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CHANNEL-BED DEGRADATION IN MAJOR OKLAHOMA STREAMS VOLUME I OF V: ARKANSAS RIVER

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15. Abstract

The purpose of this research is to analyze the flowline data and relate it to the degradation of the river bed at bridge locations in the river. This information may then be used to replace or rehabilitate those bridges that experienced severe degradation.

This report evaluates channel degradation in 252-mile reach of Arkansas River in Oklahoma. In this study, the 252 mile river length is divided into two Reaches: Reach 1- Kaw Lake to Keystone Dam, and Reach 2- Keystone Dam to Webbers Falls Dam. The flowlines of Arkansas River in Oklahoma were observed for a long-term period. In Reach-1, river station (RS) 3 shows the maximum degradation of 3 feet in 30 years from 1963 to 1993. Similarly, in Reach-2, RS 16, located 7 miles downstream of Webbers Falls Dam shows the maximum degradation of 12 feet in 28 years. On the other hand, channel aggradation of 3.50 feet is observed at RS 1 in Reach-1. The study of river-bed elevation change elucidates that the Arkansas River is not stable for 80.5 miles below Keystone Dam.

The I-40 bridge located at RS 16 (Bridge Key b17051) has experienced a degradation degradation of 12.2 feet in 32 years. When this bridge is replaced in replacement cycle, it is recommended that a detailed hydraulic and geotechnical analysis be performed before reconstruction.

It is recommended that degradation of tributaries is evaluated to determine the structures where flowline is severely degrading in Arkansas River basin.

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SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units

Symbol	When you know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	25.40	millimeters	mm
ft	feet	0.3048	meters	m
yd	yards	0.9144	meters	m
mi	miles	1.609	kilometers	km
	AREA			
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.0929	square meters	m^2
yd^2	square yards	0.8361	square meters	m^2
ac	acres	0.4047	hectacres	ha
mi^2	square miles	2.590	square kilometers	km^2
	VOLUME			
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallon	3.785	liters	L
ft^3	cubic feet	0.0283	cubic meters	m^3
yd^3	cubic yards	0.7645	cubic meters	m^3
	MASS			
oz	ounces	28.35	grams	g
lb	pounds	0.4536	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	TEMPERATURE (exact)			
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C
	FORCE and PRESSURE or STRESS			
lbf	poundforce	4.448	Newtons	N
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa

Approximate Conversions from SI Units

Symbol	When you know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.0394	inches	in
m	meters	3.281	feet	ft
m	meters	1.094	yards	yds
km	kilometers	0.6214	miles	mi
	AREA			
mm^2	square millimeters	0.00155	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.196	square yards	yd^2
ha	hectacres	2.471	acres	ac
km^2	square kilometers	0.3861	square miles	mi^2
	VOLUME			
mL	milliliters	0.0338	fluid ounces	fl oz
L	liters	0.2642	gallon	gal
m^3	cubic meters	35.315	cubic feet	ft^3
m^3	cubic meters	1.308	cubic yards	yd^3
	MASS			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.1023	short tons (2000 lb)	T
	TEMPERATURE (exact)			
°C	degrees Fahrenheit	9/5(°C)+32	degrees Celsius	°F
	FORCE and PRESSURE or STRESS			
N	Newtons	0.2248	poundforce	lbf
kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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CHANNEL-BED DEGRADATION IN MAJOR OKLAHOMA STREAMS

VOLUME I of V: ARKANSAS RIVER

Final Report
ODOT Item Number 2191

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I. INTRODUCTION

Natural alluvial rivers are seldom in a state of equilibrium. The fluvial process in an alluvial river is a dynamic system which is subject to continuous changes such as changes in discharge, flow characteristics, sediment injection by tributaries, bed material composition, and characteristics of the sediment complex. Man-made activities and natural events are the major factors which disturb the stability of a river, causing readjustment of energy slope, sediment load, and cross-sectional geometry. If the stream-bed continues to lower as a result of the aforementioned activities, it is called "degradation" and, if the reverse is true, it is called "aggradation".

A river channel is considered stable if the stream-bed does not change its average bed elevation over a relatively long river reach and long period of time. Whether the hydraulic, hydrologic, and sedimentological characteristics of the alluvial rivers are altered naturally or by human interference, the river will adjust dynamically and geometrically as the fluvial system seeks to establish a state of equilibrium. The river equilibrium concept was explained by Macklin (1948) as the "graded" river in which channel size, cross-sectional shape, and slope are adjusted to the quantities of sediment and water transported so that the river-bed neither degrades nor aggrades.

Most of the degradation problems in alluvial rivers are not related to natural river changes, but are caused by dams or reservoirs which completely intercept the motion of sediment (Tinney, 1962). The post-dam annual suspended-sediment load below 5 miles downstream of Gavin Points Dam in the

Colorado River was observed to be less than 1 percent of the pre-dam load (Williams and Wolman, 1985). As a result of dam or reservoir construction on a river, the river downstream of a dam or reservoir begins to scour, and this lowers its channel bed as the sediment-depleted water emerging from the dam attempts to replenish its sediment load.

Graf (1999) reports that the impact of dams on river discharge is several times greater than impacts deemed likely as a result of global climate change. Physical changes to stream channels below dams can range from bed degradation and narrowing, to changes in channel-bed texture or armouring, to bed aggradation, bar construction, and channel widening, to no measurable changes whatsoever (Petts, 1979; Wolman, 1984; Chien, 1985; Gilvear and Winterbottom, 1992; Collier et al., 1985; Fassnacth and McClure, 2003). Numerous dams such as Kaw Lake Dam, Keystone Lake Dam, Webbers Falls Reservoir Dam, and Robert S. Kerr Dam have been built on Arkansas River in Oklahoma.

The purpose of this research is to analyze the flowline data and relate it to the degradation of the river bed different at bridge locations in the river. This information may then be used to replace or rehabilitate those bridges that experienced severe degradation.

II. STUDY AREA

The Arkansas River is a major tributary of the Mississippi River. The Arkansas River generally flows to the east and southeast, and traverses the states of Colorado, Kansas, Oklahoma, and Arkansas. At 1,469 miles (2,364 km), it is the sixth longest river in the United States (Kammerer, 1990). The river originates in the Colorado Rockies in Lake County near Leadville, Colorado, and ends at the historic site of Napoleon, Arkansas. It is the second-longest tributary in the Mississippi-Missouri system. It has a drainage basin of nearly 195,000 square miles. In terms of volume, it is smaller than both the Missouri and Ohio, with a mean discharge of 8,460 ft^3/s (240 m^3/s).

In Oklahoma, Arkansas River flows through nine counties namely: Kay, Noble, Osage, Pawnee, Tulsa, Wagoner, Muskogee, Sequoyah, and Haskell. The Arkansas River and its tributaries drain two-thirds of the state's northern area. Major tributaries to the Arkansas River include Canadian River, Cimarron River, Verdigris River, and Illinois River.

The focus of this study is the middle 252-mile reach of the Arkansas River between State Highway 11 crossing in the Kaw Lake near the Oklahoma-Kansas and the I-40 crossing upstream of the Robert S. Kerr reservoir in Oklahoma (Fig.1). The Arkansas River in the study reach is characterized by meandering and the fine & coarse sand-mix channel. The channel slope averages about 2.1 feet per mile and the river-bank height varies from 30 to 55 feet. Throughout the study reach, the Arkansas River has been impounded in three large reservoirs: Kaw Lake, Keystone Lake, and Webbers Falls Reservoir.

Kaw Lake Dam is on the Arkansas River at mile 653.7 in Osage County, about 8 miles east of Ponca City, Oklahoma. According to Oklahoma Water Resources Board (1990), the lake has a shore length of about 168 miles, a drainage area of 46,530 square miles, and a flood pool capacity of about 1,348,000 acre-feet. The lake occupies 38,020 acres of area for conservation pool. Keystone Lake Dam on the Arkansas River at mile 538.8, is located in Tulsa County, 8.5 miles west of Sand Springs. The dam has a shore length of 330 miles, a drainage area of 74,504 square miles, and a flood pool capacity of 1,737,600 acre-feet. The coverage area for the conservational pool is 54,320 acres. Webbers Falls Dam at navigation mile of 368.9 is located in Muskogee County about 5 miles northwest of the town of Webbers Falls. This reservoir covers 11,600 acres of area for conservation pool and the reservoir has 97,033 square miles of drainage area and a normal pool capacity of 170,100 acre-feet. The construction of Kaw Lake Dam, Keystone Lake Dam and Webbers Falls Dam were completed in 1976, 1964 and 1970 respectively, the Army Corps of Engineers.

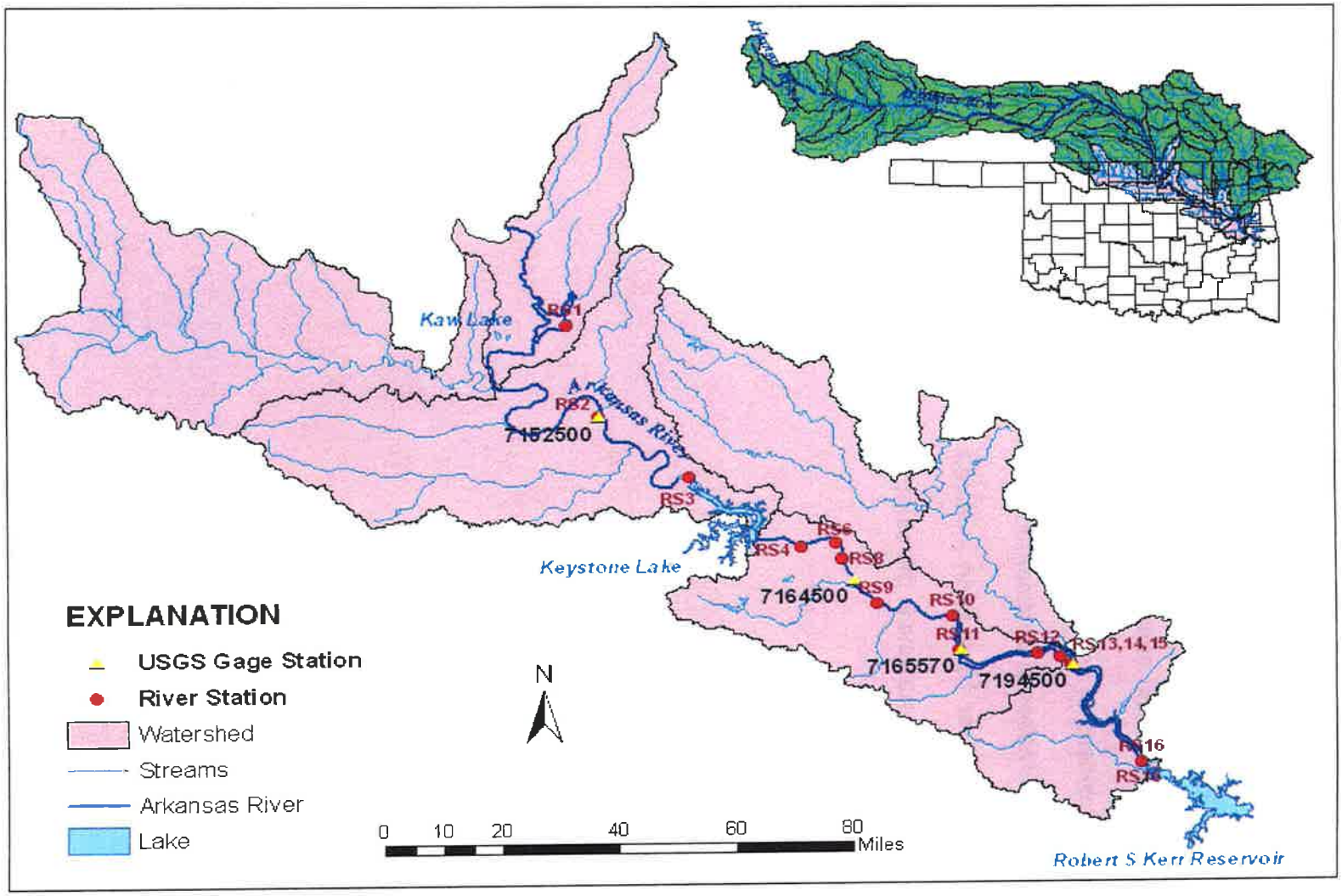


Figure 1. Location of study points and USGS gage stations along the Arkansas River

III. HYDROLOGY

When the hydrology of a stream changes, the physical characteristics of the stream changes also. Such changes include stream channel-bed degradation, stream widening, and stream bank erosion. As the stream profile degrades and the stream widens to accommodate higher flows, stream bank erosions increase along with increases in sediment loads. USGS stream flow gage stations along the Arkansas River have been included in the study reach (Fig. 1). The four active USGS gage stations in the study reach are described in the Table 1 below.

Table 1. Description of USGS gage stations

Data Locations and descriptions	Data Available
USGS 07152500 Arkansas River at Ralston, OK Pawnee County, Oklahoma Hydrologic Unit Code 11060006 Latitude 36°30'15", Longitude 96°43'41" NAD27 Drainage area 54,465 square miles Contributing drainage area 46,850 square miles Gage datum 776.70 feet above sea level NGVD29	1925-2007
USGS 07164500 Arkansas River at Tulsa, OK Tulsa County, Oklahoma Hydrologic Unit Code 11110101 Latitude 36°08'26", Longitude 96°00'22" NAD27 Drainage area 74,615 square miles Contributing drainage area 62,074 square miles Gage datum 615.23 feet above sea level NGVD29	1925-2007
USGS 07165570 Arkansas River near Haskell, OK Wagoner County, Oklahoma Hydrologic Unit Code 11110101 Latitude 35°49'15", Longitude 95°38'19" NAD27 Drainage area 75,473 square miles Contributing drainage area 62,932 square miles Gage datum 530 feet above sea level NGVD29	1972-2007

Table 1. Continued

USGS 07194500 Arkansas River near Muskogee, OK Muskogee County, Oklahoma Hydrologic Unit Code 11110102 Latitude 35°46'10", Longitude 95°17'49" NAD27 Drainage area 96,674 square miles Contributing drainage area 84,133 square miles Gage datum 471.38 feet above sea level NGVD29	2003-2007

Annual peak discharge is the annual instantaneous maximum discharge. Changes in land use and urbanization can affect flood discharges which impact the size and stability of channels. Systematic increases or decreases in the magnitude of annual peak discharges along with the slope and width of the stream channel can cause the stream-bed to either degrade or to aggrade. The maximum scour should occur during peak discharge due to the greater stream power on the channel-bed and the shear stress (Capesius and Lehman, 2001).

To study the stream-bed scour, annual peak discharge plots were downloaded from USGS gage stations to evaluate the historical flood occurrences. In June 1923, the entire drainage area between Hutchinson and Arkansas City received excessive rains. According to USGS Arkansas Water Science, on June 8 and 9, Wichita reported 7.06 inches, Newton 5.75 inches and Arkansas city 2.06 inches of rain. Due to excessive rainfalls in this region, maximum steam flows were recorded at 200,000 cfs in Ralston OK (Fig. 2) and 244,000 cfs in Tulsa (Fig.3). In 1943 the peak stream flow of 700,000 cfs recorded in Muskogee (Fig. 5) which mimics the flood of 1943, and the peak stream flow of 307,000 cfs in Tulsa (Fig. 3) is due to the flood in 1987.

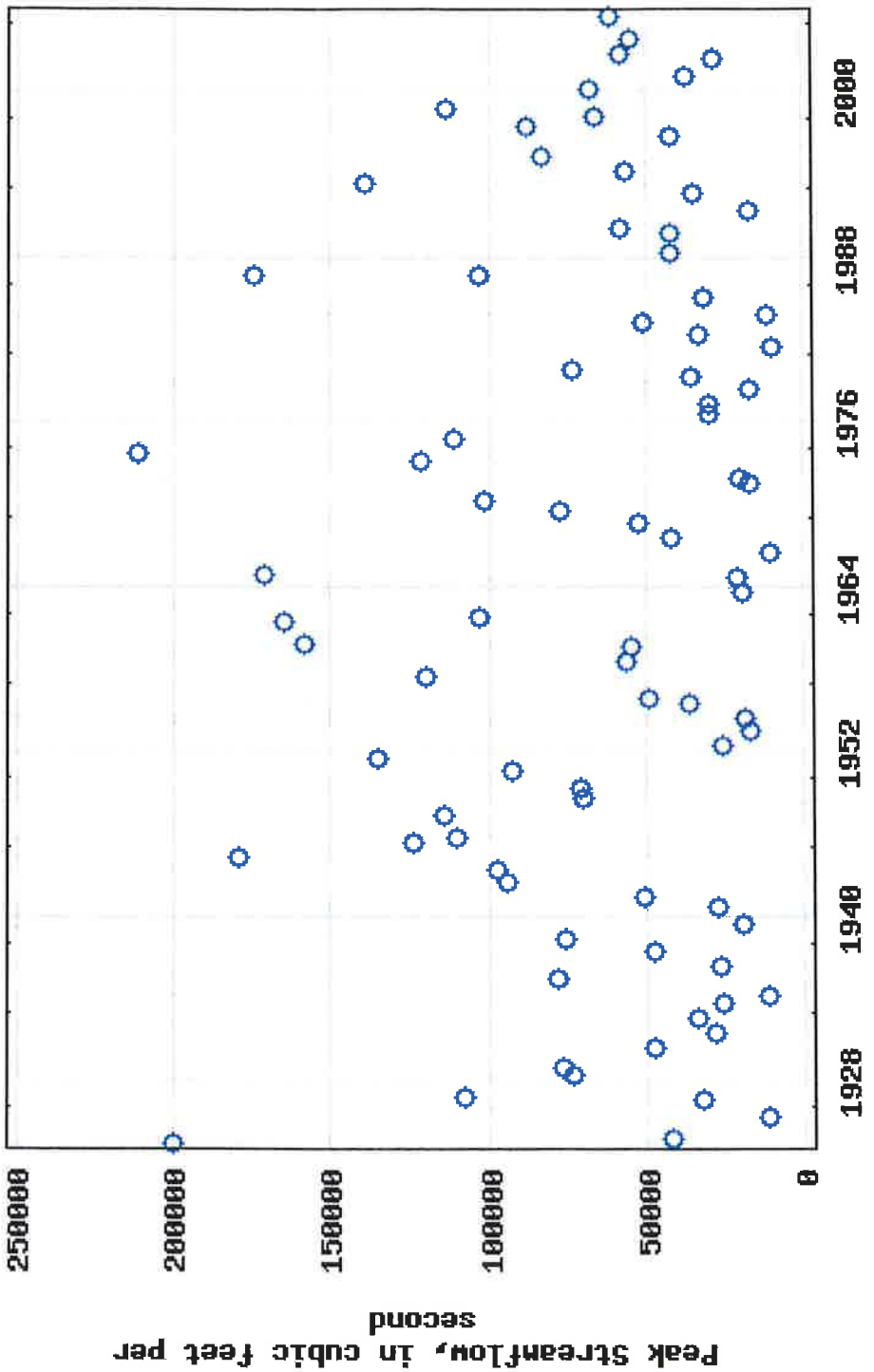


Figure 2. Annual peak streamflow in Arkansas River at Ralston (USGS 07152500), OK

