THESIS

MORPHOLOGY OF THE MIDDLE RIO GRANDE FROM COCHITI DAM TO BERNALILLO BRIDGE, NEW MEXICO

Submitted by

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In partial fulfillment of the requirements

for the degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer, 1998

COLORADO STATE UNIVERSITY

May 7, 1998

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY **CLAUDIA LEON SALAZAR** ENTITLE **MORPHOLOGY OF THE MIDDLE RIO GRANDE FROM COCHITI DAM TO BERNALILLO BRIDGE, NEW MEXICO** BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT

MORPHOLOGY OF THE MIDDLE RIO GRANDE FROM COCHITI DAM TO BERNALILLO BRIDGE, MEW MEXICO

The continuous geomorphologic changes in the Middle Rio Grande in New Mexico have been of interest for many governmental agencies involved with the management and operation of this river system. Due to sedimentation problems along this river, highly developed plans for sediment detention and flood control have been carried out. Cochiti Dam was built as a part of these plans to control floodflows and induce degradation along the main stem.

Some detailed analyses of the geomorphic changes of the river to the construction of Cochiti Dam have been performed. Since 1980, many hydraulic and hydrologic surveys have been made along the river downstream of Cochiti Dam. However, no study has included the entire period of record available up to now. This work documents the morphologic changes of the Rio Grande downstream of Cochiti Dam in a 28.5-mile reach, from 1970 to 1996 and describes the entire data set gathered for this work. Relevant data were transferred into a computer data base to facilitate analysis and management.

A quantitative approach is used for analyzing the changes in bankline position, thalweg elevation, mean bed elevation, cross sectional area and bed material size. Several conclusions were drawn based on the analysis of these data. General trends showed by the data from 1980 to 1996 are compared to the observations performed in previous geomorphic analyses of the Middle Rio Grande. Degradation and coarsening of the river bed are observed along the entire study reach, which is consistent with previous studies.

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ACKNOWLEDGMENTS

I would like to express my gratitude to the U.S. Bureau of Reclamation for giving me the opportunity to work on this project. I also extend my sincere appreciation to my advisor Dr. Pierre Julien for his guidance, encouragement and helpful suggestions.

I am grateful to some federal agencies, which readily provided the data included in this work and to Dr. Peter Lagasse for lending us several aerial photo sets.

In addition I would like to express my appreciation to Eng. Drew Baird for his invaluable assistance and interest. The field trip to the river at Albuquerque was very helpful. Thanks to Gigi Richard for the collection of the data set, for generating some of the graphs and for reading my work. Thanks to Julio Zimbron for reading and correcting my thesis. I will also extend my thanks to the other members of my Master program committee: Dr. Deborah Anthony of the Earth Resources Department and Dr. Morris Skinner of the Civil Engineering Department.

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CHAPTER I

INTRODUCTION

The Middle Rio Grande Valley in New Mexico begins at the Southern end of White Rock Canyon and ends about 143 miles downstream, at the San Marcial Constriction (Lagasse, 1994) at the headwaters of Elephant Butte Reservoir. The Middle Rio Grande flows through arid regions where water is extremely important. It supplies water for irrigation to one of the oldest areas of agricultural use in the United States and provides habitat and riparian vegetation for many species; some of them endangered due to the effects of human activities.

The continuous geomorphologic changes in the Middle Rio Grande in New Mexico have been of interest for many governmental agencies with responsibility for the management and operation of this river system. Due to the sedimentation problems along this river, highly developed plans for sediment detention and flood control have been carried out. Cochiti Dam was built as a part of these plans to control floodflows and induce degradation along the main stem.

Some detailed analyses of the geomorphic changes of the river due to the construction of Cochiti Dam have been performed. Studies of changes in time and space of cross sections, thalweg elevation and bed material and their correlation with hydraulic, hydrologic, and sediment data have allowed scientists and engineers to draw conclusions about the response of the river to dam construction.

Prior to the construction of Cochiti Dam, the configuration of the Middle Rio Grande was one of low sinuosity with some straight reaches (Woodson, 1961). From Cochiti to San Felipe the channel was braided with many bars and islands composed of coarse gravel and cobbles. At low discharges the bed was composed of sand and at higher flows it consisted of gravel and sand. Downstream of the confluence with the Jemez River, the bed of the Rio Grande was sand (Nordin and Beverage, 1965). A general trend of aggradation was observed at Albuquerque and San Marcial and by 1960, bed elevations higher than outside floodplain elevation were reached at Albuquerque (Lagasse, 1980).

In order to reverse the aggradation and resultant flooding, a channel stabilization plan was developed and floodflow and sediment controls were pursued through the construction of dams on the most important sediment contributors: Rio Chama at Abiquiu, Galisteo Creek and Jemez River. Four major diversion dams (Cochiti, Angostura, Isleta and San Acacia) together with canal headings, irrigation canals, and levees were also built by 1935 (Pemberton, 1964).

Subsequent deterioration of the floodway due to aggradation and seepage indicated the need for regulation of floodflows, sediment retention, and channel stabilization (Woodson and Martin, 1963). In 1948, the Corps of Engineers and the Bureau of

Reclamation together with various other Federal, State, and local agencies recommended the Comprehensive Plan of Improvement for the Rio Grande in New Mexico (Pemberton, 1964). This plan provided Cochiti Dam in the Middle Rio Grande together with other dams in the main tributaries.

In November 1973, Cochiti Dam started to impound water. It was intended to control floodflows and sediment as well as induce degradation in the Middle Rio Grande Valley. Two years after the closure of the dam, degradation between Cochiti and Galisteo Creek and aggradation downstream of Galisteo were observed. Following the 1979 flood a general degradation trend occurred from Cochiti to Isleta (Lagasse, 1980).

Since 1980, many hydraulic and hydrologic surveys have been performed along the river downstream of Cochiti Dam. However, no study has included the entire period of record available up to now. This work documents the morphologic changes of the Rio Grande downstream of Cochiti Dam in a 28.5-mile reach, from 1970 to 1996, as well as the compilation of the available data.

The objectives of this thesis are:

1) Develop a database compiling historic hydrologic, hydraulic, and sediment records from various federal and state agencies. Transfer relevant data into consistent electronic format to facilitate analysis and management.

2) Document changes in cross section geometry, thalweg profile, planform, and bed material of the Middle Rio Grande along the 28.5-mile reach downstream of Cochiti Dam from 1970 to 1995 and attempt to determine some of the causes of the changes.

The database developed for the analysis includes hydraulic, hydrologic and sediment records. Cross section surveys from 29 stations along the entire reach have been gathered by various entities during the pre and post-dam period. Some bed material samples and water surface elevations were also collected at the same stations. The hydrologic data collected by the U.S. Geological Survey (USGS) consists of mean daily discharges at fourteen gaging stations distributed along the river and in three major sediment tributaries: Rio Chama, Galisteo Creek and Jemez river. Suspended sediment and bed material records were also gathered at USGS gaging stations.

The reach considered in this work spans from Cochiti Dam to the New Mexico Highway 44 Bridge in Bernalillo, New Mexico. The entire reach generally shows degradation in the thalweg profile. However, from Galisteo Creek to San Felipe (Cross Section CO-17) the behavior is erratic. Therefore this analysis has been performed in three sections along the river: the first one from Cochiti Dam to Galisteo Creek, the second reach from Galisteo Creek to San Felipe, and the last section from San Felipe to Bernalillo Bridge.

A quantitative approach is used for the following:

- Changes in bankline position, thalweg position, mean bed elevation, and cross sectional area were determined from the cross section plots.

- Plots of thalweg profiles for different years show the general trend of the river bed elevation.
- Reaches of degradation and aggradation were located and total degradation at each cross-section was estimated from the analysis of changes in thalweg elevation and mean bed elevation with time.
- Plots of median bed material size along the whole reach for different years show the changes in bed material with time.

This thesis has been developed in five chapters. The introduction is presented in Chapter I. Chapter II contains a literature review of some studies performed in regard to alluvial rivers, fluvial geomorphology, sediment transport and degradation below Cochiti Dam. A historical background of the Middle Rio Grande is also summarized in this chapter. The third chapter contains a description of the entire database. This chapter has been divided into three parts. The first part explains all the data that has been compiled including sources and formats as well as survey dates for each data set. This first part also introduces all the summary tables include in the Appendices A, B, and C. The second part of Chapter III presents a detailed explanation of the organization of the data into a usable computer database. The third section of this chapter, describes the data used in the quantitative analyses developed in this work as well as the methodology used to plot the graphics included in Chapter III and in the Appendices D and E. Chapter IV contains the quantitative analysis of the morphological changes of the Middle Rio Grande based on the database presented in Chapter III as well as the literature review summarized in the second chapter. Chapter V includes the summary and conclusions of this work. The last section of this thesis contains the Appendices A to E, which consist of summary tables of data, cross section plots, thalweg elevation and mean bed elevation data plots.

CHAPTER II

LITERATURE REVIEW

2.1 The Middle Rio Grande

The Rio Grande rises in central southern Colorado, flows southward through central New Mexico and continues southeast between Texas and Mexico to the Gulf of Mexico (Rittenhouse, 1944). In New Mexico, the Middle Rio Grande comprises a reach of the river that is about 143 miles long between White Rock Canyon and Elephant Butte Reservoir (Lagasse, 1994). The river reach, which is the subject of this study, extends from Cochiti Dam to approximately 28.5 miles downstream at the Bernalillo Bridge. The Cochiti Damsite is located about 40 miles north of Albuquerque, and 22 miles southwest of Santa Fe in New Mexico (Dewey et al. 1979). Figure 2.1 contains a location map of the study reach.

The Middle Rio Grande Valley is characterized by short canyons at San Felipe, Isleta and San Acacia, which define the basins of Santo Domingo, Albuquerque, Belen, and Socorro (Lagasse, 1980). The study reach is situated in the Santo Domingo and Albuquerque Basins. The Santo Domingo Valley is about 20 miles long and ends at San Felipe Pueblo (Lagasse, 1980). At this site, the river is confined by a volcanic talus on the right bank

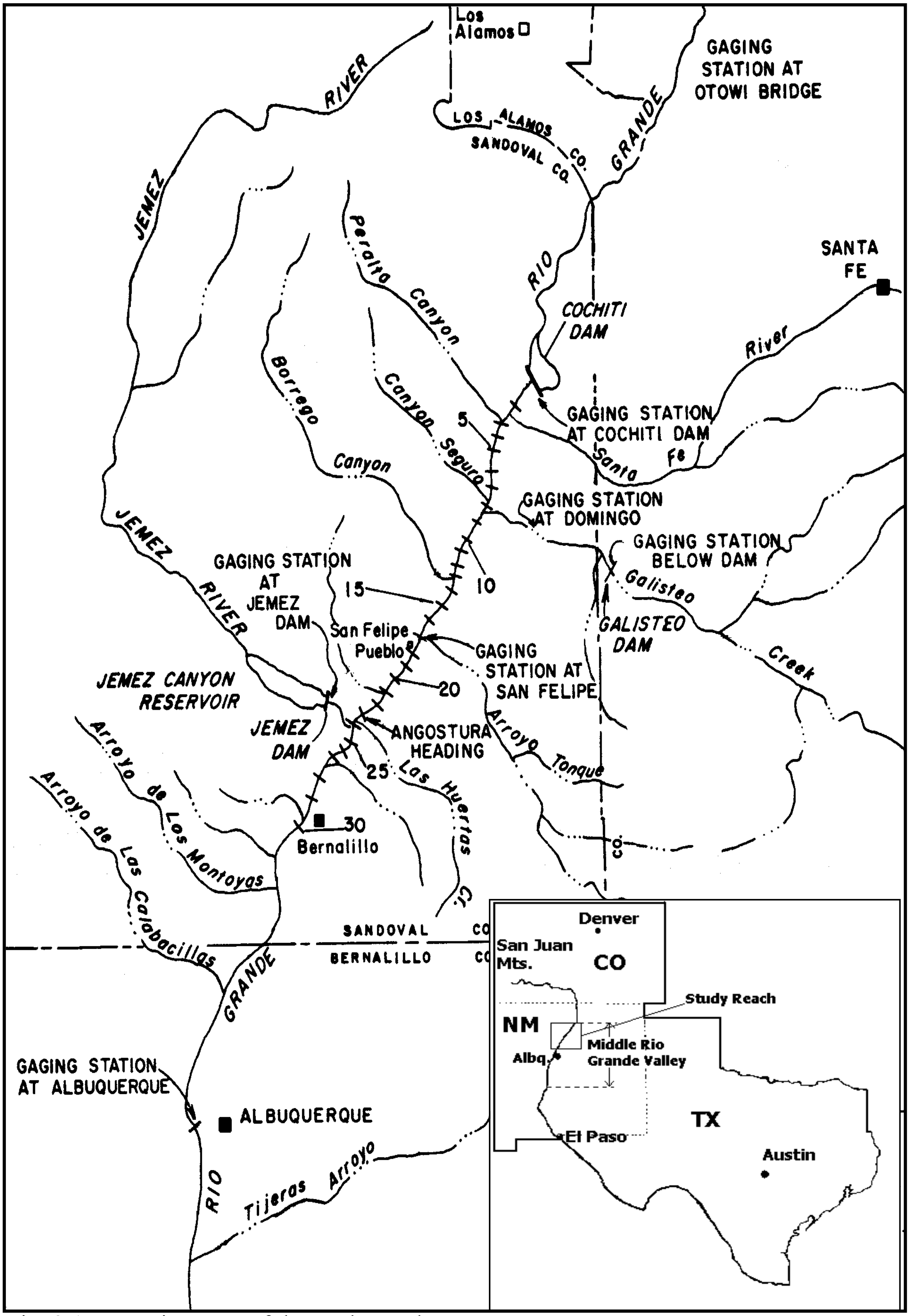

Fig. 2.1. Location map of the study reach.

and a stable clay bank on the left (Nordin and Beverage, 1965). The width of the Middle Rio Grande Valley ranges from 1 to 6 miles and is bounded on each side by mesas that rise about 300 to 500 feet above the valley floor and then slope upward to the foot of adjacent mountain ranges (Lagasse, 1980).

Along the study reach, several tributaries join the Middle Rio Grande. Galisteo Creek, which rises in the Sangre de Cristo Mountains, flows westward to enter the Rio Grande from the east about 8 miles downstream of Cochiti Dam. Galisteo Creek is a large sediment contributor and has a history of flash flood events. Arroyo Tonque, which enters the main stem from the east about 15 miles below Cochiti Dam, runs infrequently but contributes with a significant amount of sediments. Jemez River, which rises in the Jemez Mountains and flows eastward to join the Rio Grande from the west about 8 miles below San Felipe, was a large sediment contributor before the construction of Jemez Canyon Dam (Lagasse, 1980).

2.2 Historical Background

The Middle Rio Grande Basin is probably one of the oldest agricultural areas in the United States. Prior to the coming of the Spaniards in 1539, the Indians in this valley were already cultivating the land. From the date of discovery by Spaniards, settlements and developments progressed down the river to the south. Each community depended on agricultural activities and built its own ditch for irrigation from the Rio Grande (Burkholder, 1929). In the latter half of the 19^{th} century, Anglo-Americans started settling in the area, carrying on irrigation farming as well (Lagasse, 1980).

Lands for irrigation reached a maximum development by 1880, when the cultivated acreage was about 124,000 (Lagasse, 1980). Thereafter, agricultural areas were reduced, due to increasing height in the water table and increasing water shortage. The increasing use of water in Colorado reduced the flow of the river in New Mexico, and therefore, the sediment transport capacity of the river. Riverbed aggradation induced seepage from the river to the adjacent lands, raising the water table elevation close to the surface (Burkholder, 1929).

On the other hand, the amount of sediment brought into the Rio Grande was also increased in the late 1800's. It is believed that arroyo cutting in the southwestern United States began in the 1880's (Hereford, 1984). Many of the tributary streams began to deeply entrench and widen, increasing the rate of upland erosion (Rittenhouse, 1944). Three general hypotheses have been developed to explain this stream process: 1) poor land use, such as overgrazing; 2) changes in climate; and 3) random variations within the fluvial system independent of climate fluctuations (Hereford, 1984). The expansion of livestock industry in New Mexico and subsequent overgrazing and destruction of watershed cover are most commonly known as causes for the initiation of arroyo cutting (Lagasse, 1980).

The continuing aggradation of the riverbed produced a reduction of the irrigated lands to 40,000 acres by 1925. Due to the decrease in irrigated lands along the Rio Grande, the U.S. Congress authorized the Rio Grande Reclamation Project in 1905 which provided Elephant Butte Dam (Lagasse, 1980). This reservoir, which was completed and started operations in 1915, guarantees the delivery of water to Mexico and the irrigation of 155,000 acres of land in New Mexico and Texas (Burkholder, 1929).

In December 2, 1905, the Secretary of the Interior authorized the Rio Grande Project, including water diversion and delivery facilities for irrigation purposes. During 1936-1938 Caballo Dam was built and included in the Rio Grande System (Lagasse, 1980).

The Middle Rio Grande Conservancy District was organized in 1925 under the laws of the State of New Mexico for the main purpose of improving drainage, irrigation and flood control for approximately 128,000 acres of lands, including urban areas within the Middle Valley. Construction of flood control and sedimentation detention works begun in 1930 and were completed in 1935. The basic flood control element adopted for the Middle Rio Grande was a floodway. The levees were located along the existing meander pattern of the river (Woodson and Martin, 1963). Below Angostura Diversion Dam, the width of the floodway between levees was about 1,500 feet and the average height of the levees was approximately 8 feet. Above this point the levees were discontinuous and the floodway width varied from about 500 feet to 2,500 feet (Woodson, 1961). The design flow for the floodway was 40,000 cubic feet per second and an extra height of the levee was provided at the city of Albuquerque for a design flow of 75,000 cubic feet per second (Woodson and Martin, 1963).

The Conservancy District also built, operated, and maintained the El Vado Dam on the Rio Chama, as well as four major diversion dams (Cochiti, Angostura, Isleta, and San

Acacia), two canal headings, many miles of drainage canal, and main irrigation canals (Lagasse, 1980).

In 1941, a major flood of a mean daily discharge of 22,500 cubic feet per second with duration of about 2 months breached the levees in 25 places along the river and caused extensive flood damage as well (Woodson and Martin, 1963). Subsequent to this flood, in 1948 the Corps of Engineers and the Bureau of Reclamation together with various other Federal, State, and local agencies recommended the Comprehensive Plan of Improvement for the Rio Grande in New Mexico (Pemberton, 1964). Deterioration of the floodway due to aggradation and seepage indicated the need for regulation of floodflows, sediment retention, and channel stabilization (Woodson and Martin, 1963).

The Comprehensive Plan consisted of a system of reservoirs (Abiquiu, Jemez, Cochiti, Galisteo) on the Rio Grande and its tributaries, as well as the rehabilitation of the floodway constructed by the Rio Grande Conservancy District in 1935. The reservoir system would be built by the Corps of Engineers and the floodway rehabilitation by both the Corps of Engineers and the Bureau of Reclamation (Woodson and Martin, 1963).

Except for the construction of a reservoir in the main stem, this plan was authorized for construction in 1948. Later, in 1958 a restudy of the problem was made by the Corps of Engineers, and the construction of two more reservoirs was authorized in 1960, Cochiti Dam at the head of the Middle Valley and the other on the Galisteo Creek (Woodson and Martin, 1963).

The U.S. Bureau of Reclamation started a comprehensive program of data collection in 1950 in order to develop a plan for channel rectification through this area. A successful investigation was completed which resulted in determination of rates and volume of aggradation and/or degradation that had occurred in the river channel and flood plain since 1936, determination of sediment transport at some stations on the river, and determination of hydraulic and sediment transport relationships for use in establishing the design width of the channel rectification (Pemberton, 1964).

The procedure for computing the volume of aggradation or degradation was developed by the Bureau of Reclamation and the Corps of Engineers. The purpose of this study was to determine the volumetric changes in channel and floodplain between surveys of range lines from 1936 to 1953. In 1936, the Soil Conservation Service of the U.S. Department of Agriculture established and surveyed river cross sections across the floodway along the entire Middle Valley. The range lines were located about 2 miles apart. Additional cross sections were established by the Corps of Engineers in 1944, reducing the interval to a half mile. These ranges were surveyed in 1936, 1940, 1941, 1942, 1944, 1952 and 1953. The period used in this study began after the finalization of the works of the Conservancy District, reflecting the response of the river to these works. This period also included the high year floods of 1941 and 1942 (Woodson and Martin, 1963).

Based on these surveys, the Corps of Engineers and the Bureau of Reclamation concluded that the floodway had not halted the aggradation in the Middle Rio Grande. It was also determined that there was a definite relation between the annual runoff and the aggradation or degradation in the channel and flood plain. The rate of change for the period covered by the surveys within the Albuquerque division was influenced by the floods of 1941 and 1942 and also by the order of these events. It is doubtful that the changes caused by the flood of 1942 would have been the same if it had followed a sequence of low flow years (Woodson and Martin, 1963).

According to measurements in 1952, the Middle Rio Grande Valley was filling at a rate of about ½ in. per year and the river bed at Albuquerque had risen above the level of the streets (Lane and Borland, 1953).

The Corps' portion of the comprehensive plan provided the Jemez Canyon Dam in 1953, Abiquiu Dam on the Rio Chama in 1963, Galisteo Dam in 1970 and Cochiti Dam near Cochiti Pueblo on the main stem in 1973 (Lagasse, 1980). Cochiti Dam was intended for flood and sediment control, preventing aggradation and inducing degradation of the Rio Grande. A permanent pool of 50,000 acre-feet had been formed for recreation purposes (Lagasse, 1980).

In order to provide protection for the levees and decrease channel area in the interest of reducing water losses and improving water and sediment transport capacity, rectification of the channel within the floodway from Cochiti to the Rio Puerco was performed. The rehabilitation plan of the floodway reduced the design capacity above the Rio Puerco to 20,000 cubic feet per second except at Albuquerque where the capacity was 42,000 cubic feet per second. The original river width was narrowed from about 800 feet to between

550 feet and 600 feet. This was achieved by an arrangement of jetties projecting from the levees to the channel on both sides and lines of jetties paralleling the channel (Woodson and Martin, 1963).

The jetty system is appropriate for heavy silt-laden streams subject to variations in channel scour during period of high flows. This system reduces the velocity of the flow inducing deposition of sediments behind the jetty. The area of bank built behind the jetty allows the growth of vegetation and therefore more protection of the levees (Woodson and Martin, 1963). The earlier uses of the Kellner jetty system in the Middle Rio Grande were by the Santa Fe Railroad in protection of railway embankments on the Rio Galisteo in 1936. This work was at small scale, yielding satisfactory results. Construction of the stabilized channel within the Cochiti to Rio Puerco reach of the floodway began in 1954 within the Albuquerque unit. By 1956, about 17,000 additional units were installed. From 1956 to 1958 no work was accomplished. Approximately 50,000 more units were installed in 1958 and by 1962 the entire work was completed with a total of about 115,000 units installed (Woodson, 1961).

2.3 Climate of the Middle Rio Grande Valley

Above Elephant Butte Reservoir within the watershed of the Northern Rio Grande, precipitation ranges from an annual minimum of less than 400 mm near Socorro to a maximum of over 2,000 mm on some of the peaks of the San Juan Mountains. The precipitation is unequally distributed. Maximum values are concentrated in the San Juan Mountain, Sangre de Cristo Mountains and Jemez Mountains. Along its course through

New Mexico, the Rio Grande receives little additional water because precipitation decreases from north to south. Variations of precipitation with time have been observed. The frequency of rainy days and the mean daily rainfall have varied systematically since the 1850's. During the late nineteenth century the rainfalls were small but frequent and in recent decades, there have been fewer precipitation events with large amounts of rain (Graf, 1994).

The hydrology of the Rio Grande Basin is complex. It flows throughout a chain of sub-basins in New Mexico, where the surface water of the river and the groundwater are hydraulically interrelated (Lagasse, 1980). Seasonal variations of precipitation provide three types of flows in the Middle Rio Grande. Spring and early summer flows, from April to June, generally due to melted snow and rain from the mountains; summer floods, from May through October, caused by heavy local rains on one or more of the tributary areas; and fall flood, from either local or general storms (Rittenhouse, 1944). Spring flows exhibit a gradual rise to a moderate rate of discharge maintained for about two month, with peak flows of shorter duration, and high volume of runoff. Summer flows are characterized by a sharp hydrograph and relatively small volume of runoff. Flows above 5,000 cfs (cubic feet per second) are considered flood flows in this reach (Woodson, 1961).

Records of stream flow on the Rio Grande began in 1889 at Embudo gaging station. This gage is the longest-running measurement site in the United States (Graf, 1994). The International Boundary and Water Commission estimated peak flows as high as 100,000 cfs for the May-June 1828 flood. This estimation was based on records left by a Catholic priest at Tomé, New Mexico, located about 28 river miles below Albuquerque. An early newspaper described extensive damage in the Middle Rio Grande Valley from the spring floods of 1865, 1874, and 1884. The peak of the 1874 flood was estimated from records of high water marks at discharges ranging from 45,000 cfs to 125,000 cfs (Woodson, 1961).

In 1920, a 64-day flood had a peak flow of 28,800 cfs and the August-September flood of 1929 destroyed the town of San Marcial at the northern end of Elephant Butte Reservoir. In 1941, a peak flow of 24,000 cfs was reached in a flood that lasted 61 days. In contrast to these big events, some periods of zero surface flows have been observed in the river below Angostura diversion, due to irrigation diversions (Lagasse, 1980).

Historical records reveal that some flow peaks on the Rio Grande were related to logging activities in the nearby mountains in northern New Mexico. During the period 1909-1926, timber cutters harvested logs from the mountains and stored them along the tributary streams (Rio Santa Barbara and Rio del Pueblo north of Española). Temporary dams on the tributaries held the spring runoff until large volumes of water accumulated. The loggers then broke the dam, releasing the stored water and increasing the discharge in the Rio Grande in order to transport the stored logs downstream. The logs floated through the Rio Grande to an area near Cochiti pueblo, where a tie boom across the river trapped them and made them available for nearby sawmills. The high flows generated by this mechanism maintained the northern Rio Grande as a wide, shallow, braided stream during the early twentieth century. After reforestation and logging of the area, the water contribution from tributary watersheds decreased (Graf, 1994).

Temporal variations in annual water yield and flood peaks have been observed in the Middle Rio Grande. In the first two decades of the twentieth century the water yield reached a maximum value, but thereafter a general declined occurred. Two high yield years occurred in the 1940's and a minimum was recorded in the late 1950's. A steady increase has been observed from the late 1950's to the present (Graf, 1994).

2.4 Some Previous Studies in the Middle Rio Grande

Several investigations on sediment transport and river morphology have been carried out in the Middle Rio Grande, providing very good descriptions of the river bed configuration, planform configuration, and cross section geometry as well as bed material characteristics.

In 1953, Lane and Borland performed a study on river bed scour, where they described the Middle Rio Grande as a generally wide, shallow river with many islands that gave it a braided pattern. The Rio Grande had a relatively straight channel and did not have the bends and crossings that characterize large alluvial rivers, but it did have a series of alternately narrow and wide sections. They concluded in their study that in general during high flows the bed of the Rio Grande scoured at the narrow sections and that most of the eroded material was deposited in the next wide section downstream. The fact that gaging stations scoured during high flows did not imply that there was a general lowering of the river bed. Gaging stations are usually placed in narrow sections, which are not typical of the greater part of the length of the river.

The aggradation of the wide sections occasionally can promote channel changes in these sections. The greatest danger to the levees along the Middle Rio Grande is from the cutting of the banks primarily during low flows. Depositions in the wide, shallow sections can form bars to a height that reaches a considerable percentage of the flow depth. When flow recedes, the bar height can block the former channel and the stream will follow a new channel. If this channel impinges on the bank a new scour occurs (Lane and Borland, 1953).

Due to the easily eroded bed material in the Middle Rio Grande, variable channel scour produces different stages for the same discharge. By 1961, the bed material was mainly sand with the finer sizes predominating. Generally, less than 10 % of the material was silt and clay. There was some fine gravel, but the amounts were not significant. The configuration of the river was one of low sinuosity (about 1.1 and 1) with some straight reaches. The channel was braided, probably due to the combination of sediment overload and relative steep slope (Woodson, 1961).

In 1964 and 1965 several studies of sediment transport, fluvial characteristics and hydraulic variables were performed in the Middle Rio Grande based on flow discharge and sediment data collected from 1952 to 1962. Descriptions of the river planform and bed sediment presented in these studies provide a very good picture of the river characteristics by that time.

From Otowi Bridge to Cochiti, through White Rock Canyon, the river had a typical riffle-and–pool configuration. The riffles were composed of coarse, gravel, cobbles, and boulders, and seemed to be quite stable. During high flows large cobbles and boulders were moved from the riffles, but the position and shape of the riffles did not change appreciably with time. The bed material at the pools was sand at low flows, and sand and gravel at high flows. At Otowi station, the river was confined, and the maximum width at the station was 150 feet (Nordin and Beverage, 1965). At Cochiti, at about 1-mile downstream from Cochiti diversion dam, the river channel and flood plain widened considerably (Culbertson and Dawdy, 1964) and the flow width varied upward to about 350 feet (Nordin and Beverage, 1965). The river channel became characteristic of that of sand-bed stream. However at large discharges, the predominant bed materials were large gravel and rock. It was also observed that Cochiti diversion dam did not appear to retain any appreciable sand load (Culbertson and Dawdy, 1964).

From Cochiti to San Felipe the channel was braided between many bars and islands composed of coarse gravel and cobbles. At low discharges, the bed was composed of sand and at higher flows of sand and gravel (Nordin and Beverage, 1965).

The river channel at San Felipe station is narrow, being confined by a volcanic talus slope on the right bank and stable clay on the left bank. Velocities were relatively high and bed material in the sand range, which was brought in by Galisteo Creek and Tonque Arroyo. Evidence of aggradation was also observed at this station (Culbetson and Dawdy, 1964).

The Middle Rio Grande from Angostura diversion to San Marcial was described as a sand-bed channel. Analysis of bed material samples taken at locations downstream from Angostura heading generally indicated that the median diameter did not change with discharge. Upstream of Angostura diversion dam, the channel was defined as a sand-gravel channel. Analysis of bed-material samples collected in this reach indicated bimodal size distribution and wide variation in median diameter with discharge (Culbertson and Dawdy, 1964).

Downstream from Jemez River confluence, the river was a sand-bed stream (Nordin and Beverage, 1965). At the Bernalillo station, 8 miles downstream from the mouth of Jemez River the river has a narrow section confined by a calcareous sandstone high bluff on the right bank and a silty clay bank on the left (Culbertson and Dawdy, 1964). This section keeps a width of about 270 feet for all discharges greater than 2,000 cfs (Nordin and Beverage, 1935).

In these studies it was also concluded that the streambed scours during rising flows and fills during recession of the flow in narrow sections, and that the opposite seems to happen in wide sections.

Post-dam observations of the river bed indicated that downstream from the dam to at about 3 miles below it, the sand material up to 1 mm approximately, was eroded in the first two months after the dam closure in November 1973. Gravel bars, that were not apparent before dam closure, were observed along the river as far downstream from the dam as Albuquerque (Dewey et al. 1975).

In 1980, Lagasse performed a geomorphic analysis of the Middle Rio Grande from Cochiti Dam to Isleta Diversion Dam during 1971 to 1975. This study revealed that the response of the river channel to the construction of Cochiti Dam had been dominated by the inflow of arroyos and tributaries. Above the Jemez River confluence, tributary deltas were sufficiently stable to affect the processes of aggradation, degradation and armoring of the main stem and to influence the river planform. From Cochiti to Galisteo Creek, the river had approached a stable condition much more rapidly than the reach below Jemez River, due to the development of an armor layer and local base level control established by tributaries and arroyos. In this geomorphic study, the channel adjustments to dam construction were documented through a qualitative analysis of planform, profile, cross section and sediment data. The methodology and analysis of these data have been used as a guide for the development of this work.

Graf performed a research about the plutonium into the Northern Rio Grande in 1994. Channel changes from 1940 to 1980 were documented in this work based on historical aerial photos and topographic maps. Before the early 1940s, the channel was broad and shallow with a typical configuration of a braided channel. Decreased amounts of water produced a progressively smaller channel throughout most of the river from Española to San Marcial. The single-thread pattern of the river resulted in larger floodplain areas and the abandonment of some minor sub-channels. The tendency toward a single small channel is often directly related to the closure of dams but also to region hydroclimatic influences, because the Rio Grande above Cochiti Dam also has shrunk. As the Rio Grande became narrower, the instability increased. Lateral migration from one side of the valley floor to the other occurred in unconfined sections of the river. During 1940s-1980s period, the main channel of the Rio Grande changed horizontal position by as much as 1 kilometer. These changes occurred during high flows when sediment plugged old courses and flow over poorly consolidated banks originated new courses (Graf, 1994).

From Cochiti Dam to the New Mexico Highway 44 bridge in Bernalillo, the active channel width has decreased from 1918 to 1995. The wider braided channel has changed toward a narrow single channel. The river sinuosity was 1.10 between 1918 and 1936 and increased to 1.13 in 1949. The sinuosity decreased to 1.07 from 1949 to 1972 due to the channalization activities and the reduced peak flows from the watershed. The river sinuosity has increased after 1972, but it still has not reached the sinuosity of 1949. The historical channel forming discharge of 11,166 cfs has never been released from Cochiti Dam. Since flow regulation started at Abiquiu Dam in 1963 and Cochiti Dam in 1973, the regulated two-year return flow has decreased to 5,650 cfs. The lack of large peak flows, the channalization works and the construction of Cochiti Dam account for the channel narrowing that has occurred since 1942 (Baird and Sanchez, 1996). Figure 2.2 shows the planform comparison among 1918, 1935, 1936, 1984 and 1992 surveys.

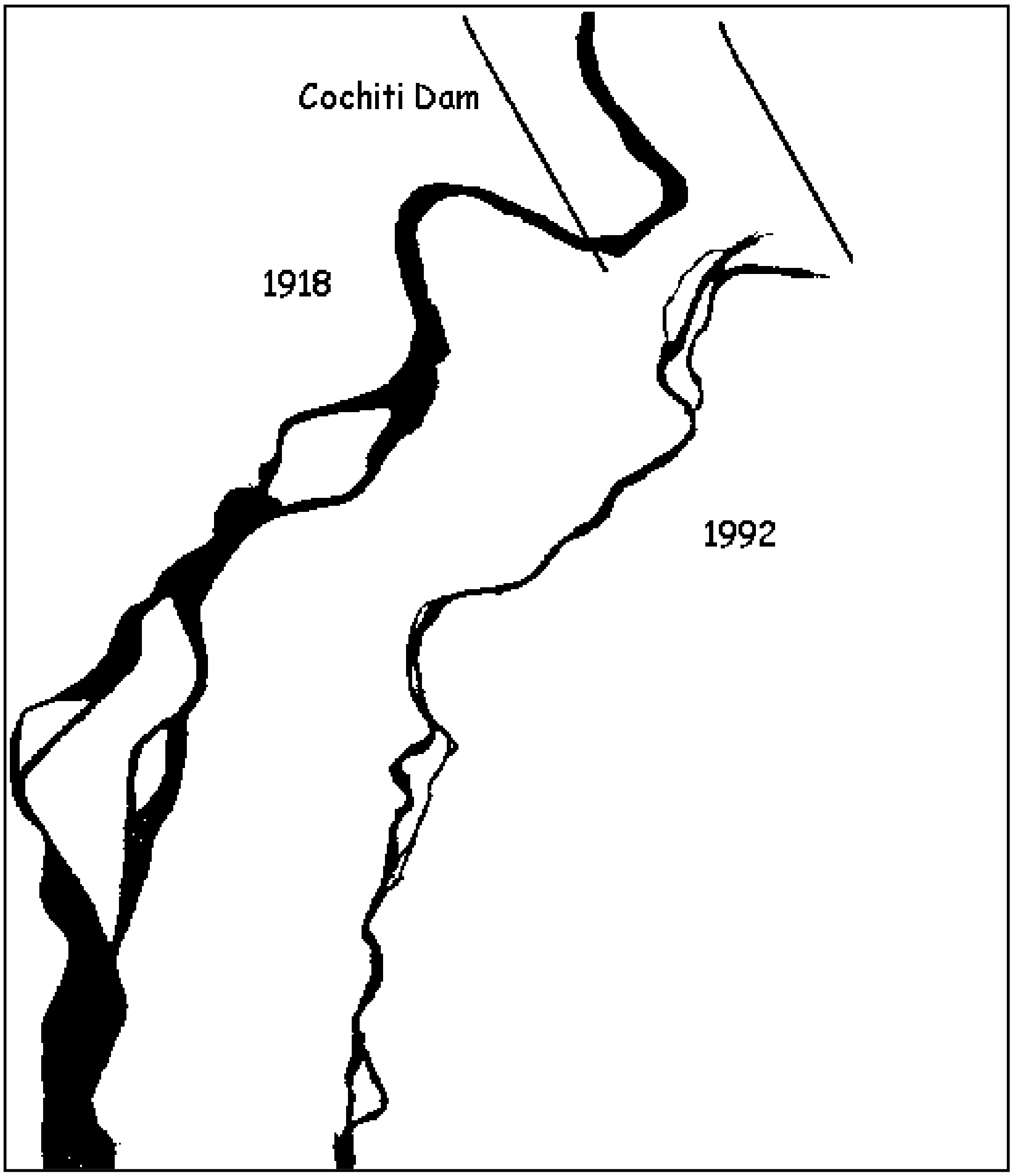

Fig. 2.2. Planform comparison below Cochiti Dam from 1918 to 1992.

CHAPTER III

DATA BASE

The data set gathered for this work is very extensive, specifically in the river reach between Cochiti Dam and Bernalillo Bridge. The entire data set includes: cross section surveys at several range lines, flow discharge records and bed material and suspended sediment data at different cross section range lines and USGS gaging stations as well as aerial photos and planform plots for several years. A computer database was created in order to keep track of the different sources, and type of information gathered. This chapter describes the compiled data and introduces all the summary tables in appendices A to C (Section 3.1). A detailed explanation of the database developed in the computer is presented in Section 3.2. This chapter finally discusses the data used in the analysis of changes in morphology of the Rio Grande downstream of Cochiti Dam as well as the methodology utilized in developing the different plots and charts included in this chapter and in the Appendices D and E (Section 3.3).

3.1 Data Base Compilation

A. Cross Section Data

A total of 12 cross section range line sets have been located along the Middle Rio Grande from Cochiti Dam to Elephant Butte Dam. These range lines are identified as follows:

Soil Conservation Service Range Lines (SCS lines), Aggradation/Degradation Range Lines (Agg/Deg lines), Cochiti Range Lines (CO lines), Cochiti Pueblo Range Lines (CI lines), Santo Domingo Range Lines (SD lines), San Felipe Pueblo Range Lines (SFP lines), Angostura Range Lines (AR lines), Bernalillo Island Range Lines (BI lines), Calabacillas Range Lines (CA lines), Casa Colorada Range Lines (CC lines), San Acacia Range Lines (SA lines) and Socorro Range Lines (SO lines).

Of these 12 sets of range lines, 7 are located within the study reach. Cochiti Range Lines, Agg/Deg Lines and SCS Lines are distributed along the reach between Cochiti Dam and Bernalillo Bridge, extending farther downstream from Bernalillo Bridge. The other 4 range line sets are localized in shorter reaches within the study reach. Table A-1 in Appendix A contains the relative location of the seven sets of range lines distributed in the 28.5-mile reach contemplated in this study.

a.1. Soil Conservation Service Range Lines:

These range lines were first established by the Soil Conservation Service during the fall of 1936 and 1937. They were spaced about 3 to 4 miles apart. Other surveys were performed in 1939, 1940 and after the flood of 1941. By 1944, the Corps of Engineers resurveyed the SCS Lines and added a new set of ranges, which reduced the distance between them to about 1-mile. In 1947 a limited number of ranges were resurveyed again and during the period 1952 to 1954, the U.S. Bureau of Reclamation together with the Corps of Engineers resurveyed the entire set of ranges lines (Pemberton, 1964).

The numbering system used in the SCS Lines was based on the railroad mileage. The numbers range from 860 in the northern part of the surveyed area to 1,006 at the south. (Memorandum from Head, Sedimentation Section of the USBR to Chief, Hydrology Branch of the USBR dated January 21, 1966. Denver, Colorado).

The SCS range line data are available in hardcopy plots from 1937 to 1964. According to the above description of the SCS lines, these sections were first ground surveyed in 1936. However, a set of SCS cross section plots for 1918 are also available in hardcopies. These plots were obtained from topographic maps performed by the United States Reclamation Service. Table A-2 in Appendix A, lists the SCS range lines compiled for this work.

From Cochiti Dam to Bernalillo Bridge, the SCS Lines located in this reach range from number 868.0A to cross-section called Bernalillo Highway Bridge and without number. These data were obtained from the U.S. Bureau of Reclamation, Denver Office.

a.2. Aggradation / Degradation Lines:

These range lines were established in 1962 in a photogrammetric survey, which covered the area from the Cochiti Diversion Dam to Elephant Butte Reservoir. These ranges were established approximately 500 feet apart and were numbered from 1 to 1,962 in the downstream direction (Memorandum from Head, Sedimentation Section of the USBR to Chief, Hydrology Branch of the USBR dated January 21, 1966. Denver, Colorado).

Some Agg/Deg lines coincide with the SCS system. Table A-2 lists the Agg/Deg ranges, which match with the SCS Lines.

Within the study reach the Agg/Deg Lines go from number 17 downstream of Cochiti Dam to 299 downstream of the Bernalillo Bridge. Agg/Deg Line Surveys are not ground surveys and are available in electronic format for 1962, 1972 and 1992 from section 19 to section 299. These data were obtained from the U.S. Bureau of Reclamation, Denver Office.

a.3. Cochiti Range Lines:

These range lines were established by the USGS. Their location were selected based on the "Summary Report, Rio Grande, Aggradation or Degradation, 1936-1962, Middle Rio Grande Project", prepared by U.S. Bureau of Reclamation, U.S. Army Corps of Engineering, and U.S. Soil Conservation Service (Dewey et. al. 1979). There are 37 range lines established from Cochiti Dam to Isleta Diversion at a spacing of about 1-mile apart. These cross sections are identified by the letters CO and span from number 2 to number 38 in the downstream direction. The river reach considered in this work comprises 29 CO-Lines, from cross section number 2 downstream of Cochiti Dam to cross section number 30 just downstream of the Bernalillo Bridge. Other CO–Lines are located downstream Isleta Diversion, identified by numbers from 668 to 1194, that correspond to the Agg/Deg range line numbers.

Table A-3 in Appendix A lists the available data for the CO–Lines between Cochiti Dam and Isleta Diversion Dam and Table A-4 contains the surveyed dates for the CO-Lines located downstream Isleta Diversion Dam. Surveyed dates go from 1970 to 1995. From 1970 to 1986 the data were surveyed by the USGS. For 1992 and 1995 the data were collected by FLO Engineering for the U.S Bureau of Reclamation and are available in the final reports titled Cross Section Surveys and Bed Material Sampling Cochiti Range (CO) Lines, July and August 1992 and August 1995. These data were obtained in electronic format from the U.S. Bureau of Reclamation, Albuquerque Office.

a.4. Cochiti Pueblo Range Lines

These are 5 range lines located between Cochiti Dam and the range line CO-2. They are identified by the letter CI and are numbered by 27, 27-1, 28, 28-1 and 29-1. The ranges CI 27-1 to CI 29-1 are located between Agg/Deg lines 27 and 30. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation in 1993 and 1995. Table A-5 lists the available data obtained in electronic format from the U. S. Bureau of Reclamation, Albuquerque Office.

a.5. Santo Domingo Range Lines

These cross sections are located downstream Santo Domingo Bridge, between ranges CO-10 and CO-14. They are identified by the letters SD and go from number 1 to 47. The Santo Domingo Phase I – Range Lines consists of 30 cross sections, from SD-1 to SD-30 located between Agg/Deg Lines 113 and 127. The Santo Domingo Phase II – Range Lines go from SD-31 to SD-47 and are located between the Agg/Deg Lines 127 and 142. The Santo Domingo Phase I - Range Lines were surveyed by FLO Engineering for the U.S. Bureau of Reclamation in 1990. Table A-6 lists the available data obtained in electronic format from the U. S. Bureau of Reclamation, Albuquerque Office.

a.6. San Felipe Pueblo Range Lines

These cross sections are located at the San Felipe Pueblo reach. They are identified by the letters SFP and go from number 170 to 200. The San Felipe Pueblo range lines span from Agg/Deg Line 170 to Agg/Deg Line 200 and between CO-16 and CO-20.

These data were collected by FLO Engineering for the U.S. Bureau of Reclamation in 1992. Table A-7 lists the available data obtained in electronic format from the U. S. Bureau of Reclamation, Albuquerque Office.

a.7. Angostura Range Lines

These cross sections are located upstream of the Angostura Diversion Dam. They are identified by the letters AR and go from number 203 to 235. The Angostura range lines span from Agg/Deg Line 203 to Agg/Deg Line 236 and between CO-20 and CO-21. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation in 1995. Table A-8 lists the available data obtained in electronic format from the U. S. Bureau of Reclamation, Albuquerque Office.

a.8. Other Range Lines

The rest of range lines, Bernalillo Island, Calabacillas, Casa Colorada, San Acacia and Socorro are located downstream from Bernalillo Bridge, and therefore out of the study reach. However data for these cross sections were also compiled and are listed in Tables A-9, A-10, A-11, A-12 and A-13 respectively. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation and were also obtained from U.S. Bureau of Reclamation, Albuquerque Office.

B. Sediment Data

Bed material and suspended sediment data were collected at some cross section range lines and USGS gaging stations.

b.1. Bed material data

These data consist of particle size distributions at 3 cross section range line sets and 6 USGS gaging stations. Bed material particle sizes are within the range of 32 mm (very coarse gravel) to 0.062 mm (very fine sand).

Data for the following cross section range line sets are available:

Cochiti Range Lines

From section 2 to 38 the available bed material data consist of particle size distributions collected for 11 years between 1970 and 1995. From 1970 to 1982 the data were collected by the U.S. Bureau of Reclamation.

From 1970 to 1975 the data are available in hardcopies and were retrieved from U.S. Geological Survey Water Resources Investigations 79-70 (Dewey et al.1979). From 1970 to 1982 other data were retrieved from a file labeled "Cochiti Division: USGS Cochiti to below Isleta Diversion – Cross Section Plots, Corps of Engineer Plots, Summary and Bed Material Size Analysis". This file contains handwritten notes by E.S. Olivas dated 1/14/86 which includes median bed material sizes obtained from gradation curves in the report "Cochiti Division River Characteristics Study, X-Sections 1 thru 23".

For 1992 and 1995 the data were collected by FLO Engineering for the U.S. Bureau of Reclamation and were retrieved in electronic format from the U.S. Bureau of Reclamation, Albuquerque Office. These data are available in the final reports titled Cross Section Surveys and Bed Material Sampling Cochiti Range (CO) Lines, July and August 1992 and August 1995 report. Table B-1 in Appendix B summarizes the surveyed dates for the 37 cross sections.

For the CO-Lines downstream from Isleta Diversion (CO-668 to CO-1194), bed material data are also available for 1992 and 1995. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation and were retrieved from the U.S. Bureau of Reclamation, Albuquerque Office. Table B-2 in Appendix B lists the surveyed dates for each one of these cross sections.

Santo Domingo Range Lines

Bed material particle size distributions are available for the SD – Lines for 1990 and 1992. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation and were retrieved in electronic format from the U.S. Bureau of Reclamation, Albuquerque Office. Table B-3 in Appendix B contains all the surveyed dates for each one of the SD-lines.

San Felipe Pueblo Range Lines

Bed material particle size distributions are available for the SFP – Lines for 1992. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation and were retrieved in electronic format from the U.S. Bureau of Reclamation, Albuquerque Office in electronic format. Table B-4 in Appendix B contains all the surveyed dates for each one of the SD-lines.

All the FLO Engineering data include particle size distribution at different stations across each cross section and values of d84, d50 and d35 for each one of the particle analyses.

Bed material data for the following USGS gaging stations were collected:

Bed material data from records of U.S.G.S gaging stations are available for 12 years between 1960 to 1992. These data consist of particle size distributions for the following gaging stations: Rio Grande at Otowi Bridge (08-3130-00), Rio Grande at Cochiti (08-

3145-00), Rio Grande at San Felipe (08-3190-00), Rio Grande near Bernalillo (08-3295-00), Galisteo Creek at Domingo (08-3180-00) and Jemez River near Jemez (08-3240-00).

These data were collected by the U.S. Bureau of Reclamation and were retrieved in electronic format from the Environmental Protection Agency (EPA) Storet Data. Table B-5 in Appendix B contains the surveyed dates for each one of the stations.

b.2. Suspended Sediment Data

The suspended sediment data consists of suspended sediment concentration, discharge, and particle size distribution. The data compiled were collected in the following USGS gaging stations: Rio Grande at Embudo (08-2795-00), Rio Chama near Abiquiu (08-2875-00), Rio Chama above Abiquiu Reservoir (08-2865-00), Rio Chama below Abiquiu Dam (08-2870-00), Rio Grande at Chamita (08-2900-00), Rio Grande at Otowi Bridge (08-3130-00), Rio Grande at Cochiti (08-3145-00), Rio Grande Below Cochiti Dam (08-3174-00), Galisteo Creek at Domingo (08-3180-00), Galisteo Creek below Galisteo Dam (08-3179-50), Rio Grande at San Felipe (08-3190-00), Jemez River near Jemez (08-3240-00), Jemez River below Jemez Canyon Dam (08-3290-00), Rio Grande near Bernalillo (08-3295-00) and Rio Grande at Albuquerque (08-3300-00).

The suspended sediment concentration data are in mg/l (milligrams per liter) and the suspended sediment discharge in tons/day (tons per day). These data are available in electronic format and were retrieved from the CD- ROM EarthInfo Inc, USGS Daily Values, West 1 1995 available at Colorado State University Library and from the EPA

Storet Data. Table B-6 in Appendix B lists the surveyed dates for the data obtained from the CD-ROM. Tables B-7 and B-8 contain the surveyed dates for the data gathered through EPA Storet Data.

Suspended sediment particle size distributions were surveyed from 1960 to 1996. The particle sizes are within the range of 2.0 mm (very coarse sand) and 0.002 mm (coarse clay). The surveyed dates at each gaging station are listed in Table B-9 in Appendix B.

C. Flow Discharge Data

The flow discharge data consist of daily mean discharge expresses in cubic feet per second (cfs). These data were collected in the following USGS gaging stations:

Rio Grande at Embudo (08-2795-00), Rio Chama near Abiquiu (08-2875-00), Rio Chama above Abiquiu Reservoir (08-2865-00), Rio Chama below Abiquiu Dam (08-2870-00), Rio Grande at Chamita (08-2900-00), Rio Grande at Otowi Bridge (08-3130-00), Rio Grande at Cochiti (08-3145-00), Rio Grande Below Cochiti Dam (08-3174-00), Galisteo Creek at Domingo (08-3180-00), Galisteo Creek below Galisteo Dam (08-3179-50), Rio Grande at San Felipe (08-3190-00), Jemez River near Jemez (08-3240-00), Jemez River below Jemez Canyon Dam (08-3290-00), Rio Grande near Bernalillo (08-3295-00) and Rio Grande at Albuquerque (08-3300-00).

These data were retrieved from the USGS Web Page, CD- ROM EarthInfo Inc, USGS Daily Values, West 1 1995 available at Colorado State University Library, and U.S.

Bureau of Reclamation, Albuquerque Office. Table B-10 in Appendix B lists the period of records at each station.

Surveys of the Cochiti range lines from 1970 to 1975 include discharge measurements. These data are available in hardcopies in the report by Dewey et al. (1979).

D. Aerial Photos and Planform Plots

Topographic maps from White Rock Canyon to San Marcial are available for 1917 and 1918 surveys at a scale of 1”:1000’. A total of 8 sheets out of 39 sheets contain the topographic maps from White Rock Canyon to Bernalillo. These topographic maps were created by the U.S. Reclamation Service in June 1922 based on data collected from November 1917 to September 1918.

Black and white aerial photos from Cochiti Dam to San Marcial are available for April 1972 at a scale of 1:24,000. This set of photography includes runs over Galisteo Creek and Jemez River. A set of color infrared aerial photographs is available from Cochiti Dam to San Felipe for April 1979 at a scale of 1:6,000. Cochiti Range Lines are indicated in the infrared photographs. These aerial photo sets were obtained from Dr. Peter F. Lagasse. Blue line reproductions of aerial photos are available from 1984 to 1996. Photographs taken over the entire study reach are available for 1992 and 1996. Table C-1 in Appendix C contains the list of blue line reproductions together with the date and scale of photography.

Planform comparison plots from Cochiti Dam to Highway 44 Bridge at Bernalillo are also available from 1918 to 1992. These plots were produced by the U.S. Bureau of

Reclamation, Remote Sensing and Geographic Information Group, Denver, Colorado. These comparison plots are grouped as follows:

Planform comparison for 1918-1935/1936

Planform comparison for 1935-1949

Planform comparison for 1949-1962

Planform comparison for 1962-1972

Planform comparison for 1972-1984

Planform comparison for 1984-1992

3.2 Computer Database

The data compiled for this work has been classified into three main categories: a) Cross section data; b) Sediment data; and c) Flow discharge data. A computer database was organized according to this classification to arrange the data in an appropriate format for further analysis. Figure 3.1 in this section shows the structure of the computer database. The entire database is included in a main folder called Rio Grande, which has been structured as follows:

a) Cross-section data folder

This folder contains the cross section surveys from 1970 to 1995. The data have been organized by years and then by cross-section range line sets. A total of 16 folders contain the cross section data by years. They are: 1970, 1971, 1972, 1973, 1974, 1975, 1979, 1980, 1982, 1983, 1986, 1990, 1992, 1993, 1995 and 1996.

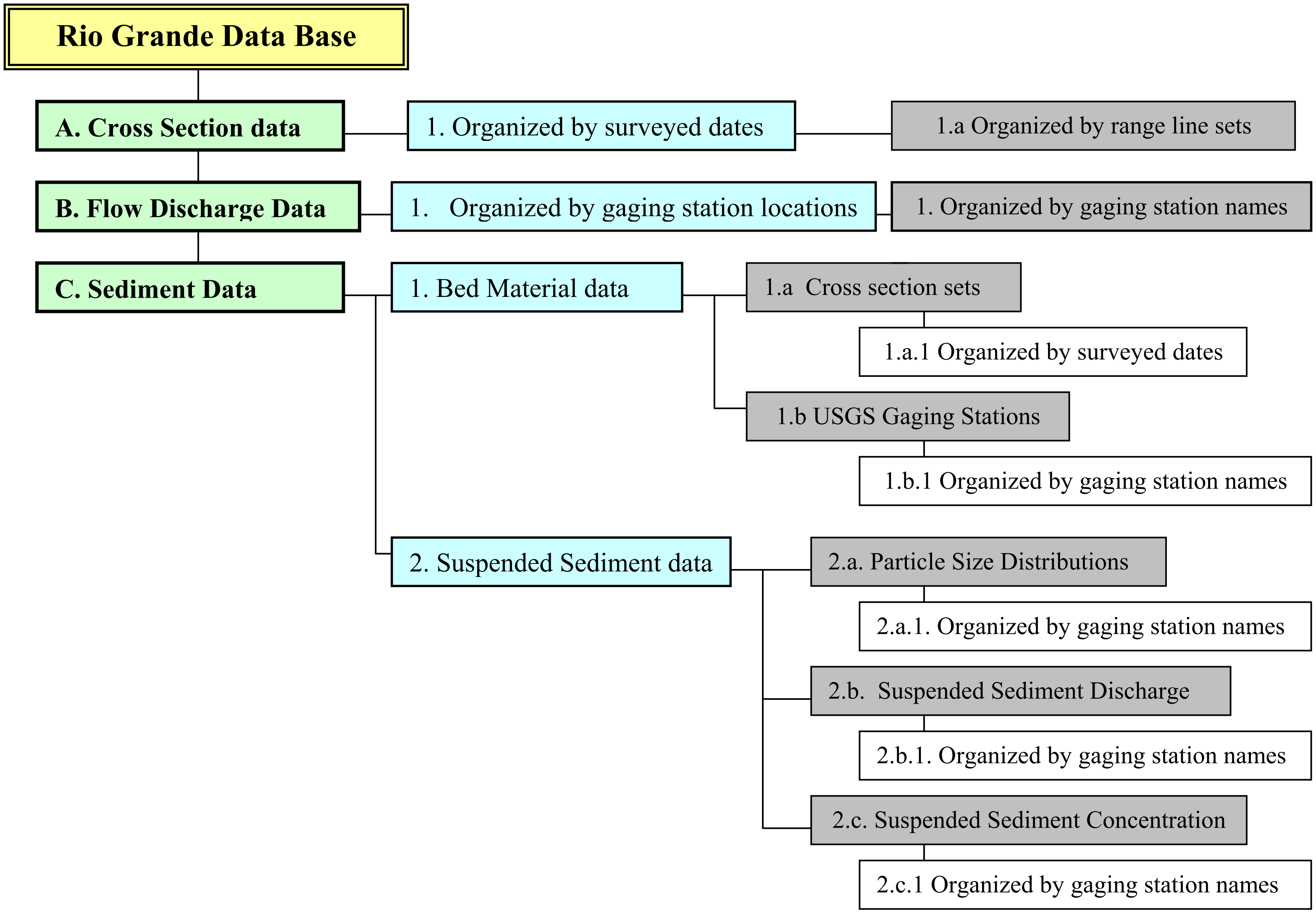

Fig. 3.1. Diagram of the computer data base.

Each one of these folders contains the cross-section data organized by range line sets. The cross-section files have kept the same name that they had when they were retrieved from the different sources. The first three digits are the range line name preceded by the letter D and the four last digits represent the surveyed date (month and year). For instance, the file DCO0571 corresponds to the CO range lines (Cochiti range lines) and the surveyed date is May 1971. Figure 3.2 shows a screen printout from Windows NT Explorer indicating the path to retrieve the CO-line data of May 1971.

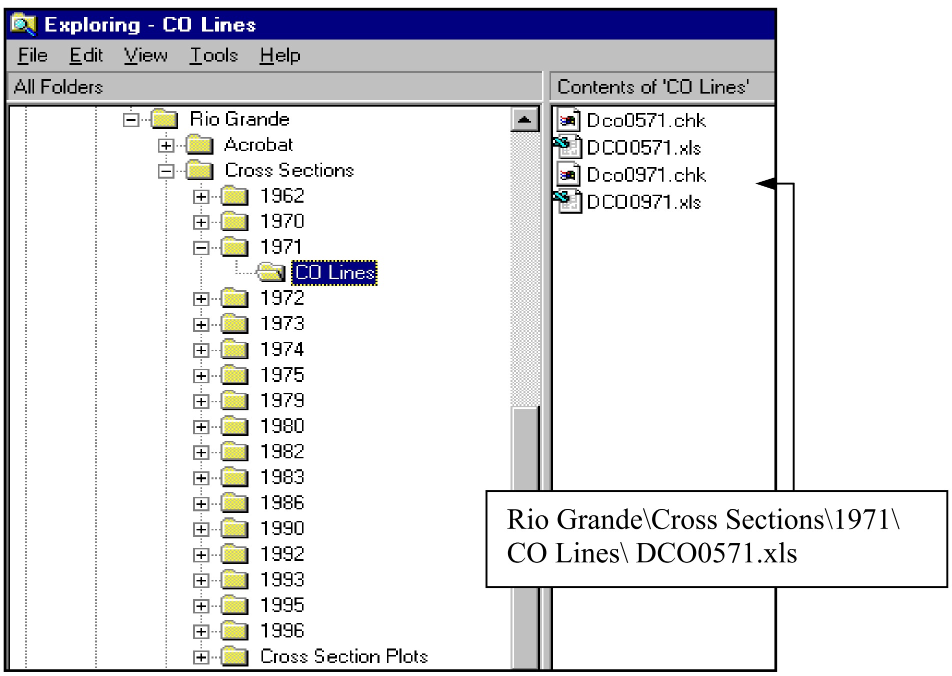

Fig. 3.2. Screen printout of the cross section data folder.

Some cross sections were surveyed more than one time during the same month. In those cases, the file names are followed by the letter A,B, or C after the survey date. For instant in November 1973, 3 surveys were performed during different days. The file names for these surveys are DCO1173A, DCO1173B and DCO1173C. The Agg-Deg line files are named differently than the rest of the files. The first two digits indicate the survey year and the last six digits indicate the cross section numbers included in the survey. For example, the file name 6219t299 corresponds to the year 1962 and to the cross sections 19 to 299.

b) Flow discharge data

This folder contains the files with flow discharge records collected at the USGS gaging stations. The data are organized according to the location of the gaging stations. For instance the folder Cochiti contains data for Rio Grande at Cochiti and Rio Grande below Cochiti Dam gaging stations. The flow discharge files are called by the gaging station name, followed by the time period at which the data have been collected. For example, the flow discharge data at Rio Grande below Cochiti Dam station are in a file named Rio G. below Cochiti Dam 1970-1997. Figure 3.3 shows a screen printout from Windows NT Explorer indicating the path to retrieve the flow discharge data at Rio Grande below Cochiti Dam gaging station.

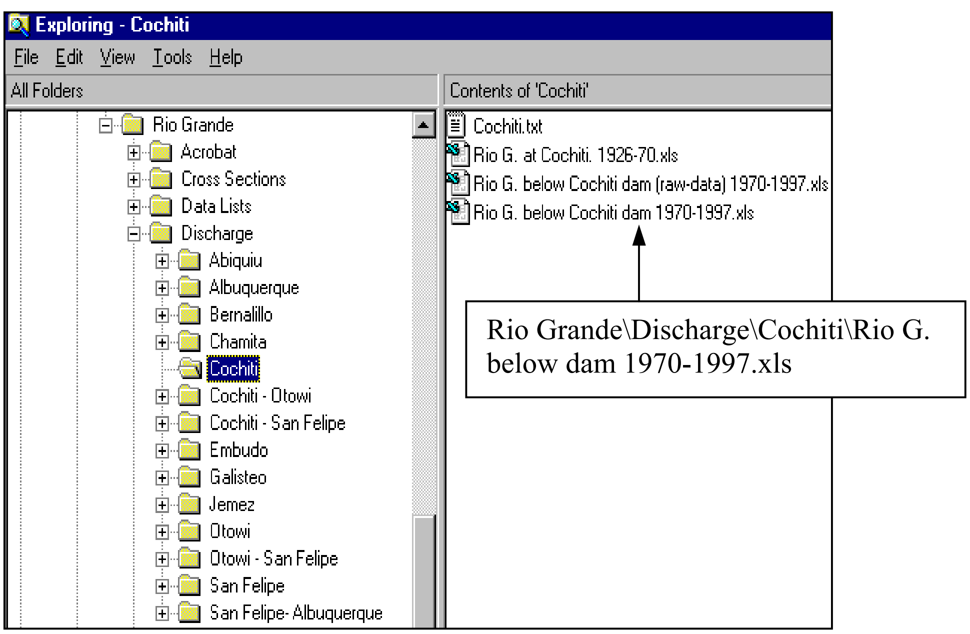

Fig. 3.3. Screen printout of the flow discharge data folder.

c) Sediment data folder

This folder contains the sediment data organized by two categories: Bed Material and Suspended Sediment data.

The bed material data are organized into two folders called Cross Sections and USGS Gaging Stations. The bed material data included in Cross Sections sub-directory are then organized by years in a total of 12 folders. These 12 folders are 1970, 1971, 1972, 1973, 1974, 1975, 1979, 1980, 1982, 1990, 1992 and 1995. The data have been organized by cross-section range line sets in each one of these folders.

The file names for bed material start with the letters BM (Bed Material) which are followed by the name of the gaging station or the initials of the cross section range line set and the surveyed date. For instance, BMSD1190 corresponds to bed material data for Santo Domingo Range Lines surveyed in November 1990. This convention was taken from the electronic files obtained from FLO Engineering reports.

The suspended sediment data are organized by Particle Size Distribution, Concentration and Discharge data. Each one of these folders contains the data organized by gaging station location and then by gaging station names followed by the period of records. The name of the files that were obtained from the EPA-Storet data base are preceding by the letters EPA. For instant, the suspended sediment concentration file for Rio Grande below Cochiti Dam station is named EPA-Rio Grande below Cochiti Dam 1974-1996. Figure 3.4 shows the sediment data folder.

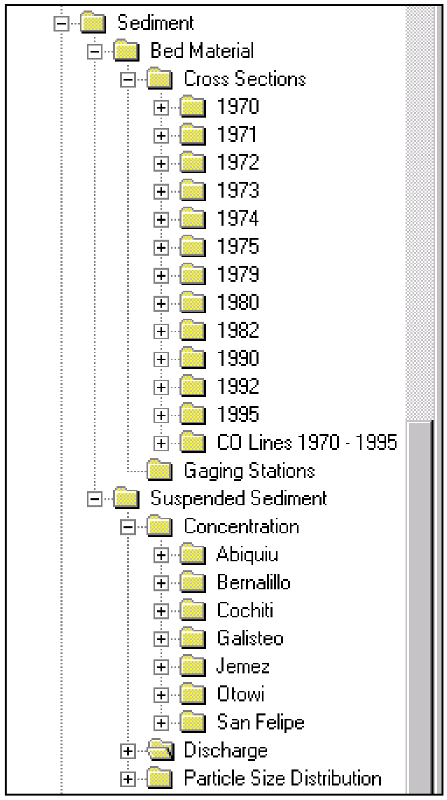

Fig. 3.4. Screen printout of the sediment data folder.

3.3 Generated Data

A. Cross-section Data

The cross-section data utilized in the analyses included in this work correspond to the Cochiti Range Line surveys. These range lines have the longest record available in electronic format.

From 1970 to 1975, the cross-section plots are included in the report by Dewey et al. (1979).

