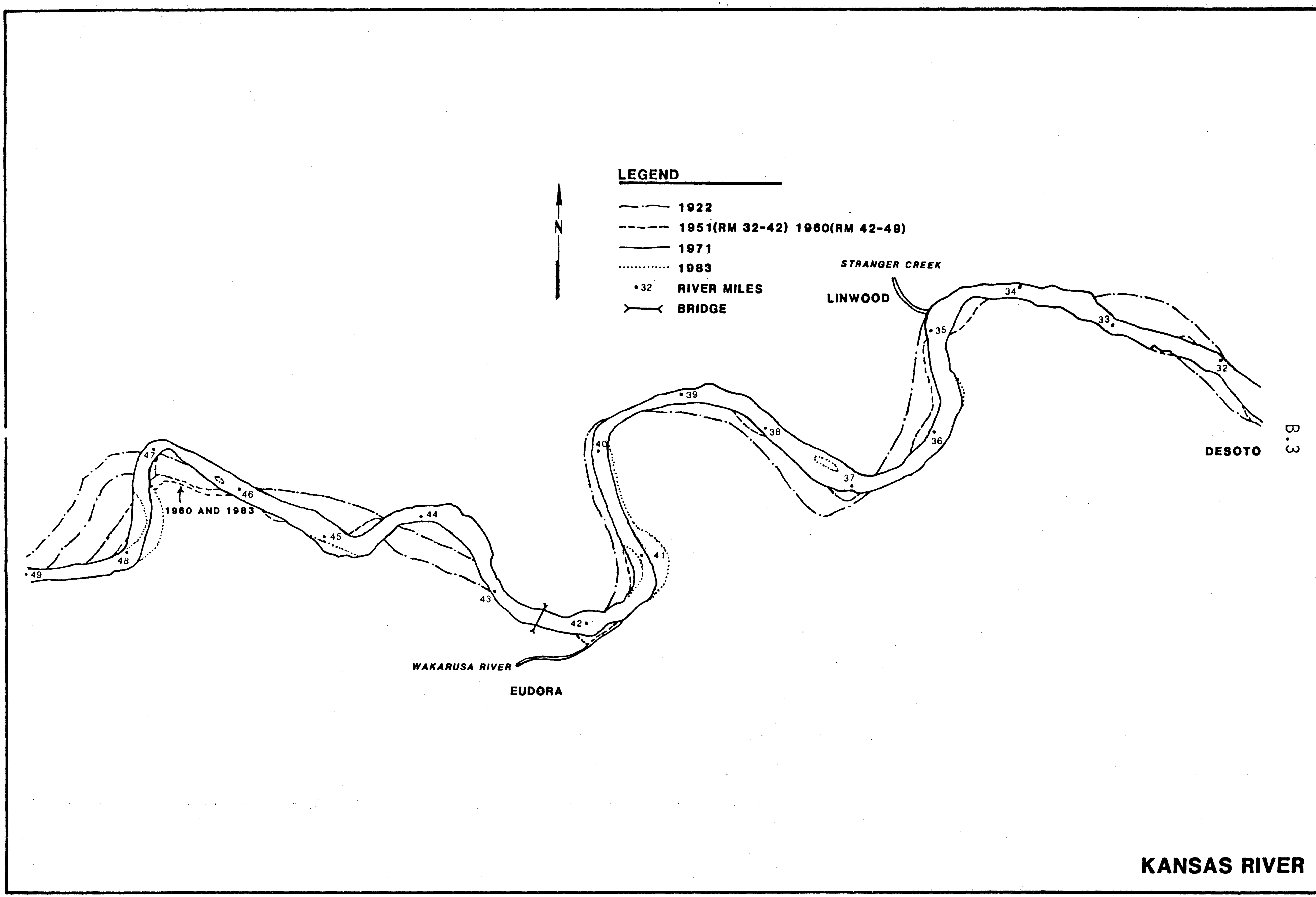
Historic Channel Migration Maps
(Prepared from information presented by Drot (1979) and the 1983 aerial photography)

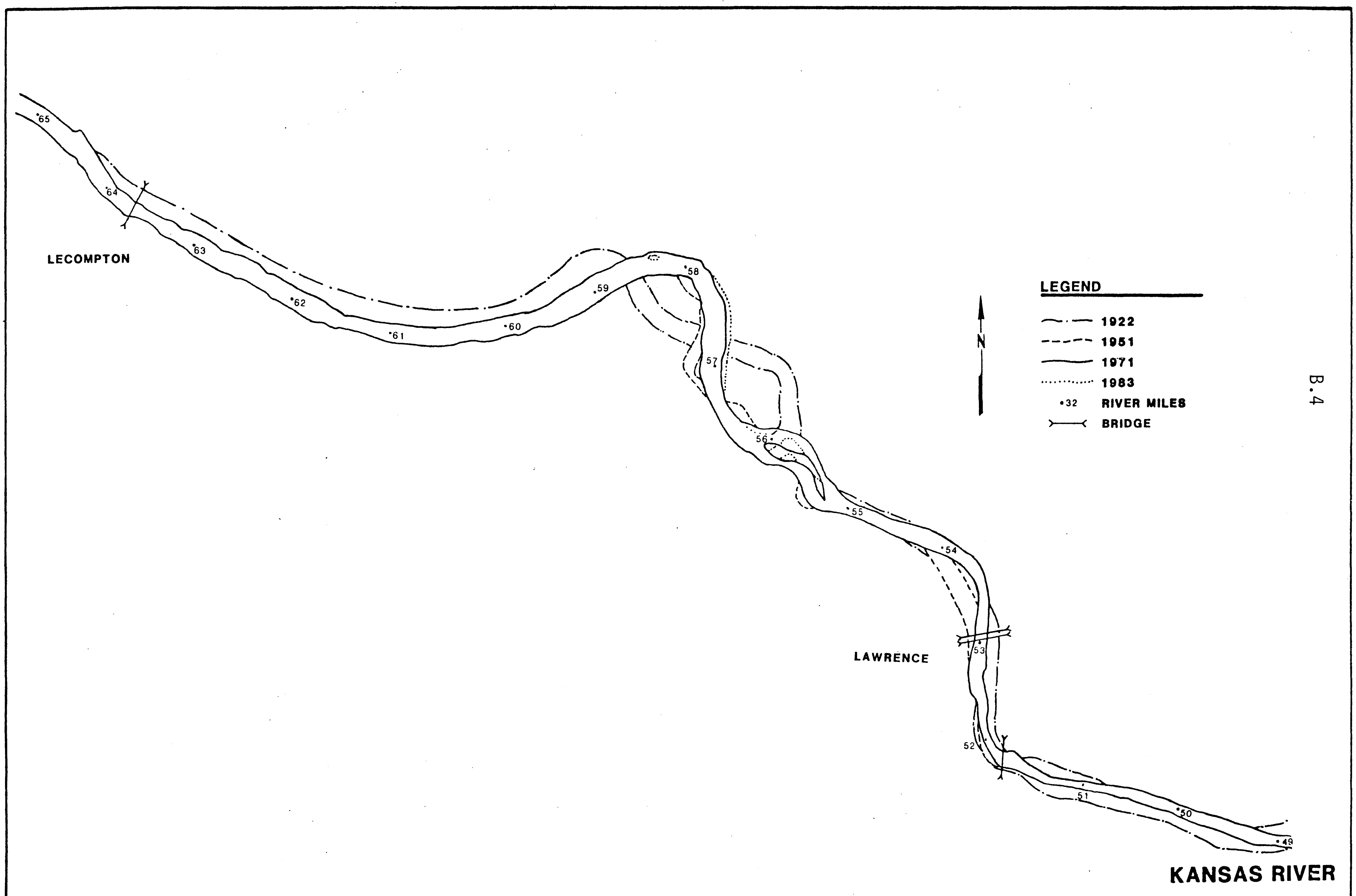


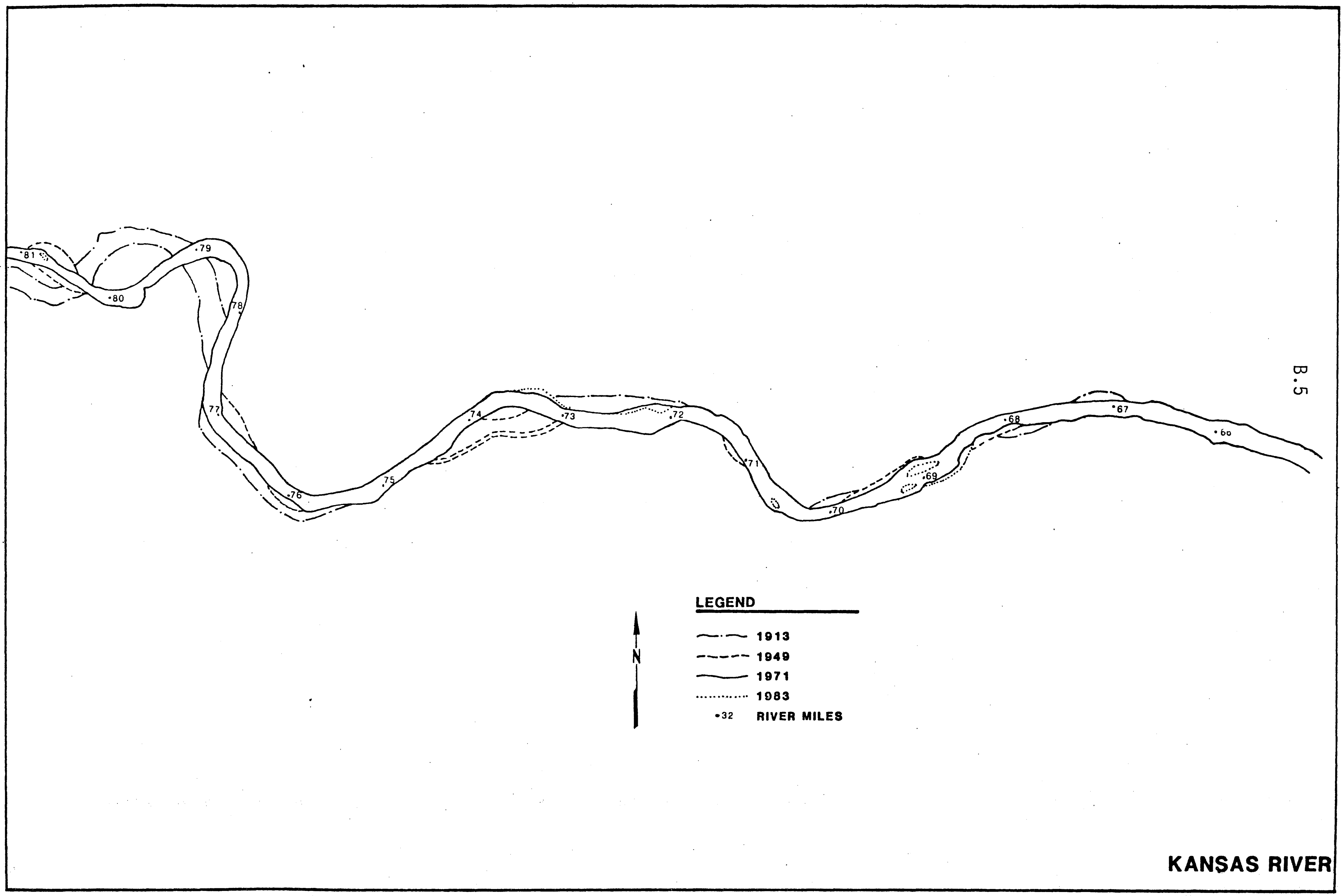
B.1

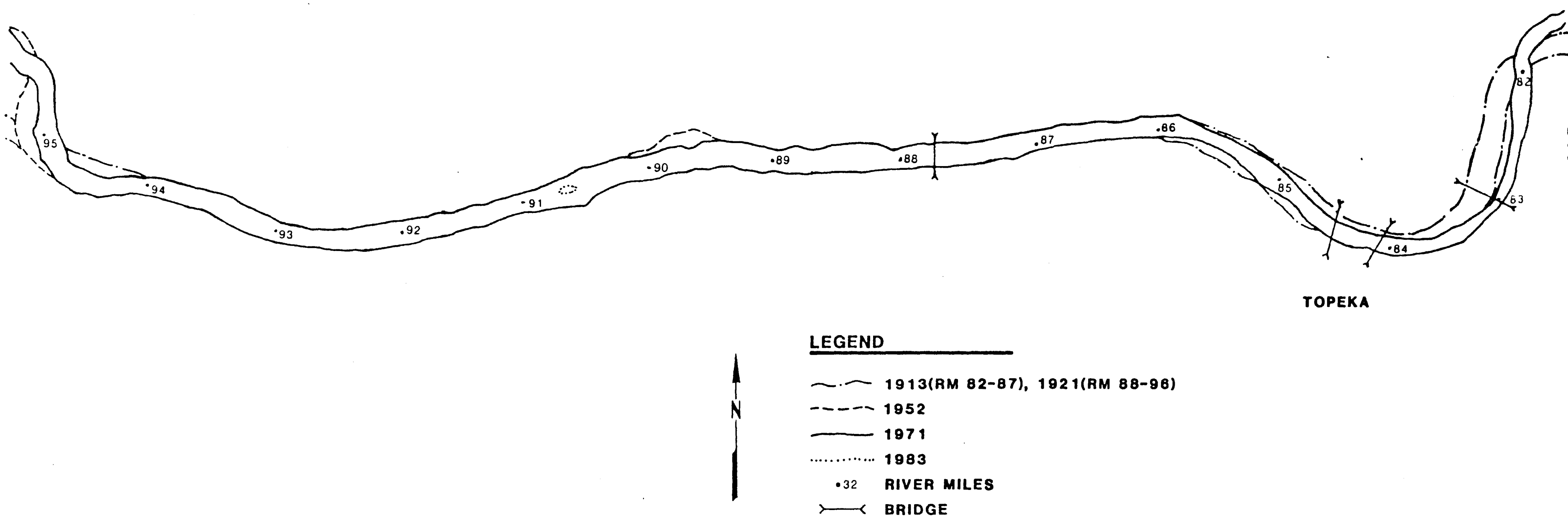
KANSAS RIVER


BONNER SPRINGS
DESOTO
LEGEND
1922
1950
1971
1983
•17 RIVER MILES
BRIDGE
N
13
14
15
16
17
18
19
20
21
22
23
24
25
26
28
29
30
31
KANSAS RIVER

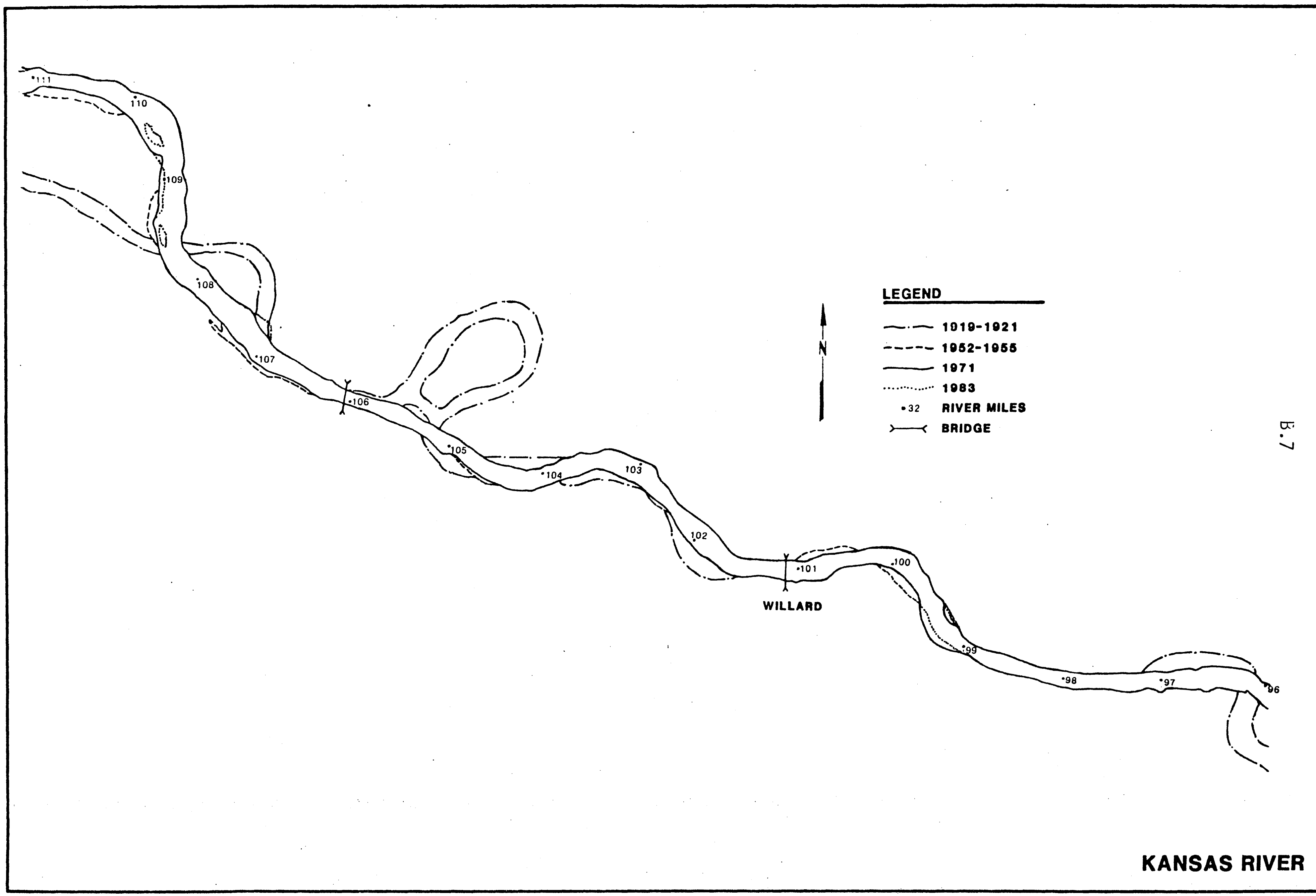

LEGEND
1922
1951(RM 32-42) 1960(RM 42-49)
1971
1983
32 RIVER MILES
BRIDGE
N
STRANGER CREEK
LINWOOD
DESOTO
WAKARUSA RIVER
EUDORA
1960 AND 1983
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
KANSAS RIVER