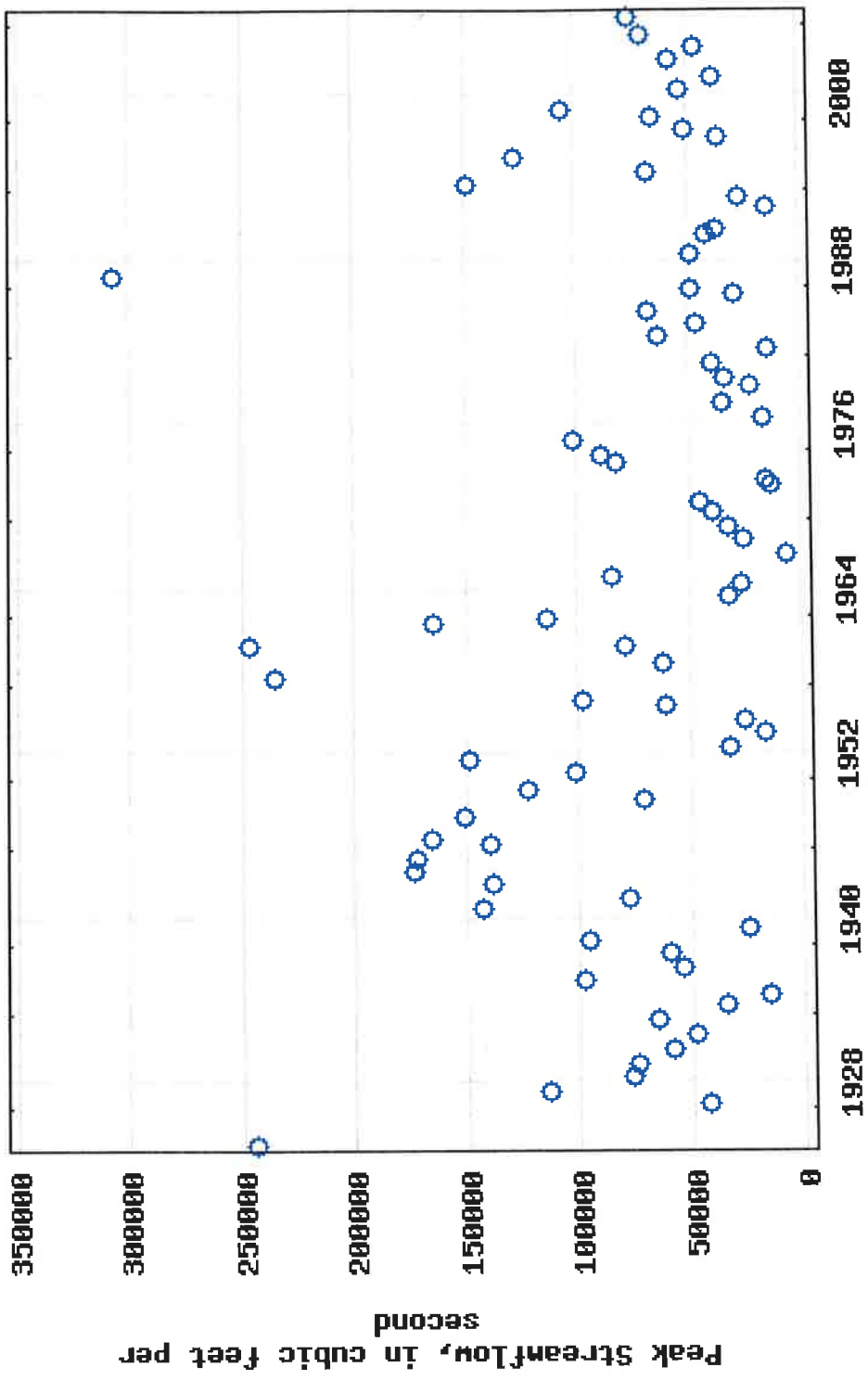


Figure 3. Annual peak streamflow in Arkansas River at Tulsa (USGS 07164500), OK

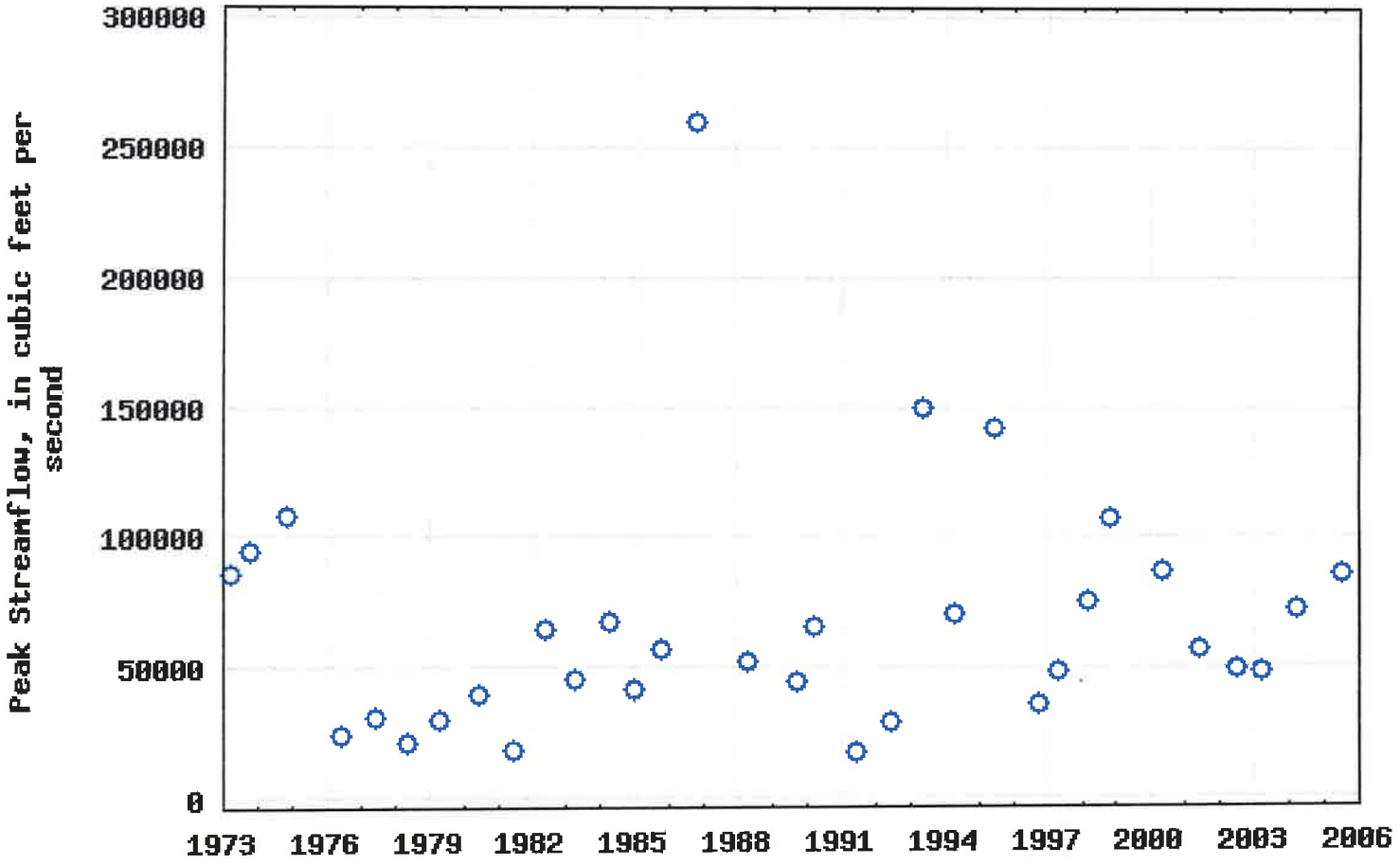


Figure 4. Annual peak streamflow in Arkansas River at Haskell (USGS 07165570), OK

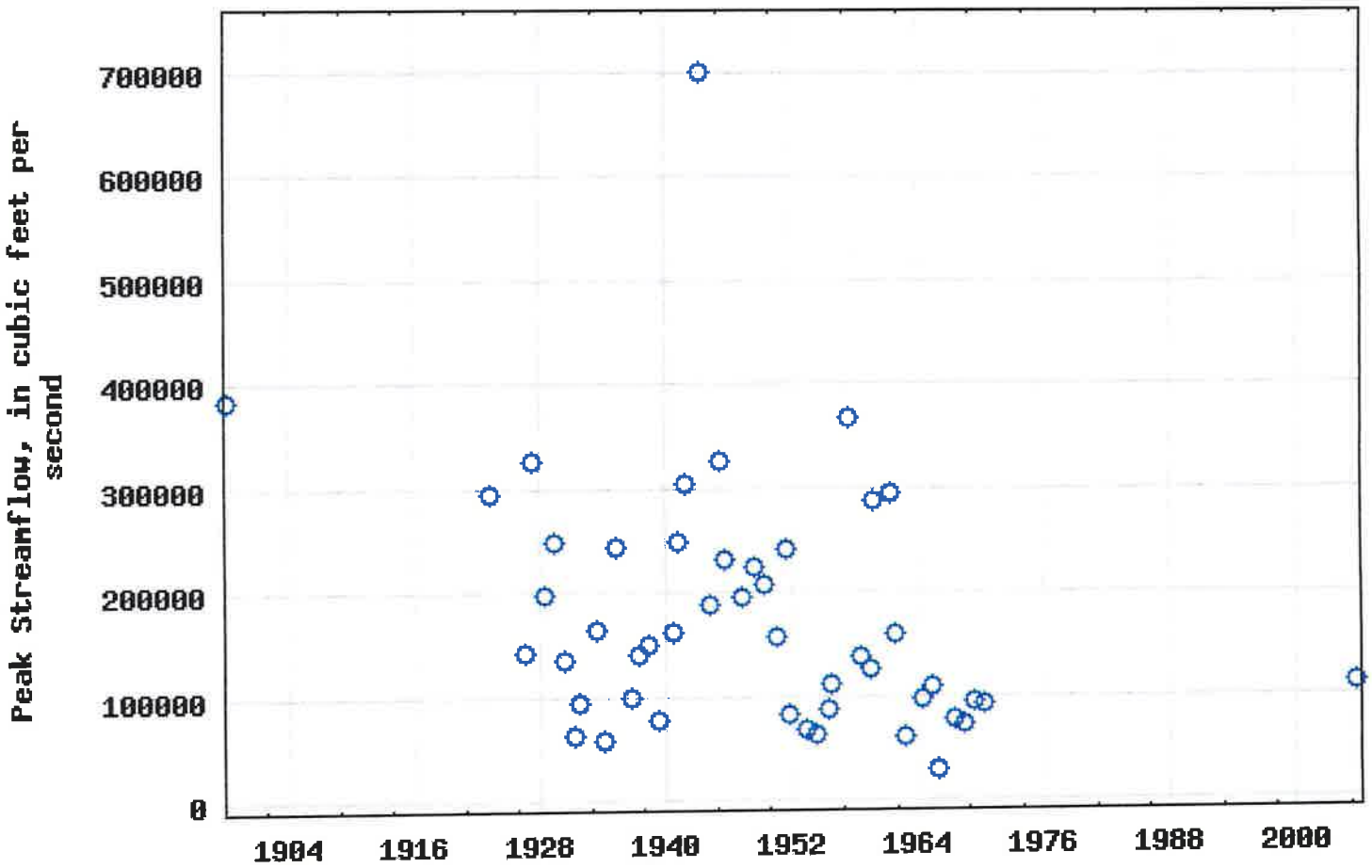


Figure 5. Annual peak streamflow in Arkansas River at Muskogee (USGS 07194500), OK

Gilvear (1999) studied number of areas of fluvial geomorphology directly relevant and beneficial to river engineering:

1) The river channel as a three dimensional form with longitudinal, transverse, and vertical dimensions (x, y, z-directions) involving changes in morphology and amounts of water and sediment.
2) The fluvial process in response to water and sediment coming from the upstream watersheds.
3) The geomorphic stability of a river system altered by activities such as river training, removing riparian vegetation, land use, and climatic change etc.

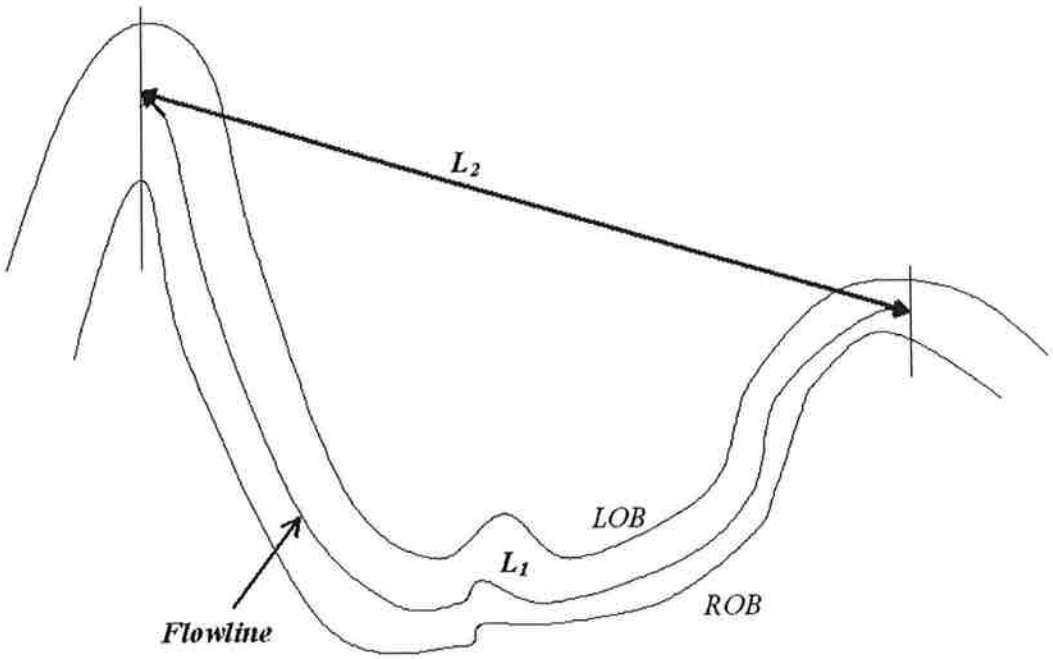
The study reach is divided into 2: Reach 1, from Kaw Lake to Keystone Lake Dam, and Reach 2, from Keystone Lake dam to Webbers Falls reservoir. The object was to study the downstream effects of each dam in river degradation. Data collected at each site included channel gradient, cross-sectional geometry, and bed material composition. Channel gradient from one river station to another was calculated arithmetically and mean taken for each study reach. River meandering between two successive river stations was determined by calculating sinuosity as shown in Figure 6 using Geographic Information System (GIS), to examine the downstream effects of dams in meandering channels. Sinuosity is defined as a ratio of total length between two river stations along the flowline to shortest length of the channel.

The Arkansas River in Oklahoma is highly meandering upstream of Keystone Lake compared to downstream and slope is also higher above

Keystone Lake (Table 2). River-bed geotechnical information for some of the stations was also abstracted from construction detail drawings of each bridge crossing provided by Oklahoma Department of Transportation (ODOT). Longitudinal and vertical changes of the channel-bed were also studied and will be discussed separately in another chapter.

Table 2. Sinuosity and slope study on Arkansas River

Study of reach				Study of River Stations		
Reach	Location	Reach slope	Reach Sinuosity	River Stations	Slope	Sinuosity
1	Kaw Lake to Keystone Dam	2.2	2.3	RS 1 to RS 2	2.527	0.253
				RS 2 to RS 3	1.981	0.533
				RS 3 to RS 4	2.470	0.739
2	Keystone Dam to Webbers Falls reservoir (I-40 crossing)	1.69	1.55	RS 4 to RS 5	22.885	7.692
				RS 5 to RS 6	1.334	0.896
				RS 6 to RS 7	4.612	0.801
				RS 7 to RS 8	0.000	9.091
				RS 8 to RS 9	1.507	0.876
				RS 9 to RS 10	1.415	0.634
				RS 10 to RS 11	5.913	1.471
				RS 11 to RS 12	1.692	0.740
				RS 12 to RS 13	-140.526	5.263
				RS 13 to RS 14	3.262	0.722
				RS 14 to RS 15	0.680	0.581
				RS 15 to RS 16	1.278	0.688



$$Sinuosity = \frac{Flowline \quad Length(L_1)}{Shortest \quad Length(L_2)}$$

Figure 6. Schematic diagram of sinuosity of natural channels

IV. ANALYSIS OF CROSS-SECTIONAL GEOMETRY

Field data measured over 50 year period by ODOT was examined in this study. Throughout the study reach, 16 River Stations (RS) were selected: RS 1 to RS 3 in Reach 1, RS 4 to RS 15 in Reach 2, and RS 16 just downstream of Webbers Falls Dam. Ten out of sixteen stations have data on cross-section geometry. These river stations are measured in bridge crossings.

River-bed degradation is evident for about 80.5 miles below Keystone Lake Dam and 6.5 miles below Webbers Falls Dam at the I-40 highway crossing. RS 1 on highway SH 11(Fig. 7), which is located in Kaw Lake, shows that the channel-bed was aggraded about 9 feet from the 1975 to 1987. The Kaw lake dam was constructed in 1975 and the dam, which completely intercepted the sediment, aggraded the river-bed. At the same location, the observed data shows that the degradation had occurred in the channel-bed in 1987 and reached about 5 feet of degradation by 2002. This corresponds to flooding in Oklahoma in 1986. The 11 inches of precipitation in this region would have allowed the dam to flow large amounts of water to the downstream of the reservoir. RS 2 (Fig.8) shows that the channel-bed below Kaw Lake Dam is not stable. Instead of channel-bed degradation, the channel-bed has shifted from one bank to another.

Another study point is 64 miles downstream Kaw Lake Dam. Geotechnical information on the channel-bed at RS 2 and any tributaries upstream was examined. The channel-bed was characterized by hard stone below 3 feet of sand deposits (Fig. 8). The figure shows that the main channel has been shifted

towards the right bank so as to act against the non-equilibrium flow condition. A large tributary, Salt Fork, joins the Arkansas River about 45 miles upstream of the study point. Hence, no conclusions can be drawn about the downstream effects of Kaw Lake Dam on river degradation with only one station below 64 miles.

Williams and Wolman (1984) studied the downstream effects of 21 dams constructed in alluvial rivers in the United States. Generally, the magnitude of river-bed changes was greatest nearest the dam and diminished with distance downstream. However, the bed-elevation change on RS 4 (Fig. 9) of for study Reach 2 does not show this. The degradation rates of RS 4, RS 5 and RS 6 are lower than its downstream RS 7, RS 8, and RS 9 (Table 3). Cross-section of RS 4 (Fig. 9) at pre-dam closure was not available, though two cross-sections after the dam closure show channel-bed degradation of about 1.5 feet on the hard rock river bed from 1976 to 1992. This might be the cause of degradation rate being lower than that of downstream points. River-bed degradation at RS 9 (Fig. 10) was found to be 2.75 feet. Approximately 2 feet of degradation in RS 10 (Fig. 11) has occurred over 15 year as the channel has exposed its hard bed materials.

RS 11, 12, 13 and 14(Figs. 12-15) have also experienced considerable channel-bed degradation. The channel-bed on RS 15 is neither aggraded nor degraded. RS 16 (Fig.16), located at I-40, 6.5 miles downstream of Webbers Falls Dam, has experienced the greatest channel-bed degradation, 12.2 feet, in the Arkansas River, Oklahoma.

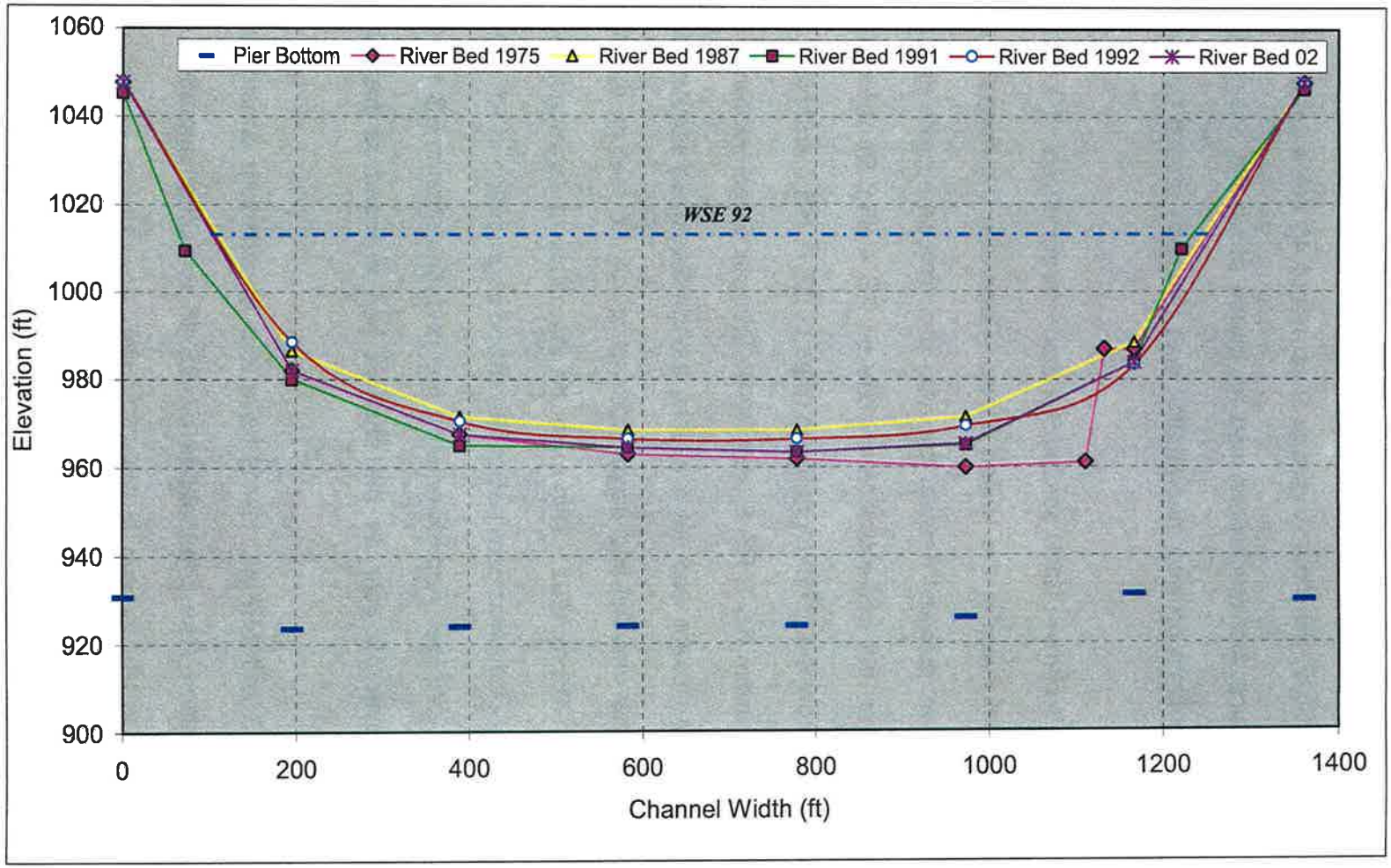


Figure 7. Cross-section at bridge (Bridge No. 19112 and RS 1) on SH 11, Arkansas River, OK

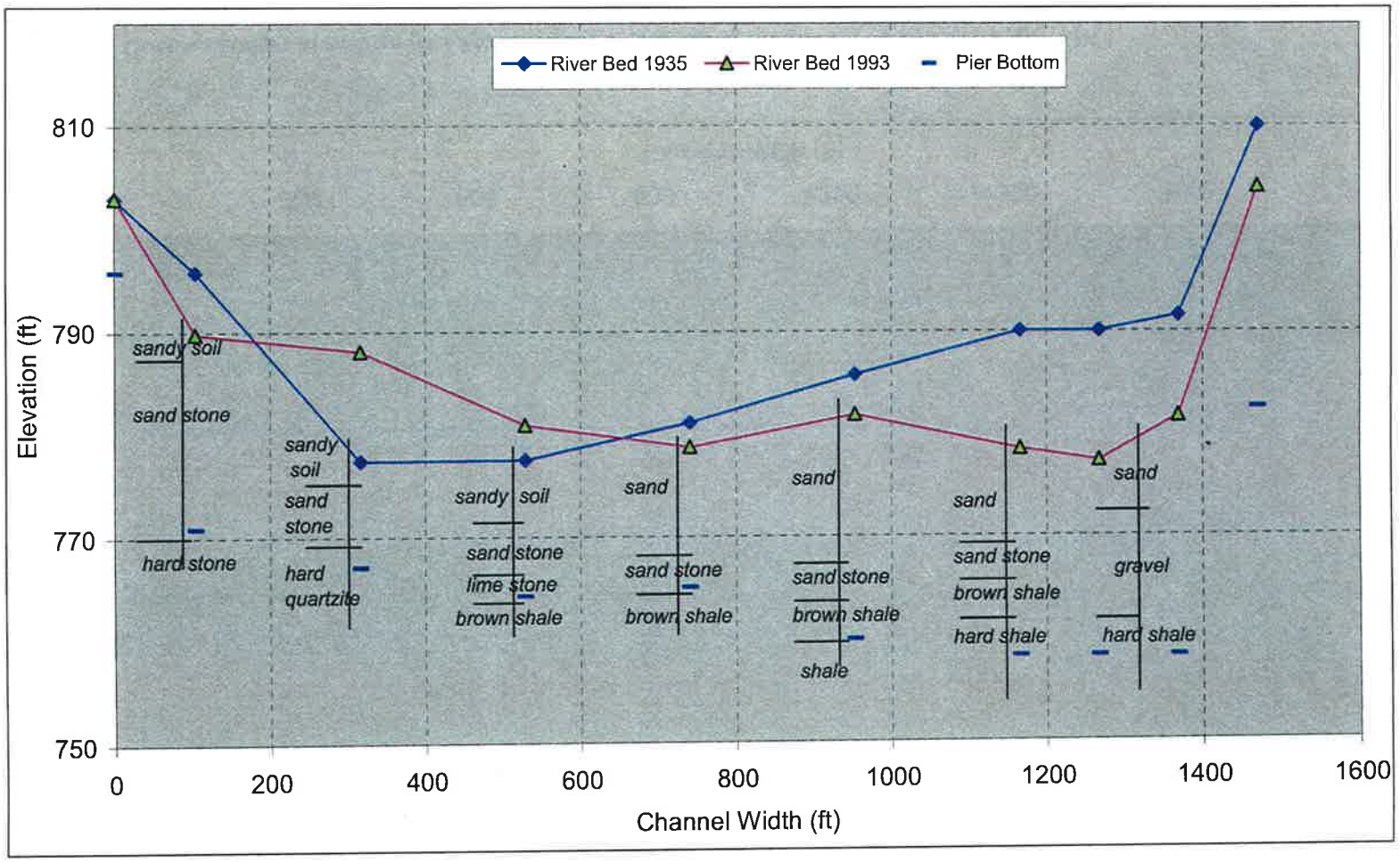


Figure 8. Cross-section at bridge (Bridge No. 04603 and RS 2) on SH 18, Arkansas River, OK