The 9 post-dam surveys plotted are: November 1975, April 1979, July 1979, January 1980, October 1982, November 1983, November 1986, July 1992 and August 1995.

These surveys were plotted together at each cross section in order to observe the cross-section changes with time.

The November 1975 survey was collected after the summer flows, which had a maximum peak of approximately 4,500 cfs. The April 1979 survey was performed during the beginning of the spring runoff of 1979, in the rising limb of the hydrograph. July 1979 survey followed the approximated 6,800-cfs peak register in Rio Grande below Cochiti Dam gaging station. January 1980 survey was performed during winter season when flows were lower than 1,000 cfs (at Rio Grande below Cochiti). The October 1982 survey followed a sequence of summer flows, which reached about 5,000 cfs in June (at Rio Grande below Cochiti). November 1983 and 1986 surveys were performed during wintertime. Two peak flows, greater than 6,000 cfs occurred in between these two surveys. However, no data were collected during this period. July 1992 and August 1995 surveys were gathered after spring flow with peak flows greater than 5,000 cfs (at Rio Grande below Cochiti).

The cross-sections were surveyed from left bank, looking downstream. Cross section plots are included in Chapter IV (Figures 4.2 to 4.10) and in Appendix D (Figures D-1 to D-20). Cross-section CO-17 coincides with Rio Grande at San Felipe gaging station. This section is located downstream of the Arroyo Tonque delta. The cross section plots at this location are shifted to the left probably because the left bank reference point position has been changed due to the influence of the Arroyo Tonque delta. Cross section data from 1975 to 1992 were modified by shifting the cross sections until all the right banks coincide with the right bank of the most recent survey (August 1995). The January 1980 survey was not only shifted but also flipped because the shape of this section was a mirror image of the other surveys. The November 1975 and August 1995 surveys of the cross section CO-5 were also shifted to the left until the right banks coincided with the right banks of the other surveys.

Records from 1970 to 1992 include water surface elevations. The water surface elevations were obtained from the cross section survey files and included into two different files. One file contains the water surface elevations organized by dates, and the other file includes the water surface elevations organized by cross section number. After checking some of these data, some errors where found in the water surface elevation values. For example, in June 12, 1973 the cross section CO-5 was surveyed and 3 water surface elevation measurements were collected during this survey. The first elevation is 5193.79 feet measured 47 feet from the left bank reference point. The second measurement was 5,201.95 feet at 330 feet from the left bank reference point, and the last elevation was 5,194.02 at station 372 feet from the left bank reference point. From these values it can be observed that the elevation measured at station 330 differs about 8 feet from the other two measurements which were collected during the same day.

The Dewey et al. (1979) report contains the average water surface elevation at each cross section for the surveys performed from 1970 to 1975. These data were transferred into the water surface elevation file organized by cross sections. Comparison of these values with the data from the cross section files shows some discrepancies.

B. Flow Discharge Data

The hydrographs at each gaging station were plotted. In order to compare the flow discharge that reaches Cochiti Reservoir and the flow discharge releases from the Dam, the hydrograph for Rio Grande at Otowi Bridge was plotted together with the hydrograph at Rio Grande below Cochiti Dam. Figure 3.5 shows the 1995 hydrograph at Rio Grande at Otowi Bridge and below Cochiti Dam. It can be observed that the peak flow of about 8,600 cfs that reaches Otowi station during June 1995 was regulated by Cochiti Dam to a peak flow of 5,700 cfs. It is also interesting to observe that the peak flow at Rio Grande below Cochiti Dam during May was bigger than the inflow discharge registered at Rio Grande at Otowi Bridge gaging station. Flow discharge data from 1974 to 1988 at Rio Grande at Otowi Bridge station and Rio Grande below Cochiti Dam station indicate that peak outflows from Cochiti can historically occur as much as 62 days after, or as much as 225 days prior to the peak inflows to the reservoir. Cochiti Dam is not operated in the traditional flood control manner (Bullard and Lane, 1993).

The hydrograph for the Rio Grande below Cochiti station was plotted along with the hydrograph for Rio Grande at San Felipe station, and the hydrograph of Rio Grande at San Felipe together with the hydrograph at Rio Grande at Albuquerque station in order to evaluate the effect of tributaries and diversions downstream Cochiti Dam. It can be observed that peak flow of the hydrograph at San Felipe station is bigger than the hydrograph below Cochiti Dam due to the inflow from tributaries and arroyos. The two - year return flow of 5,650 cfs. has been indicated in both figures.

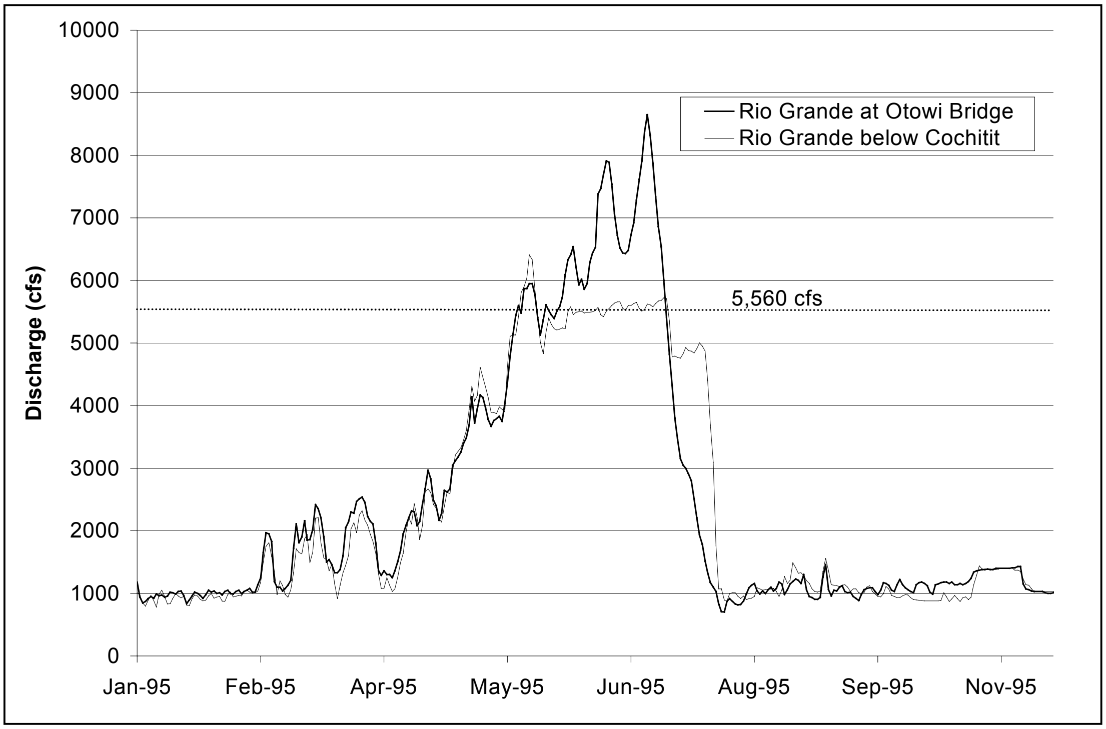

Fig. 3.5. 1995 flow hydrograph of Rio Grande at Otowi Bridge and Rio Grande below Cochiti Dam gaging stations.

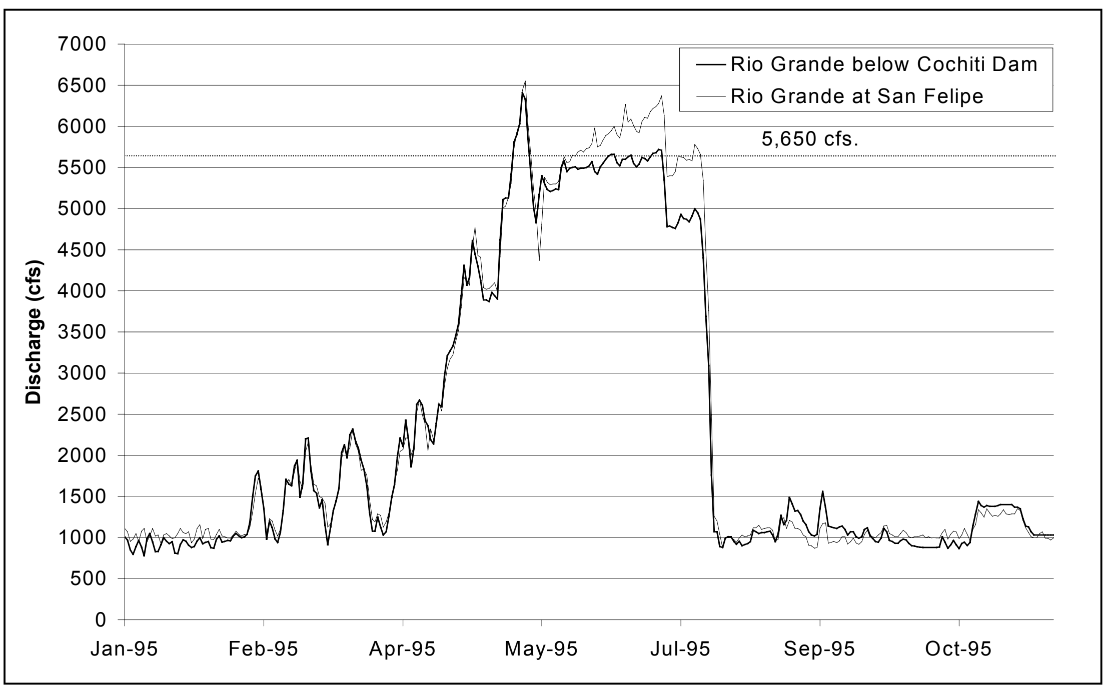

Fig. 3.6. 1995 flow hydrograph of Rio Grande below Cochiti Dam and Rio Grande at San Felipe gaging stations.

C. Longitudinal Profile

Thalweg elevations at each one of the 29 cross sections were obtained from a total of 9 surveys. The cross section data were included into HEC-RAS V. 2.0 in order to obtain the thalweg elevations, but no calibration of the model was performed. The surveyed dates considered are: May 1971, June 1973, January 1974, November 1975, April 1979, July 1979, August 1980, July 1992 and August 1995. Plots of thalweg elevations against distance downstream Cochiti Dam were created for the 9 surveys. Figures 3.7 and 3.8 show the thalweg profile of the river in two reaches, from cross section CO-2 to CO-15 and for cross section CO-15 to CO-30. The thalweg profile for the entire study reach was also divided into Figures 3.9, 3.10, and 3.11 with bigger vertical scale in order to observe the incremental changes in thalweg elevation. Distances downstream from Cochiti Dam were obtained from Dewey et al.'s report (1979). Planform comparisons among the 1972, 1984 and 1992 surveys do not show considerably difference in river length and therefore the same distances used in previous studies have been used in this work. Location of cross-section numbers, main tributaries and diversion dams are indicated in the profile plots. Where a data point was not available, a straight-line interpolation was performed from an upstream to a downstream cross section.

Another variable evaluated in this work is the mean bed elevation. At each cross section the mean bed elevation was computed using the 9 cross-section surveys mentioned above. In order to perform these calculations, an elevation was fixed at each cross section where both banks become vertical, generally at the top bank elevation. Computations of top width and cross-section area below the set elevation were performed at each cross section. The mean depth was obtained by taking the ratio of cross-section area to top-width. The mean bed elevation was obtained by subtracting the mean depth from the set elevation. The software Sec-Prop, developed at Rand Afrikaans University, Auckland Park, Republic of South Africa, was used to calculate the area and top width at each cross section. In some cases, it was difficult to establish a unique elevation for all the surveys at the same cross section. The 1971 and 1973 surveys for cross sections CO-9 and CO-17 have lower top bank elevations than the top bank elevations for the post-dam surveys. In these cases, the March 1972 survey was used. Lower elevations were proposed, but they only worked for pre-dam surveys because they were not representative of top bank elevation for the post-dam surveys. No measured water surface elevation data were used in these calculations.

Estimations of degradation and aggradation at each cross-section were performed between the most recent pre-dam survey, June 1973, and the most recent post-dam survey, August 1995 using both the thalweg elevation and the mean bed elevation. Figure 3.12 shows the difference in thalweg elevation between the 1973 and 1995 surveys and Figure 3.13 shows the difference in mean bed elevation between the June 1973 and August 1995 surveys. The changes in mean bed elevation and thalweg elevation between the May 1971 survey and the rest of the surveys were calculated at each cross section and represented in Figure 3.14. This plot gives an order of magnitude of the change in mean bed elevation that can be expected when a certain change in thalweg elevation occurs. The changes in thalweg and mean bed elevation with time at each cross section were also plotted in Figures E-1 to E-28 in Appendix E and in Figure 4.1 in Chapter IV.

Percent change in cross section area with distance along the study reach was calculated and represented in Figure 3.15. This figure compares the average area for the 2 pre-dam cross-section surveys with the average area of the 7 post-dam surveys as a percent change from the pre-dam survey value. Changes in cross-section area with time at each cross-section are represented in Figures E-29 to E-57 in Appendix E.

D. Sediment Data

Bed Material:

Median bed material size data available in hardcopies from Dewey et. al.'s report (1979) and handwritten notes from E.S. Olivas from 1970 to 1982 were transferred into electronic format as Microsoft Excel 97 Files. Median bed material size versus distance downstream from Cochiti Dam was plotted in Figure 3.16 from 1970 to 1995. An average of Dewey and Olivas' data from 1970 to 1973 (pre-dam period) and 1974 to 1975 (post-dam period) was performed. 1979 data and average of 1980-1982 data from E.S. Olivas were also plotted. 1992 and 1995 data were included in this graph taking an average of the median bed material size of all samples at each cross section. Cross-section numbers and main tributary locations are indicated in this plot. Where a data point was missing a straight line between the previous and the next data points was drawn. The median bed material size data were also plotted against time from 1970 to 1995 in Figure 3.17.

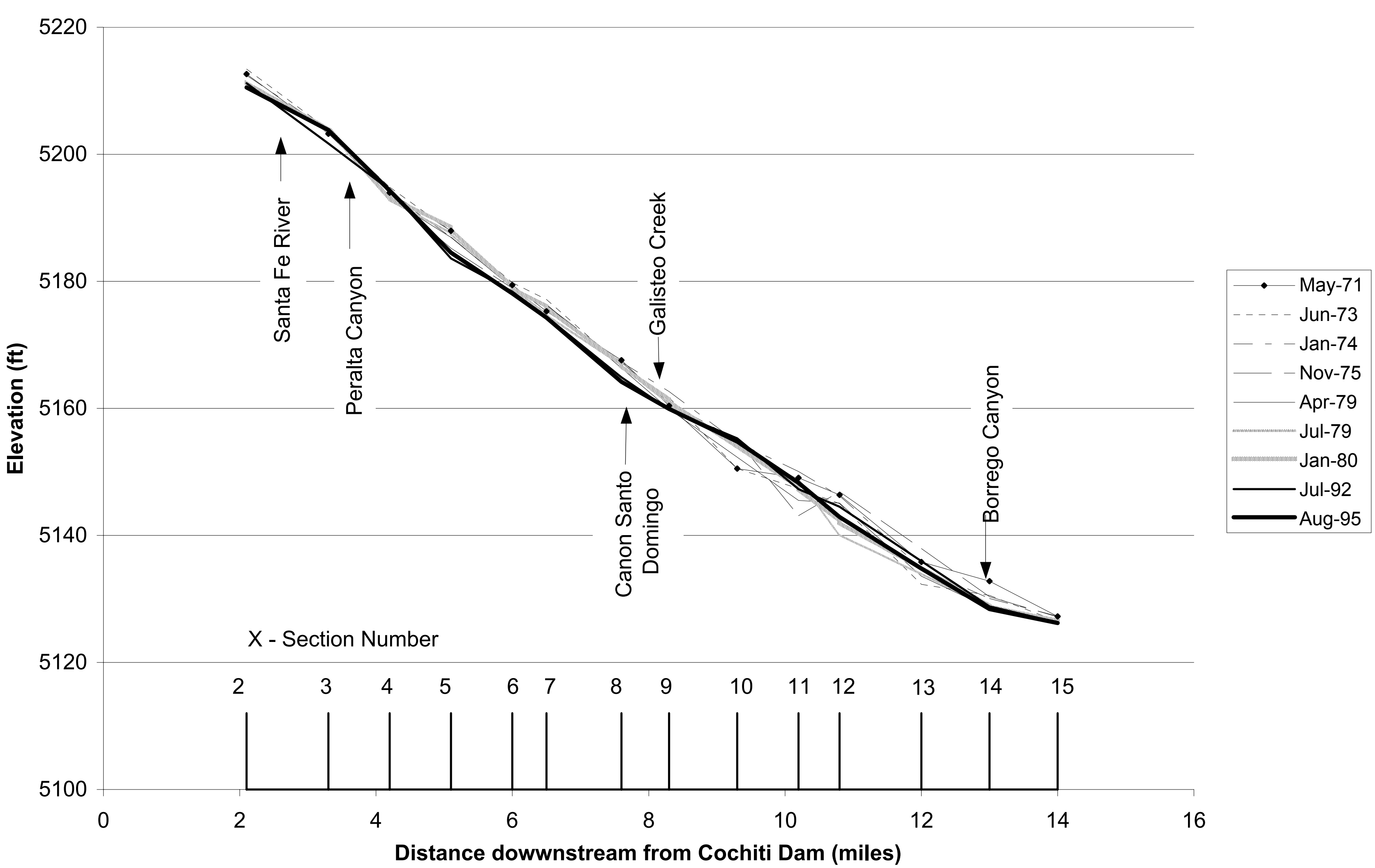

Fig. 3.7. Thalweg profile from cross section CO-2 to cross section CO-15.

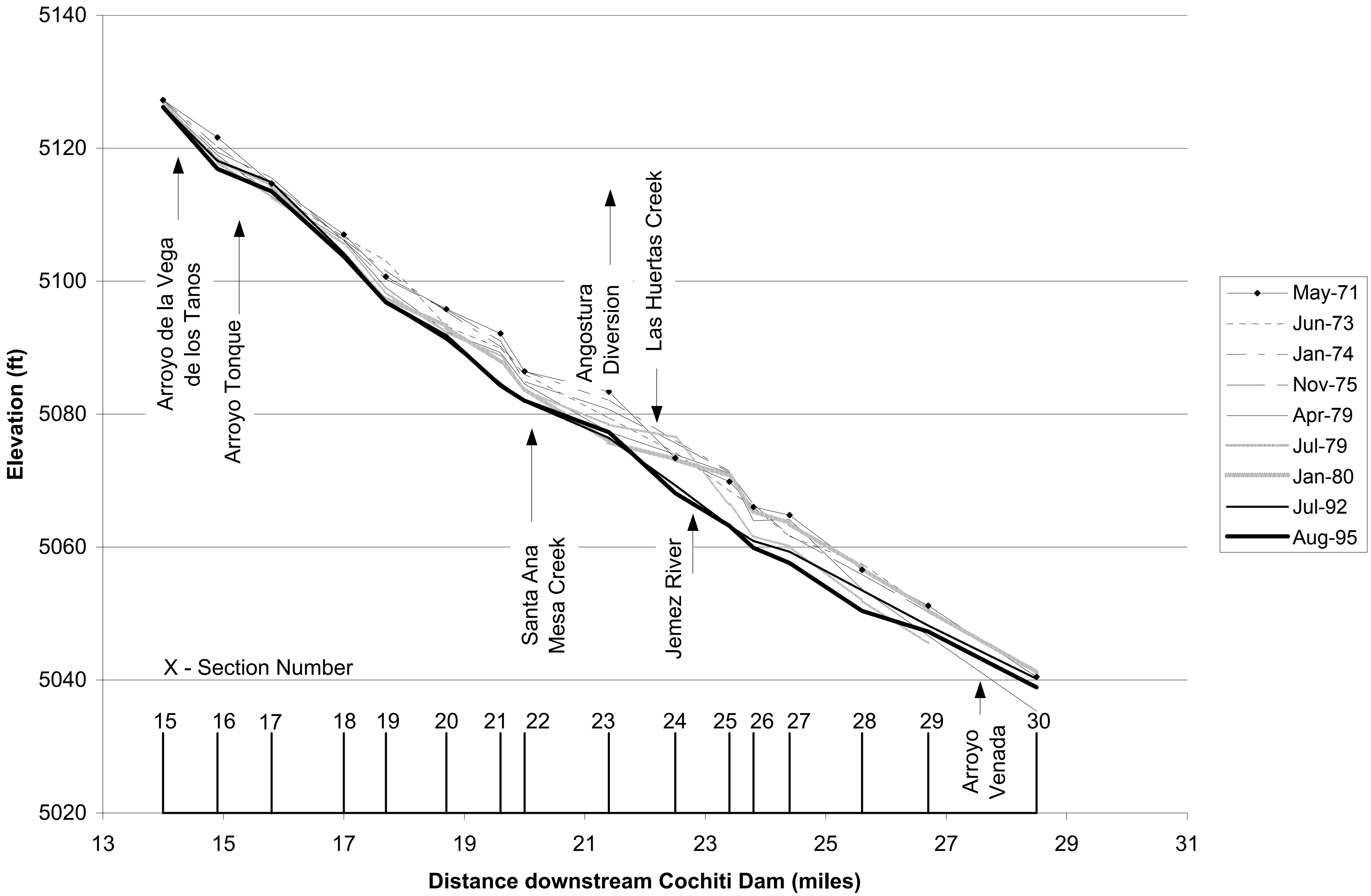

Fig. 3.8. Thalweg profile from cross section CO-15 to cross section CO-17

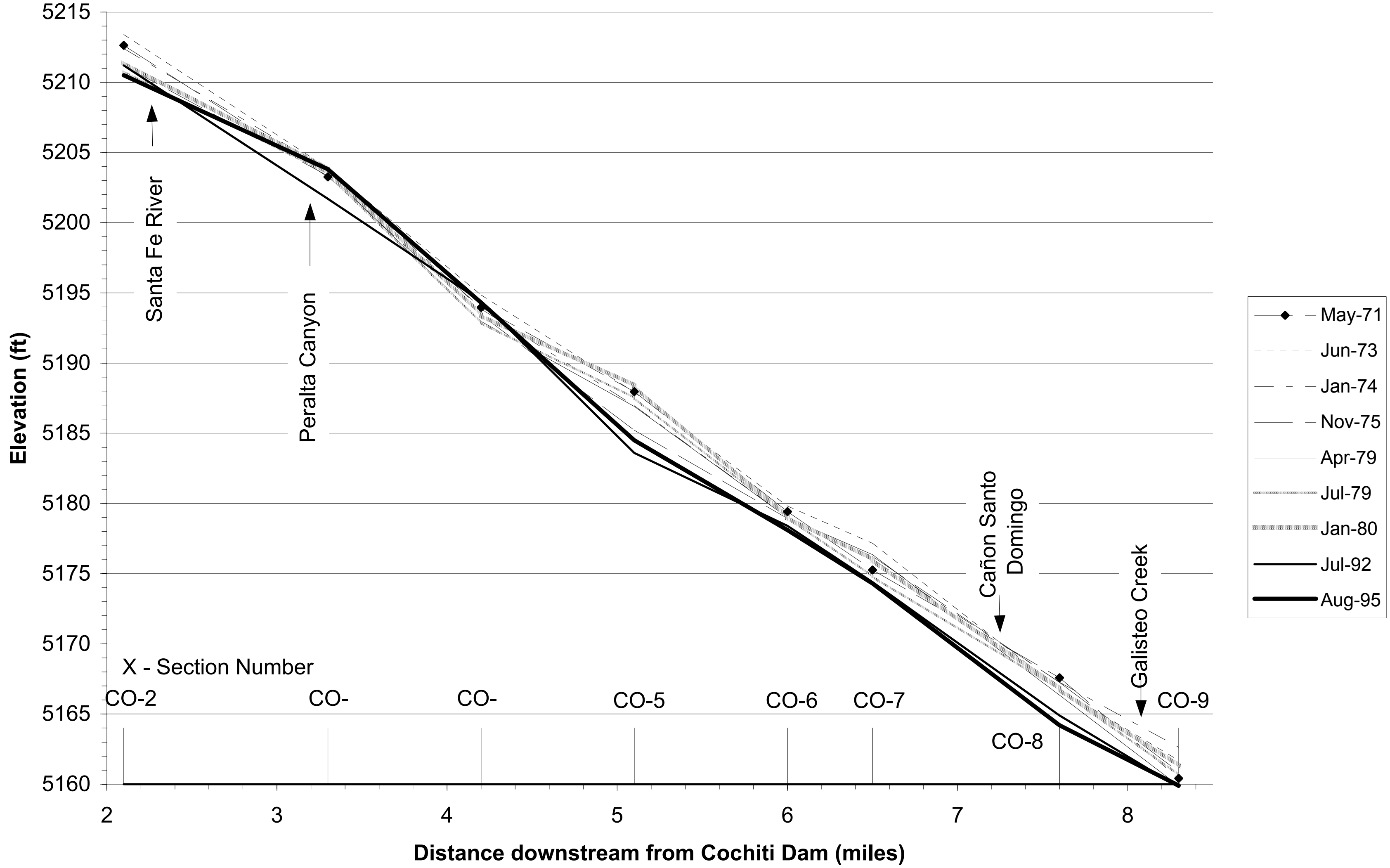

Fig. 3.9. Thalweg profile from cross section CO-2 to cross section CO-9

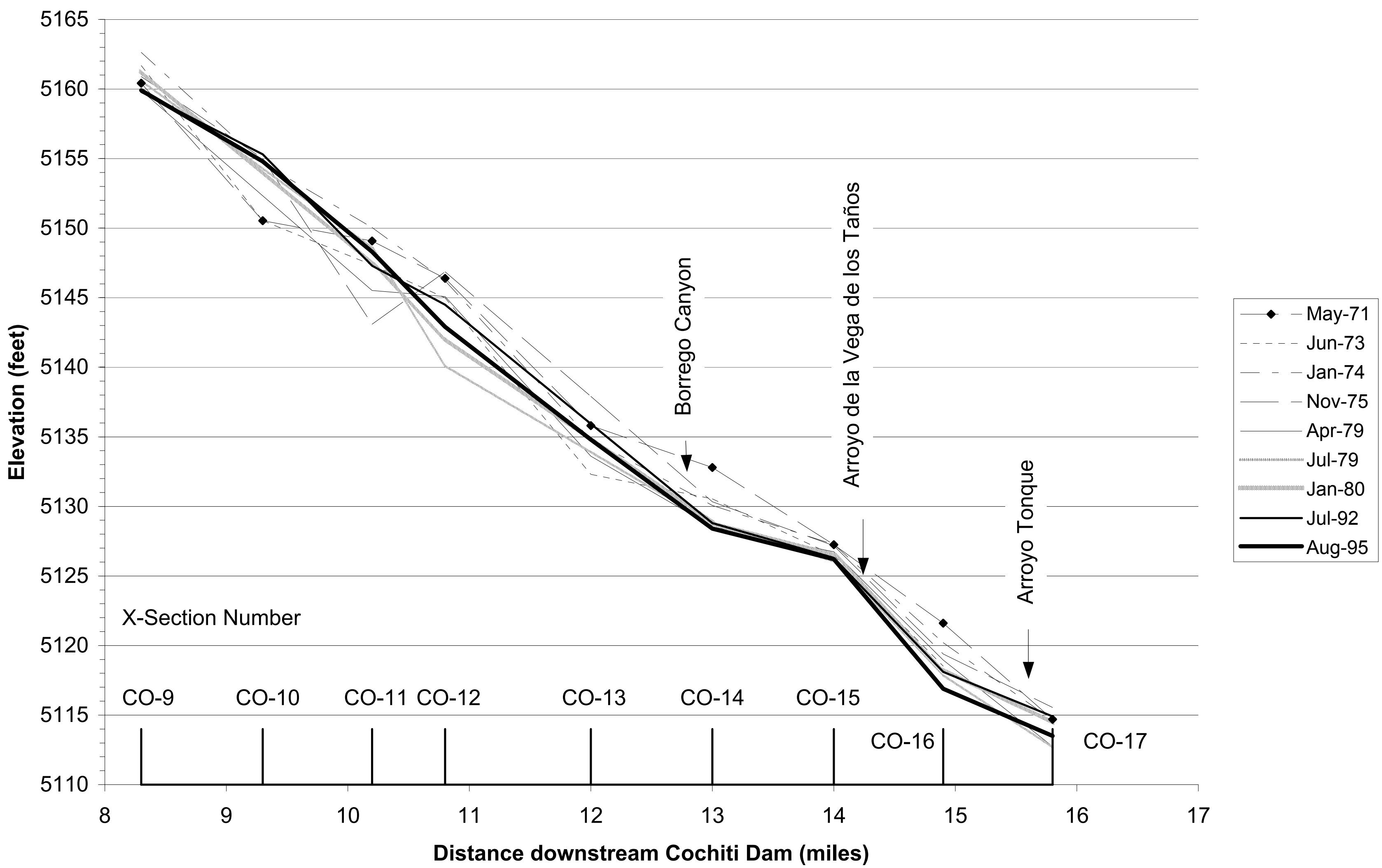

Fig. 3.10. Thalweg profile from cross section CO-9 to cross section CO-17

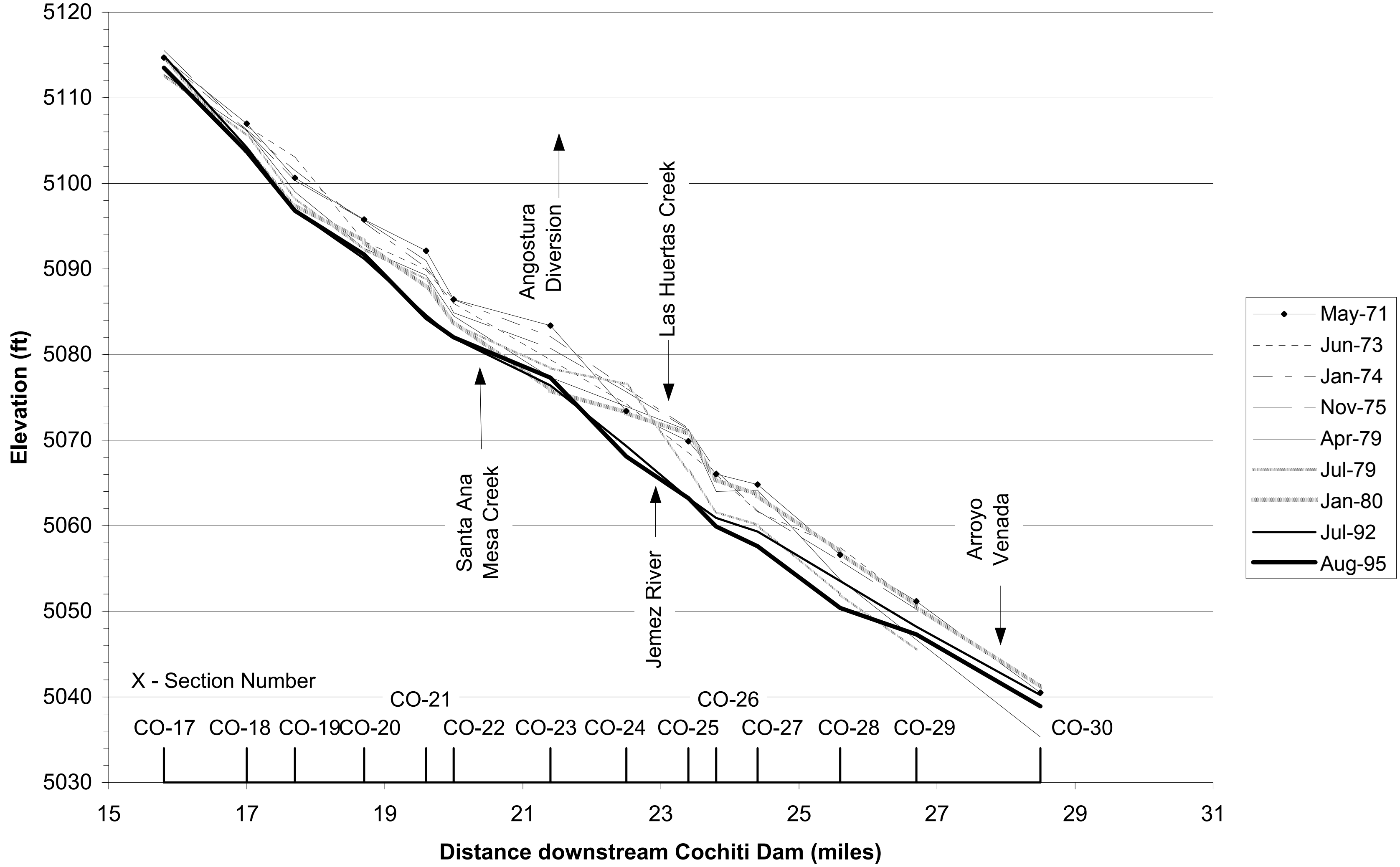

Fig. 3.11. Thalweg profile from cross section CO-17 to cross section CO-30.

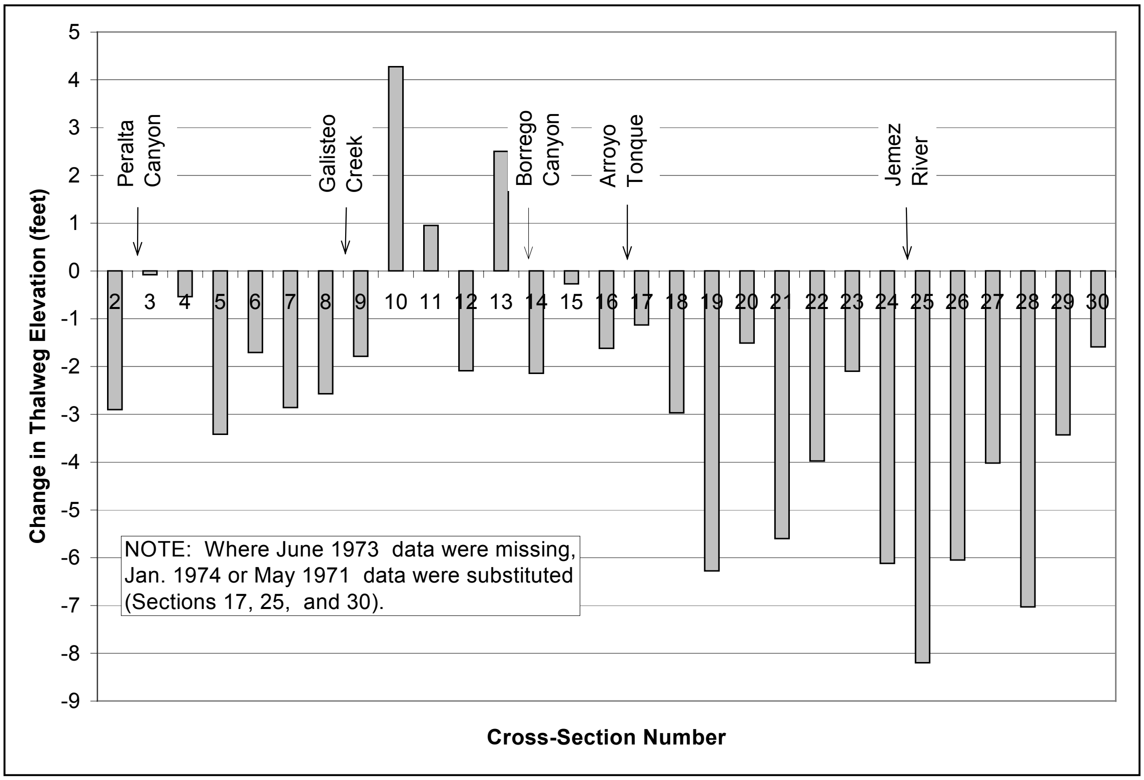

Fig. 3.12. Change in thalweg elevation between June 1973 and August 1995.

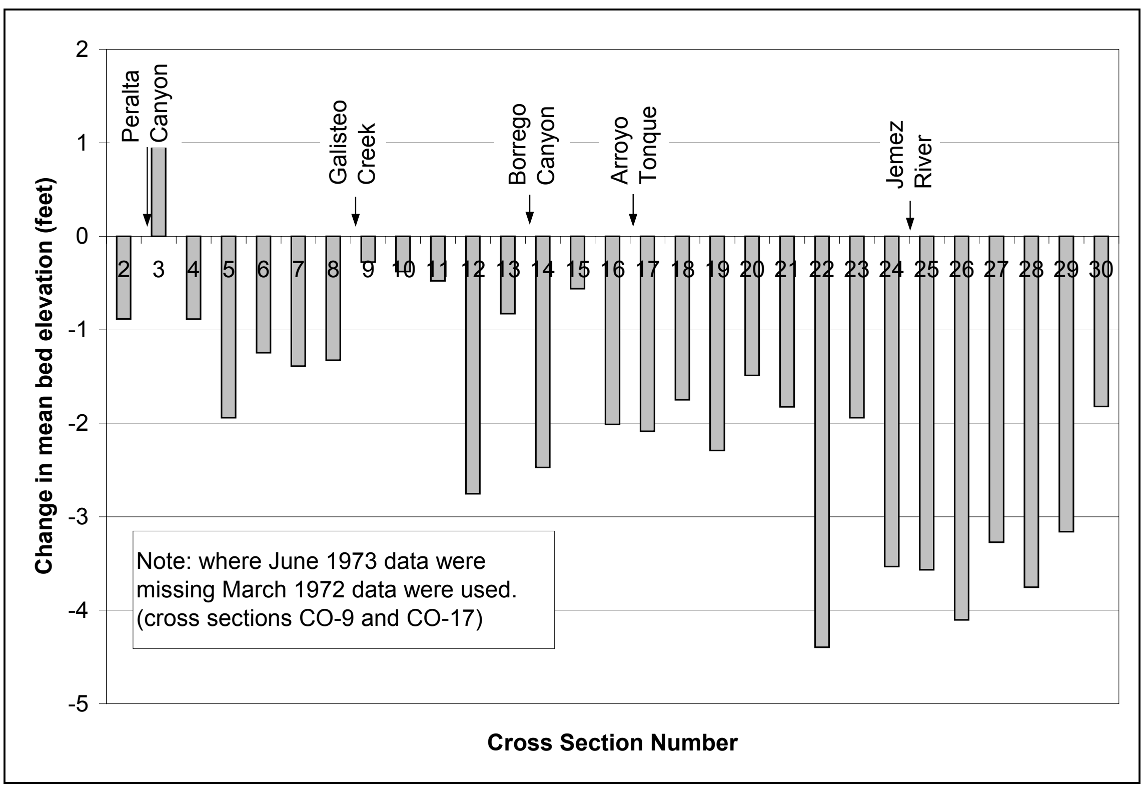

Fig. 3.13. Change in mean bed elevation between June 1973 and August 1995.

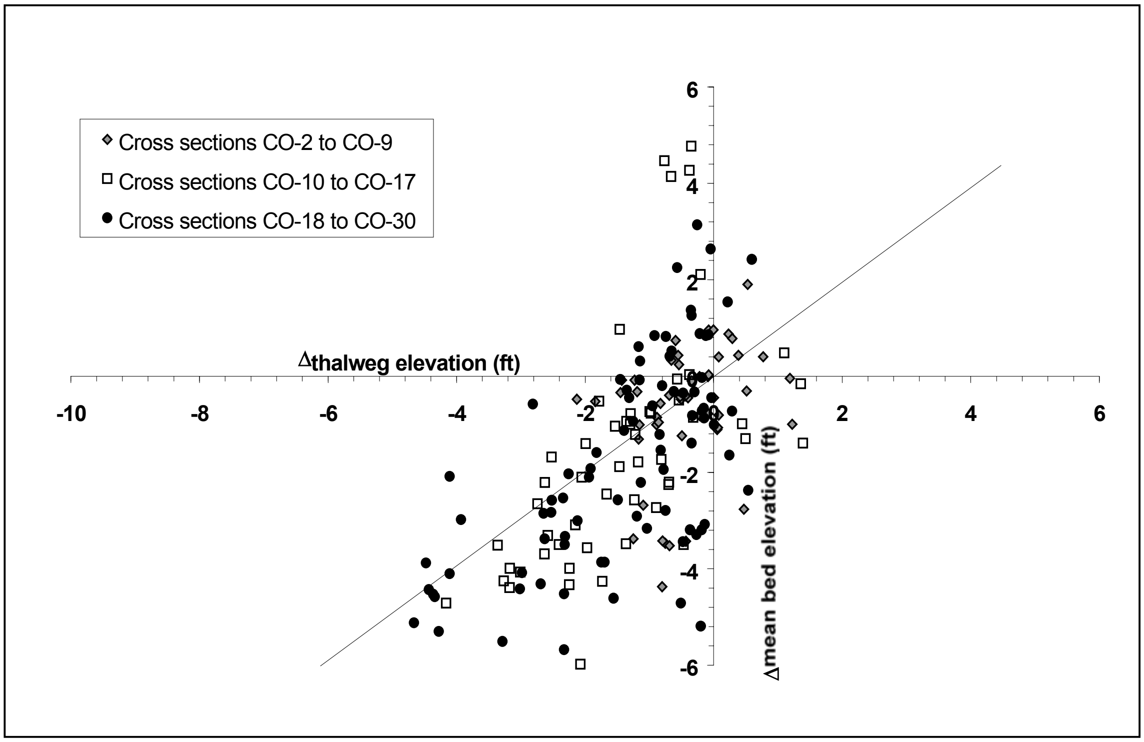

Fig. 3.14. Change referenced to 1971 in mean bed elevation against change referenced to 1971 in thalweg elevation.

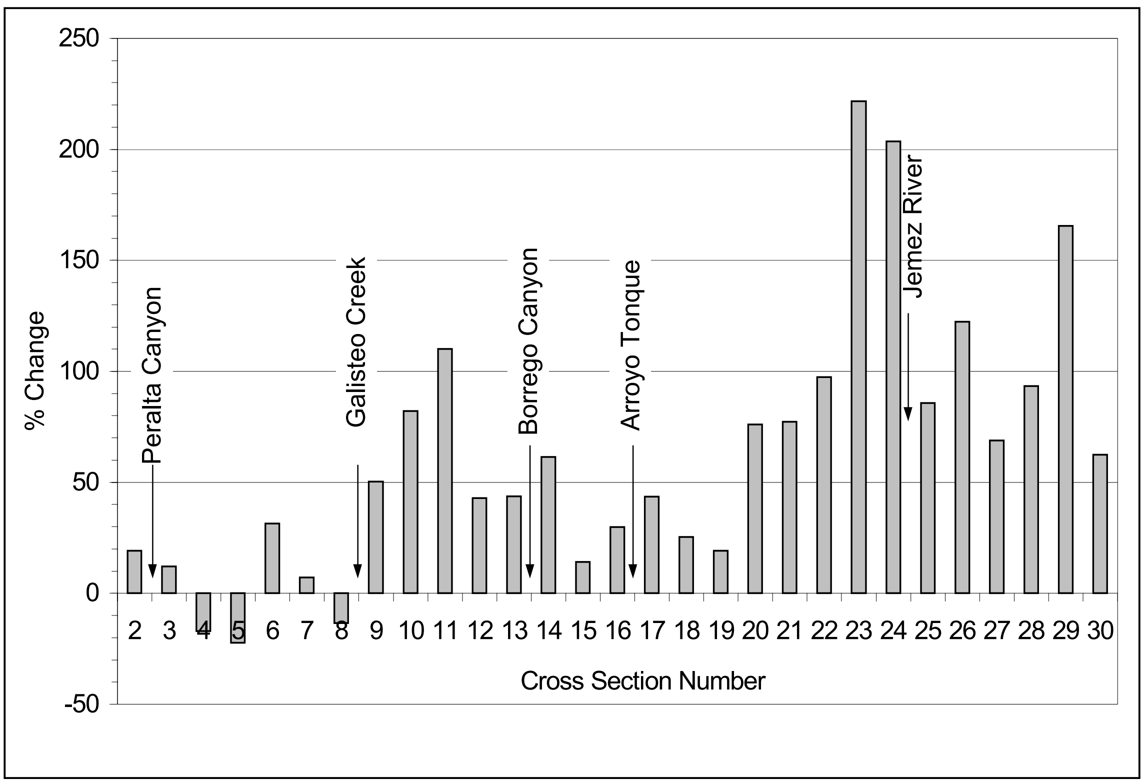

Fig. 3.15. Pre-dam to Post-dam change in cross sectional area.

The changes in median bed material size with respect to the 1971 data at each cross section were plotted against the changes in thalweg and mean bed elevations with respect to the 1971 elevations. These plots are represented in Figures 3.18 and 3.19.

Data from FLO Engineering consist of several samples across each of the cross sections. In some cases, the range of particle sizes is considerably large for the same survey. In order to represent these data in a graphic format, plots of mean, maximum and minimum median bed material sizes versus cross section numbers were performed for the 1992 and 1995 data in Figures 3.20 and 3.21 respectively.

Gradation curve data available for the USGS gaging stations were plotted and mean bed material sizes (d50) were obtained from each one of the surveys. An average median bed material size was obtained for each year at every station. Data for Rio Grande at Cochiti, Rio Grande at San Felipe and Rio Grande near Bernalillo gaging stations were plotted in Figure 3.22. Median bed material size vs. discharge was plotted at San Felipe gaging stations from 1970 to 1974 (Figure 3.23) and at Bernalillo gaging station from 1961 to 1969 (Figure 3.24).

Suspended Sediment Data:

Suspended sediment discharge and concentration data were plotted at each one of the gaging stations. Gradation curves were plotted at each gaging station and suspended median material sizes were obtained from each one of the curves.

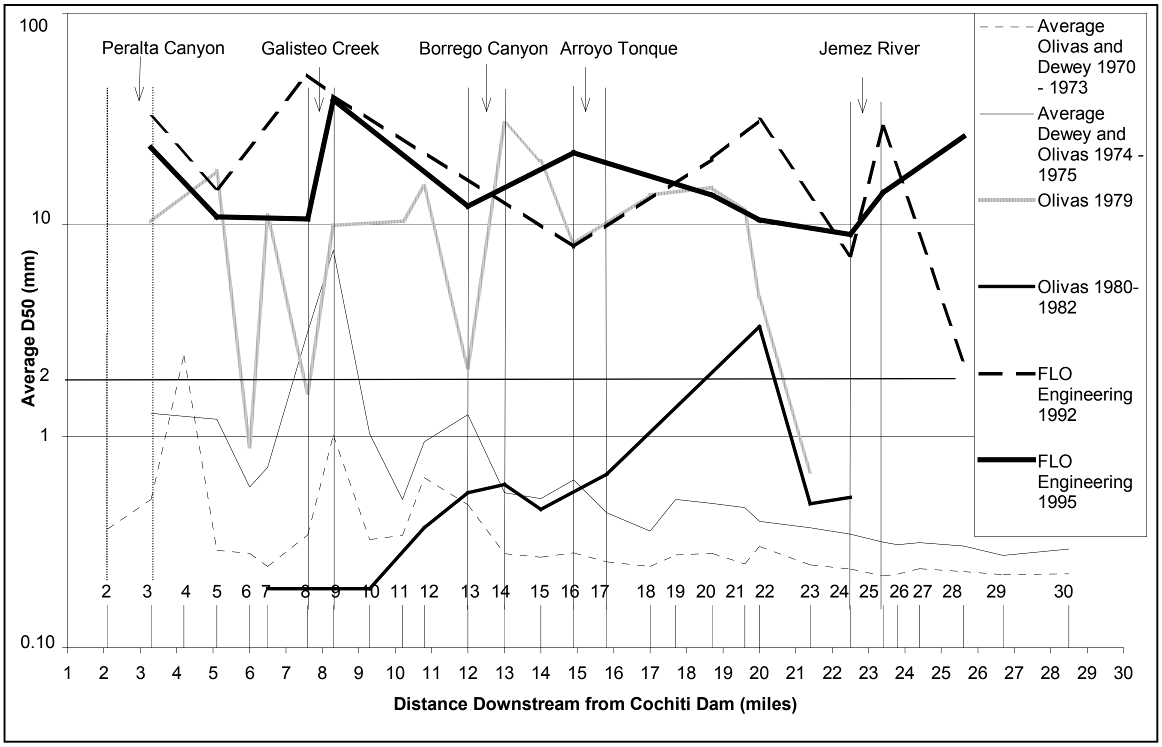

Fig. 3.16. Median bed material size downstream Cochiti Dam from 1970 to 1995.

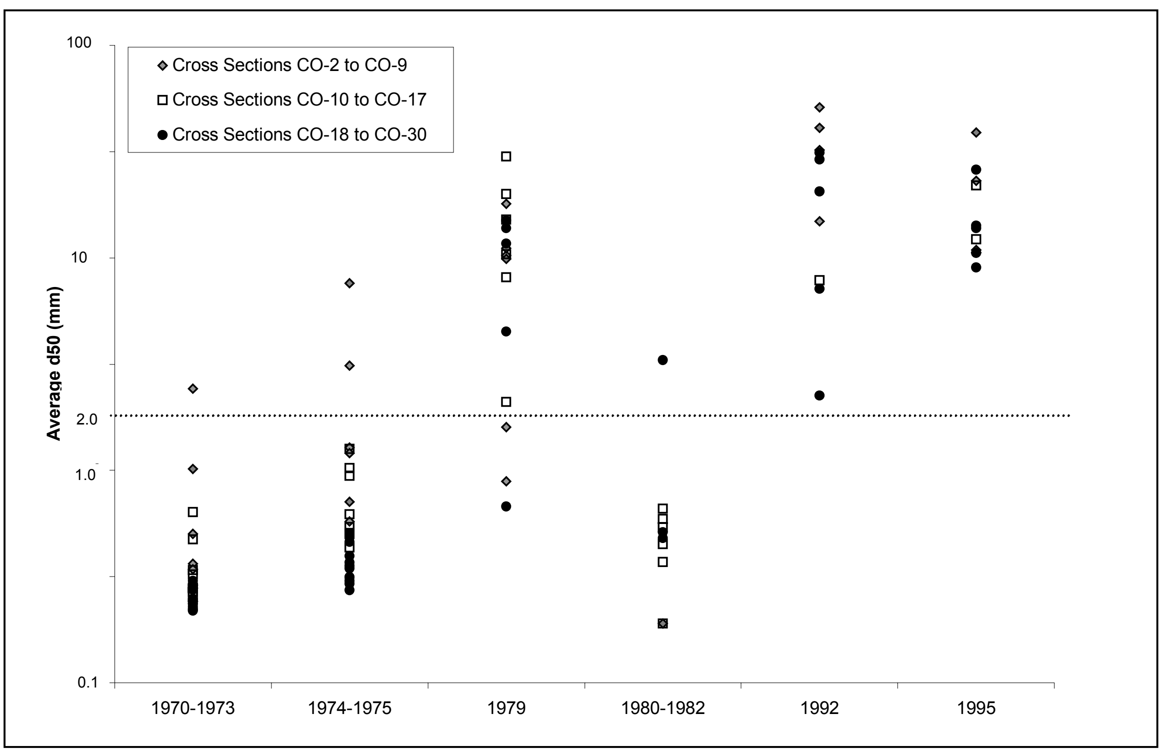

Fig. 3.17. Change in median bed material size with time.

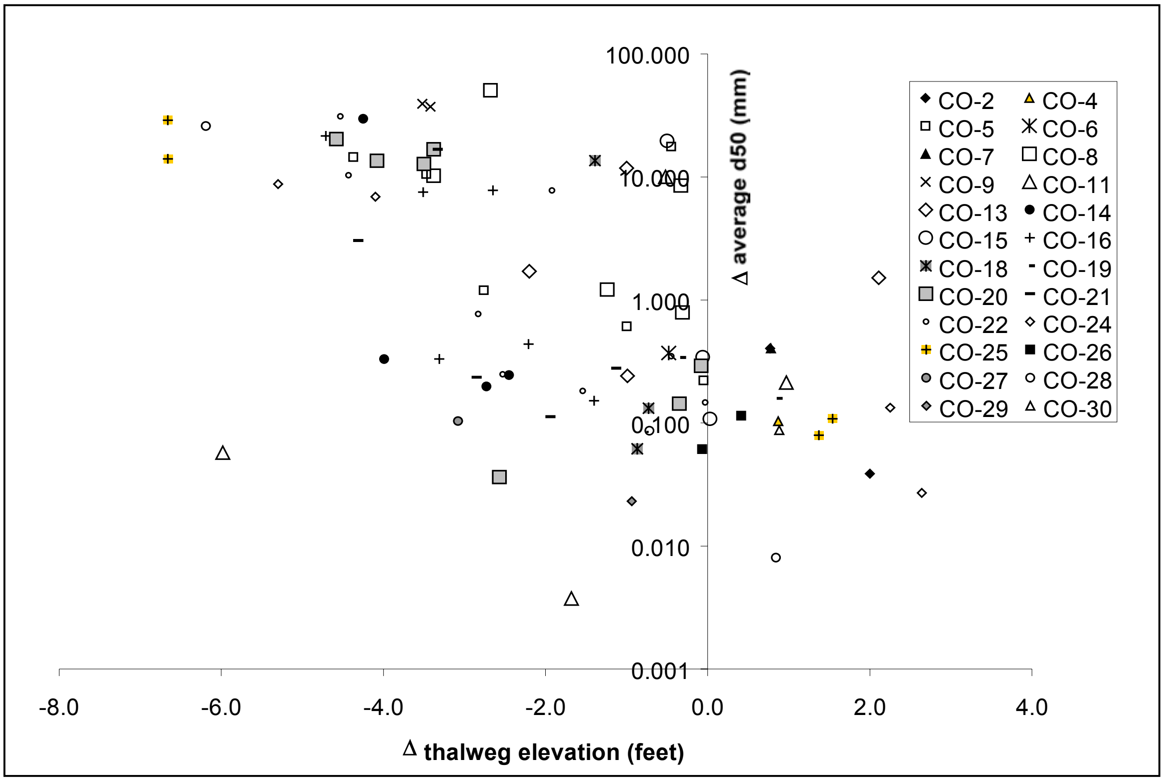

Fig. 3.18. Change in thalweg elevation versus change in median bed material size with respect to the 1971 data.

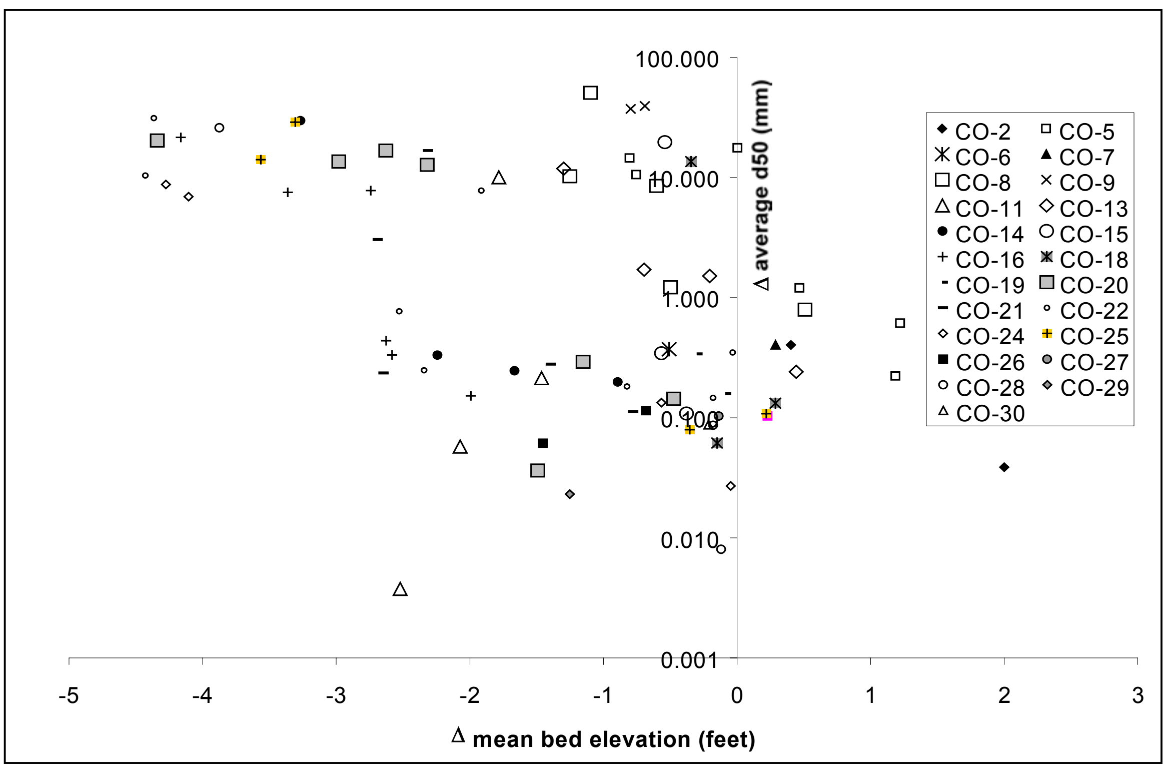

Fig. 3.19. Change in mean bed elevation versus change in median bed material size with respect to the 1971 data.

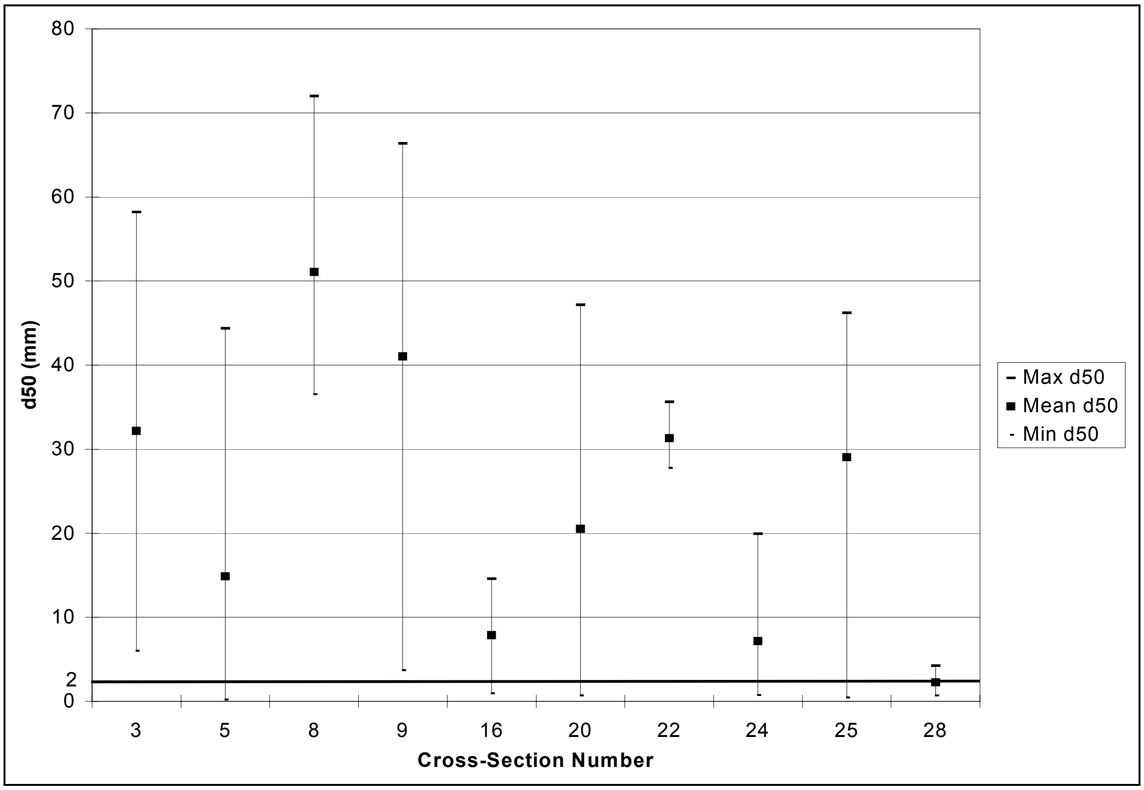

Fig. 3.20. 1992 median bed material size data.

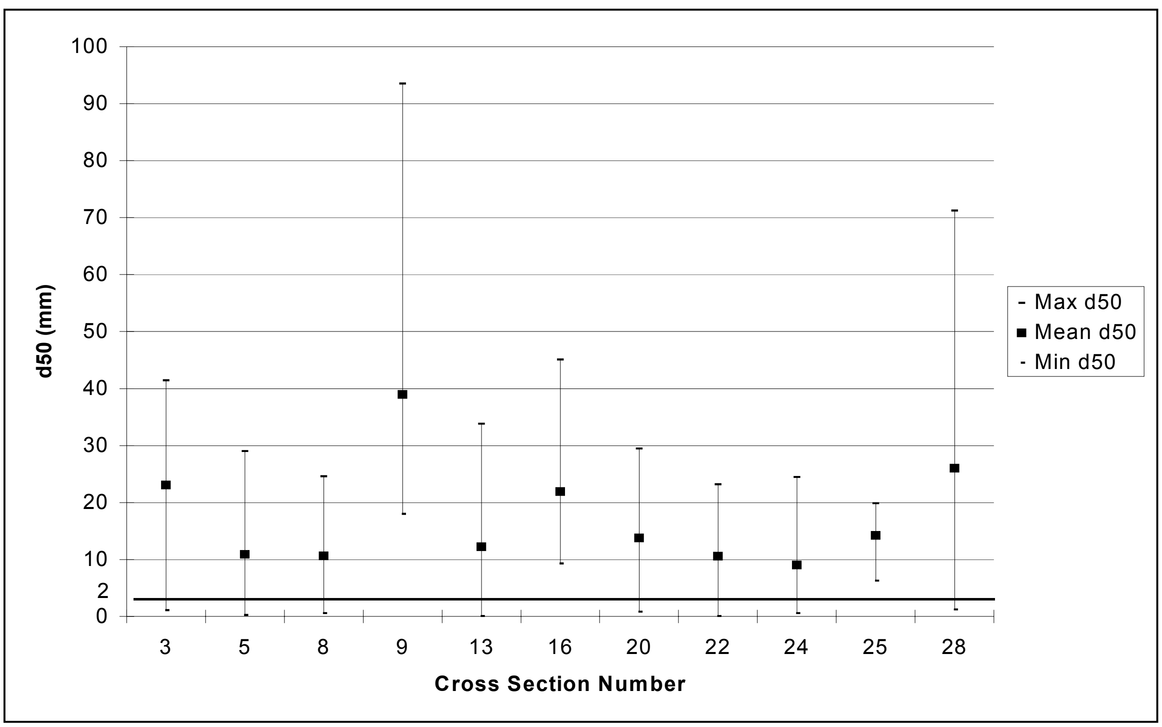

Fig. 3.21. 1995 median bed material size data.

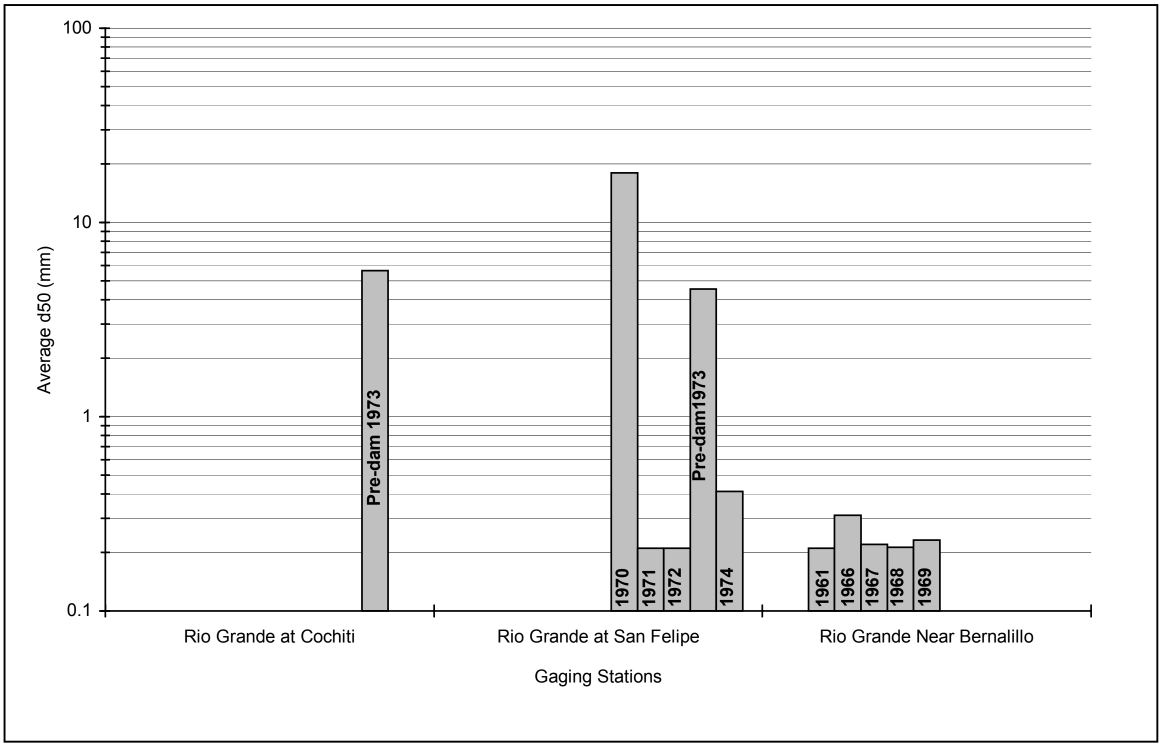

Fig. 3.22. Median bed material size at USGS gaging stations from 1961 to 1973.