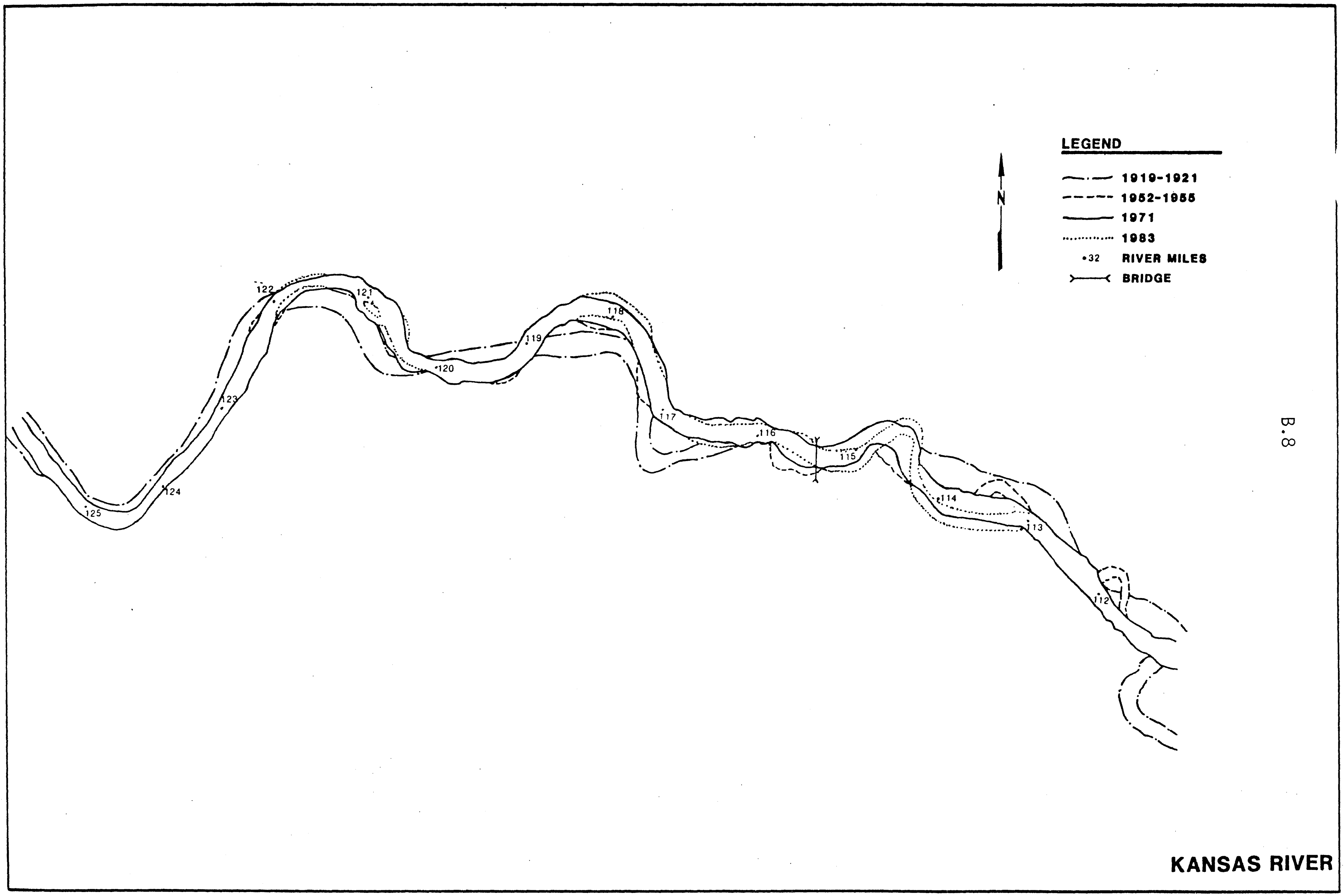

LECOMPTON
LAWRENCE
65
64
63
62
61
60
59
58
57
56
55
54
53
52
51
50
49
LEGEND
1922
1951
1971
1983
•32 RIVER MILES
BRIDGE
N
KANSAS RIVER

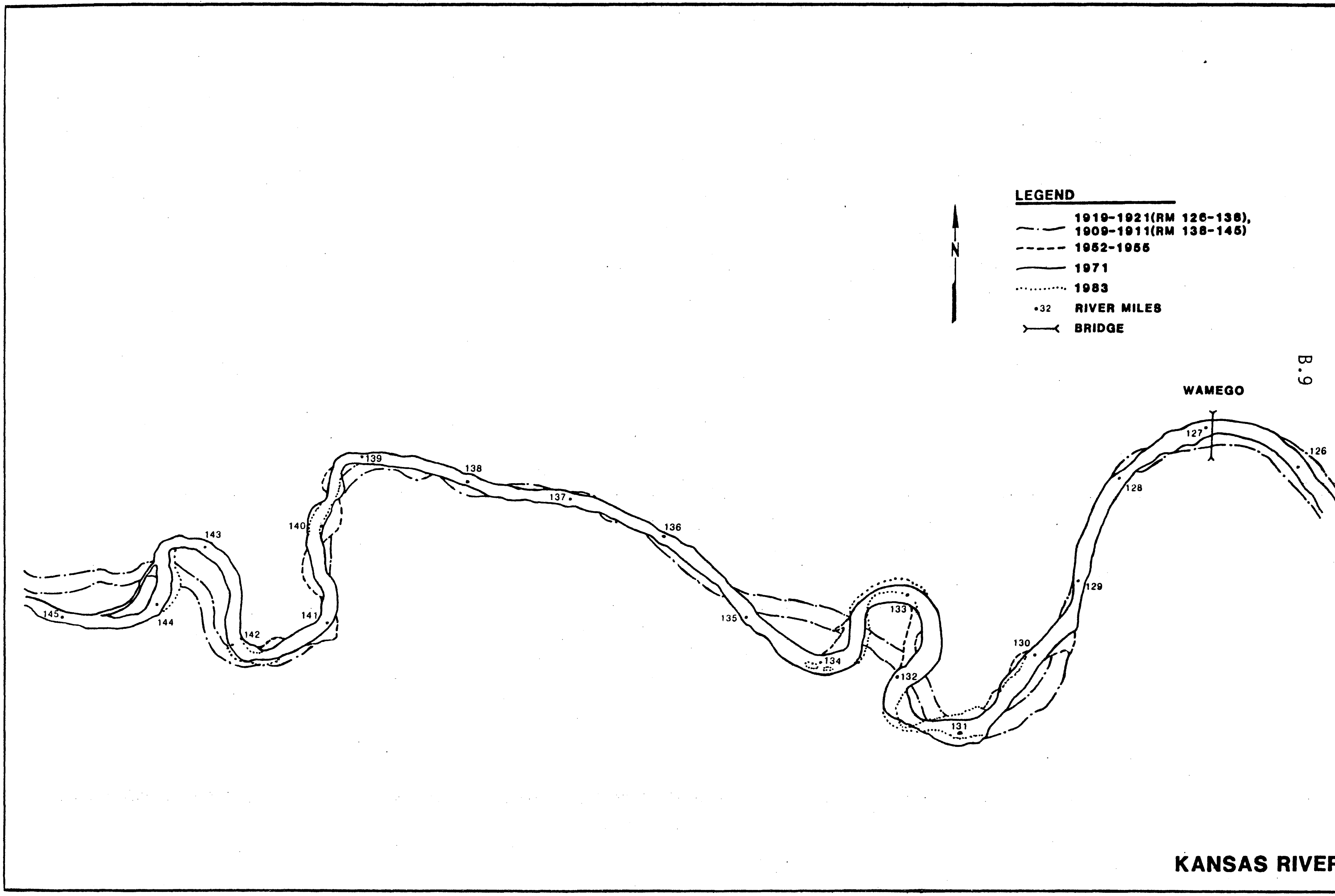

81
80
79
78
77
76
75
74
73
72
71
70
69
68
67
66
N
LEGEND
1913
1949
1971
1983
•32 RIVER MILES
KANSAS RIVER

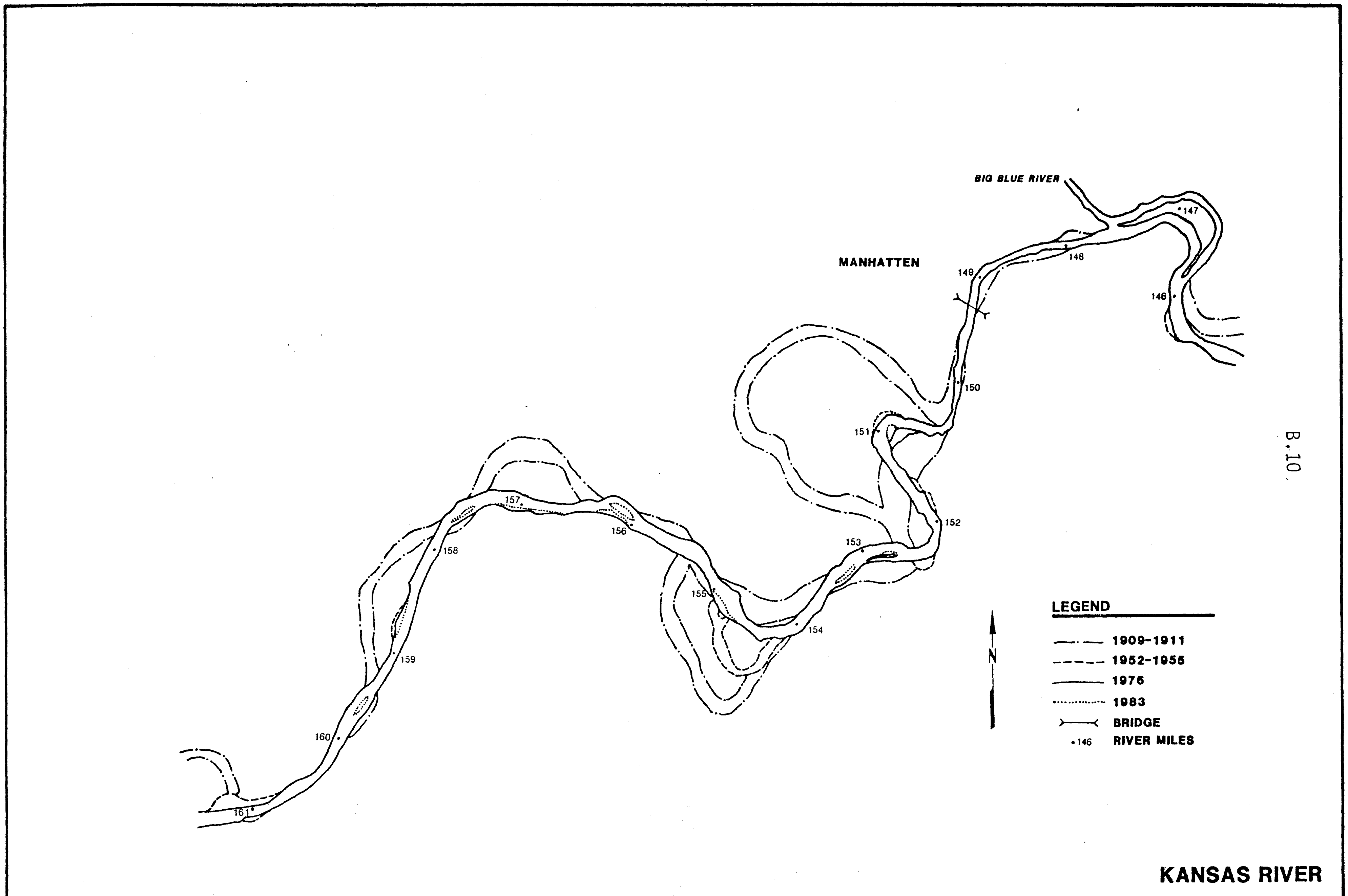


KANSAS RIVER

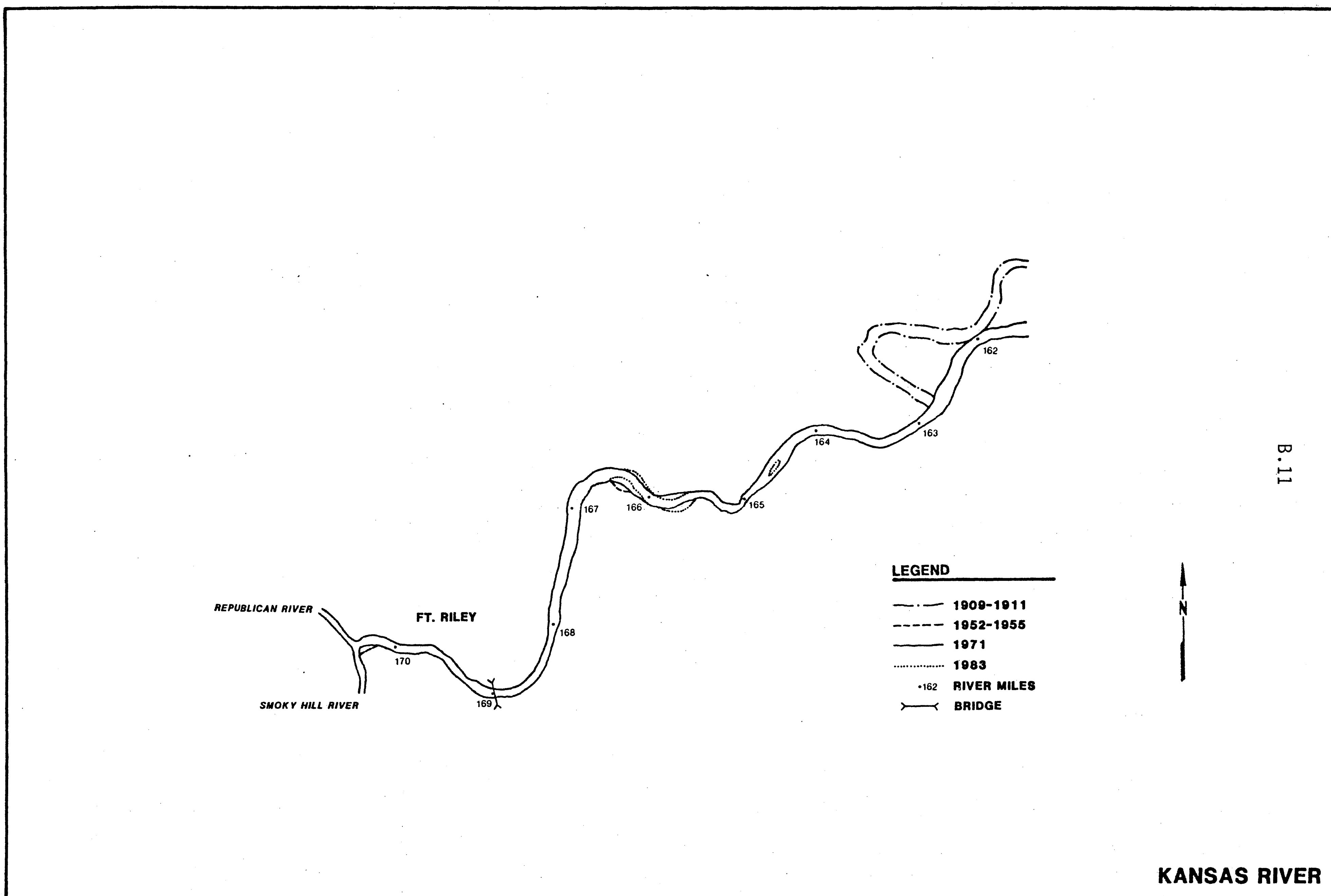

111
110
109
108
107
106
105
104
103
102
101
100
99
98
97
96
WILLARD
N
LEGEND
1919-1921
1952-1955
1971
1983
•32 RIVER MILES
BRIDGE
KANSAS RIVER


LEGEND
1919-1921
1952-1955
1971
1983
•32 RIVER MILES
BRIDGE
N
122
121
120
119
118
117
116
115
114
113
112
123
124
125
KANSAS RIVER


LEGEND
1919-1921(RM 126-138),
1909-1911(RM 138-145)
1952-1955
1971
1983
•32 RIVER MILES
BRIDGE
N
WAMEGO
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
KANSAS RIVER



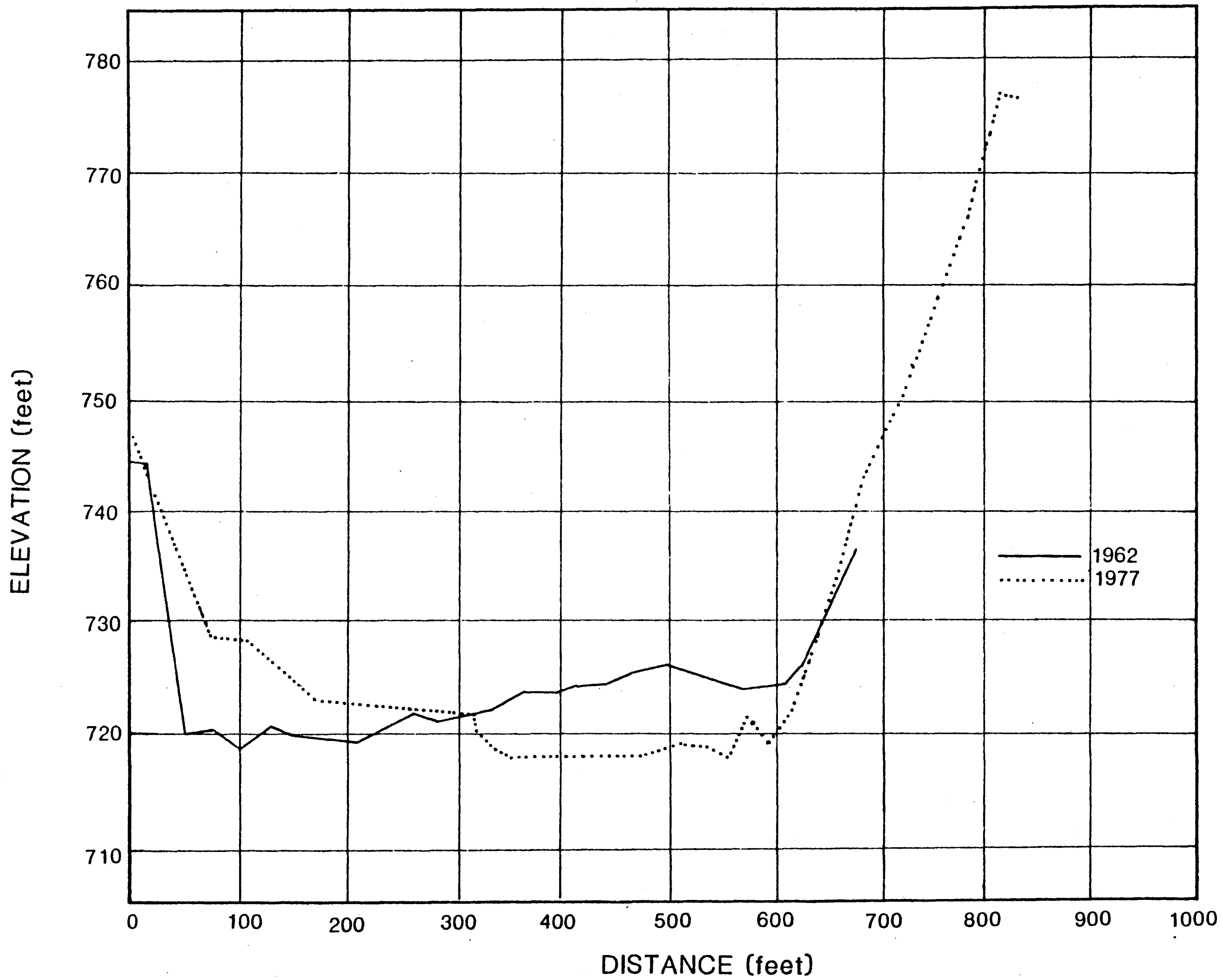
KANSAS RIVER


REPUBLICAN RIVER
FT. RILEY
SMOKY HILL RIVER
170
169
168
167
166
165
164
163
162
LEGEND
1909-1911
1952-1955
1971
1983
•162 RIVER MILES
BRIDGE
N
KANSAS RIVER