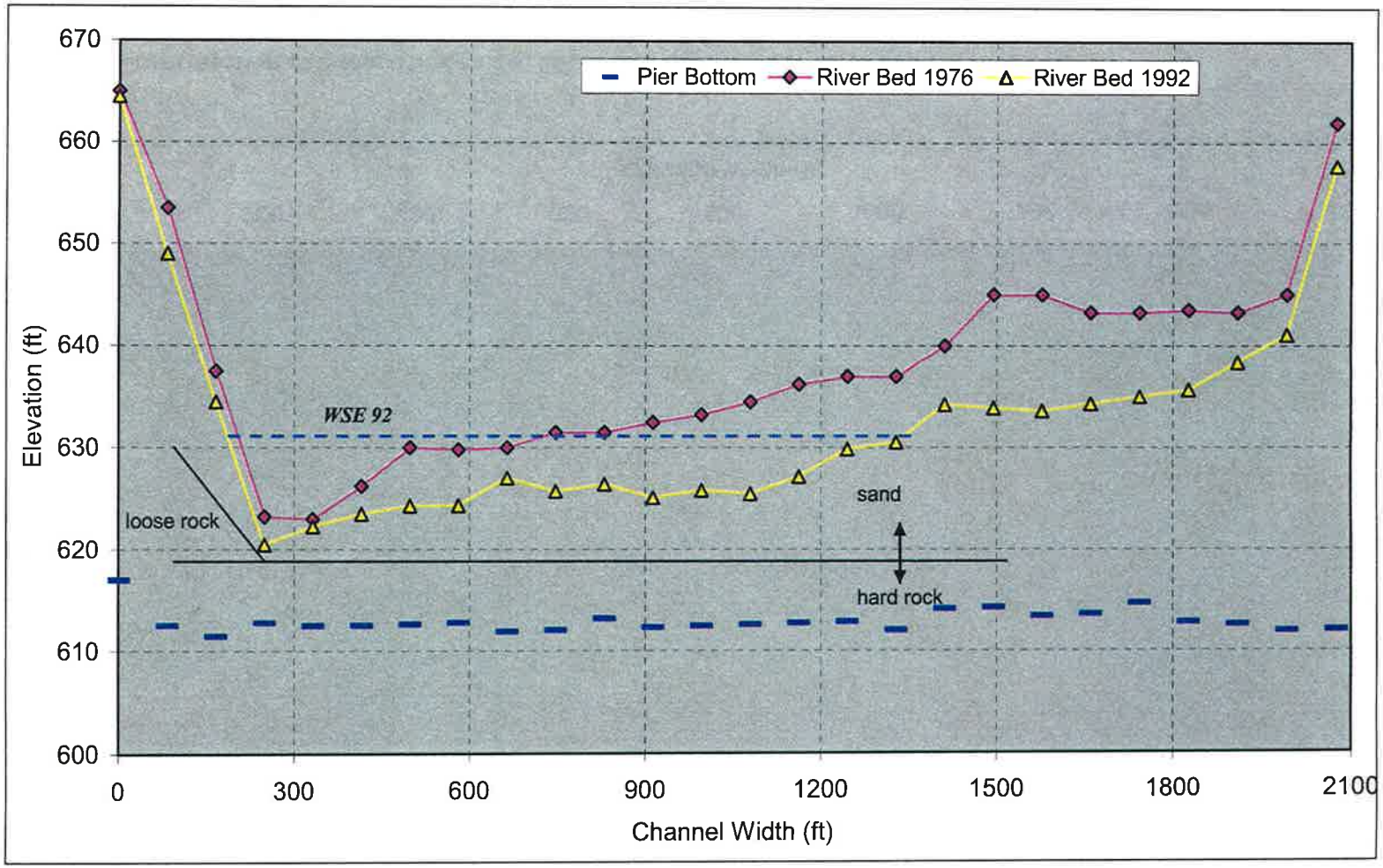


Figure 9. Cross-section at bridge (Bridge No. 19279 and RS 4) on SH 51, Arkansas River, OK

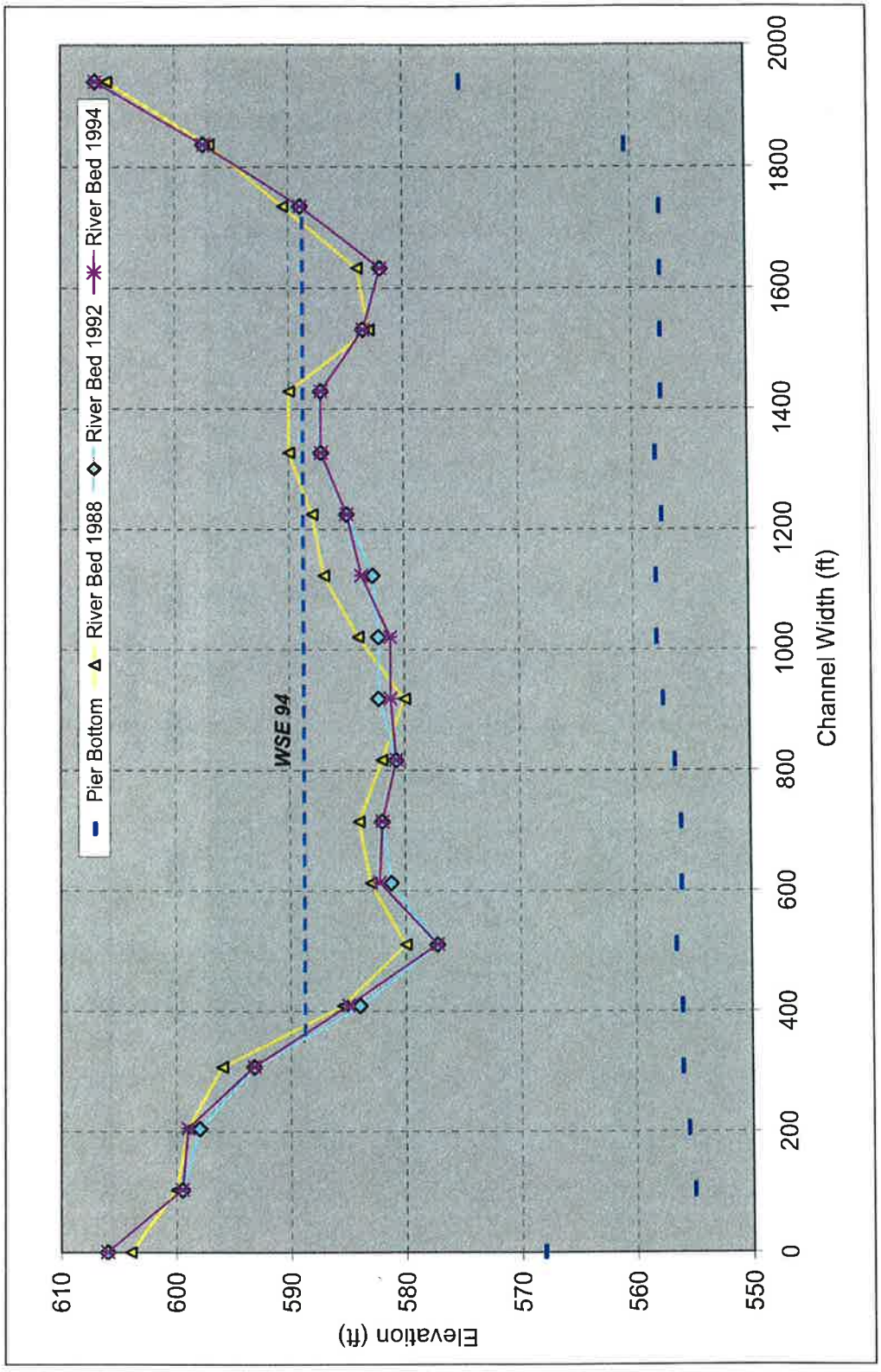


Figure 10. Cross-section at bridge (Bridge No. 22107 and RS 9) on US 64, Arkansas River, OK

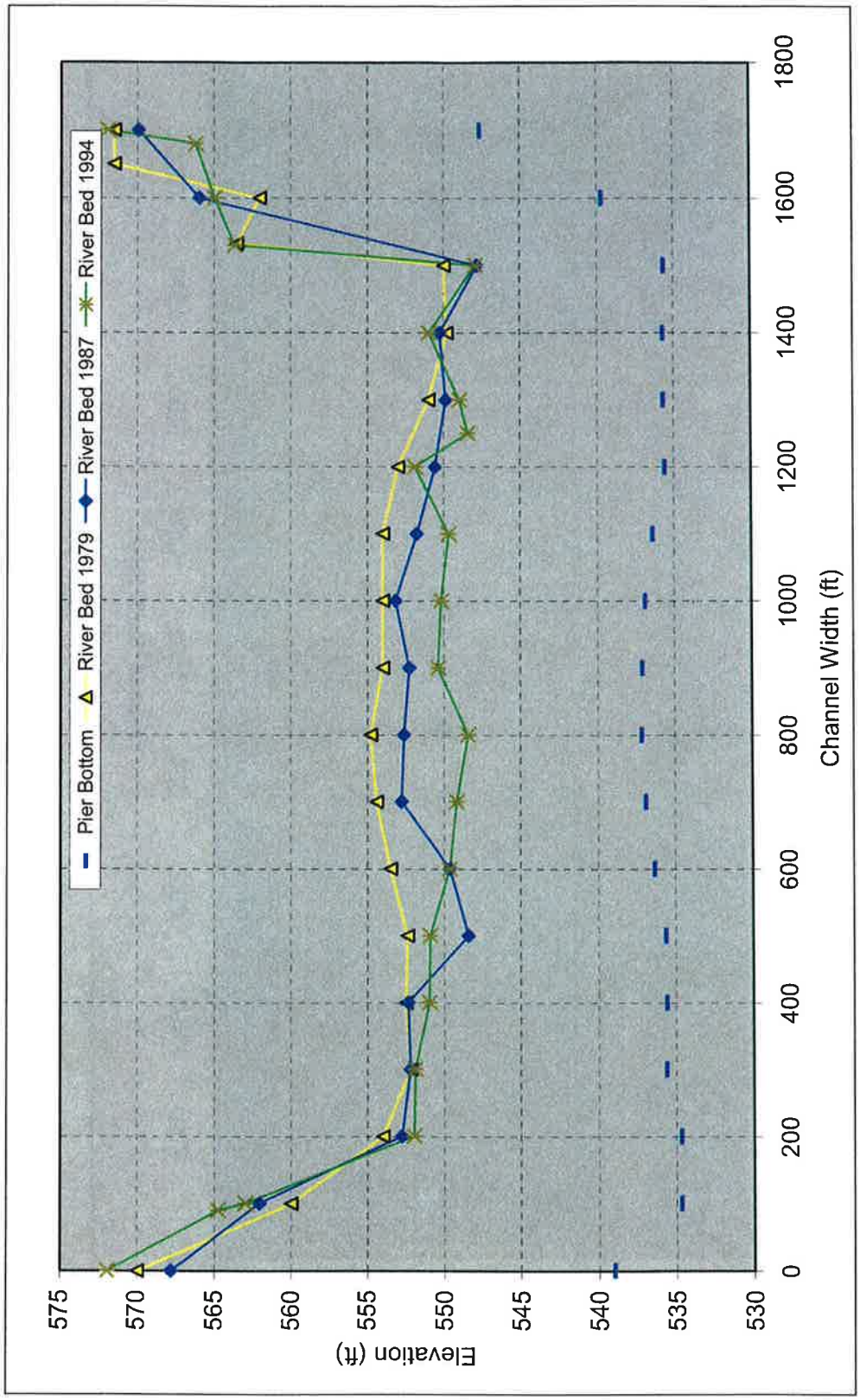


Figure 11. Cross-section at bridge (Bridge No. 19638 an RS 10) on SH 72, Arkansas River, OK

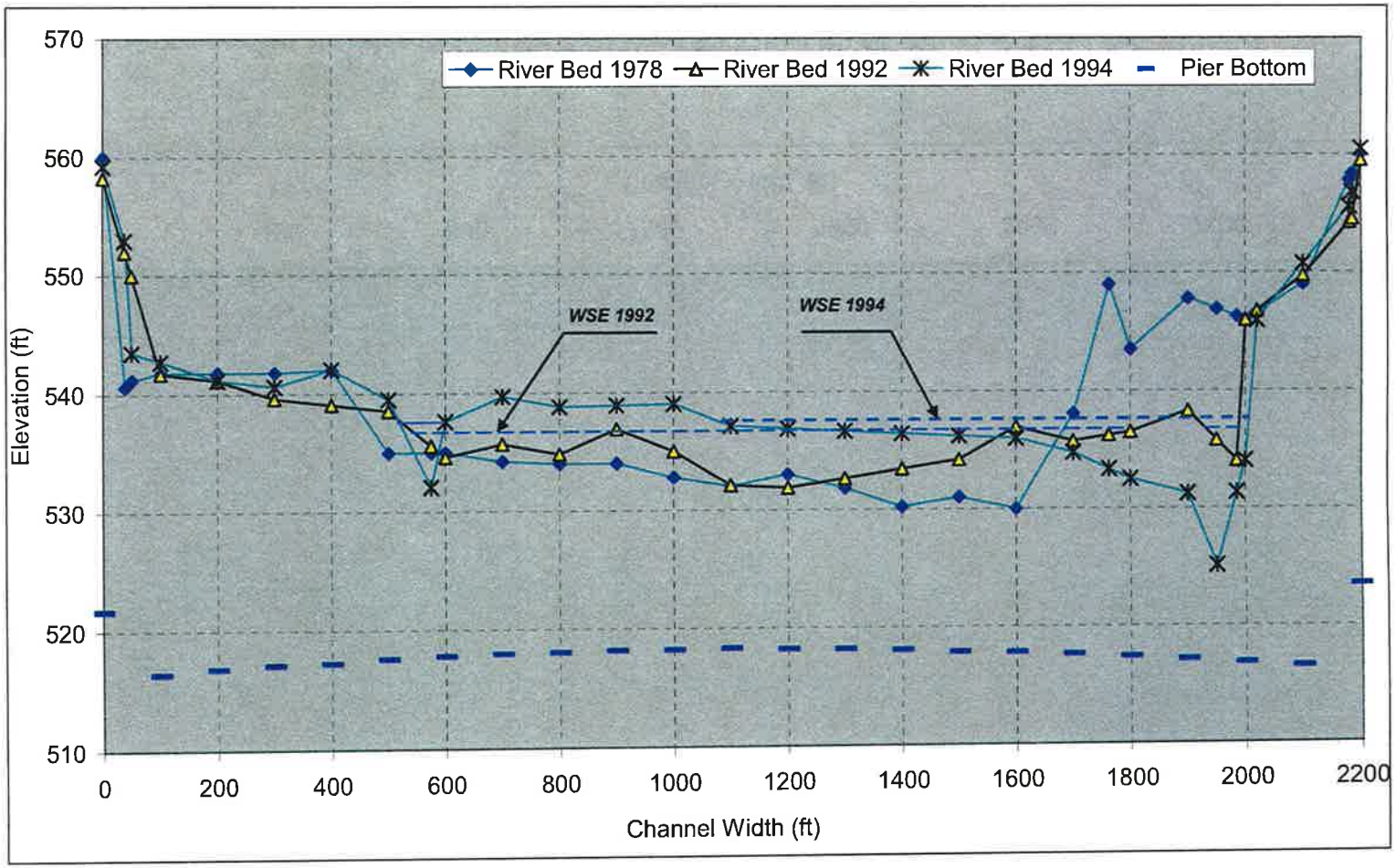


Figure 12. Cross-section at bridge (Bridge No. 19512 and RS 11) on SH 104, Arkansas River, OK

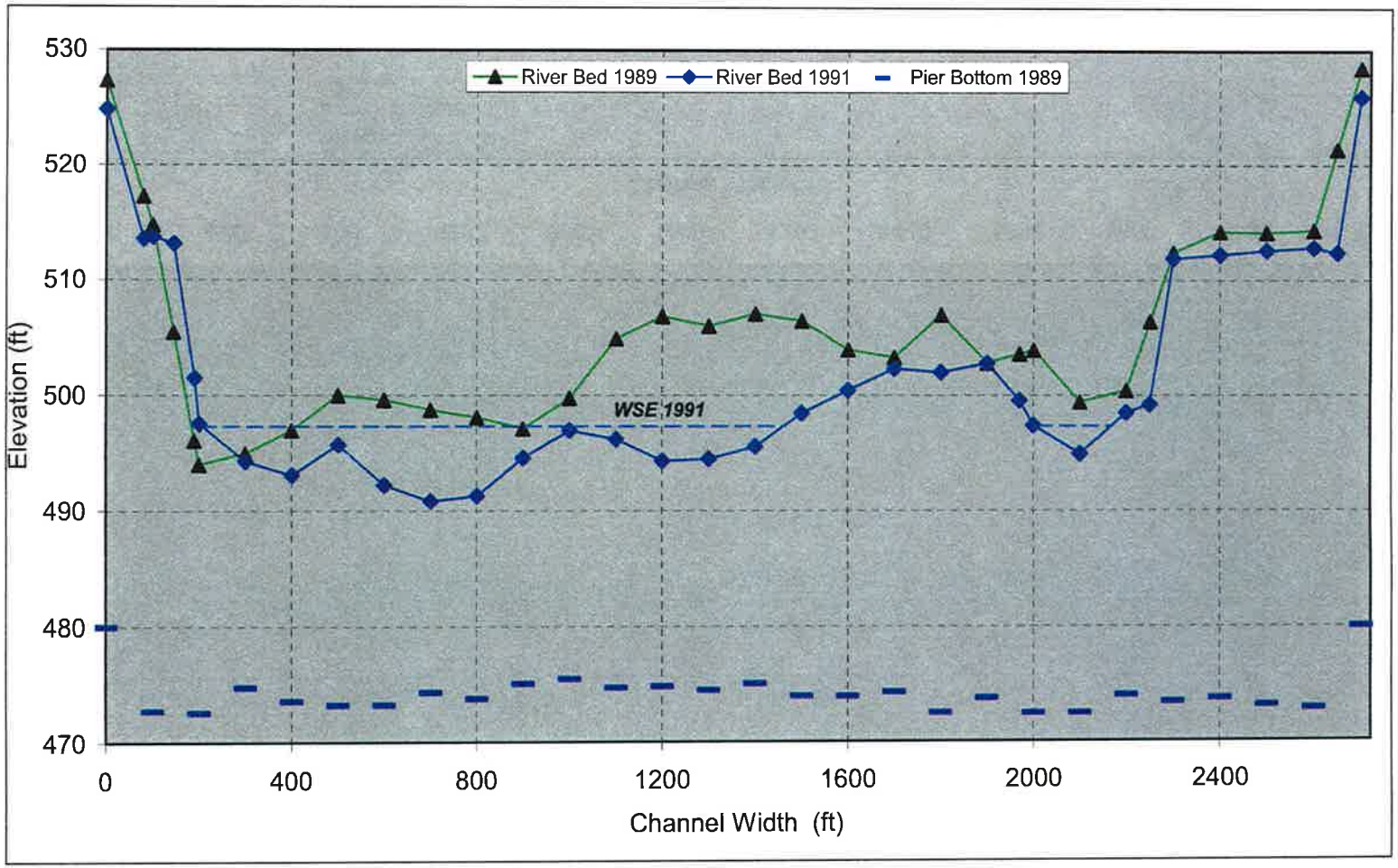


Figure 13. Cross-section at bridge (Bridge No. 22425 and RS 12) on US 69, Arkansas River, OK

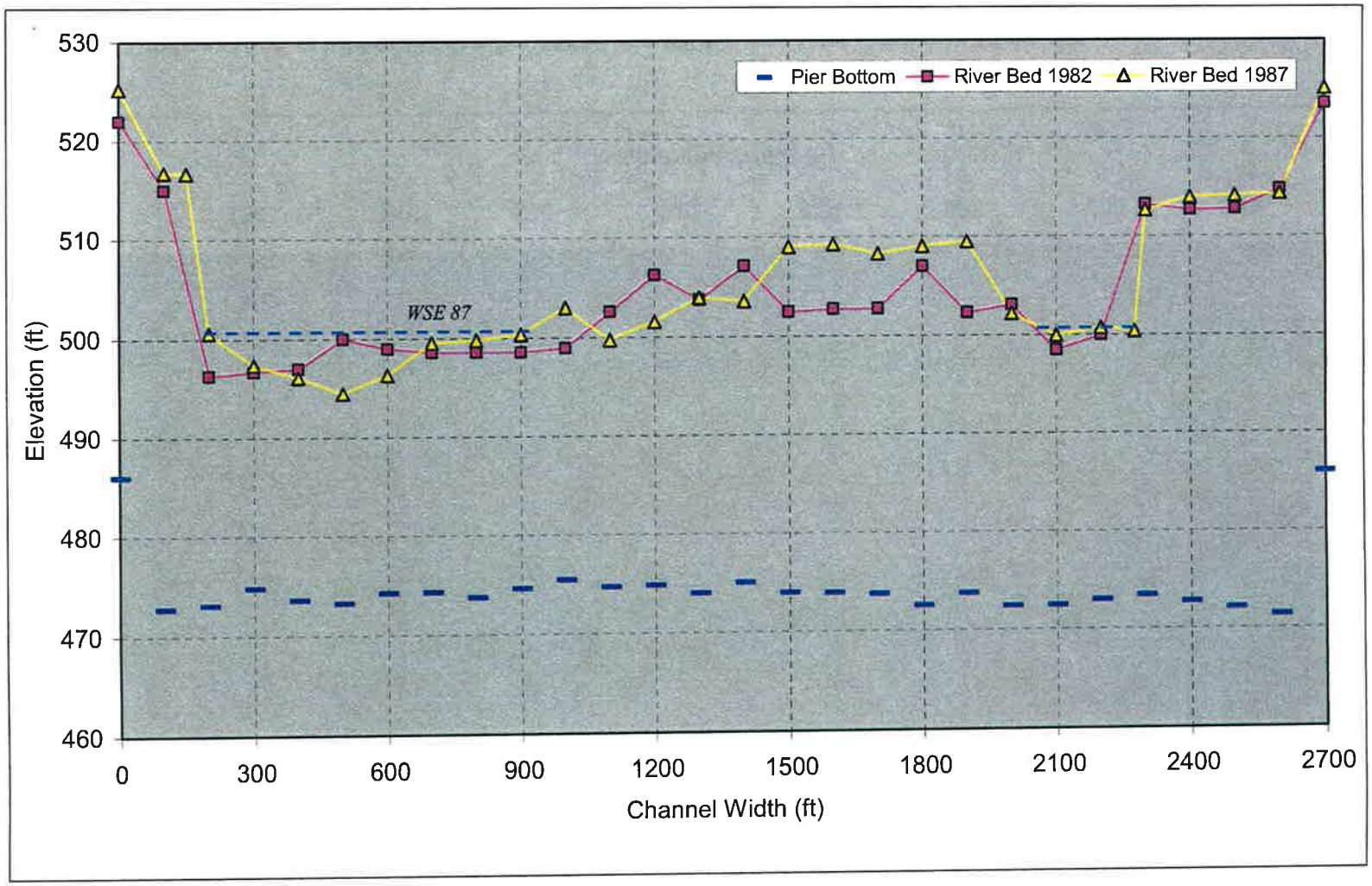


Figure 14. Cross-section at bridge (Bridge No. 20327 and RS 13) on US 69, Arkansas River, OK