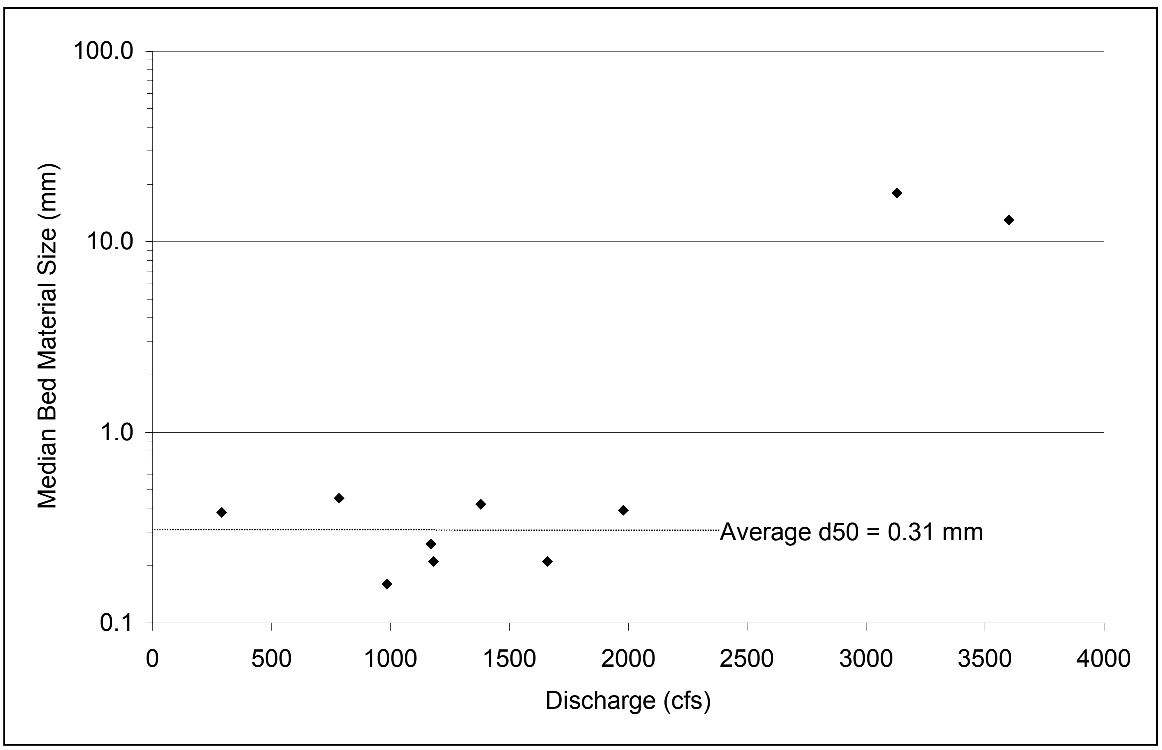

Fig. 3.23. Median bed material size versus discharge at Rio Grande at San Felipe gaging station from 1970 to 1974.

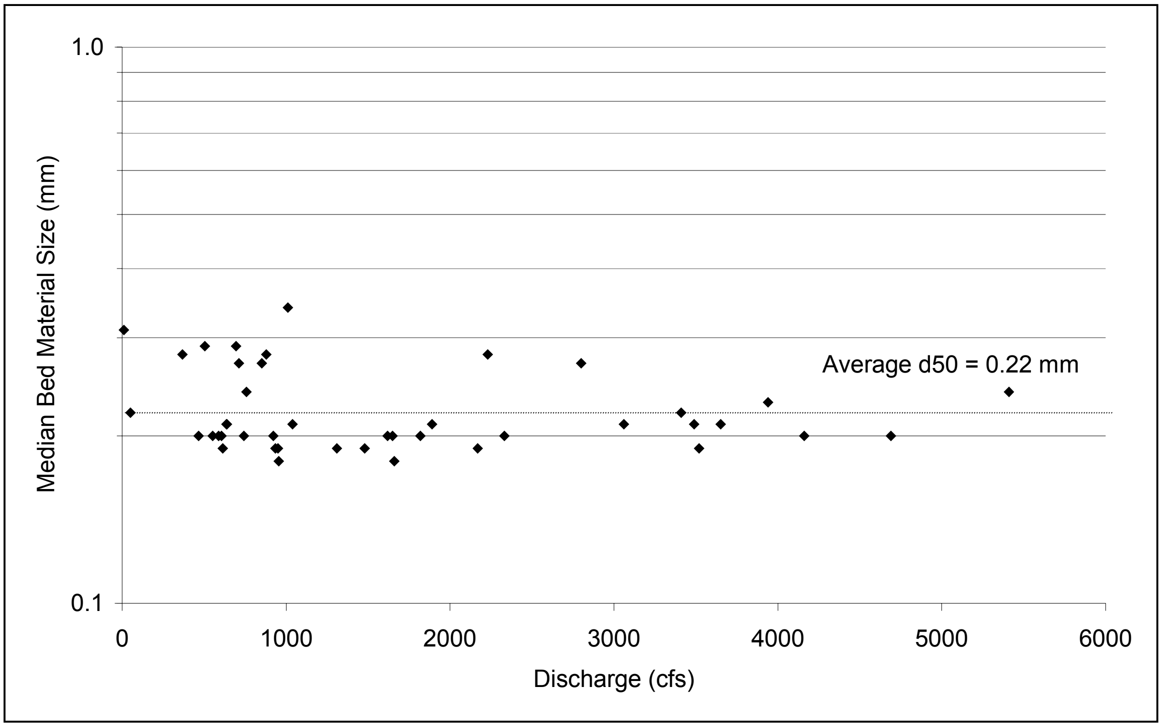

Fig. 3.24. Median bed material size versus discharge at Rio Grande near Bernalillo station from 1961 to 1969.

CHAPTER IV

ANALYSIS

Changes in planform, thalweg elevation, mean bed elevation and bed material size of the Middle Rio Grande until 1980 are compared to the changes observed from 1980 to 1995. Recent data were analyzed and summarized into five sections. The first section contains the description of river planform (Section 4.1). The second section presents the comparison between the thalweg elevation data and the mean bed elevation data along the whole study reach (Section 4.2). The third section presents the analysis of the longitudinal profile (Section 4.3). The fourth section summarizes changes in bed material with time and distance from Cochiti Dam (Section 4.4), and, finally, changes in cross section geometry are documented in the last part of this chapter (Section 4.5).

4.1 Planform

Changes in planform from Cochiti to Bernalillo from pre-dam to post-dam period have been documented in Chapter II. From the several geomorphic studies performed in previous years, it was concluded that the trend of the river planform is toward a single thread pattern due to the decreased flows from the watershed, channelization works and regulated flows from dams in the Middle Rio Grande system. Figure 2.2 in Chapter II shows the Middle Rio Grande planform comparison below Cochiti Dam among several years between 1918 and 1992.

The more recent aerial photos show the river planform as an almost straight channel. The river was almost straight from Cochiti to cross section CO-10. The channel sinuosity increases from cross section CO-10 to CO-14. Downstream of cross section CO-14 the channel straightened again and below cross section CO-27 the river seemed to have a braided configuration. The sinuosity of the river was about 1.11 in 1992 (Baird and Sanchez, 1996).

According to Lane (1957), the relationship among the mean annual discharge in cfs (Q), slope in feet per foot (S), and sand bed river pattern is $SQ^{1/4} = K$. The river planform tends toward a meandering pattern when K is less than or equal to 0.0017. Similarly, when K is greater than or equal to 0.010 the river planform is braided. The river planform is classified as intermediate sand bed stream if K is between these two values.

River slope was estimated from the 1995 thalweg profile. The slope was 0.0016 ft/ft from cross section CO-2 to cross section CO-9. The river slope was 0.0012 ft/ft from cross section CO-9 to CO-17 and the slope was 0.0011 ft/ft from CO-17 to CO-30. Although the river profile is concave upward, a straight line fitted very well along the whole reach. The mean slope from Cochiti to Bernalillo was 0.0012 ft/ft. The mean annual discharge is Q = 1,434 cfs at Rio Grande below Cochiti Dam gaging station for a 27 year period between 1970 and 1997. Lane's relationship yields to a value of K =

0.0074, which classifies the river as an intermediate channel. For the given conditions, the study reach plots very close to the braided condition on the Lane slope-discharge relationship.

Using May 1971 slope and discharge data from the Cochiti gaging station, the Rio Grande below Cochiti was classified as a high intermediate stream as well (Lagasse, 1980).

4.2 Mean Bed Elevation and Thalweg Elevation

Changes in mean bed elevation and thalweg elevation with time at each cross section are represented in Figures E-1 to E-28 in Appendix E. Both variables vary in the same manner as average river bed elevation in most of the surveys. However, in some cases the tendency is the opposite. For instance, the thalweg elevation decreases and the mean bed elevation increases, indicating bed degradation in the first case and aggradation in the last one. By examination of some of the cross section where this happened, it was concluded that the presence of islands and multiple channels influence the computation of the mean bed elevation in most of the cases by reducing the top bank width and cross sectional area.

In some cases, it is also observed that changes in thalweg elevation are bigger than changes in mean bed elevation. An example of this is shown in Figure 4.1. Estimations of aggradation and degradation using these two variables can produce significant difference in values. Changes in thalweg elevation between June 1973 and August 1995

(Figure 3.12, Chapter III) show general trend of degradation along the study reach, except for cross sections CO-10, CO-11 and CO-13 were aggradation at the thalweg occurred. On the other hand, changes in mean bed elevation between June 1973 and 1995 surveys (Figure 3.13, Chapter III) show degradation along the entire reach except for cross section CO-3 where the mean bed elevation increased almost 1 foot. This section kept almost the same thalweg elevation between 1973 and 1995, but it increased its top bank width and cross sectional area.

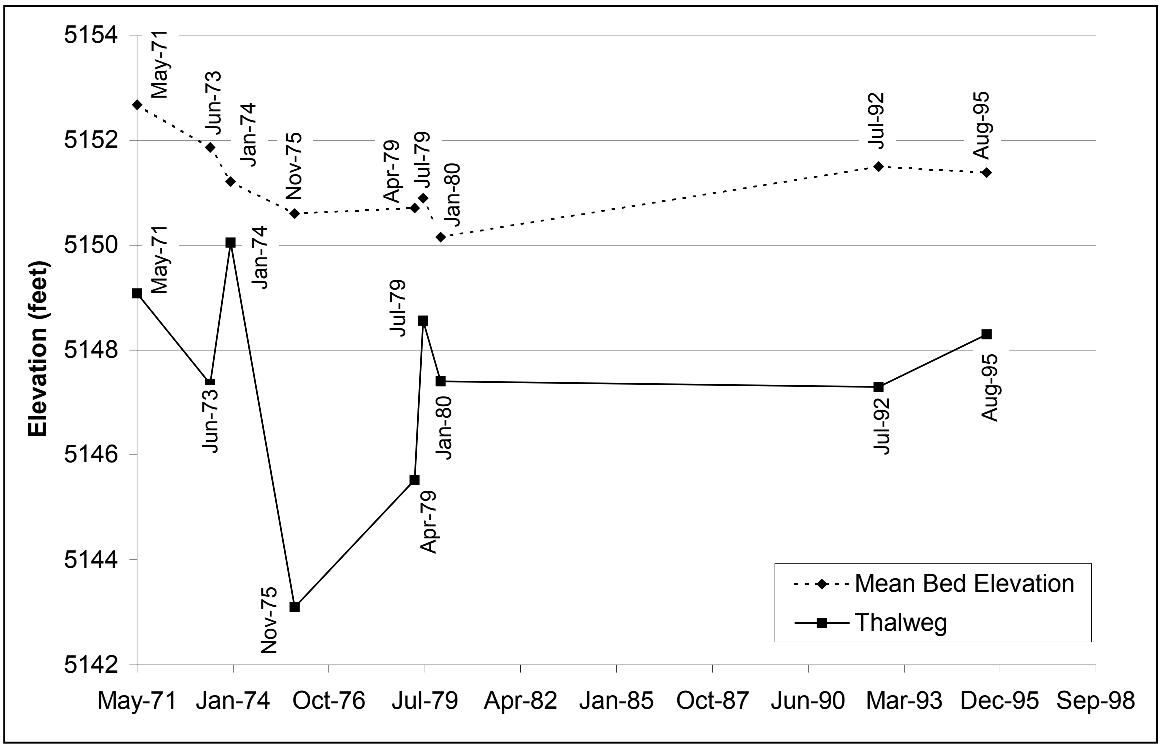

Fig. 4.1. Change in thalweg and mean bed elevation with time at cross section CO-11.

Figure 3.14 included in Chapter III shows considerably scatter among the data points. The straight line represents the points with the same change in thalweg and mean bed elevation. If a change in thalweg elevation of 2 feet occurs, a change in mean bed elevation up to 6 feet can be expected. The data points from cross section CO-2 to CO-9 are located close to the origin of the axis, indicating that this reach presents the lower degradation. In contrast, the data points for the river reach between cross section CO-10 to CO-30 are spread out. The general trend shown in this plot is degradation of the river bed.

4.3 Longitudinal Profile

Changes in thalweg profile from 1971 to 1980 were documented by Lagasse (1980). Recent data for the years 1992 and 1995 were added to the thalweg profile plots of 1971-1980. A summary of previous conclusions is presented in this section and the trend of the recent data is explained and compared with the trend of the river from 1971 to 1980.

During the pre-dam period, from May 1971 to June 1973, a general trend of aggradation occurred from cross section CO-2 to cross section CO-10. From there to cross section CO-30 a trend of degradation occurred except for the reach below the Jemez River. Apparently, lowering of the bed elevation started to happen in the 1970's as a consequence of the rectification and stabilization works performed in the channel in 1954 and 1962. From 1973 to 1975, lowering of the bed occurred between Cochiti Dam and Galisteo Creek. Aggradation was observed below Galisteo Creek and some sequential sub-reaches of deposition and scour were located between mile 8 and 11. The alternated reaches of aggradation and degradation indicate that bed material sediments move in waves through the river primarily along the channel segment adjacent to the thalweg. A trend of degradation was observed along the entire reach during the sustained high flow of 1979, except for the Jemez confluence, where an initial period of degradation (2 feet) occurred during the rising limb of the summer 1979 flood, and was followed by almost 3 feet of aggradation between the April survey and the flood recession in July. The aggradation at the Jemez confluence was attributed to the correlation of releases between Cochiti Dam and Jemez Canyon Dam. Field reconnaissance after 1979 flood revealed almost complete gravel armoring of bed, banks and bars from Cochiti Dam to San Felipe at cross section CO-17, and an appreciable armor from there to below Angostura at cross section CO-23 (Lagasse, 1980).

A strong influence from tributaries and arroyos could be also observed in the thalweg plots. Regulated flows in the Rio Grande are not able to transport the coarse sediment load brought into the river by tributaries and arroyos. Degradation just below Cochiti was limited by an armor layer and, apparently, further downstream by the volume and size of sediment in tributary and arroyo deltas. From cross section CO-2 through cross section CO-9 the profile plots are very close and appear to be controlled by sediment inflow from Peralta Canyon, Cañón Santo Domingo, and Galisteo Creek. Below cross section 9, the profile plots show more variation in thalweg elevation and through section 15, at the reach of Borrego canyon, Arroyo de la Vega de los Tanos and Arroyo Tonque, the variation in bed elevation is reduced to less than 2 feet. Below cross section 15 through cross section 24 (Jemez River confluence) the same trend is observed. After the 1979 flood, the aggradation at cross section 24 was followed by degradation of the thalweg to the lowest elevation registered during the 1971 to 1980 period. Much of the sand bed channel was converted into a gravel/cobble riffle and pool sequence. It is believed that the establishment of a permanent pool in the Jemez reservoir and cutoff of the sediment supply from this source during the fall of 1979 accelerated this degradation. Downstream from the Jemez confluence the normal regulated flows of the July to December 1979 period induced aggradation by carrying the sediment from the Jemez confluence to the downstream reach. These observations at the Jemez confluence provided evidence that the base level of the Rio Grande does not only depend on the coarse material brought into the river, but also on the volume of fine material. Except for the scour at the Jemez River confluence, the 1980 survey shows that the normal regulated flows reworked the river after the April-July 1979 flood (Lagasse, 1980).

Comparison of 1992 and 1995 profiles with 1971 to 1980 plots show a general trend of degradation in the entire study reach during the recent years. This lowering of the river bed could be induced by the high flows of the springs of 1992 and 1995. High flows between 1983 and 1986 could also induce degradation, but low flows after 1986 probably reworked the river.

The 1992 and 1995 thalweg profiles are very similar and almost no changes can be observed between these two survey years. From 1980 to 1992 three more cross section surveys were collected in October 1982, November1983 and November 1986. These surveys contain only data for the lower half reach, therefore they were not included in the profile plots.

A general trend of degradation is observed from cross section CO-2 to cross section CO-9 during the 1980 to 1992 period (Figure 3.9, Chapter III). The maximum degradation of

4.8 feet occurred at cross section CO-5. At cross section CO-3, where an almost fixed elevation has been observed since 1971, the thalweg elevation dropped 2.1 feet. At cross section CO-8, downstream of Cañón Santo Domingo the 1992 survey indicates degradation of 1.9 feet, which is relatively high when compared with the 1971 to 1980 surveys. From 1971 to 1980 this section aggraded only 0.5 feet in the 1973-1974 period and degraded 0.9 feet from 1975 to April 1979 period.

The 1992 thalweg profile is very similar to the 1980 profile from cross section CO-9 to CO-17 (Figure 3.10, Chapter III). Alternating sub-reaches of scour and fill are characteristics of this reach. By 1992, the river has kept the same tendency that it had by 1980, except for the reach at cross section CO-12 where there was an aggradation of 2.4 feet. Cross sections CO-14, CO-15 and CO-16 remained as base level controls of the river in the reach of Borrego Canyon, Arroyo de la Vega de los Tanos and Arroyo Tonque.

From cross section CO-18 to CO-30, the general trend was degradation, with a maximum value of 7.5 feet at cross section CO-25, downstream of the Jemez River confluence. The sub-reach between cross section CO-24 and CO-28 presented the highest lowering of the bed. No information about the operation of Jemez Canyon Dam was found in order to document the high degradation of this reach. However, previous analysis of the same reach indicated that fine materials brought into the main stem by the Jemez River could be carried downstream by normal regulated flows inducing degradation of the Rio Grande. From January 1980 to October 1982 the thalweg elevation increased 3 feet at cross section CO-24 (Figure 4.10), probably due to sediment input from the Jemez River. From cross section 28 to cross section 30 (Figure 3.11, Chapter III) the thalweg elevation increased and the profile became tighter at cross section CO-30, downstream of Arroyo Venada.

The 1995 survey profile is very similar to the 1992 survey from cross section CO-2 to CO-9, except for the thalweg elevation at cross section CO-3, where the thalweg aggraded 2.1 feet returning to the 1980 thalweg elevation. The general trend was degradation with a maximum lowering of the bed of 0.7 feet at cross section CO-8 (Figure 3.9, Chapter III).

From cross section CO-9 to CO-17, the two recent surveys are very close again, degradation occurred almost along the whole reach with a maximum value of 1.6 feet at cross section CO-12. Cross sections CO-14 and CO-15 continued to be base level points for the profile, but cross sections CO-16 and CO-17 degraded 1.2 and 1.4 feet respectively (Figure 3.10, Chapter III). From cross section CO-17 to CO-30 the 1995 survey has the same tendency as the 1992 survey, except for the sub-reach between cross sections CO-24 to CO-30 where the thalweg elevation degraded a little bit more than the 1992 survey (Figure 3.11, Chapter III).

4.4 Bed Material

Bed material data are very scarce along the study reach. Bed material composition along the study reach was described in Chapter II for the period 1952 to 1962. From 1961 to

1974 some bed material data were collected at 3 gaging stations: Rio Grande at Cochiti, Rio Grande at San Felipe and Rio Grande near Bernalillo.

Figure 3.22 in Chapter III shows the average median bed material diameter for every year survey at each gaging station. The Bernalillo station has an average median grain size within the range of sand material for all surveys. However, the San Felipe station shows a higher variability in the median bed material sizes. The fact that 1970 and 1973 surveys have a high average in median bed material seems to be caused by the correlation between flow magnitudes and grain size.

Data from 1970 to 1974 at San Felipe gaging station show that at discharges lower than 2,000 cfs the bed material was sand and a flows higher than 3,000 cfs the median bed material was in the range of medium to coarse gravel (Figure 3.23, Chapter III). In contrast, at Bernalillo station the median bed material size did not change with discharge and the bed material size was sand for all the surveys (Figure 3.24, Chapter III).

These observations agree with some of the conclusions drawn in previous studies in the Middle Rio Grande. From Cochiti to San Felipe, the bed was composed of sand at low discharges and of sand and gravel at high flows during the 1952 to 1962 period. Downstream from the Jemez River confluence the river was a sand bed channel (Nordin and Beverage, 1964).

Changes in bed material with time are difficult to determine through the analysis of the data represented in Figure 3.22 in Chapter III. The fact that surveys at San Felipe station show coarse material in 1970 and 1973 and finer sediments in 1971, 1972 and 1974 indicates that coarse materials were already available in that reach during high flows. Surveys performed in 1970 and 1973 during low flows show fine sediments in the bed at the same station.

Bed material data are also available at some of the Cochiti range lines. Changes in median bed material with time and distance can be observed in Figure 3.16 in Chapter III. For the pre-dam period, 1970 to 1973, the bed material was within the sand range. The immediate post-dam samples, 1974-1975, show coarsening of the bed material along the entire study reach. However, the average median bed material diameter still remained within the sand range, except for the reach at the Galisteo Creek confluence (cross sections CO-8 and CO-9) where the grain size increased almost 9 times. For the subsequent bed material surveys, consistent coarsening of the bed occurred except for the 1980-1982 surveys.

The plot of median grain size against distance downstream from Cochiti Dam shows a large scattering of data points. Sampling errors, natural variability of bed material size within local reaches, lithology and introduction of material from banks and tributaries are usually causes of perturbations in any systematic downstream trend. The contribution of sediment from tributaries increases the grain size below junctions and the magnitude of that increase is possibly related to the relative sizes of the main stream and tributary at each confluence (Knighton, 1984).

The regions of most significant increase in bed material size correlate reasonably well with arroyo and tributary locations such as Peralta Canyon (cross section CO-3), Galisteo Creek (cross sections CO-8 and CO-9) and Borrego Canyon (cross sections CO-13 and CO-14) indicating some relationship between tributary inflow and material available for armoring (Lagasse, 1980). Bed material surveys from 1970 to 1975 show this behavior clearly.

The 1970-1973 plot and the 1974-1975 plot have very similar shapes. The distance between these two plots is greater in the upper reach than in the last 10 miles of the study reach, indicating that the upper reach was coarser than the lower reach. Clear water released from Cochiti Dam was able to remove part of the finer fractions of the bed material and to transport them to the downstream reaches.

From 1970 to 1975, bed material surveys were performed generally during low flow periods, except for a survey in June 1973 performed in a period of discharges greater than 5,000 cfs. Along the whole study reach, median bed material diameters were within the sand range even for the survey performed in June 1973.

The 1979 survey shows more variability than the other surveys. The median bed material size increased along the entire reach. A significant increase in bed material size is also observed at Galisteo Creek and Borrego Canyon confluences. The 1980-1982 surveys show a significant decrease in bed material. Again, the correlation between grain size and discharge can be observed. The 1979 survey was performed during the high sustained flows of April and July. Fine materials were removed and deposited downstream. Conversely, 1980 and 1982 data were collected during very low flows, when deposition might have occurred. As it was mentioned before in Section 4.3, the 1980 cross section surveys show that the normal regulated flows reworked the river after the April-July 1979 flood (Lagasse, 1980). This decrease in bed material size during the 1980-1982 surveys can be seen in Figure 3.17 in Chapter III, where a general trend of coarsening is observed from 1970 to 1995, except for the 1980-1982 survey, which indicates sediment sizes as fine as the 1970 –1973 surveys.

The July 1992 survey shows sediments in the range of medium to very coarse gravel for the study reach, and at section CO-28, very fine gravel was found. The 1995 median bed material is in general finer than the 1992, except for cross sections CO-16 and CO-24 at the confluences of the Arroyo Tonque and the Jemez River respectively. Significant increase in grain size occurred at section CO-28 from 1992 to 1995.

Figures 3.18 and 3.19 in Chapter III show the changes in thalweg and mean bed elevation versus the changes in median bed material size with respect to the 1971 data at the CO-Lines. Data included in both figures is highly scattered. However, it can be observed that the median bed material size increases as the river incises.

4.5 Cross Sections

An analysis of the geometric characteristics at each cross section is presented in this section. Change in cross section area, bed elevation, and shifts in bank line position are discussed at each cross section. The 1992 aerial photos were used to locate the range lines with respect to the main tributaries and arroyos. This analysis is based on the cross section plots from 1975 to 1995 included in this chapter and in Appendix D. Pre-dam plots are not included in this work and are available in the report by Dewey et al. (1979).

The pre-dam aggradation was reversed after the closure of Cochiti Dam at cross section CO-2 (Lagasse, 1980). This section is located in a straight reach upstream from the Santa Fe River confluence. From 1980 to 1995 the general trend of degradation continued. Both banks shifted to the right about 15 feet and the thalweg degraded about 3 feet (Figure D-1, Appendix D). From 1971 to 1995, the cross section area increased about 19.2 % (Figure 3.15, Chapter III).

Cross section CO-3 located downstream from the delta of Peralta Canyon, shifted to the east from 1971 to 1979, as a response to Peralta Canyon confluence located at the right bank (Lagasse, 1980). From 1979 to 1995 the trend has been the opposite. The right bank shifted about 100 feet to the west, widening the section. The 1995 sediment data show sand material at the right bank and gravel at the left bank. The mean bed elevation has been almost the same since pre-dam period (Figure E-2, Appendix E), although its change indicates bed aggradation between June 1973 and August 1995 (Figure 3.12). This section represents a base level control in the longitudinal profile (Figure 3.9, Chapter III). The right channel was filled and a left channel incised lowering the thalweg elevation by 2.1 feet after 1992 spring flows. After 1995 spring flows, the 1992 left channel was filled rising the thalweg elevation to the 1980 level (Figure 4.2). Bed material data indicate significant coarsening of the bed from 1979 to 1995 (Figure 3.16, Chapter III). This cross section experienced an increase in cross sectional area of 12.2% from the pre-dam to the post-dam period (Figure 3.15, Chapter III). Channelization works were performed from cross section CO-2 to CO-3 from 1973 to 1974 (Lagasse, 1980).

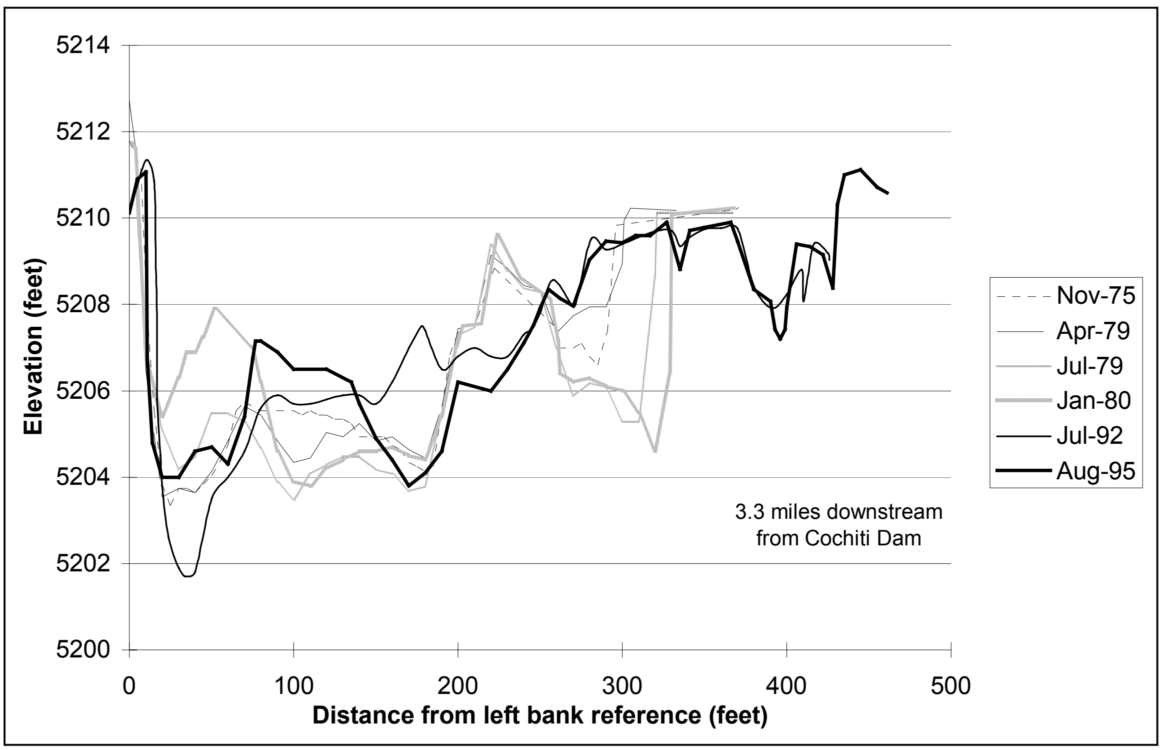

Figure 4.2. Cross section CO-3.

A large and stable alluvial island divides cross section CO-4. This section can be considered within the range of influence of coarse sediments derived from Peralta Canyon (Lagasse, 1980). The cross section area has decreased 17.1 % since 1971 (Figure

3.15, Chapter III). Although any significant change in top bank width and depth occurred from 1975 to 1995, the decrease in cross section area is due to pre-dam changes (Figure D-2, Appendix D). From May 1971 to June 1973 the alluvial island aggraded, reducing the cross section area and after 1973, the cross section area remained almost the same (Figure E-3, Appendix E).

From pre-dam to post-dam period cross section CO-5 narrowed producing a decreased in cross section area of 22.2 % (Figure 3.15, Chapter III). The pre-dam planform plot of 1972 shows this section across a big alluvial island. The 1984 and 1992 planform plots show the river as a single channel at the same location. Figure 4.3 shows the cross section plots at this location. The 1975 survey consists of two channels divided by an island and the 1979 to 1995 plots consist of a single channel at the west with a middle bar. According to the 1992 and 1995 bed material data, this bar is composed of sand.

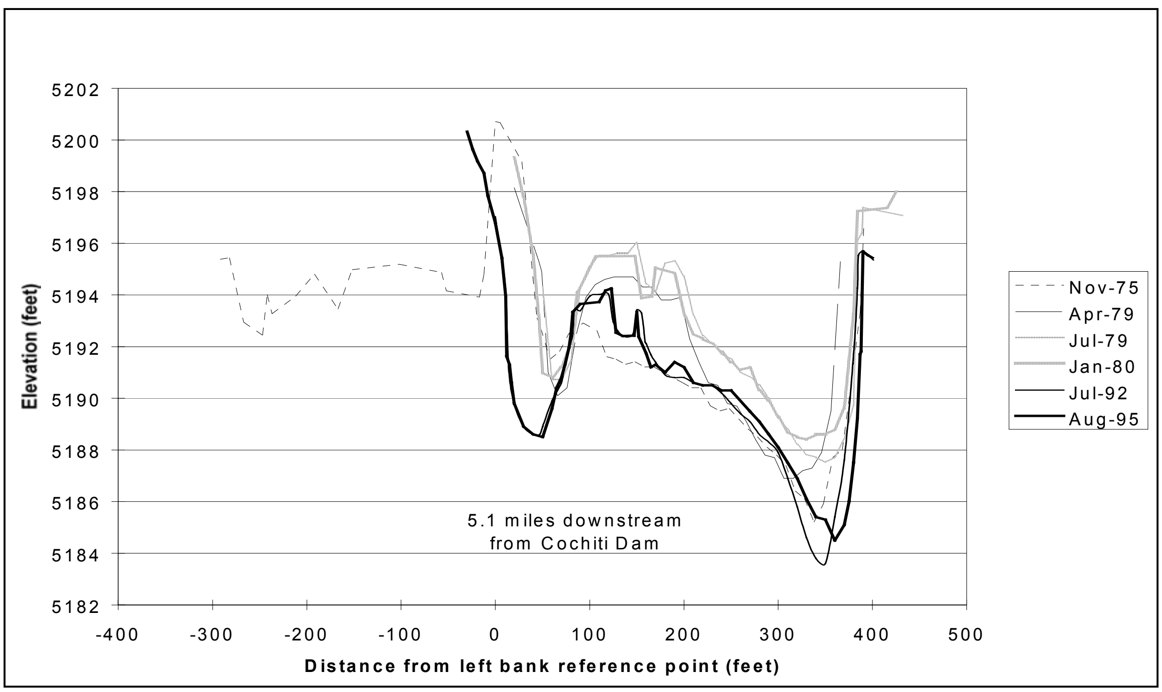

Fig. 4.3. Cross section CO-5.

From 1979 to 1995 the cross section area increased (Figure E-31, Appendix E) because the section widened and incised, but still the cross section remained smaller than the pre-dam section.

Cross section CO-6, located in a straight reach of the river, has the biggest increase in cross sectional area within the reach from Cochiti to Galisteo since the pre-dam period (Figure 3.15, Chapter III). The mean bed elevation has decreased consistently since 1973 (Figure E-5, Appendix E). The scour at this section can be due to the sand material that characterized the sediment composition at the bed from 1970 to 1979. From 1971 to 1973 the top bank width increased and from then to 1995 the width remained almost the same.

Cross section CO-7, located also in a straight section of the river, has the smallest increased in cross sectional area (7.1 %) along the study reach (Figure 3.15, Chapter III). This section has kept almost the same shape from pre-dam to post-dam period. Significant coarsening at this section occurred after the 1979 flood, but very fine material were again deposited during the low flows of 1980-1982 (Figure 3.16, Chapter III). Channelization works were performed from 1973 to 1974 (Lagasse, 1980) and from 1975 to 1995 the channel incised about 2 feet.

Cross section CO-8 is located about half mile downstream from the Cañon Santo Domingo confluence. CO-8 was also subject to channelization works from 1973 to 1974

(Lagasse, 1980). This section has decreased its cross section area in 13.5 % since the pre-dam period (Figure 3.15, Chapter III). Top bank width decreased from 1971 to 1975 and mean bed elevation increased from 1971 to 1974, and decreased in 1975 (Figure E-7, Appendix E). These changes resulted in a decreased of cross section area. From 1975 to 1995 the section widened and incised (Figure D-5, Appendix D) and an increased of cross section area occurred. However, the percentage change in area is still negative indicating a reduction of the total cross section area since the pre-dam period (Figure E-35, Appendix E).

Cross-section CO-9 located downstream from Galisteo Creek was subject to extensive channelization from September 1974 to May 1975 (Lagasse, 1980). The main channel was shifted to the left after the 1973 flood during the pre-dam period. After 1975 channelization works, the cross section did not changed its width but degraded about 4.5 feet from 1975 to 1995. Increases in cross section area can be attributed to changes in mean bed elevation due to the stability of the banks (Figure 4.4). This section has a significant increase in median bed material size with respect to cross section CO-8 due to the sediment input from Galisteo Creek. From 1974 to 1995 the bed material is gravel (Figure 3.16, Chapter III).

The river reach comprised between cross section CO-10 to cross section CO-30 is characterized by an increase of cross sectional area from pre-dam to post-dam period. Cross section CO-10 shows extreme variability in thalweg position. The top bank width increased about 480 feet from 1971 to 1995 and the mean bed elevation remained almost the same for the same period. The cross section area increased 82.2 % since the pre-dam period (Figure 3.15, Chapter III).

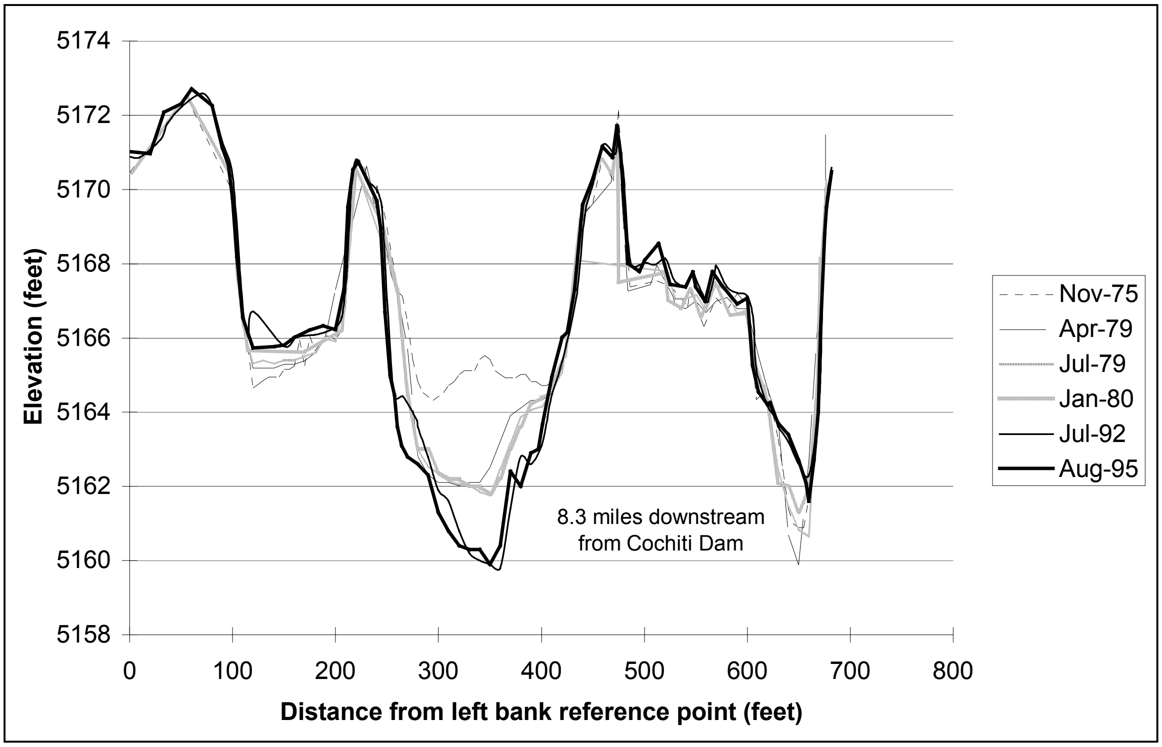

Fig. 4.4. Cross section CO-9.

This section was channelized in 1970 and 1974 (Lagasse, 1980). From 1974 to 1975 almost no change is observed. From 1975 to 1992 there are not cross section surveys at this section. In 1992 the right bank shifted to the right about 240 feet with respect to the bank position in 1975. Data from 1992 and 1995 surveys are very close. Changes in thalweg position and elevation occurred during this period. The thalweg shifted to the left about 100 feet and the thalweg degraded about 0.5 feet (Figure D-6, Appendix D). However, the mean bed elevation did not vary at all (Figure E-9, Appendix E). The bed was composed of sand from 1970 to 1975. After 1975, there are no sediment data at this section (Figure 3.16, Chapter III).

Cross section C0-11, located downstream from an ephemeral stream (without name), is characterized by high variability in thalweg position and elevation since the pre-dam period. A consistent increase in cross sectional area occurred from 1971 to 1995 (Figure E-38, Appendix E). From 1975 to 1995 the right bank shifted to the right about 160 feet. This bank is the outer bank of a bend. From April 1979 to August 1995, the cross section was divided into two channels by a middle bar, which shifted in position and size during this period (Figure D-7, Appendix D). The change in thalweg elevation from 1973 to 1995 is almost 1 foot of aggradation. However, the change in mean bed elevation shows almost half foot of degradation for the same survey dates (Figure 4.1).

Cross sections CO-12 and CO-13 are located in bends. The shape of a typical cross section in a bend characterizes the pre-dam CO-12 and CO-13 cross section plots. The change in cross sectional area for these two cross sections is almost the same. Cross section CO-12 presented the same pre-dam configuration until 1983. After 1983, the 1992 and 1995 surveys show a more symmetric cross section shape (Figure 4.5). The 1992 aerial photos show this cross section in a very wide bend of the river with a middle island on it. Between 1973 and 1995, the thalweg degraded about 2 feet (Figure E-10, Appendix E). However, thalweg elevations lower than the 1995 elevation occurred from July 1979 to November 1983 (Figure 4.5). Change in mean bed elevation also indicates degradation of about 2.75 feet (Figure E-10, Appendix E).

From 1971 to 1974, cross section CO-13 shifted its left bank to the left (outer bank of a bend) about 70 feet. At the same time, aggradation of the thalweg and inner bank occurred, producing a net reduction of cross section area (Figure 3.15, Chapter III). From 1974 to 1995 a consistent increase in cross sectional area occurred (Figure 40, Appendix E). The 1983 and 1995 surveys show the formation of a middle bar in the cross section. The displacement of the entire cross section to the right (Figure D-8, Appendix D) seems to be due to the change of the left bank reference point used during the 1995 survey. This cross section was relocated by bulldozer in 1975 (Lagasse, 1980).

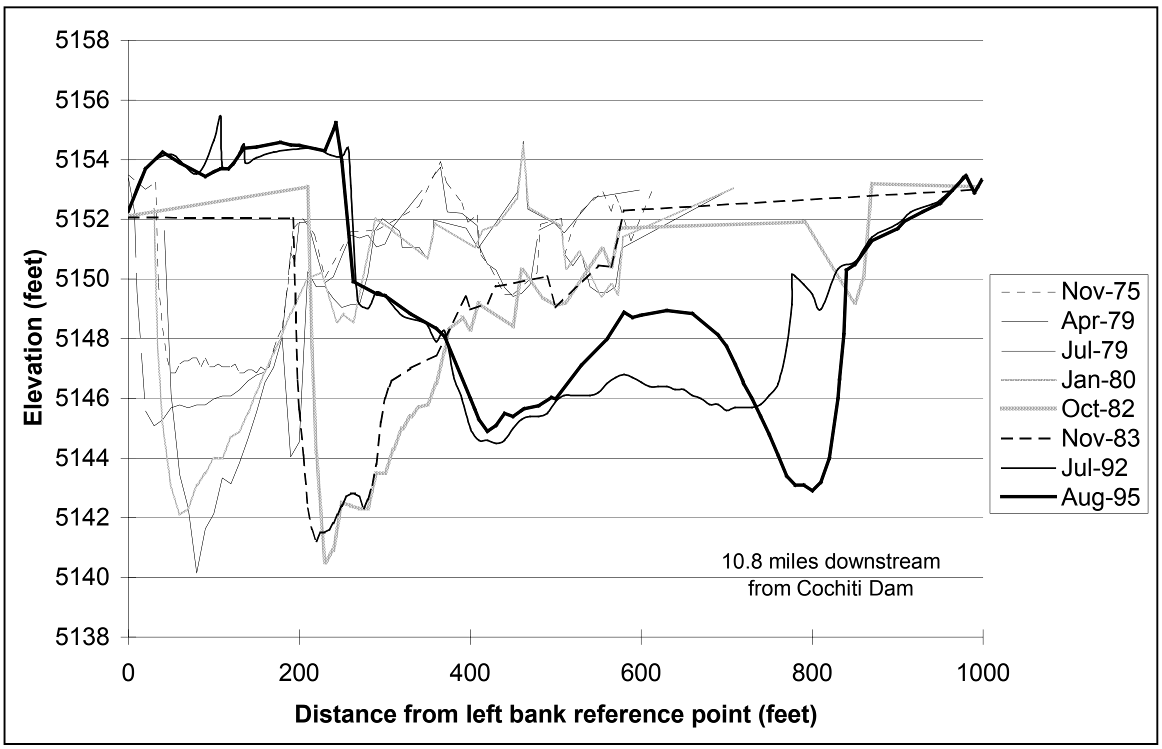

Fig. 4.5. Cross section CO-12.

Cross section CO-14 is located about one mile downstream from Borrego Canyon confluence and downstream of an old braided channel. The left bank is very steep and stable. It only eroded about 10 feet from 1975 to 1995. The right bank is much more variable. General trend of degradation can be observed at this section (Figure D-9, Appendix D). The thalweg degraded about 2 feet between 1973 and 1995 and the change in mean bed elevation is about 0.5 feet of degradation during the same period (Figure E-12, Appendix E). During the high flows of 1979, an increase in median bed material size occurred with respect to cross section CO-13 due to the sediment input from Borrego Canyon.

Cross section CO-15 is located in a straight section of the river just upstream from the confluence of the Arroyo de la Vega de los Tanos. From 1975 to 1995, this section had very steep and stable banks. General trend of bed degradation characterized this period (Figure 4.6). After 1980, the November 1983 survey shows a significant degradation of the channel bed.

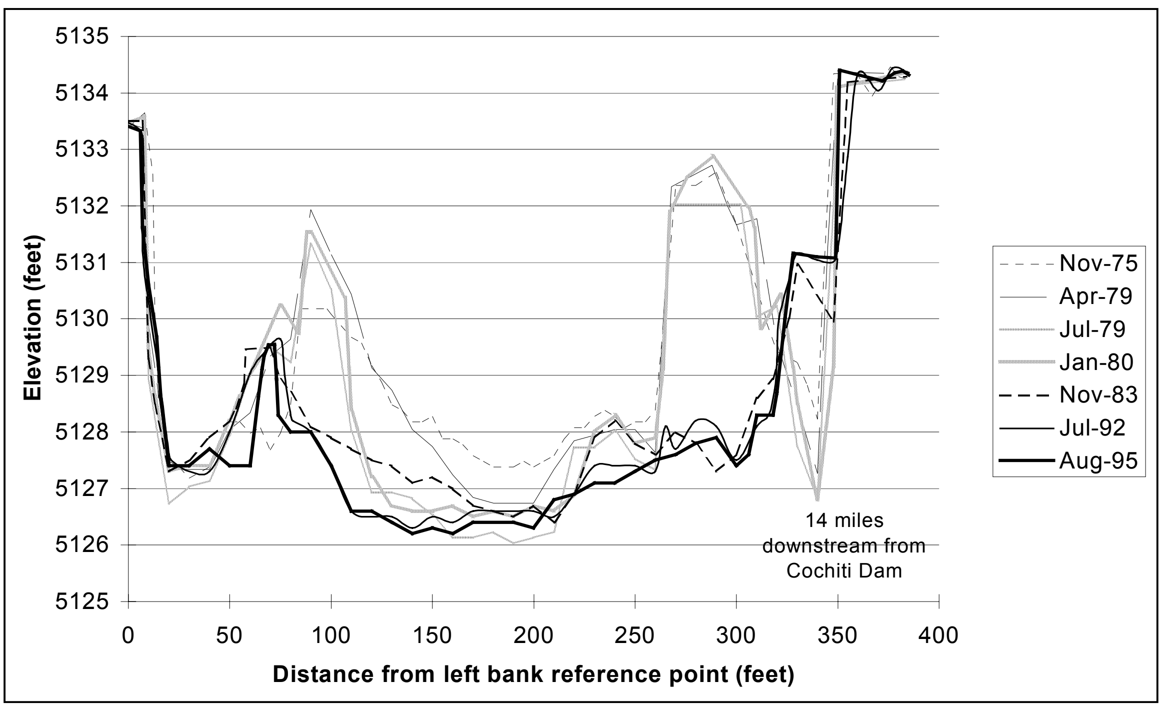

Fig. 4.6. Cross section CO-15.

The subsequent surveys in 1992 and 1995 showed the same trend of the 1983 survey. The change in thalweg elevation and mean bed elevation between 1973 and 1995 is only about half foot. The cross section area increased around 15 % since the pre-dam period (Figure 3.15, Chapter III).

Cross section CO-16 is located downstream from the Arroyo de la Vega de los Tanos in a straight reach of the river. From 1971 to 1995, there was a general trend of degradation at this section. The thalweg elevation and the mean bed elevation decreased about 1.75 feet and 2 feet respectively between 1973 and 1995 (Figure E-14, Appendix E). The left bank is very steep and has eroded about 25 feet during the post-dam period.

The Rio Grande at San Felipe USGS gaging station coincides with cross section CO-17. This section is located right at the mouth of Arroyo Tonque. The right bank is very steep. From the pre-dam to the post dam period this section degraded between 1 and 2 feet at the channel bed (Figure 4.7).

Extremely stable banklines of the San Felipe reach are apparent in sections CO-18 to CO-21, from May 1971 to July 1979 (Lagasse, 1980). From 1979 to 1995, only cross sections CO-18, CO-19 and CO-22 still maintained stable banklines (Figure 4.8). The increase in cross sectional area at this section can be attributed to the degradation of the bed of the channel. In contrast, cross sections CO-20 and CO-21 widened and degraded. The increase in cross sectional area at these last cross sections is almost the same since the pre-dam period.

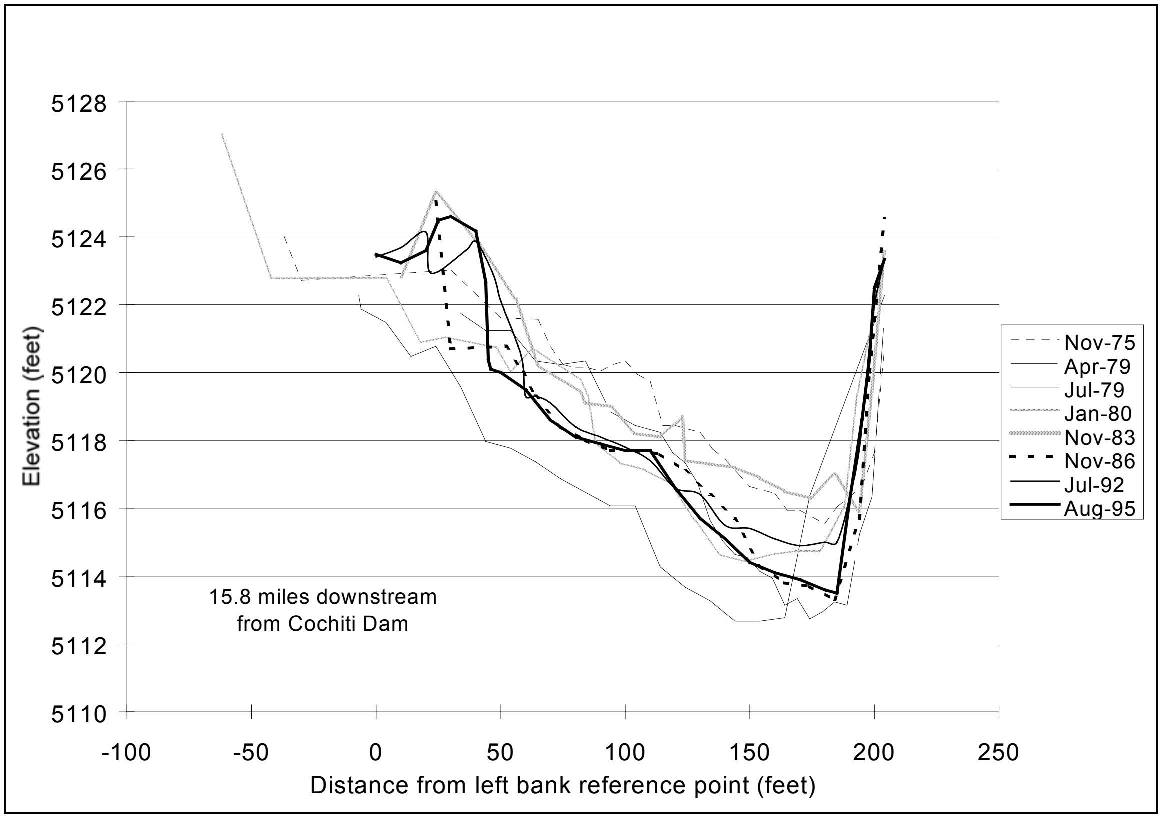

Fig. 4.7. Cross section CO-17.

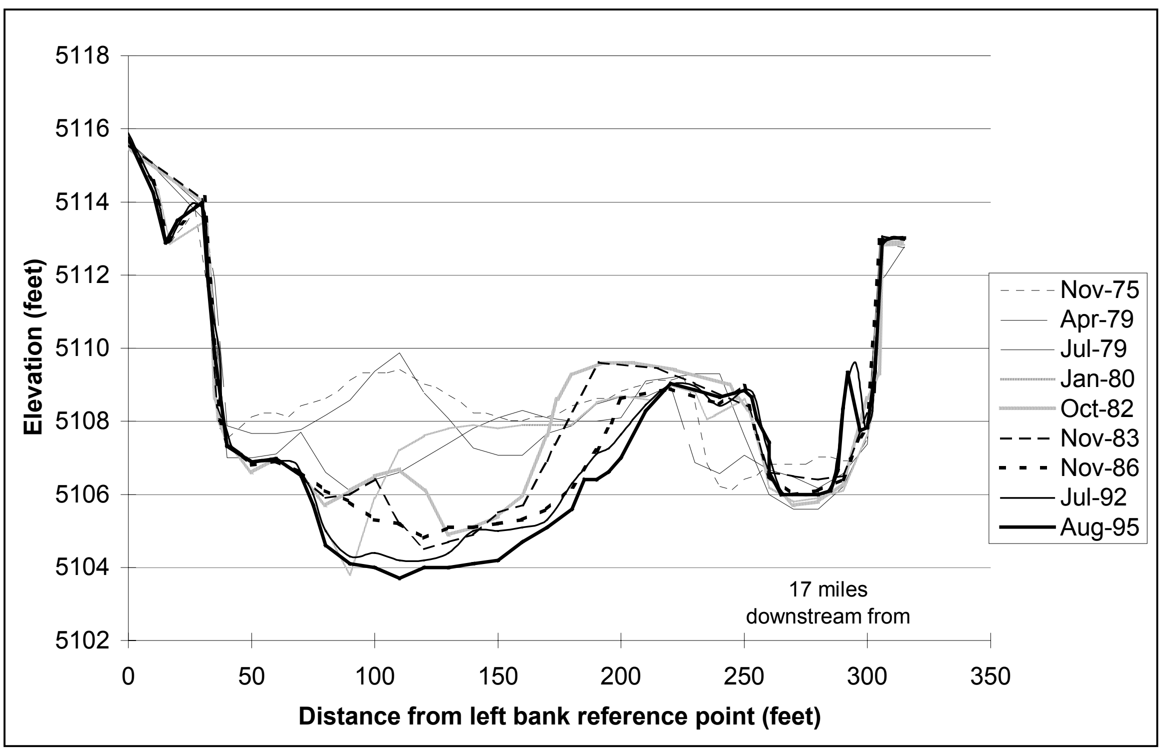

Fig. 4.8. Cross section CO-18.

An alluvial island divides cross section CO-21. From January 1980 to November 1983, the right channel deepened and widened reducing the alluvial island almost in a half. After November 1983, the island recovered its original width but the channel widened as well (Figure 4.9). Before July 1979, the left and right channels at this section scoured and filled simultaneously (Lagasse, 1980). From 1979 to 1995, the opposite behavior is observed. The right channel has degraded while the left channel has aggraded.

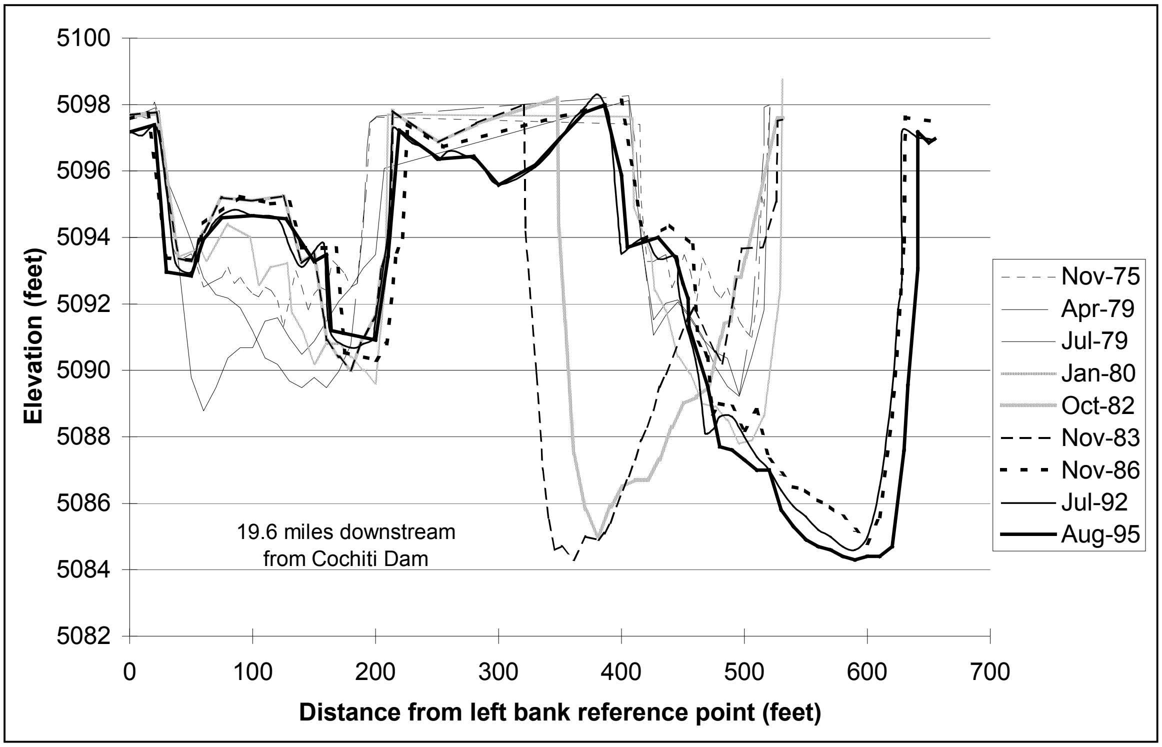

Fig. 4.9. Cross section CO-21.

The section CO-22 above Angostura Diversion Dam experienced progressive degradation across the entire channel width through the April-July 1979 high flows (Lagasse, 1980). The general trend of degradation across the entire channel width continued from 1979 to 1995 (Figure D-13, Appendix D).

Cross section CO-23 is located above the Angostura Diversion Dam. Prior to 1971, base level control established by Angostura Diversion Dam and depletion of flows by irrigation diversions had produced sediment deposition above the sill to completely bury the diversion structure. By April 1979, this aggradation trend produced more than 3 feet of deposition at cross section CO-23. However, the sustained flows of April-July 1979 caused sufficient scour to expose the diversion structure for the first time in many years (Lagasse, 1980). In July 1979, cross section CO-23 filled again and the bed reached higher elevations than the 1975 survey for almost across the entire width of the section. This cross section has continued filling and scouring alternately after July 1979. The bed elevation has been almost the same from November 1986 to August 1995. This section has the highest increased in cross sectional area along the entire study reach (220 %) (Figure 3.15, Chapter III). Considering only the surveys from 1971 to 1975, the increased in cross section area was 7 % (Lagasse, 1980). The median bed material size was sand from 1970 to 1982. Even during the high flows of 1979, the bed material remained within the sand range (Figure 3.16, Chapter III).

Cross section CO-24 is located just upstream from the Jemez River confluence. The channel width at the Jemez River reach is almost double than the width upstream Angostura Diversion Dam (Lagasse, 1980). Variable thalweg elevation and position characterize this section. Since the pre-dam period the thalweg elevation degraded about 6 feet and the mean bed elevation about 3.5 feet (Figure E-22, Appendix E). The increase in cross section area is also comparable to the increase in area at section CO-23 (Figure 3.15, Chapter III).

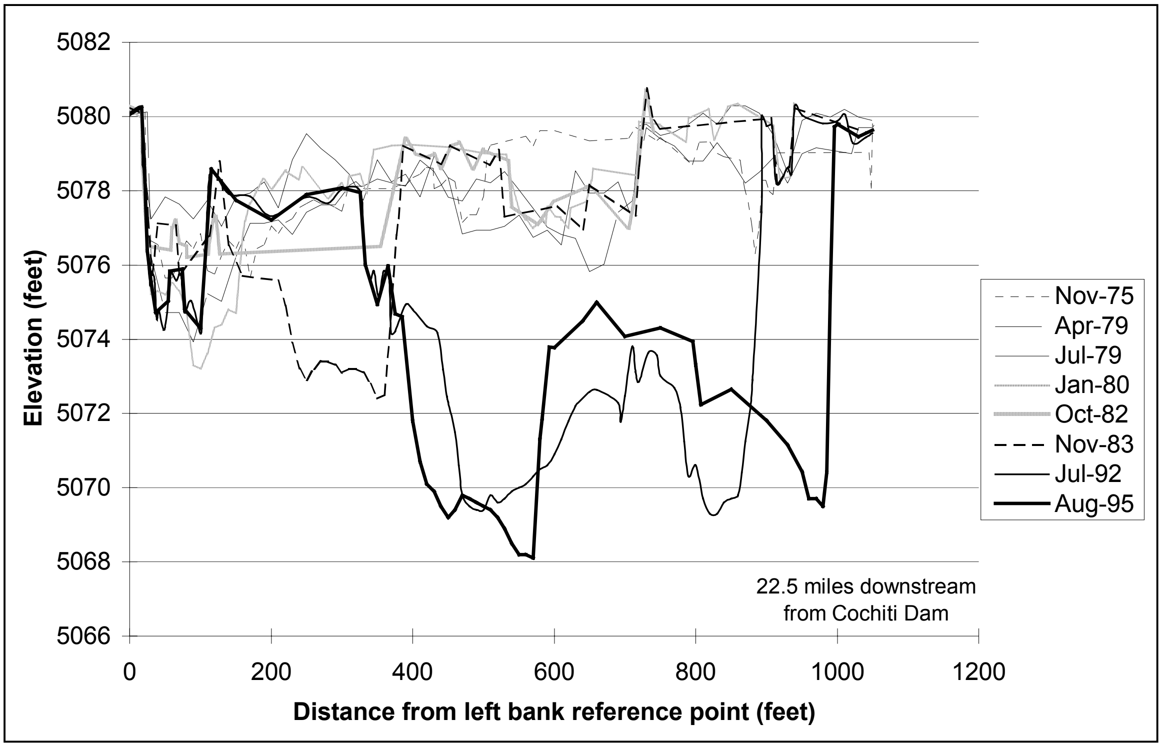

Fig. 4.10. Cross section CO-24.

During the period between 1975 to 1995, from cross section CO-25 to cross section CO-30, the river degraded consistently. These sections are located along a wide braided reach of the river, which gives them a very variable thalweg position and elevation. From CO-25 to CO-28, the 1992 and 1995 thalweg elevations are significantly lower than the thalweg elevations during the sustained high flows of 1979. Since 1975, cross sections CO-26 and CO-28 have shifted the right bank to the right. Again, an increase in median bed material size is observed in cross section CO-25 during the 1992 and 1995 surveys due to the contribution of sediments from the Jemez River (Figure 3.16, Chapter III).

CHAPTER V

SUMMARY AND CONCLUSIONS

The data set collected for this work is very extensive, specifically in the river reach between Cochiti Dam and the Bernalillo Bridge. The entire data set includes: cross section surveys, flow discharge records, bed material and suspended sediment data as well as topographic maps, aerial photos and planform plots for several years.

The cross section data include surveys of the following range lines from 1918 to 1996:

- SCS range lines collected from 1918 to 1964 and available in hardcopies.
- Agg/Deg lines collected in 1962, 1972 and 1992 and available in electronic format.
- Cochiti range lines collected from 1970 to 1995 and available in electronic format as Microsoft Excel 97 files.
- Cochiti Pueblo, Santo Domingo, San Felipe Pueblo, Angostura, Bernalillo Island, Calabacillas, Casa Colorada, San Acacia, Socorro range lines collected from 1990 to 1996 and available in electronic format.

The sediment data include bed material and suspended sediment. The bed material data consist of gradation curves for the following range lines and gaging stations:

- Cochiti range lines (CO-2 to CO-30), from 1970 to 1982. These data are available in hardcopies and the median bed material diameters were transferred into electronic format as Microsoft Excel 97 files.
- Cochiti range lines (CO-2 to CO-38), for 1992 and 1995. These data are available in electronic format as Microsoft Excel 97 files.
- From Otowi Bridge to Bernalillo Bridge gaging stations, from 1960 to 1992. These data are available in electronic format as Microsoft Excel 97 files.

The suspended sediment data consist of discharge, concentration and particle size distribution for the following range lines and gaging stations:

- From Otowi Bridge to Bernalillo Bridge gaging stations, from 1955 to 1994. These data include daily discharge and concentration records, which are available in electronic format as Microsoft Excel 97 files.
- From Otowi Bridge to Bernalillo Bridge gaging stations, from 1960 to 1996. These data include sporadic records of sediment concentration, discharge and particle size distribution and are available in electronic format as Microsoft Excel 97 files.

Daily flow discharge data were collected at a total of 14 USGS gaging stations from Embudo to Albuquerque from 1889 to 1997. These data are available in electronic format as Microsoft Excel 97 files. Some sporadic discharge measurements were performed at the Cochiti range lines (CO-2 to CO-38) from 1970 to 1975. These data are available in hardcopies.

Several topographic maps, aerial photos and planform plots were gathered for the following locations, dates and scales:

- Topographic maps from the White Rock Canyon to Bernalillo for 1917 and 1918 surveys at a scale of 1”: 1000’.
- Black and white aerial photos from Cochiti Dam to San Marcial for April 1972 at a scale of 1:24,000.
- Color infrared aerial photographs from Cochiti Dam to San Felipe for April 1979 at a scale of 1:6,000.
- Blue line reproductions of aerial photos at different locations between Cochiti Dam and Caballo Dam from 1984 to 1996.
- Planform comparison plots from Cochiti Dam to Highway 44 Bridge at Bernalillo from 1918 to 1992.

Summary tables of the entire data compiled, including sources and survey dates are contained in Appendixes A to C. Some data were transferred into electronic format and were organized into a computer database according to three categories: cross section data, sediment data and flow discharge data.

The quantitative analyses of the planform, cross section and sediment data were performed for the Cochiti range line data from 1970 to 1996. Previous geomorphic analyses of the Middle Rio Grande until 1980 were compared to the analysis of the recent data from 1980 to 1996. Six variables were considered in the analysis: planform configuration, thalweg elevation and position, mean bed elevation, cross section area, banklines position and bed material size.

To summarize the analysis, it is worthwhile to explain the procedures used to generate some of the plots utilized in the analysis of the data. The mean bed elevations were computed by setting an elevation at each cross section, where both banks become vertical, generally at the top bank elevation. Calculations of top width and cross-section area below the set elevation were performed and the mean depth was obtained by taking the ratio of cross-section area to top-width. The mean bed elevation was obtained by subtracting the mean depth from the set elevation. No measured water surface elevation data were used in these calculations.