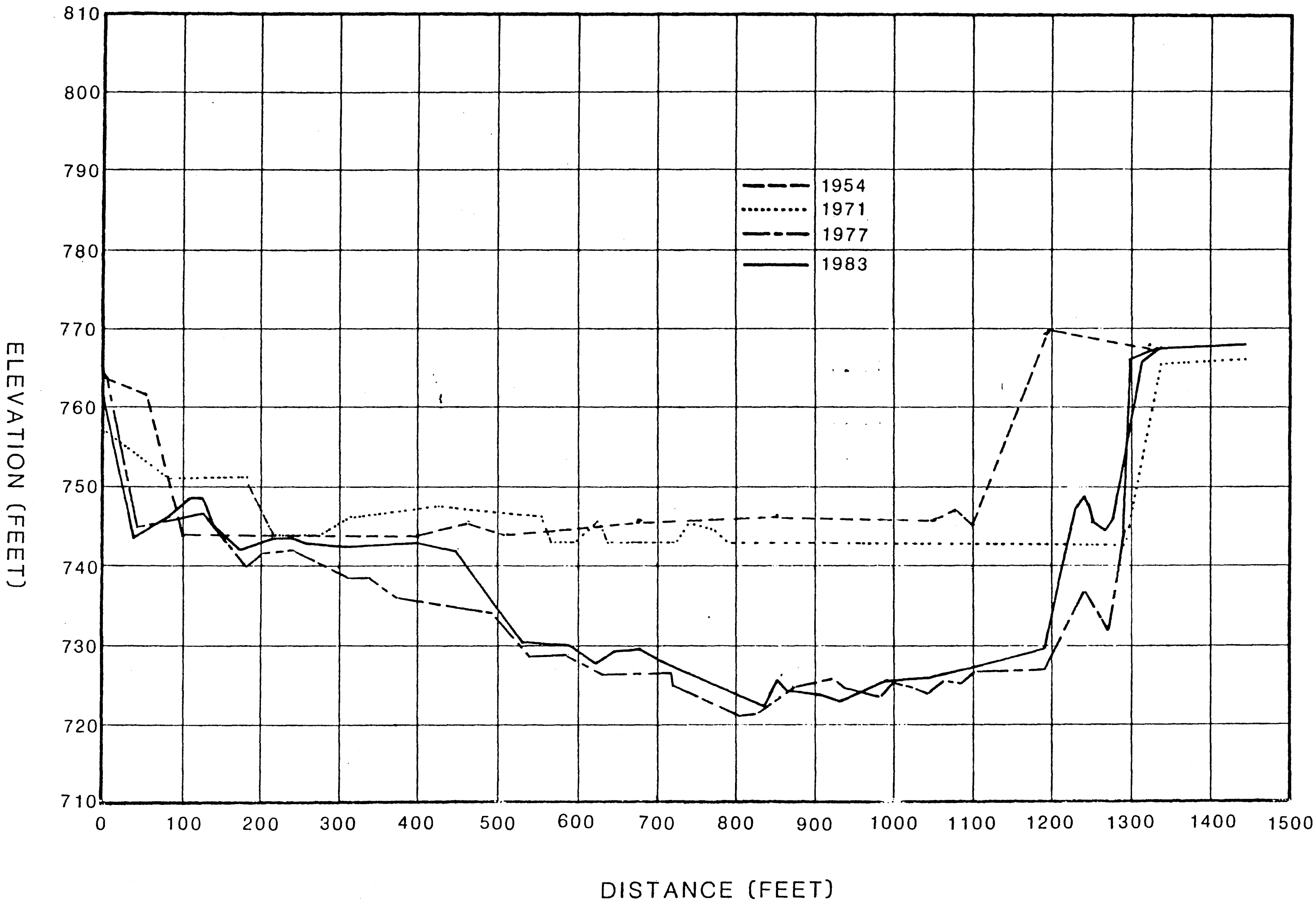
B.11

APPENDIX C

Historic Cross Sections

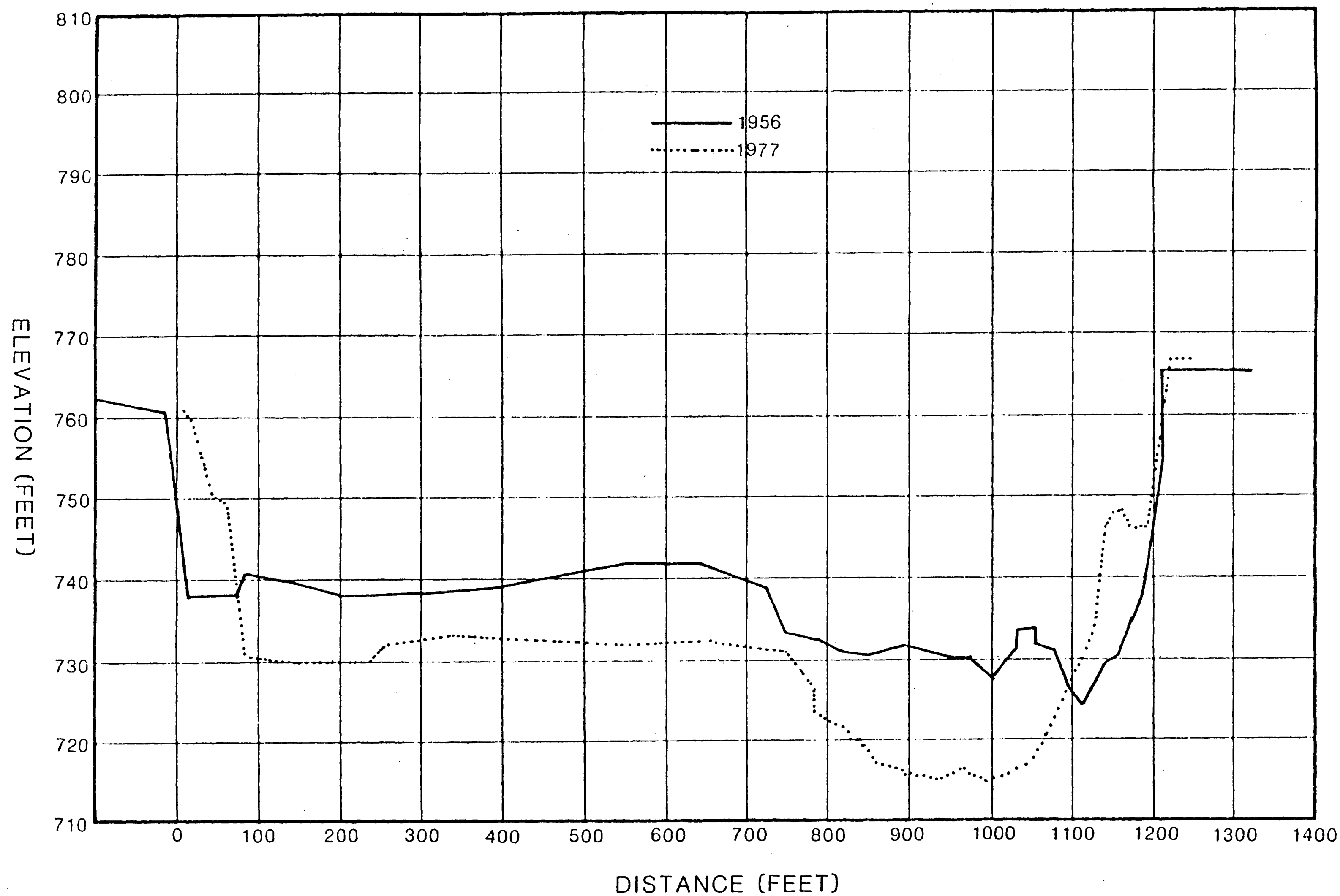


River Mile 9.5

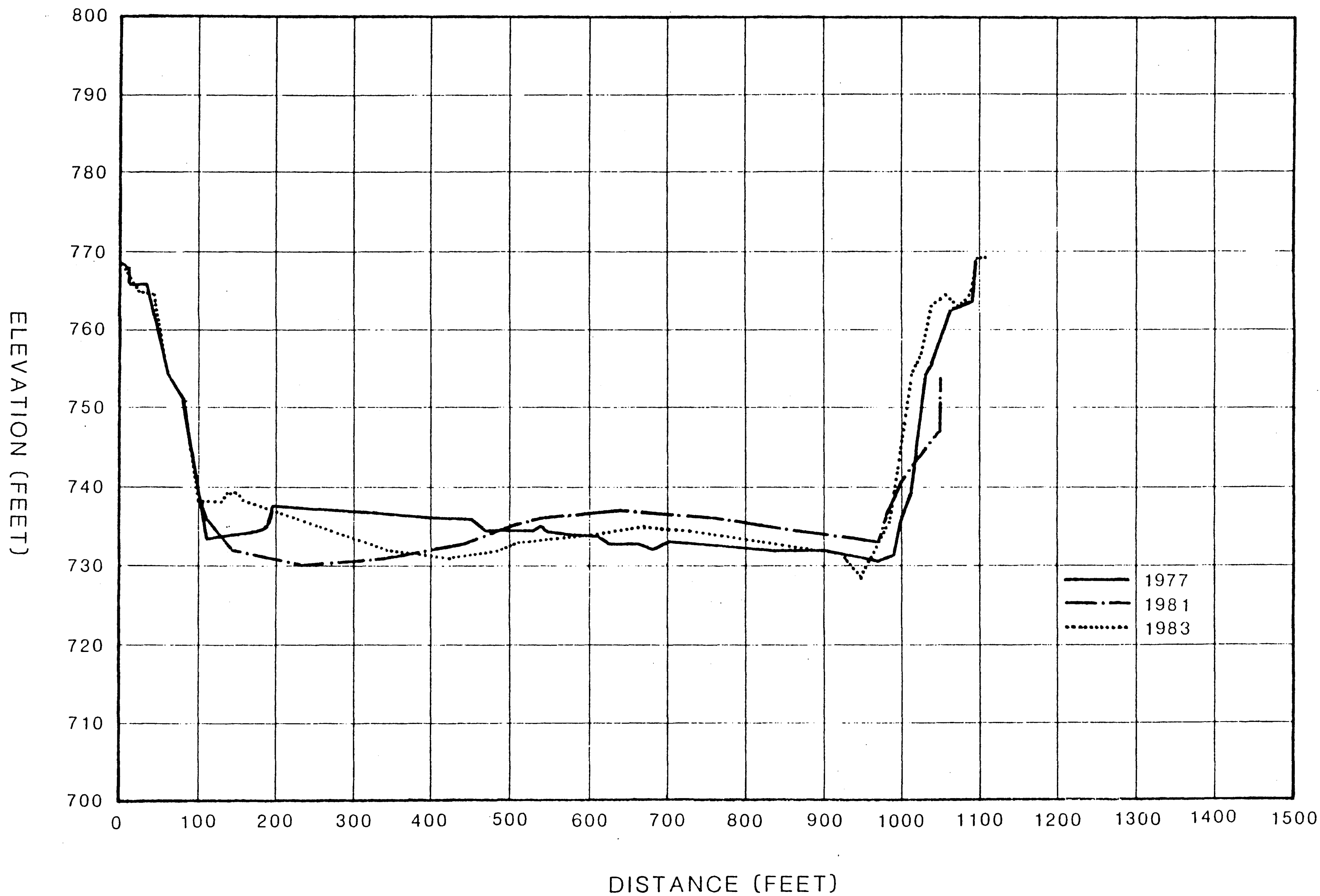


River Mile 13.68

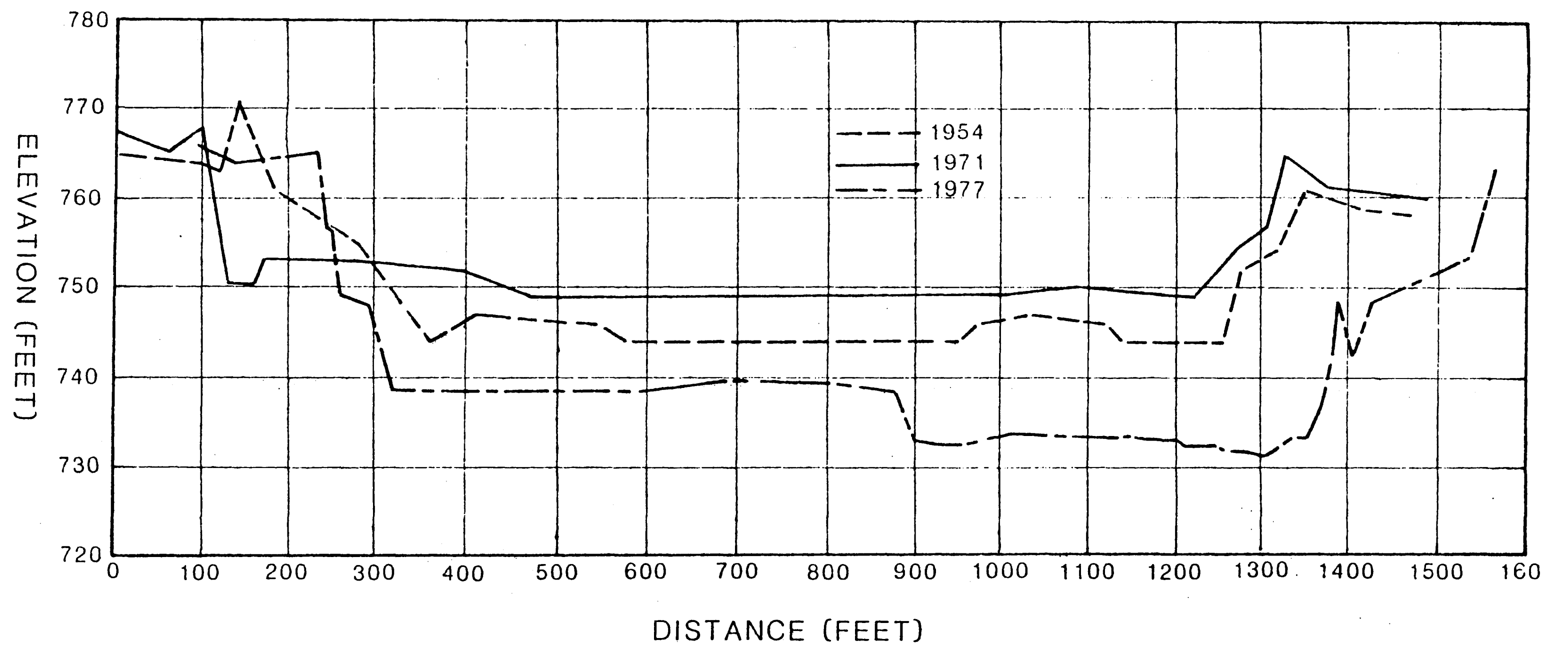
NOTE: 1954 and 1971 sections from uncontrolled aerial photography, for comparison of channel topwidth only