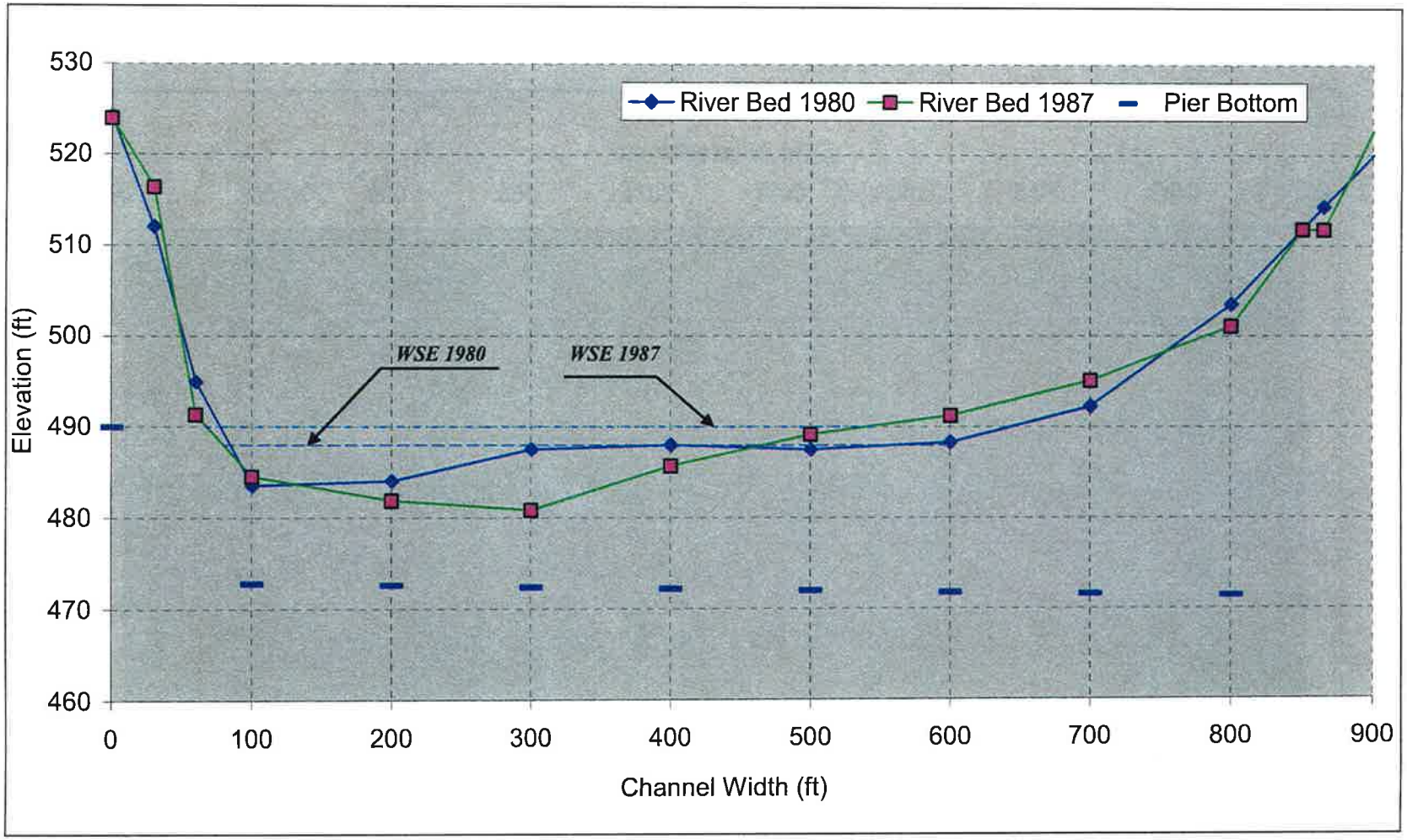


Figure 15. Cross-section at bridge (Bridge No. 19835 and RS 14) on SH 16, Arkansas River, OK

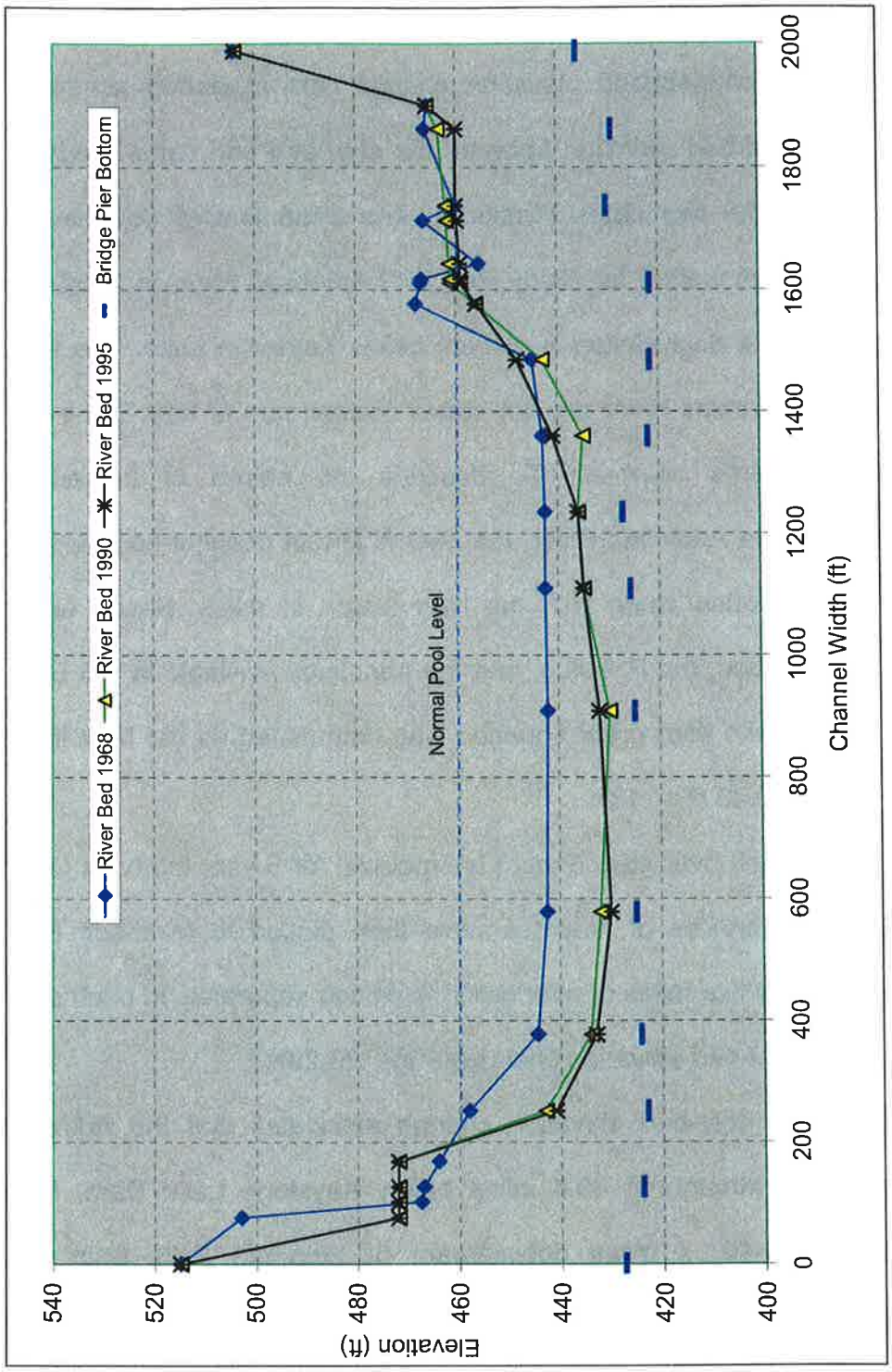


Figure 16. Cross-section at bridge (Bridge No. 17051 and RS 16) on I-40, Arkansas River, OK

V. ANALYSIS OF FLOWLINE PROFILE

The rate of channel-bed elevation change was estimated as the net difference in channel-bed elevation between the start and end dates divided by the time between the two dates (Table 3). The trend line of bed-elevation changes (Fig.17) was plotted for Study Reach of Arkansas River in Oklahoma. The trend shows that degradation is evident below Keystone Lake. The fluvial dynamics of the Arkansas River are not stable downstream of Key Stone Lake until Robert S. Kerr's reservoir. To describe the nature of degradation phenomena along the Arkansas River, the best fit line of channel-bed elevation change rate was plotted along with the river length in miles. Based on the coefficient of correlation, the R^2 value, and the trendlines available in MS Excel, the spline function with third order equation was determined as the best fit line with an R^2 value of 0.45 (Fig. 18).

Flowline at each river station were interpolated for 5-year intervals (Table 4) and longitudinal profiles of flowlines were then plotted in Microsoft Excel (Fig.19). Each twenty five miles of river reach is plotted separately in each sheet for evaluating channel-bed elevation changes (Figs. 20-29).

The study of river-bed elevation change elucidates that the Arkansas River is not stable throughout 80.5 miles below Keystone Lake Dam. River station located at I-40, 7 miles downstream of Webbers Falls Dam, has experienced 12.2 feet of channel-bed degradation, the greatest in the Arkansas River, Oklahoma.

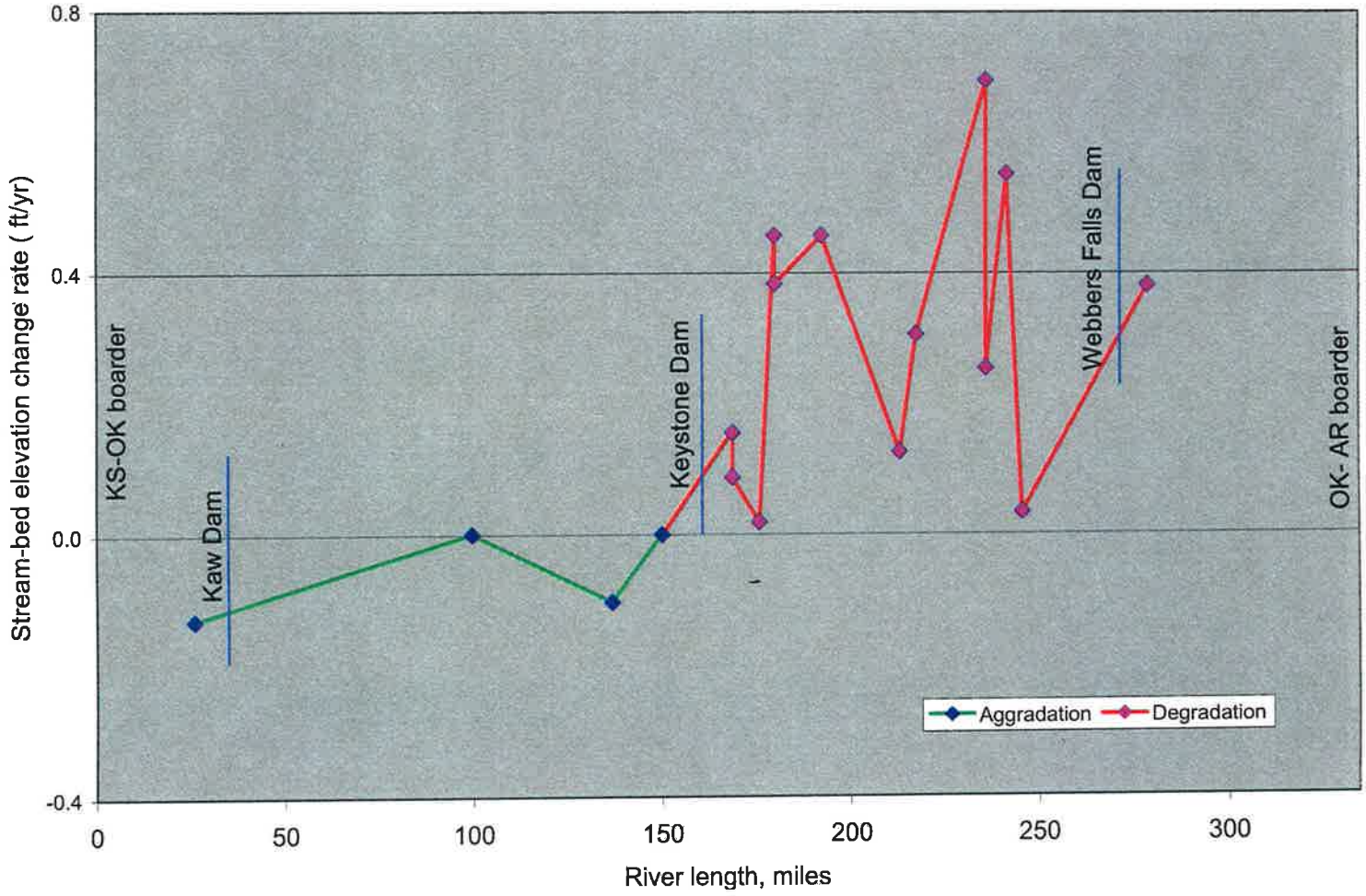


Figure 17. Trend line of stream-bed elevation changes

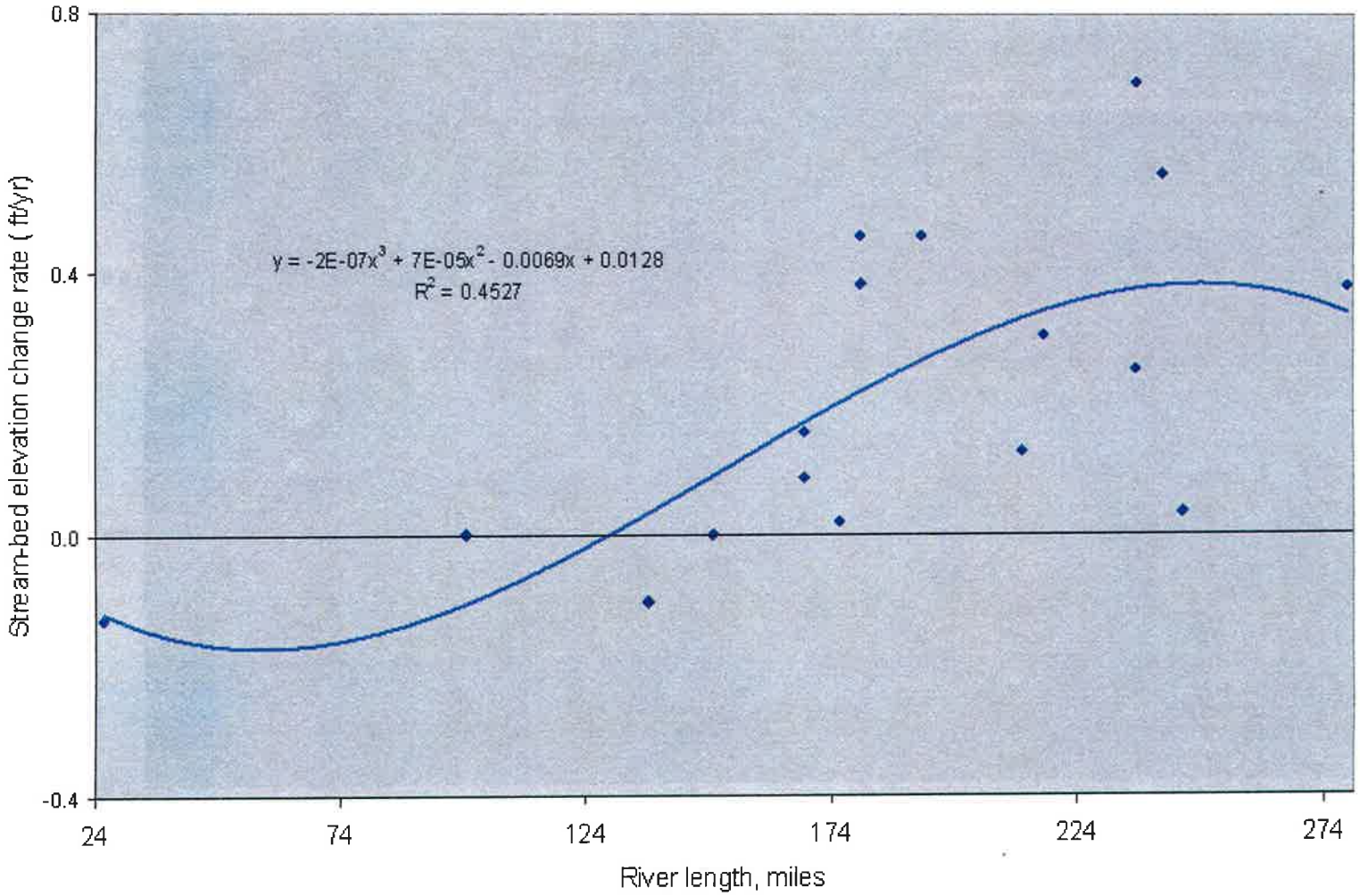


Figure 18. The best fit line of stream-bed elevation change rate (ft/yr) versus river length in miles

Table 3. Summary of channel –bed elevation change, Arkansas River

Bri_key	River stations	Miles	Bridge Installed	Highway	Stratum	Max. Scour **(ft)	Duration (yr)	Scour rate **(ft/yr)
b19112	RS1	25.74	1975	S.H.11	Coarse sand to rock	-3.50	27	-0.13
b04603	RS2	99.60	1935	S.H.18	Sand to hard quartzite	0.03	58	0.00
*b15866	RS3	136.71	1963	S.H 99	Sand to Shale	3.08	30	0.10
b19279	RS4	168.64	1976	S.H.51	Loose rock to rock	2.50	16	0.16
*b19511	RS5	168.65	1978	S.H 51	Loose rock to rock	1.40	16	0.09
*b17052	RS6	175.74	1967	I-244	Sand to hard shale	0.50	27	0.02
*b20580	RS7	179.91	1983	I-44	Fine sand to blue shale	5.50	12	0.46
*b20326	RS8	179.92	1983	I-44	Fine sand to blue shale	5.00	13	0.38
b22107	RS9	192.37	1988	U.S. 64	Sand to grey shale	2.75	6	0.46
b19638	RS10	212.94	1979	S.H. 72	Sand to hard shale	1.89	15	0.13
b19512	RS11	217.41	1978	S.H.104	Sand to hard shale	4.90	16	0.31
b22425	RS12	235.98	1989	U.S. 69	Sand to hard shale	3.17	2	1.59
b20327	RS13	235.96	1982	U.S. 69	Sand to blue shale	1.84	5	0.37
b19835	RS14	241.43	1980	S.H.16	Medium hard shale	2.68	7	0.38
*b17610	RS15	245.48	1969	U.S.62	Medium hard shale	0.50	15	0.03
b17051	RS16	278.71	1968	I-40	Medium hard shale	12.2	28	0.44

* Bridges without cross section data

**Note: (-) Aggradation
: (+) Degradation

Table 4. Flow line interpolated data for 5 years interval, Arkansas River

Location		Year							
Bri_key	River Stations	Miles	1975	1980	1985	1990	1995	2000	2005
b19112	RS1	25.74	960.00	963.54	967.08	964.74	964.00	963.64	963.29
b04603	RS2	99.60	777.38	777.38	777.38	777.37	777.37	777.37	777.36
b15866	RS3	136.71	702.33	702.85	703.36	704.39	703.87		
b19279	RS4	168.64	623.04	622.85	622.78	622.78	625.00	625.45	626.00
b19511	RS5	168.65	625.85	623.19	623.13	624.14	624.71		
b17052	RS6	175.74	615.18	614.98	614.78	614.58	615.25		
b20580	RS7	179.91		603.33	600.28	597.22	596.00	596.00	
b20326	RS8	179.92		602.00	599.50	597.00	596.00	595.00	
b22107	RS9	192.37			582.06	578.63	577.25		
b19638	RS10	212.94	550.80	550.05	551.29	546.95	548.15	549.35	550.55
b19512	RS11	217.41	528.59	530.94	533.28	532.81	521.72		
b22425	RS12	235.98				492.42	490.33	488.58	486.83
b20327	RS13	235.96		498.83	492.50	494.70	493.00	493.00	
b19835	RS14	241.43	483.63	483.50	482.00	482.46	475.22		
b17610	RS15	245.48	472.80	472.63	472.47				
b17051	RS16	278.71	438.32	435.55	432.77	430.00	430.00	430.00	430.00