Estimations of degradation and aggradation at each cross-section were performed between the most recent pre-dam survey, June 1973, and the most recent post-dam survey, August 1995 using both the thalweg elevation and the mean bed elevation. Percent change in cross section area with distance along the study reach was calculated by taking the average cross section area for the three pre-dam cross-section surveys with the average cross section area of the 6 post-dam surveys as a percent change from the pre-dam survey value.

The following conclusions are based on the quantitative analysis developed in this work. These conclusions document the general trends along the study reach and confirm many observations and findings of previous studies.

1. The 1992 aerial photos show the river planform from Cochiti Dam to cross section CO-10 as a narrow and almost straight channel. From cross section CO-10 to cross section CO-14 the channel sinuosity increased. Downstream from CO-14, the river straightened again and below cross section CO-27 it widened and seemed to have a braided configuration. Planform comparison between 1984 and 1992 shows the development of multiple channels in this lower reach.
2. Changes in thalweg and mean bed elevation vary with time in the same manner as the average river bed elevation in most of the surveys. However, a significant scatter is observed when comparing the magnitude of change of these two variables between the same survey dates.
3. Comparison of the 1992 and 1995 thalweg profiles with the 1971 to 1980 plots shows a general trend of degradation in the entire study reach during the recent years. The maximum degradation is observed downstream from cross section CO-17.
4. The 1992 and 1995 thalweg profiles seem to follow the same trend observed prior 1980. Sediment input from tributaries and arroyos controlled the thalweg elevation in the reaches upstream and downstream of the confluence with Peralta Canyon, Borrego Canyon, Arroyo de la Vega de los Tanos and Arroyo Tonque.
5. A significant coarsening of the river bed has occurred since closure of Cochiti Dam.
6. Bed material surveys from 1971 to 1975 show changes in median sizes with distance downstream of Cochiti Dam. In general, the finer fractions were found downstream from cross section CO-21. The 1992 and 1995 bed material surveys indicate a more uniform distribution of median bed material size along the study reach.

7. Bed material data seemed to have some correlation between grain size and flow discharge from 1962 to 1973 and from 1980 to 1982.
8. Cross sectional area increases and decreases alternately from Cochiti to cross section CO-8 from the pre-dam to the post-dam period. This reach presents the lowest changes in cross sectional area. A general trend of increase in cross sectional area occurred downstream from cross section CO-8, with the maximum changes downstream of cross section CO-20 and the minimum changes from cross section CO-15 to CO-20.
9. The maximum changes in cross sectional area occurred along the lower study reach, where the maximum degradation occurred and finer median bed material sizes were available. This conclusion does not mean that changes in cross sectional area only account for changes in river bed elevation.
10. Extremely stable banklines of the San Felipe reach in sections CO-18 to CO-21 were observed until 1979. From 1979 to 1995, only cross sections CO-18, CO-19 and CO-22 still maintained stable banklines.

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Appendix A

Table A-1. Relative location of the range lines.

- River Miles from Caballo Dam, CO-Lines location and Agg/Deg Lines were taken from blue line reproductions of the aerial photos for 1992
- River Miles from Cochiti Dam were taken from cross section plots from 1970 to 1975 Hydrologic Data on Channel adjustments 1970-1975, on the Rio Grande downstream from Cochiti Dam, New Mexico. Before and After closure. Dewey et.al (1979) USGS Water Resources Investigations 79-70
- SCS Line locations were taken from cross section plots from 1918 to 1941

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			17		
			18		
232			19		River Mile 232 is between Agg/Deg Lines 18 and 22
			20		
			21	860.4	
			22		
			23		
			24		
			25		
			26		
			27		Cochiti Pueblo Range Lines (from CI-27-1 to CI 29-1)
			28		CI-27-1 after 27L. CI-29-1 left end point between 28L
			29		and 29L and right end point between 29L and 30L.
			30		
			31		
231					
			32		
			33		
			34	860.4A	
	2.1	**CO-2**			
			35		
			36		
			37		
			38		
			39		
			40		
			41		
230					
			42		
			43		
			44		
			45		
			46		Peralta Canyon confluence between 46L & 47L
			47	862.2	
	3.3	**CO-3**			
			48		
			49		
			50		
			51		
229					
			52		
			53		
			54		
			55		
			56		
	4.2	**CO-4**			
			57		
			58		
			59		
			60		
			61		
228					
			62		
			63		
			64		

Table A-1. Relative location of the range lines.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			65		
			66	864	
			67		
	5.1	**CO-5**			
			68		
			69		
			70		
			71		
			72		
227					
			73		
			74		
			75		
	6	**CO-6**			
			76		
		CO-7			
	6.5		77		
			78		
			79		
			80		
			81	865.3	
226					
			82		
			83		
			84		
			85		
			86		
			87		
			88		
			89		
			90		
			91		
			92		
	7.6	**CO-8**			
			93	865.3A	
			94		
225					
			95		
			96		
			97		Galisteo Creek confluence between 97L & 98L
			98		
			99		
			100		Sto. Domingo Bridge between 99L & 100L
	8.3	**CO-9**			
			101		
			102		
			103		
224					
			104		
			105		
			106		
			107		
			108		
	9.3	**CO-10**			CO-10 right end point is between 107L and 108L and
			109	868	the left end point is between 108L and 109L
			110		
			111		
			112		
			113		SD-1 is 113L & SD-30 is 127L
223					
			114		
			115		
			116		Santo Domingo Phase I - Range Lines
			117		from SD-1 to SD-30
	10.2	**CO-11**			

Table A-1. Relative location of the range lines.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			118		
			119		
			120		
			121		
222					
			122		
			123		
	10.8	**CO-12**			CO-12 right end point is between 124L and 125L and
			124	868.0A	left end point between 123L and 124L.
			125		
			126		
			127		SD-30
			128		Santo Domingo Phase II - Range Lines
			129		from SD-31 to SD-47
			130		SD-1 after 127L & SD-47 is before 142L
			131		
221					
			132		
			133		
			134		
			135		
			136		
	12	**CO-13**		870.5	CO-13 left end point between 136L and 137L and
			137		right end point between 137L and 138L.
			138		
			139		Borrego Canyon confluence between 139L & 140L
			140		
			141		
220					
			142		
			143		
			144		
			145		
			146		
			147		
			148		
			149		
	13	**CO-14**			
			150		
			151		
			152	870.5A	
			153		
			154		
219					
			155		
			156		
			157		
			158		
			159		
	14	**CO-15**			
			160		
			161		
			162		
218					
			163	873	
			164		
			165		
			166		
	14.9	**CO-16**	167		CO-16 left end point between 166L and 167L and
			168		right end point between 167L and 168L.
			169		
			170		San Felipe Pueblo- Range Lines
217					
			171		from SFP-170 to SFP-181
			172		

Table A-1. Relative location of the range lines.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			173		
			174		Arroyo Tonque confluence between 174L & CO-17
	15.8	**CO-17**			
			175		
			176		
			177		
			178	87?.?	Cross Section Above San Felipe Bridge
			179	87?.?	Cross Section Below San Felipe Bridge
216					
			180		
			181		
			182		
			183		
			184		
			185		
			186		
215					
	17	**CO-18**	187		CO-18 left end point between 186L and 187L and
			188		right end point between 187L and 188L.
			189		
			190		
			191		
			192		
			193		San Felipe Pueblo - Ranges Lines
			194		from SFP-193 (193L) to SFP-200 (200L)
			195		
	17.7	**CO-19**			
			196		
214					
			197		
			198		
			199		
			200		
			201		
			202		
			203		
			204		
			205		
213					
	18.7	**CO-20**	206		CO-20 Left end point between 206L and 207L and
			207		right end point between 205L and 206L.
			208		
			209		Angostura Range Lines
			210		from AR-203 to AR-235
			211		
			212		
			213		
			214		
			215	878	
212					
			216		
	19.6	**CO-21**			
			217		
			218		
			219		
			220		
			221		
			222		
			223		
			224		
			225		
211					
			226		
	20	**CO-22**			
			227		

Table A-1. Relative location of the range lines.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			228		
			229		
			230		
			231		
			232		
			233		
210					
			234		
			235		
209.7	**21.4**	**CO-23**			Angostura Diversion Dam between CO-23 & 236L.
			236		
			237	88?.?	Cross Section R-Below Angostura Diversion Dam
			238		
			239		
			240		
			241		
			242		
			243		
			244		
			245		
209					
			246		
			247		
	22.5	**CO-24**	248	88?.?	Cross Section R-Angostura "A"
			249		
			250		Jemez River Confluence between 250L & 251L
			251		
			252		
			253		
208					
			254		
			255		
	23.4	**CO-25**	256		CO-25 left end point between 255L and 256L and
			257		right end point between 256L and 257L.
			258		
			259		
			260		
207					
			261		
	23.8	**CO-26**			
			262	88?.?	Cross-section R-Angostura "B"
			263		
			264		
			265		
			266		
			267		
	24.4	**CO-27**			
			268	88?.?	Cross-section R-Angostura "C"
			269		
			270		
			271		
			272		
			273		
206					
			274		
			275		
			276		
			277		
			278		
			279		
			280		
			281		
			282		
	25.6	**CO-28**			
			283		

Table A-1. Relative location of the range lines.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam	CO Lines	Agg/Deg Lines	SCS Lines	Observations
			284		
205					
			285		
			286		
			287		
			288		
			289		
			290		
			291		
			292		
			293		
			294		
	26.7	CO-29			
			295		
204					
			296		
			297		
203.8			298	88?.?	Cross Section Bernalillo Highway Bridge
			299		
			300		
			301		
			302		
			303		
			304		
			305		
			306		
			307		
			308		
			309		
			310		
			311		
			312		
			313		
	28.5	CO-30			
			314		

Table A-2. SCS Range Lines survey data (cont'd).

Collected by	Date		Cross-section Number (SCS Lines/Agg-Deg Lines)									
		SCS	860.4	860.4A	862.2	864	865.3	865.3A	868	868.0A	870.5	870.5A
		Agg/Deg	21	34	47	66	81	93	109	124	137	152
SCS	1918		x		x	x	x					
SCS	1937		x			x						
SCS	1940		x		x	x	x					
SCS	1941		x		x	x	x					
SCS	1936											
SCS	1937		x			x			x			
SCS	1939											
SCS	1940		x		x		x		x		x	
SCS	1941				x						x	
SCS	1942		x			x			x			
COE	1944		x	x	x	x	x	x	x	x	x	
COE	1947				x	x						
USBR and COE	1952											
USBR and COE	1953											
USBR and COE	1954		x	x	x	x	x	x	x	x	x	x
USBR	1964											

Table A-2. SCS Range Lines survey data (cont'd).

Collected by	Date		Cross-section Number (SCS Lines/Agg-Deg Lines)								
		SCS	873			878					
		Agg/Deg	163	178	179	215	237	248	262	268	298
SCS	1918										
SCS	1937										
SCS	1940										
SCS	1941										
SCS	1936			x	x						
SCS	1937					x	x				
SCS	1939			x	x		x				
SCS	1940		x	x	x	x	x				
SCS	1941		x			x					
SCS	1942				x		x				
COE	1944								x		
COE	1947		x								
USBR and COE	1952										x
USBR and COE	1953						x	x	x	x	
USBR and COE	1954		x	x		x					
USBR	1964				x						

Table A-3. Cochiti Range Lines survey data from Cochiti Dam to Isleta Diversion (cont'd).

Collected by	Date	Cross-section Number (CO Lines)															
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
USGS	May-70	x	x	x	x	x		x		x		x	x	x	x	x	
USGS	May-71	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Oct & Sep-71	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Mar-72	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Nov-72	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	5/8/1973	x	x	x	x	x				x						x	
USGS	5/31/1973			x	x	x											
USGS	Jun-73	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
USGS	Jul-73									x		x	x				
USGS	11/19/1973	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
USGS	11/26/1973	x	x	x	x												
USGS	11/30/1973	x	x														
USGS	12/5/1973	x	x													x	
USGS	12/18/1973	x	x	x												x	
USGS	Jan-74	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	May & Jun-74	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Sep-74	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Nov-74																
USGS	May-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Aug & Jul-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
USGS	Nov-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	May-79																
USGS	Apr-79	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x
USGS	Jul-79	x	x	x	x	x	x	x	x		x	x		x	x	x	x
USGS	Jan-80	x	x	x	x	x	x	x	x		x	x		x	x	x	x
USGS	Sept & Oct-82										x	x	x	x		x	
USGS	Dec & Nov-83										x	x	x	x	x	x	x
USGS	Dec & Nov-86															x	x
FLO Engineering	Jul-92	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
FLO Engineering	Aug-95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table A-3. Cochiti Range Lines survey data from Cochiti Dam to Isleta Diversion (cont'd).

Collected by	Date	Cross-section Number (CO Lines)																
		18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
USGS	May-70		x				x											
USGS	May-71	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Oct & Sep-71	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Mar-72	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
USGS	Nov-72	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	5/8/1973	x										x		x				x
USGS	5/31/1973																	
USGS	Jun-73	x	x	x	x	x	x	x		x	x	x	x		x	x	x	x
USGS	Jul-73																	
USGS	11/19/1973																	
USGS	11/26/1973																	
USGS	11/30/1973																	
USGS	12/5/1973																	
USGS	12/18/1973																	
USGS	Jan-74	x	x	x	x	x	x	x	x									
USGS	May & Jun-74	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x	x
USGS	Sep-74	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Nov-74			x		x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	May-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Aug & Jul-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Nov-75	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	May-79															x	x	
USGS	Apr-79	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Jul-79	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
USGS	Jan-80	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Sept & Oct-82	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Dec & Nov-83	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	Dec & Nov-86	x	x	x	x	x	x		x	x	x	x	x	x	x	x	x	x
FLO Engineering	Jul-92	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
FLO Engineering	Aug-95	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Table A-3. Cochiti Range Lines survey data from Cochiti Dam to Isleta Diversion (cont'd).

Collected by	Date	CO Lines			
		35	36	37	38
USGS	May-70	x	x	x	x
USGS	May-71	x	x	x	x
USGS	Oct & Sep-71	x	x	x	x
USGS	Mar-72	x	x	x	x
USGS	Nov-72	x	x	x	x
USGS	5/8/1973				
USGS	5/31/1973				
USGS	Jun-73	x	x	x	x
USGS	Jul-73				
USGS	11/19/1973				
USGS	11/26/1973				
USGS	11/30/1973				
USGS	12/5/1973				
USGS	12/18/1973				
USGS	Jan-74				
USGS	May & Jun-74	x	x	x	x
USGS	Sep-74	x	x	x	x
USGS	Nov-74	x	x	x	
USGS	May-75	x	x	x	x
USGS	Aug & Jul-75	x	x	x	x
USGS	Nov-75	x	x	x	x
USGS	May-79				
USGS	Apr-79	x		x	x
USGS	Jul-79	x		x	x
USGS	Jan-80	x		x	x
USGS	Sept & Oct-82	x		x	x
USGS	Dec & Nov-83	x	x	x	x
USGS	Dec & Nov-86	x	x	x	x
FLO Engineering	Jul-92	x	x	x	x
FLO Engineering	Aug-95	x	x	x	x

Table A-4. Cochiti Range Lines survey data downstream of Isleta Diversion Dam.

Collected by	Date	Cross-section Number (CO Lines)									
		668	712	713	724	725	738.1	739	765	787	806
USGS	Oct-82	x	x			x		x	x	x	x
USGS	Nov-83	x	x			x		x	x	x	x
USGS	Nov-86	x	x			x		x	x	x	x
FLO Engineering	Jul-92	x		x	x		x		x	x	
FLO Engineering	Aug-92										x
FLO Engineering	Aug-95	x		x	x		x		x	x	

Collected by	Date	Cross-section Number (CO Lines)									
		833	840	858	858.1	877	895	926	945	966	986
USGS	Oct-82			x		x	x				
USGS	Nov-83		x	x		x	x	x			
USGS	Nov-86			x		x	x	x			
FLO Engineering	Jul-92										
FLO Engineering	Aug-92	x			x	x	x	x	x	x	x
FLO Engineering	Aug-95										

Collected by	Date	Cross-section Number (CO Lines)								
		1006	1026	1044	1064	1091	1104	1164	1179	1194
USGS	Oct-82									
USGS	Nov-83									
USGS	Nov-86									
FLO Engineering	Jul-92									
FLO Engineering	Aug-92	x	x	x	x	x	x	x	x	x
FLO Engineering	Aug-95									

Table A-5. Cochiti Pueblo Range Line survey data.

Collected by	Date	Cochiti Pueblo Range Lines (CI-Lines)			
		CI-27	CI-28	CI-28-1	CI-29-1
FLO Engineering	Oct-93	x	x	x	x
FLO Engineering	Aug-95	x	x	x	x

Table A-6. Santo Domingo range line survey data.

Collected by	Date	Santo Domingo Range Lines (SD-Lines)																
		SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-8-1	SD-9	SD-10	SD-11	SD-12	SD-13	SD-14	SD-15	SD-16
FLO Engineering	Nov-90	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
FLO Engineering	Feb-92																	

Collected by	Date	Santo Domingo Range Lines (SD-Lines)																
		SD-17	SD-18	SD-18-1	SD-19	SD-20	SD-21	SD-22	SD-23	SD-24	SD-24-1	SD-25	SD-26	SD-27	SD-28	SD-29	SD-30	SD-31
FLO Engineering	Nov-90	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
FLO Engineering	Feb-92		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x

Collected by	Date	Santo Domingo Range Lines (SD-Lines)															
		SD-32	SD-33	SD-34	SD-35	SD-36	SD-37	SD-38	SD-39	SD-40	SD-41	SD-42	SD-43	SD-44	SD-45	SD-46	SD-47
FLO Engineering	Nov-90																
FLO Engineering	Feb-92	x	x														

Table A-7. San Felipe Range Line survey data.

Collected by	Date	San Felipe Range Lines (SFP-Lines)									
		SFP-170	SFP-170.1	SFP-171	SFP-171.1	SFP-172	SFP-172.1	SFP-173	SFP-175	SFP-176	SFP-177
FLO Engineering	Jun-92	x		x	x	x	x	x			

Table A-8. Angostura Range Line survey data

Collected by	Date	Angostura Range lines (AR-Lines)									
		AR-203	AR-204	AR-205	AR-206	AR-207	AR-209	AR-211	AR-214.5	AR-215	AR-216
FLO Engineering	Aug-95	x	x	x	x	x	x	x	x	x	x

Collected by	Date	Angostura Range lines (AR-Lines)									
		AR-216.5	AR-217.5	AR-218.5	AR-219.5	AR-220.5	AR-222	AR-224	AR-227	AR-227.5	AR-228
FLO Engineering	Aug-95	x	x	x	x	x	x	x	x	x	x

Collected by	Date	Angostura Range lines (AR-Lines)						
		AR-229	AR-230	AR-231	AR-232	AR-233	AR-234	AR-235
FLO Engineering	Aug-95	x	x	x	x	x	x	x

Table A-9. Bernalillo Island range line survey data.

Collected by	Date	Bernalillo Island Range Lines (BI-Lines)							
		BI-286	BI-289	BI-291	BI-292	BI-293	BI-294	BI-295	BI-296
FLO Engineering	May-95	x	x	x	x	x	x	x	x
FLO Engineering	Jun-95	x	x	x	x	x	x	x	x
FLO Engineering	Jul-95	x	x	x	x	x	x	x	x

Table A-10. Calabacillas Range Line survey data.

Collected by	Date	Calabacillas Arroyo (CA-Lines)											
		CA-1	CA-2	CA-3	CA-4	CA-5	CA-6	CA-7	CA-8	CA-9	CA-10	CA-11	CA-12
FLO Engineering	May-96		x						x				

Table A-11. Casa Colorada Range Line survey data.

Collected by	Date	(CC-Lines)	
		CC-936	CC-943
FLO Engineering	May-96	x	x

Table A-12. San Acacia Range Line survey data.

Collected by	Date	(SA-Lines)		
		SA-1209	SA-1256	SA-1268
FLO Engineering	May-96	x	x	x

Table A-13. Socorro Range Line survey data.

Collected by	Date	(SO-Lines)			
		SO-1327	SO-1380	SO-1414	SO-1470.5
FLO Engineering	May-96	x	x	x	

Appendix B

Table B-1 Bed material survey data at Cochiti range lines from Cochiti Dam to Isleta Diversion Dam (cont'd).

Collected by	Date	Cross-section Number (CO Lines)													
		2	3	4	5	6	7	8	9	10	11	12	13	14	15
USGS	1970	x	x	x	x	x	x	x		x	x	x	x	x	x
USGS	1971	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	1972	x	x	x	x		x	x	x	x	x	x	x	x	x
USGS	1973	x	x	x	x							x		x	
USGS	1974		x		x		x	x	x	x	x	x	x	x	x
USGS	1975		x		x	x		x	x	x	x	x	x	x	x
USGS	1979		x		x	x	x	x	x		x	x	x	x	x
USGS	1980					x			x		x	x	x	x	
USGS	1982												x	x	
FLO Engineering	1992		x		x			x	x						
FLO Engineering	1995		x		x			x	x				x		

Table B-1 Bed material survey data at Cochiti range lines from Cochiti Dam to Isleta Diversion Dam (cont'd).

Collected by	Date	Cross-section Number (CO Lines)													
		16	17	18	19	20	21	22	23	24	25	26	27	28	29
USGS	1970	x			x		x		x					x	
USGS	1971	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	1972	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	1973				x	x		x				x		x	
USGS	1974	x	x	x	x	x	x	x	x	x	x	x	x	x	x
USGS	1975	x		x	x	x	x	x	x	x	x	x	x	x	x
USGS	1979	x		x		x	x	x	x						
USGS	1980	x					x	x	x						
USGS	1982								x						
FLO Engineering	1992	x				x		x		x	x			x	
FLO Engineering	1995	x				x		x		x	x			x	

Table B-1 Bed material survey data at Cochiti range lines from Cochiti Dam to Isleta Diversion Dam (cont'd).

Collected by	Date	Cross-section Number (CO Lines)								
		30	31	32	33	34	35	36	37	38
USGS	1970				x	x	x	x	x	x
USGS	1971	x	x	x	x	x	x	x	x	x
USGS	1972	x	x	x	x	x	x	x	x	x
USGS	1973			x					x	
USGS	1974	x	x	x	x	x	x	x	x	x
USGS	1975	x	x	x	x	x	x	x	x	x
USGS	1979									
USGS	1980									
USGS	1982									
FLO Engineering	1992		x		x		x			
FLO Engineering	1995		x		x		x			

Table B-2. Bed material survey data at Cochiti range lines downstream of Isleta Diversion Dam.

Collected by	Date	Cross-section Number (CO Lines)									
		668	738.1	787	833	877	966	1006	1044	1091	1104
FLO Engineering	1992	x	x	x	x	x	x	x	x	x	x
FLO Engineering	1995	x	x	x	x	x	x	x	x	x	x

Collected by	Date	CO-Lines	
		1164	1194
FLO Engineering	1992	x	x
FLO Engineering	1995	x	x

Table B-3. Bed material survey data at Santo Domingo range lines.

Collected by	Date	Santo Domingo Range Lines (SD-Lines)										
		SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-8-1	SD-9	SD-10
FLO Engineering	Nov-90	x	x	x	x	x	x	x	x	x	x	x
FLO Engineering	Feb-92											

Collected by	Date	Santo Domingo Range Lines (SD-Lines)										
		SD-11	SD-12	SD-13	SD-14	SD-15	SD-16	SD-17	SD-18	SD-19	SD-20	SD-21
FLO Engineering	Nov-90	x	x	x	x	x						
FLO Engineering	Feb-92									x		x

Collected by	Date	Santo Domingo Range Lines (SD-Lines)										
		SD-22	SD-23	SD-24	SD-25	SD-26	SD-27	SD-28	SD-29	SD-30	SD-31	SD-32
FLO Engineering	Nov-90											
FLO Engineering	Feb-92		x				x					x

Table B-4. Bed material survey data at San Felipe range lines.

Collected by	Date	San Felipe Range Lines (SFP-Lines)			
		SFP-171	SFP-171.1	SFP-172	SFP-172.1
FLO Engineering	Jun-92	x	x	x	x

Table B-5. Bed material survey data at USGS gaging stations.

Collected by	Date	Gaging Station					
		Rio Grande at Otowi Bridge	Rio Grande at Cochiti	Rio Grande at San Felipe	Rio Grande Near Bernalillo	Galisteo at Domingo	Jemez River Near Jemez
USGS	1960	x					
USGS	1961	x			x		
USGS	1966				x	x	
USGS	1967				x		
USGS	1968				x		
USGS	1969				x		
USGS	1970			x			
USGS	1971			x			
USGS	1972			x			
USGS	1973		x	x			
USGS	1974			x			
USGS	1992						x

Table B-6. Suspended sediment data at USGS gaging stations.

USGS Station	USGS Station Number	Daily Sediment Discharge (tons/day)	Sediment Concentration (mg/L)
Rio Chama AB **Abiquiu** RE	08-2865-00	10/1/62 – 12/31/75	10/1/62 – 12/31/75
Rio Chama BL **Abiquiu** Dam	08-2870-00	10/1/62 – 12/31/75	10/1/62 – 12/31/75
Rio Grande at **Otowi**	08-3130-00	10/1/55 – 9/30/94	10/1/55 – 9/30/94
Rio Grande Below **Cochiti** Dam	08-3174-00	7/1/74 – 9/30/88	7/1/74 – 9/30/88 Gap from 9/30/84 – 10/1/85
Galisteo Creek at Domingo	08-3180-00	10/1/55 – 6/30/71	10/1/55 – 6/30/71
Galisteo Creek below Galisteo Dam	08-3179-50	7/1/71 – 9/30/78	7/1/71 – 9/30/78
Jemez River Below Jemez Canyon Dam	08-3290-00	10/1/55 – 9/30/58	10/1/55 – 9/30/58 10/1/60 – 9/30/62
Rio Grande near **Bernalillo**	08-3295-00	10/1/55 – 9/30/69	10/1/55 – 9/30/69

Table B-7. Suspended sediment concentration data at USGS gaging stations.

Collected by	Date	Gaging Station								
		Rio Grande at Otowi Bridge	Rio Grande at Cochiti	Rio Grande Below Cochiti Dam	Rio Grande at San Felipe	Rio Grande Near Bernalillo	Galisteo Creek below Galisteo	Galisteo at Domingo	Jemez River Below Jemez	Jemez River Near Jemez
USGS	1960	x				x		x		
USGS	1961	x				x		x		
USGS	1962	x				x		x		
USGS	1963	x				x		x		
USGS	1965	x				x		x		
USGS	1966	x				x		x		
USGS	1967	x				x		x		
USGS	1968	x				x		x		
USGS	1969	x				x		x		
USGS	1970				x					
USGS	1971	x			x		x			
USGS	1972	x			x		x			
USGS	1973	x	x		x		x			
USGS	1974	x		x	x		x		x	
USGS	1975	x			x		x			
USGS	1976	x			x		x			
USGS	1977	x			x		x			
USGS	1978	x		x	x		x			
USGS	1979	x		x	x		x			
USGS	1980	x		x	x					x
USGS	1981	x			x					x
USGS	1982	x		x	x					x
USGS	1983	x		x	x					x
USGS	1984	x		x	x					x
USGS	1985	x		x	x					x
USGS	1986	x		x	x					x
USGS	1987	x		x	x					x
USGS	1988	x		x	x					x
USGS	1989	x			x					x
USGS	1990	x			x					x
USGS	1991	x		x	x					
USGS	1992	x			x					x
USGS	1993	x			x					x
USGS	1994	x			x				x	x
USGS	1995	x			x				x	x
USGS	1996	x		x	x				x	

Table B-8. Suspended sediment discharge data at USGS gaging stations.

(Shaded cells include total suspended sediment discharge in tons/d)

Collected by	Date	Gaging Station							
		Rio Grande at Otowi Bridge	Rio Grande Below Cochiti Dam	Rio Grande at San Felipe	Rio Grande Near Bernalillo	Galisteo Creek at Domingo	Galisteo Creek Below Galisteo Dam	Jemez River Below Jemez Canyon Dam	Jemez River Near Jemez
USGS	1960	x			x	x			
USGS	1961	x			x	x			
USGS	1962	x			x	x			
USGS	1963	x			x	x			
USGS	1965	x			x	x			
USGS	1966	x			x	x			
USGS	1967	x			x	x			
USGS	1968	x			x	x			
USGS	1969	x			x	x			
USGS	1970			x					
USGS	1971	x		x			x		
USGS	1972	x		x			x		
USGS	1973	x		x			x		
USGS	1974	x	x	x			x	x	
USGS	1975	x		x			x		
USGS	1976	x		x			x		
USGS	1977	x		x			x		
USGS	1978	x	x	x			x		
USGS	1979	x	x	x			x		
USGS	1980	x	x	x					x
USGS	1981	x		x					x
USGS	1982	x		x					x
USGS	1983			x					

Table B-9. Suspended sediment particle size distribution data at USGS gaging ststions (cont'd).

Collected by	Date	Gaging Station								
		Rio Grande at Otowi Bridge	Rio Grande at Cochiti	Rio Grande Below Cochiti Dam	Rio Grande at San Felipe	Rio Grande Near Bernalillo	Galisteo Creek below Galisteo Dam	Galisteo at Domingo	Jemez River Below Jemez Canyon Dam	Jemez River Near Jemez
USGS	1960					x		x		
USGS	1961	x				x		x		
USGS	1962	x				x		x		
USGS	1963	x				x		x		
USGS	1965	x				x		x		
USGS	1966	x				x		x		
USGS	1967	x				x		x		
USGS	1968	x				x		x		
USGS	1969	x				x		x		
USGS	1970				x					
USGS	1971	x			x		x			
USGS	1972	x			x		x			
USGS	1973	x	x		x		x			
USGS	1974	x		x	x		x		x	
USGS	1975	x			x		x			
USGS	1976	x			x		x			
USGS	1977	x			x		x			
USGS	1978	x		x	x		x			
USGS	1979	x		x	x					
USGS	1980	x		x	x					x
USGS	1981	x			x					x
USGS	1982	x		x	x					x
USGS	1983	x		x	x					x
USGS	1984	x		x	x					x
USGS	1985	x		x	x					x
USGS	1986	x		x	x					x
USGS	1987	x		x	x					x
USGS	1988	x		x	x					x
USGS	1989	x			x					x

Table B-9. Suspended sediment particle size distribution data at USGS gaging ststions (cont'd).

Collected by	Date	Gaging Station								
		Rio Grande at Otowi Bridge	Rio Grande at Cochiti	Rio Grande Below Cochiti Dam	Rio Grande at San Felipe	Rio Grande Near Bernalillo	Galisteo Creek below Galisteo Dam	Galisteo at Domingo	Jemez River Below Jemez Canyon Dam	Jemez River Near Jemez
USGS	1990	x			x					x
USGS	1991	x		x	x					
USGS	1992	x			x					x
USGS	1993	x			x					x
USGS	1994	x			x				x	x
USGS	1995	x			x				x	x
USGS	1996	x			x				x	

Table B-10. Daily Mean Discharge Data

USGS Stations	USGS Station Number	Dates
Rio Grande at Embudo	08-2795-00	1/1/89 to 3/31/1904 9/1/12 to 5/25/97
Rio Chama AB Abiquiu RE	08-2865-00	8/1/1961 to 9/30/93
Rio Chama BL Abiquiu Dam	08-2870-00	11/1/61 to 9/30/93
Rio Chama near Chamita	08-2900-00	10/1/12 to 25/5/97
Rio Grande at Otowi Bridge	08-3130-00	2/1/1895 to 12/31/1905 7/1/1909 to 9/30/1914 10/1/18 to 5/25/97
Rio Grande at Cochiti	08-3145-00	6/1/26 to 10/30/70
Rio Grande below Cochiti Dam	08-3174-00	10/1/70 to 5/25/97
Galisteo Creek at Domingo	08-3180-00	10/1/41 to 6/30/71
Galisteo Creek below Galisteo Dam	08-3179-50	3/20/70 to 9/30/94
Rio Grande at San Felipe	08-3190-00	1/1/27 to 12/31/28 Sporadic 1929 & 1930 10/1/30 to 1/2/97
Jemez River near Jemez	08-3240-00	10/1/36 to 9/30/94 (Gap from 4/30/41 to 10/1/49 and 10/1/50 to 3/1/53)
Jemez River below Jemez Canyon Dam	08-3290-00	4/1/36 to 9/30/94 (Gap from 10/1/37 to 4/1/43)
Rio Grande near Bernalillo	08-3295-00	9/23/29 to 6/17/69 (no daily - peaks above the base flow)
Rio Grande at Albuquerque	08-3300-00	3/1/42 to 5/25/97

Appendix C

Table C-1. Blue line aerial photo reproductions (cont'd).

Label	Date of Photography	Scale	Scale of Photography	Sheet #
Middle Rio Grande Project - NM Cochiti Dam Range Lines.	February 3, 1984	1" = 400'		163-518-5391
Middle Rio Grande Project - NM San Felipe Pueblo Range Lines South Side-Aerial	February 3, 1984	1" = 400'	Negative scale 1:9600	163-518-5661
Middle Rio Grande Project - NM San Felipe Pueblo Range Lines North Side-Aerial	February 3, 1984	1" = 400'	Negative scale 1:9600	163-518-5672
Middle Rio Grande Project - NM Santo Domingo Phase I Range Lines SD-1 thru SD-30	February 3, 1984	1" = 400'		163-518-5404
Middle Rio Grande Project - NM San Felipe Range Lines SFP 175 thru SFP-200	December 9, 1987		1:24000	2 sheets without number
Middle Rio Grande-Project USGS-Cochiti to San Acacia Range Lines CO-2 thru CO-29	February 21, 1992	1" = 400'	1:24000	163-518-6100 163-518-6101 163-518-6102 163-518-6103 163-518-6104 163-518-6105 163-518-6106 163-518-6107 163-518-6109 163-518-6110 163-518-6111 163-518-6112 163-518-6113

Table C-1. Blue line aerial photo reproductions (cont'd).

Label	Date of Photography	Scale	Scale of Photography	Sheet #
Middle Rio Grande Project - NM Angostura Range Lines. Range Lines 203 thru 235	February 21, 1992	1" = 400'	1:24000	163-518-6043 163-518-6044
Middle Rio Grande Project Calabacillas Arroyo Range Lines. CA-1 thru CA-13	February 24, 1992	1" = 400'		163-518-5824 163-518-5826
Middle Rio Grande Project Bridge Street A-Lines. A-1 thru A-9	February 24, 1992	1" = 400'	1:24000	163-518-5810 163-518-6061
Middle Rio Grande Project - NM Aggradation - Degradation Range Lines. Cochiti Dam to Range Line 1794	February 21, 1992	1" = 400'	1:24000	Sheet 4 of 79
Middle Rio Grande Project Santo Domingo Phase II Range Lines SD-31 thru SD-47	February 21, 1992	1" = 400'		163-518-5811
Middle Rio Grande Project - NM Rio Grande Photo Mosaic Map 1992. Velarde to Caballo Dam	February 27, 1992	1" = 2000'		23 sheets
Middle Rio Grande Project Santa Ana Pueblo. TA-Environmental Lines	October 10, 1994	1" = 400'	1:24000	163-518-6083
Middle Rio Grande Project Bernalillo Island Site. Range lines 286 thru 296	October 10, 1994	1" = 400'	1:24000	163-518-6098 163-518-6142
Cochiti Dam to State Highway 44 Bridge at Bernalillo	June 19,1996	1" = 400'	1:24000	13 sheets

Appendix D

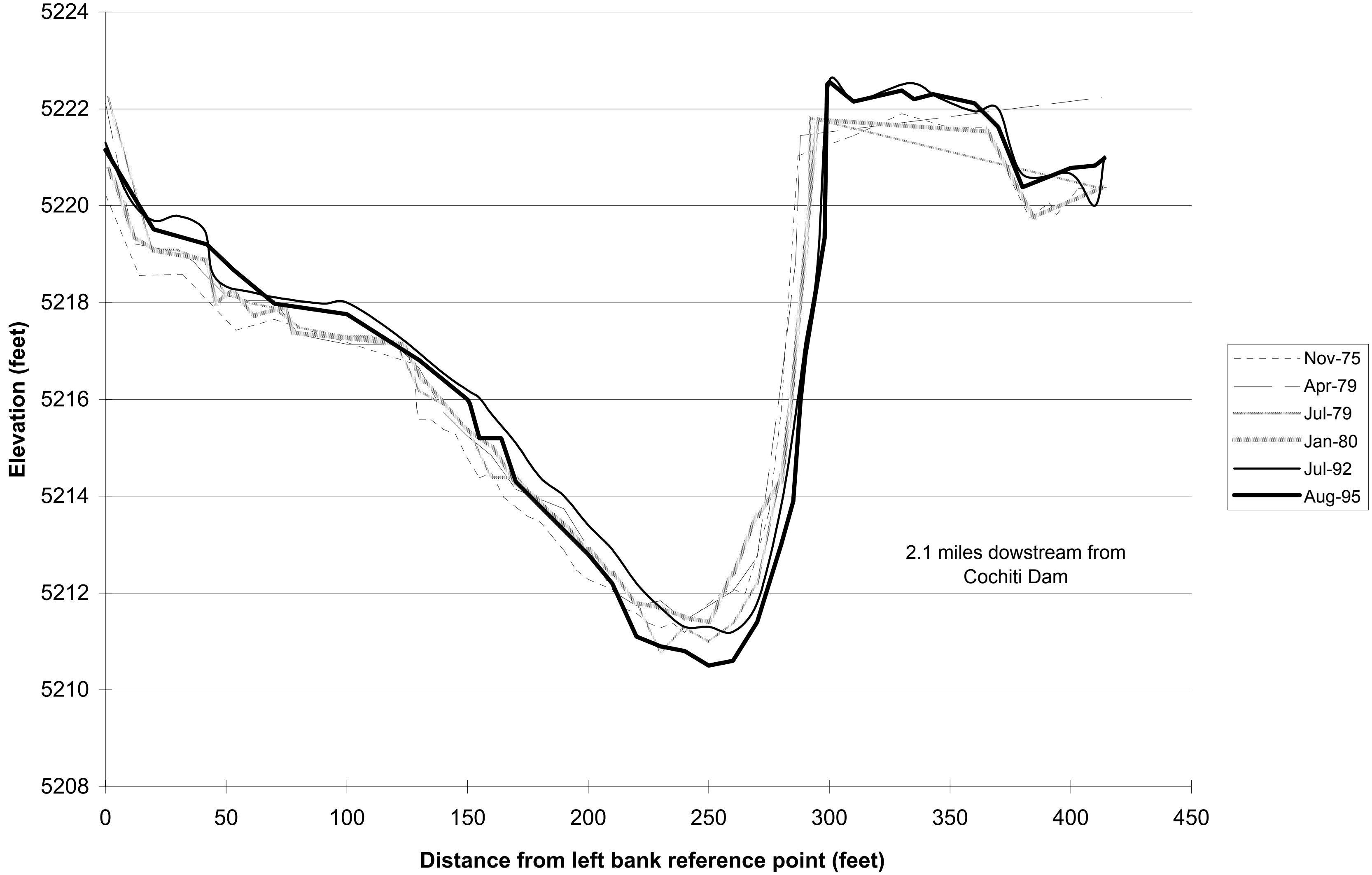

Fig. D-1. Cross Section CO-2.

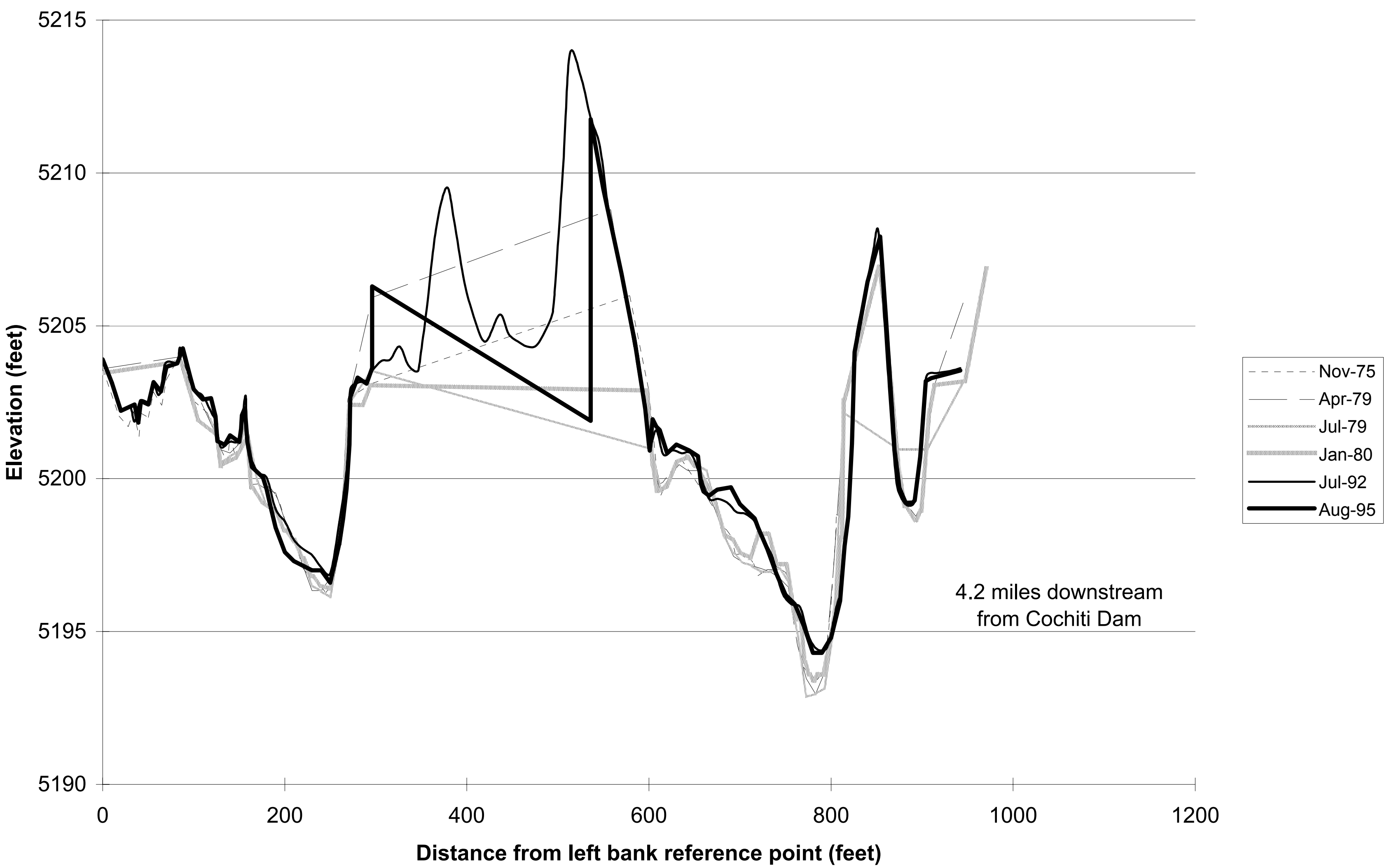

Fig.D-2. Cross Section CO-4.

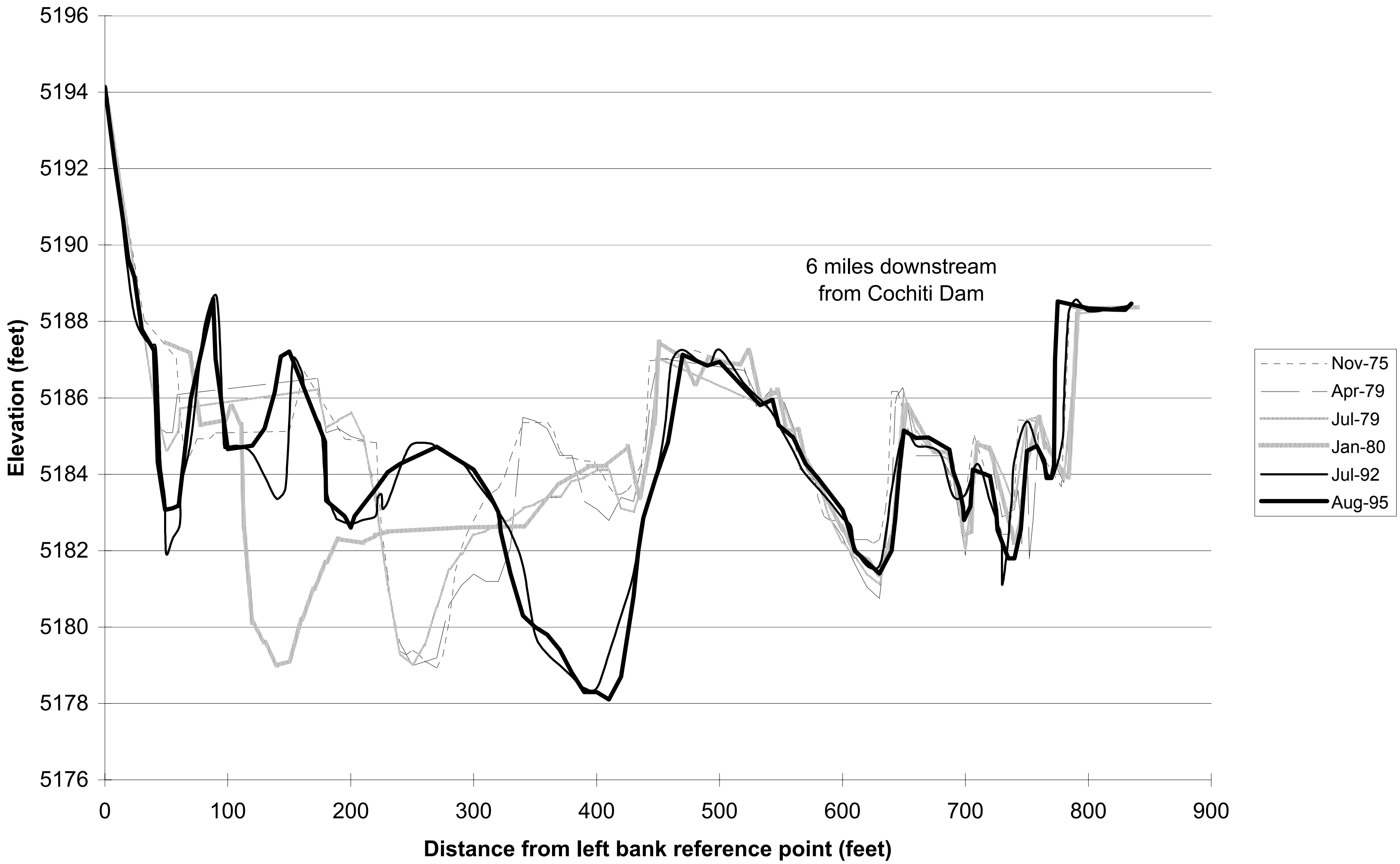

Fig.D-3. Cross Section CO-6.

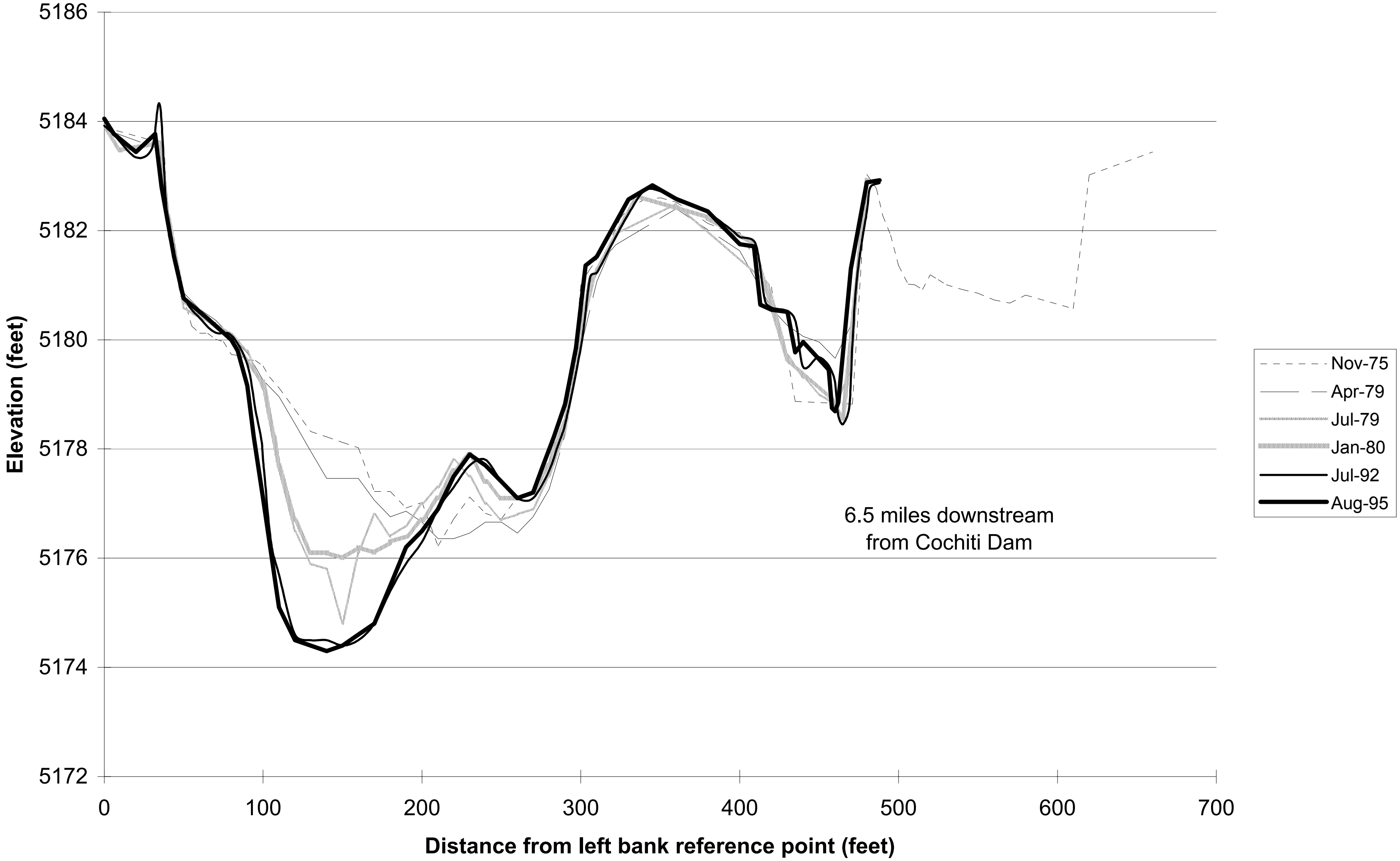

Fig.D-4. Cross Section CO-7.

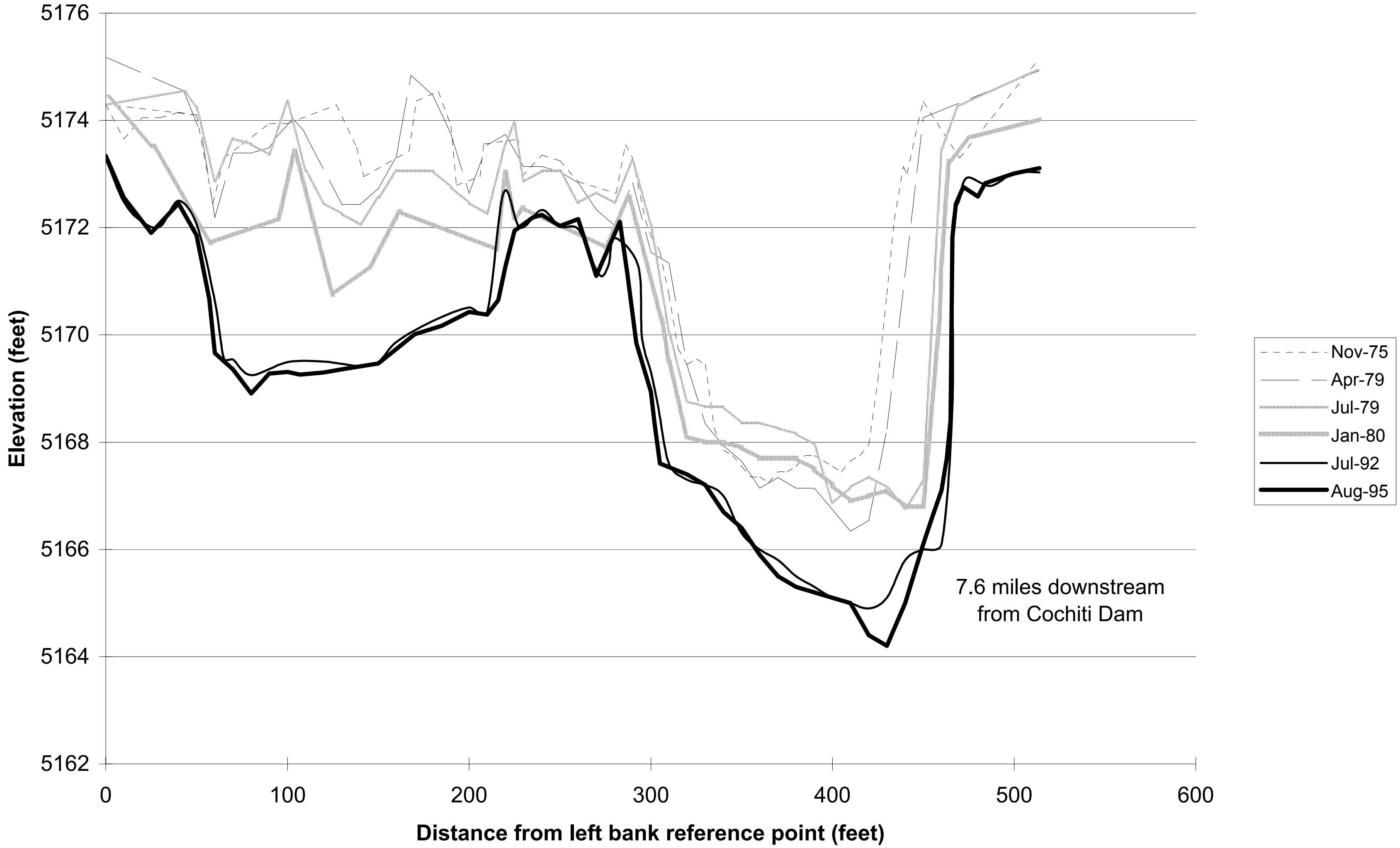

Fig.D-5. Cross Section CO-8.

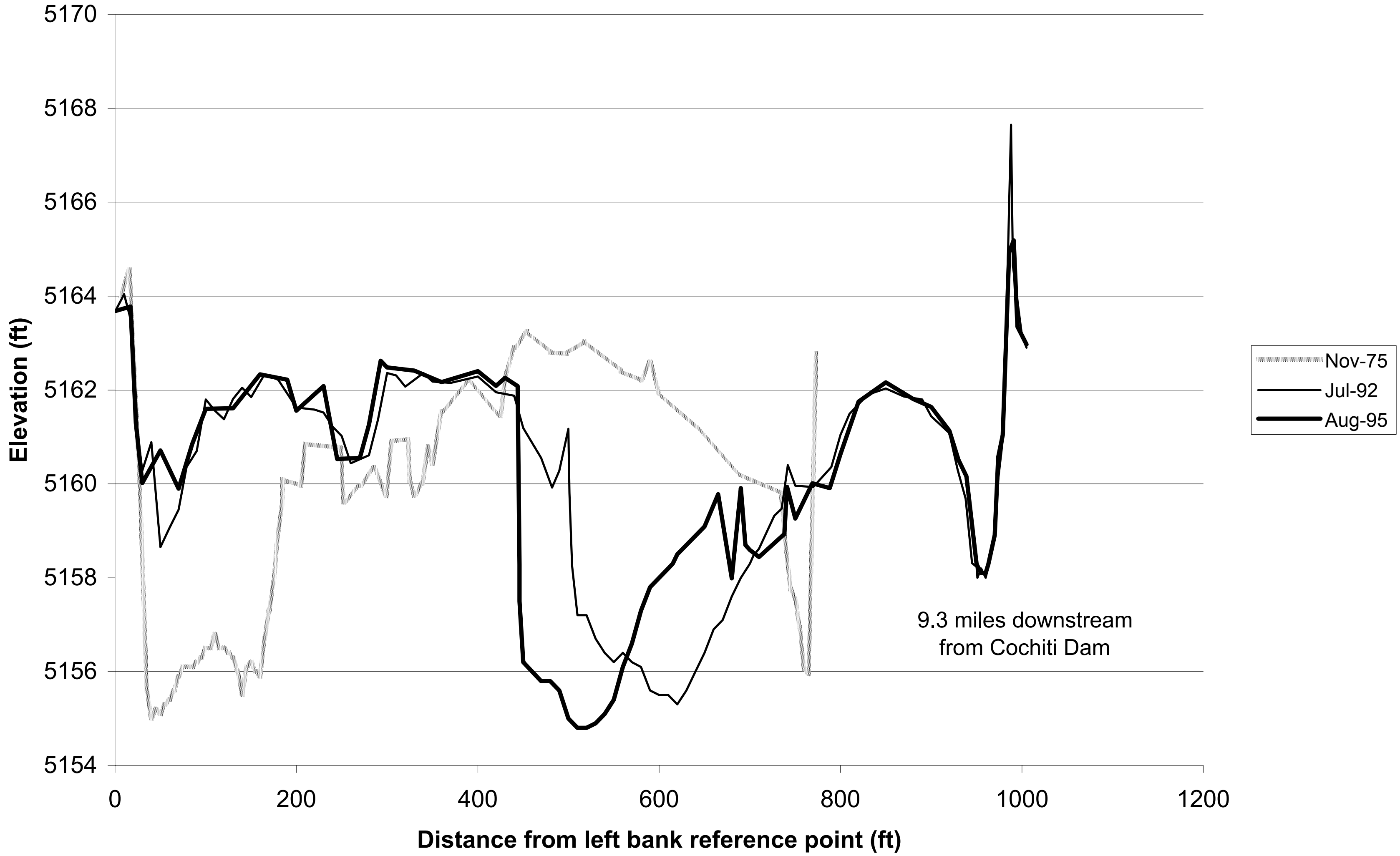

Fig.D-6. Cross Section CO-10.

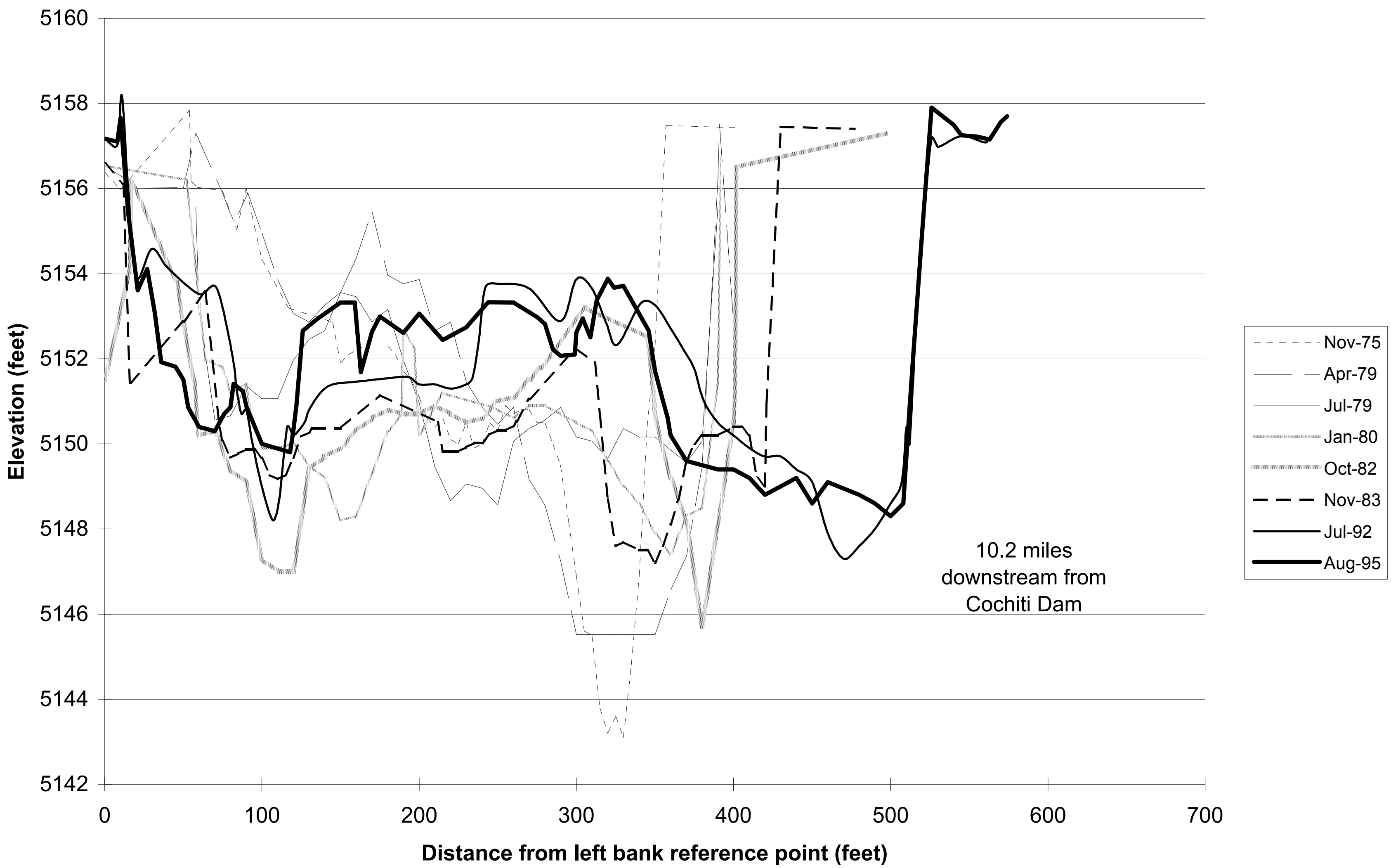

Fig.D-7. Cross Section CO-11.

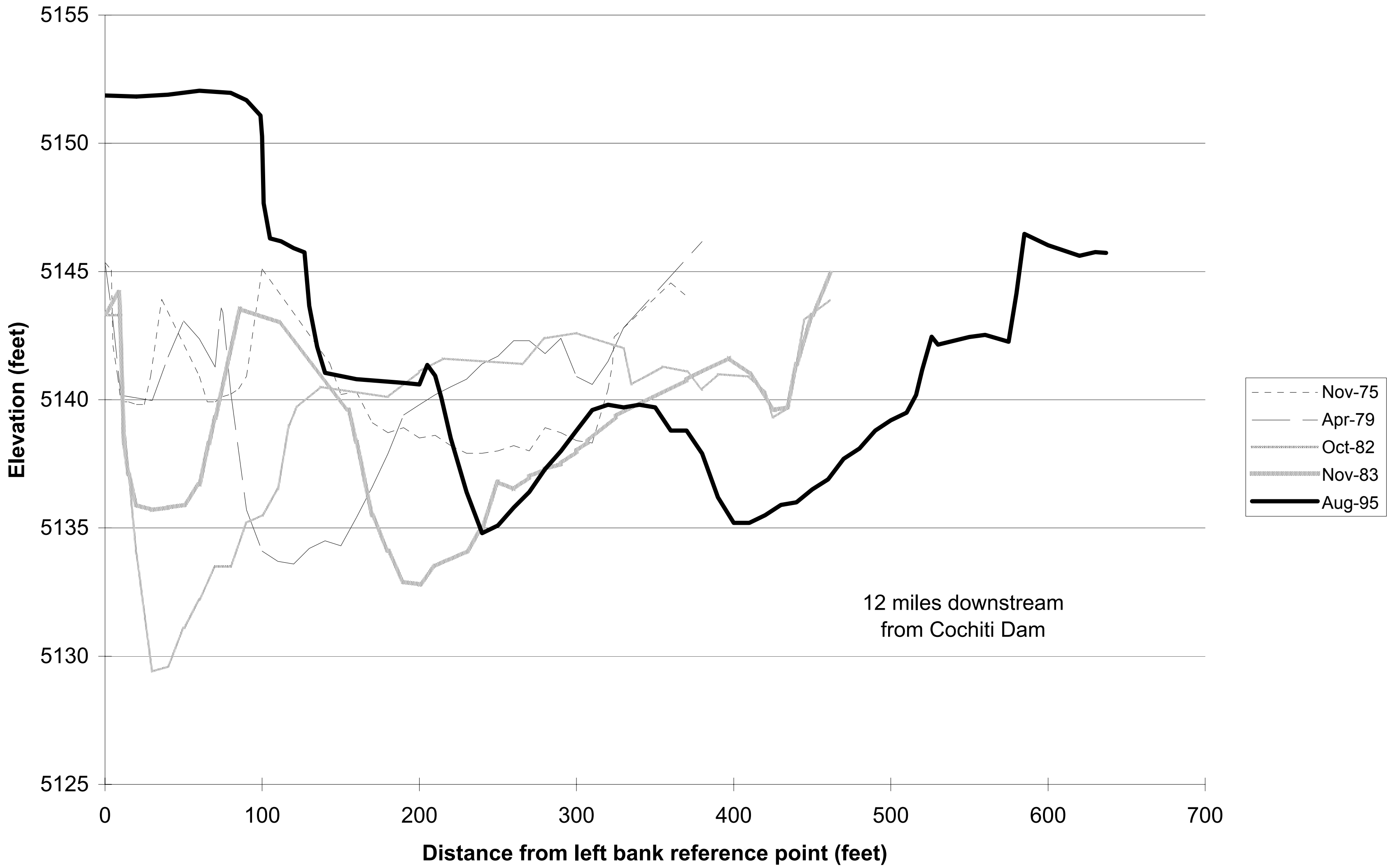

Fig.D-8. Cross Section CO-13.

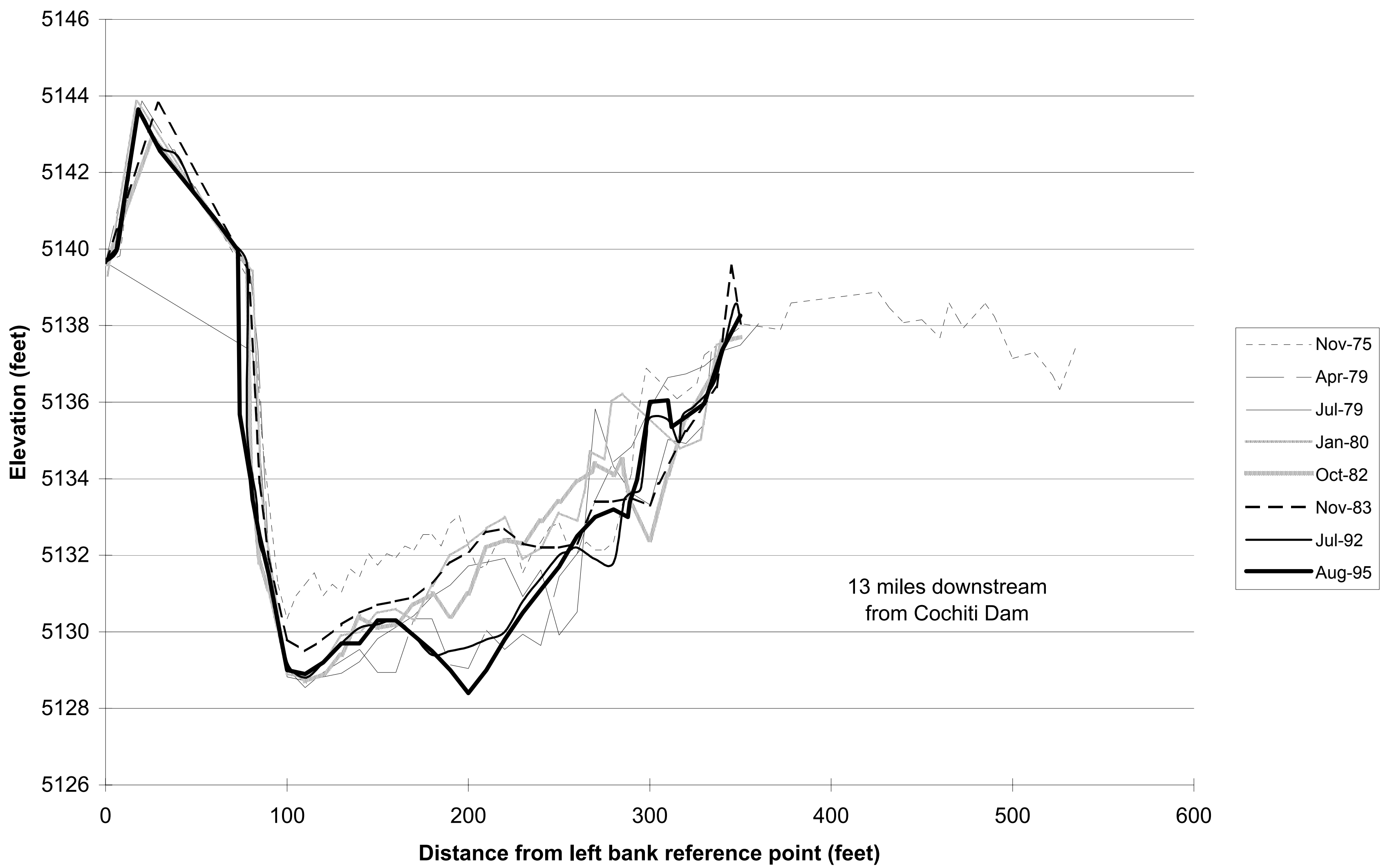

Fig.D-9. Cross Section CO-14.

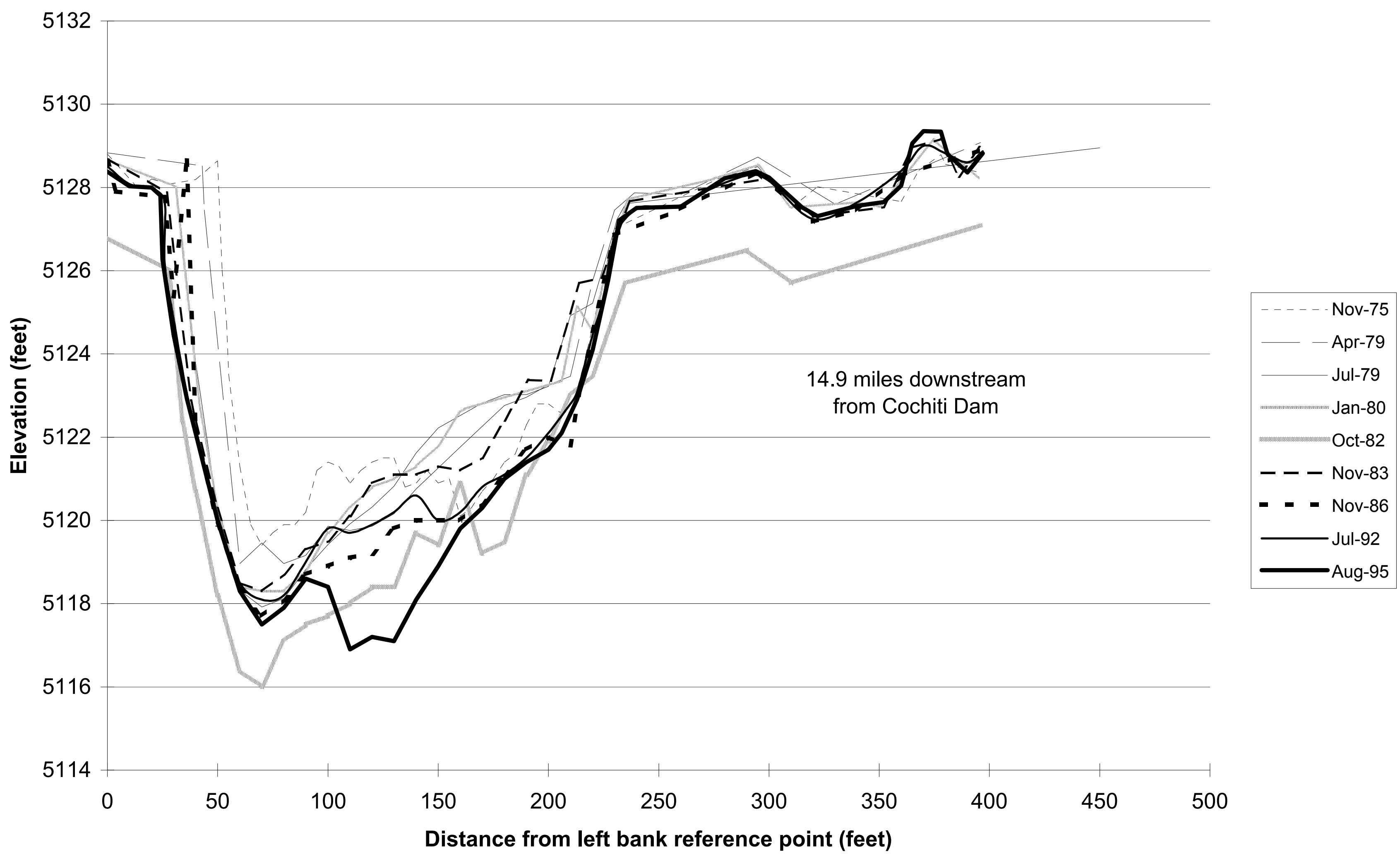

Fig.D-10. Cross Section CO-16.

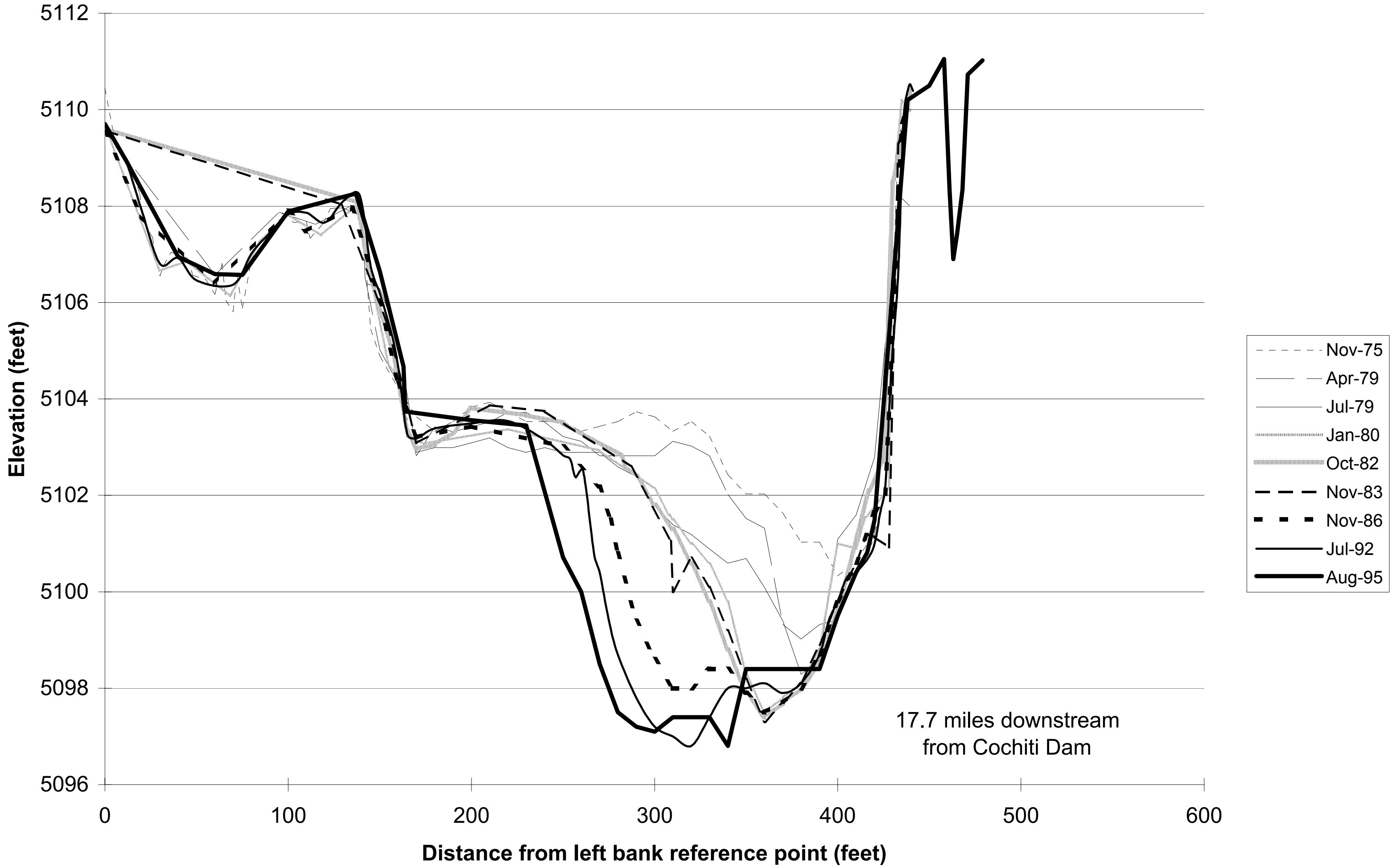

Fig.D-11. Cross Section CO-19

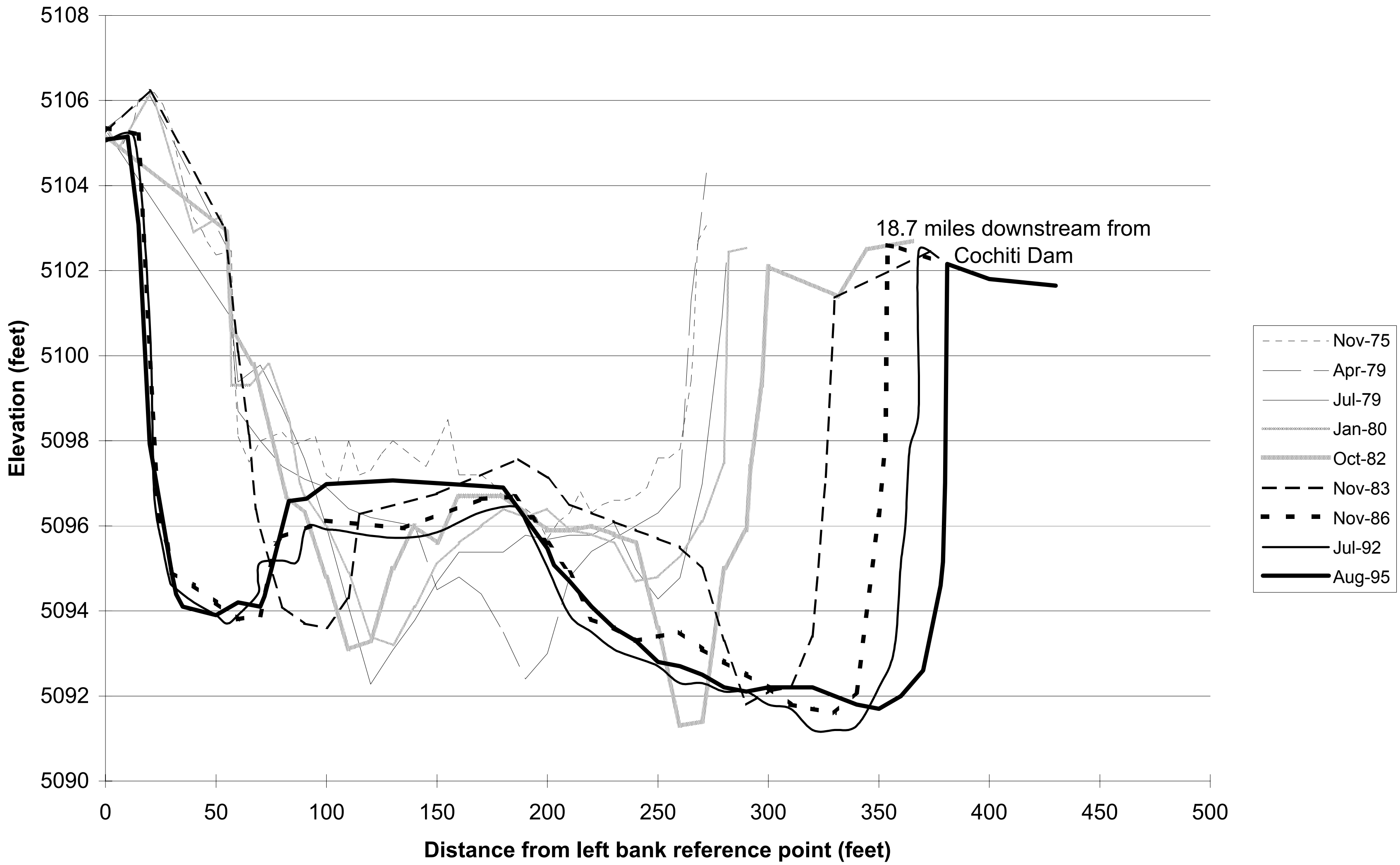

Fig.D-12. Cross Section CO-20

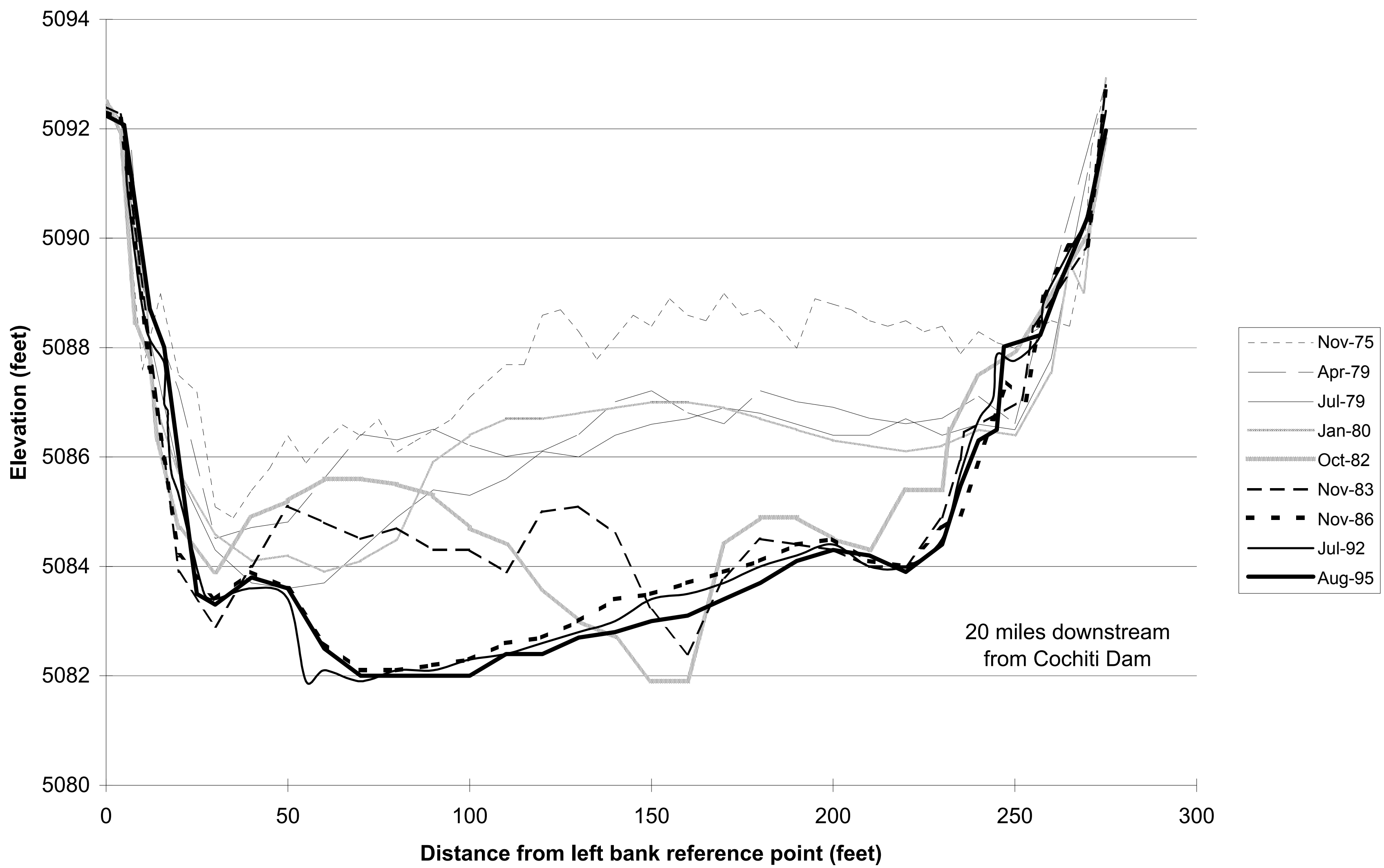

Fig.D-13. Cross Section CO-22.

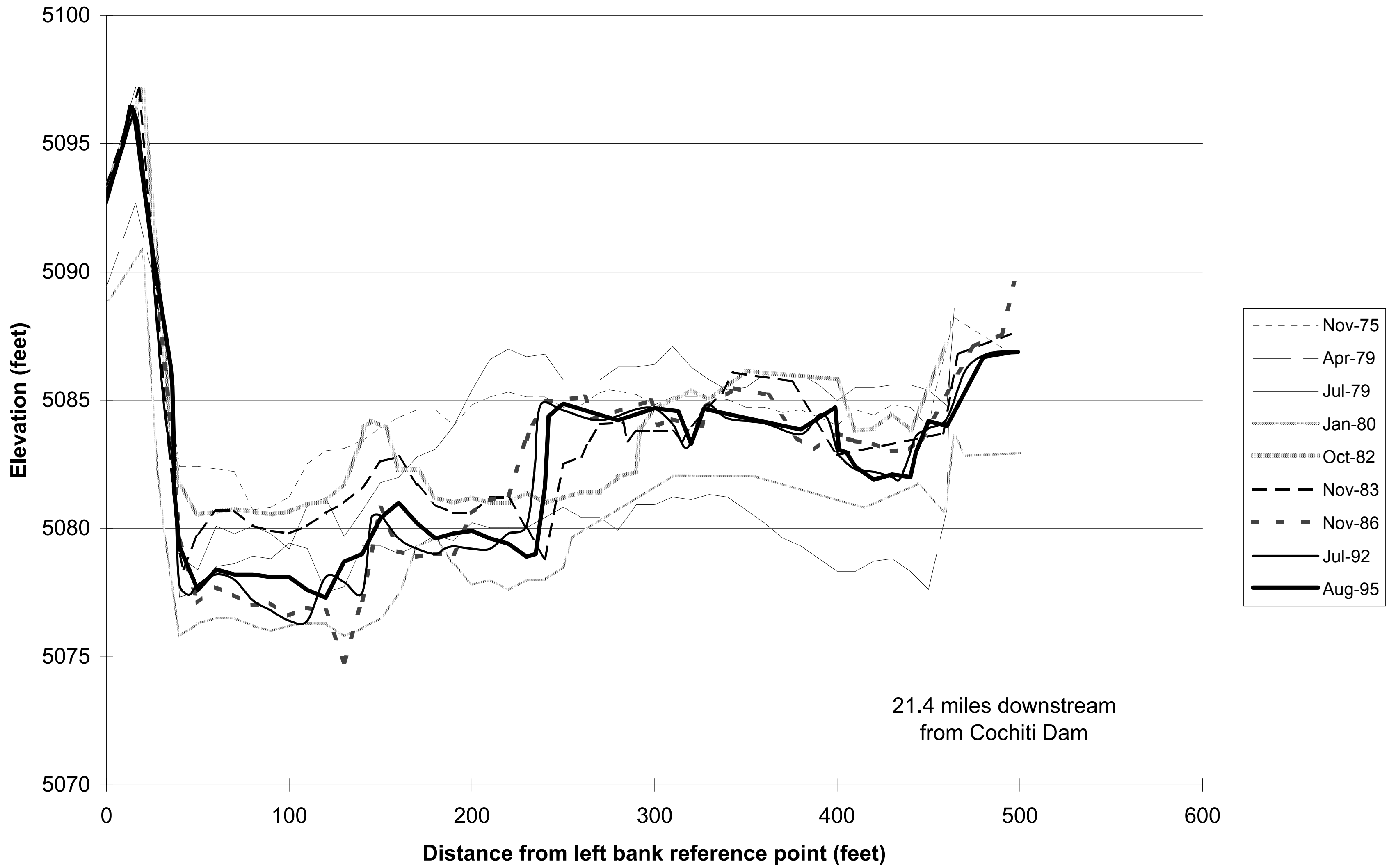

Fig.D-14. Cross Section CO-23.

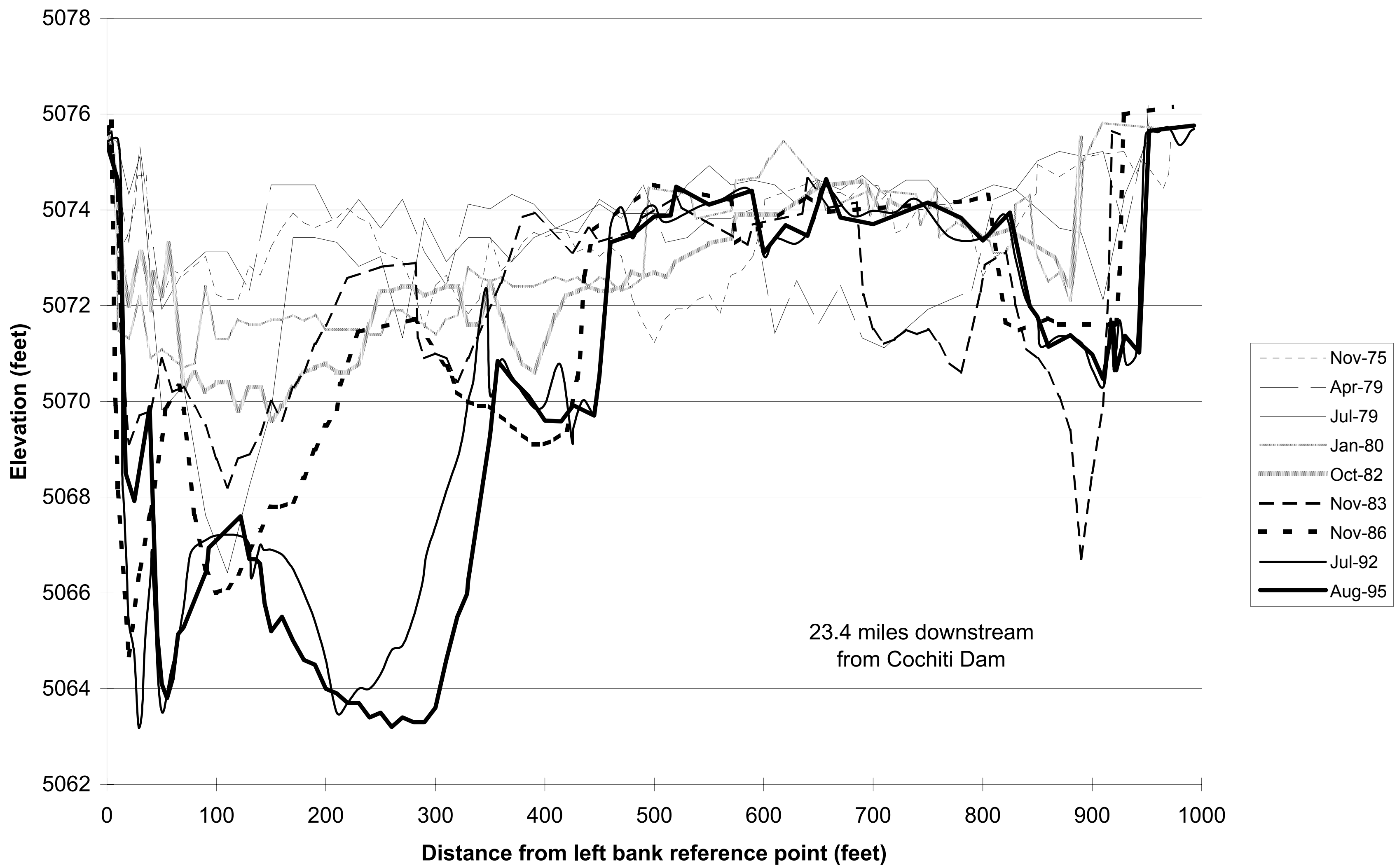

Fig.D-15. Cross Section CO-25.

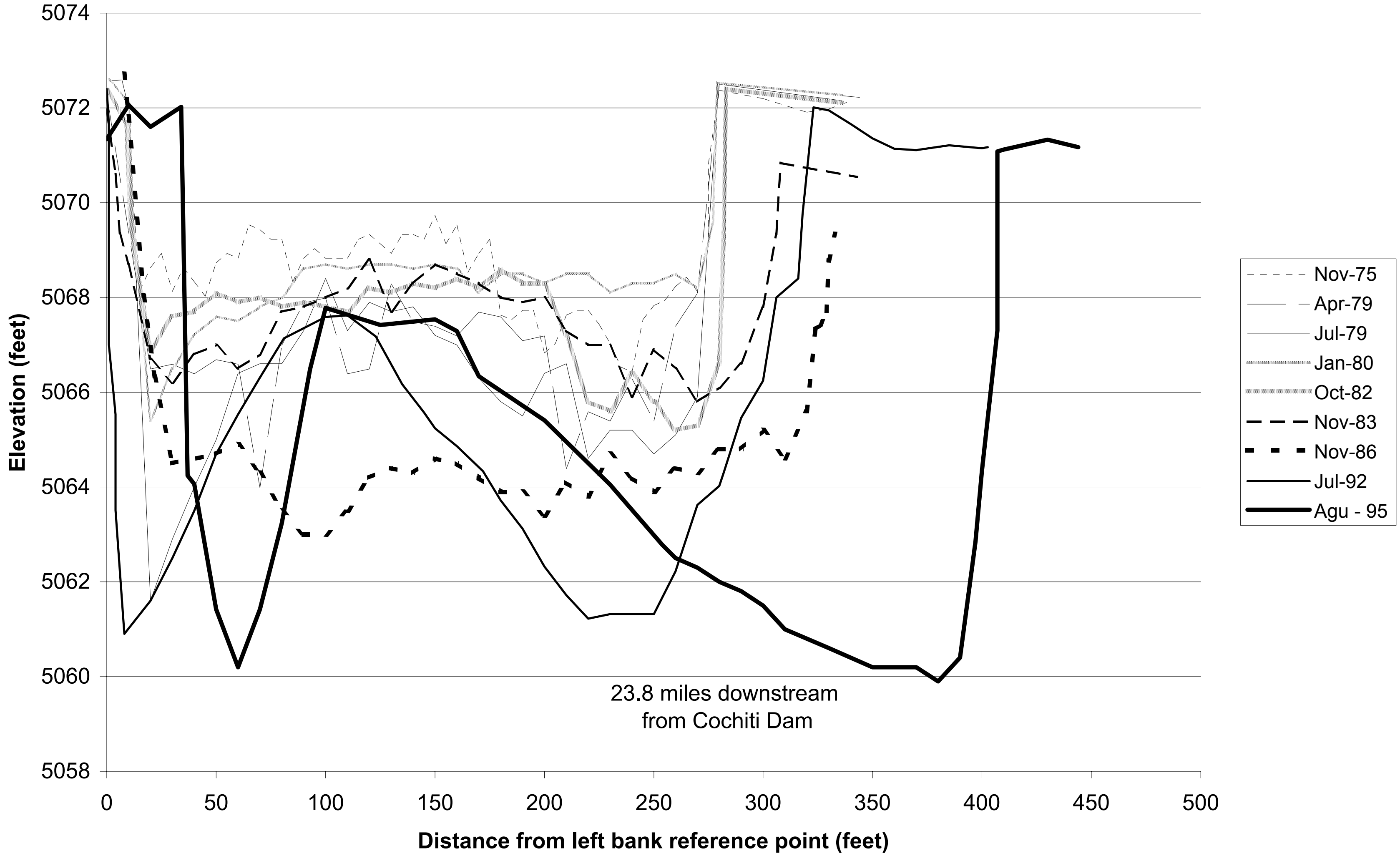

Fig.D-16. Cross Section CO-26

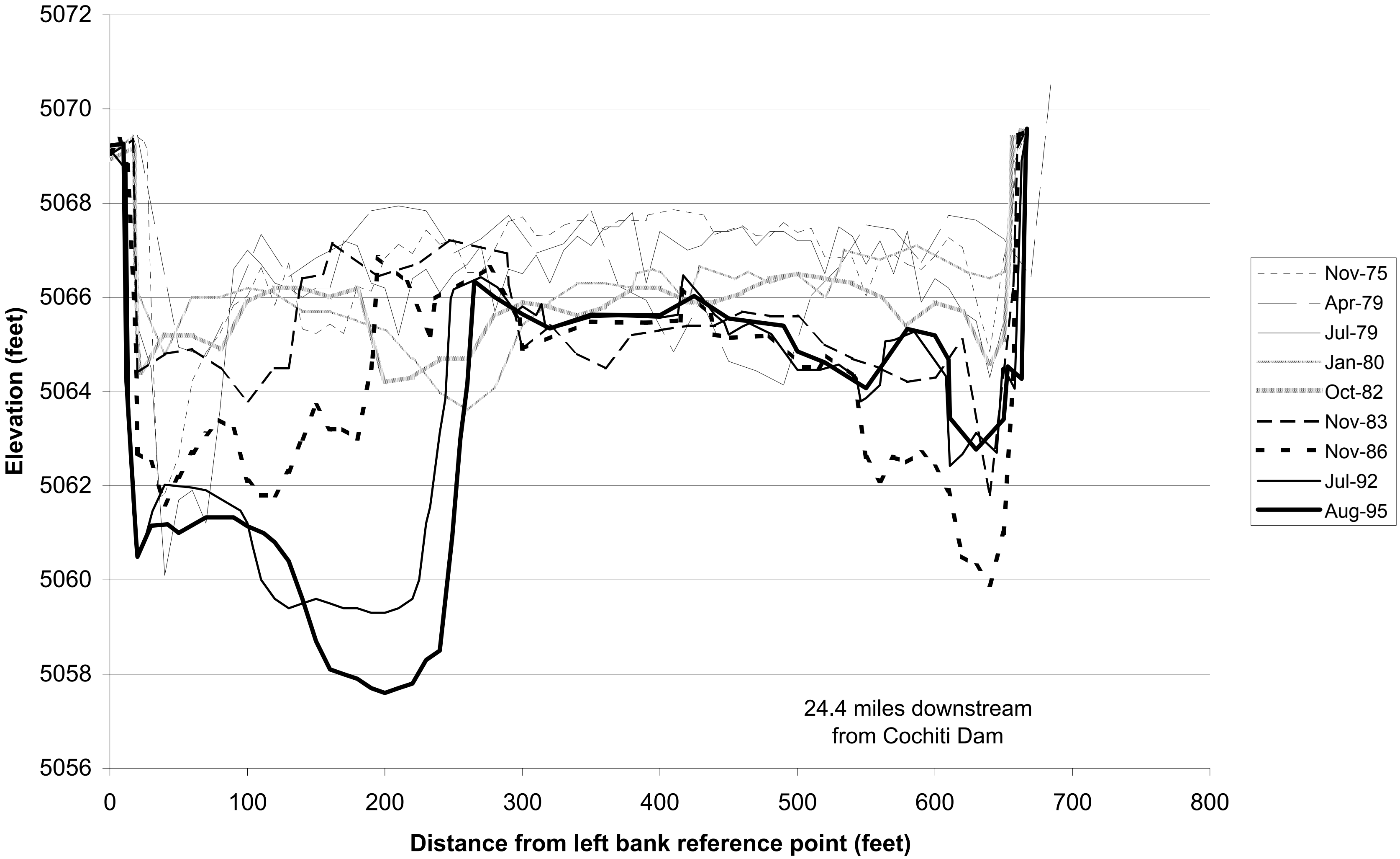

Fig.D-17. Cross Section CO-27.

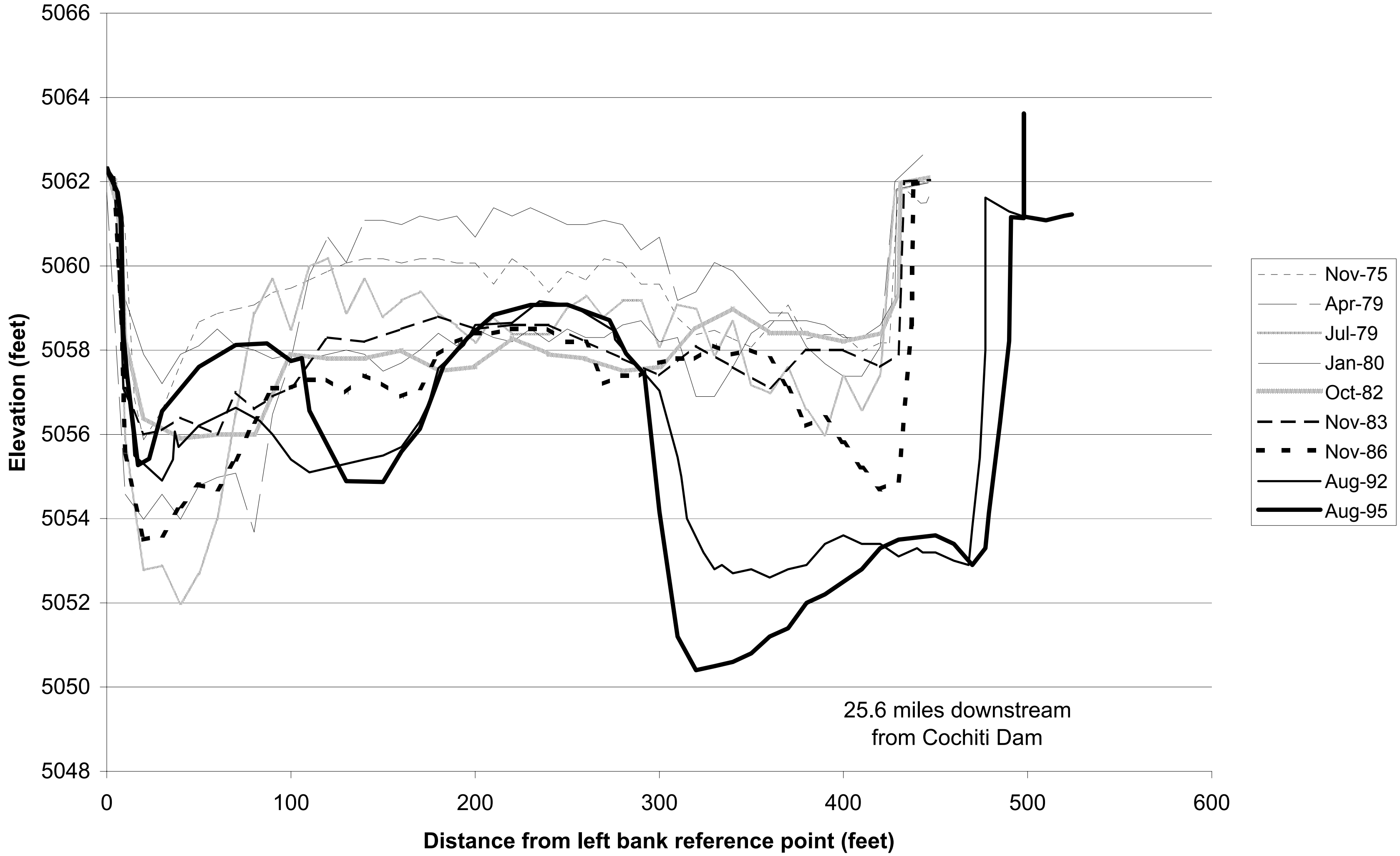

Fig.D-18. Cross Section CO-28.

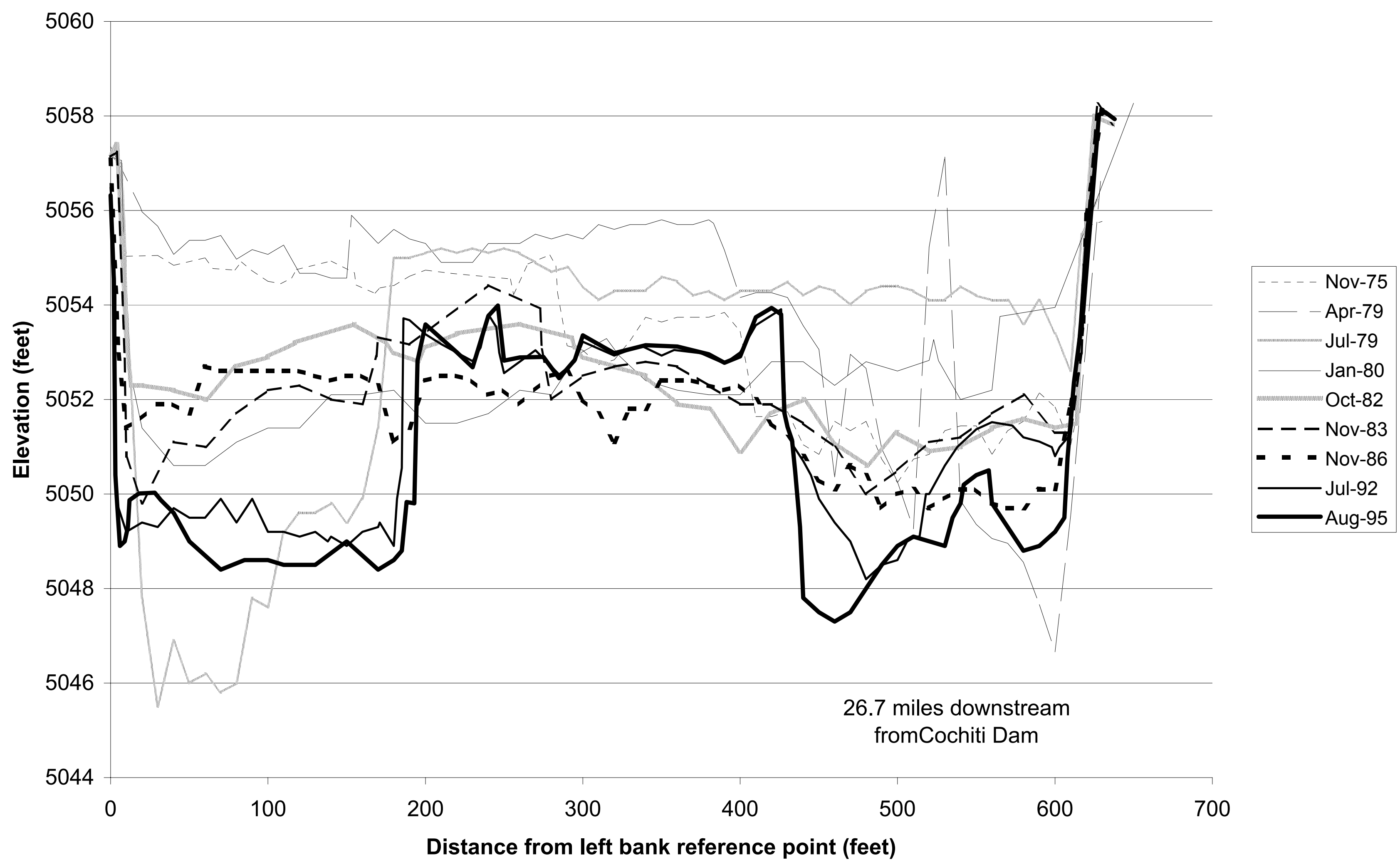

Fig.D-19. Cross Section CO-29

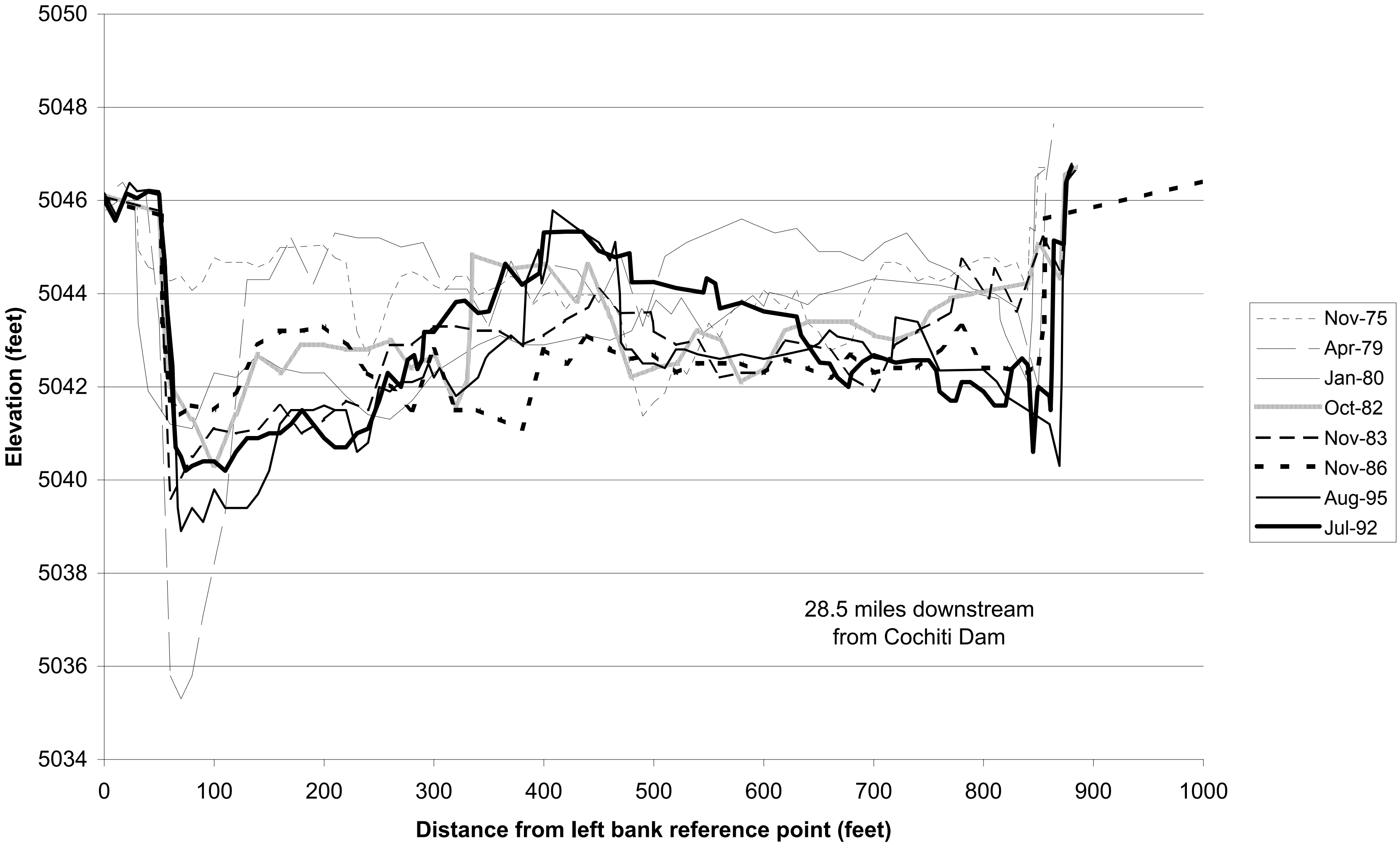

Fig.D-20. Cross Section CO-30.

Appendix E

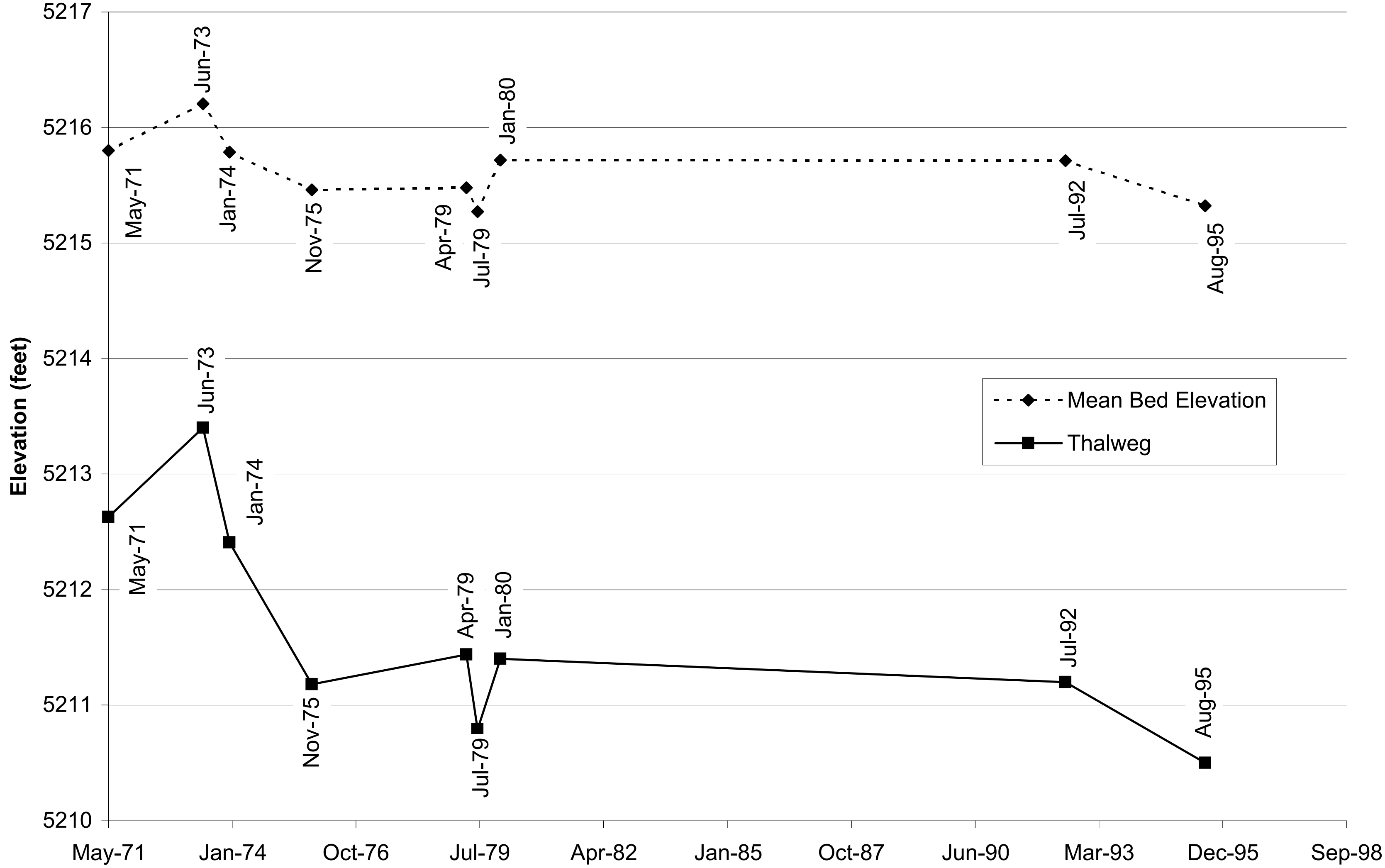

Fig. E-1. Change in thalweg elevation and mean bed elevation with time at cross section CO-2.

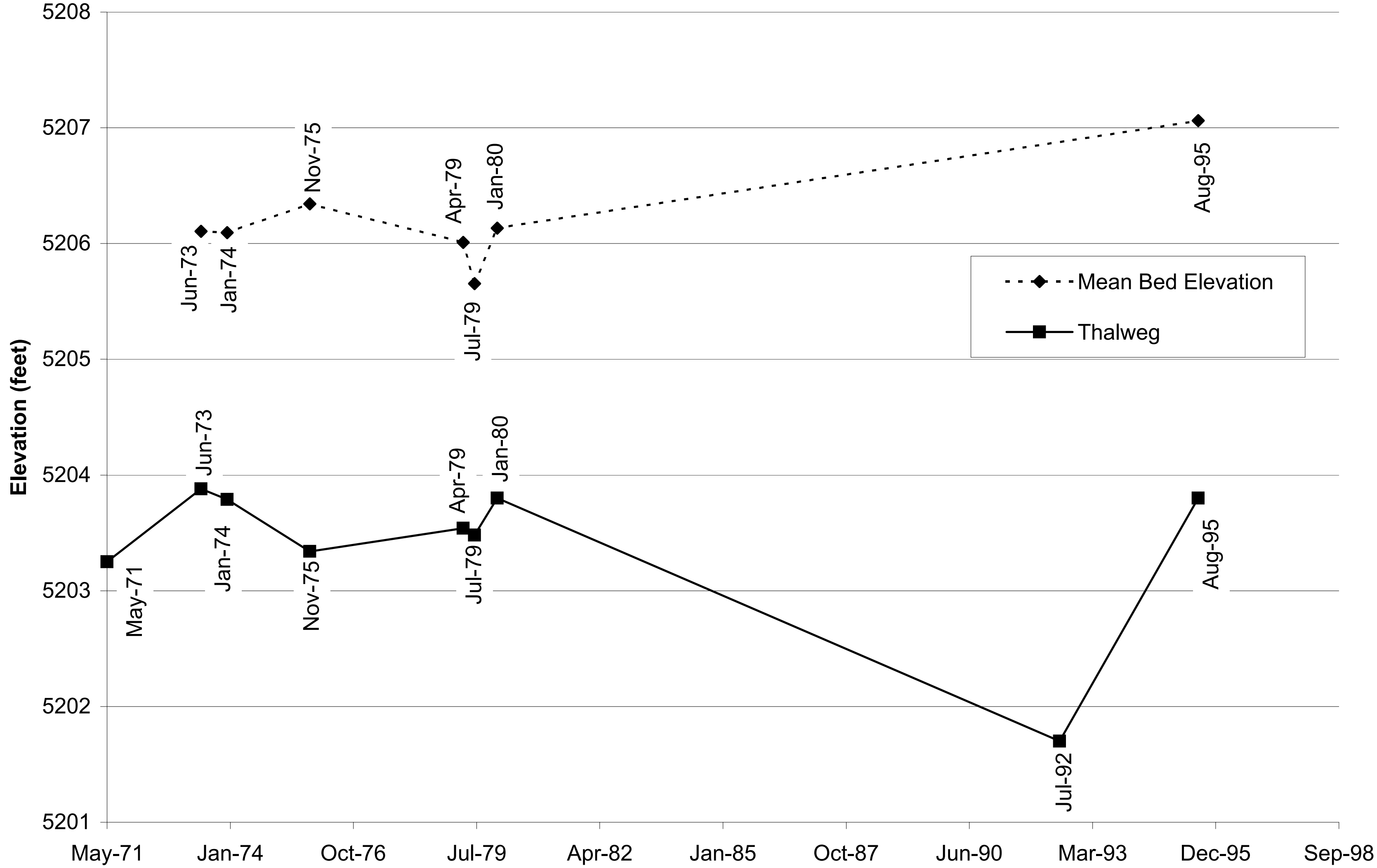

Fig. E-2. Change in thalweg elevation and mean bed elevation with time at cross section CO-3.

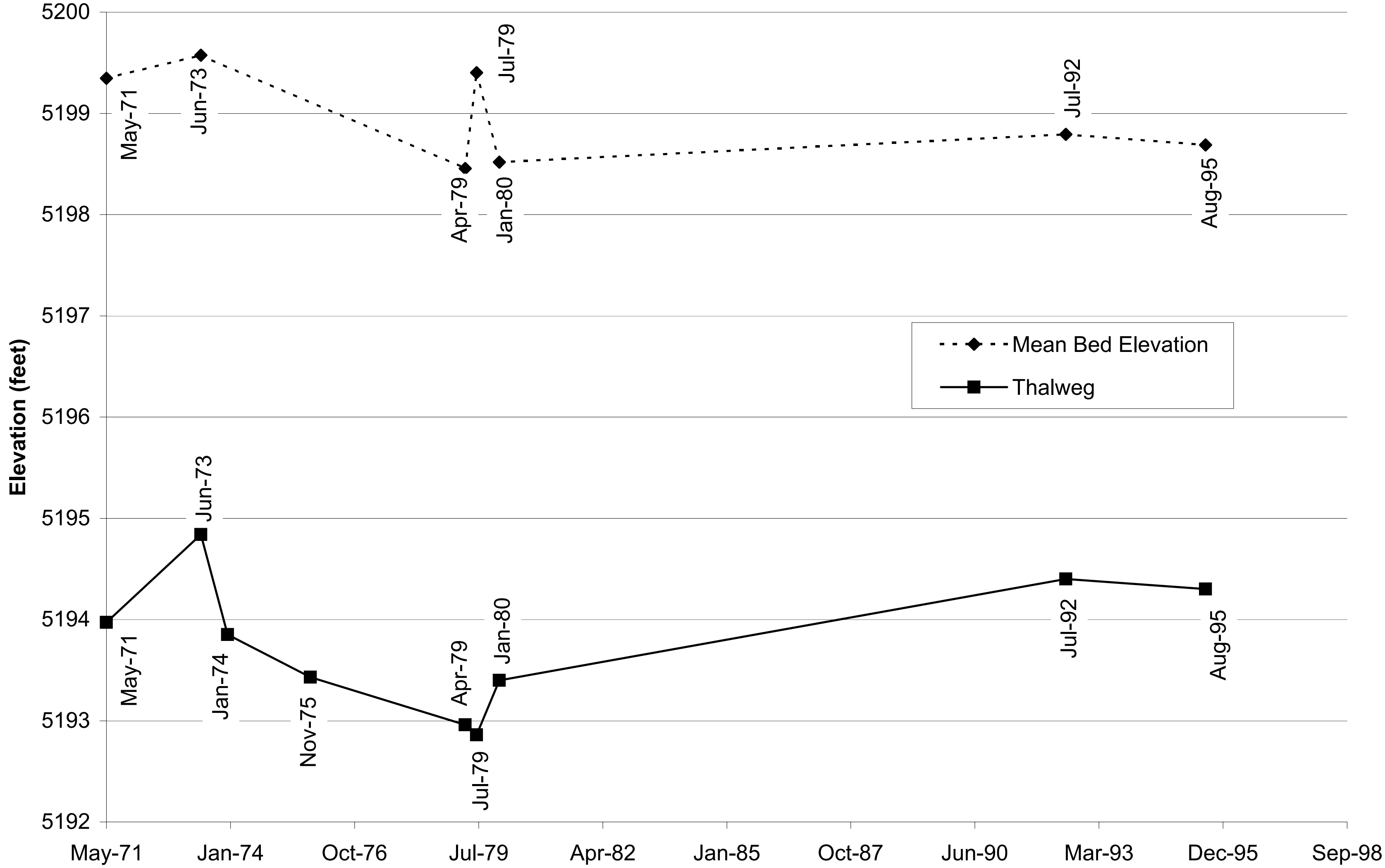

Fig. E-3. Change in thalweg elevation and mean bed elevation with time at cross section CO-4.

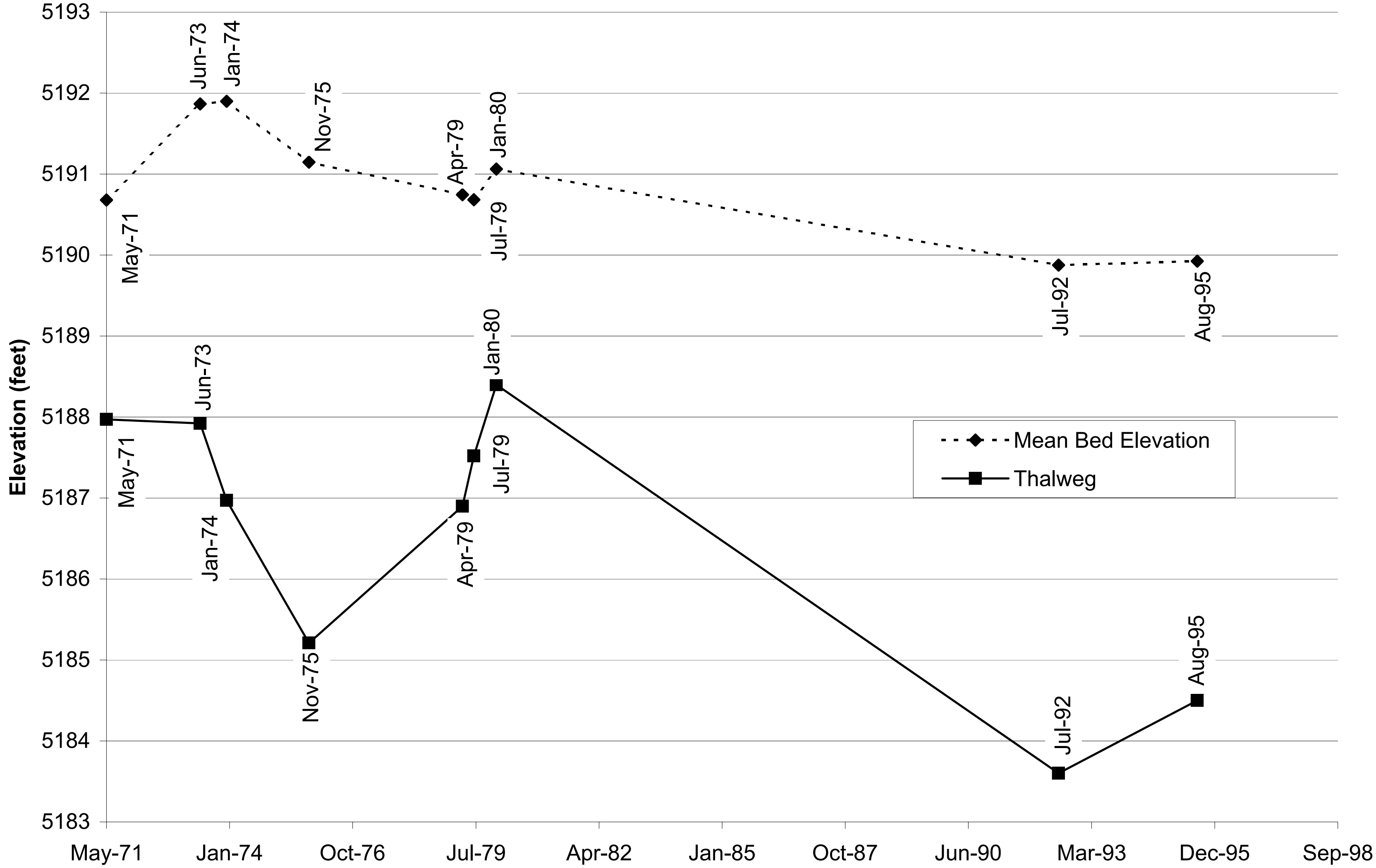

Fig. E-4. Change in thalweg elevation and mean bed elevation with time at cross section CO-5.

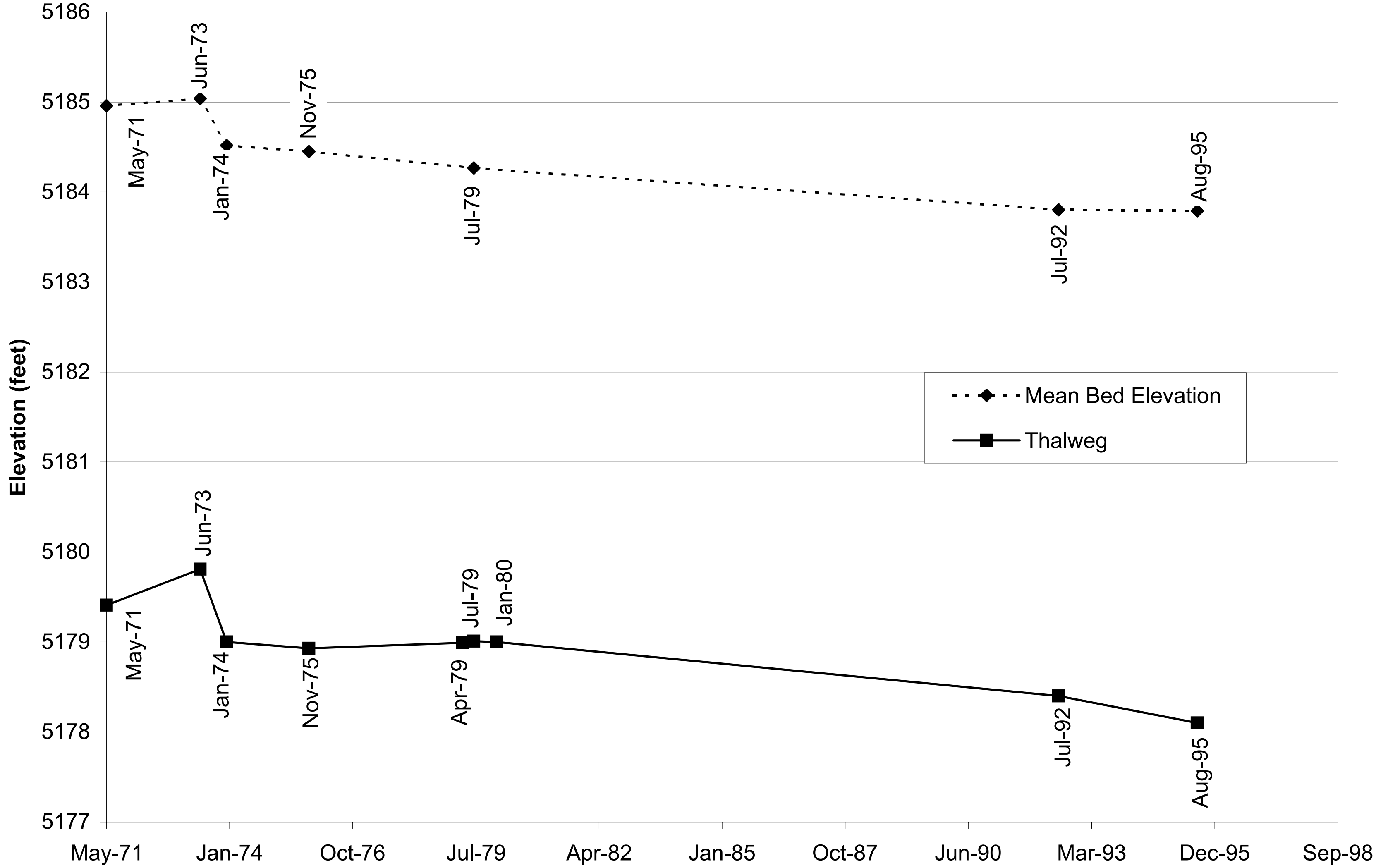

Fig. E-5. Change in thalweg elevation and mean bed elevation with time at cross section CO-6.