River Mile 14.10

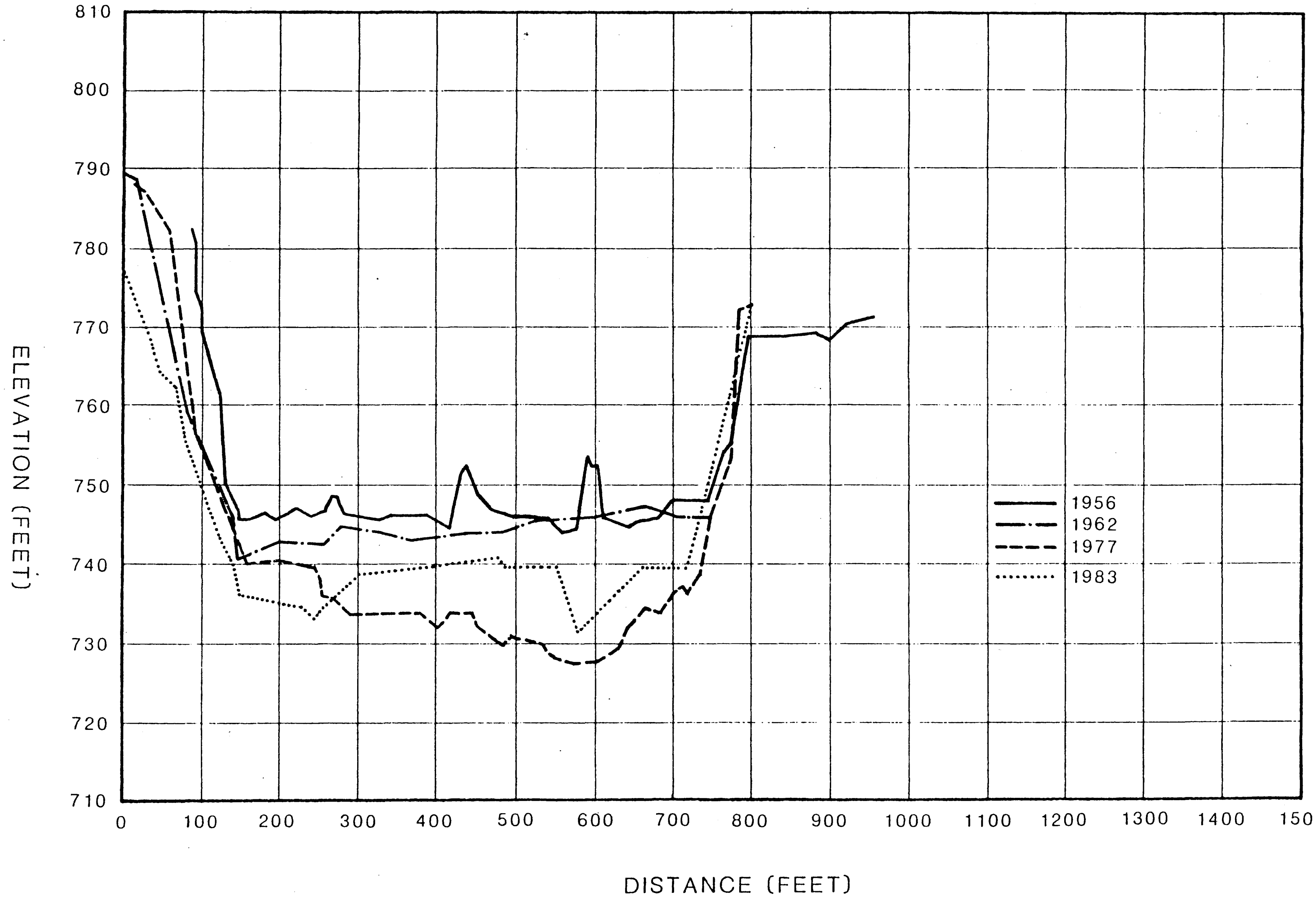


River Mile 17.07

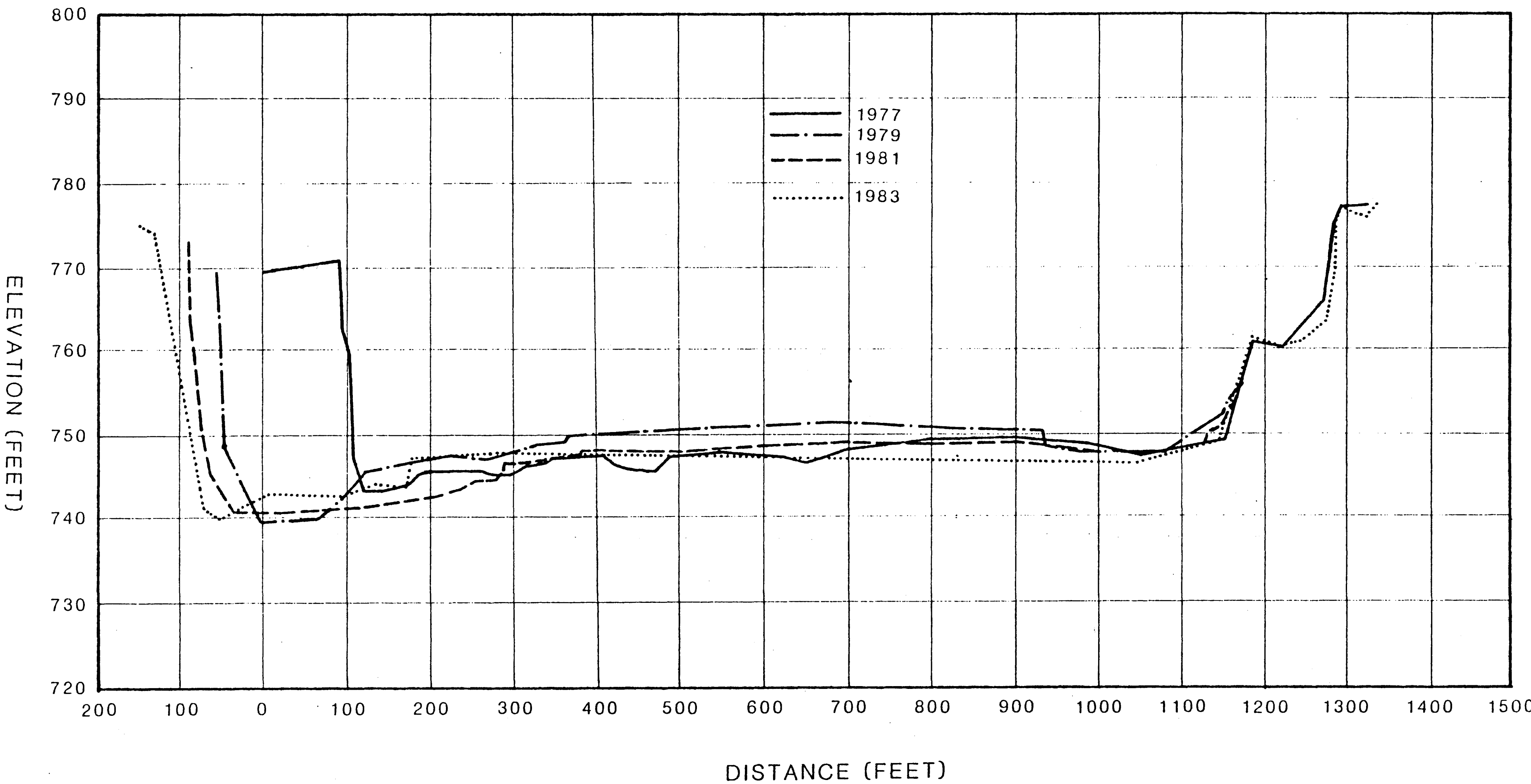


River Mile 17.55

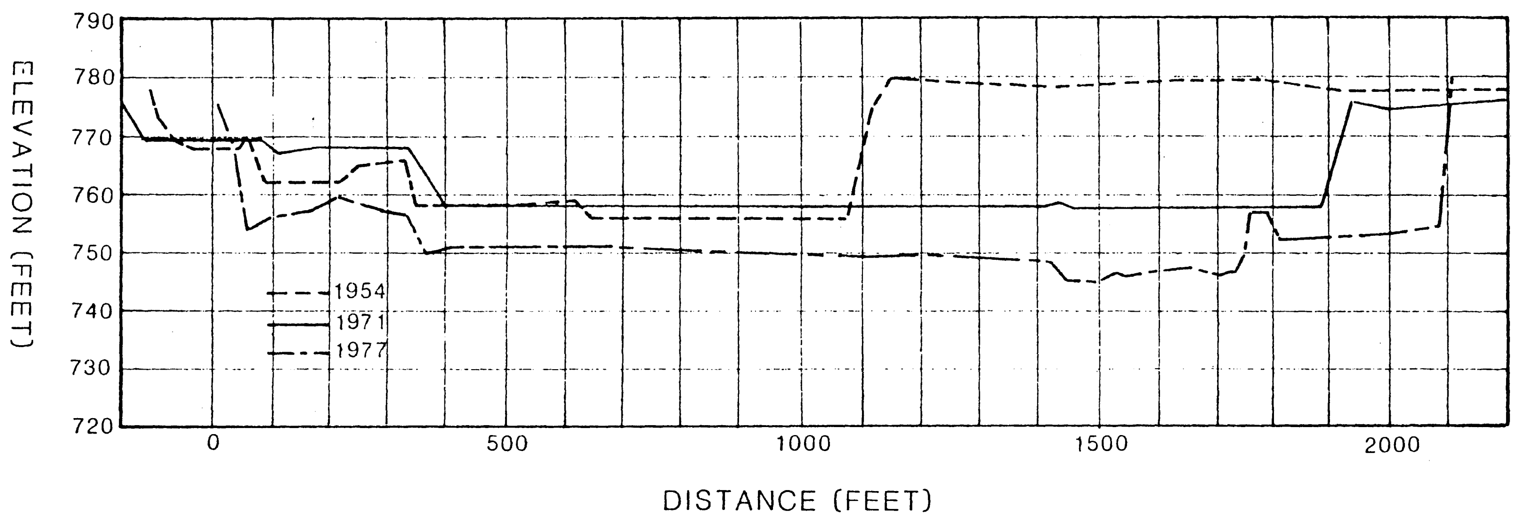
Note: 1954 and 1971 sections from uncontrōlled aerial photography. For comparison of channel width only.



River Mile 21.00

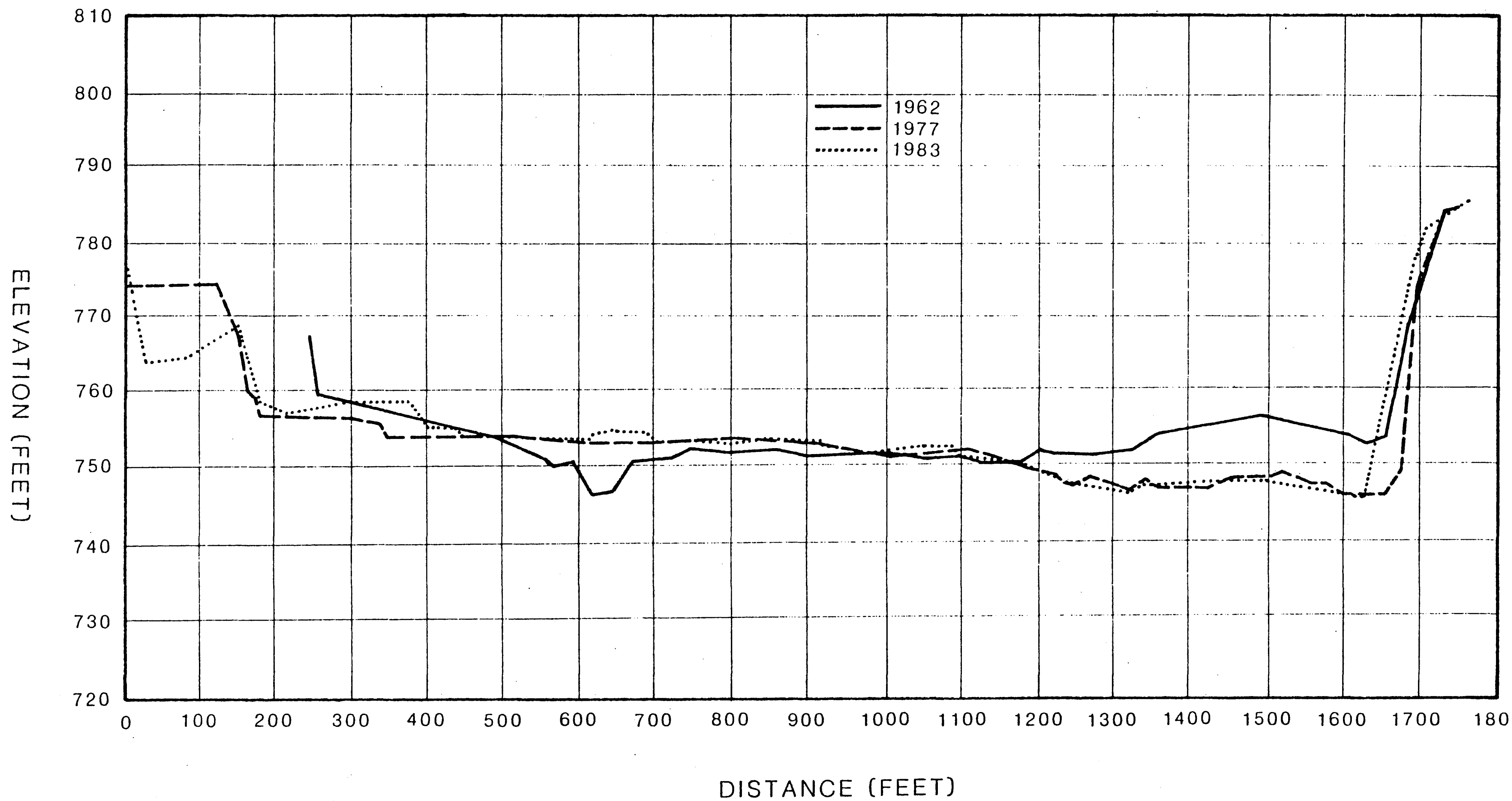


River Mile 22.68

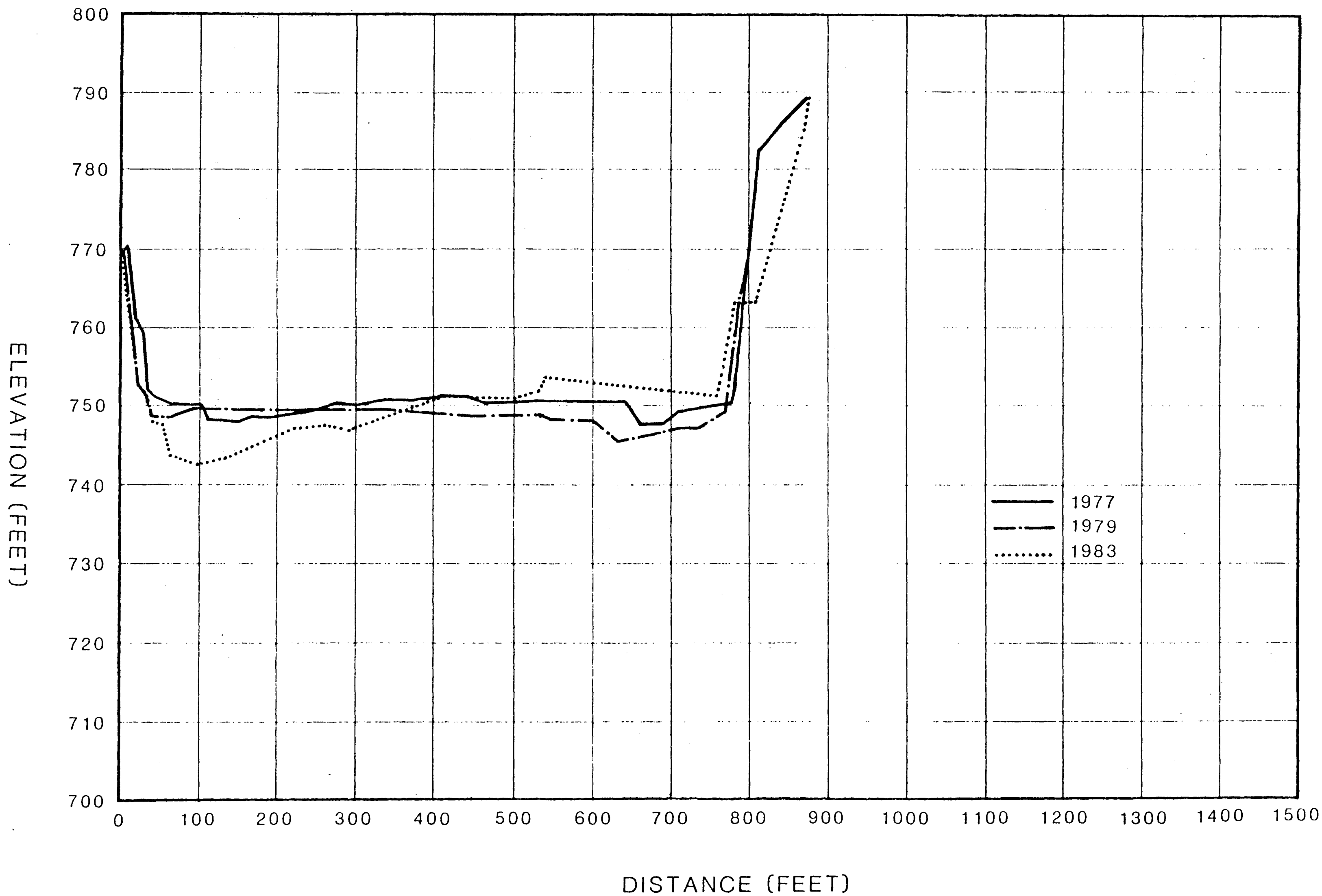


River Mile 23.17

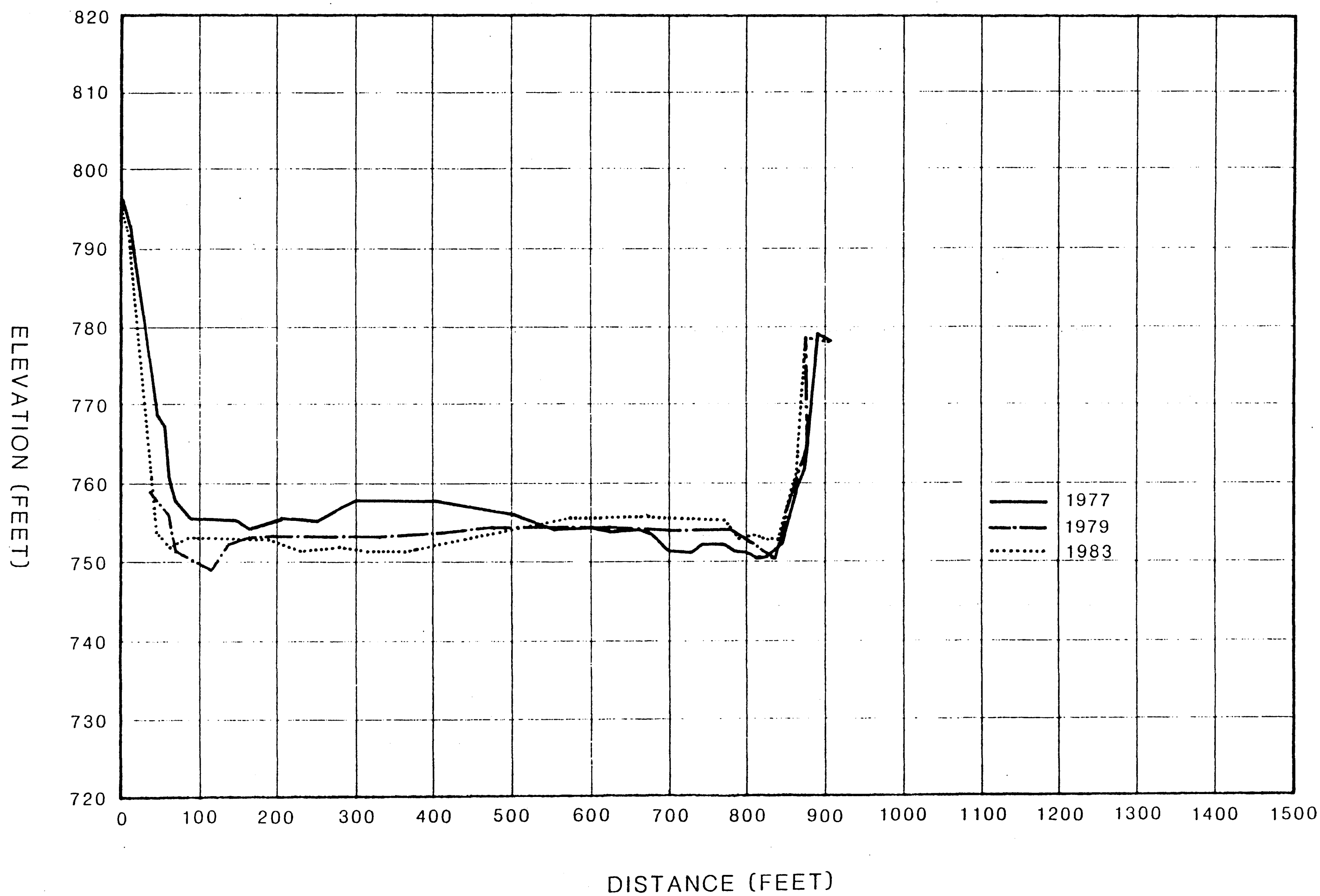
Note: 1954 and 1971 sections from uncontrolled aerial photography. For comparisons of channel width only.



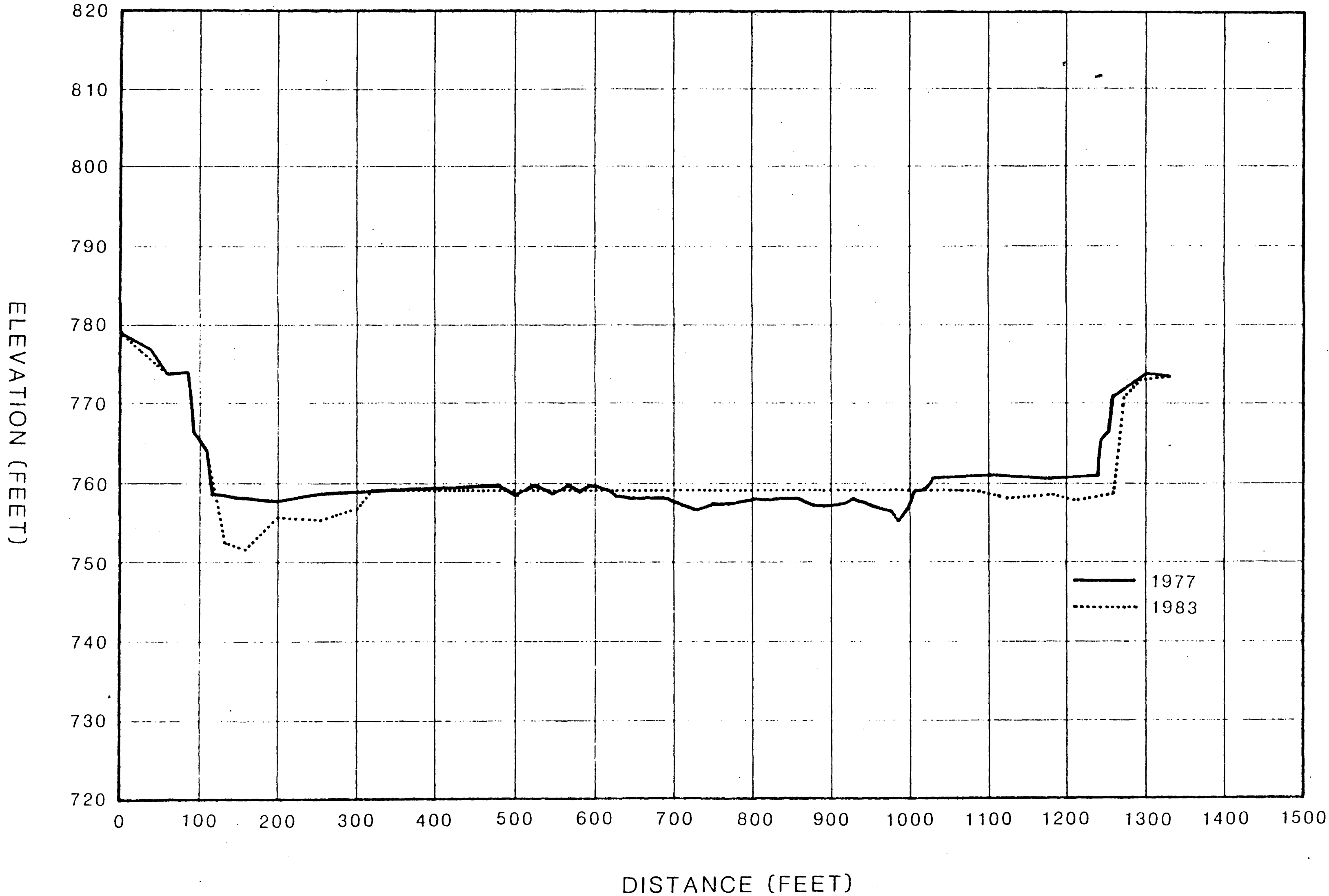
River Mile 23.70



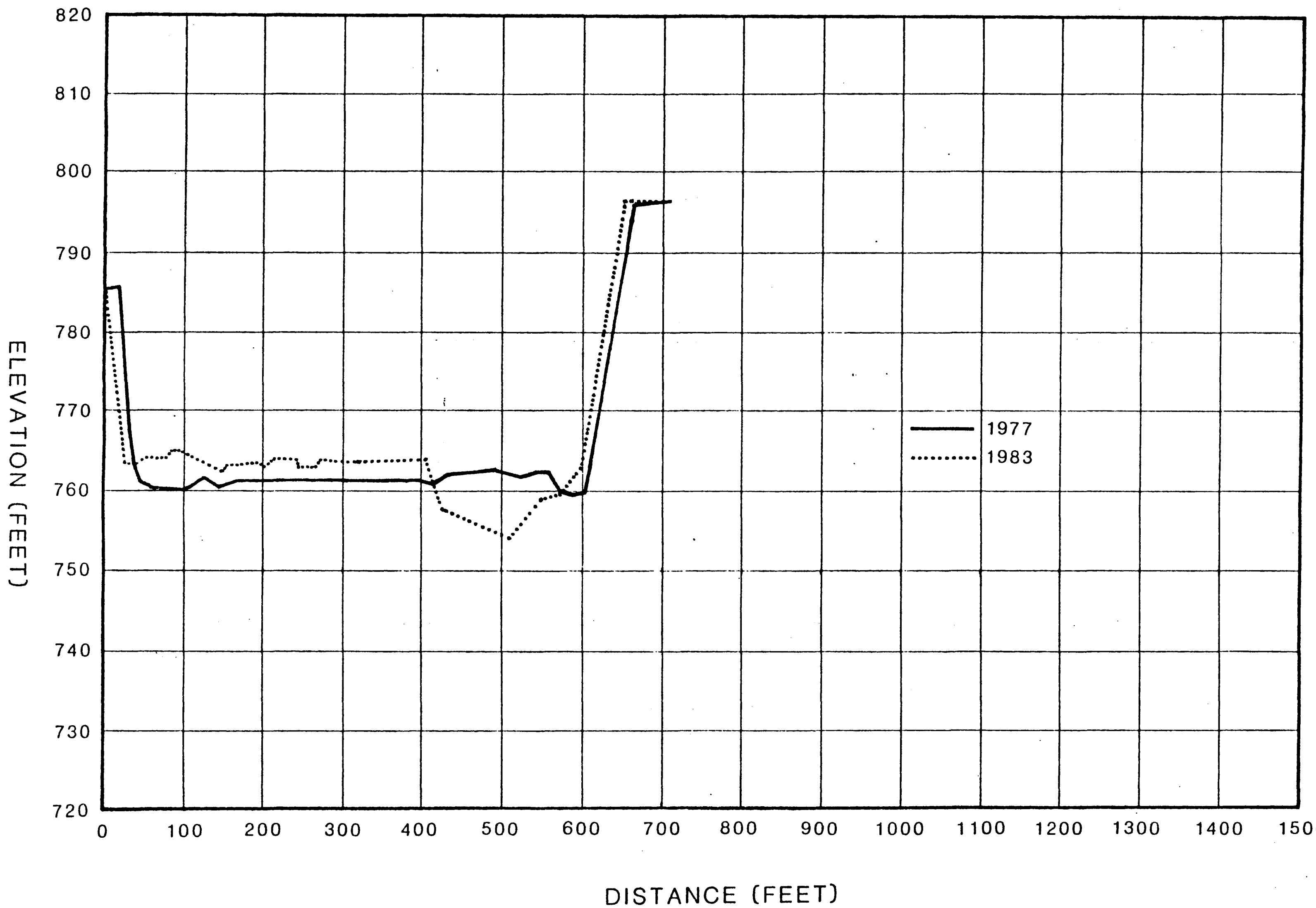
River Mile 24.85



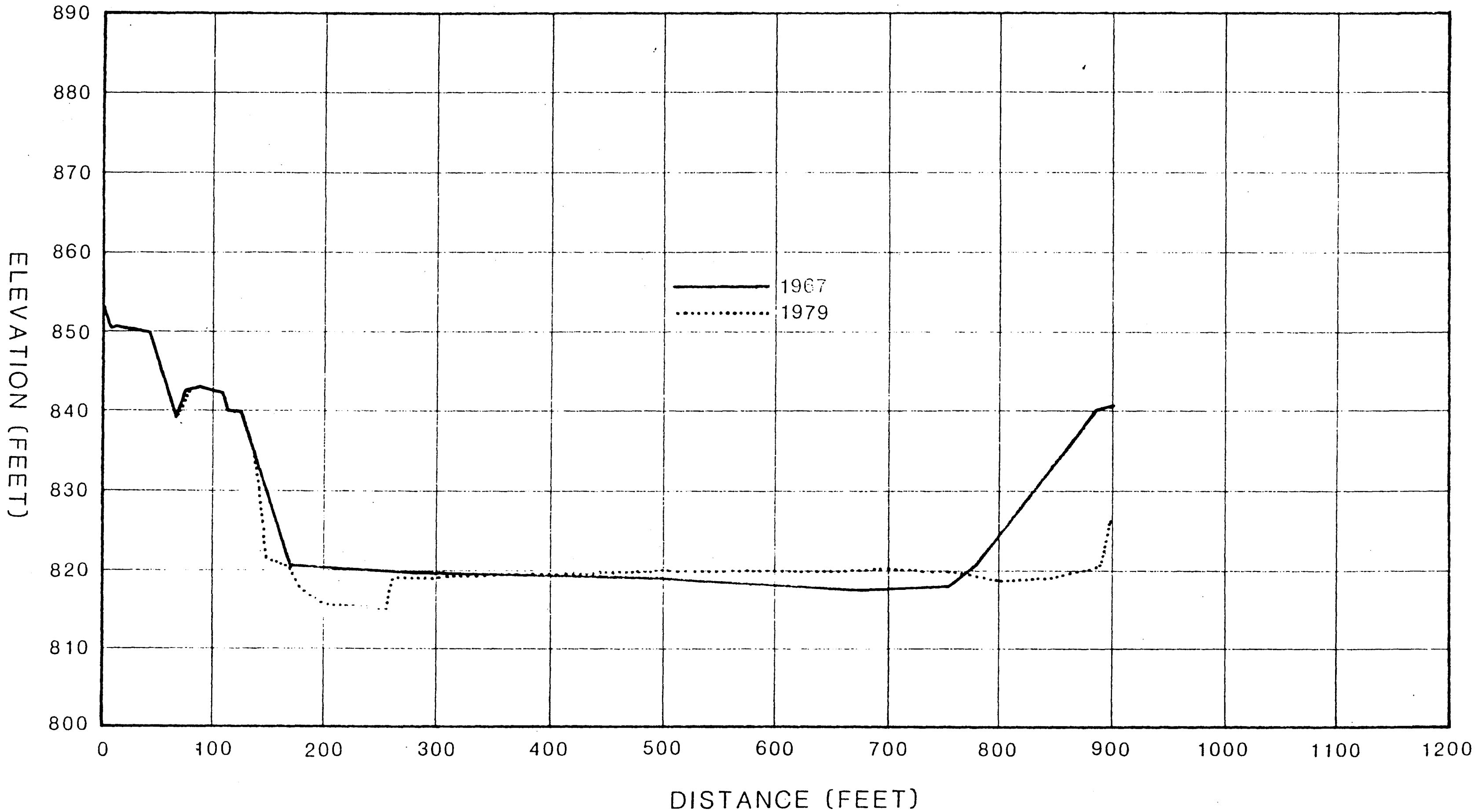
River Mile 26.91



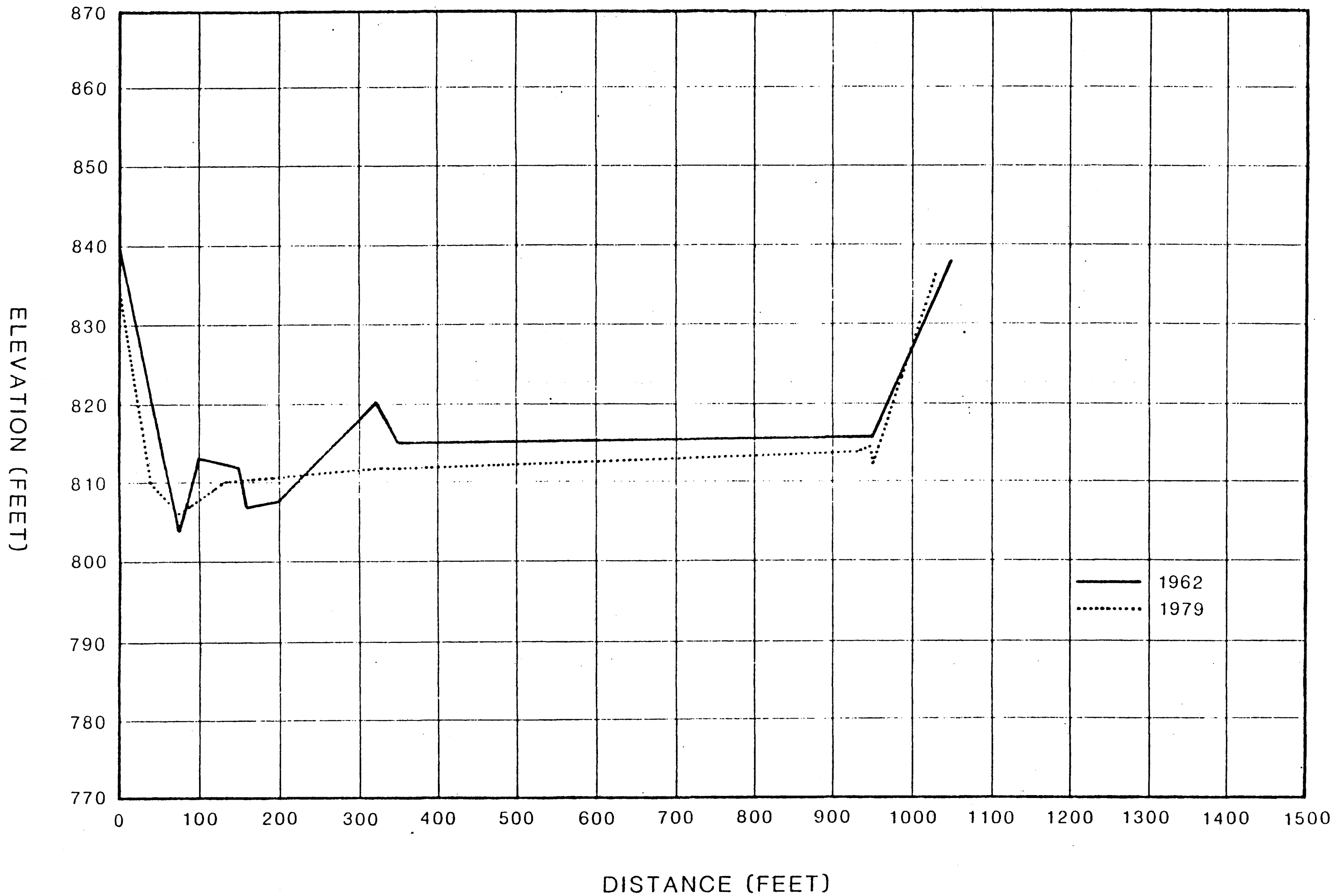
River Mile 28.96



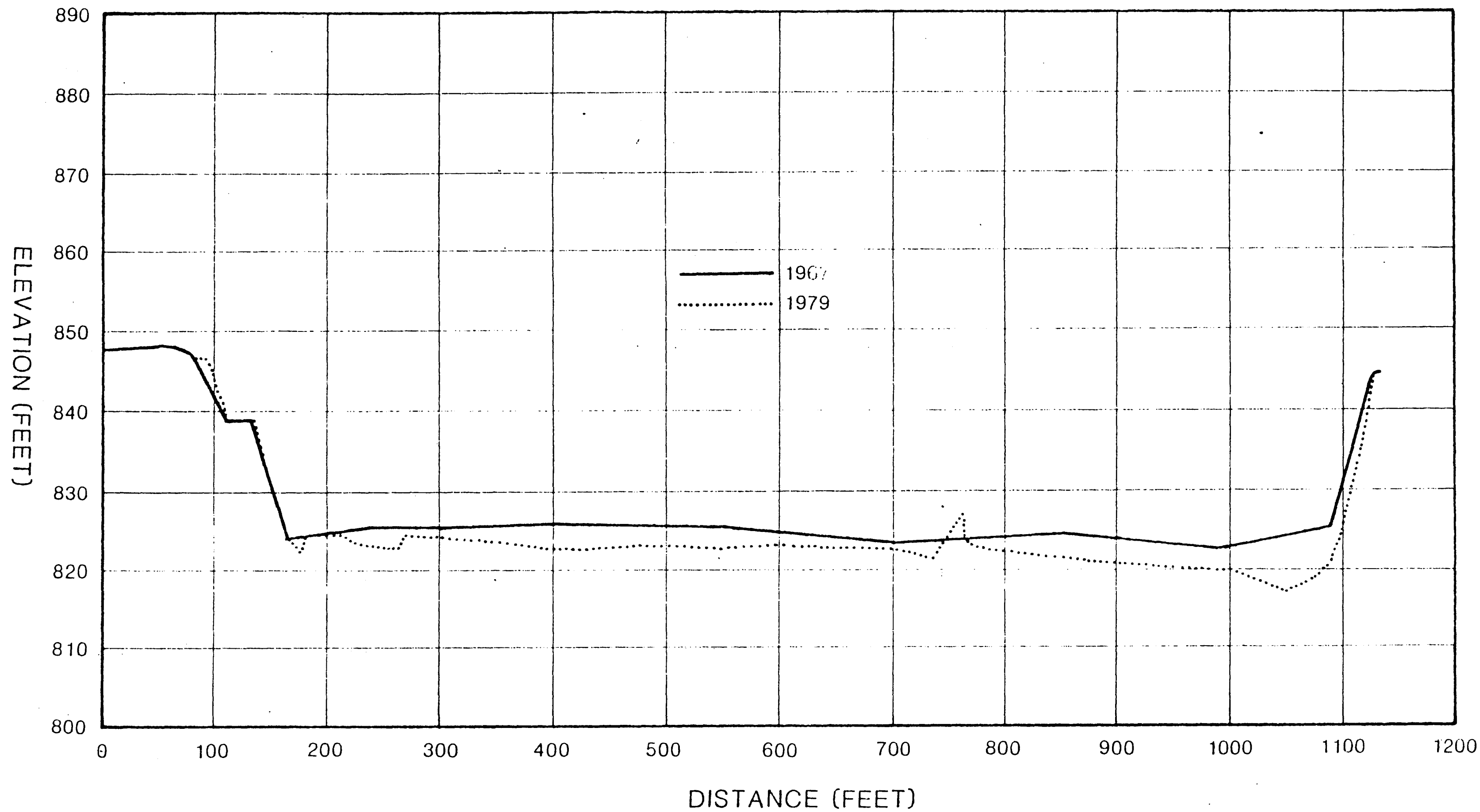
River Mile 31.04



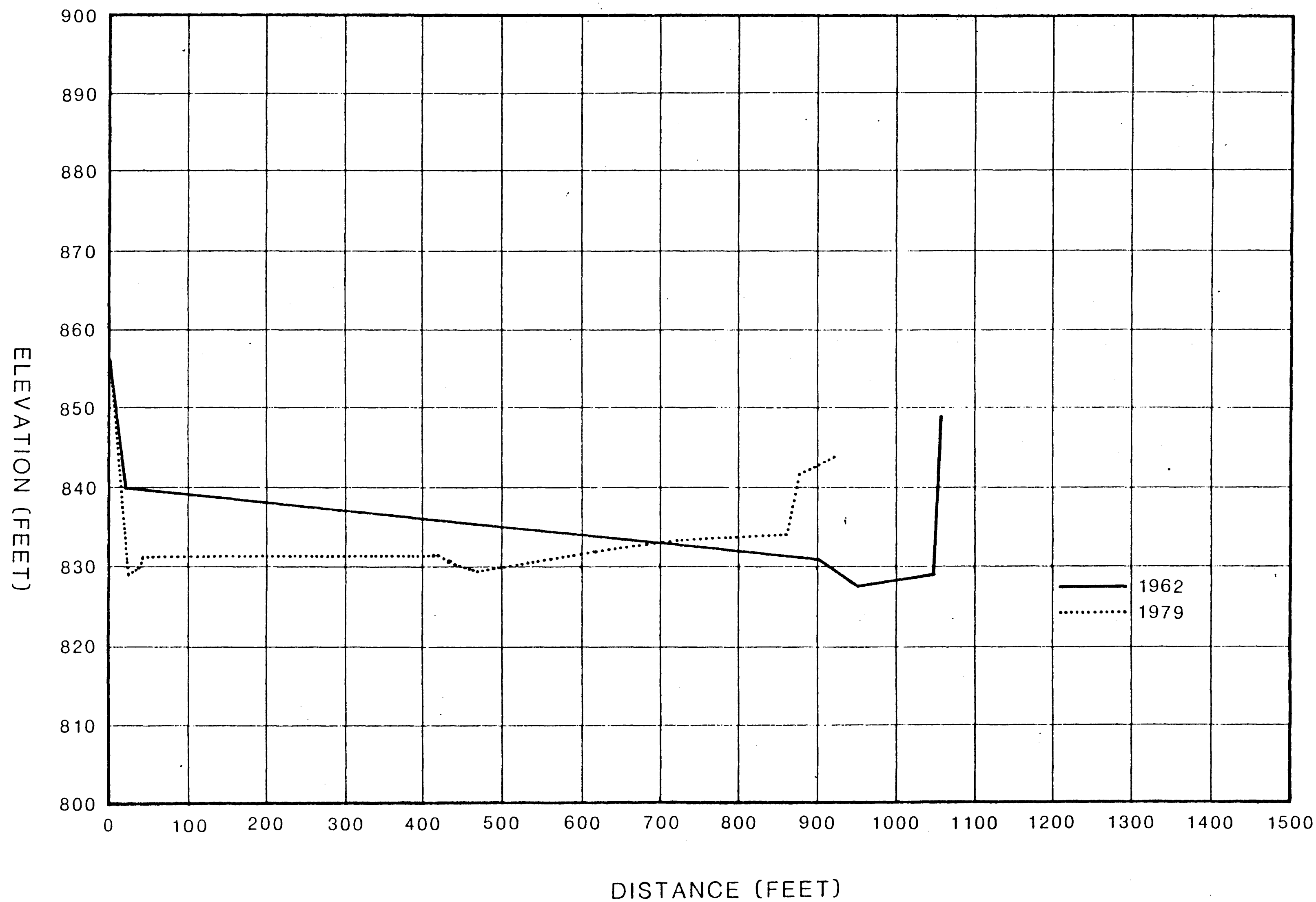
River Mile 61.4



River Mile 63.8

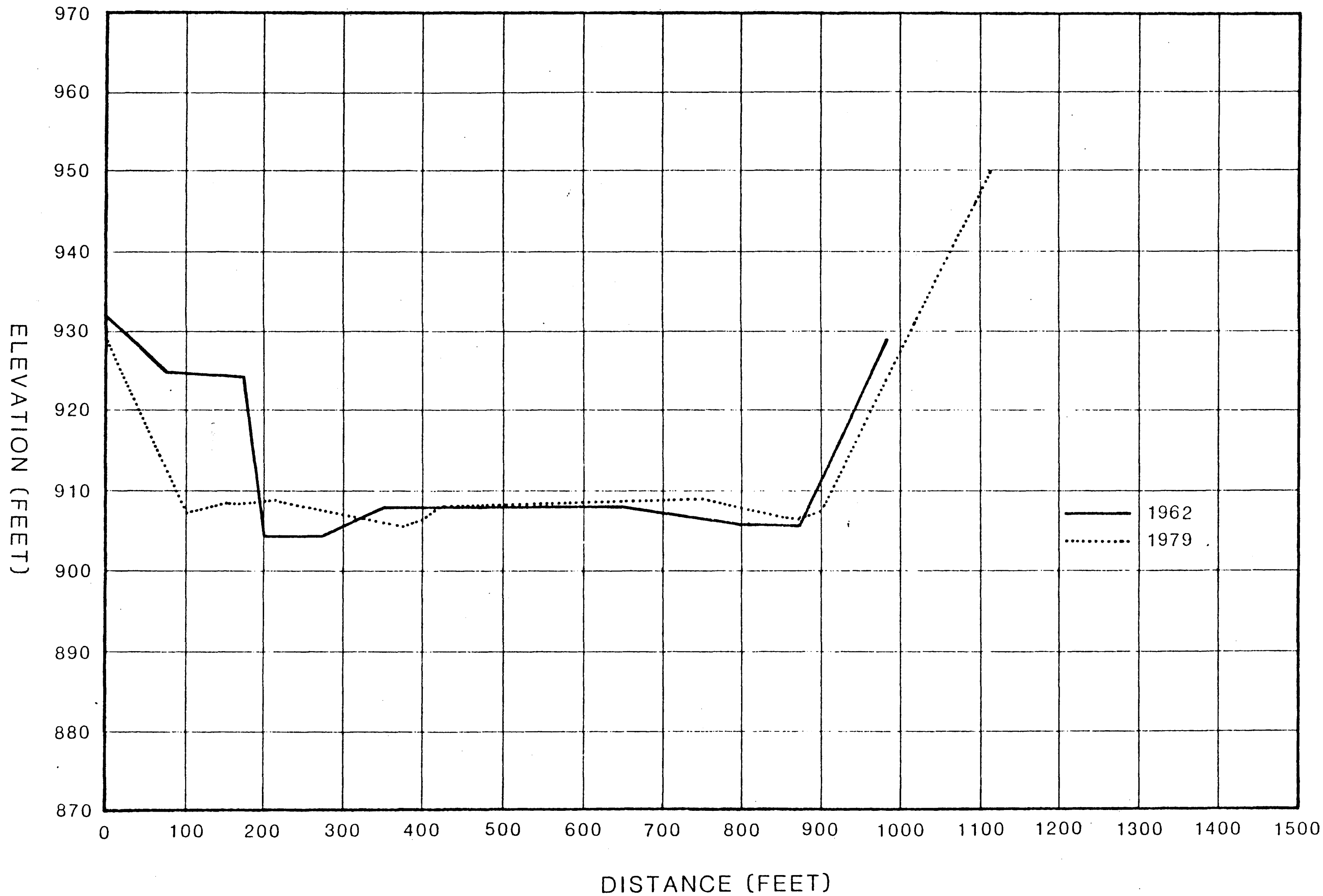


River Mile 63.9



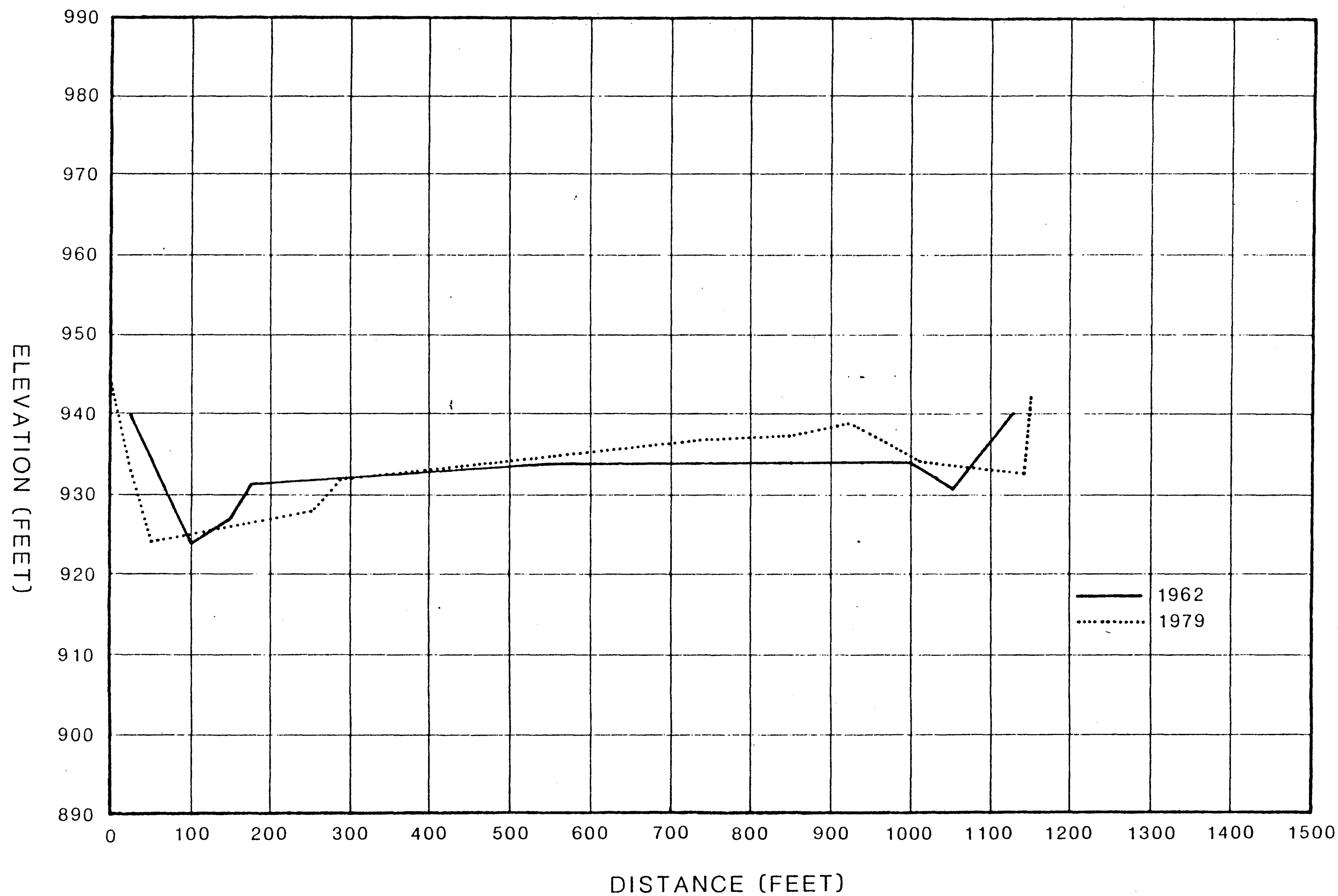
River Mile 68.2 1979

River Mile 68.6 1962



River Mile 106.2 1979

River Mile 106.1 1962



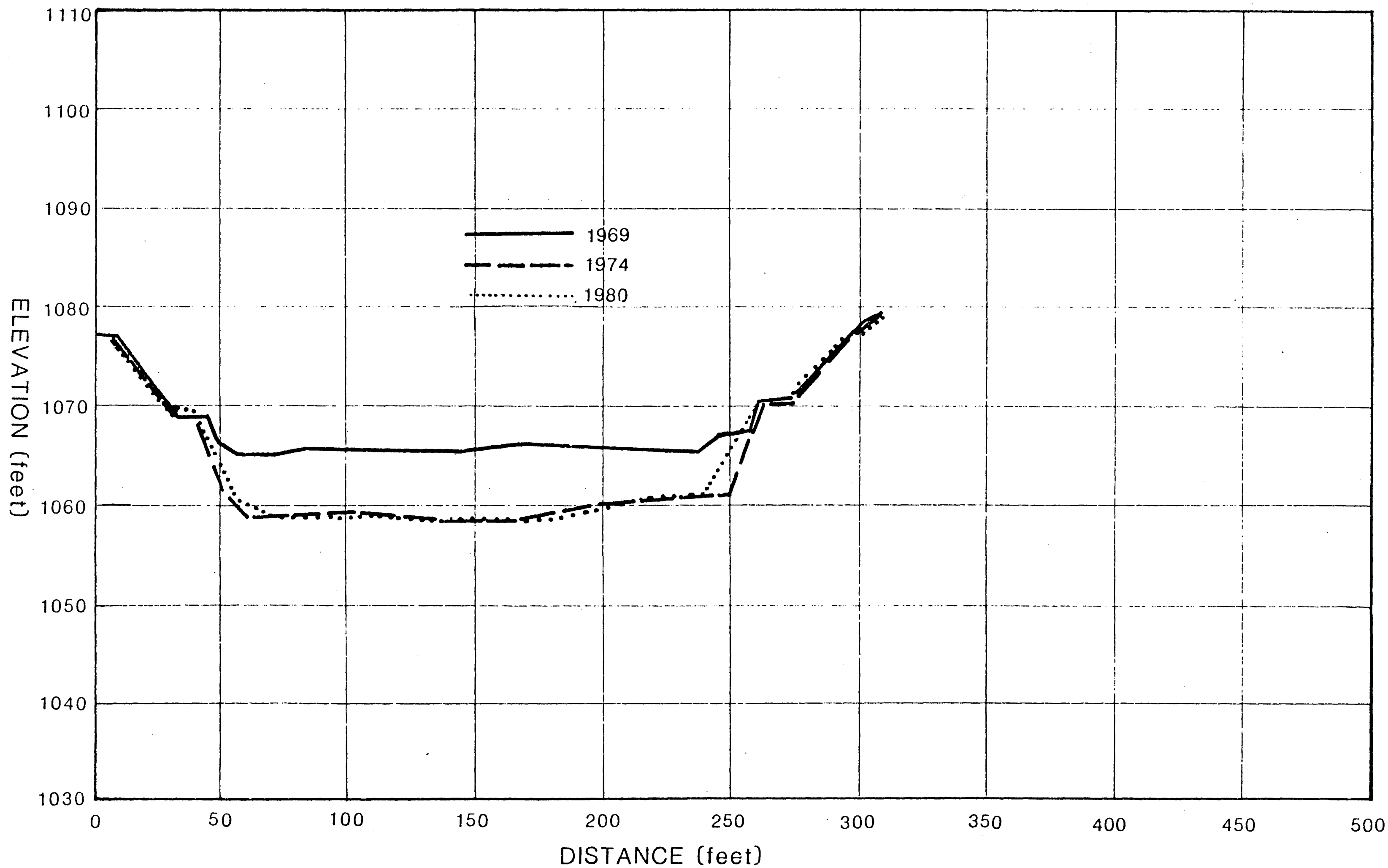
River Mile 115.6 1979

River Mile 115.4 1962

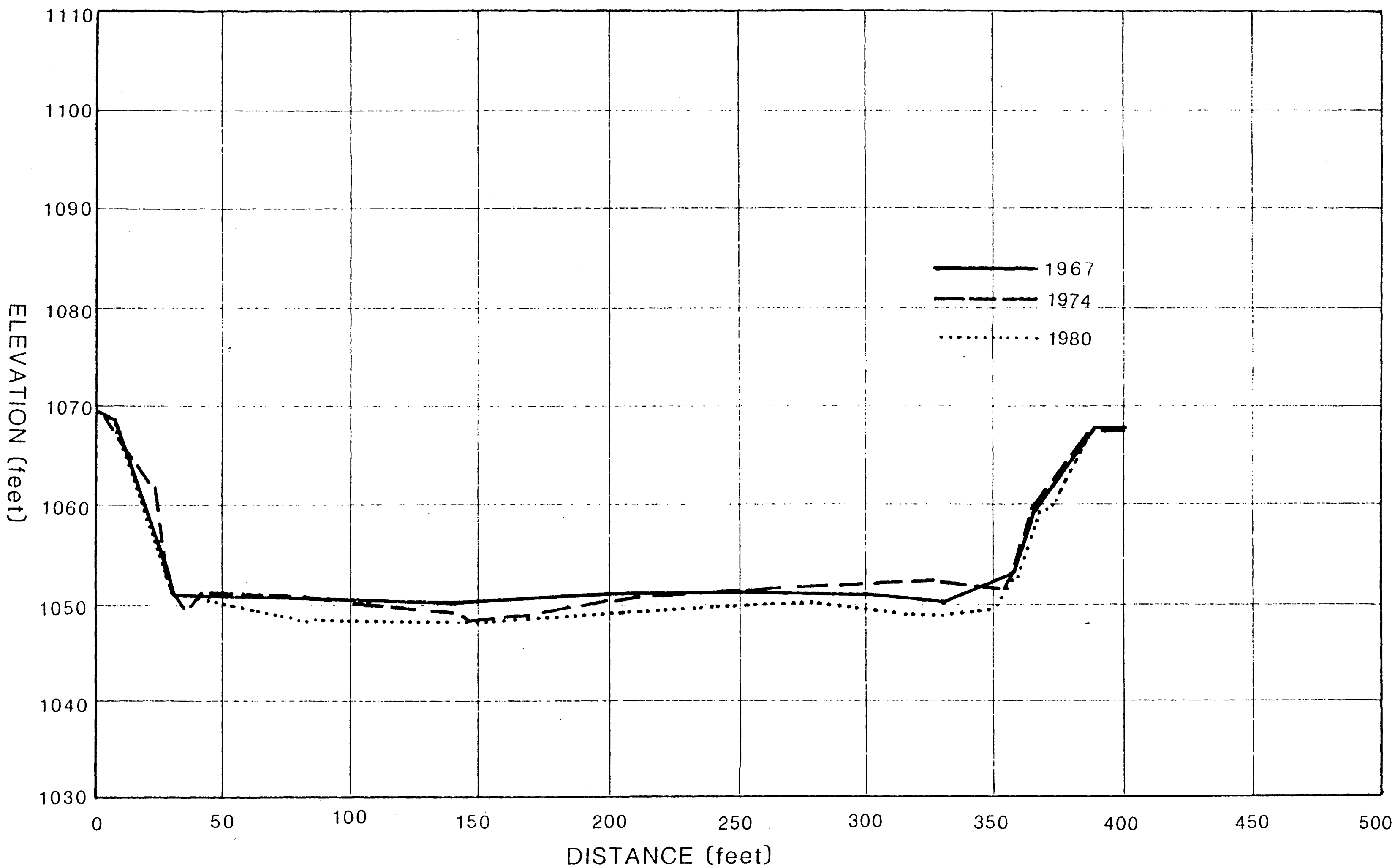