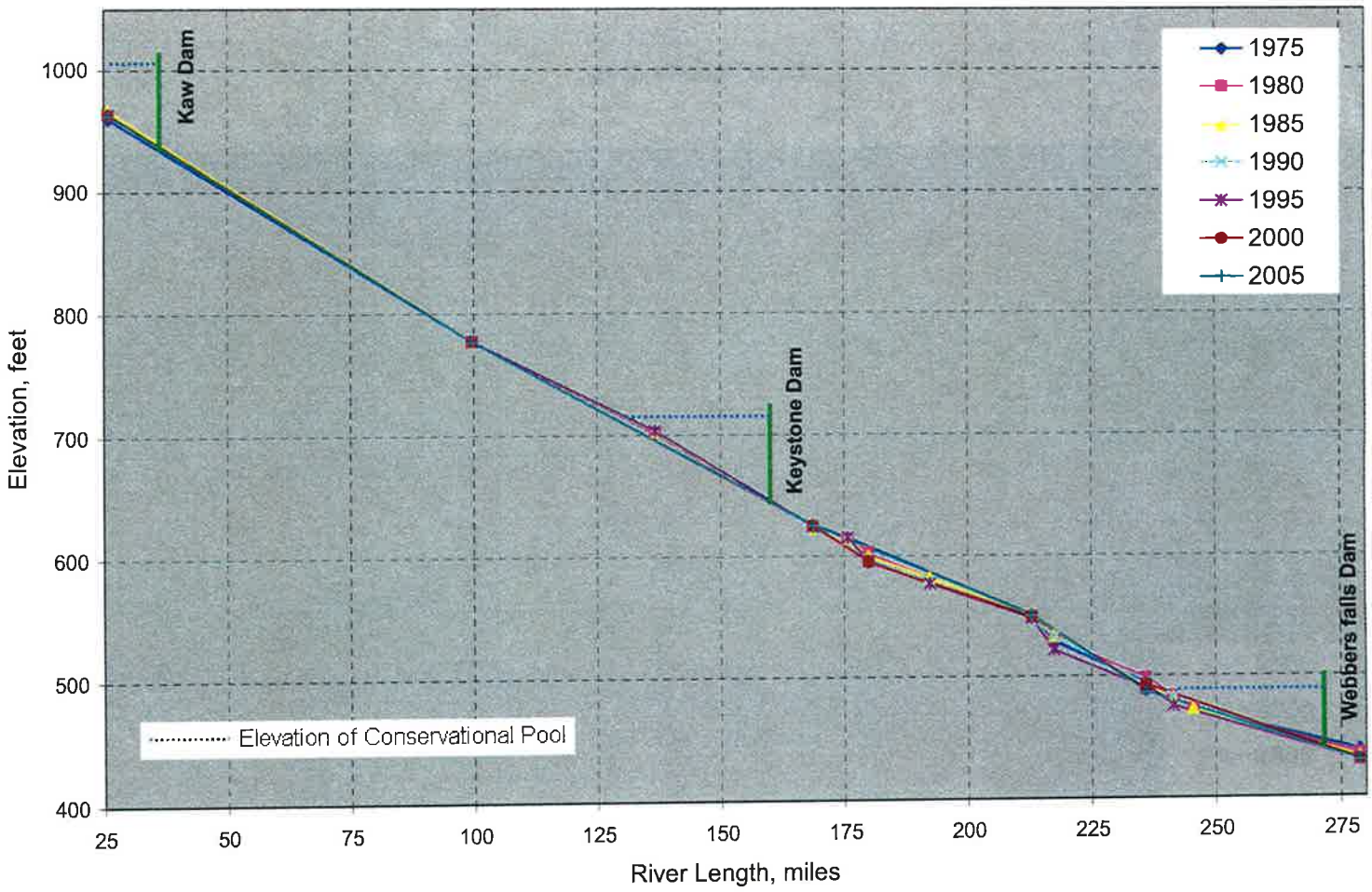


Figure 19. Longitudinal Profile of Arkansas River Bed, Oklahoma

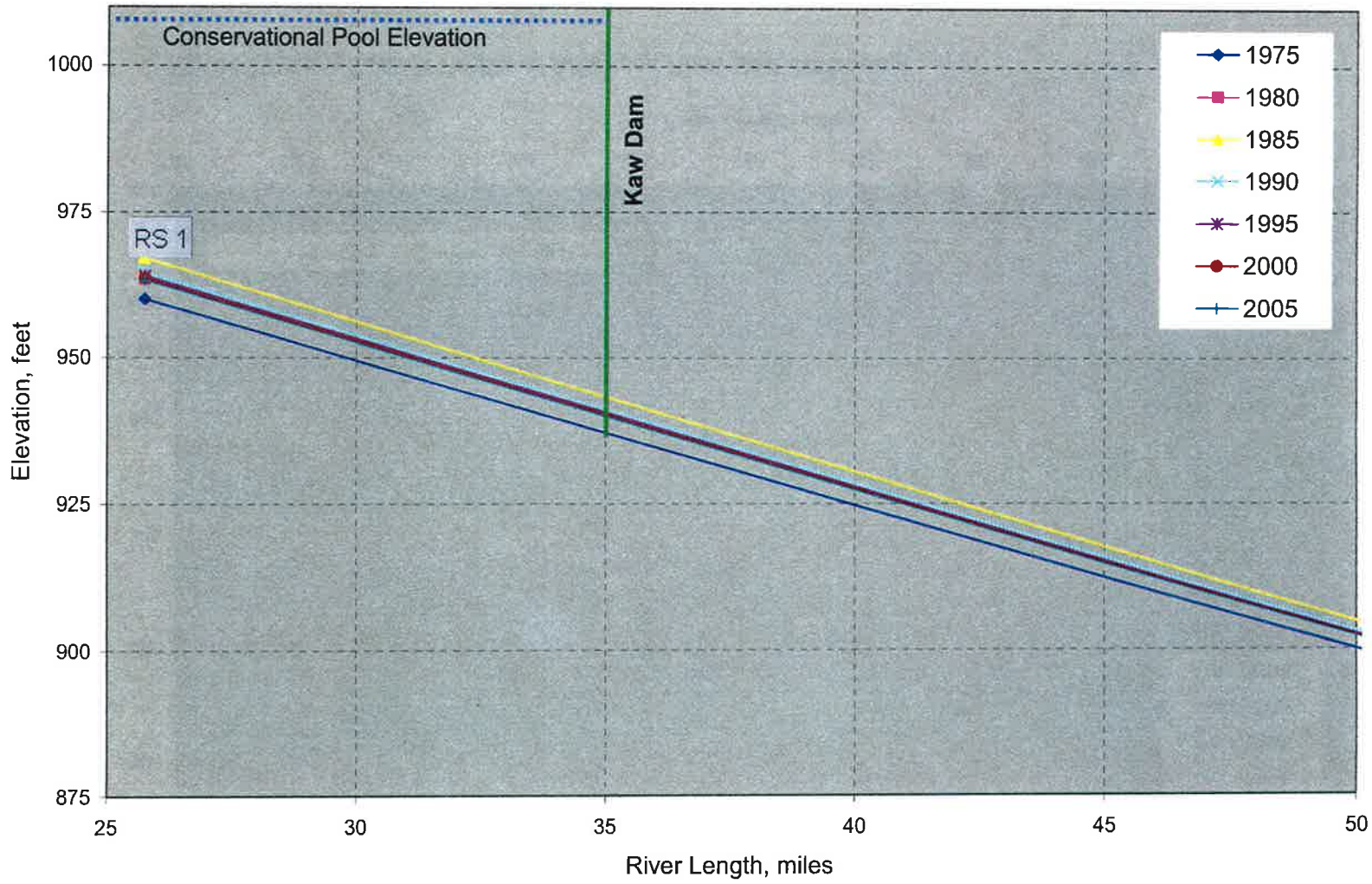


Figure 20. Longitudinal profile of Arkansas River Bed, Oklahoma

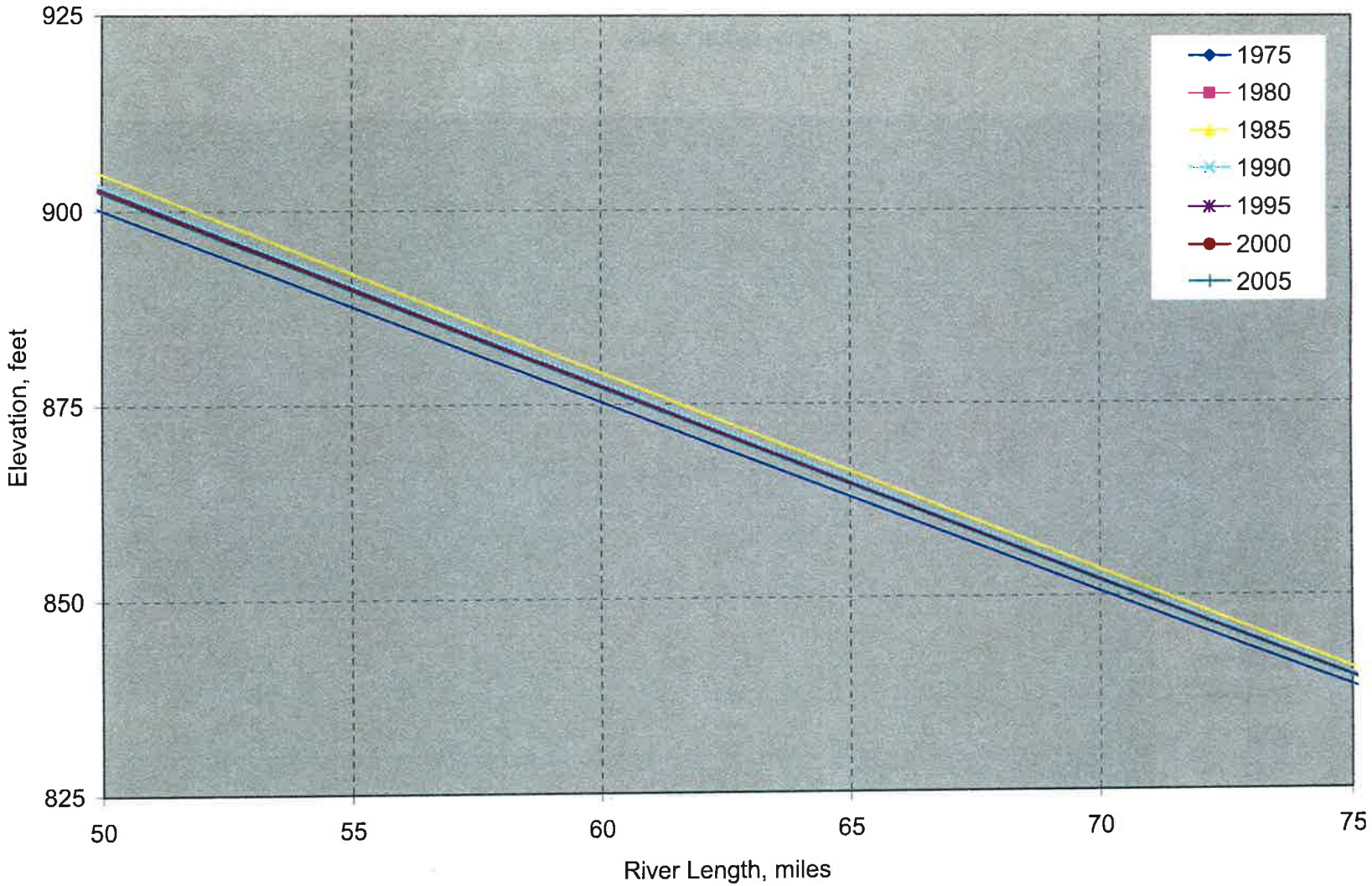


Figure 21. Longitudinal profile of Arkansas River Bed, Oklahoma

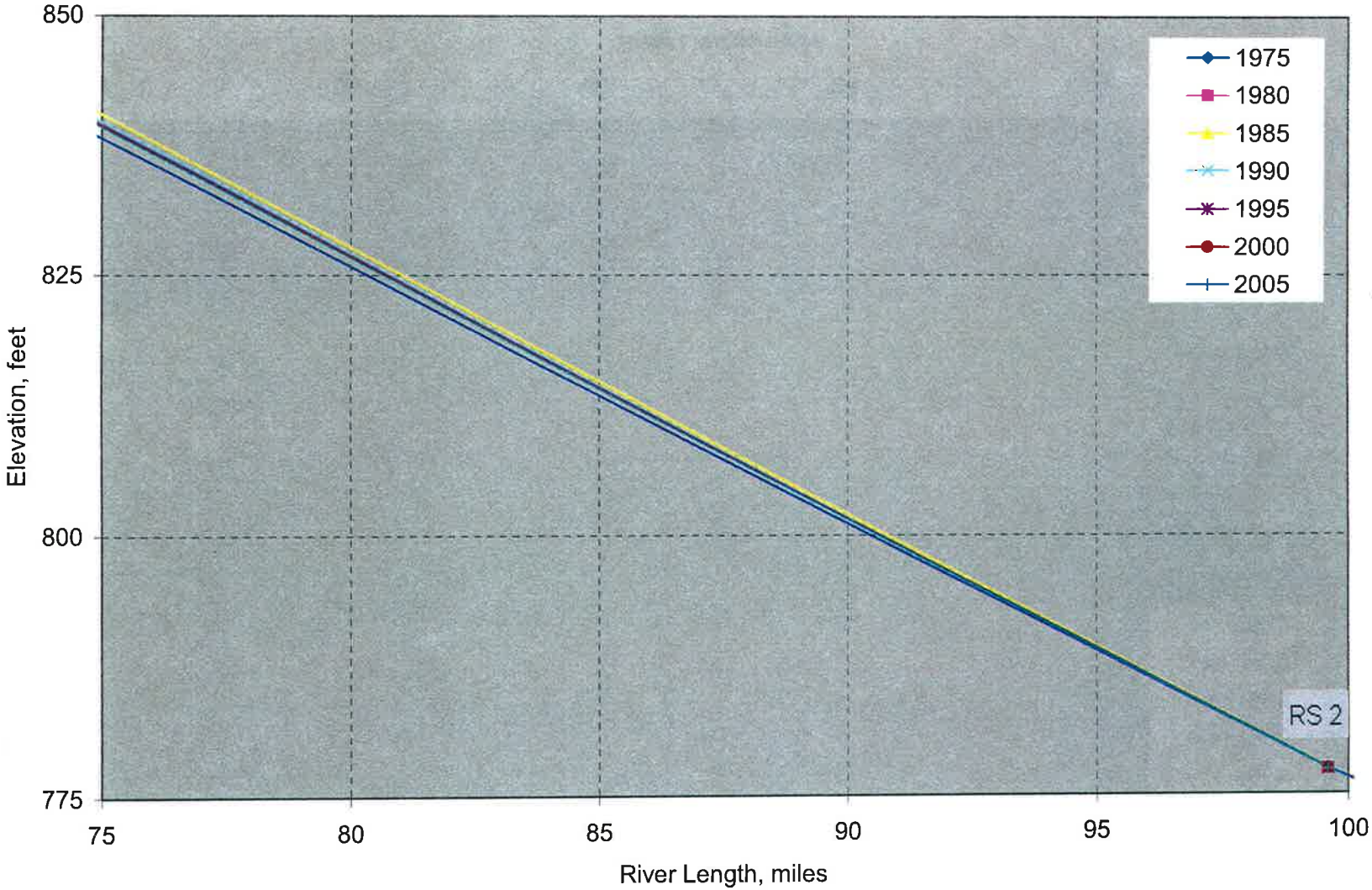


Figure 22. Longitudinal profile of Arkansas River Bed, Oklahoma

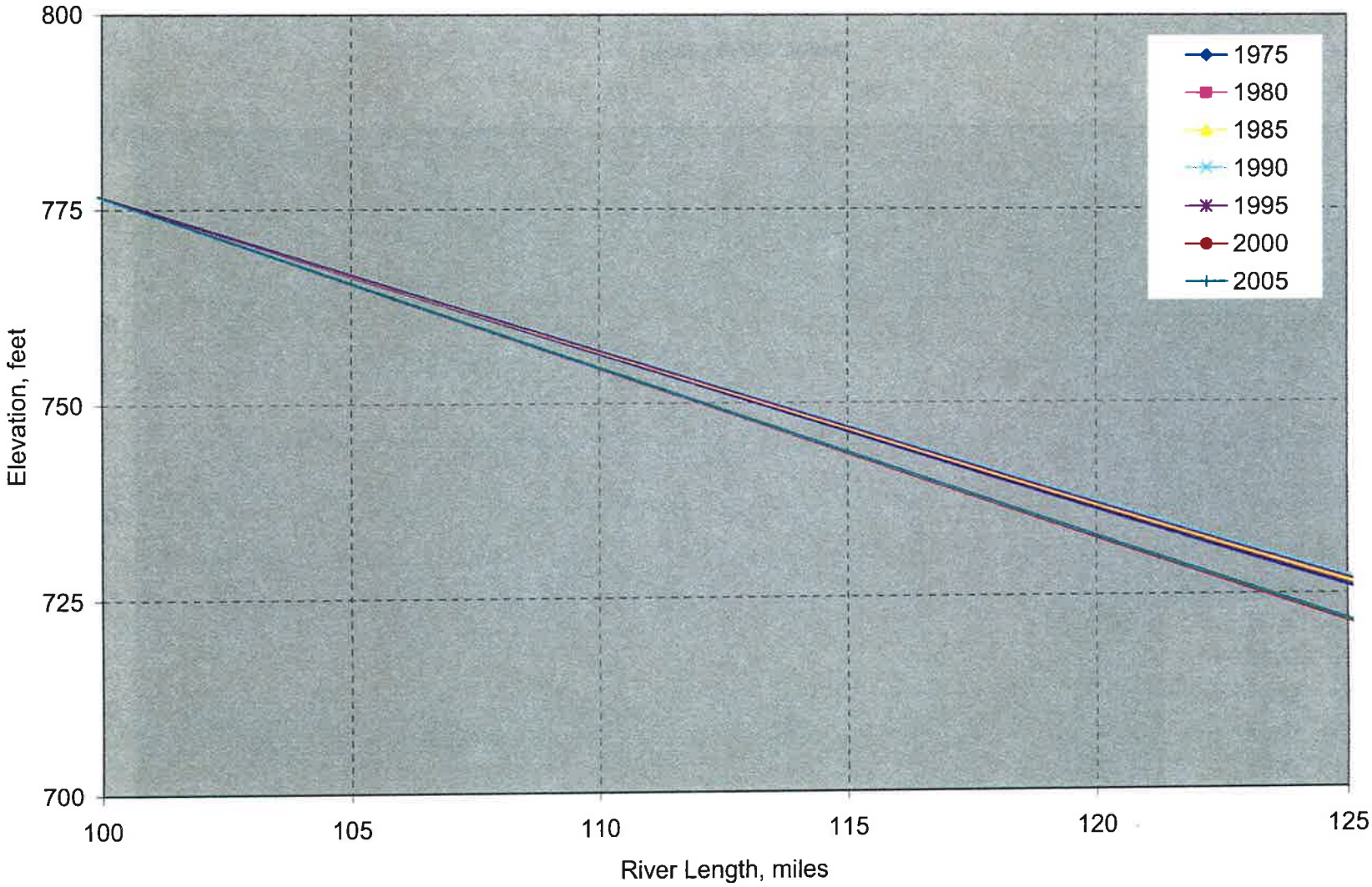


Figure 23. Longitudinal profile of Arkansas River Bed, Oklahoma

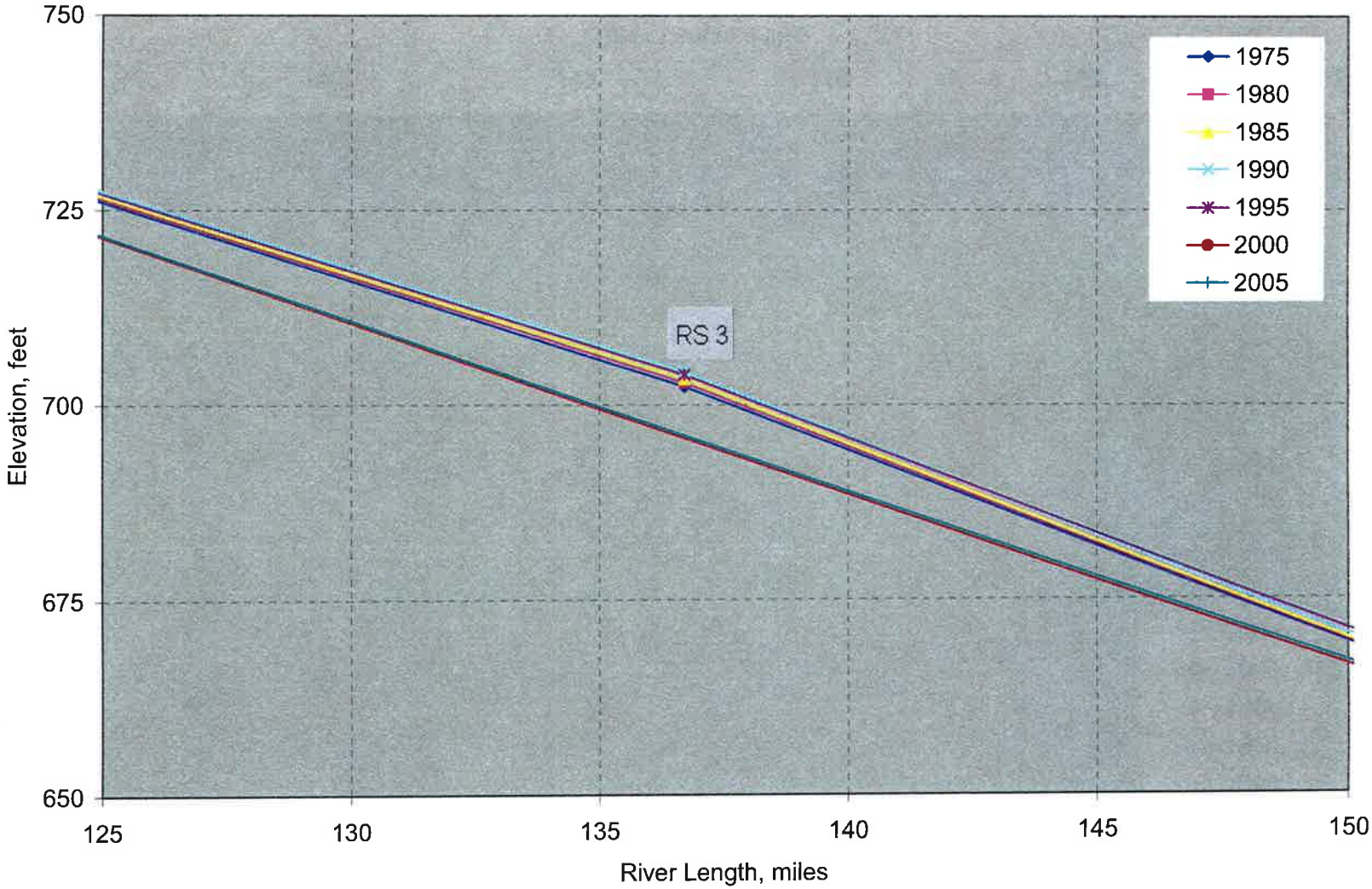


Figure 24. Longitudinal profile of Arkansas River Bed, Oklahoma

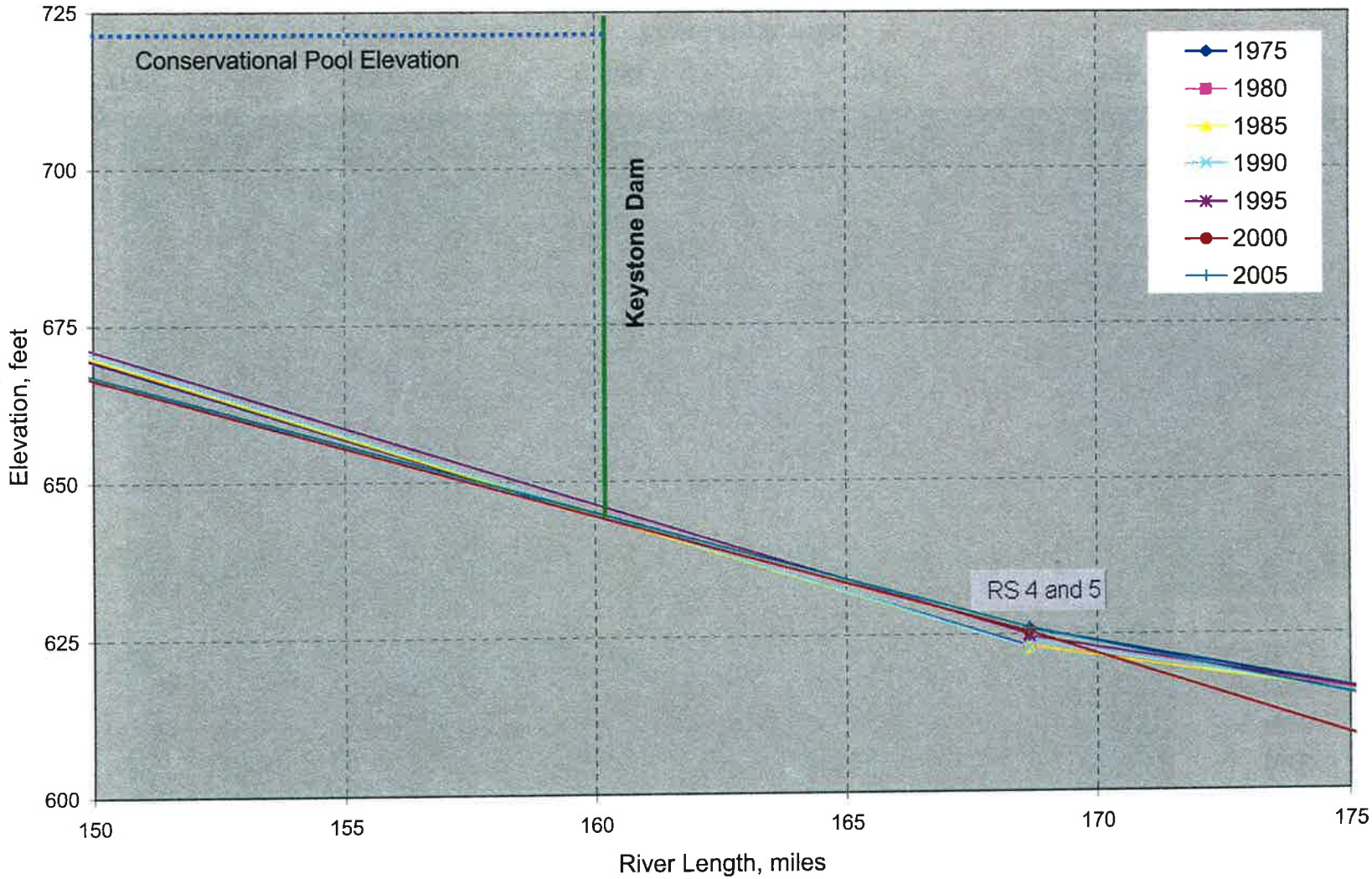


Figure 25. Longitudinal profile of Arkansas River Bed, Oklahoma

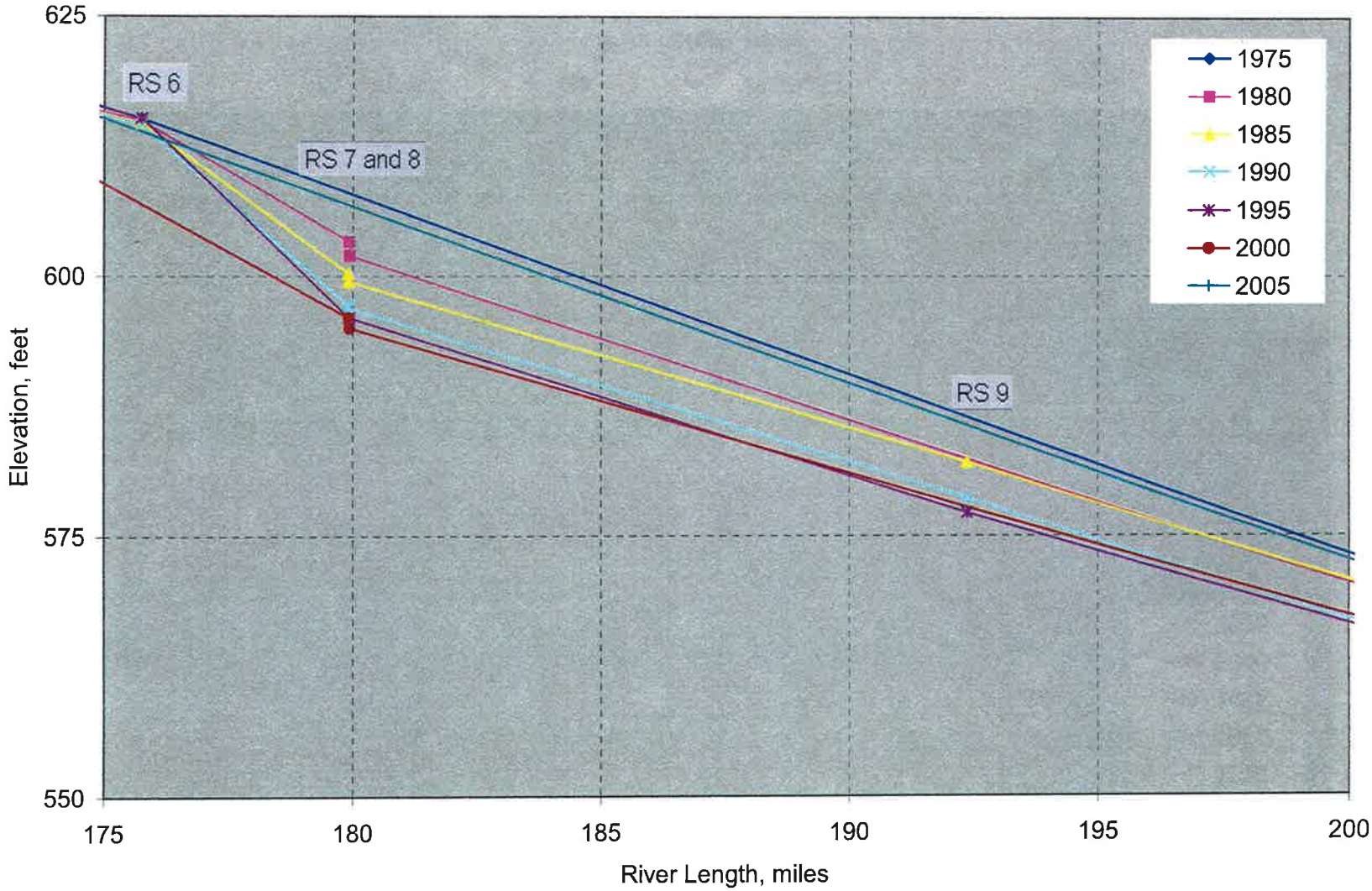


Figure 26. Longitudinal profile of Arkansas River Bed, Oklahoma

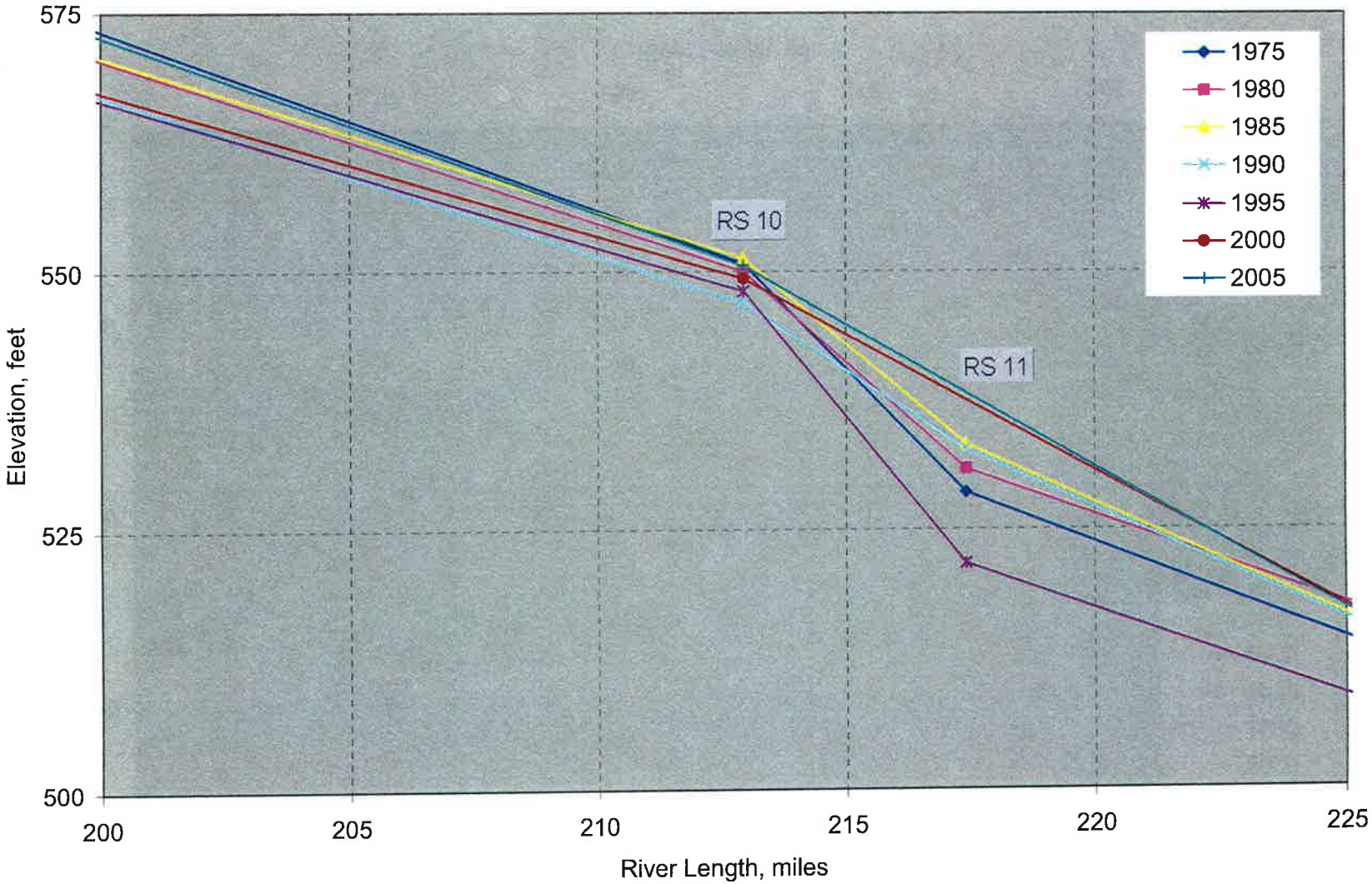


Figure 27. Longitudinal profile of Arkansas River Bed, Oklahoma

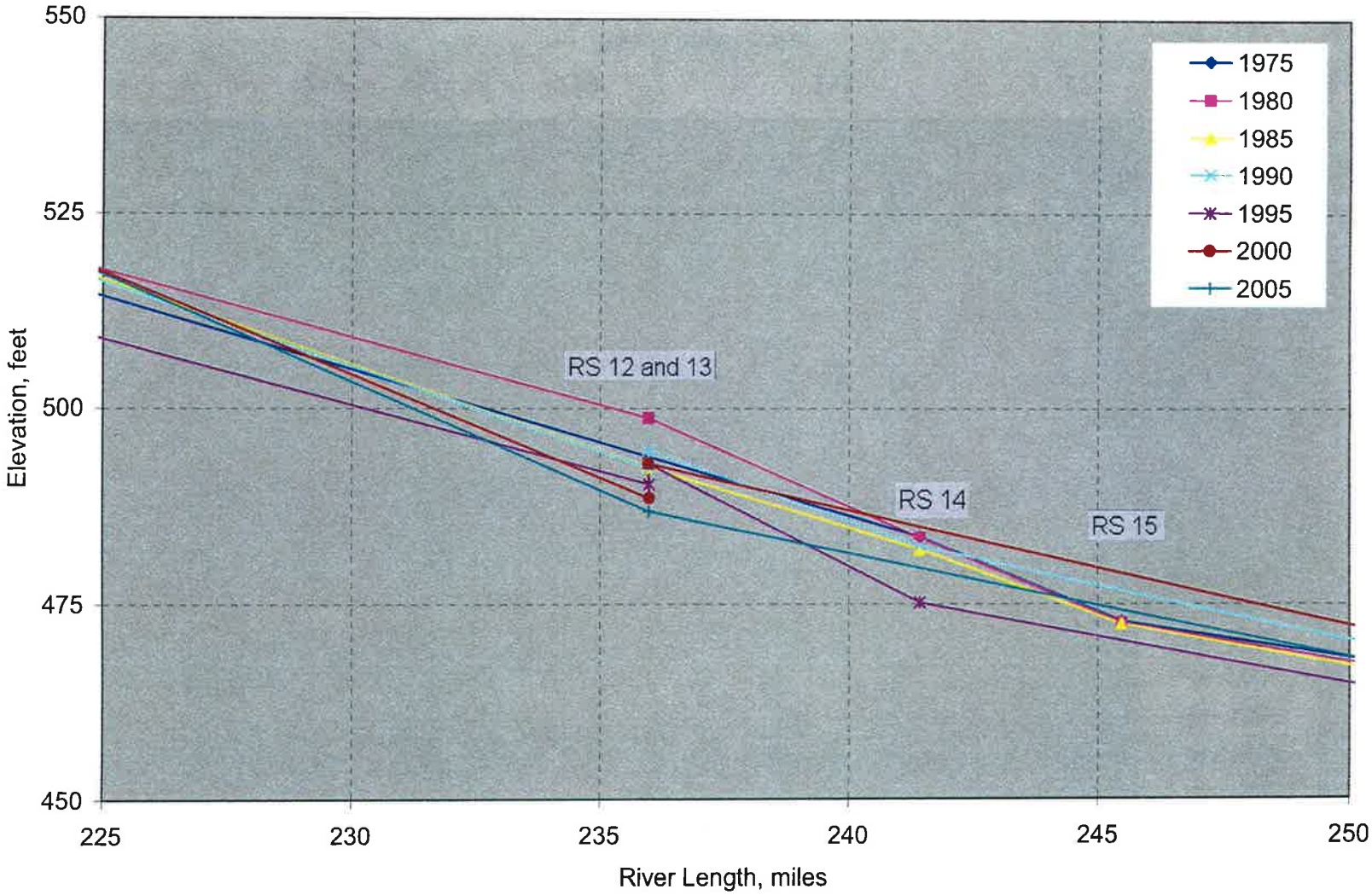


Figure 28. Longitudinal profile of Arkansas River Bed, Oklahoma

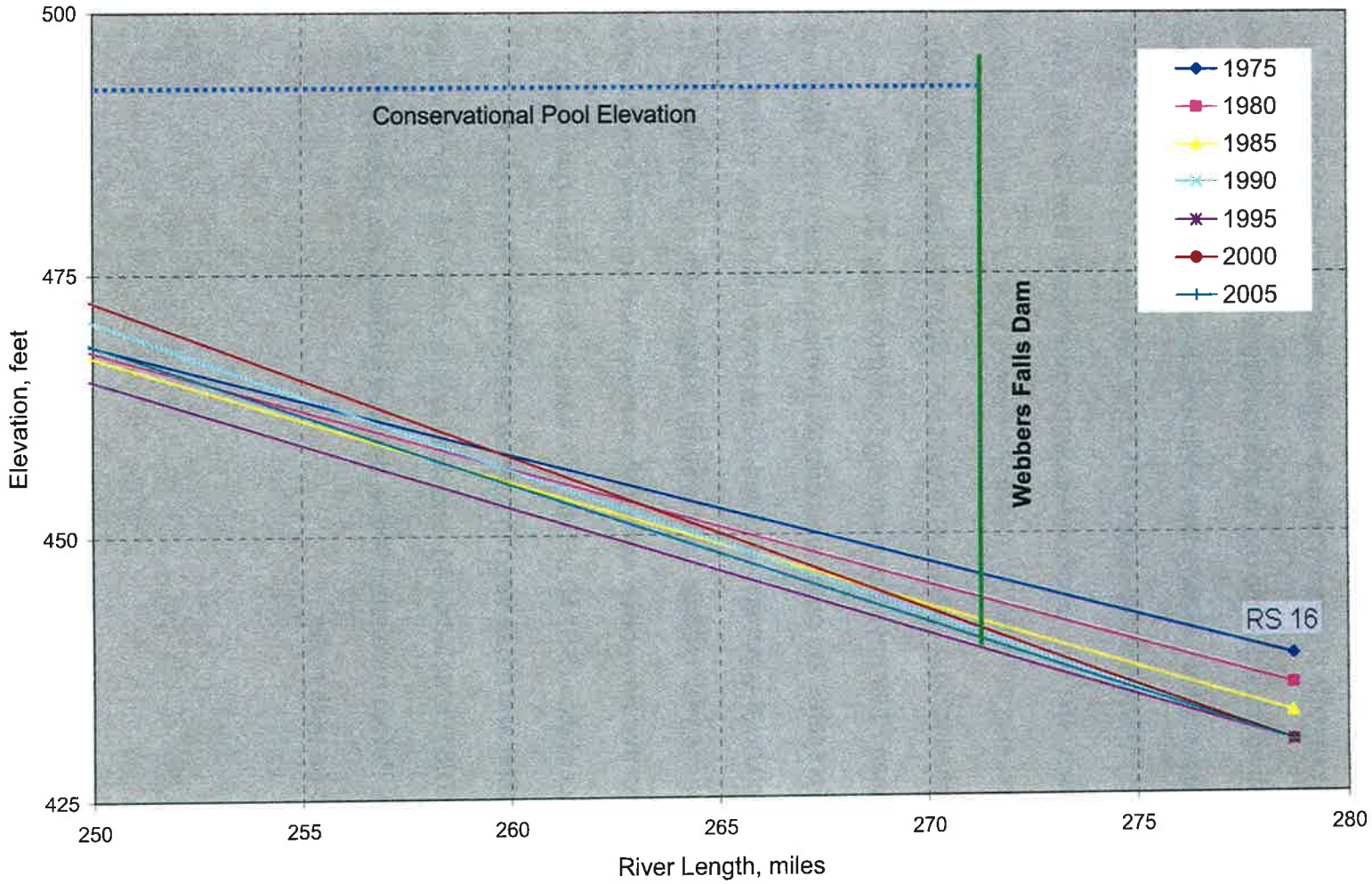


Figure 29. Longitudinal profile of Arkansas River Bed, Oklahoma

VI. DISCUSSION OF RESULTS

Table 5 presents the summary of bridges which have experienced degradation. Along the 252-mile reach of Arkansas River, fourteen bridges have experienced degradation. Among these fourteen bridges, eleven bridges have experienced degradation in the range of 0-5 feet, two have experienced in the range of 5-10 feet, one has experienced degradation more then 10 feet. Sixth and seventh columns in Table 5 present the service year of the bridges through 2007 and corresponding degradation in river bed. Seven bridges in the study reach of Arkansas River have been serving from more then 30 years.

Table 6 presents the number of bridges in the five major river basins of Oklahoma which have experienced degradation more than 5 and 10 feet with 10 year and all service year criteria. In this study, bridges with degradation of 10 feet or more and that have been serving from more then 10 years are determined as critical. River station (RS) 16 at I-40 in Arkansas River has experienced 12.20 feet of degradation and it has been in service since 1968. Therefore, RS 16 (Bridge Key b17051) is determined as critical and recommended for rehabilitation or replacement. Before reconstruction, a detailed hydraulic and geotechnical analysis should be performed.