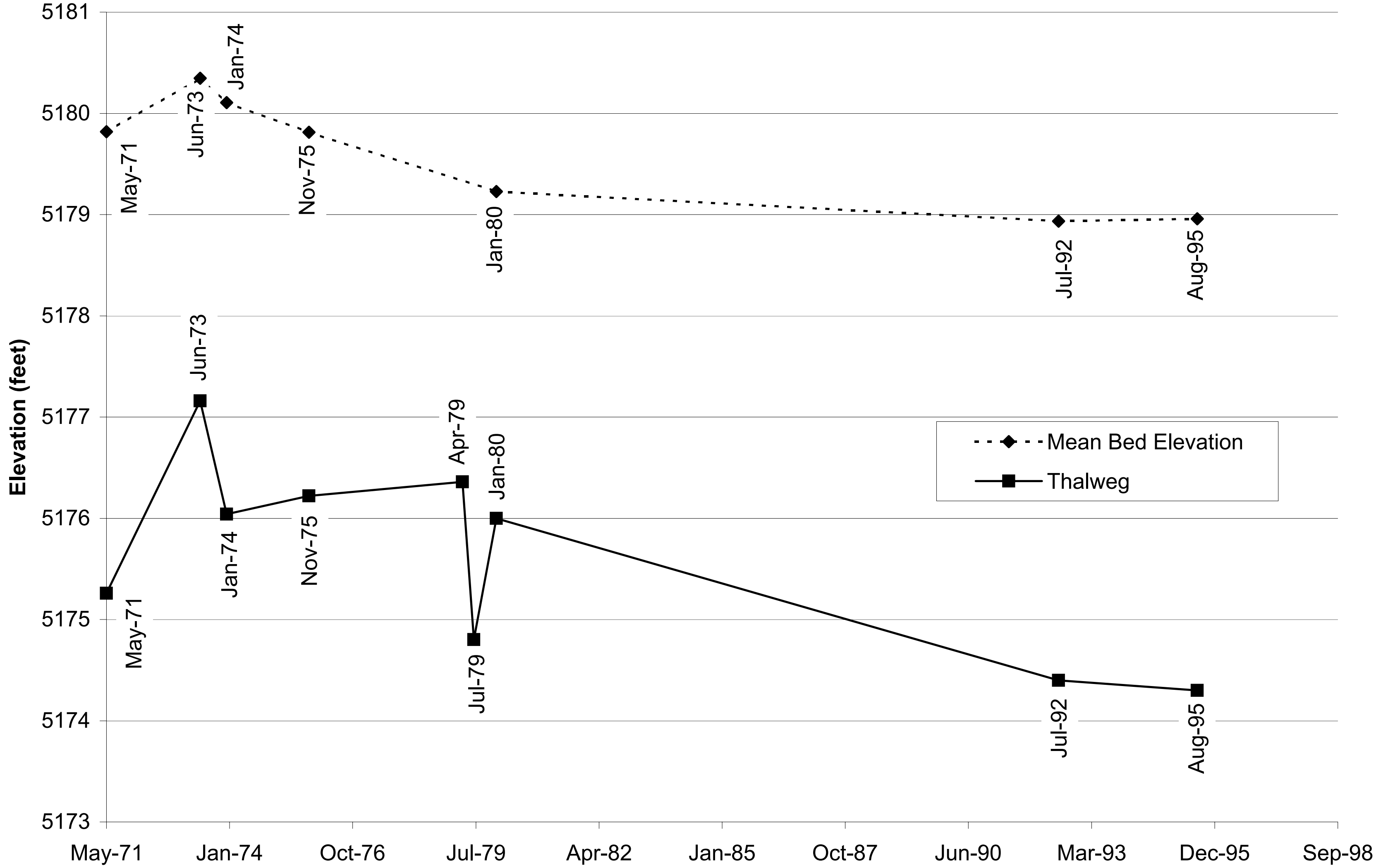

Fig. E-6. Change in thalweg elevation and mean bed elevation with time at cross section CO-7.

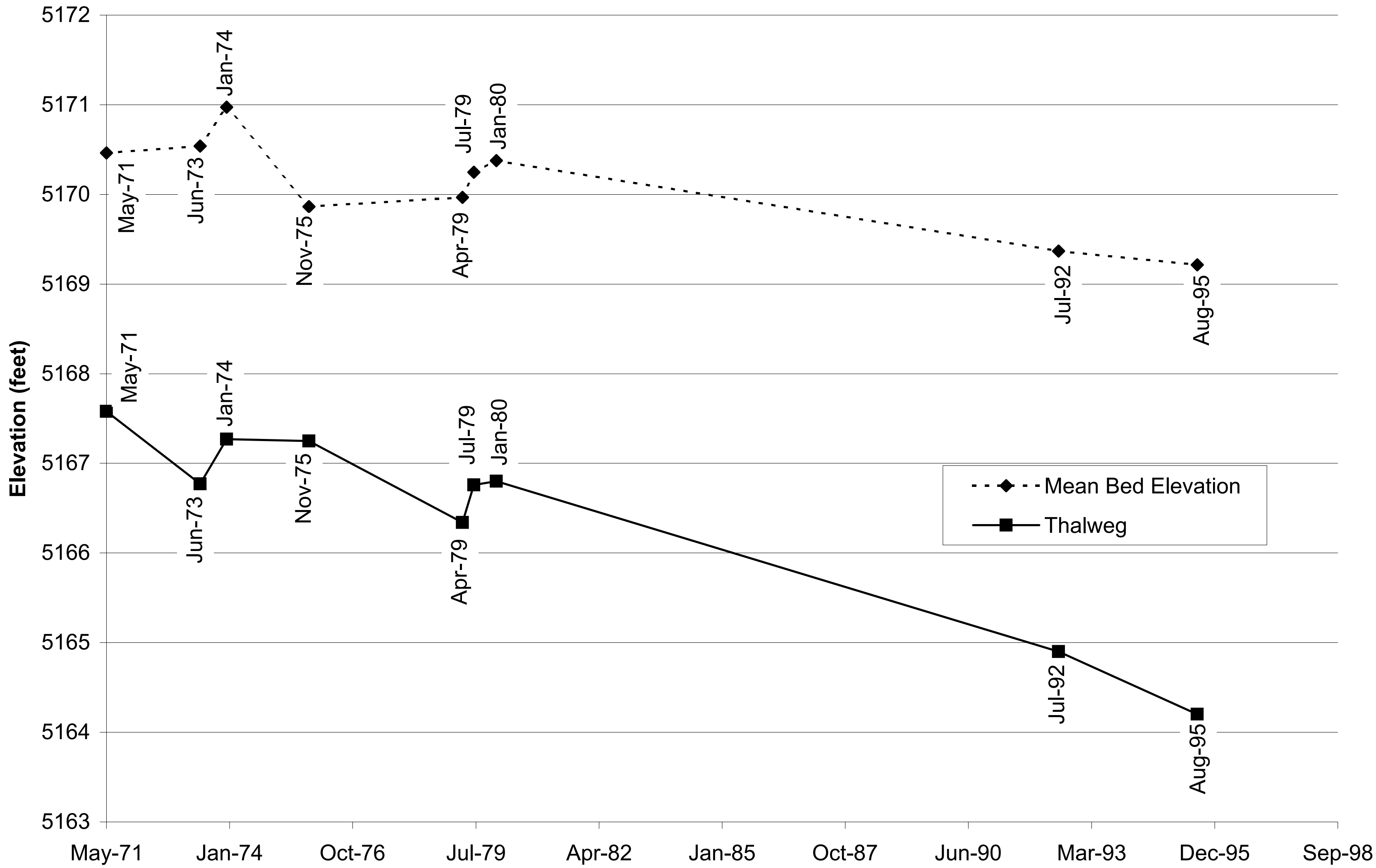

Fig. E-7. Change in thalweg elevation and mean bed elevation with time at cross section CO-8.

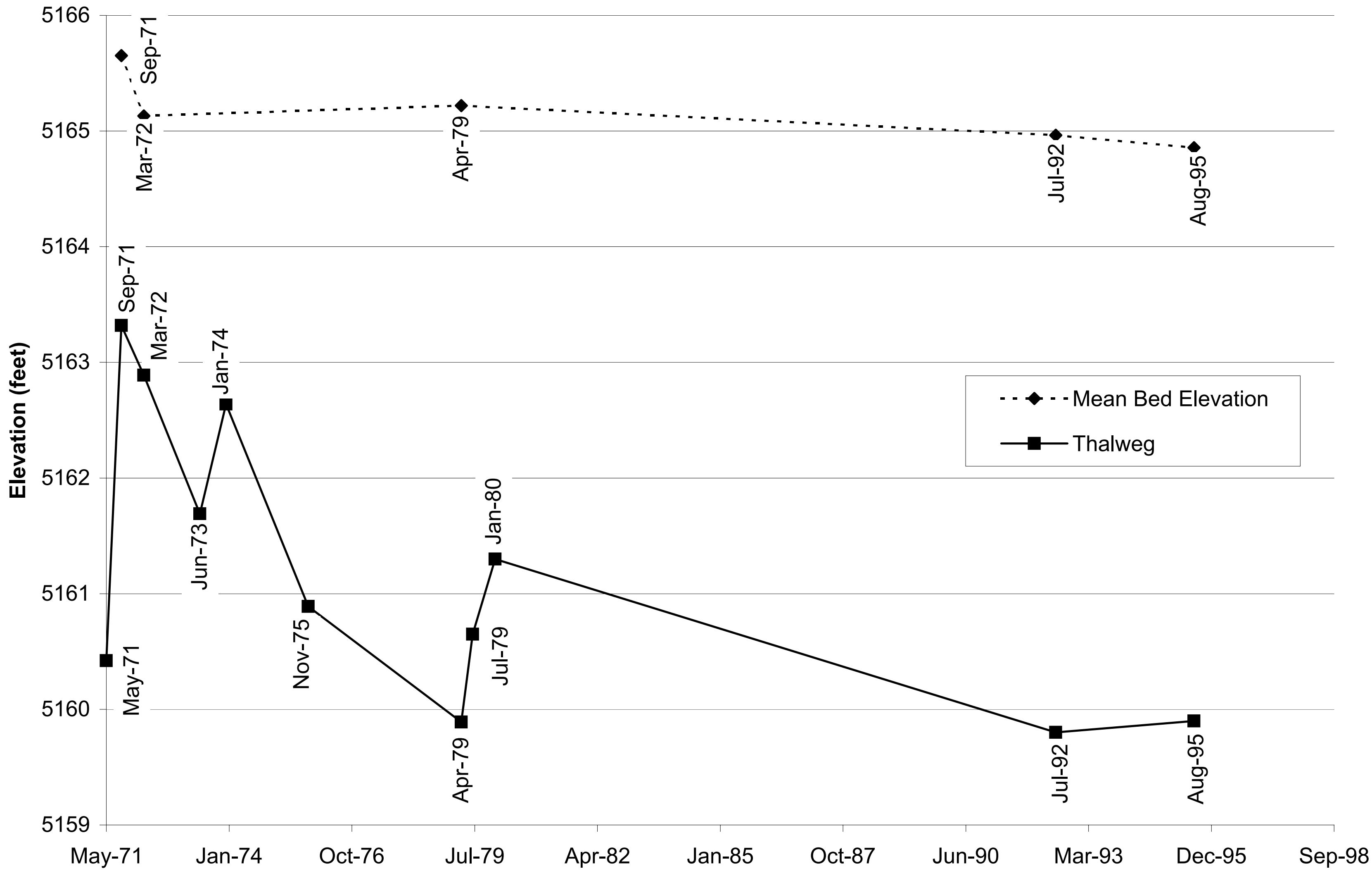

Fig. E-8. Change in thalweg elevation and mean bed elevation with time at cross section CO-9.

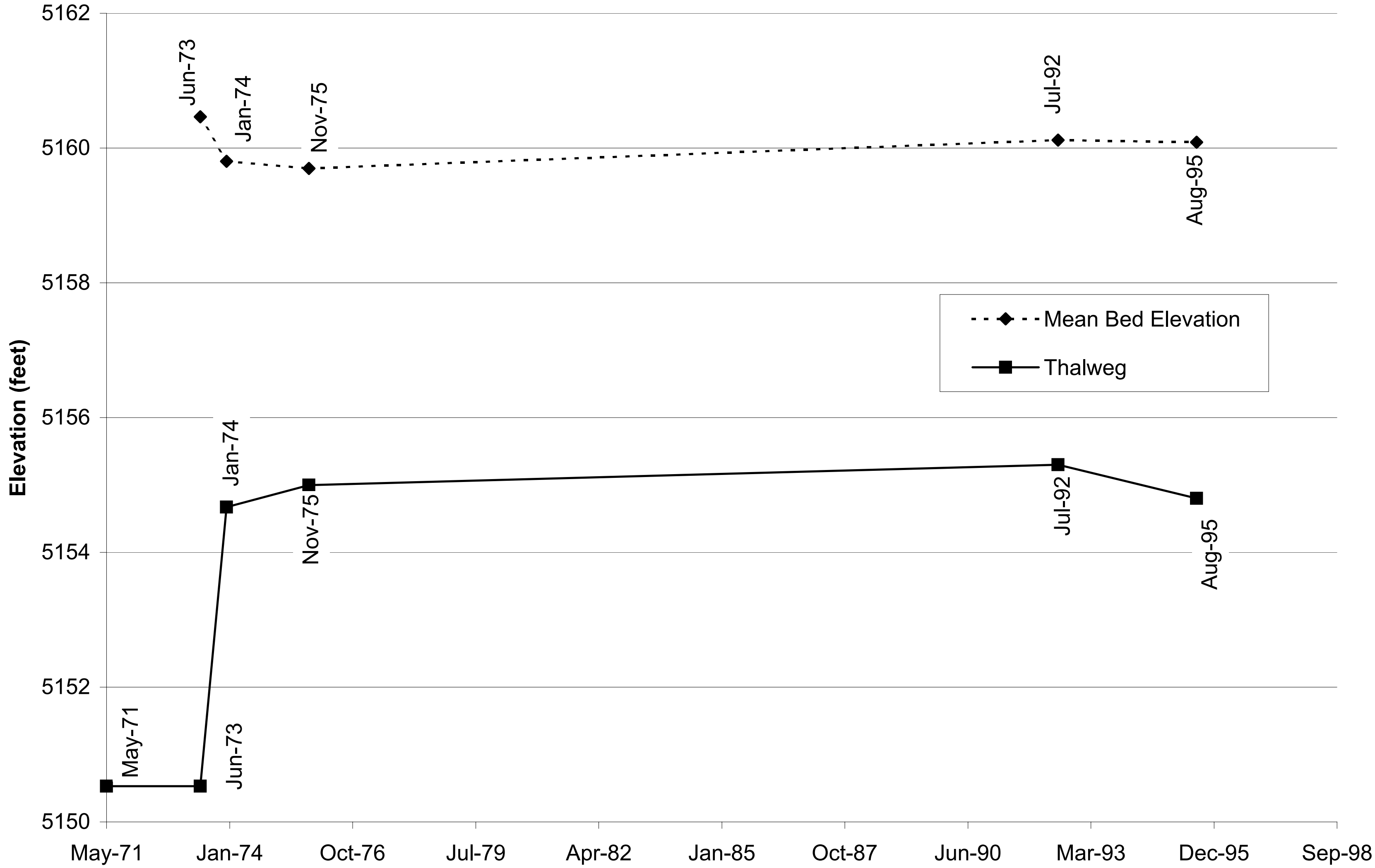

Fig. E-9. Change in thalweg elevation and mean bed elevation with time at cross section CO-10.

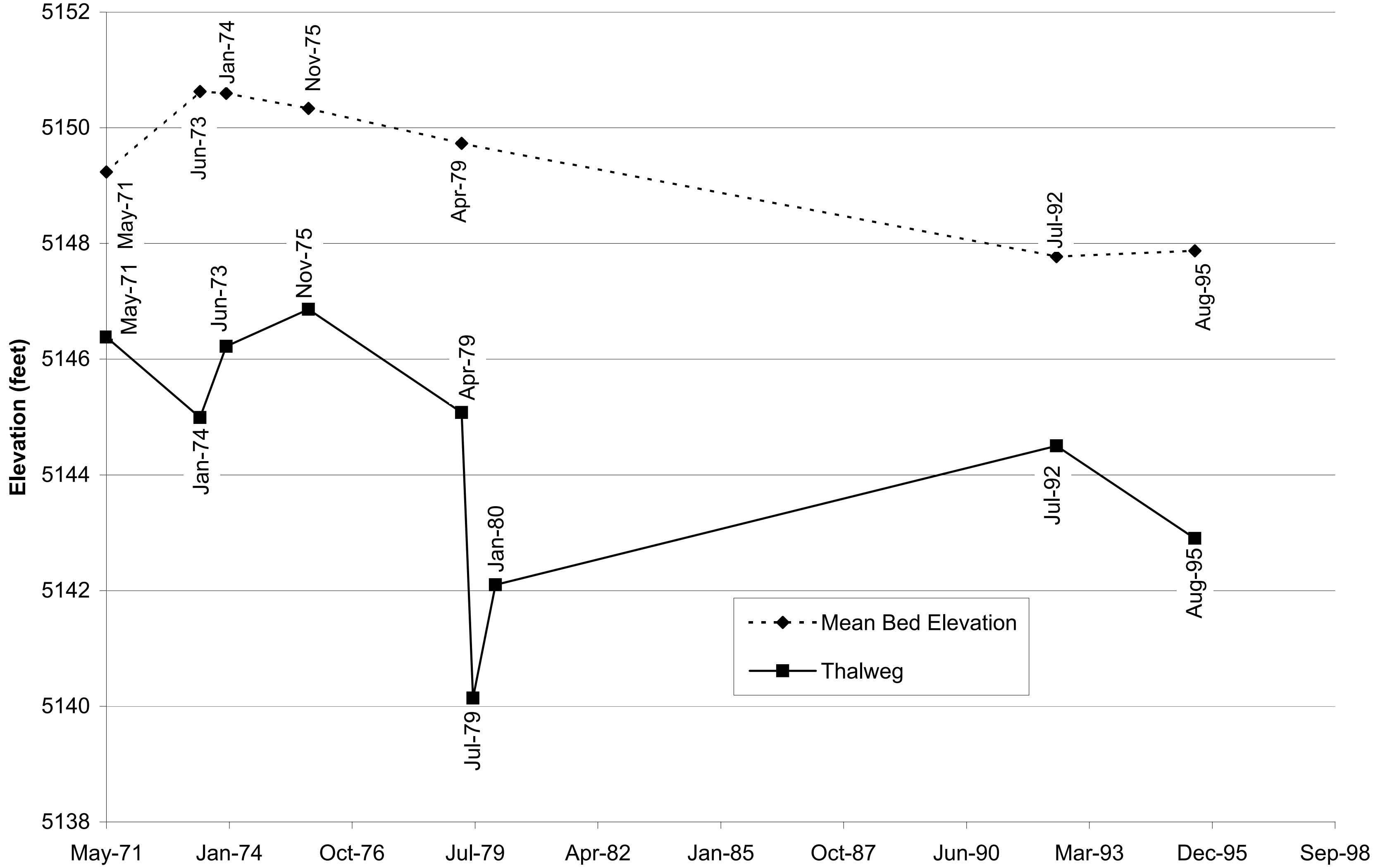

Fig. E-10. Change in thalweg elevation and mean bed elevation with time at cross section CO-12.

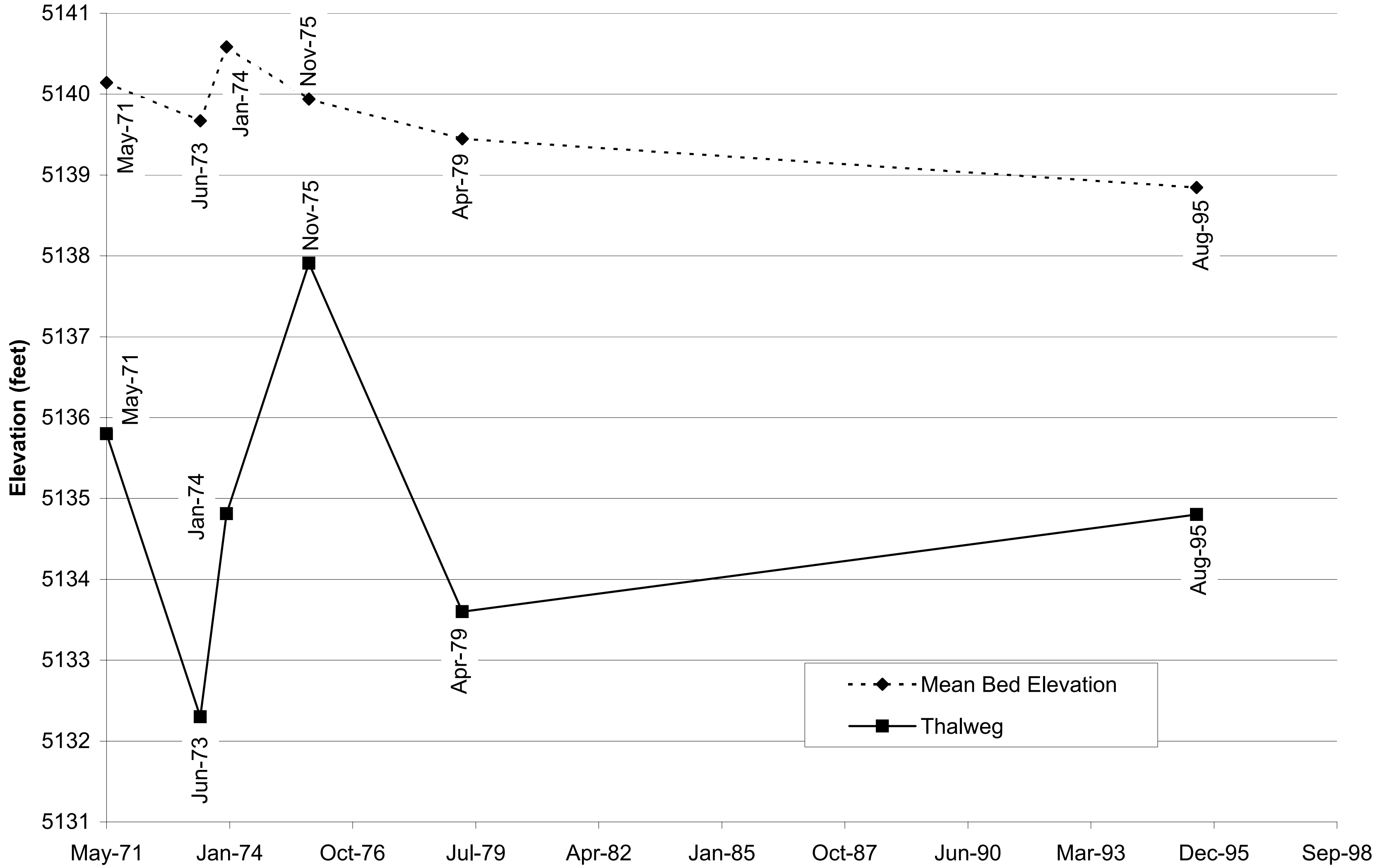

Fig. E-11. Change in thalweg elevation and mean bed elevation with time at cross section CO-13.

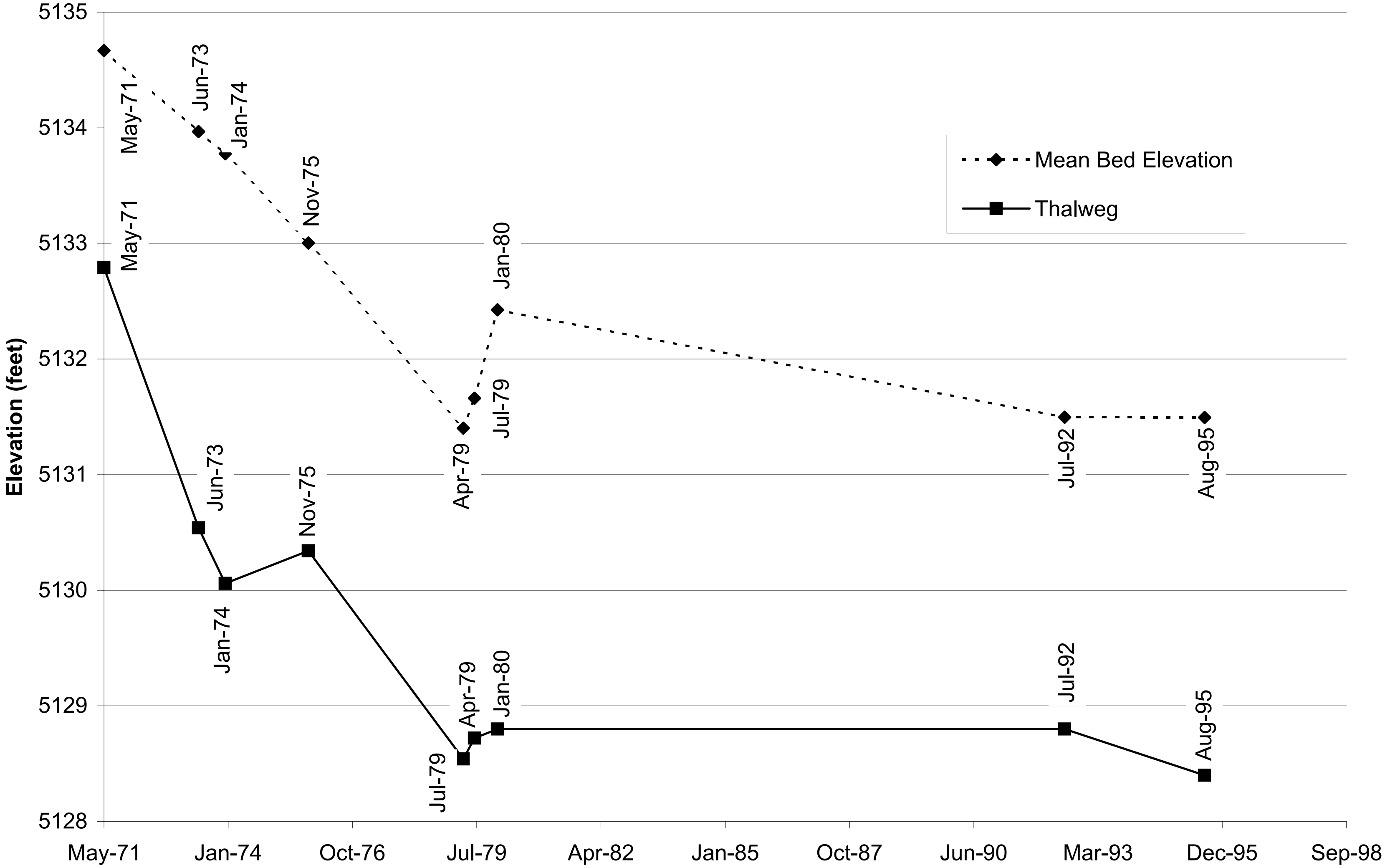

Fig. E-12. Change in thalweg elevation and mean bed elevation with time at cross section CO-14.

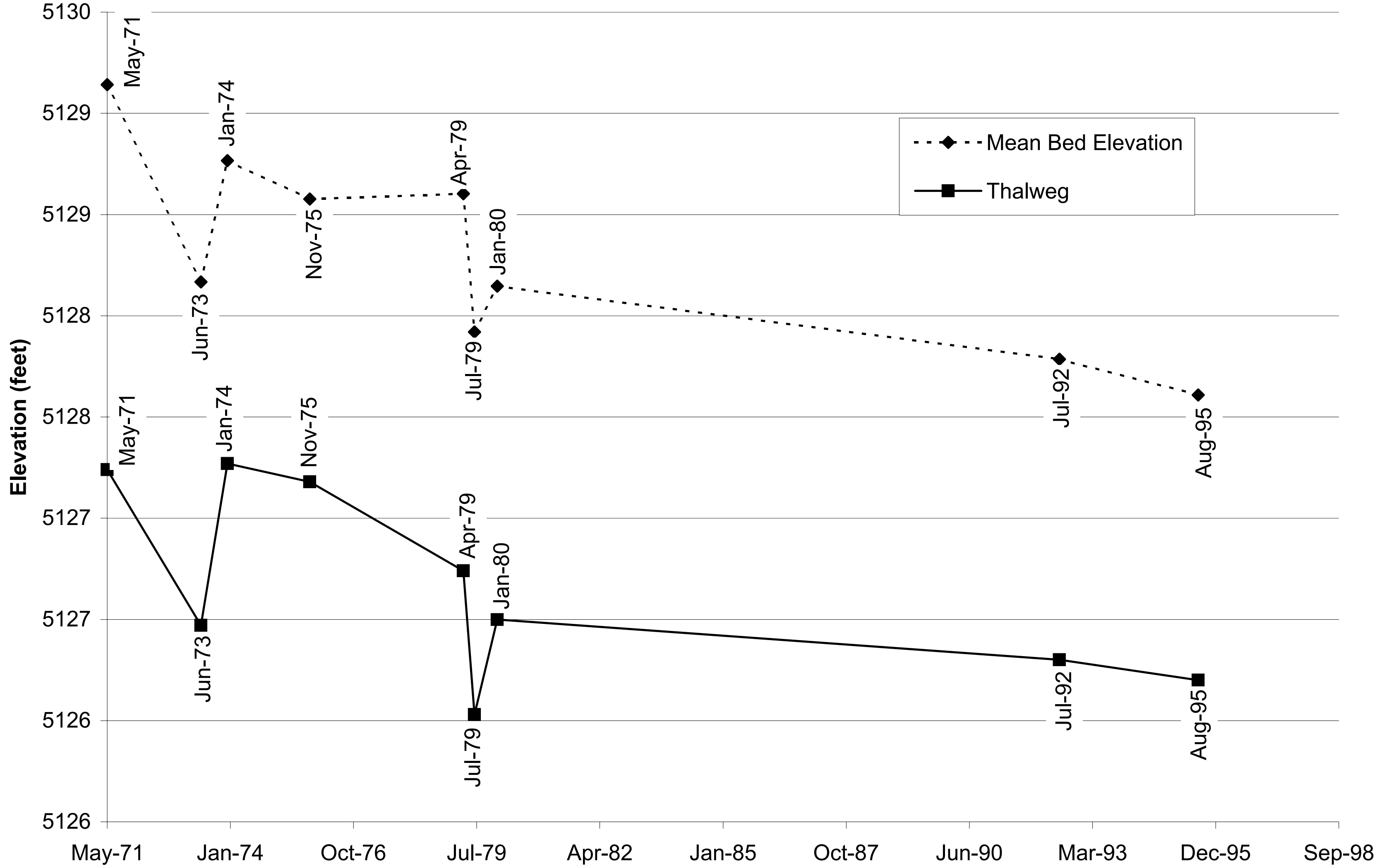

Fig. E-13. Change in thalweg elevation and mean bed elevation with time at cross section CO-15.

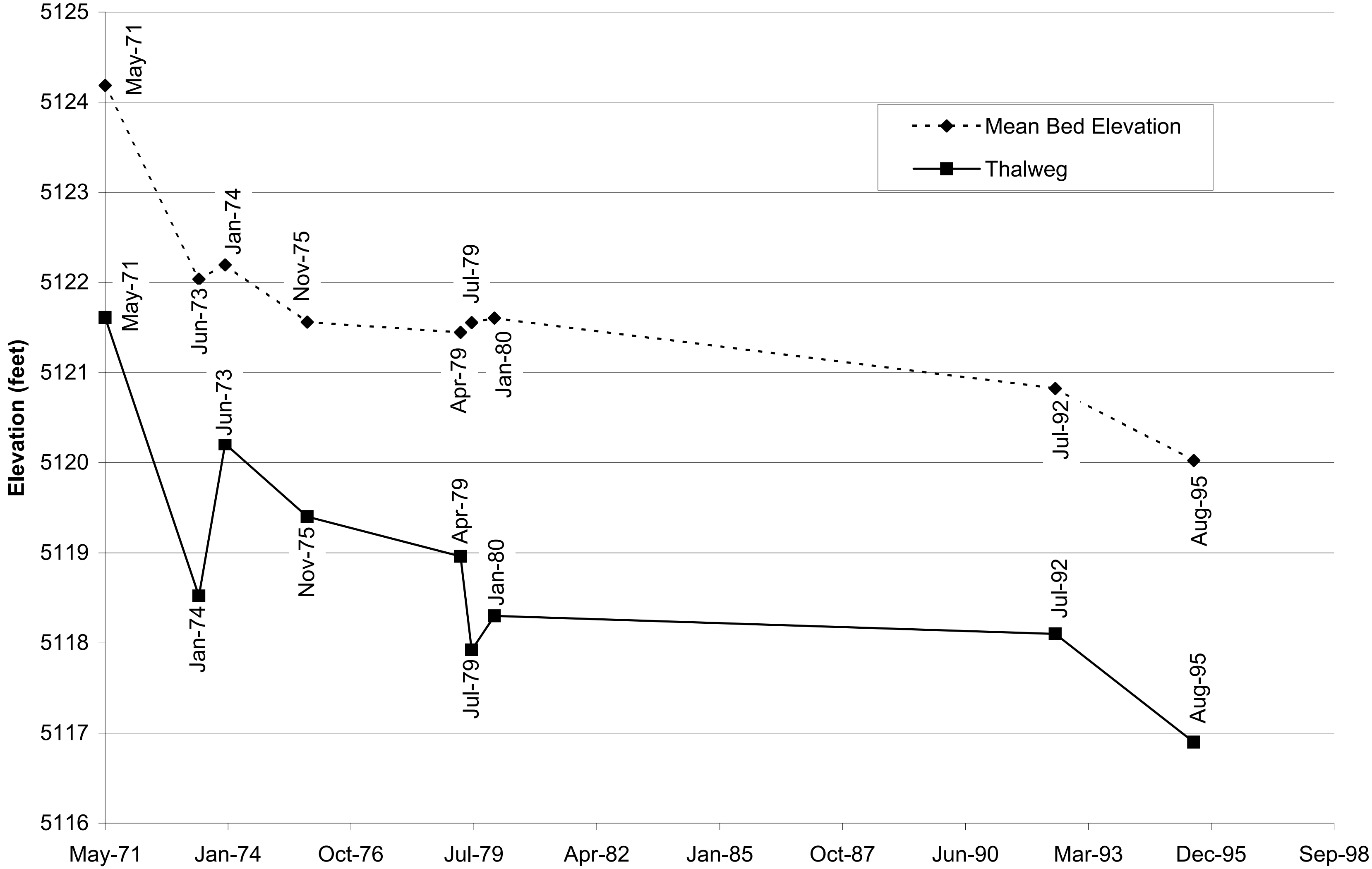

Fig. E-14. Change in thalweg elevation and mean bed elevation with time at cross section CO-16.

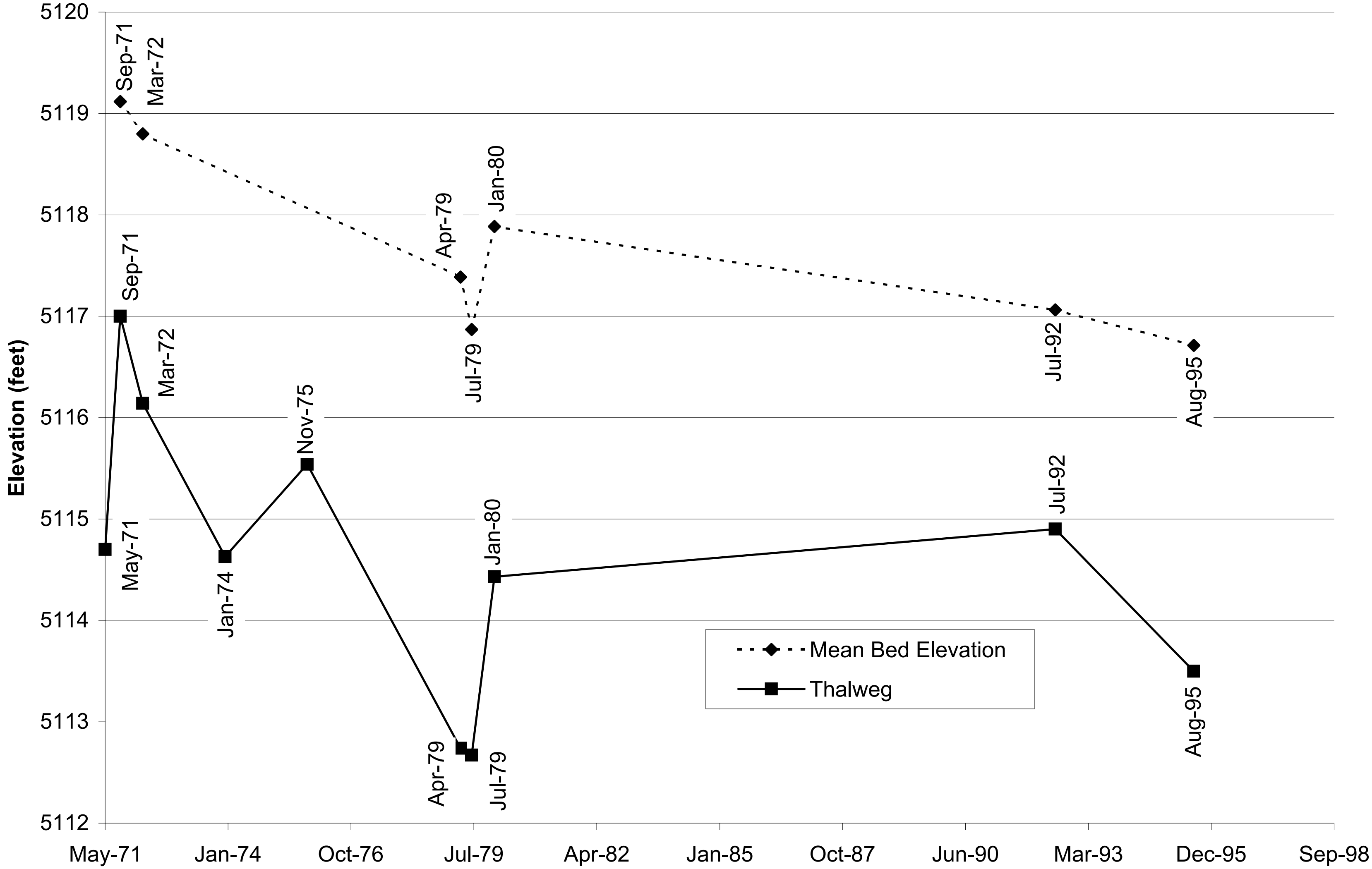

Fig. E-15. Change in thalweg elevation and mean bed elevation with time at cross section CO-17.

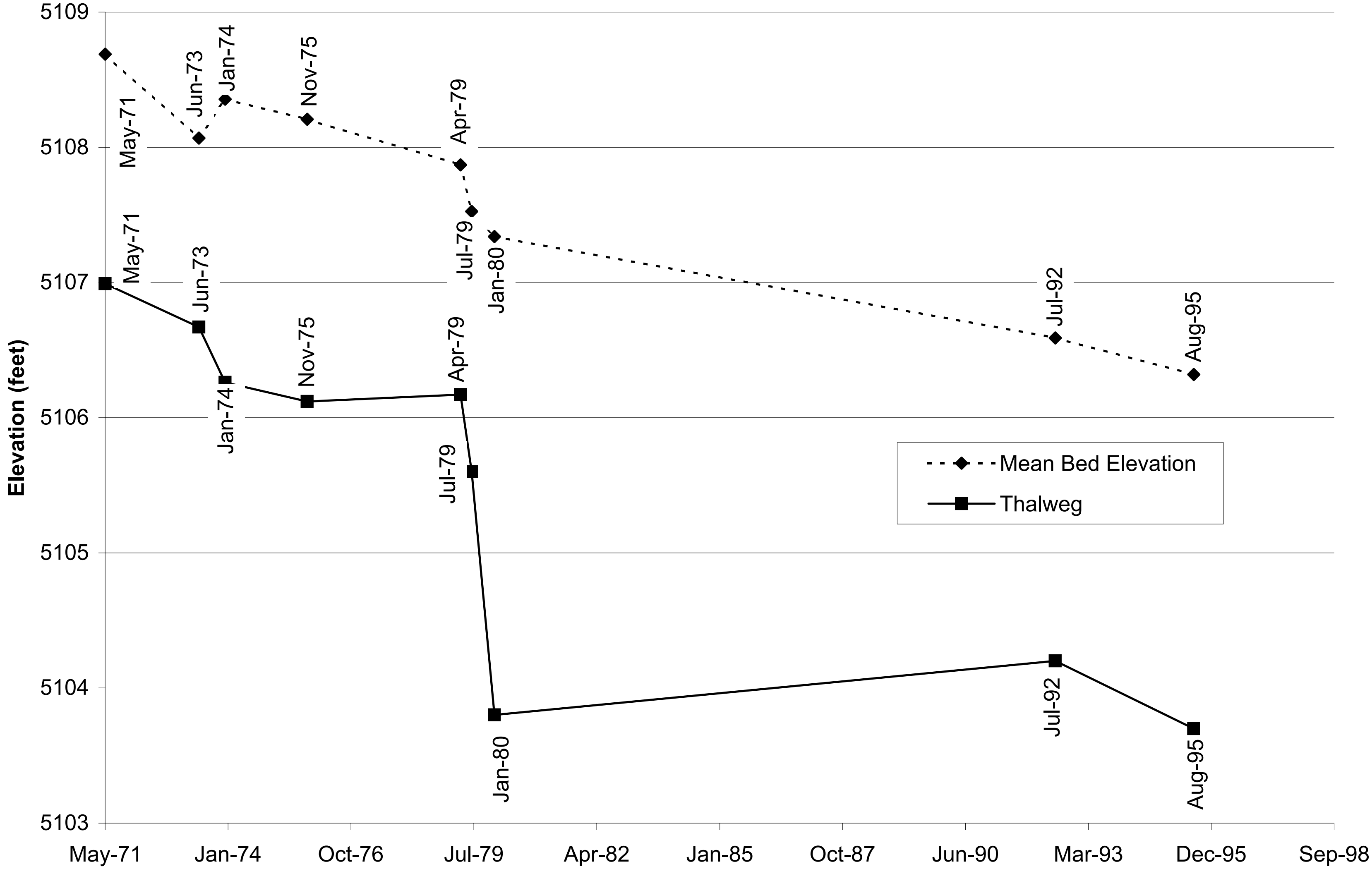

Fig. E-16. Change in thalweg elevation and mean bed elevation with time at cross section CO-18.

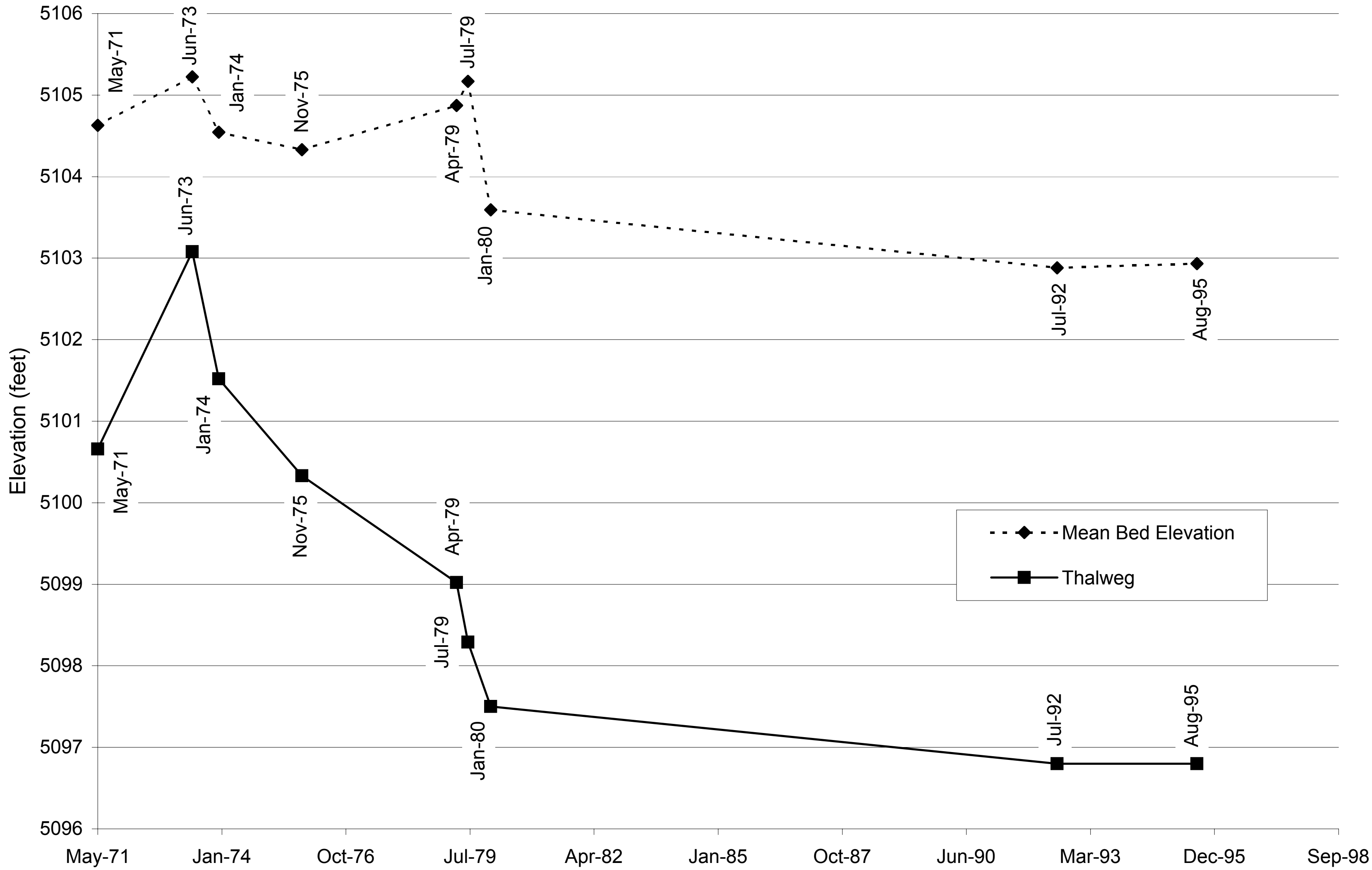

Fig. E-17. Change in thalweg elevation and mean bed elevation with time at cross section CO-19.

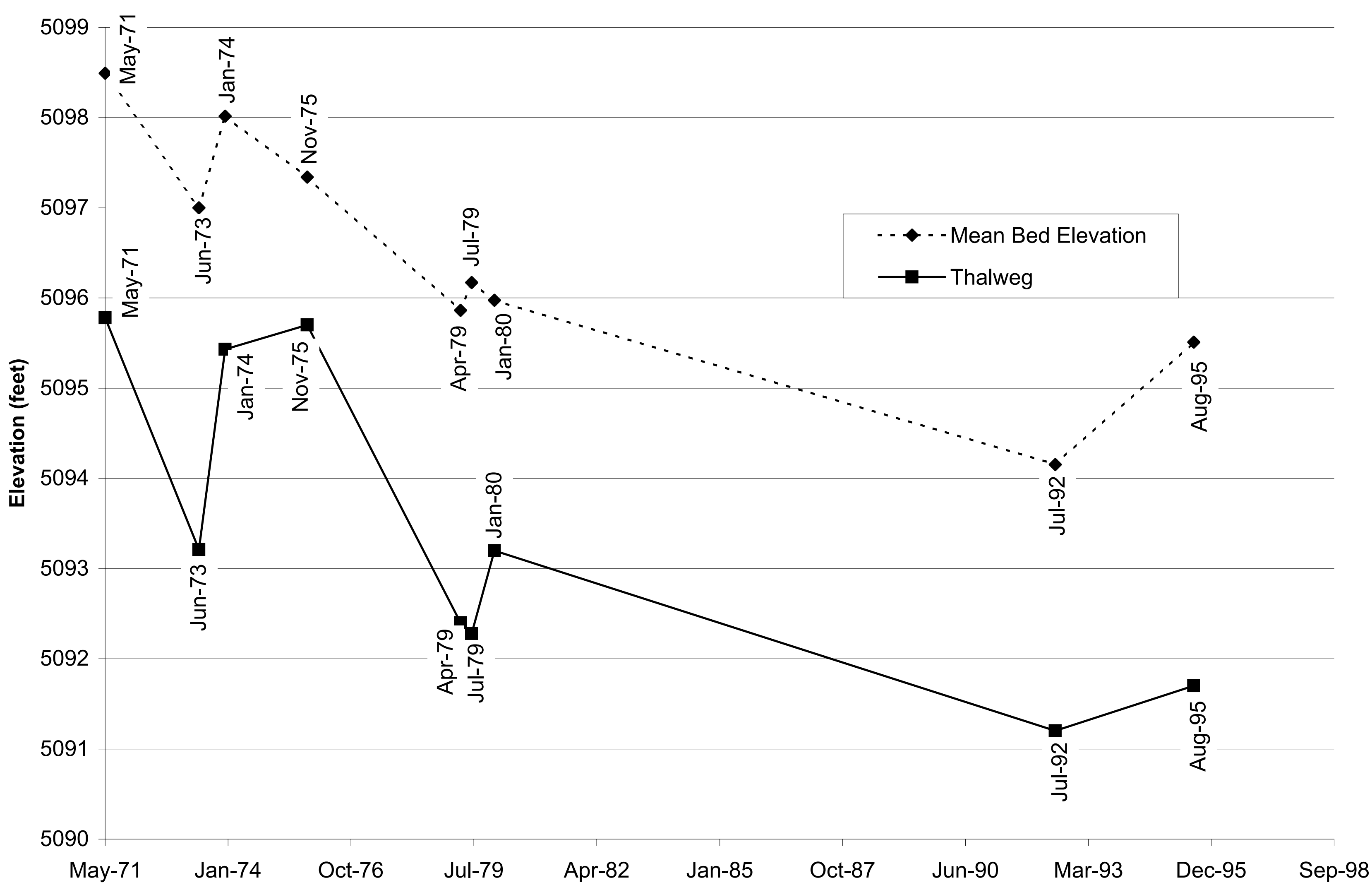

Fig. E-18. Change in thalweg elevation and mean bed elevation with time at cross section CO-20.

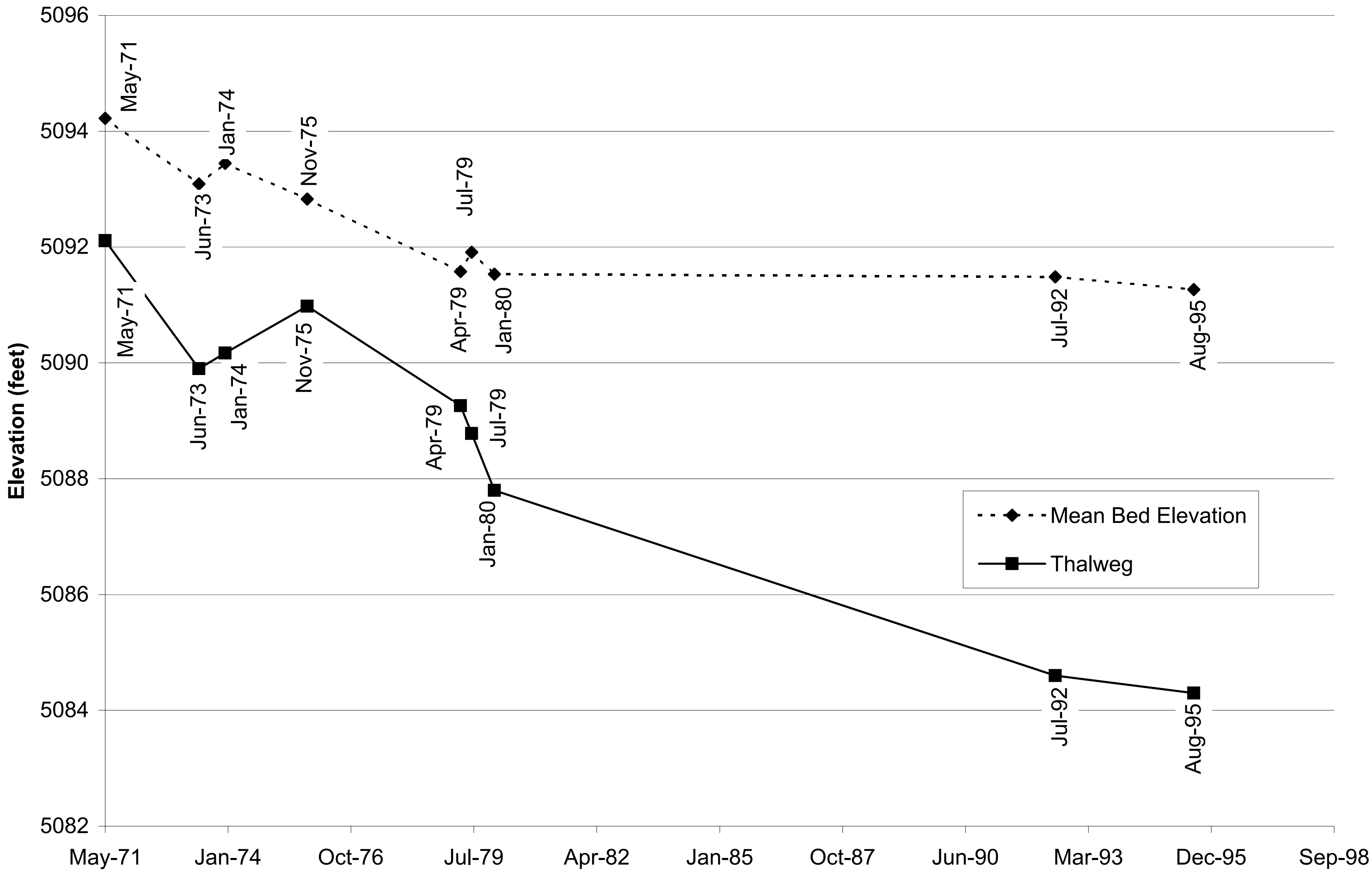

Fig. E-19. Change in thalweg elevation and mean bed elevation with time at cross section CO-21.

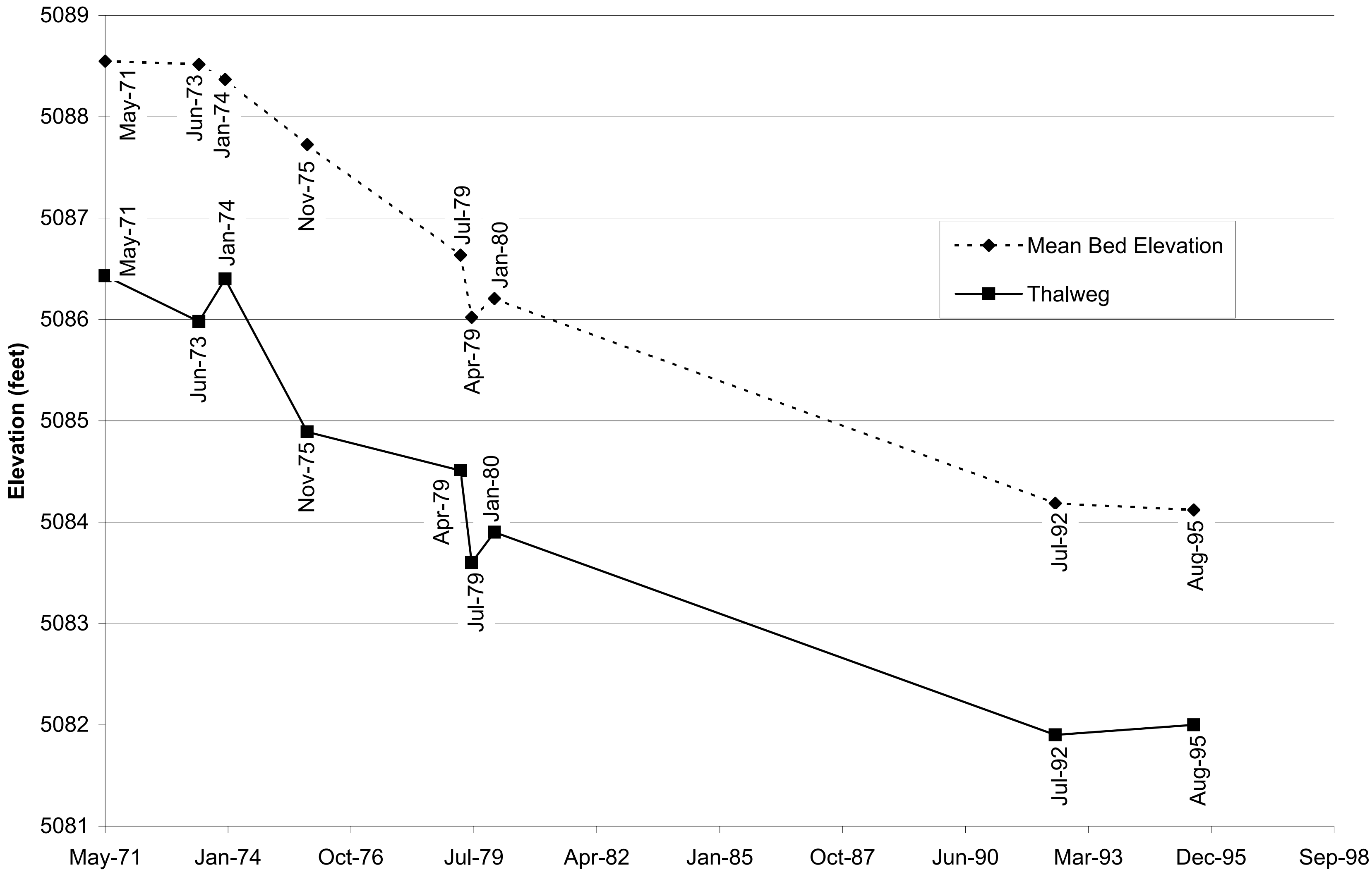

Fig. E-20. Change in thalweg elevation and mean bed elevation with time at cross section CO-22.

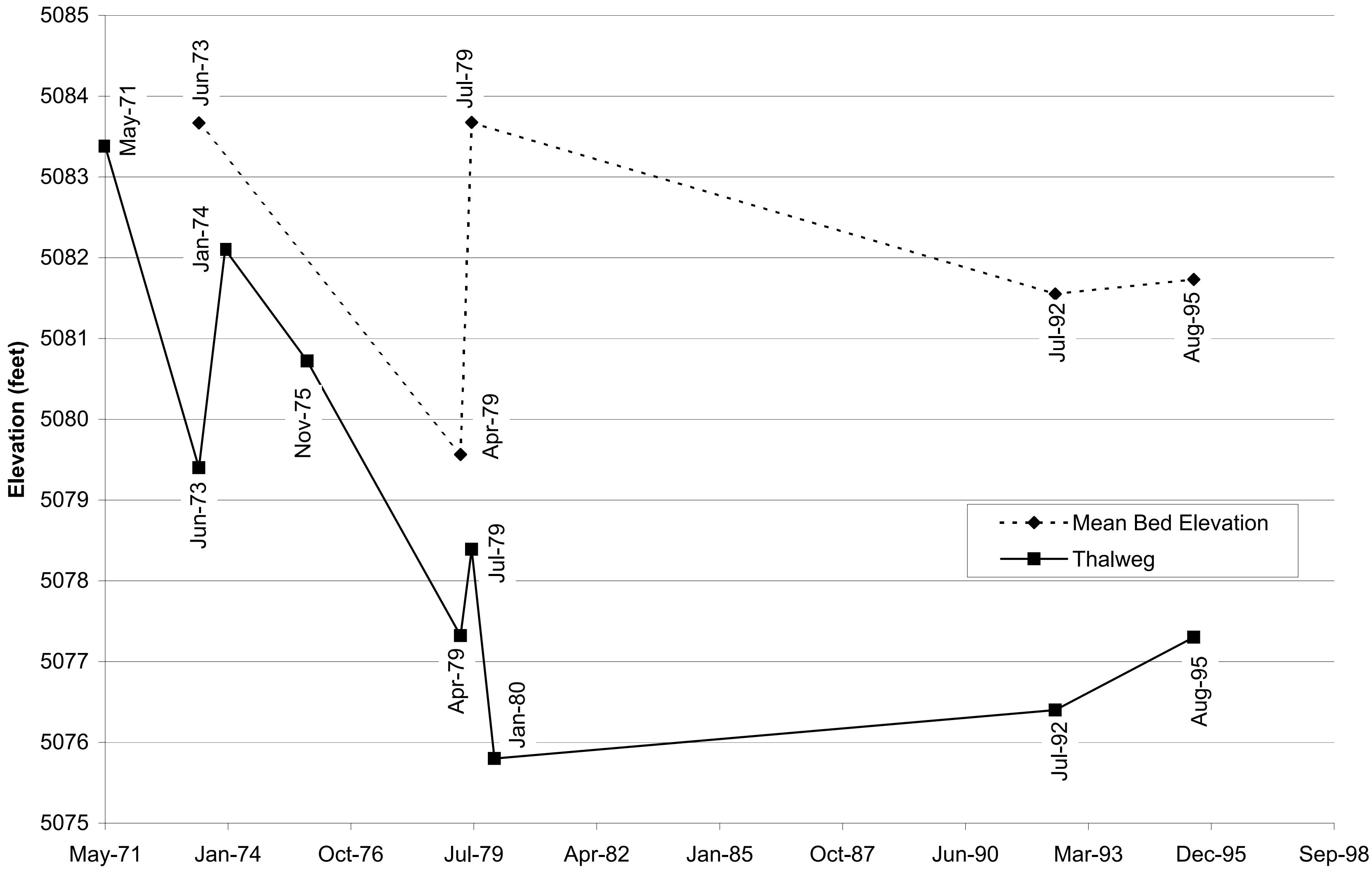

Fig. E-21. Change in thalweg elevation and mean bed elevation with time at cross section CO-23.

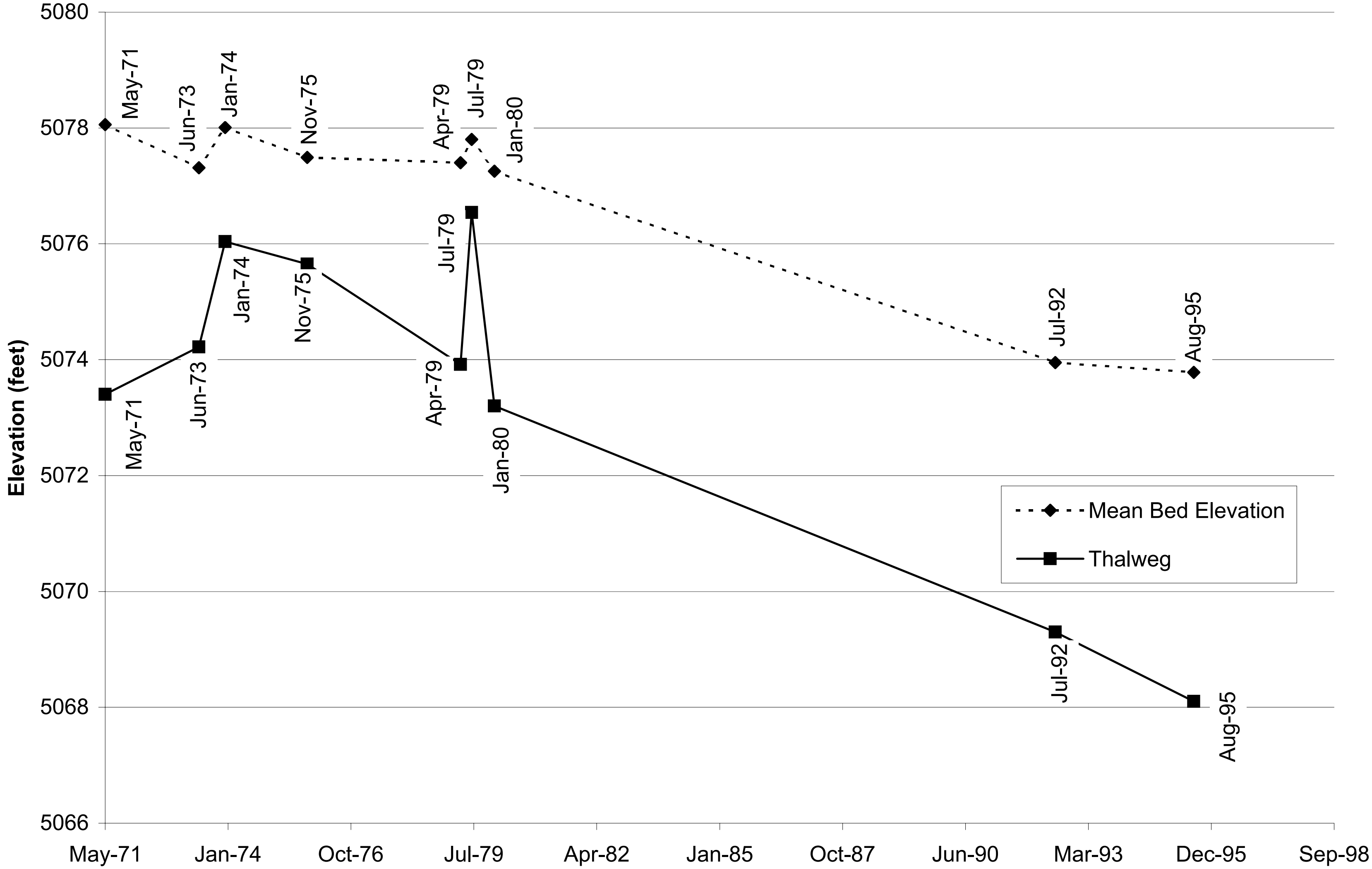

Fig. E-22. Change in thalweg elevation and mean bed elevation with time at cross section CO-24.