APPENDIX D

Historic Cross Sections

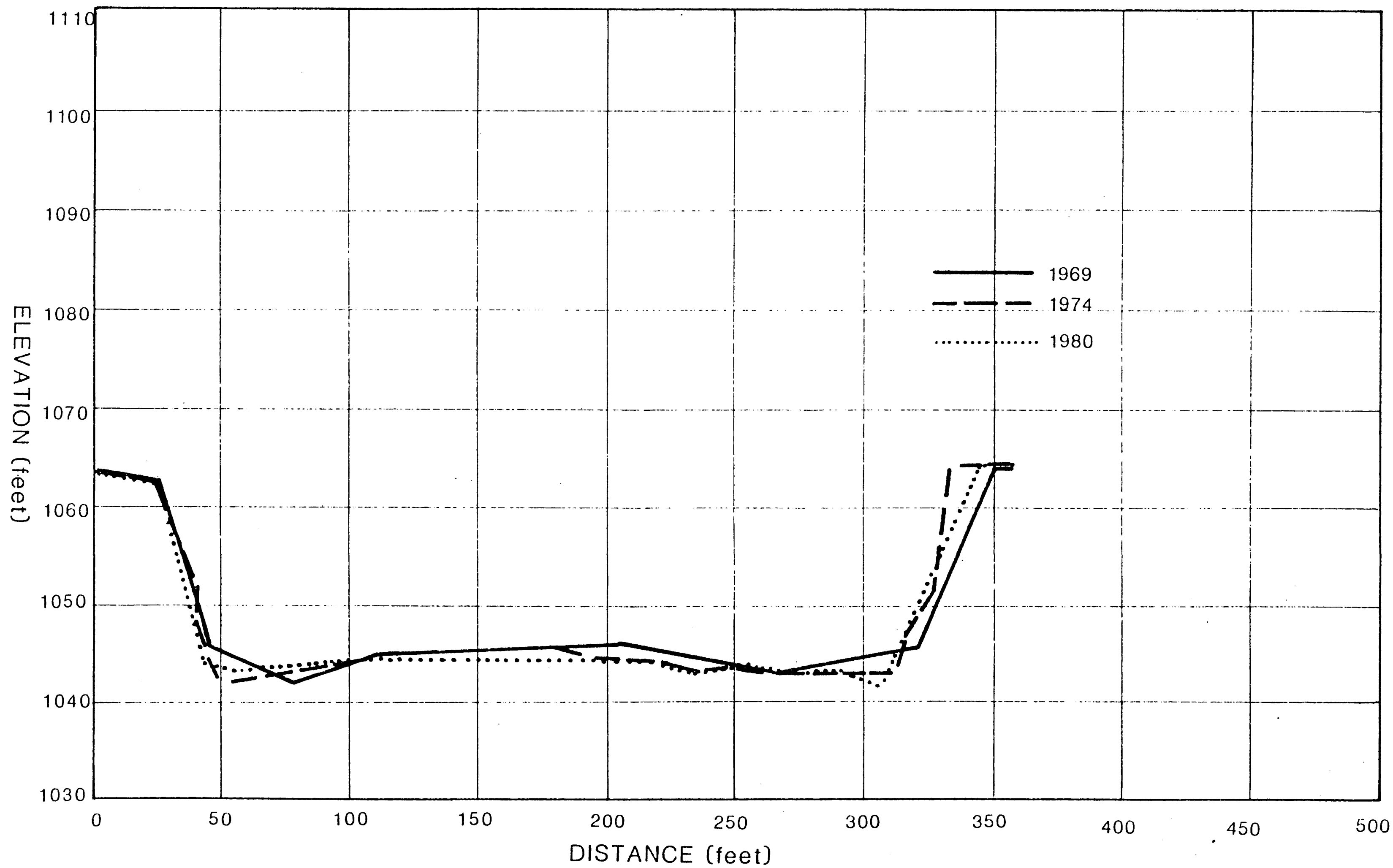
Below Federal Reservoirs



0.9 Miles Downstream from Milford Reservoir Outlet.

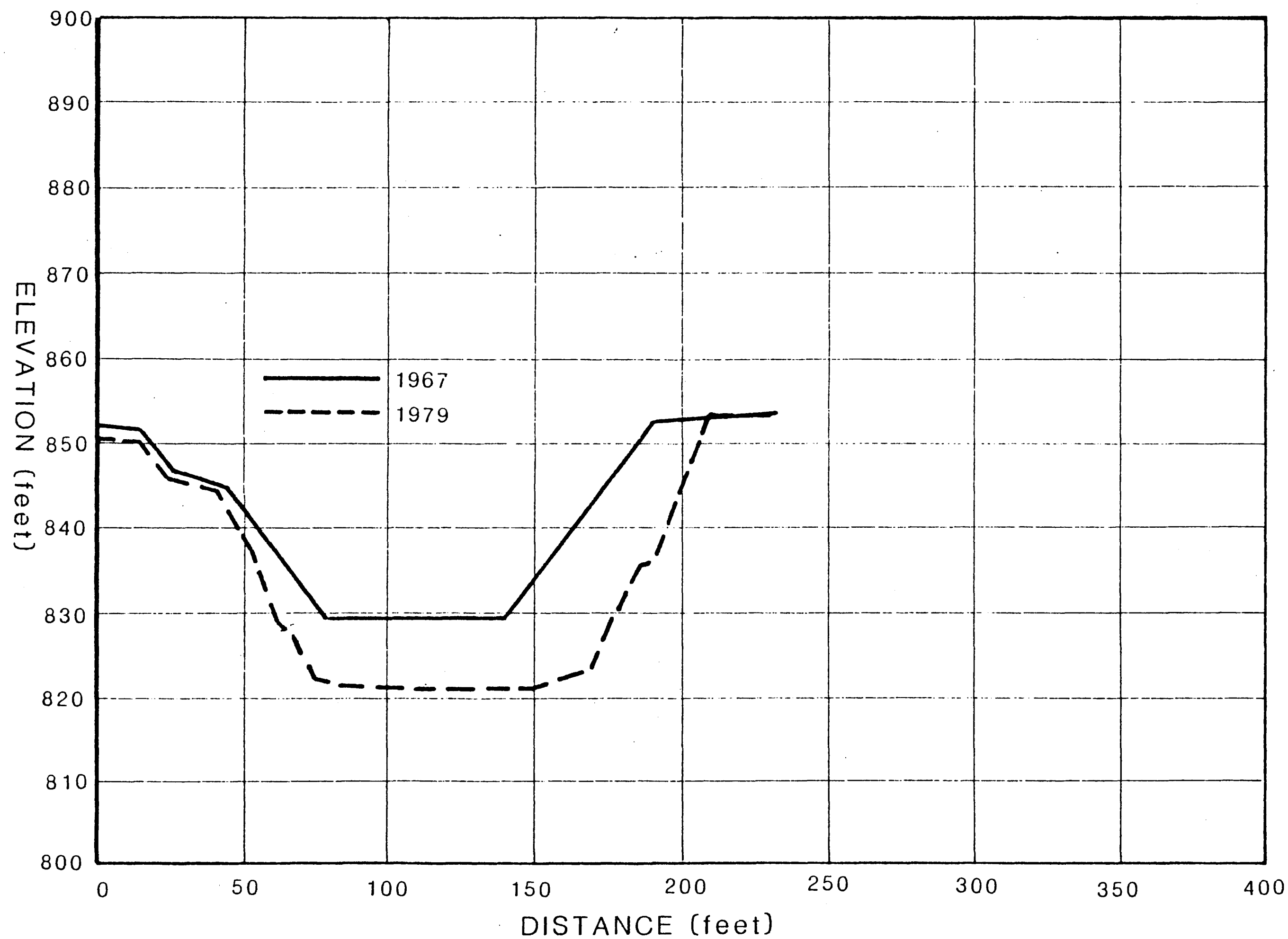


5.3 Miles Downstream from Milford Reservoir Outlet.

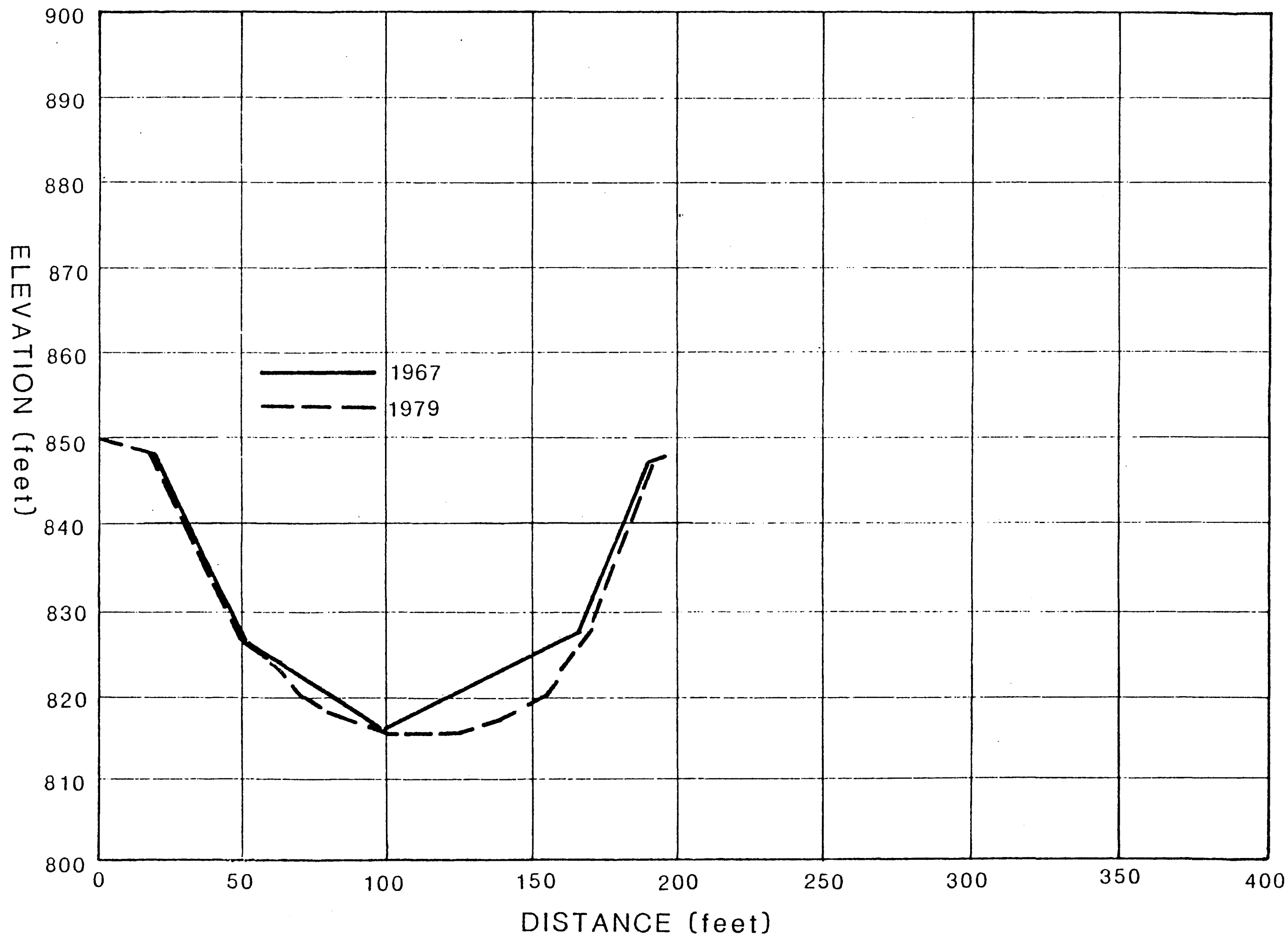


7.0 Miles Downstream from Milford Reservoir Outlet.

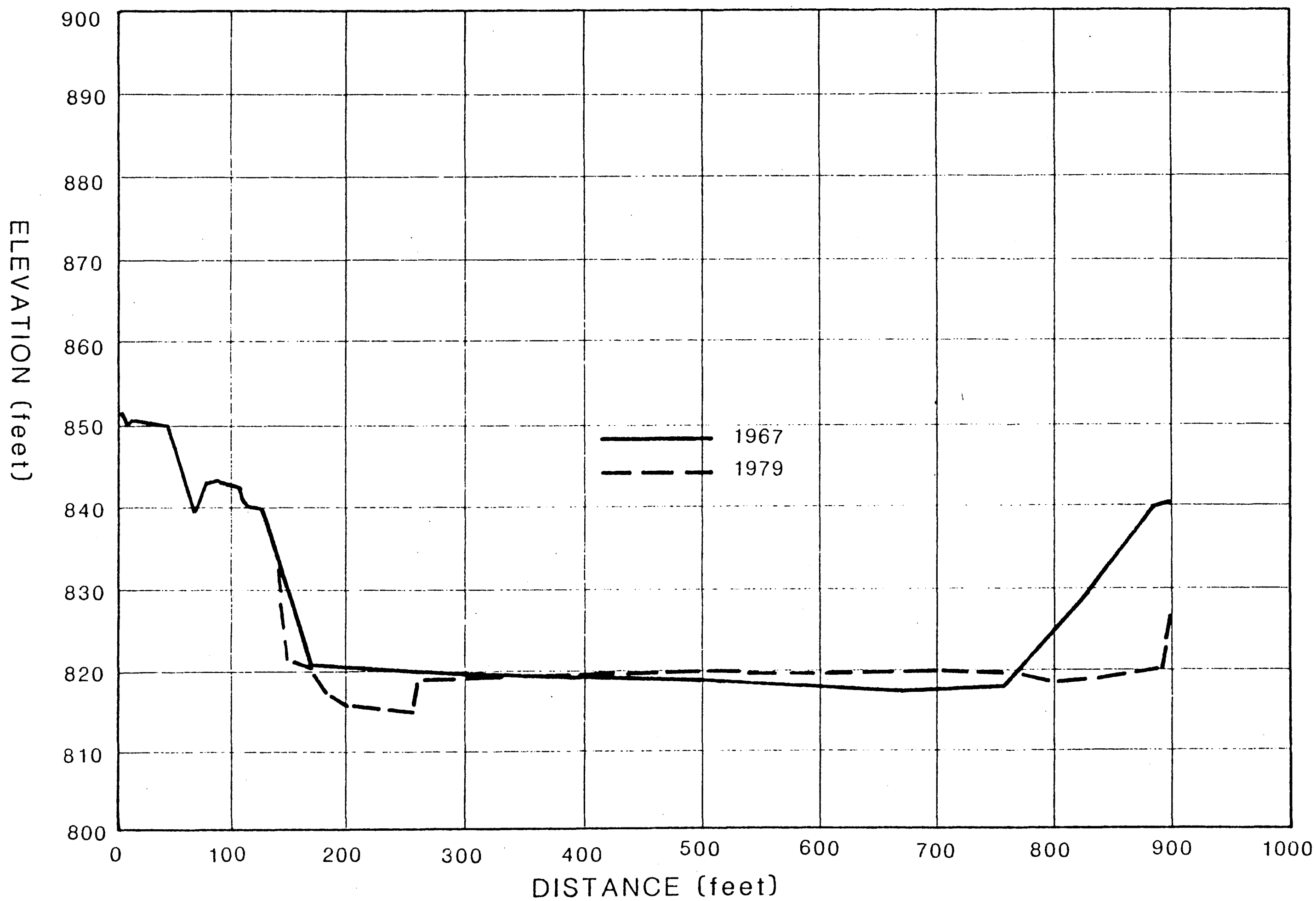
D.3



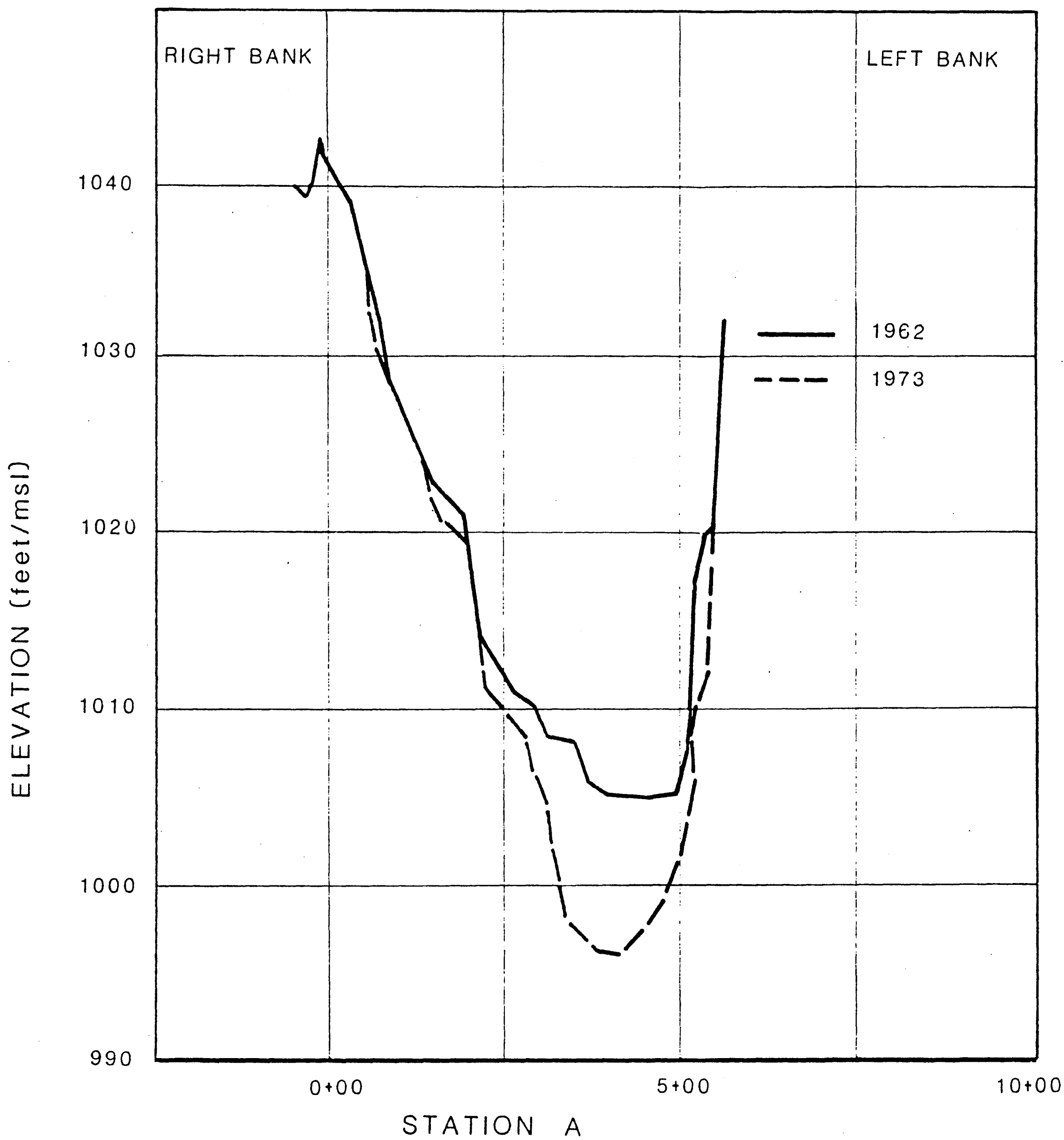
1.5 Miles Downstream of Perry Reservoir Outlet.



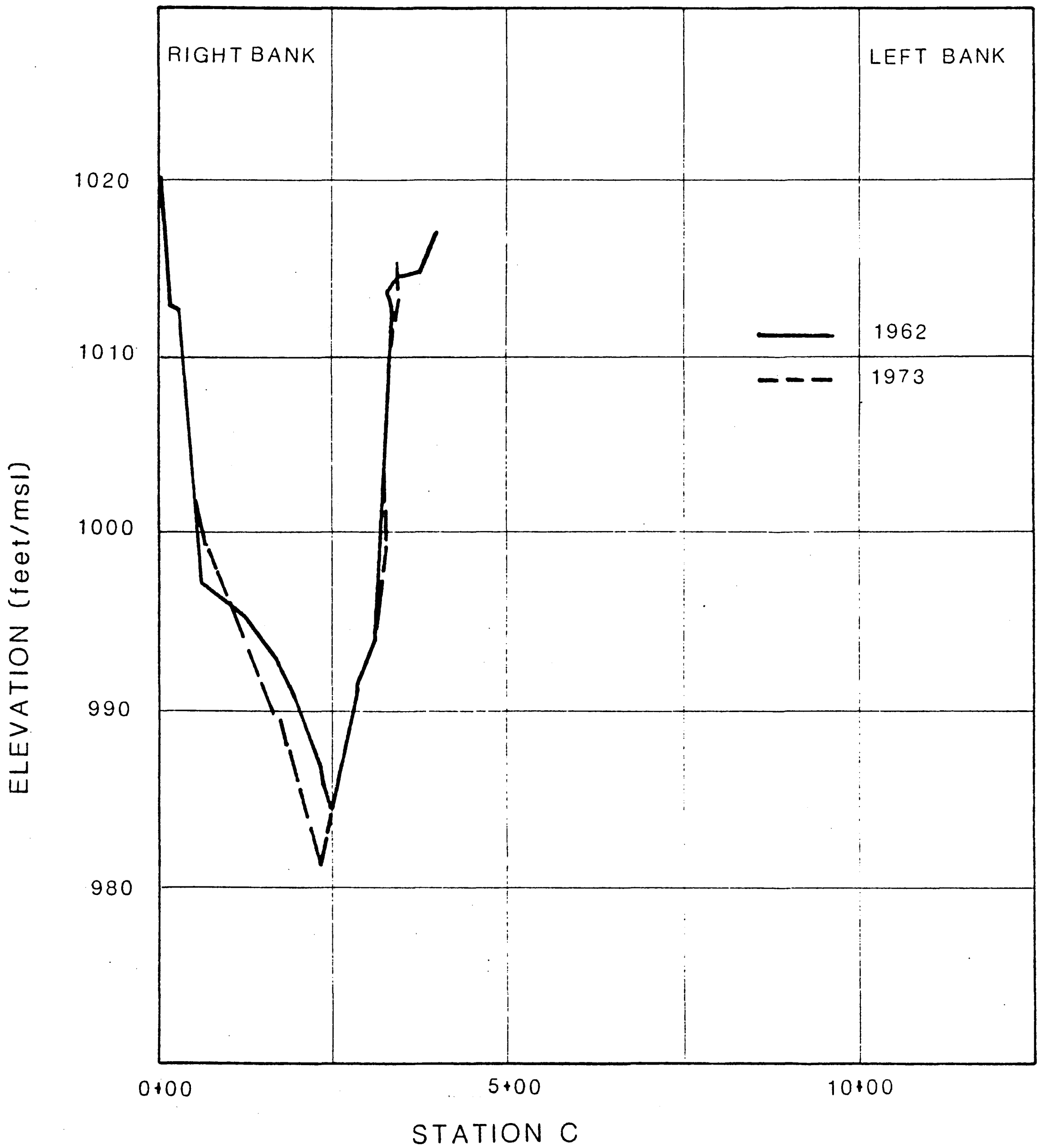
3.2 Miles Downstream of Perry Reservoir Outlet.



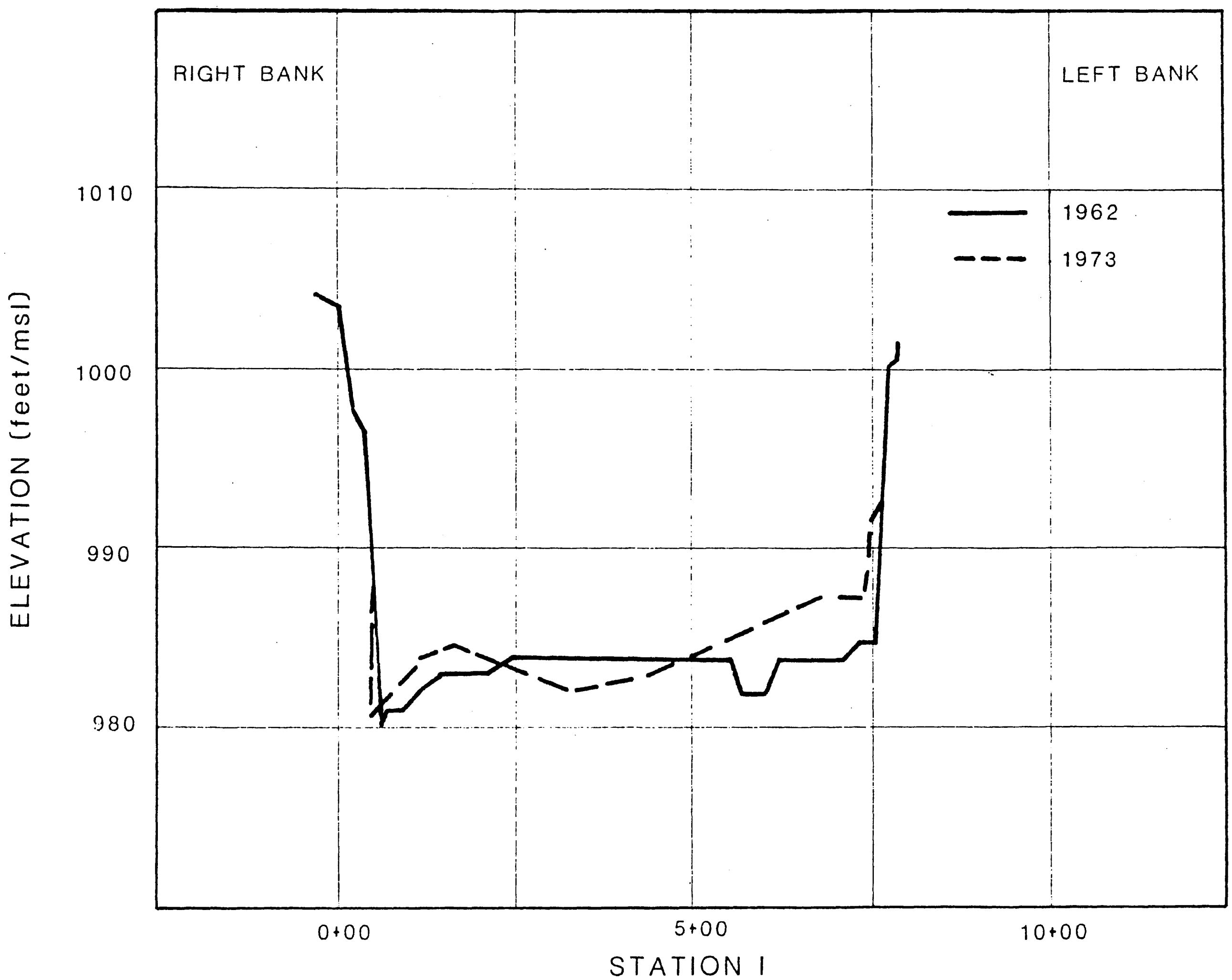
12.8 Miles Downstream of Perry Reservoir Outlet on Mainstem of the Kansas River.



0.4 Miles Downstream of Tuttle Creek Reservoir Outlet.



2.9 Miles Downstream of Tuttle Creek Reservoir Outlet.



12.0 Miles Downstream of Tuttle Creek Reservoir Outlet on Mainstem Kansas River.

APPENDIX E

Calibration of Sediment Transport Relations

Figures E.1 through E.4 are plots of log measured suspended sediment (minus wash load) versus log discharge for Fort Riley, Wamego, Lecompton, and Desoto, respectively. The figures show COE observer samples, COE composite samples, USGS data, and the best fit regression line. As can be seen from Figure E.2, the USGS data is consistently lower than the COE data at Wamego. For reasons discussed in Chapter IV, only the USGS data was used at this station.

The relationships obtained from the initial regression analysis were used in conjunction with the actual flow record at each site to obtain annual bed material loads in the measured zone. These computed loads were compared to loads computed by the COE for equivalent years. The COE values are based on a relatively sophisticated discreet analysis of sediment and discharge data. In all cases except Wamego, the initial regression relations underestimated the COE annual loads. The coefficients of the initial regression relations were adjusted so that computed annual measured zone sand loads matched the COE values. Table E.1 gives the initial suspended sand regressions, the relations adjusted for the COE loadings, and the adjustment factor. Since only the USGS data at Wamego was used, there were no annual loads to check against. Therefore, the average adjustment factor of the other three stations was used to adjust the Wamego relation.

The next step in the calibration of the bed material transport relations was to account for sediments moving in the unmeasured zone. A computational procedure using the Meyer-Peter-Muller bed-load function and the Einstein approximation for suspended bed material load was utilized to determine the ratio of measured to total bed material load. Table E.2 gives the computed ratios for a wide range of discharges at each station. Using these ratios, the corresponding discharges and the adjusted relations from Table E.1, a set of discharge versus total bed material load data is easily generated. Plotting these data and fitting curves to it yielded the following relations:

Fort Riley: $Q_{st} = 6.06 * 10^{-6}\ Q^{1.28}$ for $Q \leq 20{,}000$ cfs

$Q_{st} = 2.29 * 10^{-7}\ Q^{1.61}$ for $Q > 20{,}000$ cfs

Wamego: $Q_{st} = 5.10 * 10^{-8}\ Q^{1.75}$ for $Q \leq 22{,}000$ cfs

$Q_{st} = 1.26 * 10^{-9}\ Q^{2.12}$ for $Q > 22{,}000$ cfs

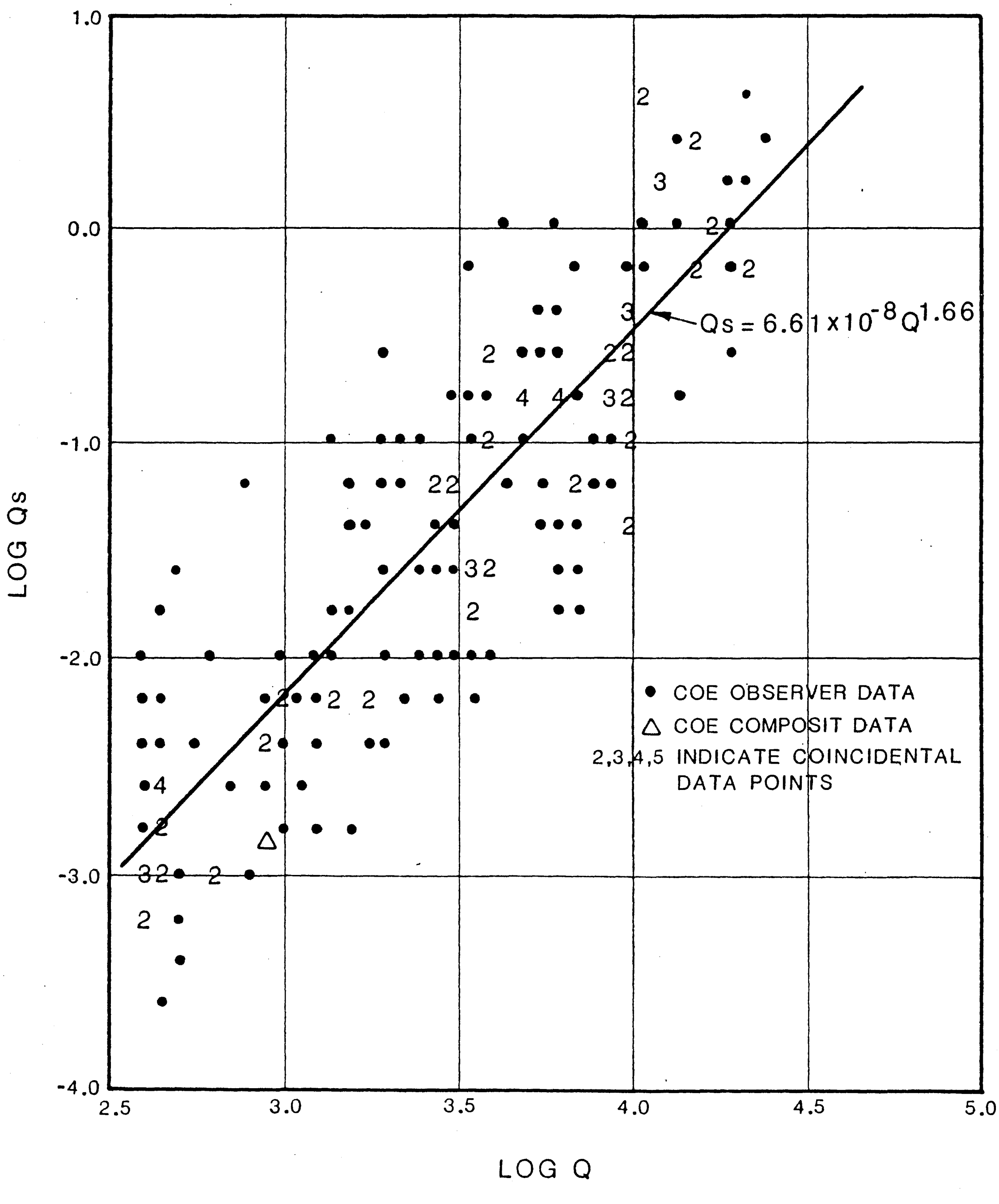


Figure E.1. Log measured sand load (cfs) versus log discharge (cfs) at Fort Riley.

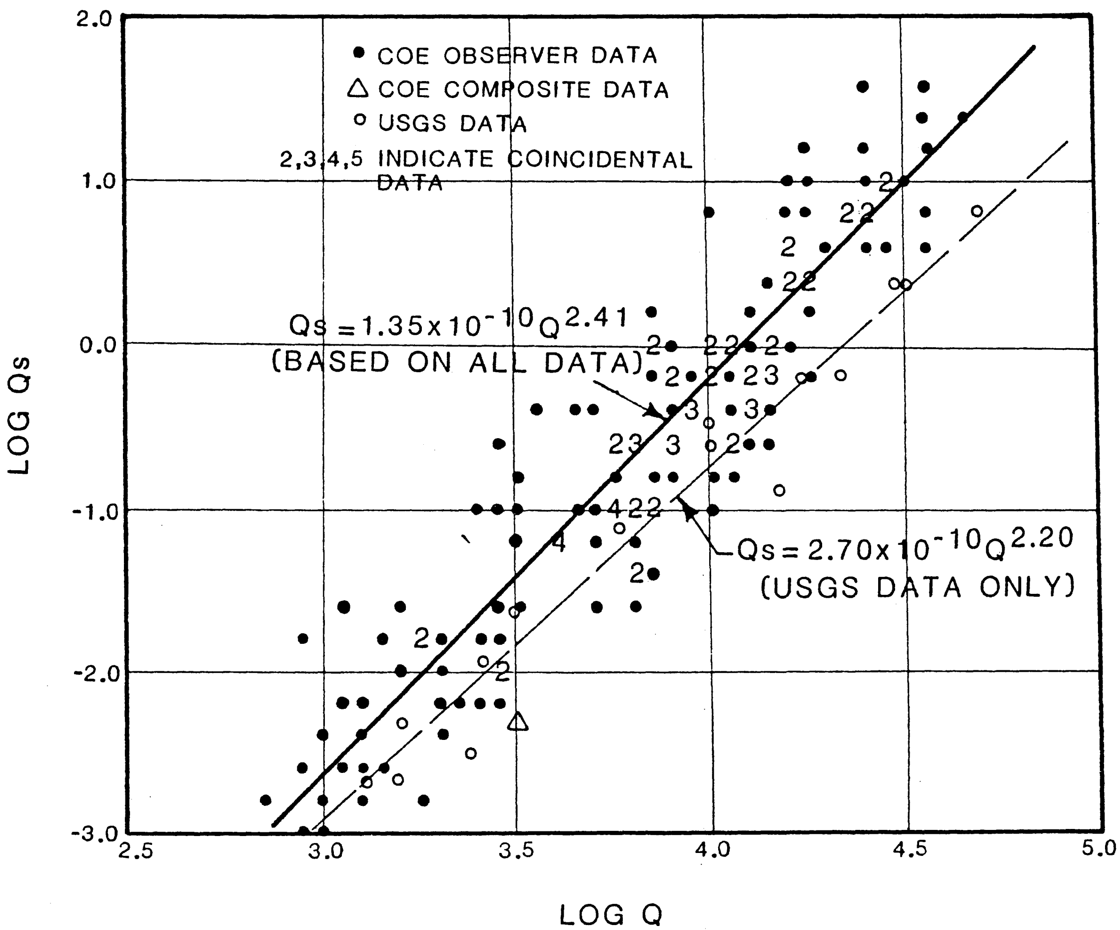


Figure E.2. Log measured sand load (cfs) versus log discharge (cfs) at Wamego.

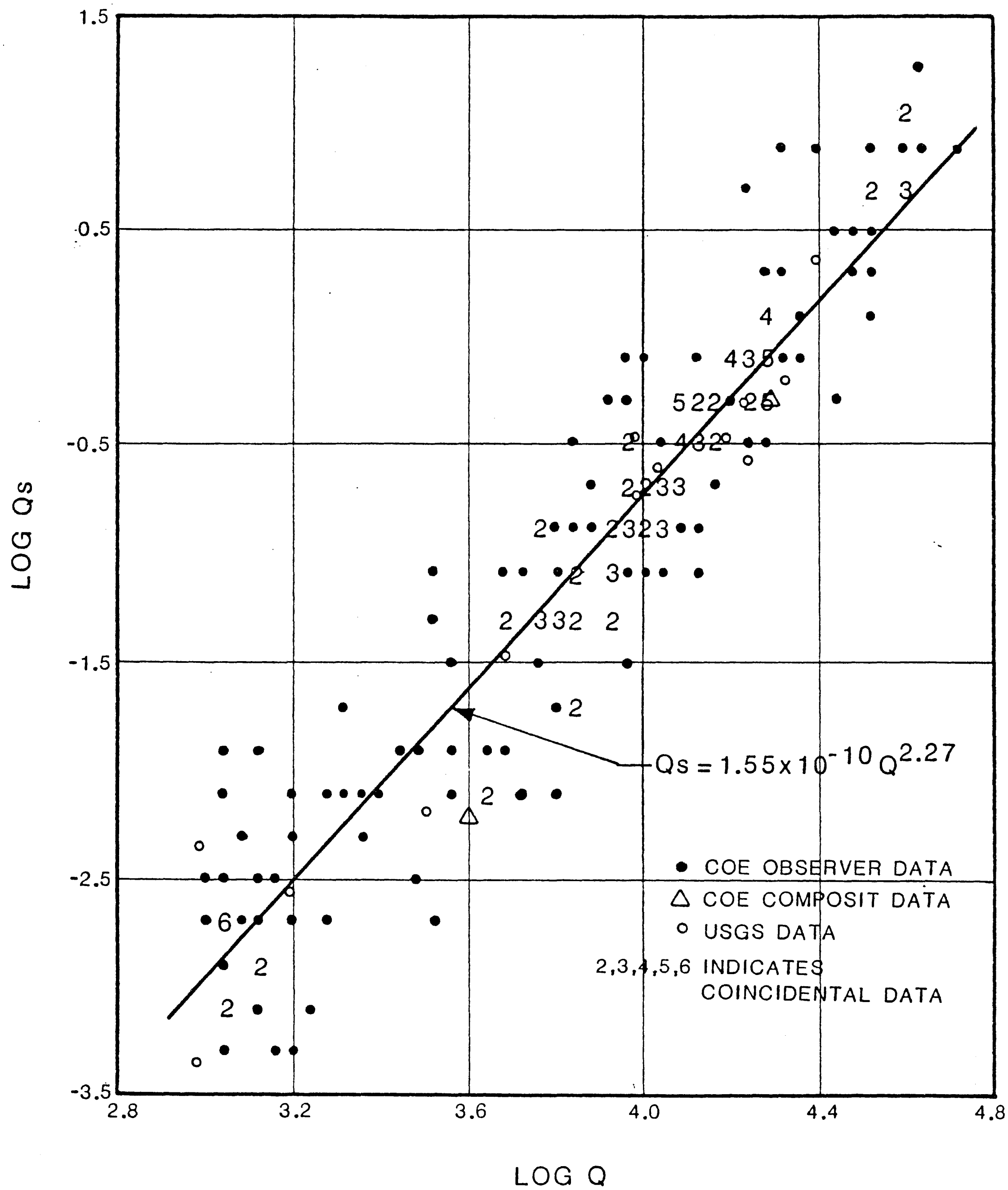


Figure E.3. Log measured sand load (cfs) versus log discharge (cfs) for Lecompton.

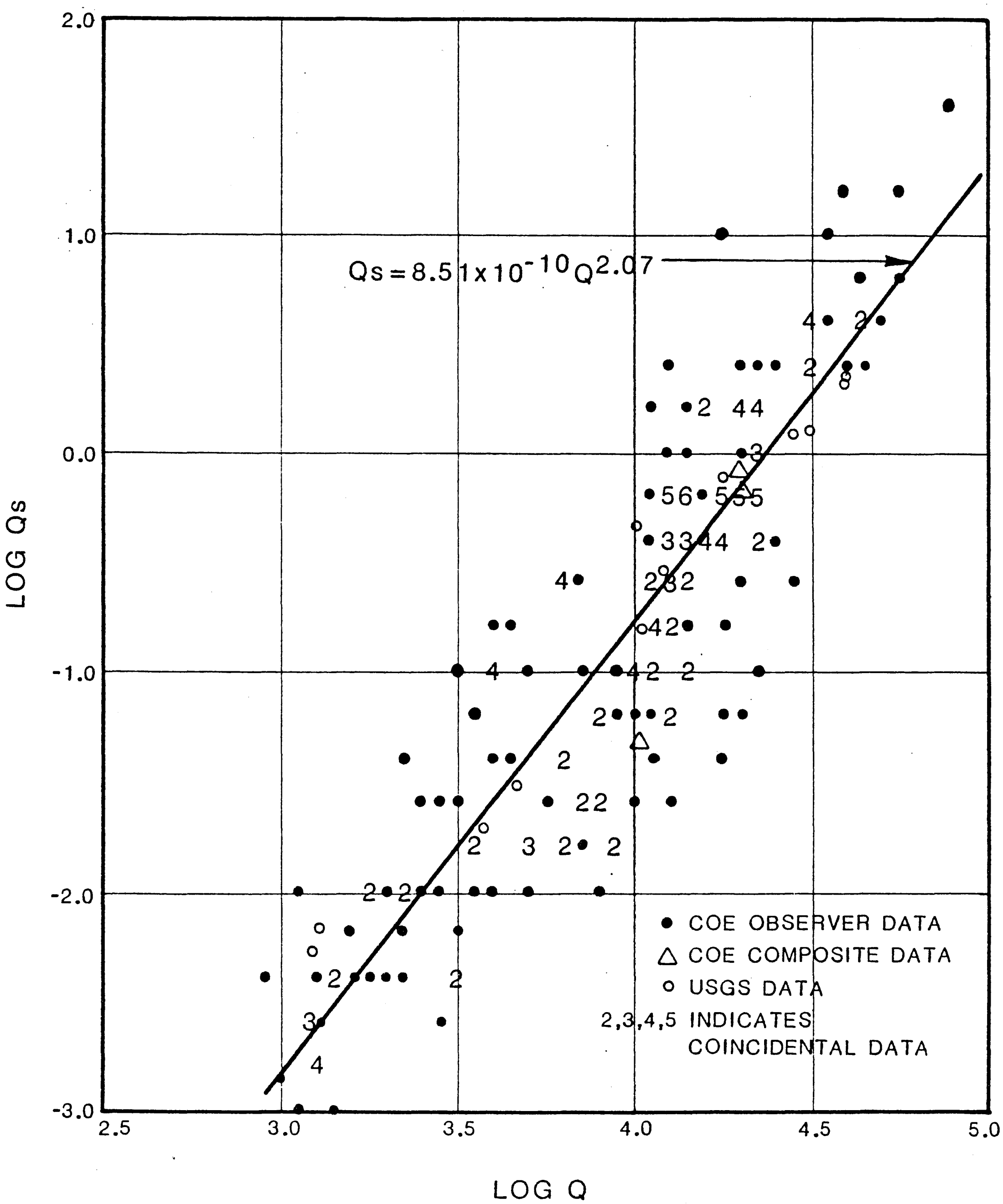


Figure E.4. Log measured sand load (cfs) versus log discharge (cfs) for Desoto.

Table E.1. Initial Regression Relations and Annual Load Adjusted Relations for Suspended Sand Load on the Kansas River.

Station	Initial Regression Relation	Adjusted Relation	Adjustment Factor
Fort Riley	$Q_s = 6.61 * 10^{-8}\ Q^{1.66}$	$1.18 * 10^{-7}\ Q^{1.66}$	1.79
Wamego	$Q_s = 2.70 * 10^{-10}\ Q^{2.20}$	$4.89 * 10^{-10}\ Q^{2.20}$	1.81*
Lecompton	$Q_s = 1.55 * 10^{-10}\ Q^{2.27}$	$2.54 * 10^{-9}\ Q^{2.27}$	1.64
Desoto	$Q_s = 8.51 * 10^{-10}\ Q^{2.07}$	$1.69 * 10^{-9}\ Q^{2.07}$	1.99

NOTE: Q_s = bed material load in the measured zone (cfs)
Q = discharge (cfs)

*Wamego relation based on USGS data only,
1.81 = average of other three station adjustment factors

Table E.2. Theoretical Ratio of Total Bed Material Load to Measured Bed Material Load.

Fort Riley		Wamego		Lecompton		Desoto	
Q (cfs)	Ratio	Q (cfs)	Ratio	Q (cfs)	Ratio	Q (cfs)	Ratio
1,310	3.265	1,440	3.122	1,890	2.510	1,700	2.847
1,840	2.811	2,510	3.309	3,300	2.453	2,950	2.402
2,300	2.568	3,590	2.867	4,720	2.230	5,090	1.970
2,760	2.572	5,390	2.272	8,490	1.878	7,390	1.712
3,280	2.360	14,400	1.336	14,200	1.646	10,000	1.542
4,920	1.955	21,600	1.263	18,900	1.319	14,000	1.382
5,900	1.815	28,800	1.214	28,300	1.240	20,000	1.195
9,840	1.522	43,300	1.151	37,700	1.189	28,000	1.134
13,100	1.228	65,100	1.108	56,600	1.132	38,000	1.097
19,700	1.162	118,000	1.066	84,600	1.094	50,000	1.072
26,200	1.122	176,000	1.056	157,000	1.057	64,000	1.055
39,400	1.085	197,000	1.052	209,000	1.046	78,000	1.045
59,000	1.057	236,000	1.048	261,000	1.046	94,000	1.039
108,000	1.036			313,000	1.043	150,000	1.027
144,000	1.031					200,000	1.023
180,000	1.030					250,000	1.020
216,000	1.026					300,000	1.018

Lecompton: $Q_{st} = 6.95 * 10^{-9}\ Q^{1.97}$ for $Q \leq 38{,}000$ cfs

$Q_{st} = 5.80 * 10^{-10}\ Q^{2.21}$ for $Q > 38{,}000$ cfs

Desoto: $Q_{st} = 5.84 * 10^{-8}\ Q^{1.74}$ for $Q \leq 28{,}000$ cfs

$Q_{st} = 3.00 * 10^{-9}\ Q^{2.03}$ for $Q > 28{,}000$ cfs

where Q_{st} is total bed material load in cfs, and Q is discharge in cfs. Using continuity considerations as discussed in Section 4.3, these relations were adjusted to obtain the final bed material transport relations given in Section 4.3.

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