THESIS

MORPHOLOGY OF THE MIDDLE RIO GRANDE
FROM BERNALILLO BRIDGE TO THE SAN ACACIA DIVERSION DAM,
NEW MEXICO

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY **TRAVIS R. BAUER** ENTITLED **MORPHOLOGY OF THE MIDDLE RIO GRANDE FROM BERNALILLO BRIDGE TO THE SAN ACACIA DIVERSION DAM, NEW MEXICO** BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate work

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Advisor ______________________________

Department head ______________________________

ABSTRACT

MORPHOLOGY OF THE MIDDLE RIO GRANDE FROM BERNALILLO BRIDGE TO THE SAN ACACIA DIVERSION DAM, NEW MEXICO

The Middle Rio Grande in New Mexico is a dynamic river that is continually changing. Collection of discharge measurements began as early as 1895 and cross section surveys began in 1918. With the construction of Cochiti Dam in 1973 data collection increased along the middle Rio Grande. Beginning in 1970 the Cochiti Range lines were added to study the effects of Cochiti Dam.

A database has been created with hydrologic, hydraulic, and sediment data collected from several state and federal agencies. Data from the 88-mile reach between Bernalillo Bridge and the San Acacia diversion dam were collected and organized into a database. Data were grouped by cross section, discharge, reports, and sediment. The data were analyzed quantitatively by comparing cross section plots, longitudinal profile, bed material, bankline position, cross section area, and changes in mean bed and thalweg elevation.

The Rio Grande is a low sinuosity sandbed river that is partly controlled by tributaries

such as the Rio Salado and Arroyo Rosa de Castillo. Abandoned channels are apparent in aerial photos indicating lateral migration of the Rio Grande at the mouths of these tributaries. Average bed material size in the first 5 miles below the Bernalillo Bridge between 1971 and 1992 had increased from fine sand to fine gravel. Beyond the first 5 miles of the reach, the average bed material size has increased from fine sand to medium sand but size decreases with distance downstream. The channel of the Rio Grande has degraded in the first 5 miles of the study reach as mean bed elevations have decreased by more than 3 feet since 1962. Minimal changes in mean bed elevation have occurred below the first 5 miles except at the mouth of the Rio Puerco where degradation of over 4.5 feet between 1962 and 1992 was experienced.

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CHAPTER I

INTRODUCTION

The Middle Rio Grande in New Mexico comprises a section of river that lies between Bandelier National Monument and the upper end of Elephant Butte Reservoir. The Middle Rio Grande and its seven major tributaries—Santa Fe River, Galisteo Creek, Jemez River, Las Heurtas Creek, Rio Puerco, Rio San Jose, Rio Salado—play a key role in the existence of life in the Middle Rio Grande Valley (Scurlock, 1998). It supplies water for agriculture and provides habitat for many aquatic and terrestrial species.

The Middle Rio Grande is a dynamic system that has been changing for thousands of years. One of the reasons for this is the Rio Grande rift. The Rio Grande rift is a feature that separates the Great Plains from the Colorado Plateau. The rift is characterized by high extension, high heat flow, high seismicity, and recent volcanism (Lagasse, 1980). The rift is filled with thousands of feet of sediment in which the Middle Rio Grande has made its course.

The large proportion of sand and fine sediment in the Middle Rio Grande Valley presents a complex situation. The Middle Rio Grande has historically been known as wide, shallow, braided river that periodically shifts course. The Rio Grande has long been an aggrading river, but the influence of humans accelerated the process in the late nineteenth century. Poor land use practices exposed the easily erodable soils and periods of intense rainfall transported these soils into the rivers (Scurlock, 1998). This period of arroyo cutting corresponds to a period of accelerated aggradation on the Rio Grande. The aggradation was causing many problems in the regions irrigation canals but more importantly it was causing severe flooding. As the riverbed rose it could carry less water within the banks so during periods of high discharge much of the water spilled over the banks damaging structures and property.

To reverse the aggradation and alleviate flooding in the area the Middle Rio Grande Conservancy District was formed in 1925. Their plan called for the construction and operation of El Vado Dam and storage reservoir on the Rio Chama, four diversion dams on the Rio Grande, two canal headings and miles of drainage canal, levees along the Rio Grande, and main irrigation canals (Lagasse, 1980).

Despite the efforts of the Middle Rio Grande Conservancy District many problems still existed. The riverbed was still aggrading which was raising the surrounding water table and causing continued flooding. By 1960 the riverbed was 6 to 8 feet above the flood plain near Albuquerque (Lagasse, 1980). In 1948 The Army Corps of Engineers and the Bureau of Reclamation called for a new plan to end the problems. The Army Corps of Engineers would be responsible for constructing the Jemez Canyon Dam in 1953, Abiquiu Dam and Reservoir in 1963 on the Rio Chama, Galisteo Dam in 1970 and

Cochiti Dam and Reservoir in 1973. These dams would operate in conjunction to detain sediment and reduce flood peaks entering the Middle Rio Grande Valley. The Bureau of Reclamation and the Corps were responsible for channel rectification measures such as rehabilitation of the irrigation system put into service by the Middle Rio Grande Conservancy District, improvements to the existing levees, and stabilizing the channel within the levees (Lagasse, 1980).

Cochiti Dam began to impound water in November 1973. The dam and reservoir were intended to control floodwaters and sediment entering the upper Middle Rio Grande as well as induce degradation below the dam. Degradation immediately below the dam was clearly visible within the first two years of operation. Following high flows in 1979 and the establishment of a permanent pool at the Jemez Canyon Dam degradation continued from Cochiti Dam to the Isleta diversion dam (Lagasse, 1980).

The initial studies on the Middle Rio Grande below Cochiti Dam were concentrated on the upper reach. In 1980, Lagasse summarized the current state of the river between Cochiti Dam and the Isleta diversion dam. This study indicated that since construction of Cochiti Dam in 1973 the riverbed as far downstream as the Isleta diversion dam had degraded.

In 1998, Leon conducted a comprehensive analysis of the first 28.5 miles below Cochiti Dam. The study reach spanned from Cochiti Dam to the New Mexico Highway 44

Bridge near Bernalillo. The study concluded that there is a general trend for degradation in the reach similar to the results of Lagasse.

Little is known about the effects of Cochiti Dam on the Middle Rio Grande below the New Mexico Highway 44 Bridge. The Middle Rio Grande has between the Bernalillo Bridge and the Isleta diversion dam was included in the 1980 study by Lagasse and the Middle Rio Grande between the Isleta diversion dam and the San Acacia diversion dam has yet to be studied.

The objectives of this thesis are:

1) Develop a database of historic hydrologic, hydraulic, and sediment records from various state and federal agencies and to transfer the relevant data into a consistent electronic format that will facilitate the analysis and management of the data.
2) Document changes in cross section geometry, thalweg profile, mean bed profile, planform, and bed material of the Middle Rio Grande between New Mexico Highway 44 bridge near Bernalillo to the San Acacia diversion dam.

The database used in the analysis contains hydraulic, hydrologic, and sediment records. The hydraulic information consists of cross section surveys conducted at 32 stations along the reach. Some cross section surveys also collected bed material samples and recorded the water surface elevation. The hydrologic portion of the database contains the discharge records taken by the U.S. Geological Survey at stations located on the Rio

Grande between Bernalillo and the San Acacia diversion dam as well as stations located near the confluence of the Rio Puerco and Rio Salado with the Rio Grande. The Sediment data included in the database consists of bed material, suspended sediment, and sediment discharge. Bed material data is collected primarily during cross section surveys while suspended sediment and sediment discharge record are collected primarily from the U.S. Geological Survey gaging stations.

The section of river used in the analysis begins at the New Mexico Highway 44 Bridge in Bernalillo, New Mexico and ends approximately 87.6 river miles downstream at the San Acacia diversion dam. In order to facilitate the analysis, the reach will be broken into three sub-reaches.

A quantitative approach is used for the following:

- Changes in bankline position, thalweg position, mean bed elevation, and cross sectional area were determined from cross section plots.
- Plots of thalweg and mean bed profiles for different years show the general trend of riverbed elevation.
- Reaches of aggradation and degradation were located and the total aggradation or degradation was estimated by comparing changes at a cross section over time.
- Plots of median bed material size for different years show how the bed material has changed over time.

This thesis is developed in five chapters. Chapter I begins with the introduction. A literature review that presents some history of the Middle Rio Grande and some studies regarding fluvial geomorphology, sediment transport, and channel degradation is presented in Chapter II. Chapter III contains a description of the database. This chapter is broken into three sections. The first section explains the data that has been compiled including the sources, formats, and dates. The second section of Chapter III explains the organization of the database. The third section of Chapter III explains the data that is specifically used in the quantitative analysis and the methodology for conducting the analysis. Chapter IV consists of the quantitative analysis of the morphological changes on the Middle Rio Grande. The analysis is based on data from the database described in Chapter III. The final chapter, Chapter V, includes the summary and conclusions. The final section of this thesis contains appendices, which consists of summary tables, cross section plots, thalweg elevation plots and mean bed elevation plots.

CHAPTER II

LITERATURE REVIEW

2.1 The Middle Rio Grande

The Rio Grande begins in the mountains of southern Colorado, flows south through central New Mexico, and heads southeast where it forms the border between Texas and Mexico until it reaches the Gulf of Mexico (Leon, 1998). The Middle Rio Grande Valley extends from Cochiti Dam to the headwaters of Elephant Butte Reservoir near San Marcial, New Mexico (Crawford et al. 1993). The reach of the Middle Rio Grande considered in this study begins approximately 28.5 miles downstream from Cochiti Dam and extends 88 miles to the San Acacia diversion dam. Figure 2.1 shows the location of the study reach.

The Middle Rio Grande Valley is lies in the Rio Grande Rift Zone and consists of three interconnected basins. The three basins, Santo Doming, Albuquerque, and Belen, provide a broad interconnected valley that is filled with fluvial sediments up to depths of 6000 m in certain locations (Graf, 1994). Short canyons at San Felipe, Isleta, and San Acacia separate the basins (Lagasse, 1980).

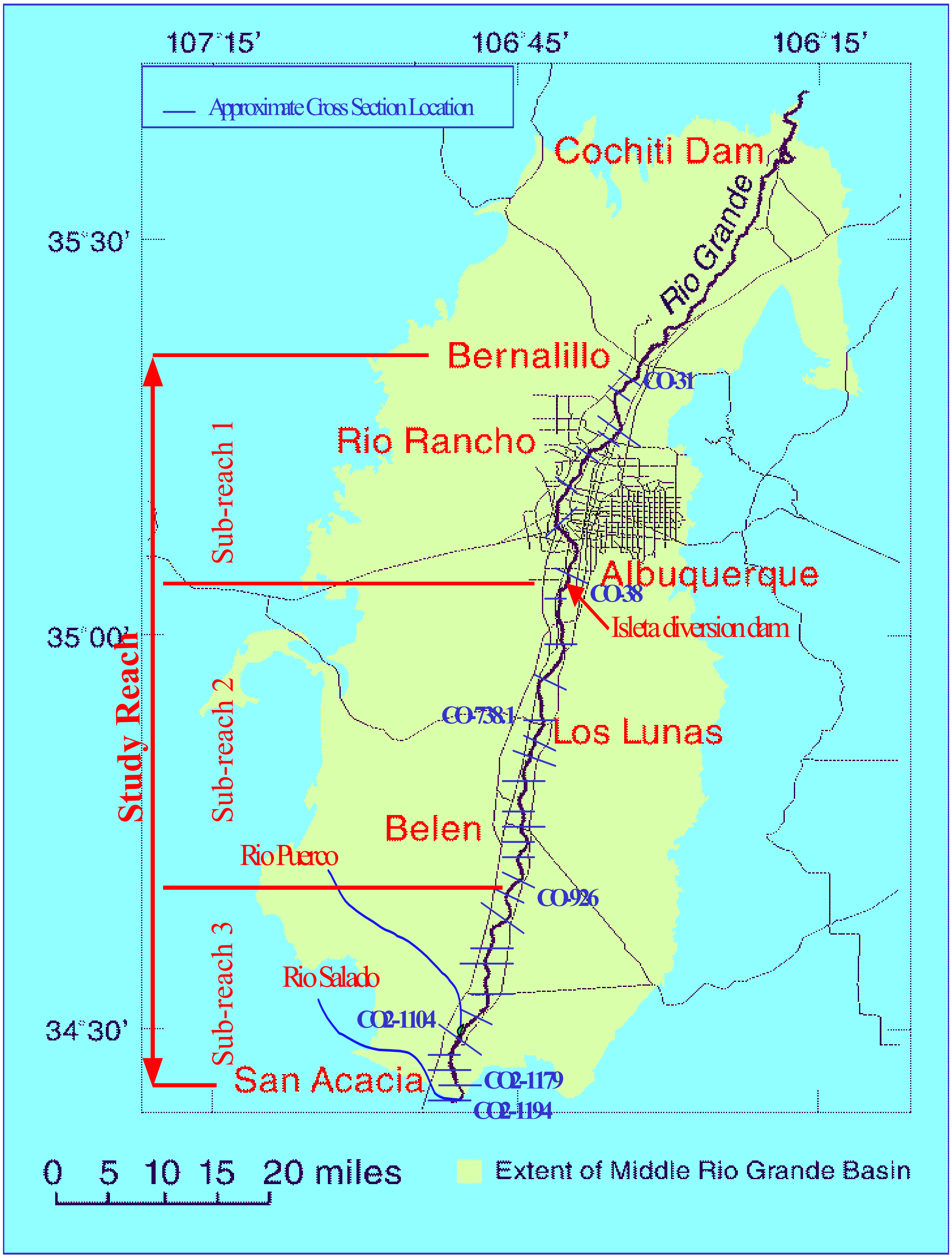

Figure 2.1. Location of the study reach.

When combined, the Albuquerque and Belen basins are roughly 85 miles long and 25 to 30 miles wide. The river valley flowing through these basins ranges from 1 to 6 miles wide and is contained within mesas that rapidly rise 300 to 500 feet above the valley floor. The abrupt rise of the mesas gives way to a more gentle slope as the land gently rises to the foot of nearby mountain ranges (Lagasse, 1980).

The study reach is largely devoid of tributaries. There are many small arroyos that enter the river along its course but only two main tributaries enter the 83-mile study reach. The Rio Puerco and Rio Salado join the Rio Grande near the end of the study reach just above the San Acacia constriction (Lagasse, 1980). Both rivers enter the Rio Grande from the west and drain many square miles of Colorado Plateau terrain. The terrain consists primarily of easily erodible sandstones and shales which leads to the high sediment loads that the rivers carry. The Rio Puerco is major sediment contributor to the Rio Grande. It typically delivers over twice the amount of sediment the Rio Grande carries past Albuquerque. Measurements of suspended sediment on the Rio Puerco are frequently in the range of 400,000 ppm during floods (Graf, 1994).

2.2 Historical Background

The Middle Rio Grande Valley has been inhabited for thousands of years. The earliest inhabitants of the valley were nomadic hunters that arrived 11,000 to 15,000 years ago. Eventually the dependence on hunting and gathering gave way with the advent of agriculture. The prehistoric farmers in the Middle Rio Grande Valley were known as the Anasazi and were later renamed Pueblo Indians by the Spanish explorers (Crawford et al. 1993). When the Spanish explorer, Coronado, first reached the valley in 1540 he estimated that 25,000 acres were being farmed by the Pueblo Indians (Burkholder, 1929). The villages of Pueblo Indians generally date back to the early to mid 1300's (Scurlock, 1998).

Settlement of the Middle Rio Grande Valley came in the late 1500's and the Spanish settlers found the Pueblo Indians living on elevated portions of the floodplain or on the valley edges to avoid flood waters. The lands adjacent to the river were farmed using small irrigation ditches or overflow waters from the river. Use of the Middle Rio Grande and its tributaries rose sharply in 1846 with the arrival of the first Anglo-Americans (Scurlock, 1998). Shortly after the arrival of the Anglo-Americans the amount of land under irrigation peaked. By 1880, there was 125,000 acres under cultivation (Burkholder, 1928). During this same period the livestock industry was also expanding as figures indicate that there were well over six million head of sheep and cattle in the area (Scurlock, 1998).

The extensive grazing, increased withdraw of water, and periods of intense rainfall are all credited with contributing to the arroyo cutting that began in the southwestern United States in the late 1800's (Lagasse, 1980). Many of the tributaries began to incise and widen as sediment load and discharge increased from the intense periods of rainfall. While the tributaries were delivering more sediment to the main stem of the Middle Rio

Grande the Rio Grande had less water because of irrigation diversions. With less water, the Middle Rio Grande was unable to transport the extra sediment being delivered. In response to the deficit in sediment transport capacity the Middle Rio Grande began to aggrade.

Aggradation of the Middle Rio Grande ultimately led to a decrease in the amount of irrigated land in the valley (Graf, 1994). Incising tributaries, such as the Rio Puerco, and a rising riverbed on the Middle Rio Grande made it more difficult to fill irrigation canals. In many cases the land adjacent to the Middle Rio Grande had a shallow water table as the result of unlined irrigation ditches and seepage from the aggrading Rio Grande (Scurlock, 1998).

By 1925 the Middle Rio Grande Valley had seen a reduction from 125,000 acres of irrigated land in 1880 to just 40,000 acres of irrigated land. This dramatic and visible decline in agriculture in the Middle Rio Grande Valley prompted Congress to authorize the Rio Grande Reclamation Project in 1905 (Leon, 1998). This project was responsible for the construction of Elephant Butte Dam, which was completed and began operation in 1915 (Lagasse, 1980). This project guarantees the delivery of water to Mexico and the irrigation of 155,000 acres of land in New Mexico and Texas (Burkholder, 1928). The Rio Grande Project also included the construction of water diversion and delivery facilities for irrigation in the Middle Rio Grande Valley (Lagasse, 1980).

In 1925 the Middle Rio Grande Conservancy District was formed. This agency was formed by the State of New Mexico and was responsible for establishing useful diversions, drain fields, and dealing with existing problems in the valley. By 1935 the district had constructed El Vado Dam on the Rio Chama, as well as diversion dams at Cochiti, Angostura, Isleta, and San Acacia. The district has also completed more than 180 miles of riverside drains and 160 miles of interior drains that irrigated approximately 128,000 acres. As part of the drain project, linear piles of spoils were placed between the riverside drains and the river. These piles followed the existing river planform and eventually became levees that were used for flood control (Graf, 1994). The system of levees the Conservancy District employed consisted of a floodway that averaged 1,500 feet wide between 8 foot levees (Lagasse, 1980). The levees were built to withstand a design discharge of 40,000 cubic feet per second and the levees near the city of Albuquerque were raised to pass a design flow of 75,000 cubic feet per second (Woodson and Martin, 1963).

High flows in 1941 and 1942 with discharges over 21,000 cubic feet per second persisted for several months at a time. These high flows caused severe damage in the valley. As much as 50,000 acres (Scurlock, 1998) were inundated as the levees were breached in 27 different locations (Graf, 1994). After these devastating floods the Bureau of Reclamation and the Army Corps of Engineers devised the Rio Grande Comprehensive Plan (Lagasse, 1980). The Comprehensive Plan called for the construction of a system of reservoirs on the Rio Grande and its tributaries, as well as the rehabilitation of the floodway constructed by the Conservancy District. The Army Corps of Engineers would construct the reservoir system and the Army Corps of Engineers as well as the Bureau of Reclamation (Woodson and Martin, 1963) would conduct the floodway rectification.

The initial plan, which was approved in 1948, called for the construction of two reservoirs, Abiquiu and Jemez. A later study in 1958 concluded that two additional dam should be built. The additional dams were placed on the Rio Galisteo and on the main stem of the Rio Grande near Cochiti Pueblo at the head of the Middle Rio Grande Valley (Woodson and Martin, 1963).

Beginning in the 1950 the Bureau of Reclamation began an intensive data collection program in order to properly implement channel rectification measures. The goal of the program was to determine the design width for the rectified channel. The process of finding the design width included detailed studies of sediment transport and the relationship between hydraulic properties and sediment transport. The study also focused on finding the rates and volumes of aggradation and or degradation within the river and floodplain (Pemberton, 1964).

In order to determine the volume of aggradation or degradation in the river and floodplain, the Bureau of Reclamation and Army Corps of Engineers compared cross section surveys between 1936 and 1953. The Soil Conservation Service of the U.S.

Department of Agriculture first surveyed the cross sections in 1936, which were spaced 2 miles apart. Subsequent surveys in conducted in 1940, 1941, 1942, 1944, 1952, and 1953 (Woodson and Martin, 1963).

The study period begins immediately after the work of the Conservancy District and includes the high flow years of 1941 and 1942. When the study was conducted the river was still responding the work done by the Conservancy District. It is also likely that the response of the river to the 1942 flood would not have occurred if it had followed a period of low flow (Woodson and Martin, 1963).

The results of the study indicated that the Middle Rio Grande was aggrading at a rates as high as two feet every 50 years near Albuquerque and as high as 16 feet in 50 years near San Marcial. By 1960, the riverbed was 6 to 8 feet above the floodplain near Albuquerque (Lagasse, 1980).

The Army Corps of Engineers completed the Jemez Canyon Dam in 1953, Abiquiu Dam on the Rio Chama in 1963, Galisteo Dam in 1970 and Cochiti Dam in 1973. Cochiti Dam was intended for flood control and sediment detention. By creating a permanent pool of 50,000 acre-feet behind the dam almost all sediment entering Cochiti Reservoir is trapped. The sediment detention was intended to prevent further aggradation below Cochiti Dam and the clear-water discharges induced degradation below the dam (Lagasse, 1980).

The channel rectification plan had several stages. First of all, the levees had to be protected to prevent future flood damage. Second, the channel area was to be reduced. A reduction in channel area would reduce water losses and improve sediment and hydraulic transport capacity. Channel rectification was carried out from Cochiti Dam to just above the Rio Puerco and the design capacity was reduced to 20,000 cubic feet per second except in Albuquerque where the design capacity was reduced to 42,000 cubic feet per second. The width of the river was reduced from roughly 800 feet to 550 feet by placing lines of jetties. Some jetties were projected out from the levees into the flow while others were placed parallel to the levees (Leon, 1998).

Permeable jetties, such as the ones used on the Rio Grande, are appropriate for rivers that have high suspended sediment loads and are subject to scour during high flows. The jetties narrow the river and protect banks by slowing velocities and inducing sedimentation behind the jetties. Over time the amount of sediment can accumulate and be vegetated further protecting the new deposit as well as the levees. Kellner jack jetties were first successfully used in the Middle Rio Grande Valley in 1936 when the Santa Fe Railroad used them to protect railway embankments on the Rio Galisteo (Woodson and Martin, 1963). The installation of the Kellener jack jetties began in 1954 and continued intermittently until 1962 when a total of 115,000 units had been installed (Lagasse, 1980).

2.3 Climate of the Middle Rio Grande Valley

The middle Rio Grande Valley is characterized by light precipitation, a wide range of diurnal annual temperatures, abundant sunshine, low relative humidity, and high evaporation over water surfaces. The basins of the Middle Rio Grande Valley contain three distinct climatic subtypes. Lowland areas (below 5,000 feet) are classified as arid and range from Bernalillo to Elephant Butte Reservoir. Adjacent to the lowlands, the upland areas that lie to east, west, and north of Albuquerque are classified as semi-arid (below 9,000 feet). The mountainous areas (above 9,000 feet) are classified as sub-humid (Scurlock, 1998).

Precipitation generally decreases from north to south while temperature increases from north to south in the Middle Rio Grande Valley (Scurlock, 1998). Precipitation ranges from an annual minimum of 400 mm near Socorro, New Mexico to a maximum of over 2,000 mm in the San Juan Mountains in Southern Colorado. The maximum values of precipitation are unequally distributed in the mountainous areas in the watershed. The San Juan Mountains receive the most precipitation followed by the Sangre de Cristo Mountains, and the Jemez Mountains. Most of this precipitation comes in the form of snow. Snow pack depths up to 9 m have been reported in the San Juan Mountains (Graf, 1994).

The frequency and intensity of rainfall has varied over time in the Middle Rio Grande Valley. While there in no clear long-term trend in the precipitation data (Graf, 1994) it is clear that the valley is affected by the El Nino and La Nina weather patterns of the Pacific Ocean. Drought years associated with the La Nina pattern often occur in clusters, while the wet years associated with the El Nino pattern typically occur after an extended drought and generally last only one year (Scurlock, 1998).

The Middle Rio Grande Valley has a complex hydrologic system. Water flows through a system of basins where surface water and ground water interrelated (Lagasse, 1980). The valley also sees two distinct flows in the Middle Rio Grande. Spring and early summer flows are dominated by runoff from snowmelt. The hydrograph for these flows has a gradual rise that is maintained for a month or two. These flows generally have a moderate discharge with a high volume of runoff. The second type of flow seen in the Middle Rio Grande generally comes in the later summer months as the result of short but intense thunderstorms localized on one or more of the tributaries to the Middle Rio Grande. These flows have a short duration, and have a low runoff volume. A sharp peak that recedes quickly generally characterizes the hydrograph for these events (Lagasse, 1980).

Historical records of flows in the Middle Rio Grande date back to the early explores and settlers. These records consist mainly of personal accounts and give a visual description of events (Scurlock, 1998). While these descriptions may not be entirely accurate, they do provide an extended period of record. In contrast to the historical accounts in the Middle Rio Grande Valley, the longest running stream gage in the United States, Embudo gaging station, is located on the Rio Grande. This gage began operating in 1885 and provides valuable historic information (Graf, 1994).

The Middle Rio Grande Valley has experienced many severe floods. Historical records show repeated flooding and the relocation of communities after being destroyed by floods. In 1828 a large flood occurred and inundated the entire valley from Albuquerque to El Paso. Records left by a Catholic priest at Tome, New Mexico indicate the flood may have reached a discharge of 100,000 cfs (cubic feet per second). Floods of 1872 and 1884 were also estimated to crest at 100,000 cfs. The flood of flood of 1874 crested at about 40,000 cfs, the 1904 flood crested at 33,000 cfs, the 1912 flood crested at 29,000 cfs, the 1920 flood crested at 28,000 cfs, and the 1942 flood crested at 21,000 cfs. Each of these floods did significant damage and in many cases destroyed entire towns (Scurlock, 1998). Flows above 5,000 cubic feet per second are considered floods (Woodson, 1961).

Not all floods on the Middle Rio Grande have been natural. Between 1906 and 1926 some of the peaks on the Middle Rio Grande are associated with logging. Temporary dams on tributaries were used to catch spring runoff. When these dams would fill, timber cut throughout the year would be floated downstream to Cochiti Pueblo where they were caught in a tie boom stretched across the river. Poor land use practices such as extensive logging and overgrazing have also influenced water delivery to the Middle Rio Grande. They may have accelerated runoff by removing vegetation from hillslopes. High flows generated by logging and poor land use contributed to the maintenance of the Middle Rio Grande as a wide, shallow, braided river. After the hillslopes were revegetated, the erratic and unpredictable flows in tributaries to the Middle Rio Grande occurred less often (Graf, 1994).

2.4 Previous Studies on the Middle Rio Grande

The Middle Rio Grande has been the focus of many sediment transport and morphology studies. These studies provide useful information on the planform configuration, cross section geometry and bed material composition, but most of the studies focus on the section of river that lies between Cochiti Dam and Albuquerque.

In 1965 Nordin and Beverage provide an excellent pre-dam description. They described the river below the Cochiti diversion dam as being a wide, unconfined, braided channel with many coarse gravel and cobble islands. The bed of the river is mostly sand during low flows and sand and gravel during high flows. Below the confluence of the Jemez River the Middle Rio Grande is a sand bed river.

The assessment of the upper reaches of the Middle Rio Grande by Nordin and Beverage closely resembles that of Lane and Borland (1953). Lane and Borland concluded that the Middle Rio Grande was a wide, shallow river with many islands and a braided pattern. The river was relatively straight and did not have the bends and crossings that characterize other large alluvial rives.

Lane and Borland (1953) also concluded that the narrow sections in the river were scoured during high flows and the wide sections experience local aggradation during high flows. This was an important finding because most gaging stations were located in narrow sections along the river. During high flows the bed would be scoured at gaging stations which gave the appearance of bed degradation.

In sand bed channels much of the flow resistance comes from the bed configuration. Flow can be classified into upper and lower regime. During low flows the flow is in the lower regime as it flows over dunes. Dunes provide a high resistance to flow and are generally characterized by low sediment transport rates. High flows are classified into the upper regime and flow over a plane bed or anitdunes. The upper regime bed forms provide little flow resistance and are characterized by high sediment transport rates (Nordin and Beverage, 1965).

In a 1962 report, Woodson and Martin concluded that the system of reservoirs (Abiquiu, Jemez, Galisteo, and Cochiti) would reduce the sediment inflow into Bernalillo by roughly 75 percent after 20 years. They also concluded that the current trend of aggradation would be reversed. The degradation would begin at Cochiti Dam and progress as far downstream as the Rio Puerco. The degradation would, however, be limited by the formation of an armor layer and was expected to be no more than 3 feet from Bernalillo to Albuquerque.

A similar study by the Bureau of Reclamation also concluded that the trend of aggradation in the Bernalillo to Albuquerque reach would be reversed in the 1960's and net degradation was expected by 1965. The study also estimated that there would be more than a foot of net degradation by 1985 (Schembera, 1962).

After Cochiti Dam was closed in November 1973, observers noted that within the first two months after closure the first 3 miles below channel were now devoid of substrate smaller than 1 mm. Gravel bars that had not been apparent before closure were now showing up as far downstream as Albuquerque (Dewey et al. 1979).

In a 1980 report, Lagasse reported that from just below Galisteo Creek to cross section CO-37 (nine miles above the Isleta diversion dam) there had been a lowering of the bed through degradation between 1971 and 1979. Lagasse also observed aggradation at cross section 38, which is just upstream from the Isleta diversion dam and the lower end of the study reach. The aggradation is a strong indication that the high sediment loads being carried from upstream degradation could not be carried any farther. This is in part due to reduced gradients downstream from this point, diversion of water from the main channel for irrigation, and the base level control of the Isleta diversion dam.

Leon conducted additional analysis of the upper reach in 1998. The reach used in her analysis extended from Cochiti Dam to Bernalillo Bridge. The results of this study confirm the findings of Lagasse. Leon found a general trend of degradation in the reach with maximum degradation occurring in the lower part of the reach. Some cross sections experienced lowering of the thalweg elevation by as much as 8 feet between 1971 and 1995.

The study reach also experienced a significant coarsening of the bed. Bed material surveys taken in the early 1970's indicated that the median bed material size for much of the reach was 1mm or less. By 1995 the median bed material for most of the reach had increased to over 10 mm. The coarsening reported by Dewey in 1979 had significantly increased and had progressed over 28 miles below Cochiti Dam.

In 1994 Graf conducted a study on the transport of plutonium in the Rio Grande. Part of this study focused on planform changes on the Rio Grande based on analysis of aerial photos. Prior to 1940 the channel was wide and shallow with a braided pattern. As the Comprehensive Plan began to be implemented the amount of water delivered to the channel became progressively smaller as flood peaks were detained in upstream reservoirs. The decreased flows in the Middle Rio Grande eventually led to the development of a single thread channel, a larger floodplain, and the abandonment of many minor sub-channels. The change from a braided pattern to that of a single channel is often associated with the closure of dams but it can also be affected by regional hydroclimatic influences, because the Rio Grande above Cochiti Dam has also shrunk. Instability of the Middle Rio Grande also increased, as the river became narrower. The river began to laterally migrate within unconfined reaches and between 1940-1980, some sections of river changed horizontal position by as much as 1 kilometer. These changes typically occur when the channel becomes filled with sediment and the river breaks out and forms a new channel (Graf, 1994).

Other studies have indicated that the sediment and flood control structures in the upper Middle Rio Grande accelerated the reversal of channel aggradation between Cochiti and Albuquerque. The lowering of the riverbed led to a more incised and sinuous single-channel river. This pattern becomes less pronounced with downstream distance from Cochiti and Jemez Canyon Dams (Crawford et al. 1993).

The reduction in peak flows has helped establish a single channel in the Middle Rio Grande Valley, but it has also complicated the hydraulics where tributaries join the main stem. Unregulated tributaries often carry more sediment than the Middle Rio Grande can transport (Crawford et al. 1993). The inability to transport the sediment results in the formation of local base levels that change the slope of the river and often affect river planform and cross section geometry (Lagasse, 1980). Lagasse (1980) also notes that an arroyo contributing sediment from a drainage area of 60 square miles or more will likely exercise some control over main stem channel characteristics.

The Rio Puerco is a 170-mile-long tributary that drains an area of 6,220 square miles and enters the Middle Rio Grande approximately 10-miles upstream from the San Acacia diversion dam (Scurlock, 1993). Historically, the Rio Puerco has not been as stable as the Rio Grande. In the last 3,000 years the valley floor of the Rio Puerco has aggraded and at least three major channels have been cut and filled in that time. The current period of entrenchment began in the 1760's and has resulted in fluctuating sediment levels entering the Rio Grande (Crawford et al. 1993).

The Rio Puerco contributes more than twice the amount of suspended sediment as the Rio Grande carries past Albuquerque. It is estimated that half of the suspended sediment carried by the Rio Puerco and Rio Salado remain in near-channel deposits upstream from the San Marcial gaging station. It is also estimated that the bedload of the Rio Puerco is close to 71 percent of the total load, two thirds of which remain in near-channel deposits above the San Marcial gaging station. Estimates of annual bedload transport for the Rio Puerco are close to 2 million Mg per year (Graf, 1994).

CHAPTER III

DATABASE

There is a large amount of data available for the Middle Rio Grande and the river reach between Bernalillo and San Acacia. The data set includes: cross section surveys for several different range lines, flow discharge records, suspended sediment records, bed material records, and aerial photos. A computer database was created in order to manage the data more efficiently. This chapter describes the compiled data and introduces all the summary tables in appendices A to C (Section 3.1). The development of the database is detailed in Section 3.2. Section 3.3 discusses the use of data to analyze changes in morphology between Bernalillo and San Acacia as well as the methodology utilized in developing the different plots and charts included in this chapter and Appendices D and E.

3.1 Database Compilation

A. Cross Section Data

A total of 16 cross section range line sets have been established 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), Santa Ana Range Lines (TA lines), Bernalillo Island Range Lines (BI lines), Calabacillas Range Lines (CA lines), Albuquerque Range Lines (A lines), Casa Colorada Range lines (CC lines), Abeytas Heading Range Lines (AH lines), Bernardo Jack Site Range Lines (BJ lines), San Acacia Range Lines (SA lines), and Socorro Range Lines (SO lines).

Of the 16 sets of range lines in the Middle Rio Grande, 7 are located in the study reach. Cochiti Range Lines, Agg/Deg Lines, and SCS Lines are distributed between the Bernalillo Bridge and the San Acacia diversion dam. The remaining 4 sets of range lines are localized in shorter reaches requiring special attention within the study reach. Table A-1 in Appendix A contains the relative location of each of the range lines within the 88-mile reach considered in this work.

a.1. Soil Conservation Service Range Lines

The Soil Conservation Service first established the SCS lines in the fall of 1936. They were originally spaced approximately 3 to 4 miles apart. Additional surveys were conducted in 1937, 1939, 1940, and following the flood of 1941. In 1944 the Army Corps of Engineers resurveyed the SCS lines and added new lines so the spacing was reduced to approximately 1-mile. A limited number of cross sections were resurveyed in 1947 and between 1952 and 1954 the entire set of range lines were resurveyed (Pemberton, 1964).

The SCS lines are numbered according to railroad mileage. The cross sections range from 860 in the northern area to 1006 at the southern end (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. The first ground survey of the SCS lines occurred in 1936 but earlier plots taken from 1918 United States Reclamation Service topographic maps are also available in hardcopy form. Table A-2 in Appendix A, lists the SCS range lines compiled for this work.

a.2. Aggradation / Degradation Lines

The Agg/Deg lines were first established in 1962 and were surveyed photogrametrically. The cross sections were spaced 500 feet apart and were numbered from 1 near Cochiti Pueblo to 1,962 near Elephant Butte Reservoir (Memorandum from Head, Sedimentation Section of the USBR to Chief, Hydrology Branch of the USBR dated January 21, 1966. Denver, Colorado).

The Agg/Deg lines within the study reach begin at cross section 314 just below the Bernalillo Bridge and continue downstream to cross section 1206 at the San Acacia diversion dam. Agg/Deg surveys from 1962 1972, and 1992 were obtained in electronic format from the U.S. Bureau of Reclamation, Denver Office. The 1962 and 1972 surveys do not provide true bed elevations, but they do provide an estimate for an average bed. The 1992 survey does not give any indication of the riverbed and stops at the water surface. The water surface is indicated by blank spaces left after x and y coordinates.

a.3. Cochiti Range Lines

These range lines were first established by the USGS in 1970. The location of the Cochiti Range lines was selected based on the "Summary Report, Rio Grande, Aggradation or Degradation, 1932-1962, Middle Rio Grande Project", prepared by the U.S. Bureau of Reclamation, U.S. Army Corps of Engineering, and U.S. Soil Conservation Service (Dewey et. al. 1979). Between Cochiti Dam and the San Acacia diversion dam there are 61 cross sections spaced approximately 1 mile apart in the upper reach and spaced more randomly in the lower reach. These cross sections are identified by the letters CO and span from number 2 just below Cochiti Dam and number 1194 just above the San Acacia diversion dam. The study reach for this work begins at cross section CO-31 and ends at cross section CO2-1194. Cross sections are numbered sequentially from CO-2 to CO-38, which is just above the Isleta diversion dam. Below the Isleta diversion dam the cross section numbers correspond to the Agg/Deg range line numbering. Cross sections CO-31 to CO-38 were part of the original 37 cross sections established in 1970. The 12 cross sections from CO-668 to CO-926 were added in 1982, while the remaining 12 cross sections (CO2-945 to CO2-1194) were added in 1992 and are preceded by CO2 instead of CO.

The available data for the CO lines between Bernalillo Bridge and the San Acacia diversion dam is listed in Table A-3 in Appendix A. Survey dates begin in 1970 and extend through 1998. From 1970 to 1986 the data were collected by the USGS. From 1992 to 1998 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. The Cochiti Range Line files were obtained in electronic format from the U.S Bureau of Reclamation, Albuquerque Office. Leon summarized the availability of cross section data between Cochiti Dam and Bernalillo Bridge in 1998.

a.4. Calabacillas Range Lines

These are 13 cross sections that are located between cross sections CO-34 and CO-35 and begin just upstream from the Alameda Boulevard Bridge. They are identified by the letters CA and are numbered from 1 to 13 in the downstream direction. The cross sections were surveyed yearly by FLO Engineering for the U.S. Bureau of Reclamation from 1988 to 1996. Table A-4 in Appendix A lists the available data, which was obtained in electronic format from the U.S Bureau of Reclamation, Albuquerque Office.

a.5. Albuquerque Range Lines

The Albuquerque Range Lines are a set of 9 cross sections located between cross section CO-36 and CO-37. They begin approximately 2 miles upstream from the Rio Bravo Bridge and end immediately upstream from the bridge. They are identified by the letter A and are numbered from 1 to 9 in the downstream direction. These data were collected by FLO Engineering for the U.S. Bureau of Reclamation in 1987 and from

1990 to 1998. Table A-5 in Appendix A lists the available data, which was obtained in electronic format from the U.S Bureau of Reclamation, Albuquerque Office.

a.6. Casa Colorada Range Lines

This set of range lines consists of 10 cross sections located between cross section CO-926 and CO2-945. The cross sections are identified by the letters CC and are numbered from 924 to 945 in the downstream direction. The cross section are placed approximately 1,000 feet apart are named according to the Agg/Deg lines. The cross sections were surveyed yearly by FLO Engineering for the U.S. Bureau of Reclamation from 1990 to 1996. Table A-6 in Appendix A lists the available data, which was obtained in electronic format from the U.S Bureau of Reclamation, Albuquerque Office.

a.7. Abeytas Heading Range Lines

These are a set of 7 cross section located between cross sections CO2-1006 and CO2-1026. These cross sections are identified by the letters AH and are numbered from 1 to 7 in the downstream direction. This set of lines is located in a wide section of river that widens just before entering a contraction and a bend. The cross sections were surveyed by FLO Engineering for the U.S. Bureau of Reclamation in 1989, 1990, 1993, 1994, and 1996. Table A-7 in Appendix A lists the available data, which was obtained in electronic format from the U.S Bureau of Reclamation, Albuquerque Office.

B. Sediment Data

Bed material and suspended sediment data were collected at some cross sections as well as certain USGS gaging stations.

b.1. Bed material data

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

Data for the following range line sets are available:

Cochiti Range Lines

From cross sections CO-31 to CO-38 the bed material data consists of 12 years of particle size distributions taken from 1970 to 1998. From 1970 to 1982 the U.S Bureau of Reclamation collected the data and from 1992 to 1998 FLO Engineering collected the data for 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 by Leon in 1998. Leon also retrieved other data from 1970 to 1982 in 1998 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".

The data in 1992, 1995, and 1998 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, August and July 1995, and August and September 1998 report. Table B-1 in Appendix B summarizes the available data for the 32 cross sections between Bernalillo Bridge and the San Acacia diversion dam. Bed material data for cross sections between Cochiti Dan and Bernalillo Bridge were summarized by Leon in 1998.

Calabacillas Range Lines

Bed material particle size distributions are available for the CA-Lines for 1988 to 1989 and from 1991 to 1996. 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-2 in Appendix B lists the survey dates and the corresponding cross sections surveyed.

Albuquerque Range Lines

Bed material particle size distributions are available for the A-Lines for 1987, 1991 to 1994, 1996, and 1998. 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 dates that each cross section was surveyed.

Casa Colorada Range Lines

Bed material particle size distributions are available for the CC-Lines from 1990 to 1996. 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-4 in Appendix B contains all the dates that each cross section was surveyed.

Abeytas Heading Range Lines

Bed material particle size distributions are available for the AH-Lines for 1994 and 1996. 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-5 in Appendix B contains all the dates that each cross section was surveyed.

The FLO Engineering data include particle size distributions at several sites at each cross section surveyed. After 1989 the files include particle size distributions as well as the d84, d50, and d35 for each sample.

USGS Gaging Stations

Bed material records were collected at the following USGS gaging stations: Rio Grande at Albuquerque (08-3300-00), Rio Grande Floodway near Bernardo (08-3320-10), Rio Puerco near Bernardo (08-3530-00), and Rio Grande Floodway at San Acacia (08-3549-00). The records begin in the late 1960's and extend through 1996 providing more than 26 years of data and several samples were often taken each year. These data were collected by the U.S. Geological Survey Water Resources Divisions and were retrieved in electronic format from the Environmental Protection Agency (EPA) Storet Database. Table B-6 in Appendix B contains the period of record for each sample.

b.2. Suspended Sediment Data

The suspended sediment data consists of suspended sediment concentration, discharge, and particle size distribution. The information was originally collected at the following USGS gating stations: Rio Grande at Albuquerque (08-3300-00), Rio Grande Conveyance Channel near Bernardo (08-3319-90), Rio Grande near Bernardo (08-3320-00), Rio Grande Floodway near Bernardo (08-3320-10), Rio Puerco near Bernardo (08-3530-00), Rio Grande at San Acacia (08-3544-00), Rio Grande Conveyance Channel at San Acacia (08-3548-00), and Rio Grande Floodway at San Acacia (08-3549-00).

The suspended sediment concentration data are in mg/l (milligrams per liter) and the suspended 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 1997 available at Colorado State University Library. Table B-7 in Appendix B contains the period of record for each gage that suspended sediment data were collected.

Suspended sediment particle size distributions are available from the late 1960's through 1996 at USGS gaging stations as well as several range line surveys. The particle sizes range from 2.0 mm (very coarse sand) to 0.002 mm (coarse clay). The surveyed dates at each gaging station and cross section are available in Table B-8 in Appendix B.

C. Flow Discharge Data

Daily mean flow discharge values expressed in cubic feet per second (cfs) were collected at the following USGS gaging stations: Rio Grande at Albuquerque (08-3300-

00), Rio Grande near Belen (08-3315-00), Rio Grande Conveyance Channel near Bernardo (08-3319-90), Rio Grande near Bernardo (08-3320-01), Rio Grande Floodway near Bernardo (08-3320-10), Rio Grande at Isleta (08-3310-00), Rio Puerco near Bernardo (08-3530-00), Rio Salado near San Acacia (08-3315-00), Rio Grande at San Acacia (08-3544-00), Rio Grande Conveyance Channel at San Acacia (08-3548-00), and Rio Grande Floodway at San Acacia (08-3549-00), Rio Grande at San Acacia (08-3550-00), Rio Grande at San Acacia (08-3550-01).

These data were retrieved from the USGS Web Page, CD-Rom EarthInfo Inc, USGS Daily Values, West 1 1997 available at Colorado State University Library. Table B-9 in Appendix B lists the period of record for each gaging station.

Instantaneous discharge measurements are also available from the EPA Storet Database and several range line surveys. Instantaneous discharge measurements are available at the following gaging stations: Rio Grande at Albuquerque (08-3300-00), Rio Grande Floodway near Bernardo (08-3320-10), and Rio Grande Floodway at San Acacia (08-3549-00). These measurements are available for the following range lines: Calabacillas Range Lines (CA), Albuquerque Range Lines (A), and Casa Colorada Range Lines (CC). Tables B-10 and B-11 in Appendix B list the dates on which this data were collected.

D. Aerial Photos and Planform Plots

Blue line reproductions of aerial photographs of the entire study reach are available for 1992 and 1997. The Cochiti Range Lines, Agg/Deg Range Lines, Calabacillas Range Lines, Albuquerque Range Lines, Casa Colorada Range Lines, and Abeytas Heading Range Lines are indicated on these blue line reproductions. Table C-1 in Appendix C contains a list of all blue line reproductions together with the date and scale of photography.

Planform comparison plots between 1935 and 1989 are also available. The 1935 data and map was produced by the National Ecology Research Center Fish and Wildlife Services, U.S. Department of the Interior and the 1989 data and map was produced by the National Wetlands Inventory Fish and Wildlife Service, U.S. Department of the Interior. These plots are available in a publication by Crawford et al (1993).

3.2 Computer Database

The data compiled for this work has been classified into three main categories: a) Cross section data; b) Flow discharge data; c) Reports; and d) Sediment Data. The computer database was organized in this format to facilitate analysis and ease of use. Figure 3.1 in this section shows the structure of the computer database. The entire database is included in a main folder called MRGD (Middle Rio Grande Database). This folder is divided into 2 reaches, Cochiti and Albuquerque. The Cochiti reach is arranged the same as the Albuquerque folder but contains work done by Leon in 1998 on a different

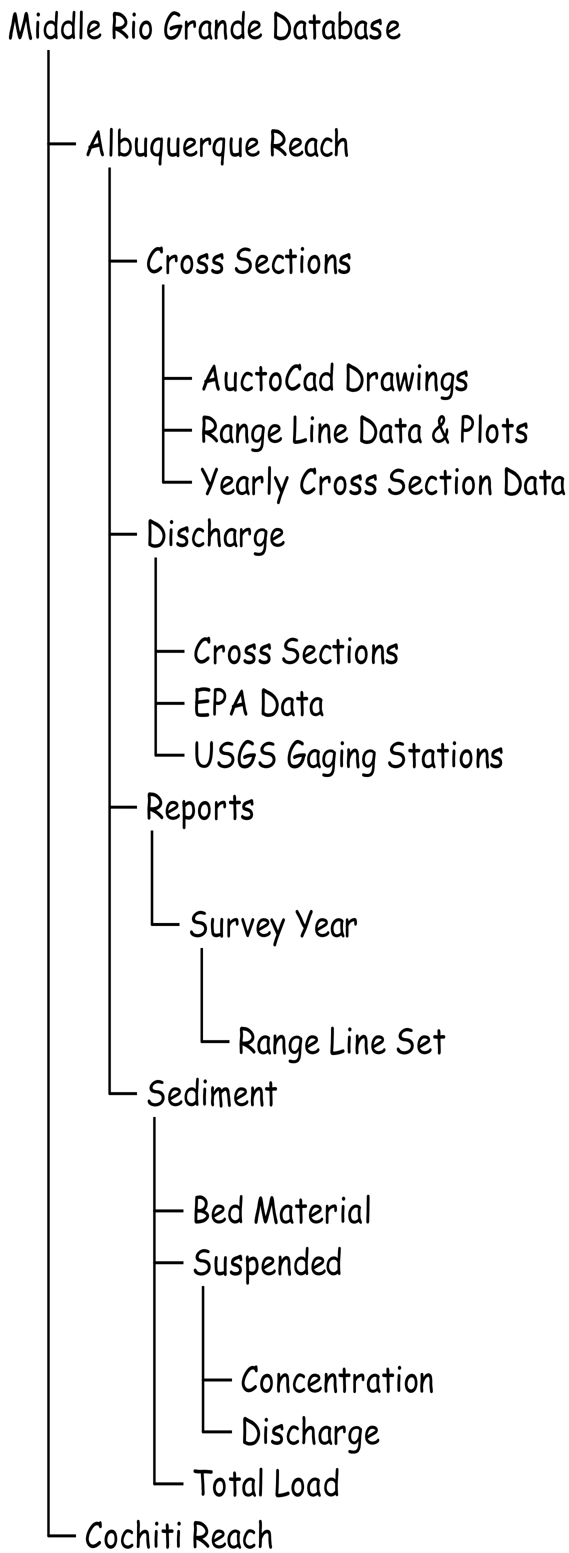

Fig. 3.1. Diagram of the computer database

reach and will not be discussed further. The Cochiti and Albuquerque folders are arranged as follows:

a) Cross section data folder

This folder contains cross section surveys from 1962 to 1998. There are 92 folders containing 432 files in the cross section folder. The cross section data is divided into 3 folders: Range Line Data & Plots, AutoCAD Plots, and Yearly Data.

The Range Lines Data & Plots folder contains six folders (AggDeg Data & Plots, AH-line Data, A-line Data, CA-line Data, CC-line Data, and CO-line Data & Plots). Each folder contains files for a specific set of range lines. The files in these folders are arranged by cross section. All the data for a specific cross section is compiled so that changes at a single cross section can be traced over time.

The folder AggDeg Data & Plots does not have all the Agg/Deg cross sections; however, it does include cross sections that correspond to the Cochiti Range Lines. The file *AggDeg CO line location plots* includes the Agg/Deg lines from 1962 and 1972 that correspond to the Cochiti Range Lines in the study reach and plots the cross sections.

The Cochiti Range Lines are organized slightly different. Each cross section is located in a separate file. Each file contains all the available cross section surveys as well as plots of the cross sections. Cross sections CO-31 to CO-38 have include 4 separate cross section plots. The remaining cross section files include only one plot since all the cross sections fit onto one plot.

The Bernardo Jack Site Range Lines were not included in this folder because the cross section surveys did not give elevations and only gave rod readings and water depths at selected stations. Depths were calculated from an assumed datum of 100 feet.

In the Yearly Data folder the data is arranged by year and then by range line set. A total of 24 folders contain the cross section data by years. They are 1962, 1970, 1970, 1971, 1972, 1972, 1973, 1974, 1975, 1970, 1980, 1982, 1983, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998.
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. The first three digits are the range line name preceded by the letter D. The last four digits represent the month and year of the survey. For example, the file *DCO0792* corresponds to the CO range lines (Cochiti Range Lines) and a survey data of July 1992. Figure 3.2 shows a screen printout from Windows Explorer indicating the retrieval path for the CO-line data collected in November 1972.

The Agg/Deg are named differently. When these files were retrieved they were in an unusable format and very large. In order to use these files, they had to be reformatted. After the files were reformatted they were renamed according to survey year and the

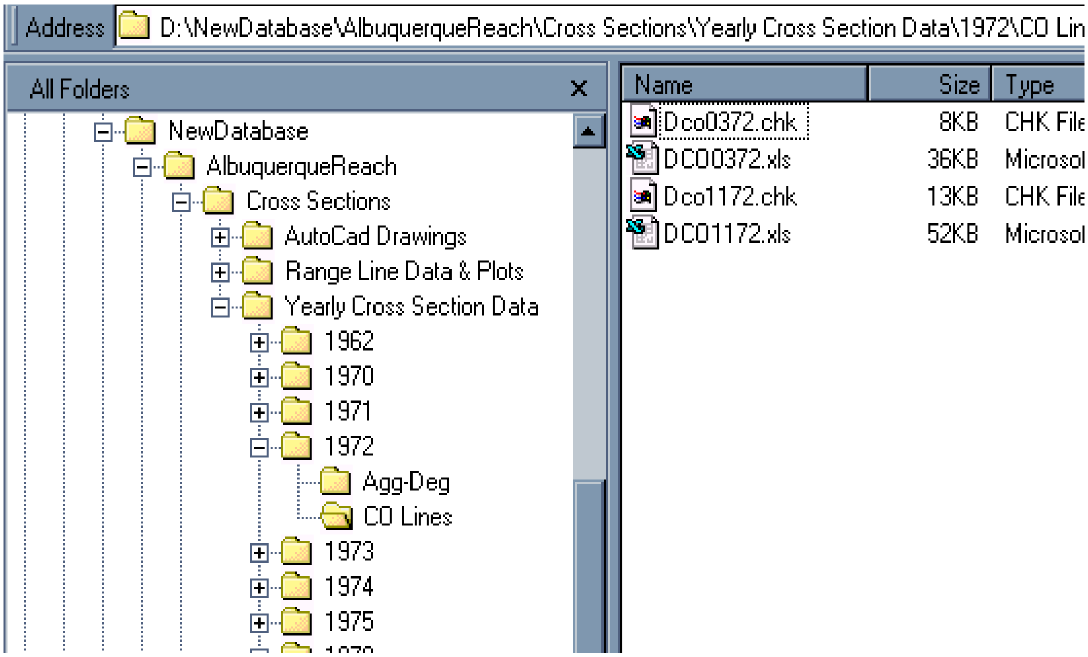

Figure 3.2. Screen printout of the cross section data folder

cross sections in each file. For instance, the file *1962 AggDeg 314-520* contains was surveyed in 1962 and contains cross sections 314 to 520.

The AutoCAD Plots folder contains cross section plots created by FLO Engineering. There are plots for each of the surveys conducted by FLO Engineering but can only be accessed from AutoCAD.

b) Flow discharge data

This folder contains files with flow discharge records. The discharge folder is divided into three folders: Cross Sections, EPA Data, and USGS Gaging Stations. The Cross Sections folder contains discharge measurements taken during cross section surveys. This folder is further divided into survey year and range line set. The files are named by range line, cross section number, and survey date. For example, the file *Ca80329.96q* was surveyed on the Calabacillas Range Lines at cross section number 8. The survey was done on March 29, 1996 and the last character, q, represent discharge. Figure 3.3 shows a screen printout from Windows Explorer indicating the path to retrieve the above mentioned flow discharge file.

The EPA Data folder contains data that were retrieved from the Storet Database in Electronic format. These data are instantaneous discharge readings taken at USGS

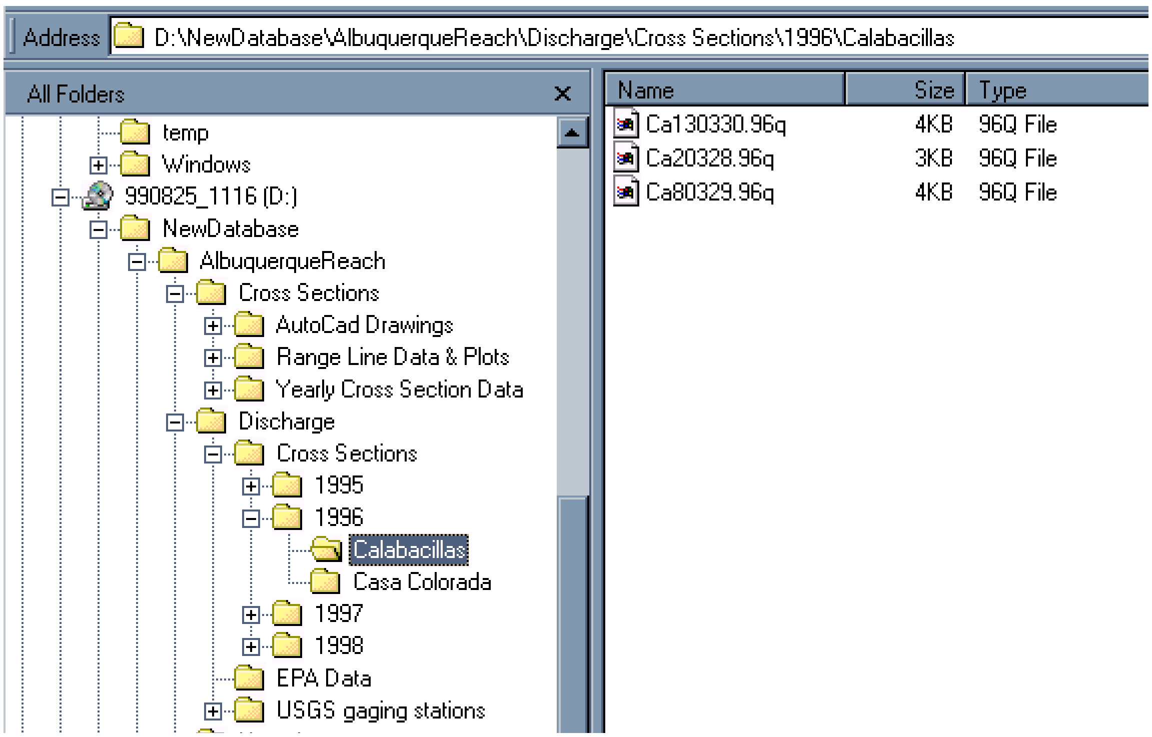

Figure 3.3. Screen printout of the flow discharge data folder.

gaging stations. The main EPA Data folder is divided into folders based on location and the files in the EPA Data folder are named according to the gage location where they were collected and the period of record.

The USGS gaging stations folder contains mean daily discharge values taken at USGS gaging stations. The files are located in the main folder based on gage location. For example, under the USGS gaging stations folder there are 7 folders. Each of these folders is a different location. The files in these folders are named according to the gage description and the period of record at each gage. For example, the file *Rio Grande Floodway at San Acacia, NM 1958-97* contains mean daily discharge values for the Rio Grande Floodway taken at San Acacia, New Mexico. The period of record for this particular gage runs from 1958 through 1997.

c) Reports

This folder is organized by year and by range line set. The folder contains reports done by FLO Engineering for the Bureau of Reclamation as part of the cross section and bed material surveys. These reports contain field notes and describe the site conditions and problems encountered during the surveys. The first two characters of the file name represent the range line set and the following four digits represent the month and year of the survey. For example, the file *Co0792.rep* details the July 1992 survey of the Cochiti Range Lines. Figure 3.4 shows a screen printout from Windows Explorer indicating the path to retrieve a file from the report data folder.

d) Sediment Data

This folder contains sediment data and is organized into three categories: Bed Material, Suspended Sediment, and Total Load.

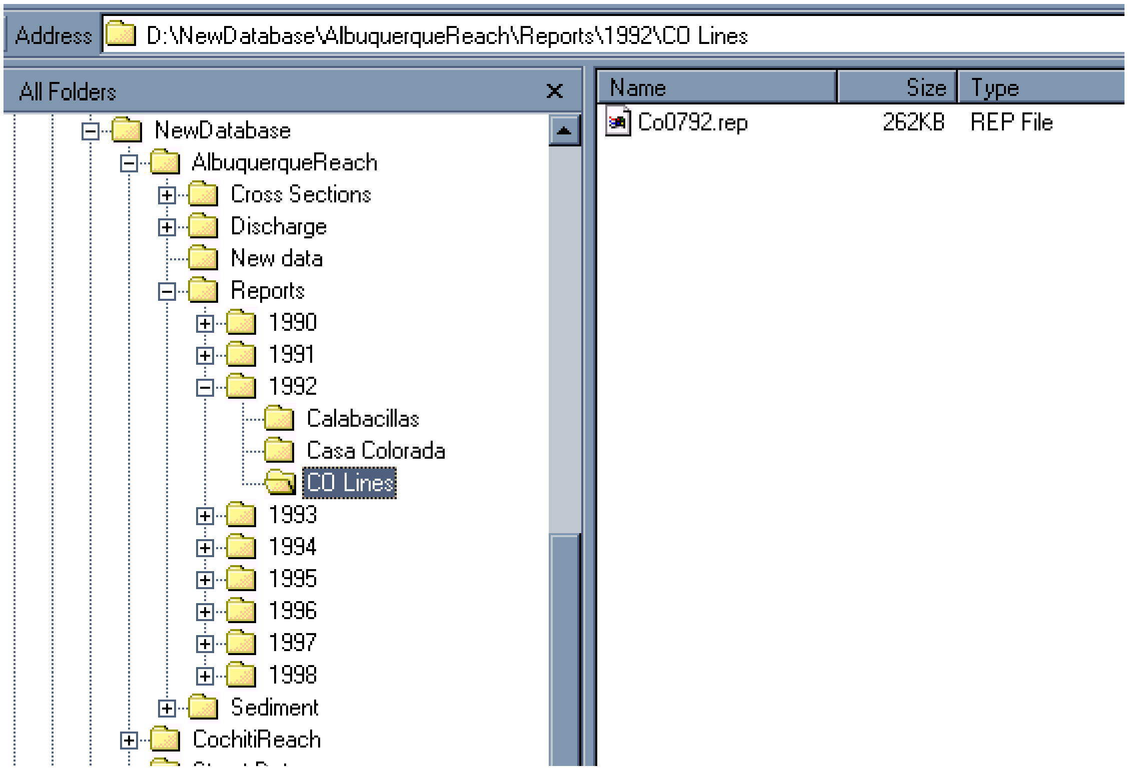

Figure 3.4. Screen printout of the report data folder.

The bed material data are organized into two folders called Cross sections and USGS Gaging Stations. The data included in the Cross Sections sub-directory are arranged by year in a total of 14 folders. These 14 folders are 1970-95, 1971, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, and 1998. The data are further organized by range line set within each one of these folders.

The names of bed material files from cross section surveys start with the letters BM (Bed Material) which are followed by the initial of the range line set followed by the month and year of the survey. For example, the file Bmco0792 corresponds to bed material data for the Cochiti Range (CO) Lines surveyed in July 1992. This convention for naming files was taken from FLO Engineering in order to maintain uniformity.

Figure 3.5 shows a screen printout from Windows Explorer indicating the path to retrieve a file from the bed sediment folder.

The bed material data collected at USGS gaging stations is divided into sub-directories based on the location of the gage. This information was retrieved from the EPA Storet Database and is named accordingly. The file names are preceded by the letters EPA and followed by the gage description as well as the period of record at the gage.

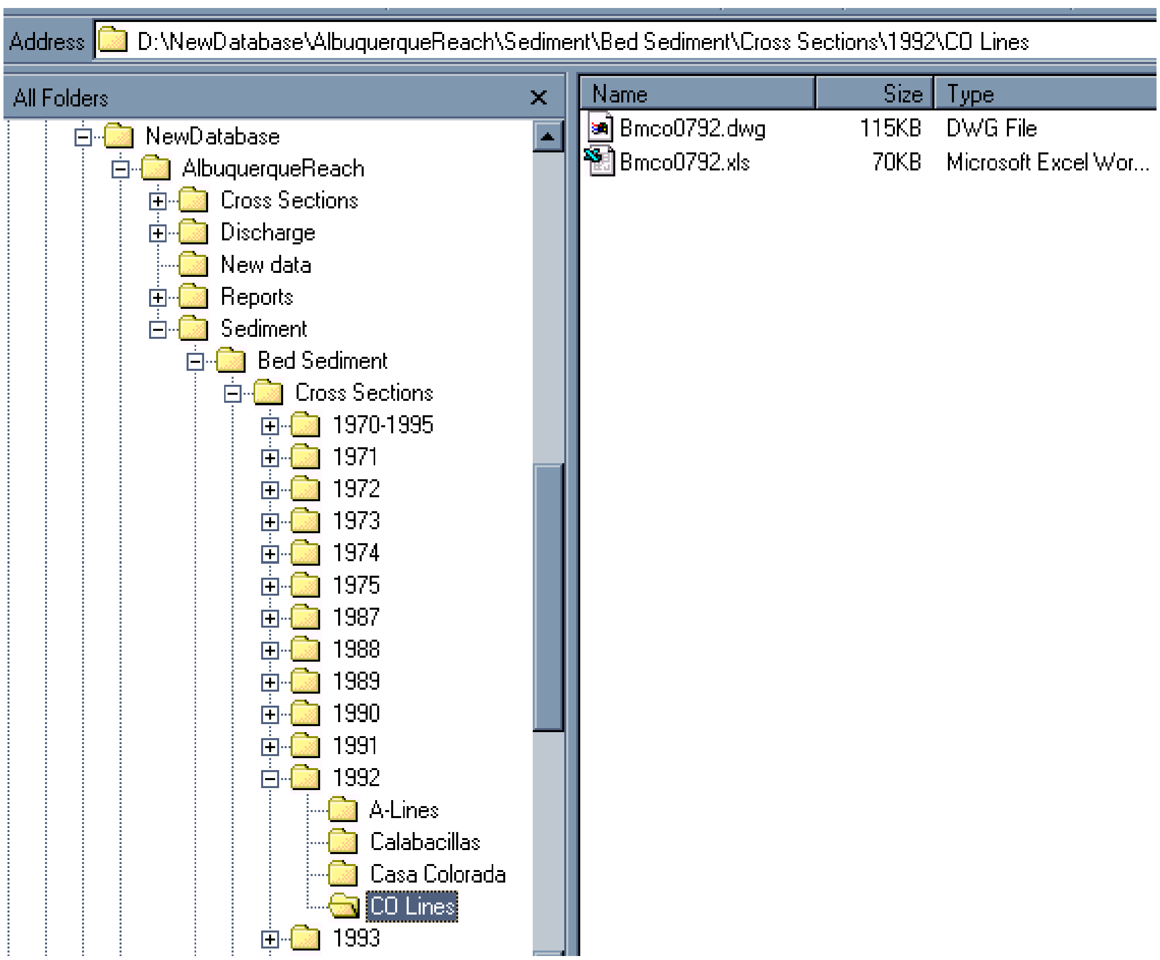

Figure 3.5. Screen printout of the bed sediment folder.

The suspended sediment data are organized by Concentration, Discharge, and Particle Size Distribution. Each of the folders contains data organized by cross section and by USGS gaging station. The data collected during cross section surveys is grouped by year and for each year the data is grouped by range line sets. The data collected at USGS gaging stations is organized by locations and files are named according to the gage description and period of record. The letters EPA precedes files that contain information collected from the EPA Storet Database.

Total sediment load data is included in the Total Load folder. This folder is contains information that was retrieved from the U.S. Bureau of Reclamation, Albuquerque Office in electronic format. The files are organized into three sub-directories, which are further organized by year. Each range line set is then placed into the corresponding year in which the data was collected.

3.3 Generated Data

A. Cross Section Data

The cross section data used in the analysis included in this work correspond to the Cochiti Range Lines. These range lines provide the longest detailed record available for the entire study reach.

Plots of cross sections CO-31 to CO-38 from 1970 to 1975 are included in the report by Dewey et al. (1979).

The 11 post-dam surveys plotted are: November 1975, April 1979, July 1979, January 1980, October 1982, November 1983, November 1986, July 1992, August 1995, May 1996, and September 1998. These and the pre-dam surveys were plotted to observe changes at each cross section with time.

The November 1975 survey was conducted after the summer flows, which peaked near 6,000-cfs at Albuquerque. The April 1979 survey was performed during the beginning of the spring runoff season in the rising limb of the hydrograph. The July 1979 survey followed a peak flow of nearly 7,900-cfs, which was registered at the Albuquerque gage. The January 1980 survey was performed during winter and flows were less than 1,000-cfs. The October 1982 survey was performed after peak summer of flows in June, which reached 4,600-cfs at Albuquerque. The 1983 and 1986 surveys were both conducted in the winter months, however, flows in the summers of 1984 and 1985 peaked at over 8,000-cfs in Albuquerque. The 1992 and 1995 surveys were conducted after summer flows peaked near 6,000-cfs. The May 1996 survey was performed during a low runoff year with spring and summer flows peaking at less than 2,000 cfs at Albuquerque. Data is not currently available for discharges during the September 1998 but field notes from the survey indicate that flows were sustained between 500 and 1,000 cfs during the survey.

The cross sections were surveyed from left bank, looking downstream. Cross section plots for the CO-lines and the corresponding Agg/Deg lines are included in Chapter IV (Figures 4.2 to 4.7) and in Appendix D (Figures D-1 to D-32). Cross section data from

1975 to 1992 at cross sections CO-32 to CO-37, CO-668 to CO-724, CO-765 to CO-806, and CO-858.1 to CO-926 were modified by the U.S. Bureau of Reclamation, Albuquerque Office by shifting the cross section until proper bank alignment was achieved. Water surface elevations for most surveys were also collected.

B. Flow Discharge Data

The hydrograph for each gaging station was plotted and provides several decades of record. In order to determine the effects of tributaries and water withdraw the hydrographs from Cochiti, Albuquerque, Bernardo, and San Acacia were all plotted. Figure 3.6 shows the 1995 hydrograph for each of the gaging stations. As expected the

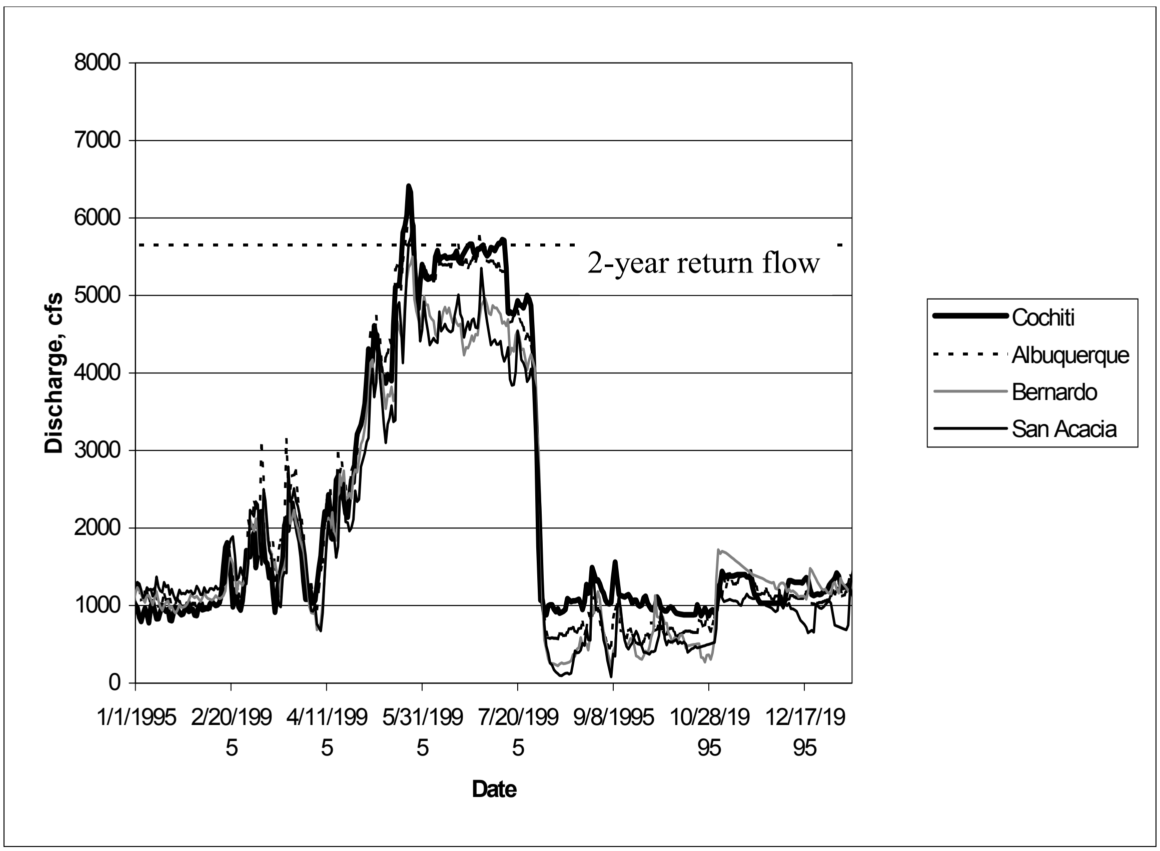

Figure 3.6. 1995 flow hydrograph of Rio Grande at Cochiti, Albuquerque, Bernardo, and San Acacia gaging stations.

lag time between hydrograph peaks at the upstream (Cochiti) and downstream (San Acacia) end of the reach is evident. What is perhaps less expected is the decrease in discharge as distance from Cochiti Dam increases. Except for the month of January, the discharge decreases with distance from Cochiti Dam. This condition is likely due to water withdraw and loss though seepage and evaporation. The two-year return flow of 5,650-cfs in indicated in the figure.

C. Longitudinal Profile

The thalweg and mean bed elevation for each of the 32 cross sections were obtained from 9 surveys for cross sections CO-31 to CO-38, 6 surveys for cross sections CO-668 to CO-926, and 5 surveys for cross sections CO2-945 to CO2-1194. The 1962 Agg/Deg survey was used for all cross sections and the 1972 Agg/Deg survey was used for cross sections CO-668 to CO2-1194 in order to extend the period of record and obtain a baseline for comparisons where pre-dam surveys were not conducted. For cross sections CO-31 to CO-38 the 1962 Agg/Deg, May 1971, June 1973, November 1975, April 1979, January 1980, July 1992, August 1995, and September 1998 surveys were used. Cross sections CO-668 to CO-926 used the 1962 Agg/Deg, 1972 Agg/Deg, October 1982, July 1992, August 1995, and September 1998 surveys to generate the longitudinal profile. Cross sections CO2-945 to CO2-1194 used the same surveys except for the October 1982 survey. At cross section CO-833 data was not available for October 1982 so it was replaced by the November 1983 survey.

The cross section data for all 32 cross sections for each of the surveys listed above were entered into the computer program Scour and Fill version 7.1. This program calculated the top width, mean depth, maximum depth, wetted perimeter, cross section area, and hydraulic radius. In order to perform these calculations a water surface elevation, which was generally near the bank-full condition, was fixed at each cross section. The mean bed elevation and thalweg elevations were then found by subtracting the mean and maximum depth for each survey from the fixed water surface elevation. At cross sections where significant changes in the bed elevation have occurred it is difficult to establish a single water surface elevation. In these cases one surface was chosen that best fit the data. This sometimes resulted in large variations in the output.

The longitudinal profile was created from mean bed elevations taken at each cross section. The mean bed elevations were used instead of thalweg elevations in order to extend the period of record. The locations of each cross section was obtained from aerial photos and the distance below Cochiti Dam for each cross section was measured from the same aerial photos. The longitudinal profile is divided into three sections (CO-31 to CO-38, CO-668 to CO-926, and CO2-945 to CO2-1194). Figures 3.7 to 3.9 show the mean bed profile for each of the three sections. Cross section locations and major tributaries are indicated on the plots. If a data point was not available, a straight-line interpolation was performed from the nearest data points.

Estimations of aggradation and degradation at each cross section were performed between the earliest (1962) and latest (1998) surveys. Changes in mean bed elevation from 1962 to 1998 and 1992 to 1998 are shown in Figures 3.10 to 3.12. Changes in thalweg and mean bed elevation over the longest period of record that each is available at a cross section with the Cochiti Range lines are shown in Figure 3.13. This plot shows a significant amount of scatter. The change in mean bed and thalweg elevation at each cross section from 1962 to 1998 was also plotted and can be seen in Figures E-1 to E-32 in Appendix E.

Cross section area for each cross section over time was plotted in order to denote changes as in Figure 3.14 for cross section CO-31. Cross section area with time at each cross section is shown in Figures E-33 to E-64 in Appendix E.

D. Sediment Data

Bed Material:

Median bed material size data in hardcopy format from the Dewey et al. (1979) report were transferred by Leon (1998) into Microsoft Excel 97 files. This data was combined with bed material data collected by FLO Engineering to create Figure 3.15, which shows median bed material size versus distance below Cochiti Dam. Where more than one sample per cross section was taken, the average of the d50's is used for the median bed material size. Cross section numbers and other major feature are indicated on the plot. When a data point was missing a straight line was drawn between the adjacent points.

Bed material data from FLO Engineering consist of several samples across each cross section. The range of the median bed material size could vary considerably. In order to give a better representation of the riverbed the minimum, mean, and maximum median bed material size for each cross section were plotted for the 1992, 1995, and 1998 surveys. Figures 3.16 to 3.18 show the range of median bed material size at each cross section for the three surveys.

Bed material particle size distributions for USGS gages near Albuquerque, Bernardo, and San Acacia were plotted for sever years and shown in Figures 3.19 to 3.21.

Suspended Sediment Data:

Suspended sediment discharge and concentration were plotted at each of the gaging stations. Where available, the suspended sediment particle size distributions were plotted to obtain the median grain size.

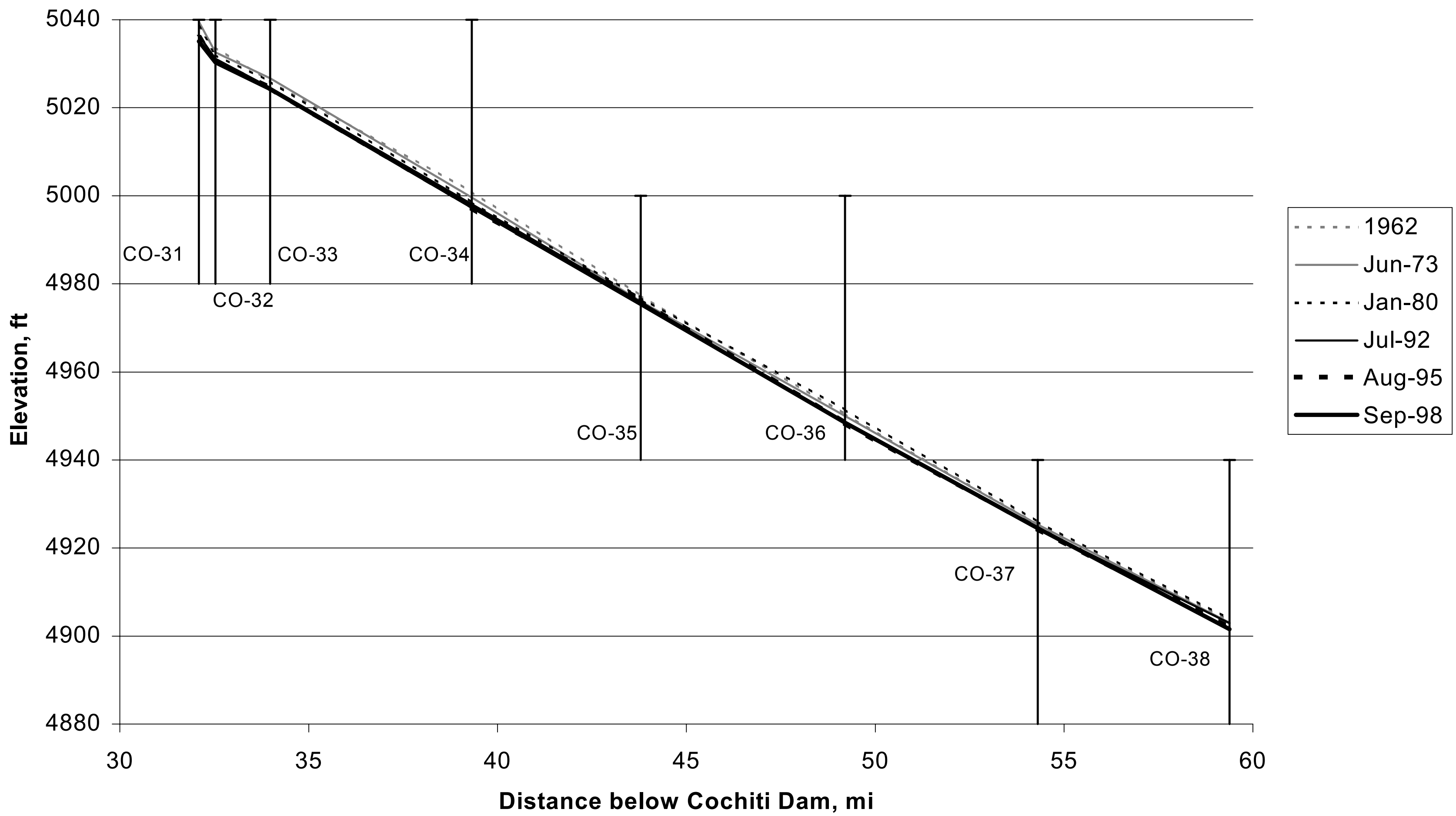

Figure 3.7. Mean bed profile fom cross section CO-31 to cross section CO-38

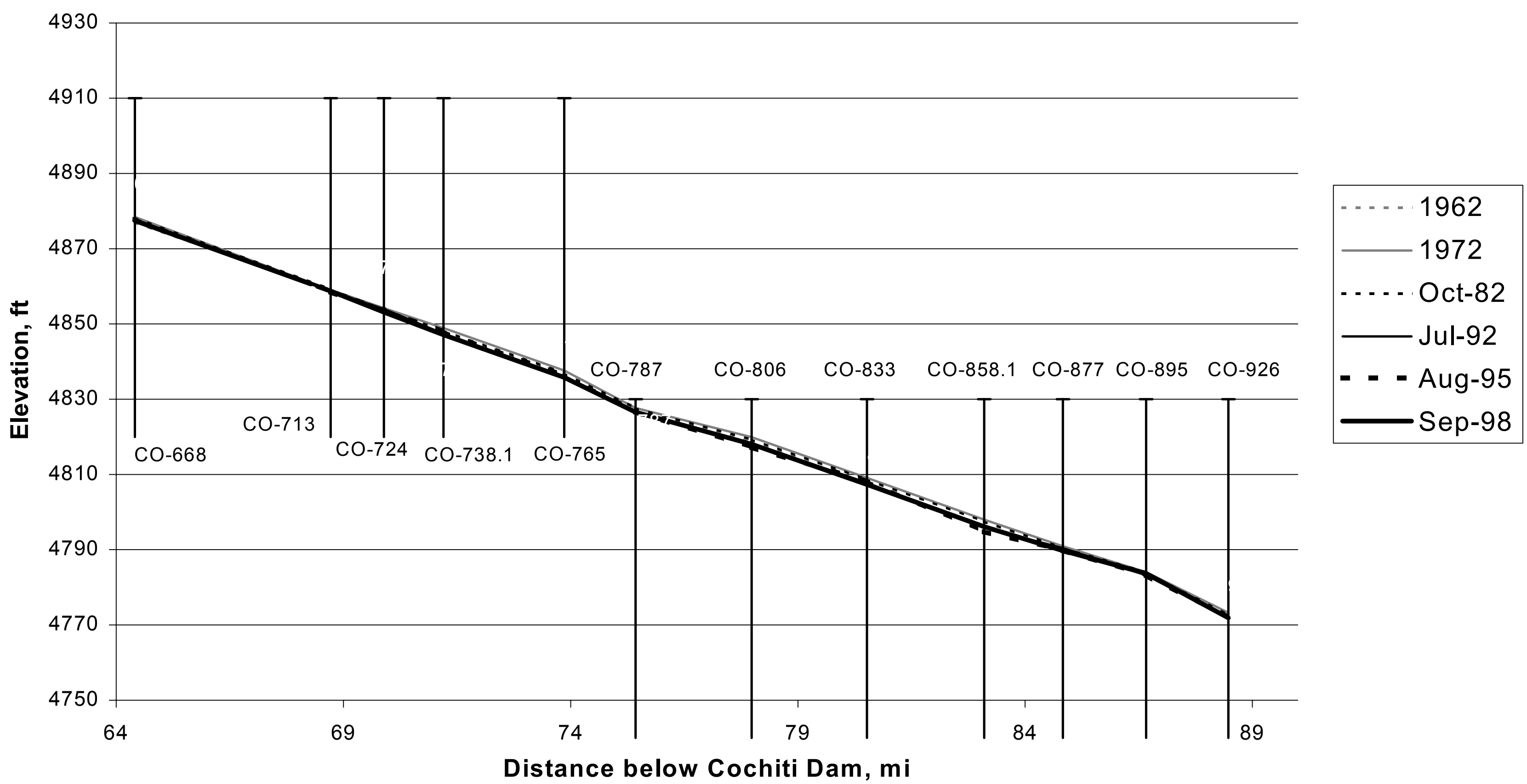

Figure 3.8. Mean bed profile from cross section CO-668 to cross section CO-926

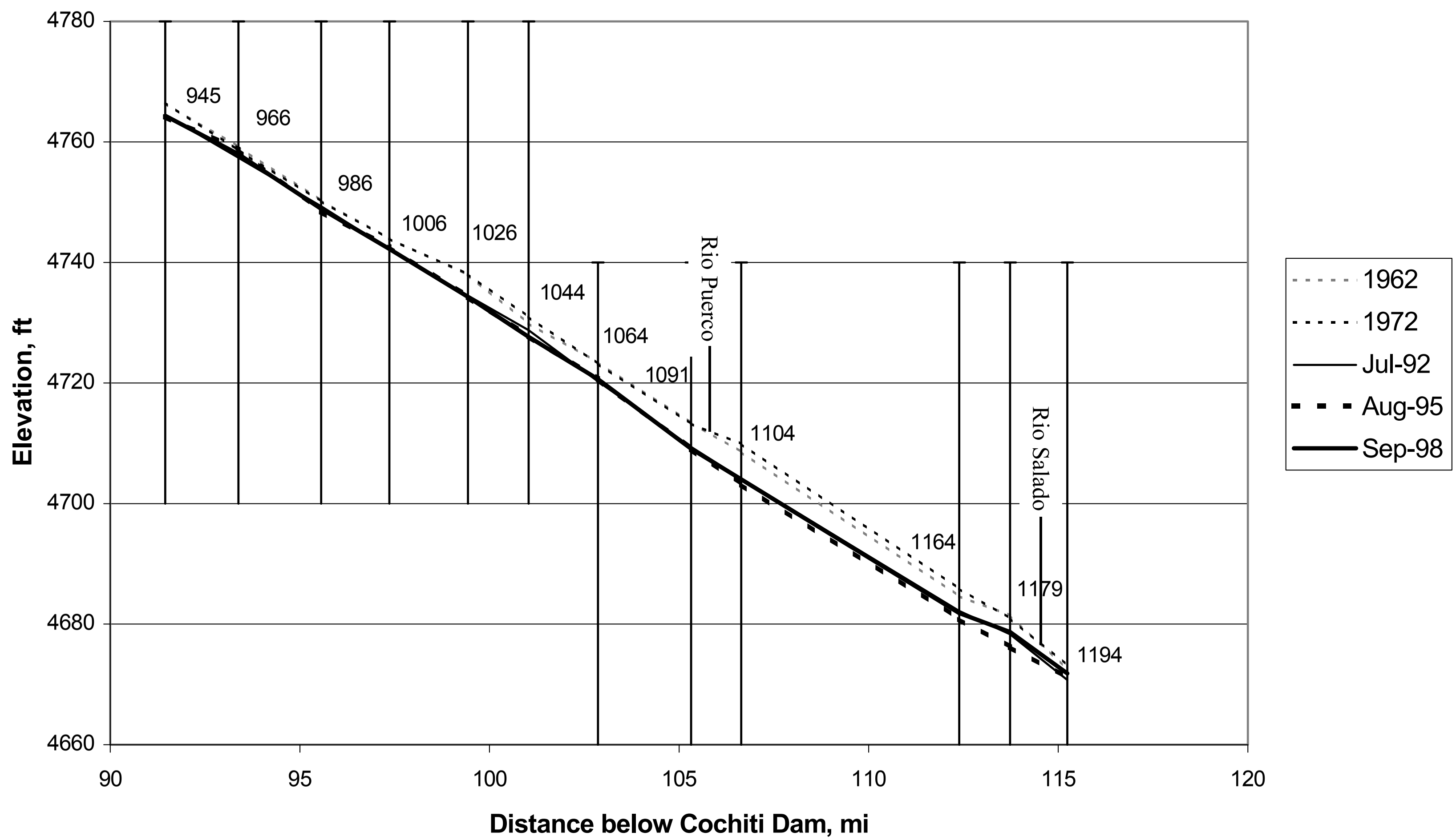

Figure 3.9. Mean bed profile from cross section CO2-945 to cross section CO2-1194

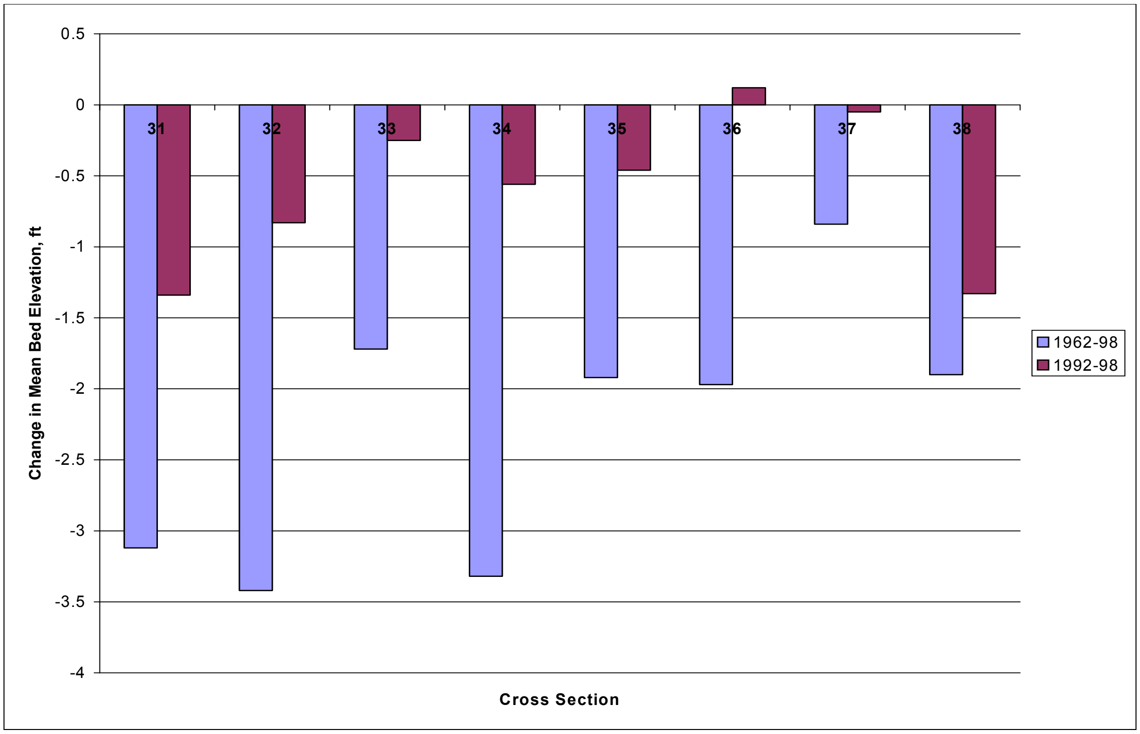

Figure 3.10. Change in mean bed elevation from cross section CO-31 to cross sectin CO-38.

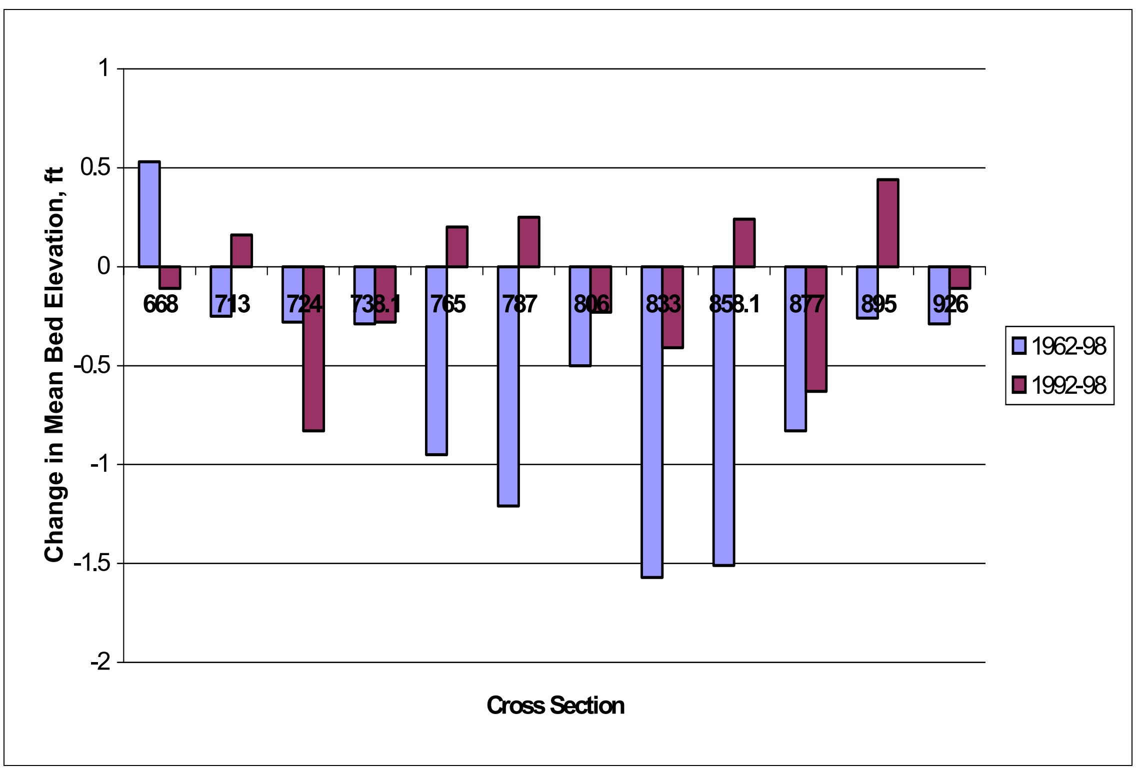

Figure 3.11. Change in mean bed elevation from cross section CO-668 to cross section CO-926.

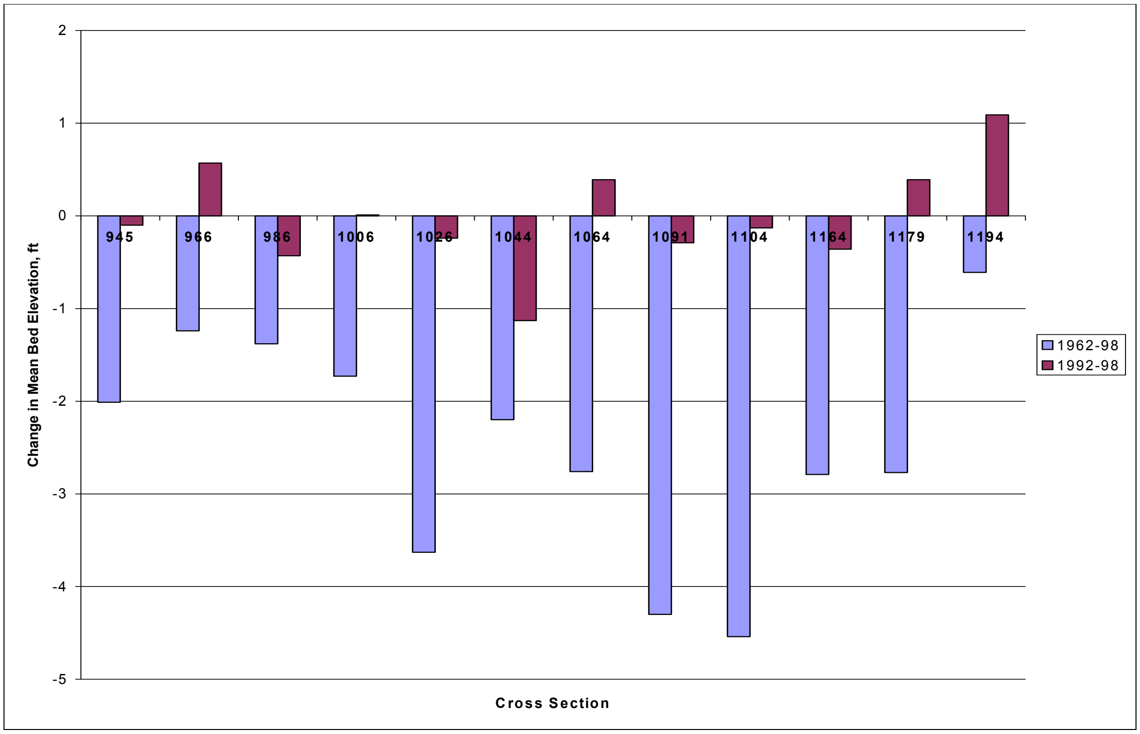

Figure 3.12. Change in mean bed elevation from cross section CO2-945 to cross section CO2-1194.

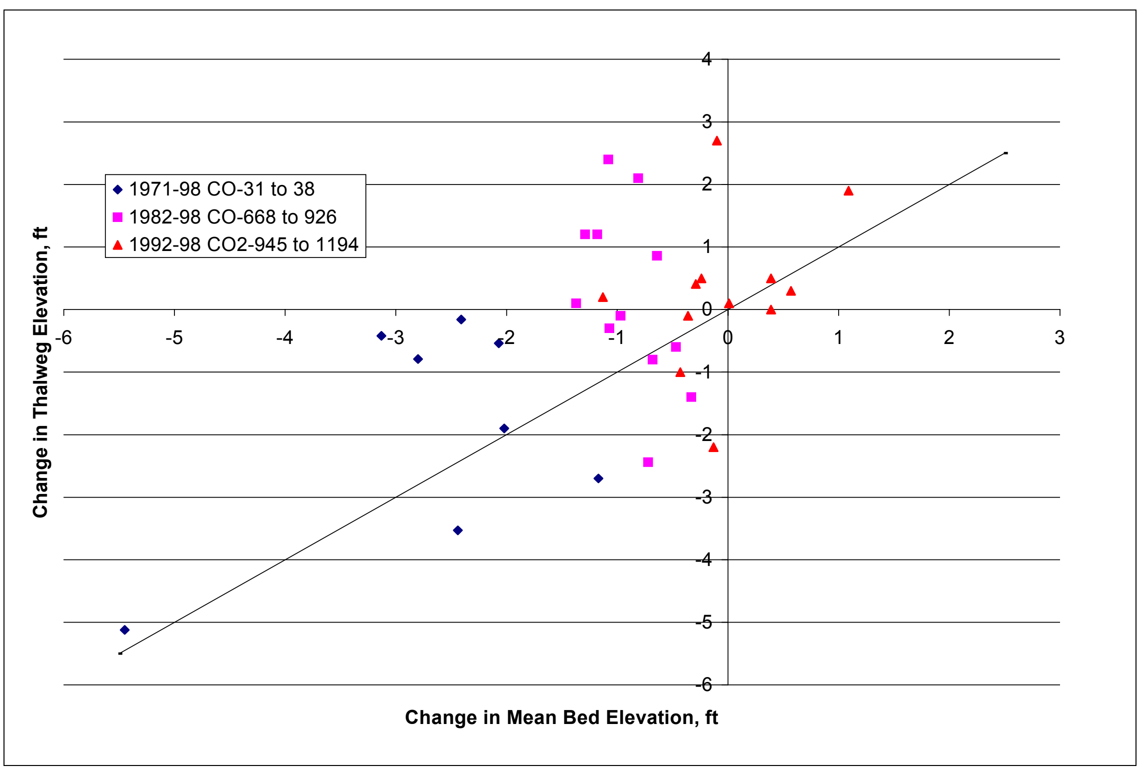

Figure 3.13. Change in mean bed elevation against change in thalweg elevation.

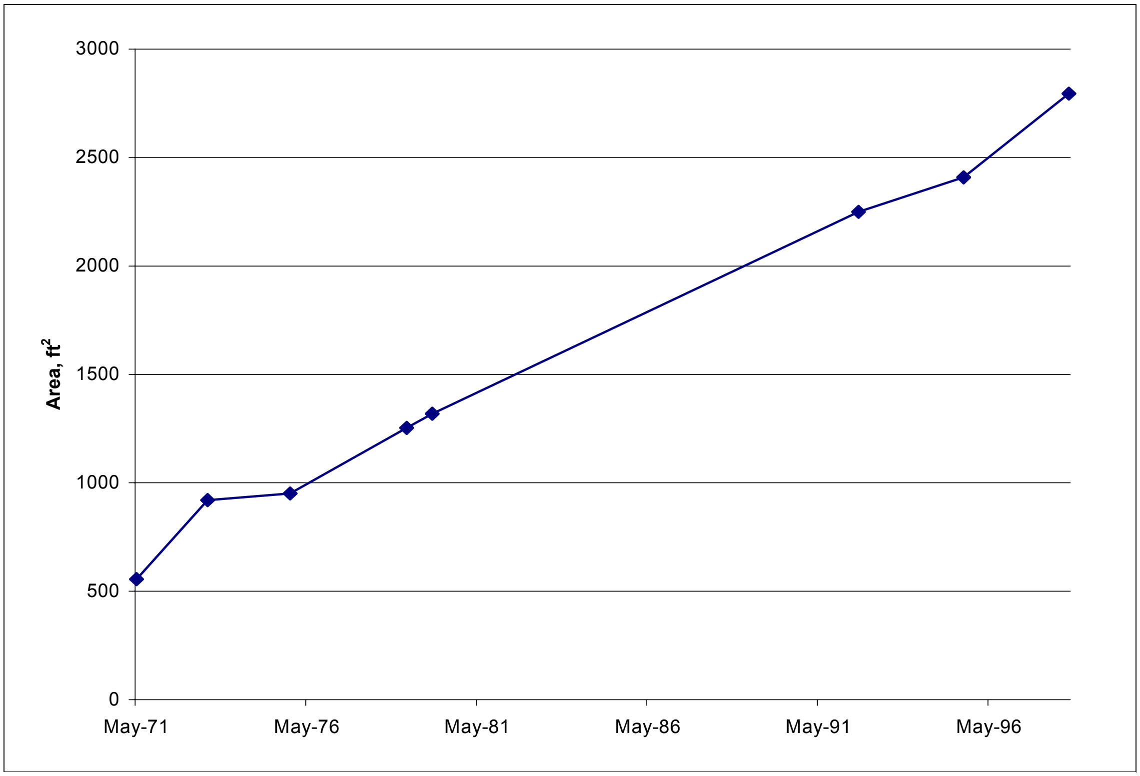

Figure 3.14. Cross section area over time for cross section CO-31.

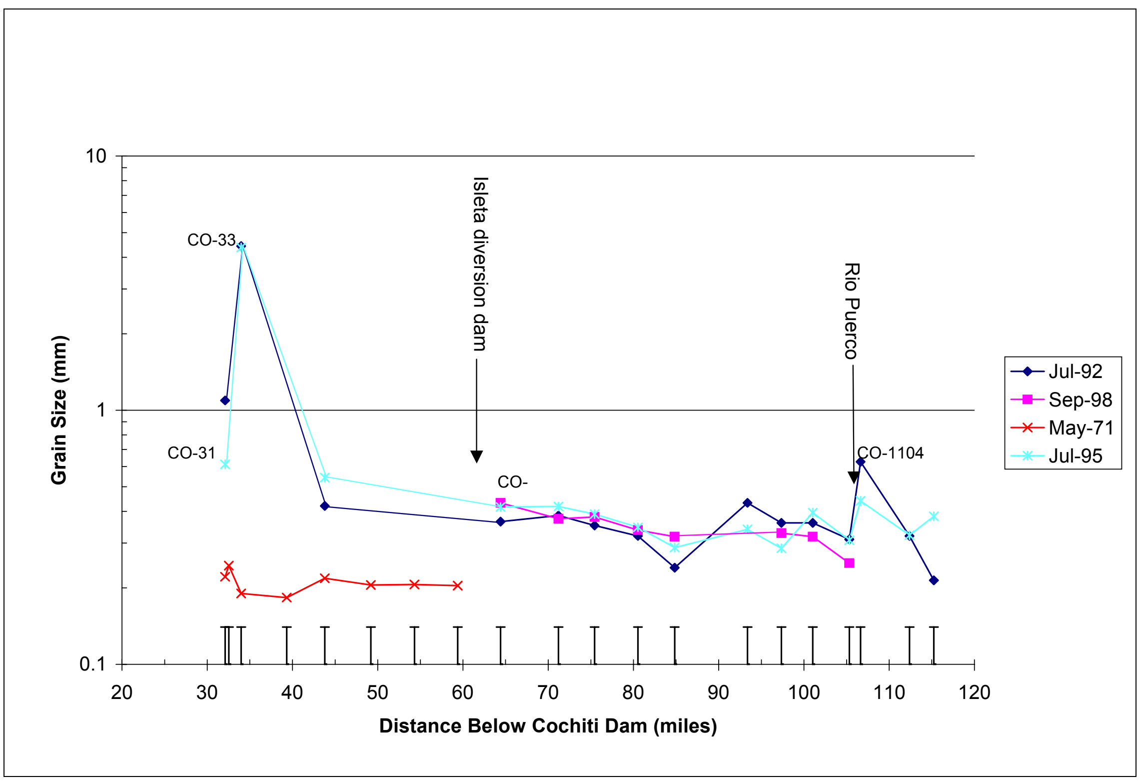

Figure 3.15. Median bed material grain size vs distance below Cochiti Dam.