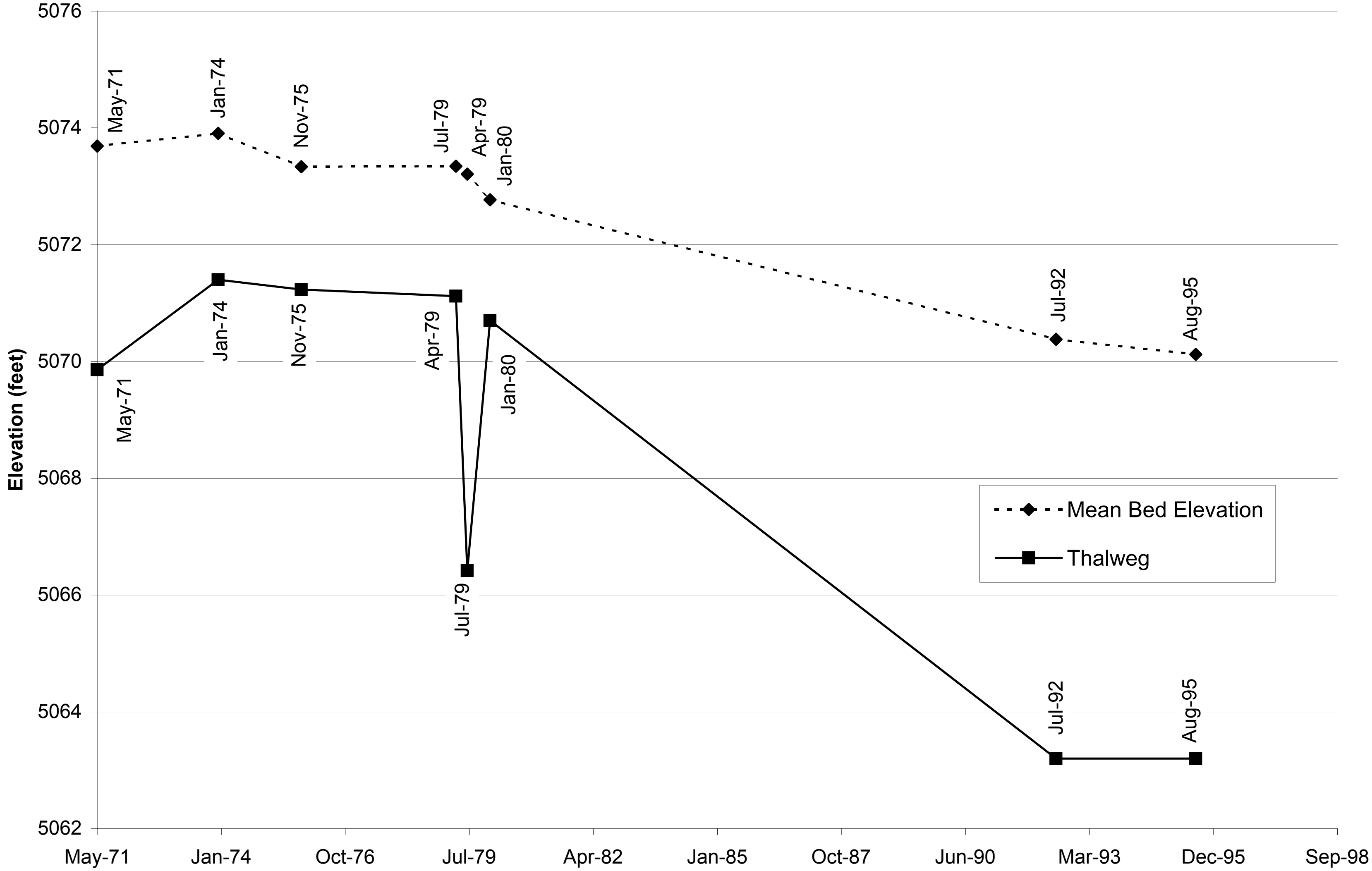

Fig. E-23. Change in thalweg elevation and mean bed elevation with time at cross section CO-25.

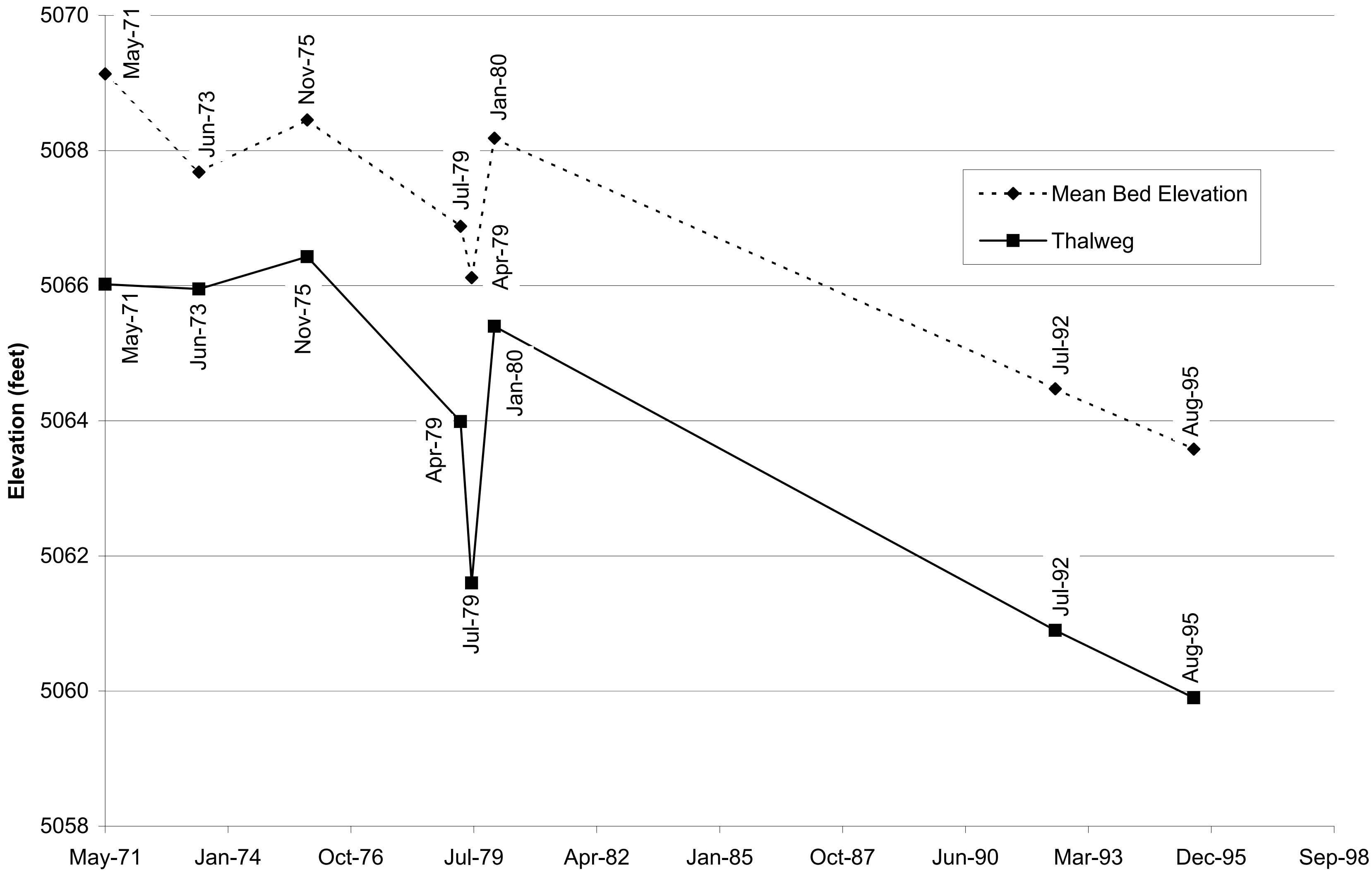

Fig. E-24. Change in thalweg elevation and mean bed elevation with time at cross section CO-26.

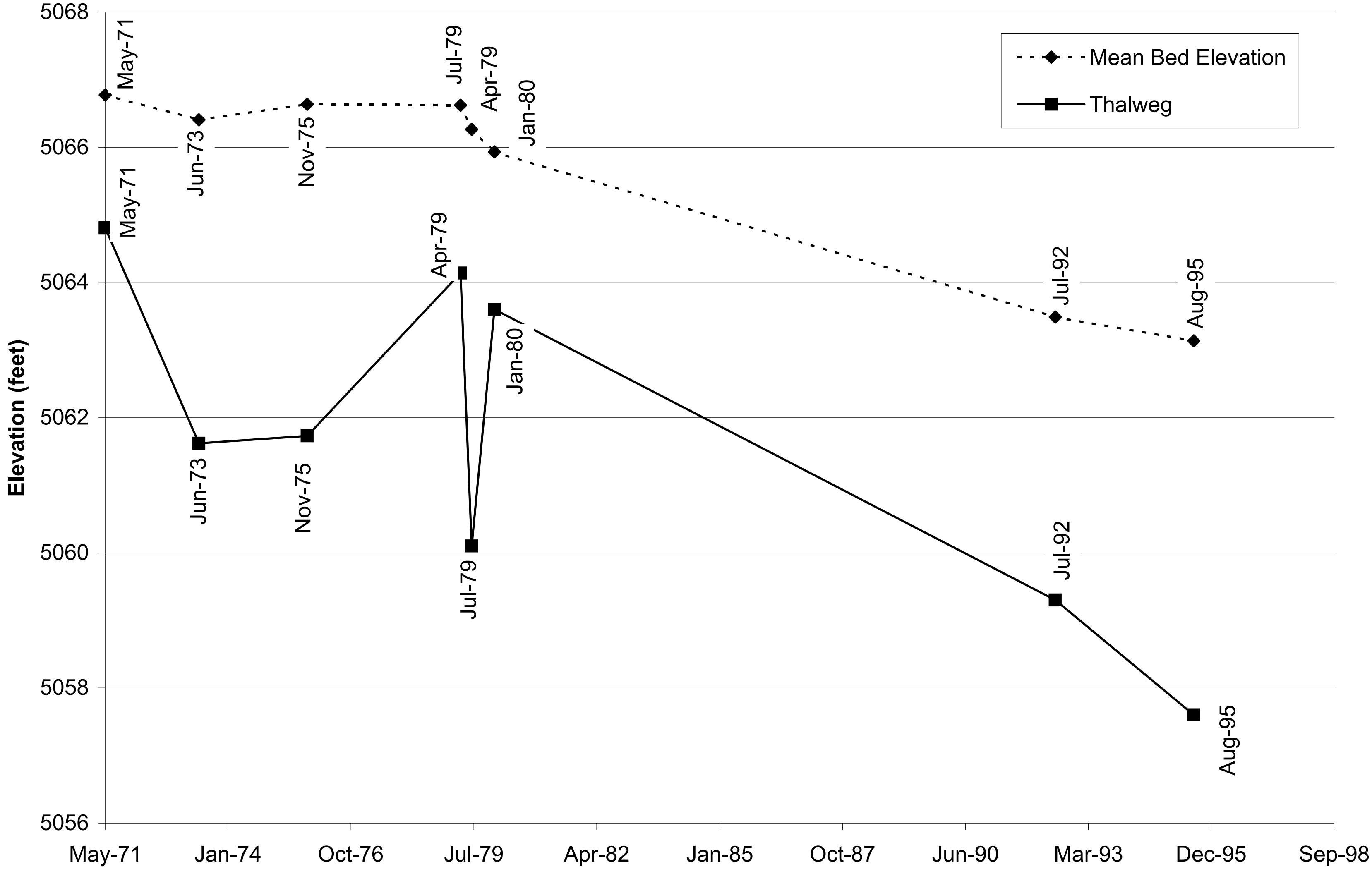

Fig. E-25. Change in thalweg elevation and mean bed elevation with time at cross section CO-27.

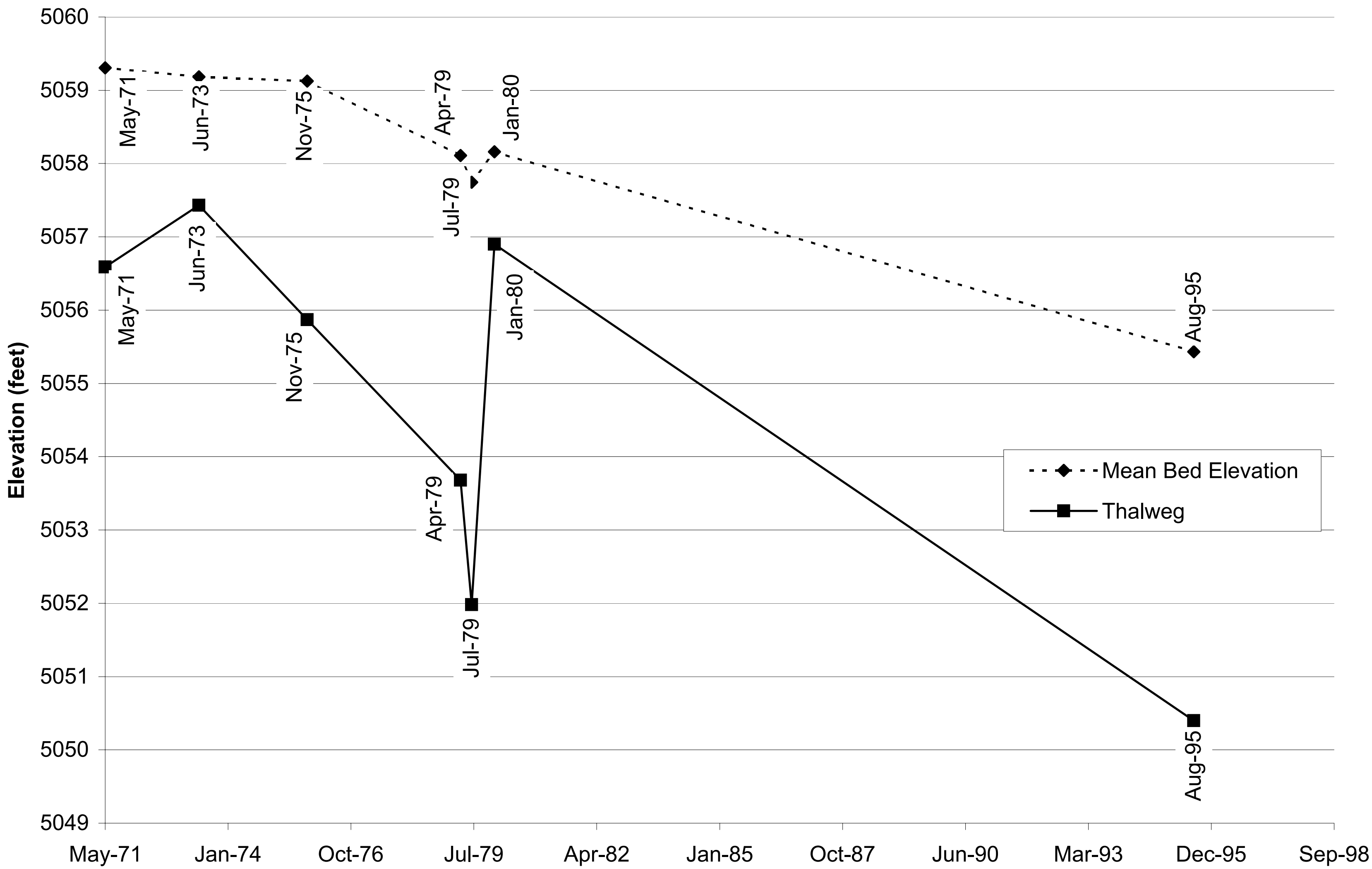

Fig. E-26. Change in thalweg elevation and mean bed elevation with time at cross section CO-28.

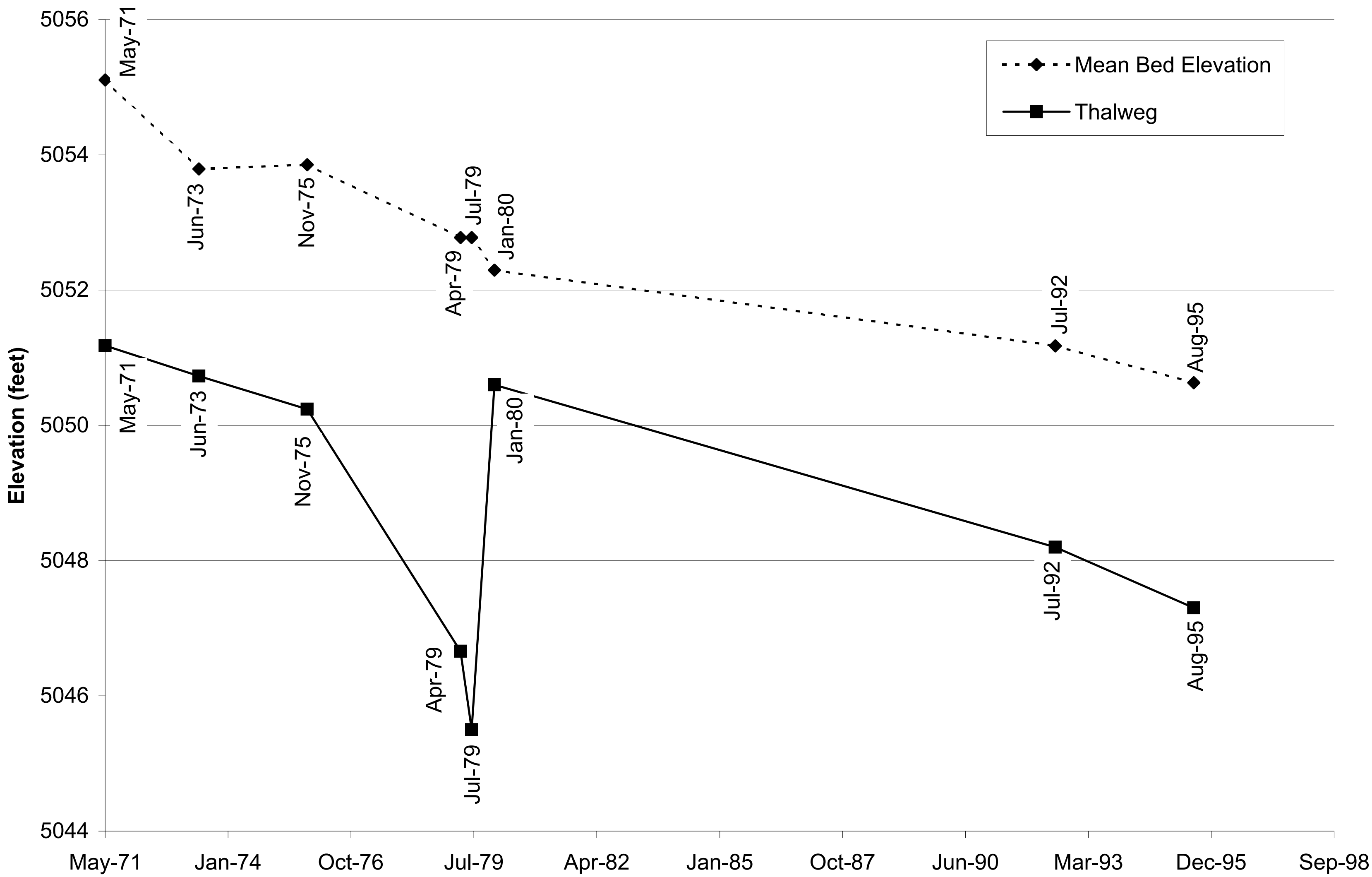

Fig. E-27. Change in thalweg elevation and mean bed elevation with time at cross section CO-29.

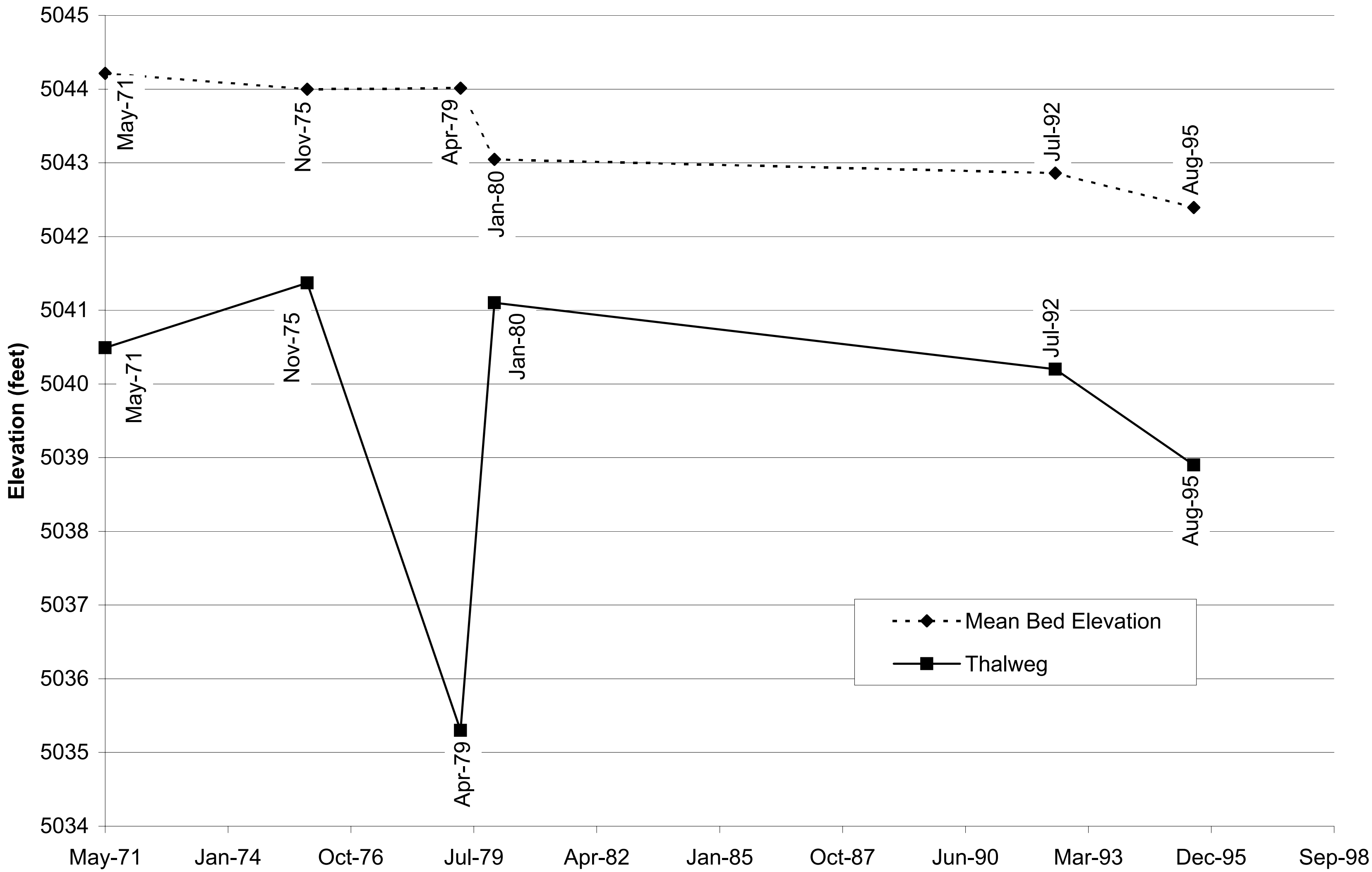

Fig. E-28. Change in thalweg elevation and mean bed elevation with time at cross section CO-30.

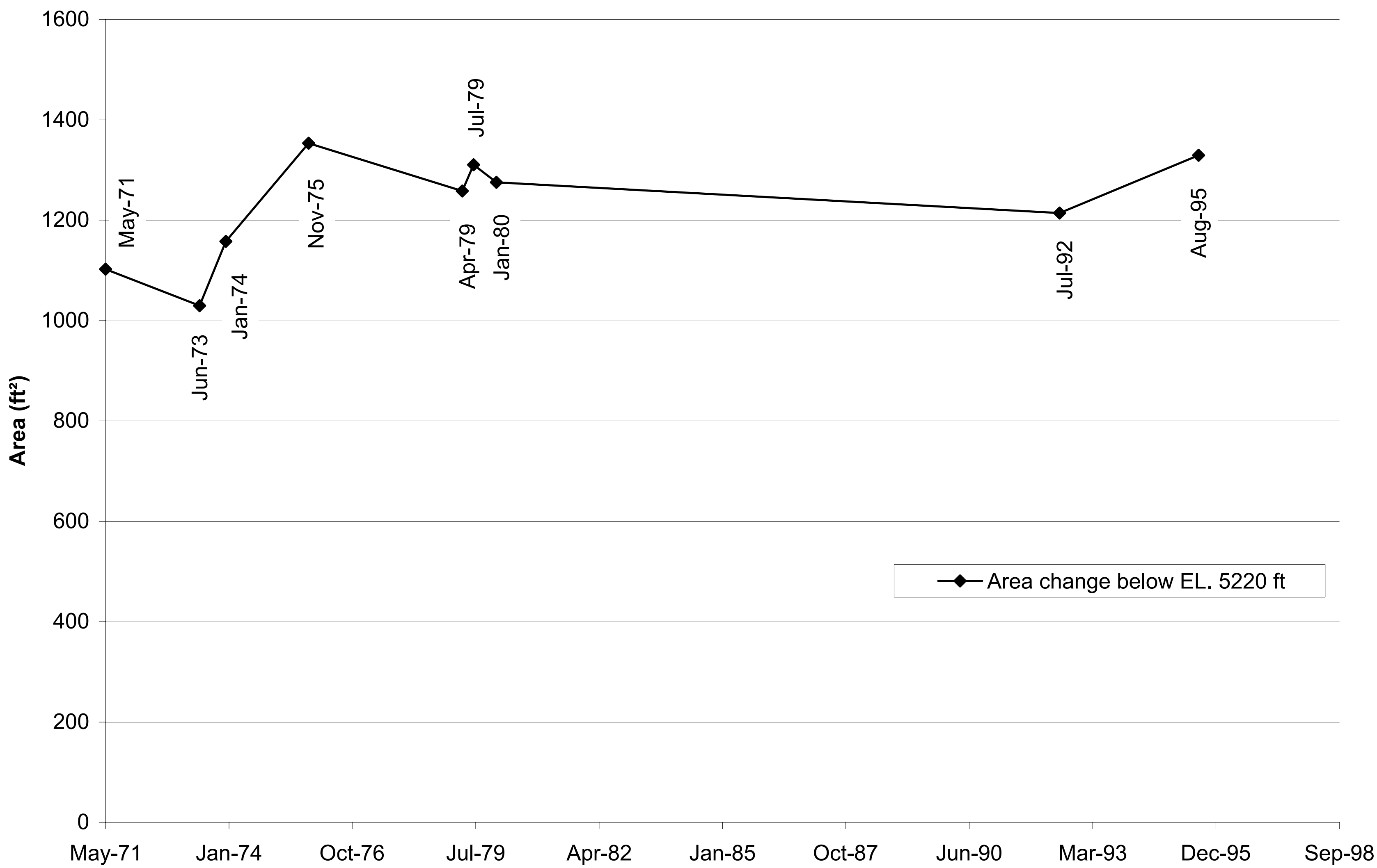

Fig.E-29. Change in cross section area with time at cross section CO-2.

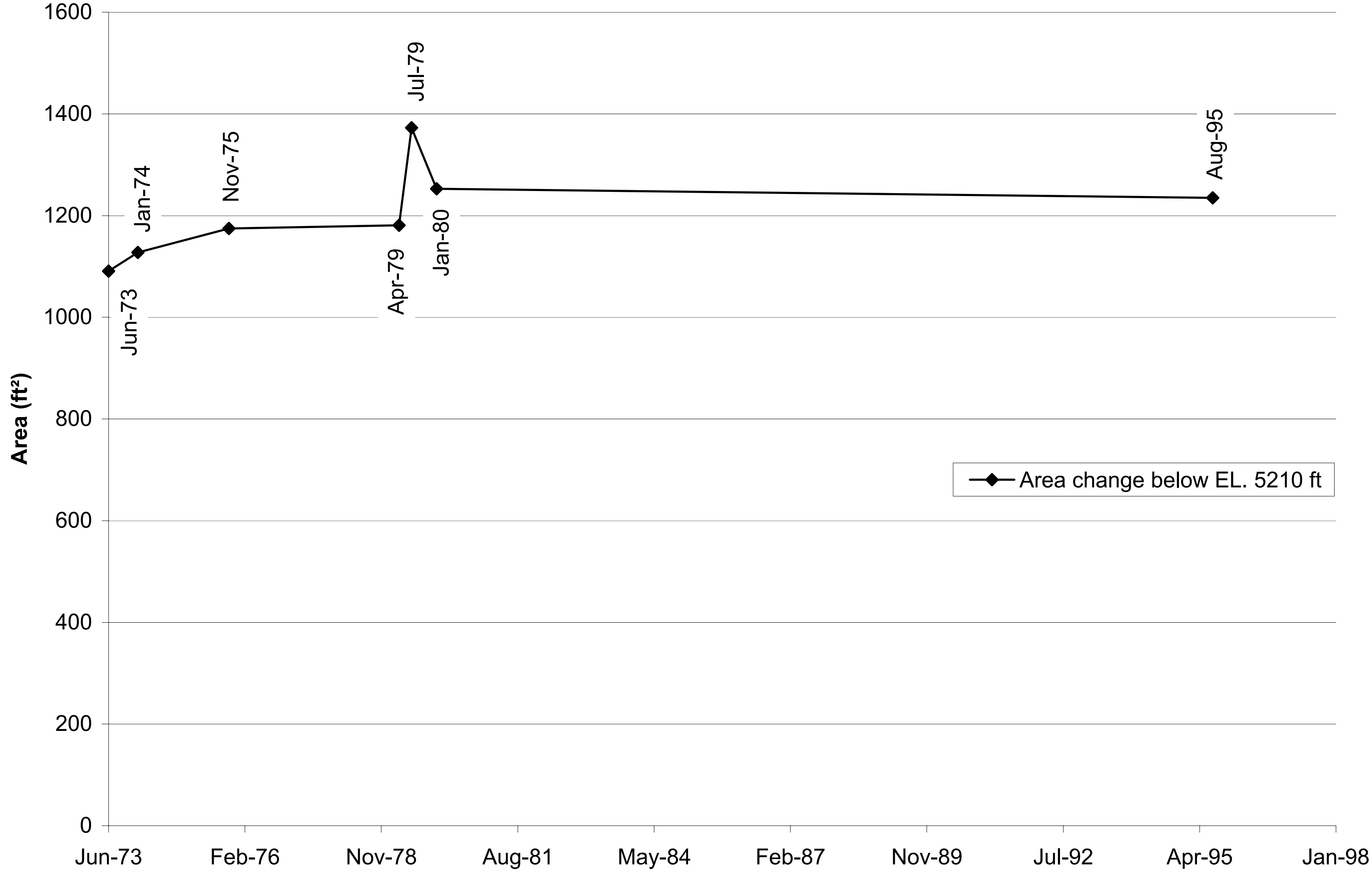

Fig. E-30. Change in cross section area with time at cross section CO-3.

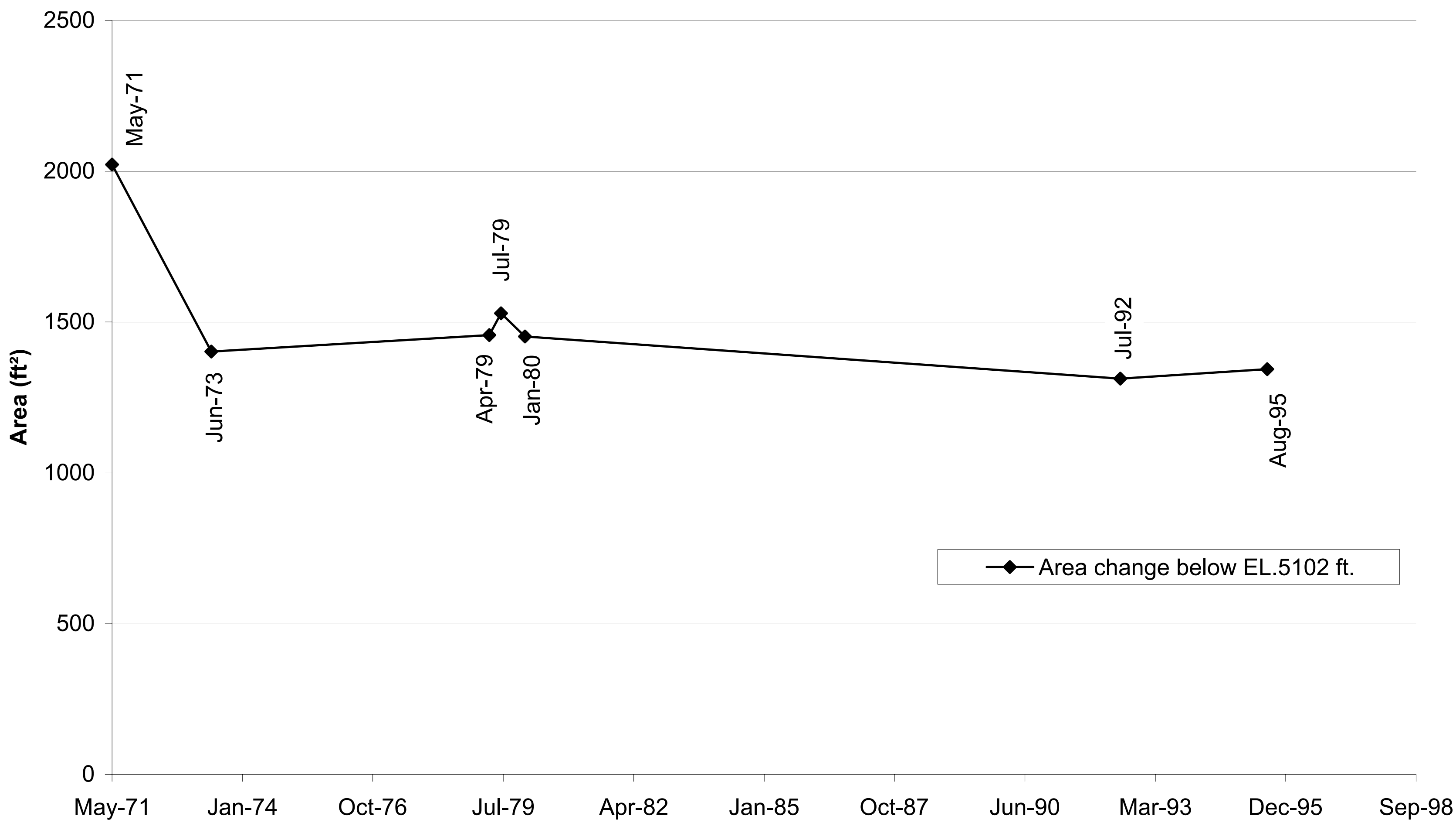

Fig. E-31. Change in cross section area with time at cross section CO-4.

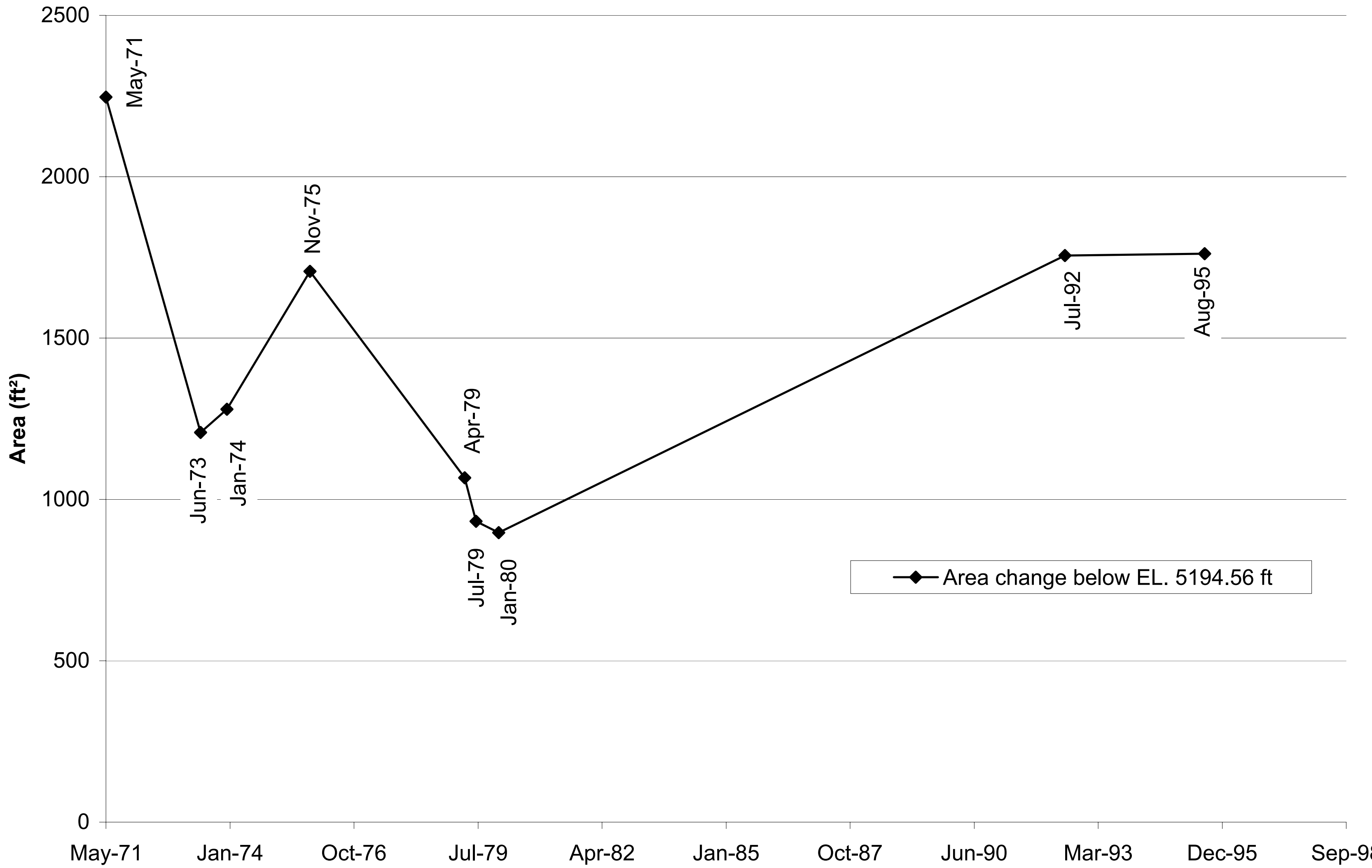

Fig. E-32. Change in cross section area with time at cross section CO-5.

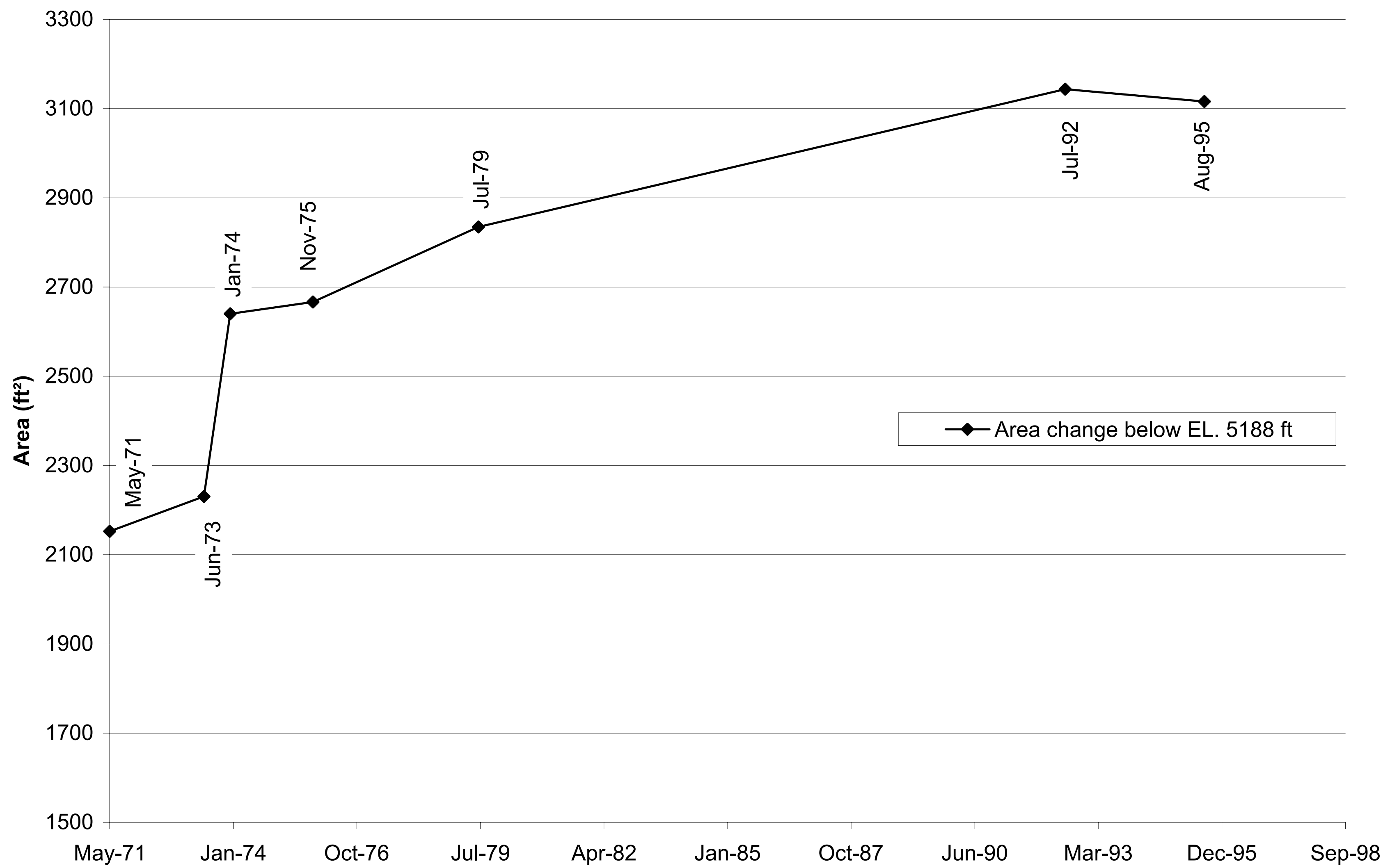

Fig. E-33. Change in cross section area with time at cross section CO-6.

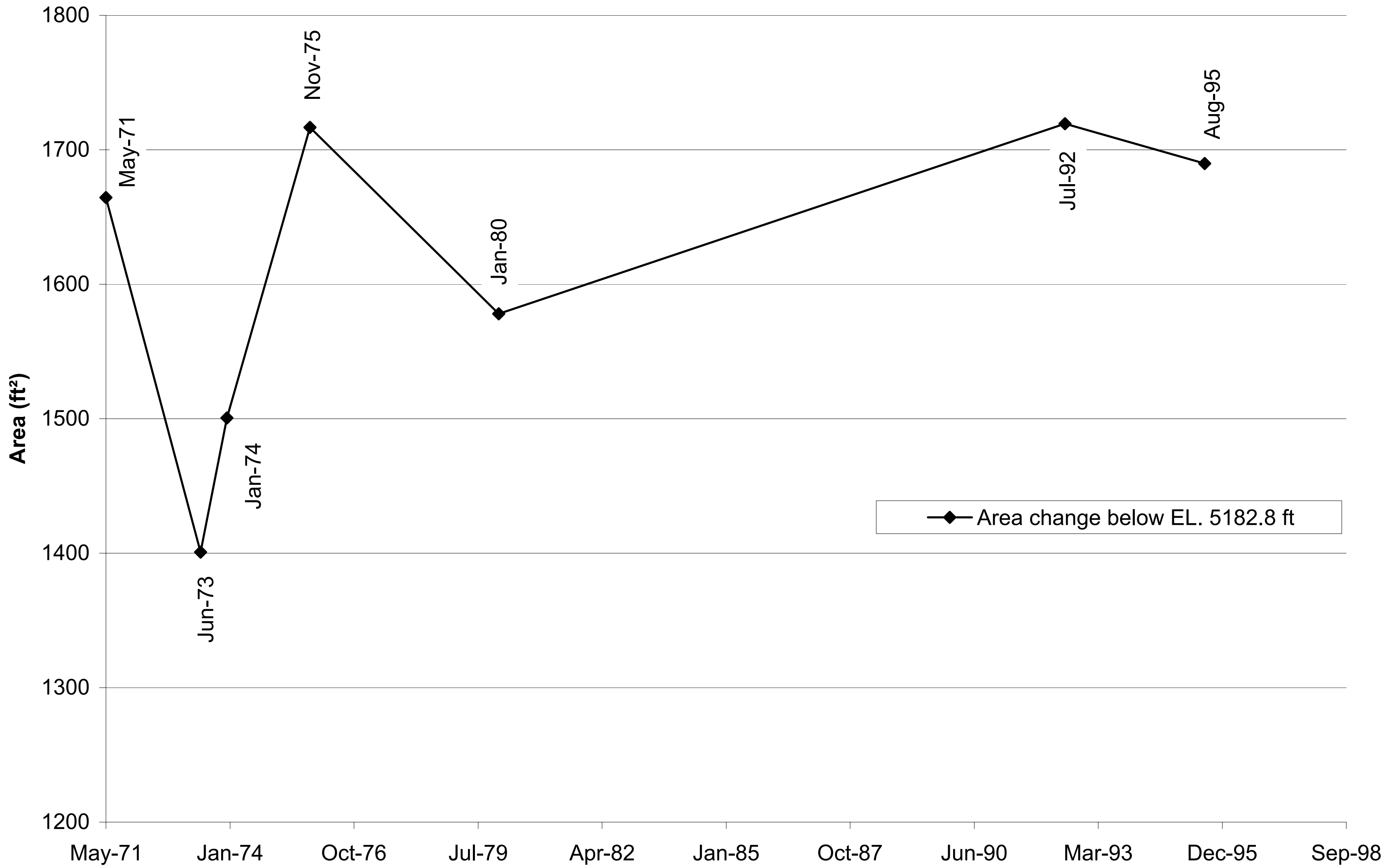

Fig. E-34. Change in cross section area with time at cross section CO-7.

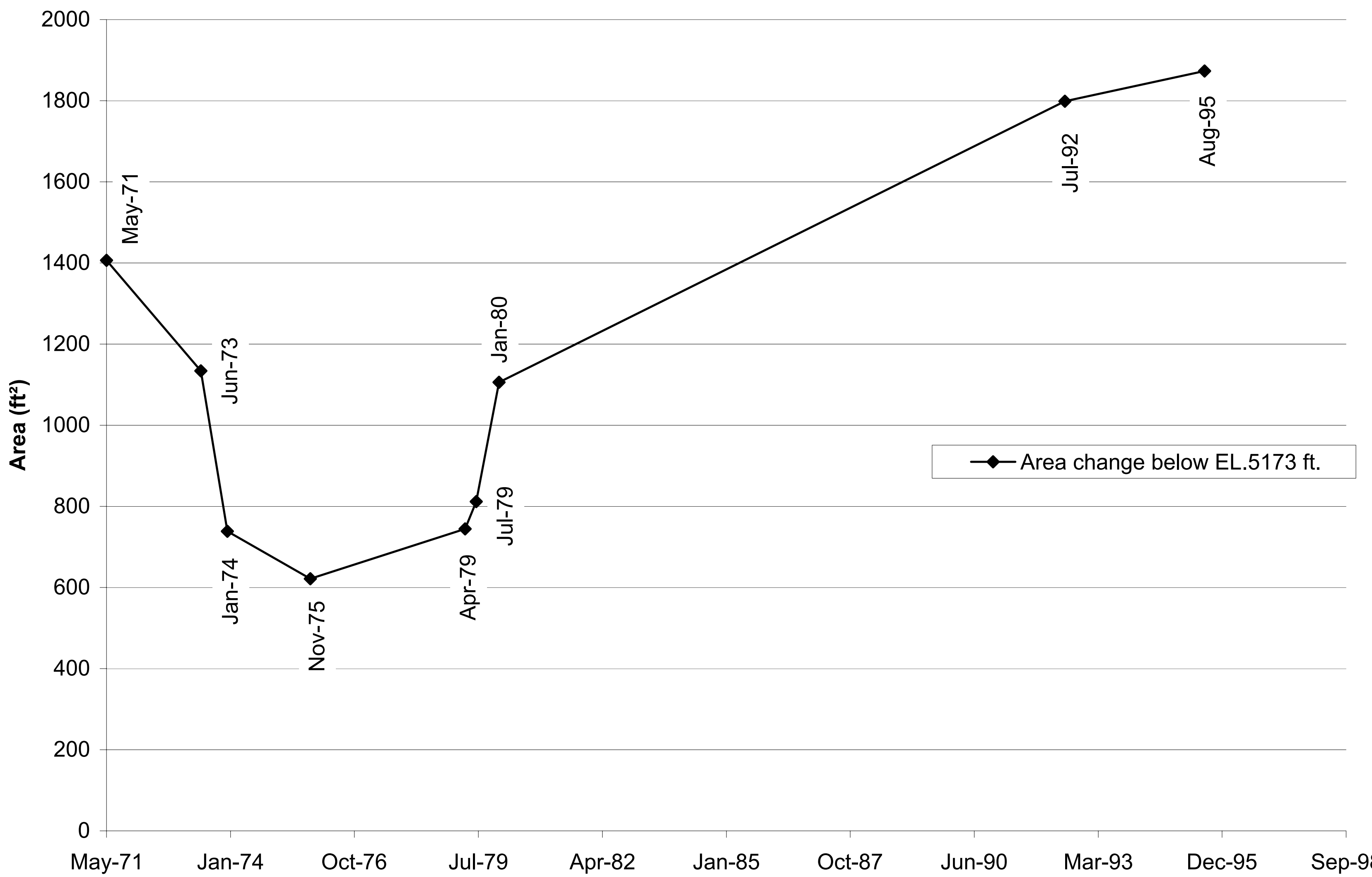

Fig. E-35. Change in cross section area with time at cross section CO-8.

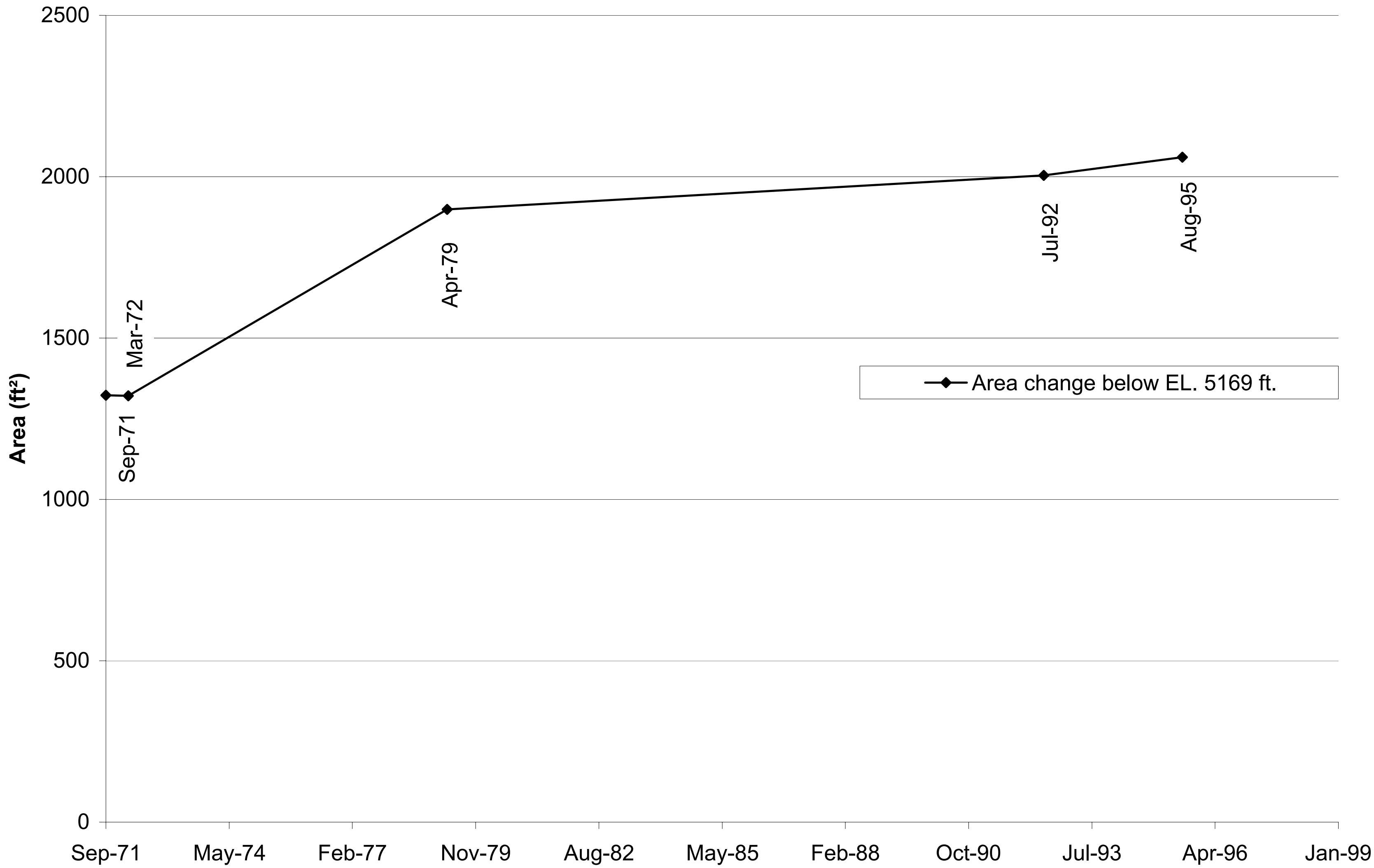

Fig. E-36. Change in cross section area with time at cross section CO-9.

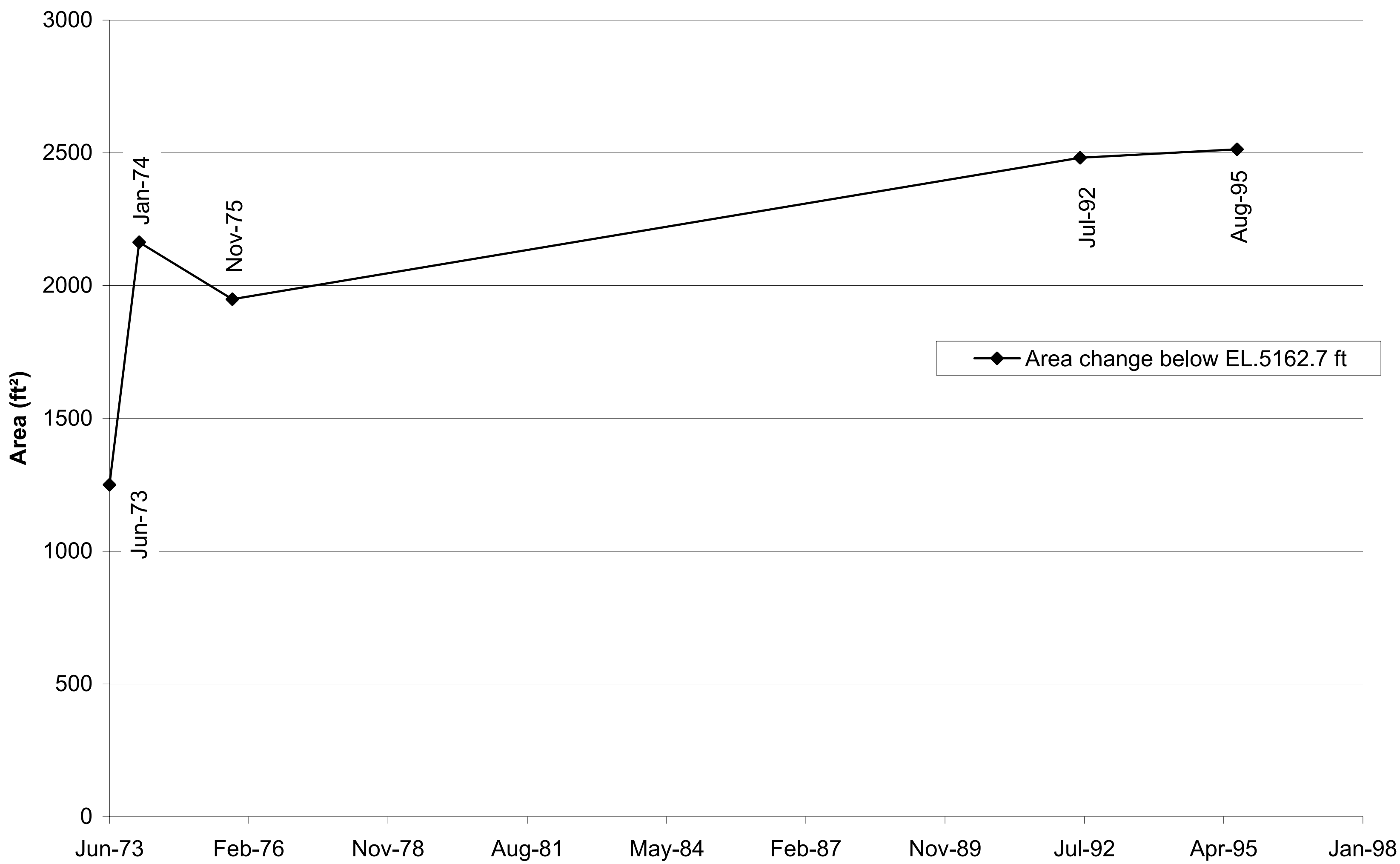

Fig. E-37. Change in cross section area with time at cross section CO-10.

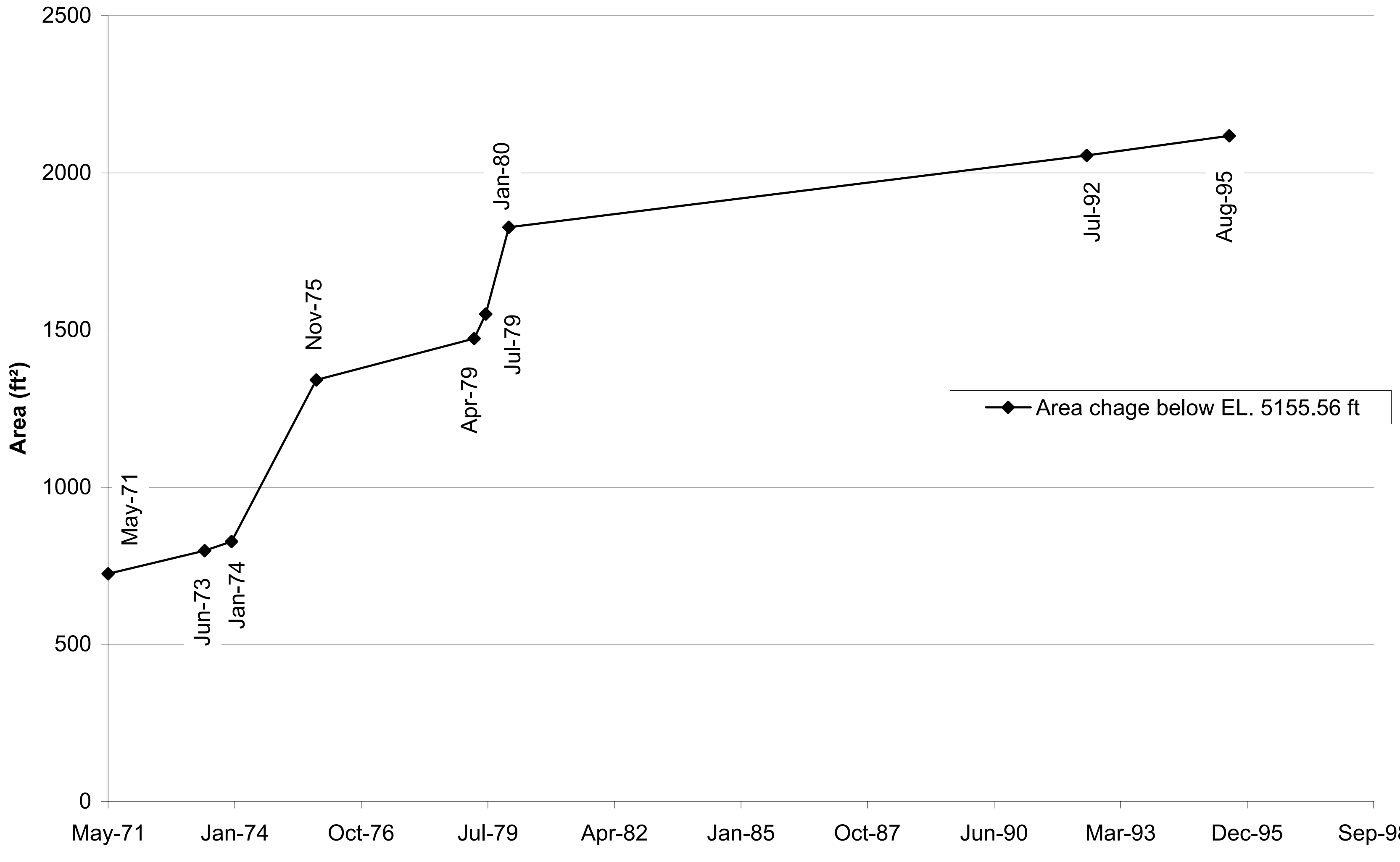

Fig. E-38. Change in cross section area with time at cross section CO-11.

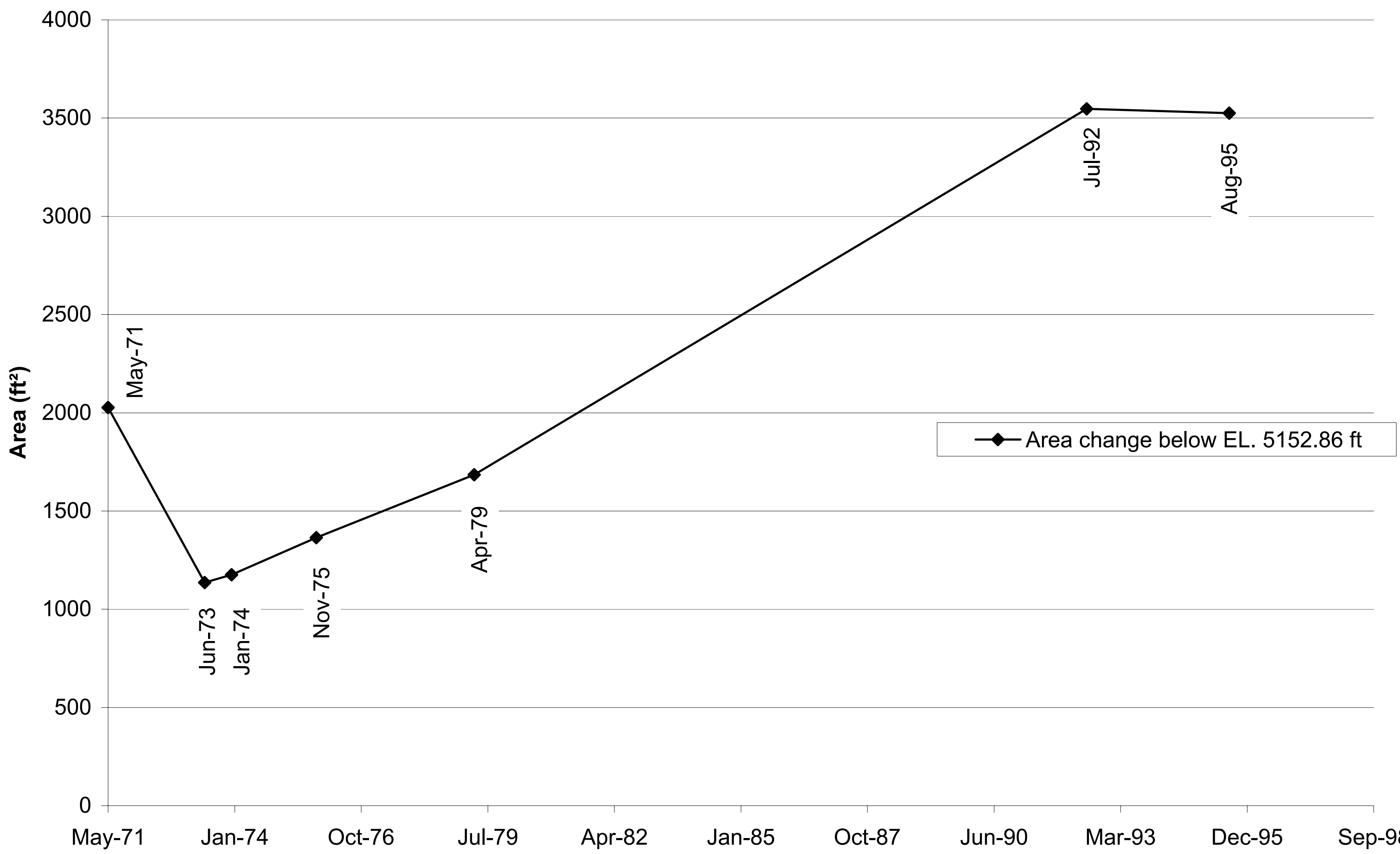

Fig. E-39. Change in cross section area with time at cross section CO-12.

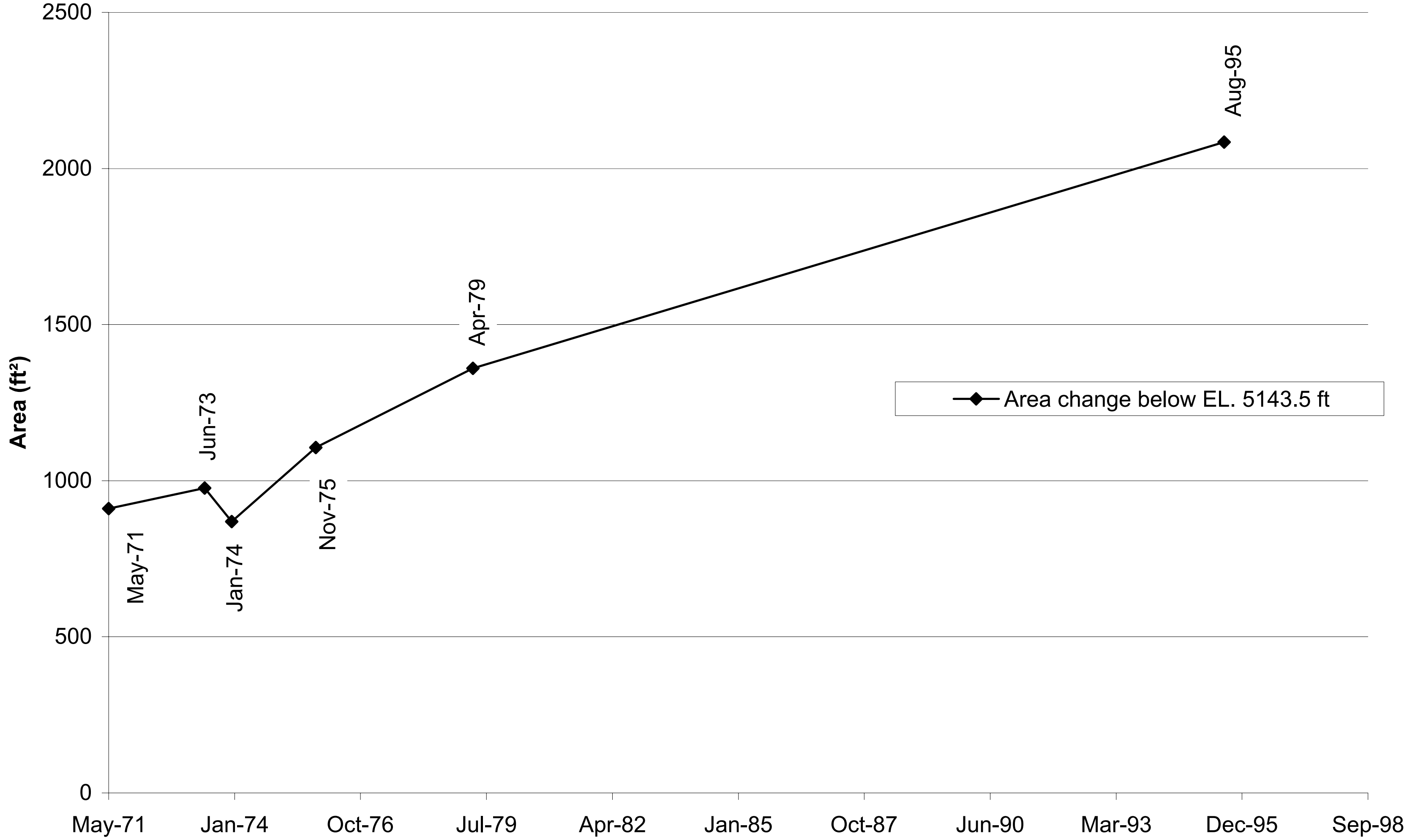

Fig. E-40. Change in cross section area with time at cross section CO-13.