Table 5. Summary of river bed degradation, Arkansas River

Bri_Key	River Stations	Miles	Highway	Bridge Installed	Years of Construction through 2007	Max. Scour (ft)	Duration (yr)	Scour Rate (ft/yr)
b04603	RS2	99.60	S.H.18	1935	72	0.03	58	0.0005
b19279	RS4	168.64	S.H.51	1976	31	2.50	16	0.1563
b19511	RS5	168.65	S.H 51	1978	29	1.40	16	0.0875
b17052	RS6	175.74	I. 244	1967	40	0.50	27	0.0185
b20580	RS7	179.91	I. 44	1983	24	5.50	12	0.4583
b20326	RS8	179.92	I. 44	1983	24	5.00	13	0.3846
b22107	RS9	192.37	U.S. 64	1988	19	2.75	6	0.4583
b19638	RS10	212.94	S.H 72	1979	28	1.89	15	0.1260
b19512	RS11	217.41	S.H.104	1978	29	4.90	16	0.3063
b22425	RS12	235.98	U.S 69	1989	18	4.17	6	0.6950
b20327	RS13	235.96	U.S 69	1982	25	3.30	13	0.2538
b19835	RS14	241.43	S.H.16	1980	27	8.28	15	0.5520
b17610	RS15	245.48	U.S.62	1969	38	0.50	15	0.0333
b17051	RS16	278.71	I.40	1968	39	12.20	32	0.3813

Table 6. Summary of bridges with degradation in five river basins

River Basin	Degradation in ≥10 years		Degradation with all service year criteria	
	≥ 5.0 feet	≥ 10.0 feet	≥ 5.0 feet	≥ 10.0 feet
Arkansas*	5	1	5	1
Cimarron	6	2	6	2
North Canadian	8	3	9	3
Canadian	7	3	9	5
Washita	12	1	12	1
Total	38	10	41	12

* This report includes the river basin as indicated. Refer to other volumes **I** through **V** for different river basins.

VII. CONCLUSIONS AND RECOMMENDATION

Following conclusions are drawn based on this research:

1. In reach 1 from Kaw Lake to Keystone Dam, maximum degradation of 2.5 feet is observed at river station 4 at S.H. 51.
2. In reach 2 there is severe degradation of river bed downstream of Keystone Lake. The degradation of river bed below Keystone Lake Dam to Webbers Falls Dam occurs over 80.5 miles. The maximum degradation in this reach is 12.2 feet in 32 years at river station 16 at I-40.
3. When I-40 bridge on Arkansas River (Bridge Key b17051) is rehabilitated or replaced, a detailed hydraulic and geotechnical analysis should be performed before reconstruction.

It is recommended that degradation of tributaries is evaluated to determine the structures where flowline is severely degrading in Arkansas River basin.