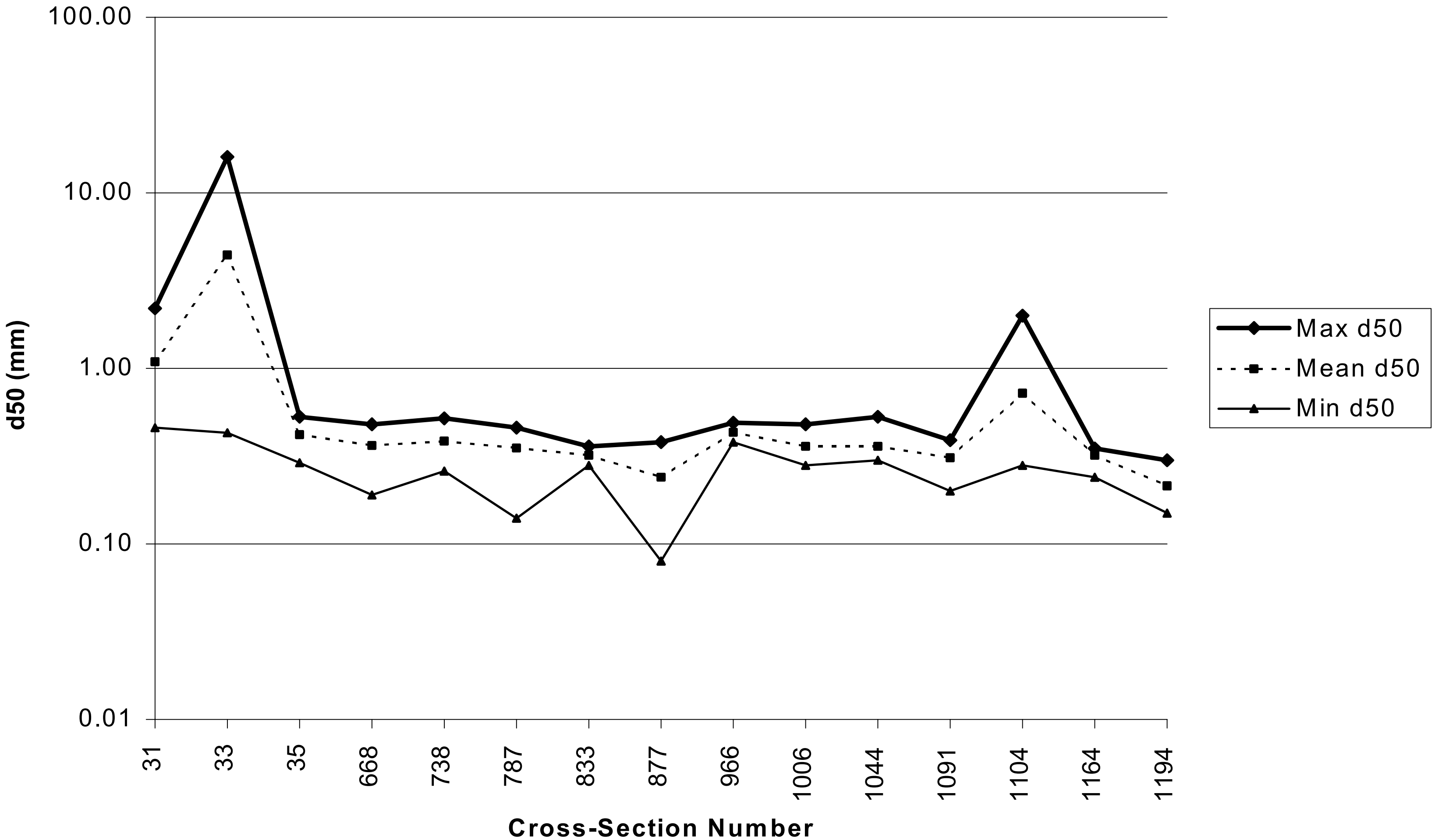

Figure 3.16. 1992 maximum, mean, and minimum bed material grain size.

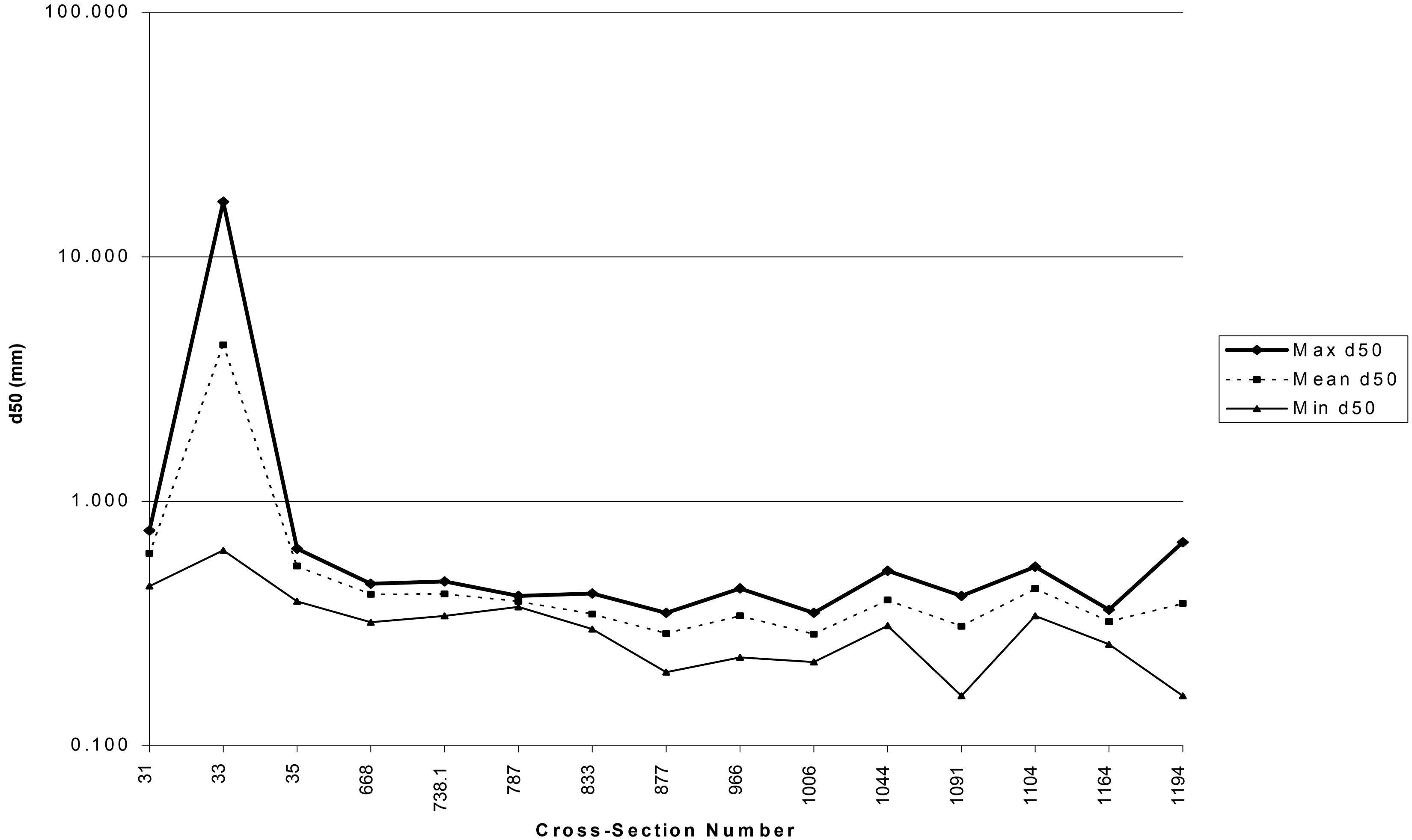

Figure 3.17. 1995 maximum, mean, and minimum bed material grain size.

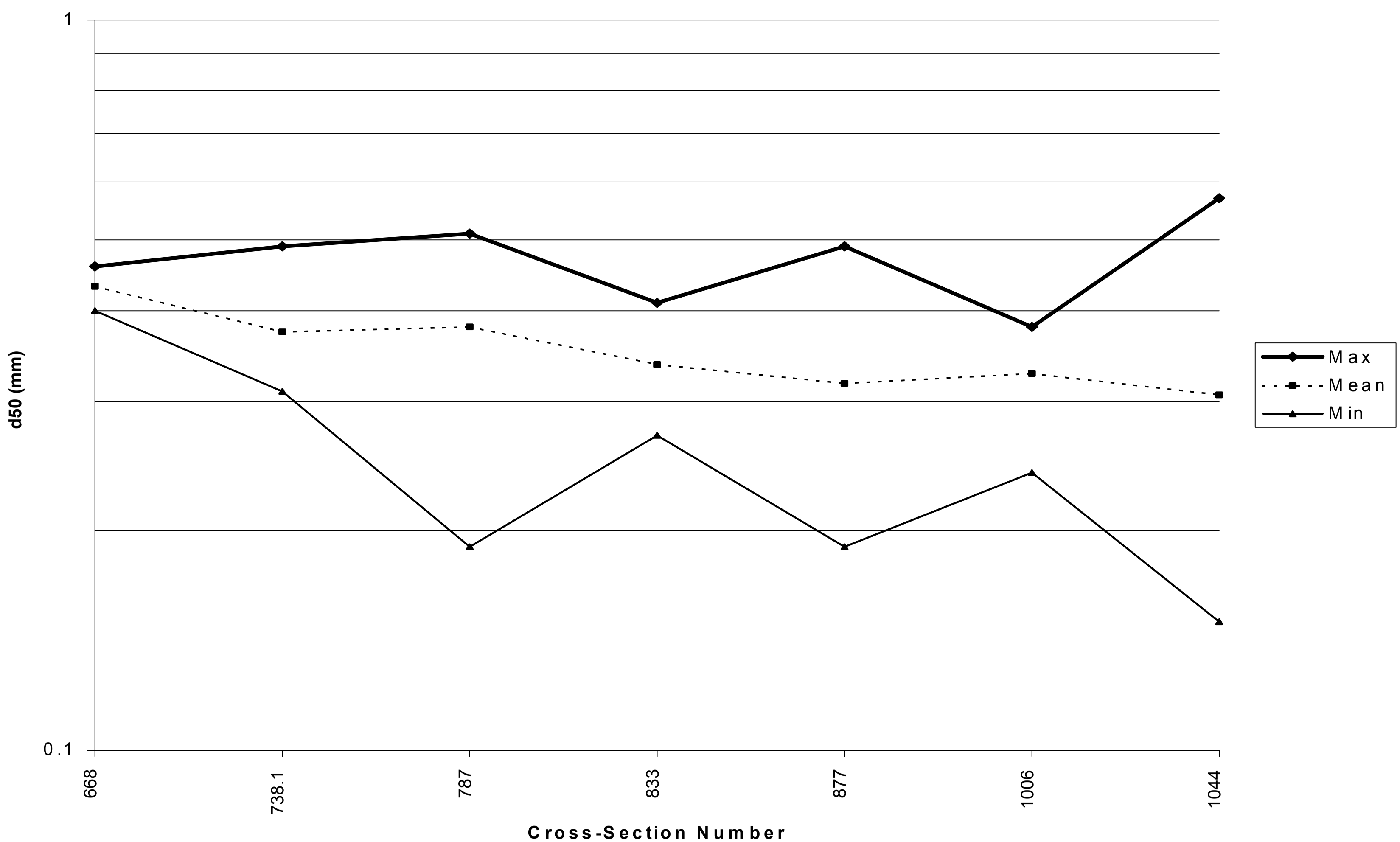

Figure 3.18. 1998 meaximum, mean, and minimum bed material grain size.

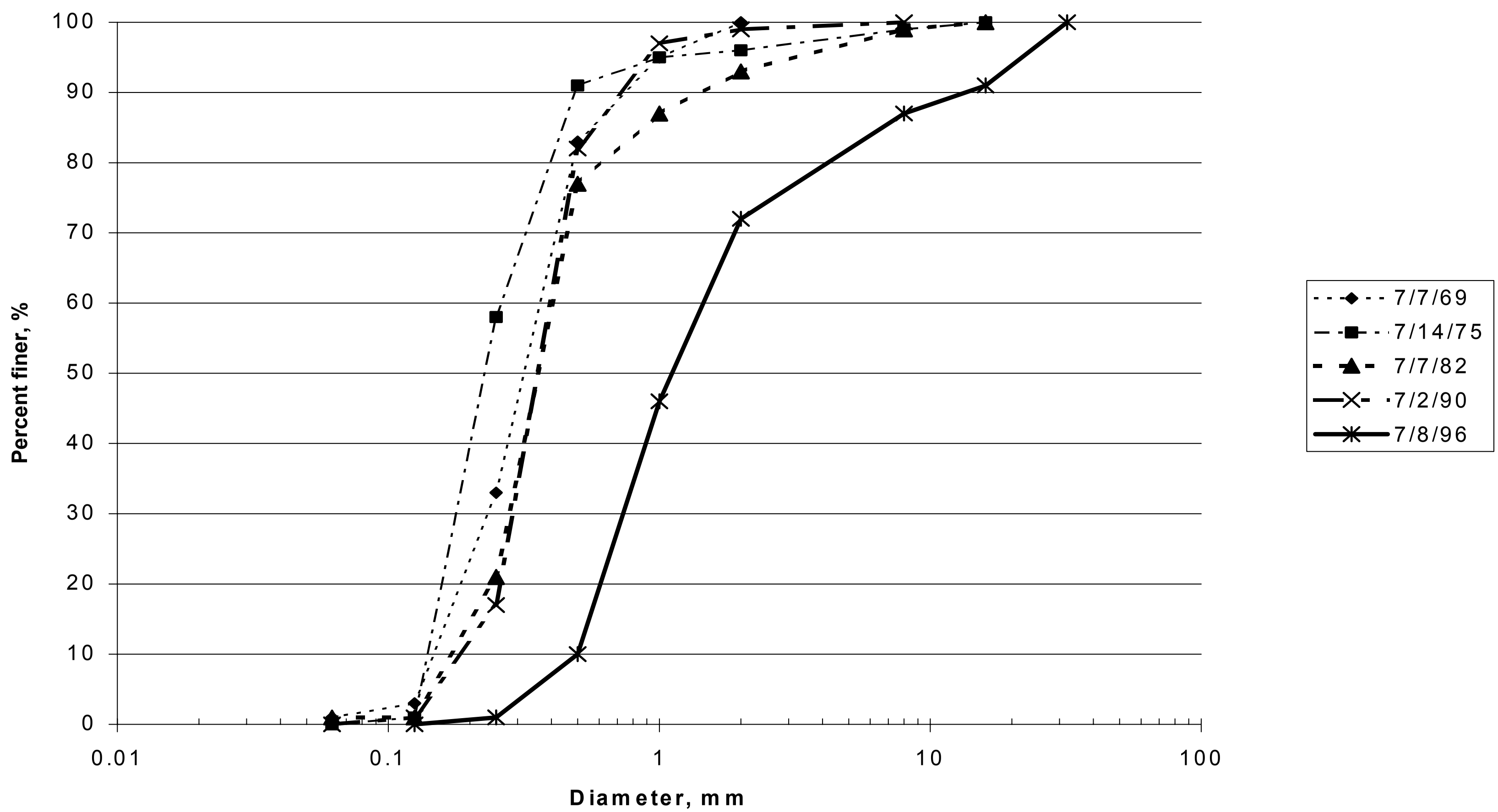

Figure 3.19. Bed material particle size distribution for USGS gaging station on the Rio Grande in Albuquerque, New Mexico.

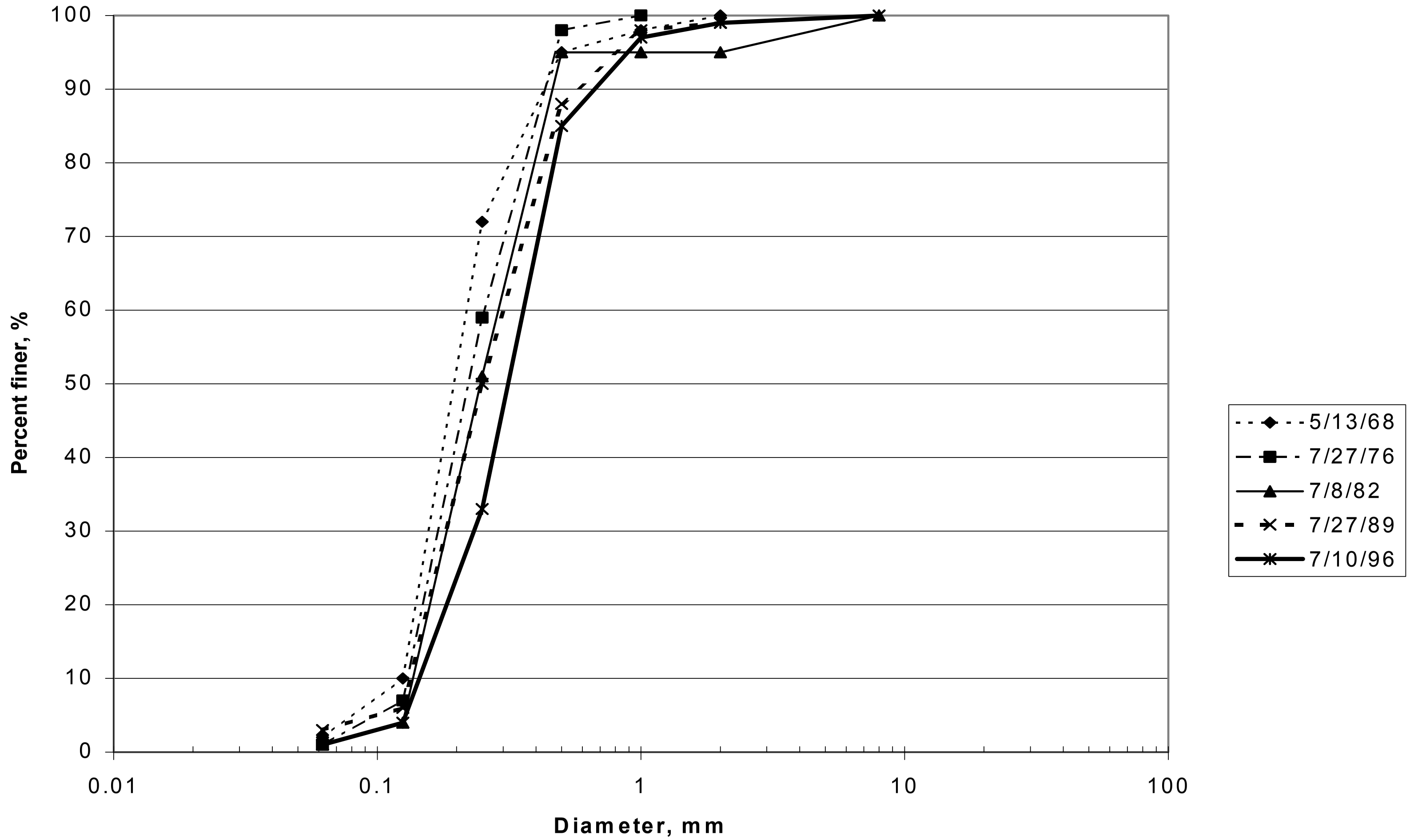

Figure 3.20. Bed material particle size distribution for USGS gaging station on the Rio Grande near Bernardo, New Mexico.

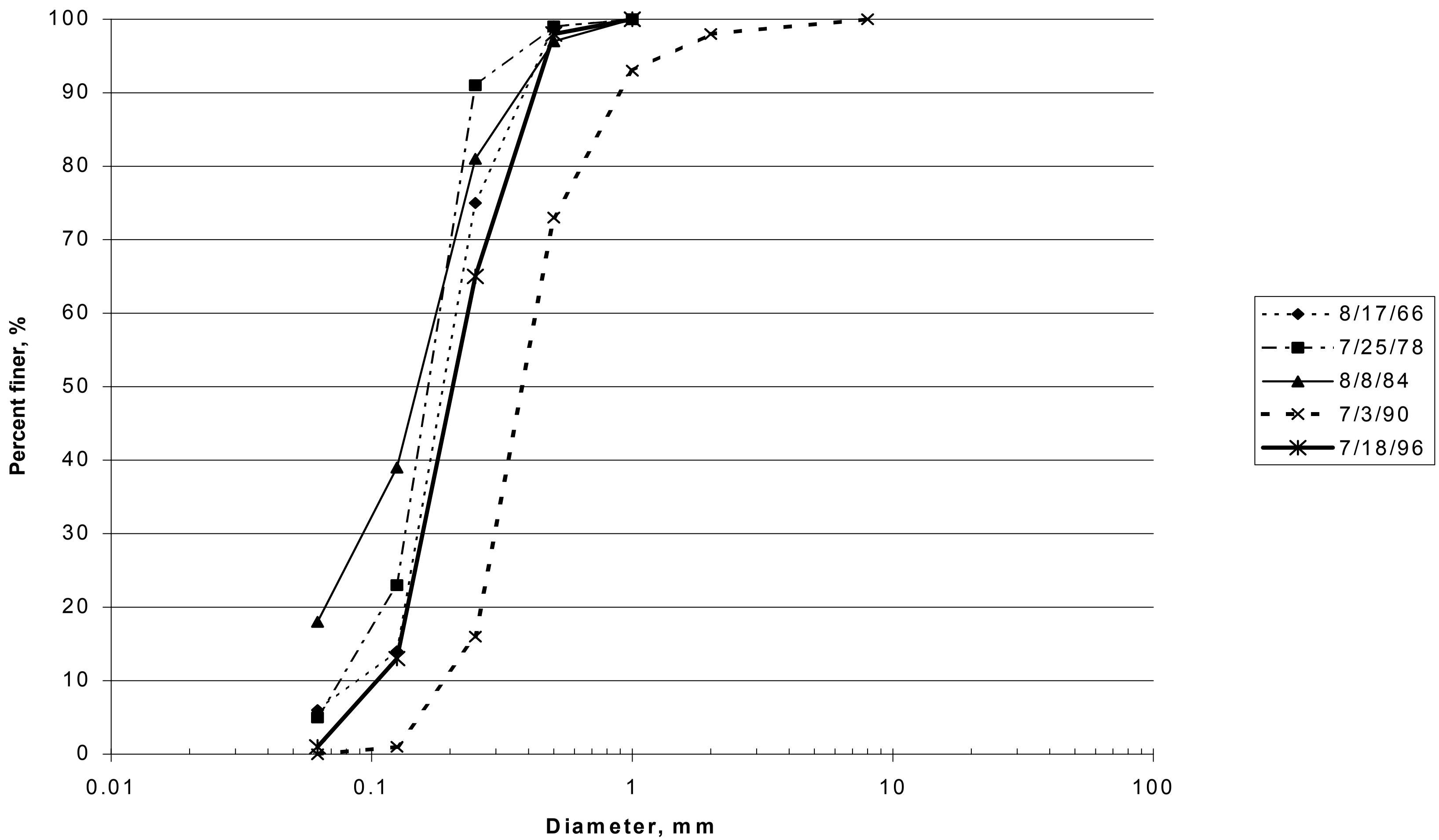

Figure 3.21. Bed material particle size distribution for USGS gaging station on the Rio Grande at San Acacia, New Mexico.

CHAPTER IV

ANALYSIS

Data compiled in the database is used to identify changes in planform, thalweg elevation, mean bed elevation, and bed material size in the Middle Rio Grande since closure of Cochiti Dam. Recent data were analyzed and summarized into five sections. The first section details changes in river planform (Section 4.1). The second section presents a comparison between thalweg elevation and mean bed elevation along the study reach (Section 4.2). Analysis of the longitudinal profile is presented in the third section (Section 4.3). The fourth section describes the changes in bed material in time and space along the reach (Section 4.4), while changes in cross section geometry are documented in the fifth section of this chapter.

4.1 Planform

Changes in planform below Cochiti Dam since construction have been discussed in Chapter II. Based on several geomorphic studies of the Middle Rio Grande, it was concluded that the surface area of the river was decreasing as the river changed from a braided multi-channel river to a river with a single thread channel. This change is primarily associated with decreased flows, channel rectification works, and regulated flows from the dams in the Middle Rio Grande Valley. The change from a braided channel to a single thread channel is primarily associated with the first 26 miles below Cochiti Dam as the conversion has yet to take place in the remainder of the river.

Analysis of planform plots indicates that the channel has decreased in width between 1935 and 1989. Inspection of 1992 aerial photos clearly shows a single thread channel between Cochiti Dam and New Mexico Highway 44 near Bernalillo. Below this point the channel still appears to be braided with many bars in the channel. Several small arroyos and diversion drains enter the Middle Rio Grande between Bernalillo and the Isleta diversion dam. The amount of sediment and number of bars present in the channel appear to increase just above the Isleta diversion dam.

Downstream from the Isleta diversion dam the channel still has a braided configuration but there seems to be fewer bars extending beyond the water surface. This river pattern exists for much of the reach between the Isleta diversion dam and Bernardo.

The Rio Puerco joins the Rio Grande near the town of Bernardo and immediately below the confluence of the Rio Puerco and Rio Grande the channel narrows to a single thread. After a distance of approximately 2,000 feet the channel begins to widen and resumes a braided pattern for several miles.

Beginning at the confluence of the Rio Grande and Rio Puerco, three arroyos enter the Rio Grande from the East. The Salas Arroyo enters the Rio Grande near the entrance of the Rio Puerco. The Arroyo Los Alamos enters the Rio Grande approximately 2 miles downstream of the Rio Puerco and the Bernardo Arroyo enters the Rio Grande approximately 4 miles below the Rio Puerco. The Salas Arroyo and the Arroyo Los Alamos each have a well-developed delta in the floodway.

Just below the Bernardo Arroyo the Rio Grande enters a constriction and begins to make a large bend. In the constriction two more arroyos enter the Rio Grande from the East. As the Rio Grande exits the confined the Rio Salado enters from the West. An extensive delta has formed at the mouth of the Rio Salado. As the Rio Grande reaches the delta the channel makes a sharp turn away from the Rio Salado. At this point the river widens and returns to a braided pattern. The Arroyo Rosa de Castillo enters the Rio Grande approximately 4,000 feet below the Rio Salado and at this point the Rio Grande makes another sharp turn away from the incoming arroyo.

The San Acacia diversion dam marks the end of the study reach, which is located approximately 2 miles below the Rio Salado. Between the entrance of the Arroyo Rosa de Castillo and the San Acacia diversion dam the Rio Grande is mostly straight with a braided configuration.

Inspection of 1992 aerial photos shows an extensive delta at the confluence of the Rio Salado. The Rio Grande makes an abrupt turn to the left as it reaches the delta (Figures 4.1 and 4.2). Several abandoned channels are apparent in the photos and indicate the Rio Grande channel has moved over 1,000 feet.

The Arroyo de Castillo appears to have a similar effect on the Rio Grande. Several abandoned channels can also be seen in the aerial photos. The current position of the

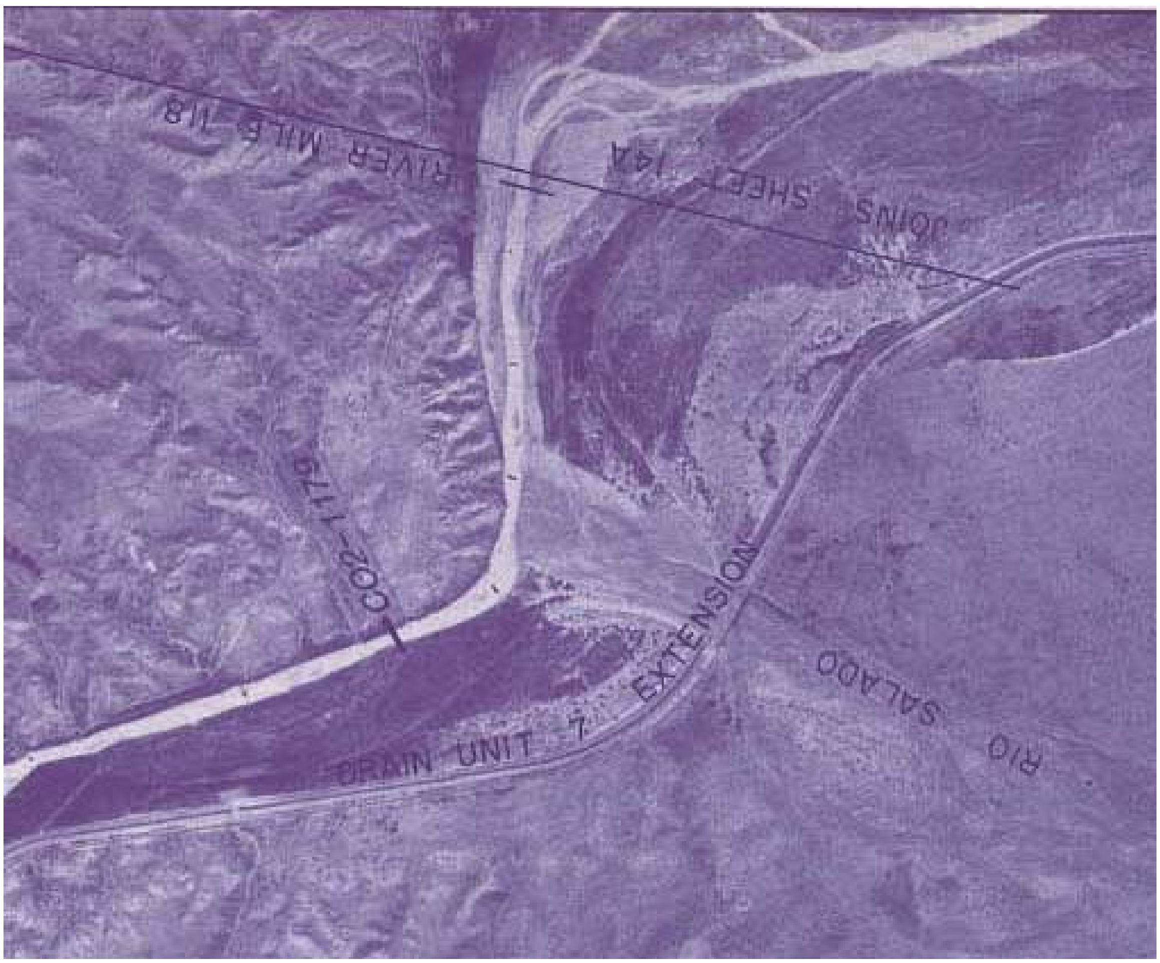

Figure 4.1. Rio Grande flowing from left to right. Notice the abrupt change of course as the Rio Grande reaches the delta of the Rio Salado. The channel also narrows considerable at the confluence. Several abandoned channels or terraces are evident in the photo to the right of the current channel location. The Arroyo Rosa de Castillo enters the Rio Grande near the top center in the photo.

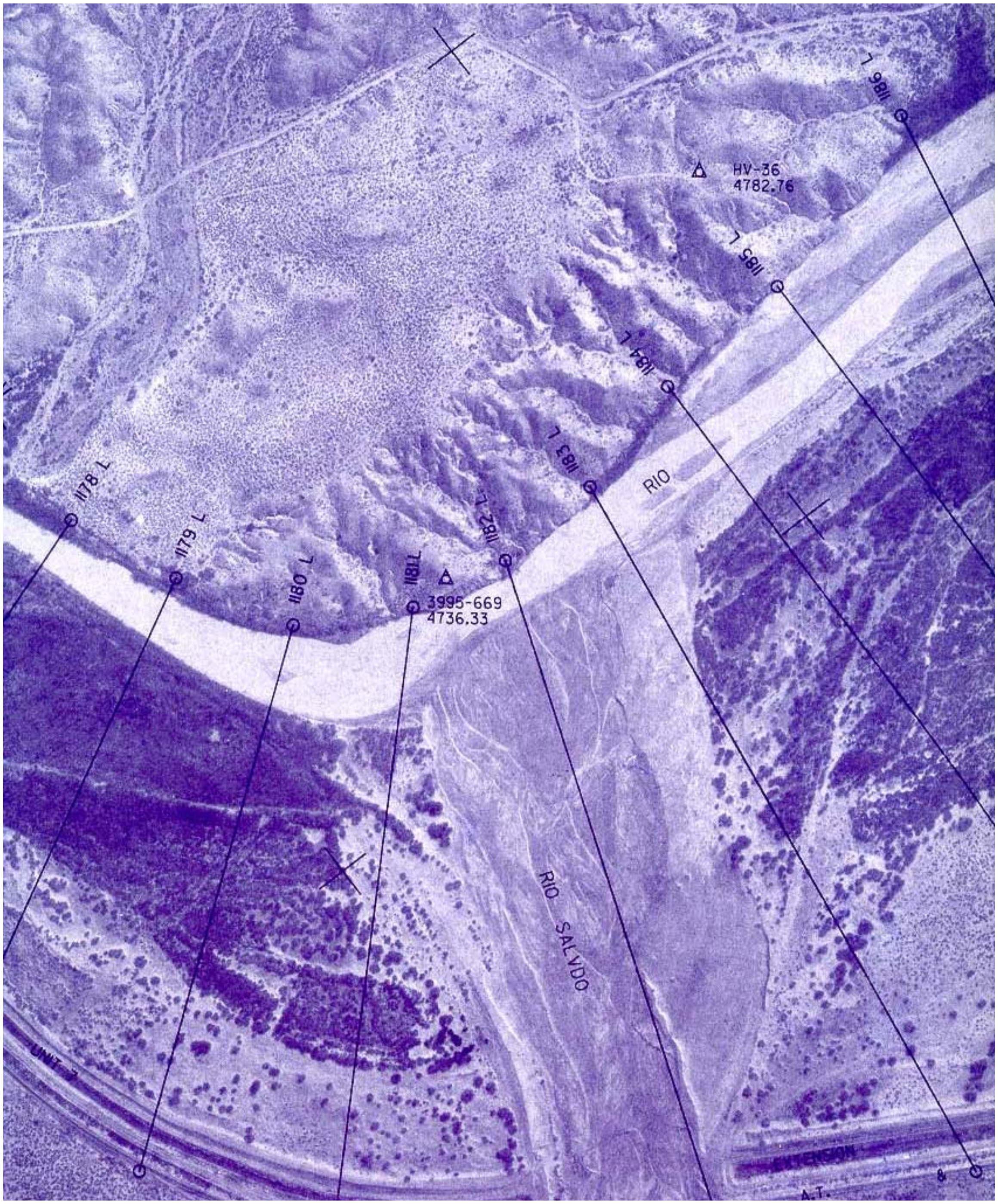

Figure 4.2. Rio Grande flowing from left to right. Note the channel constriction and abrupt change of course as the Rio Grande converges with the Rio Salado delta. The width of the delta as it contacts the Rio Grande is approximately 1,400 feet. Cross section CO2-1179 is the second cross section line from the left. Several abandoned channels on the right side of the Rio Grande are visible.

Rio Grande is much farther to the right and has also moved more than 1,000 feet. Figure 4.3 shows the Arroyo Rosa de Castillo entering the Rio Grande as well as several abandoned channels.

The photos also indicate that the river planform is almost straight. From cross section CO-31 to cross section CO-38 the channel sinuosity is estimated to be 1.07. The sinuosity increases slightly below the Isleta diversion dam but is still mostly straight as the sinuosity increases to 1.09.

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

River Slope was estimated from the 1998 thalweg profile. The slope is 0.00092 ft/ft between Bernalillo and the Isleta diversion dam. Similarly, the slope between the Isleta diversion dam and the San Acacia diversion dam is 0.00078 ft/ft. The slope between Bernalillo and the San Acacia diversion dam is 0.00083ft/ft. The mean annual discharge of the Middle Rio Grande at Albuquerque between 1974 and 1997 is 1,453 cfs. With these values Lane's relationship yields K = 0.0051, which classifies the river as an intermediate sandbed channel.

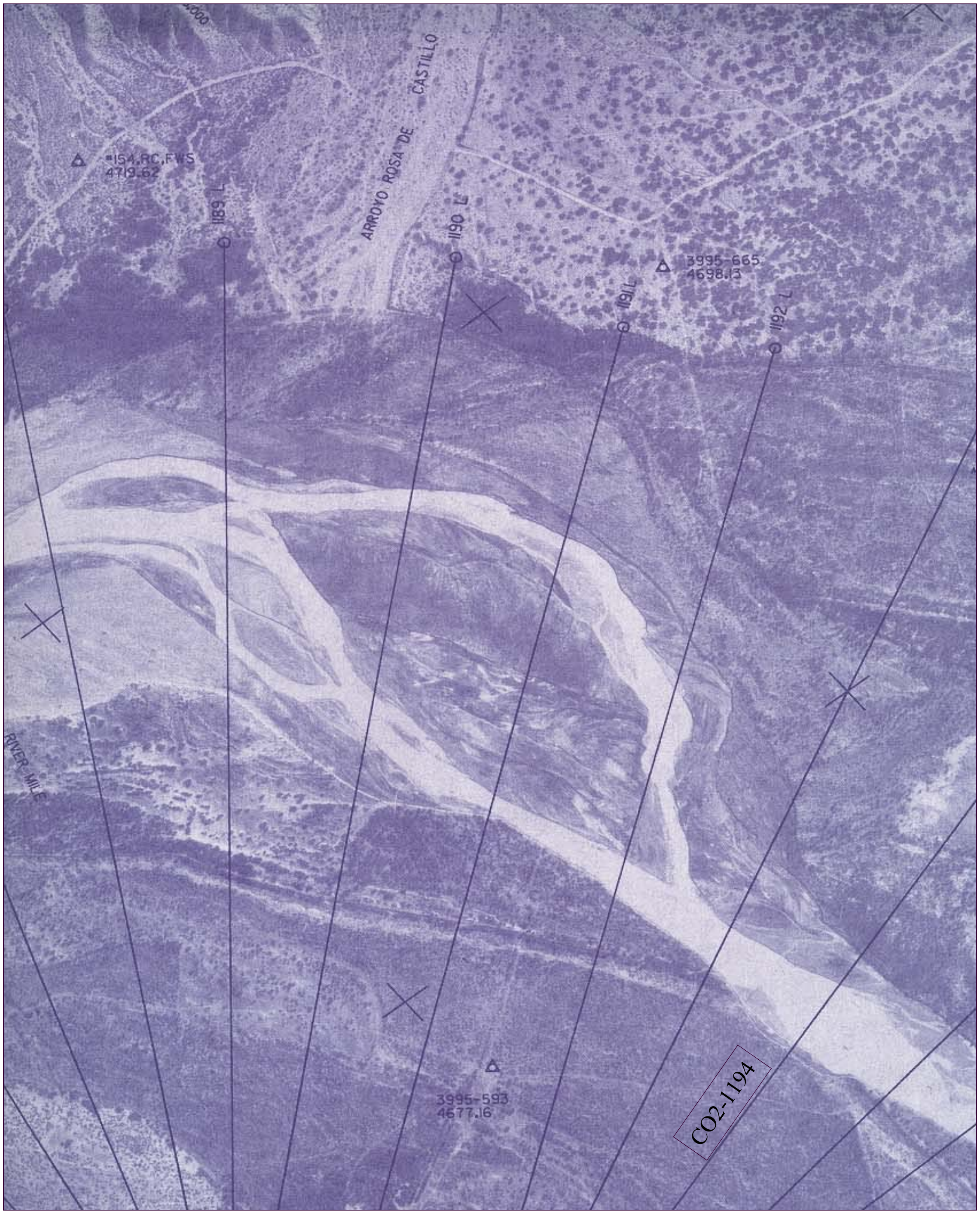

Figure 4.3. Rio Grande flowing from center left to lower right. The Arroyo Rosa de Casillo enters the Rio Grande from the top center. The Rio Salado enters joins the Rio Grande less than 1 mile upsteam (see Figure 4.1). Note the irregular change of course near the confluence of the Arroyo Rosa de Casitllo and the Rio Grande as well as the presence of abandoned channels.

Tributaries to the Middle Rio Grande are generally able to exhibit a certain degree of control on main-stem planform processes. This has been documented for several reaches of the Middle Rio Grande (Lagasse, 1980). As the Rio Puerco enters the Rio Grande, the channel narrows to form a single thread. The Rio Salado and the Arroyo Rosa de Castillo, which enter just upstream from the San Acacia diversion dam, also seem to exhibit a certain degree of control on the planform of the Rio Grande. As the Rio Grande encounters the delta formed by each of these tributaries, the river makes an abrupt change of direction and flows away from the most probable direction of flow and can be seen in Figures 4.1 to 4.3.

4.2 Mean Bed Elevation and Thalweg Elevation

Changes in mean bed elevation and thalweg elevation with time at each cross section can be seen in Figures E-1 to E-32 in Appendix E. Although the temporal density of the data is limited both mean bed elevation and thalweg elevation tend to follow similar trends throughout most of the surveys. Figure 4.4 shows the apparent decrease in mean bed elevation of approximately 6 feet between 1972 and 1992 at cross section CO2-1104.

In general, both the mean bed elevation and the thalweg elevation are decreasing, but there are some differences in the trends. A closer inspection of these plots shows that the mean bed elevation has decreased since 1962 at all but one of the cross sections (CO-668). There is a general trend of degradation but some variation exits between

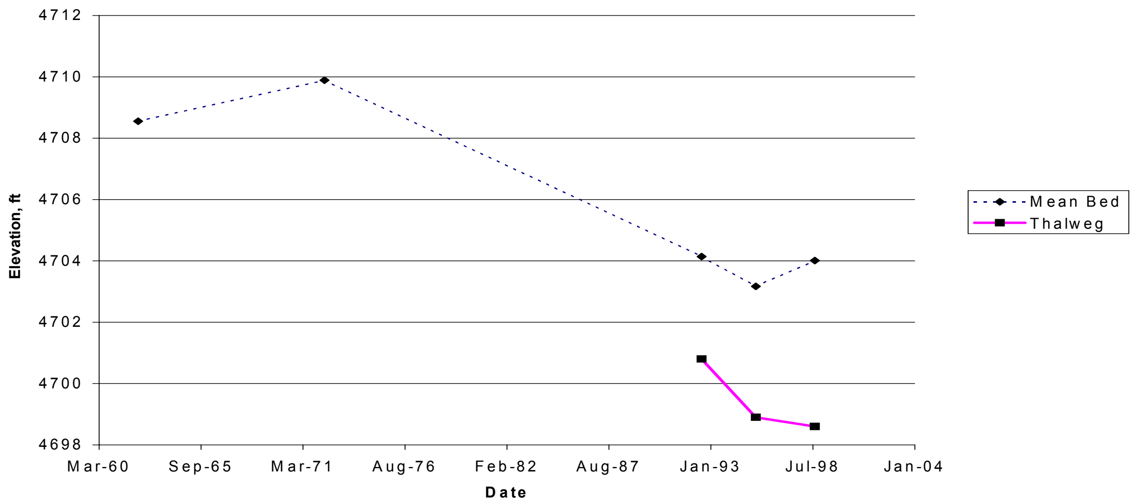

Figure 4.4. Change in mean bed elevation and thalweg elevation over time at cross section CO2-1104

surveys. Surveys taken in 1992, 1995, and 1998 often show fluctuations of 1 foot in mean bed elevations and 2 feet in thalweg elevations.

The other noticeable change is that the thalweg elevation from the 1995 survey is often much lower than the thalweg elevation from the 1992 survey. The degradation seen in 1995 is not generally seen in the 1998 survey. The thalweg elevation for 1998 at most cross sections was at or above the thalweg elevation of 1992. The aggradation between 1995 and 1998 is may be due to the timing of the 1995 survey. The 1992 and 1998 surveys were conducted during relatively low flows while the 1995 survey was completed near the end of the snow melt period when flows were sustained at over 5,000 cfs for over two months. Differences in mean bed elevation and thalweg elevation can also be attributed to the presence of islands and multiple channels since these affect the cross section geometry by reducing top width and cross sectional area.

At cross sections where the mean bed elevation and thalweg elevation follow different trends it is difficult to obtain an estimate of aggradation or degradation. Estimates can drastically vary depending on which of the two variables is used. From cross section CO-31 to cross section CO-38 both the mean bed elevation and thalweg elevation have decreased between 1971 and 1998. Cross sections between CO-668 and CO-926 show a decrease in mean bed elevation from 1982 to 1998, but cross sections CO-668, CO-724, CO-738.1, CO-806, CO-833, and CO-858.1 show an increase in thalweg elevation for the same time period. From cross section CO2-945 to CO2-1194 there were alternating reaches of increasing and decreasing mean bed elevations between 1992 and 1998. Each of the cross sections that increased in both mean bed elevation and thalweg elevation (CO2-966, CO2-1006, CO2-1064, and CO2-1194 between 1992 and 1998 had an increase in width to depth ratio and a decrease in cross sectional area.

Figure 3.13 in Chapter III shows considerable scatter among the data points. The majority of the points are located on the left side of the plot indicating a decrease in mean bed elevation. The points associated with cross sections CO-31 to CO-38 fall in the lower left portion of the plot indicating decreases in mean bed and thalweg elevation. The points associated with the remaining cross sections generally fall closer to the origin indicating lower amounts of degradation between the Isleta diversion dam and the San Acacia diversion dam.

4.3 Longitudinal Profile

Lagasse (1980) and Leon (1998) have previously documented changes in the longitudinal profile of the Middle Rio Grande below Cochiti Dam by using a thalweg profile. The longitudinal profile (Figures 3.7 to 3.9) for the reach of river between Bernalillo and San Acacia is generated from mean bed elevations. Mean bed elevations, rather than thalweg elevations are used in this section primarily because the 1962 and 1972 Agg/Deg surveys provide an additional 30 years of record for the lower end of the study reach.

The 88-mile reach of the Middle Rio Grande between Bernalillo and the San Acacia diversion dam shows degradation. Two general groupings can be seen here. The 1962, 1973, and 1980 surveys are more often than not grouped close together. The 1992, 1995, and 1998 surveys are also generally grouped in a similar fashion. The reach did not show much degradation before 1992. Most of the degradation within the reach took place between 1980 and 1992 with smaller amounts of degradation taking place after 1992.

Between cross section CO-31 and CO-35 (Figure 3.7) the mean bed profile for the 1980 survey is lower that the 1962 and 1973 profiles. At cross section CO-34 the 1980 profile had been lowered 1.09 feet below the 1973 profile. Below cross section CO-35 the 1980 profile shows signs of aggradation as it lies above the 1962 and 1973 profiles.

The 1992, 1995, and 1998 profiles are grouped relatively close together and generally show over two feet of degradation. Between cross section CO-31 and CO-33 the degradation increased with each survey year (1992, 1995, and 1998). At cross section CO-34 the 1995 profile dipped below the 1992 and 1998 profiles indicating temporary scour. Cross section CO-35 immediately downstream from cross section CO-34 showed a significant amount of temporary filling during the 1995 survey. The filling was reversed as the 1998 survey showed continued degradation.

Cross section CO-38 had not experienced any significant lowering of the mean bed elevation by 1992. The mean bed elevation had risen since the 1962 and 1973 surveys and was highest during 1980. By 1992 the bed had degraded just 0.93 feet. Between 1992 and 1995 the mean bed elevation decreased 1.01 feet in the three years. Between 1995 and 1998 there were minimal changes in the mean bed elevation as the bed elevation decreased 4 inches.

The first sub-reach below the Isleta diversion dam includes cross sections CO-668 to CO-926. Within this reach there are alternating reaches of scour and fill. The earliest Cochiti Range Line survey was completed in 1982 for this section of the river so the 1962 and 1972 Agg/Deg surveys were included to extend the period of record.

Between 1962 and 1972 the cross sections in this reach experienced an average of 0.6 feet of aggradation. The mean bed elevations shown in the 1972 profile (Figure 3.8) were the highest elevations recorded between 1962 and 1998. Cross section CO-668, which is downstream from the Isleta diversion dam, had an increase in mean bed elevation of 1.48 feet between 1962 and 1972. Between 1972 and 1992 the mean bed elevation decreased 0.84 feet. Since 1992 the mean bed elevation has been relatively stable and has not undergone any significant changes. Despite the decrease in mean bed elevation between 1972 and 1992, the mean bed elevation had not returned to the 1962 level by 1998 resulting in net aggradation for cross section CO-668.

The amount of degradation seen in this section of river is generally much lower than that seen in the previous reach. The trend for alternating reaches of aggradation and degradation is very evident in the profile between cross sections CO-668 and CO-926. The 1962 mean bed profile at cross section CO-668 has the lowest elevation. From cross section CO-668 to cross section CO-765 the 1962 bed profile gradually rises above all the bed profiles except the 1972 profile. The 1962 bed profile stays above the 1992, 1995, and 1998 bed profiles for the entire reach but begins to degrade at cross section CO-926 as the 1962 bed profile comes within 0.3 feet of the 1992, 1995 and 1998 bed profiles.

The 1992, 1995 and 1998 bed profiles more or less follow the same pattern described earlier. Sediment supplied from upstream sources and the riverbed moves through the reach in waves. The 1992 bed profile (Figure 3.8) shows scour from cross sections CO-668 to CO-738.1. There is filling from cross section CO-738.1 to CO-877 and scour from cross section CO-877 to CO-926. The bed profile for the 1995 survey shows filling from cross section CO-724 to CO-787. From cross section CO-787 to CO-806 the bed is scoured, from CO-806 to CO-833 the bed is filled and from CO-833 to CO-926 the bed is scoured. The bed profile for 1998 is in direct contrast to the 1995 bed profile. The 1998 bed profile was scoured where the 1995 bed profile was filled and was filled where the 1995 bed profile was scoured.

It is difficult to estimate actual amounts of degradation or aggradation in this reach. Changes in mean bed elevation from one year to the next are often less than 1 foot. It is hard to tell if the channel is experiencing local scour/fill or degradation/aggradation. As seen in Figure 3.11 the mean bed elevation has decreased at each cross section, except cross section CO-668, between 1962 and 1998 and illustrates that these changes were minimal.

The third sub-reach in the study reach, cross section CO2-945 to cross section CO-1194, has a longitudinal bed profile (Figure 3.9) similar to the bed profile of the previous sub-reach. In this sub-reach the 1962 and 1972 bed profiles are close together except between cross sections CO2-1104 to CO2-1164 where the 1972 bed profile is approximately 1.29 feet higher than the 1962 bed profile. The 1962 and 1972 bed profiles are also on average approximately 2.5 feet higher than the 1992, 1995, and 1998 bed profiles. This reach has also experienced more degradation than the previous sub-reach. The mean bed elevation at cross section CO2-1104 decreased 4.54 feet between 1962 and 1998 and the entire sub-reach degraded an average of 2.5 feet.

In contrast to the previous sub-reach, the 1992 and 1995 bed profiles appear to be out of phase rather that the 1995 and 1998 bed profiles. Between cross section CO2-945 and CO2-966 the 1992 bed profile is degrading while the 1995 bed profile shows aggradation. From cross sections CO2-966 to CO2-986 the 1992 bed is aggrading and the 1995 bed is degrading. Between cross sections CO2-986 and CO2-1006 the 1992 bed profile is degrading while the 1995 bed profile is aggrading. From cross section CO2-1006 to cross section CO2-1044 the 1992 bed profile is aggrading and the 1995 bed profile is degrading. Between cross sections CO2-1044 and CO2-1064 the 1992 bed profile is degrading and the 1995 bed profile is aggrading. From cross section CO2-1064 to CO2-1194 the 1995 bed profile is degrading while the 1992 bed profile is aggrading between cross section CO2-1064 to cross section CO2-1179 where it begins to degrade.

The 1998 bed profile remains between the 1992 and 1995 bed profiles from cross section CO2-945 to cross section CO2-986. From cross sections CO2-986 to CO2-1044 the 1998 bed profile appears to be degrading but aggradation occurs at cross section CO2-1064. From cross section CO2-1064 to cross section CO2-1091 the 1998 bed profile degraded. From cross sections CO2-1091 to CO2-1194 the 1998 bed profile aggraded.

The 4.5 feet of degradation seen at cross sections CO2-1091 and CO2-1104 occurred near the mouth of the Rio Puerco. In a similar fashion, Leon (1998) reported over 8 feet of degradation near the mouth of the Jemez River. Both rivers were large sediment contributors to the Middle Rio Grande and had deposited extensive amounts of fine sediment in the flood plain. As the sediment supply for the Jemez River was eliminated through the creation of a permanent pool behind the Jemez Canyon Dam, the deltaic deposits began to be eroded and significant amounts of degradation occurred.

The data suggests that a similar trend for the Rio Puerco. Suspended sediment discharge records for the Rio Grande and Rio Puerco (Figures 4.5 to 4.8) show years of high sediment discharge between 1957 and 1972 on the Rio Puerco. Evidence also suggests that much of this sediment was deposited in near channel deposits. In 1971 3.2 million tons of suspended sediment were transported on the Rio Grande through the gage in Albuquerque. Similarly, 3.9 million tons of sediment was transported past the gage on the Rio Puerco near Bernardo. That same year approximately 5.5 million tons of sediment were transported past the San Acacia diversion dam in the floodway and low flow conveyance channel leaving roughly 1.6 million tons of sediment to be deposited along the Rio Grande.

Similarly, the 1972 Agg/Deg survey revealed that the mean bed elevation at cross section CO2-1104, which is just below the mouth of the Rio Puerco, (Figure 4.4) had risen approximately 1.34 feet since the previous survey. The next cross section survey in 1992 shows the mean bed elevation had decreased by 6 feet since 1972. During this time period suspended sediment discharge decreased in the Rio Puerco and Rio Grande

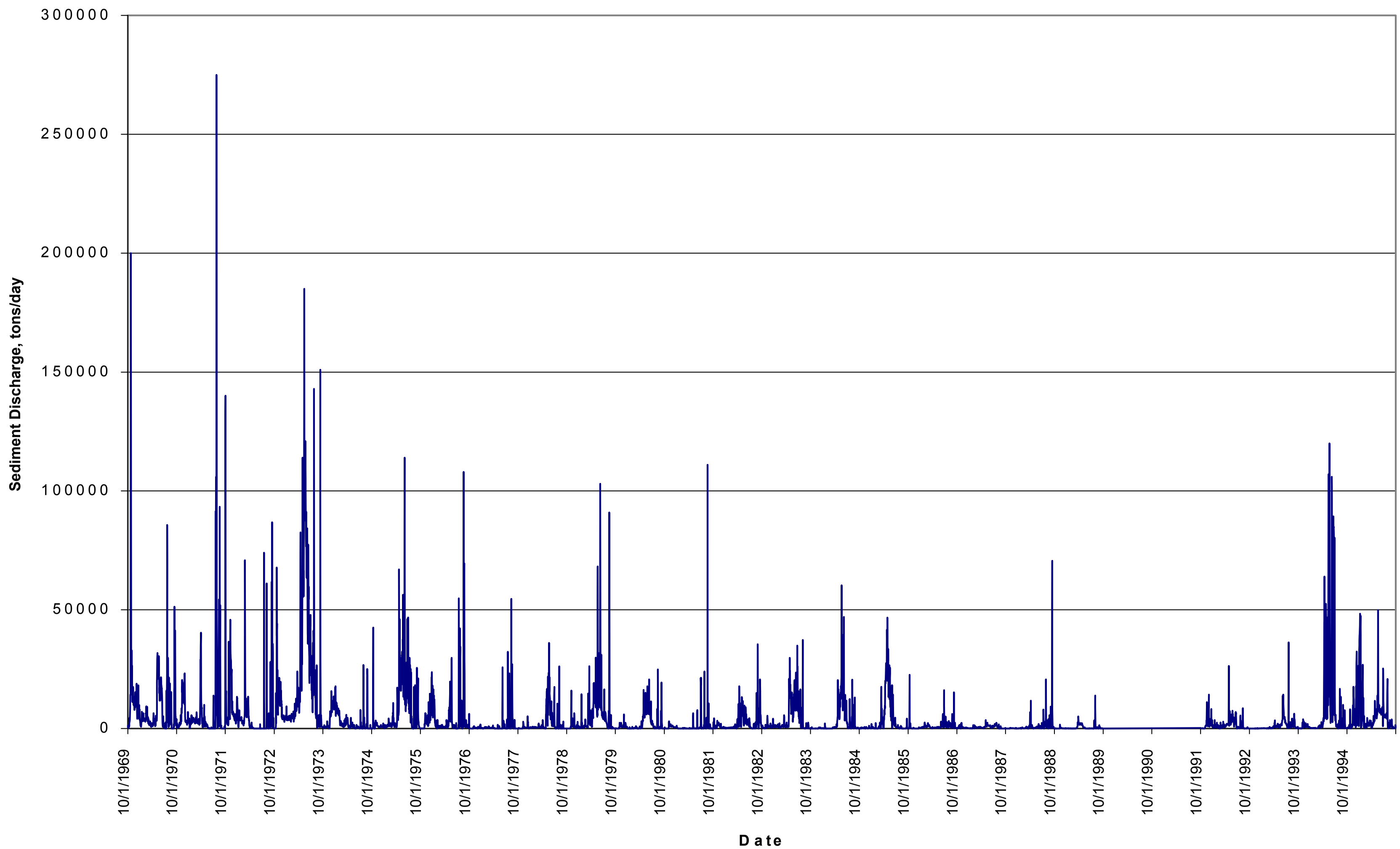

Figure 4.5. Suspended sediment discharge on the Rio Grande in tons/day at USGS gaging station (08-3300-00) near Albuquerque.

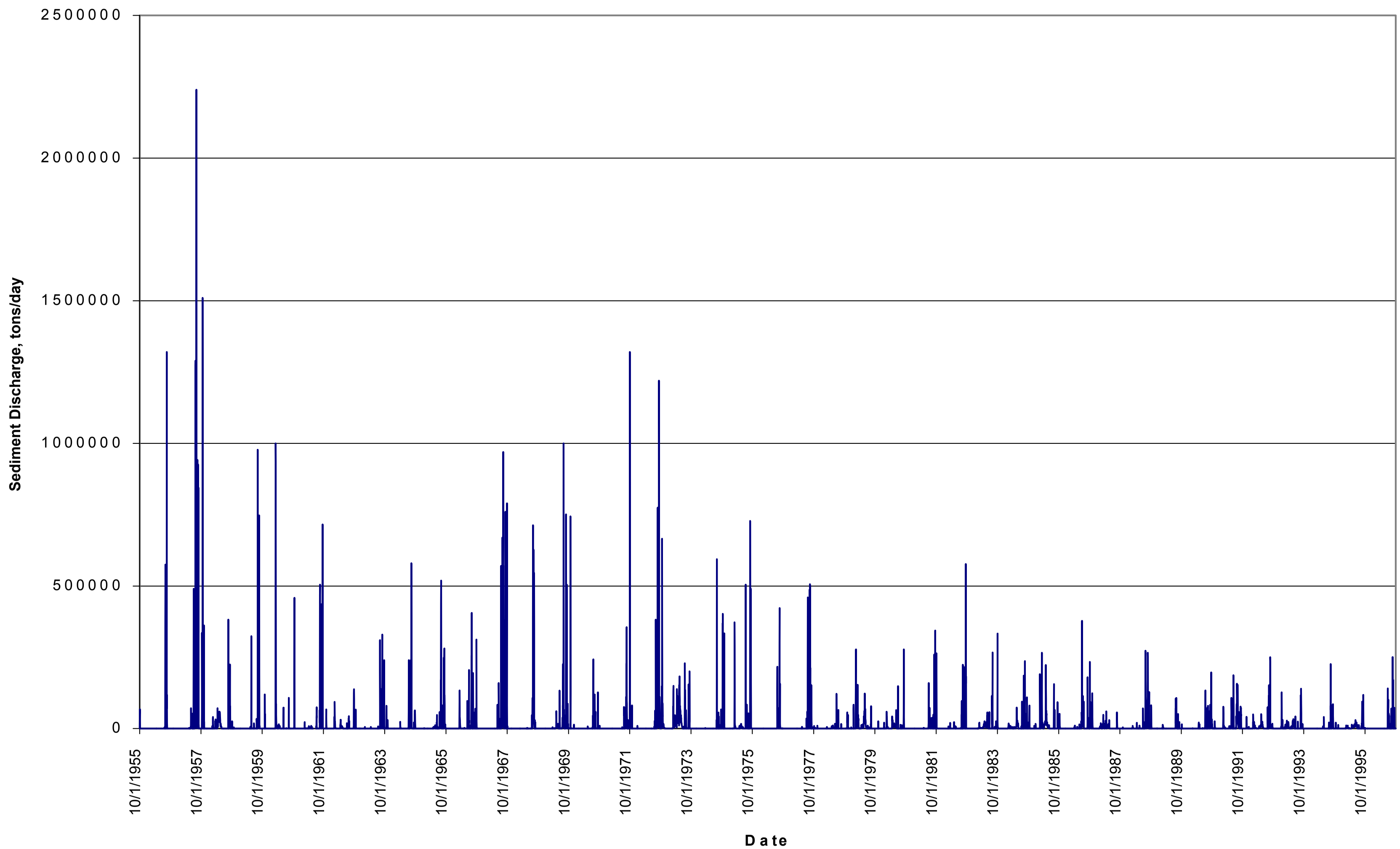

Figure 4.6. Suspended sediment discharge for the Rio Puerco near Bernardo in tons/day (USGS gage number 08-3530-00).

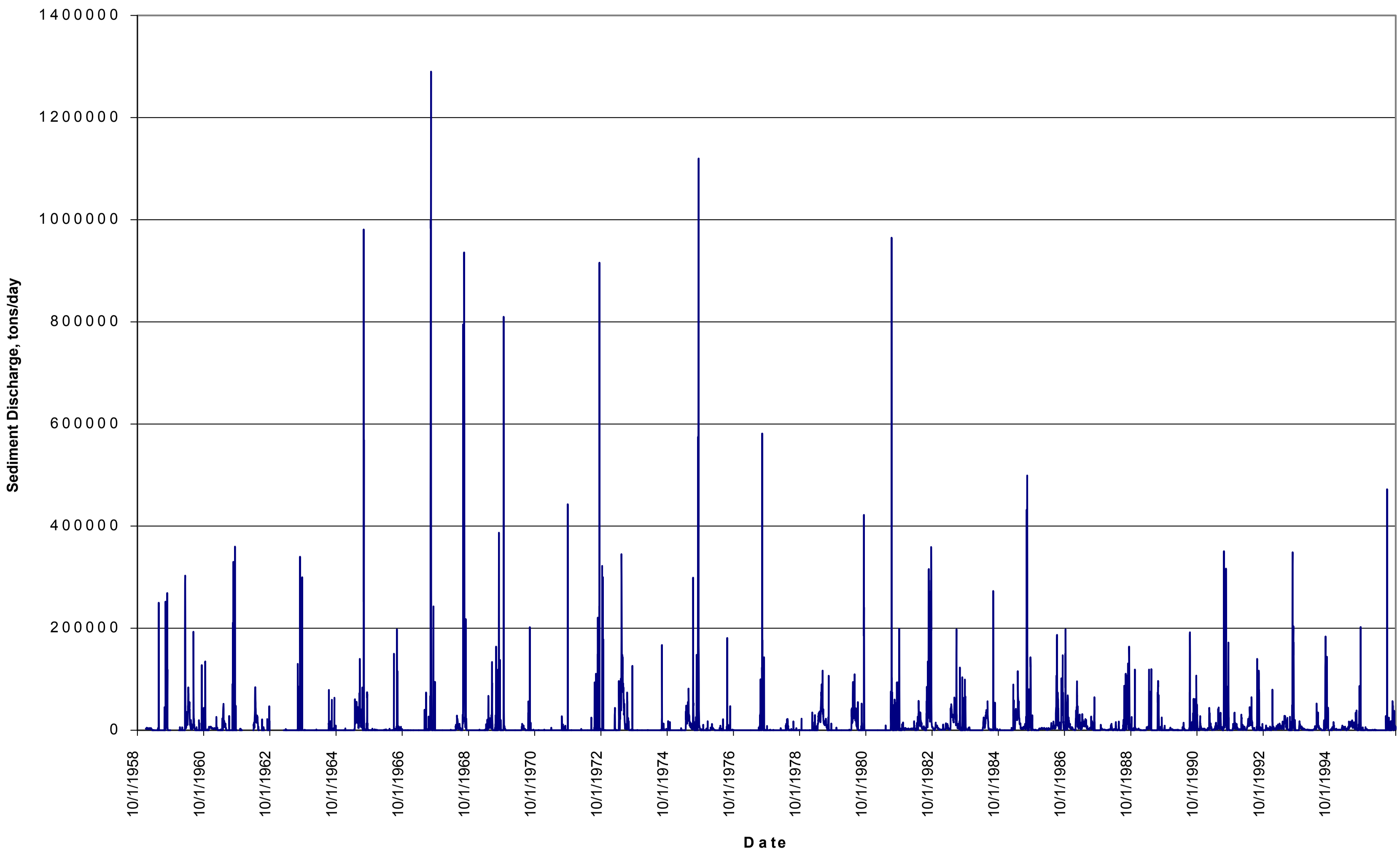

Figure 4.7. Suspeded sediment discharge for the Rio Grande at San Acacia in tons/day (USGS gage number 08-3549-00).

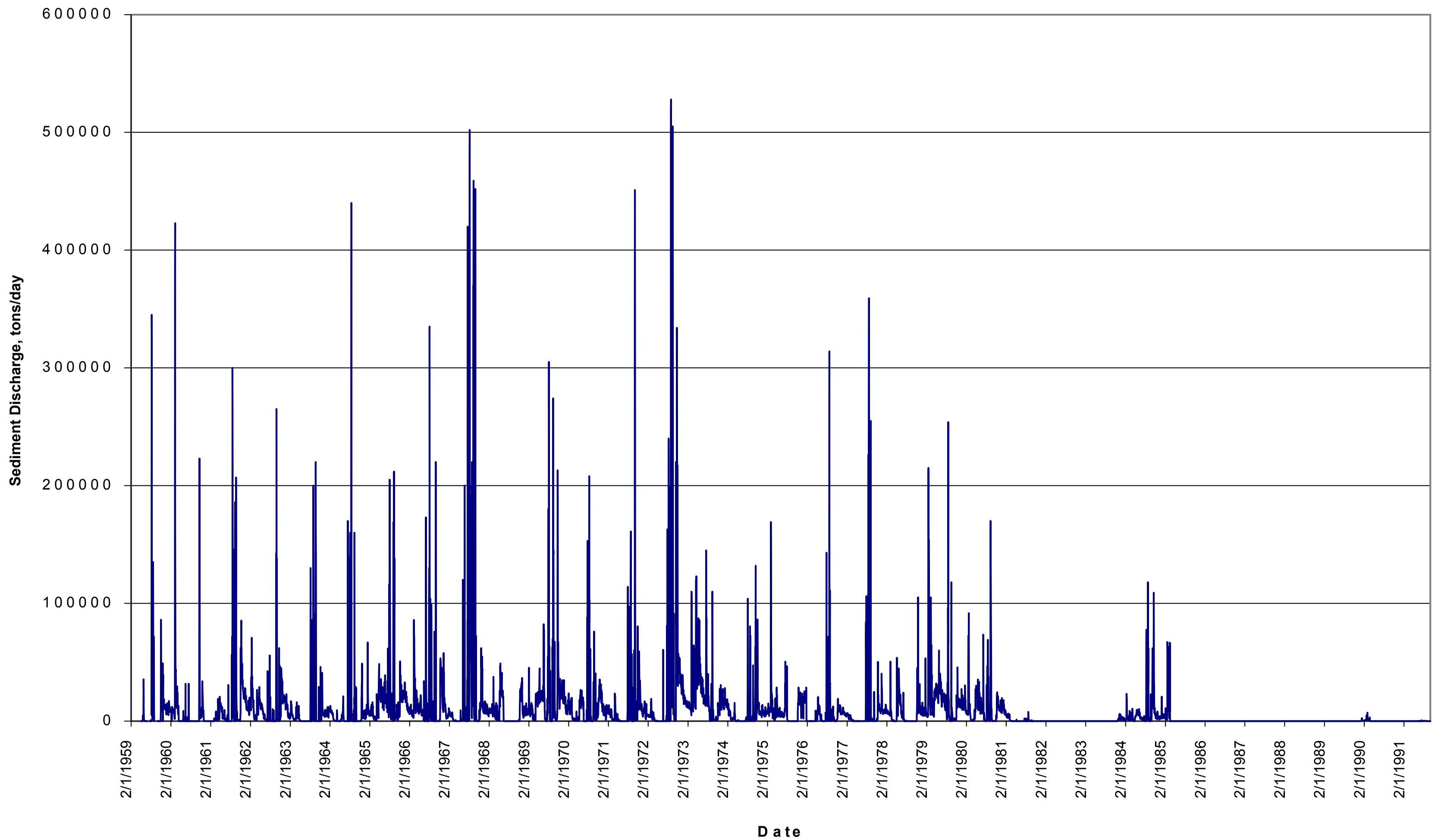

Figure 4.8. Suspeded sediment discharge for the Rio Grande Conveyance Channel at San Acacia in tons/day (USGS gage number 08-3548-00).

had decreased. In 1992 approximately the Rio Puerco and Rio Grande at Albuquerque transported 2.4 million tons of suspended sediment into the reach while roughly 2.9 million tons were transported out of the reach past the San Acacia diversion dam.

The cause of the degradation near the mouth of the Rio Puerco is similar to the degradation at the mouth of the Jemez River, degradation began after the sediment supply was reduced. The 6 feet of degradation at cross sections CO2-1091 and CO2-1104 between 1972 and 1992 is likely the result of channel incision through the deltaic deposits at the mouth of the Rio Puerco.

4.4 Bed Material

Bed material data for the study reach are spatially and temporally diverse and in some ways very limited. As described in Chapter II, the bed of the Rio Grande below the confluence of the Jemez River was sand. The data available for analysis consists of samples taken at USGS gage sites and samples taken at cross sections during surveys. Neither source provides a complete record of bed material during the study period but each provides useful insight into the coarsening of the riverbed subsequent to closure of Cochiti Dam in 1973.

USGS gaging stations at Albuquerque, Bernardo and San Acacia provide bed material particle size distributions from the late 1960’s to 1996. All three gage sites have an average median grain size that is less than 0.5 mm for the period of record. The average median grain size becomes progressively smaller as the distance below Cochiti Dam increases. At Albuquerque the median grain size ranged from just over 0.2 mm to just over 1 mm. At Bernardo the median grain size ranged from 0.2 mm to just over 0.3 mm. The median grain size at San Acacia ranged from approximately 0.14 mm to just under 0.4 mm.

The particle size distributions from the Albuquerque gage indicate that the bed is becoming gradually coarser. Despite the presence of coarse bed material as early as the summer of 1973, the bed did not show any significant signs of coarsening until 1996. By 1996 the median grain size had more than doubled and was just over 1 mm. This is still a small grain size in comparison to bed material sizes in the reach immediately below Cochiti Dam where the average bed material size is near 10 mm.

At Bernardo and San Acacia the particle size distributions for bed material samples are similar in that they are both dominated by fine-grained materials, however the bed material at the San Acacia gage is generally slightly coarser. Samples taken in 1989 indicate a median grain size of 0.25 mm at the Bernardo gage and 0.4 mm at the San Acacia gage.

Bed material samples taken from the Rio Puerco USGS gage site near Bernardo are somewhat different than those taken on the Rio Grande. Samples were taken in 1961 and 1989. The median grain size for samples taken in 1961 ranged from 1.5 mm to 4 mm. In 1989 the bed material sample had a median grain size of 0.2 mm. The median grain size for 1989 was similar to the median grain size taken at the USGS gage site on the Rio Grande near Bernardo.

The data from bed material samples taken during cross section surveys is similar to the USGS gaging site data. By 1992 the bed had coarsened as far downstream as cross section CO-33 with a median grain size of 4.43 mm. Below this cross section the mean grain size was roughly 0.3 mm which agrees with data from gaging sites along the reach. Figure 3.15 in Chapter III shows the increase in median grain size from cross sections CO-31 to CO-38 between 1971 and 1992. At cross section CO-668 the median grain size increased slightly from 0.36 mm to 0.43 mm between 1992 to 1998. Since no bed material samples were taken upstream of cross section CO-668 in 1998 it is not clear if the increase in median grain size is due to the downstream progression the coarsening process or variations in bed material samples.

The influence of the Rio Puerco on the Rio Grande is also evident in Figure 3.15 in Chapter III. At cross section CO2-1104 there is a marked increase in median grain size. This cross section is located just downstream of the confluence of the Rio Puerco and the Rio Grande. The increase in median grain size directly below the junction of the Rio Grande and the Rio Puerco coincides with the increase in coarse material found at the gaging station located at San Acacia.

4.5.1 Cross Sections: Sub-Reach I

This section presents an analysis of the geometric characteristics of each cross section. Changes in cross section area, bed elevation and shifts in bank line position are discussed at each cross section. The position of arroyos and tributaries with respect to cross sections is found by using the 1992 aerial photos. This analysis is based on the changes from the earliest and most recent Cochiti range line surveys available at each cross section. Table E-1 in Appendix E contains the cross section geometry for cross sections CO-31 to CO-38.

Cross section CO-31 is located in a straight stretch of river 3.1 miles downstream from New Mexico highway 44. Cross section plots of cross section CO-31 from 1971 to 1975 show slight changes in bed arrangement from year to year. The variation from year to year is likely due shifting bed features such as sandbars. Between 1971 and 1975 the thalweg remained near the left bank but degraded approximately 4 feet. Between 1979 and 1998 (Figure 4.9) the thalweg shifted position several times. In 1995 the thalweg was on the right bank, but by 1998 the thalweg had shifted back to the left bank. Sustained degradation of the cross section is apparent by 1992. By 1998 the thalweg had degraded approximately 5 feet and the mean bed elevation was lowered by just over 3 feet. The top width increased from 378 feet to 404 feet and the mean depth increased from 1.47 feet to 6.92 feet between 1971 and 1998. The cross section had an increase in area of over 400 percent and a decrease in width to depth ratio of 77 percent.

Located approximately 2000 feet down stream of the previous cross section, cross section CO-32 is also located in a straight section of river. Cross section CO-32 is much narrower than the previous cross section, but shows many of the same trends. Between 1971 and 1975 bars shift across the channel but the thalweg remains near the right bank. The 1979 survey revealed extensive scouring of the thalweg. The thalweg elevation was nearly 4 feet lower than the thalweg elevation during latest survey taken in 1998. Even though the thalweg degraded in 1979 the mean bed elevation rose sharply as the left portion of the bed aggraded extensively. In 1998 there was relatively little change in thalweg elevation from 1971 but the mean bed elevation had degraded nearly 3.5 feet. The top width increased slightly from 270 feet to 279 feet and the mean depth rose from 2.16 feet to 5.29 feet. The decrease in mean bed elevation resulted in an increase in cross section area by 152 percent and a decrease of width to depth ratio of 58 percent between 1971 and 1998.

Cross section CO-33 is located in a straight stretch of river running north and south. Arroyo de la Baranca joins the Rio Grande just upstream from the cross section and Arroyo de Las Lomatas Negras enters the Rio Grande just downstream from the cross section. Pre-dam cross section plots reveal a mobile channel. In 1971 the thalweg was on the right bank. In the March 1972 survey the thalweg had shifted to the left bank with extensive filling of the right half of the channel. By November of the same year, the entire channel had aggraded several feet and the thalweg was located nearly three feet higher than it had been eight months earlier and was now in the middle of the channel. In the summer of 1973 the left half of the channel continued to aggrade while the right half degraded. After closure of Cochiti Dam the bed continued to move with the thalweg shifting from one bank to the other. The thalweg elevation did not change very much between 1971 and 1998 but the bed was lowered just over 1.5 feet. Th width of the cross section increased slightly from 640 feet to 651 feet as the right bank moved to the right just over 10 feet. The cross section area also increased by 138 percent while the width to depth ratio fell by 56 percent from 1971 to 1998 as the mean depth increased from 1.81 feet to 4.22 feet.

Cross section CO-34 is located on a slight bend in the river just upstream from the Alameda Boulevard Bridge. This cross section is similar to previous cross sections in that the thalweg is prone to shifting from one bank to the other and as the thalweg shifts the portion of the channel where the thalweg moved from is filled in. The cross section shows a general trend of degradation but when the thalweg degrades extremely as in 1975 and 1982 there tends to be extreme aggradation in the remainder of the cross section. Between 1971 and 1998 the width of the cross section increased by 10 feet from 457 feet to 467 feet as the right bank shifted outward. The increase in width accompanied by an increase in mean depth from 1.64 to 4.44 led to a 176 percent increase in cross section area and a 62 percent decrease in width to depth ratio.

Cross section CO-35 is located 4.5 miles downstream from the previous cross section in a straight section of river. The cross section is not perpendicular to the channel as it is

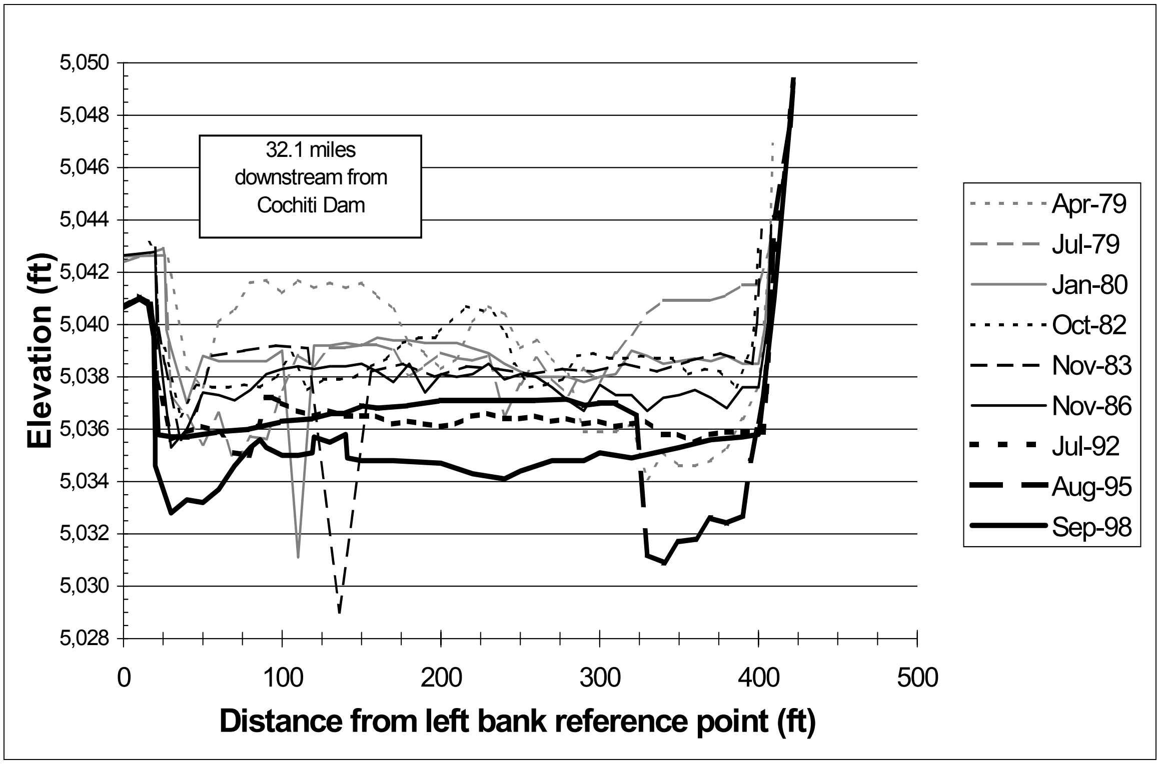

Figure 4.9. Cross section CO-31

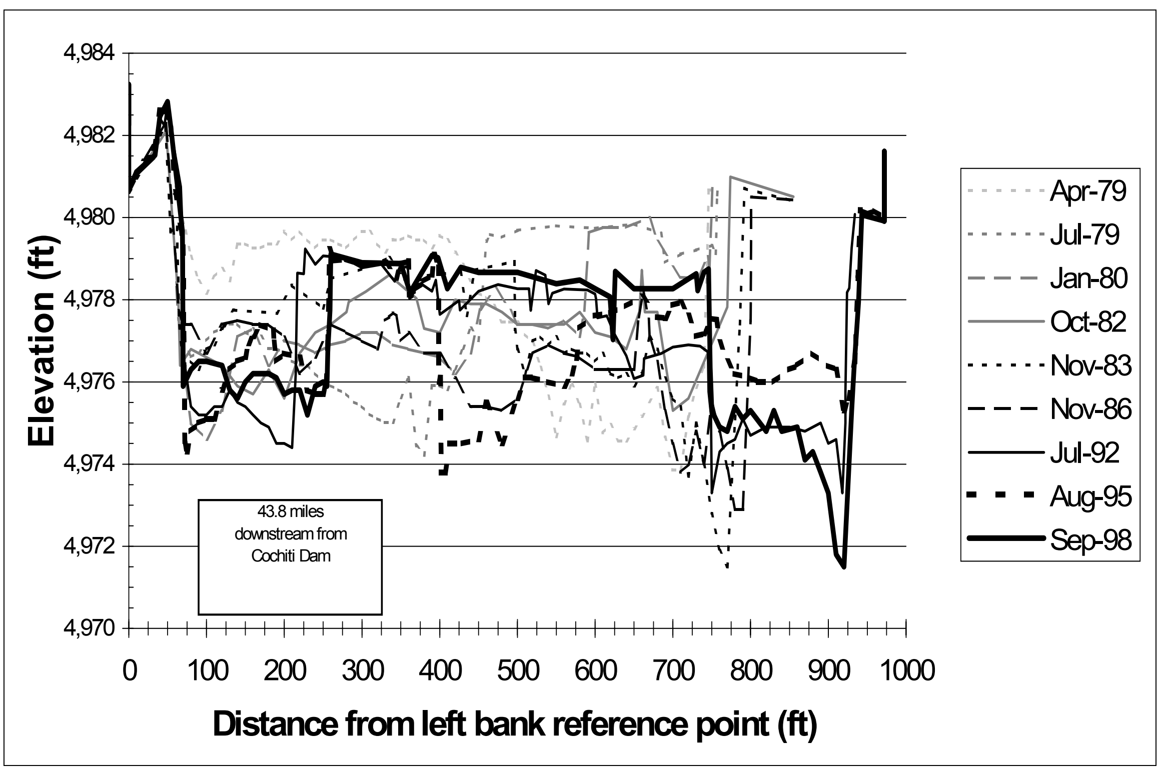

Figure 4.10. Cross section CO-35.

slightly skewed. Since the cross section is skewed, changes in width, cross section area, and width to depth ratio will not be discussed. Surveys from 1971 indicated that the middle of the cross section was shallow with some small channels or chutes. In the two years following the closure of Cochiti Dam the left side of the cross section was filled in and the flow was no longer split, which left the thalweg on the right bank. Subsequent to high flows in 1979 the right bank began to migrate outward. From 1979 to 1998 (Figure 4.10) the cross section reverted into the previous split-flow pattern with a mid-channel bar. The bed has degraded from 1970 to 1998 but the decrease in mean bed elevation is largely due to the channel to the right of the bar. The right bank shifted to the right by more than 200 feet as the width increased from 188 fee to 402 feet between 1970 and 1998.

Cross section CO-36 is located approximately 50 miles below Cochiti Dam on the downstream side of the Central Avenue Bridge. This is a fairly narrow cross section with sustained widths ranging from 320 feet to just over 400 feet. Cross section CO-36 is best characterized by a relatively consistent location of the thalweg near the right bank. The exceptions to this came in September 1974 and November 1983 when the thalweg was close to the left bank. In general, the bed slopes from the left bank downward to right bank. From 1971 to 1998 the right bank migrated outward by roughly 60 feet as the width increased from 341 feet to 404 feet and the mean bed elevation decreased by nearly 3 feet as the mean depth increased from 1.58 feet to 4.02 feet. For the same time period the cross section area was increased by almost 200 percent while the width to depth ratio was decreased by 54 percent.

Cross section CO-37, located at the Rio Bravo Bridge, is located on a straight stretch of river approximately 54 miles below Cochiti Dam. The pre-dam plots of this cross section generally show the thalweg near the left bank but the thalweg position is not stable and it shifted several times during the study period. From 1970 to 1979 the cross section is fairly narrow with top widths under 400 feet. Beginning in 1980 the top width began to increase. The increase in top width occurred when the left bank migrated outward after the high flows 1979. The width increased form 282 feet in 1971 to 528 feet in 1998. From 1971 to 1998 the mean bed elevation was lowered 0.84 feet as the mean depth increased from 1.07 feet to 3.14 feet. The cross section area increased by 450 percent and the width to depth ratio decreased 36 percent. The sharp rise in cross section area was due to the lowering of the bed and the dramatic widening of the channel.

Cross section CO-38 is located in straight stretch of river approximately 4000 feet upstream from the Interstate 25 Bridge and 4 miles upstream from the Isleta diversion dam. This cross section generally shows aggradation and shifting thalweg positions. Aggradation appears to have taken place from 1970 to 1979. Subsequent to the high flows of 1979 and the creation of a permanent pool at the Jemez Canyon Dam the channel began to degrade. Surveys in the 1980's reveal a gradual lowering of the bed. The 1992 survey not only revealed continued degradation but also a mid-channel bar. This bar is seen again in 1995 and 1998 only it becomes smaller between each survey. The mean bed elevation decreased 2 feet and from 1971 to 1998 while the thalweg elevation shows very little change. During the study period the width decreased from 658 feet to 634 feet and the mean depth increased from 1.55 feet to 3.57 feet. The cross section area increased 122 percent while the width to depth ratio decreased by 58 percent. Both banks have moved during the study period. The left bank moved outward 5 to 10 feet and the right bank moved inward over 30 feet for a decrease in top width of approximately 25 feet.

4.5.2 Cross Sections: Sub-reach II

The next section of river to be analyzed consists of 12 cross sections (CO-668 to CO-926). This section of the Cochiti range lines was established and first survey in 1982. Changes in mean bed elevation, thalweg elevation, bank position, cross section area, top width, and with to depth ratio will be referenced to the earliest survey date available for this reach, which is 1982 or 1983 depending on the cross section. Table E-2 in Appendix E contains the hydraulic geometry for cross sections CO-668 to CO-926.

Cross section CO-668 is located about 1 mile below the Isleta diversion dam on a straight section of river. When first surveyed in 1982, the cross section had a mid-channel bar with the thalweg on the left bank. In 1983 the mid-channel bar was more developed but closer to the left bank and the thalweg was now on the right bank. In 1986 the mid-channel bar was more or less eliminated as the left side channel was filled and the thalweg elevation was also lowered nearly 4 feet on the right bank. The 1992 survey showed aggradation and a return of the mid-channel bar. By 1995 the mid-channel bar had become less pronounced, however, the thalweg had returned to the left bank. In 1998 the mid-channel bar was even less pronounced as it extended just over 2 feet above the thalweg. Both the right and left side of the channel had thalweg elevations that were nearly equal. The width of the cross section increased from 524 feet to 591 feet and the mean depth increased from 1.2 feet to 2.01 feet. The cross section saw an increase in area of 89 percent and a decrease of 33 percent in width to depth from 1982 to 1998.

Cross section CO-713 is located 68.7 miles downstream from Cochiti Dam in a straight section of river. This cross section has seen very little bed degradation. Since 1982 the mean bed elevation has decreased less than 0.5 feet. The cross section can be best described as having a shifting bed. The thalweg has consistently been near the left bank but bed features, such as bars, move from year to year and show no consistent patterns. Between 1982 and 1998 the cross section width changed less than one foot and remained approximately 679 feet. The mean depth of the cross section increased from 2.21 feet to 2.68 feet. The cross section had a 20 percent increase in cross section area and an 18 percent decrease in width to depth ratio.

Cross section CO-724 is located approximately 70 miles downstream from Cochiti Dam. The cross section is located in a straight section of river just over one mile below the previous cross section. This cross section is similar to the previous cross section in that it has bed features that change from year to year and bar position does not seem to be permanent. The thalweg position is also variable, as it has been found near the right and left bank as well as near the center of the channel. The cross section has remained relatively stable from 1982 to 1998 as mean bed elevation decreased approximately 0.5 feet, cross section area increased 33 percent, width to depth ration decreased 18 percent, and top width increased by 25 feet. The top width increased from 564 feet to 589 feet and the mean depth increased from 2.36 feet to 3.0 feet.

Cross section CO-738.1 is located approximately 71 miles downstream from Cochiti Dam on the upstream side of the New Mexico Highway 49 Bridge. This cross section is best characterized by shifting bed features and relatively stable thalweg position. Except for the 1992 survey the thalweg for cross section CO-738.1 was located near the right bank. In general the cross section is deepest near the right bank with thalweg depths ranging from 4.87 feet to 7.19 feet The channel bottom is highest just to the right of the channel mid-point. The channel also appears to be degrading at this cross section with each successive survey yielding lower mean bed elevations. From 1982 to 1998 the mean bed elevation decreased just over 1 foot as the mean depth increased from 1.88 feet to 2.96 feet. Similarly the cross section area increased by 68 percent while the width to depth ration decreased by 32 percent. The bank lines of the cross section experienced some instability as the top width increased nearly 50 feet from 30 feet to 777 feet.

Cross section CO-765 is located approximately 74 miles downstream from Cochiti Dam on a straight section of river. This cross section is characterized as having a dominant mid-channel bar. The bar is present in all surveys from 1982 to 1998 and results in split flow around the bar. The height of the bar appears to be decreasing and the mean bed elevation has decreased approximately 1 foot as the mean depth has increased from 2.02 feet to 3.09 feet. The channel to the right of the bar is generally deeper than the left side. Thalweg elevations for the left channel are typically 2 to 4 feet higher than seen on the right channel with the exception of 1986 and 1998 where this pattern was reversed. The cross section has seen some changes as the cross section area increased by 66 percent, the width to depth ratio decreased by 29 percent and the top width increased from 567 feet to 613 feet.

Cross section CO-787 is located just over 75 miles below Cochiti Dam on a straight section of river. The cross section has a fairly dominant mid-channel bar that is present in most cross section surveys. Except for the 1982 survey, the thalweg is consistently located near the right bank. The left half of the channel is much shallower and slopes down from the center toward the left bank. Surveys from 1983, 1986 and 1995 have the deepest thalweg depths on the right half of the channel and range from roughly, but tend to have higher bed elevations on the left half of the channel. The cross section did show signs of degradation as the mean bed elevation decreased nearly 1 foot from 1982 to 1998 as the mean depth increased from 1.47 feet to 2.44 feet. The cross section area increased by 66 percent, the width to depth ratio decreased by 40 percent and the top width remained virtually unchanged at roughly 570 feet.

Cross section CO-806 is located 78 miles below Cochiti Dam just below the town of Tome. This cross section is typical of others in the reach in that that it has a mobile bed. In 1982 the thalweg was located near the right bank but each survey since then has shown the thalweg moving to the left. In 1983 and 1986 the thalweg was near the center of the channel and midway between the center and left bank in 1992. The entire bed was scoured in 1995 and the thalweg shifted slightly to the right. In 1996 the thalweg had moved to the left bank where it still remains. The cross section has very stable banks as the top width increased approximately 6 feet from 555 feet to 561 feet. A 69 percent increase in cross section area, a 39 percent decrease in width to depth ratio, and a decrease in mean bed elevation of 1.18 feet accompanied the slight increase in top width. The mean depth increased from 1.76 feet to 2.94 feet.

Cross section CO-833 is located approximately 80 miles downstream form Cochiti Dam. 1982 survey data is not available for this cross section so the November 1983 survey is used as a reference cross section. In 1983 the thalweg was located near the right bank and there was a bar near the left bank. By 1992 the thalweg depth had increased from 6.67 feet to 7.87 feet but was still along the right bank. The 1995 survey once again indicated that the thalweg was along the right bank and that the depth had increased to 8.97 feet. The entrenchment of the thalweg in 1995 was accompanied by aggradation to the left of the thalweg in the center of the channel. By 1998 the thalweg had shifted to the left bank and the thalweg depth had decreased to 5.47 feet. The riverbed in 1998 had many small bars with deeper water located near the banks. From 1983 to 1998 the cross section area increased by 62 percent and the width to depth ratio decreased by 37 percent. The mean bed elevation decreased 1.25 feet as the mean depth increased from 2.13 feet to 3.42 feet, and the banks remained stable as the top width increased from 585.11 feet to 591.87 feet.

Cross section 858.1 is located on the upstream side of the New Mexico Highway 6 Bridge approximately 83 miles below Cochiti Dam near the town of Belen. This cross section has changed significantly as the right bank has migrated over 100 feet (Figure 4.11). The lateral bank migration occurred after 1986. The 1992 survey shows that the right bank had migrated 100 feet to the right since the previous survey. The right bank continued to migrate and surveys from 1995 and 1996 show continued lateral migration. By 1998, however, the lateral migration had ceased and the right bank had shifted back to the left. Despite the shift back to the left the bank was still farther to the right than it had been in 1992. In 1982 and 1983 the thalweg was located near the left bank and there was also a bar near the left bank. In 1986 the bar near the left bank remained but the thalweg shifted to the right bank. The 1992 and 1995 cross section surveys show a

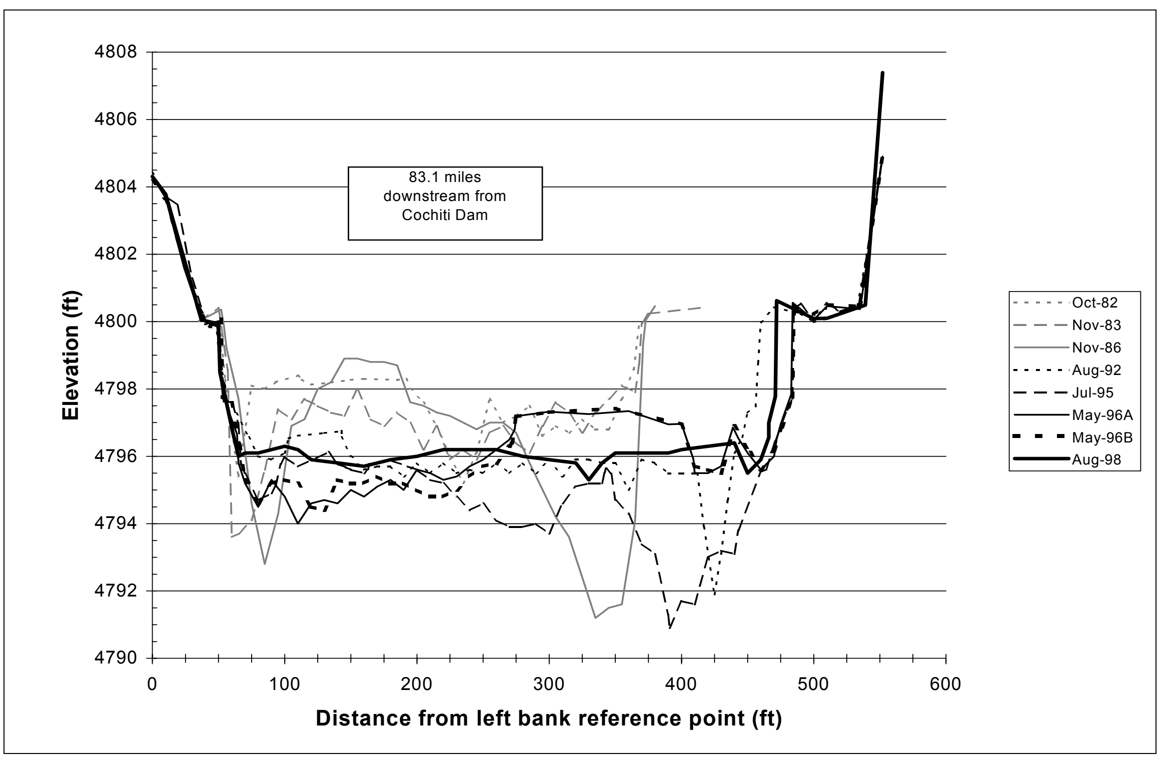

Figure 4.11. Cross Section CO-858.1.

general lowering of the bed and the thalweg remaining near the right bank. By 198 the bed had become much more uniform with few features and no dominant thalweg. The mean bed elevation in 1998 was higher than it was in 1992 and 1995 but nearly 1.4 feet of degradation had occurred since 1982. From 1982 to 1998 the mean depth increased 2.45 feet to 3.82 feet and the top width increased from 317 feet to 422 feet The cross section area increased 108 percent and the width to depth ration decreased only 14 percent.

Cross section CO-877 is located on the upstream side of the A.T & S.F Rail Road Bridge approximately 85 miles below Cochiti Dam. This cross section is characterized by shifting bed features and narrow bar near the right bank. The narrow bar forms the right bank in 1982 but in 1983, 1986, and 1992 the right bank is farther to the right. The cross section top width increased from 338 feet to 414 feet from 1982 to 1992. The cross section area increased 56 percent and the width to depth ration decreased 4 percent. The mean bed elevation decreased progressively and by 1998 the cross section had degraded 0.68 feet as the mean depth increased from 2.45 feet to 3.13 feet.

Cross section CO-895 is located roughly 87 miles below Cochiti Dam near the town of Jarales. This cross section is characterized by mobile bed features. From 1982 to 1998 the thalweg is consistently located in the left half of the channel and ranges from 3.4 feet to 4.8 feet, however, the thalweg position changes within the left half of the channel from year to year. The general pattern for this cross section is deeper water near the left bank with shallow sections near the center and deeper sections near the right bank. The cross section has degraded since 1982 but the minimum mean bed elevation occurred in 1992. Between 1982 and 1998 the mean bed elevation decreased only 4 inches as the mean depth increased from 1.12 feet to 1.53 feet. The cross section area increased 40 percent, the width to depth ration decreased 15 percent, and the top width increased approximately 45 feet from 485 feet to 528 feet.

Cross section CO-926 is located 88.5 miles below Cochiti Dam on a straight section of river. This cross section is similar to many of the previous cross sections and is characterized by a mobile be with shifting features. The thalweg has been located along both banks and near the center of the channel. Thalweg depths range from 3.01 feet to 8.65 feet. When the thalweg was scoured deeply there was usually aggradation near the center of the channel. Since 1982 the mean bed elevation has decreased as the mean depth increased from 1.63 feet to 2.35 feet, the cross section area has increased 28 percent, and the width to depth ratio has decreased 38 percent. The top width also decreased from 545 feet to 480 feet between 1982 and 1998 with a maximum width in 1995 at 609 feet.

4.5.3 Cross Sections: Sub-reach III

The next section of river to be analyzed consists of 12 cross sections (CO2-945 to CO2-1194). This section of the Cochiti range lines was established and first surveyed in 1992. Changes in mean bed elevation, thalweg elevation, bank position, cross section area, top width, and with to depth ratio will be referenced to the earliest survey date available for this reach, which is 1992 for this sub-reach. Table E-3 in Appendix E contains the cross section geometry for cross sections CO2-945 to CO2-1194.

Cross section CO2-945 is located in a narrow section of river just upstream from the Jarales Road Bridge 91 miles downstream from Cochiti Dam. This cross section is also the same as Casa Colorada range line 945. The bed of this cross section is similar to other cross sections upstream. In 1992 the thalweg depth was 8.25 feet and near the left bank, but by 1995 the thalweg depth had increased to 12.45 feet and was near the right bank. In 1998 the thalweg was still near the right bank but a significant amount of filling had taken place as the depth had decreased to 5.5 feet. As with other cross sections, the deep thalweg of 1995 was accompanied by aggradation of the remainder of the bed. The mean bed elevation decreased from 1992 to 1995 and then increased from 1995 to 1998. Between 1992 and 1998 the mean bed elevation was lowered 0.1 feet as the mean depth increased from 3.81 feet to 3.91 feet. The cross section area and width to depth ratio changed very little and the top width increased slightly from 57 feet to 361 feet as the right bank migrated approximately 4 to the right.

Cross section CO2-966 is located approximately 93 miles down stream from Cochiti Dam. Like the previous cross section, this cross section has also experienced variable thalweg position. In 1992 the thalweg is located near the left bank and 6.79 feet deep. The 1995 survey indicated that the thalweg depth had increased to 9.09 feet and was near the right bank. By 1998 the thalweg depth had decreased to 6.49 feet and was once again near the left bank and the bed profile was similar to the 1992 bed. Between 1992 and 1998 the cross section aggraded as the mean bed elevation increased 0.57 feet from an decrease in mean depth from 4.4 feet to 3.83 feet. The cross section area decreased 13 percent and the width to depth ratio increased 15 percent. The cross section proved to be very stable as the bank lines changed less than 5 feet and the top width remained near 555 feet.

Cross section CO2-986 is located on a slight bend in the river 96 miles below Cochiti Dam. The thalweg position for this cross section is also variable as the 1992 position was in the center of the channel. The thalweg had deepened from 5.41 feet to 10.21 feet and moved to the right bank by 1995. In 1998 the thalweg had filled in to a depth of 6.41 feet but remained near the right bank. The mean bed elevation had decreased nearly 1 foot from 1992 to 1995 but then degraded another 0.5 feet by 1998. From 1992 to 1998 the mean depth increased from 3.98 feet to 4.41 feet. The cross section area increased approximately 12 percent from 1992 to 1998 but the width to depth ratio and bank lines changed very little and the top width ranged from 389 feet to 418 feet.

Cross section CO2-1006 is located in a straight section of river 97 miles downstream from Cochiti Dam. The cross section does not have a constant thalweg position. In 1992 the thalweg depth is 5.94. In 1995 the thalweg depth had increased to 9.04 feet and had shifted to the left bank where a large bar occupied most of the channel. By 1998 the thalweg depth had decreased to 5.84 feet and had shifted to the right bank. In the process of shifting, the deep thalweg of 1995 had been filled and the bar was more or less removed. Cross section area, mean bed elevation, and width to depth ratio for cross section CO2-1006 changed very little between 1992 and 1998. The mean depth remained near 3.9 feet and the top width remained near 580 feet.

Cross section CO2-1026 is located 99 miles downstream from Cochiti Dam between two bends in the river. This cross section is approximately 450 feet wide and the thalweg is generally located between the left bank and the center of the channel. The 1992 thalweg was located near the center of the channel while in 1995 and 1998 the thalweg was located near the left bank. In 1992 and 1995 the left half of the channel was fairly deep while the right half of the channel was much shallower. By 1998 the bed had become much more uniform as channel bottom elevations were all within 1 or 2 feet. Despite the changes in the shape of the cross section there was little in the way of change. The cross section area, width to depth ratio, bank position, and mean bed elevation showed no noticeable signs of change between 1992 and 1998. The mean depth increased slightly from 4.43 feet to 4.67 feet.

Cross section CO2-1044 is located 101 miles downstream from Cochiti Dam on straight section of river just upstream from the U.S. Highway 60 Bridge. This cross section shows signs of degradation. The mean bed elevation decreased 1.13 feet from 1992 to 1998 as the mean depth increased from 3.73 feet to 4.86 feet. The decrease in mean bed elevation and an increase in top width from 670 feet to 689 feet led to an increase in cross section area of 34 percent and a decrease in width to depth ratio of 21 percent. The thalweg position is variable as the 1992 and 1998 thalweg position was near the left bank and the 1995 thalweg position was near the right bank. Thalweg depths ranged from 7.95 feet to 10.65 feet.