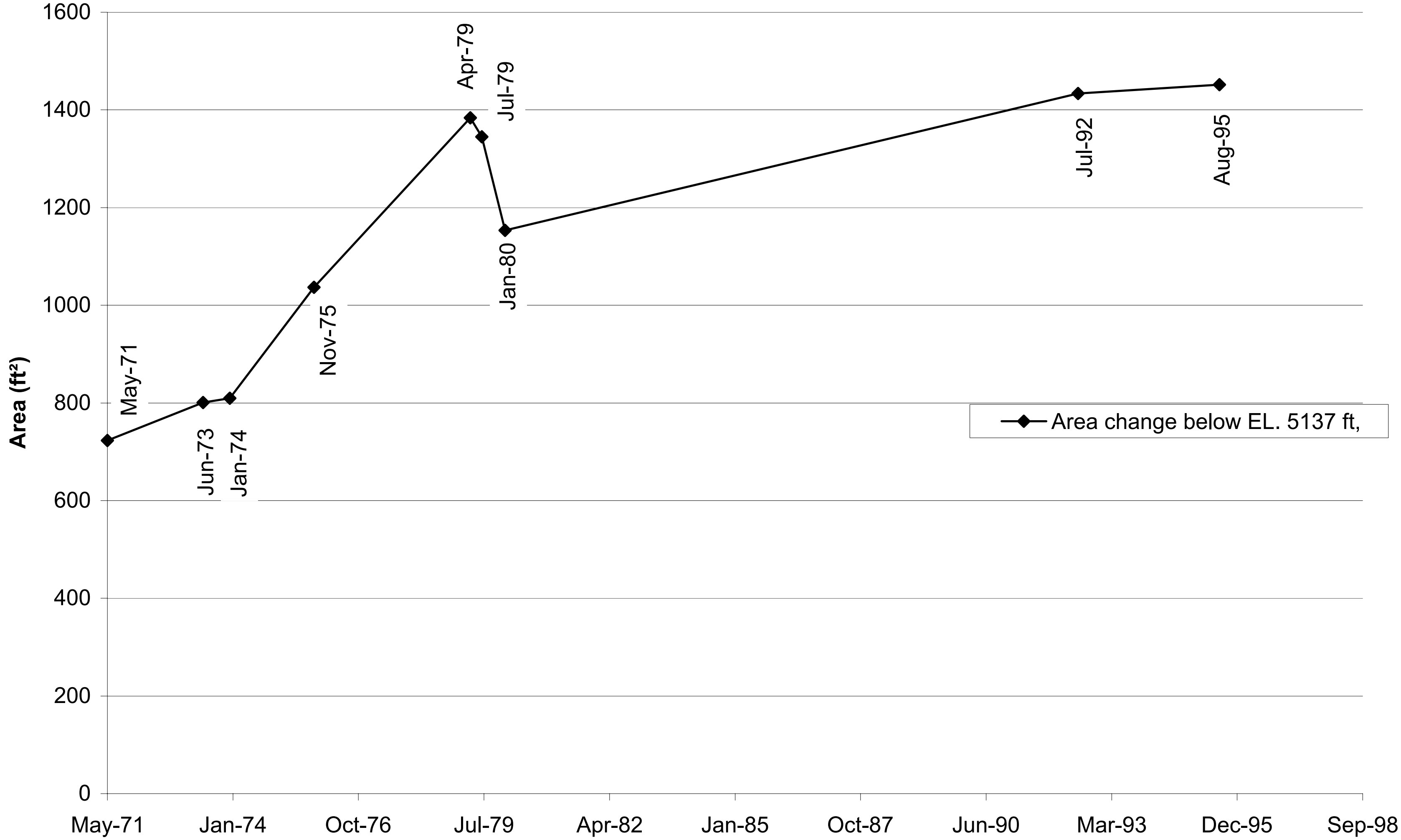

Fig. E-41. Change in cross section area with time at cross section CO-14.

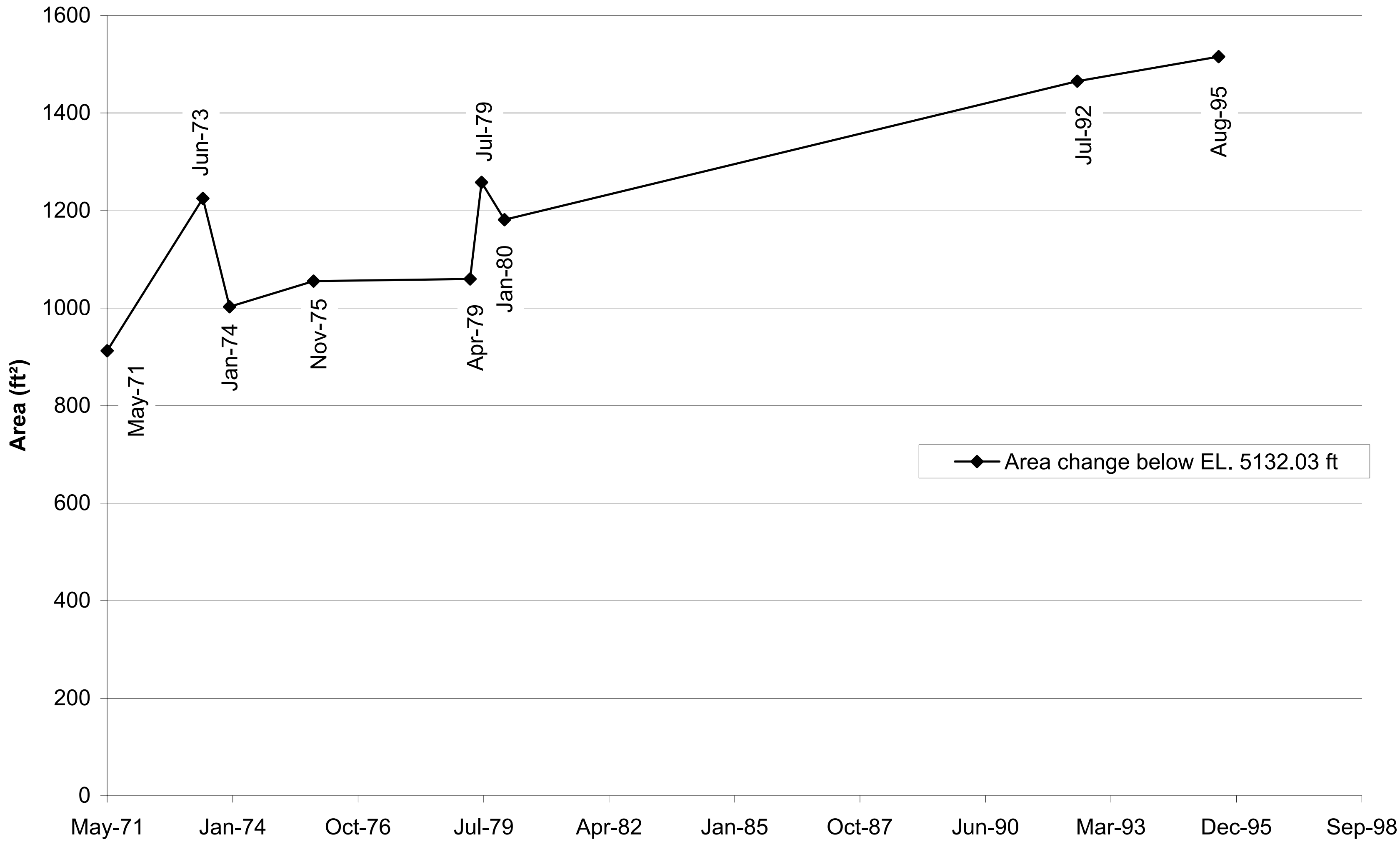

Fig. E-42. Change in cross section area with time at cross section CO-15.

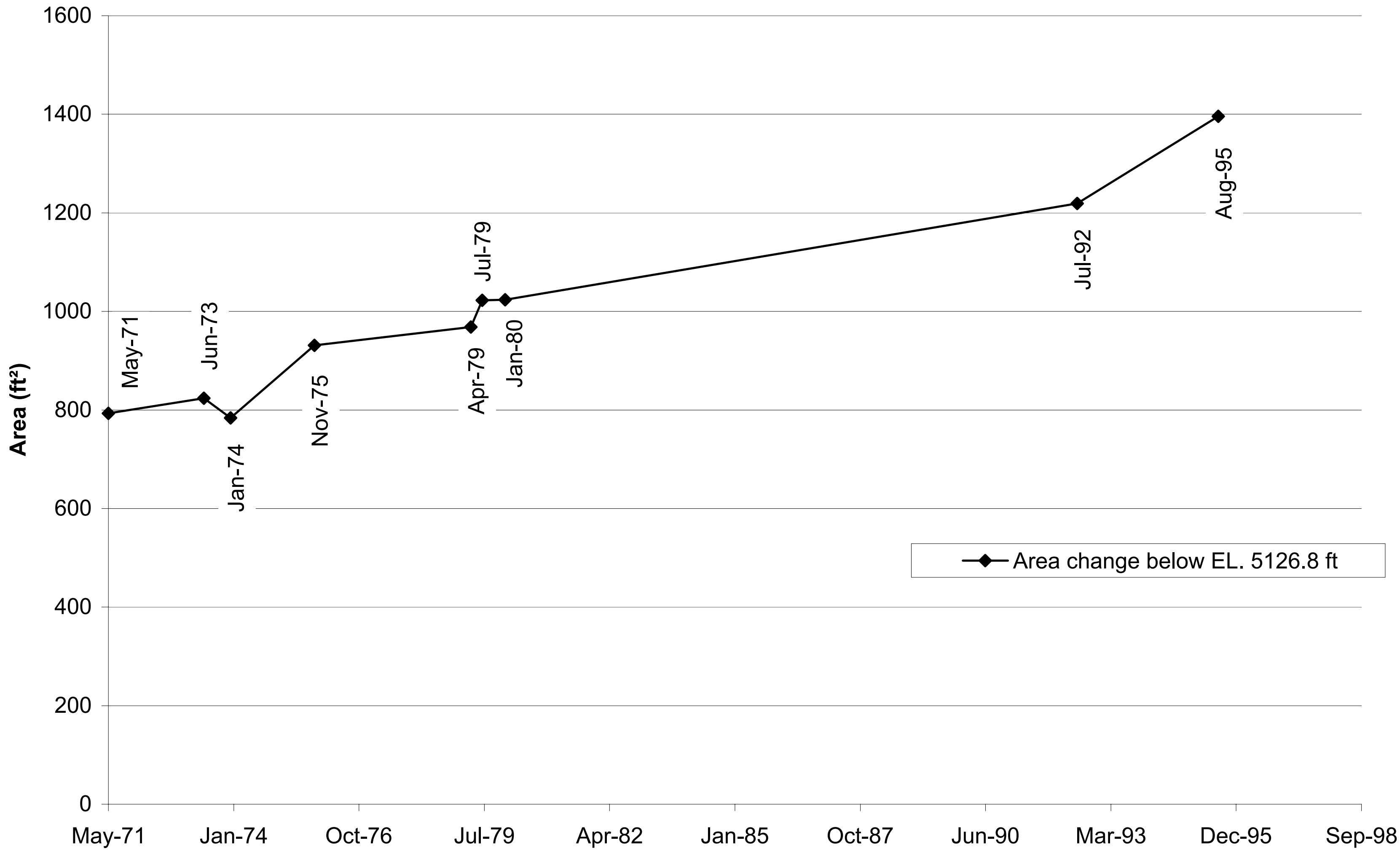

Fig. E-43. Change in cross section area with time at cross section CO-16.

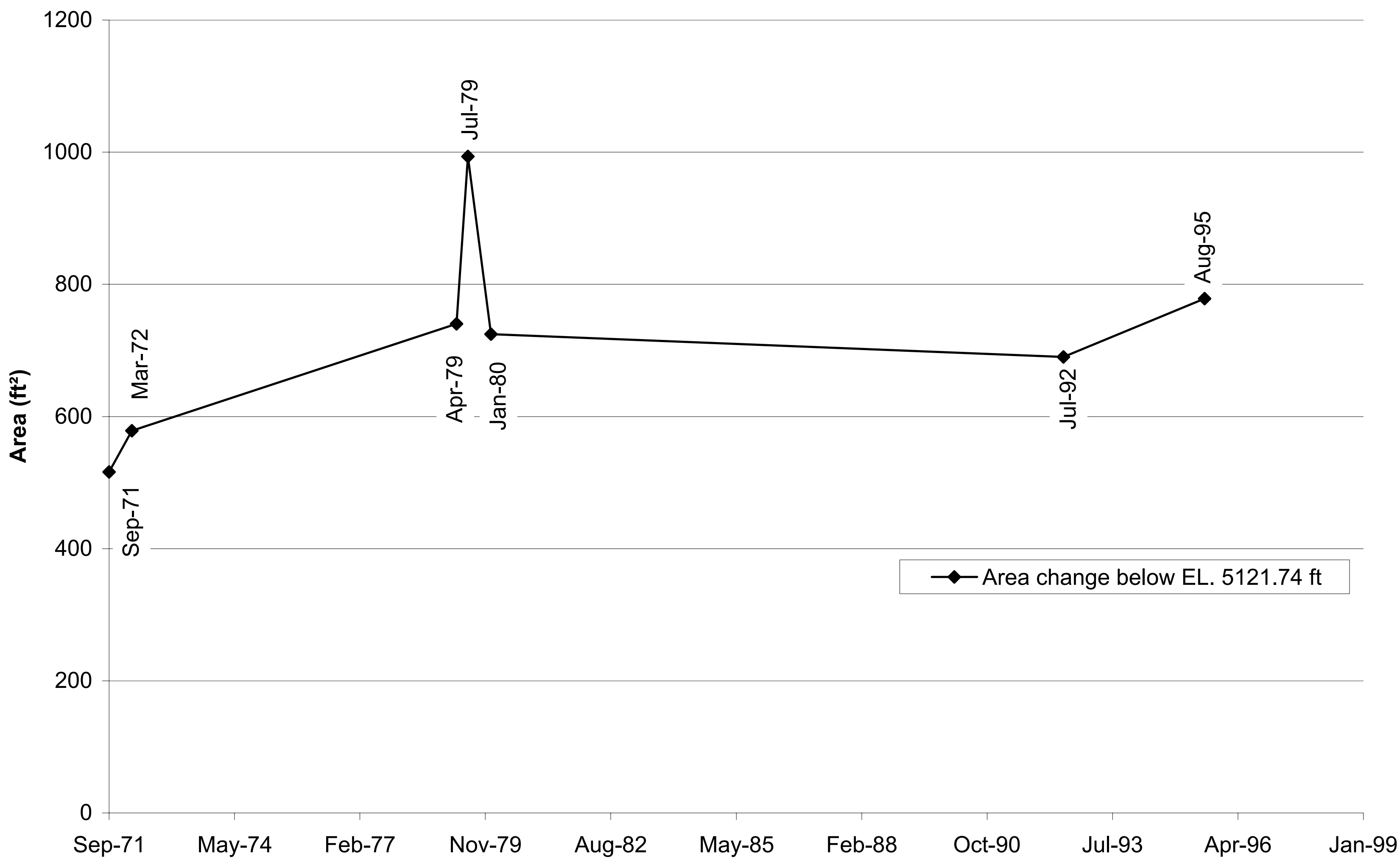

Fig. E-44. Change in cross section area with time at cross section CO-17.

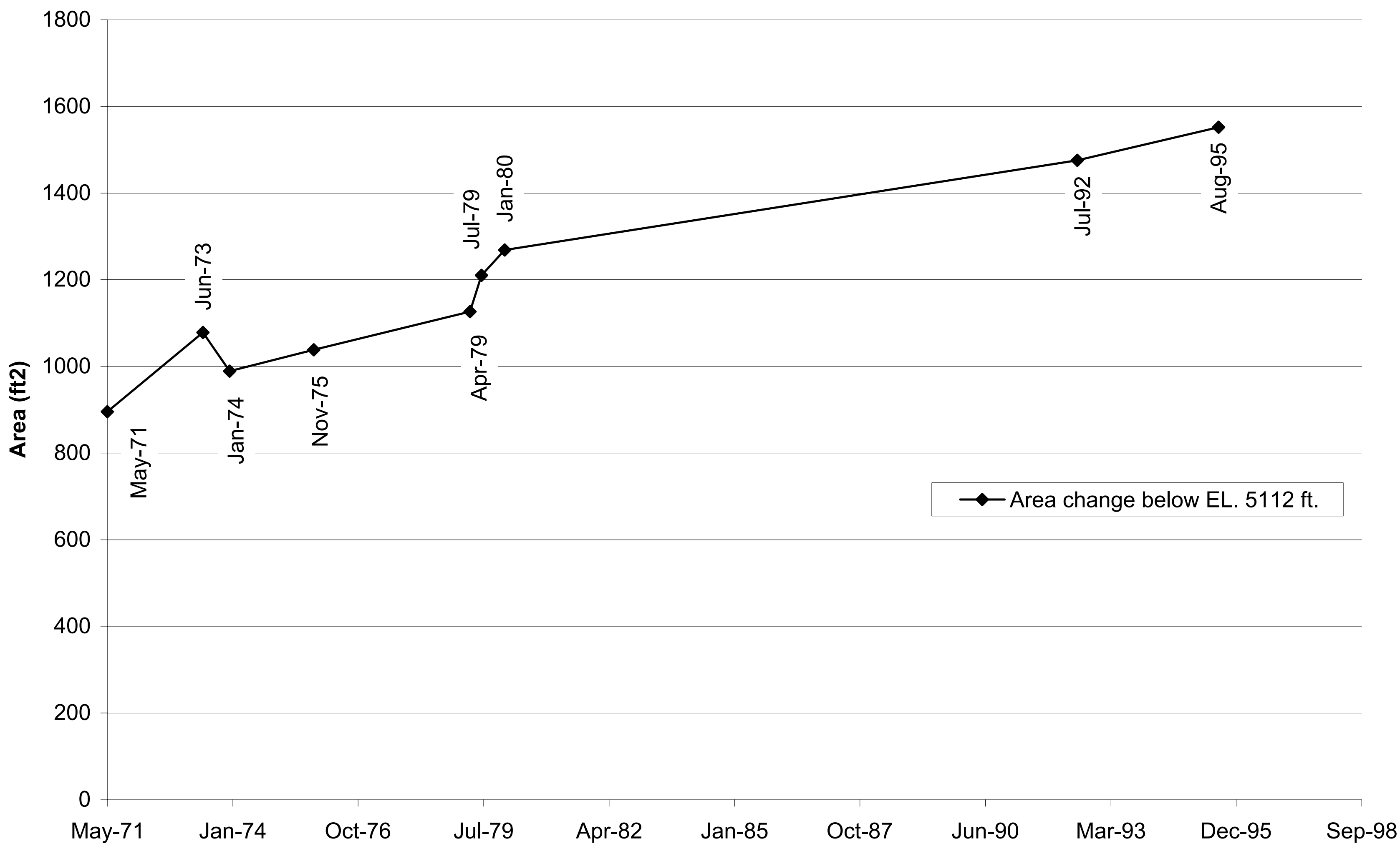

Fig. E-45. Change in cross section area with time at cross section CO-18.

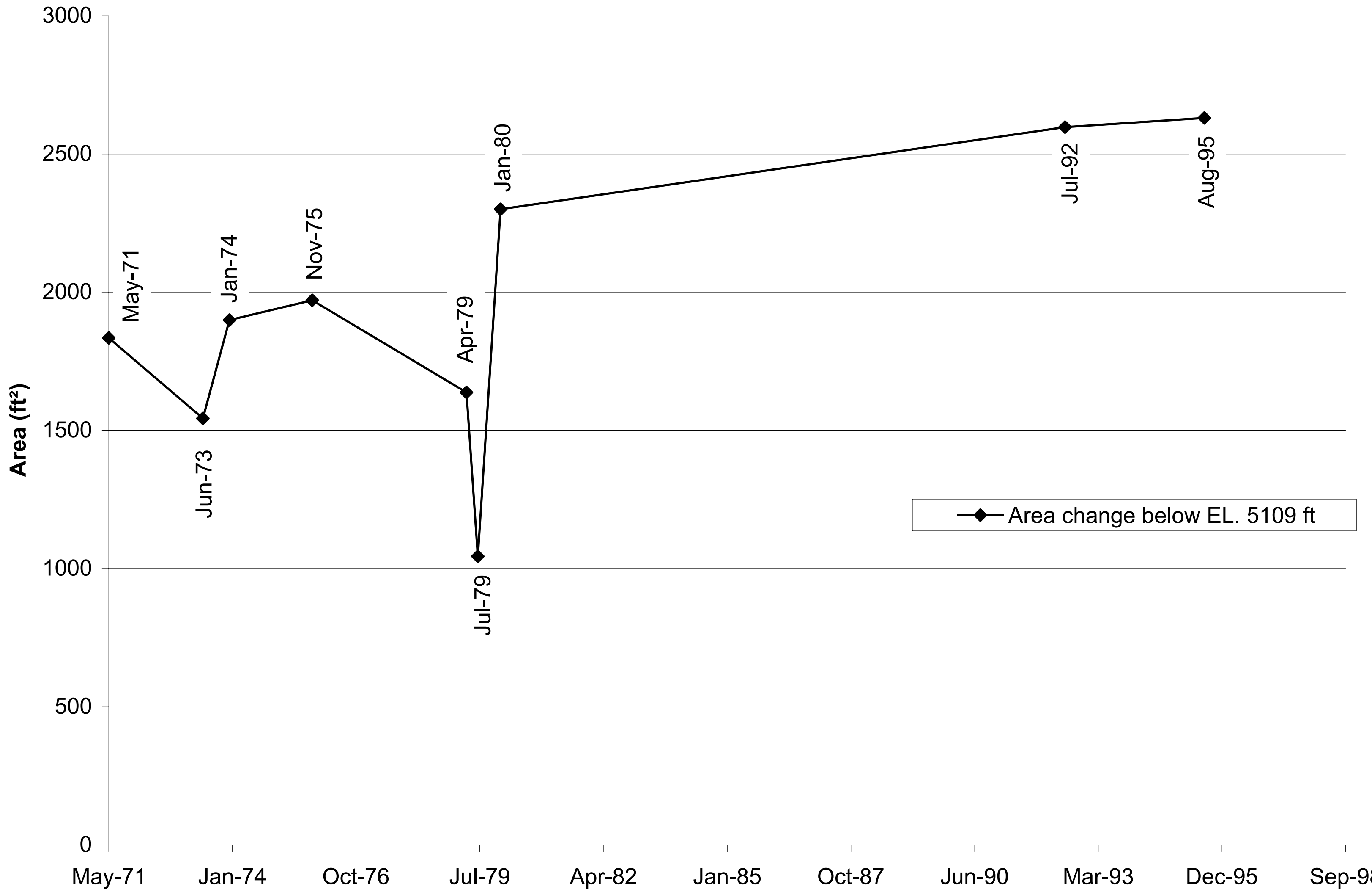

Fig. E-46. Change in cross section area with time at cross section CO-19.

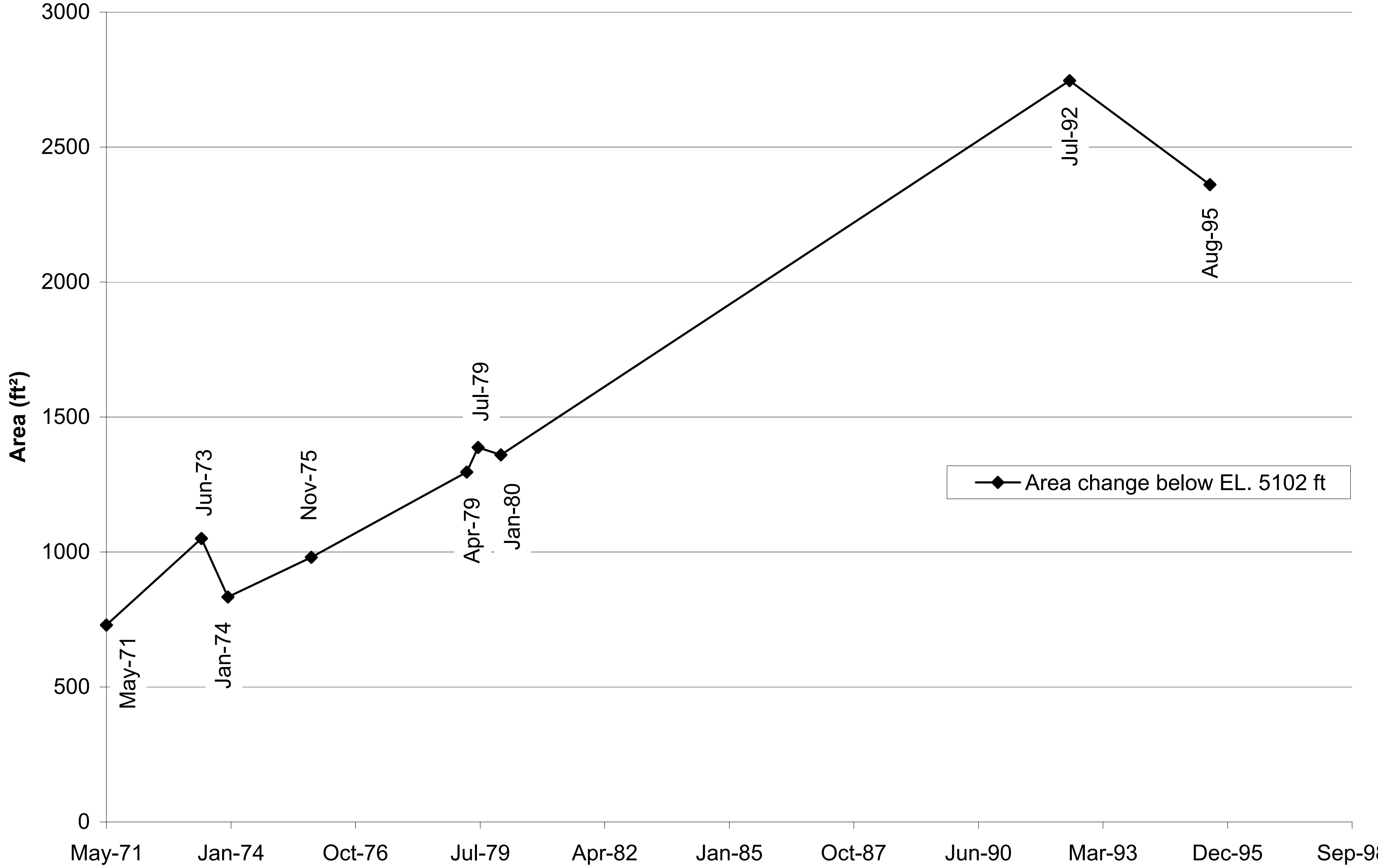

Fig. E-47. Change in cross section area with time at cross section CO-20.

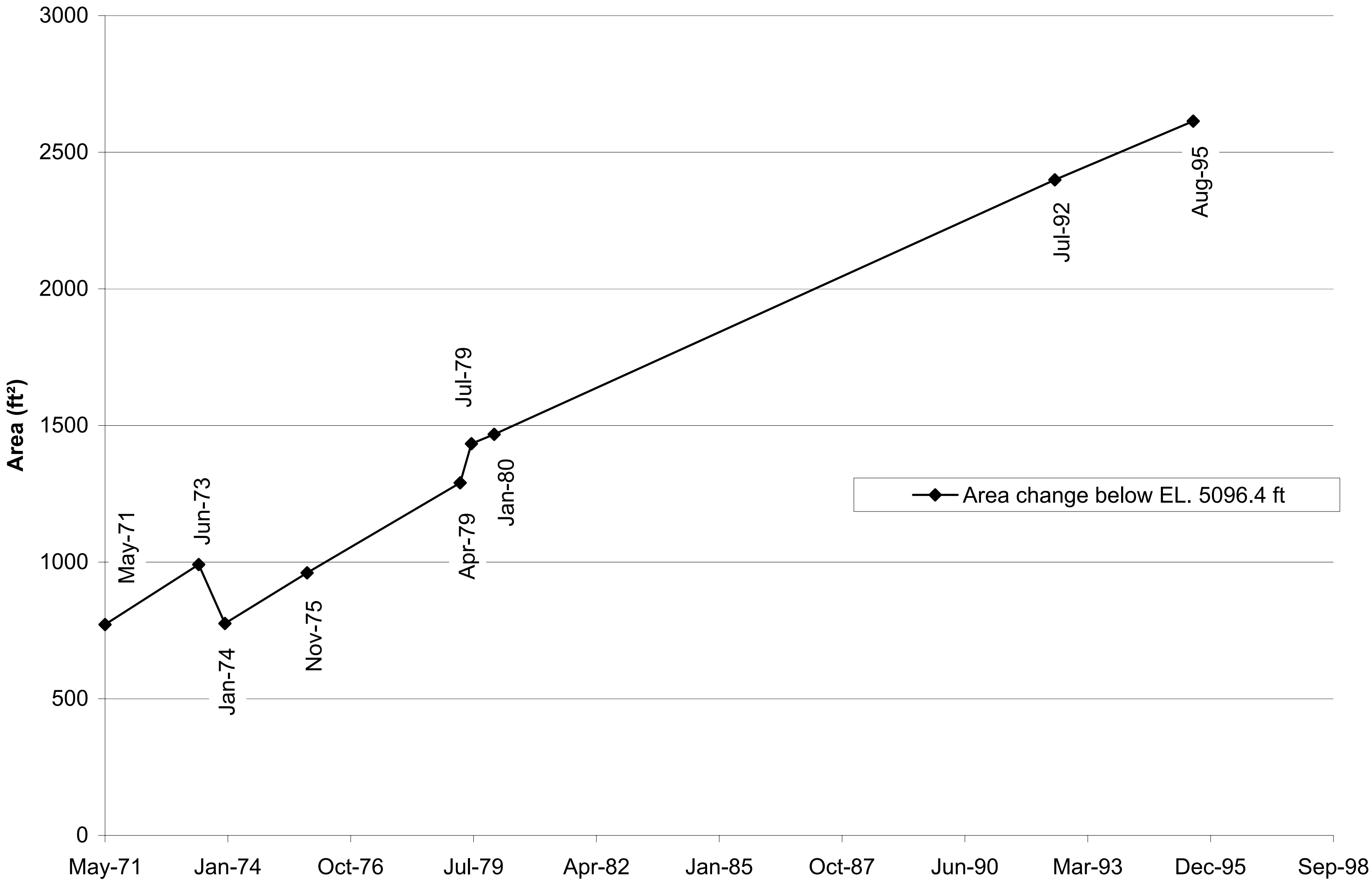

Fig. E-48. Change in cross section area with time at cross section CO-21.

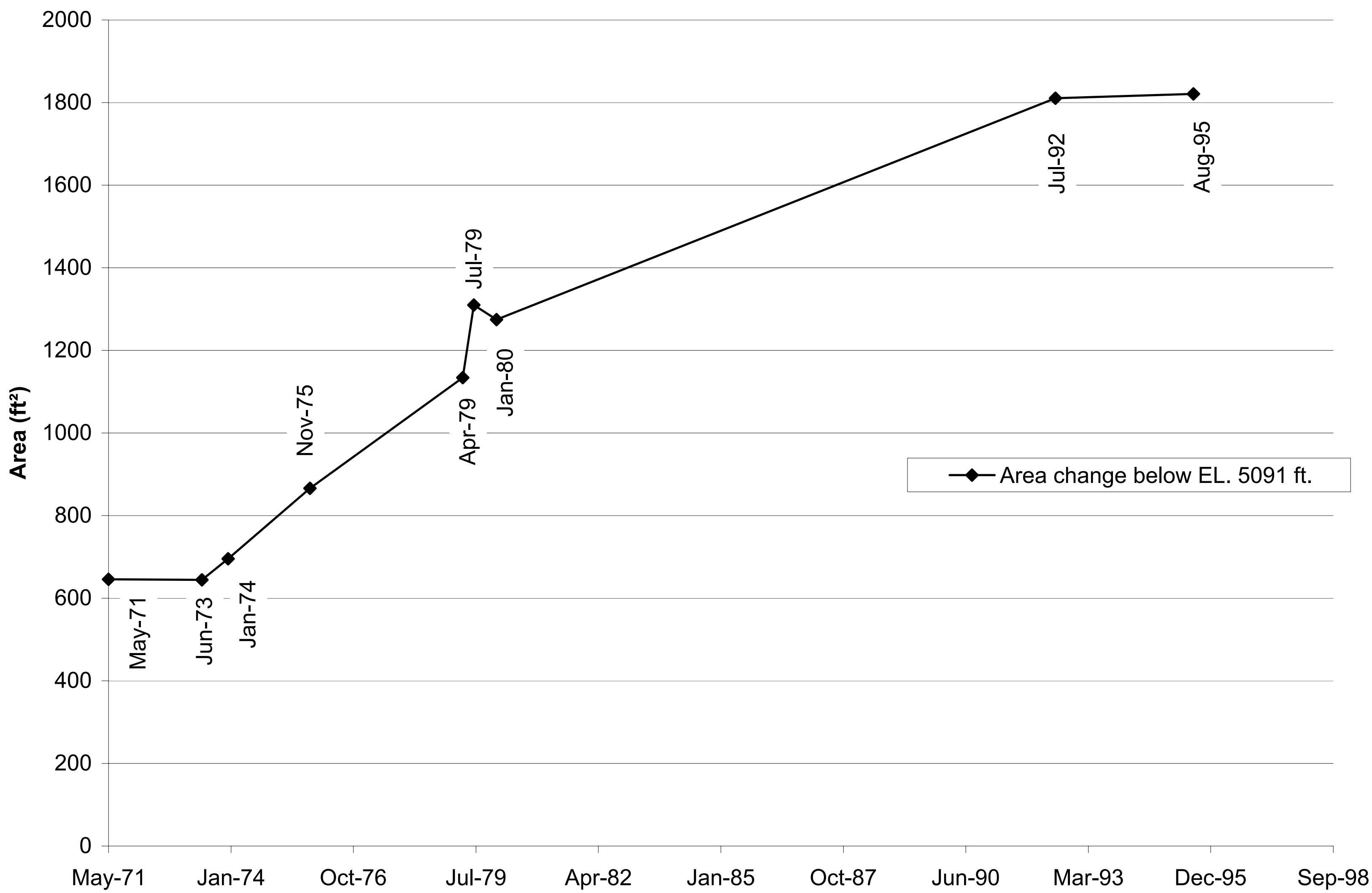

Fig. E-49. Change in cross section area with time at cross section CO-22.

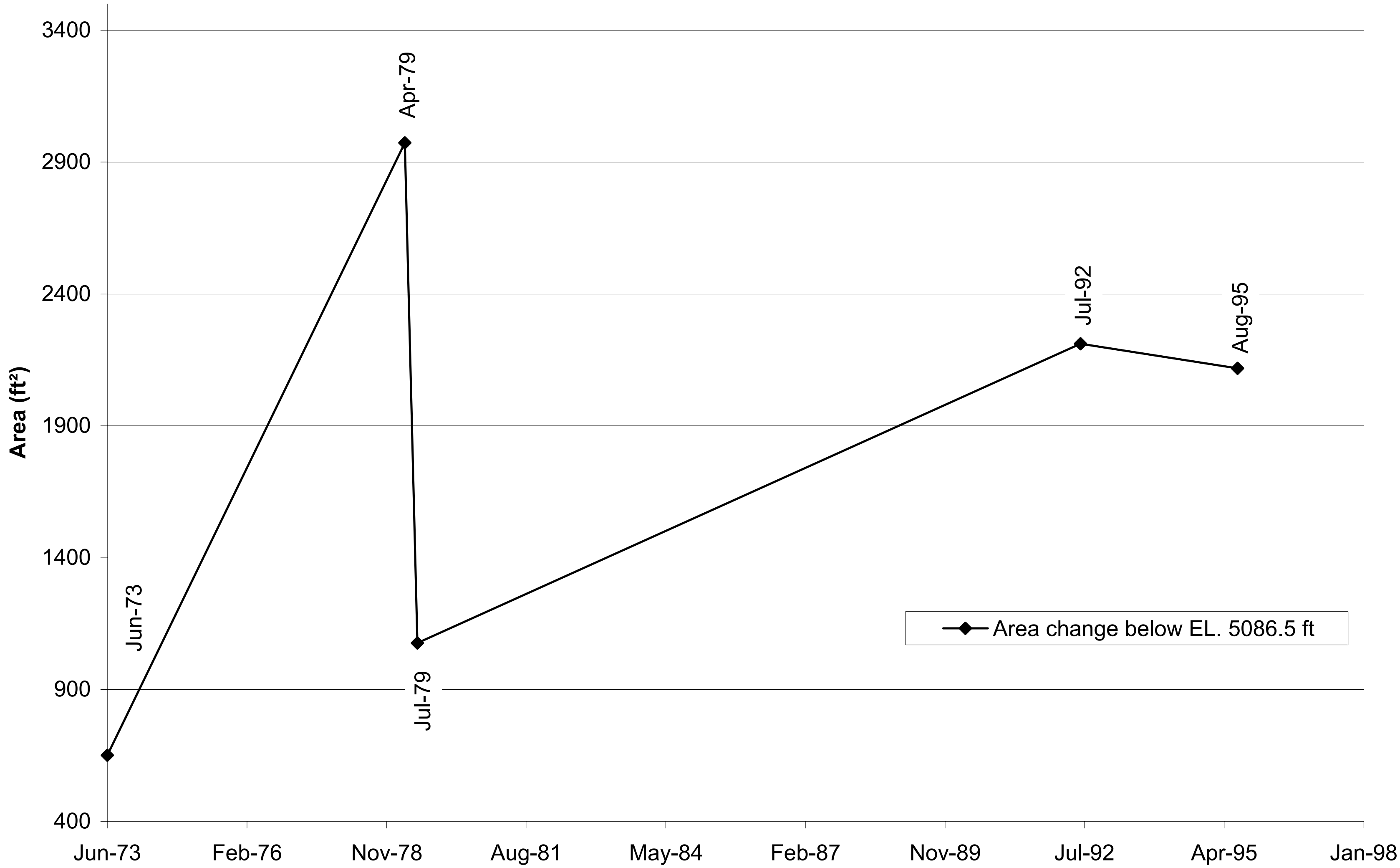

Fig. E-50. Change in cross section area with time at cross section CO-23.

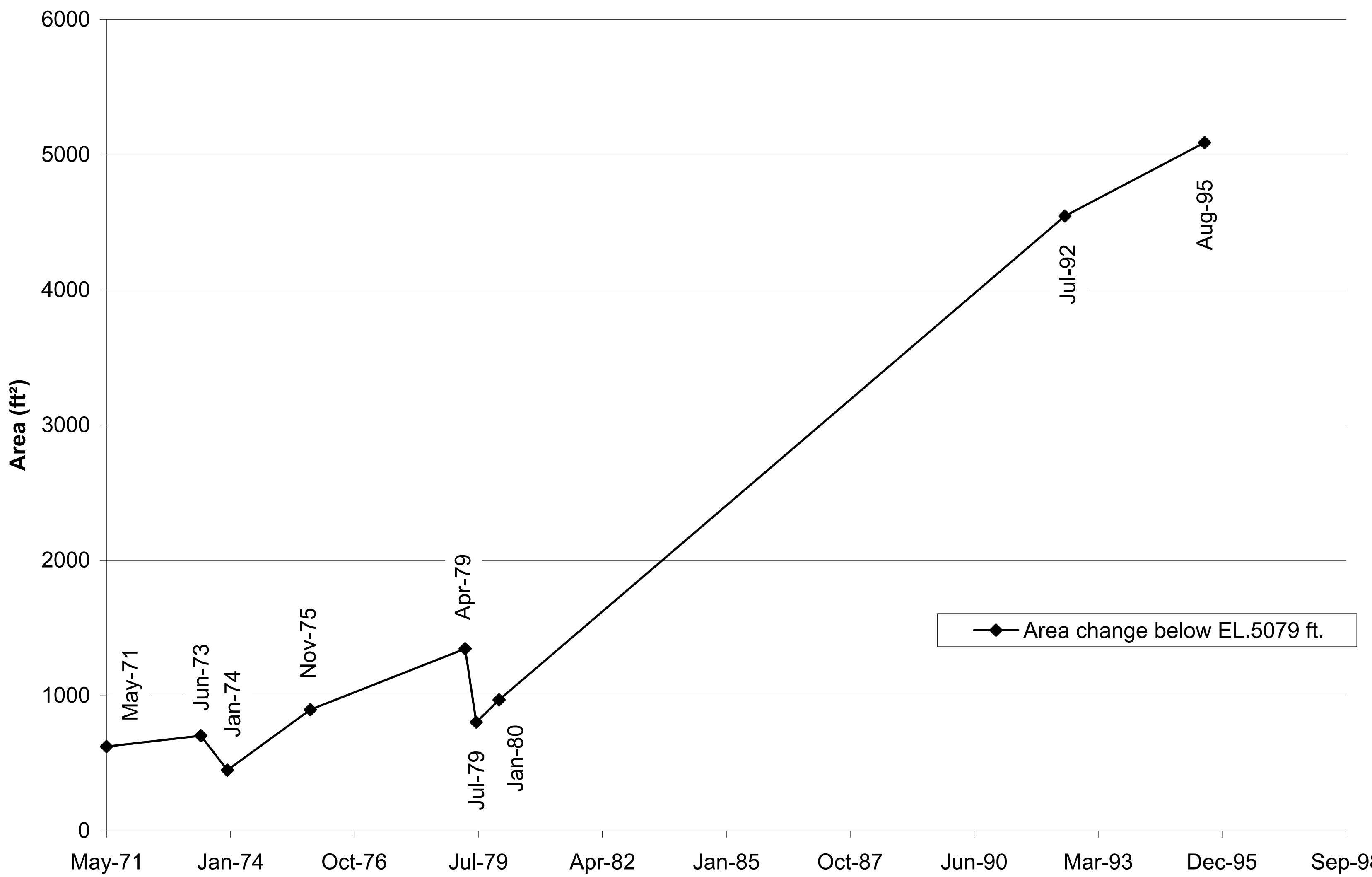

Fig. E-51. Change in cross section area with time at cross section CO-24.

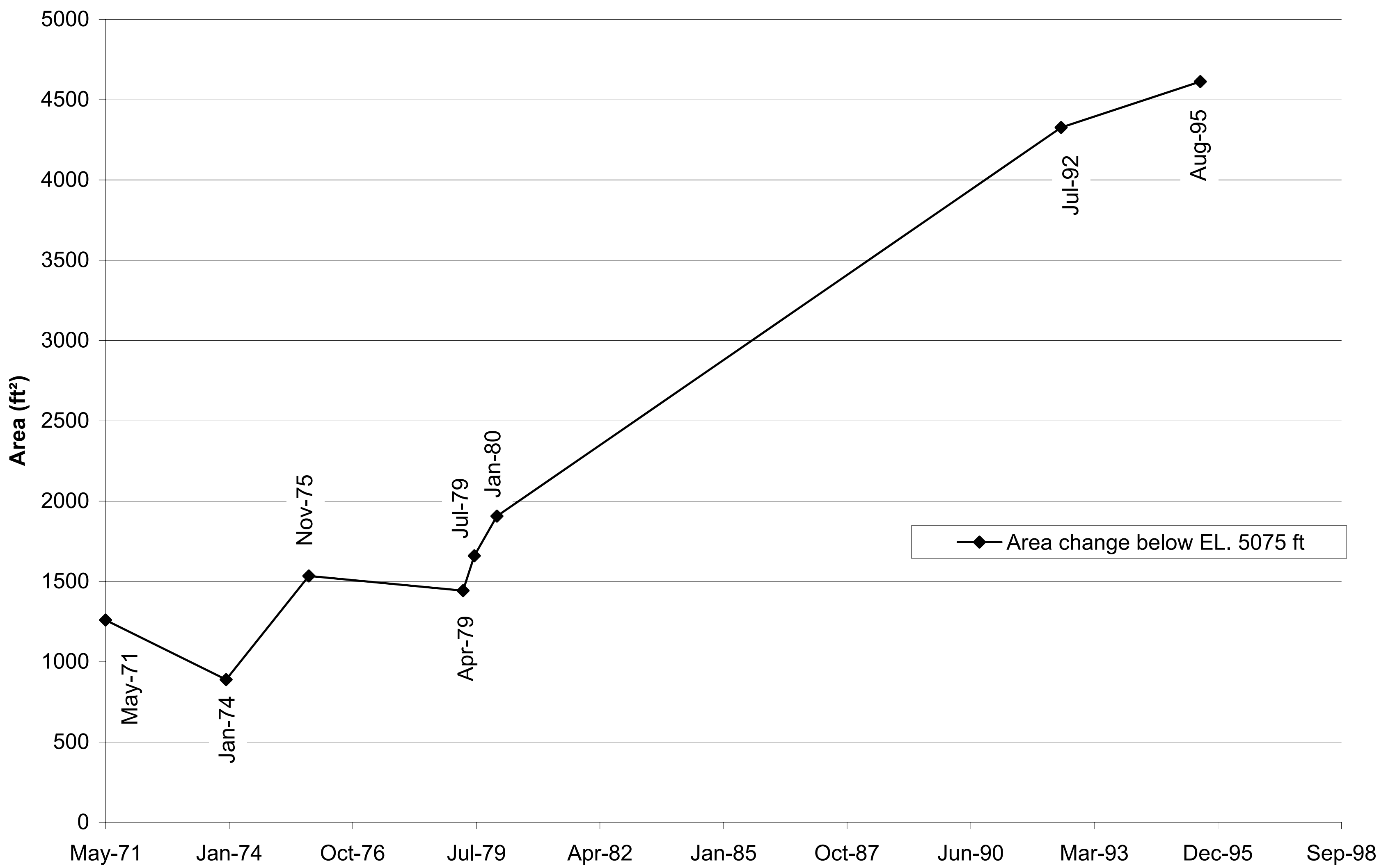

Fig. E-52. Change in cross section area with time at cross section CO-25.

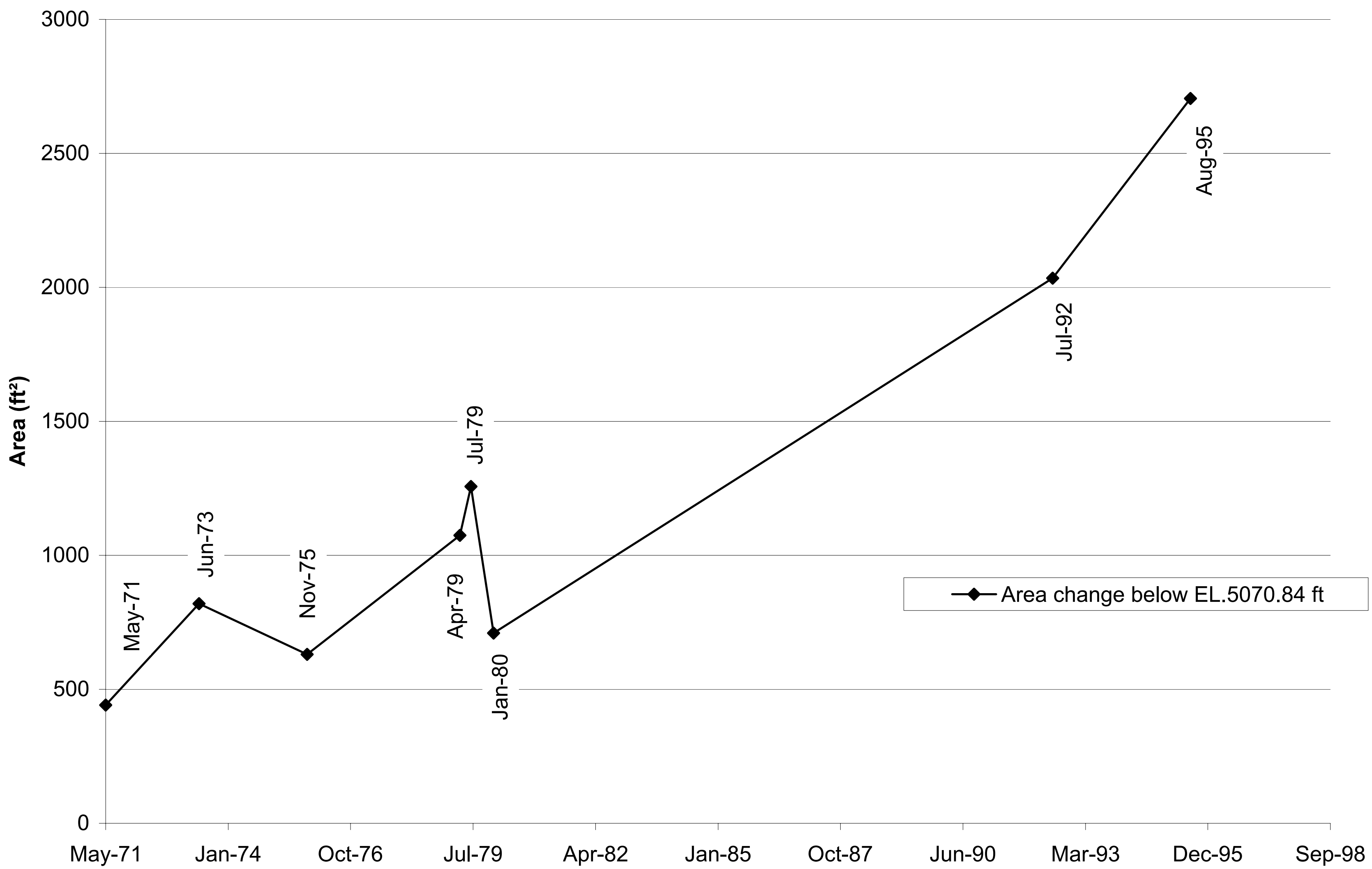

Fig. E-53. Change in cross section area with time at cross section CO-26.

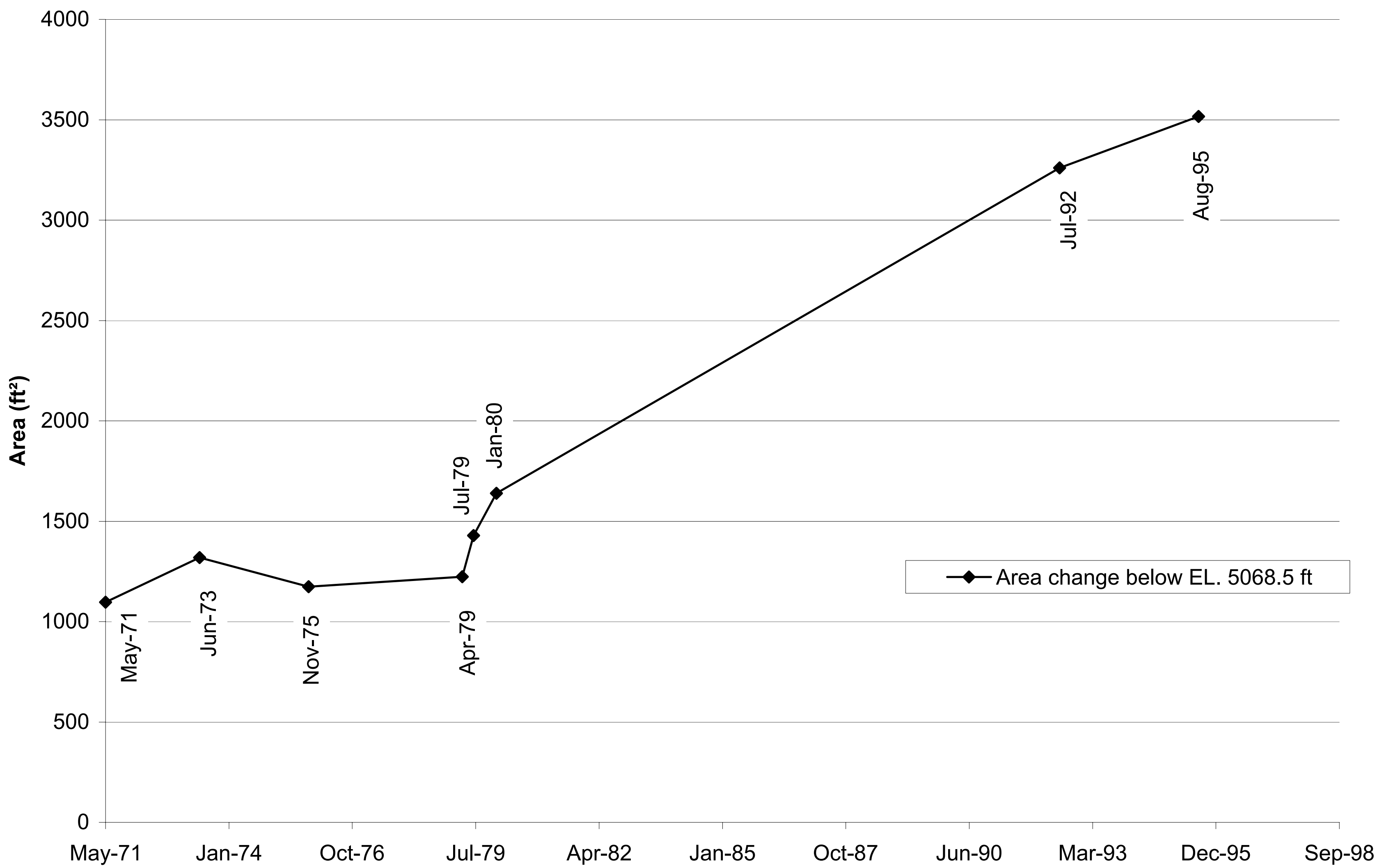

Fig. E-54. Change in cross section area with time at cross section CO-27.

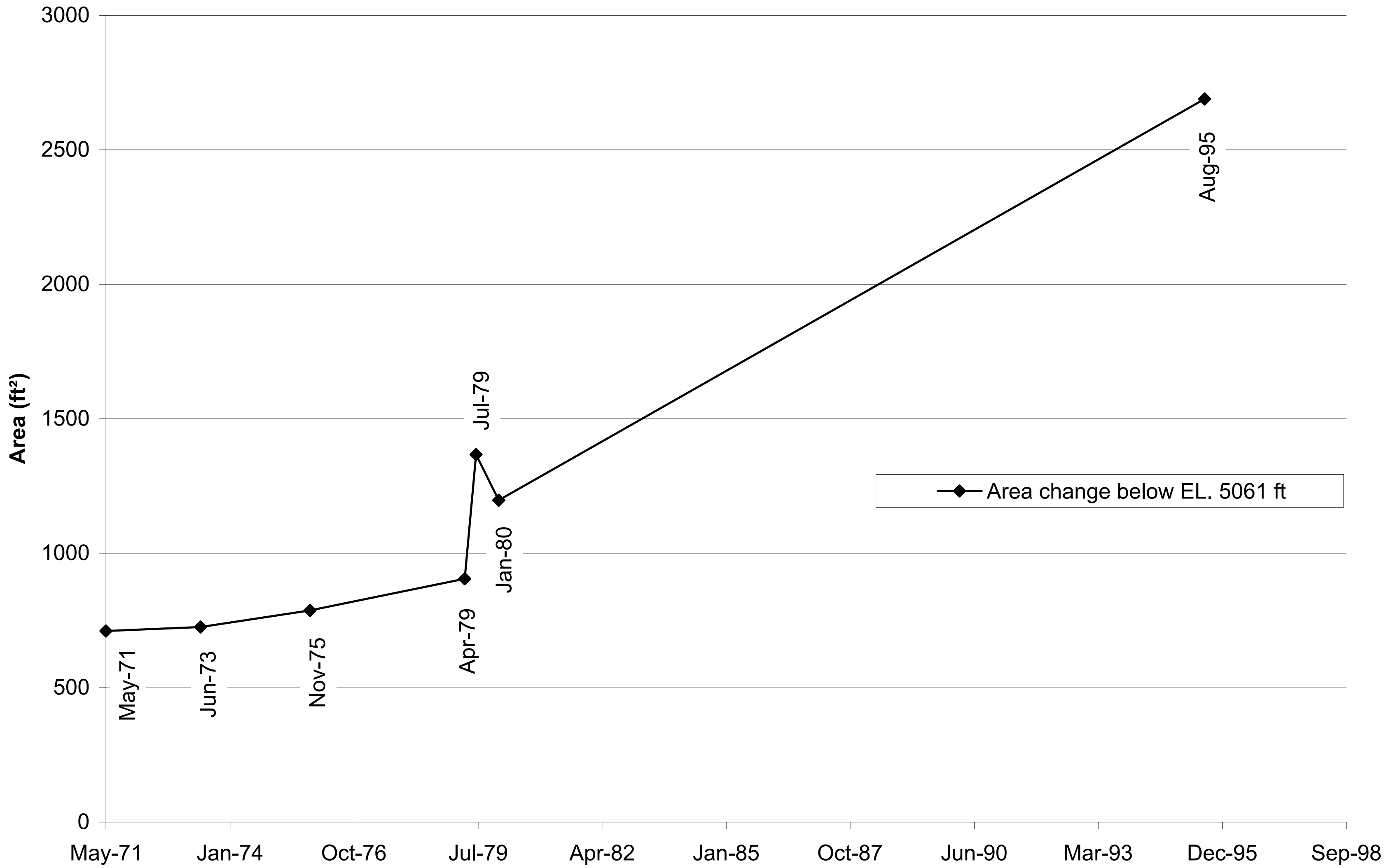

Fig. E-55. Change in cross section area with time at cross section CO-28.

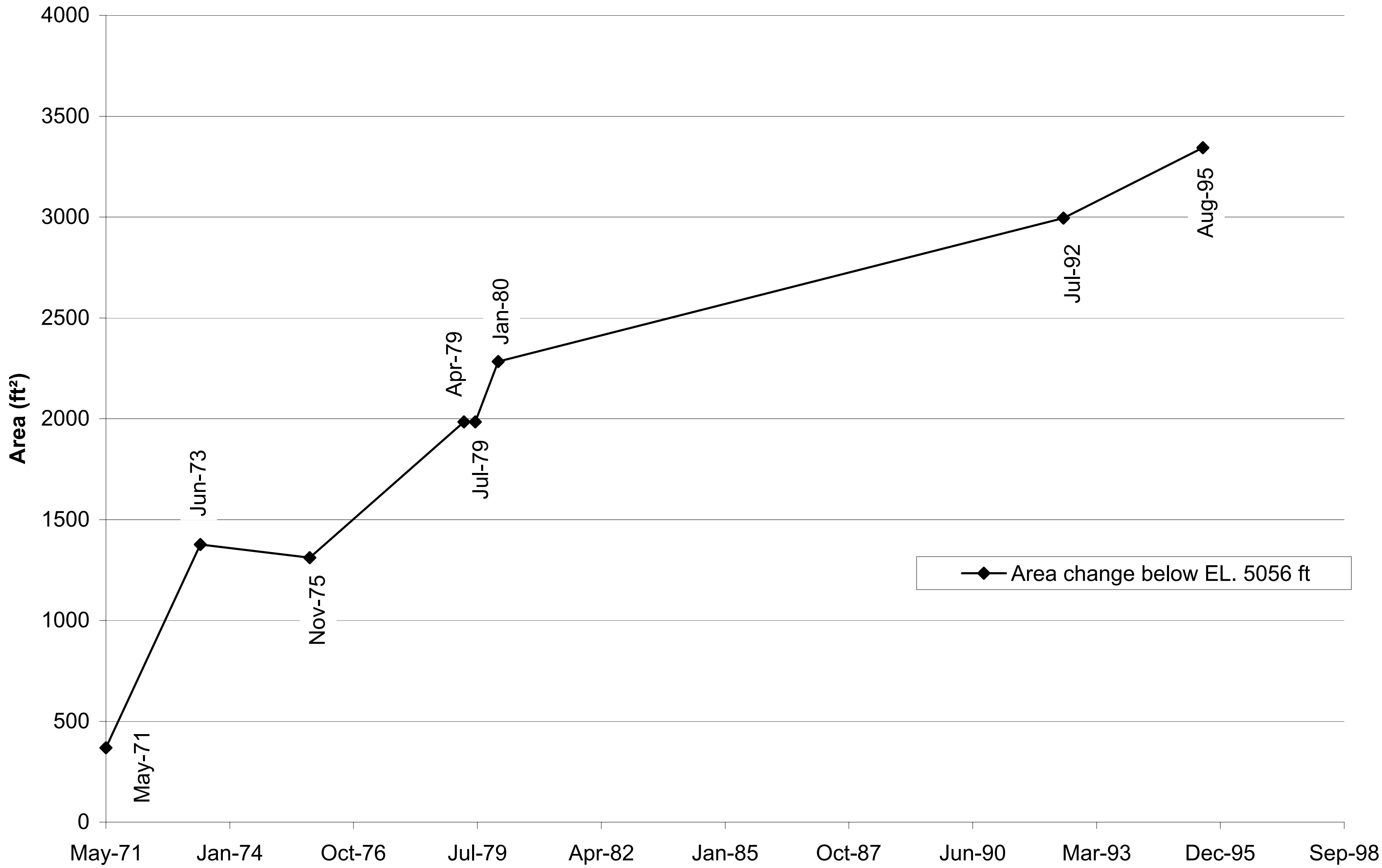

Fig. E-56. Change in cross section area with time at cross section CO-29.

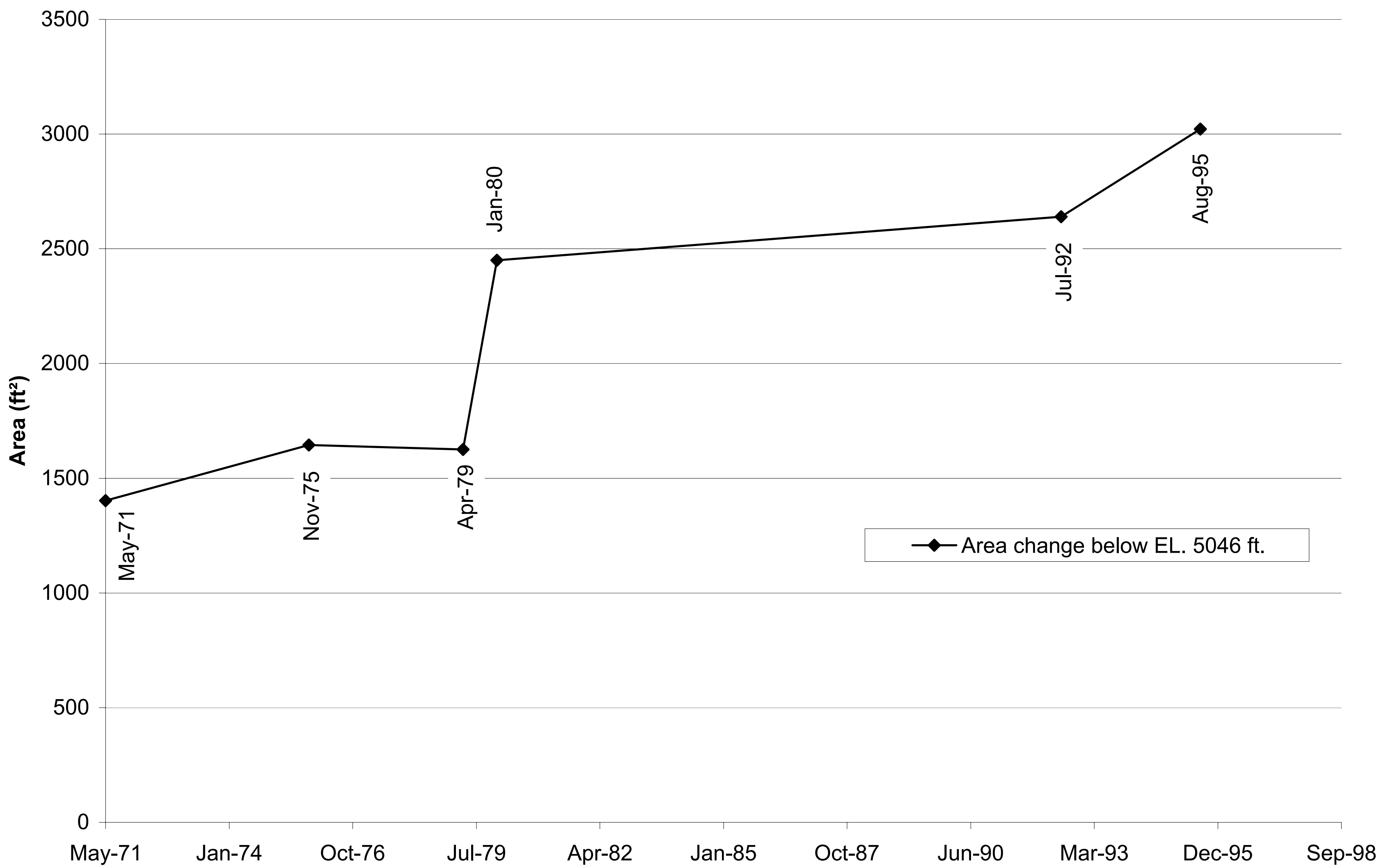

Fig. E-57. Change in cross section area with time at cross section CO-30.