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APPENDIX A

TABLES OF CROSS-SECTIONAL GEOMETRIES, ARKANSAS RIVER, OK

Table 7. Structure, Cross-section, and Flowline – Bridge No. 19112 (RS 1) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design Year	Length
b19112	14.1 mi E JCT US 77	36-45-54	96-49-12	SH 11	1975	1363

				D / S							U/S		D/S
Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed75	R-bed87	W s e 8 7	D a t a 9 1	R-bed91	R-bed92	W s e 9 2		R-bed93	R-bed02
W-A	0	930.81	1062.35	1047.84	1047.84	1014	17	1045.35	1047.84	1014	16.3	1046.05	1047.84
	72		1062.45				53	1009.45					
1	195.25	923.47	1062.97	982.00	986.5		83	979.97	988.5		18.3	981.67	982
2	389.25	923.93	1064.99	967.5	971.5		100	964.99	970.5		97	967.99	967.5
3	583.25	925.04	1064.54	963.0	968.5		100	964.54	966.5		100.41	964.14	964.5
4	778.25	923.99	1064.49	962.0	968.5		102	963.49	966.5		100.8	964.69	963.5
5	973.25	925.87	1065.07	960.0	971.5		100	965.07	969.5		98.3	966.77	965.5
	1111.2			961.2									
	1132.8			987.0									
6	1167.3	931.01	1063.00	987.0	988.5		79	984	983.5		79.3	987.7	984
	1221.3		1062.72				53	1009.72					
E-A	1361.3	929.64	1062.35	1047.84	1047.84		16	1046.35	047.84		16.1	1046.25	1047.84

Year	1975	1987	1991	1993	2002
Flowline	960	968.5	963.49	964.14	963.5

Table 8. Structure, Cross-section, and Flowline Details
Bridge No. 4603 (RS 2) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b04603	Pawnee-Osage c/l	36-30-12	96-43-48	SH 18	1935	1470.1

Pier-No	Distance	R-bed35	wse35	Pier-Btm	Top-Crb	Data93	R-bed93	wse93
W-A	0	803.00	778.60	795.87	820.50	17.42	803.08	782.37
1	103.58	795.87		770.93	819.84	30.00	789.84	
2	315.97	777.40		767.15	818.47	30.33	788.14	
3	528.26	777.50		764.32	817.11	36.17	780.95	
4	740.56	781.11		765.11	815.75	37.00	778.75	
5	952.85	785.75		760.00	814.39	32.50	781.89	
6	1165.68	790.00		758.30	813.02	34.50	778.52	
7	1267.26	790.00		758.30	812.37	35.00	777.37	
8	1368.84	791.50		758.30	811.72	30.00	781.72	
E-A	1470.51	810.00		782.50	811.07	7.00	804.07	

Year	1975	1980	1985	1990	1995	2000	2005
Flowline	777.38	777.38	777.38	777.37	777.37	777.37	777.36

Table 9. Structure and Flowline Details - Bridge No. 15866 (RS 3) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b15866	Pawnee-Osage c/l	36-19-42	96-27-24	SH 99	1963	1019

Year	1963	1993
Flowline	701.1	704.18

Table 10. Structure, Cross-section, and Flowline Details
Bridge No. 19279 (RS 4) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b19279	Sand Springs	36-07-48	96-06-30	SH 51	1977	2077.1

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed76	data92	R-bed92
S-A	0.00	617.00	674.50	665.00	10.00	664.50
1	83.25	612.50	674.00	653.50	25.00	649.00
2	166.25	611.45	673.50	637.50	39.00	634.50
3	249.25	612.77	671.50	623.25	51.00	620.50
4	332.25	612.45	672.30	623.00	50.00	622.30
5	415.25	612.48	672.50	626.25	49.00	623.50
6	498.25	612.61	673.30	630.00	49.00	624.30
7	581.25	612.75	672.33	629.80	48.00	624.33
8	664.25	611.89	672.02	630.00	45.00	627.02
9	747.25	612.02	671.71	631.50	46.00	625.71
10	830.25	613.16	671.40	631.50	45.00	626.40
11	913.25	612.29	671.09	632.50	46.00	625.09
12	996.25	612.43	670.78	633.25	45.00	625.78
13	1079.25	612.57	670.47	634.50	45.00	625.47
14	1162.25	612.70	670.16	636.25	43.00	627.16
15	1245.25	612.84	669.85	637.00	40.00	629.85
16	1328.25	611.98	669.54	637.00	39.00	630.54
17	1411.25	614.11	669.23	640.00	35.00	634.23
18	1494.25	614.25	668.92	645.00		933.92
19	1577.25	613.38	668.61	645.00	35.00	633.61
20	1660.25	613.57	668.360	643.25	34.00	634.30
21	1743.25	614.366	667.99	643.25	33.00	634.99
22	1826.25	612.76	667.68	643.50	32.00	635.68
23	1909.25	612.54	667.37	643.25	29.00	638.37
24	1992.25	611.90	667.06	645.00	26.00	641.06
N-A	2075.50	612.00	666.75	662.00	9.00	657.752

Year	1976	1982	1988	1990	1992	1994
Flowline	623.00	622.78	622.78	622.78	620.50	624.78

Table 11. Structure, Cross-section, and Flowline Details
Bridge No. 19511 (RS 5) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b19511		36-07-48	96-06-30	SH 51	1978	2077.6

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed78	Data92	R-bed92
N-A	0	616	673.59	662	11	662.59
1	83.25	612.19	672.19	662	27	645.19
2	166.25	612.14	671.14	650	29	642.14
3	249.25	612.46	670.46	624.25	32	638.46
4	332.25	612.14	670.14	624.25	33	637.14
5	415.25	612.17	670.17	626.25	34	636.17
6	498.25	612.31	670.31	628.75	35	635.31
7	581.25	612.44	670.44	628.75	36	634.44
8	664.25	612.58	670.58	628	37	633.58
9	747.25	612.71	670.71	628	41	629.71
10	830.25	612.85	670.85	629	42	628.85
11	913.25	610.99	670.99	630	43	627.99
12	996.25	611.12	671.12	635	No Data	
13	1079.25	612.26	671.26	637		
14	1162.25	612.4	671.4	637		
15	1245.25	612.53	671.53	637.5		
16	1328.25	612.67	671.67	637		
17	1411.25	612.8	671.8	637		
18	1494.25	612.94	671.94	644		
19	1577.25	612.08	672.08	641.5		
20	1660.25	612.21	672.21	640		
21	1743.25	611.35	672.35	641		
22	1826.25	611.45	672.45	641.25		
23	1909.25	611.23	672.23	642.5		
24	1992.25	610.59	671.59	649		
S-A	2075.5	616	670.55	661.55		

Year	1978	1982	1988	1990	1992	1994
Flowline	624.25	622.12	624.14	624.14	619.14	622.85

Table 12. Structure and Flowline Details Bridge No. 17052 (RS 6) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b17052	4.1 ml N I-44, Tulsa	36-09-42	95-55-54	I-244	1967	2966

Year	1967	1992	1994
Flowline	615.5	614.5	615

Table 13. Structure and Flowline Details Bridge No. 20580 (RS 7) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b20580	0.7 mi E UF 75	36-09-42	95-48-24	I-44	1983	2404.9

Year	1983	1992	1994	1995
Flowline	601.5	596	596	596

Table 14. Structure and Flowline Details Bridge No. 20326 (RS 8) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b20326	0.7 mi E UF 75	36-09-42	95-48-24	I-44	1983	2404.9

Year	1982	1992	1994	1995
Flowline	601	596	596	596

Table 15. Structure, Cross-section and Flowline Details
Bridge No. 22107 (RS 9) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b22107	4.5 mi S of Turnpike	35-54-30	95-45-24	US 64	1988	1939.92

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed88	Data92	R-bed92	Data94	R-bed94	wse 94
N-A	0	568	616	604	10	606	10	606	588.75
1	102.958	555	617.5	600	18	599.5	18	599.5	
2	204.958	555.5	619	599	21	598	20	599	
3	306.958	556	620.25	596	27	593.25	27	593.25	
4	408.958	556	621	585.5	37	584	36	585	
5	510.958	556.5	621.25	580	44	577.25	44	577.25	
6	612.958	556	622.25	583	41	581.25	40	582.25	
7	714.958	556	623	584	41	582	41	582	
8	816.958	556.5	623.75	582	43	580.75	43	580.75	
9	918.958	557.5	625.25	580	43	582.25	44	581.25	
10	1020.958	558	625.25	584	43	582.25	44	581.25	
11	1122.958	558	623.75	587	41	582.75	40	583.75	
12	1224.958	557.5	623	588	38	585	38	585	
13	1326.958	558	622.25	590	35	587.25	35	587.25	
14	1428.958	557.5	621.25	590	34	587.25	34	587.25	
15	1530.958	557.5	620.5	583	37	583.5	37	583.5	
16	1632.958	557.5	619	584	37	582	37	582	
17	1734.958	557.5	618	590.5	29	589	29	589	
18	1836.958	560.5	617.5	597	20	597.5	20	597.5	
S-A	1939.916	575	616	606	9	607	9	607	

Year	1985	1990	1995
Flowline	582.0625	578.625	577.25

Table 16. Structure, Cross-section, and Flowline Details Bridge No. 19638 (RS 10) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design Year	Length
b19638	4.6 mi N Muskogee Co	35-55-54	95-39-18	SH 72	1979	1700.5

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed79	data87	R-bed87	Data94	R-bed94
S-A	0	539.00	582.91	570.00	15.10	567.81	11	571.91
	90		583.77				19	564.77
1	100.25	534.69	583.96	560.00	21.90	562.06	21	562.96
2	200.25	534.69	584.96	554.00	32.20	552.76	33	551.96
3	300.25	535.64	585.91	552.20	33.70	552.21	34	551.91
4	400.25	535.60	586.96	552.50	34.60	552.36	36	550.96
5	500.25	535.65	587.92	552.4	39.50	548.42	37	550.92
6	600.25	536.36	588.63	553.50	39.00	549.63	39	549.63
7	700.25	536.9	589.17	554.4	36.40	552.77	40	549.17
8	800.25	537.15	589.42	554.80	36.80	552.62	41	548.42
9	900.25	537.11	589.38	554.00	37.10	552.28	39	550.38
10	1000.25	536.90	589.17	554.00	36.00	553.17	39	550.17
11	1100.25	536.40	588.67	554.00	36.90	551.77	39	549.67
12	1200.25	535.61	587.88	553.00	37.30	550.58	36	551.88
	1250.00		587.42				39	548.42
13	1300.25	535.69	586.96	551.00	37.10	549.86	38	548.96
14	1400.25	535.69	585.96	549.80	35.70	550.26	35	550.96
15	1500.25	535.64	584.91	550.00	37.10	547.81	37	547.91
	1530.00		584.63				21	563.63
	1532.75			563.50				
	1550.00		584.44					
16	1600.25	539.69	583.96	562.00	18.00	565.96	19	564.96
	1650.32			571.50				
	1680.00		583.20				17	566.20
N-A	1700.50	547.60	582.91	571.50	13.00	569.91	11	571.91

Year	1979	1987	1989	1994
Flowline	549.80	547.81	546.71	547.91

Table 17. Structure, Cross-section, and Flowline Details – Bridge No. 19512 (RS 11) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design Year	Length
B19512	2 mi E JCT US 64	35-49-12	95-40-06	SH 104	1978	2202.5

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed78	Data87	R-bed87	Data92	R-bed92	Wse92	Data94	R-bed94	Wse94
W-A	0.00	521.70	569.27	560.00	10.30	558.97	11.00	558.27	536.87	10.00	559.27	537.10
	38.00			540.60		552.81		552.00			553.00	
	50.00		569.49	541.20		550.86		550.01		26.00	543.49	
1	100.25	516.40	569.72	541.80	27.00	542.72	28.00	541.72		27.00	542.72	
2	200.25	516.82	570.16	541.80	29.00	541.16	29.00	541.16		29.00	541.16	
3	300.25	517.11	570.61	541.80	30.50	540.11	31.00	539.61		30.00	540.61	
4	400.25	517.27	571.05	542.00	30.50	540.55	32.00	539.05		29.00	542.05	
5	500.25	517.60	571.50	535.00	31.00	540.50	33.00	538.50		32.00	539.50	
	575.25		571.07	535.00		538.33		535.58		39.00	532.07	
6	600.25	517.79	571.60	535.00	34.00	537.60	37.00	534.60		34.00	537.60	
7	700.25	517.95	571.70	534.20	31.00	540.70	36.00	535.70		32.00	539.70	
8	800.25	518.07	571.80	534.00	31.50	540.30	37.00	534.80		33.00	538.80	
9	900.25	518.16	571.90	534.00	31.00	540.90	35.00	536.90		33.00	538.90	
10	1000.25	518.21	572.00	532.80	32.20	539.80	37.00	535.00		33.00	539.00	
11	1100.25	518.29	572.10	532.00	31.50	540.60	40.00	532.10		35.00	537.10	
12	1200.25	518.21	571.87	533.00	29.80	542.07	40.00	531.87		35.00	536.87	
13	1300.25	518.16	571.63	531.80	30.90	540.73	39.00	532.63		35.00	536.63	
14	1400.25	518.07	571.40	530.20	30.00	541.40	38.00	533.40		35.00	536.40	
15	1500.25	517.85	571.17	531.00	31.30	539.87	37.00	534.17		35.00	536.17	
16	1600.25	517.79	570.93	530.00	36.00	534.93	34.00	536.93		35.00	535.93	
17	1700.25	517.60	570.70	538.00	34.80	535.90	35.00	535.70		36.00	534.70	

Table 17 Cont.

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed78	Data87	R-bed87	Data92	R-bed92	Wse92	Data94	R-bed94	Wse94
	1762.75			549*0		536.38		536.18			533.30	
18	1800.25	517.37	570.46	543.50	33.80	536.66	34.00	536.46		38.00	532.46	
18	1900.25	517.11	570.22	547.80	36.00	534.22	32.00	538.22		39.00	531.22	
	1950.25		570.10	546.90		540.35		535.74		45.00	525.10	
	1985.25		570.00	546.27		544.64	36.00	534.00			531.32	
20	2000.25	516.82	569.98	546.00	23.50	546.48	24.00	545.98		36.00	533.98	
	2020.25		569.93	546.60		547.33		546.73		24.00	545.93	
21	2100.25	516.49	569.74	549.00	19.00	550.37	20.00	549.74		19.00	550.74	
	2180.25		569.55	557.78		558.05		554.25		14.00	555.55	
	2185.25		569.53	558.33		558.51	15.00	554.53			556.77	
E-A	2200.50	523.50	569.50	560.00	9.60	559.90	10.00	559.50		9.00	560.50	

Year	1978	1987	1992	1994
Flowline	530.00	534.22	53.87	525.10

Table 18. Structure, Cross-section, and Flowline Details
Bridge No. 22425 (RS 12) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b22425	3.5 mi N JCT US62 W	35-48-30	95-24-00	US 69	1989	2700.3

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed89	Data91	R-bed91	wse91
S-A	0	480	535.85	527.35	11	524.85	497.28
	80		536.57	517.286102	23	513.57	
1	100.16	472.75	536.75	514.75	23	513.75	
	145		537.15	505.4457	24	513.15	
	190		537.48	496.1082	36	501.48	
2	200.16	472.58	537.58	494	40	497.58	
3	300.16	474.79	538.29	495	44	494.29	
4	400.16	473.58	539.08	497	46	493.08	
5	500.16	473.23	539.73	500	44	495.73	
6	600.16	473.24	540.24	499.6	48	492.24	
7	700.16	474.33	540.83	498.75	50	490.83	
8	800.16	473.78	541.28	498.1	50	491.28	
9	900.16	475.08	541.58	497.12	47	494.58	
10	1000.16	475.47	541.97	499.75	45	496.97	
11	1100.16	474.71	542.21	504.9	46	496.21	
12	1200.16	474.82	542.32	506.82	48	494.32	
13	1300.16	474.5	542.5	506	48	494.5	
14	1400.16	475.05	542.55	507.05	47	495.55	
15	1500.16	473.95	542.45	506.45	44	498.45	
16	1600.16	473.93	542.43	503.93	42	500.43	
17	1700.16	474.29	542.28	503.26	40	502.28	
18	1800.16	472.48	541.98	506.98	40	501.98	
19	1900.16	473.76	541.76	502.78	39	502.76	
	1970.16		541.55	503.564	42	499.55	
20	2000.16	472.4	541.4	503.9	44	497.4	
21	2100.16	472.4	540.9	499.4	46	494.9	
22	2200.16	473.98	540.48	500.4	42	498.48	
	2250.16		540.195	506.405	41	499.195	
23	2300.16	473.41	539.91	512.41	28	511.91	
24	2400.16	473.71	539.21	514.21	27	512.21	
25	2500.16	473.09	538.09	514.15	26	512.59	
26	2600.16	472.83	537.83	514.33	25	512.83	
	2650.16		537.385	521.37373	25	512.385	
N-A	2700.32	480	536.94	528.44	11	525.694	

Year	1989	1991	1995
Flowline	494	490.83	489.83

Table 19. Structure, Cross-section, and Flowline Details
Bridge No. 20327 (RS 13) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
b20327	3.4 mi N JCT US 62 W	35-48-30	95-24-00	US 69	1982	2700

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed82	Data87	R-bed87	wse87
S-A	0	486.00	536.92	522.00	11.70	525.22	500.76
1	100	472.77	537.77	515.00	21.00	516.77	
	150		538.19		21.50	516.69	
2	200	473.11	538.61	496.30	38.00	500.61	
3	300	474.85	539.35	496.70	42.00	497.35	
4	400	473.61	540.11	497.00	44.00	496.11	
5	500	473.26	540.76	500.00	46.30	494.46	
6	600	474.30	541.30	499.00	45.00	496.30	
7	700	474.35	541.85	498.60	42.30	499.55	
8	800	473.80	542.30	498.60	42.50	499.80	
9	900	474.64	542.64	498.60	42.30	500.34	
10	1000	475.49	542.99	499.00	40.00	502.99	
11	1100	474.74	543.24	502.60	43.50	499.74	
12	1200	474.87	543.37	506.25	41.80	501.57	
13	1300	474.02	543.52	503.75	39.60	503.92	
14	1400	475.07	543.57	507.10	40.00	503.57	
15	1500	474.00	543.50	502.50	34.50	509.00	
16	1600	473.95	543.45	502.75	34.20	509.25	
17	1700	473.80	543.30	502.76	35	508.30	
18	1800	472.53	543.03	507.00	34	509.03	
19	1900	473.78	542.78	502.3	33.3	509.48	
20	2000	472.42	542.42	503.1	40.2	502.22	
21	2100	472.45	541.95	498.5	42	499.95	
22	2200	473	541.5	500	40.8	500.70	
	2275		541.18		40.8	500.38	
23	2300	473.44	540.964	513.25	28.3	512.64	
24	2400	472.77	540.27	512.7	26.3	513.97	
25	2500	472.11	539.631	512.8	25.5	514.11	
26	2600	471.35	538.85	514.8	24.5	514.35	
N-A	2700	486	538.02	523.5	13	525.02	

Year	1982	1985	1987	1990	1991	1995
Flowline	496.30	492.5	495.2	494.75	493	493

Table 20. Structure, Cross-section, and Flowline Details
Bridge No. 19835 (RS 14) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design year	Length
B19835	1.7 mi n JCT U.S. 62	35-47-25	95-19-48	SH 16	1980	900.50

Pier-No	Distance	Pier-Btm	Top-Ppw	R-bed80	Data87	R-bed87	wse87
S-A	0	489.94	536.46	524.20	12.5	523.96	490.82
	30		536.4	512.02	20	516.4	
	60		536.33	494.95	45	491.33	
1	100.25	472.78	536.26	483.50	51.8	484.46	
2	200.25	472.58	536.06	484.00	54.2	481.86	
3	300.25	472.34	535.82	487.50	55	480.82	
4	400.25	472.18	535.66	488.00	50	485.66	
5	500.25	471.98	535.46	487.50	46.3	489.16	
6	600.25	471.74	535.22	488.30	44	491.22	
7	700.25	471.58	535.06	492.25	40	495.06	
8	800.25	471.38	534.86	503.50	33.8	501.06	
	850.62		534.74	511.79	23	511.74	
	865.62		534.71	514.26	23	511.71	
n-a	900.5	480	534.62	520.00	12	522.62	

Year	1980	1984	1985	1987	1990	1992	1995
Flowline	483.50	483	482	480.82	482.46	481.46	475.22

Table 21. Structure and Flowline Details
Bridge No. 17610 (RS 15) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design Year	Length
b17610	2.4 Mi E JCT SH 16	35-46-24	95-15-54	US 62	1969	1497

Year	1969	1984
Flowline	473.00	472.50

Table 22. Structure, Cross-section, and Flowline Details

Bridge No. 17051 (RS 16) on Arkansas River

Bridge No.	Location	Latitude	Longitude	Highway	Design Year	Length
b17051	Muskogee- Sequoyah	35-29-06	95-04-42	I-40	1968	1988.5

Pier-No	Distance	Wse68	R-bed68	Pier-Btm	R-bed90	R-bed95
W-A	0		515.00	427.50	515.00	515.00
	75.75		503.04		472.00	472.00
	101.25		467.50		472.00	472.00
1	126.25		467.00	423.98	472.00	472.00
	168.25	460	464.03		472.00	472.00
2	251.25	460	458.00	422.97	443.00	441.00
3	377.25	460	444.50	424.13	434.00	433.00
4	578.25	460	442.50	424.96	432.00	430.00
5	908.25	460	442.20	425.02	430.00	432.00
6	1109.25	460	442.50	425.72	435.00	435.00
7	1235.25	460	442.50	427.16	436.00	436.00
8	1360.25	460	443.00	422.13	435.00	441.00
9	1485.25	460	445.00	421.70	443.00	448.00
	1577.25	460	468.00		456.14	456.03
10	1611.25	460	467.00	421.68	461.00	459.00
	1617.375	460	466.80		461.05	459.05
	1642.87	460	455.50		461.25	459.25
	1713.25	460	466.50		461.81	459.81
11	1737.25	460	460.00	430.18	462.00	460.00
12	1862.25	460	466.20	429.13	463.50	460.00
	1900.12	460	465.75		465.75	465.75
E-A	1988.50	460	504.20	436.00	504.00	504.00

Year	1975	1980	1985	1990	1995	2000	2005
Flowline	438.32	435.55	432.77	430	430	430	430