Cross section CO2-1064 is located 103 miles downstream from Cochiti Dam just above a large expansion in the river. This cross section is similar to upstream cross sections. The thalweg position varies with each survey and bed features are not retained from one survey to the next. Deep souring of the thalweg also tends to be offset by filling areas adjacent to the thalweg. Between 1992 and 1998 the mean bed elevation increased slightly as the mean depth decreased from 6.42 feet to 6.03 feet. The cross section area also increased and the width to depth ratio decreased. The top width increased from 762 feet to 778 feet while thalweg depths ranged from 7.88 feet to 12.68 feet.

Cross section CO2-1091 is located in a narrow stretch of river between two wide expansions approximately 105 miles downstream from Cochiti Dam. The cross section is also located just above the confluence of the Rio Puerco and Rio Grande. The cross section is more or less triangular in shape (Figure 4.12) with the thalweg on the left bank and point bars on the right bank. This cross section is fairly stable. The mean bed elevation decreased 0.3 feet as the mean depth increased from 4.04 feet to 4.33 feet. The cross section area increased 8 percent, and the width to depth ratio decreased 6 percent from 1992 to 1998. During the survey period the top width changed very little and remained close to 510 feet. Changes in riverbed elevation from one survey to the next seem to balance out, as the cross section area remains relatively stable from one year to the next.

Cross section CO2-1104 is located just downstream from the confluence of the Rio Puerco and Rio Grande and the Salas Arroyo, which lie approximately 107 miles downstream from Cochiti Dam. The cross section appears to be stable and is fairly narrow, as the top width is less than 300 feet (Figure 4.13) and top width ranges from 266 feet to 268 feet. Thalweg elevation declined progressively with each successive survey as the thalweg depth increased from 9.94 feet to 12.14 feet. Mean bed elevation did not, however, follow the same declining pattern. In 1992 and 1995 the river bottom was basically flat with some. The 1995 riverbed was roughly 1 foot lower than the 1992 riverbed. In 1998 a deep scour hole developed near the left bank. Like many other cross sections in this reach when a deep scour hole develops, aggradation occurs in areas adjacent to the scour hole. The right half of the channel filled to levels that were above the 1992 riverbed. From 1995 to 1998 the mean bed elevation increased less than 1 foot resulting in a mean bed elevation that was just lower than the 1992 mean bed elevation. Mean depths increased from 6.6 feet to 6.73 feet. Cross section area and width to depth ratio showed no noticeable changes from 1992 to 1998.

Cross section CO2-1164 is located approximately 112 miles downstream from Cochiti Dam. The cross section is located near the start of a large bend and just downstream

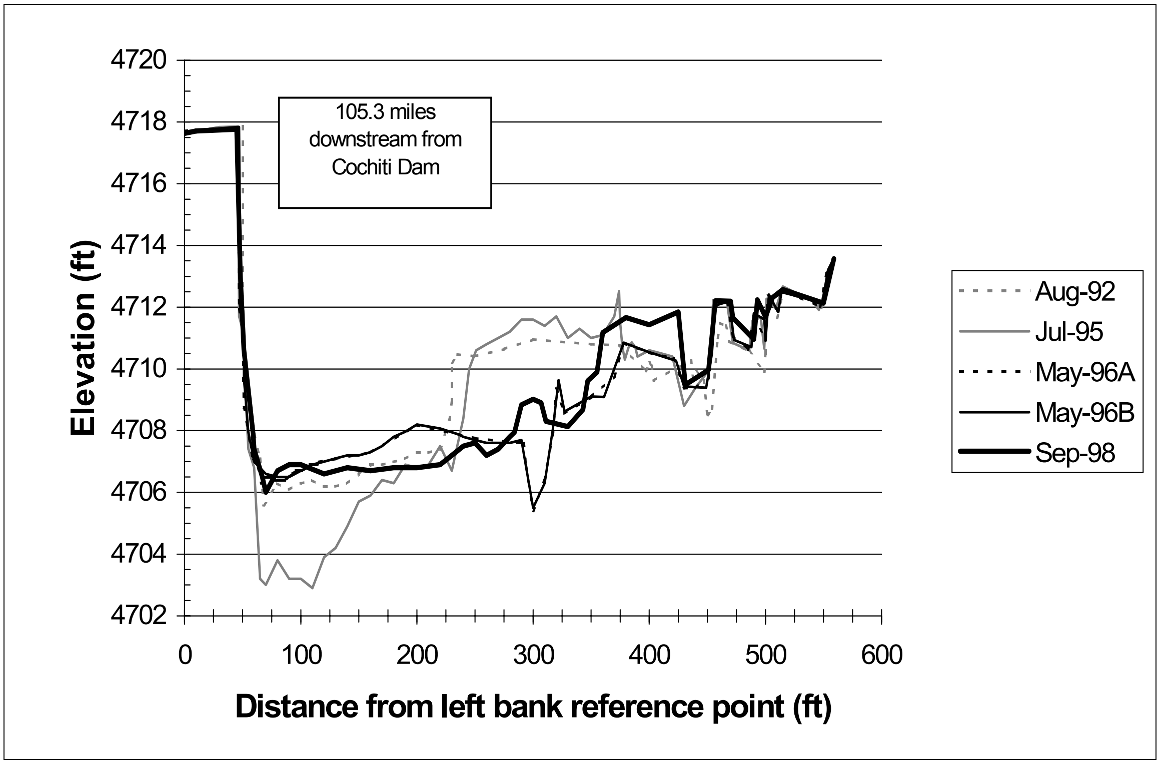

Figure 4.12. Cross section CO2-1091.

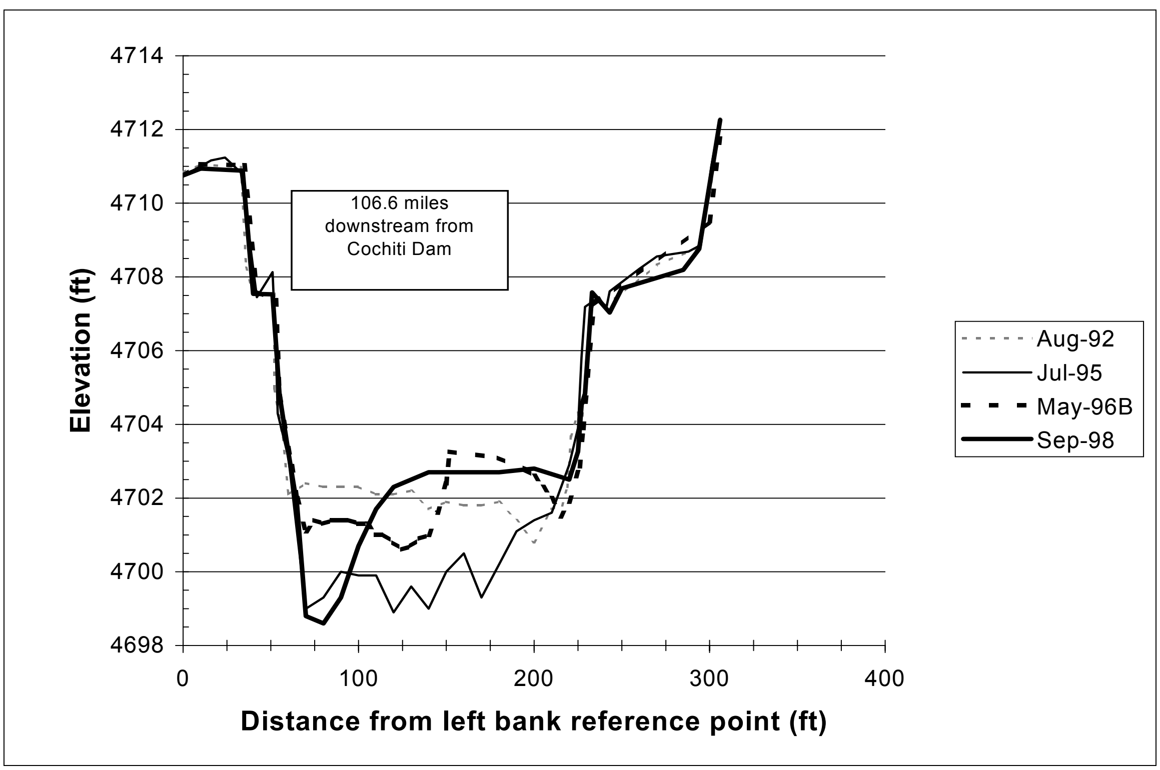

Figure 4.13. Cross section CO2-1104.

from several small arroyos. The cross section is also very narrow with top ranging between 170 and 172 feet. In 1992 there was a large scour hole near the left bank with aggradation appearing on the adjacent areas. By 1995 the thalweg had migrated to the center of the channel and the entire riverbed was scoured. Surveys in 1996 and 1998 revealed a thalweg position near left bank and a uniform and fairly flat river bottom. The banklines at this cross section seem very stable, as there were no appreciable changes in bankline position. The mean bed elevation decreased slightly as well as the cross section area and width to depth ratio. The mean depth increased from 5.21 feet to 5.27 feet and the thalweg depth ranged from 7.37 feet in 1992 and 10.01 feet in 1995.

Cross section CO2-1179 is located approximately 114 miles downstream from Cochiti Dam at the downstream end of a large bend. This cross section is located just upstream from the confluence of the Rio Salado and Rio Grande in narrow section of river. The river bottom at this cross section is almost flat and the cross section has a rectangular appearance. The 1992 and 1998 riverbeds are very similar and are approximately 2 feet above the 1995 riverbed. Other than changes in mean bed elevation, the cross section appears to be stable with no noticeable changes in cross section area or width to depth ration between 1992 and 1998. The mean depth of the cross section ranged from 7.43 feet in 1992 to 9.95 feet in 1995. Thalweg depths followed a similar pattern with the maximum depth of 12.02 feet occurring in 1995.

Cross section CO2-1194 is located approximately 115 miles below Cochiti Dam. The cross section lies just downstream from Arroyo Rosa de Castillo and just over 1 mile upstream from the San Acacia diversion dam. This cross section is much wider than the previous three cross sections and the right bank is migrating outward (Figure 4.14). The cross section is very shallow with mean depths ranging from 2.22 feet to 3.31 feet. The thalweg is located near the right bank in 1992 and 1995 but it is located near the left bank in 1998. Thalweg depths range from 4.04 feet in 1998 to 8.04 feet in 1995. The width to depth ratio increased 94 percent from 1992 to 1998 as the depth decreased slightly and the top width increased over 150 feet as the top width increased from 502 feet to 651 feet. Mean bed elevation increased approximately 1 foot from 1992 to 1998 as deeper scour holes were filled.

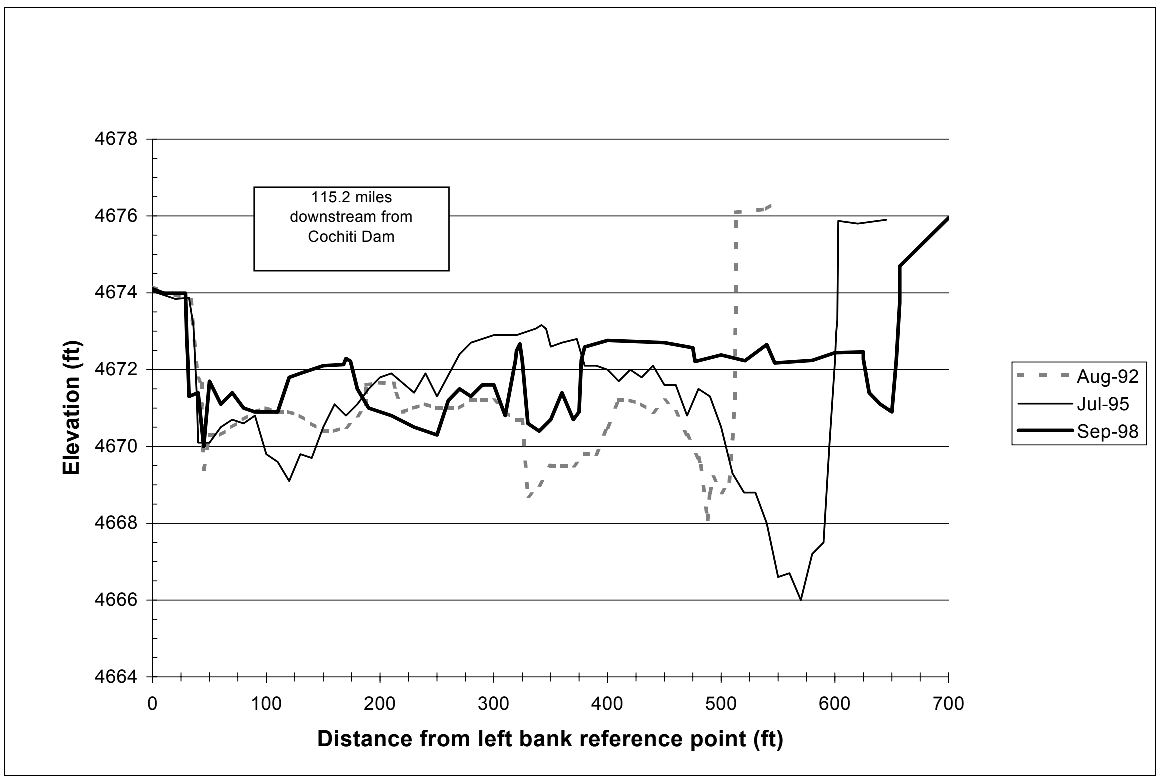

Figure 4.14. Cross Section CO2-1194.

CHAPTER V

SUMMARY AND CONCLUSIONS

A large amount of data has been collected for this work on the Middle Rio Grande between Bernalillo Bridge and the San Acacia diversion dam. The data set includes cross section surveys, flow discharge records, bed material surveys, suspended sediment records, aerial photos, planform plots, and reports.

The cross section data includes surveys of the following range lines from 1918 to 1998:

- 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 as Microsoft Excel 97 files.
- Cochiti range lines collected from 1970 to 1998 and available in electronic format as Microsoft Excel 97 files.
- Calabacillas, Albuquerque, Casa Colorada, Abeyta's Heading, and Bernardo Jack Site lines collected from 1987 to 1998 and available in electronic format.

The bed material data consist of particle size distributions for the following range lines and gaging stations from 1964 to 1998.

- Cochiti range lines (CO-31 to CO-38) from 1970 to 1982. These data are available in hardcopy and have been transferred into electronic format as Microsoft Excel 97 files.
- Cochiti range lines (CO-31 to CO2-1194) for 1992, 1995, 1997 and 1998. These data are available in electronic format as Microsoft Excel 97 files.
- USGS gaging stations at Albuquerque, Bernardo, and San Acacia from 1964 to 1996. These data are available in electronic format as Microsoft Excel 97 files.
- Calabacillas, Albuquerque, Casa Colorada, Abeyta's Headings, and Bernardo Jack Site range lines collected from 1987 to 1998.

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

- Cochiti range lines (CO-31 to CO-38) from 1970 to 1982. These data include sediment concentration, discharge, and particle size distribution and are available in hardcopies and have been transferred into electronic format as Microsoft Excel 97 files.
- USGS gaging stations near Albuquerque, Bernardo, and San Acacia from 1946 to 1996. These data include mean daily sediment discharge and concentration records and are available in electronic format as Microsoft Excel 97 files.
- USGS gaging stations near Albuquerque, Bernardo, and San Acacia from 1969 to 1996. These files contain particle size distributions and are available in Microsoft Excel 97 format.

- Calabacillas, Albuquerque, and Abeyta's Headings range lines from 1991 to 1997. These files are available in electronic format and include sediment concentration and particle size distribution.

The discharge data consist of mean daily discharge, instantaneous discharge, and unit discharge measurements taken at the following locations:

- USGS gaging stations from Albuquerque to San Acacia from 1920 to 1997. There are 13 gages in the reach with varying periods of record. These files contain mean daily discharge values and are available in electronic format as Microsoft Excel 97 files.
- USGS gaging stations at Albuquerque, Bernardo, and San Acacia from 1969 to 1996. These files contain instantaneous discharge measurements and are available as Microsoft Excel 97 format.
- Calabacillas, Albuquerque, and Casa Colorada range lines from 1991 to 1997. These files are available in electronic format and contain discharge measurement taken during cross section surveys.

Several sets of aerial photographs and planform plots were gathered for the following locations, dates, and scales:

- Blue line reproduction of aerial photos between Velarde to Caballo Dam for Feb. 27, 1992 at a scale of 1"= 2000'. These reproductions contain the location of the CO, CA, A, CC and AH range lines.

- Blue line reproduction of aerial photos between Cochiti Dam and Range Line 1794 for Feb. 21, 1992 at a scale of 1:24,000. These reproductions contain the location of the Agg/Deg lines.
- Planform and land use comparison plots from 1935 to 1989 at a scale of 1:147,000 from Cochiti Dam to San Marcial.

Reports detailing survey procedures and field conditions from 1990 to 1998 are available in electronic format for the Cochiti, Calabacillas, Albuquerque, Casa Colorado, and Abeyta's Headings range lines.

Tables summarizing the compiled data, sources, and survey dates are contained in Appendixes A to C. Data that were transferred into electronic format or were already in electronic format were organized in a computer database. The database is divided into four categories: cross section data, flow discharge data, reports, and sediment data.

Data from the Cochiti range lines and the Agg/Deg lines were used to perform the quantitative analyses of the Middle Rio Grande between Bernalillo Bridge and the San Acacia diversion dam. The analyses focused on changes in planform, thalweg position, men bed elevation, cross section area, bed material size, and bank position.

Mean bed elevations were calculated by first assuming a fixed water surface elevation near the bank-full condition for each cross section. Each cross section was entered into the computer program Scour & Fill version 7.1. This computer program calculates mean depth, maximum depth, wetted perimeter, cross section area, and hydraulic radius. The mean bed elevation is calculated by subtraction the mean depth from the fixed water surface elevation for each cross section. No measured water surface elevations were used in these calculations.

Aggradation or degradation at each cross section was estimated by comparing the mean bed elevation from the most recent survey to the earliest survey. Mean bed elevation was used instead of thalweg elevation to extend the period of record from 6 year to 36 years for cross section CO2-945 to CO2-1194. Percent change in cross section area with distance below Cochiti Dam was calculated by comparing the most recent and earliest CO-line surveys at each cross section.

The following conclusions are based on the quantitative analysis developed in this work. These conclusions document general trends along the study reach, confirm observations and findings of similar studies, and document the current condition of the Middle Rio Grande.

1. The effect of tributaries on main-stem river processes can be seen just upstream from cross section CO2-1194. Figures 4.1 to 4.3 show the Rio Grande has shifted away from both the Rio Salado and Arroyo Rosa de Castillo making irregular changes of course at each delta. Abandoned channels are also apparent in the figure indicating channel migration over time. The 150 feet of lateral migration on the right bank of the Rio Grande between 1992 and 1998 at cross section CO2-1194 may have been caused as the channel moves away from sediment deposits from the Arroyo Rosa de Castillo on the left bank.

2. Between 1971 and 1998 the bed material has coarsened between Cochiti Dam and cross section CO-33. The median grain size, as seen in Figure 3.15, at cross section CO-33 has increased from 0.19 mm to 4.37 mm. Below the Isleta diversion dam bed material samples indicate that median bed material size decreases with distance below the Isleta diversion dam. The 1998 samples range from 0.43 mm near the Isleta diversion dam to 0.25 mm near the Rio Puerco.
3. Comparisons of mean bed elevations in Figures 3.10 to 3.12 indicate that degradation up to approximately 4.5 feet occurred between 1962 and 1998; however fewer locations indicate aggradation up to 1 foot. Most degradation occurred between 1962 and 1992 with little change between 1992 and 1998. Maximum degradation of 4.5 feet occurred in sub-reach 3 near the mouth of the Rio Puerco at cross sections CO2-1091 and CO2-1104. Cross sections CO-31, CO-32, and CO-34 in sub-reach 1 had decreases in mean bed elevation of more than 3 feet while sub-reach 2 experienced minimal changes in mean bed elevation. If the gaging data is available, a specific gage analysis should be considered to verify the potential degradational trend.
4. Analysis of suspended sediment discharge data and mean bed elevations suggests that the 6 foot change in mean bed elevation between 1972 and 1992 at the mouth of the Rio Puerco (cross sections CO2-1091 and CO2-1104) is similar to degradation seen at the mouth of the Jemez River. As with the Jemez River, reduction in sediment supply to the Rio Grande (Figures 4.5 to 4.8) and easily erodible deltaic deposits are the likely reason for the comparatively large amounts of degradation at the mouth of the Rio Puerco.

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Appendix A

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

- River Miles from Caballo Dam, River Miles Cochiti Dam, CO Line location, and the location of other range lines were taken from blue line reproductions of 1992 aerial photos.

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
200.51	32.09	31	324		
			325		
201			326		
			327		
			328		
			329		
			330		
			331		
			332		
			333		
			334		
200.07	32.53	32	335		
			336		
200			337		
			338		
			339		
			340		
			341		
			342		
			343		
			344		
			345		
199			346		
			347		
			348		
			349		
			350		
198.62	33.98	33	351		
			352		
			353		
			354		
			355		
			356		
198			357		
			358		
			359		
			360		
			361		
			362		
			363		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			364		
			365		
			366		
			367		
197			368		
			369		
			370		
			371		
			372		
			373		
			374		
			375		
			376		
			377		
196			378		
			379		
			380		
			381		
			382		
			383		
			384		
			385		
			386		
195			387		
			388		
			389		
			390		
			391		
			392		
			393		
			394		
			395		
			396		AMAFCA North diversion channel enters Rio Grande.
			397		
			398		
194			399		
			400		
			401		
			402		
			403		
			404		
			405		
			406		
193.28	39.32	34	407		
			408		
			409		
			410		
193			411		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			412		
			413		
			414		
			415		
			416		
			417		
			418	CA-1	Calabacillas Lines (CA-1 to CA-13).
			419		
192.2			420		Alameada Blvd. Bridge
192			421	CA-2	
			422		
			423	CA-3	
			424		
			425	CA-4	
			426	CA-5	
			427	CA-6	
			428	CA-7	
			429	CA-8	
			430	CA-(9-10)	
191			431	CA-11	Paseo del Norte Bridge.
			432		
			433	CA-12	
			434		
			435		
			436		
			437	CA-13	
			438		
			439		
			440		
190			441		
			442		
			443		
			444		
			445		
			446		
			447		
			448		
			449		
			450		
			451		
189			452		
188.81	43.79	35	453		
			454		
			455		
			456		
			457		
			458		
			459		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			460		
			461		
188			462		
			463		
			464		
			465		
			466		
			467		
			468		
			469		
			470		
			471		
187			472		
			473		
			474		
			475		
			476		
			477		
			478		
			479		
			480		
			481		
			482		
186			483		
			484		
			485		
			486		
			487		
			488		
			489		
			490		
			491		
			492		
			493		
185			494		Interstate-40 Bridge.
			495		
			496		
			497		
			498		
			499		
			500		
			501		
			502		
184			503		
			504		
			505		
			506		
			507		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			508		
183.4	232.6	36	509		Central Ave. Bridge.
			510		
			511		
			512		
183			513		
			514		
			515		
			516		
			517		
			518		
			519		
			520		
			521		
			522		
182			523		
			524		
			525		
			526		
			527		
181.6			528		Bridge Blvd. Bridge.
			529		
			530		
			531		
181			532		
			533		
			534		
			535		
			536		
			537		
			538		
			539		
			540	A-1	Albuquerque Range Lines (A1 to A-9).
			541		
			542	A-2	
180			543		
			544	A-3	
			545		
			546	A-4	
			547		
			548	A-5	
			549		
			550	A-6	
			551		
			552		
			553		
179			554		
			555	A-7	

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			556		
			557	A-8	
			558		
			559		
			560	A-9	
			561		Rio Bravo Bridge between Agg/Deg Lines 561 & 562.
178.3	54.3	37	562		
			563		
			564		
178			565		
			566		
			567		
			568		
			569		
			570		
			571		
			572		
			573		
			574		
			575		AMAFCA South diversion channel enters Rio Grande.
177			576		
			577		
			578		
			579		
			580		
			581		
			582		
			583		
			584		
			585		
176			586		
			587		
			588		
			589		
			590		
			591		
			592		
			593		
			594		
			595		
175			596		
			597		
			598		
			599		
			600		
			601		
			602		
			603		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			604		
			605		
			606		
174			607		
			608		
			609		
			610		
			611		
			612		
			613		
			614		
			615		
173.22	59.38	38	616		
			617		
173			618		
			619		
			620		
			621		
			622		
172.6			623		Interstate-25 Bridge.
			624		
			625		
			626		
			627		
			628		
172			629		
			630		
			631		
			632		
			633		
			634		
			635		
			636		
171.1			637		A.T. & S.F. RR Bridge.
171			638		
			639		
			640		
			641		
			642		
			643		
			644		
			645		
			646		
			647		
170			648		
			649		
			650		
			651		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			652		
			653		
			654		
169.3			655		Isleta Bridge.
			656		Isleta diversion dam.
			657		
			658		
			659		
			660		
169			661		
			662		
			663		
			664		
			665		
			666		
			667		
168.19	64.41	668	668		
			669		
168			670		
			671		
			672		
			673		
			674		
			675		
			676		
			677		
			678		
			679		
167			680		
			681		
			682		
			683		
			684		
			685		
			686		
			687		
			688		
			689		
166			690		
			691		
			692		
			693		
			694		
			695		
			696		
			697		
			698		
			699		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			700		
165			701		
			702		
			703		
			704		
			705		
			706		
			707		
			708		
			709		
			710		
164			711		
			712		
163.88	68.72	713	713		
			714		
			715		
			716		
			717		
			718		
			719		
			720		
			721		
163			722		
			723		
162.71	69.89	724	724		
			725		
			726		
			727		
			728		
			729		
			730		
			731		
162			732		
			733		
			734		
			735		
			736		
			737		
161.4	71.2	738.1	738		
161.4			739		New Mexico Hwy 49 Bridge.
			740		
			741		
161			742		
			743		
			744		
			745		
			746		
			747		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			748		
			749		
			750		
			751		
			752		
			753		
160			754		
			755		
			756		
			757		
			758		
			759		
			760		
			761		
			762		
			763		
159			764		
158.74	73.86	765	765		
			766		
			767		
			768		
			769		
			770		
			771		
			772		
158			773		
			774		
			775		
			776		
			777		
			778		
			779		
			780		
			781		
			782		
157			783		
			784		
			785		
			786		
157.17	75.43	787	787		
			788		
			789		
			790		
			791		
			792		
156			793		
			794		
			795		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			796		
			797		
			798		
			799		
			800		
			801		
			802		
155			803		
			804		
			805		
154.62	77.98	806	806		
			807		
			808		
			809		
			810		
			811		
			812		
154			813		
			814		
			815		
			816		
			817		
			818		
			819		
			820		
			821		
			822		
153			823		
			824		
			825		
			826		
			827		
			828		
			829		
			830		
			831		
			832		
152.08	80.52	833	833		
152			834		
			835		
			836		
			837		
			838		
			839		
			840		
			841		
			842		
			843		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
151			844		
			845		
			846		
			847		
			848		
			849		
			850		
			851		
			852		
			853		
150			854		
			855		
			856		
			857		
149.5	232.6	858.1	858		New Mexico Hwy 6 Bridge.
			859		
			860		
			861		
			862		
			863		
149			864		
			865		
			866		
			867		
			868		
			869		
			870		
			871		
			872		
			873		
148			874		
			875		
			876		
147.7	232.6	877	877		A.T. & S.F. RR Bridge.
			878		
			879		
			880		
			881		
			882		
			883		
147			884		
			885		
			886		
			887		
			888		
			889		
			890		
			891		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			892		
			893		
146			894		
145.94	86.66	895	895		
			896		
			897		
			898		
			899		
			900		
			901		
			902		
			903		
145			904		
			905		
			906		
			907		
			908		
			909		
			910		
			911		
			912		
			913		
			914		
144			915		
			916		
			917		
			918		
			919		
			920		
			921		
			922		
			923		
143			924	CC-924	Casa Colorada Range Lines (CC-924 to CC-945).
			925		
142.95	89.65	926	926		
			927	CC-927	
			928		
			929		
			930	CC-930	
			931		
			932	CC-932	
			933		
			934	CC-934	
			935		
142			936	CC-936	
			937		
			938		
			939	CC-939	

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			940		
			941	CC-941	
			942		
			943	CC-943	
			944		
141.15	91.45	945	945	CC-945	
141			946		
			947		
140.8			948		Jarales Rd. Bridge.
			949		
			950		
			951		
			952		
			953		
			954		
			955		
			956		
140			957		
			958		
			959		
			960		
			961		
			962		
			963		Abo Arroyo enters Rio Grande.
			964		
			965		
139.22	93.38	966	966		
139			967		
			968		
			969		
			970		
			971		
			972		
			973		
			974		
			975		
			976		
138			977		
			978		
			979		
			980		
			981		
			982		
			983		
			984		
			985		
137.04	95.56	986	986		
137			987		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			988		
			989		
			990		
			991		
			992		
			993		
			994		
			995		
			996		
136			997		
			998		
			999		
			1000		
			1001		
			1002		
			1003		
			1004		
			1005		
135.24	97.36	1006	1006		
			1007		
135			1008		
			1009		
			1010	AH-1	Abeyta's Headings Range Lines (AH-1 to AH-7).
			1011		
			1012		
			1013	AH-2	
			1014		
			1015	AH-(3 & 4)	
			1016	AH-5	
			1017		
134			1018	AH-6	
			1019	AH-7	
			1020		
			1021		
			1022		
			1023		
			1024		
			1025		
133.17	99.43	1026	1026		
			1027		
133			1028		
			1029		
			1030		
			1031		
			1032		
			1033		
			1034		
			1035		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			1036		
			1037		
			1038		
132			1039		
			1040		
			1041		
			1042		
			1043		
131.57	101.03	1044	1044		
			1045		
			1046		
			1047		
			1048		
131			1049		
			1050		
			1051		
			1052		
130.6			1053		U.S. Hwy 60 Bride.
			1054		
			1055		
			1056		
			1057		
			1058		
			1059		
130			1060		
			1061		Maes Arroyo enters Rio Grande.
			1062		
			1063		
129.74	102.86	1064	1064		
			1065		
			1066		
			1067		
			1068		
			1069		
			1070		
			1071		
129			1072		
			1073		
			1074		
			1075		
			1076		
			1077		
			1078		
			1079		
			1080		
			1081		
			1082		
			1083		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
128			1084		
			1085		
			1086		
			1087		
			1088		
			1089		
			1090		
127.28	105.32	1091	1091		
			1092		
			1093		
127			1094		
			1095		
			1096		
			1097		
			1098		Salas Arroyo enters Rio Grande.
			1099		Rio Puerco delta from Agg/Deg lines 1099 to 1100.
			1100		
			1101		
			1102		
			1103		
126	232.6	1104	1104		
			1105		
			1106		
			1107		
			1108		
			1109		
			1110		
			1111		
			1112		
			1113		
			1114		
125			1115		
			1116		
			1117		
			1118		
			1119		
			1120		
			1121		
			1122		
			1123		
124			1124		
			1125		
			1126		Arroyo Los Alamos enters Rio Grande.
			1127		
			1128		
			1129		
			1130		
			1131		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			1132		
			1133		
123			1134		
			1135		
			1136		
			1137		
			1138		
			1139		
			1140		
			1141		
			1142		
			1143		Bernardo Arroyo enters Rio Grande.
			1144		
122			1145		
			1146		
			1147		
			1148		
			1149		
			1150		
			1151		
			1152		
			1153		
			1154		
			1155		
121			1156		
			1157		
			1158		
			1159		Canada Ancha enters Rio Grande.
			1160		
			1161		
			1162		
			1163		
120.21	112.39	1164	1164		
			1165		
120			1166		
			1167		
			1168		
			1169		
			1170		
			1171		
			1172		
			1173		
			1174		
			1175		
119			1176		
			1177		
			1178		
118.87	113.73	1179	1179		

Table A-1. Relative location of the range lines (cont'd).

River Miles from Caballo Dam (1992)	River Miles from Cochiti Dam (1992)	CO Lines	Agg/Deg Lines	Other Lines	Observations
			1180		
			1181		Rio Salado enters Rio Grande.
			1182		Delta spans from Agg/Deg line 1181 to 1184.
			1183		
			1184		
			1185		
			1186		
118			1187		
			1188		
			1189		Arroyo Rosa de Castillo enters Rio Grande.
			1190		
			1191		
			1192		
			1193		
117.36	115.24	1194	1194		
			1195		
			1196		
117			1197		
			1198		
			1199		
			1200		
			1201		
			1202		
			1203		
			1204		
			1205		
116.2			1206		San Acacia diversion dam.

Table A-2. SCS Range line survey data.

Cross Section Number	Year Surveyed and Agency Responsible for Collection														
	1897 SCS	1904 SCS	1918 SCS	1927 SCS	1928 SCS	1931 SCS	1934-A SCS	1934-B SCS	1936 SCS	1937 SCS	1938 SCS	1939 SCS	1940 SCS	1941 SCS	1944 COE
892.9			x							x			x	x	
898			x							x			x		
903.4			x	x						x				x	
RR Below Alameda Bridge									x			x	x	x	
RR Below Hwy 85 Bridge									x			x	x		
RR Below Hwy 66 Bridge									x			x	x		
RR Above Hwy 66 Bridge									x			x	x	x	
907.6			x							x			x	x	
913.1									x			x		x	
913.2			x	x					x				x		
918									x			x	x		
918.3			x	x					x				x		
922			x								x			x	
Below Isleta Dam									x			x	x	x	
Above Isleta Dam									x			x			
RR Bridge 913-A	x	x					x	x							
925.8			x	x					x						
926.5									x			x	x		
929.9			x											x	
934						x			x						
937.5			x							x					
939-A		x					x		x			x			

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

Cross Section Number	Year Surveyed and Agency Responsible for Collection														
	1897 SCS	1904 SCS	1918 SCS	1927 SCS	1928 SCS	1931 SCS	1934-A SCS	1934-B SCS	1936 SCS	1937 SCS	1938 SCS	1939 SCS	1940 SCS	1941 SCS	1944 COE
Above Belen Hwy Bridge									x			x			
Below Los Lunas									x			x		x	
Below San Juan Bridge									x			x			
951									x						x
952									x						x
953									x						x
954									x						x
956.3-B													x		x
959.8													x		x
961.1													x		x
962.9													x		x
963.5													x		x
964													x		x
964.1													x		x
964.1-A													x		x
966.7													x		x
956.3			x		x				x			x			
959.8			x	x					x					x	
961.1			x										x		
962.9			x										x	x	
963.5			x		x				x			x			
964			x						x				x	x	
964.1			x	x						x		x			
966.7			x											x	

Table A-3. Cochiti Range Lines survey data from Bernalillo Bridge to San Acacia diversion dam.

Collected by	Date	Cross-section number (CO-Lines)																		
		31	32	33	34	35	36	37	38	668	713	724	738.1	765	787	806	833	858.1	877	895
USGS-Dewey	May-70					x	x	x	x											
USGS-Dewey	May-71	x	x	x	x	x	x	x	x											
USGS-Dewey	Sep-71	x	x	x	x	x	x	x	x											
USGS-Dewey	Mar-72	x	x	x	x	x	x	x	x											
USGS-Dewey	Nov-72	x	x	x	x	x	x	x	x											
USGS-Dewey	May-73				x															
USGS-Dewey	Jun-73	x	x	x	x	x	x	x	x											
USGS-Dewey	May-74	x	x	x	x	x	x	x	x											
USGS-Dewey	Sep-74	x	x	x	x	x	x	x	x											
USGS-Dewey	Nov-74	x	x	x	x	x	x	x												
USGS-Dewey	May-75	x	x	x	x	x	x	x	x											
USGS-Dewey	Jul-75	x	x	x	x	x	x	x	x											
USGS-Dewey	Nov-75	x	x	x	x	x	x	x	x											
USGS-Dewey	Apr-79	x	x	x	x	x	x	x	x											
USGS-Dewey	May-79		x	x																
USGS-Dewey	Jul-79	x	x	x	x	x		x	x											
USGS-Dewey	Jan-80	x	x	x	x	x		x	x											
	Oct-82	x	x	x	x	x		x	x	x	x	x	x	x	x	x		x	x	x
	Nov-83	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x
	Dec-86	x	x	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					
FLO Engineering	Aug-92															x	x	x	x	x
FLO Engineering	Jul-95															x	x	x	x	x
FLO Engineering	Aug-95	x	x	x	x	x	x	x	x	x	x	x	x	x	x					
FLO Engineering	May-96														x	x		x		
FLO Engineering	Aug & Sep 98	x	x	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 Bernalillo Bridge to San Acacia diversion dam (cont'd).

Collected by	Date	Cross-section numbers (CO-Lines												
		926	2-945	2-966	2-986	2-1006	2-1026	2-1044	2-1064	2-1091	2-1104	2-1164	2-1179	2-1194
USGS-Dewey	May-70													
USGS-Dewey	May-71													
USGS-Dewey	Sep-71													
USGS-Dewey	Mar-72													
USGS-Dewey	Nov-72													
USGS-Dewey	May-73													
USGS-Dewey	Jun-73													
USGS-Dewey	May-74													
USGS-Dewey	Sep-74													
USGS-Dewey	Nov-74													
USGS-Dewey	May-75													
USGS-Dewey	Jul-75													
USGS-Dewey	Nov-75													
USGS-Dewey	Apr-79													
USGS-Dewey	May-79													
USGS-Dewey	Jul-79													
USGS-Dewey	Jan-80													
	Oct-82	x												
	Nov-83	x												
	Dec-86	x												
FLO Engineering	Jul-92													
FLO Engineering	Aug-92	x	x	x	x	x	x	x	x	x	x	x	x	x
FLO Engineering	Jul-95	x	x	x	x	x	x	x	x	x	x	x	x	
FLO Engineering	Aug-95													
FLO Engineering	May-96									x		x		
FLO Engineering	Aug & Sep 98	x	x	x	x	x	x	x	x	x	x	x	x	x

Table A-4. Calabacillas Range Line survey dates.

		Calabacillas Range Lines (CA-Lines)												
Collected by	Date	CA-1	CA-2	CA-3	CA-4	CA-5	CA-6	CA-7	CA-8	CA-9	CA-10	CA-11	CA-12	CA-13
FLO Engineering	Nov-88	X	X	X	X									
FLO Engineering	Dec-88					X	X	X	X	X	X	X	X	X
FLO Engineering	Oct-89	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jul-90	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-91	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-92	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Apr-93	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-93-A	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-93-B	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-94A		X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-94B		X	X	X	X	X	X	X					
FLO Engineering	Jun-94A		X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-94B									X	X	X	X	X
FLO Engineering	May-95			X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-95	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jul-95	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Mar-96	X	X	X	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-96A		X						X					
FLO Engineering	May-96B		X											
FLO Engineering	Jun-96	X	X	X	X	X	X	X	X	X	X	X	X	X

Table A-5. Albuquerque Range Line survey dates.

Collected by	Date			Albuquerque Range Lines (A-Lines)						
		A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
FLO Engineering	Jun-87	X	X	X	X	X	X			
FLO Engineering	Sep-90	X	X	X	X	X	X	X	X	X
FLO Engineering	Apr-91	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-91	X	X	X	X	X	X	X	X	X
FLO Engineering	May-92	X	X	X	X	X	X	X	X	X
FLO Engineering	Apr-93	X	X	X	X			X	X	X
FLO Engineering	May-93	X	X	X	X			X	X	X
FLO Engineering	Jun-93	X	X	X	X		X	X	X	X
FLO Engineering	Jul-93A			X	X		X	X	X	X
FLO Engineering	Jul-93B							X		
FLO Engineering	Apr-94	X	X	X	X					
FLO Engineering	Jun-94	X	X	X	X	X	X	X	X	X
FLO Engineering	Jul-94	X		X						
FLO Engineering	Mar-95		X	X						
FLO Engineering	Apr-95	X		X	X	X	X	X	X	X
FLO Engineering	May-95A	X	X	X	X	X				
FLO Engineering	May-95B		X							
FLO Engineering	Jun-95A	X	X		X	X	X	X	X	X
FLO Engineering	Jun-95B						X	X	X	
FLO Engineering	Jul-95			X						
FLO Engineering	Apr-96	X	X	X	X	X	X	X	X	X
FLO Engineering	May-96-A	X	X	X	X	X	X	X	X	X
FLO Engineering	May-96-B	X			X	X	X	X	X	X
FLO Engineering	May-96-C	X					X			
FLO Engineering	May-96D						X			
FLO Engineering	Aug-96	X	X	X	X					
FLO Engineering	Apr-97	X	X	X		X	X	X	X	X
FLO Engineering	May-98-A	X	X	X	X	X	X	X	X	X
FLO Engineering	May98-B	X	X	X	X	X	X	X	X	X
FLO Engineering	May98-C	X			X		X			
FLO Engineering	Jun-98-A	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-98-B	X			X		X			
FLO Engineering	Jun-98-C	X			X		X			

Table A-6. Casa Colorada Range Line survey dates.

Collected by	Date	Casa Colorada Range Lines (CC-Lines)									
		924	927	930	932	934	936	939	941	943	945
FLO Engineering	Sep-90	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-91	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-92	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Apr-93	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-93	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-93	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-94-A	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-94-B	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-94	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-95	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jun-95	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Jul-95	X	X	X	X	X	X	X	X	X	X
FLO Engineering	Mar-96	X	X	X	X	X	X	X	X	X	X
FLO Engineering	May-96A						X			X	
FLO Engineering	May-96B						X			X	

Table A-7. Abeytas Heading Range Line survey dates.

Collected by	Date	Abeytas Heading Range Lines (AH-Lines)						
		AH-1	AH-2	AH-3	AH-4	AH-5	AH-6	AH-7
FLO Engineering	Jan-89	X	X	X	X	X	X	X
FLO Engineering	May-90	X	X	X	X	X	X	X
FLO Engineering	Oct-93	X	X	X	X	X	X	X
FLO Engineering	Feb-94	X	X	X	X	X	X	X
FLO Engineering	Feb-94B			X				
FLO Engineering	Jul-94					X	X	X
FLO Engineering	Aug-94	X	X	X	X			
FLO Engineering	Apr-96			X	X			

Appendix B

Table B-1. Bed material survey dates at Cochiti Range Lines from Bernalillo Bridge to San Acacia diversion dam.

Collected by	Date	Cross-section number (CO-Lines)																		
		31	32	33	34	35	36	37	38	668	713	724	738.1	765	787	806	833	858.1	877	895
USGS	1970	X	X	X	X	X	X	X	X											
USGS	1971	X	X	X	X	X	X	X	X											
USGS	1972	X	X	X	X	X	X	X	X											
USGS	1973	X	X	X	X	X	X	X	X											
USGS	1974	X	X	X	X	X	X	X	X											
USGS	1975	X	X	X	X	X	X	X	X											
FLO Engineering	1992	X		X		X				X			X		X		X		X	
FLO Engineering	1995	X		X		X				X			X		X		X		X	
FLO Engineering	1997	X	X																	
FLO Engineering	1998									X			X		X		X		X	

Table B-1. Bed material survey dates at Cochiti Range Lines from Bernalillo Bridge to San Acacia diversion dam (cont'd).

Collected by	Date	Cross-section number (CO-Lines)												
		926	2-945	2-966	2-986	2-1006	2-1026	2-1044	2-1064	2-1091	2-1104	2-1164	2-1179	2-1194
USGS	1970													
USGS	1971													
USGS	1972													
USGS	1973													
USGS	1974													
USGS	1975													
FLO Engineering	1992			X		X		X		X	X	X		X
FLO Engineering	1995			X		X		X		X	X	X		X
FLO Engineering	1997													
FLO Engineering	1998					X		X		X				X

Table B-2. Bed material survey dates for Calabacillas range lines.

Collected by	Date	Calabacillas Range Lines (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	CA-13
FLO Engineering	1988	X			X		X		X		X		X	
FLO Engineering	1989	X			X		X		X		X		X	
FLO Engineering	1991	X			X				X		X	X	X	
FLO Engineering	1992	X			X		X		X		X		X	
FLO Engineering	1993	X	X		X		X		X		X		X	X
FLO Engineering	1994		X						X					X
FLO Engineering	1995		X						X					X
FLO Engineering	1996		X		X		X		X		X		X	X

Table B-3. Bed material survey dates for Albuquerque range lines.

Collected by	Date	Albuquerque Range Lines (A-Lines)								
		A-1	A-2	A-3	A-4	A-5	A-6	A-7	A-8	A-9
FLO Engineering	1987	X	X	X	X	X	X			
FLO Engineering	1990	X	X	X	X	X	X	X	X	X
FLO Engineering	1991	X			X		X			
FLO Engineering	1992	X			X		X			
FLO Engineering	1993	X			X		X			
FLO Engineering	1994	X			X		X			
FLO Engineering	1996	X			X		X			
FLO Engineering	1998	X			X		X			

Table B-4. Bed material survey dates for Casa Colorada Range lines.

Collected by	Date	Casa Colorada Range Lines (CC-Lines)									
		924	927	930	932	934	936	939	941	943	945
FLO Engineering	1990	X	X	X	X	X	X	X	X	X	X
FLO Engineering	1991		X				X			X	
FLO Engineering	1992		X				X			X	
FLO Engineering	1993		X				X			X	
FLO Engineering	1994		X				X			X	
FLO Engineering	1995		X				X			X	
FLO Engineering	1996		X				X			X	

Table B-5. Bed material survey dates for Abeytas Heading range lines.

Collected by	Date	Abeytas Heading Range Lines (AH-Lines)						
		AH-1	AH-2	AH-3	AH-4	AH-5	AH-6	AH-7
FLO Engineering	1994		X	X	X			
FLO Engineering	1996			X	X			

Table B-6. Period of record for bed material samples taken at USGS gages.

USGS Stations	USGS Station Number	Dates
Rio Grande at Albuquerque	(08-3300-00)	5/8/69 to 9/6/96
Rio Grande Floodway near Bernardo	(08-3320-10)	5/13/68 to 10/17/96
Rio Puerco near Bernardo	(08-3530-00)	7/10/61 to 9/20/61 & 8/7/89
Rio Grande Floodway at San Acacia	(08-3549-00)	8/17/66 to 9/4/96

Table B-7. Period of record for suspended sediment concentration and discharge at USGS gaging stations.

USGS Stations	USGS Station Number	Daily Sediment Discharge (tons/ day)	Sediment Concentration (mg/L)
Rio Grande at Albuquerque	08-3300-00	1969-1995	1969-1995
Rio Grande Conveyance Channel near Bernardo	08-3319-90	1964-1974	1964-1974
Rio Grande near Bernardo	08-33200-00	1955-1964	
Rio Grande Floodway near Bernardo	08-3320-10	1964-1996	1964-1996
Rio Puerco near Bernardo	08-3530-00	1955-1996	1955-1996
Rio Grande at San Acacia	08-3544-00	1946-1956	1946-1956
Rio Grande Conveyance Channel at San Acacia	08-3548-00	1959-1990	1959-1990
Rio Grande Floodway at San Acacia	08-3549-00	1959-1996	1959-1996

Table B-8. Period of record for suspended sediment particle size distributions at USGS gaging stations.

USGS Stations	USGS Station Number	Dates
Rio Grande at Albuquerque	(08-3300-00)	5/8/69 to 9/6/96
Rio Grande Floodway near Bernardo	(08-3320-10)	11/6/65 to 9/6/96
Rio Grande Floodway at San Acacia	(08-3549-00)	10/2/60 to 9/4/96

Table B-9. Period of record for flow discharge at USGS gaging station along the Middle Rio Grande between Bernalillo Bridge and San Acacia.

USGS Stations	USGS Station Number	Dates
Rio Grande at Albuquerque	08-3300-00	3/1/42 to 5/25/97
Rio Grande near Isleta	08-3310-00	10/1/26 to 9/30/38 and 10/1/95 to 9/30/96
Rio Grande near Belen	08-3315-00	1/1/42 to 6/30/57
Rio Grande Conveyance Channel near Bernardo	08-3319-90	10/1/95 to 9/30/95
Rio Grande near Bernardo	08-3320-01	10/1/36 to 9/30/86
Rio Grande Floodway near Bernardo	08-3320-10	10/1/57 to 9/30/97
Rio Puerco near Bernardo	08-3530-00	11/1/39 to 9/30/97
Rio Salado near San Acacia	08-3315-00	10/1/47 to 9/30/84
Rio Grande Conveyance Channel at San Acacia	08-3548-00	10/1/58 to 9/30/94
Rio Grande (A) at San Acacia	08-3550-01	10/1/36 to 9/30/86
Rio Grande (B) at San Acacia	08-3550-00	5/1/36 to 9/30/64
Rio Grande (C) at San Acacia	08-3544-00	4/1/1936 to 9/30/60
Rio Grande Floodway at San Acacia	08-3549-00	10/1/58 to 9/30/97

Table B-10. Period of record for instantaneous discharge measurements taken at USGS gaging stations.

USGS Stations	USGS Station Number	Dates
Rio Grande at Albuquerque	08-3300-00	5/4/70 to 9/6/96
Rio Grande Floodway near Bernardo	08-3320-10	3/5/72 to 3/3/97
Rio Grande Floodway at San Acacia	08-3549-00	1/20/72 to 3/3/97

Table B-11. Discharge data collected during cross section surveys.

Collected by	Date	Range Line Set		
		CA-Lines	A-Lines	CC-Lines
FLO Engineering	1995	X		X
FLO Engineering	1996	X		X
FLO Engineering	1997		X	
FLO Engineering	1998		X	

Appendix C

Table C-1. Blue line aerial photo reproductions

Label	Date of Photography	Scale	Scale of Photography	Sheet #
Middle Rio Grande Project - NM Rio Grande Photo Mosaic Map - 1992 Velarde to Caballo Dam	2/21&24/1992	1" = 2000'		7A to 14A
Middle Rio Grande Project - NM Rio Grande Photo Mosaic Map - 1992 Velarde to Caballo Dam	2/21&24/1992	1" = 2000'		7A to 14A
Middle Rio Grande Project - NM Rio Grande Photo Mosaic Map - 1992 Velarde to Caballo Dam	2/21&24/1992	1" = 2000'		1 sheet missing
Middle Rio Grande Project - NM Rio Grande Photo Mosaic Map - 1992 Velarde to Caballo Dam	10/19&30/97	1" = 2000'		7A to 14A
Middle Rio Grande Project - NM Aggradation - Degradation Range Lines 1992 Orthophoto Maps	2/21&24/92	1" = 400'	1 : 24000	13/79 to 53/79

Appendix D

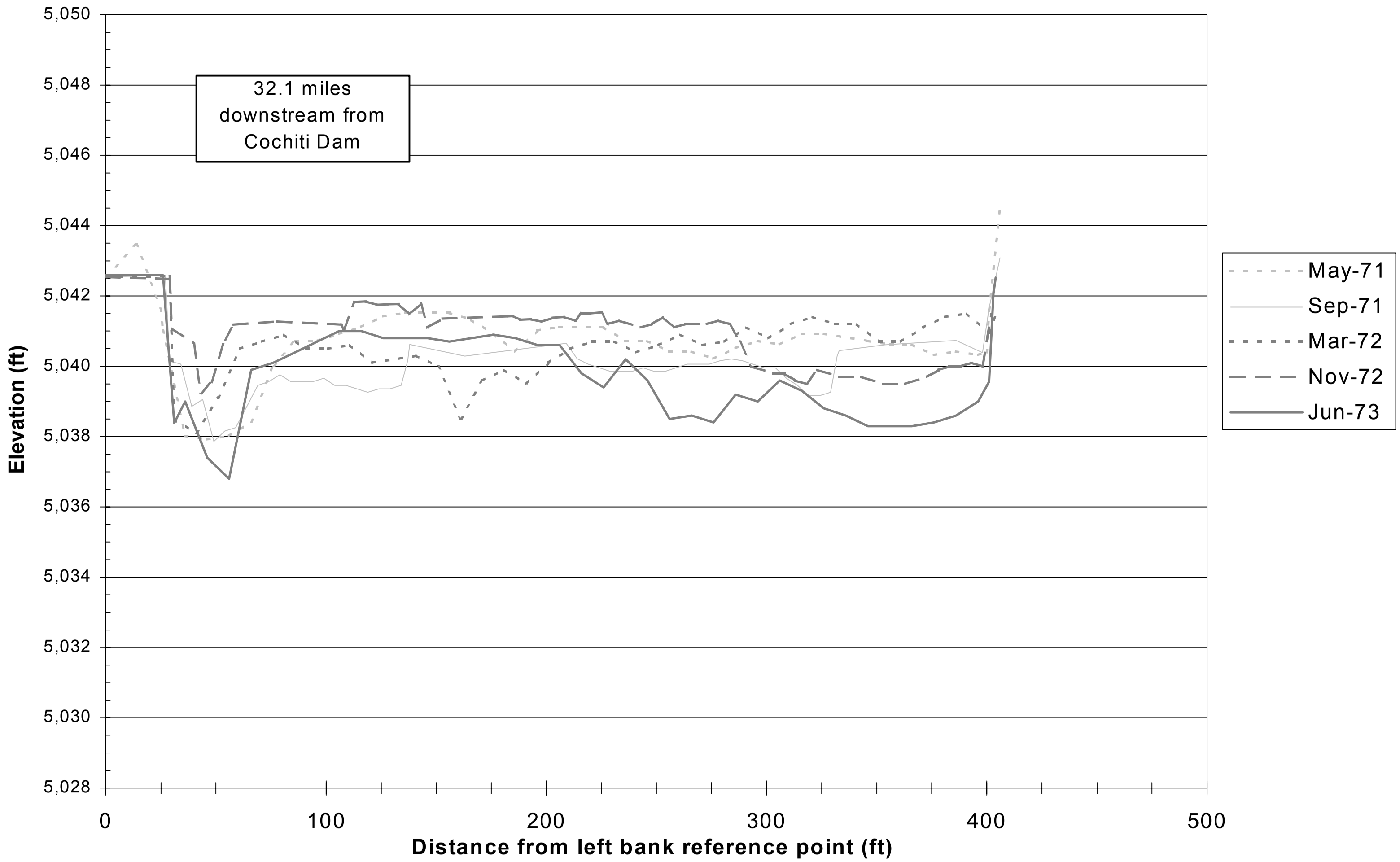

Figure D-1. Cross Section CO-31 (pre-dam).

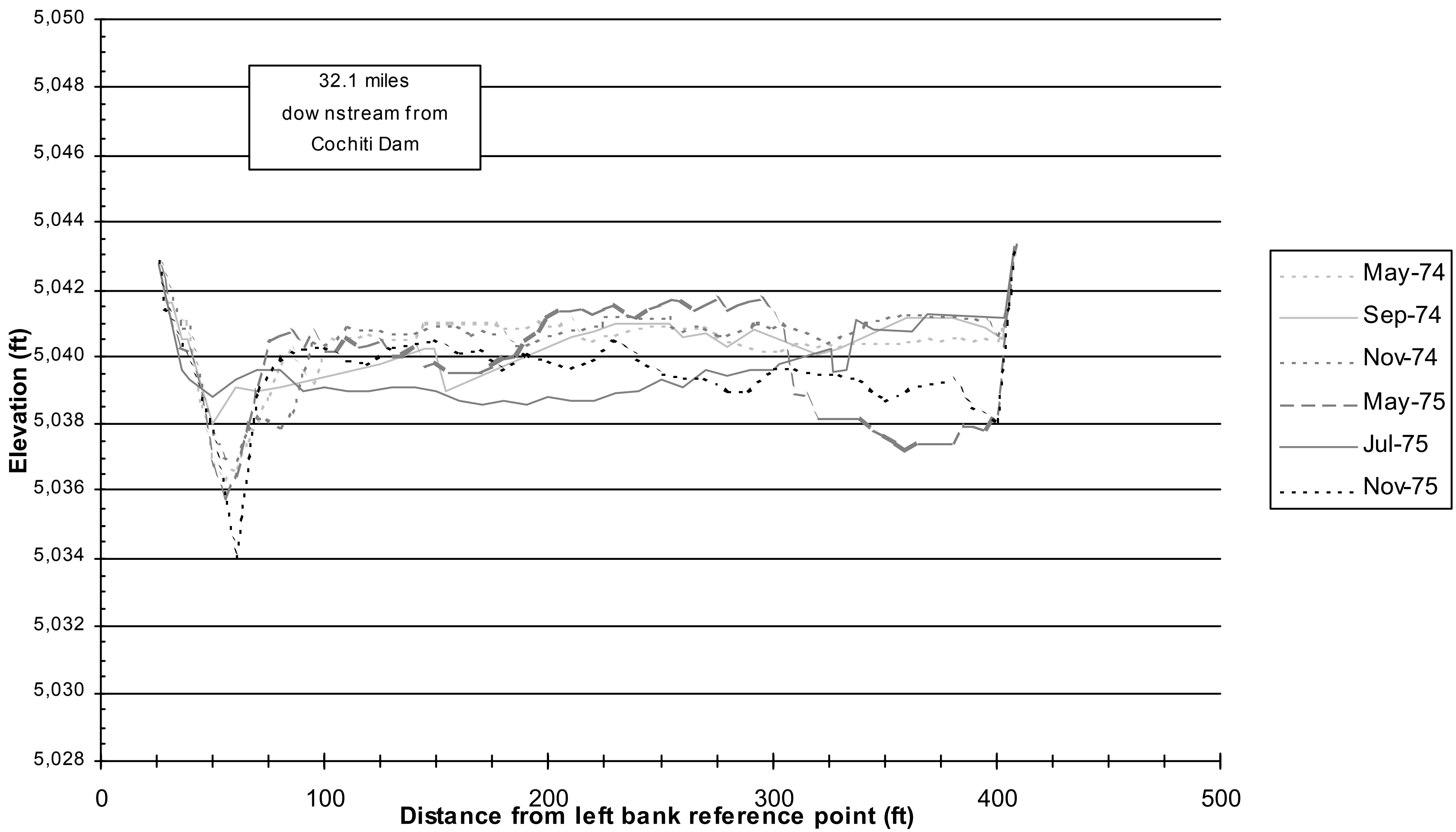

Figure D-2. Cross Section CO-31 (post-dam).

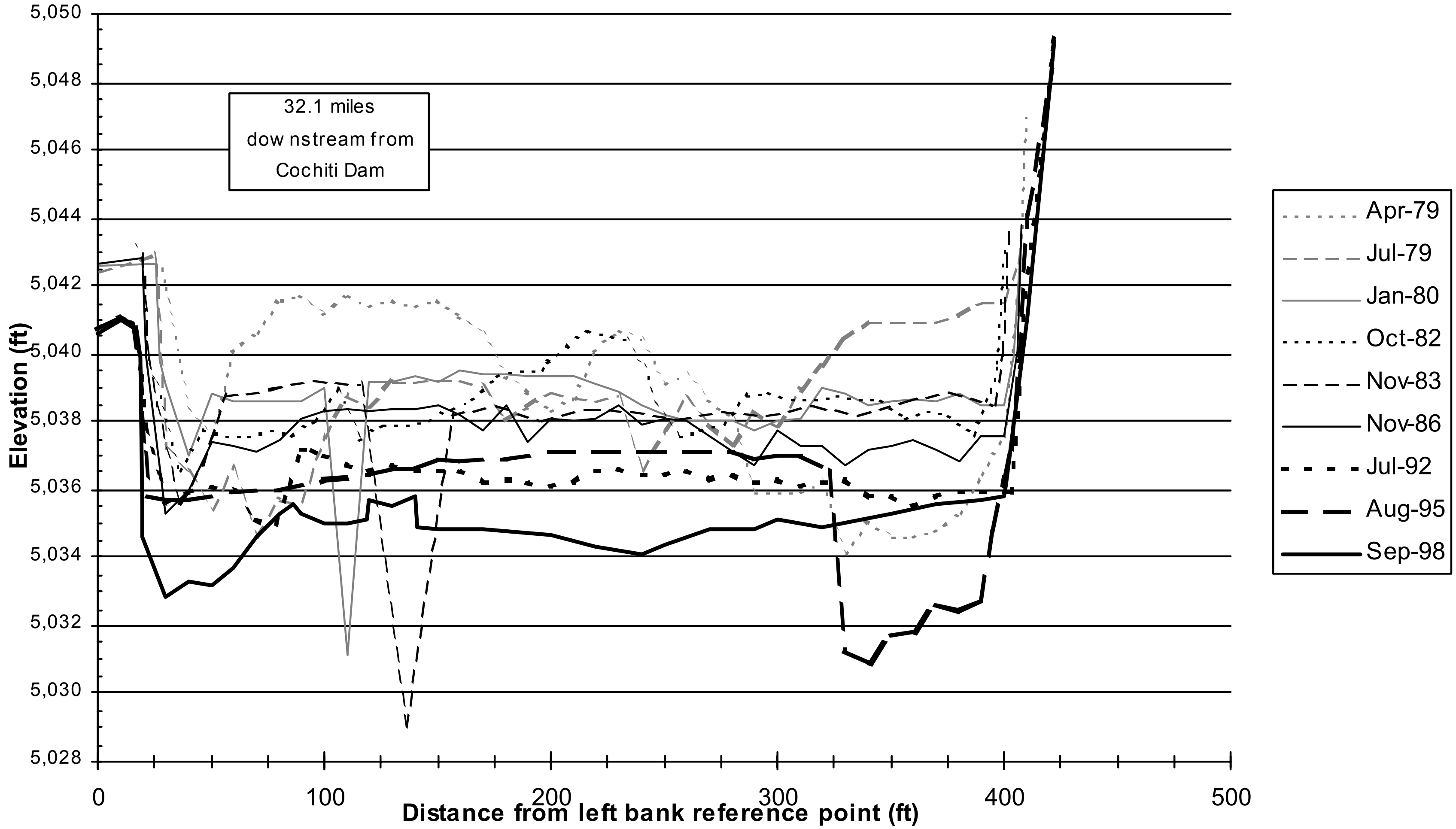

Figure D-3. Cross Section CO-31 (post-dam cont'd).

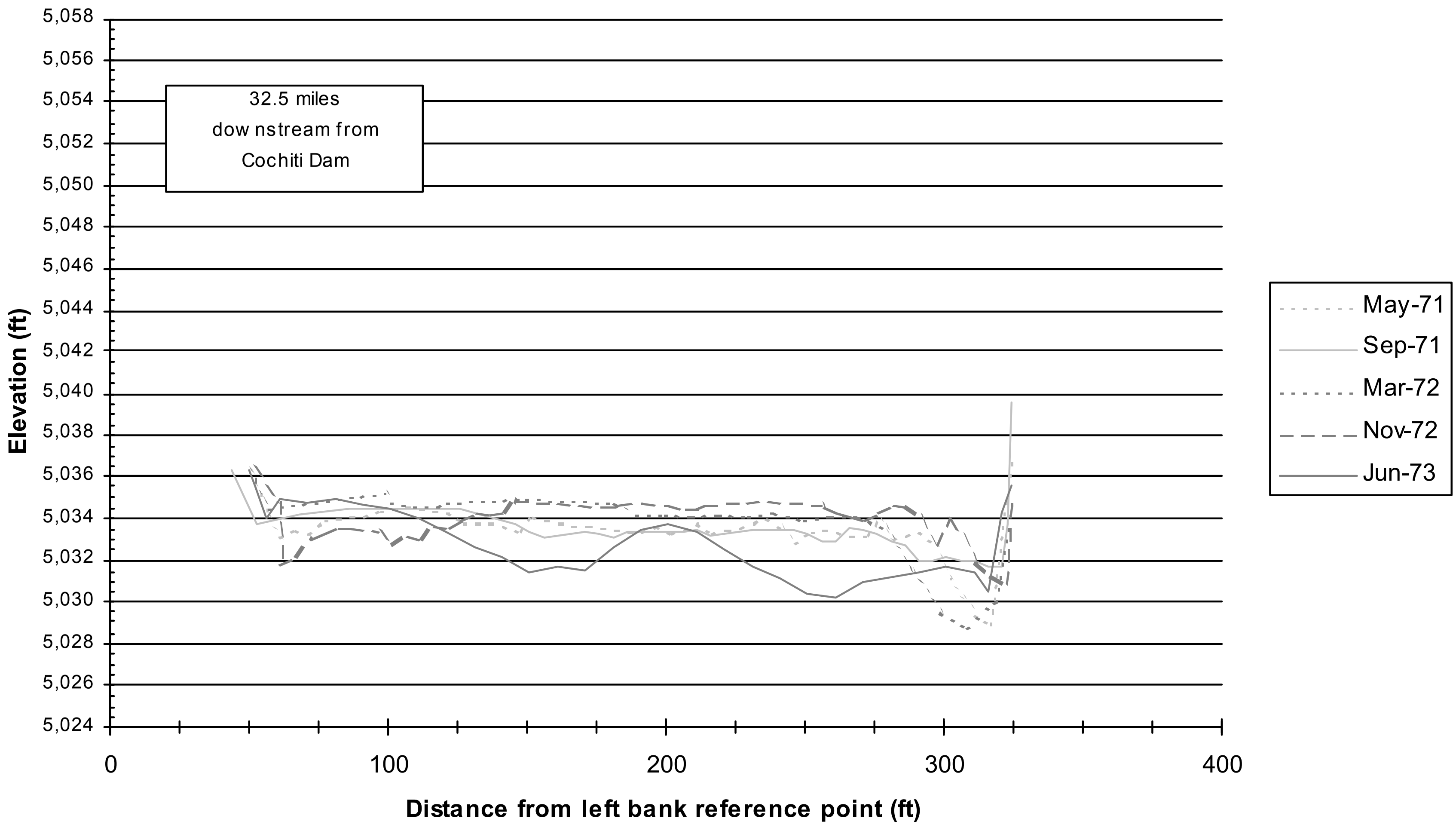

Figure D-4. Cross Section CO-32 (pre-dam).

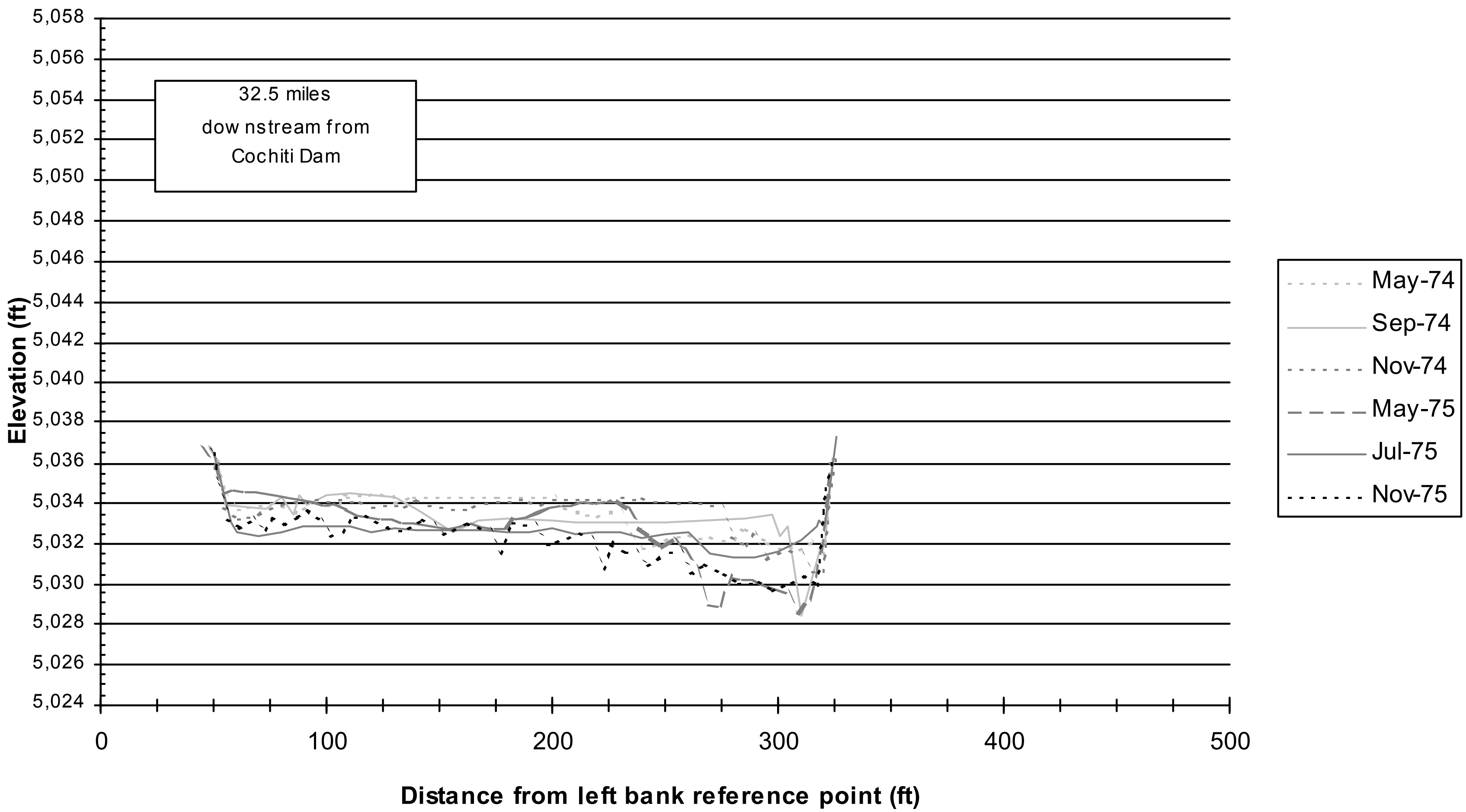

Figure D-5. Cross Section CO-32 (post-dam).

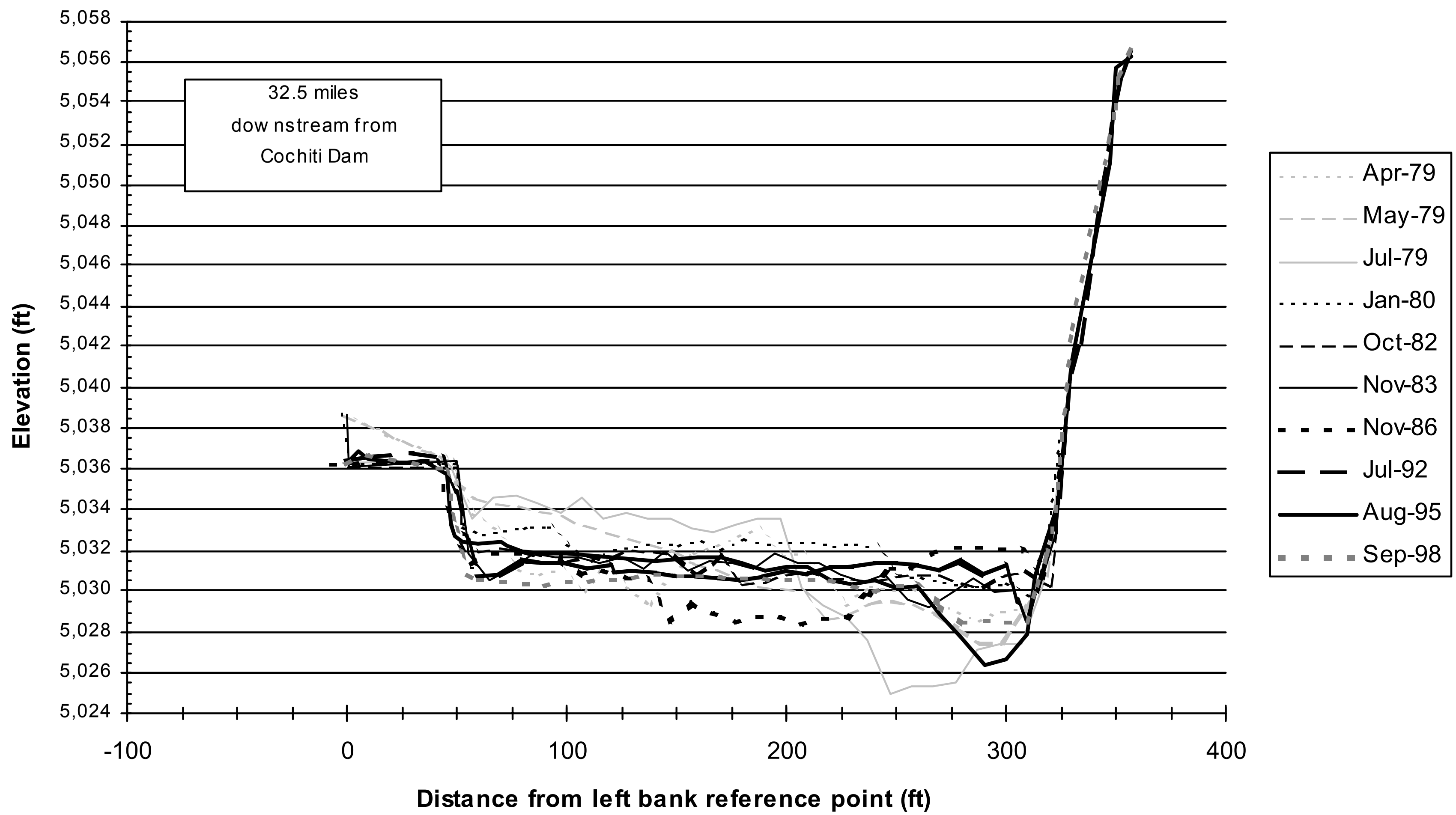

Figure D-6. Cross Section CO-32 (post-dam cont'd).

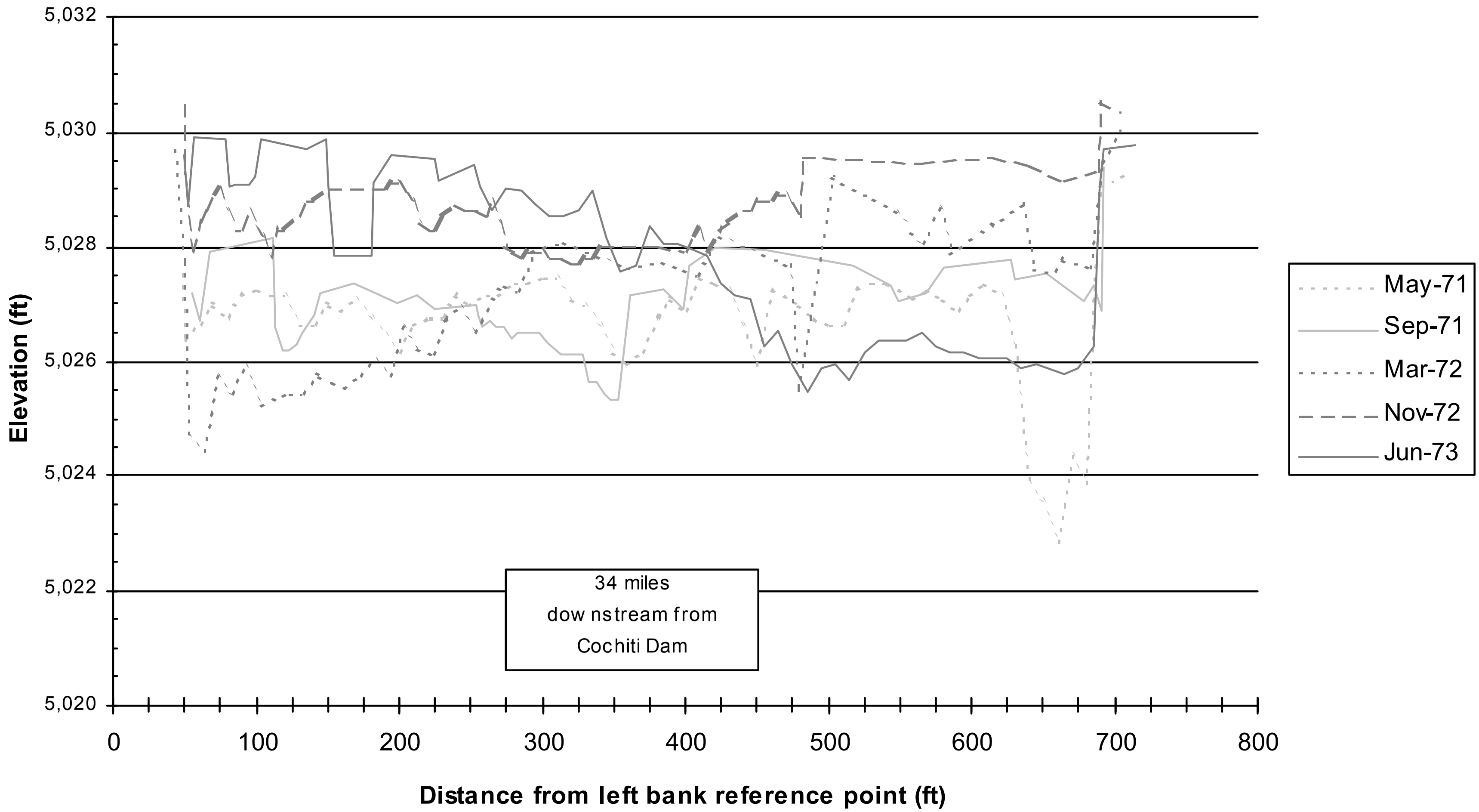

Figure D-7. Cross Section CO-33 (pre-dam).

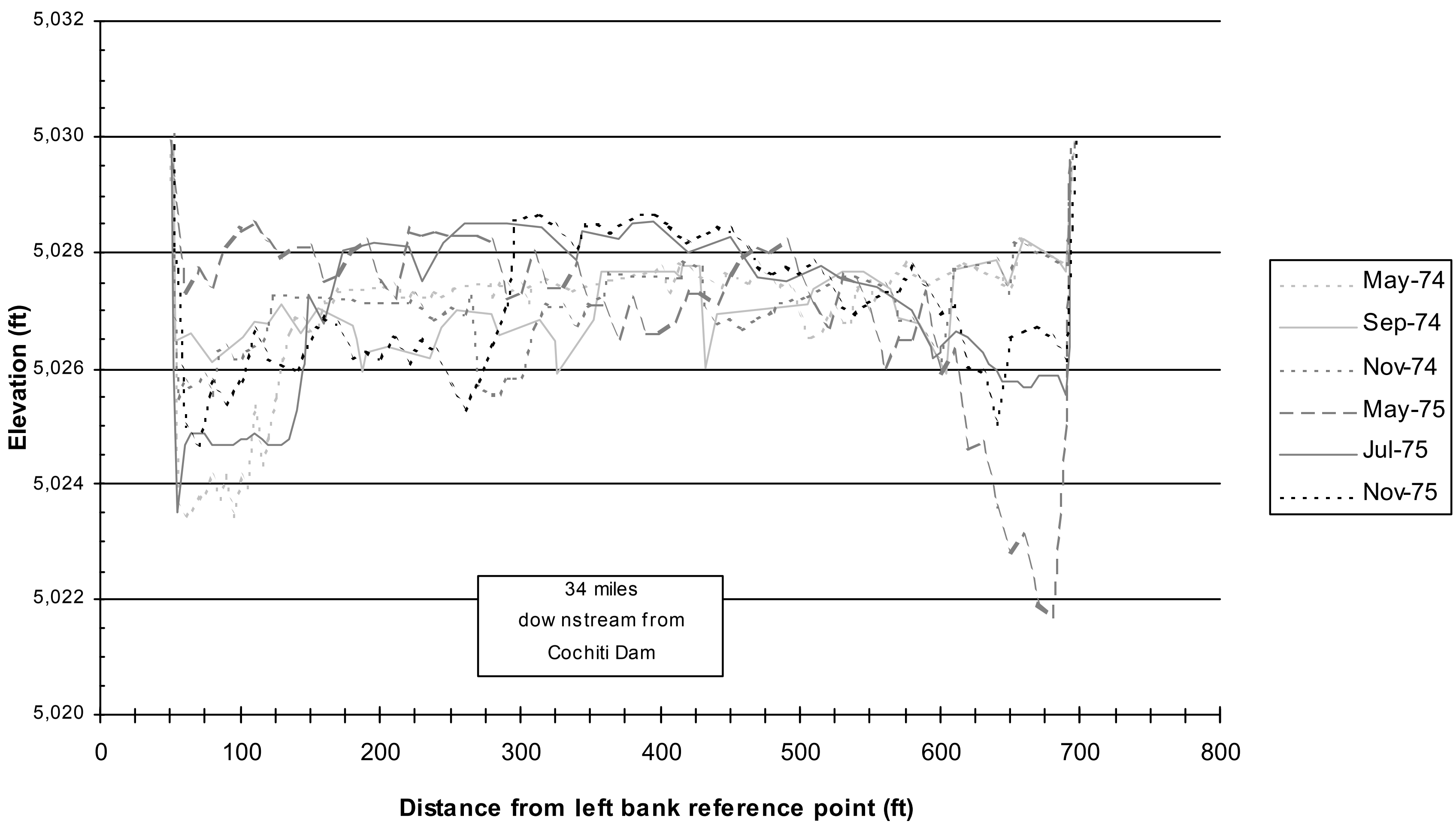

Figure D-8. Cross Section CO-33 (post-dam).

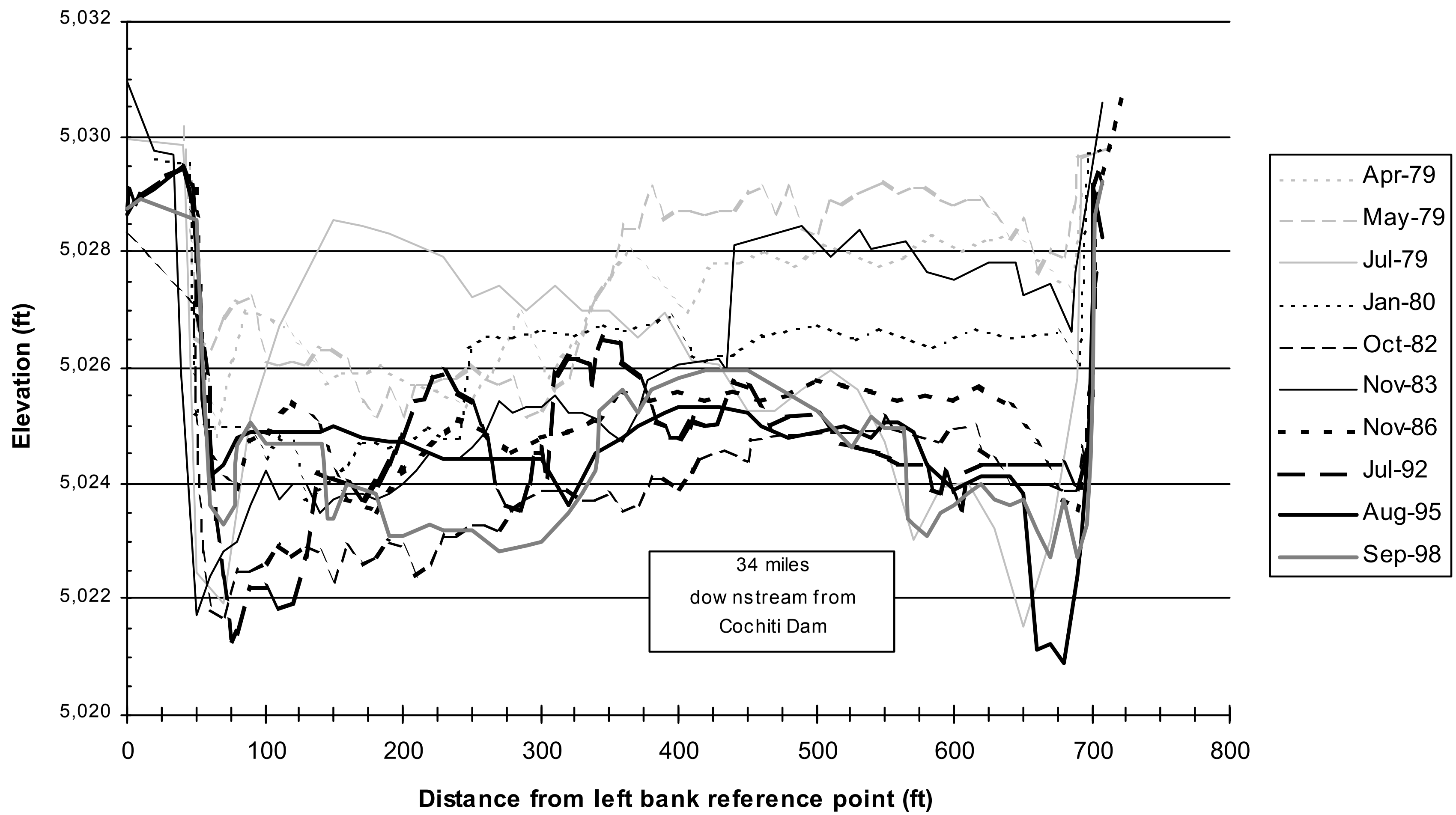

Figure D-9. Cross Section CO-33 (post-dam cont’d).

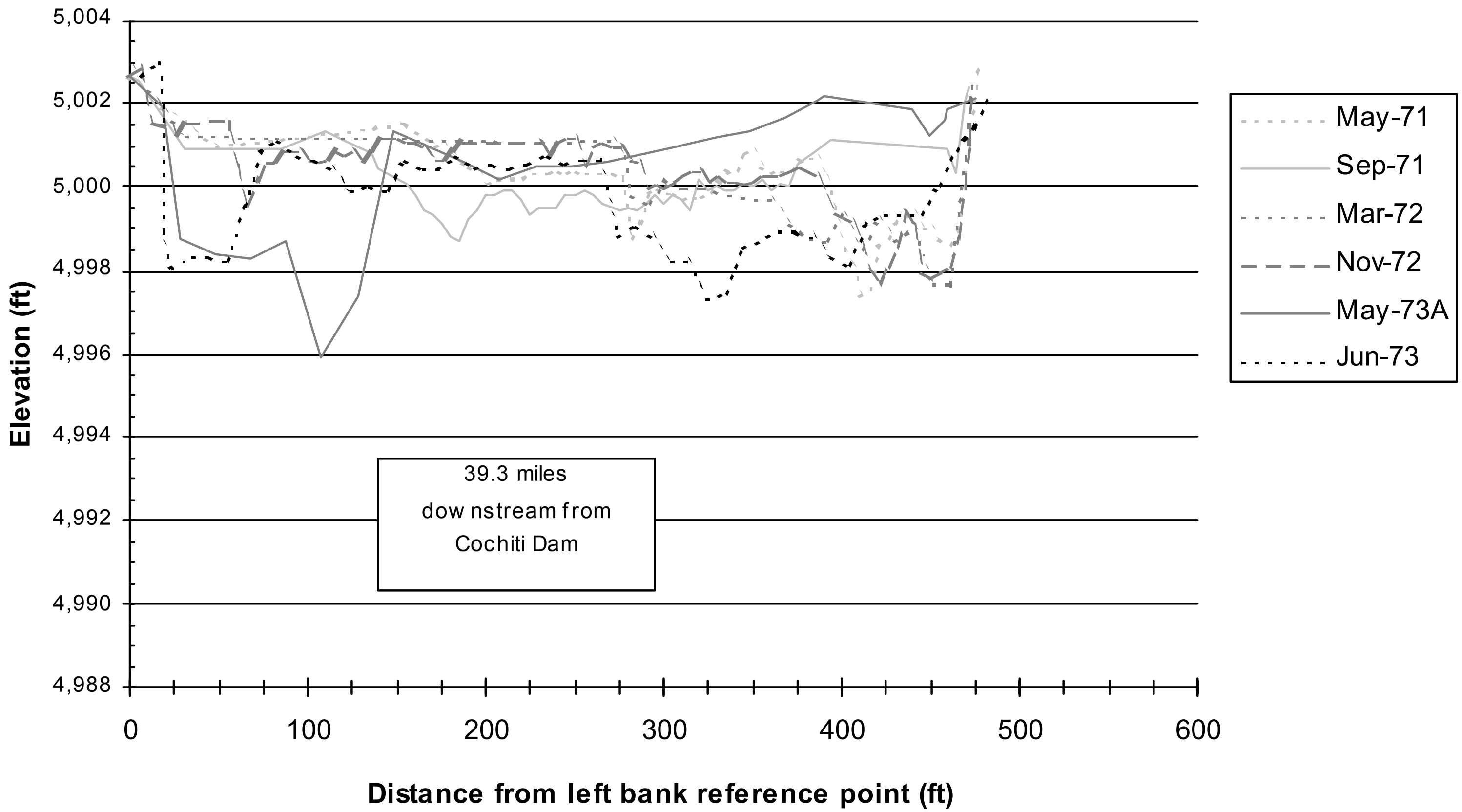

Figure D-10. Cross Section CO-34 (pre-dam).

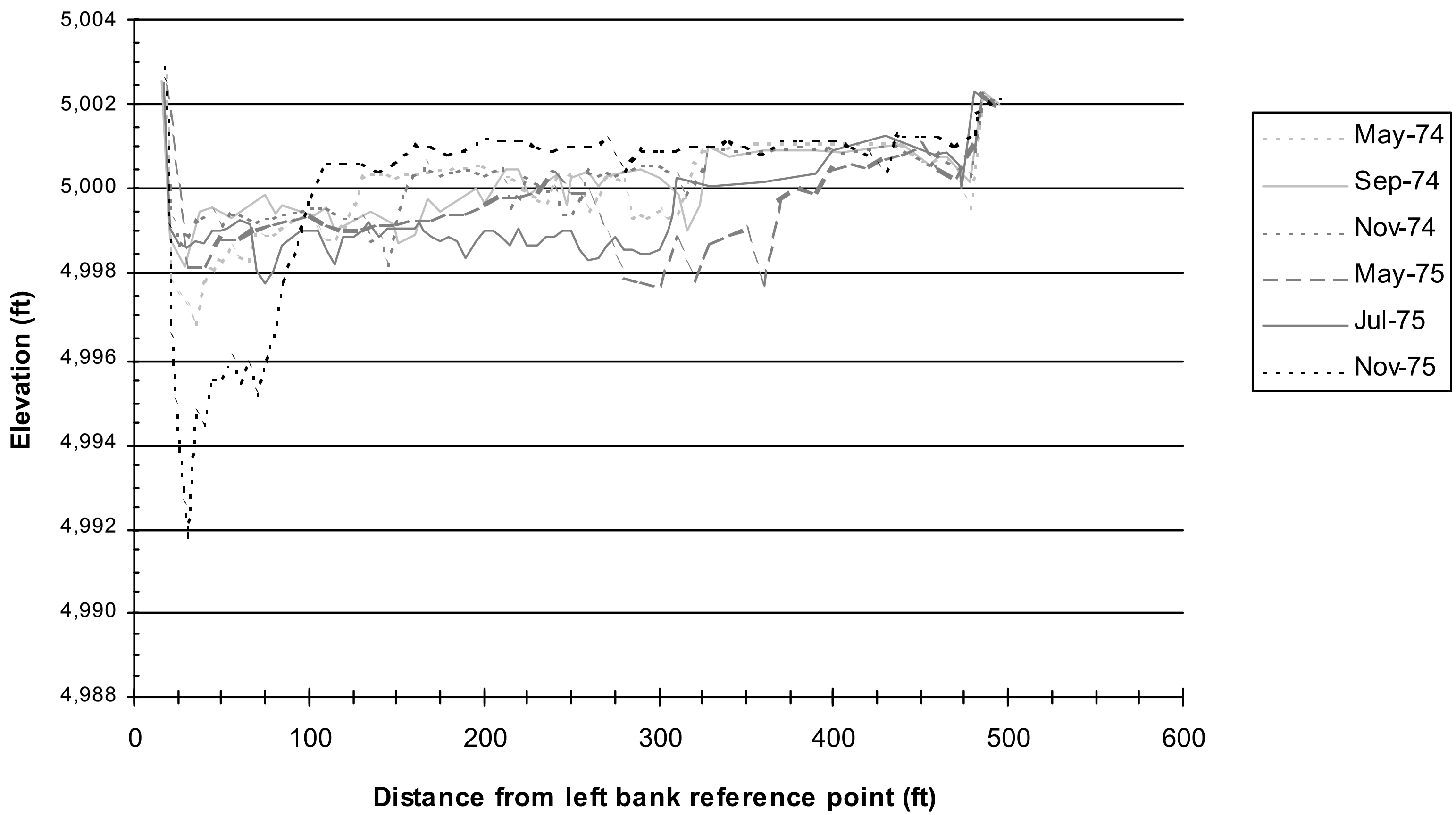

Figure D-11. Cross Section CO-34 (post-dam).

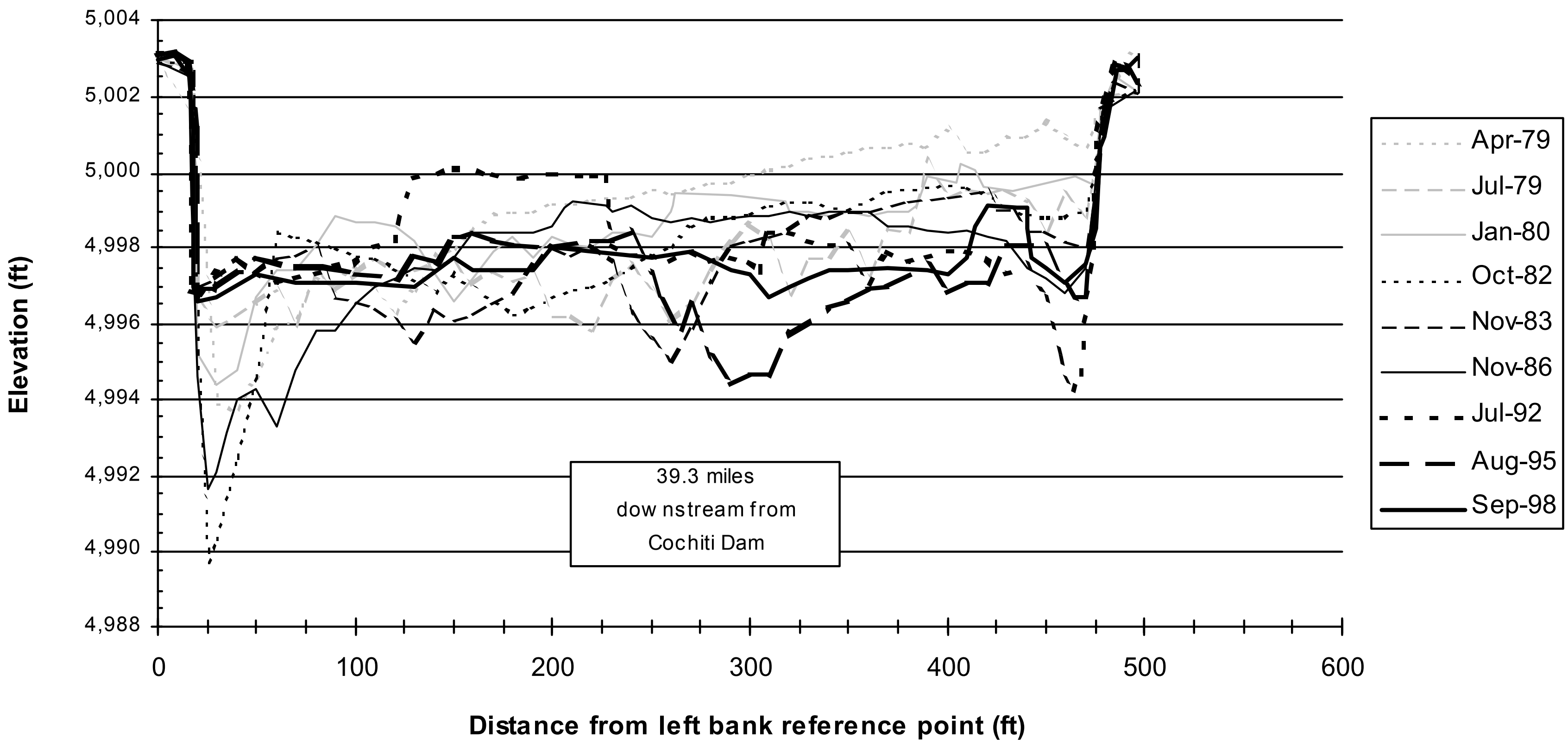

Figure D-12. Cross Section CO-34 (post-dam cont'd).

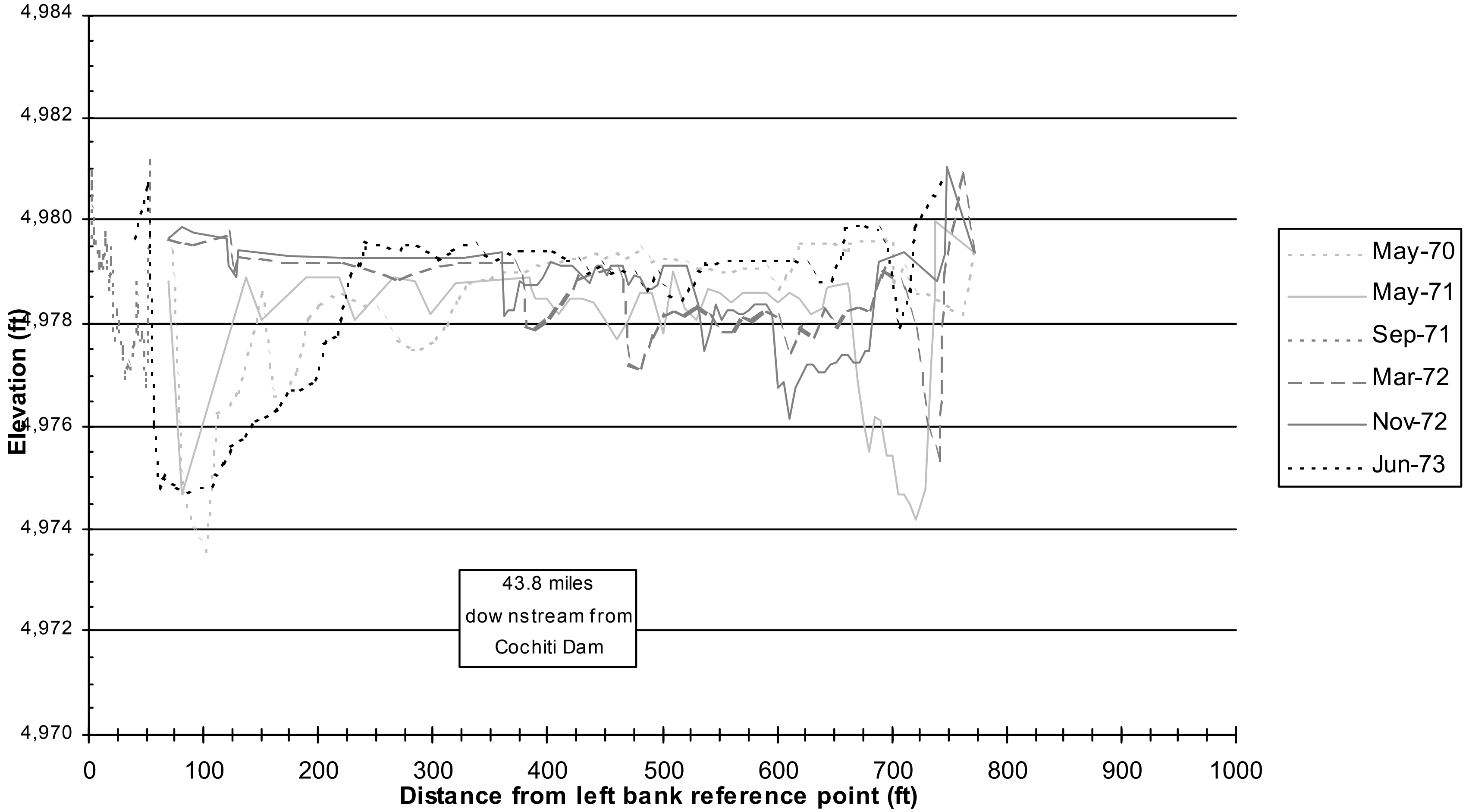

Figure D-13. Cross Section CO-35 (pre-dam).

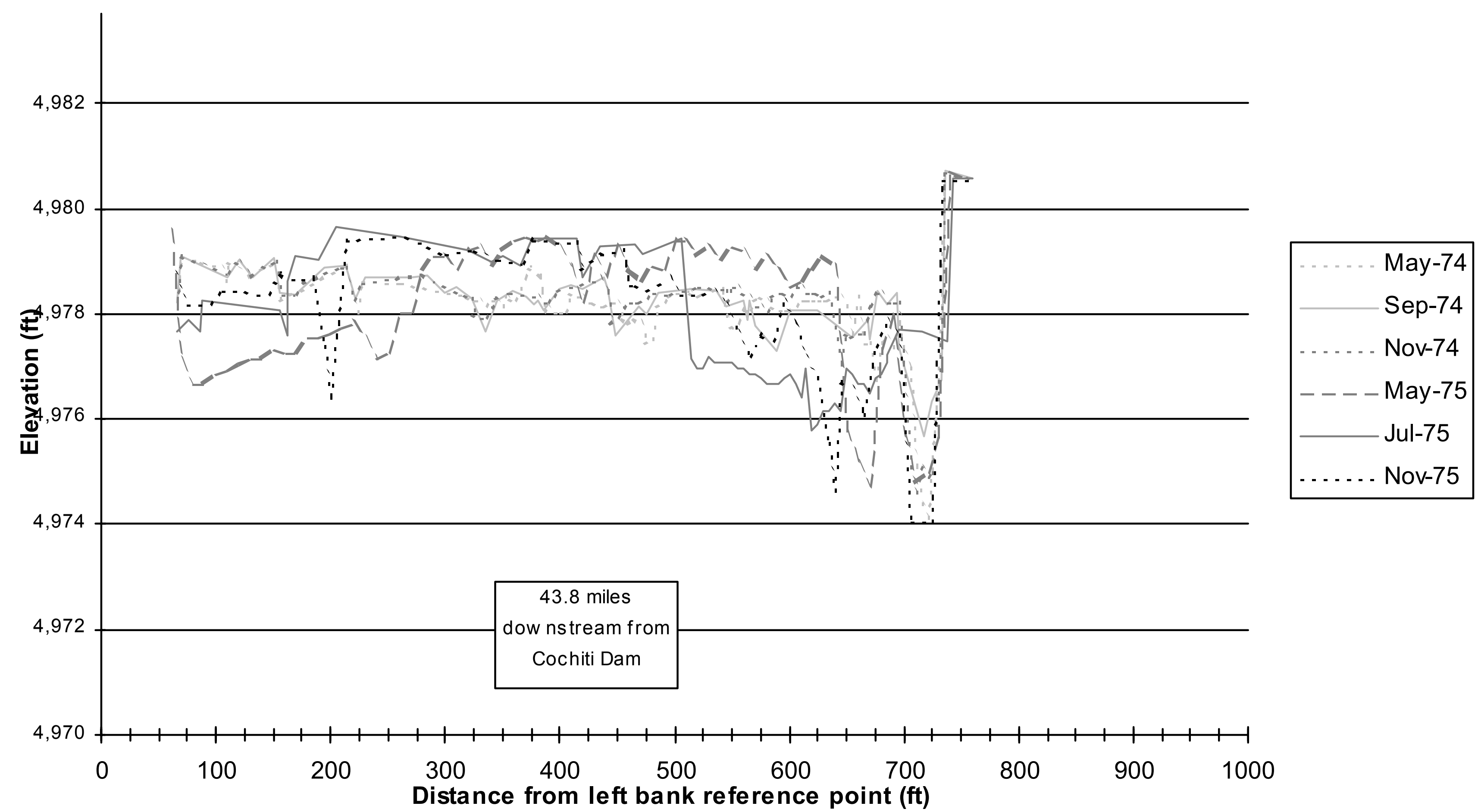

Figure D-14. Cross Section CO-35 (post-dam).

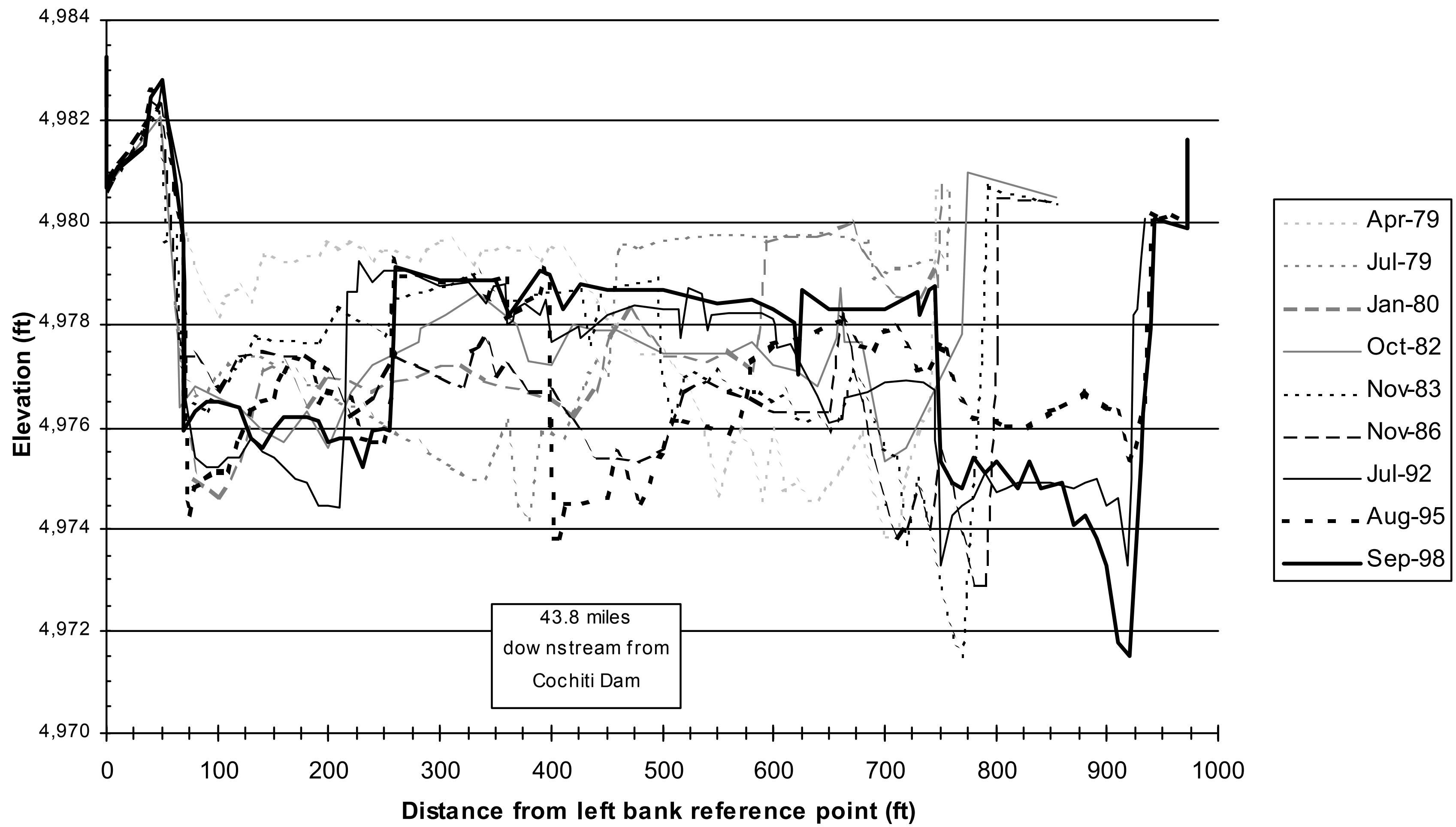

Figure D-15. Cross Section CO-35 (post-dam cont'd).

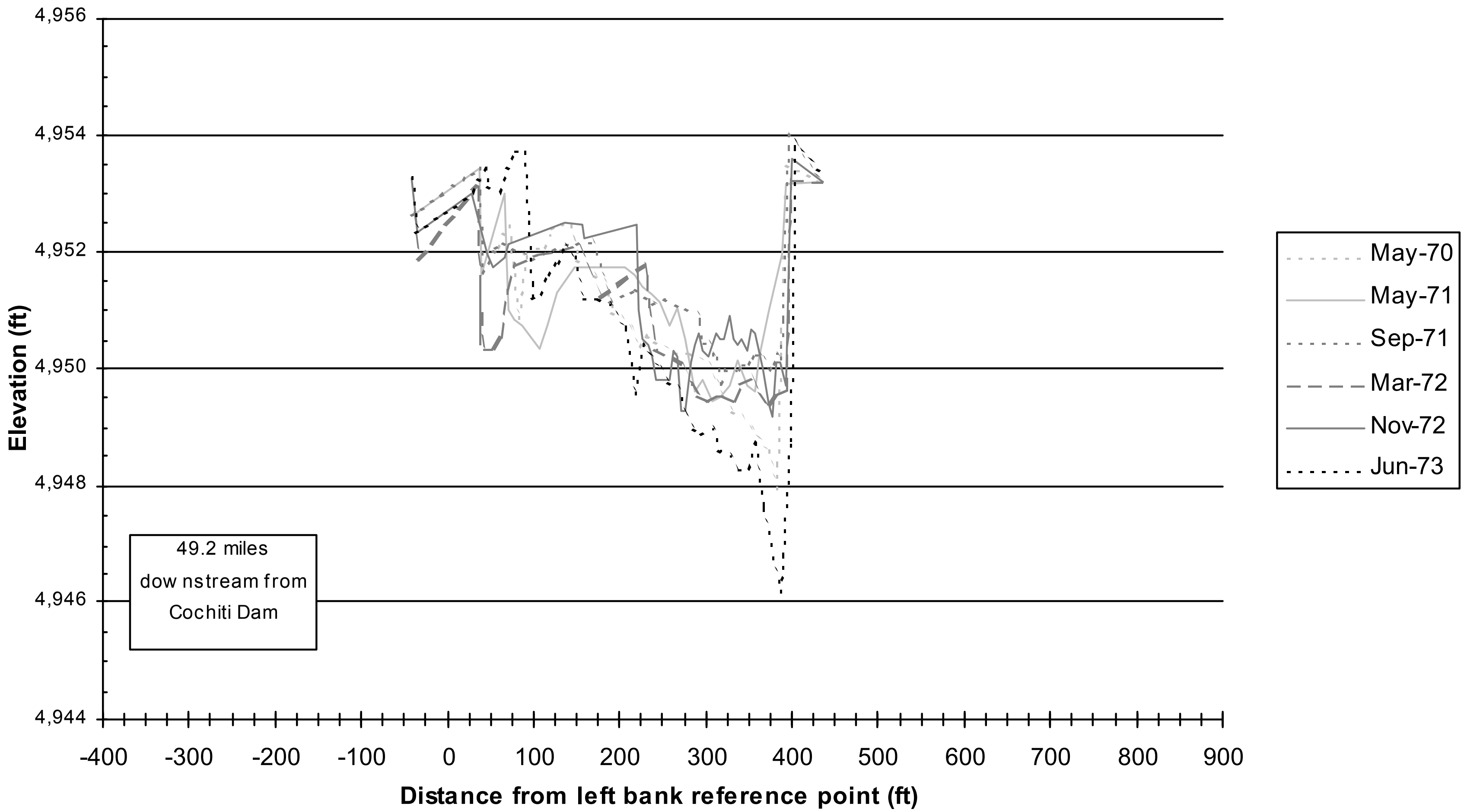

Figure D-16. Cross Section CO-36 (pre-dam).

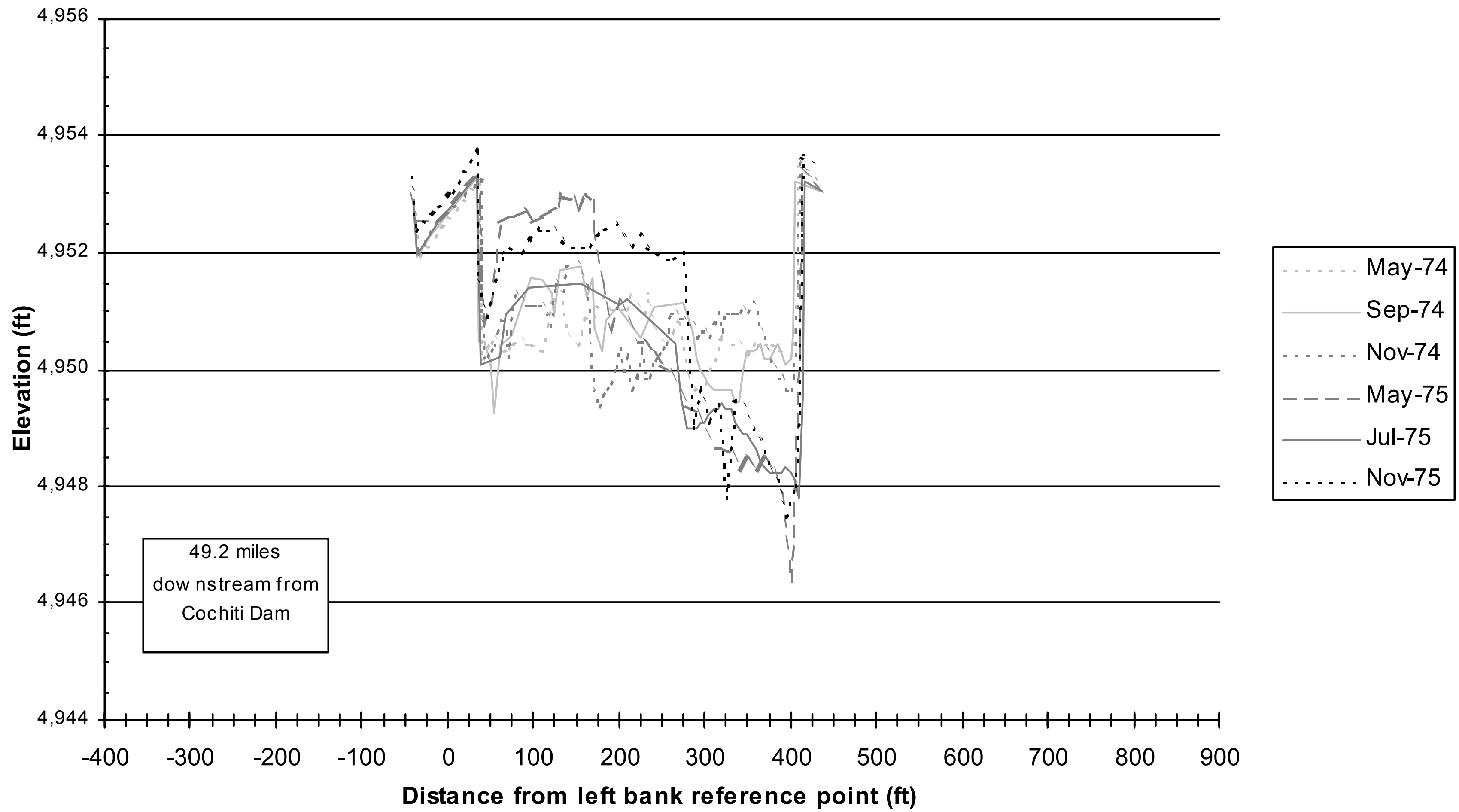

Figure D-17. Cross Section CO-36 (post-dam).

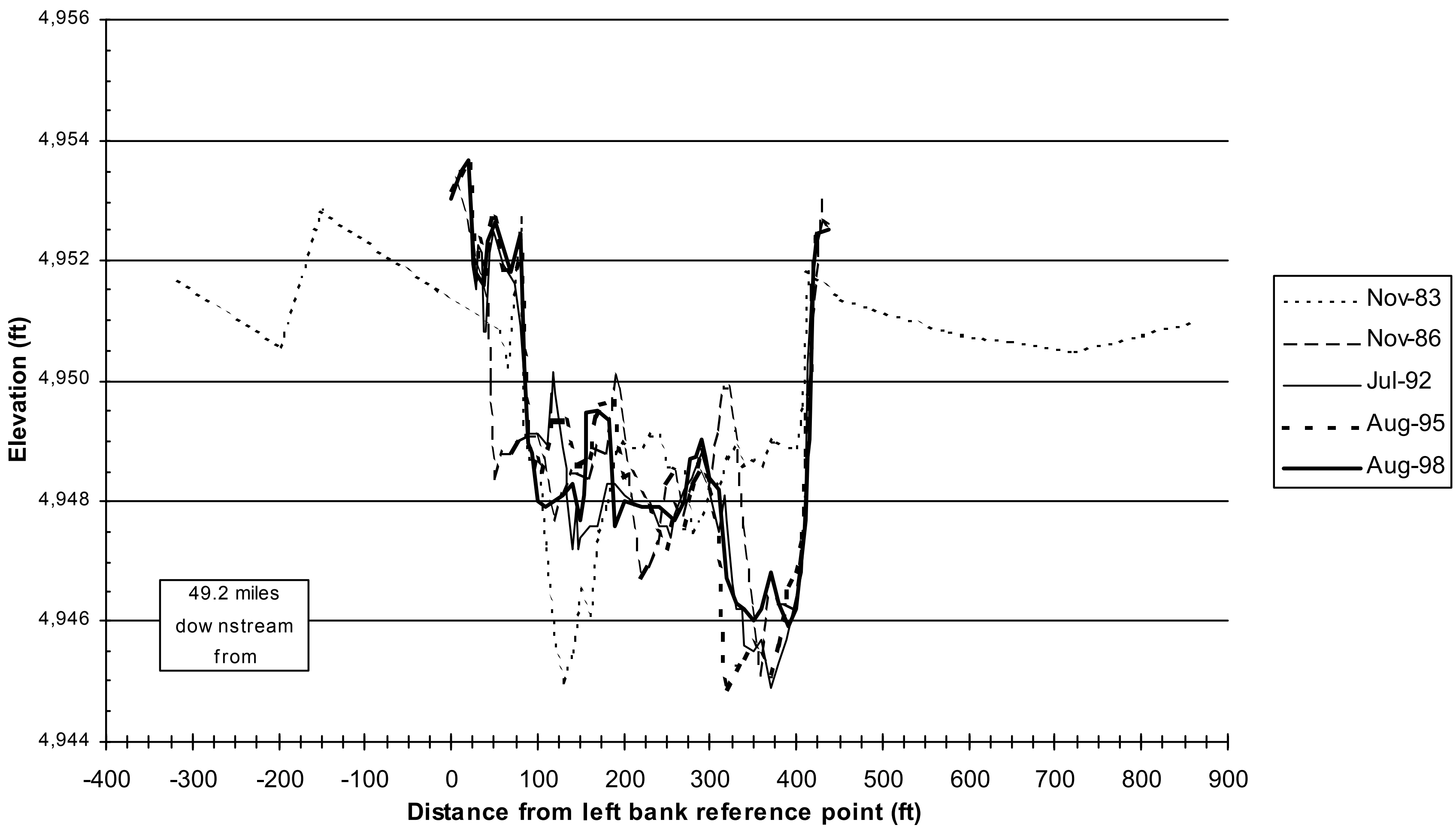

Figure D-18. Cross Section CO-36 (post-dam cont'd).

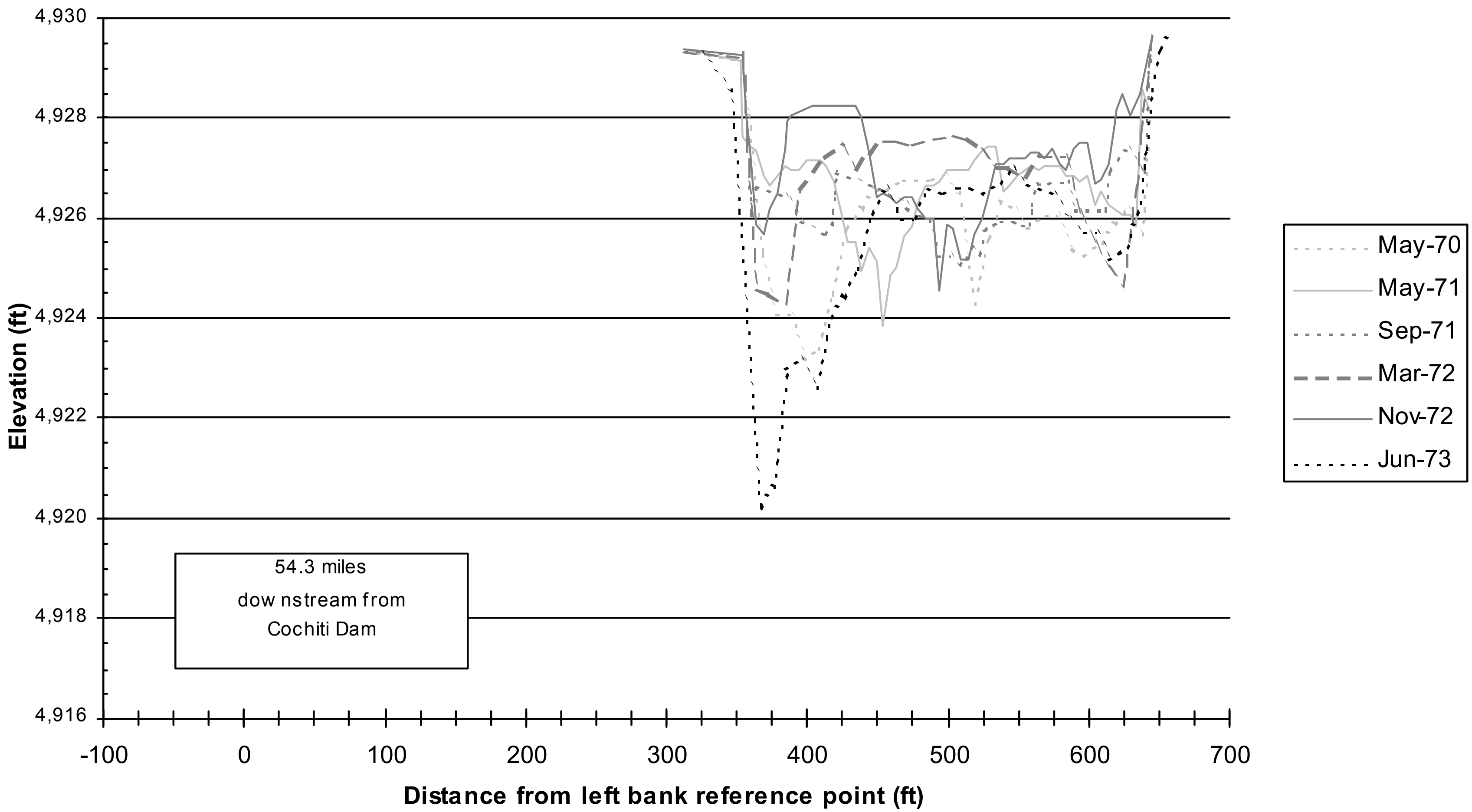

Figure D-19. Cross Section CO-37 (pre-dam).

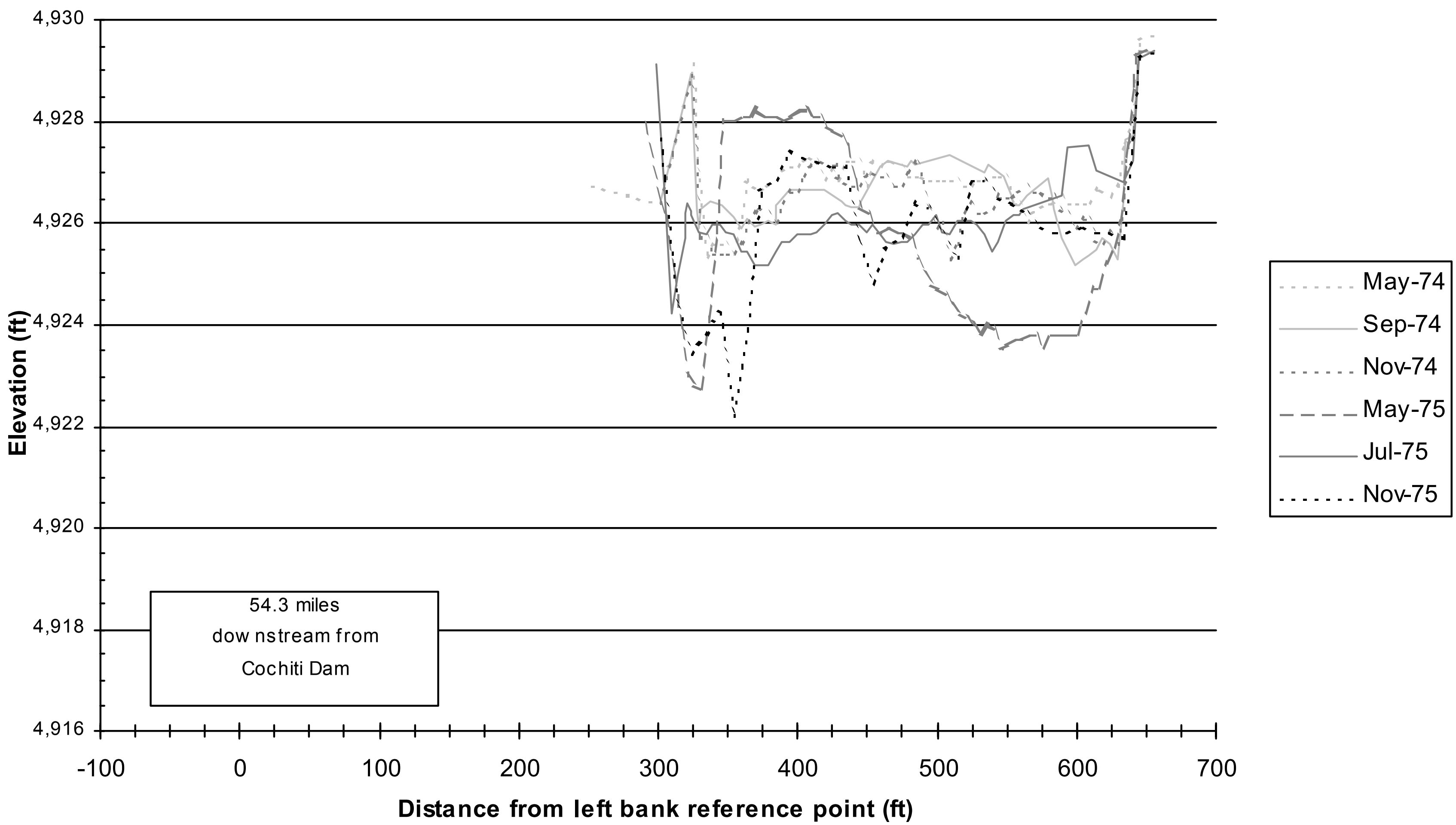

Figure D-20. Cross Section CO-37 (post-dam).

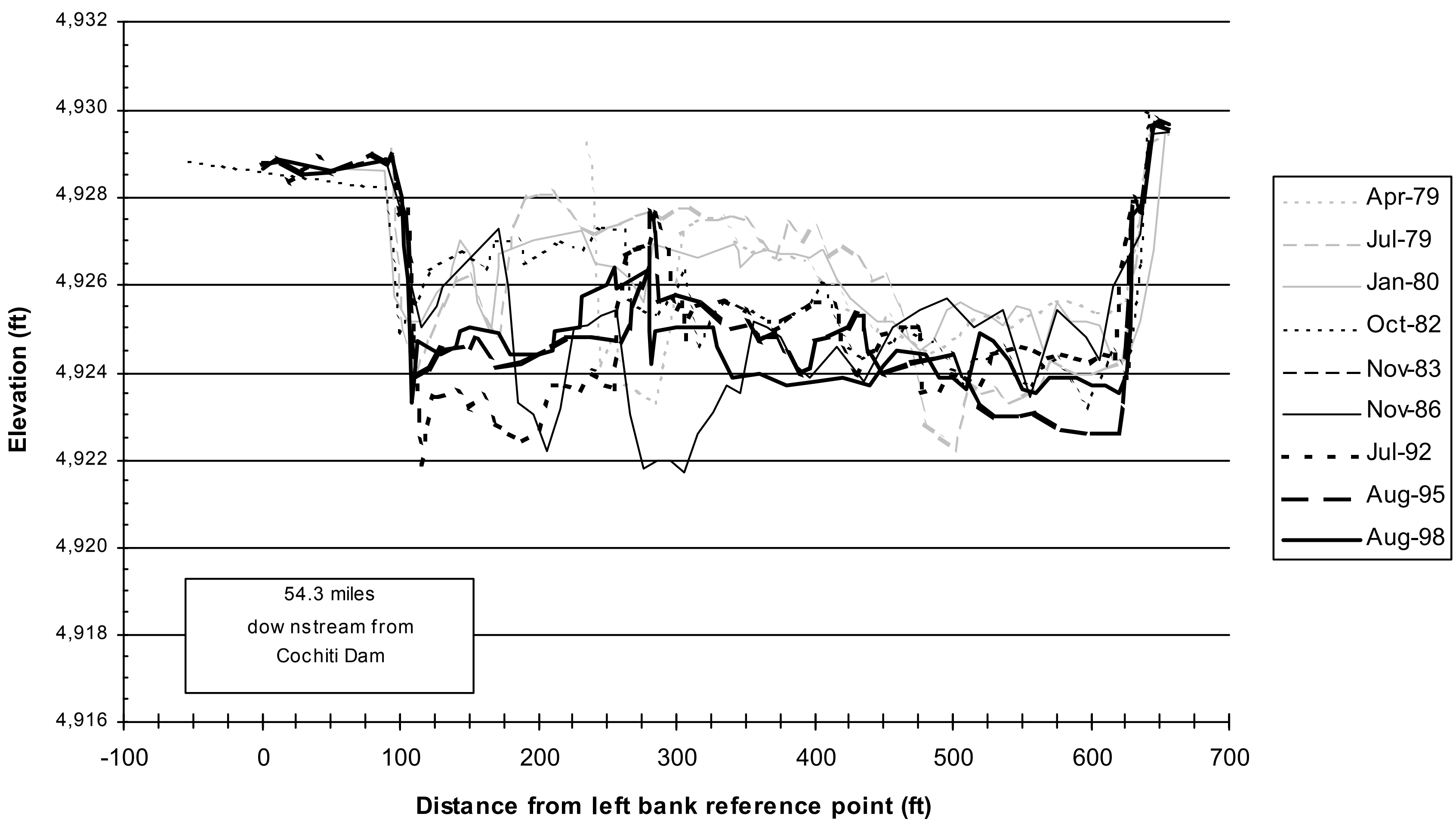

Figure D-21. Cross Section CO-37 (post-dam cont'd).

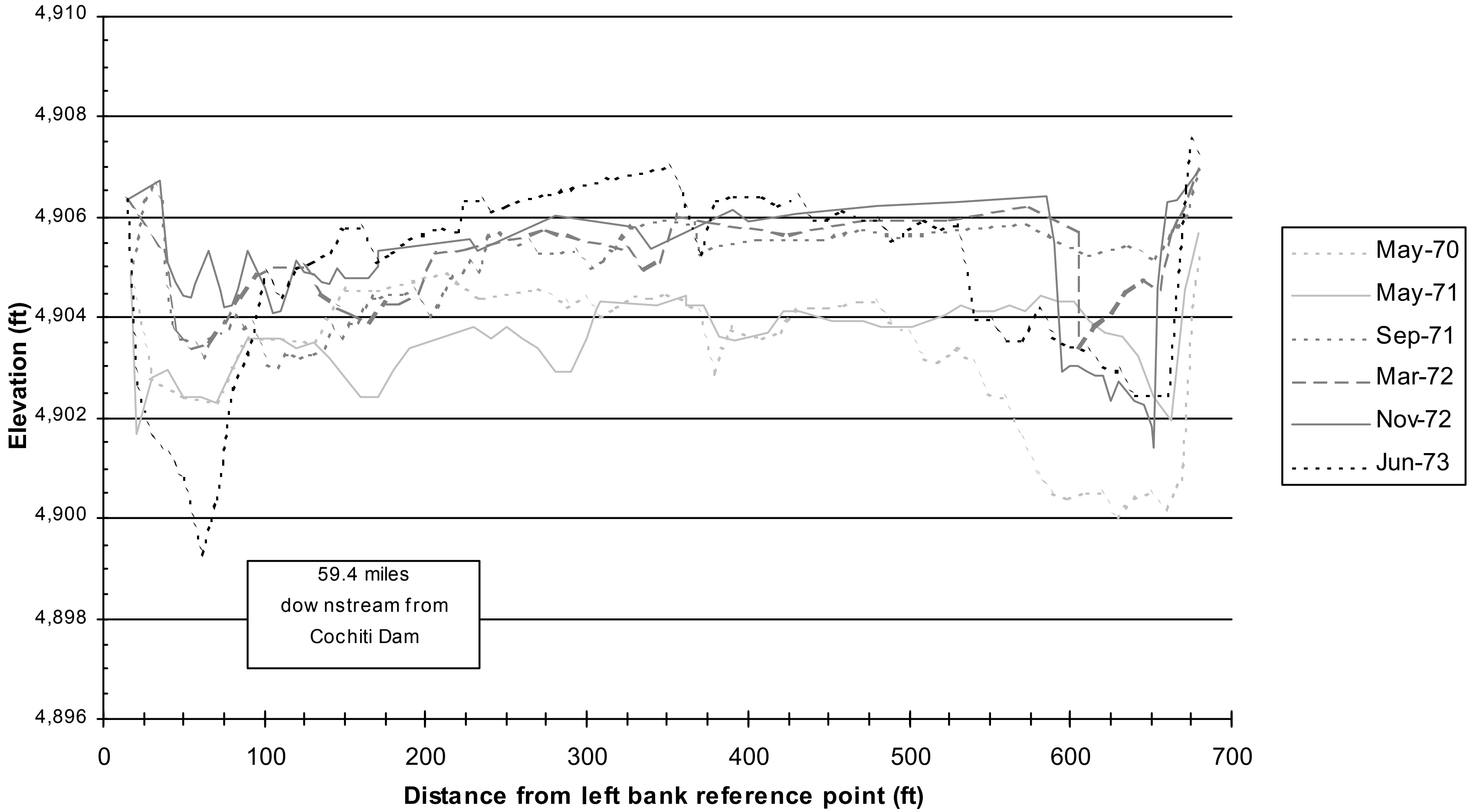

Figure D-22. Cross Section CO-38 (pre-dam).

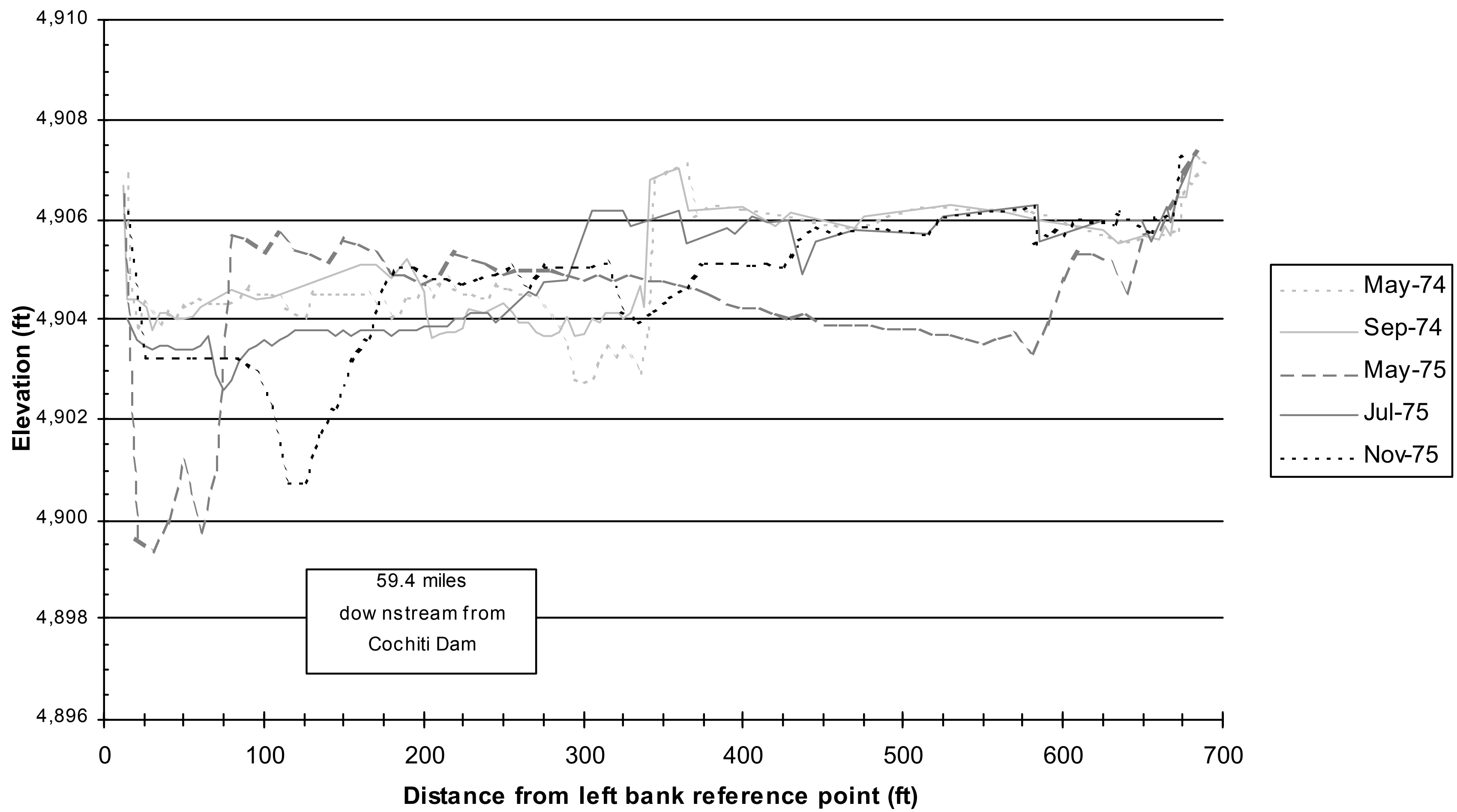

Figure D-23. Cross Section CO-38 (post-dam).

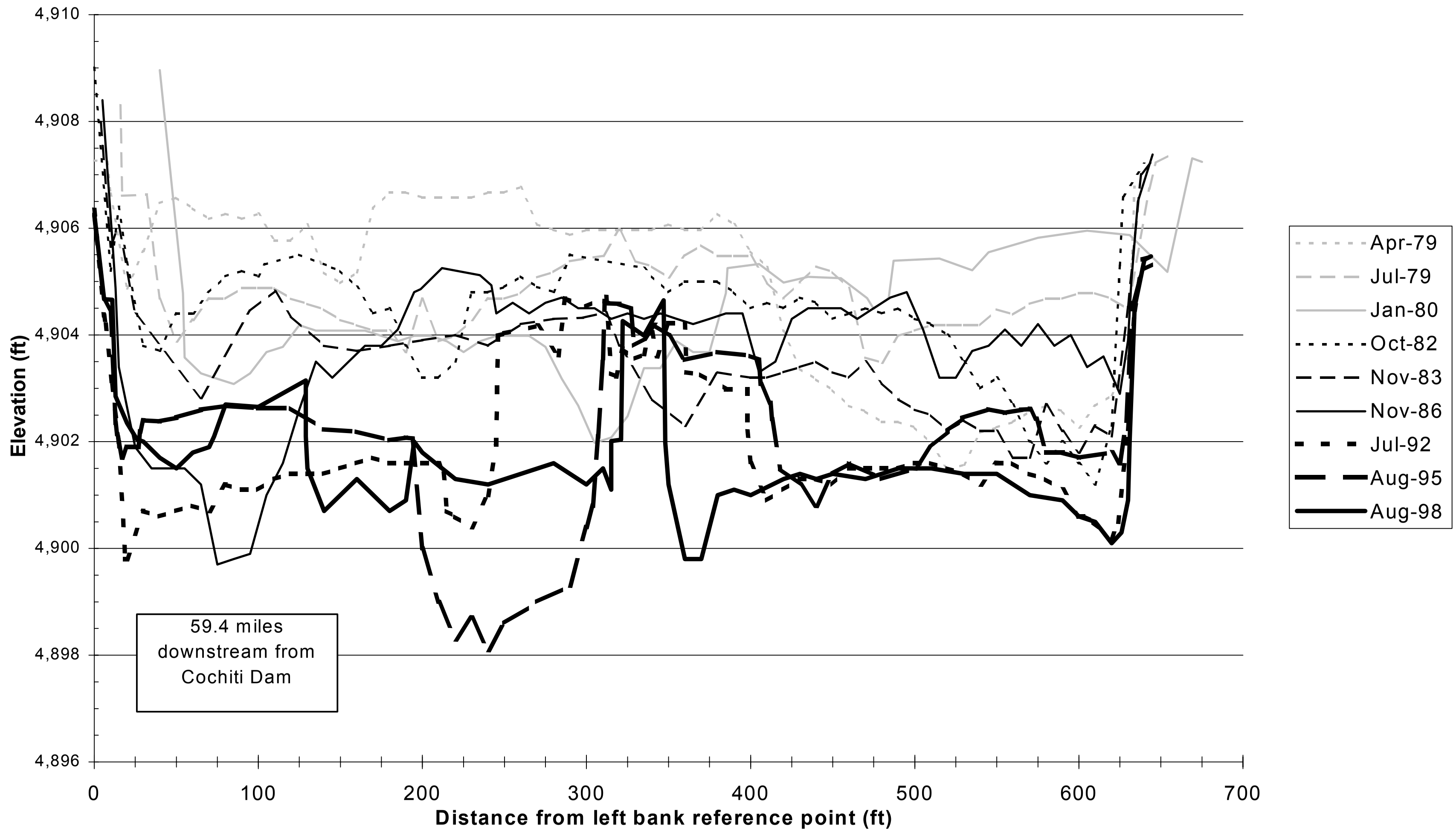

Figure D-24. Cross Section CO-38 (post-dam cont'd).

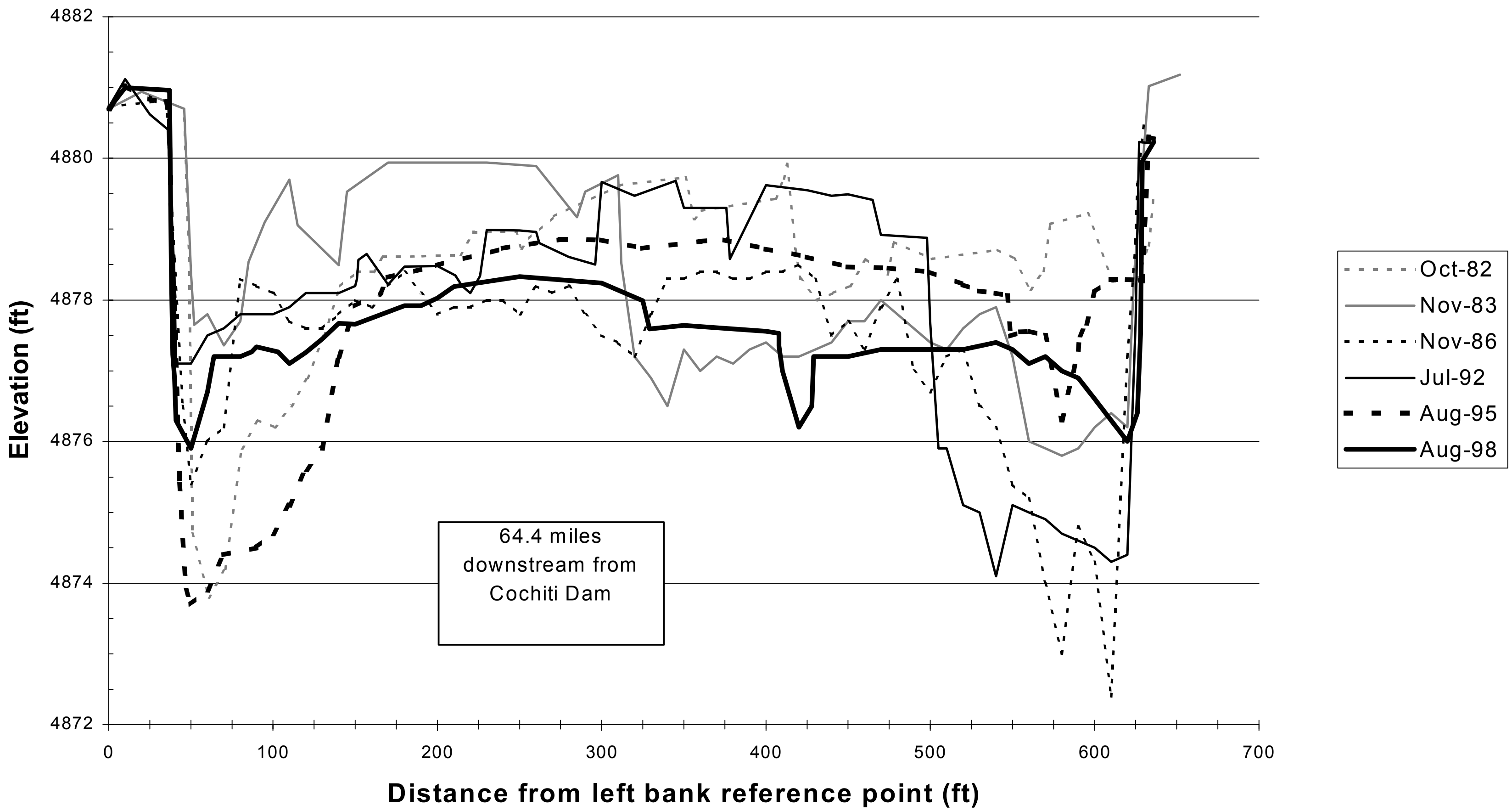

Figure D-25. Cross Section CO-668.

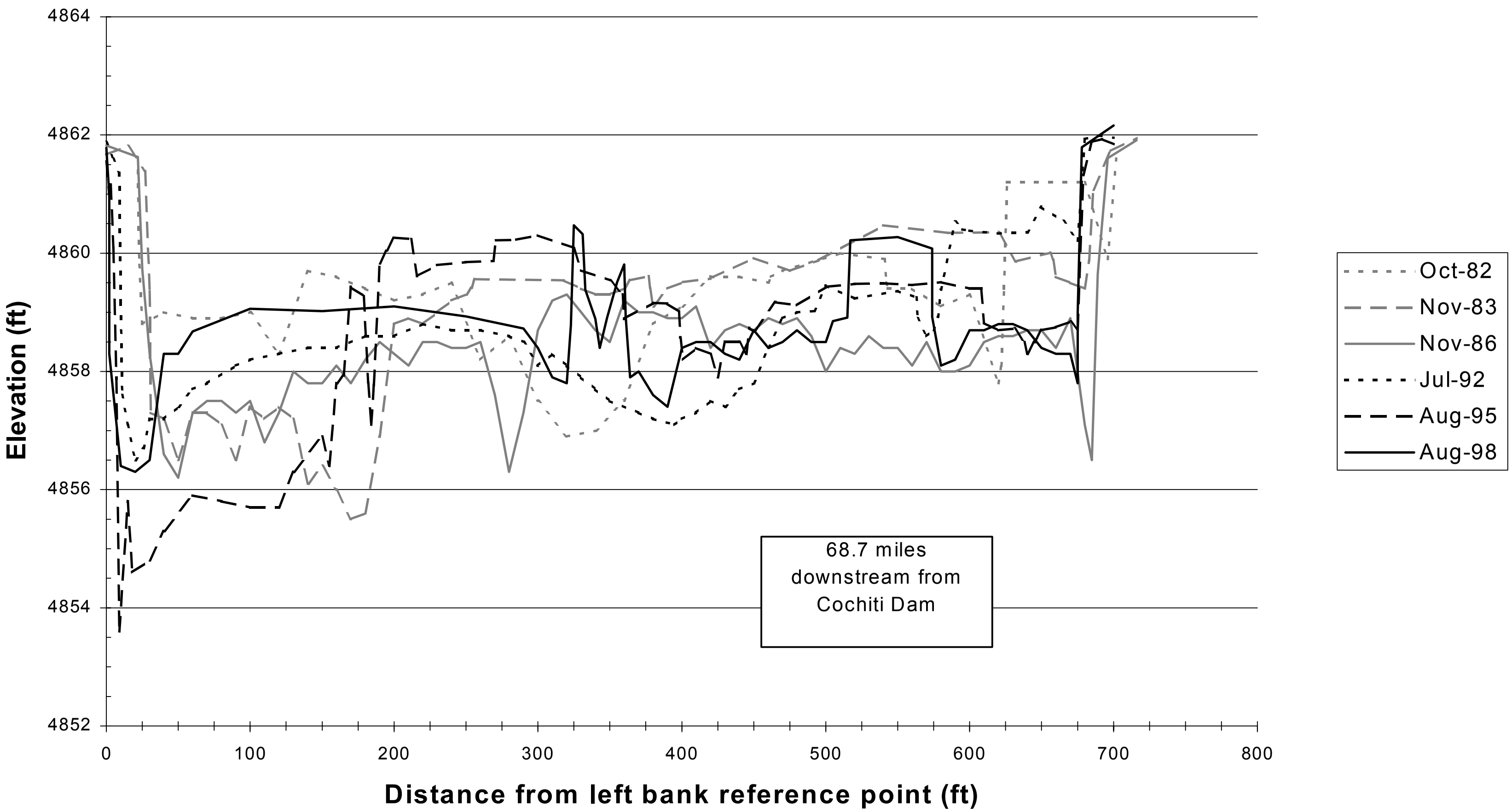

Figure D-26. Cross Section CO-713.

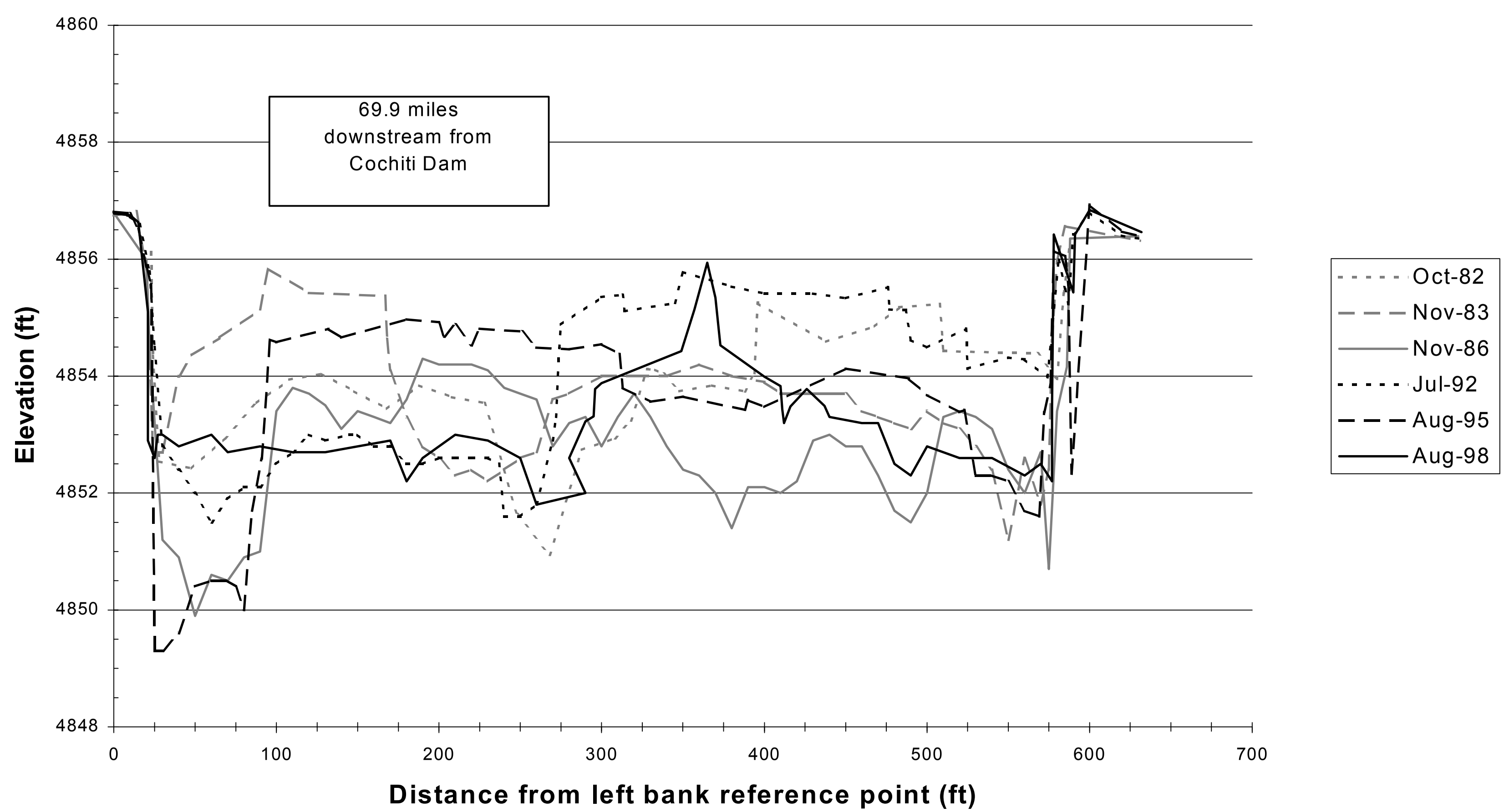

Figure D-27. Cross Section CO-724.

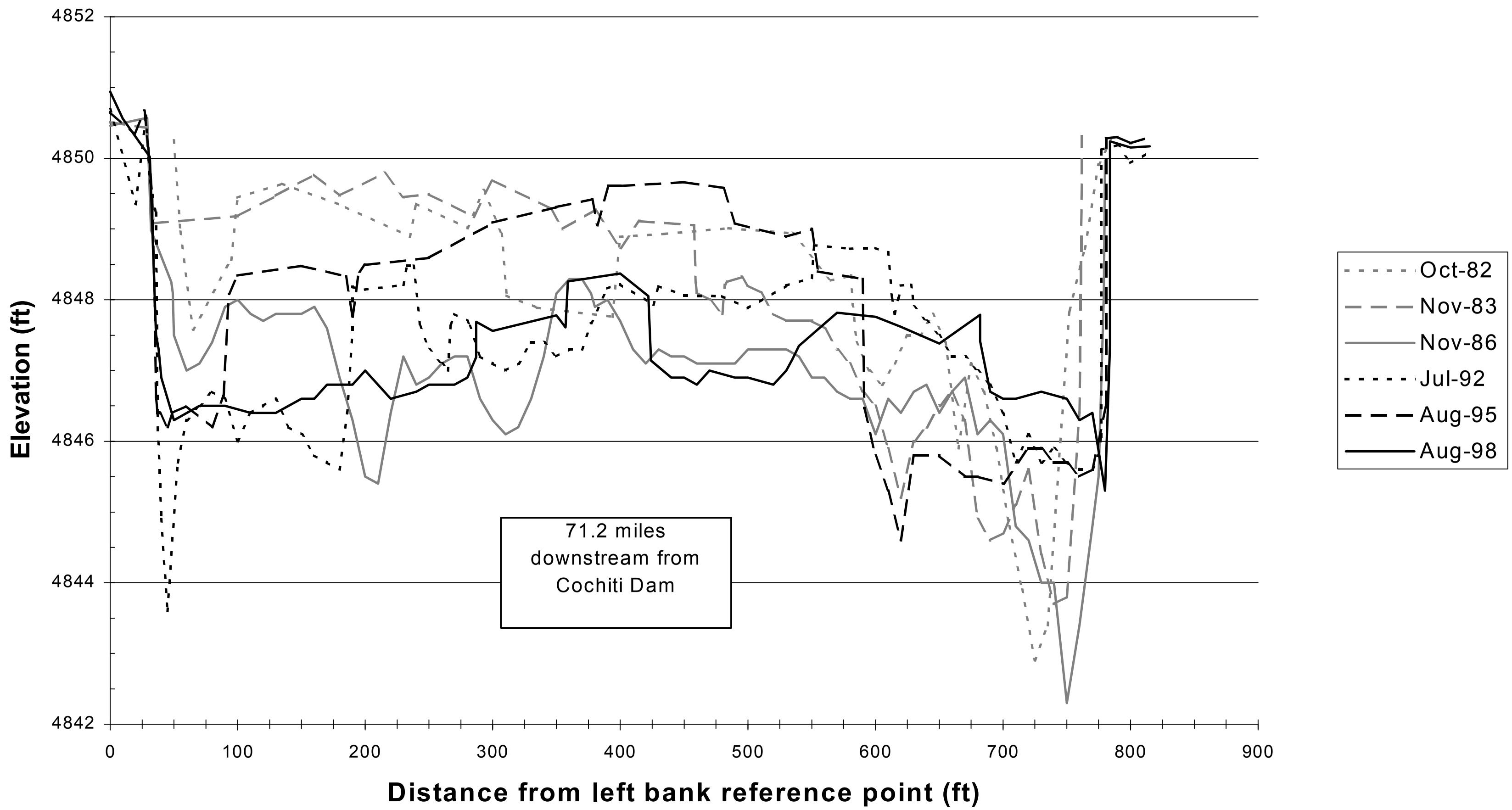

Figure D-28. Cross Section CO-738.1.

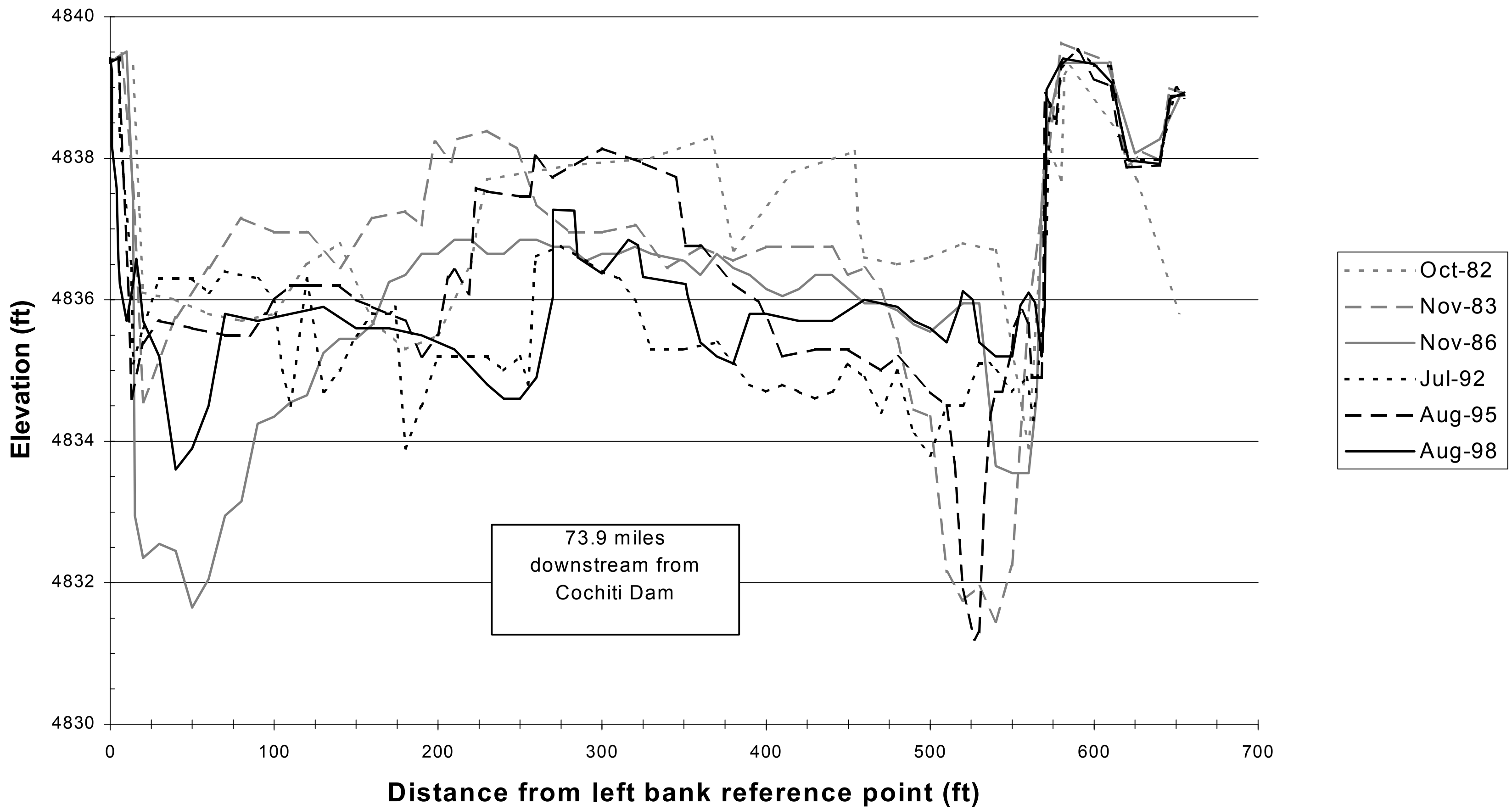

Figure D-29. Cross Section CO-765.

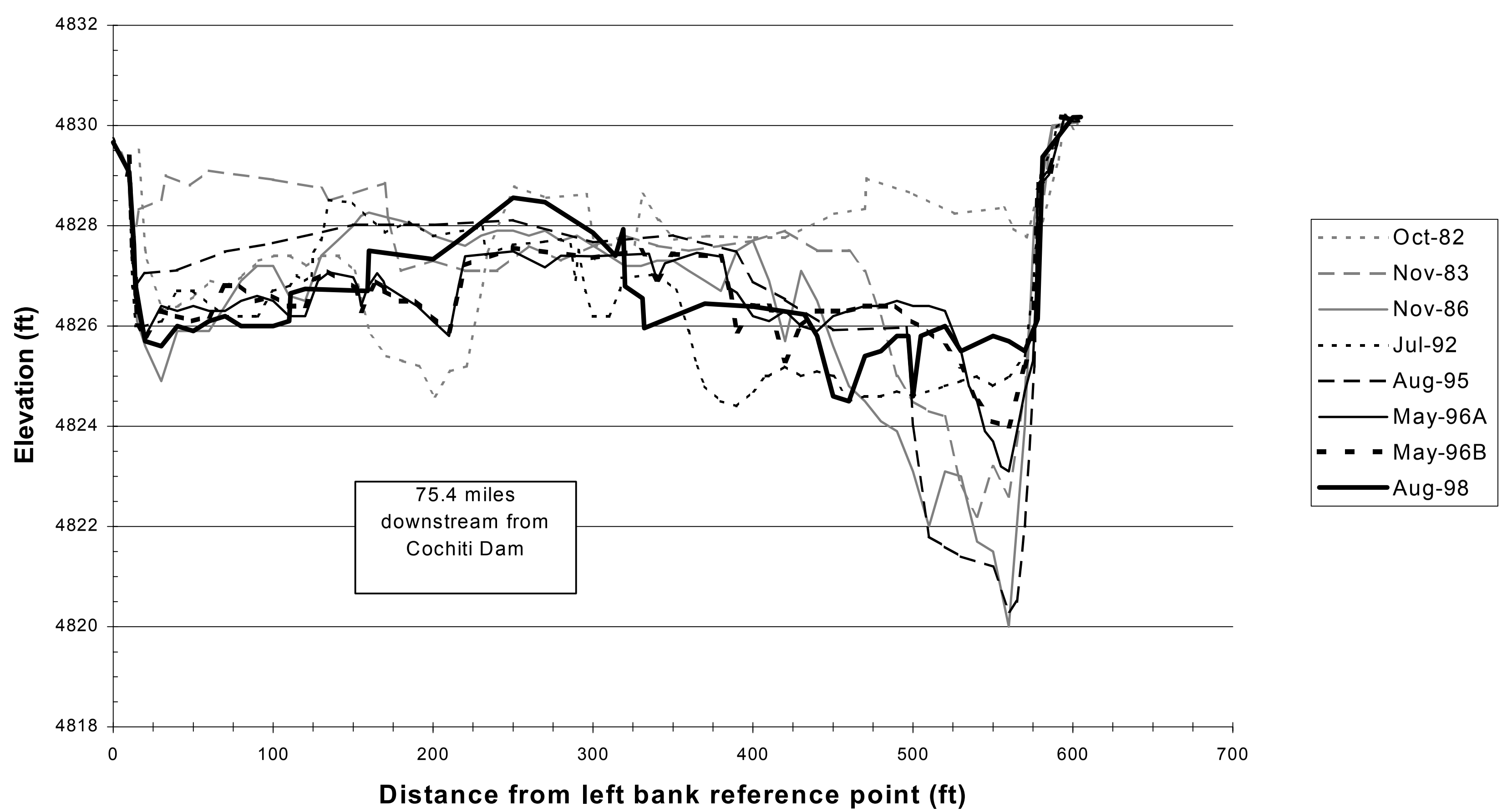

Figure D-30. Cross Section CO-787.

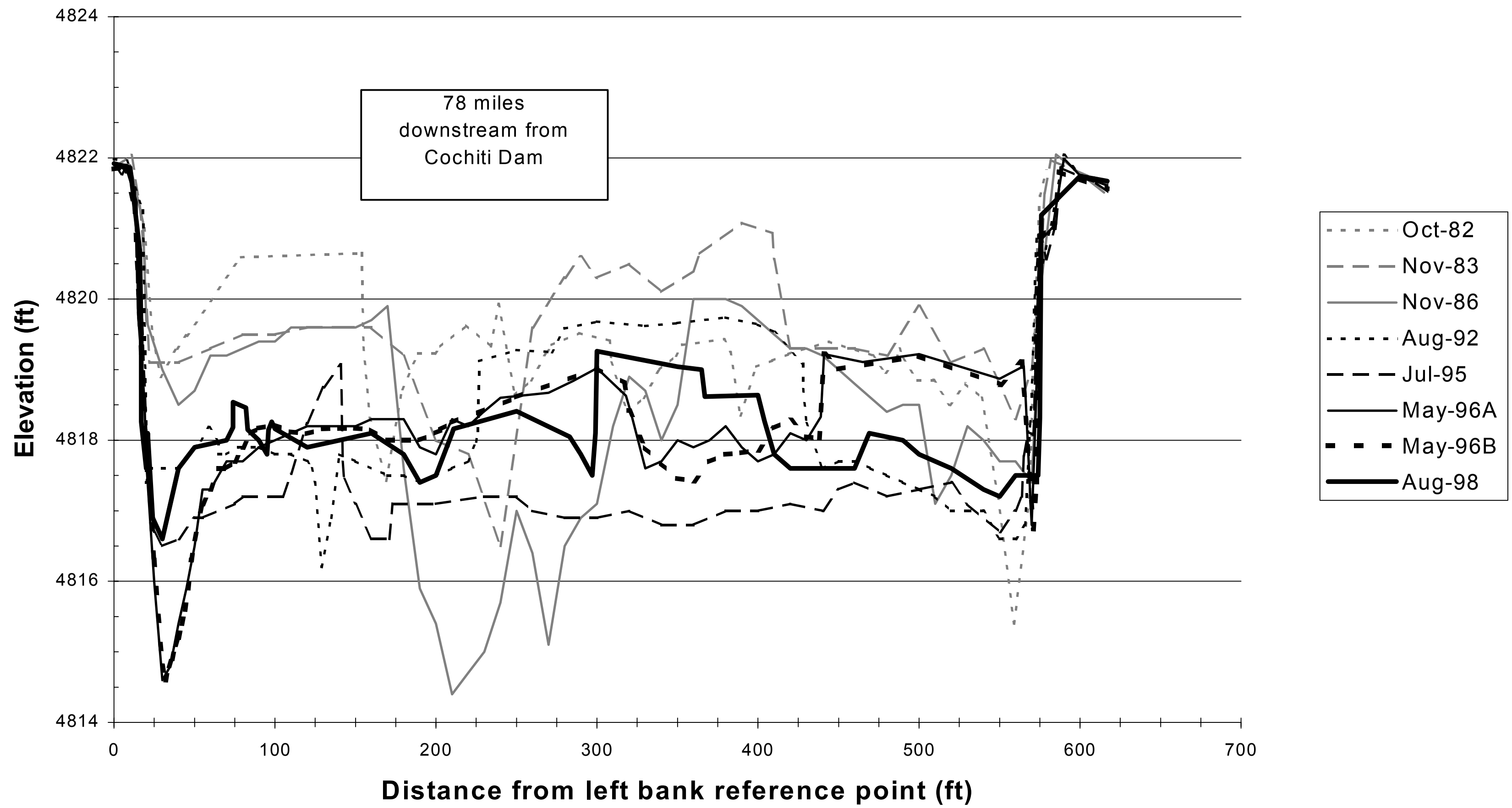

Figure D-31. Cross Section CO-806.

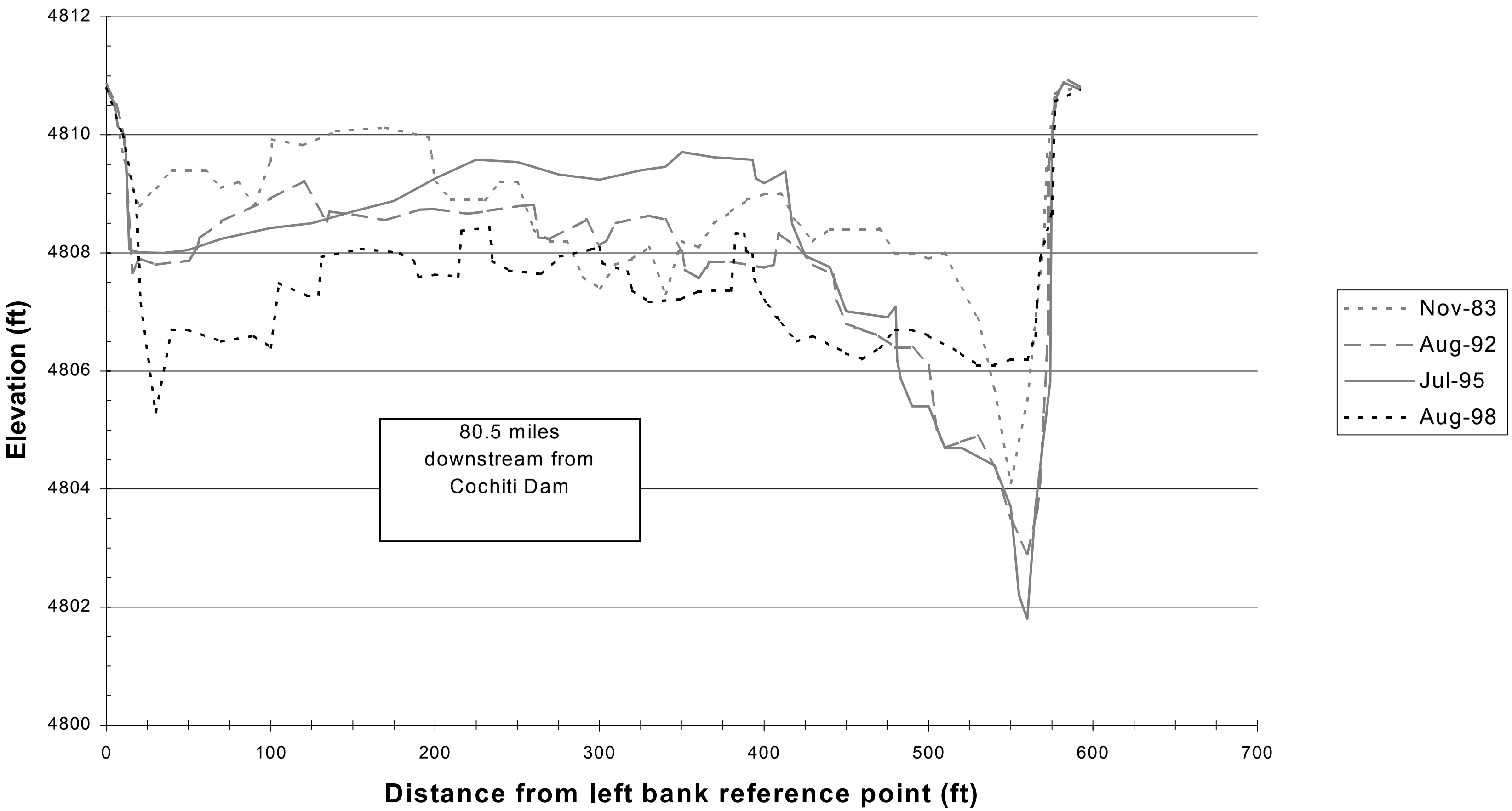

Figure D-32. Cross Section CO-833.

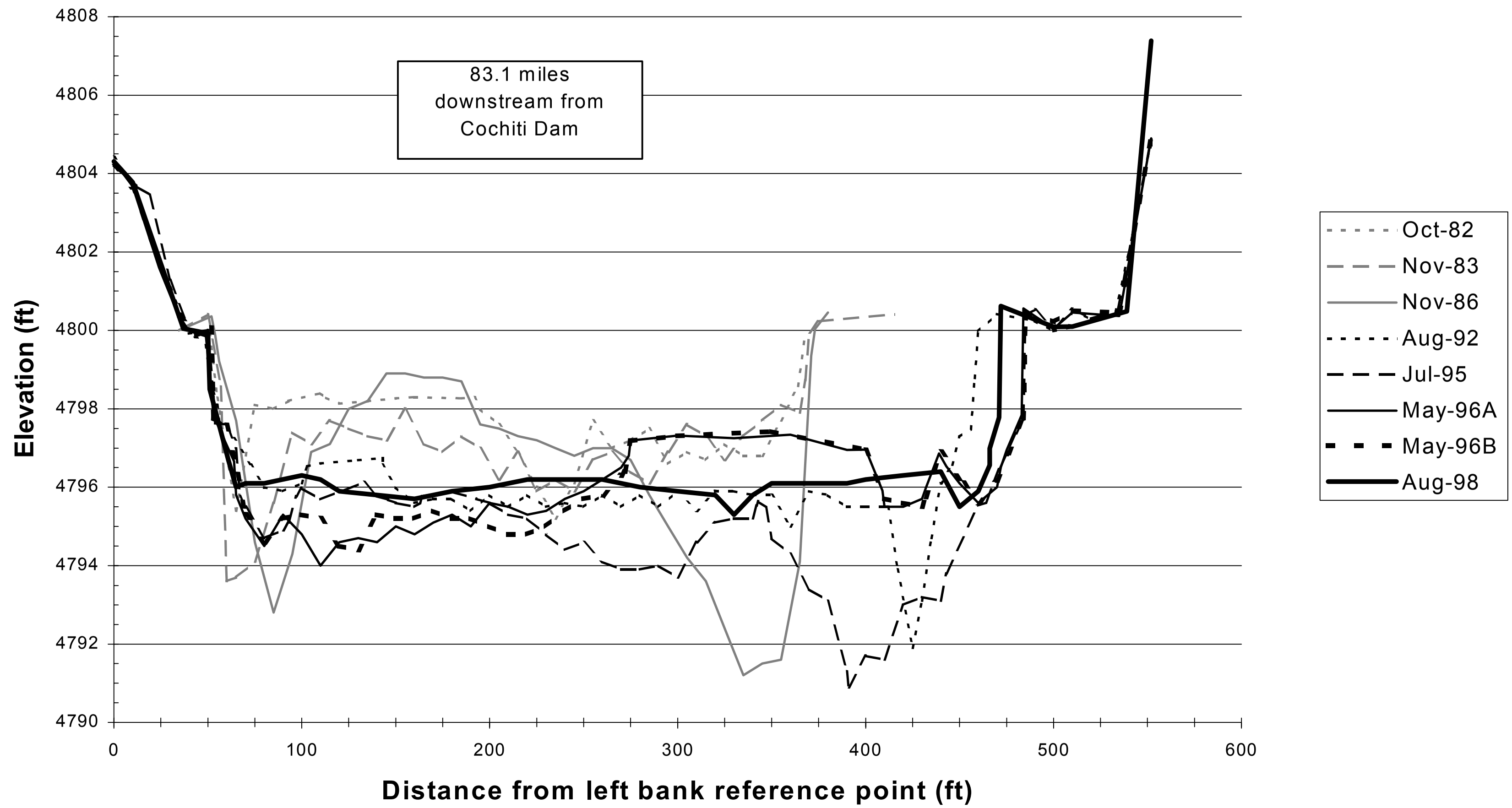

Figure D-33. Cross Section 858.1.

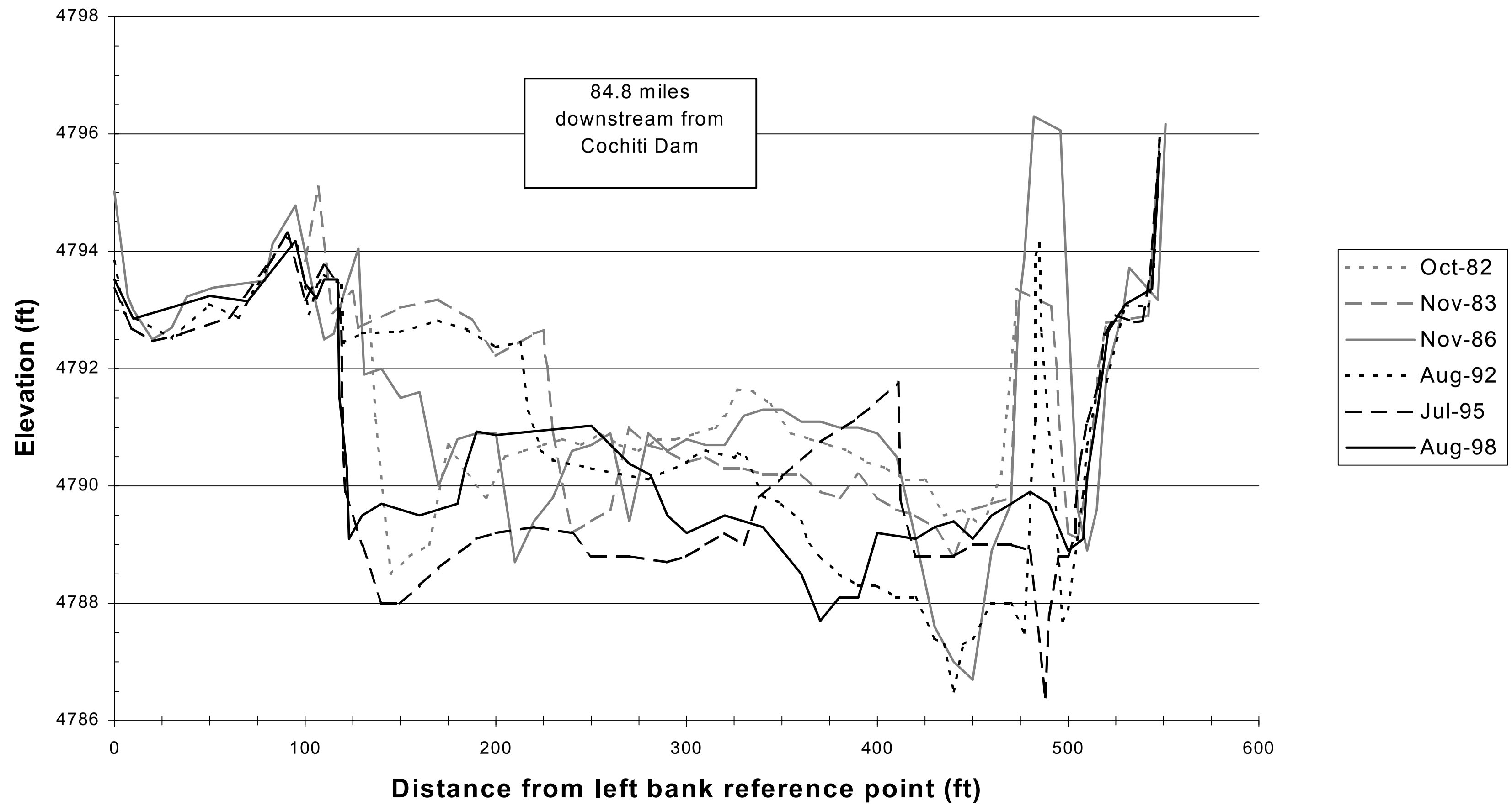

Figure D-34. Cross Section CO-877.

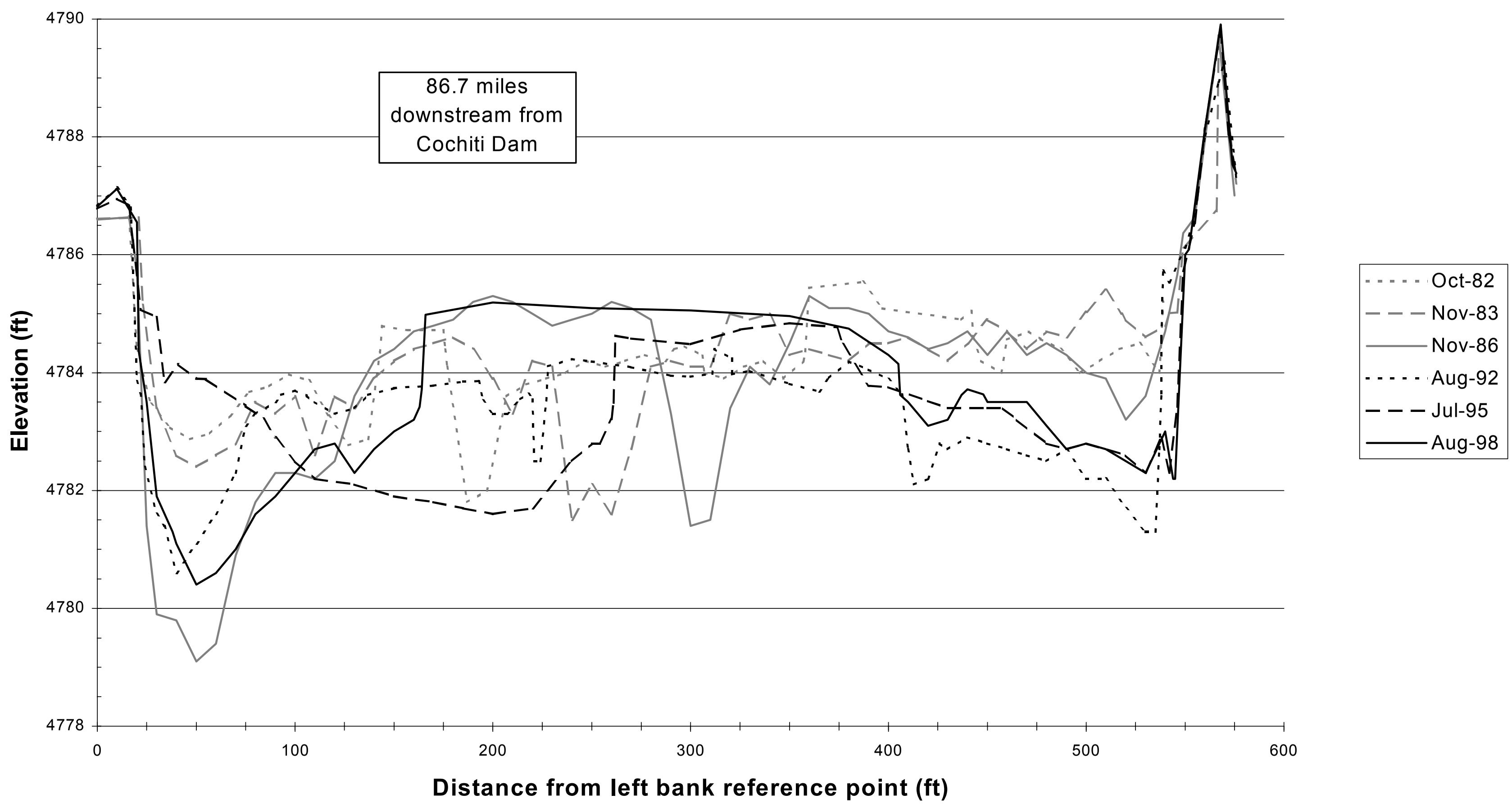

Figure D-35. Cross Section CO-895.

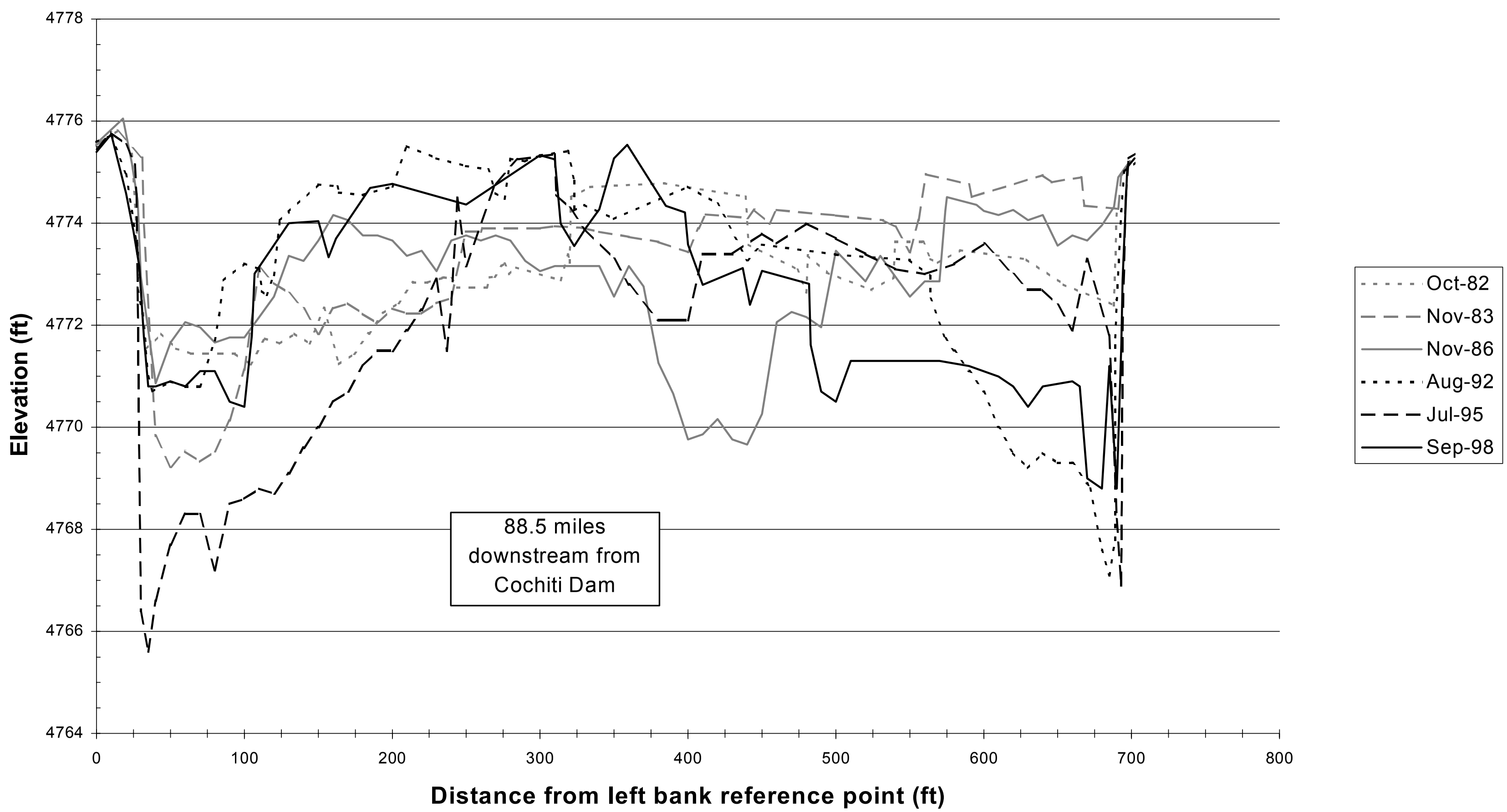

Figure D-36. Cross Section CO-926.

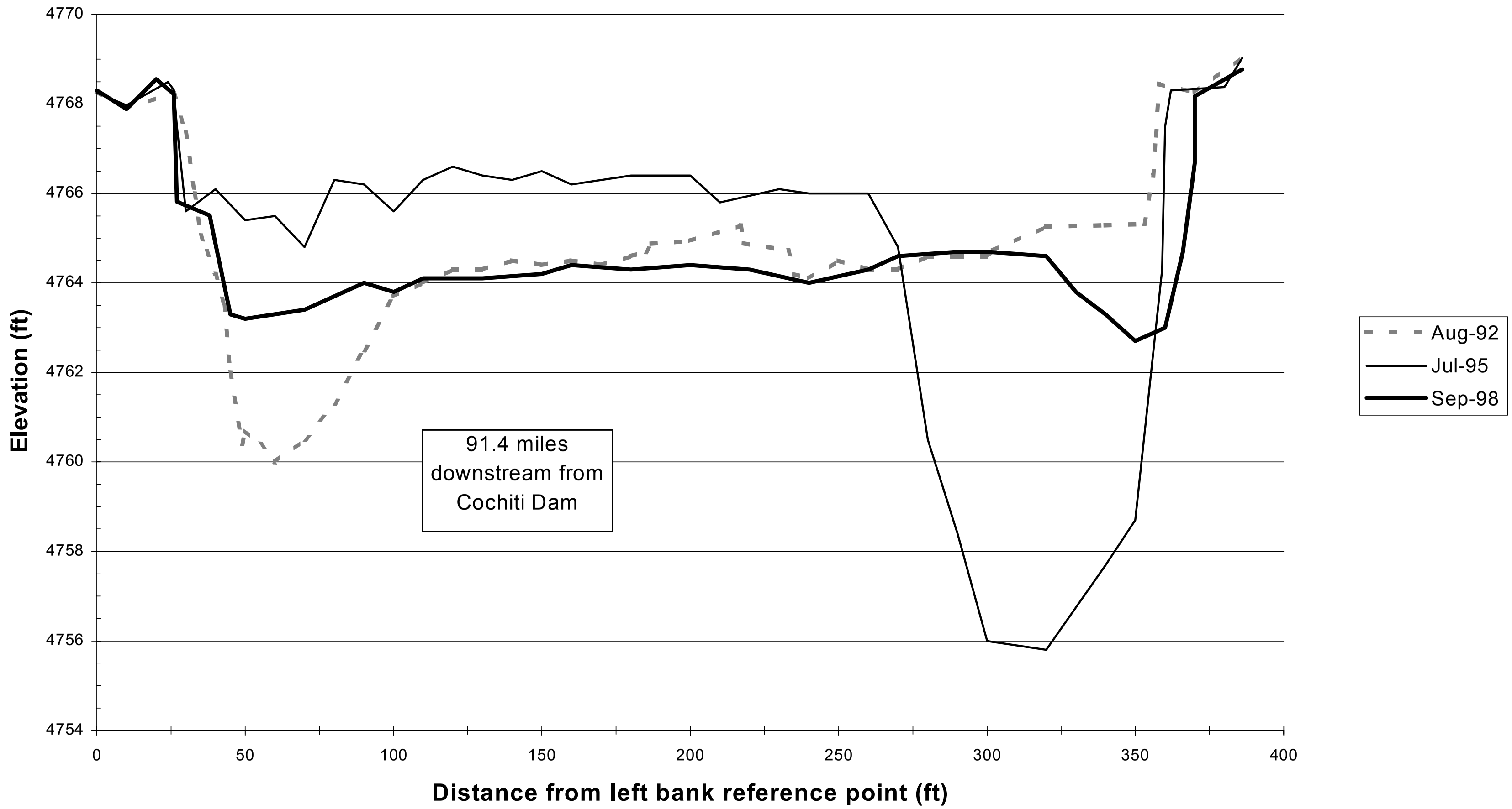

Figure D-37. Cross Section C02-945.

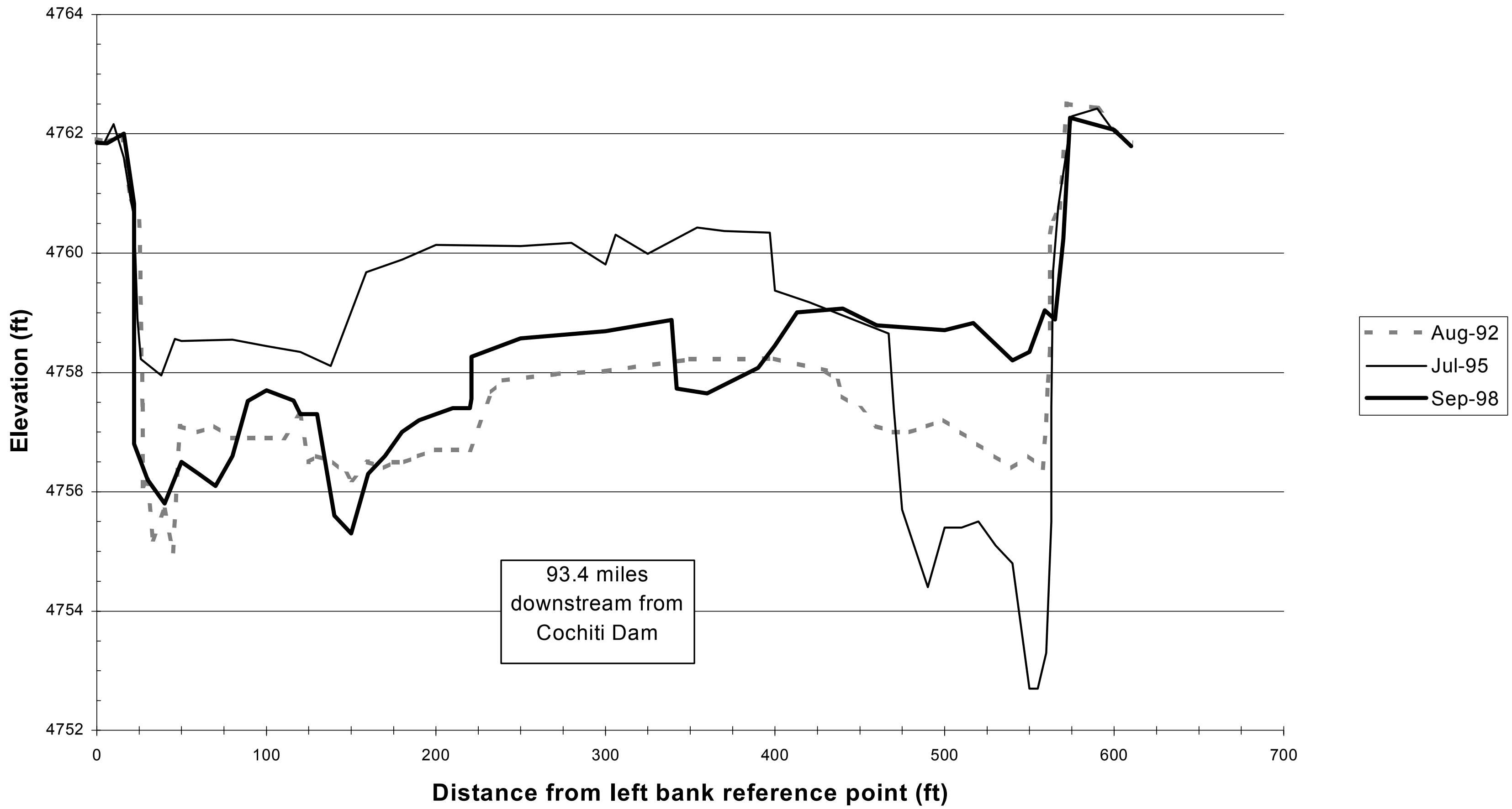

Figure D-38. Cross Section CO2-966.

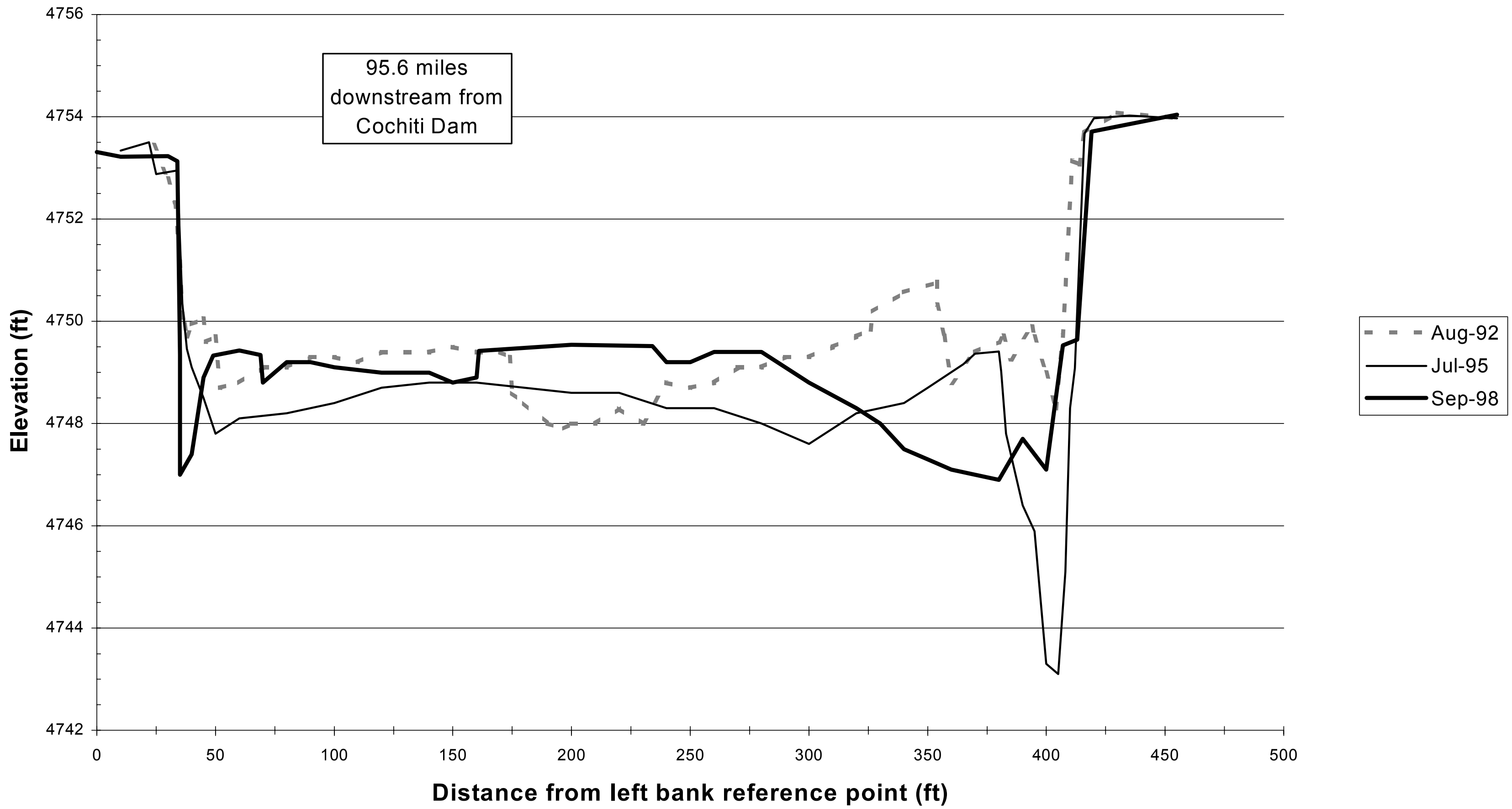

Figure D-39. Cross Section CO2-986.

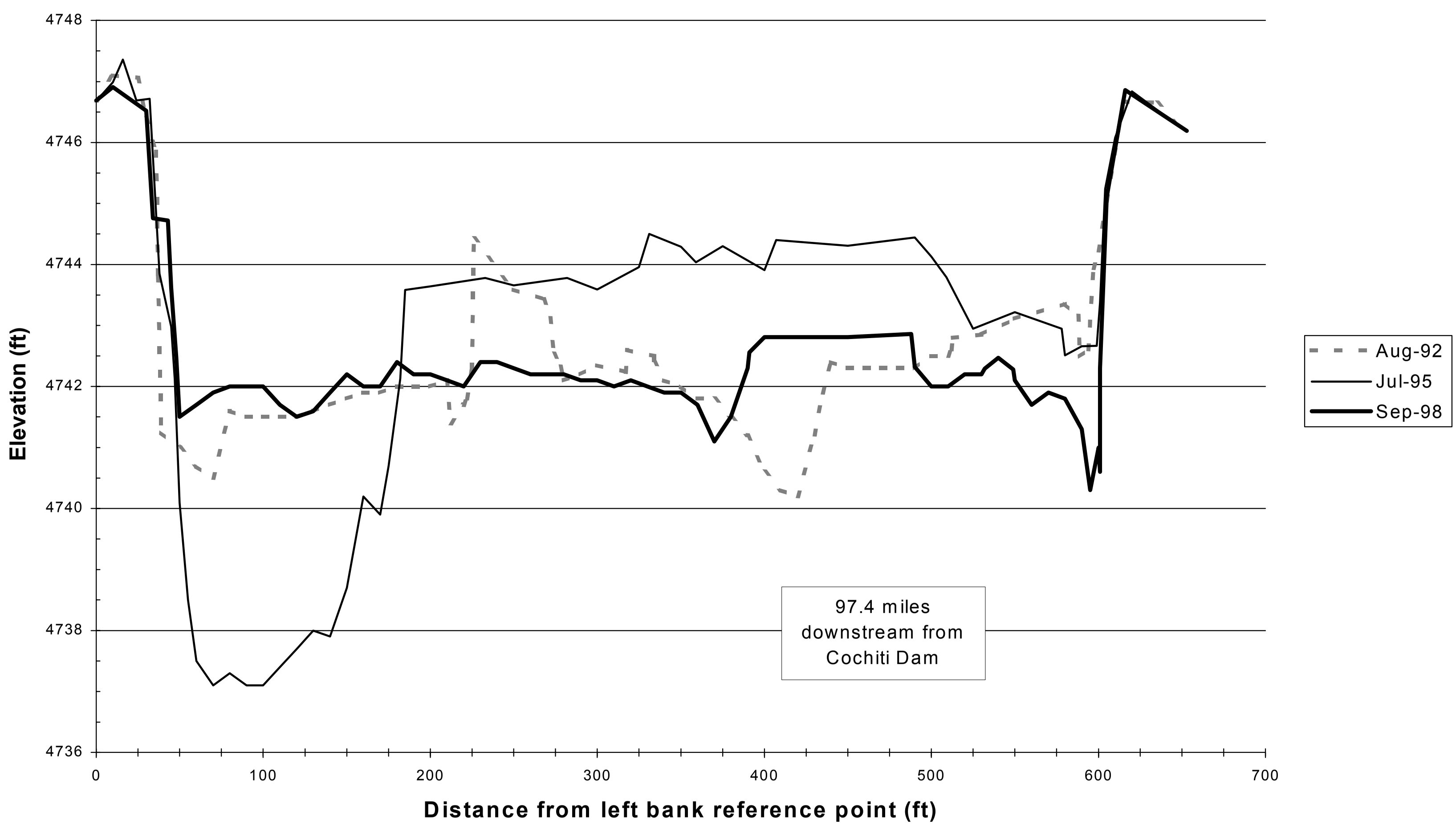

Figure D-40. Cross Section CO2-1006.

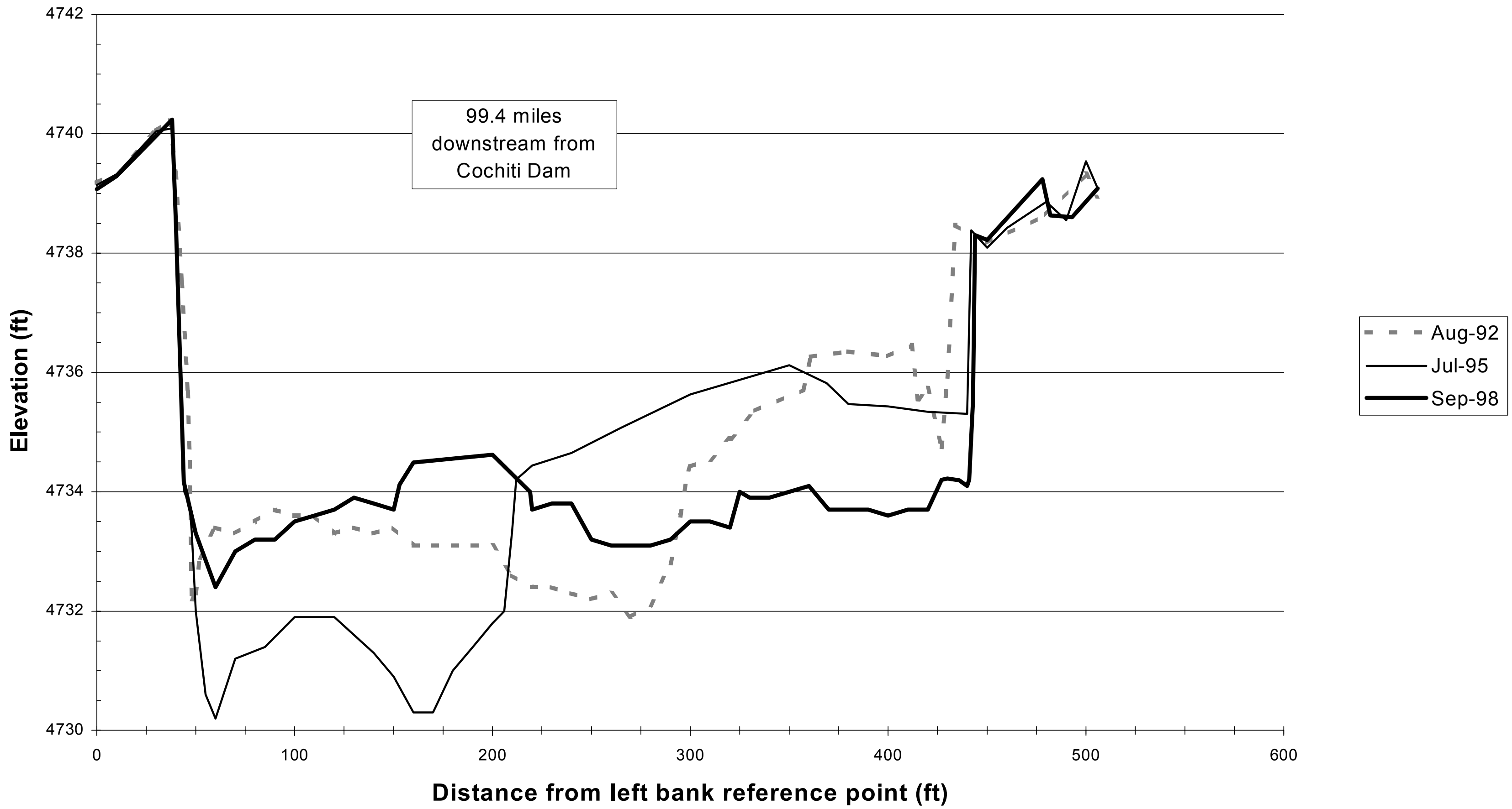

Figure D-41. Cross Section CO2-1026.

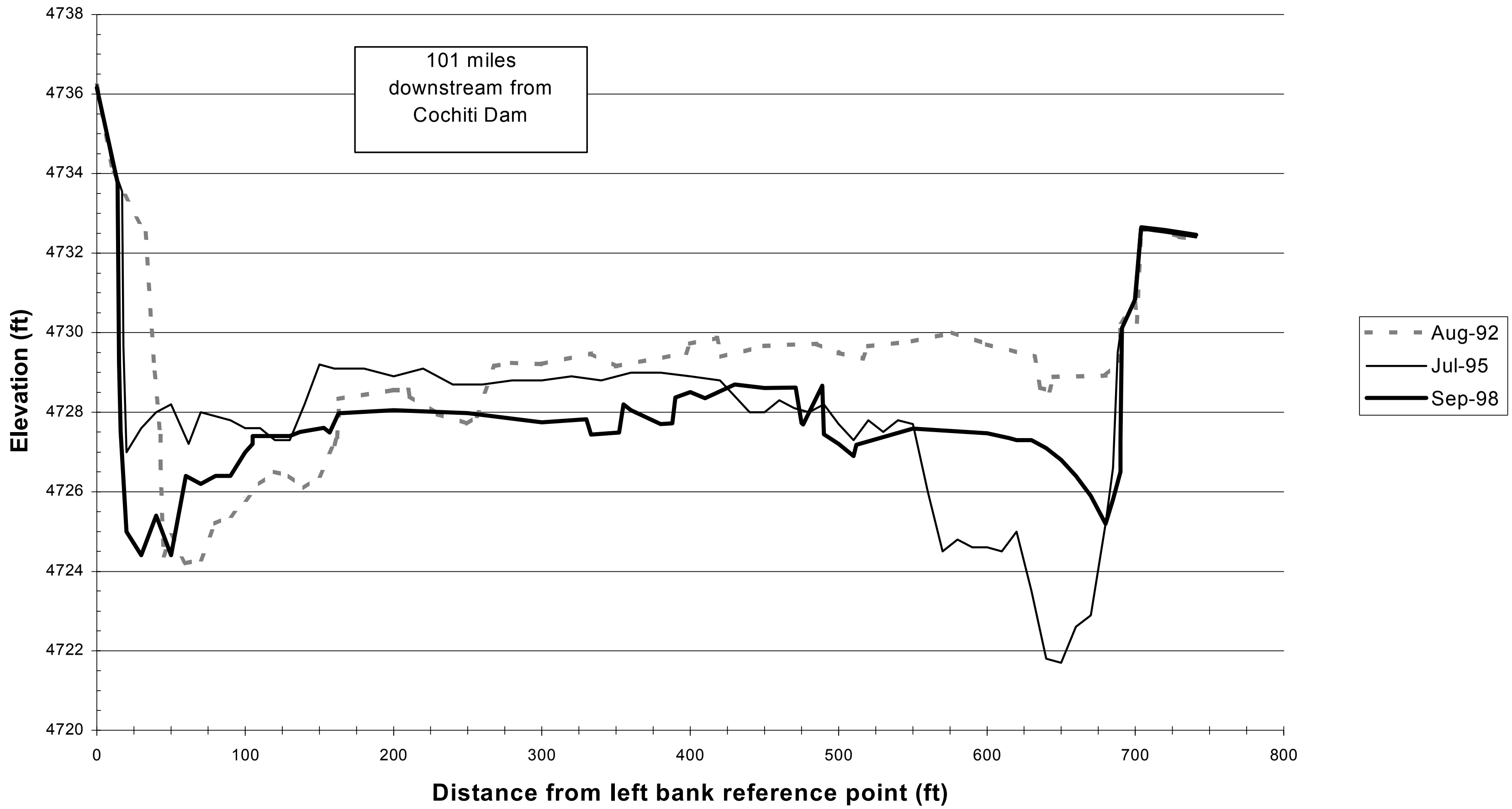

Figure D-42. Cross Section CO2-1044.

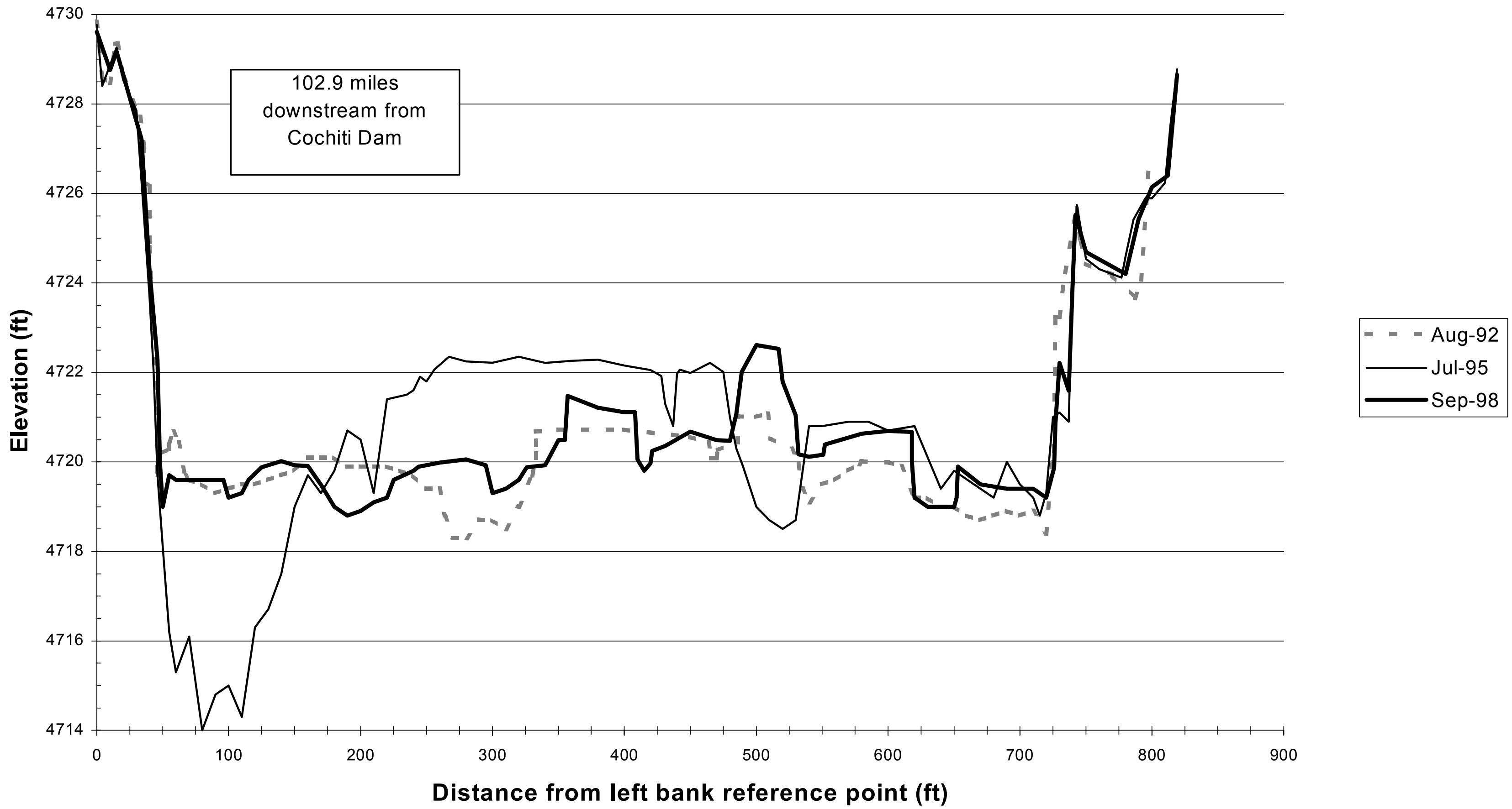

Figure D-43. Cross Section CO2-1064.

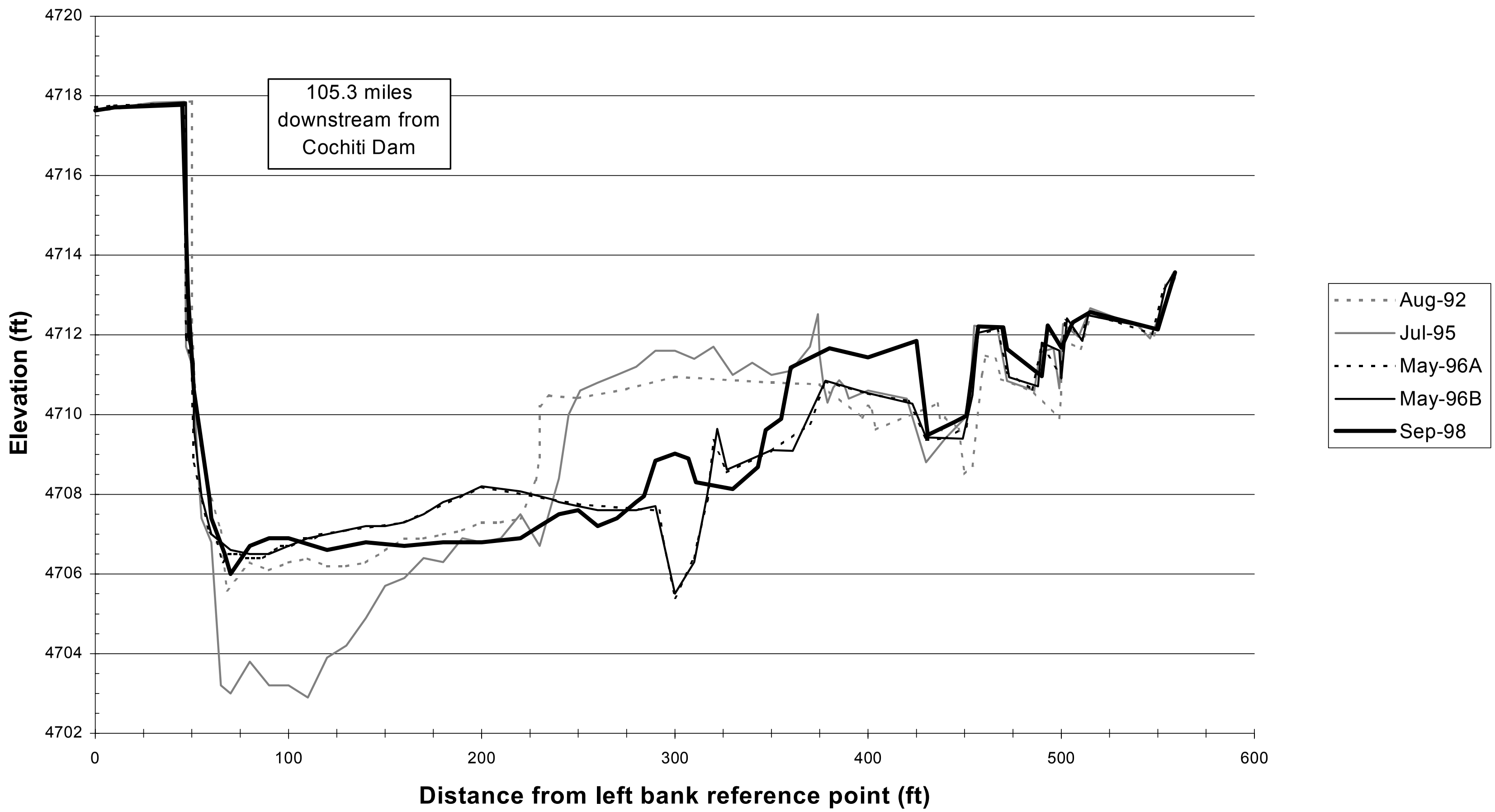

Figure D-44. Cross Section CO2-1091.

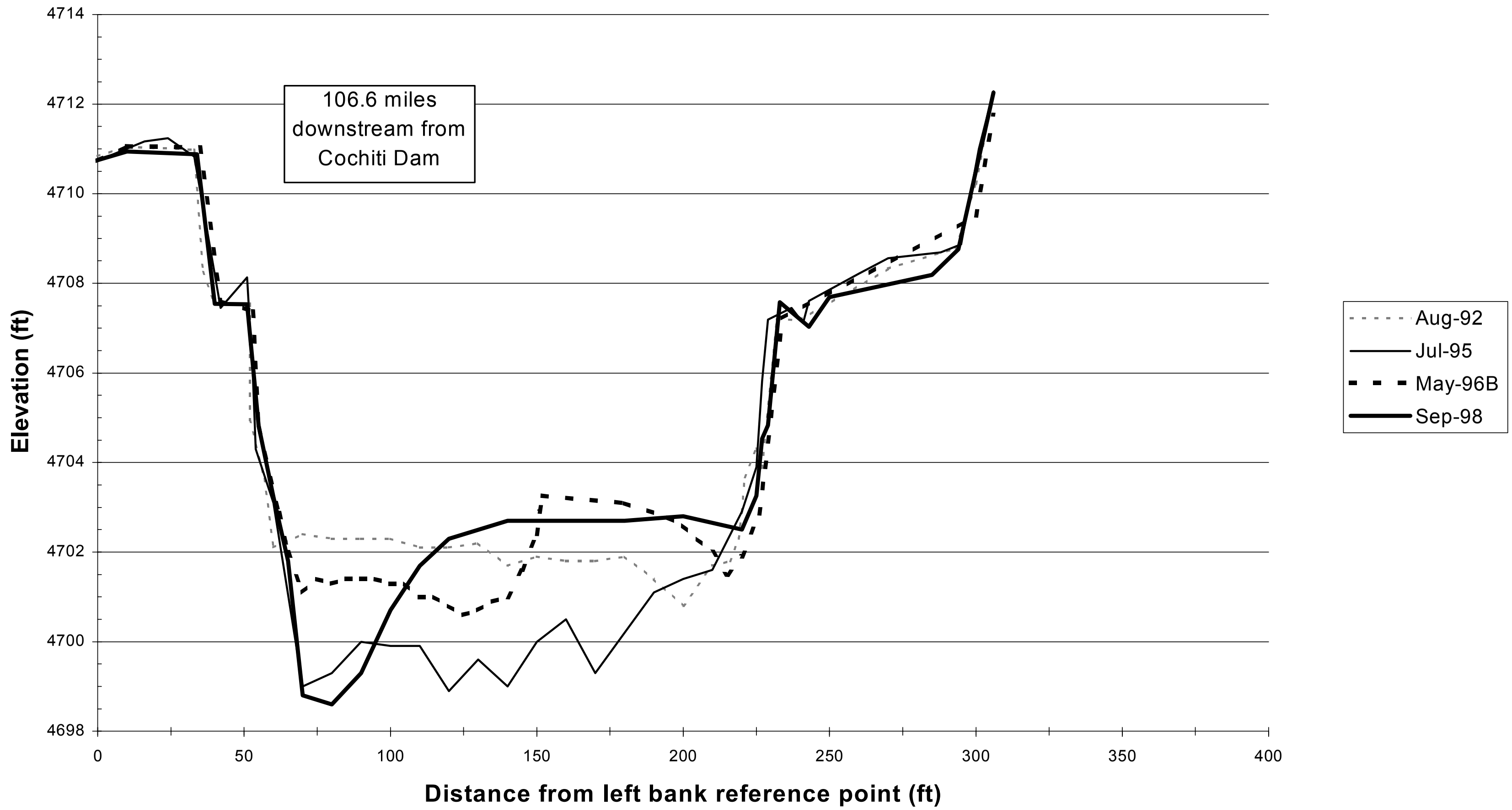

Figure D-45. Cross Section CO2-1104.

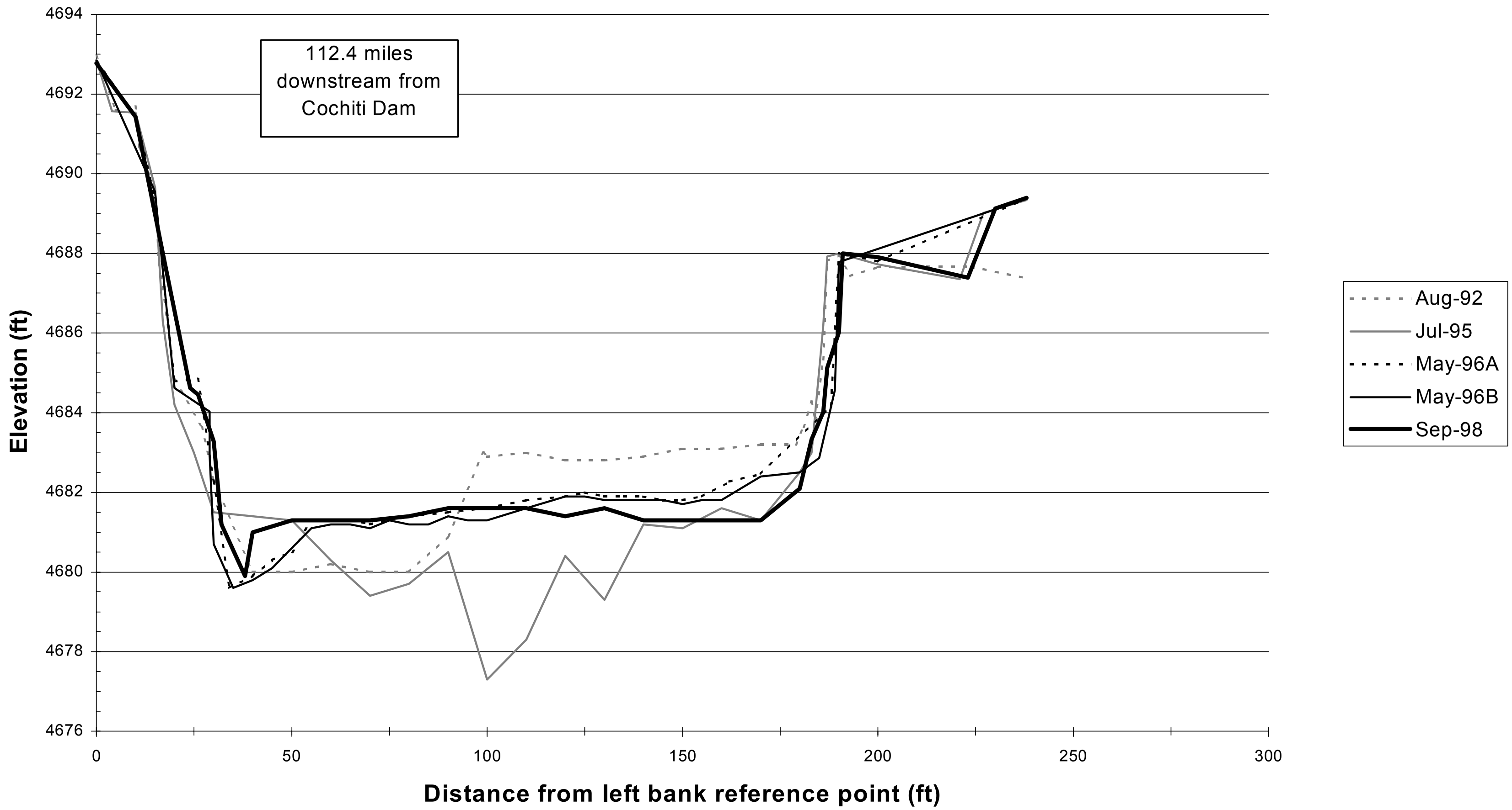

Figure D-46. Cross Section CO2-1164.

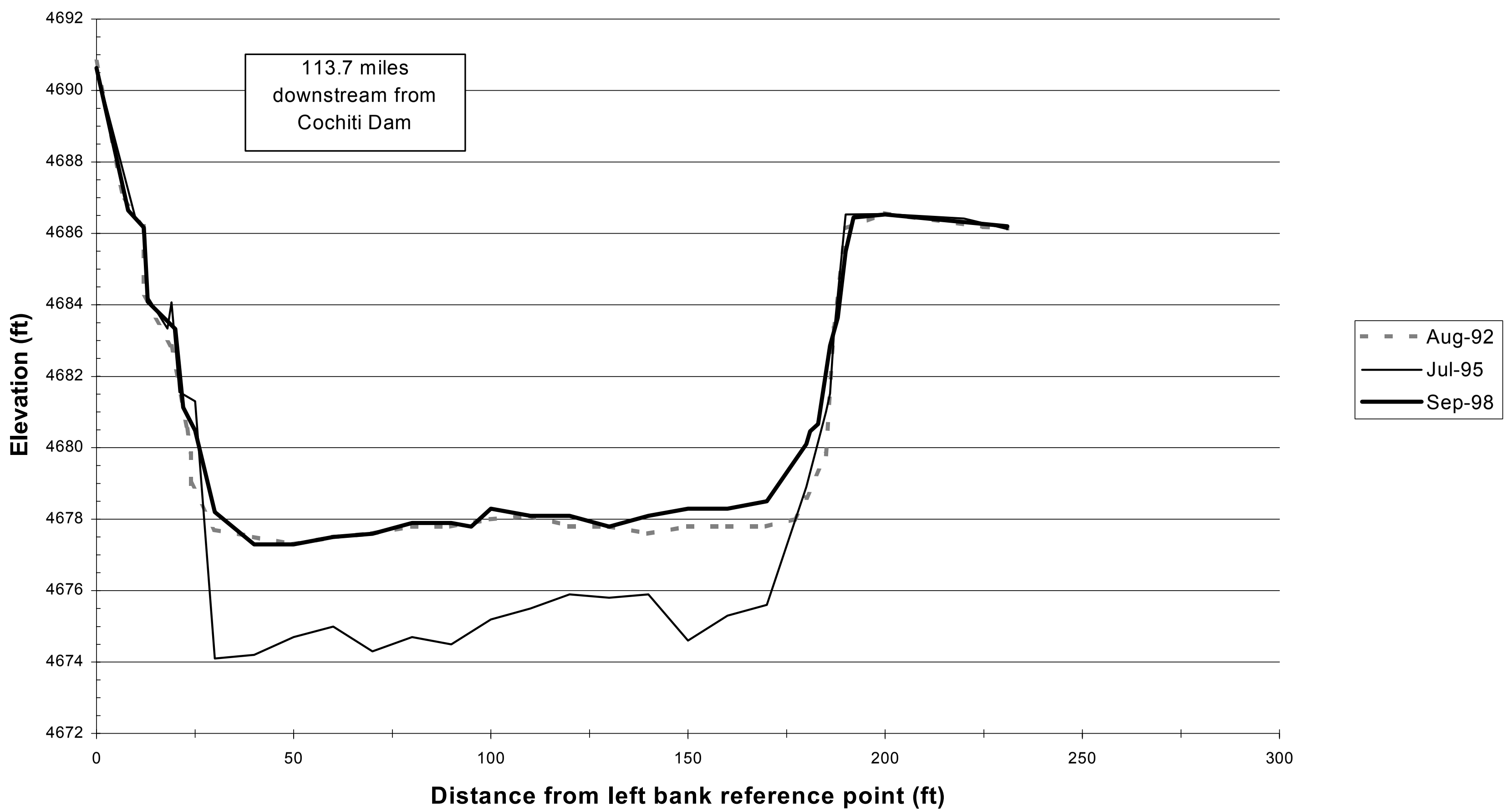

Figure D-47. Cross Section CO2-1179.

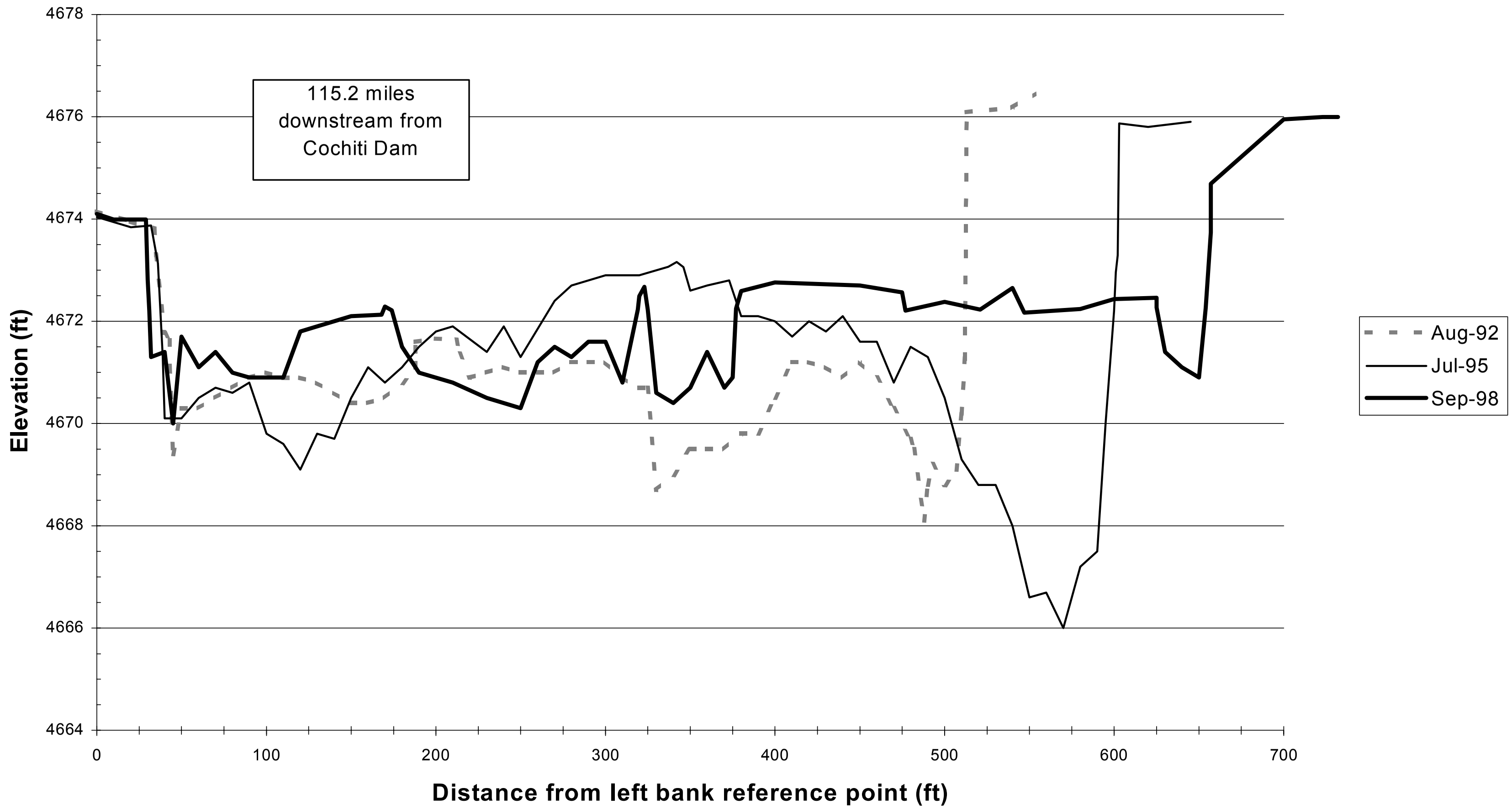

Figure D-48. Cross Section CO2-1194.

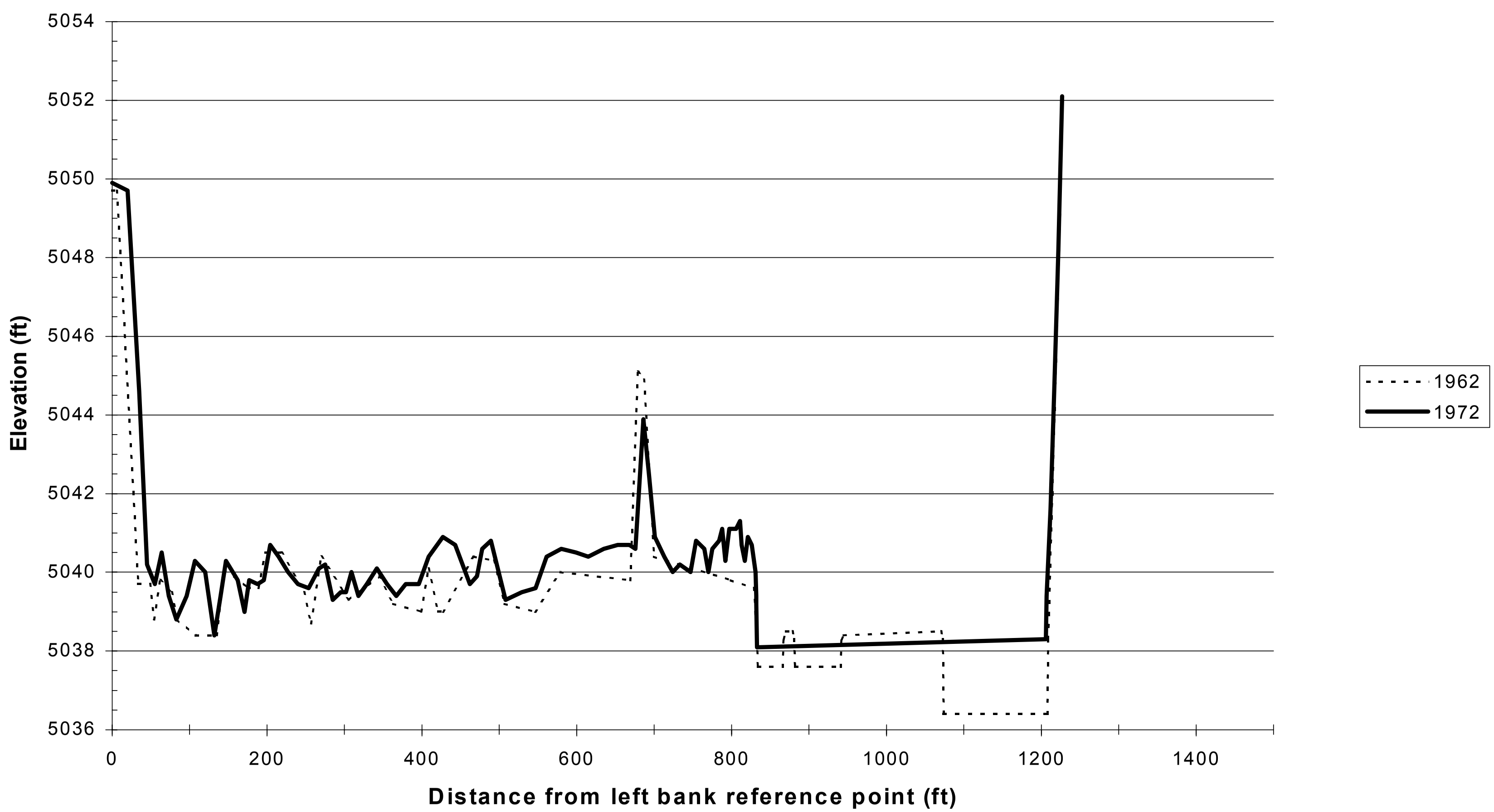

Figure D-49. Cross Section Agg/Deg 324 (CO-31).

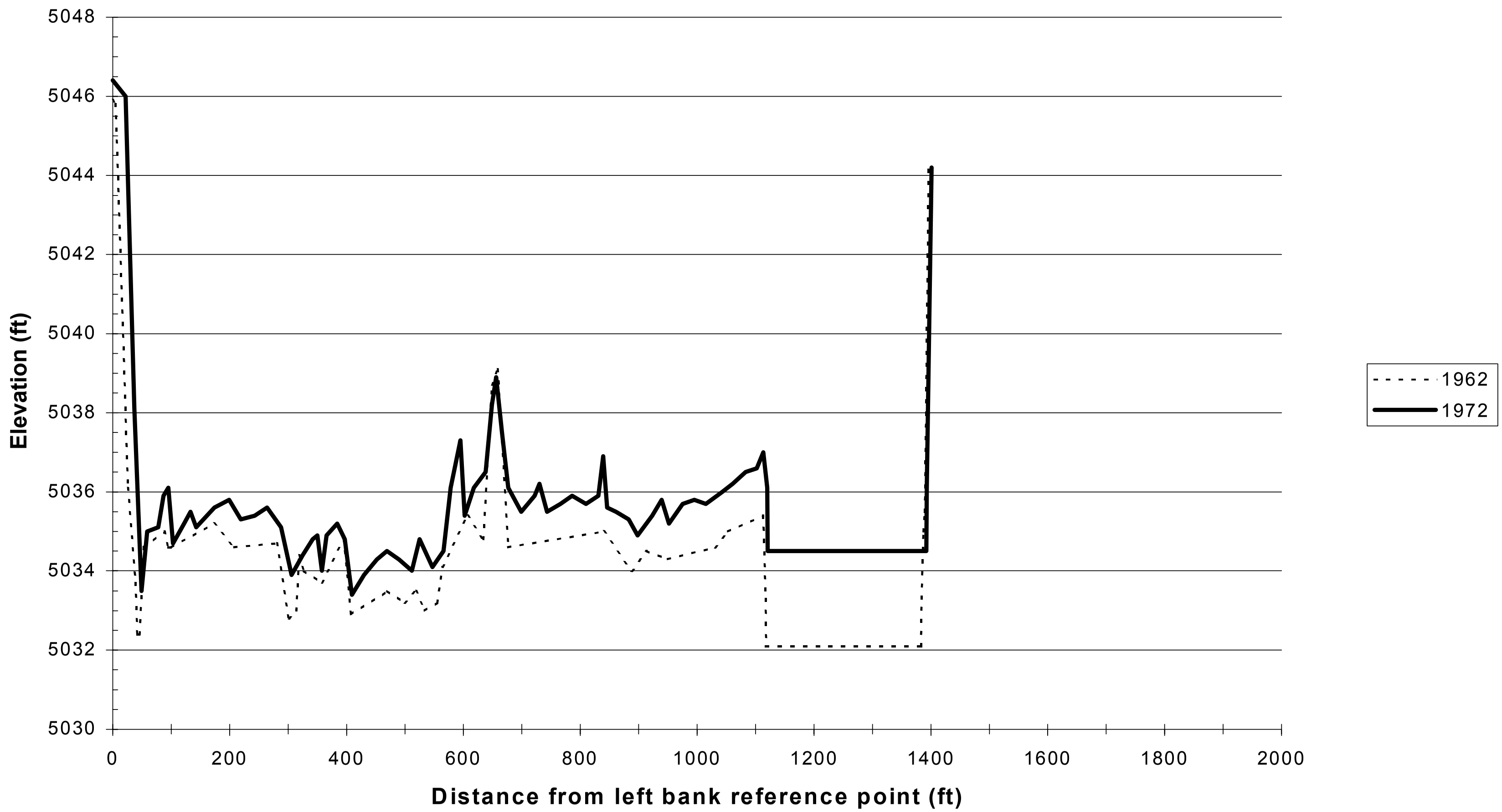

Figure D-50. Cross Section Agg/Deg 335 (CO-32).

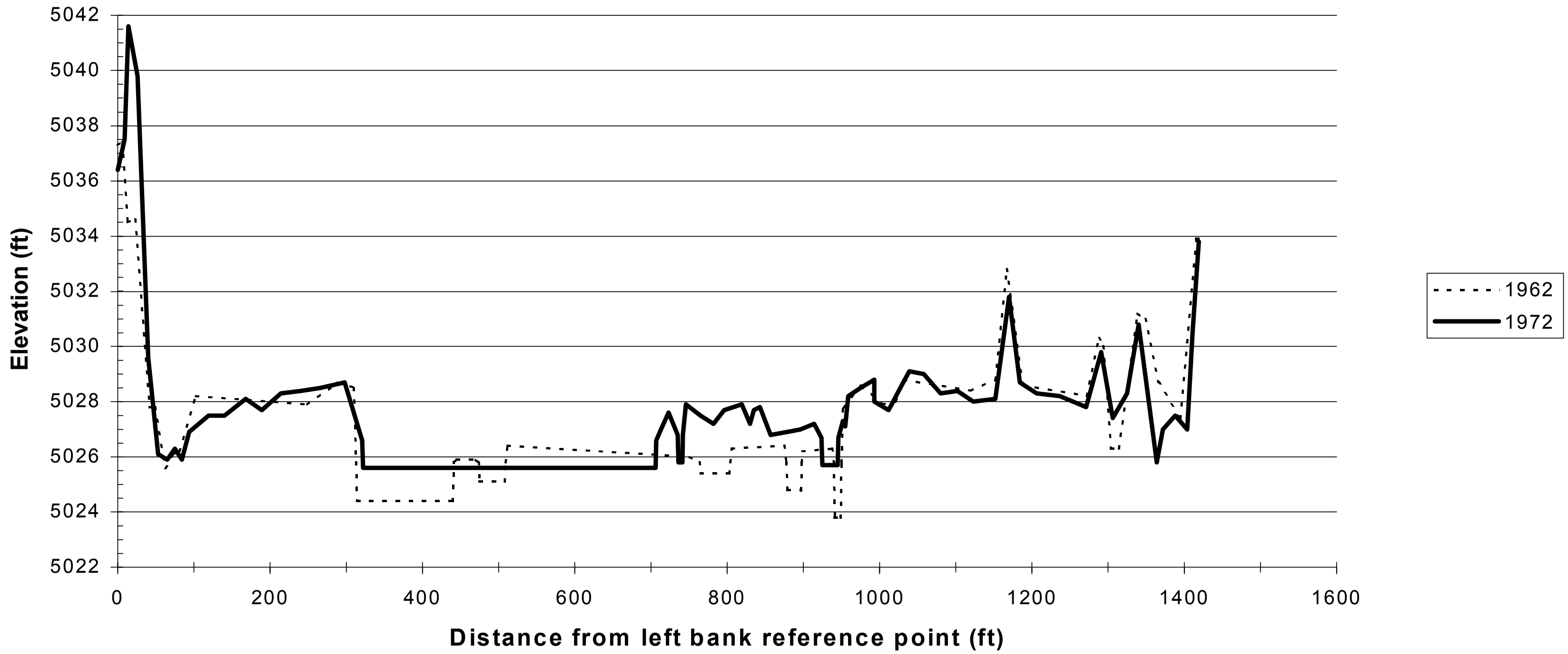

Figure D-51. Cross Section Agg/Deg 351 (CO-33)

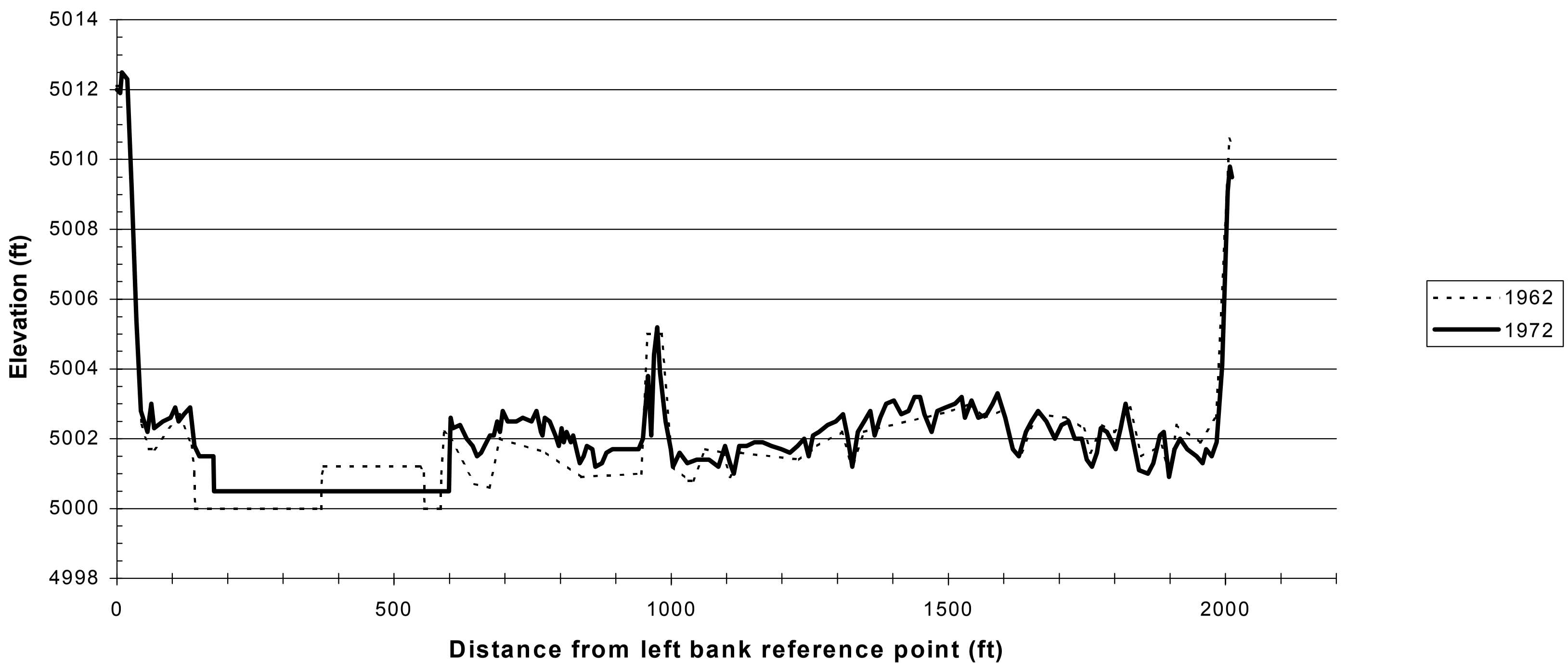

Figure D-52. Cross Section Agg/Deg 407 (CO-34).

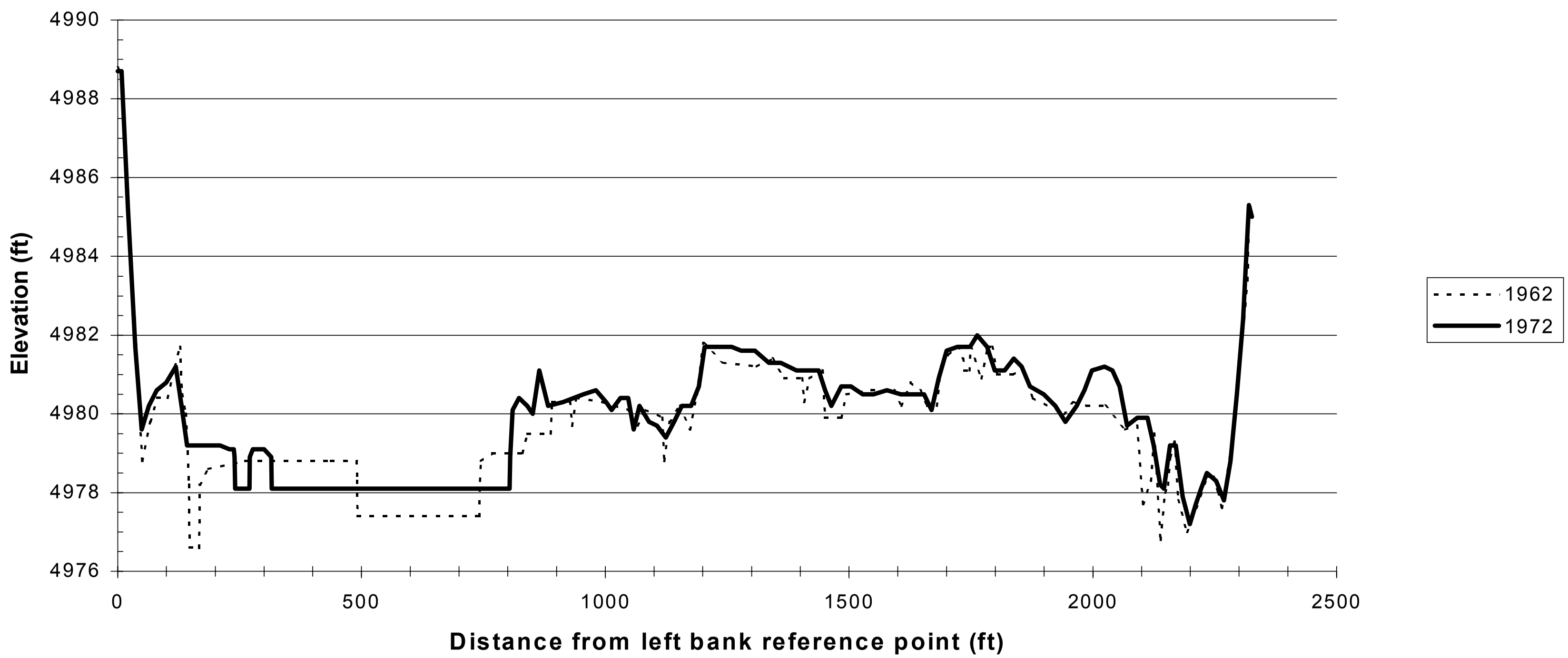

Figure D-53. Cross Section Agg/Deg 453 (CO-35).

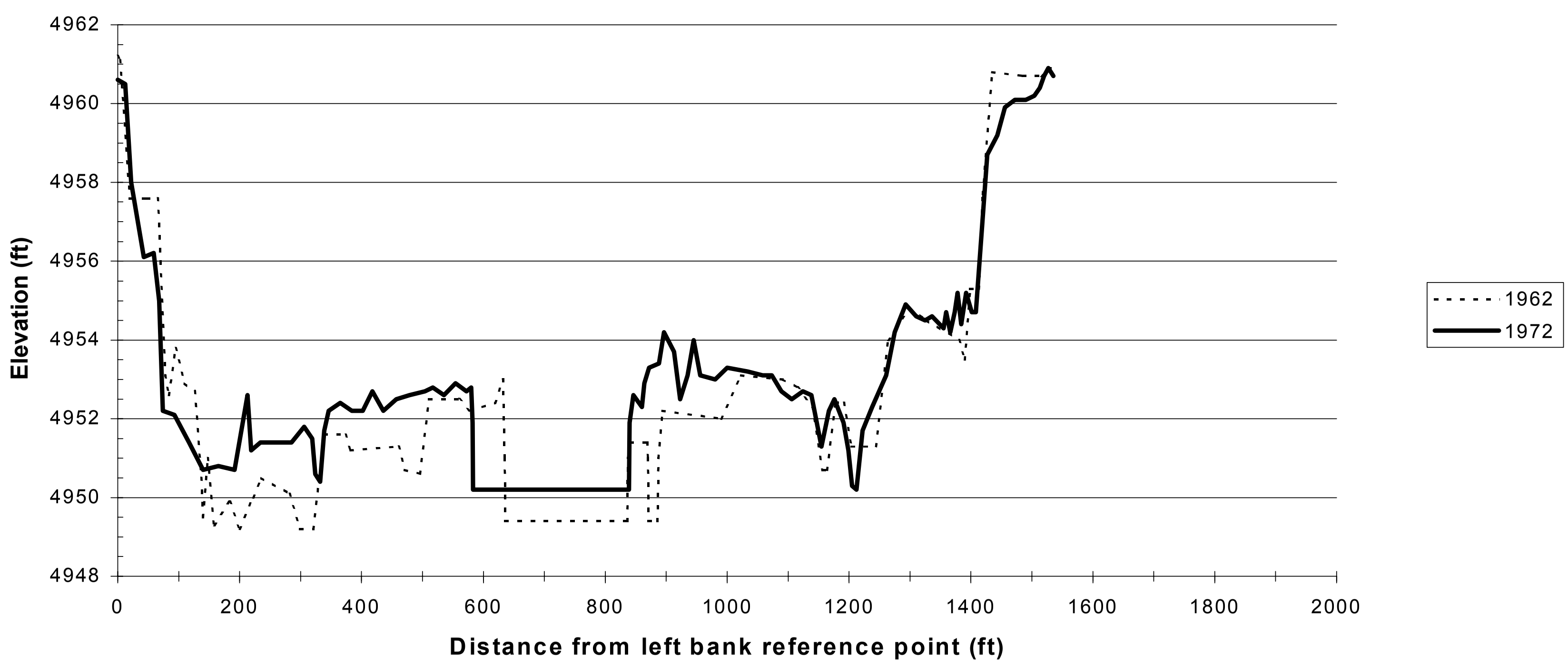

Figure D-54. Cross Section Agg/Deg 509 (CO-36).

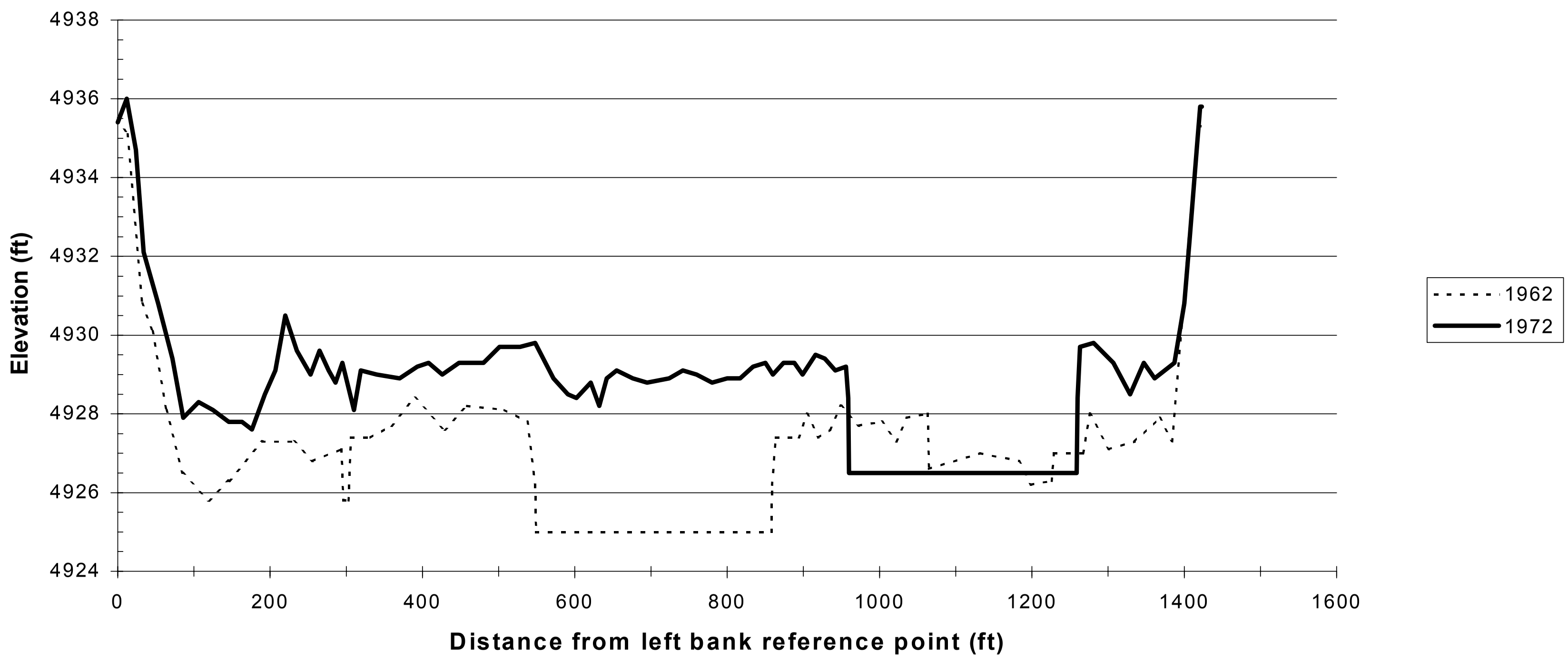

Figure D-55. Cross Section Agg/Deg 562 (CO-37).

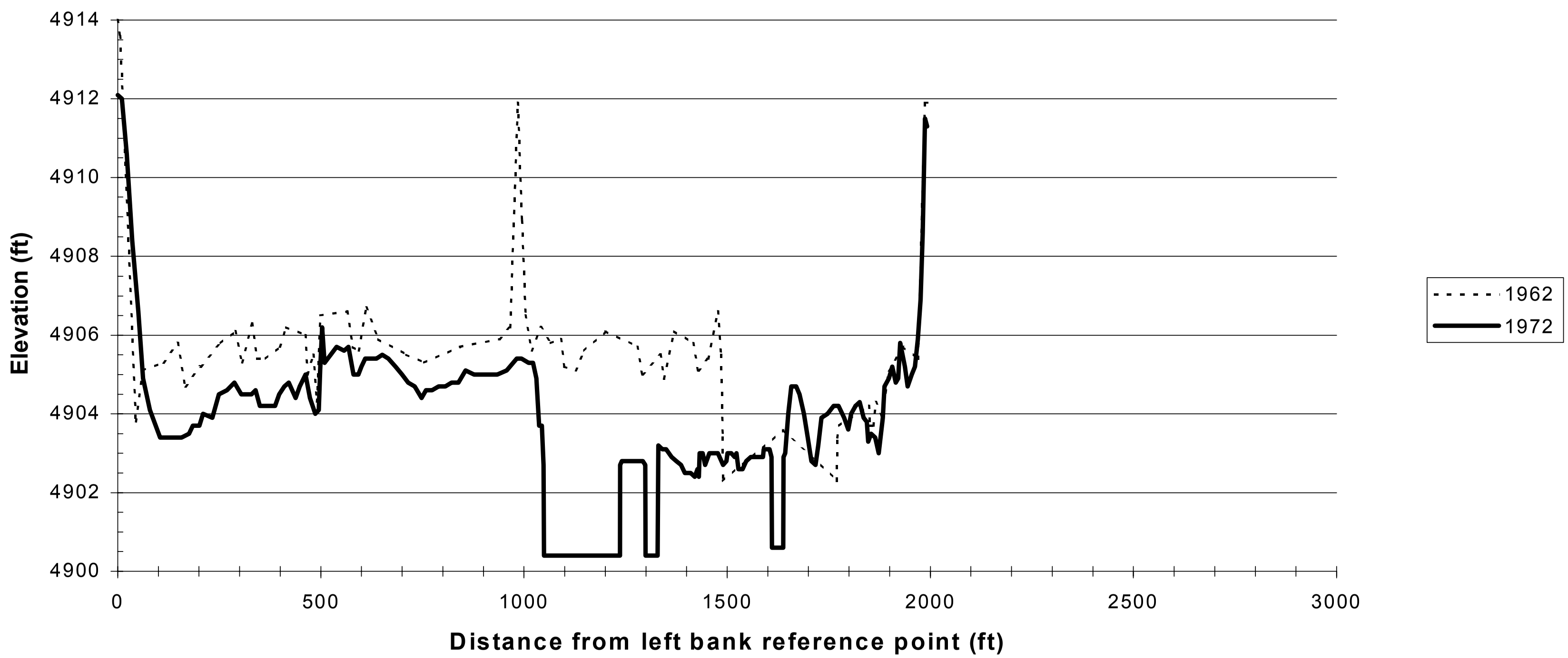

Figure D-56. Cross Section Agg/Deg 616 (CO-38).

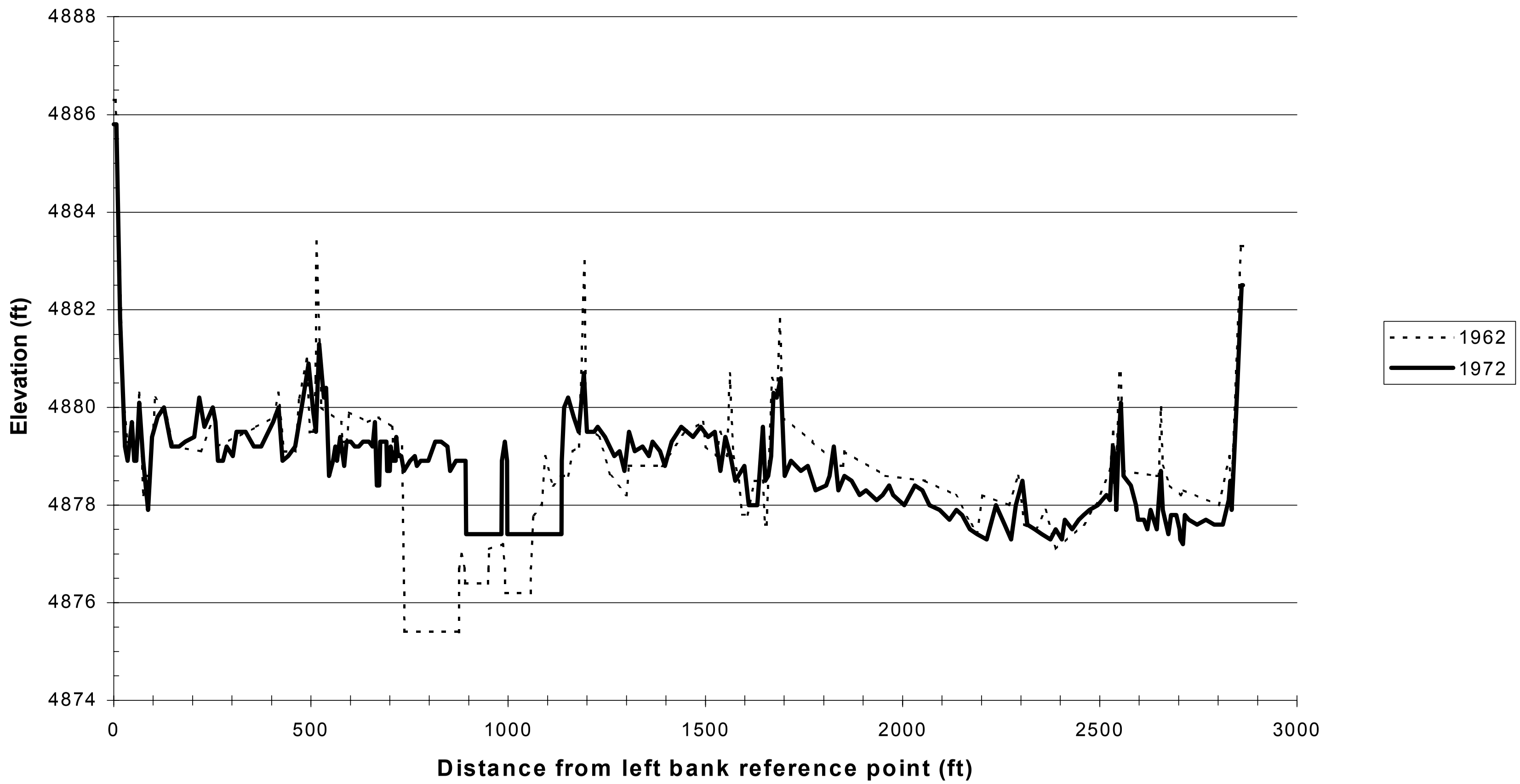

Figure D-57. Cross Section Agg/Deg 668 (CO-668).

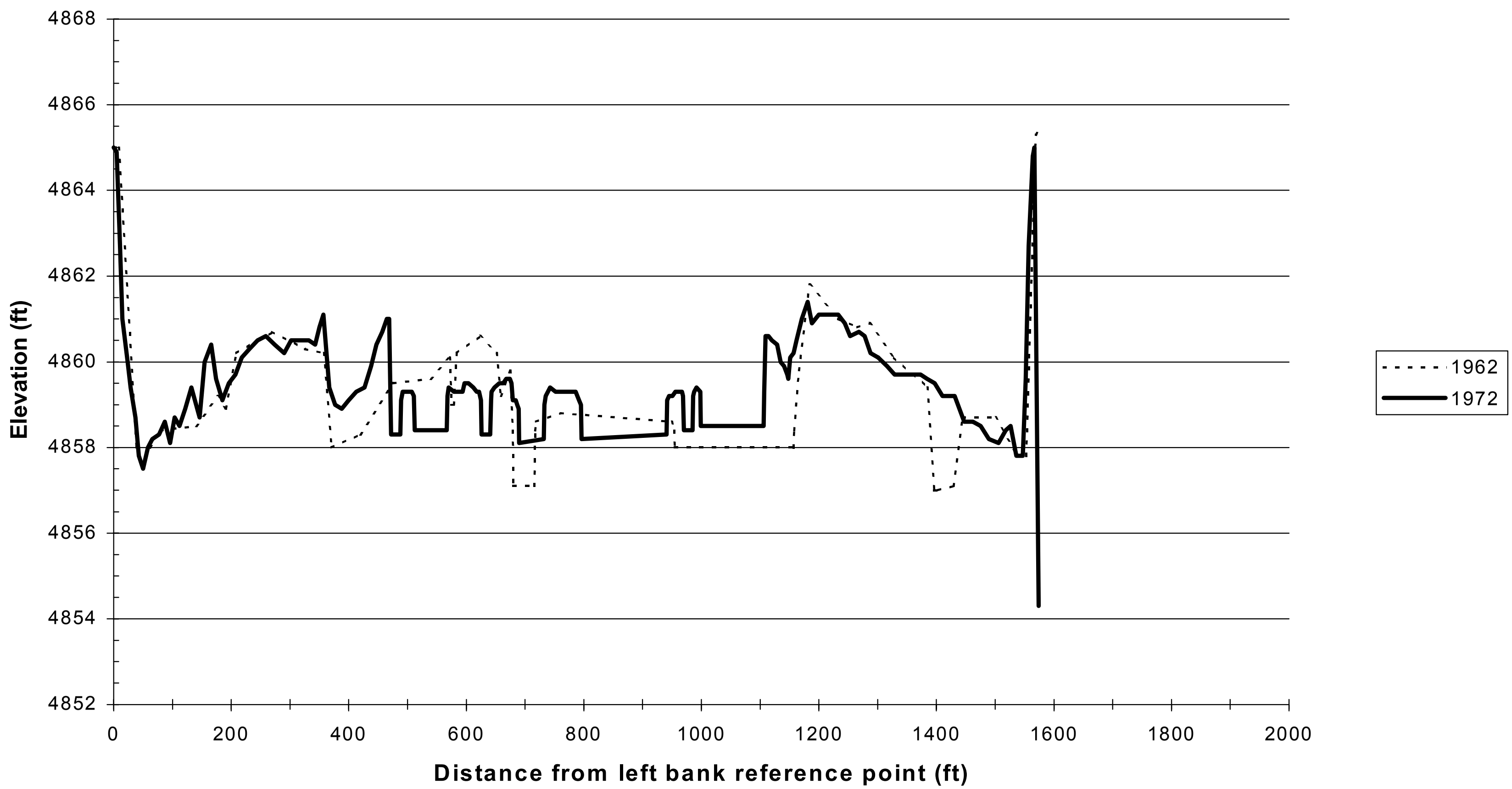

Figure D-58. Cross Section Agg/Deg 713 (CO-713).

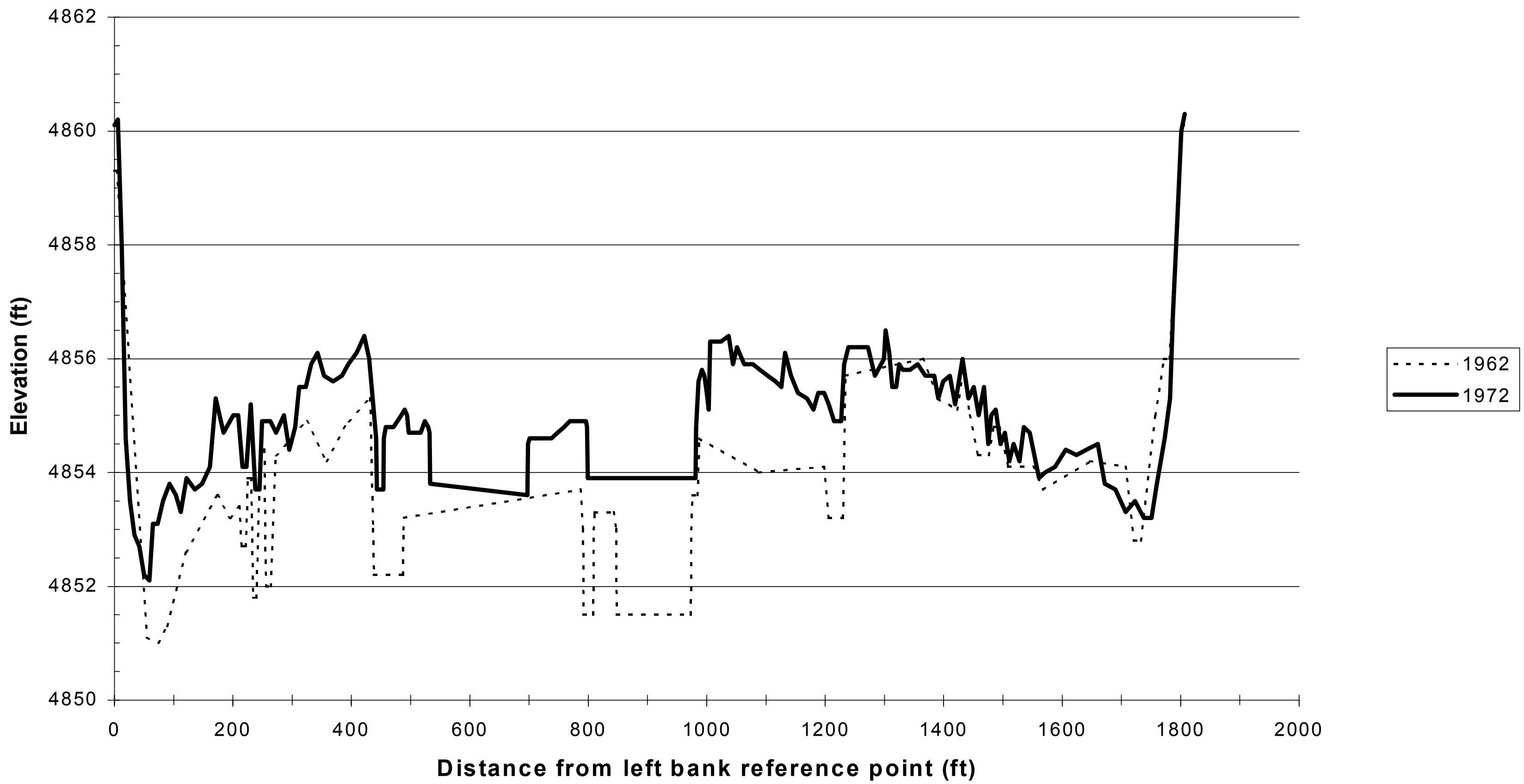

Figure D-59. Cross Section Agg/Deg 724 (CO-724).

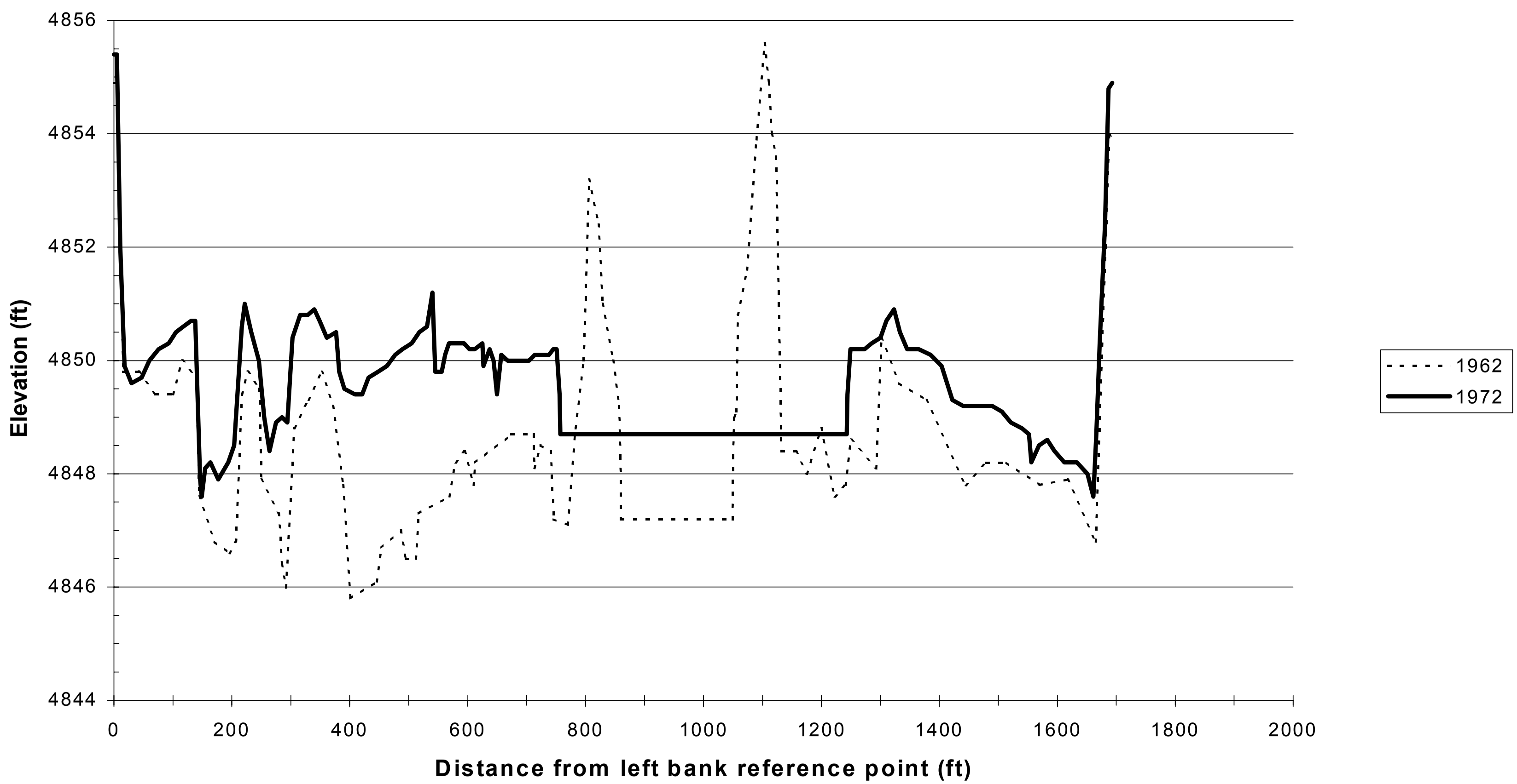

Figure D-60. Cross Section Agg/Deg 738 (CO-738.1).

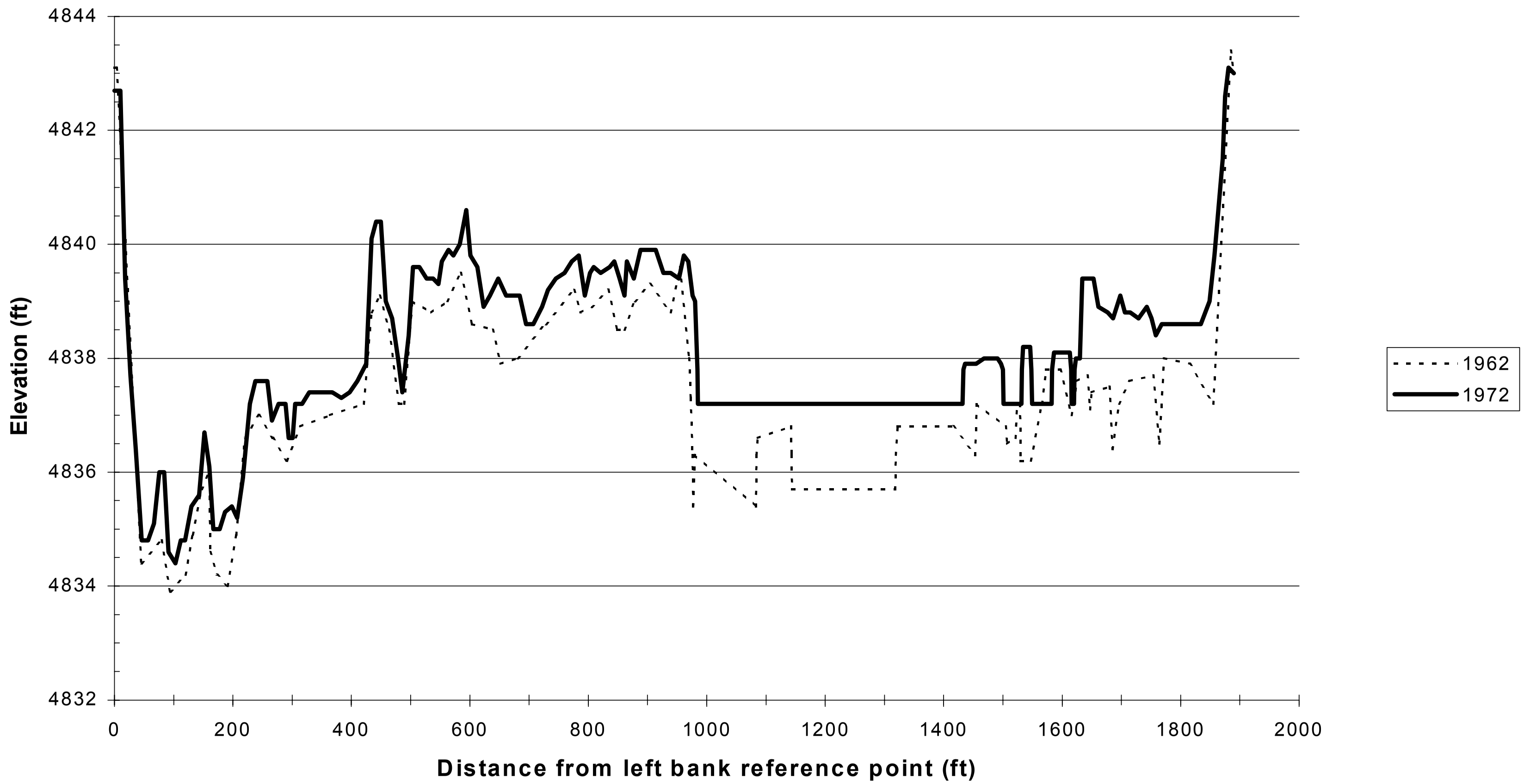

Figure D-61. Cross Section Agg/Deg 765 (CO-765).

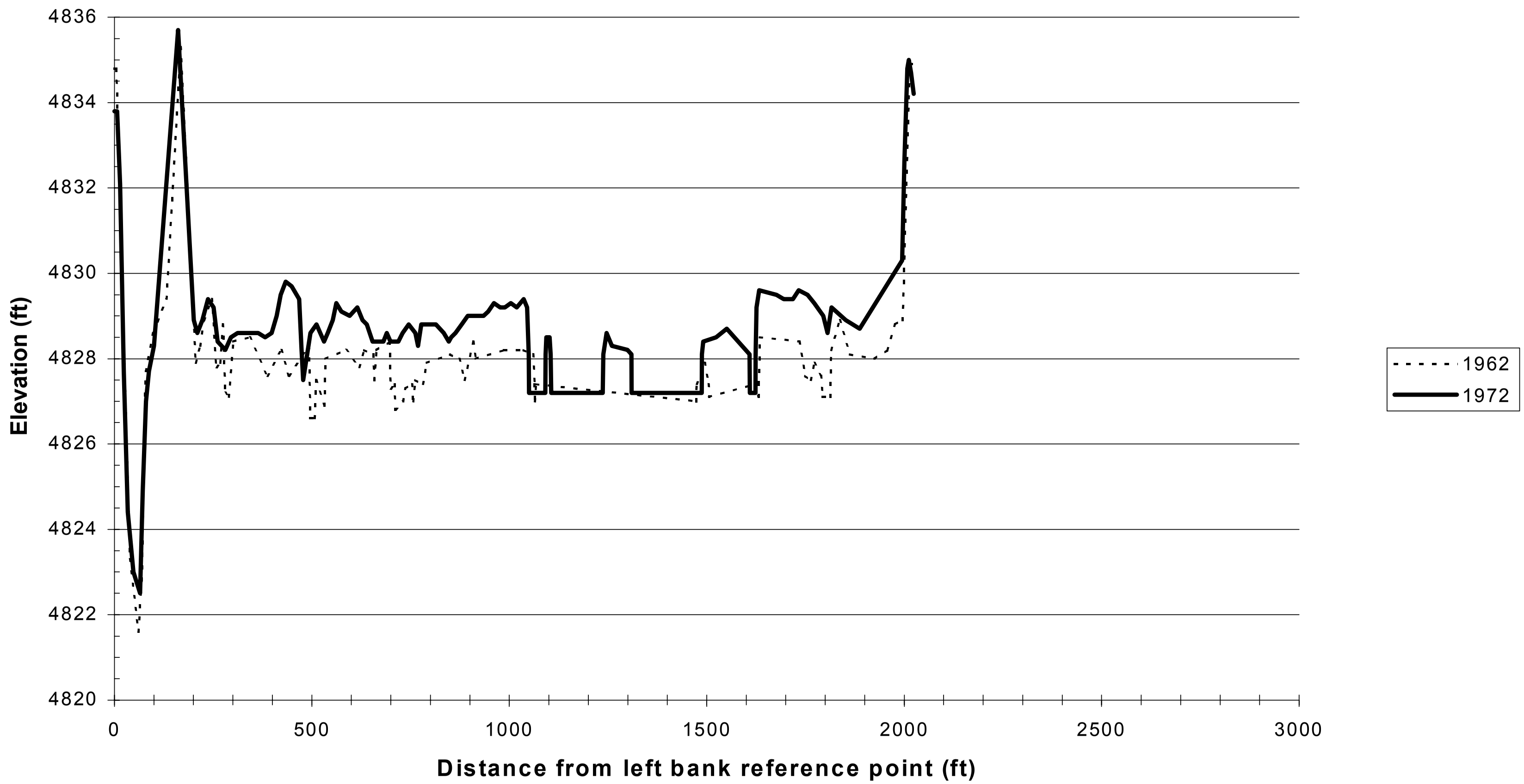

Figure D-62. Cross Section Agg/Deg 787 (CO-787).

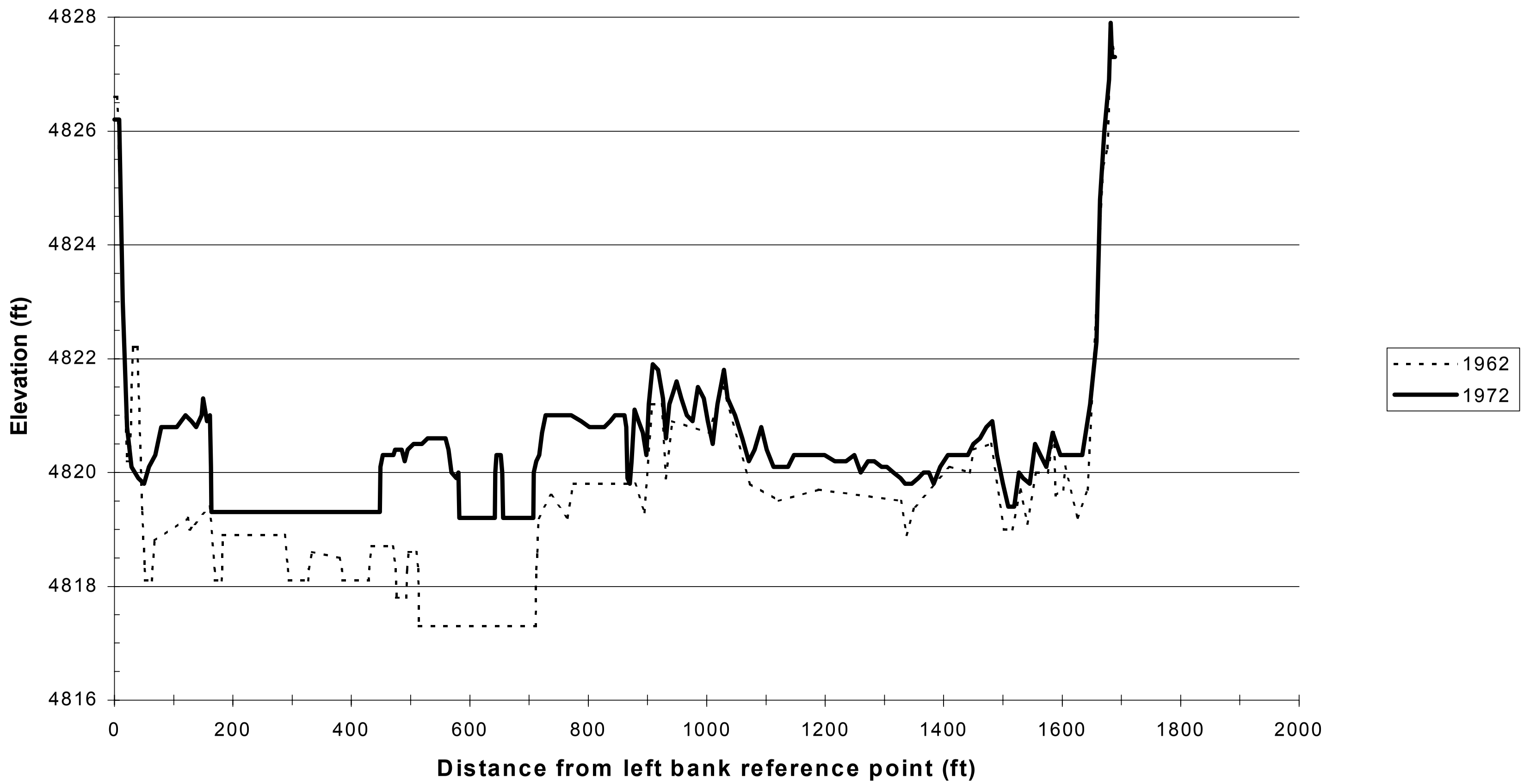

Figure D-63. Cross Section Agg/Deg 806 (CO-806).

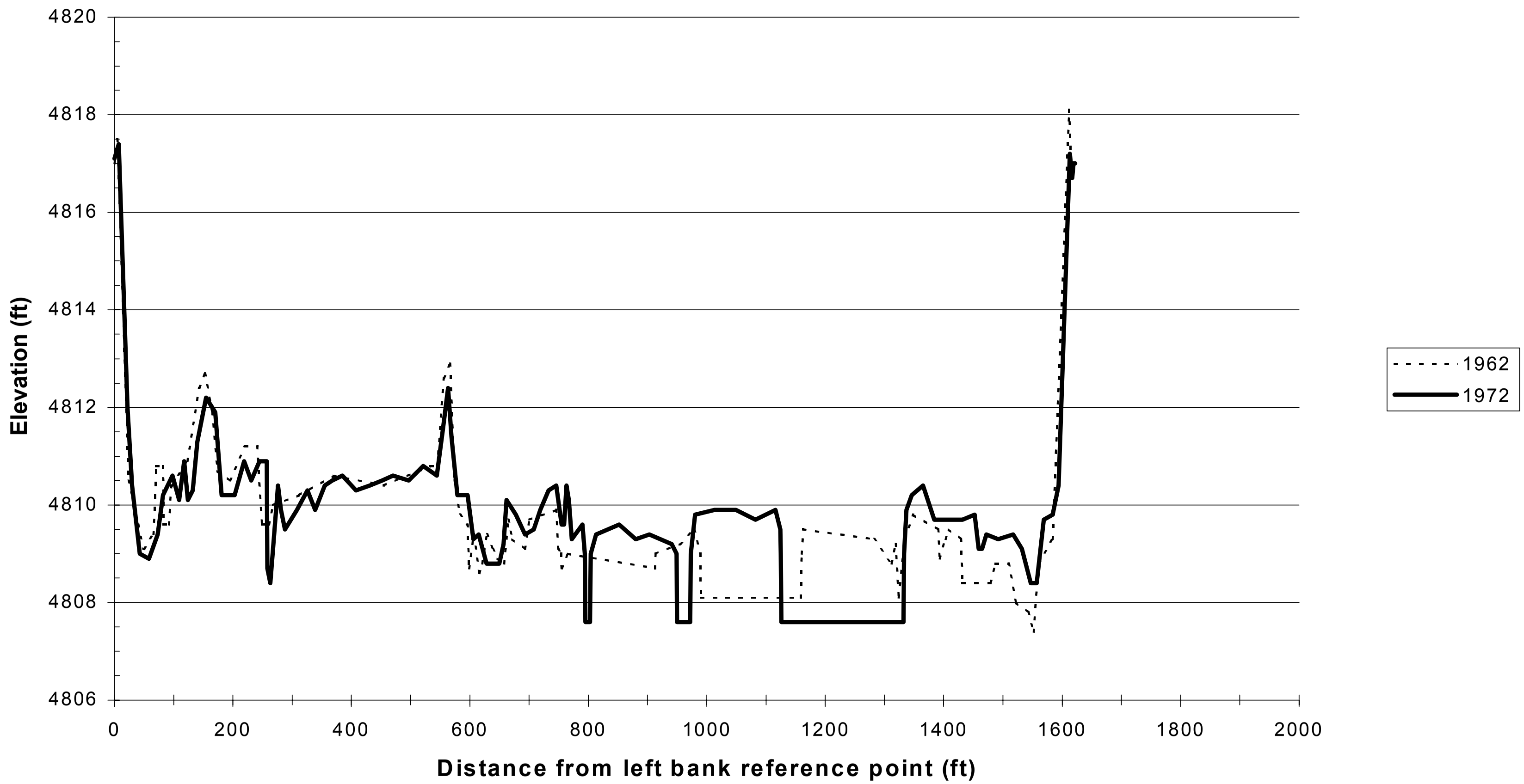

Figure D-64. Cross Section Agg/Deg 833 (CO-833).

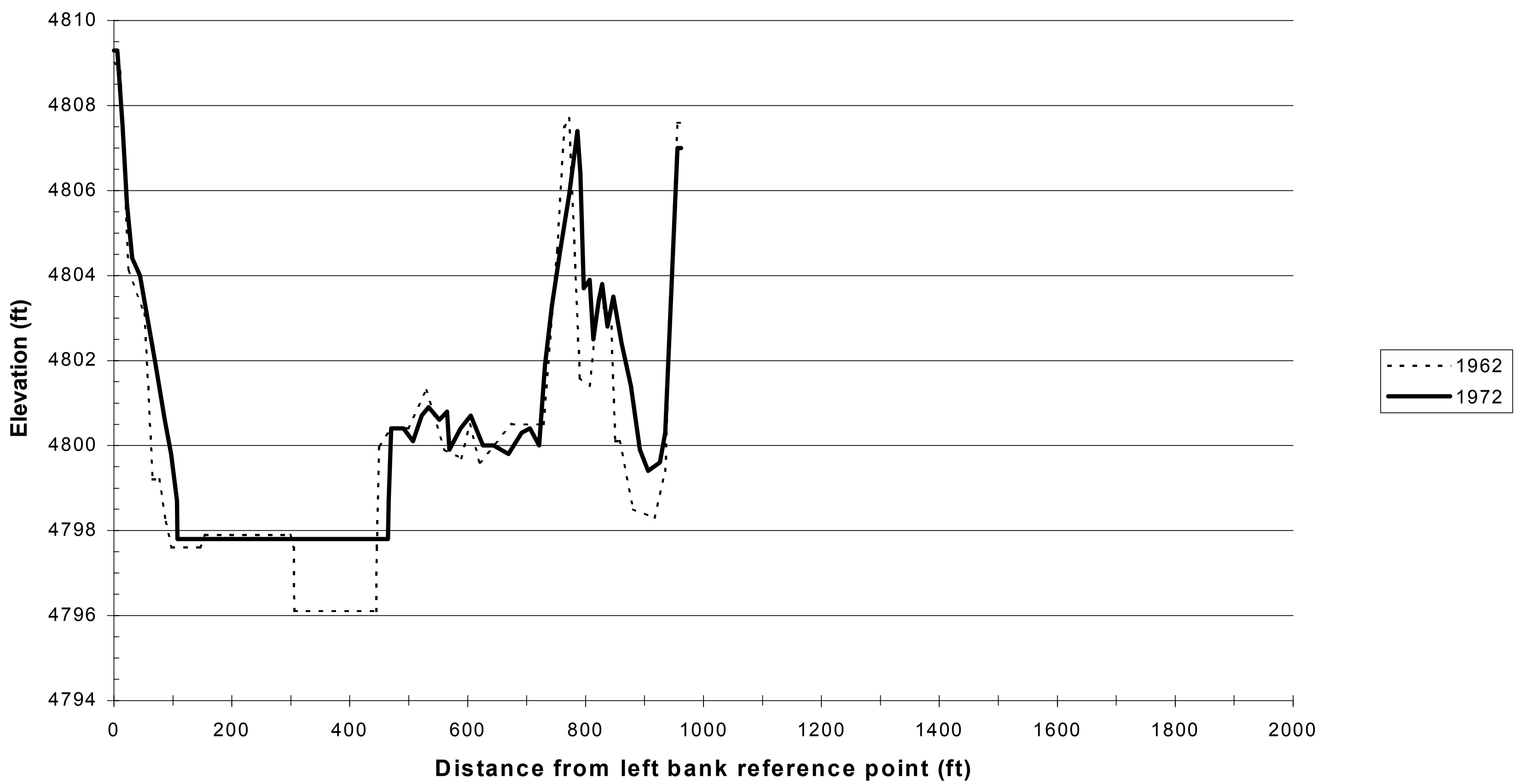

Figure D-65. Cross Section Agg/Deg 858 (CO-858.1).

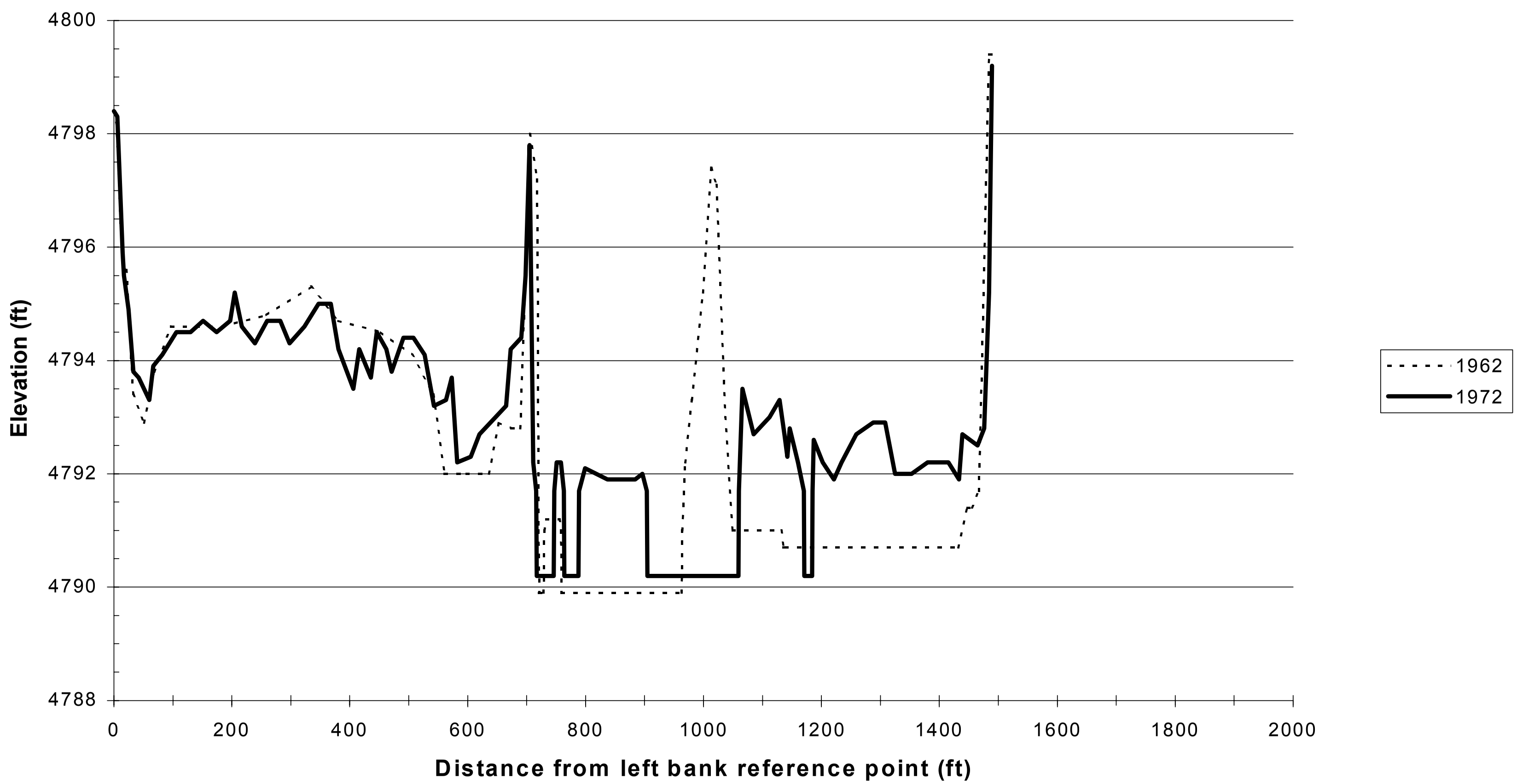

Figure D-66. Cross Section Agg/Deg 877 (CO-877).

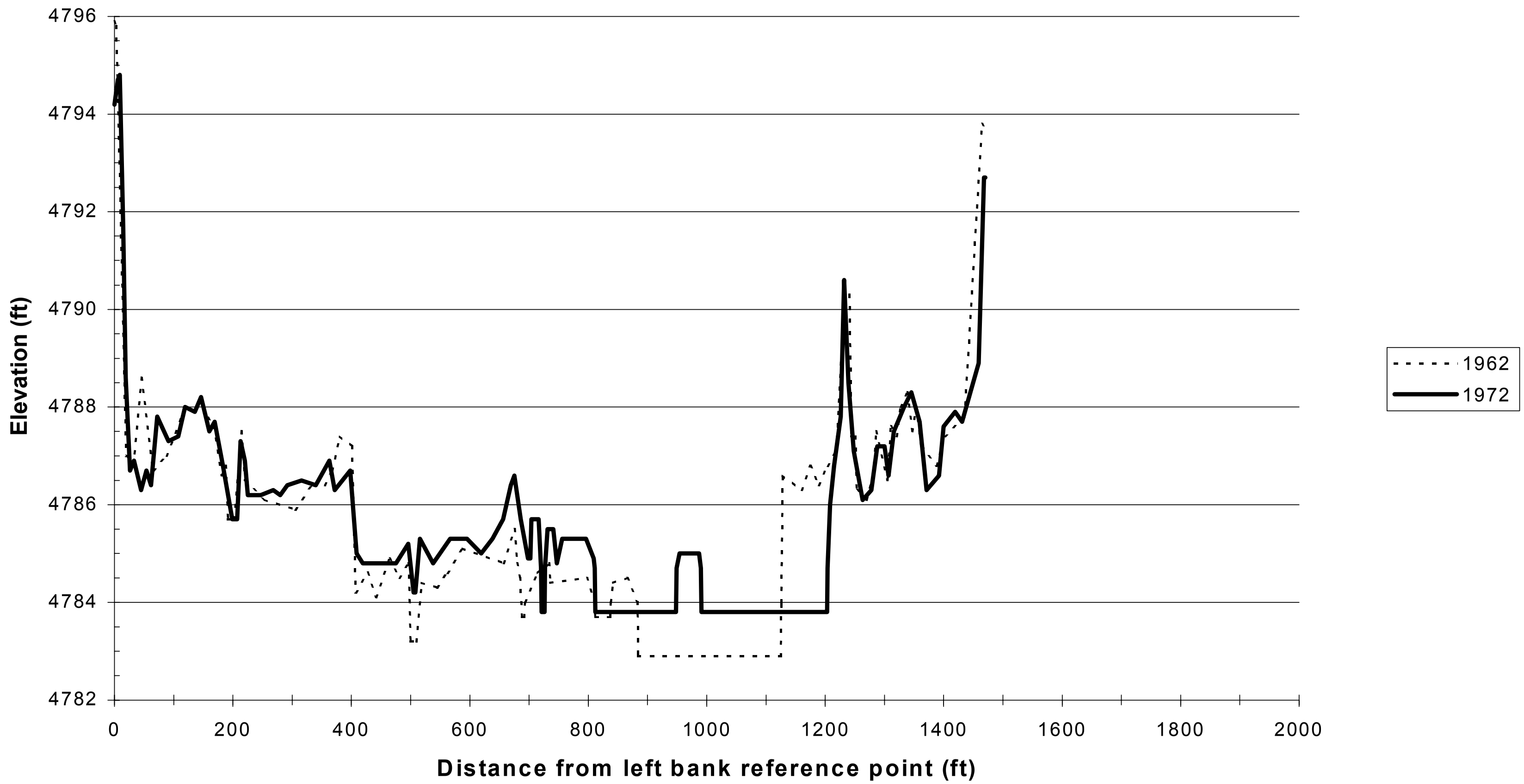

Figure D-67. Cross Section Agg/Deg 895 (CO-895).

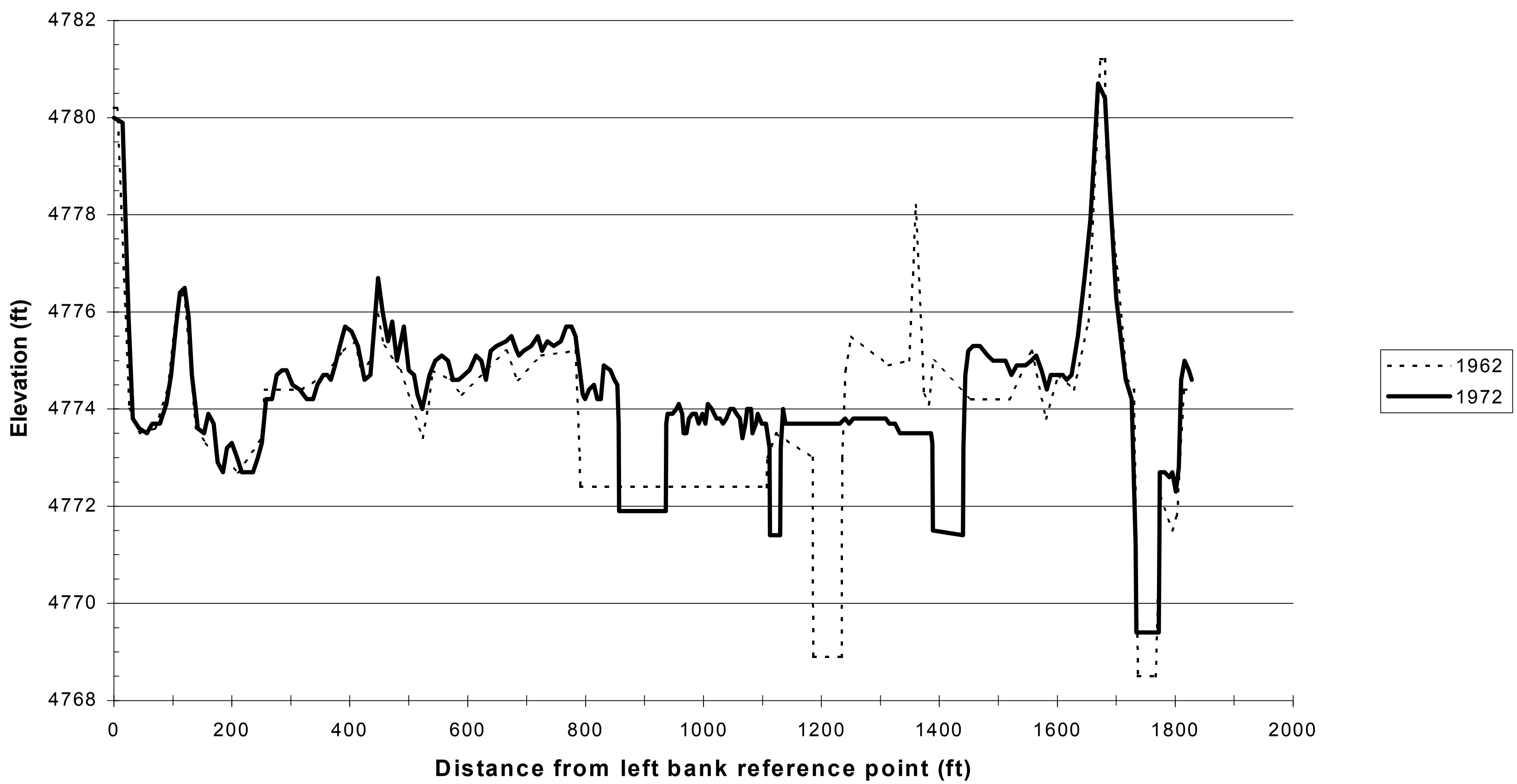

Figure D-68. Cross Section Agg/Deg 926 (CO-926).

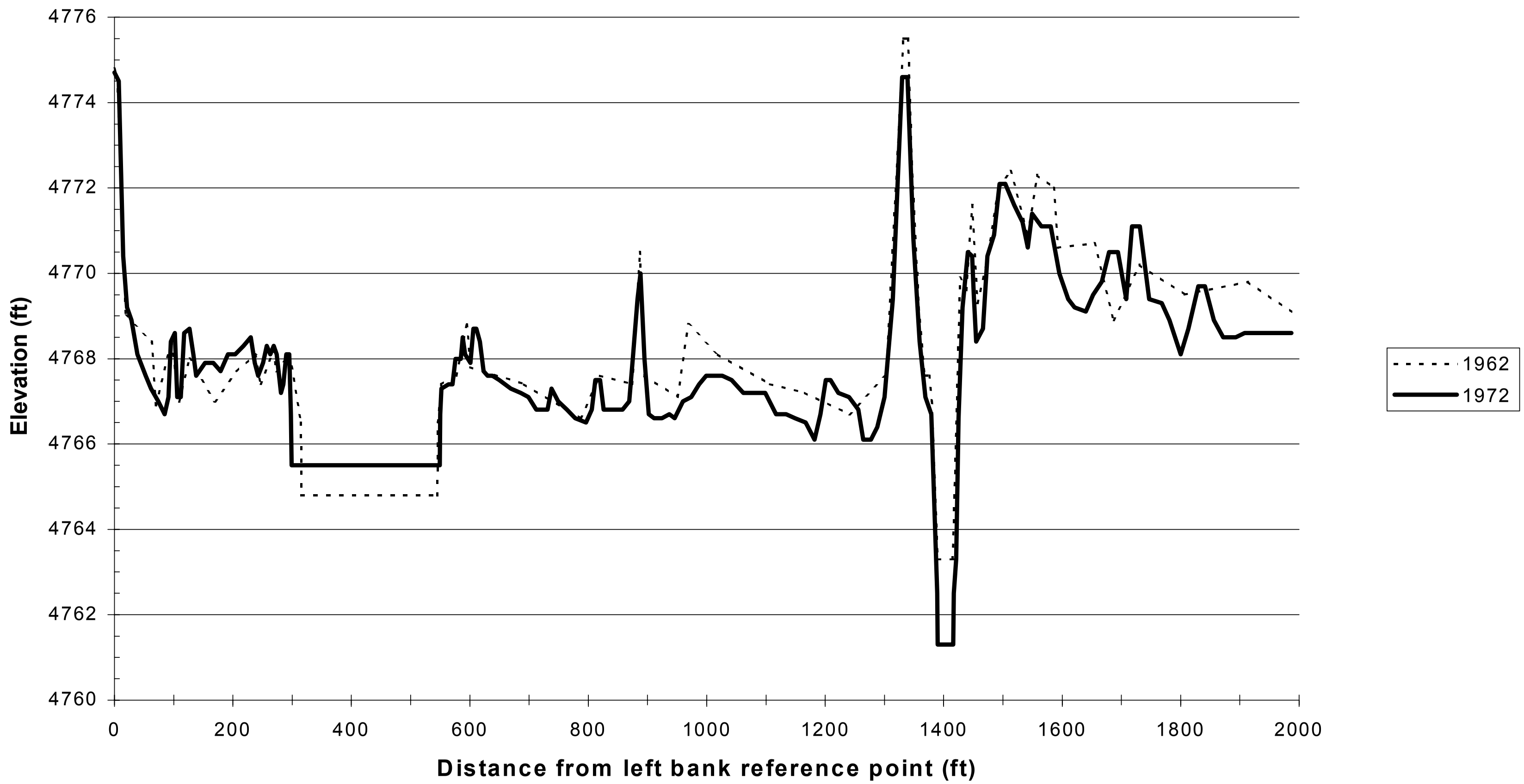

Figure D-69. Cross Section Agg/Deg 945 (CO2-945).

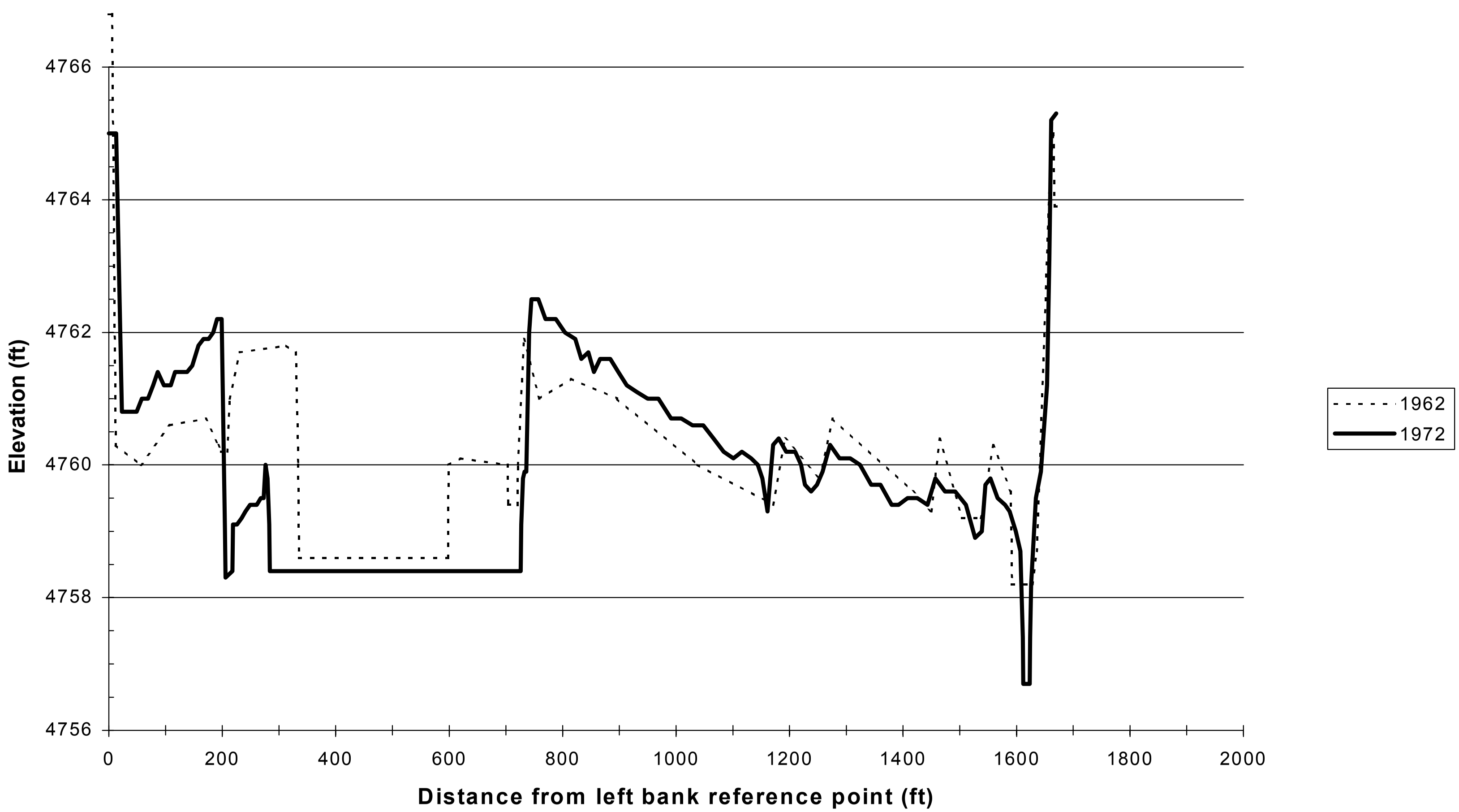

Figure D-70. Cross Section Agg/Deg 966 (CO2-966).

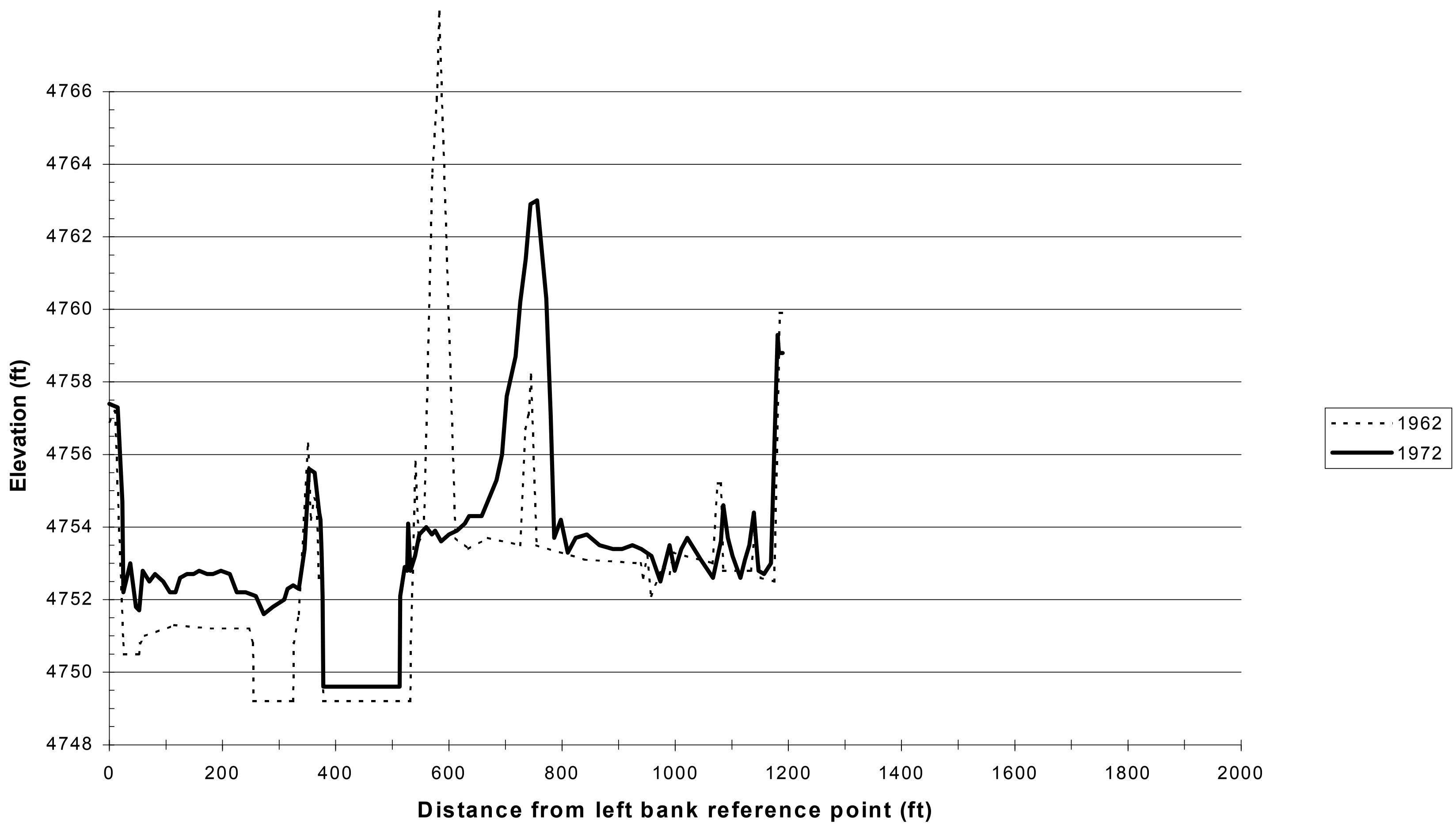

Figure D-71. Cross Section Agg/Deg 986 (CO2-986).

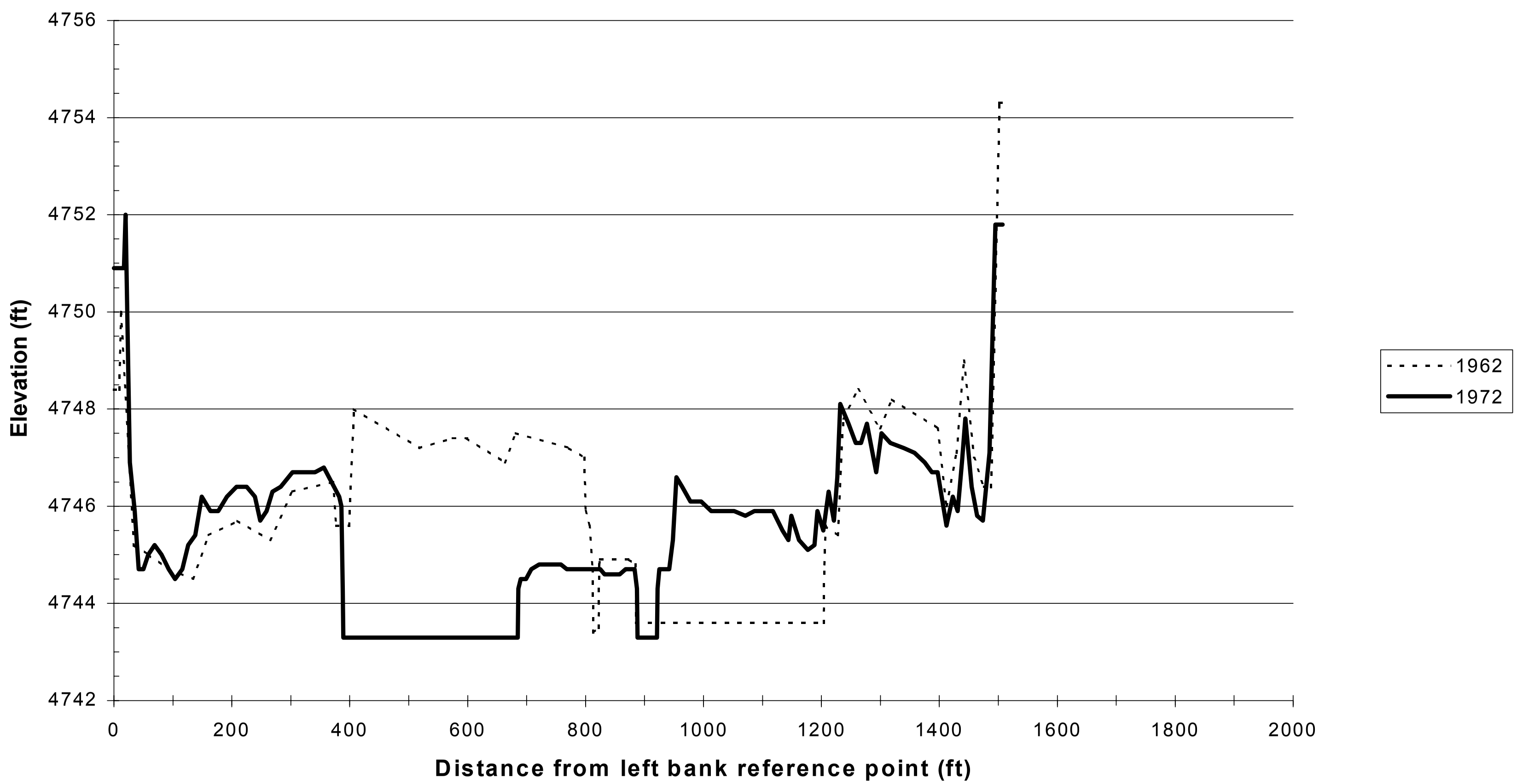

Figure D-72. Cross Section Agg/Deg 1006 (CO2-1006).

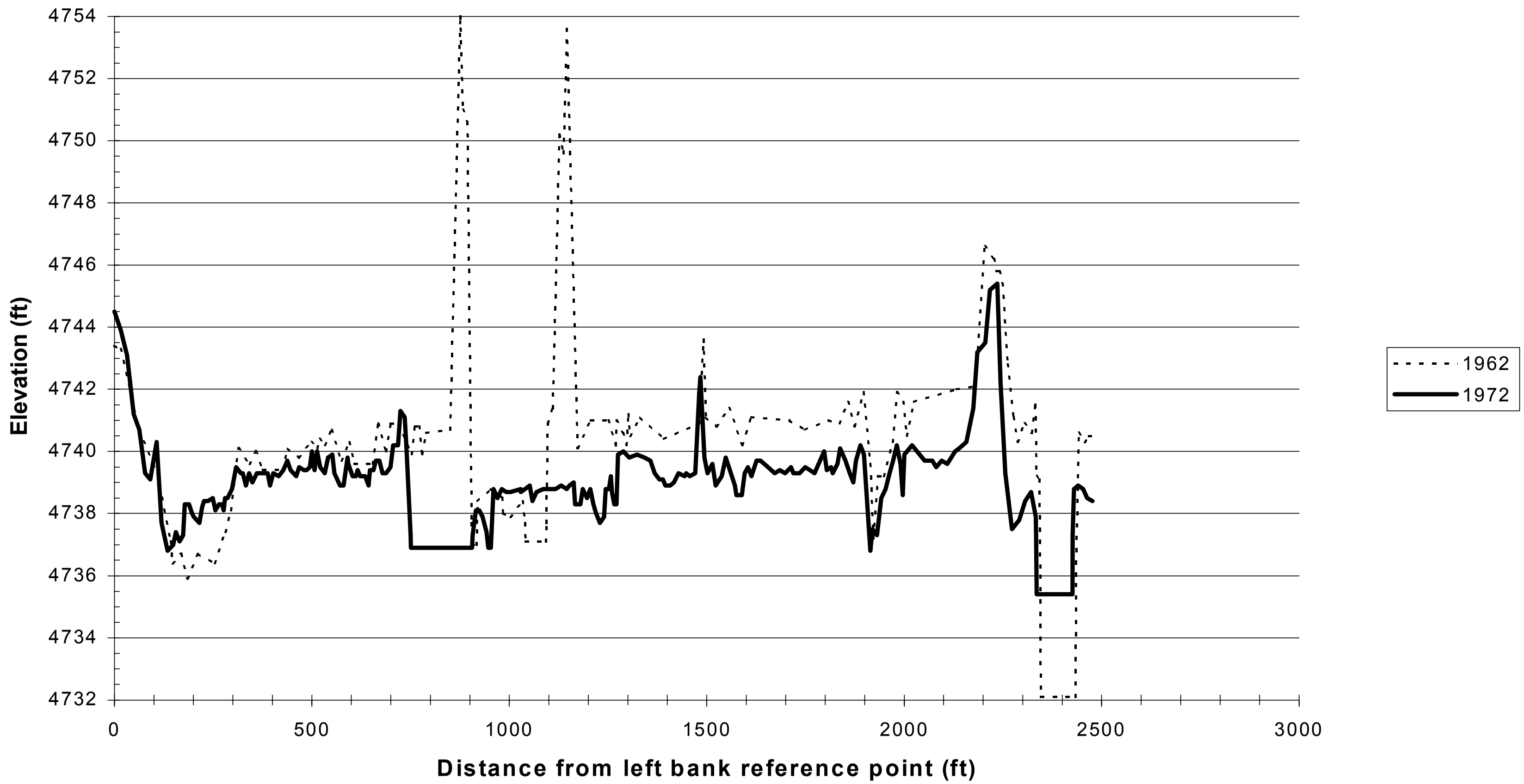

Figure D-73. Cross Section Agg/Deg 1026 (CO2-1026).

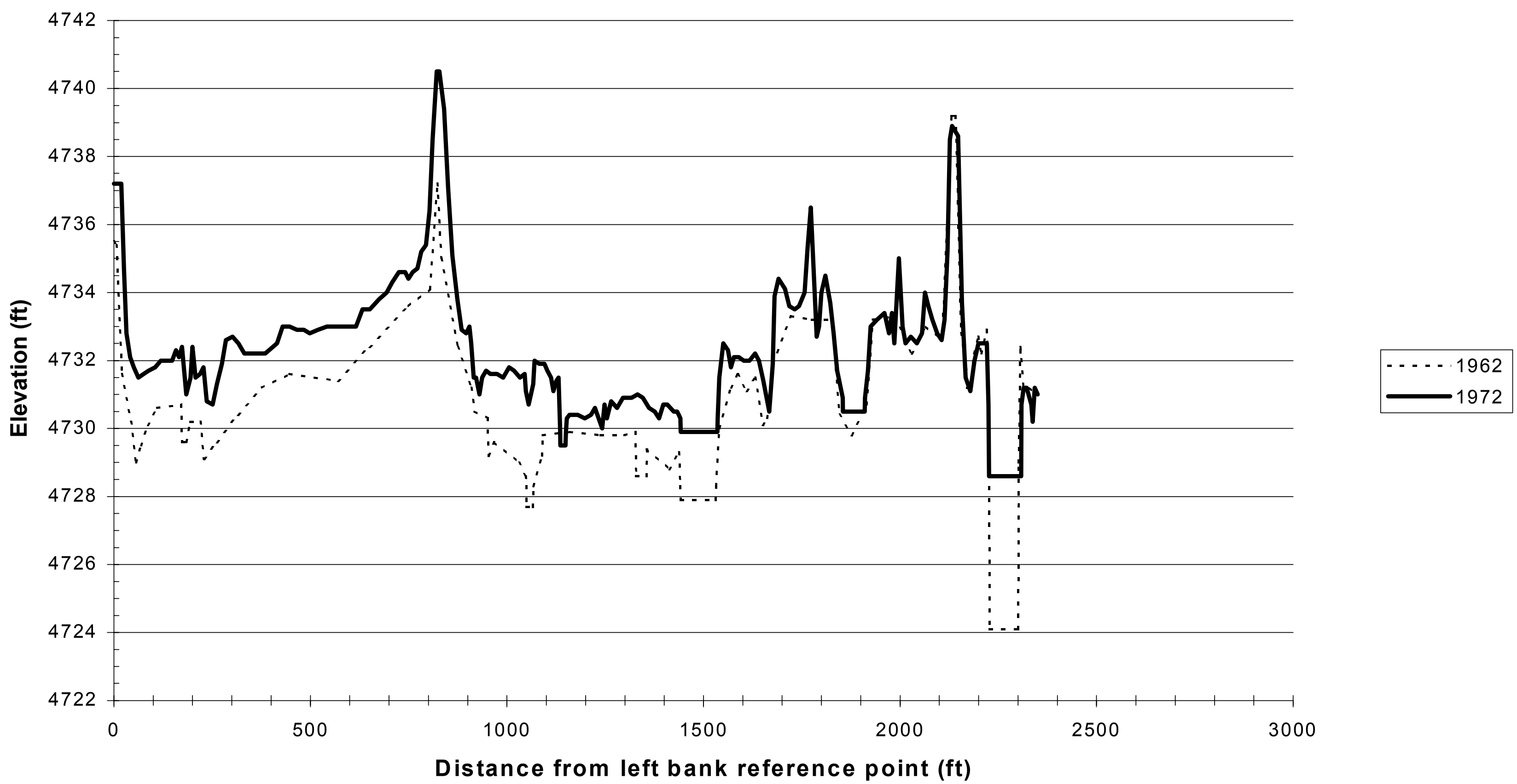

Figure D-74. Cross Section Agg/Deg 1044 (CO2-1044).

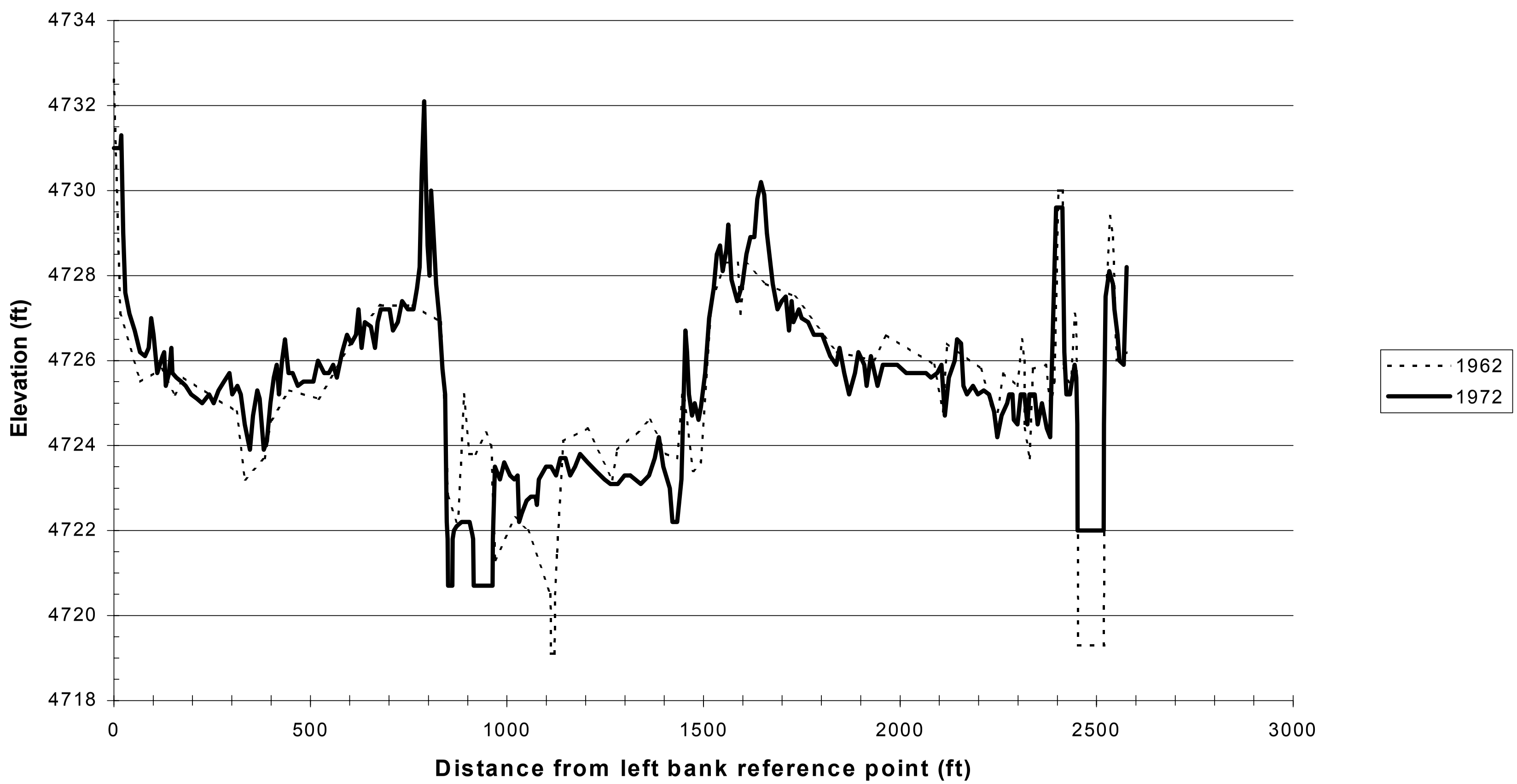

Figure D-75 Cross Section Agg/Deg 1064 (CO2-1064).

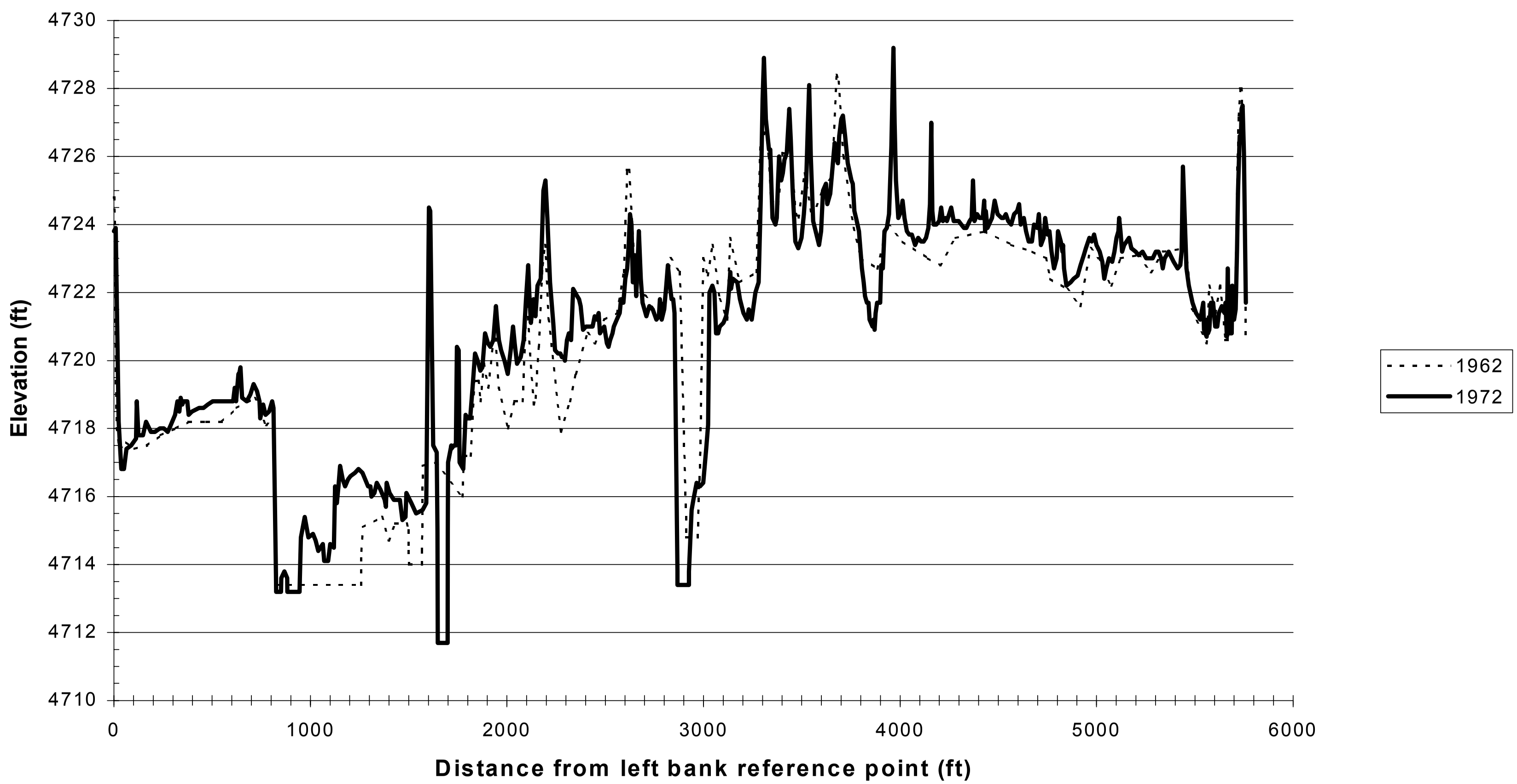

Figure D-76. Cross Section Agg/Deg 1091 (CO2-1091).

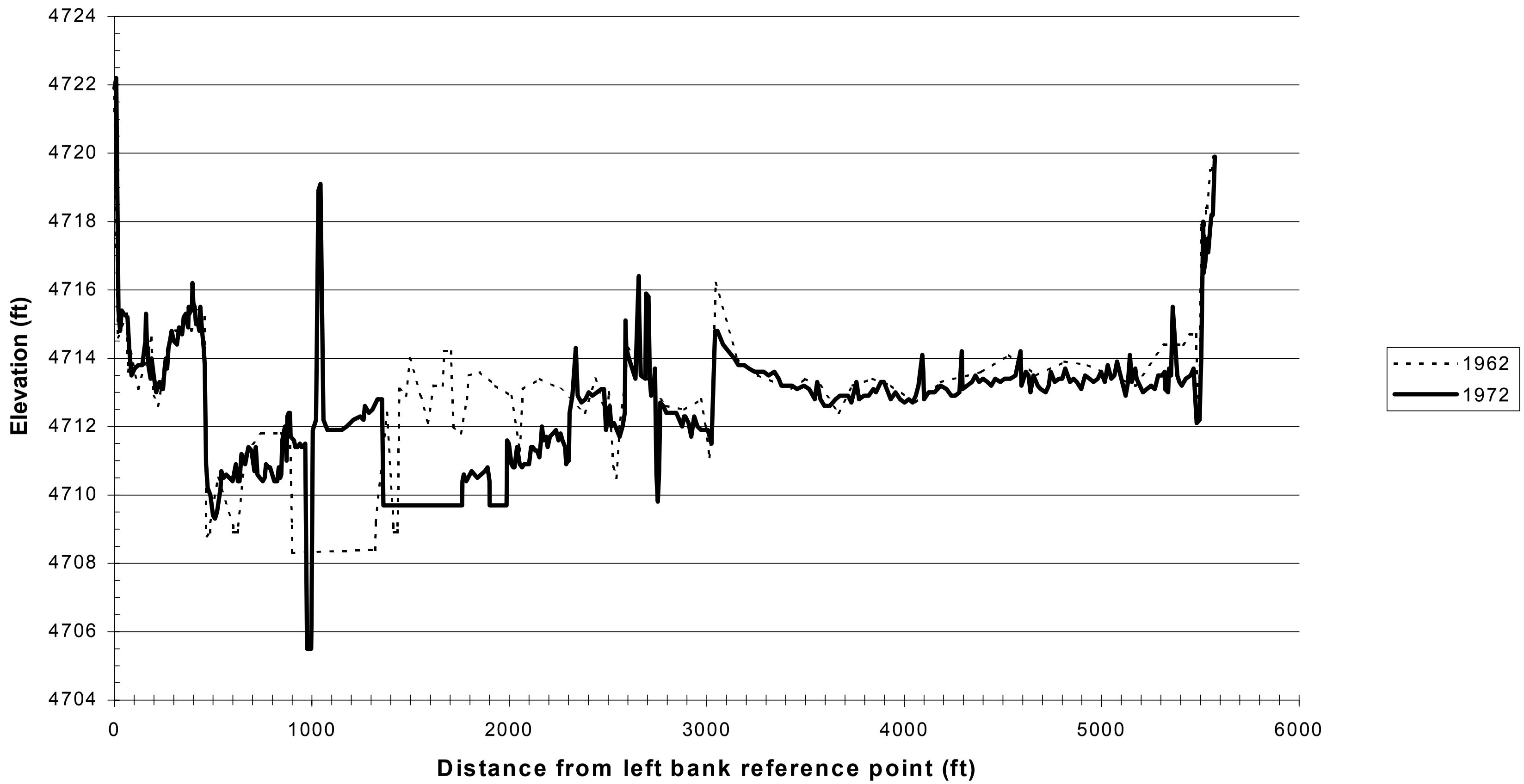

Figure D-77. Cross Section Agg/Deg 1104 (CO2-1104).

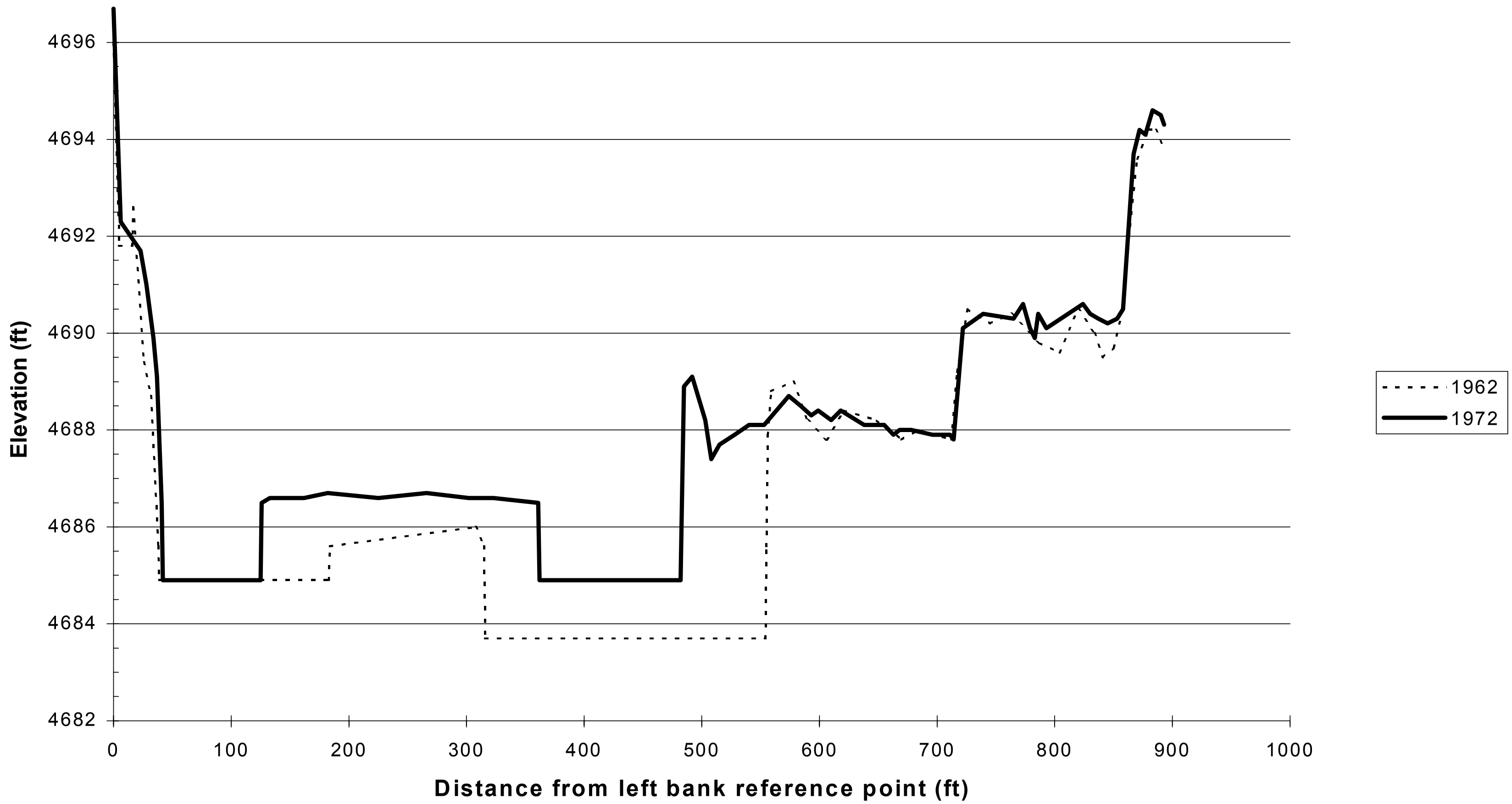

Figure D-78. Cross Section Agg/Deg 1164 (CO2-1164).

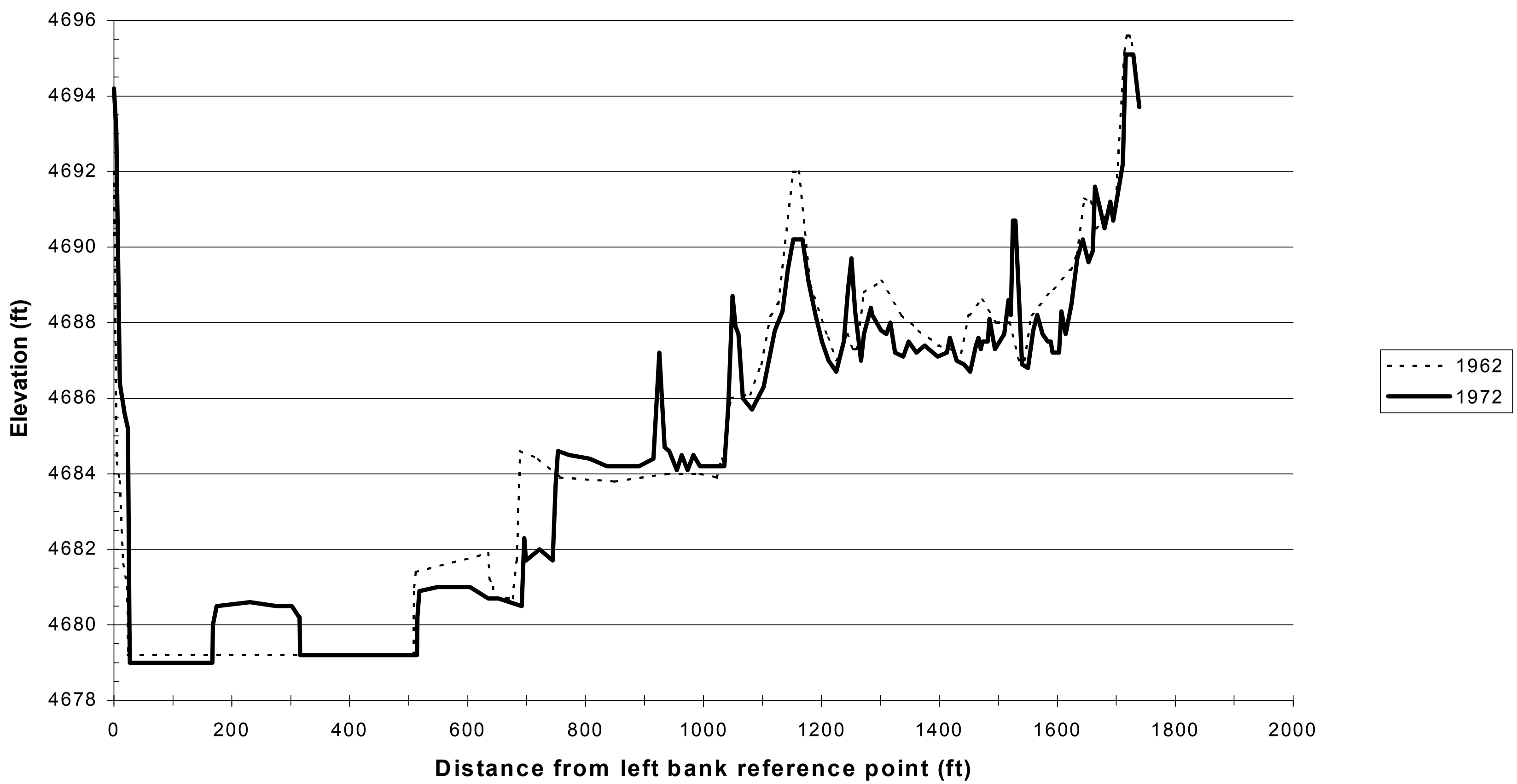

Figure D-79. Cross Section Agg/Deg 1179 (CO2-1179).

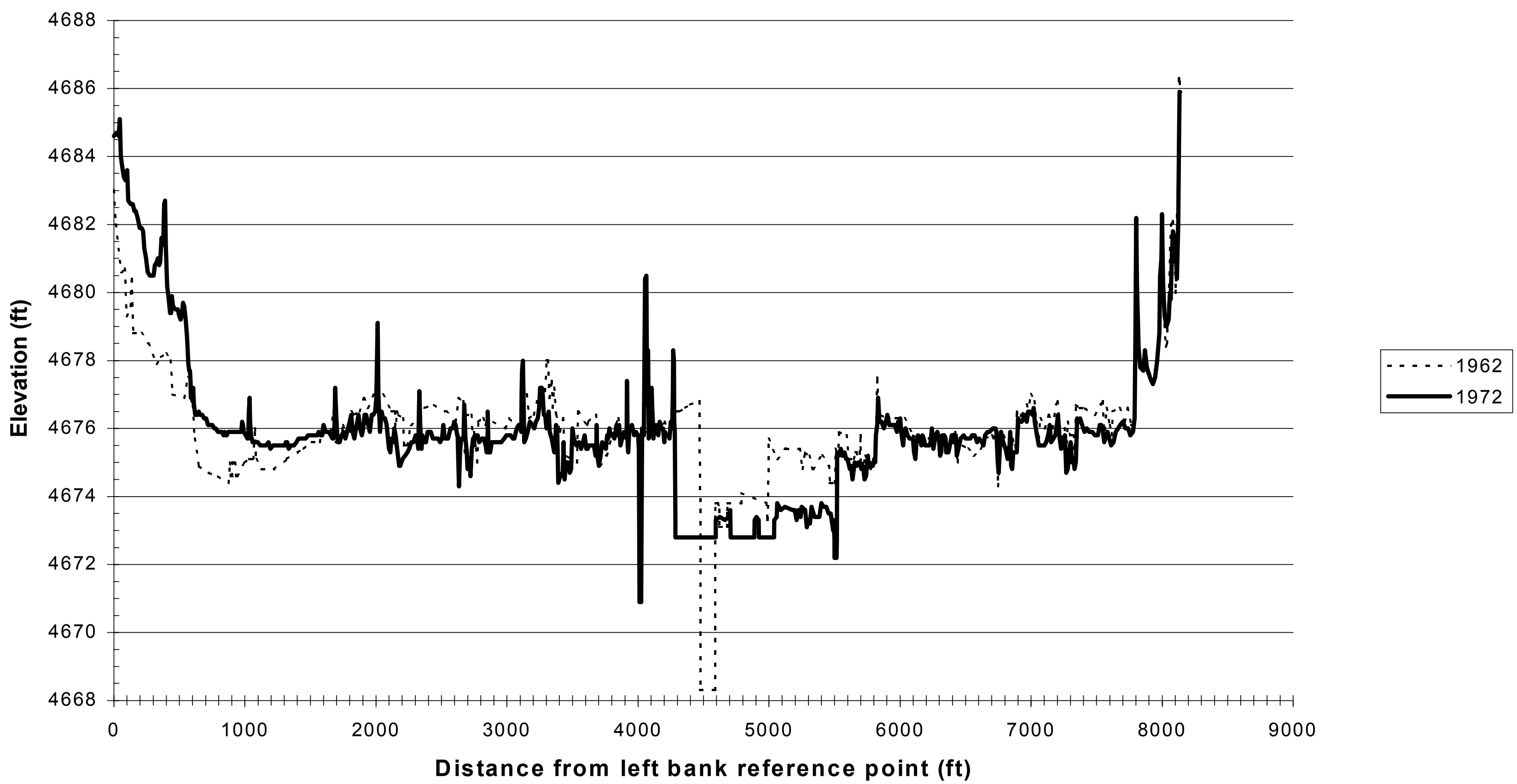

Figure D-80. Cross Section Agg/Deg 1194 (CO2-1194).

Appendix E

Table E-1. Cross section geometry for cross section CO-31 to CO-38.

- W = Cross section top width.
- P = Wetted perimeter.
- A = Cross section area.
- R = Hydraulic radius.
- w/d = Width to depth ratio.

Cross Section	Date	Water Surface Elevation ft	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation ft	Thalweg Elevation ft
31(aggdeg 324)	May-62	5042	518.94	3.8	5.6	523.78	1972.6	3.77	136.5632	5038.2	5036.4
31	May-71	5042	378.91	1.47	4.08	380.47	556.06	1.46	257.7619	5040.53	5037.92
31	Jun-73	5042	376.3	2.45	5.2	379.78	920.41	2.42	153.5918	5039.55	5036.8
31	Nov-75	5042	378.6	2.51	7.91	382.36	951.25	2.49	150.8367	5039.49	5034.09
31	Apr-79	5042	376.47	3.33	7.92	380.05	1253	3.3	113.0541	5038.67	5034.08
31	Jan-80	5042	380.09	3.47	10.9	388.86	1318.9	3.39	109.536	5038.53	5031.1
31	Jul-92	5042	403.09	5.58	7	407.42	2249.8	5.52	72.23835	5036.42	5035
31	Aug-95	5042	402.16	5.99	11.1	408.9	2408.9	5.89	67.13856	5036.01	5030.9
31	Sep-98	5042	403.59	6.92	9.2	410.83	2794.6	6.8	58.32225	5035.08	5032.8
32(aggdeg 335)	May-62	5035.6	717.05	1.87	3.5	719.38	1339.2	1.86	383.4492	5033.73	5032.1
32	May-71	5035.6	269.8	2.16	6.68	274.17	583.9	2.13	124.9074	5033.44	5028.92
32	Jun-73	5035.6	271.83	3.01	5.36	274.18	819.31	2.99	90.30897	5032.59	5030.24
32	Nov-75	5035.6	271.51	3.45	5.9	276.05	937.45	3.4	78.69855	5032.15	5029.7
32	Apr-79	5035.6	274.67	4.65	7.02	277.61	1278.3	4.6	59.06882	5030.95	5028.58
32	Jan-80	5035.6	272.12	3.64	5.9	274.78	991.16	3.61	74.75824	5031.96	5029.7
32	Jul-92	5035.6	279.64	4.46	7	282.82	1246.7	4.41	62.69955	5031.14	5028.6
32	Aug-95	5035.6	279.01	4.81	9.2	383.28	1340.9	4.73	58.00624	5030.79	5026.4
32	Sep-98	5035.6	277.99	5.29	7.1	281.44	1470.9	5.23	52.55009	5030.31	5028.5

Table E-1. Cross section geometry for cross section CO-31 to CO-38 (cont'd).

Cross Section	Date	Water Surface Elevation ft	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation ft	Thalweg Elevation ft
33(aggdeg 351)	May-62	5028.5	740.93	2.5	4.7	748.49	1850.5	2.47	296.372	5026	5023.8
33	May-71	5028.5	640.64	1.81	5.64	643.56	1156.5	1.8	353.9448	5026.69	5022.86
33	Jun-73	5028.5	376.41	1.79	3.04	377.47	674.33	1.79	210.2849	5026.71	5025.46
33	Nov-75	5028.5	577.37	1.6	3.81	580.01	923.67	1.59	360.8563	5026.9	5024.69
33	Apr-79	5028.5	640.61	1.43	3.68	641.56	913.27	1.43	447.979	5027.07	5024.82
33	Jan-80	5028.5	649.43	2.52	4.8	651.95	1634	2.51	257.7103	5025.98	5023.7
33	Jul-92	5028.5	650.64	3.97	7.2	656.75	2581.4	3.93	163.8892	5024.53	5021.3
33	Aug-95	5028.5	651.53	4	7.6	655	2603.7	3.97	162.8825	5024.5	5020.9
33	Sep-98	5028.5	651.86	4.22	5.8	656.67	2752.7	4.19	154.4692	5024.28	5022.7
34(aggdeg 407)	May-62	5002	833.56	1.12	2	835.67	932.88	1.12	744.25	5000.88	5000
34	May-71	5002	457.29	1.64	4.61	58.66	750.39	1.64	278.8354	5000.36	4997.39
34	Jun-73	5002	463.57	2.4	4.66	466.75	1111	2.38	193.1542	4999.6	4997.34
34	Nov-75	5002	469.73	1.88	10.15	476.44	884.44	1.86	249.8564	5000.12	4991.85
34	Apr-79	5002	469.27	2.94	8.24	472.1	1379.7	2.92	159.6156	4999.06	4993.76
34	Jan-80	5002	463.11	3.49	7.6	469.81	1615.1	3.44	132.6963	4998.51	4994.4
34	Jul-92	5002	464.21	3.88	7.7	473.8	1799.5	3.8	119.6418	4998.12	4994.3
34	Aug-95	5002	464.16	4.76	7.6	470.57	2207.5	4.69	97.51261	4997.24	4994.4
34	Sep-98	5002	466.92	4.44	5.4	473.04	2071.9	4.38	105.1622	4997.56	4996.6
35(aggdeg453)	May-62	4978.2	273.77	0.85	1.6	276.15	233.45	0.85	322.0824	4977.35	4976.6
35	May-71	4978.2	187.96	1.6	4	190.05	301.53	1.59	117.475	4976.6	4974.2
35	Jun-73	4978.2	171	2.2	3.5	172.26	375.96	2.18	77.72727	4976	4974.7
35	Nov-75	4978.2	192.45	1.38	4.07	195.67	265.02	1.35	139.4565	4976.82	4974.13
35	Apr-79	4978.2	296.05	2.38	4.34	297.25	705.7	2.37	124.3908	4975.82	4973.86
35	Jan-80	4978.2	520.18	1.36	3.6	520.78	707.65	1.36	382.4853	4976.84	4974.6
35	Jul-92	4978.2	551.27	2.31	4.9	558.76	1271	2.27	238.645	4975.89	4973.3
35	Aug-95	4978.2	730.27	1.84	4.4	738.31	1345.1	1.82	396.8859	4976.36	4973.8
35	Sep-98	4978.2	402.08	2.77	6.7	407.71	1113.6	2.73	145.1552	4975.43	4971.5

Table E-1. Cross section geometry for cross section CO-31 to CO-38 (cont'd).

Cross Section	Date	Water Surface Elevation ft	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation ft	Thalweg Elevation ft
36(aggdeg 509)	May-62	4952.5	372.23	2.05	3.1	376.44	762.97	2.03	181.5756	4950.45	4949.4
36	May-71	4952.5	341.37	1.58	3.07	342.45	538.79	1.57	216.057	4950.92	4949.43
36	Jun-73	4952.5	324.19	2.53	6.3	326.6	821.13	2.51	128.1383	4949.97	4946.2
36	Nov-75	4952.5	388.47	1.53	5.01	391.72	596.1	1.52	253.902	4950.97	4947.49
36	Jul-92	4952.5	404.17	4.14	7.6	407.62	1672.1	4.1	97.6256	4948.36	4944.9
36	Aug-95	4952.5	390.12	4.14	7.6	393.37	1606.8	4.08	94.23188	4948.36	4944.9
36	Sep-98	4952.5	398.89	4.02	6.6	401.98	1604.6	3.99	99.22637	4948.48	4945.9
37(aggdeg 509)	May-62	4927.6	358.41	2.3	2.6	359.79	823.75	2.29	155.8304	4925.3	4925
37	May-71	4927.6	281.75	1.07	3.76	285.95	301.41	1.07	263.3178	4926.53	4923.84
37	Jun-73	4927.6	293.25	2.29	7.4	295.52	670.25	2.27	128.0568	4925.31	4920.2
37	Nov-75	4927.6	3338.2	1.77	5.37	340.06	598.25	1.76	1885.994	4925.83	4922.23
37	Apr-79	4927.6	394.59	2.02	4.34	396.66	795.7	2.01	195.3416	4925.58	4923.26
37	Jan-80	4927.6	556.53	1.65	3.3	558.29	916.84	1.64	337.2909	4925.95	4924.3
37	Jul-92	4927.6	522.63	3.09	5.7	528.08	1612.9	3.05	169.1359	4924.51	4921.9
37	Aug-95	4927.6	525.12	3.24	5	529.56	1701.1	3.21	162.0741	4924.36	4922.6
37	Sep-98	4927.6	527.66	3.14	4.3	533.63	1658.6	3.11	168.0446	4924.46	4923.3
38(aggdeg 509)	May-62	4905.15	462.94	1.67	2.85	464.54	772.9	1.66	277.2096	4903.48	4902.3
38	May-71	4905.15	658.01	1.55	3.45	660.66	1020.2	1.54	424.5226	4903.6	4901.7
38	Jun-73	4905.15	255.48	2.09	5.87	257.65	534.97	2.08	122.2392	4903.06	4899.28
38	Nov-75	4905.15	409.09	1.08	4.4	409.78	443.62	1.08	378.787	4904.07	4900.75
38	Apr-79	4905.15	244.41	2.29	3.68	245.18	559.86	2.28	106.7293	4902.86	4901.47
38	Jan-80	4905.15	406.18	1.31	3.17	407.15	532.59	1.31	310.0611	4903.84	4901.98
38	Jul-92	4905.15	634.01	2.24	5.35	639.38	2054.5	3.21	283.0402	4902.91	4899.8
38	Aug-95	4905.15	634.39	3.25	7.05	638.02	2061.2	3.23	195.1969	4901.9	4898.1
38	Sep-98	4905.15	634.05	3.57	5.35	642.37	2263.8	3.52	177.605	4901.58	4899.8

Table E-2. Cross section geometry for cross section CO-668 to CO-926.

- W = Cross section top width.
- P = Wetted perimeter.
- A = Cross section area.
- R = Hydraulic radius.
- w/d = Width to depth ratio.

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation ft	Thalweg Elevation ft
668	May-62	4879.47	488.05	2.54	4.07	490.59	1239.6	2.53	192.1457	4876.93	4875.4
668	May-72	4879.47	593.32	1.06	2.07	597.39	629.87	1.03	559.7358	4878.41	4877.4
668	Oct-82	4879.47	524.35	1.2	5.67	527.65	629.12	1.19	436.9583	4878.27	4873.8
668	Jul-92	4879.47	482.69	1.9	5.37	486.62	918.72	1.89	254.0474	4877.57	4874.1
668	Aug-95	4879.47	593.47	1.66	5.77	596.15	986.78	1.66	357.512	4877.81	4873.7
668	Aug-98	4879.47	591.2	2.01	3.57	594.89	1188.38	2	294.1294	4877.46	4875.9
713	May-62	4861.4	1156	2.43	4.3	1158.95	2808.65	2.42	475.7078	4858.97	4857.1
713	May-72	4861.4	1166.9	2.33	3.19	1173	2599.4	2.22	500.8326	4859.07	4858.21
713	Oct-82	4861.4	679.29	2.21	4.5	682.13	1502.5	2.2	307.371	4859.19	4856.9
713	Jul-92	4861.4	670.15	2.84	4.9	673.02	1903.24	2.83	235.9683	4858.56	4856.5
713	Aug-95	4861.4	679.35	2.88	7.8	686.89	1957.25	2.85	235.8854	4858.52	4853.6
713	Aug-98	4861.4	678.63	2.68	5.1	685.3	1810.34	2.64	253.2201	4858.72	4856.3
724	May-62	4856.12	1252.4	2.72	5.12	1260.88	3403.47	2.7	460.4375	4853.4	4851
724	May-72	4856.12	577.93	1.91	2.52	580.43	1100.98	1.9	302.5812	4854.21	4853.6
724	Oct-82	4856.12	564.27	2.36	5.18	566.8	1333.1	2.35	239.0975	4853.76	4850.94
724	Jul-92	4856.12	569.69	2.17	4.62	571.86	1235.72	2.16	262.53	4853.95	4851.5
724	Aug-95	4856.12	578.32	2.49	6.82	588.13	1442.77	2.45	232.257	4853.63	4849.3
724	Aug-98	4856.12	589.93	3	4.32	596.41	1766.87	2.96	196.6433	4853.12	4851.8
738	May-62	4850.09	211.74	2.67	2.89	213.42	565.57	2.65	79.30337	4847.42	4847.2
738	May-72	4850.09	592.45	1.17	1.39	593.14	693.95	1.17	506.3675	4848.92	4848.7
738.1	Oct-82	4850.09	729.57	1.88	7.19	731.38	1370.58	1.87	388.0691	4848.21	4842.9
738.1	Jul-92	4850.09	784.26	2.68	6.49	792.66	2098.33	2.65	292.6343	4847.41	4843.6
738.1	Aug-95	4850.09	750.78	2.2	5.49	757.34	1648.68	2.18	341.2636	4847.89	4844.6
738.1	Aug-98	4850.09	777.38	2.96	4.87	782.67	2303.33	2.94	262.6284	4847.13	4845.22

Table E-2. Cross section geometry for cross section CO-668 to CO-926 (cont'd).

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation ft	Thalweg Elevation ft
765	May-62	4838.86	901.1	2.14	3.46	904.05	1932.25	2.14	421.0748	4836.72	4835.4
765	May-72	4838.86	810.31	1.24	1.66	812.09	1001.97	1.23	653.4758	4837.62	4837.2
765	Oct-82	4838.86	566.71	2.02	4.96	596.5	1142.2	2.01	280.5495	4836.84	4833.9
765	Jul-92	4838.86	607.93	3.29	5.06	612.31	2000.92	3.27	184.7812	4835.57	4833.8
765	Aug-95	4838.86	606.75	2.71	7.66	612.77	1642.62	2.68	223.893	4836.15	4831.2
765	Aug-98	4838.86	612.8	3.09	5.33	618.7	1893.12	3.06	198.3172	4835.77	4833.53
787	May-62	4829	1777.2	1.23	2.4	1780.2	2191.8	1.23	1444.862	4827.77	4826.6
787	May-72	4829	579.91	1.36	1.8	583.12	789.59	1.35	426.4044	4827.64	4827.2
787	Oct-82	4829	571.38	1.47	4.4	5.72.74	840.35	1.47	388.6939	4827.53	4824.6
787	Jul-92	4829	569.85	2.69	4.6	5.72.46	1530.96	2.67	211.8401	4826.31	4824.4
787	Aug-95	4829	572.01	2.35	8.7	576.76	1344.85	2.33	243.4085	4826.65	4820.3
787	Aug-98	4829	570.51	2.44	4.5	574.27	1394.54	2.43	233.8156	4826.56	4824.5
806	May-62	4821	864.32	2.44	3.7	866.63	2109.43	2.43	354.2295	4818.56	4817.3
806	May-72	4821	809.59	1.08	1.8	812.06	875.1	1.08	749.6204	4819.92	4819.2
806	Oct-82	4821	555.16	1.76	5.6	558.44	977.78	1.75	315.4318	4819.24	4815.4
806	Aug-92	4821	563.37	2.71	4.8	568.29	1524.21	2.68	207.8856	4818.29	4816.2
806	Jul-95	4821	570.46	3.76	4.5	573.81	2147.28	3.74	151.7181	4817.24	4816.5
806	Aug-98	4821	561.53	2.94	4.4	567.27	1650.26	2.91	190.9966	4818.06	4816.6
833	May-62	4810.77	1015.5	1.85	3.37	1017.65	1873.79	1.84	548.8973	4808.92	4807.4
833	May-72	4810.77	1020.8	1.64	3.17	1026.06	1676.26	1.63	622.4207	4809.13	4807.6
833	Nov-83	4810.77	585.11	2.13	6.67	586.86	1247.07	2.13	274.6995	4808.64	4804.1
833	Aug-92	4810.77	577.67	3.01	7.87	582.39	1737.9	2.98	191.9169	4807.76	4802.9
833	Jul-95	4810.77	579.88	2.64	8.97	585.36	1532.93	2.62	219.6515	4808.13	4801.8
833	Aug-98	4810.77	591.87	3.42	5.47	594.64	2025.36	3.41	173.0614	4807.35	4805.3
858	May-62	4799.92	444.49	2.31	3.82	446.93	1027.54	2.3	192.4199	4797.61	4796.1
858	May-72	4799.92	395.34	1.95	2.12	396.35	770.78	1.94	202.7385	4797.97	4797.8
858.1	Oct-82	4799.92	316.95	2.45	4.72	318.73	775.39	2.43	129.3673	4797.47	4795.2
858.1	Jul-92	4799.92	411.73	4.06	8.02	414.4	1670.03	4.03	101.4113	4795.86	4791.9
858.1	Jul-95	4799.92	434.66	5.13	9.02	438.29	2229.8	5.09	84.72904	4794.79	4790.9
858.1	Aug-98	4799.92	421.74	3.82	4.62	424.83	1612.71	3.8	110.4031	4796.1	4795.3

Table E-2. Cross section geometry for cross section CO-668 to CO-926 (cont'd).

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation	Thalweg Elevation ft
877	May-62	4792.9	688.59	2.3	3	692.56	1586.1	2.29	299.387	4790.6	4789.9
877	May-72	4792.9	353.75	1.99	2.7	359.11	702.21	1.96	177.7638	4790.91	4790.2
877	Oct-82	4792.9	338.39	2.45	4.4	340.08	828.8	2.44	138.1184	4790.45	4788.5
877	Jul-92	4792.9	442.94	2.5	6.4	448.46	1105.95	2.47	177.176	4790.4	4786.5
877	Jul-95	4792.9	474.59	3.06	6.5	479.44	1452.07	3.03	155.0948	4789.84	4786.4
877	Aug-98	4792.9	414.62	3.13	5.2	417.07	1296.223	3.11	132.4665	4789.77	4787.7
895	May-62	4785.2	712.02	1.27	2.3	714.72	901.05	1.26	560.6457	4783.93	4782.9
895	May-72	4785.2	437	1.18	1.4	439.77	516.7	1.17	370.339	4784.02	4783.8
895	Oct-82	4785.2	485.43	1.2	3.4	487.35	580.88	1.19	404.525	4784	4781.8
895	Jul-92	4785.2	519.9	1.97	4.6	524.56	1026.6	1.96	263.9086	4783.23	4780.6
895	Jul-95	4785.2	526.75	1.95	3.6	528.43	1028.5	1.95	270.1282	4783.25	4781.6
895	Aug-98	4785.2	528.34	1.53	4.8	531.07	807.08	1.52	345.3203	4783.67	4780.4
926	May-62	4774.25	453.15	2.06	5.35	460.31	933.45	2.03	219.9757	4772.19	4768.9
926	May-72	4774.25	599.31	1.02	2.85	606.38	609.59	1.01	587.5588	4773.23	4771.4
926	Oct-82	4774.25	544.89	1.63	3.01	547.48	886.51	1.62	334.2883	4772.62	4771.24
926	Jul-92	4774.25	402.75	2.24	7.15	409.59	901.49	2.2	179.7991	4772.01	4767.1
926	Jul-95	4774.25	609.16	2.36	8.65	623.07	1440.21	2.31	258.1186	4771.89	4765.6
926	Aug-98	4774.25	480.65	2.35	5.45	486.36	1128.45	2.32	204.5319	4771.9	4768.8

Table E-3. Cross section geometry for cross section CO2-945 to CO2-1194.

- W = Cross section top width.
- P = Wetted perimeter.
- A = Cross section area.
- R = Hydraulic radius.
- w/d = Width to depth ratio.

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevatio	Thalweg Elevatio n ft
945	May-62	4768.25	519.08	1.9	3.45	521.56	984.31	1.89	273.2	4766.35	4764.8
945	May-72	4768.25	444.5	1.73	2.75	446.32	769.86	1.72	256.9364	4766.52	4765.5
945	Aug-92	4768.25	357.07	3.81	8.25	360.07	1362.17	3.78	93.71916	4764.44	4760
945	Jul-95	4768.25	353.34	4.06	12.45	360.1	1436.23	3.99	87.02956	4764.19	4755.8
945	Sep-98	4768.25	361.1	3.91	5.55	365.36	1411.84	3.86	92.35294	4764.34	4762.7
966	May-62	4761.79	416.7	2.59	3.19	418.97	1081.04	2.58	160.888	4759.2	4758.6
966	May-72	4761.79	540.73	3.21	3.49	542.9	1736.51	3.2	168.4517	4758.58	4758.3
966	Aug-92	4761.79	554.61	4.4	6.79	561.37	2440.78	4.35	126.0477	4757.39	4755
966	Jul-95	4761.79	558.39	3.07	9.09	564.81	1713.3	3.03	181.886	4758.72	4752.7
966	Sep-98	4761.79	555.98	3.83	6.49	561.98	2129.25	3.79	145.1645	4757.96	4755.3
986	May-62	4753.31	489.75	3.03	4.11	495.82	1482.17	2.99	161.6337	4750.28	4749.2
986	May-72	4753.31	162.79	3.18	3.71	166.8	518	3.11	51.19182	4750.13	4749.6
986	Aug-92	4753.31	389.31	3.98	5.41	393.54	1550.85	3.94	97.81658	4749.33	4747.9
986	Jul-95	4753.31	392.77	4.89	10.21	400.11	1920.03	4.8	80.32106	4748.42	4743.1
986	Sep-98	4753.31	418.41	4.41	6.41	425.84	1731.18	4.07	94.87755	4748.9	4746.9
1006	May-62	4746.14	431.2	2.18	2.74	434.01	940.48	2.17	197.7982	4743.96	4743.4
1006	May-72	4746.14	568.64	2.24	2.84	5.71	1275.8	2.23	253.8571	4743.9	4743.3
1006	Aug-92	4746.14	578.9	3.92	5.94	584.17	2268.86	3.88	147.6786	4742.22	4740.2
1006	Jul-95	4746.14	577.59	3.59	9.04	580.87	2076.35	3.57	160.8886	4742.55	4737.1
1006	Sep-98	4746.14	580.65	3.91	5.84	584.81	2268.46	3.88	148.5038	4742.23	4740.3
1026	May-62	4738.95	192.14	1.04	1.95	194.3	199.59	1.03	184.75	4737.91	4737
1026	May-72	4738.95	536.85	0.92	2.05	538.08	491.75	0.91	583.5326	4738.03	4736.9
1026	Aug-92	4738.95	448.35	4.43	7.05	452.87	1985.06	4.38	101.2077	4734.52	4731.9
1026	Jul-95	4738.95	454.37	4.66	8.75	459.61	2119.56	4.61	97.50429	4734.29	4730.2
1026	Sep-98	4738.95	452.95	4.67	6.55	457.72	2115.88	4.62	96.99143	4734.28	4732.4

Table E-3. Cross section geometry for cross section CO2-945 to CO2-1194 (cont'd).

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation	Thalweg Elevation ft
1044	May-62	4732.5	814.66	2.66	4.65	816.93	2167.76	2.65	306.2632	4729.84	4727.85
1044	May-72	4732.5	638.58	1.54	2.85	639.84	983.22	1.54	414.6623	4730.96	4729.65
1044	Aug-92	4732.5	670.48	3.73	8.15	676.2	2500.65	3.7	179.7534	4728.77	4724.35
1044	Jul-95	4732.5	685.14	4.75	10.65	691.47	3255.61	3.71	144.24	4727.75	4721.85
1044	Sep-98	4732.5	689.02	4.86	7.95	698.04	3346.27	4.79	141.7737	4727.64	4724.55
1064	May-62	4726.68	681.92	3.27	7.58	685.31	2232.51	3.26	208.5382	4723.41	4719.1
1064	May-72	4726.68	681.14	3.5	5.98	685.74	2386.22	3.48	194.6114	4723.18	4720.7
1064	Aug-92	4726.68	762	6.42	8.38	771.78	4891.27	6.34	118.6916	4720.26	4718.3
1064	Jul-95	4726.68	778.45	6.01	12.68	785.29	4678.2	5.96	129.5258	4720.67	4714
1064	Sep-98	4726.68	777.76	6.03	7.88	784.52	4688.23	5.98	128.9818	4720.65	4718.8
1091	May-62	4713.43	433.06	0.03	0.03	433.08	12.69	0.03	14435.33	4713.4	4713.4
1091	May-72	4713.43	89.26	0.22	0.23	89.43	19.88	0.22	405.7273	4713.21	4713.2
1091	Aug-92	4713.43	506.56	4.04	7.84	513.85	2044.43	3.98	125.3861	4709.39	4705.59
1091	Jul-95	4713.43	512.28	4.39	10.53	519.83	2247.72	4.32	116.6925	4709.04	4702.9
1091	Sep-98	4713.43	510.38	4.33	7.43	513.97	2210.87	4.3	117.8707	4709.1	4706
1104	May-62	4710.74	497.46	2.19	2.44	498.82	1090.05	2.19	227.1507	4708.55	4708.3
1104	May-72	4710.74	617.76	0.85	1.04	618.82	525.89	0.85	726.7765	4709.89	4709.7
1104	Aug-92	4710.74	268.24	6.6	9.94	274.37	1770.44	6.45	40.64242	4704.14	4700.8
1104	Jul-95	4710.74	267.03	7.57	11.84	272.61	2020.9	7.41	35.27477	4703.17	4698.9
1104	Sep-98	4710.74	266.54	6.73	12.14	271.33	1792.59	6.61	39.60475	4704.01	4698.6
1164	May-62	4687.37	521.19	2.78	3.67	252.53	1447.72	2.75	187.4784	4684.59	4683.7
1164	May-72	4687.37	444.06	1.54	2.47	448.28	684.8	1.53	288.3506	4685.83	4684.9
1164	Aug-92	4687.37	170.19	5.21	7.37	174.12	887.13	5.1	32.66603	4682.16	4680
1164	Jul-95	4687.37	171.32	6.58	10.01	176.28	1127.8	6.4	26.03647	4680.79	4677.36
1164	Sep-98	4687.37	172.36	5.57	7.47	176.29	759.29	5.44	30.94434	4681.8	4679.9

Table E-3. Cross section geometry for cross section CO2-945 to CO2-1194 (cont'd).

Cross Section	Date	Water Surface Elevation	W ft	Mean Depth ft	Max Depth ft	P ft	A ft^2	R ft	w/d	Mean Bed Elevation	Thalweg Elevation ft
1179	May-62	4686.12	1075.7	4.66	6.92	1080.42	5014	4.64	230.8455	4681.46	4679.2
1179	May-72	4686.12	908.32	5.18	7.12	914.89	4707.98	5.15	175.3514	4680.94	4679
1179	Aug-92	4686.12	177.99	7.82	8.82	185.22	1392.75	7.52	22.76087	4678.3	4677.3
1179	Jul-95	4686.12	177.63	9.95	12.02	187.61	1766.97	9.42	17.85226	4676.17	4674.1
1179	Sep-98	4686.12	179.31	7.43	8.82	184.17	1332.83	7.24	24.13324	4678.69	4677.3
1194	May-62	4674.04	478.84	1.61	5.74	488.17	769.86	1.58	297.4161	4672.43	4668.3
1194	May-72	4674.04	1235.4	0.91	1.84	1237.24	1119.91	0.91	1357.571	4673.13	4672.2
1194	Aug-92	4674.04	501.57	3.31	5.94	507.29	1658.27	3.27	151.5317	4670.73	4668.1
1194	Jul-95	4674.04	602.29	2.96	8.04	606.06	1782.38	2.94	203.4764	4671.08	4666
1194	Sep-98	4674.04	651.44	2.22	4.04	655.35	1447.2	2.21	293.4414	4671.82	4670

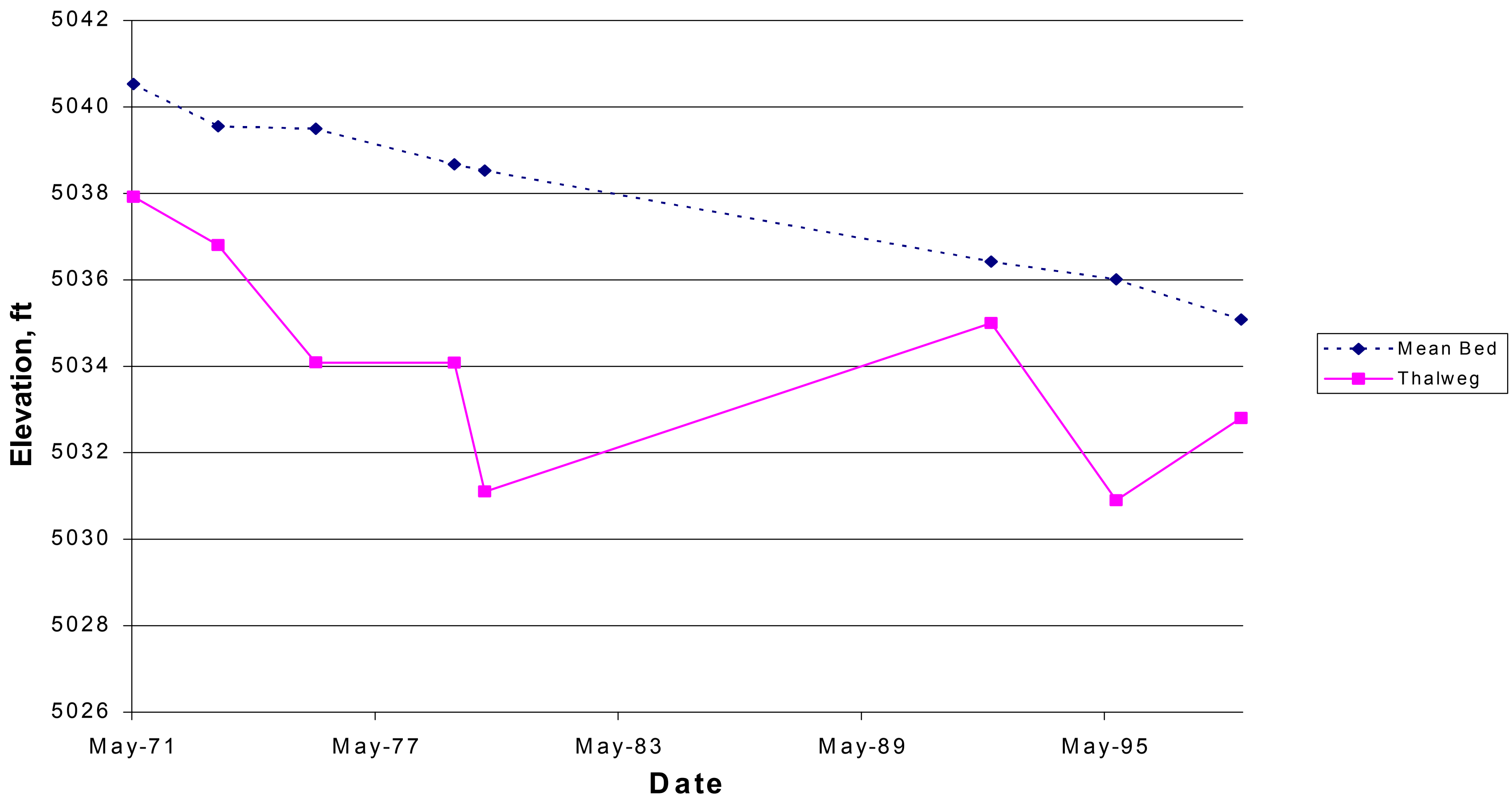

Figure E-1. Change in thalweg and mean bed elevation with time at cross section CO-31.

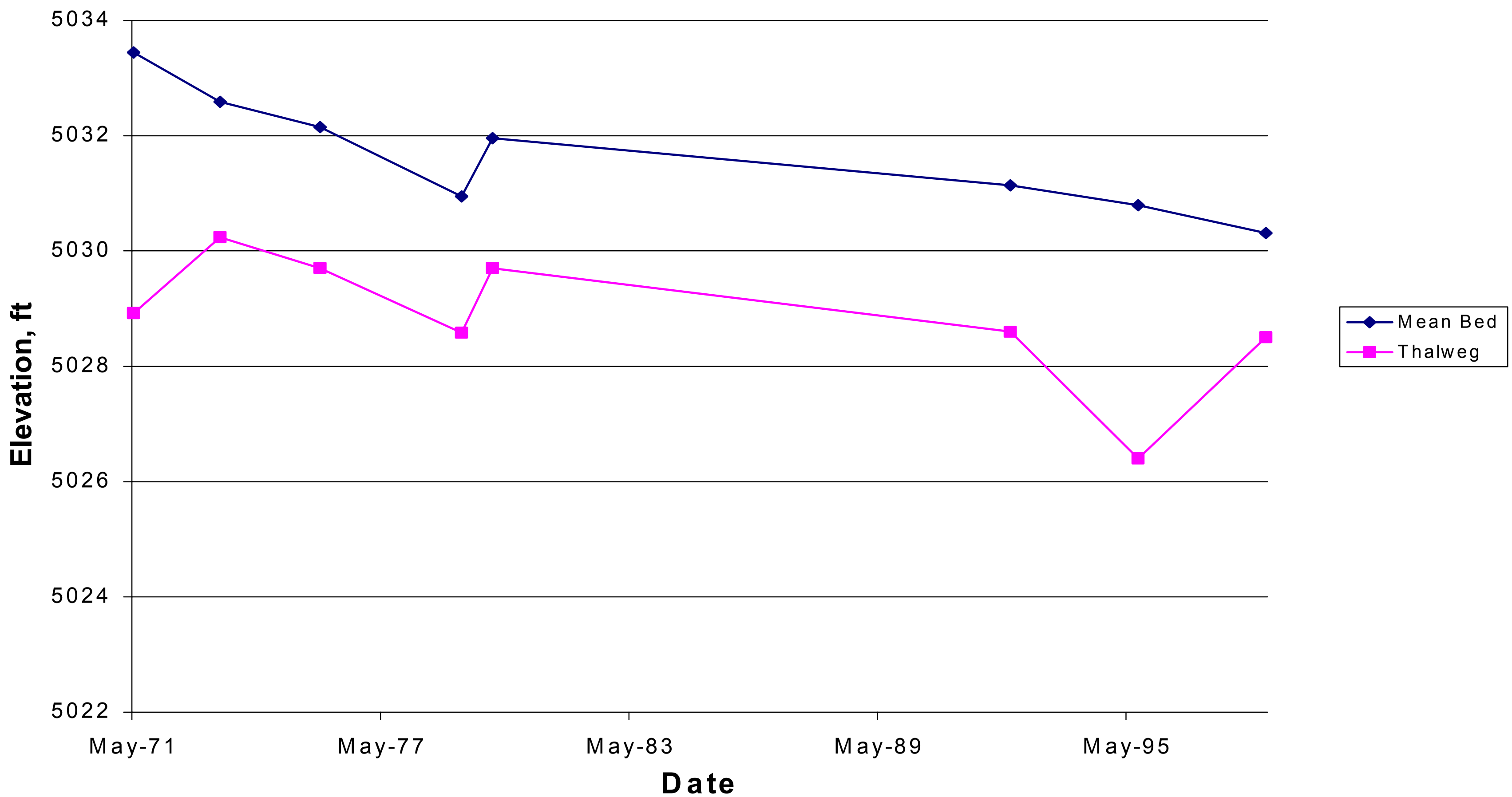

Figure E-2. Change in thalweg and mean bed elevation with time at cross section CO-32.

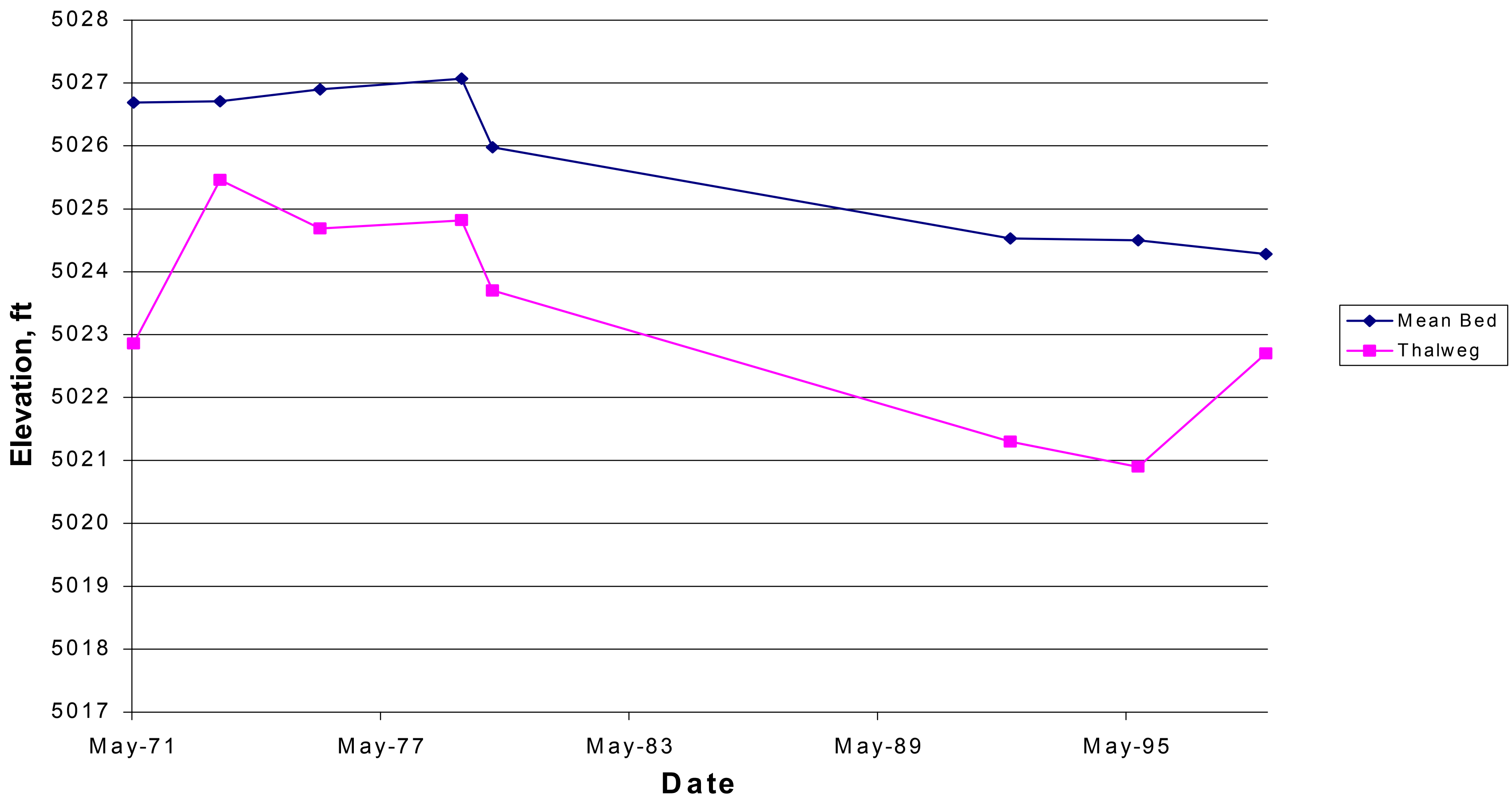

Figure E-3. Change in thalweg and mean bed elevation with time at cross section CO-33.

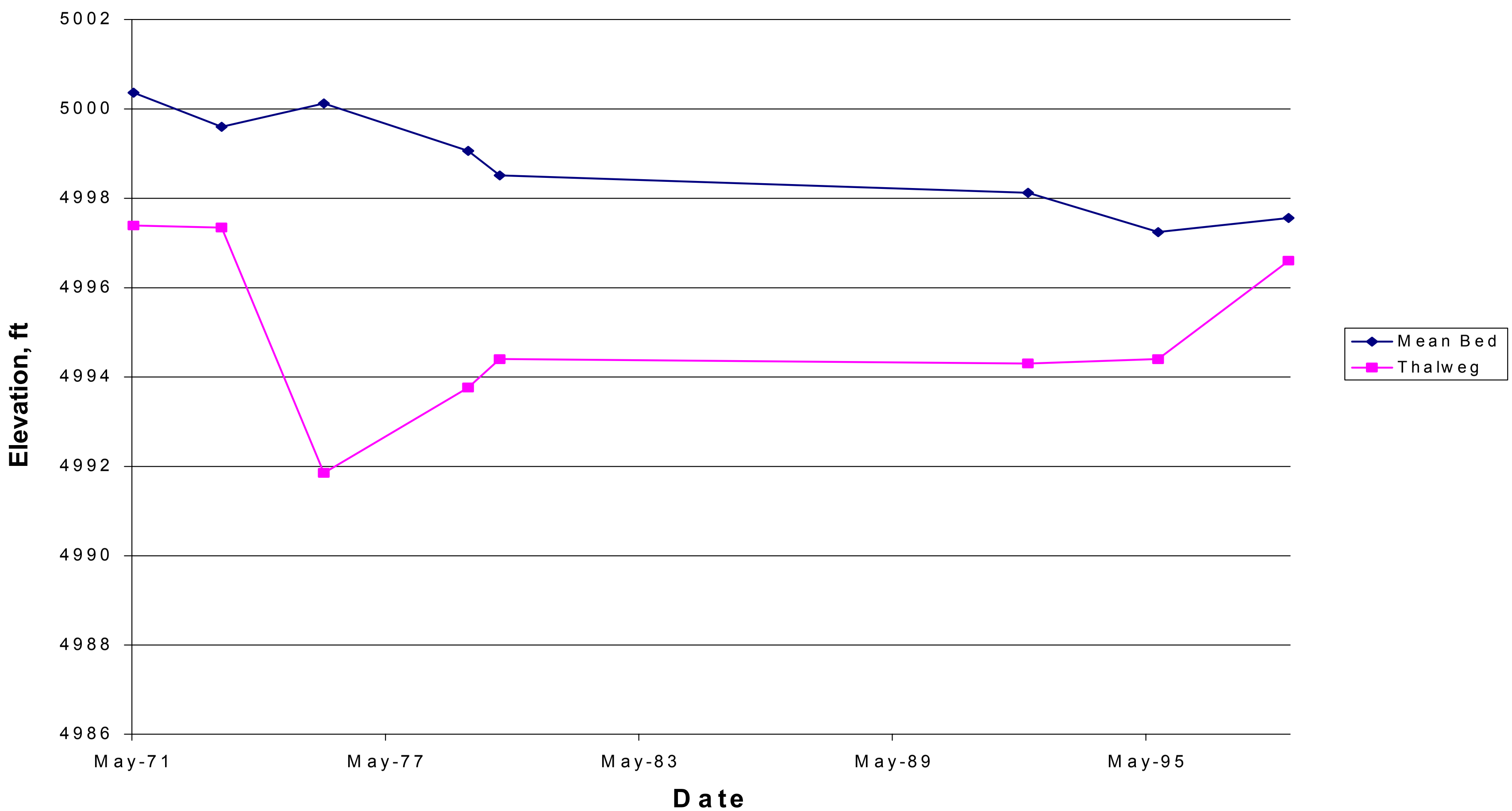

Figure E-4. Change in thalweg and mean bed elevation with time at cross section CO-34.

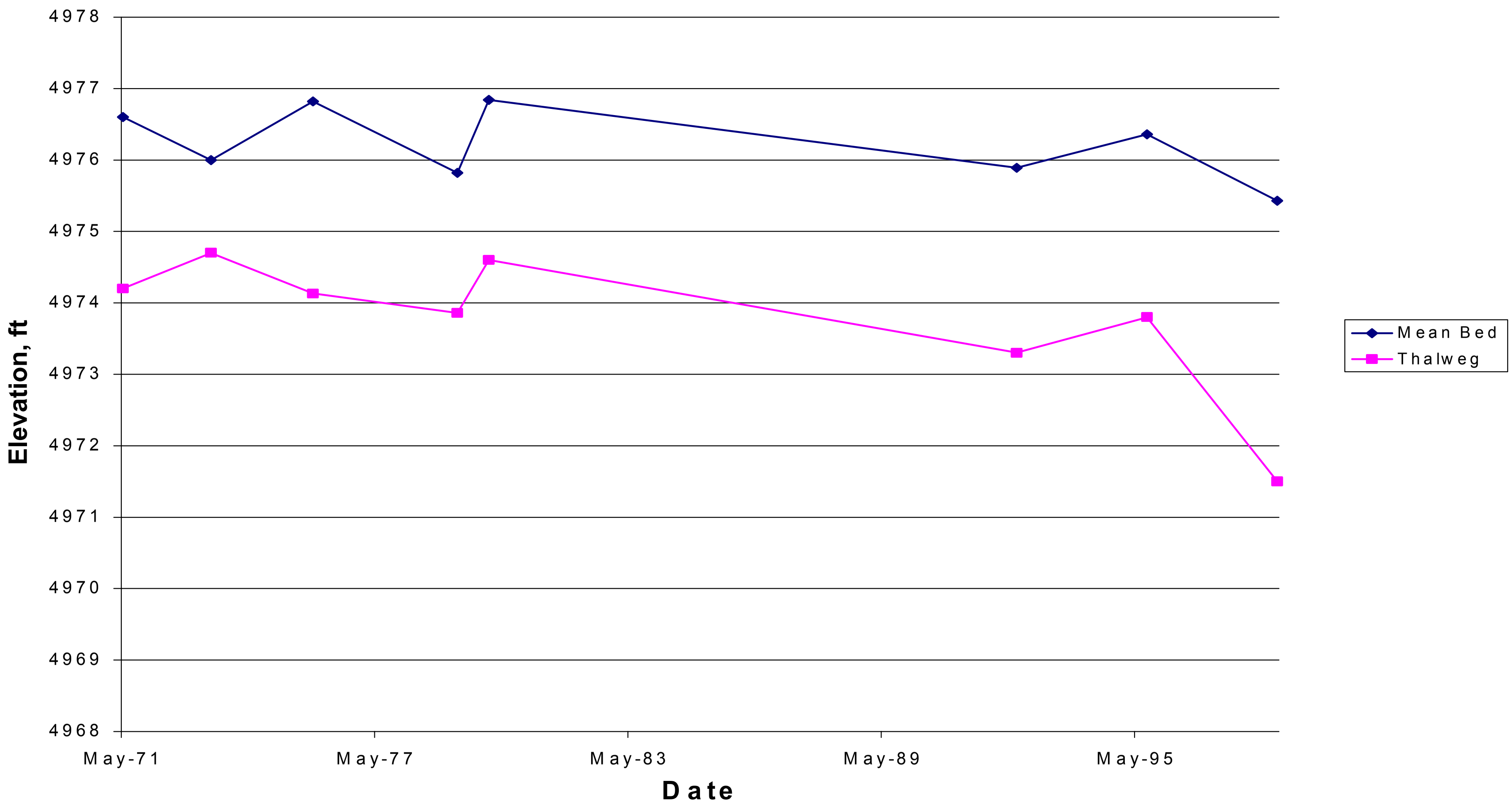

Figure E-5. Change in thalweg and mean bed elevation with time at cross section CO-35.

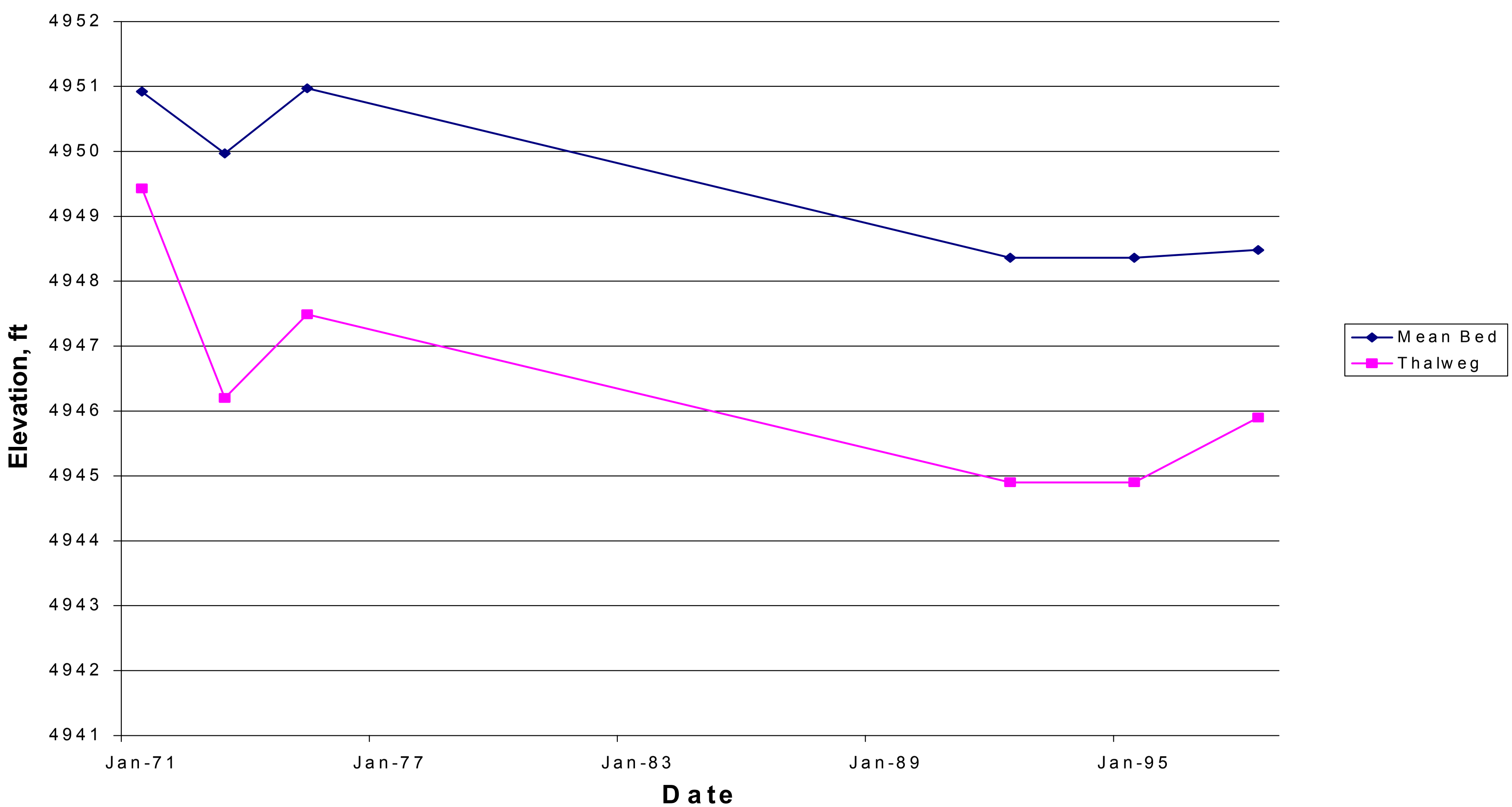

Figure E-6. Change in thalweg and mean bed elevation with time at cross section CO-36.

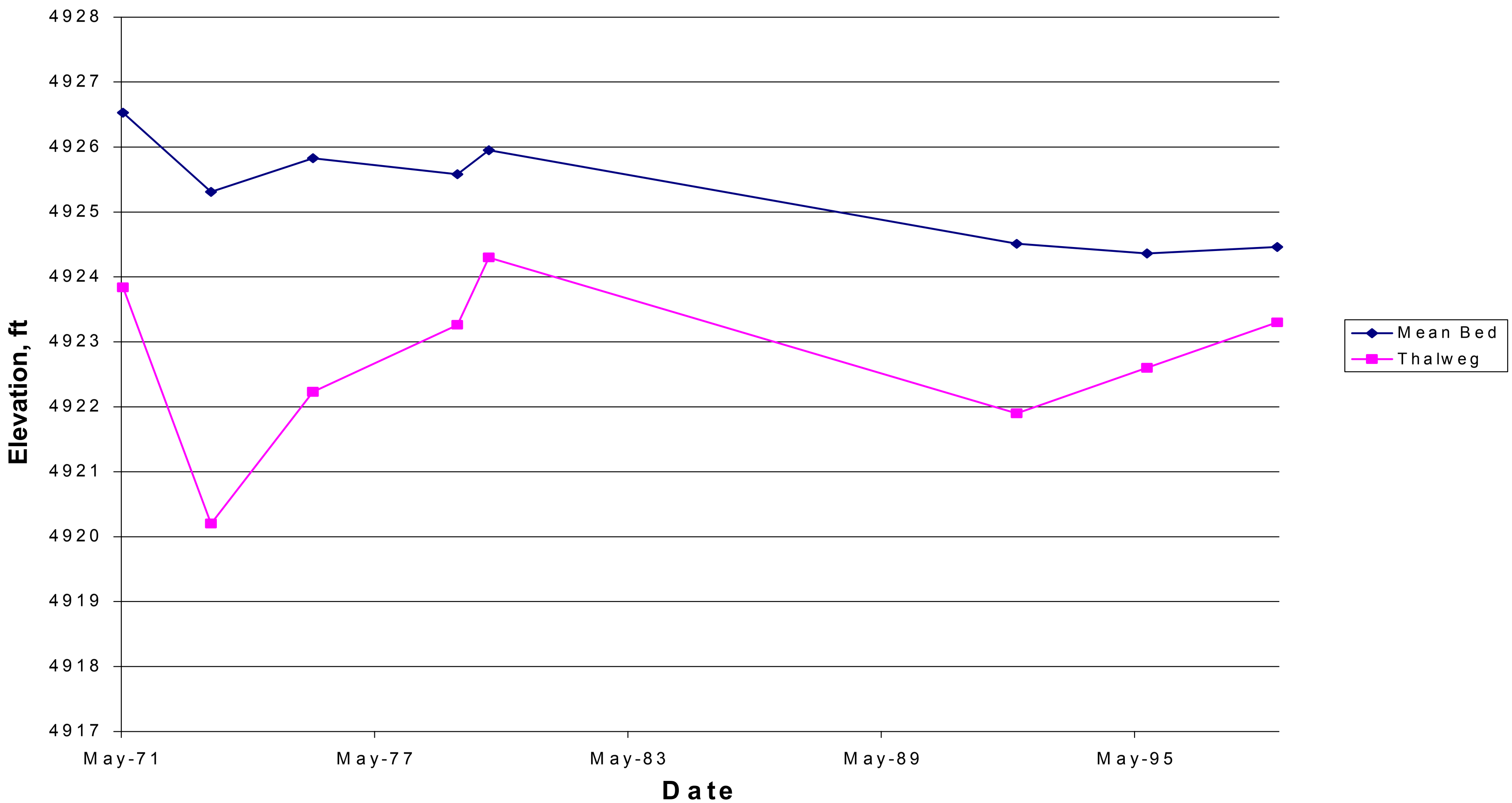

Figure E-7. Change in thalweg and mean bed elevation with time at cross section CO-37.

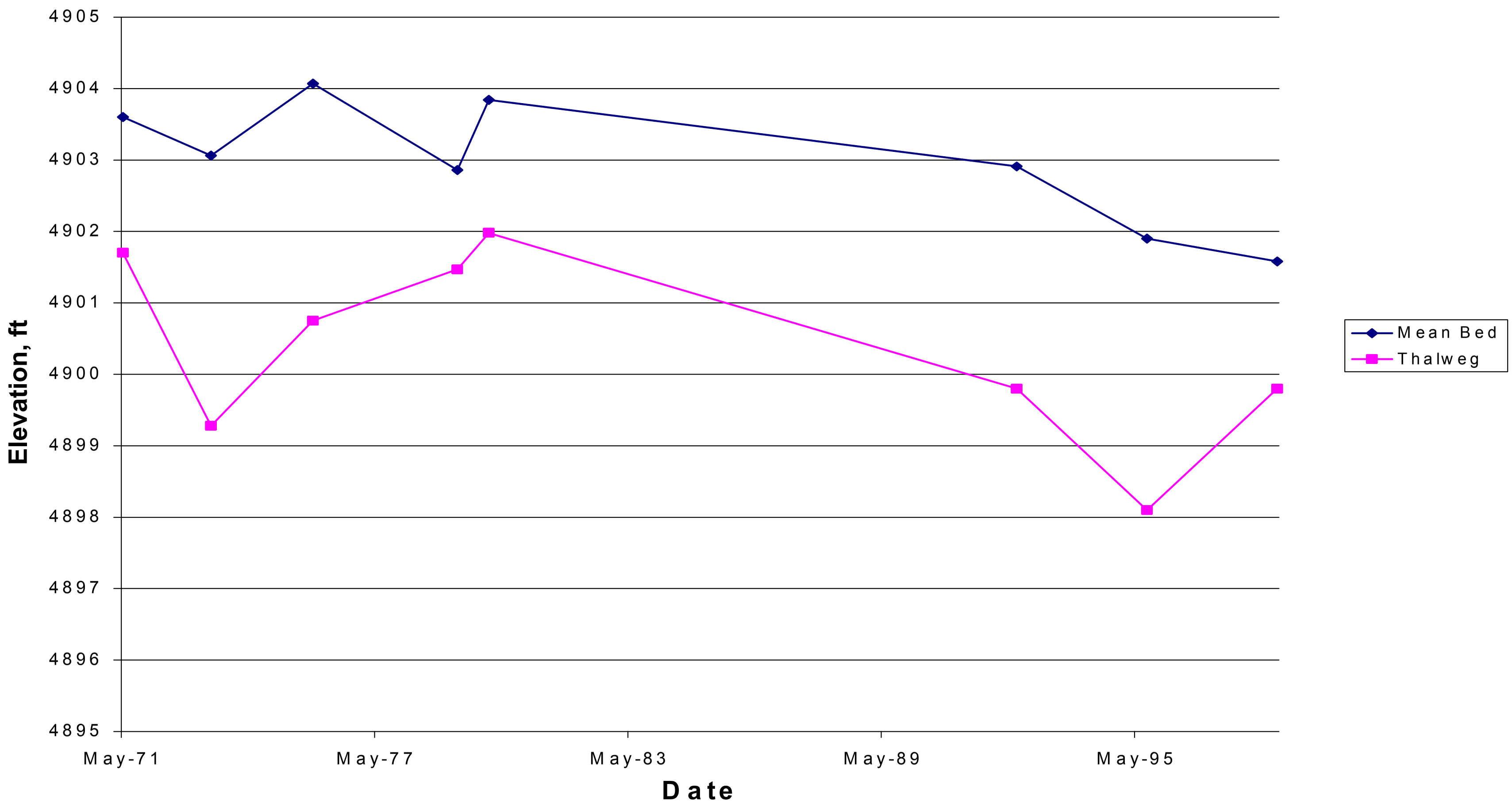

Figure E-8. Change in thalweg and mean bed elevation with time at cross section CO-38.

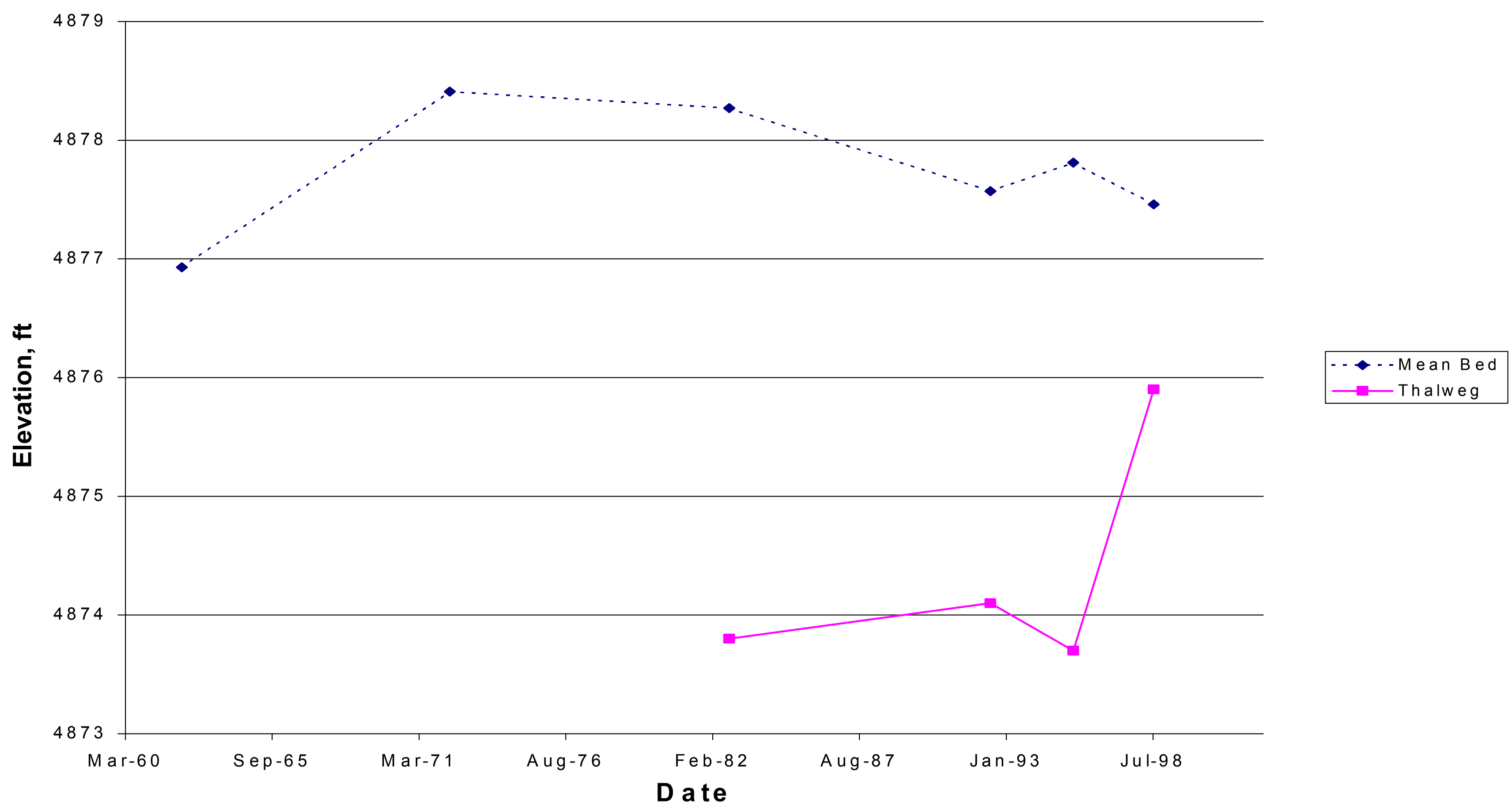

Figure E-9. Change in thalweg and mean bed elevation with time at cross section CO-668.

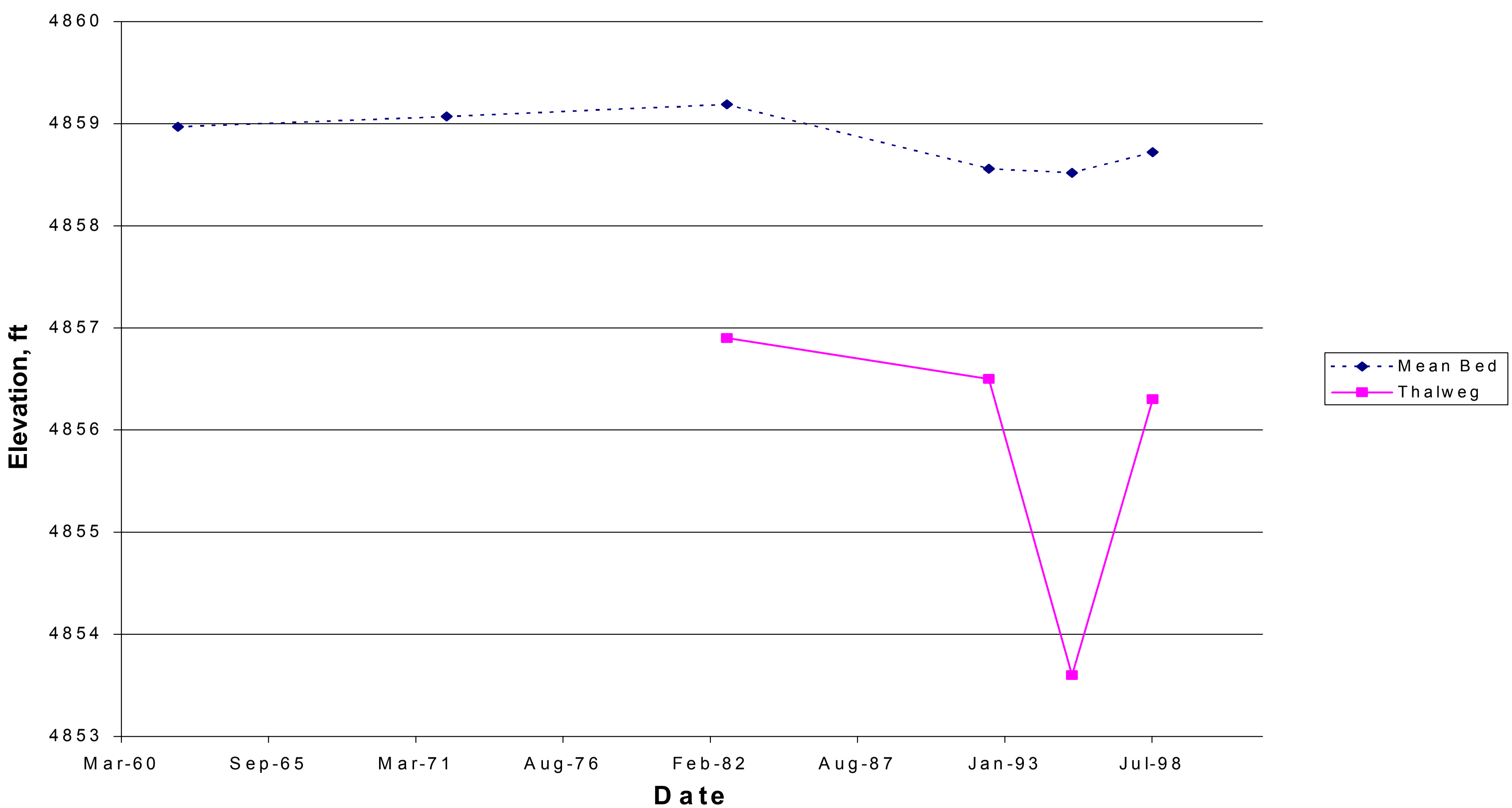

Figure E-10. Change in thalweg and mean bed elevation with time at cross section CO-713.

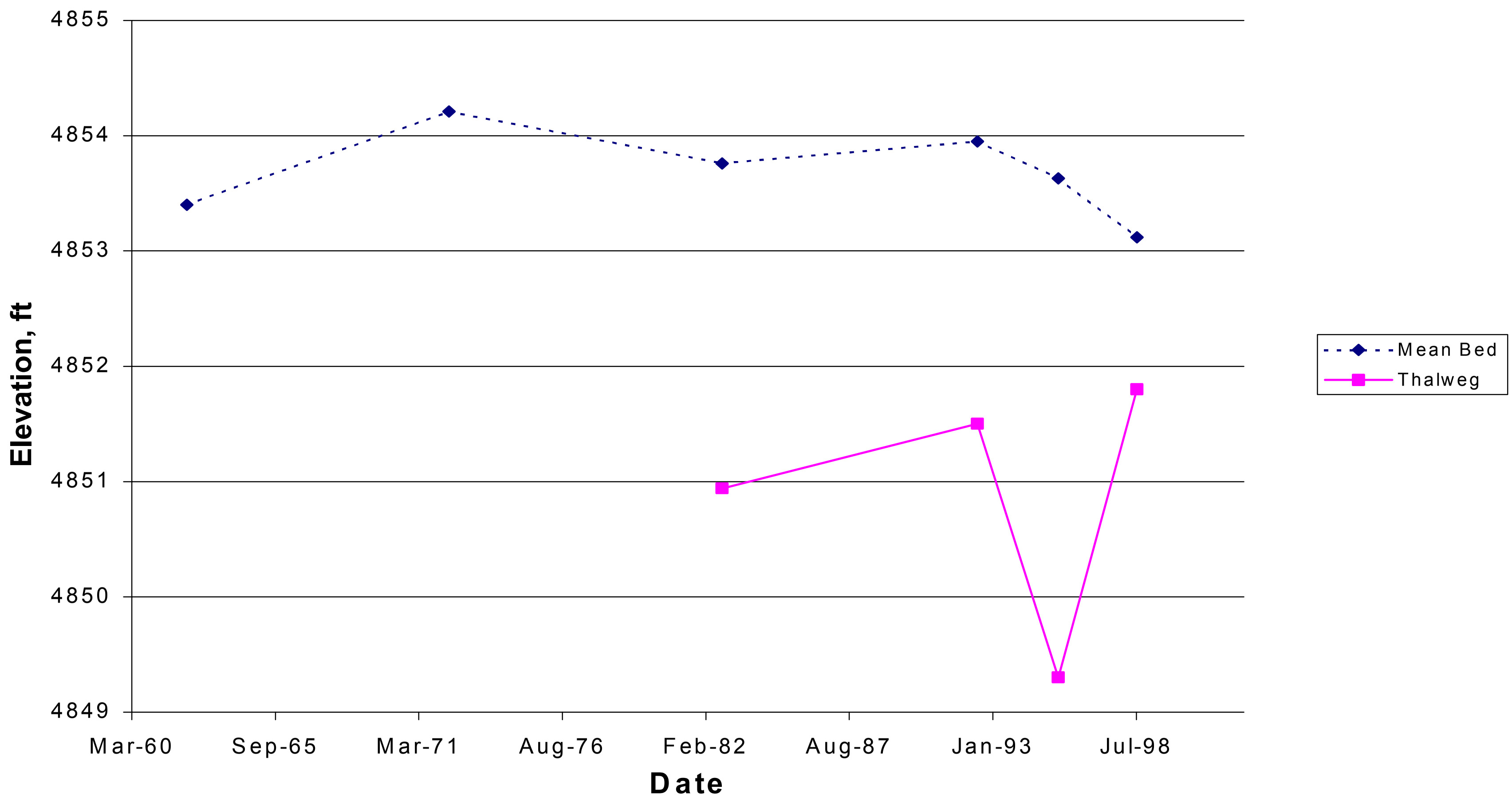

Figure E-11. Change in thalweg and mean bed elevation with time at cross section CO-724.

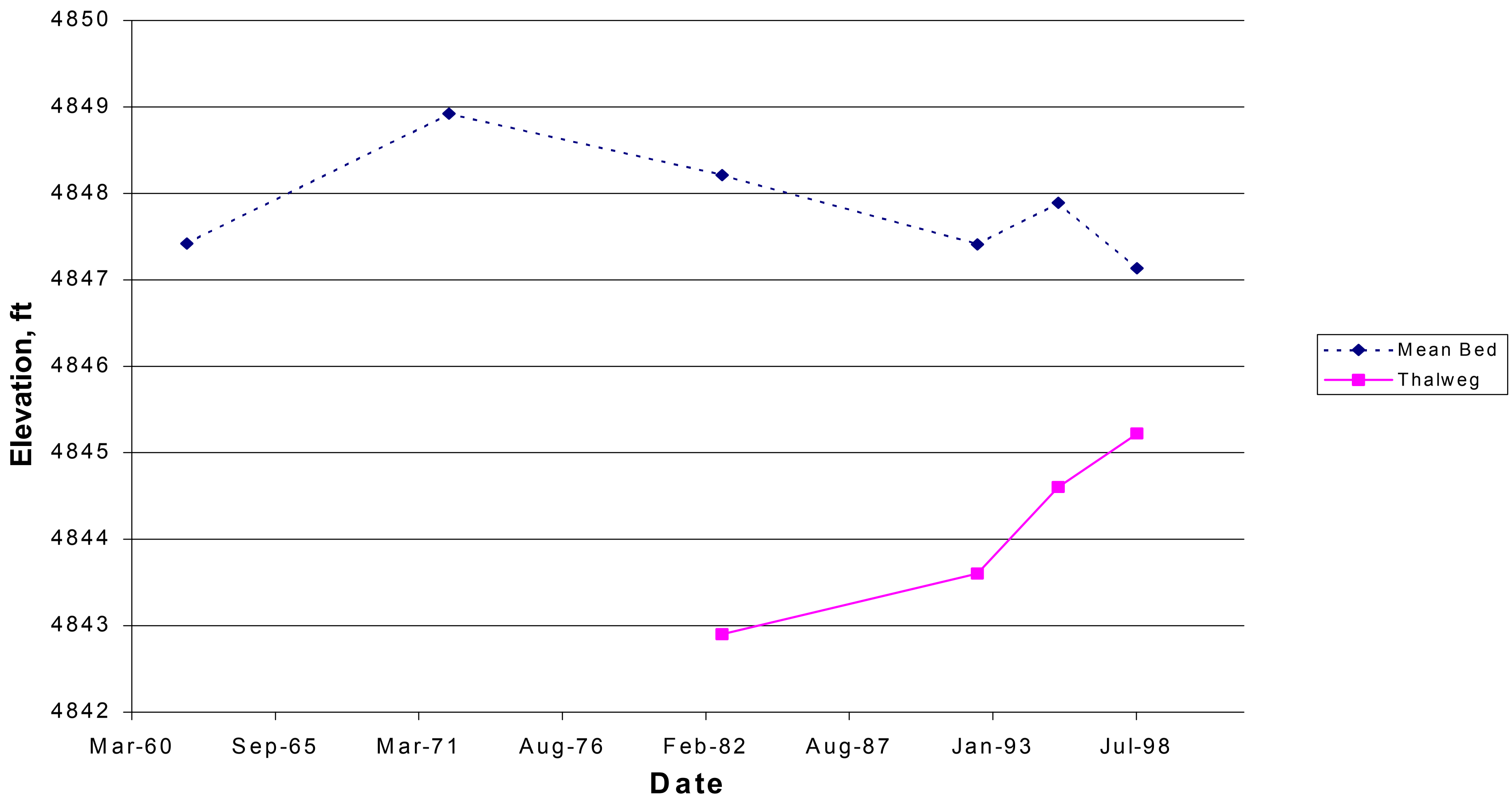

Figure E-12. Change in thalweg and mean bed elevation with time at cross section CO-738.1.

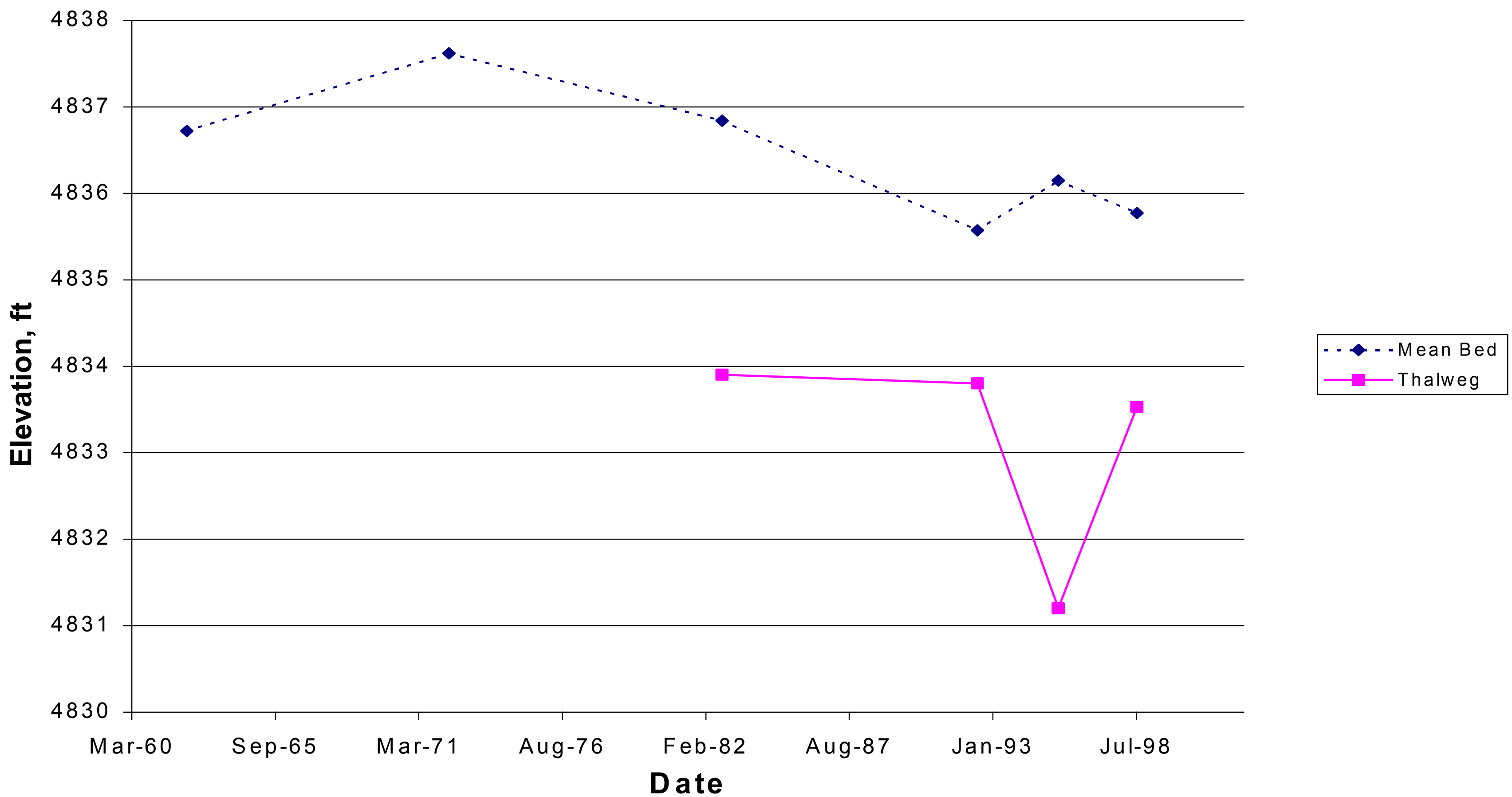

Figure E-13. Change in thalweg and mean bed elevation with time at cross section CO-765.

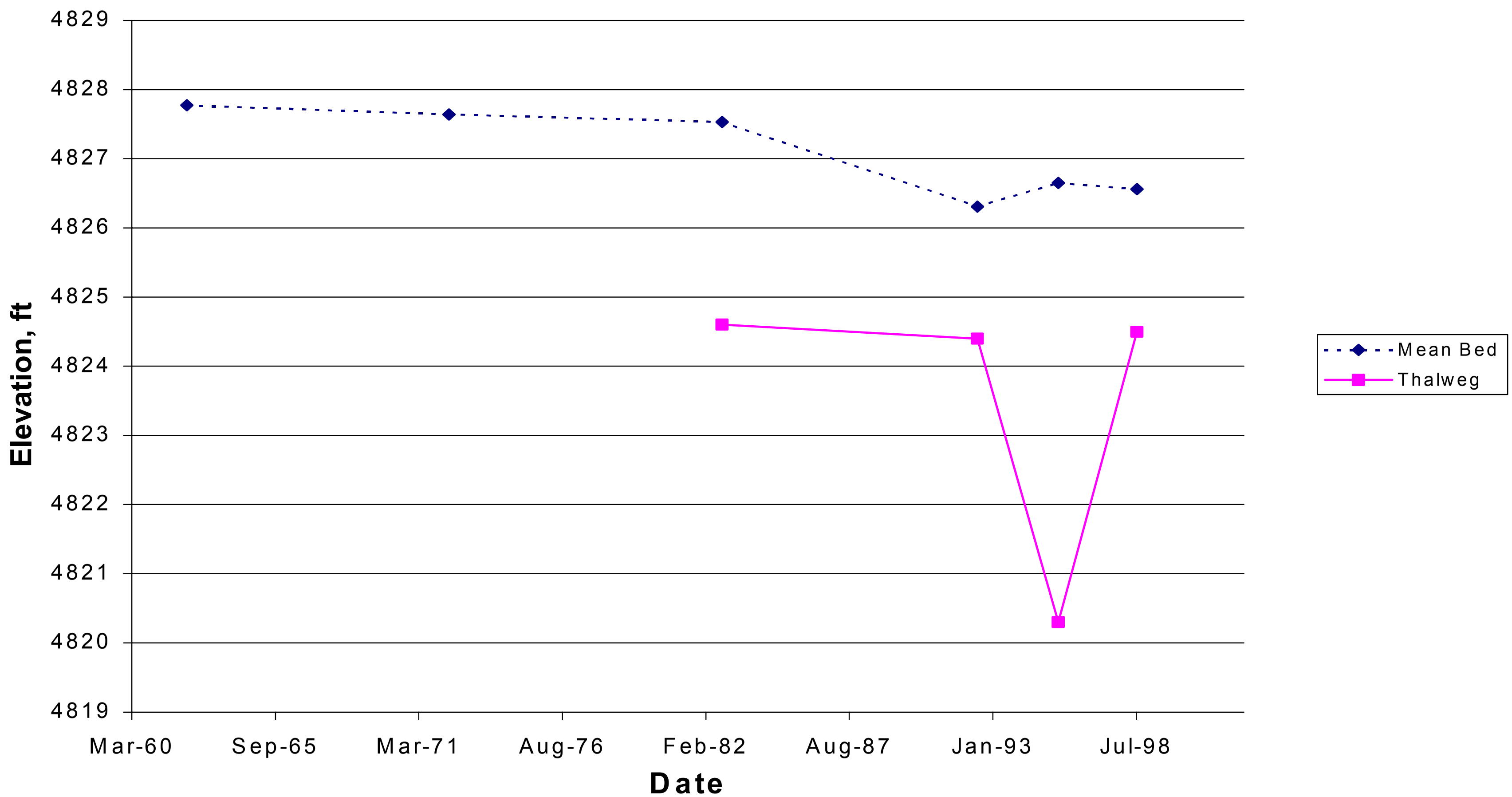

Figure E-14. Change in thalweg and mean bed elevation with time at cross section CO-787.

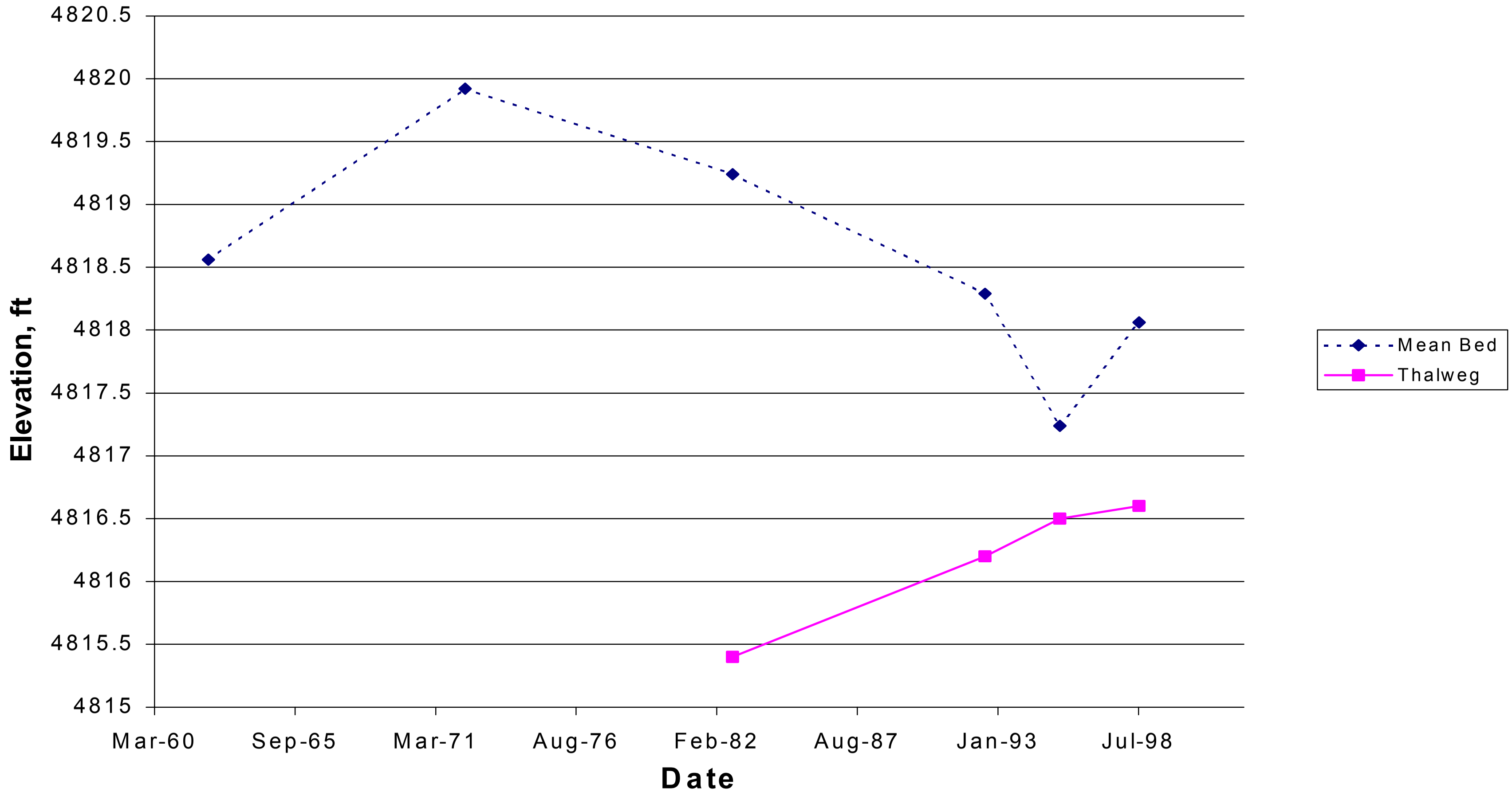

Figure E-15. Change in thalweg and mean bed elevation with time at cross section CO-806.

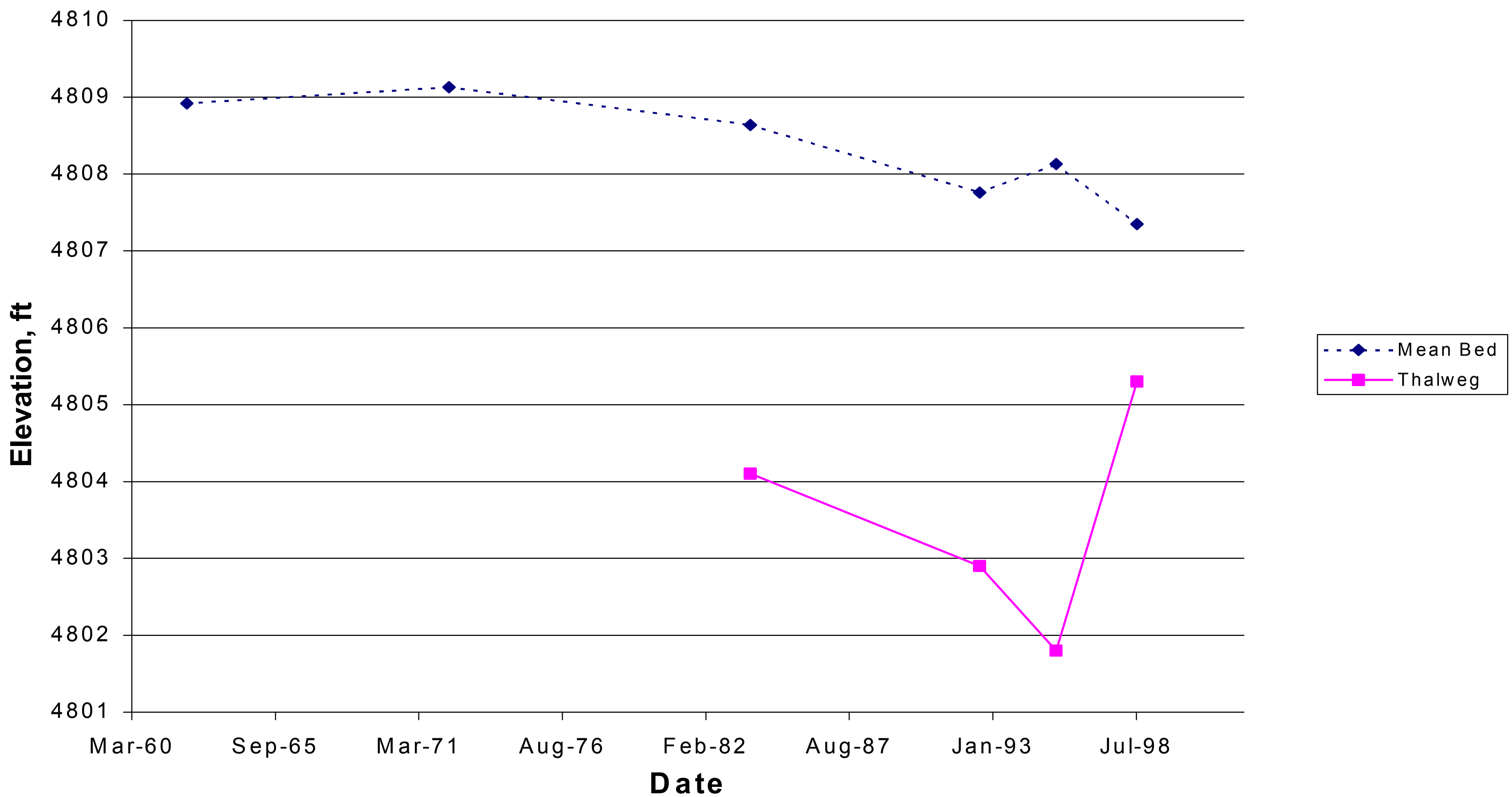

Figure E-16. Change in thalweg and mean bed elevation with time at cross section CO-833.

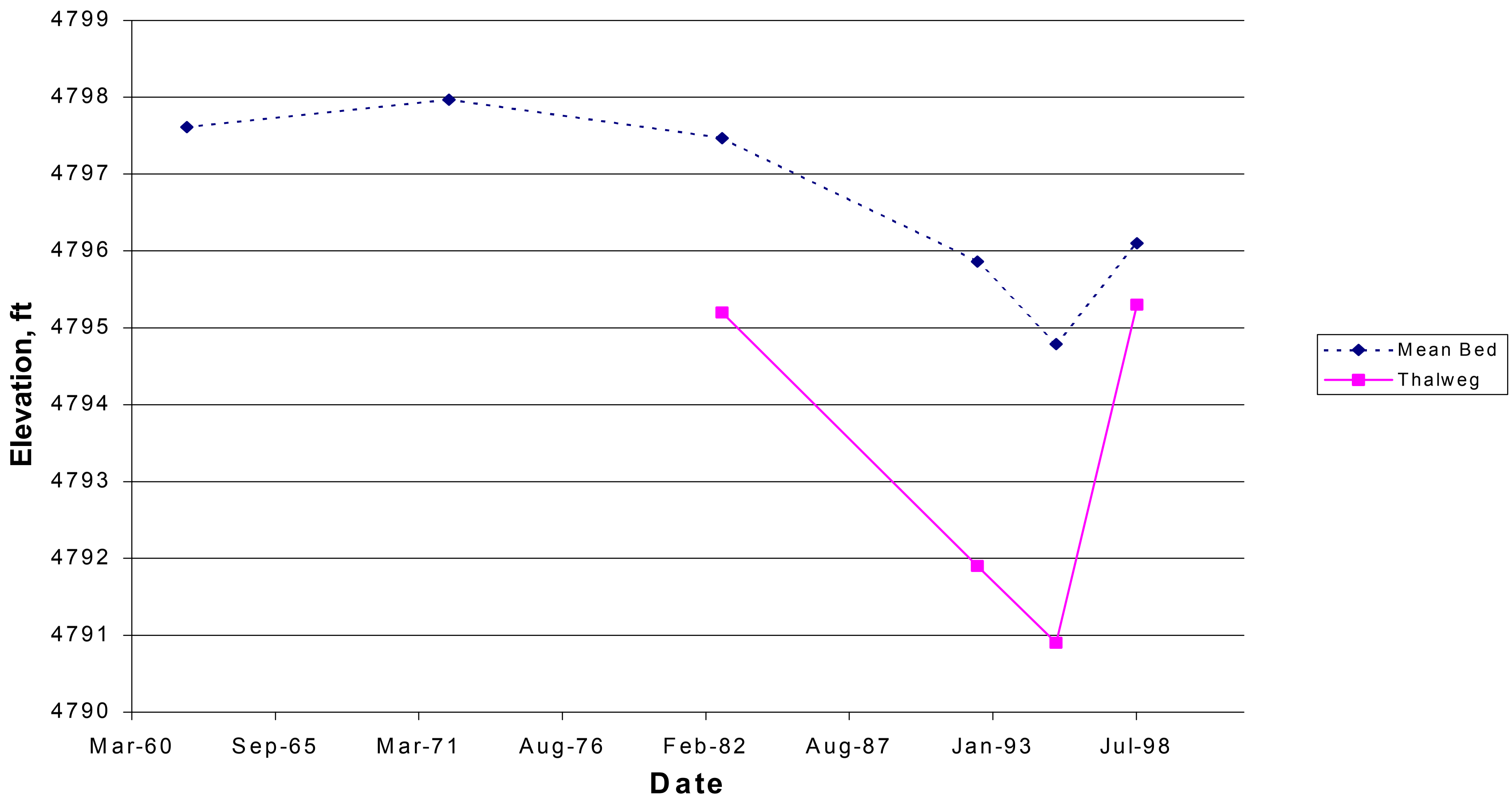

Figure E-17. Change in thalweg and mean bed elevation with time at cross section CO-858.1.

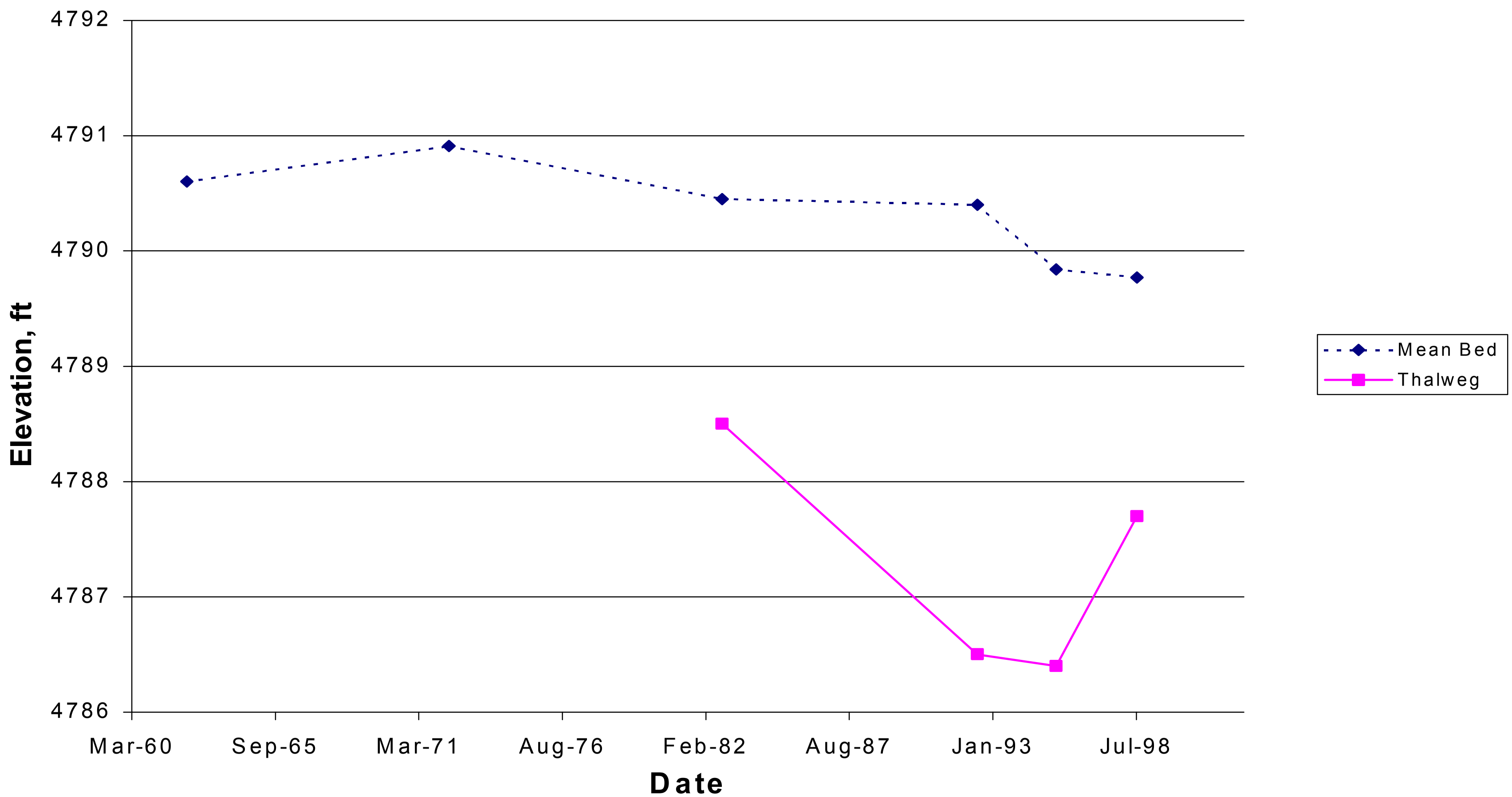

Figure E-18. Change in thalweg and mean bed elevation with time at cross section CO-877.

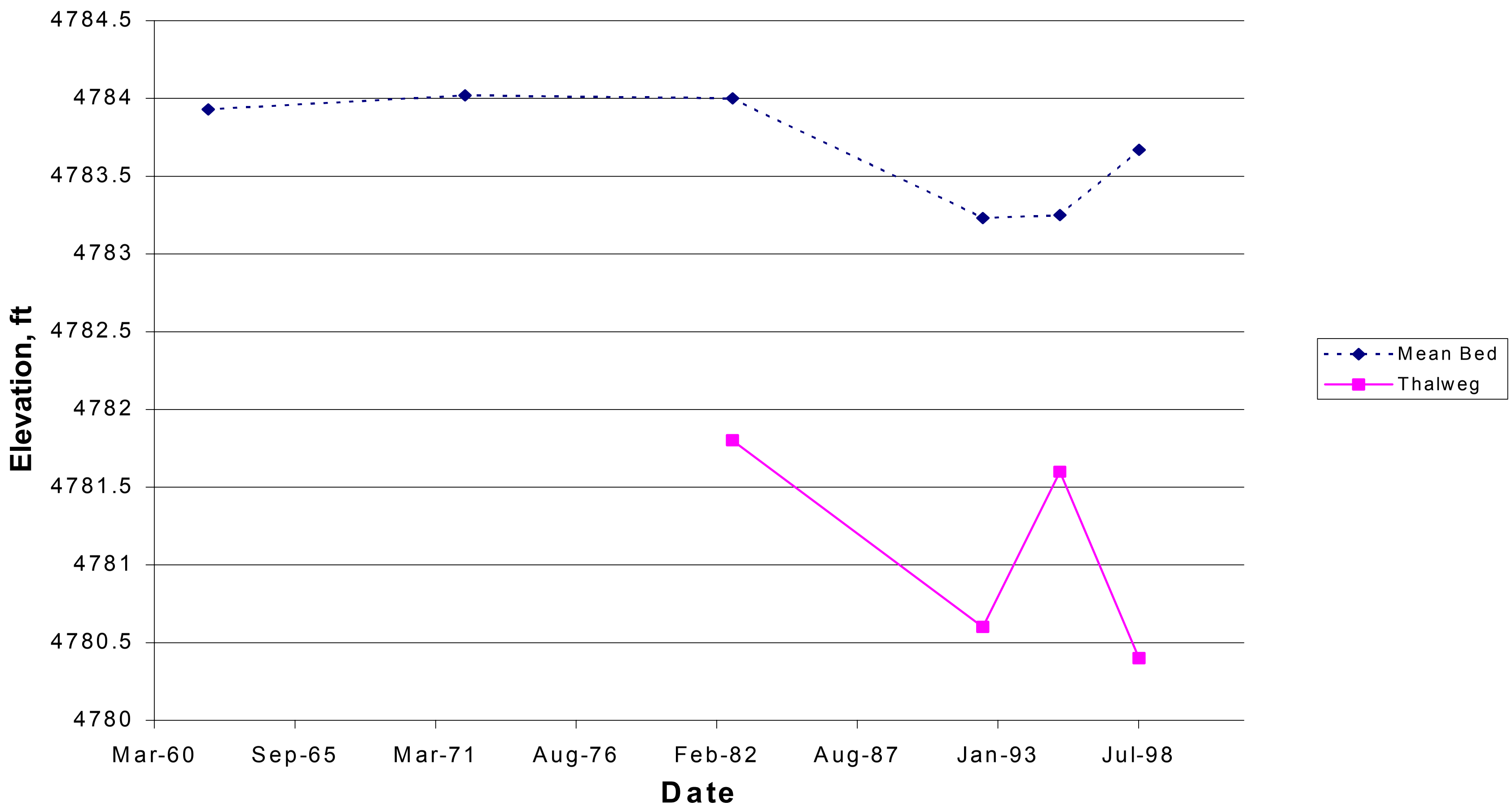

Figure E-19. Change in thalweg and mean bed elevation with time at cross section CO-895.

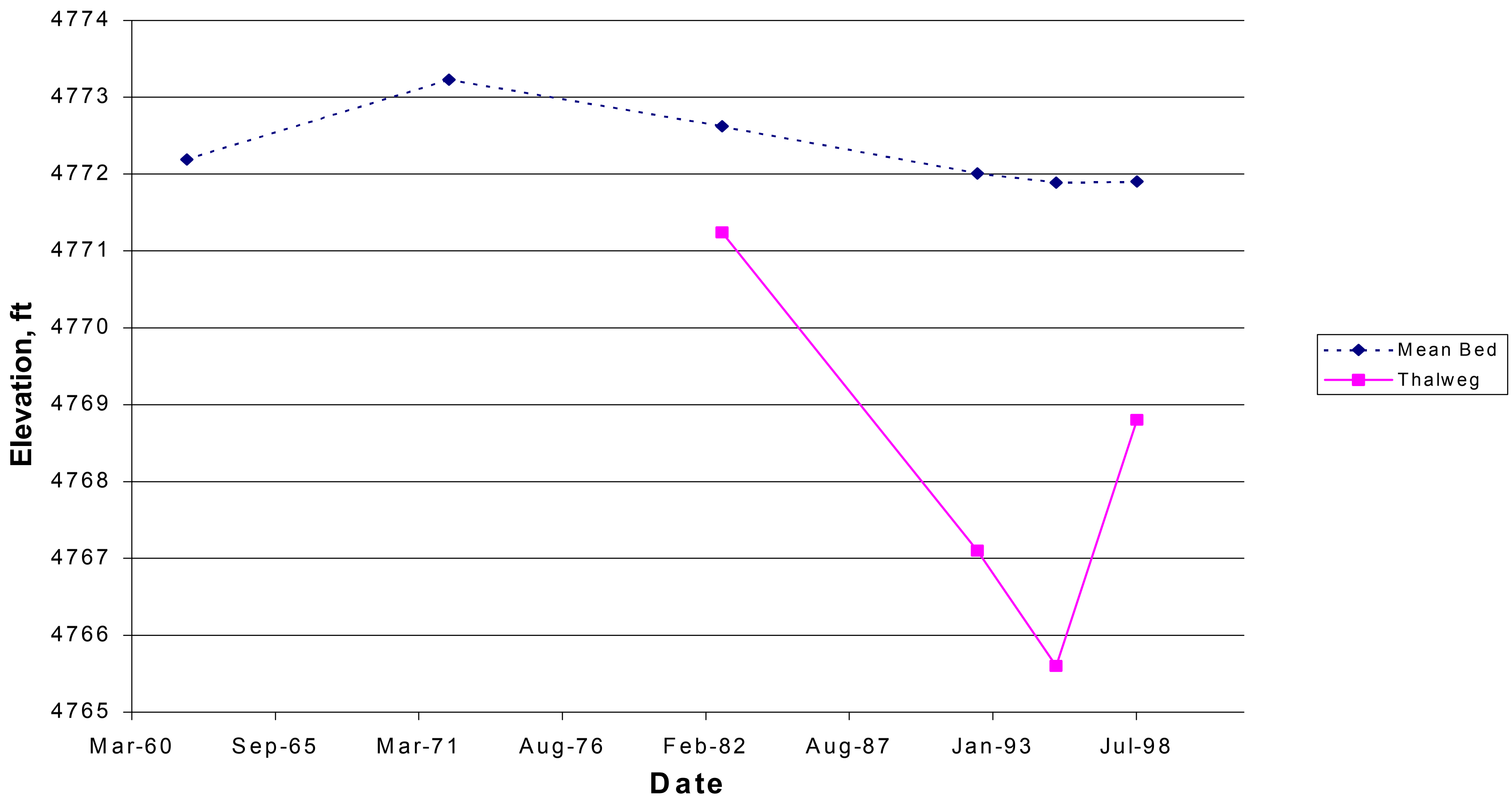

Figure E-20. Change in thalweg and mean bed elevation with time at cross section CO-926.

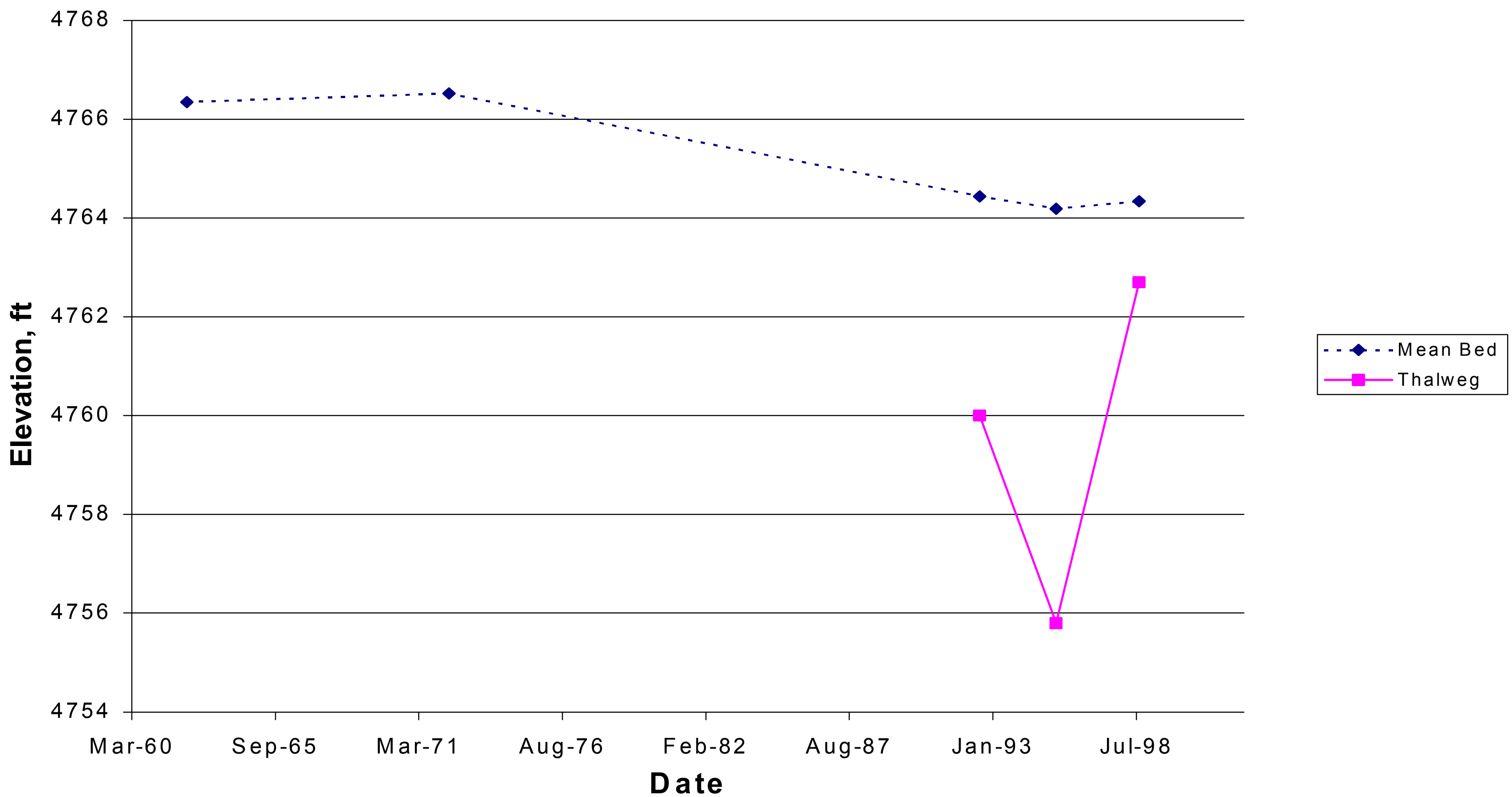

Figure E-21. Change in thalweg and mean bed elevation with time at cross section CO2-945.

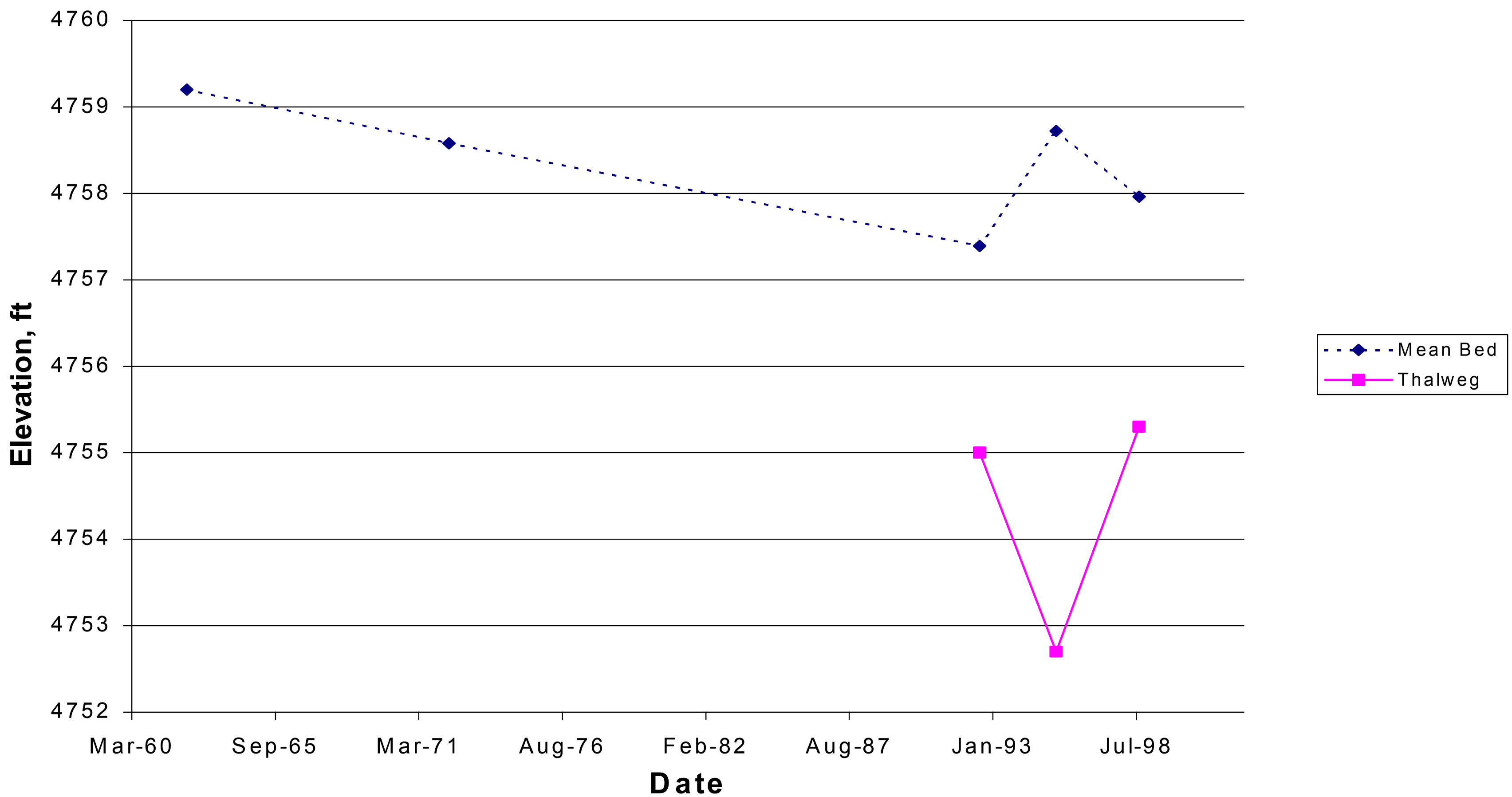

Figure E-22. Change in thalweg and mean bed elevation with time at cross section CO2-966.

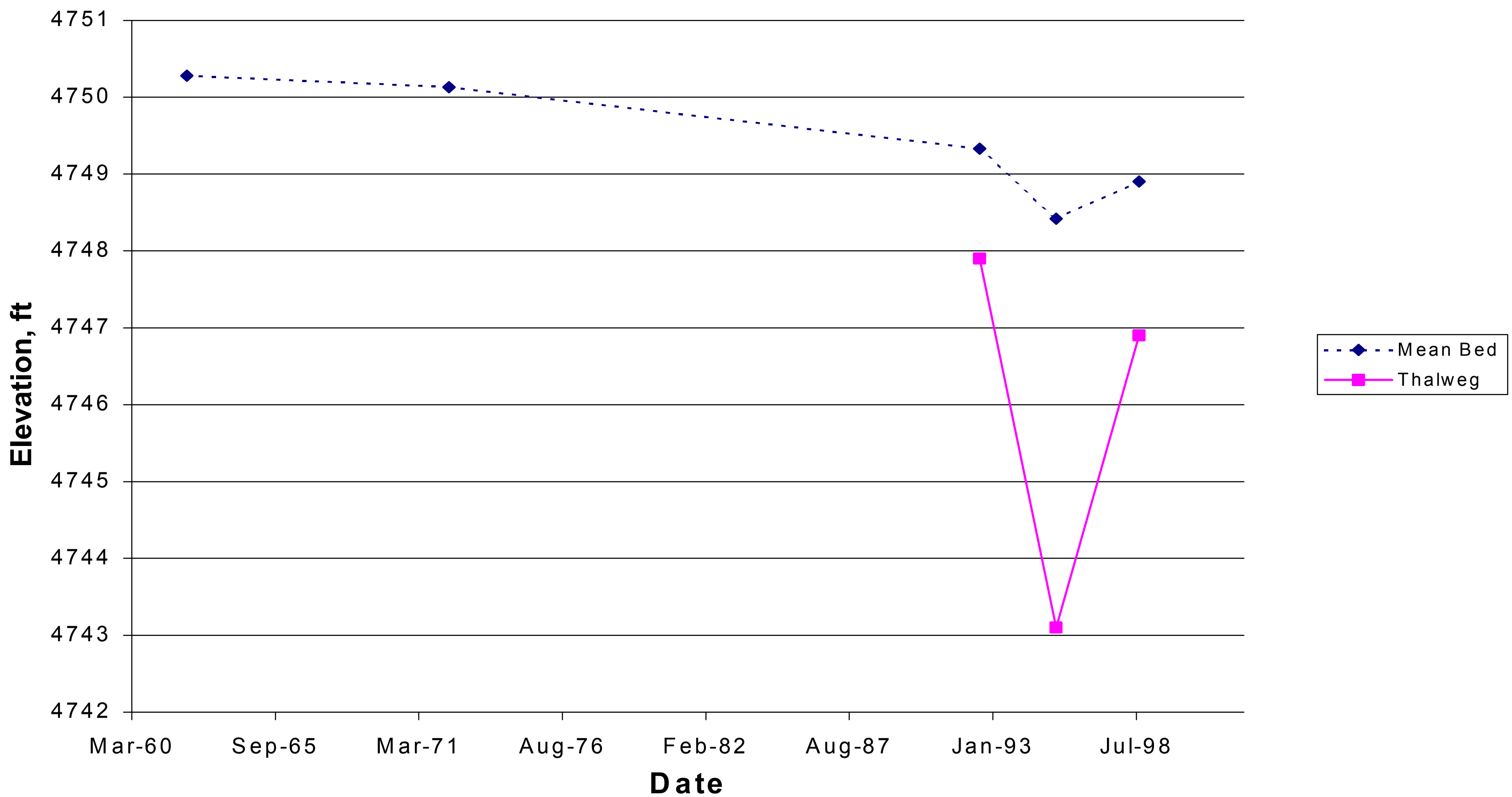

Figure E-23. Change in thalweg and mean bed elevation with time at cross section CO2-986.

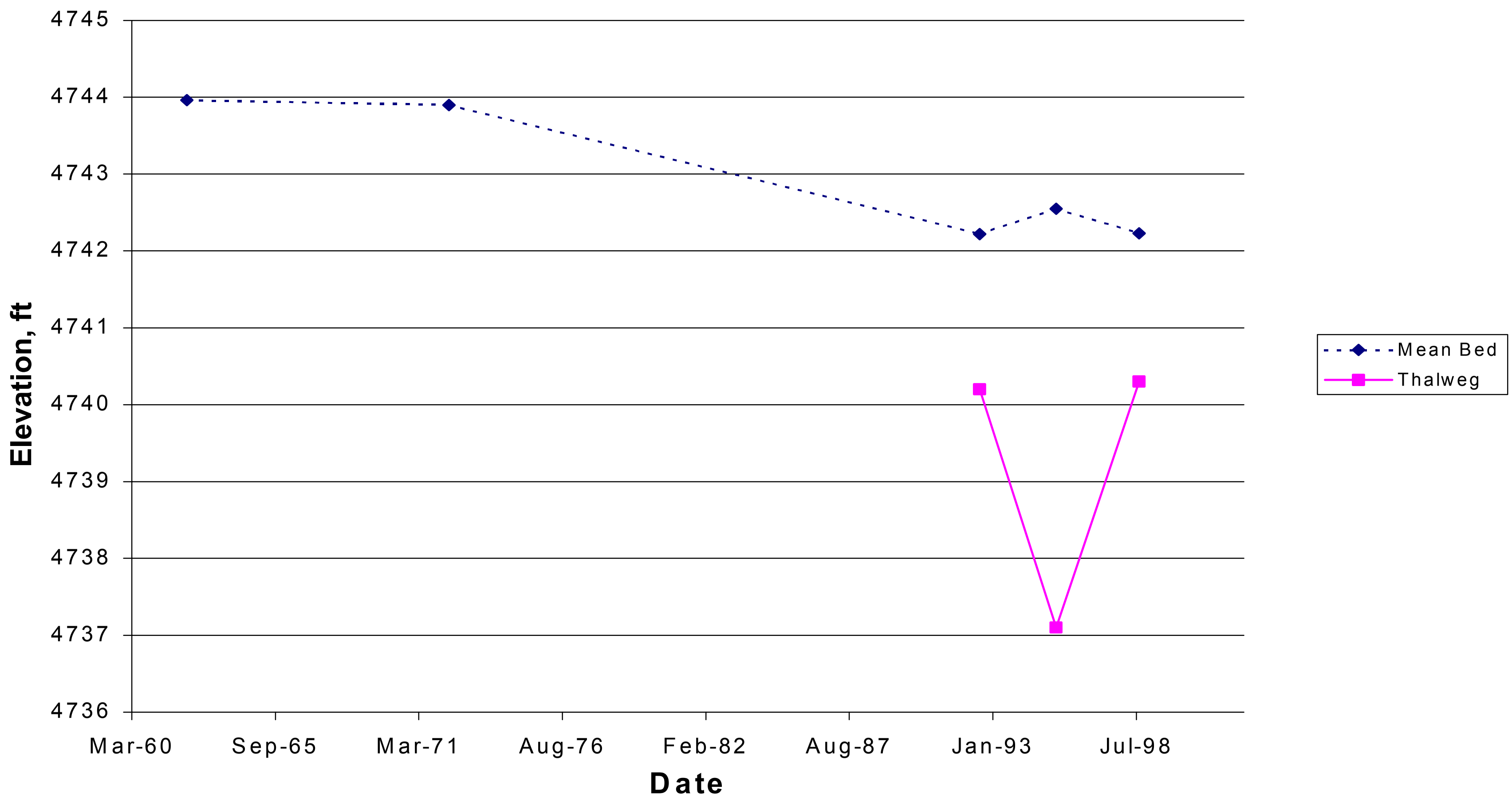

Figure E-24. Change in thalweg and mean bed elevation with time at cross section CO2-1006.

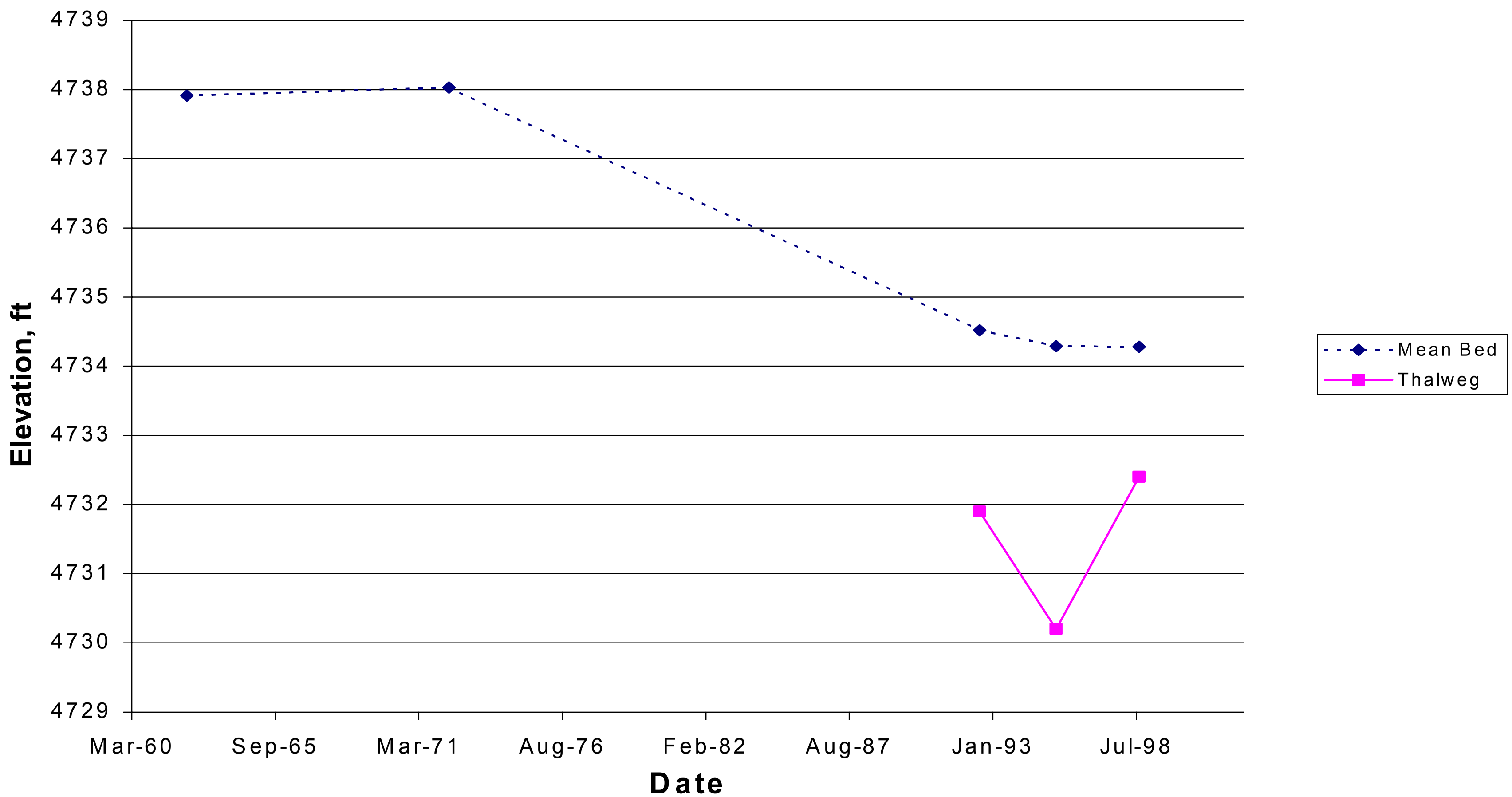

Figure E-25. Change in thalweg and mean bed elevation with time at cross section CO2-1026.

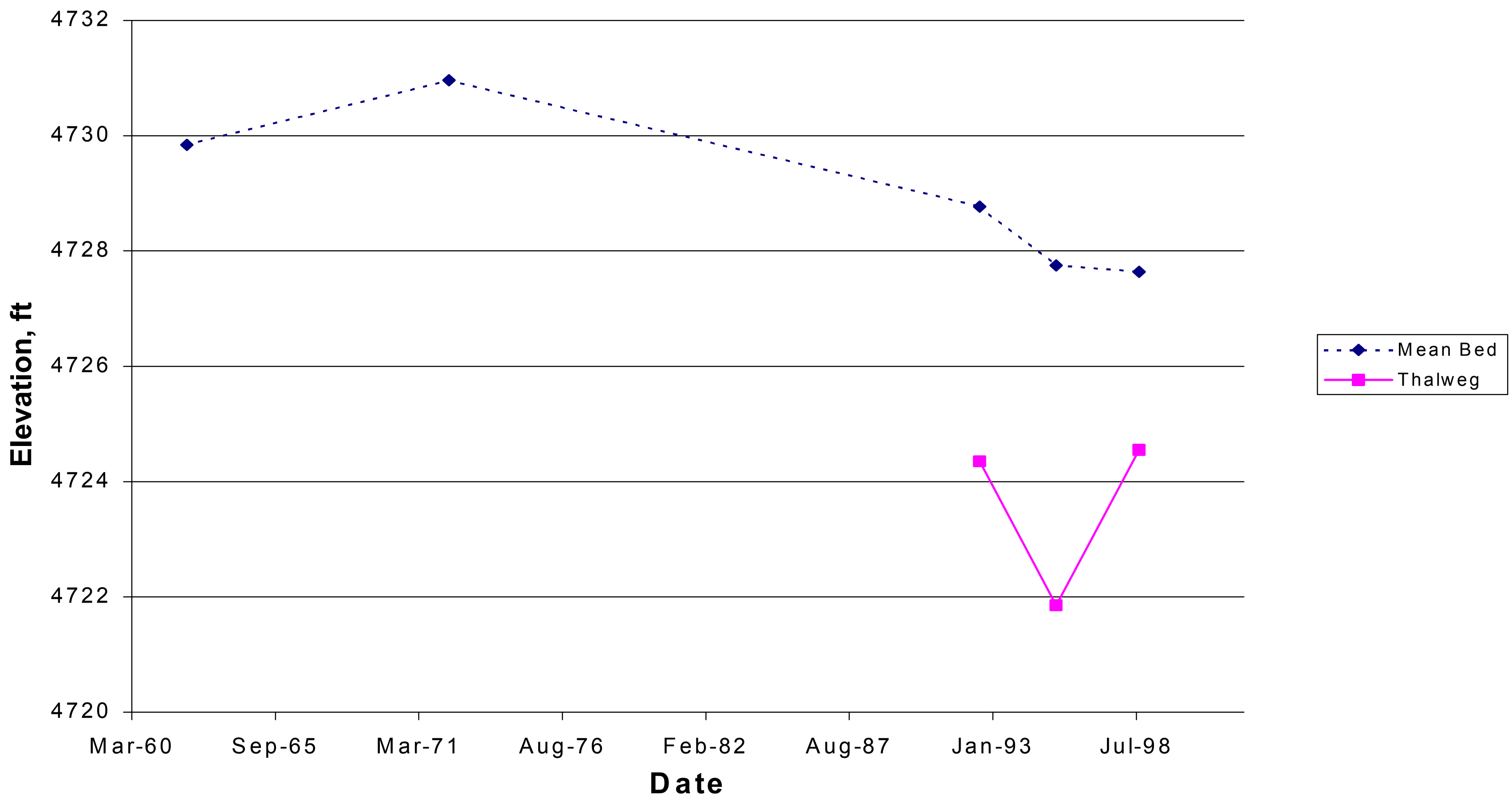

Figure E-26. Change in thalweg and mean bed elevation with time at cross section CO2-1044.

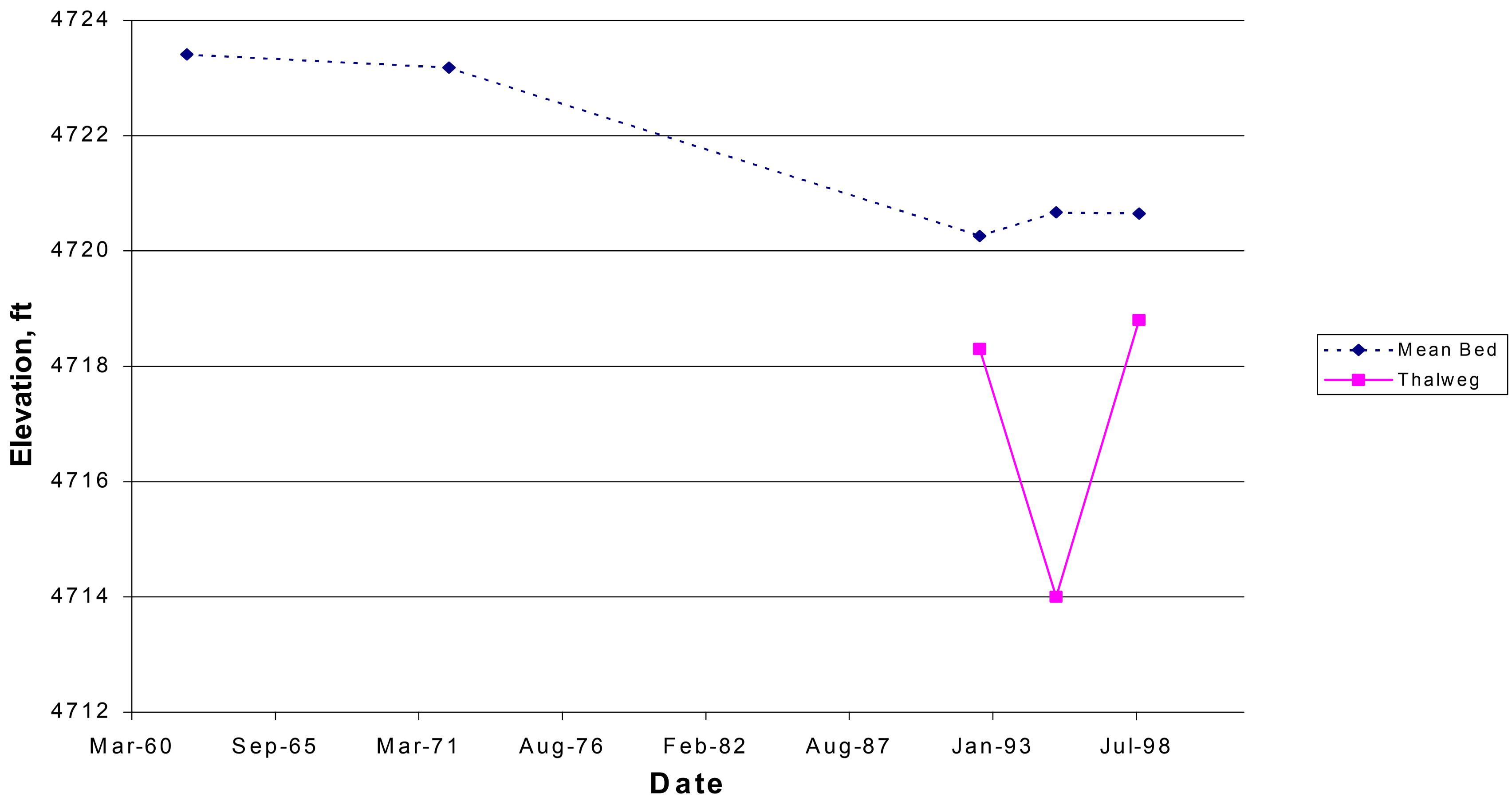

Figure E-27. Change in thalweg and mean bed elevation with time at cross section CO2-1064.

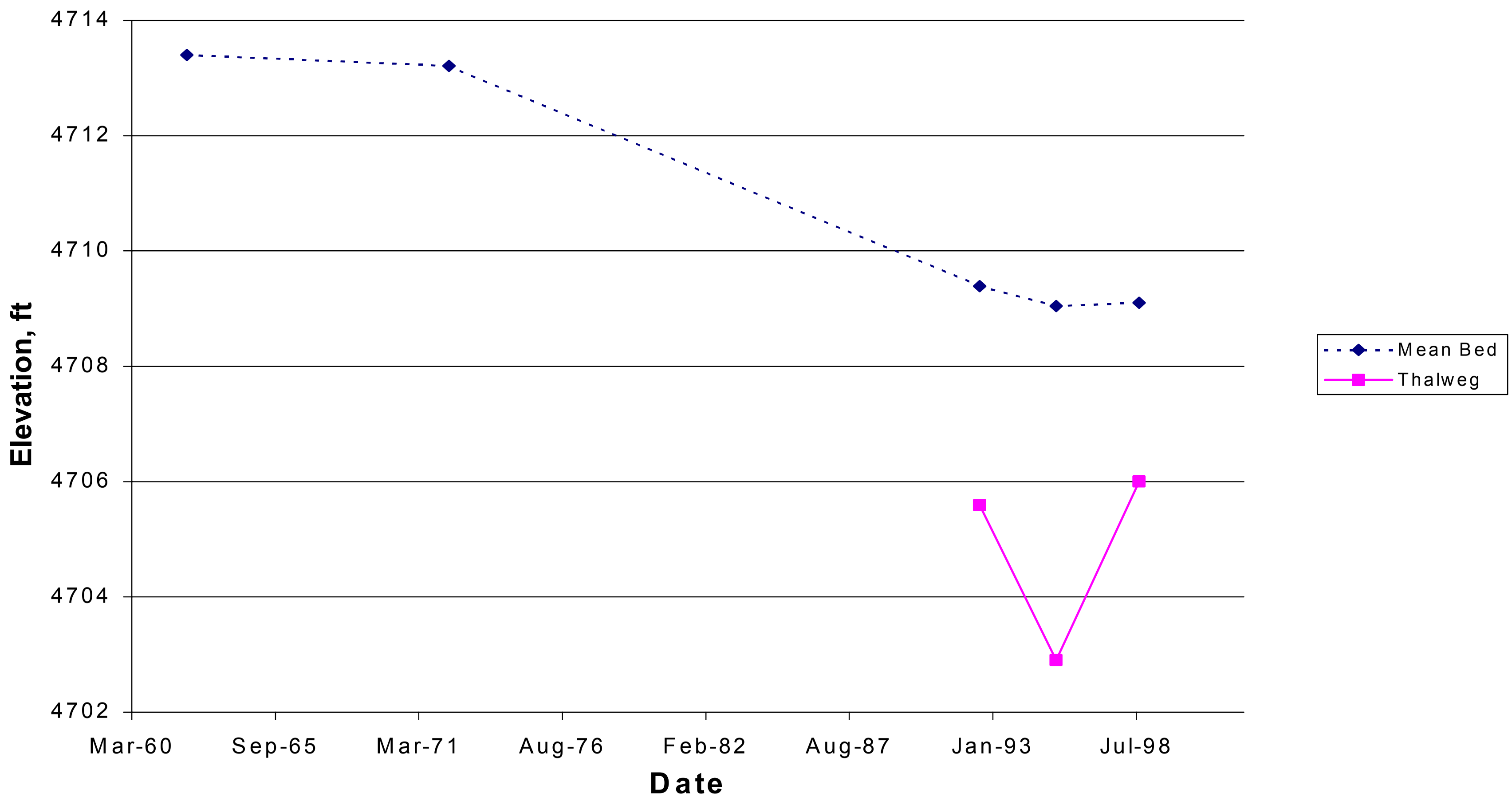

Figure E-28. Change in thalweg and mean bed elevation with time at cross section CO2-1091.

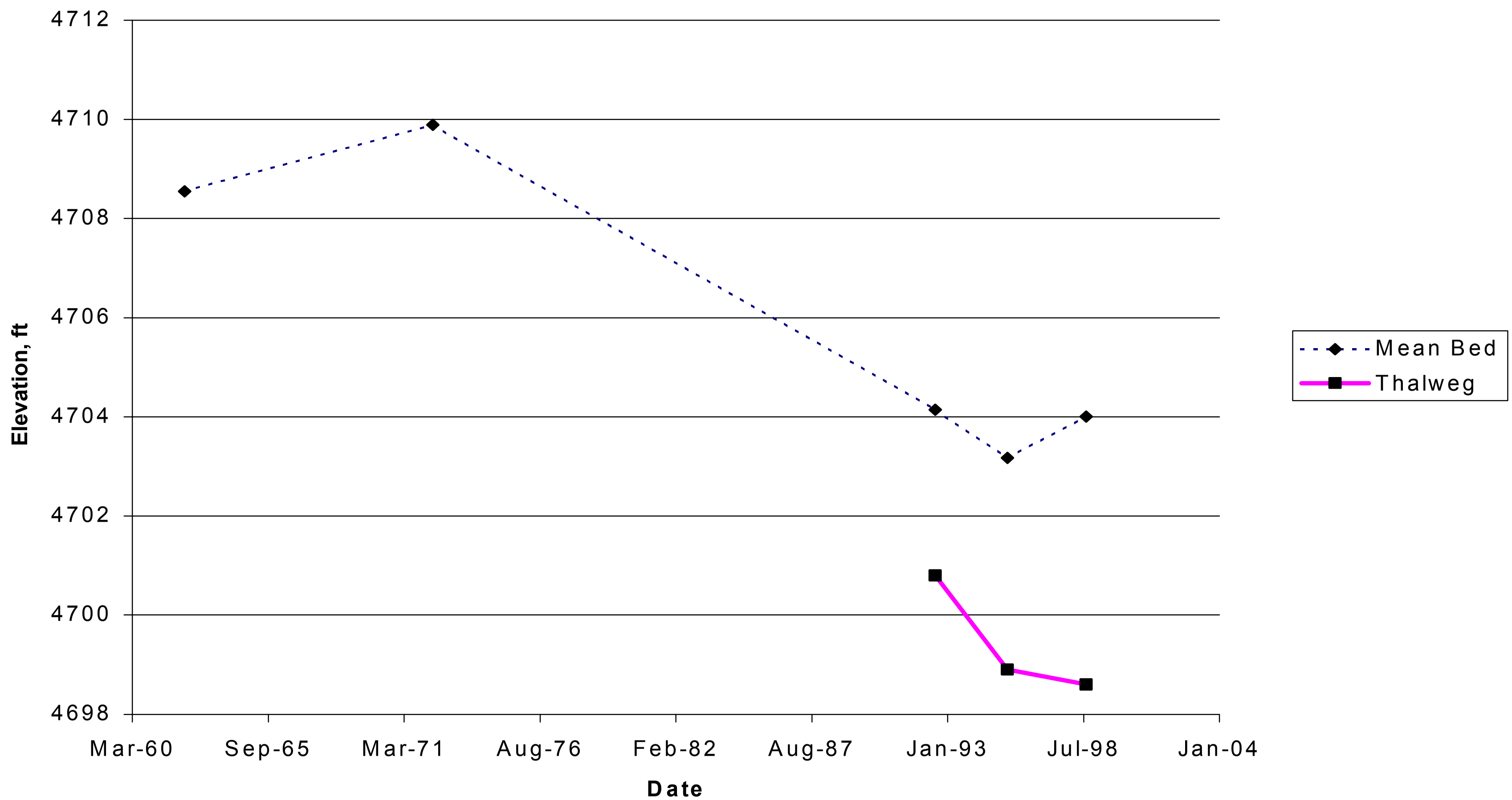

Figure E-29. Change in thalweg and mean bed elevation with time at cross section CO2-1104.

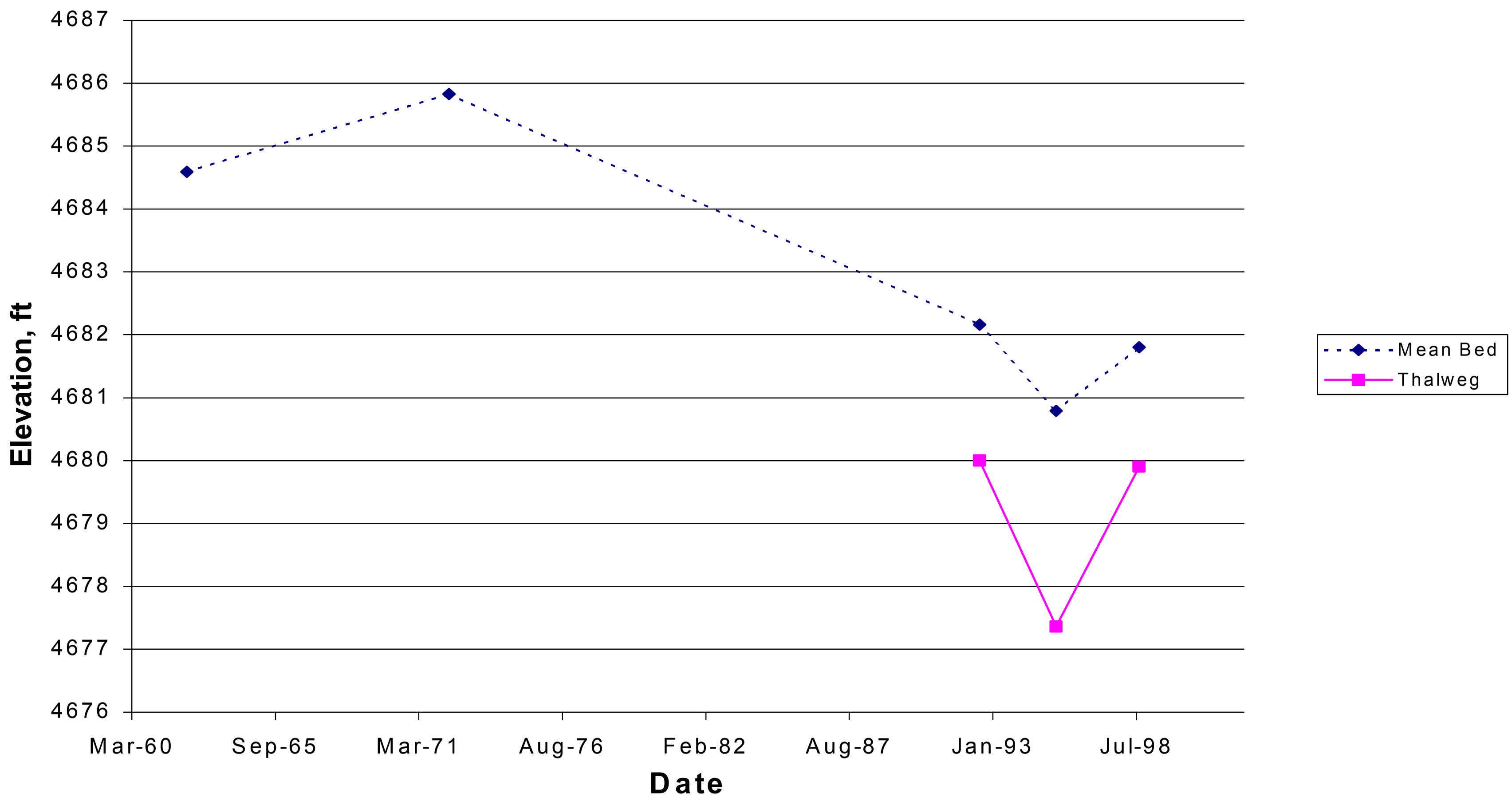

Figure E-30. Change in thalweg and mean bed elevation with time at cross section CO2-1164.

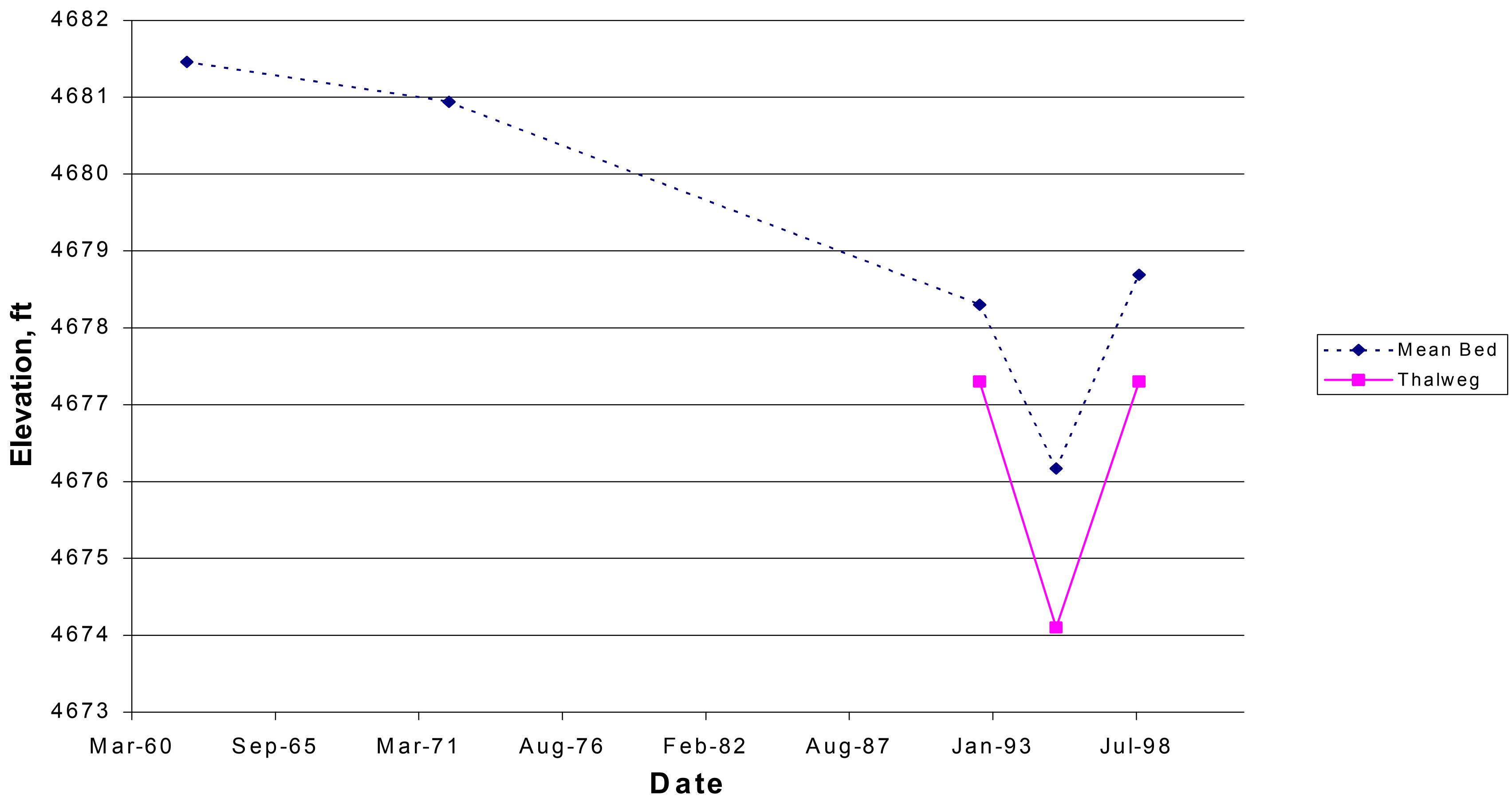

Figure E-31. Change in thalweg and mean bed elevation with time at cross section CO2-1179

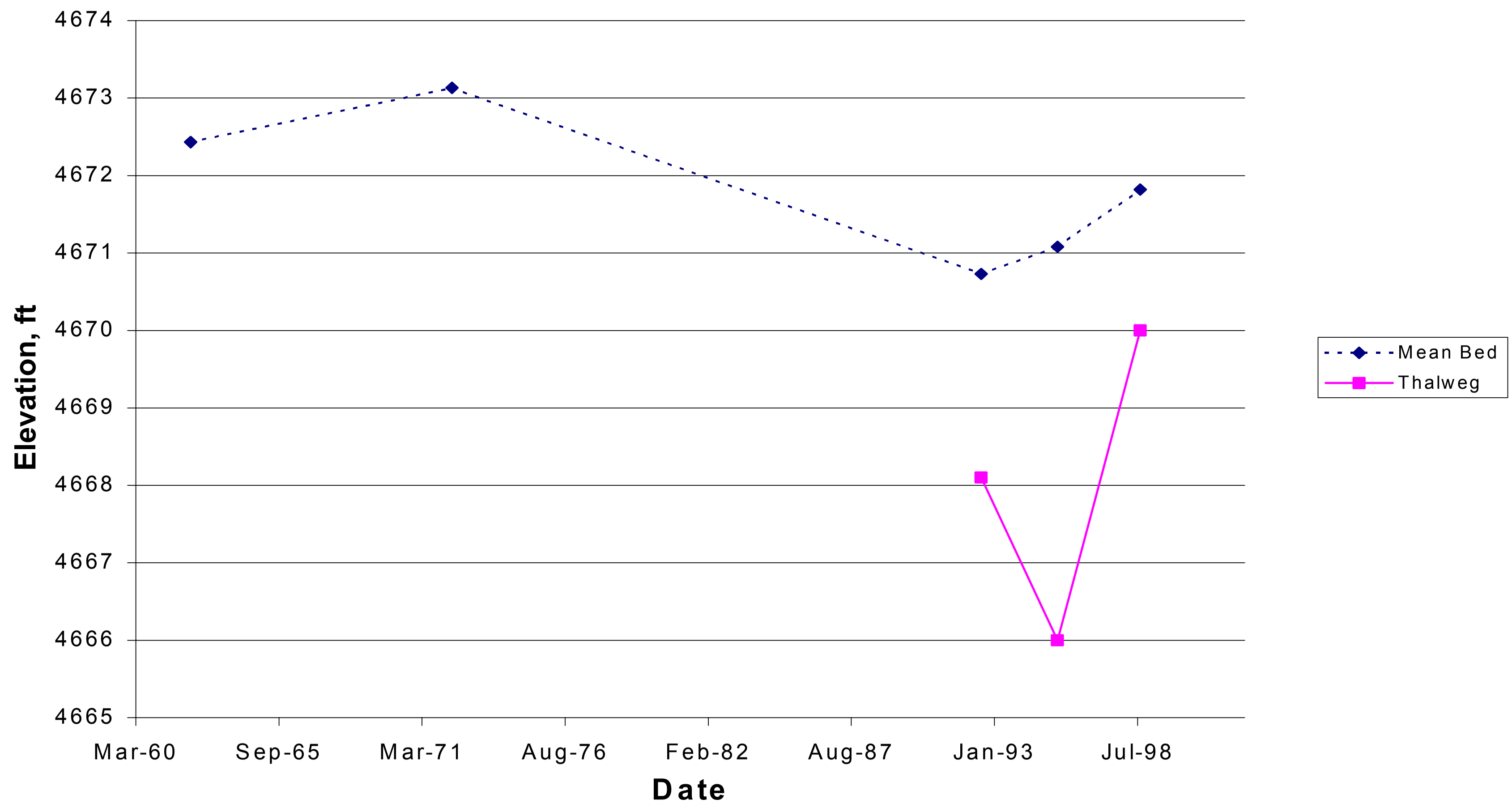

Figure E-32. Change in thalweg and mean bed elevation with time at cross section CO2-1194.

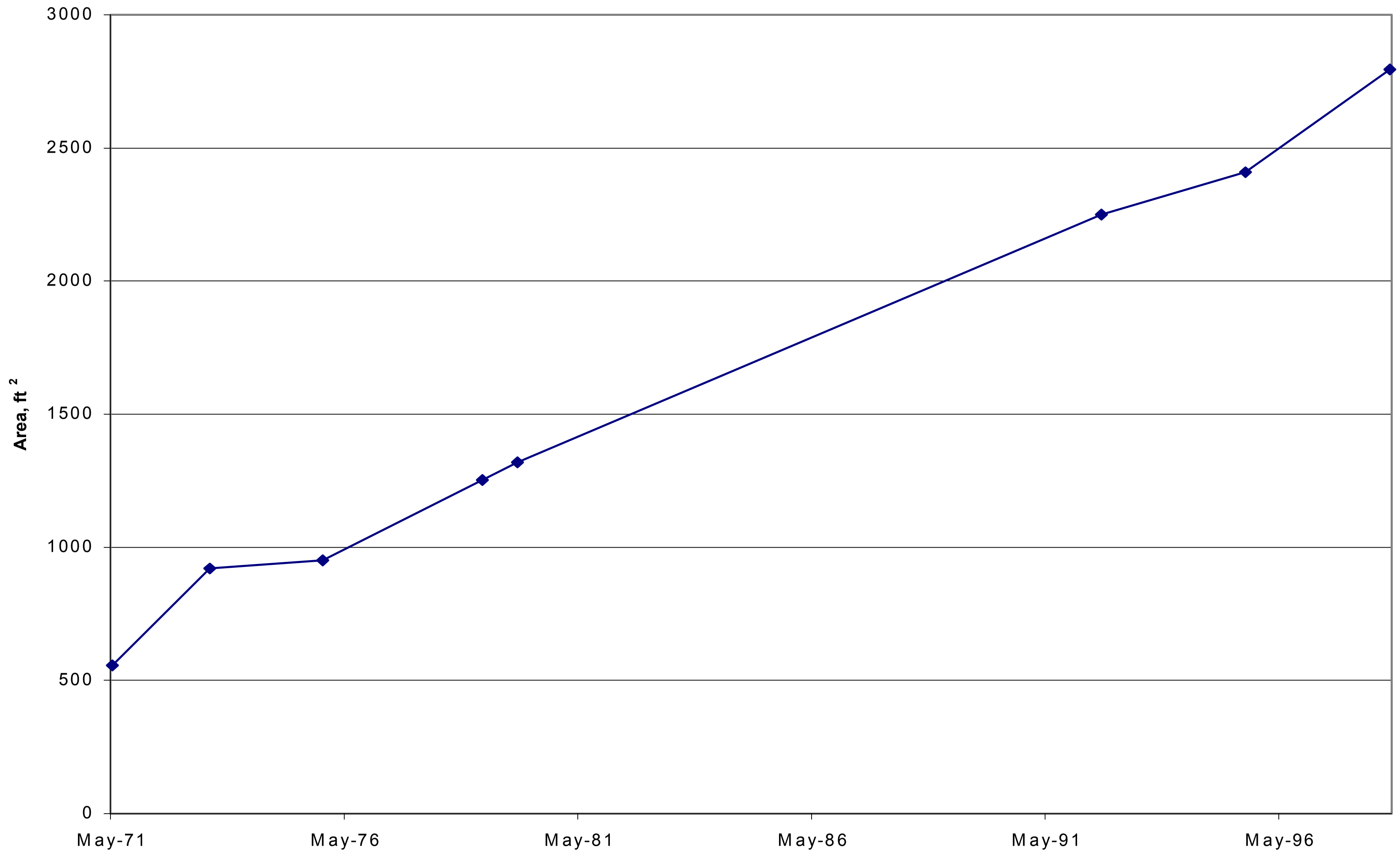

Figure E-33. Change in cross section area with time at cross section CO-31.

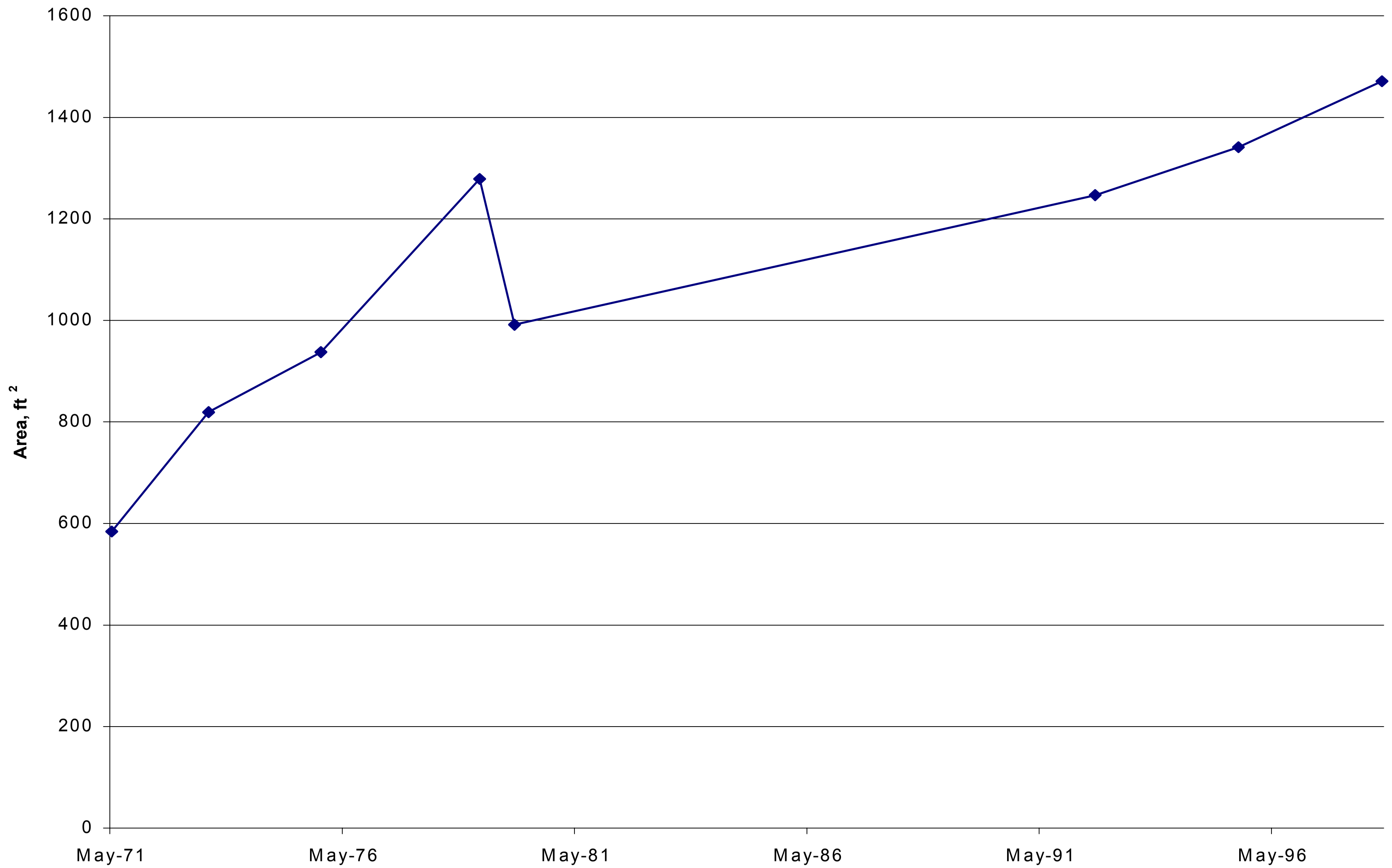

Figure E-34. Change in cross section area with time at cross section CO-32.

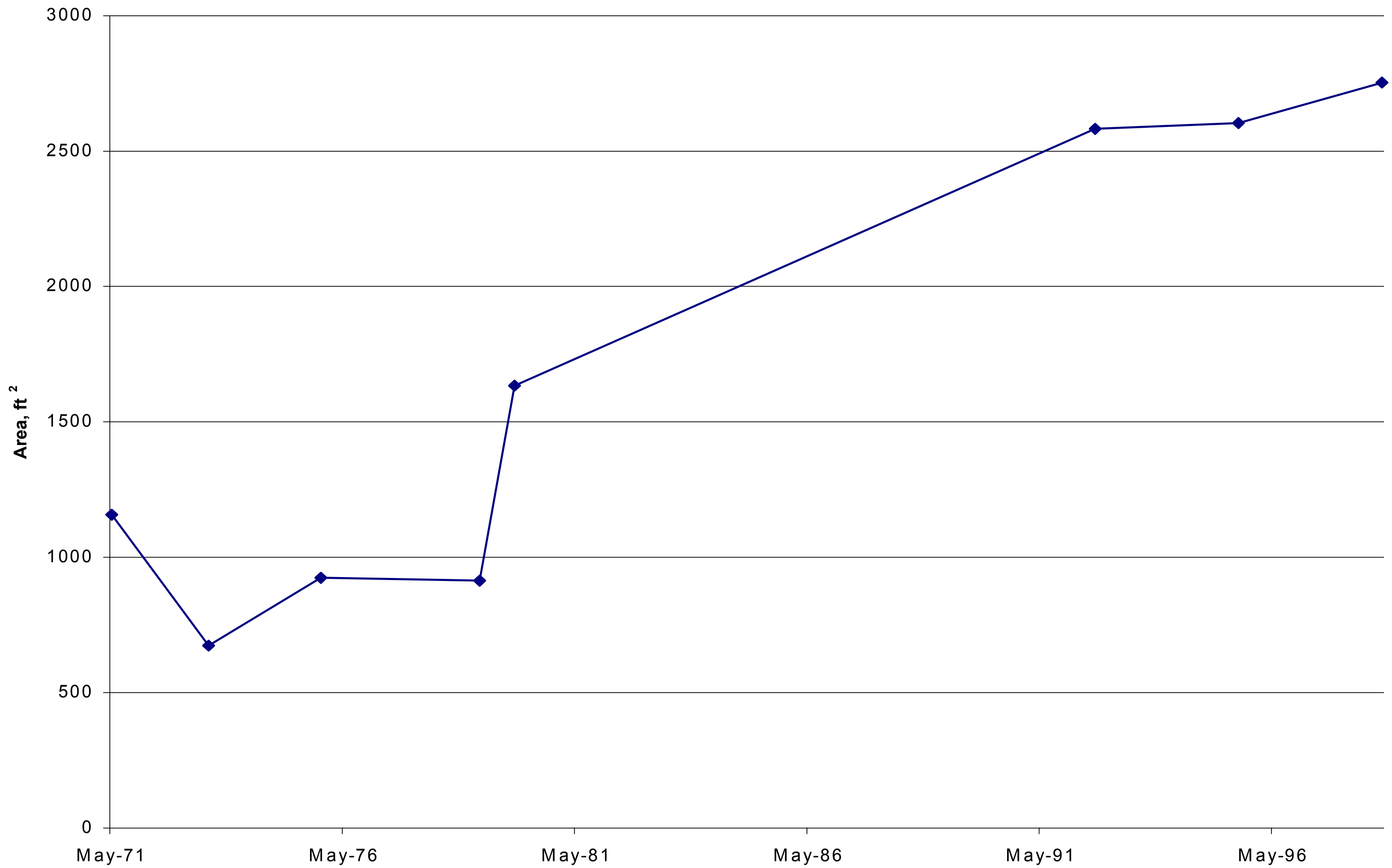

Figure E-35. Change in cross section area with time at cross section CO-33.

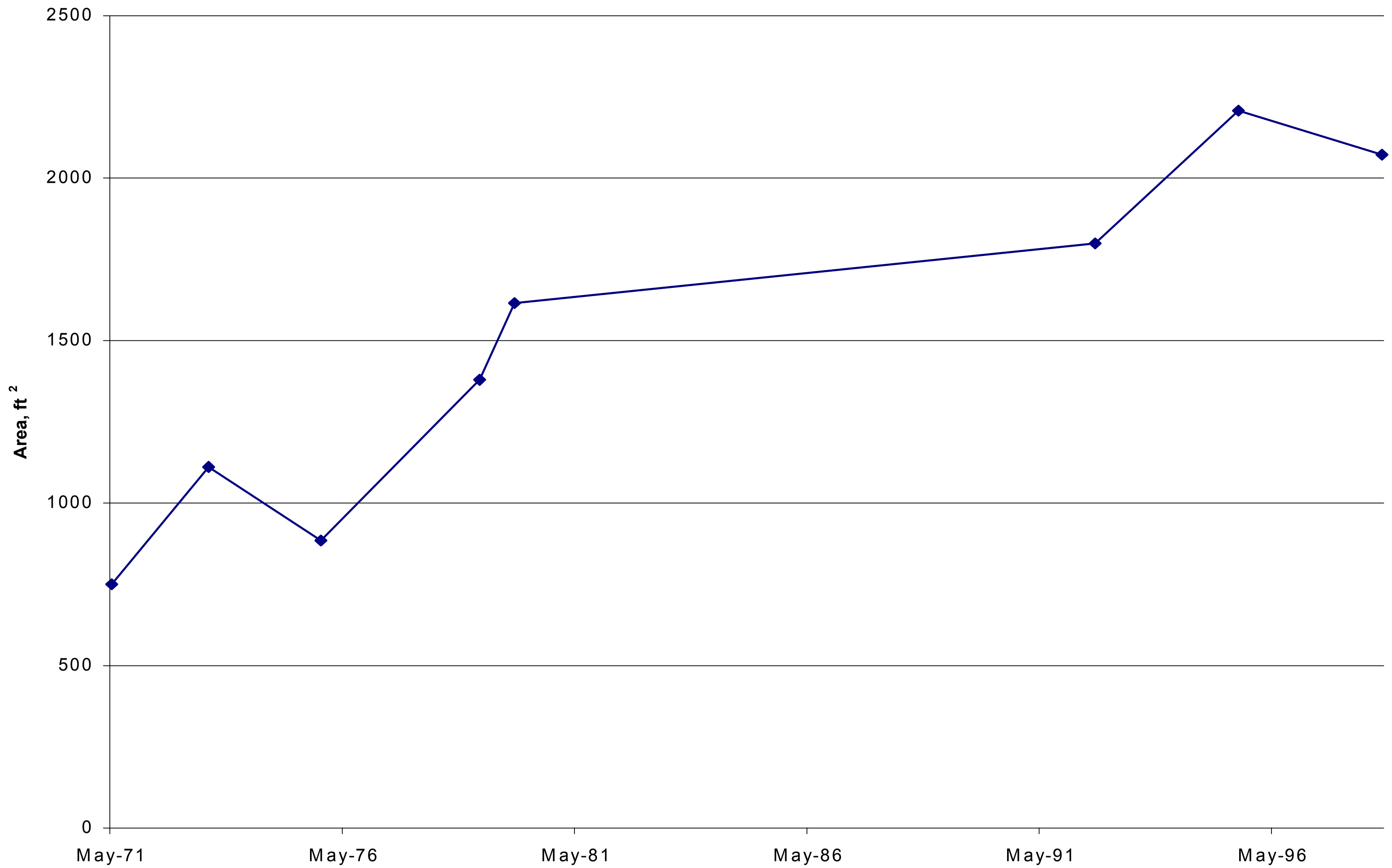

Figure E-36. Change in cross section area with time at cross section CO-34.

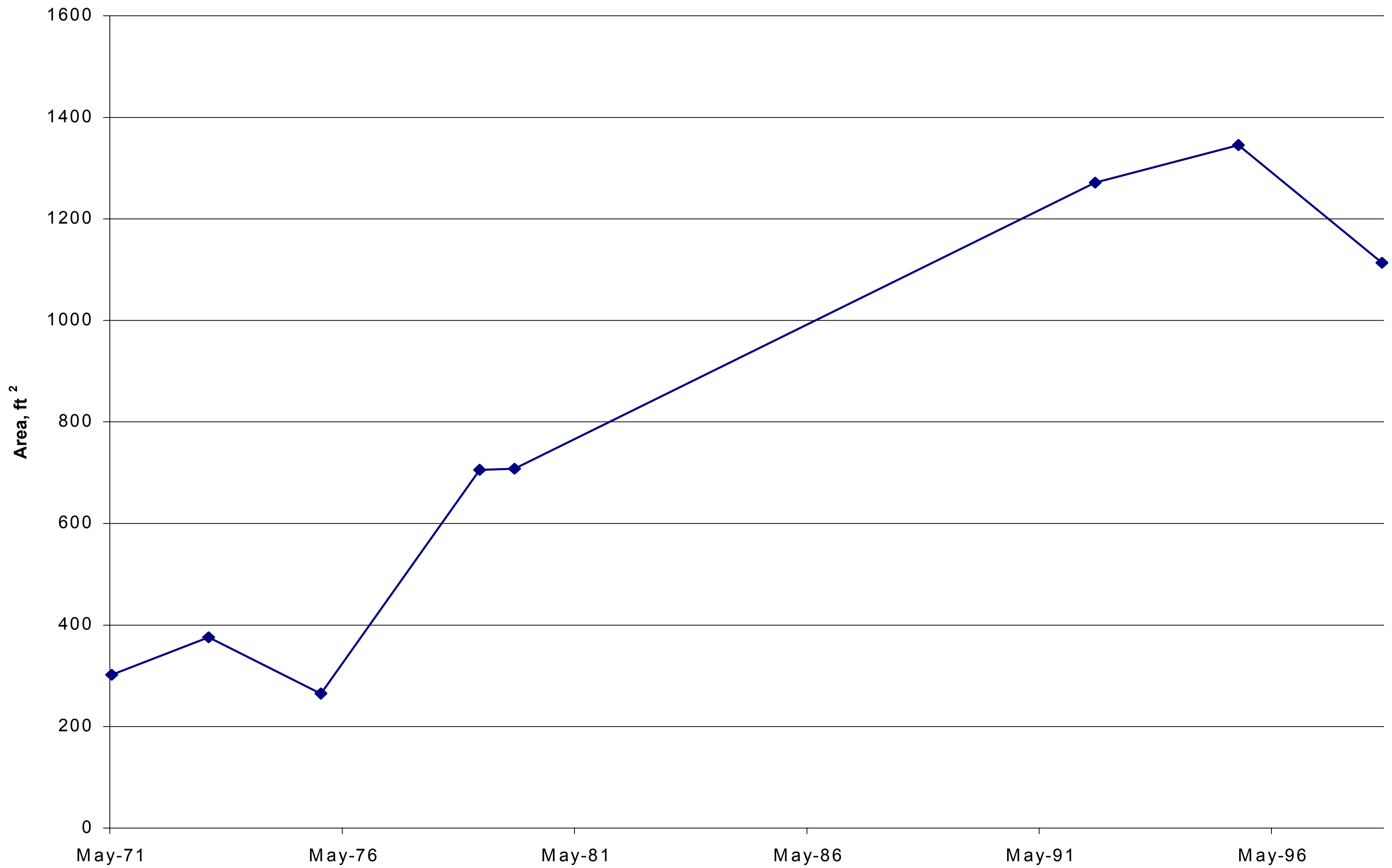

Figure E-37. Change in cross section area with time at cross section CO-35.

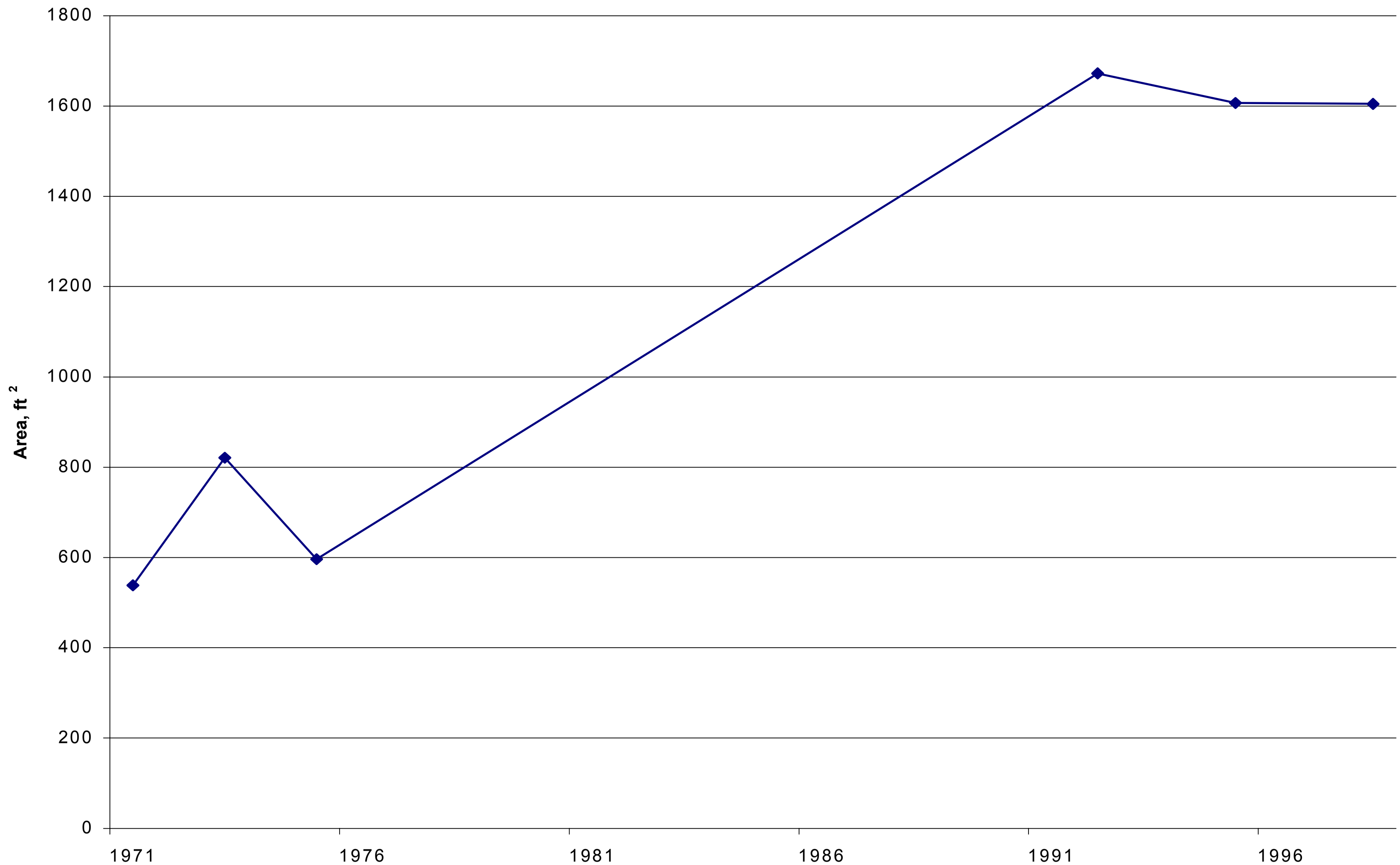

Figure E-38. Change in cross section area with time at cross section CO-36.

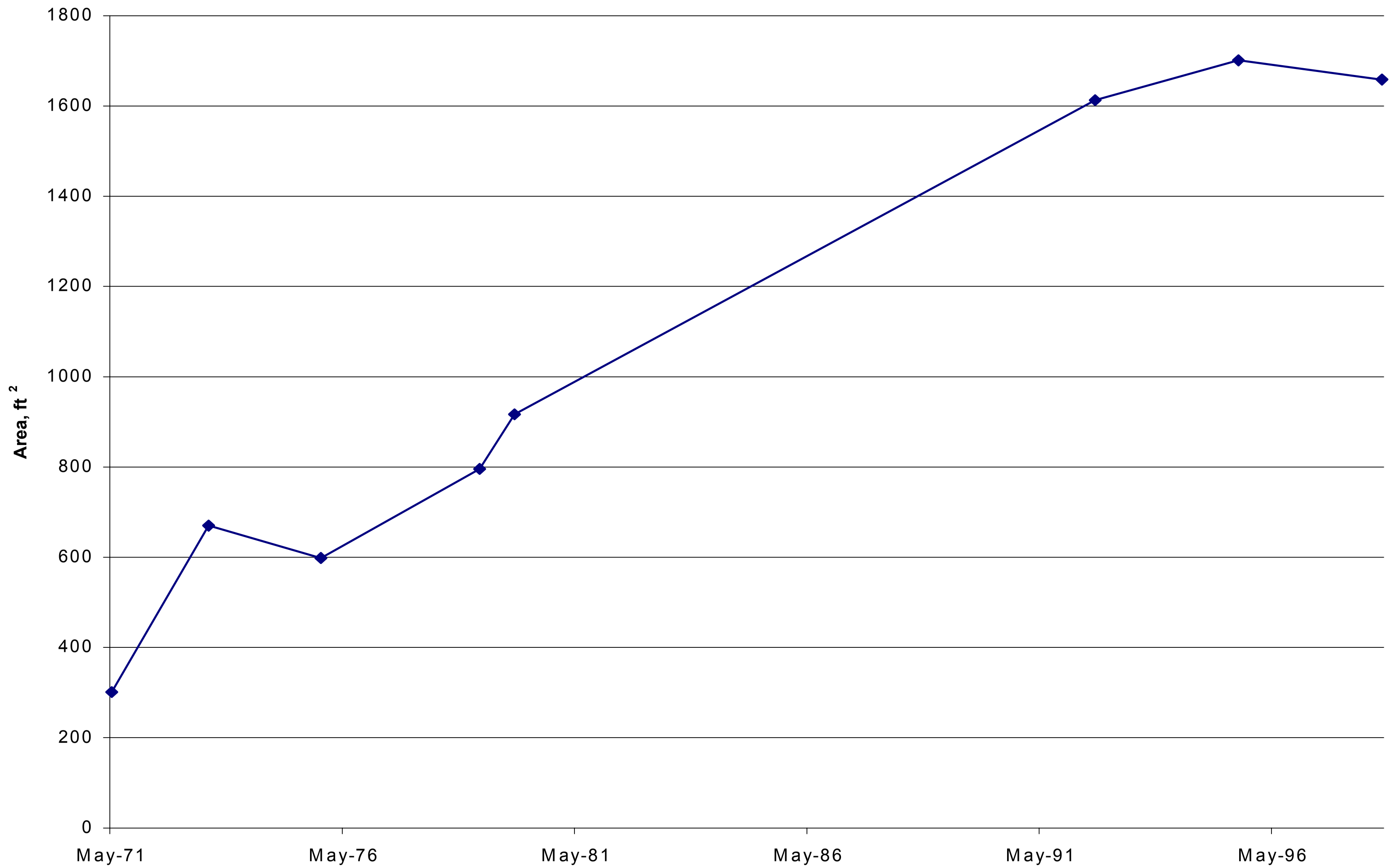

Figure E-39. Change in cross section area with time at cross section CO-37.

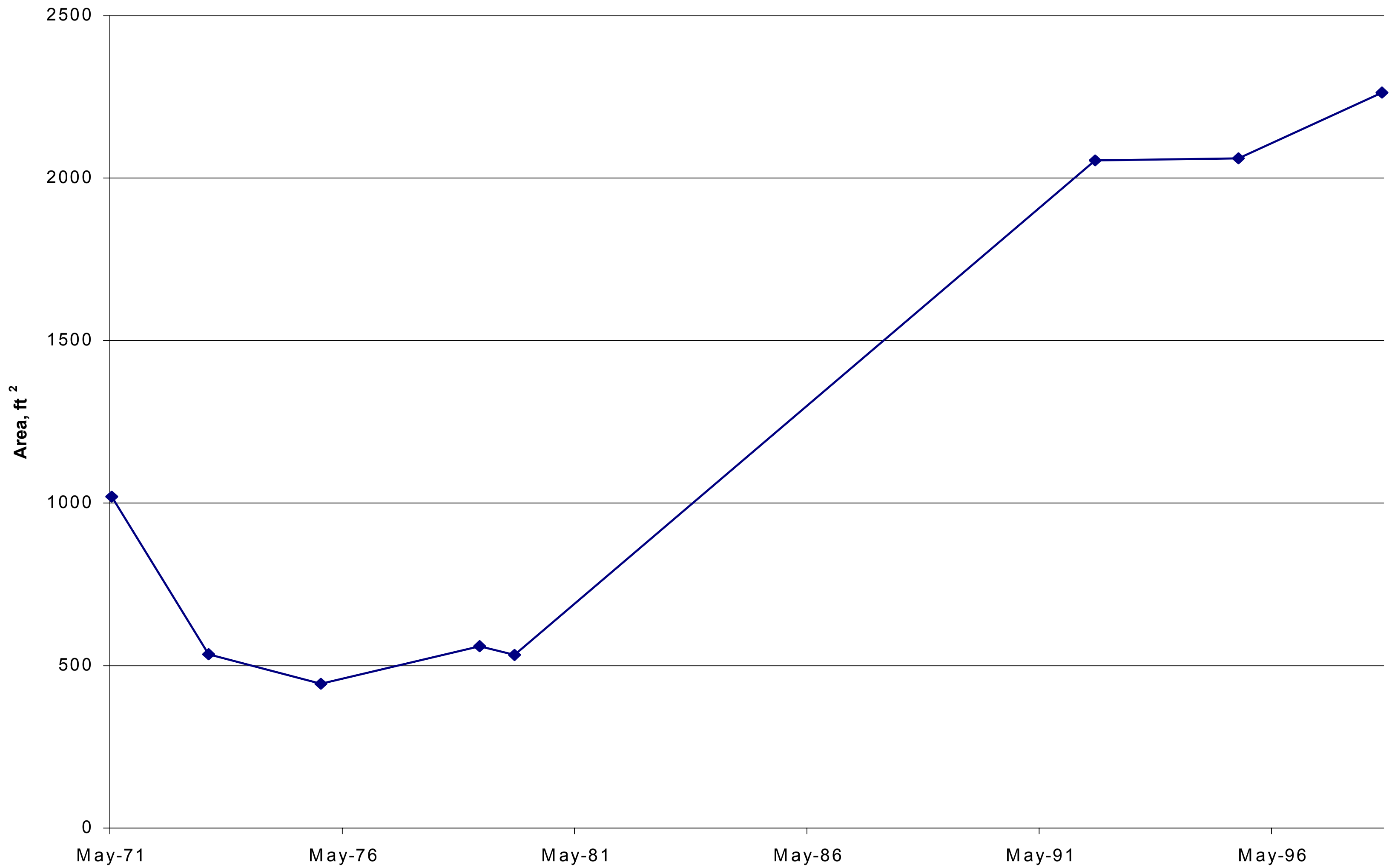

Figure E-40. Change in cross section area with time at cross section CO-38.

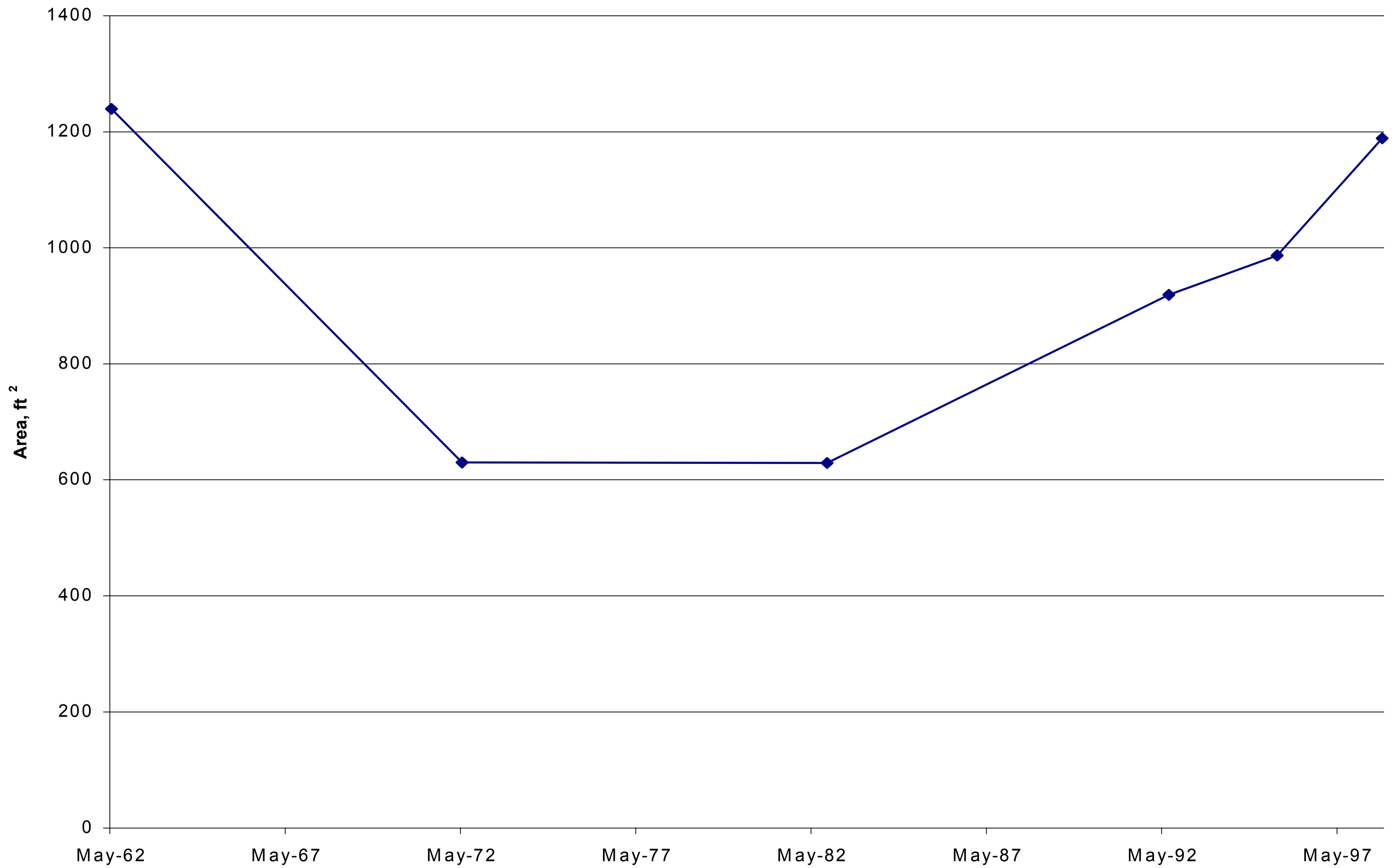

Figure E-41. Change in cross section area with time at cross section CO-668.

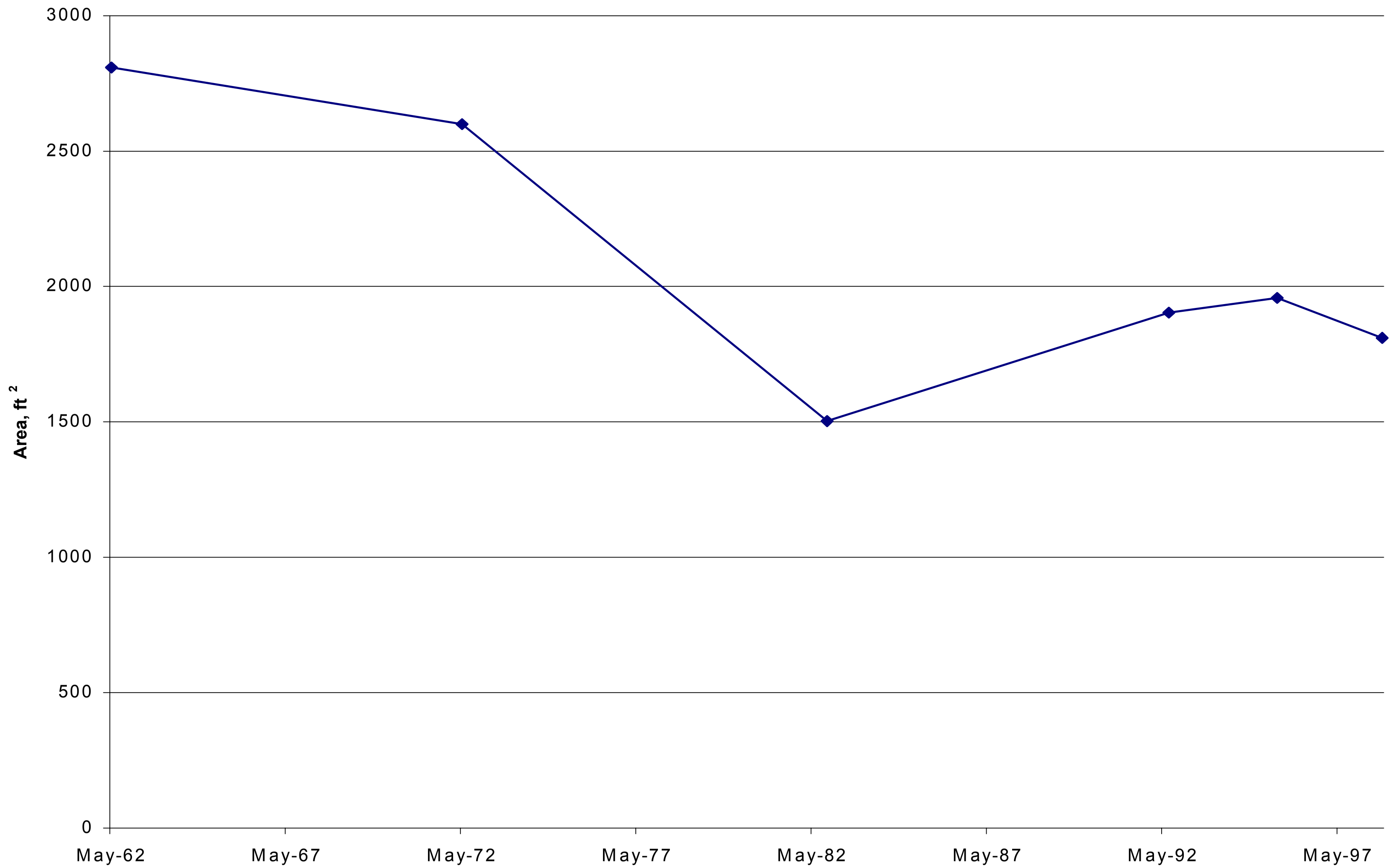

Figure E-42. Change in cross section area with time at cross section CO-713.

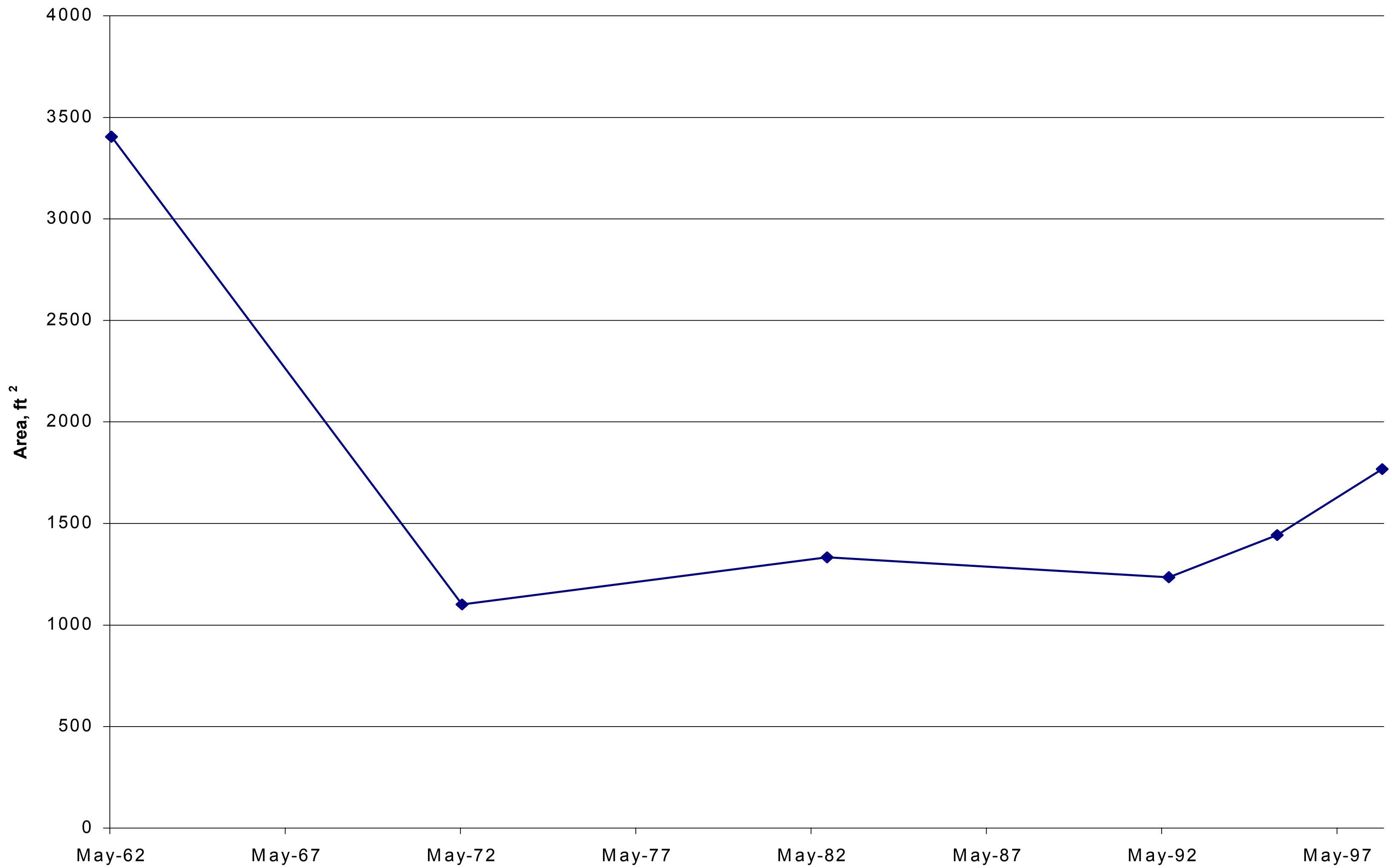

Figure E-43. Change in cross section area with time at cross section CO-724.

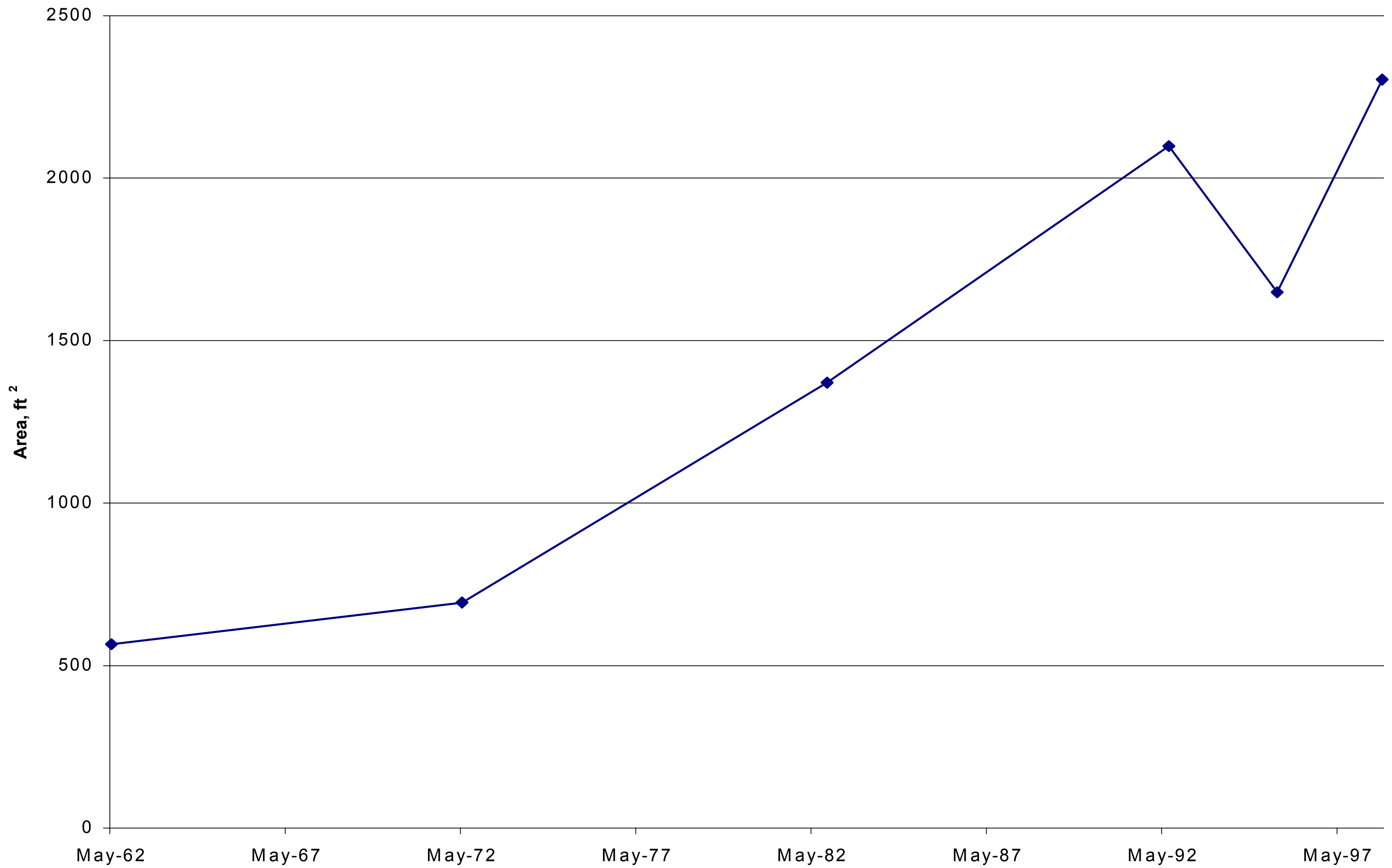

Figure E-44. Change in cross section area with time at cross section CO-738.1.

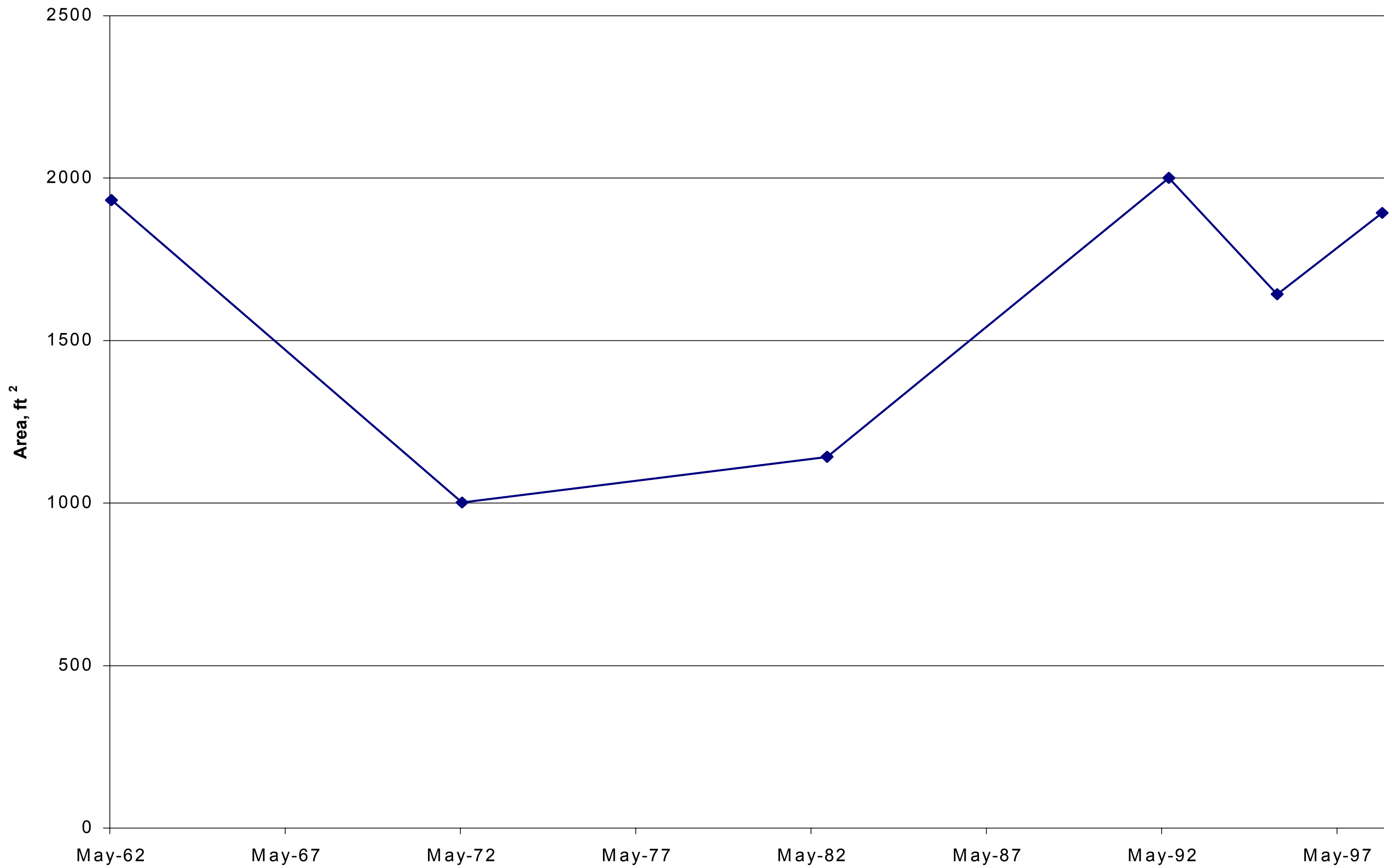

Figure E-45. Change in cross section area with time at cross section CO-765.

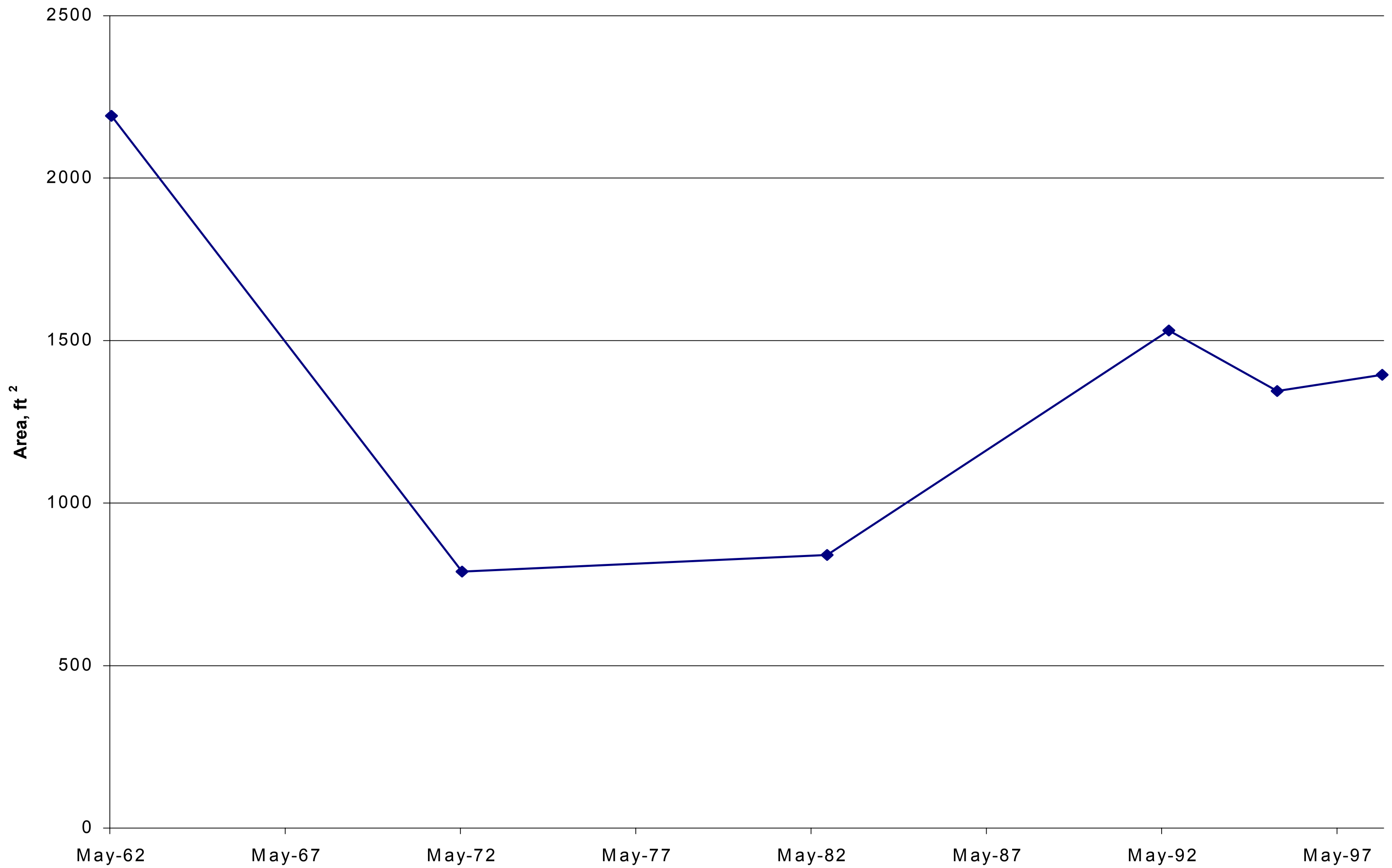

Figure E-46. Change in cross section area with time at cross section CO-787.

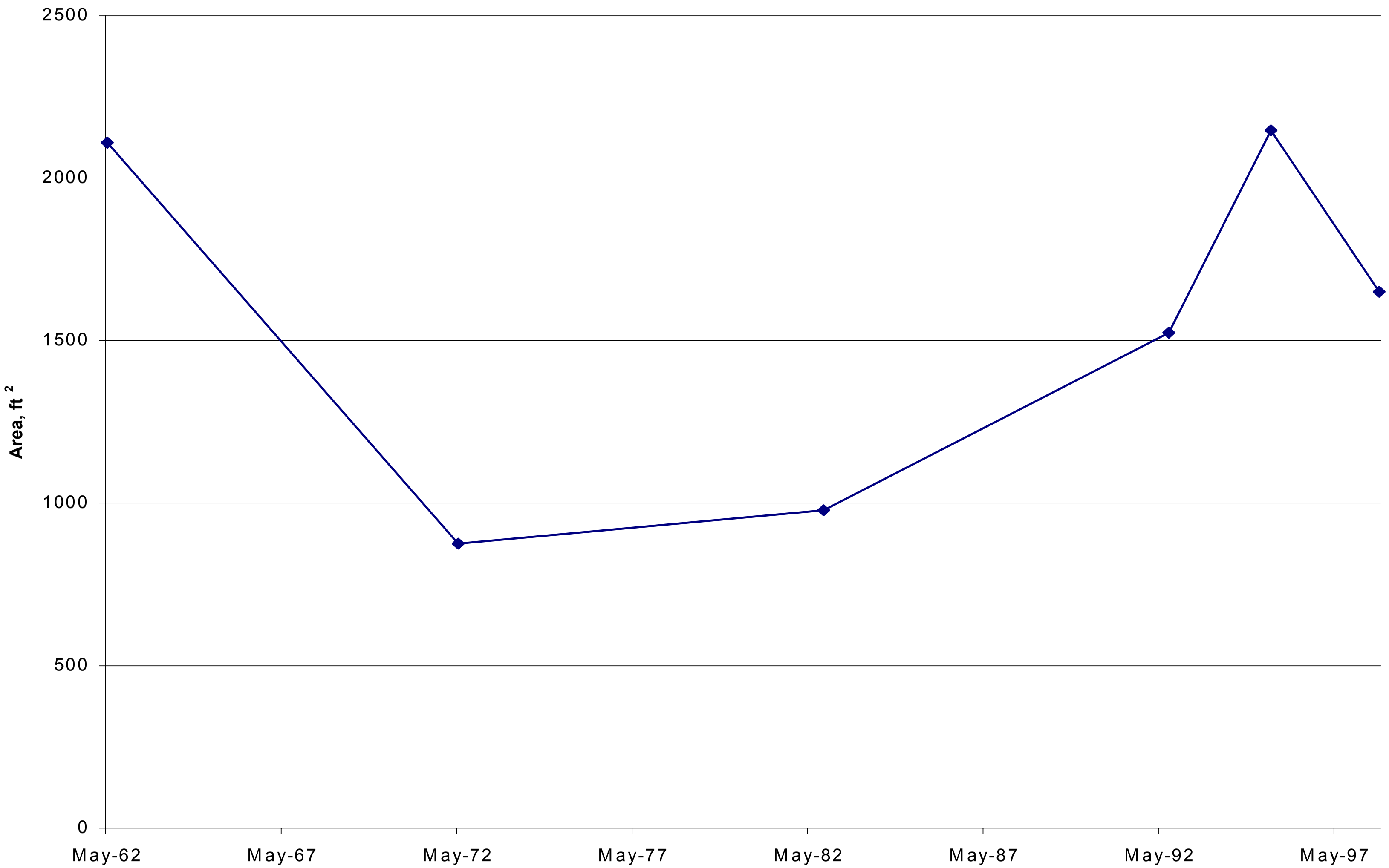

Figure E-47. Change in cross section area with time at cross section CO-806.

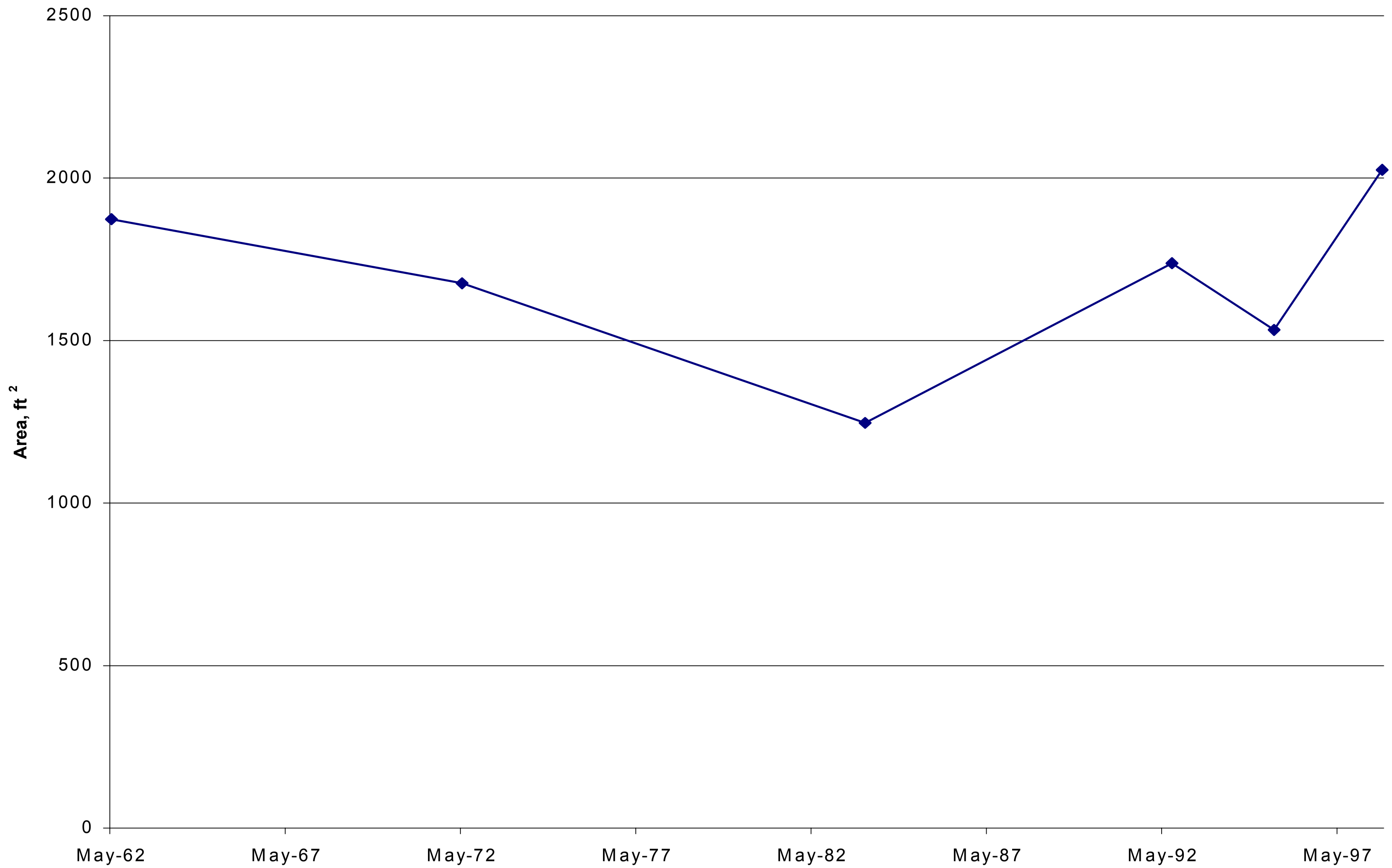

Figure E-48. Change in cross section area with time at cross section CO-833.

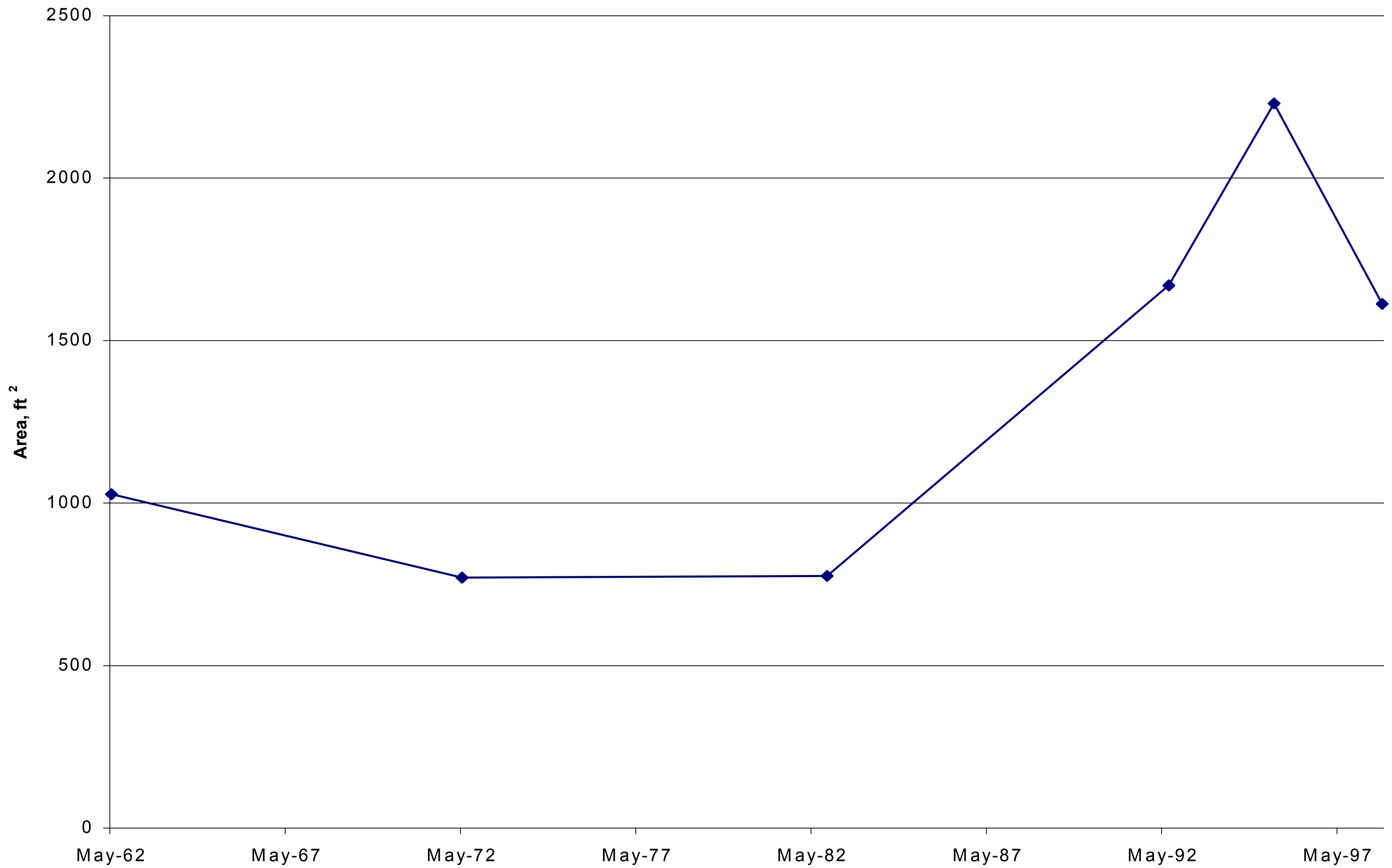

Figure E-49. Change in cross section area with time at cross section CO-858.1.

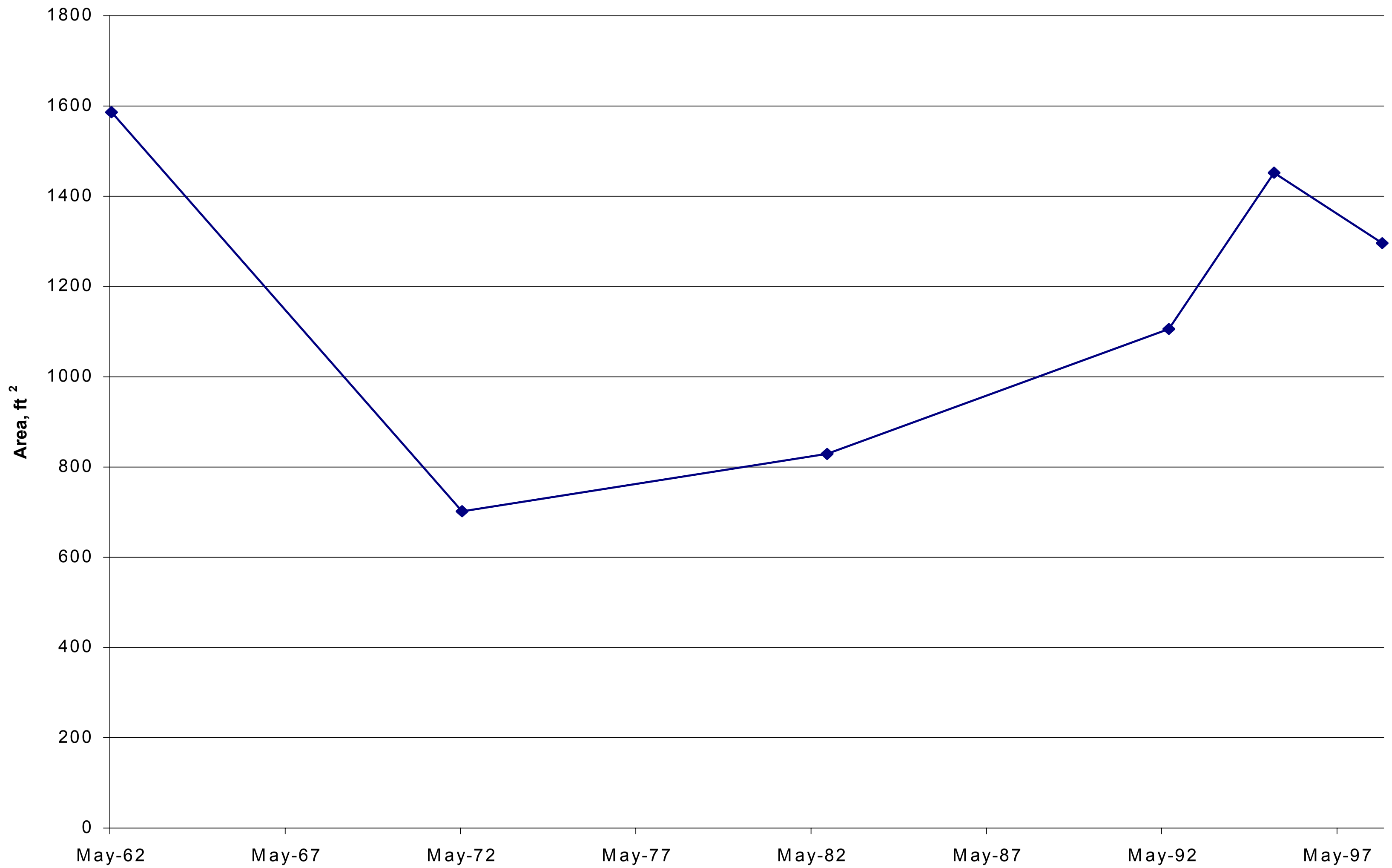

Figure E-50. Change in cross section area with time at cross section CO-877.

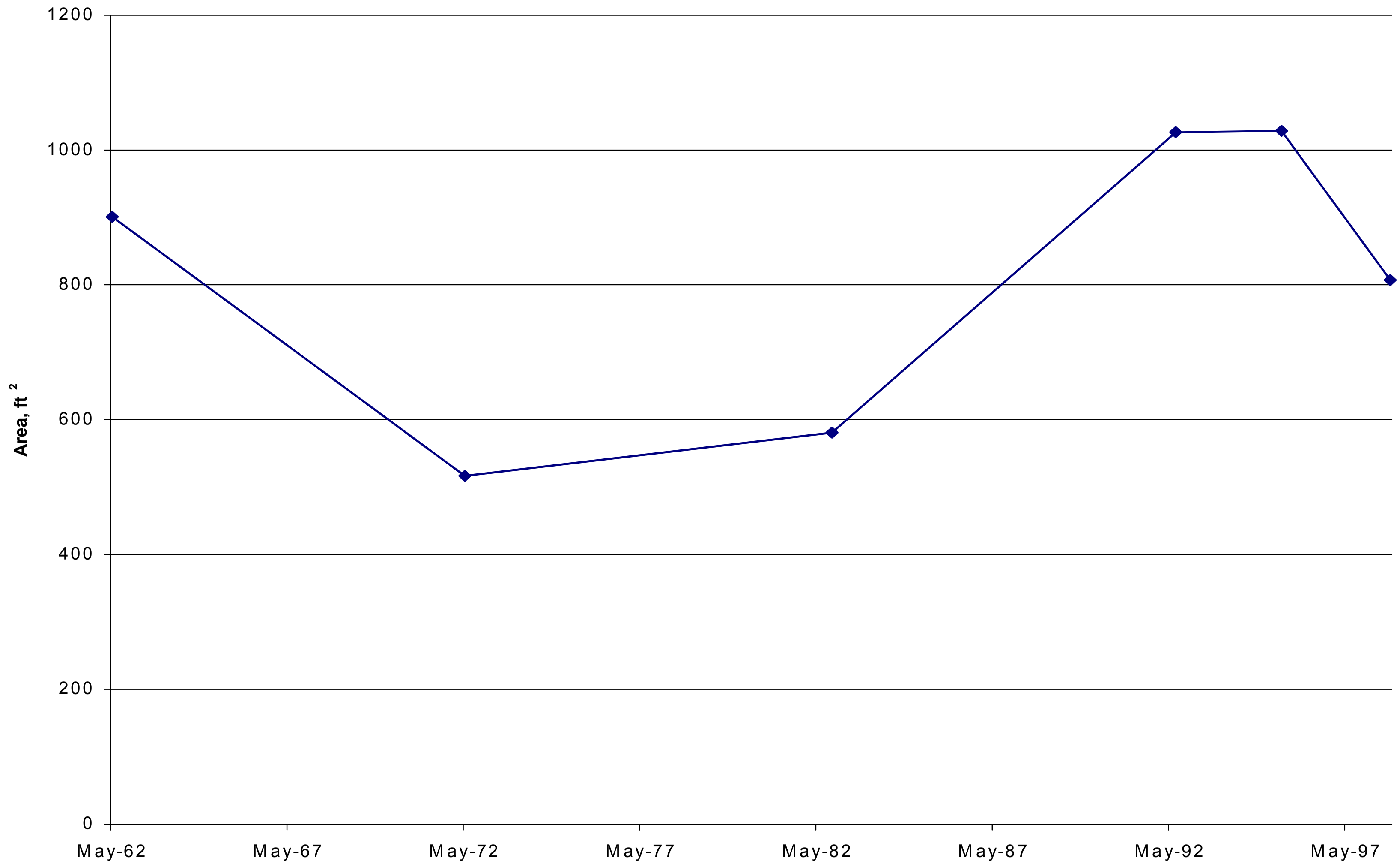

Figure E-51. Change in cross section area with time at cross section CO-895.

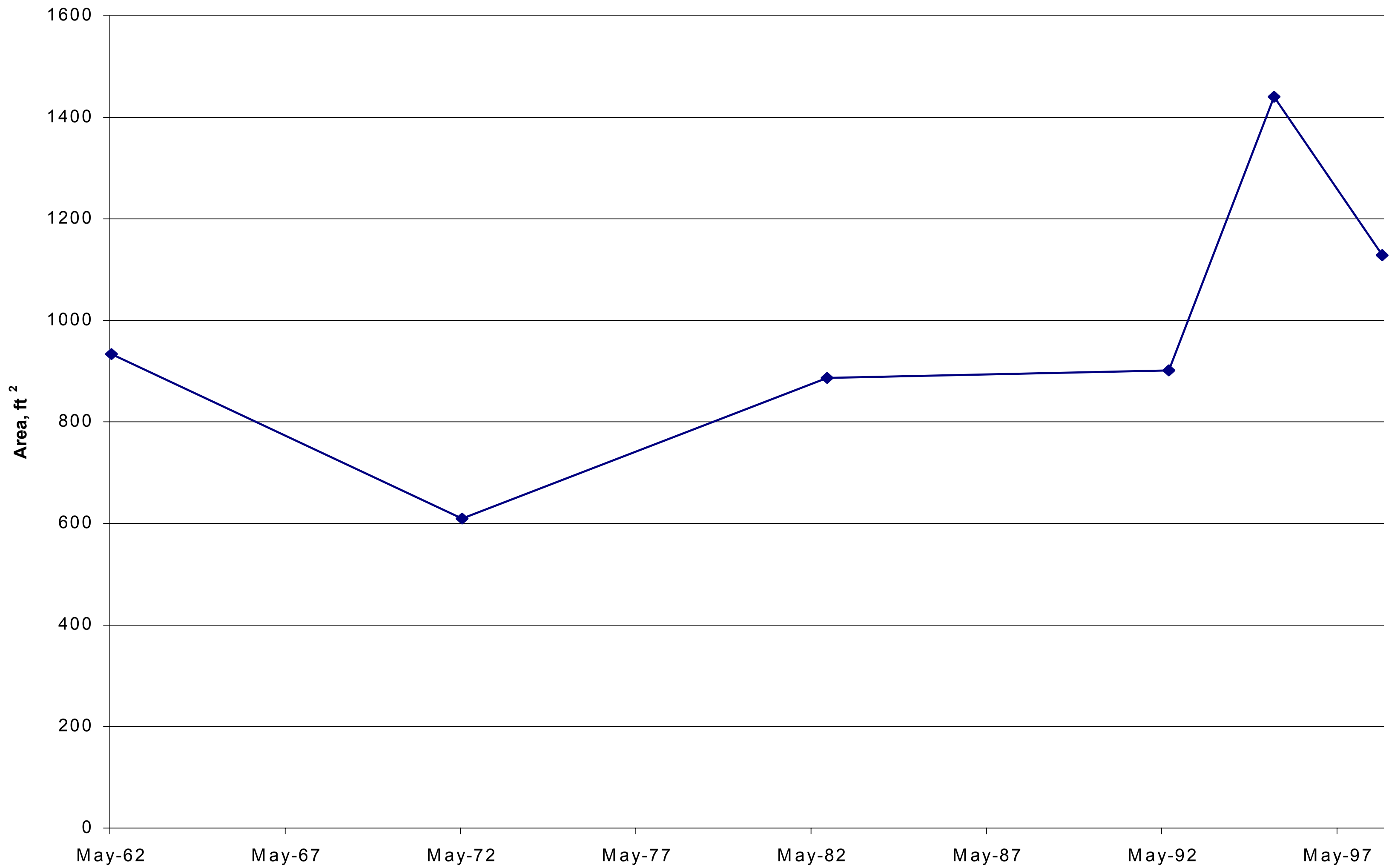

Figure E-52. Change in cross section area with time at cross section CO-926.

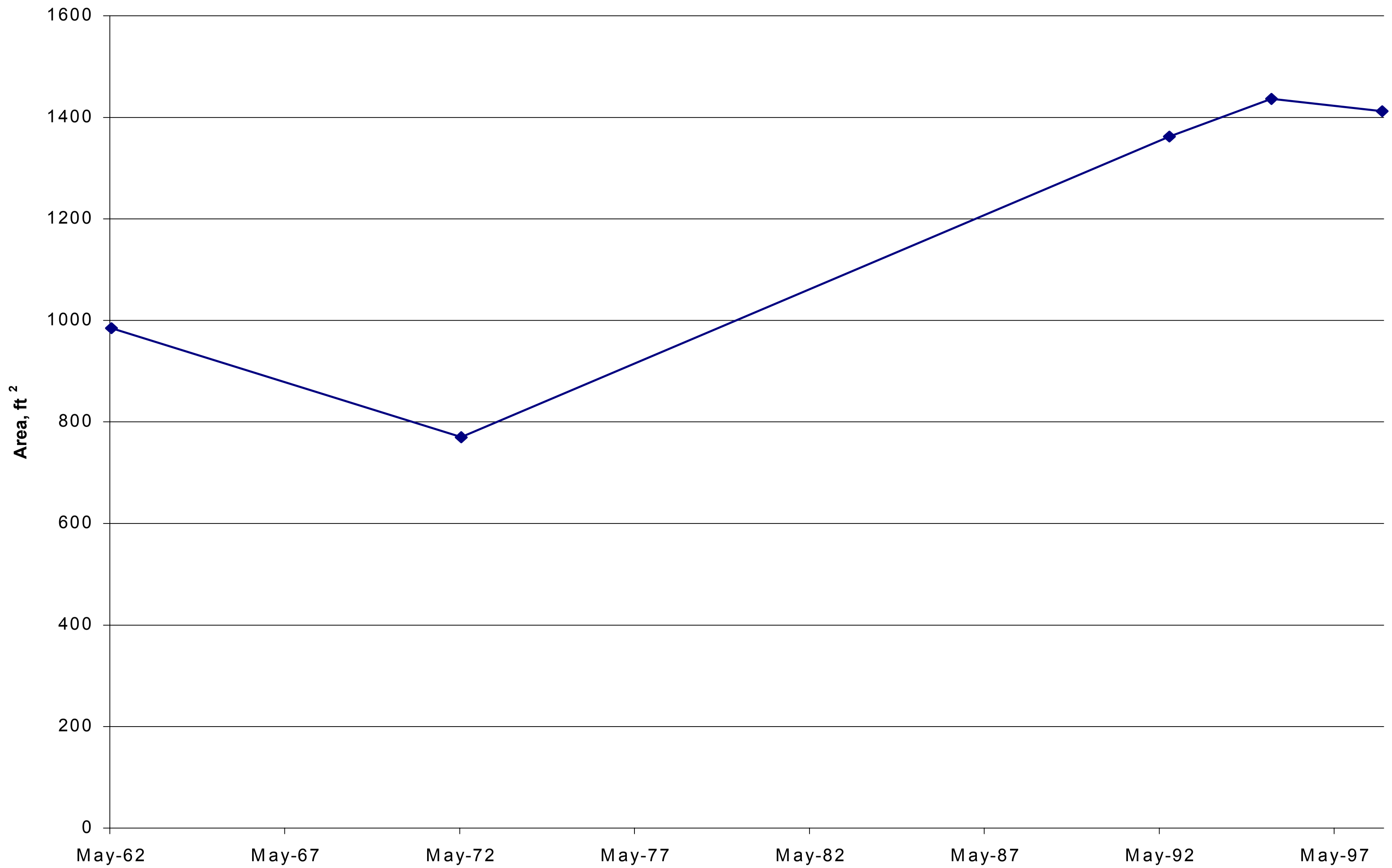

Figure E-53. Change in cross section area with time at cross section CO2-945.

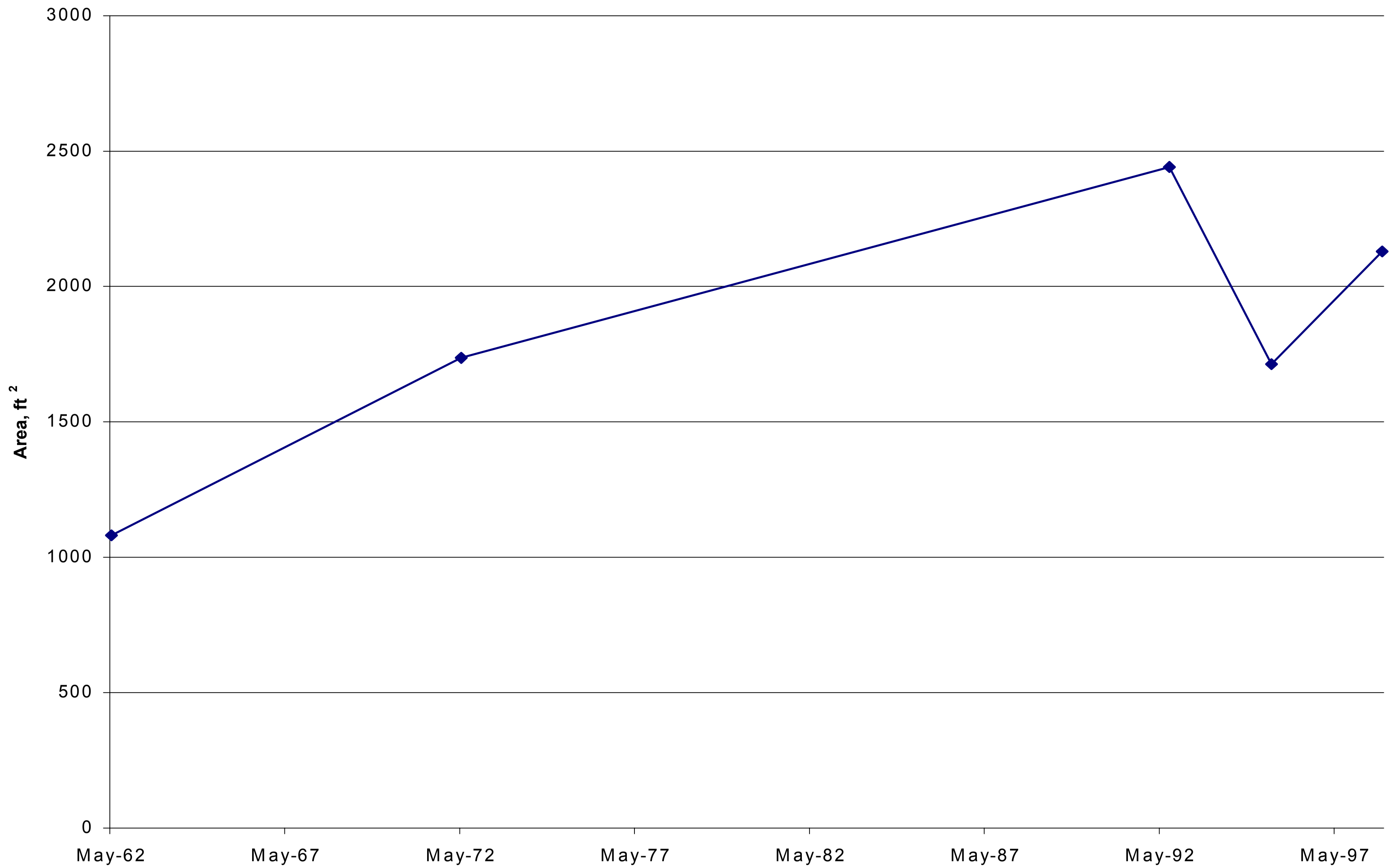

Figure E-54. Change in cross section area with time at cross section CO2-966.

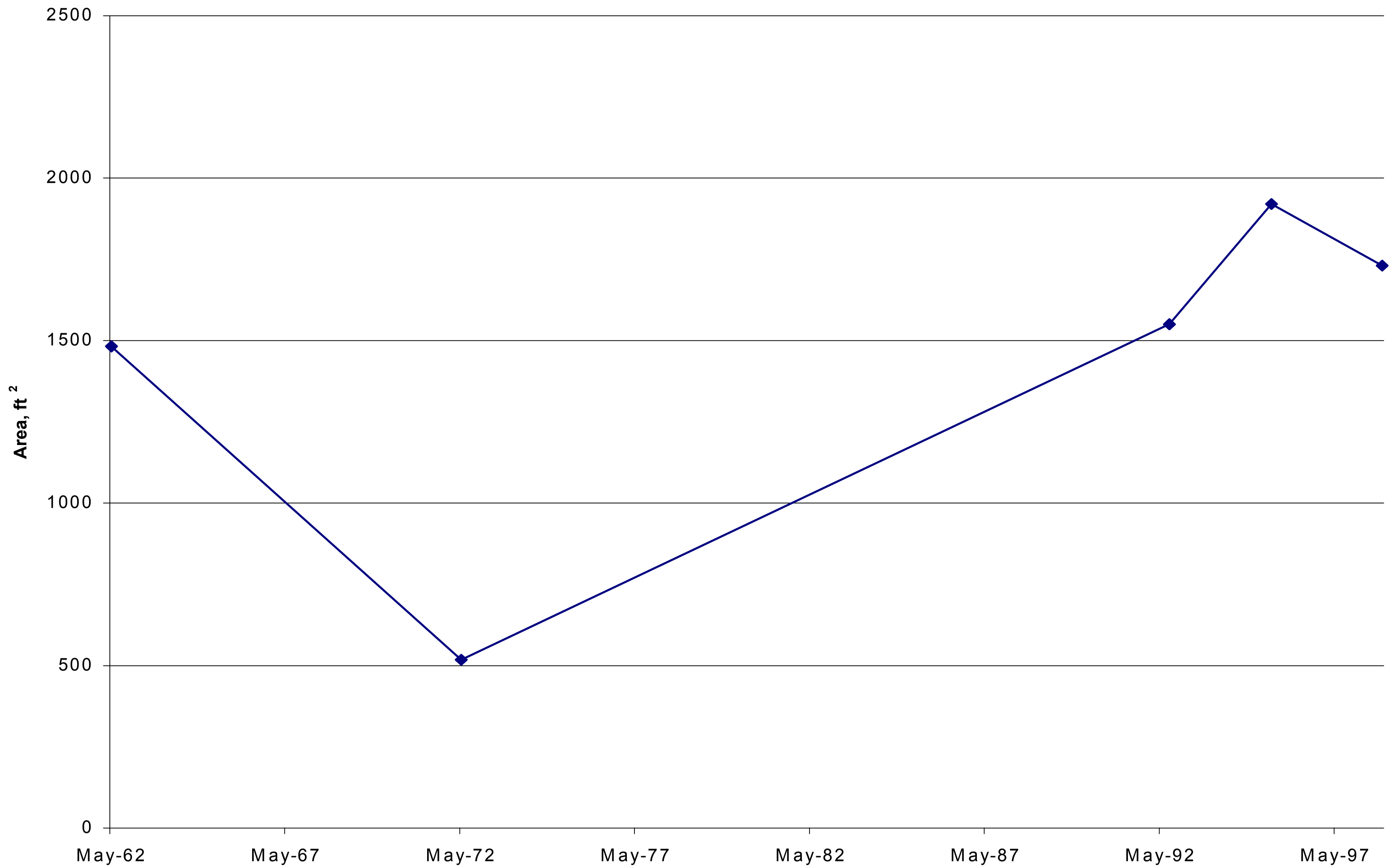

Figure E-55. Change in cross section area with time at cross section CO2-986.

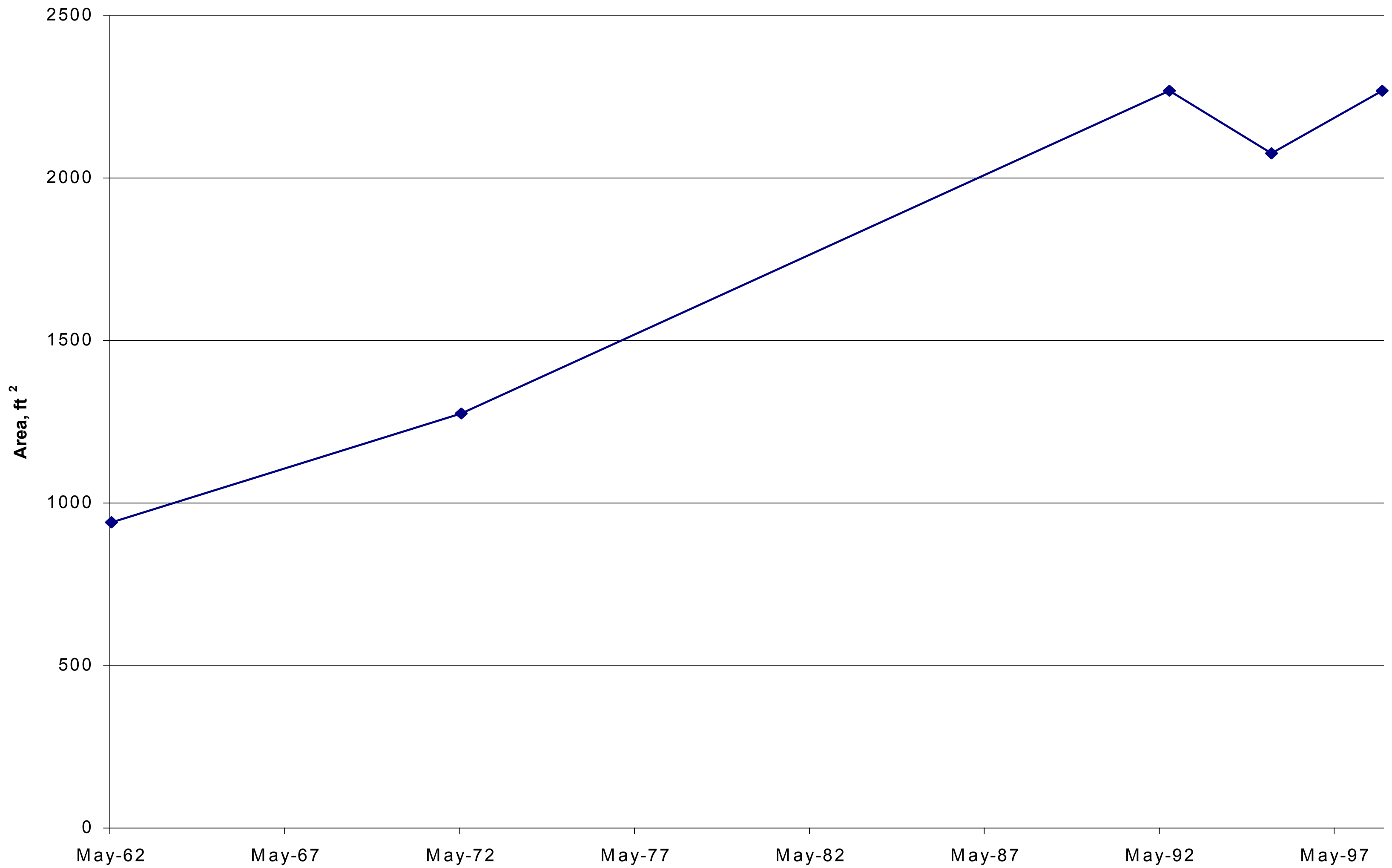

Figure E-56. Change in cross section area with time at cross section CO2-1006.

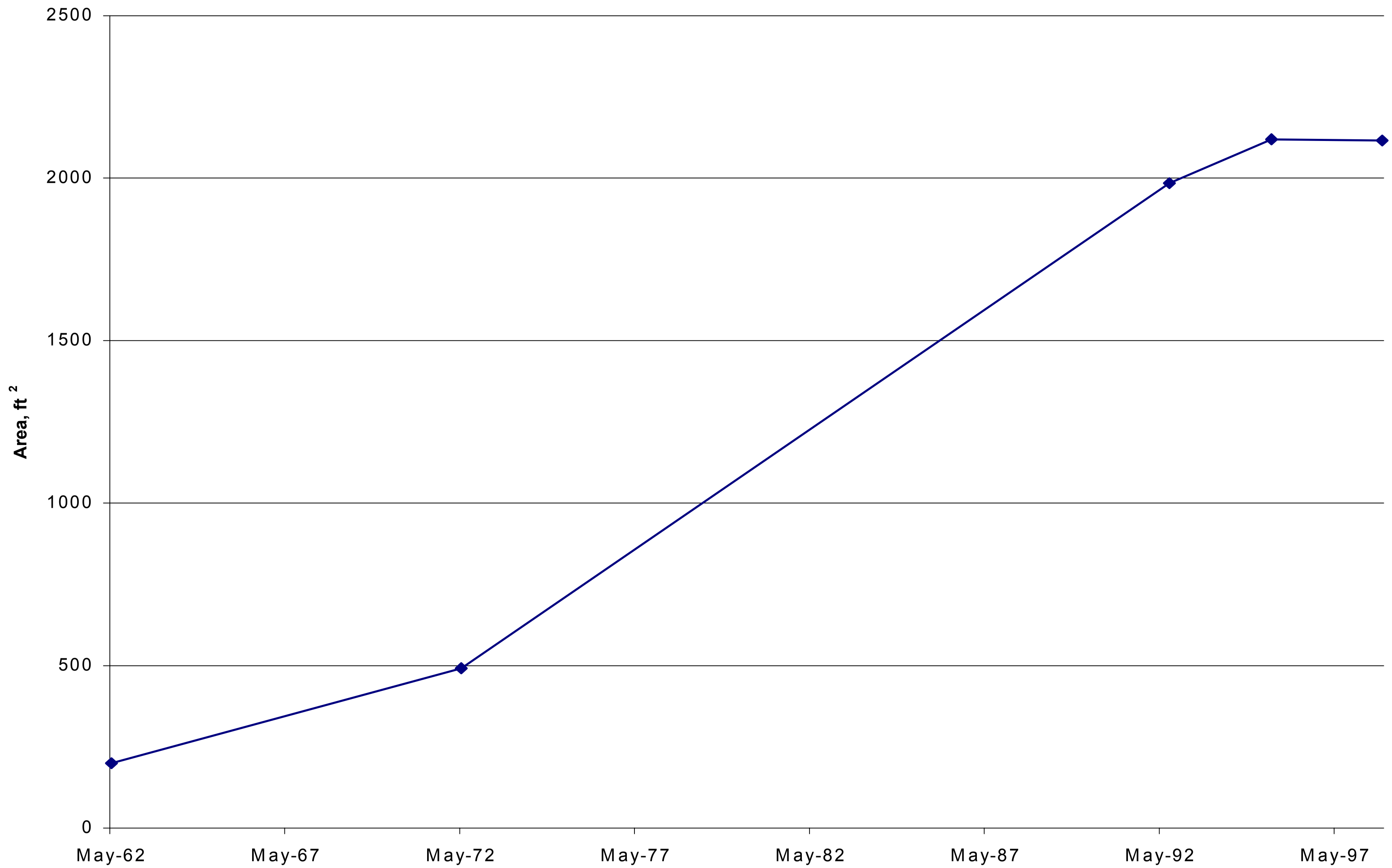

Figure E-57. Change in cross section area with time at cross section CO2-1026.

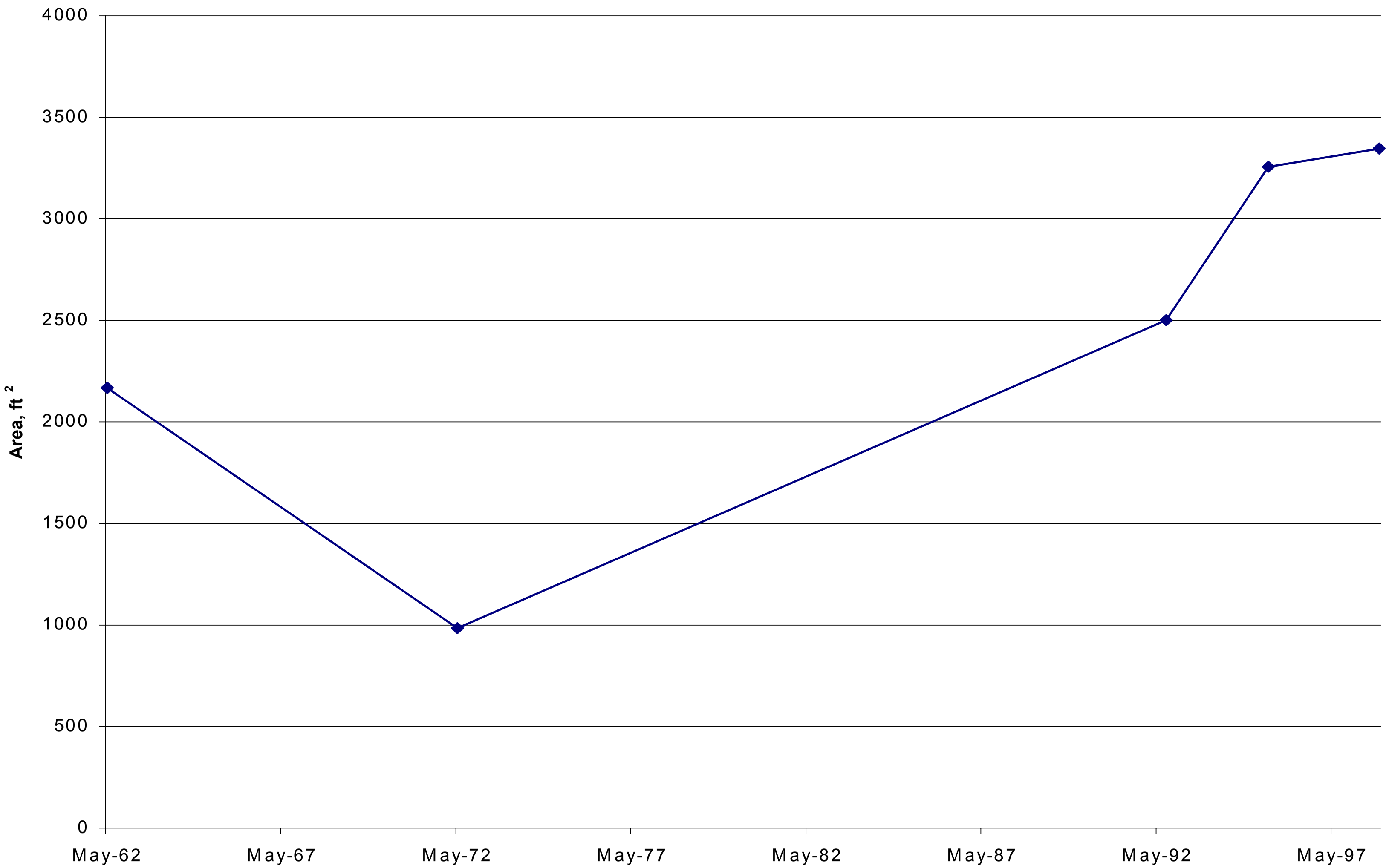

Figure E-58. Change in cross section area with time at cross section CO2-1044.

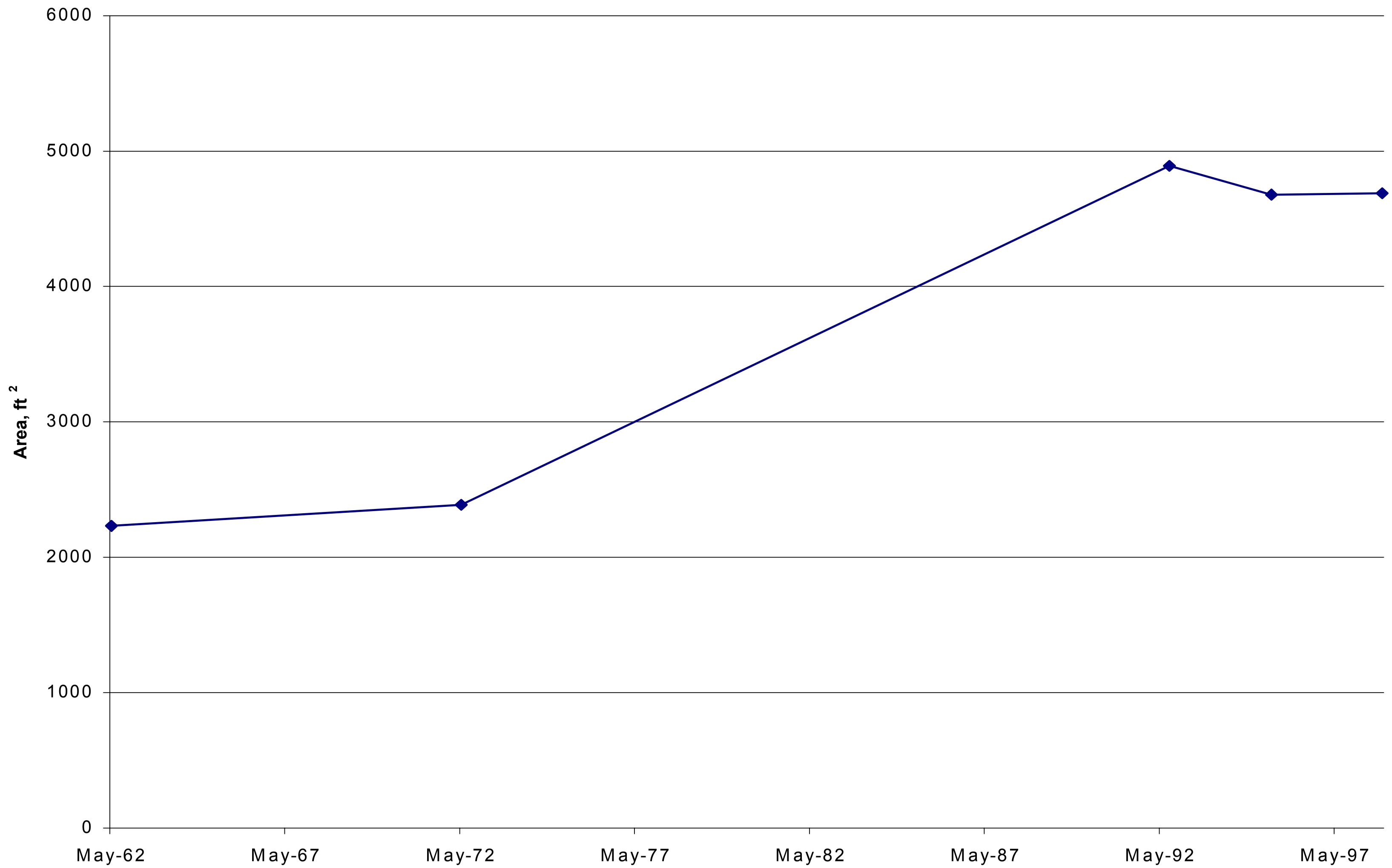

Figure E-59. Change in cross section area with time at cross section CO2-1064.

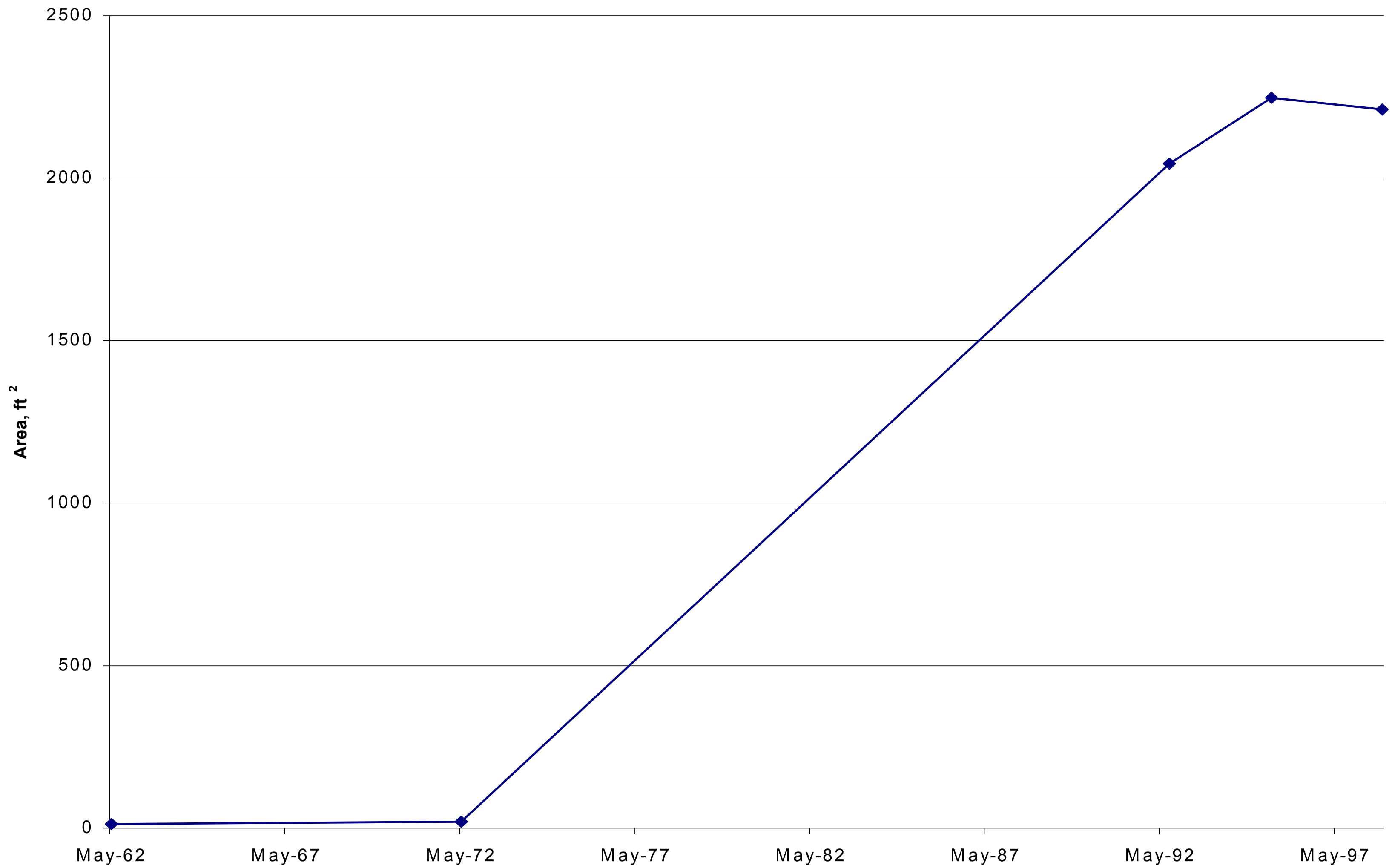

Figure E-60. Change in cross section area with time at cross section CO2-1091.

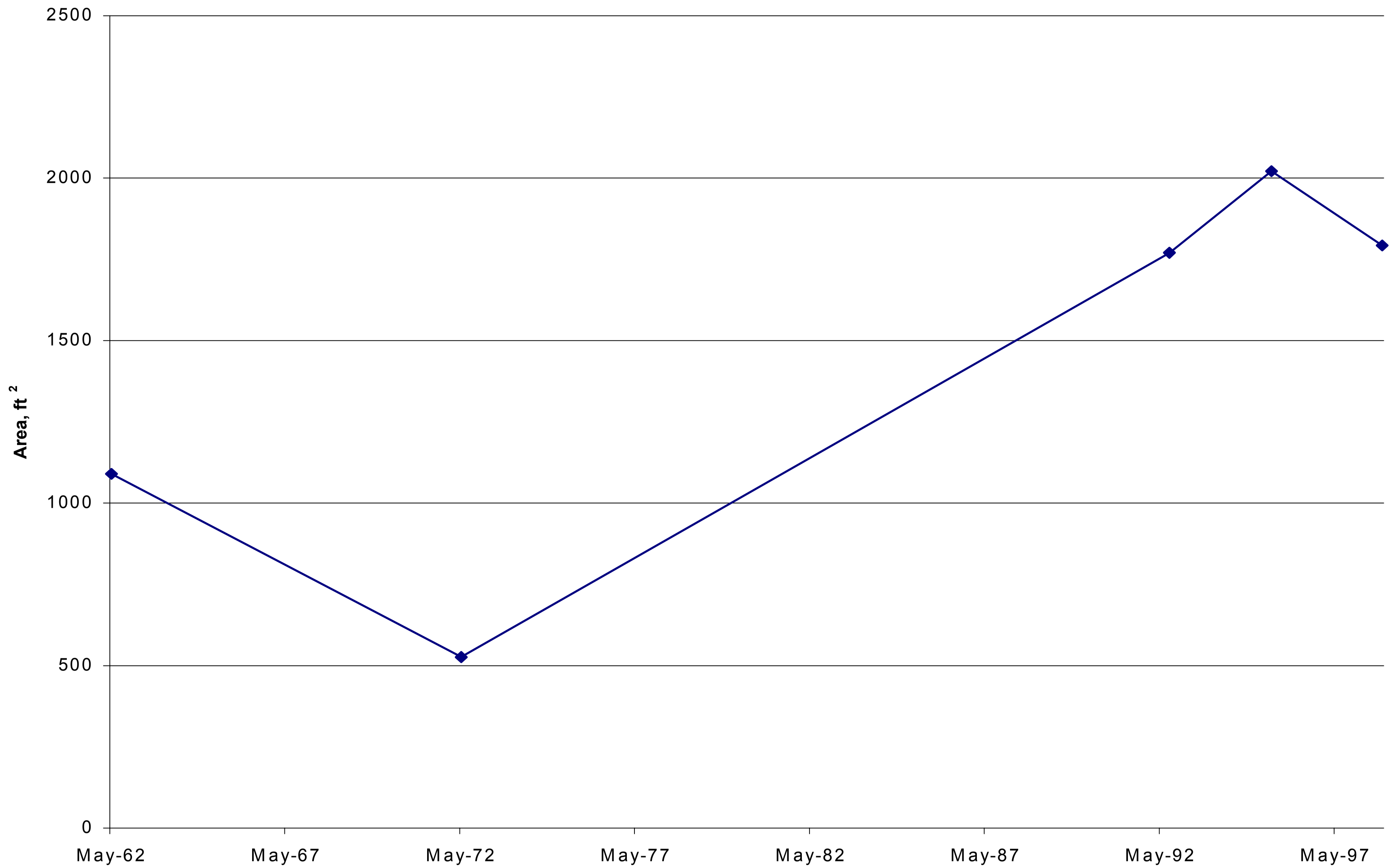

Figure E-61. Change in cross section area with time at cross section CO2-1104.

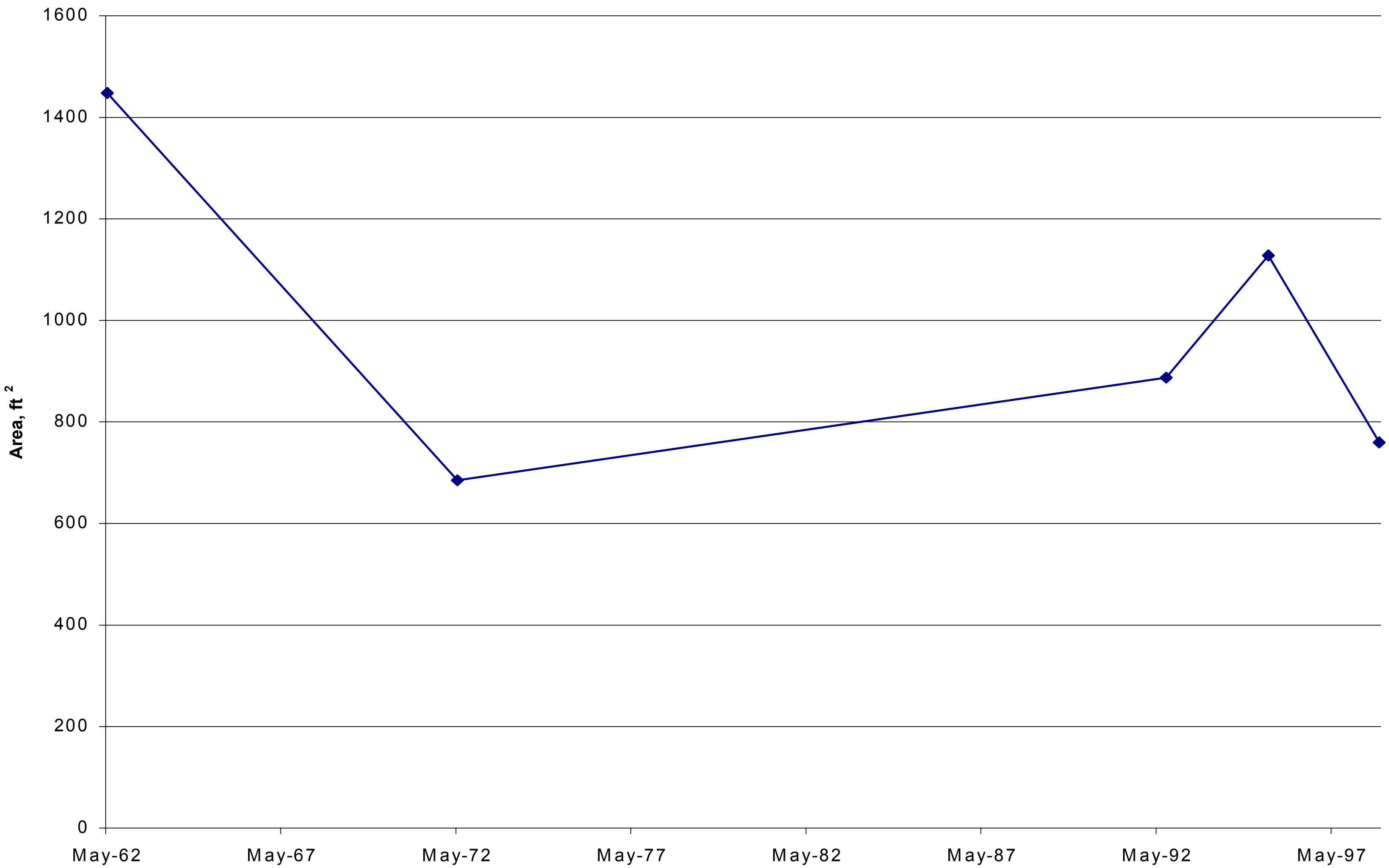

Figure E-62. Change in cross section area with time at cross section CO2-1164.

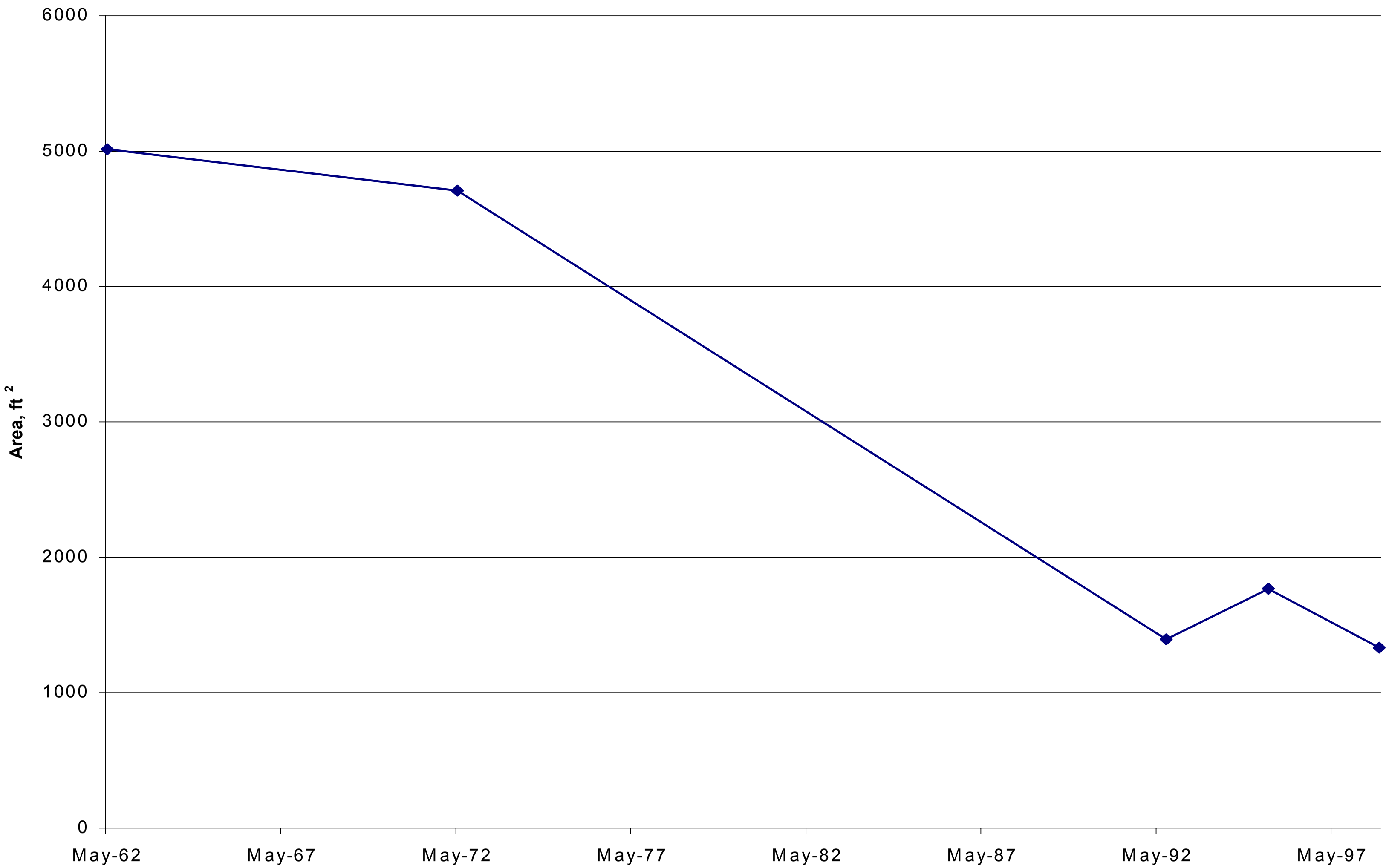

Figure E-63. Change in cross section area with time at cross section CO2-1179.

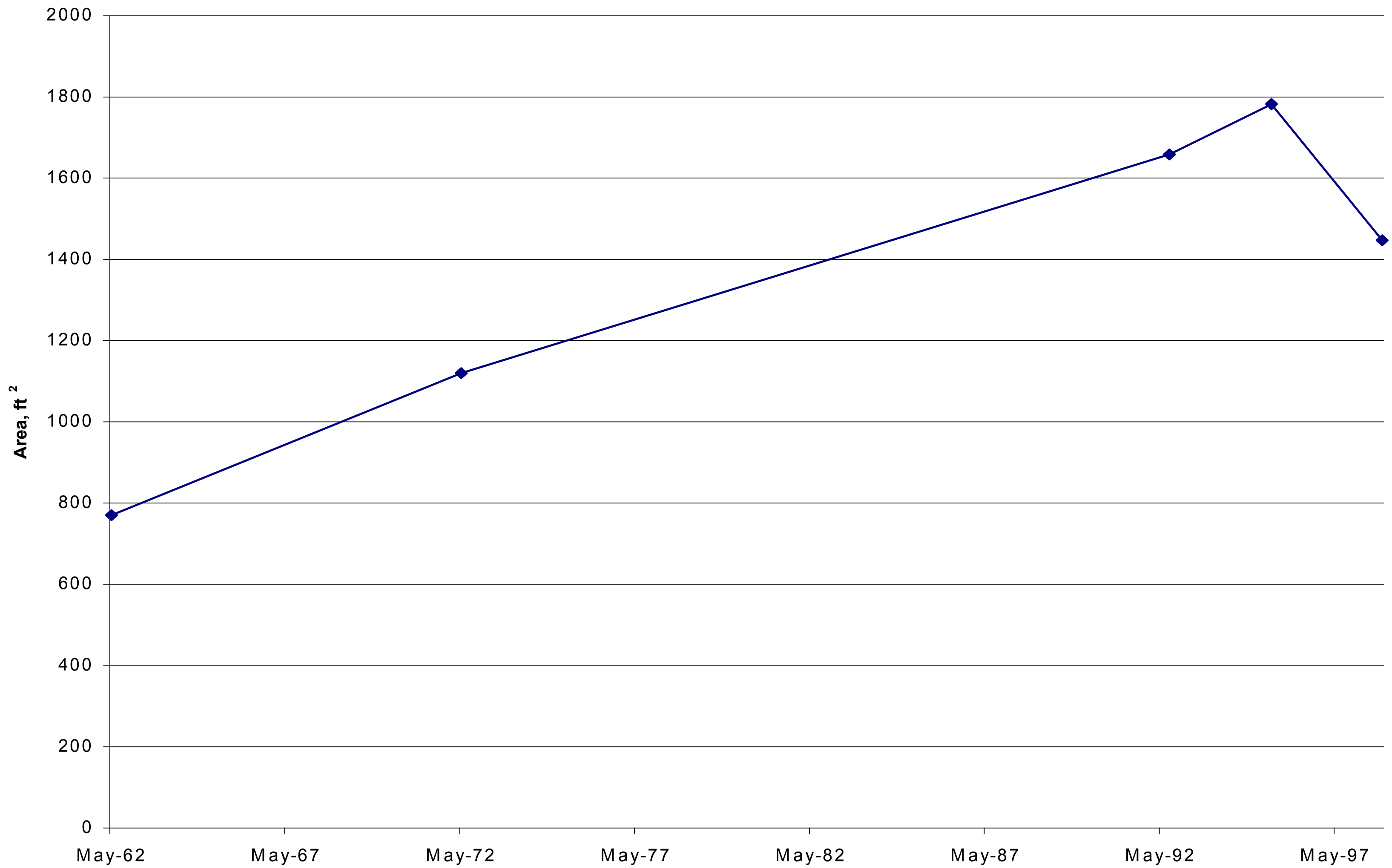

Figure E-64. Change in cross section area with time at cross section CO2-1194.