APPENDIX B

FLOWPATH OF ARKANSAS RIVER IN OKLAHOMA

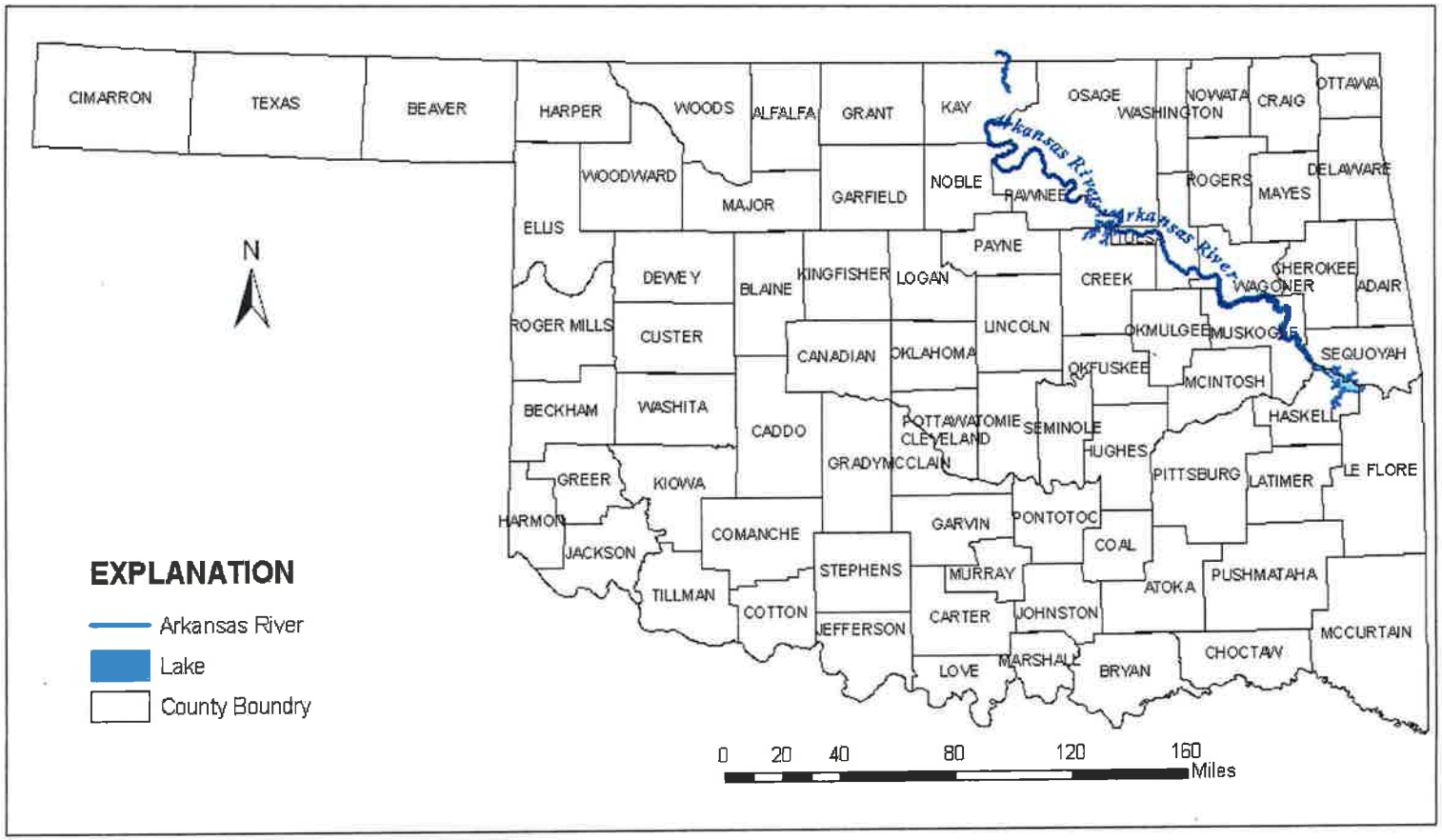
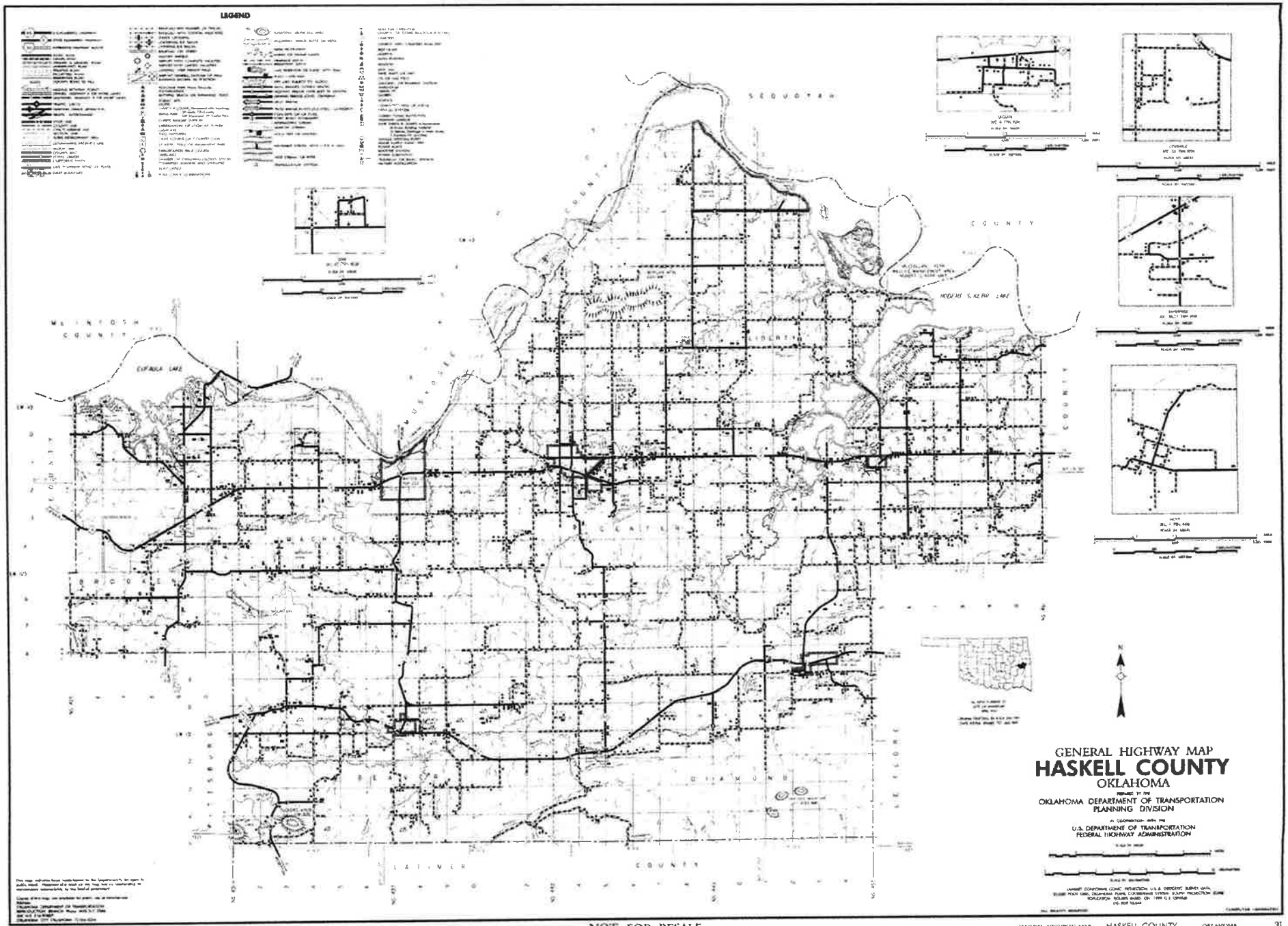


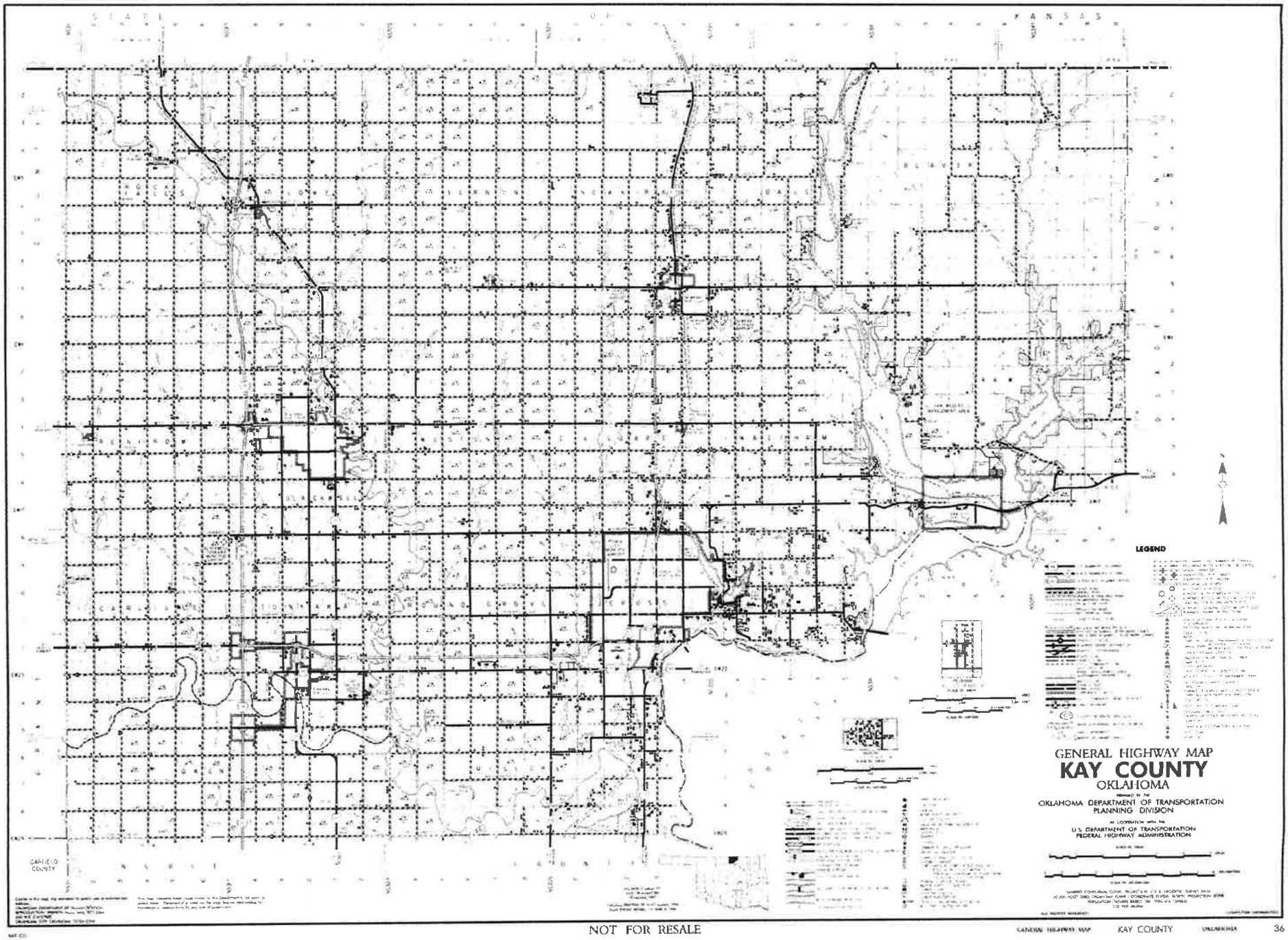
Figure B-1. Flowpath of Arkansas River in Oklahoma

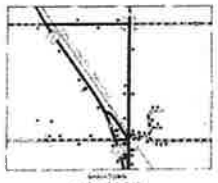
QUAD MAP LEGEND
ARKANSAS RIVER, OKLAHOMA

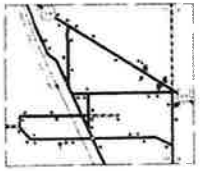
Source: http://www.okladot.state.ok.us/hqdiv/p-r-div/maps/2003county/index.htm

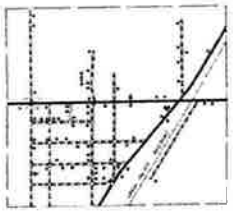
County Name
Kay
Noble
Osage
Pawnee
Tulsa
Wagoner
Muskogee
Sequoyah
Haskell

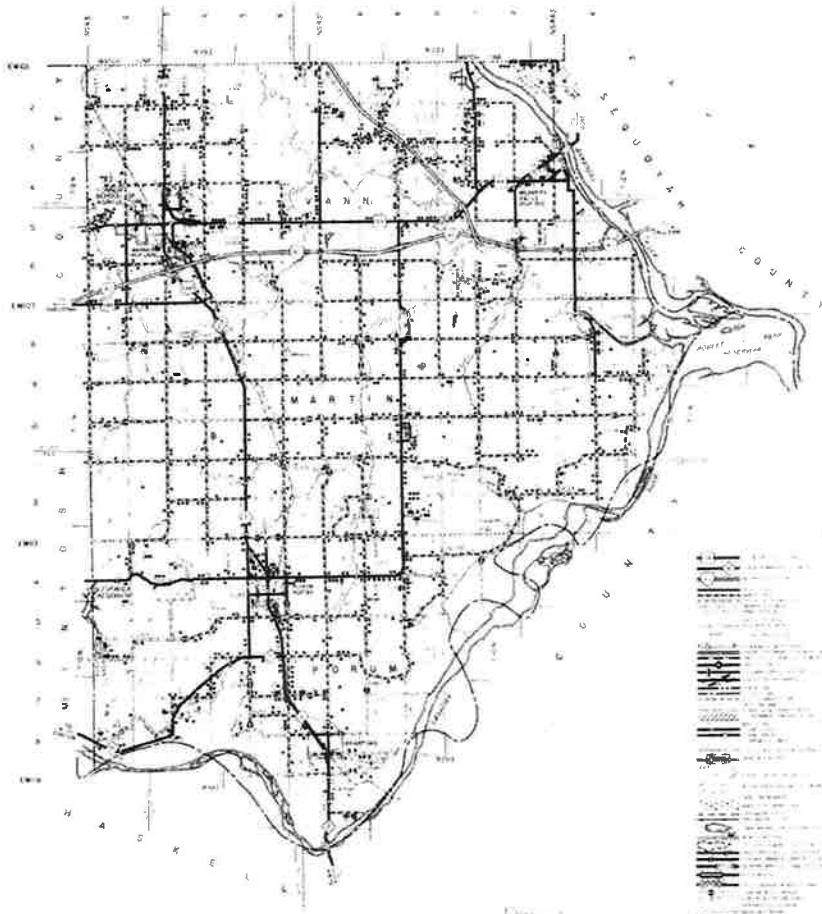






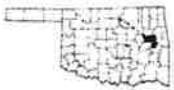






LEGEND

N



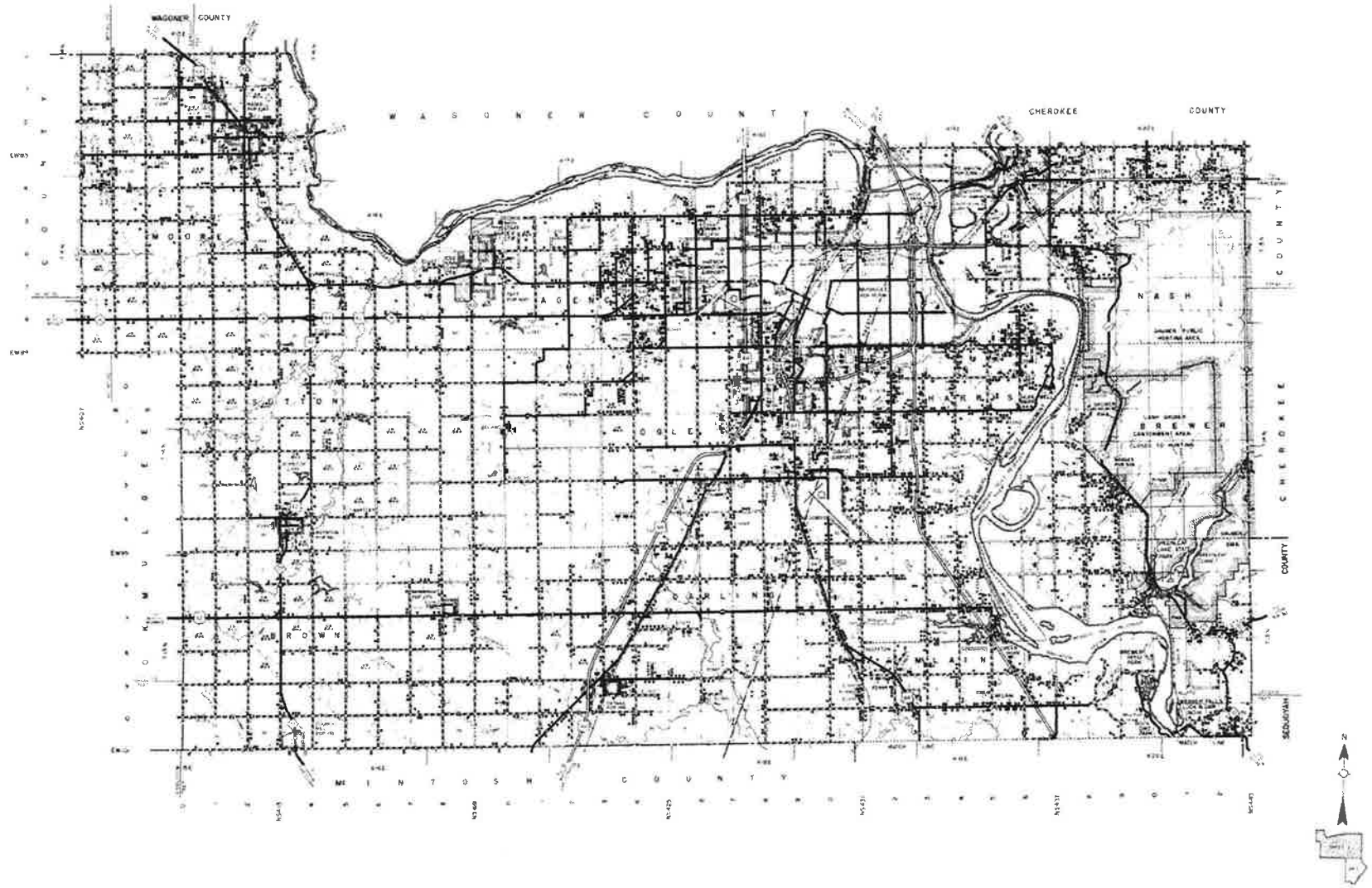
GENERAL HIGHWAY MAP

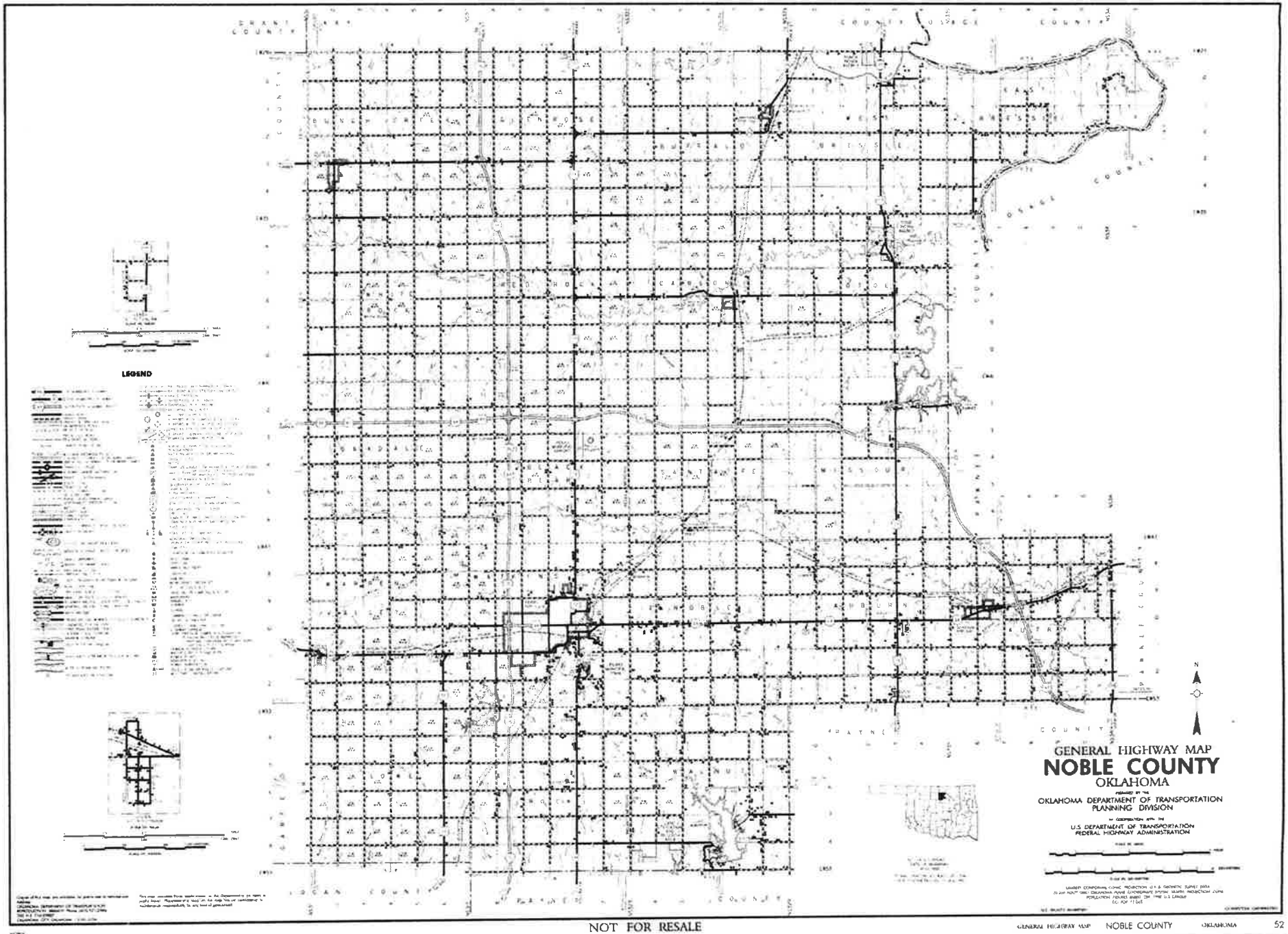
MUSKOGEE COUNTY

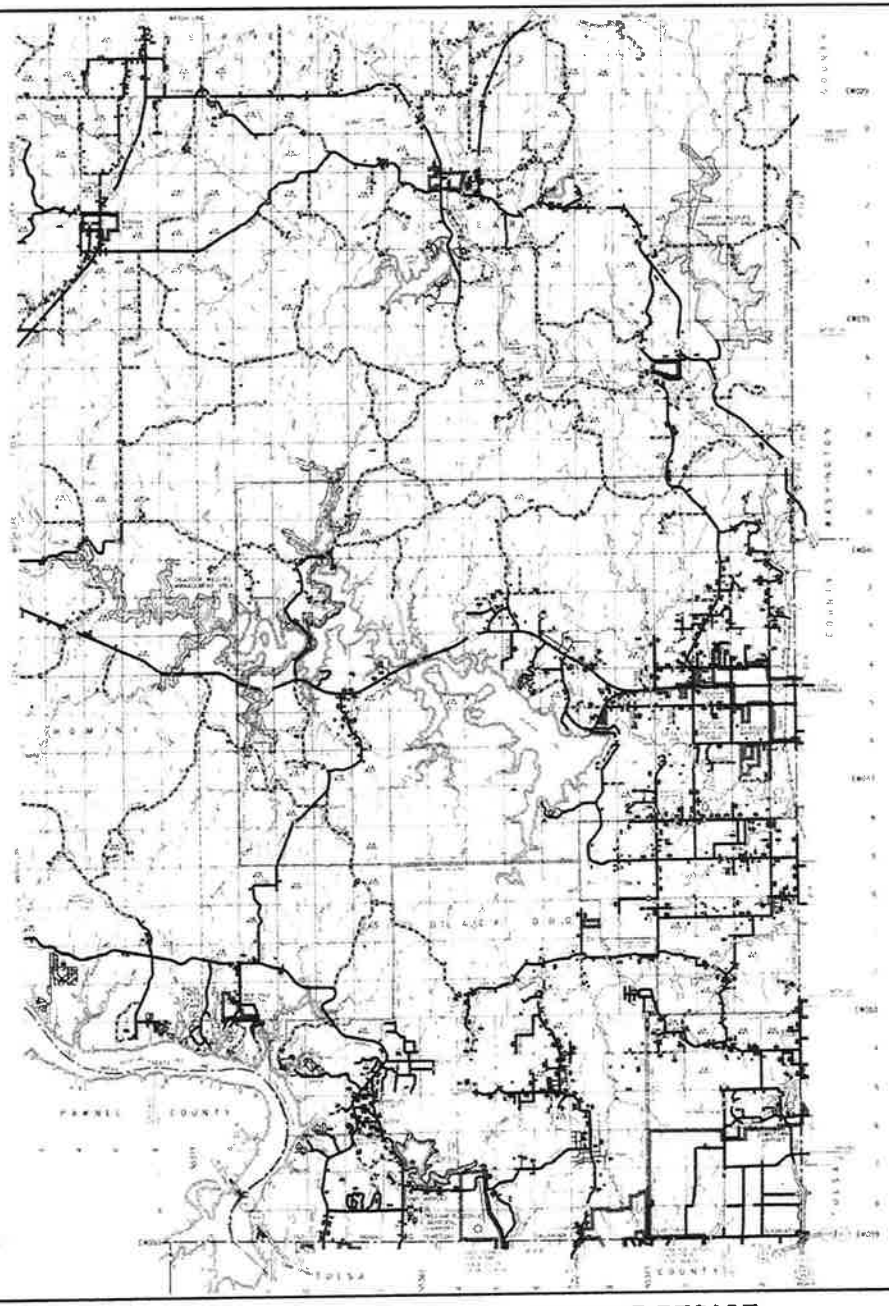
OKLAHOMA

OKLAHOMA DEPARTMENT OF TRANSPORTATION
PLANNING DIVISION

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION







LEGEND

GENERAL HIGHWAY MAP

OSAGE COUNTY

OKLAHOMA

OKLAHOMA DEPARTMENT OF TRANSPORTATION
PLANNING DIVISION

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION