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Results and Analysis of STARS  
(Sediment Transport and River Simulation)  
Modeling Efforts of Colorado River in  
Grand Canyon

(U.S.) Glen Canyon Environmental Studies  
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RESULTS AND ANALYSIS OF  
STARS MODELING EFFORTS OF THE  
COLORADO RIVER IN GRAND CANYON

By

Timothy J. Randle

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February 1987

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# RESULTS AND ANALYSIS OF STARS MODELING EFFORTS OF THE COLORADO RIVER IN GRAND CANYON

By

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February 1987

## ABSTRACT

The Colorado River in the Grand Canyon has a large capacity to store sand along its streambed. Sand supplied by the tributaries will either be carried downstream by the main channel flow or stored on the streambed. Sand that is stored along the streambed is a possible source of material for beach deposition during high flow events. If there is little or no sand stored in the streambed prior to a high flow event the beaches could experience significant erosion. The Sediment Transport and River Simulation (STARS) model was used to evaluate the relative impacts of powerplant operations on the storage of sand in the main channel. Based on sand material in the streambed and that supplied by tributaries, the STARS model computed changes in sand-load transport, channel shape, and bed material size gradation with time for the Colorado River downstream from Lees Ferry.

## INTRODUCTION

Alluvial sand deposits (commonly referred to as beaches) along the Colorado River in the Grand Canyon are a critical resource to recreation, vegetation, and animal habitats. The ultimate source of these sand deposits is the tributaries in the Grand Canyon. Once sand from the tributaries enters the Colorado River it is either temporarily deposited on the streambed or transported downstream. Sand being transported in the main channel of the river can enter eddies or recirculating zones where it may deposit or there could also be a net loss of sediment from a recirculating zone. The stability of alluvial sand deposits is related to sand transport in the main channel. This report documents the relationships of flow releases from Glen Canyon Dam to the sand-load transport of the Colorado River's main channel.

The STARS (Sediment Transport and River Simulation) mathematical model was used to quantify the relative impacts of powerplant operation scenarios, at Glen Canyon Dam, on the Colorado River streambed in the Grand Canyon. Results from this study will be combined with other studies concerning rapids, eddy currents, and beaches in order to describe the system of the Colorado River and how it responds to operations at Glen Canyon Dam.

Use of the STARS model for the Glen Canyon Environmental Studies provides a predicted sand load at any river cross section within the Grand Canyon for any discharge. By routing different operation scenarios of the Glen Canyon Powerplant, comparisons of sediment transport are possible. This comparison of sand loads in the river under different operating patterns provides a means to evaluate the relative impacts of streambed erosion and deposition. Results

from these model studies will be used in conjunction with other studies on sandbar changes and eddy currents and many other studies for projecting the short and long term environmental impacts to recreation, fisheries, vegetation, and beach erosion in the Grand Canyon.

The STARS model was used to provide a mathematical simulation of movement of water and sediment through the Grand Canyon (figure 1). The model combines the mathematical procedure of computing river channel hydraulics with sediment transport equations in the prediction of sediment movement for any river discharge sequence. The unique feature of this one-dimensional steady-state model is the use of streamtubes (tubes of equal discharge) to vary the hydraulic and sediment transport characteristics across a cross section. This feature allows a more realistic representation of sediment movement within the cross section making STARS a pseudo two-dimensional model unlike many of the purely one-dimensional models. The STARS model automatically applies instantaneous rates of scour or fill to only small increments of time.

The STARS model was chosen for the Glen Canyon Environmental Studies for several reasons. The model has the ability to handle steep channels with bedrock outcrops and the input of water and sediment from tributaries. The model will allow the user to vary initial bed material conditions in three dimensions. Another reason was that the STARS model is easy to use and could be modified if necessary.

An additional model was developed for the Colorado River to augment the STARS model. The STAB (Sediment Transport Analysis Budget) model was constructed and run as a check on the STARS model. The STAB model computes a mass balance of sand between Glen Canyon Dam and the five sampling stations. Input to the STAB model is the discharge hydrographs at the dam and five sampling stations on the Colorado River plus discharge hydrographs for the Paria River, Little Colorado River, and Kanab Creek. Also needed is sand load-discharge rating curves for each sampling station on the main stem and tributaries. From this information the STAB model derives a sand-load hydrograph for the sampling stations on the main stem and tributaries. From the computed sand inflow and outflow from a reach the change in sand storage was determined for a given release scenario from the dam. Although the STAB model does not account for all the physical processes included in the STARS model, the STAB model was useful for short term analysis and provided a quick and inexpensive method to evaluate Glen Canyon Dam release patterns.

#### DESCRIPTION OF STARS MODEL

A complete description of the STARS model is presented by Orvis and Randle (1987). It is a one-dimensional, steady-state model which uses streamtubes to help simulate the lateral variation of hydraulic and sediment parameters. The model can be used either as a fixed bed or moveable bed model.

As a fixed bed model, water surface profiles are computed which gives water surface elevations and channel hydraulic characteristics for any discharge assuming an unchanged bed.

When used as a moveable bed model, cross section elevation coordinates and bed material size gradations are allowed to vary with time. Water surface profiles are computed for a given flow, and each cross section is divided into streamtubes of equal discharge. With the computed hydraulic properties for each streamtube and corresponding bed material size gradation, sediment transport rates are computed for each streamtube and the amount of scour or fill is determined. From the computed scour or fill a new size gradation of the bed is computed and the cross section coordinates are adjusted. The cross sections with updated bed material size gradations are used in the next time step. The process of combining channel hydraulics and sediment transport is then repeated for the next flow under a specified discharge hydrograph.

The STARS model was broadened in scope to handle a number of special features prevalent in the Colorado River through the Grand Canyon. One of the most difficult tasks was modeling the flow through the many rapids. The large boulders and rocks create a tremendous wave action at a rapid with the river tumbling down, over, and among the rocks. The rapids are a highlight to the rafters in the Grand Canyon. In addition to the large rocks at the rapids, the streambed consists of boulders and bedrock outcrops, smooth bottom areas of sand or gravel, and sediment waves (Wilson, 1987).

#### SUMMARY OF STARS MODEL VERIFICATION

Special efforts were made to make STARS applicable to the Colorado River with the bed controls created by the rapids and the variable streambed material as described above. A verification study was performed to make sure that STARS could be used on the Colorado River. This study was conducted on the reach of Colorado River from Glen Canyon Dam to Lees Ferry (Orvis and Randle, 1987). Surveys of river cross sections below Glen Canyon Dam before and after construction provided an good opportunity to test the models capability of predicting degradation below a dam.

The observed field data on the Colorado River below Glen Canyon Dam provided an opportunity to verify the model for use on the Colorado River. Surveys of cross sections and detailed bottom sediment sampling (Pemberton, 1976) were available before construction (1956) and subsequent to construction of the dam (1959 and 1965). The reach of river covered by these surveys was about 15 miles extending from Glen Canyon Dam to the mouth of the Paria River near Lees Ferry.

The model successfully predicted the volume of sediment removed using bed material and channel geometry obtained in 1956, prior to construction of the dam, along with recorded river discharges from February 1959 to September 1965. Cross sections surveyed in November 1959 and September 1965 were used to check the model. Although the dam was officially closed in March 1963,

degradation was initiated with clear water releases in 1959 because of closure of the construction cofferdam. Therefore, the beginning date of the model simulation was February 11, 1959, when the river was first forced through the right diversion tunnel. The report by Orvis and Randle (1987) describes the verification of the model for the 6.6 years (2,424 days) from February 1, 1959, to September 30, 1965. The verification consisted of simulating the volume of material removed from the 15-mile reach to an amount 11 percent higher than the measured volume.

## APPLICATION TO THE COLORADO RIVER

The STARS modeling efforts on the Colorado River were divided into two stages. The first stage was computing water surface profiles as a fixed bed in order to calibrate initial cross section data. The second stage was the simulation of sediment transport with a moveable bed.

Steep channels with rapids can present problems for water surface profile computations because of the transitions from subcritical to supercritical flow. The STARS model computed a continuous water surface profile for 225 miles of the Colorado River in the Grand Canyon. The important parts of this water surface profile are the reaches of river between the rapids and also the drop in water surface elevation through the rapids. Cross sections were carefully located at the bottom and crest of a rapid requiring no additional cross sections to represent geometries within a rapid. In general, the flow in the reaches of river between rapids is subcritical; the flow at the crest of the rapids is critical; and the flow in the rapids is a mixture of subcritical, critical, and supercritical regimes. When a computed water surface elevation was below the critical depth the water surface elevation was set equal to the critical depth.

The data requirements for the STARS model were initial cross section geometry and bed material as well as boundary conditions at the upstream and downstream ends. The downstream boundary condition consisted of water surface elevations varying with time. Upstream boundary information was provided for the main stem and tributaries. This information consisted of discharge, sand supply and size gradation, and water temperature each varying with time.

In the 225 miles of Colorado River from Lees Ferry to Diamond Creek, input to the model consisted of 199 measured or surveyed cross sections and 509 interpolated sections. This stage of the river simulation computed water surface profiles for a range in river discharge from 5,000 to about 90,000 ft<sup>3</sup>/s all the way from Diamond Creek to Lees Ferry. The computed water surface profile included elevations through all of the rapids. Values obtained were within about a foot of surveyed elevations by the Geological Survey Mapping Service and observed elevations at the sampling stations.

The second stage of the modeling efforts was the simulation of the river with a moveable bed. This meant the inclusion of sediment data to the model in the form of sediment supply at the upstream boundaries and initial bed material

conditions. Initial bed material conditions for the STARS model were determined from low level aerial photographs (taken in October 1984 at a river discharge of about 5,000 ft<sup>3</sup>/s), the bottom sediment identification described by Wilson, 1987, and the 976 bed material samples taken at the five sampling stations (Pemberton, 1987).

With the capability of STARS model to define streamtubes or areas of different bed materials in each cross section, the model was able to vary the sediment transport rates across the section. The bed material of the Colorado River was identified by Wilson (1987) to be of three types: boulders and bed rock, B; smooth bottom, S; and sediment waves, SW. The S type material, based upon limited samples, was assumed to be a sand and gravel mixture and the SW material was assumed to be predominately sand. The use of three streamtubes in STARS would adequately handle the three different bed material classifications.

The Toffaleti equation was used in all STARS model simulations. The report by Pemberton (1987) indicated that either the Velocity-Xi Adjusted Einstein or Toffaleti equations would be more applicable for the STARS model simulations of the Colorado River in the Grand Canyon. Both of these equations compute sand-load transport by size fraction and use a hiding factor to help simulate the armoring process. Since both of these equations predicted about the same sand load for a given discharge, the final decision was made based on computer costs. Calibration and verification runs in the sensitivity analysis showed use of the Toffaleti equation could reduce computer costs by a half.

The model provides information on hydraulic and sediment parameters at each cross section and shows changes with time and discharge. Thus, the relative impacts of the various flow scenarios at Glen Canyon Dam can be evaluated and comparisons made of sediment transport rates, the depths of scour or fill, and the net volume change in the streambed.

#### BASIC DATA REQUIREMENTS

Application of the STARS model to the Colorado River involved obtaining data on the two principal parameters: (1) river cross sections for the entire 225 miles for computing the channel hydraulics, and (2) bed material size gradation over the channel bottom. Also important to the above basic data requirements were the discharge hydrograph and sediment supply. Since the sediment supply to each reach of the Colorado River had been determined, the inflow of sediment to a given reach was used as a check on the model's computed outflow of sediment from the next upstream reach.

The channel geometry for 225 miles of the Colorado River was estimated from 708 cross sections. Of these 708 cross sections, 199 were measured with sonar and the remainder were interpolated using top widths from low flow aerial photographs, depths from a depth-profile survey, and side slopes similar to the 199 measured cross sections. The large number of interpolated cross sections were necessary because the model required four cross sections near each rapid

in order to compute a reasonable water surface profile. Calibration of the cross section data were performed by vertically adjusting the interpolated cross sections until the model's computed water surface profiles matched well with measured water surface elevations. Measured water surface elevations were obtained from the following sources: The five sampling stations (1983 and 1985-86); the 1923 water surface profile, adjusted for a discharge of 10,000 ft<sup>3</sup>/s from observed elevations (Birdseye, 1923); the Geological Survey Mapping Service measurements at 15 major rapids; and 1983 high water marks collected in May 1985.

### STARS HYDRAULIC COMPUTATIONS

The backwater features of the STARS model were used to calibrate the channel geometry for eventual use in the sediment transport aspects of the model. Water surface elevations were computed assuming steady-state conditions using the standard step method. The downstream boundary water surface elevations were expressed by a stage-discharge rating curve developed by computing critical depth starting at a section near the crest of a downstream rapid. From the initial water surface elevation, calculations proceed upstream satisfying the conditions of conservation of energy. The friction slope was computed using the Manning's equation. A Newton algorithm with special checks for convergence problems was used to solve the energy, normal depth, and critical depth equations. An important feature of the model, because of numerous rapids, is the special treatment of critical water surface elevations at the crest of a rapid. When water surface elevations are computed below the critical depth, the model brings the water surface up to the critical depth.

To provide a better control on operation of the model and to utilize the sediment data being collected at the five sampling stations, the 225 miles of Colorado River were subdivided into five subreaches. The five subreaches are as follows:

<u>Reach</u>	<u>Length-Miles</u>
0 - Glen Canyon Dam to Lees Ferry	15
1 - Lees Ferry to Little Colorado River	61
2 - Little Colorado River to near Grand Canyon	26.5
3 - Near Grand Canyon to National Canyon	78.5
4 - National Canyon to Diamond Creek	59.5

### **CROSS SECTION DATA**

Cross sections used to define channel geometry were obtained during the depth sounding survey made by the Geological Survey in April-May 1984. A total of 212 cross sections were surveyed at that time from Lees Ferry to Diamond Creek.

A high frequency sonar was used to trace the water depths of the Colorado River below Lees Ferry in March 1984. In many cases, the depth profile

approximated the thalweg profile. The depth profile, along with the surveyed cross sections and 1984 aerial low flow (5,000 ft<sup>3</sup>/s) photos, provided basic data on existing (1984) conditions. Elevation adjustments were made to the 1984 cross section and depth survey data to derive a mean sea level streambed profile utilizing (1) the 1923 profile and strip topography surveyed by Colonel C. H. Birdseye (1 inch = 1/2 mile), (2) the May 16, 1973, aerial photographs (1 inch = 600 feet), and (3) the low level aerial photographs of October 21 and 22, 1984, (1 inch = 250 feet). The dates on which river data were collected along with river mile location and mean daily discharge at the Lees Ferry and Grand Canyon gages are given in table 1 for the five reaches.

The Birdseye (1923) profile was first assumed to vary with discharges during August 1 to 13, 1923 (table 1). This assumption had been made because the discharge was uncontrolled and did vary during the Birdseye expedition. Also, the 14 strip topographic maps and 7 profiles surveyed in 1923 titled "Plan and Profile of Colorado River from Lees Ferry, Arizona, to Black Canyon Arizona-Nevada, and Virgin River, Nevada" gave no information on the river discharge for the 1923 profiles. During the study, information was obtained from Water Supply Paper 556 by E. C. LaRue in the footnote on page 53 as follows: "For that part of the river below Lees Ferry the figures given indicate the elevation of the water surface at low water have been obtained by adjusting the recorded data so as to represent the elevation when the discharge of the river is 10,000 second-feet." A search was made of background material for the 1923 Birdseye Survey and Water Supply Paper 556 through the NCIC (National Chart and Information Center) at the Geological Survey Mapping Service and the National Archives. To date no information was found on either the original field notes or the procedure used to adjust the profile to the 10,000 ft<sup>3</sup>/s discharge.

The cross section and depth profile data were converted to proper format for use in the backwater computation in the STARS program. The first phase of this conversion was the digitization of the depth profile of 1984 and the 1923 profile and then the plotting of the two profiles together as shown on figures 2 through 17. The water surface elevations in 1984 were assumed to be parallel to the 1923 profile, thus providing a means to compute elevations for the unadjusted 1984 streambed profile.

The 199 cross sections sounded in 1984 were also digitized assuming the 1984 water surface profile was parallel and for computation purposes equal to the 1923 profile. Channel widths to represent the zone between the boat and riverbank were taken from the 1984 aerial photographs for river miles 0 to 210 and from the 1973 photos for river miles 210 to 226. Location of the cross sections and horizontal controls on the 1984 depth profile were based on topographic features on the 1923 strip topography, and the 1973 and 1984 aerial photographs.

All of the cross section and profile data were collected by the Tucson Office of the Geological Survey with the digitizing done by the Bureau of Reclamation office in Durango.

Data used to check and adjust the 1984 measured depth profile and cross sections to a mean sea level elevation consisted of the five stage-discharge rating curves for the sampling stations on the Colorado River, 21 water surface elevations surveyed by the Geological Survey Mapping Service during February-March 1985, and high-water marks for the peak flow of about 95,000 to 96,200 ft<sup>3</sup>/s in June 1983 as surveyed in May 1985 at 19 locations.

The Manning's roughness coefficient ( $n$ ) selected for use on the Colorado River below Lees Ferry was 0.035. The  $n$  of 0.035 for the river below Lees Ferry was based on a field inspection of the river and observed changes in streambed below Lees Ferry. It is slightly higher than the 0.033 computed by Pemberton, 1976, for the reach above Lees Ferry but is considered better for the reach below Lees Ferry because of increased roughness and increased turbulence. With the numerous rapids and critical depths, the computed water surface elevations are less sensitive to a change in  $n$  values than those computed for rivers with milder slopes.

**Measured Sections.** - There were 212 measured sections in the 225 miles from Lees Ferry to Diamond Creek. An attempt was made to measure the cross sections perpendicular to the flow, but because of strong currents this was not always possible. Corrections for skewness were made to cross section data where necessary. The number of sections was reduced to 199 surveyed sections in the STARS model due to severe skewness of some sections and excessive computer time required for running STARS when sections are disproportionately close together. The survey dates for these measured sections are shown in table 1.

A preliminary study was made to determine if the water surface profiles could realistically be computed by use of only the 199 measured sections. This study was made for a short reach with a rapid between measured sections. The results clearly showed that the computed channel hydraulics and especially the slopes and velocities at a section were extremely high when only using measured sections without cross sections interpolated at a rapid. Any sediment transport computations with these high velocities would be unrealistic. For this reason, there was a definite need to develop interpolated sections on the river to help define the rapids or controls in the river as shown by the 1923 water surface profile (figures 2 through 17).

**Interpolated Sections.** - The 509 interpolated sections in the 225 miles of river were developed to hydraulically define the changes in water surface elevations above and below each rapid or control point in the river as shown by the breaks in the observed water surface (figures 2 through 17).

The criteria used to develop the interpolated cross sections was to rely almost entirely on the surveyed data. Each interpolated section was first located on the October 1984 low level photograph ( $Q$  about 5,000 ft<sup>3</sup>/s) or on the 1973 photographs for the 15 miles of river just above Diamond Creek. All interpolated sections were assumed to have a trapezoidal shape. The bottom elevation was taken directly from the depth profiles (figures 2 through 17).



The top widths were measured from the aerial photographs. The scale of these photographs was about 250 feet per inch for 1984 and 600 feet per inch for 1973 with some adjustments for distortion of the photos. The underwater side slopes were made equal to average side slopes of the measured sections within the reach under study. The side slopes above the water surface were extended, based on either the upper portion of the measured sections or photographic inspection, to either vertical banks or 2:1 side slopes.

The other criteria for including interpolated sections was location with respect to a rapid. A section was located near the downstream toe of the rapid. A second section was added at the crest, and a third about 50 feet upstream. An additional section was needed 150 feet upstream from the crest of the rapid in order to properly account for bed material areal coverage. Those interpolated sections with eddy currents below a rapid were reduced in top width to the width of the cross section with active downstream flow patterns. For any interpolated sections where the aerial photographs showed sandbars on the bank caused by eddies, the top widths were corrected to reflect only the downstream portion of the flow.

#### WATER SURFACE PROFILE CALIBRATION

The objective of calibrating cross section data for the Colorado River was to determine the best possible river hydraulic data for use in computing sediment transport in the STARS model. To develop the appropriate geometric data, all of the basic data described above were used in deriving the 708 cross sections adjusted to mean sea level datum. One source for calibration of the computed profiles was possible because the Rocky Mountain Mapping Center of the Geological Survey was conducting field surveys for the 7-1/2-minute Quad Sheet Mapping Program. With additional funds from the Bureau of Reclamation they obtained water surface elevations above 21 major rapids during February-March 1985 shown in table 2.

The 1923 water surface profile was presented for a discharge of  $10,000 \text{ ft}^3/\text{s}$ . Elevations for the cross section coordinates were computed by subtracting the measured depths from the water surface elevation given by the 1923 profile. However, the cross section depths and depth profile were measured at a discharge of about  $25,000 \text{ ft}^3/\text{s}$ . Thus, the computed cross section elevation coordinates would be at a datum below mean sea level and would later be adjusted to a datum of mean sea level.

The computed water surface profile for a discharge at the time when the cross sections were measured should match the 1923 profile. Interpolated cross sections were added and adjusted until a good match between the computed and measured profiles was obtained. Then a water surface profile was computed for a discharge of  $10,000 \text{ ft}^3/\text{s}$  which gave elevations below and approximately parallel to the 1923 profile (see figures 2 to 17). The elevation difference between these two profiles was computed to determine the proper elevation adjustment for the cross sections to reflect a mean sea level datum.

Water surface profiles were computed for discharges of 25,700; 24,300; 24,800; and 24,900  $\text{ft}^3/\text{s}$  for reaches 1, 2, 3, and 4, respectively. These discharges corresponded to the weighted mean river discharges when the depth profiles were run on March 1-10, 1984 (table 1). A list of all the measured and interpolated sections used in the water surface profile computations is given in table 3. Most of the interpolated sections were added to give the best possible match for the river discharges in March 1984 with the 1923 profile. The results of the water surface profile computations (for discharges of 25,700; 24,300; 24,800; and 24,900  $\text{ft}^3/\text{s}$ ) were compared to the 1923 profile to determine the elevation correction of the 1984 thalweg profiles to arrive at a mean sea level datum.

A comparison was made of the 1923 profile with the computed profiles for the 1984 discharges (figures 18 through 23). The locations listed below indicate points on the river where a good match (within 1 foot) was not possible.

<u>Reach</u>	<u>Location</u>	<u>River Mile</u>
1	24 Mile Rapid	24.05
1	Buck Farm Canyon	41.09
1	Kwagunt Rapid	55.72
2	Little Colorado River	61.31
2	Unkar Rapid	72.35
2	Near Grand Canyon Gage	87.37
3	Crystal Rapid	98.17
3	Bass Rapid	107.98
3	Hakatai Rapid	110.80
3	Waltenberg Rapid	113.83
3	Kanab Creek Rapid	144.20
3	Near 164 Mile Rapid	163.12
4	Lava Falls	179.22
4	Below River Mile 183	183.00
4	Below River Mile 213	213.00
4	Above River Mile 219	219.00

Some of the differences were caused by interpolated cross sections having too high an elevation at the rapid. The depth profile when surveyed in 1984 may have missed the low point at the rapid crest, or side canyon inflows at the rapid may have raised its crest between 1923 and 1984. At six of these locations it was possible to calibrate the computed water surface elevations with the observed elevations from the 1985 Geological Mapping Service data (table 2). Tributary inflow was a definite cause for change as exemplified by Unkar Creek and Bright Angel Creek at river miles 72.35 and 87.37. Throughout most of the river, the comparisons on figures 18 through 23 were close. The 1923 profile could not be very precise because straight lines were drawn between original survey points and adjustments were made to the 1923 survey data to reflect a discharge of 10,000  $\text{ft}^3/\text{s}$ .

## ADJUSTMENT TO DEPTH PROFILE

The streambed profile shown on figures 18 through 23 does not represent a mean sea level elevation. The technique selected to adjust the streambed elevation to a mean sea level datum was to determine the differences in elevation between the computed 10,000 ft<sup>3</sup>/s (1923) and the 1984 computed elevations. This difference,  $h$ , was computed at those cross sections where critical discharge occurred. Other cross sections influenced by backwater fluctuations due to velocity head or eddy losses were avoided. The sections selected are shown in table 4 and subdivided by reaches. The average adjustment was +4.0 feet for reach 1 and +5.0 feet for reaches 2, 3, and 4. In reach 1, the elevation datum adjustment was +3.3 feet upstream from river mile 20.48. The +3.3 feet adjustment was required to provide a better check on the stage-discharge relationship at the Lees Ferry gaging station. The physical reason for this special adjustment for cross sections upstream from river mile 20.48 was a general break in slope of river at the point shown on figure 18.

## WATER SURFACE PROFILES

The test on reliability of the adjusted cross sections to 1984-1985 conditions was checked by comparison of the computed water surface elevations (after elevation datum adjustment) with observed elevations from the three sources; Geological Survey Mapping Service surveys (table 1), stage-discharge relationships at the sampling stations, and high water marks surveyed in 1985. The Geological Survey Mapping Service elevations are considered to have an accuracy of plus or minus 1 foot. The gaging station data is better than the 1 foot while the high water marks are probably plus or minus about 5 feet. Results of the water surface profile computations are described by reaches.

**Reach 1.** - The computed water surface elevations for a discharge of 27,700 ft<sup>3</sup>/s checked well against the water surface elevations at 36 Mile Rapid, President Harding Rapid, and at the mouth of the Little Colorado River, which were surveyed in 1985 by the Geological Survey. Nankoweap and Kwagunt Rapid showed a computed water surface 4.4 feet lower and 3.3 feet higher, respectively, just above the crest of these two rapids. By moving upstream for Nankoweap Rapid or less than 53 feet downstream for Kwagunt Rapid, a better check on the observed water surface was possible as shown in table 5. Differences in the computed elevations of 0.3 foot and 0.5 foot downstream from Nankoweap and Kwagunt Rapid, respectively, are shown in table 5. A plot of the 27,700 ft<sup>3</sup>/s computed water surface profile along with the 1985 surveyed water surface elevations above the five rapids is shown in figure 24. Also plotted on figure 24 are the water surface elevations from the rating table at the Lees Ferry gage. For a discharge of 27,700 ft<sup>3</sup>/s, the computed water surface elevation of 3117.85 feet checks very well with the rating curve at the gage (table 7).

A comparison of the computed water surface profile for 10,000 ft<sup>3</sup>/s after adjusting the streambed elevations to mean sea level datum was made with the 1923 Birdseye profile for 10,000 ft<sup>3</sup>/s shown on figure 25. There are several

areas shown on figure 25 with significant differences between the two profiles. The major differences are in the reach near river mile 10 or just above Soap Creek Rapid and at the mouth of Little Colorado River. These differences could easily be due to the procedure used to adjust the 1923 survey to a 10,000 ft<sup>3</sup>/s discharge or to physical changes in the streambed occurring between 1923 and 1984. Other differences in the profiles shown on figure 25 are considered minor based on accuracy of the surveys by Birdseye in 1923, the adjustment to develop the 1923 profile, and the 1984 survey.

Another check on the computed water surface profiles after adjustment was for the peak discharge in June 1983. High water marks at several points, surveyed in May 1985, and the stage-discharge relationship at the Lees Ferry gage for a peak discharge of about 95,000 ft<sup>3</sup>/s are compared in tables 7 and 8. The comparison of high water marks (table 8) is erratic with computed values being both higher and lower than the observed. Location of a good high water mark after about 2 years is questionable, with the Lees Ferry gage considered the most reliable (table 7). The Manning's n value of 0.035 gave a computed elevation of 3125.2 or 1.0 foot high at the Lees Ferry gage which was reduced only 0.2 feet by using a roughness coefficient n of 0.02 as shown in table 8. The plotted profile for 95,000 ft<sup>3</sup>/s along with the observed elevations is shown on figure 26.

The most reliable check on adequacy of the adjustments in the streambed profile as well as location of interpolated cross sections is the comparison of computed water surface elevations with the Lees Ferry gage data (table 7). The small differences between computed elevations and elevations from the stage-discharge rating table were possible by changing the adjusted streambed elevations or h by 3.3 feet for the reach upstream from river mile 20.48 as described previously. Plotted water surface profiles for discharges of 5,000; 7,500; 17,000; and 24,000 ft<sup>3</sup>/s are shown in figure 27.

An interesting check on observed data is the note in Birdseye's diary in 1923 where he gives an actual elevation of water at the mouth of Little Colorado River as 2,718 feet on August 13, 1923. On August 13, 1923, the discharge at Lees Ferry (table 1) was 22,300 ft<sup>3</sup>/s. The computed water surface elevations as plotted on figure 27 at the river mile 61.32 are 2719.4 feet for 17,000 ft<sup>3</sup>/s and 2720.4 feet for 24,000 ft<sup>3</sup>/s. Although the influence of inflow of water from Little Colorado River on water levels or actual discharge at the time the Birdseye water elevation was surveyed is not known, the above comparisons are close.

**Reach 2.** - The comparison of computed water surface elevations with observed elevations shown in table 5 for reach 2 shows values downstream from each rapid or control from 0.8 to 3.0 feet lower than the observations. This difference is probably due to the assumptions made in the interpolated cross sections at the point of measurement. The difference of 3.6 feet below the observed elevation just above the Unkar Rapid would also be due to the interpolated cross section. Change in location or elevation of the interpolated sections could improve the comparison, but the values given in table 5 and plotted on figure 28 are well within the accuracy of the computations.

A comparison of the computed water surface profile for 10,000 ft<sup>3</sup>/s after adjusting the streambed elevations by 5.0 feet (to account for mean sea level datum) was made with the 1923 Birdseye profile shown in figure 29. The differences between these profiles are possibly due to changes as previously mentioned at the mouth of Unkar Creek and at Bright Angel Creek plus those based on accuracy of the surveys by Birdseye in 1923, the adjustments to develop the 1923 profile, and accuracy of the 1984 survey.

A check on the high water marks for the June 1983 peak flow of 96,200 ft<sup>3</sup>/s is given in the plot on figure 30 and in table 8. By reducing the Manning's roughness coefficient (n) to 0.02, a check to within 1 to 2 feet was possible for Unkar and Hance Rapids. The computed water surface at the Grand Canyon gage was 2 feet higher than gage height records for the 96,200 ft<sup>3</sup>/s discharge. The 2-foot difference is acceptable considering the accuracy of the computed as well as the observed water surface elevations.

The comparison of computed elevations with observed data for the gage near Grand Canyon at river mile 87.37 is shown in table 7. The gage data and the other comparisons proved a good check on the adjustments of 5.0 feet on streambed, the Manning's n of 0.035, and the use of interpolated cross sections for reach 2. There was a slight improvement in the computed water surface at the peak flow of 96,200 ft<sup>3</sup>/s by reducing the Manning's n from 0.035 to 0.02. The plotted water profiles for discharges of 5,000; 7,500; 17,000; and 24,000 ft<sup>3</sup>/s are shown on figure 31.

**Reach 3.** - The estimated discharges at each of the rapids at the time of the survey of February-March 1985, by the Geological Survey Mapping Service were computed by adjusting the discharges at the Grand Canyon gage with appropriate travel times. Travel times were based on a mean velocity of 6 ft/s or 4 mi/h. The 6 ft/s was an average from the water surface profile computations at the 24,800 ft<sup>3</sup>/s discharge. The estimated discharge computations at each of the 10 rapids in reach 3 are given in table 6. The estimated discharges are also shown in table 2. Table 6 shows the average discharges used in the computer computations for obtaining computed water surface elevations at each of the 10 rapids.

The comparison of computed water surface elevations with observed elevations (see table 5) shows values downstream from each rapid or control matching from -1.8 to +0.6 foot (except for Bass Rapid) with most values within 1.0 foot. Above the rapids good agreement between computed and observed elevations was obtained near the brink of the rapid and a section 53 feet upstream from the brink with differences varying from -1.2 to +1.4 feet. Observed elevations further upstream from the rapid showed greater differences with the greatest difference of +2.0 feet, +3.2 feet, and -1.7 feet, occurring at Bass, Blacktail, and Kanab Creek, respectively. The above differences are probably due to the assumptions made in the interpolated cross sections at and below the point of measurement. The process of obtaining even this good a check with observed values as shown in table 5 included moving or adding interpolated sections with minor adjustments in streambed or width. The values

shown in table 5 and plotted on figures 32, 33, and 34 are well within the accuracy to be expected in these computations.

A comparison of the computed water surface profile for 10,000 ft<sup>3</sup>/s after adjusting the streambed elevations by 5.0 feet (mean sea level datum adjustment), was made with the 1923 Birdseye profile shown in figures 35, 36, and 37. The differences between these profiles are primarily due to changes caused by adding or adjusting the interpolated cross sections to obtain better agreement with the observed Geological Survey Mapping Service elevations shown in table 5. More credibility was placed on the observed elevations obtained in 1985 than the 1923 profile because the data are more recent, modern survey techniques should be more accurate, field data adjusted by Birdseye to develop the 1923 profile at 10,000 ft<sup>3</sup>/s.

A check was made on the high water marks for the June 1983, peak flow of 96,200 ft<sup>3</sup>/s. This comparison is given in table 8 with the results plotted on figure 38. Water surface profiles for the 96,200 ft<sup>3</sup>/s discharge were computed with Manning's n values of 0.035 and 0.02. The n of 0.02 as shown in table 8 gave the best check on the high water marks. Computed values given in table 8 are at the brink of the rapids which showed a better comparison with observed values over the computed elevations at a section 53 feet upstream from the rapids. The differences shown in table 8 are acceptable considering the accuracy of the computed elevations as well as the high water marks observed about 2 years after the 1983 peak discharge.

A good check on the adequacy of the adjustments in the streambed profile and the use of interpolated sections is by comparing the computed water surface elevations throughout a range in discharges with corresponding values from the rating table for the gage near Grand Canyon. The comparison of computed elevations with the rating table values at the gage are given in table 7.

The comparison in tables 5, 7, and 8 is considered an excellent check on the elevation datum adjustment of 5.0 feet on streambed, the Manning's n of 0.035, and the use of interpolated cross sections. There was a slight improvement in the match of computed water surface elevations and high water marks at the peak flow of 96,200 ft<sup>3</sup>/s produced by reducing the n from 0.035 to 0.02. The 2-foot difference in elevation for the peak discharge is acceptable. The plotted water surface profiles for the remaining discharges of 5,000; 7,500; 17,000; and 24,000 ft<sup>3</sup>/s are shown on figure 39.

**Reach 4.** - Estimated discharges at each of the rapids in reach 4 at the time of the survey of February-March 1985, by the Geological Survey Mapping Service was computed by adjusting the discharges at the Grand Canyon gage with appropriate travel times. Travel times were based on a mean velocity of 6 ft/s or 4 mi/h. The 6 ft/s was an average velocity from the water surface computations at the 24,900 ft<sup>3</sup>/s discharge. The adjusted discharge computations at each of the three rapids are given in table 6. The computed discharges are also shown in table 2. Table 6 shows the discharge used in the computer computations for obtaining water surface elevations at each of the

three rapids. Discharges at each of the rapids where observed elevations were surveyed in 1985 were either 18,800 or 27,600  $\text{ft}^3/\text{s}$ .

The comparison of computed water surface elevations with observed elevations (see table 5) shows values downstream from each rapid or control matching from -0.9 to +0.7 feet. Above the rapids good agreement between computed and observed elevations was obtained in vicinity of the brink of the rapid and a section 53 feet upstream from the brink with differences varying from -0.2 to +0.3 foot. Observed elevations further upstream from the rapid showed greater differences with the greatest difference of -1.1 occurring above Lava Falls. A good comparison of computed with observed elevations was found just above the control and at the National Canyon sampling location from the stage-discharge rating table based upon 1983 and 1985-86 data. Comparison of elevations are shown in tables 5 and 7 and observed elevations are plotted on figure 40 which are well within the accuracy to be expected in these computations.

A comparison of the computed water surface profile for 10,000  $\text{ft}^3/\text{s}$  after adjusting the streambed elevations by 5.0 feet (to mean sea level datum) was made with the 1923 Birdseye profile shown in figures 41, 42, and 43. The differences between these profiles are due to changes caused by adding or adjusting the interpolated cross sections to obtain better agreement with the observed Geological Survey Mapping Service elevations shown in table 5 and within short reaches defined entirely by surveyed cross sections. More credibility was placed on use of surveyed cross sections and observed elevations obtained in 1985 than the 1923 profile for the aforementioned reasons.

A check was made on the high water marks for the June 1983 peak flow of 96,200  $\text{ft}^3/\text{s}$ . This comparison is given in table 8 with the results plotted on figure 44. Water surface profiles for the 96,200  $\text{ft}^3/\text{s}$  discharge were computed with  $n$  values of 0.035 and 0.02. Computations for the  $n$  of 0.02 as shown in table 8 gave the best check on the high water marks. Computed values given in table 8 are an average of elevations at the brink of the rapid with elevations at a section 53 feet upstream from the rapid. The differences shown in table 8 are acceptable considering the accuracy of the computed elevations as well as the problem in observing high water marks about 2 years after the 1983 peak discharge. The difference of -7.4 feet at Lava Falls may be due to the difficulty in interpreting high water marks.

A check on the adjustments made to the streambed profile and use of interpolated sections was made by comparing computed water surface elevations throughout a range in discharges with corresponding elevations from the rating table for the sampling cableway above National Canyon. The comparison of computed elevations with the rating table values at the gage are given in table 7.

The comparison in tables 5, 7, and 8 is considered an excellent check on the adjustment of 5.0 feet to the streambed elevations, the Manning's  $n$ , and use of interpolated cross sections. The computed water surface at the peak flow

of 96,200 ft<sup>3</sup>/s is based on an  $n$  of 0.02. The plotted water surface profiles for the remaining discharges of 5,000; 7,500; 17,000; 27,600; and 25,000 ft<sup>3</sup>/s are shown on figures 45 and 46.

A rating table has been established for the Diamond Creek sampling station from the 1983 data and is given in table 7.

Summary. - The method selected for developing streambed and water surface profiles adjusted to mean sea level datum, for reaches 1, 2, 3, and 4 was checked by comparison of the 1923 profile with measured water surface elevations. Although there may be some inaccuracies in the procedure, it is considered the best procedure available. The computed water surface elevations compared favorably with the observed water surface elevations at the sampling stations, rapids, and high water marks. The channel geometry represented by both the surveyed and interpolated cross sections is acceptable for use in the STARS model.

#### STARS - SEDIMENT INPUT DATA

Upon completion of the first stage of STARS modeling, which was the fixed bed feature described in the previous section, the second stage of modeling was performed to predict the sediment transport with a moveable bed. This moveable bed feature for computing sediment transport in a reach of river utilizes the cross sections of the river (stage one) and the sediment data needed to compute bed material transport by one of the predictive sand load transport equations (Pemberton, 1987). The three main parts of sediment input data are: (1) total sand load and size gradation at the upstream most cross section, (2) tributary sediment inflow and size gradation, and (3) initial bed material size gradation at each cross section.

Information on the bed material size gradations was estimated from the channel bottom maps provided by USGS (Wilson, 1987). These maps were constructed from side scan sonar charts, low flow aerial photography, and bed material samples. The maps divide the channel bottom into two major categories: transportable material (sands and gravels) and immovable material ("boulders and bedrock"). The transportable material is further divided by bed form; classified as either "sediment wave" or "smooth bottom" patterns. As a first approximation, the "smooth bottom" material is assumed to be coarser than the "sediment wave" material. Bed material samples collected at and between the sampling gages indicate that, in general, the "sediment wave" pattern can be represented as sand and the "smooth bottom" material can be represented as a sand and gravel mixture.

#### SAND LOAD AT SAMPLING STATIONS

The recommended sand-load rating curves by Pemberton (1987) at the five sampling stations represent control points for sand load in the Colorado River to be used in the STARS model. The sand load rating curves shown in table 9 (table 9 from Pemberton, 1987) were used as input sand loads for reaches 1, 2, 3, and 4 as well as check on the computed transport out of each reach.



The sand loads given in table 9 represent a best fit regression relationship for the total sand load computed by the Modified Einstein Method for the 1983 and 1985-86 sediment sampling data. The sand loads computed from these equations represent the sand load at the sampling station to be used as input to the STARS model for each of the four reaches and for any specified discharge hydrograph.

The size analysis of the sand load computed by the equations in table 9 was derived from the total sand-load computations by the Modified Einstein Method. The average size gradation for total sand load at the gaging stations is given in table 10. These gradations were used with the sand load equations in table 9 for input to the STARS model at the upstream most cross section at each of the four reaches.

#### TRIBUTARY SEDIMENT INFLOW

The sediment data collection program on the Colorado River established in 1983 included suspended sediment sampling at the three major tributaries (1) Paria River at Lees Ferry, Arizona, (2) Little Colorado River near Cameron, Arizona, and (3) Kanab Creek near Fredonia, Arizona. These tributaries were selected because they contribute the majority of sediment supplied by all tributaries. Also samples previously collected were for a period of record as follows:

<u>Location</u>	<u>Period of Sediment Samples</u>
Paria River at Lees Ferry	October 1948 to September 1976
Little Colorado River near Cameron	October 1959 to September 1970
Kanab Creek near Fredonia	October 1967 to September 1973

The objectives for the 1983 sampling program were to sample sediment inflow to the Colorado River during the 1983 period to assist in verifying the STARS model, to determine if the 1983 data were in agreement with previously collected data which would be used for computing the sediment yield from the larger gaged tributaries, and to apply the Modified Einstein computation on a few samples for unmeasured sediment load computations.

**Basic Data-1983.** - Data collected at the three tributary stations consisted of 82 suspended sediment samples on Paria River at Lees Ferry for the period from July 1 to December 3, 1983; 120 suspended samples on Little Colorado River near Cameron from July 27 to November 28, 1983; and 31 suspended sediment samples on Kanab Creek from August 8 to December 13, 1983. All samples collected were analyzed in the laboratory for concentration in Mg/L (milligrams per liter). Most of these were analyzed for size gradation except for several at the Little Colorado River station due to similarity in concentrations and apparent gradations (Pemberton, 1987). Gage height information was taken at the time of sampling so that the instantaneous discharge was computed from current rating tables. Miscellaneous discharge measurements taken on the day of sampling at the three gaging stations provided input for use in total sediment load computations by the Modified Einstein Method. Bed

material samples were not taken at the time of sampling; but size gradations for bed material taken on other dates or in some cases earlier years were used in the Modified Einstein computations. The assumption that bed material did not change over time was not critical for any of the Modified Einstein computations because of the predominance and high concentrations of material in suspension less than 0.0625 mm or clay-silt size sediments.

Paria River Sediment Load. - A suspended sediment discharge rating curve was developed for 10,189 data points (excluding values with zero discharge or zero sediment) collected between October 1948 and September 1976. All of these data points are plotted on figure 47. The plot shows two distinct relationships: one for discharges greater and the other for discharges less than about 80 ft<sup>3</sup>/s. The upper curve had 423 data points and the lower curve had 9,766 data points. For water discharges above 1,100 ft<sup>3</sup>/s an additional curve was developed to represent a average maximum concentration of about 500,000 mg/L. A regression analysis for these two curves along with an adjustment to match observed data resulted in the following equations:

Q<sub>w</sub> less than 80 ft<sup>3</sup>/s

$$Q_s = 0.030677 Q_w^{3.1342}$$

$$\left( \frac{Q_s}{0.030677} \right)^{\frac{1}{3.1342}} = Q_w$$

Q<sub>w</sub> greater than 80 ft<sup>3</sup>/s < 1100 ft<sup>3</sup>/s

$$Q_s = 3.7956 Q_w^{1.8319}$$

$$Q_w = \left( \frac{Q_s}{3.7956} \right)^{\frac{1}{1.8319}}$$

Q<sub>w</sub> greater than 1100 ft<sup>3</sup>/s

$$Q_s = 1440 Q_w$$

where Q<sub>w</sub> is water discharge in ft<sup>3</sup>/s and Q<sub>s</sub> is sediment discharge in tons/day. The 82 suspended samples collected in 1983 were also used in a regression analysis with the following results:

Q<sub>w</sub> less than 60 ft<sup>3</sup>/s

$$Q_s = 0.051131 Q_w^{3.0932}$$

\*

$$Q_w = \left( \frac{Q_s}{0.051131} \right)^{\frac{1}{3.0932}}$$

Q<sub>w</sub> greater than 60 ft<sup>3</sup>/s

$$Q_s = 5.0944 Q_w^{1.7575}$$

Although the above regression was made at a slightly different break in discharge, the 1983 data as indicated by the regression equations shown above and plotted on figure 48 supports the use of the longer period (figure 47) as representative of the 1983 period.

There were four sets of samples at the Paria River gage taken in 1983 where total load computations were possible by the Modified Einstein Method (Colby

and Hembree, 1955). The only missing data to make these computations were bed material size gradations at the time of sampling. Samples of bed material on Paria River in the vicinity of the gage collected in 1983 and checked with samples at the gage collected in previous years were used to define an average bed material as shown in figure 49. The sampled bed material was considered applicable to bed material at the gage when the suspended samples were collected. The plots of size gradation for suspended sediment are also shown in figure 49. Modified Einstein computations for total sediment were made for the four sets of 1983 samples with results shown in table 11. Although these computations showed an unmeasured load varying from 3.9 to 11.6 percent, it appeared that an average unmeasured load of about 7.5 percent could be applied to the suspended sediment rating curve (figure 47).

The total sediment load of the Paria River was computed by the flow-duration, sediment rating curve method (Miller, 1951). Because this method combines daily flow records from 1924 through 1984 with the sediment-discharge rating curve from figure 47, the resulting sediment yield from the Paria River represents a long time average (see table 12). The long term (61 year) average flow-duration curve for Paria River used in sediment load computations is shown on figure 50.

Total sand load from the Paria River was computed by developing sand load equations from the suspended load equations derived from figure 47. The percent sand ( $>.0625$  mm) at the Paria River gage for the long term average was found to be 19.4 percent. This was computed by averaging the 143 size gradations available from 1954 through 1975 plus the 82 gradations collected in 1983. Combining the 19.4 percent sand of measured load with the 7.5 percent unmeasured load (table 11) gave the sand load equations for tributary inflow given in table 13.

The size gradation for sand load inflow is shown in table 14 and was determined by computing an average gradation for all the size analysis data from 1954 through 1983 (described above) and adjusted by a ratio of suspended sand load to total sand load computed from the four Modified Einstein total sand loads.

The results of tributary inflow from Paria River for use in the STARS model are summarized in table 15 and 16.

**Little Colorado River Sediment Load.** - A seasonal variation was observed in the data for the Little Colorado River so two suspended sediment rating curves were developed from 2,134 data points (excluding values for zero discharge or zero sediment) collected between October 1959 and September 1970. The two 6-month relationships at this sampling station are shown for data points in December-May (figure 51) and June-November (figure 52). A few of the outliers were identified where data from a month in 1 or 2 years are not clearly associated with other data points in the 6-month period. There were 1,100 data points in the December-May period and 1,034 data points in the June-November period. A regression analysis for these two curves shows the following:

<u>Season</u>	<u>Equation</u>
December-May	$Q_w = 1.817 Q_w^{1.4777}$
June-November	$Q_w = 31.136 Q_w^{1.2769}$

The 1983 data consisting of 124 suspended samples were used in a regression analysis as shown in the plot on figure 53 with the following results:

$$Q_s = 12.166 Q_w^{1.3560}$$

The regression line from data points for sampling on the Little Colorado River from July through November 1983 falls closer to the June to November curve (figure 52) than the December to May curve. However, the data points for 1983 (figure 53) plot well within the range in data for that period from June-November (figure 52).

Three sets of samples at the Little Colorado River gage taken in 1983 were analyzed for total load by the Modified Einstein Method. Bed material samples were not collected in 1983, therefore, an average from two bed material size gradations collected in 1967 and 1969 were used in the computations. The results of the Modified Einstein computations are shown in table 17. The average unmeasured load for these samples gave about 3 percent to be applied to the suspended sediment rating curves (figures 51 and 52).

Total sediment load from the Little Colorado River was computed by the flow-duration, sediment-rating curve method. A long term average sediment load was computed by using the flow records from June 1947 through May 1985, to develop a flow-duration curve (figure 54) with the sediment rating curves (table 18 and 19).

Total sand load from Little Colorado River was computed by developing sand load equations from the suspended load equations derived from figures 51 and 52. The percent sand ( $> .062$  mm) at the Little Colorado River gage for long term average was 10.4 percent. This was computed as an average of 198 size gradations available from 1959 to 1970. Combining the 10.4 percent sand with the 3.0 percent unmeasured load (table 17) gave the sand load equations shown in table 13.

Size gradations for the sand load inflow from Little Colorado River are given in table 14. This was derived the same way as for Paria River utilizing all the available size analysis data and adjusted by use of the three Modified Einstein computations. The result of the tributary inflow from Little Colorado River for use in the STARS model is shown in tables 15 and 16.

**Kanab Creek Sediment Load.** - The suspended sediment-discharge rating curve was developed from data points (excluding values of zero discharge or zero sediment) collected between October 1967 and September 1973. All of the data points are plotted on figure 55. The plot shows two relationships, one for discharge below  $20 \text{ ft}^3/\text{s}$  and the other for discharges greater than  $20 \text{ ft}^3/\text{s}$ .

The upper curve had 132 data points and the lower curve had 923 data points. A regression analysis for the two curves gave the following equations:

Qw less than 20 ft<sup>3</sup>/s

$$Q_s = 14.289 Q_w^{1.5005}$$

Qw greater than 20 ft<sup>3</sup>/s

$$Q_s = 1.6581 Q_w^{2.0711}$$

A regression analysis of the 31 data points collected in 1983 (figure 56) gave the following equation:

$$Q_s = 23.107 Q_w^{1.3485}$$

The regression line for the 1983 data supports the use of the equation developed from the longer period as representative of sediment loads on Kanab Creek.

There were three sets of samples on Kanab Creek in 1983 where total load was computed by the Modified Einstein Method. Bed material was not taken in 1983 but an average of three samples taken in 1969 and 1971 was used in the computations. The pertinent data from these total load computations is given in table 20. The average unmeasured load was 3 percent which was applied to the suspended sediment rating curve (figure 55).

Total sediment load from Kanab Creek was computed by the flow-duration, sediment-rating curve method. The flow-duration curve, for the period of record from 1964 to 1980, (figure 57) was combined with the sediment rating curves in sediment yield computation (table 21).

Total sand load equations for Kanab Creek were developed from the suspended load equations (figure 55). The percent sand (>.062 mm) of the measured load at the Kanab Creek gage was 14.9 percent. This was a long term average of 50 sample points available from 1967 through 1972. The sand load equations for Kanab Creek are presented in table 13.

Size gradation for the sand load inflow from Kanab Creek is given in table 14. This size gradation was the average size analysis of all data with an adjustment based on the three Modified Einstein computations. The sediment inflow from Kanab Creek is summarized in tables 15 and 16.

**Moenkopi Wash Sediment Load.** - The Moenkopi Wash sediment yield was computed to assist in determining the average sediment yields from ungaged areas along the Colorado River through the Grand Canyon. The Moenkopi Wash near Moenkopi, Arizona is a tributary to the Little Colorado River which has a drainage area of 1,660 square miles. The 1884 suspended sediment and discharge data points collected from 1973 to 1979, were plotted on figure 58. A sediment yield was computed from the flow-duration curve (figure 59) and sediment-discharge

rating curve (table 22). To compute total sand load a 3 percent addition for unmeasured load as determined for Little Colorado River, was used and results are shown in table 16.

The sediment load equations for Moenkopi Wash rating curve (figure 58) are as follows:

$Q_w$  less than  $2 \text{ ft}^3/\text{s}$

$$Q_s = 1.2958 Q_w^{1.4346}$$

$Q_w$  greater than  $2 \text{ ft}^3/\text{s}$  and less than  $8 \text{ ft}^3/\text{s}$

$$Q_s = 1.6592 Q_w^{2.6258}$$

$Q_w$  greater than  $8 \text{ ft}^3/\text{s}$  less than  $1900 \text{ ft}^3/\text{s}$

$$Q_s = 6.8234 Q_w^{1.6458}$$

**Ungaged Tributary Sediment Load.** - The Paria and Little Colorado Rivers, together represent 72 percent of the total sand supply from tributaries. Sediment from ungaged tributaries is delivered to the Colorado River from infrequent floods either by normal channel runoff inflow or debris flows (Howard and Dolan, 1981 and Webb, 1987). Debris flows transport large boulders, but the volume of sand inflow to the river is small relative to the normal tributary sediment yield because debris flow events are rare (approximately 20 to 30 year recurrence intervals). The sediment supply from ungaged tributaries for short term studies (less than 1 year) was assumed to be zero. The average volume of sediment supplied from ungaged tributaries from the infrequent floods is small when compared with the average volume of sediment supplied by the Paria River, Little Colorado River, and Kanab Creek, but is important in a long term study of sediment transport.

Total sediment yields derived from measured sediment data on the four tributaries are shown in table 16. The method selected for determining the long term average sediment yields from ungaged areas on the Colorado River was a sediment yield versus drainage area relationship derived for the semiarid region of the United States (Strand and Pemberton, 1982 and UNESCO, 1982). This relationship, in metric units, is plotted on figure 61 and shows sediment yields for four Colorado River tributaries. Applying figure 61 to ungaged areas on the Colorado River involved drawing a line through the Colorado River tributary data points which was parallel to the relationship from reservoir surveys in the semiarid climate of the United States. The data point for the Paria River at Lees Ferry was an outlier and not considered applicable because of the high sediment yield especially from the Bryce Canyon portion of the drainage area. The total sediment yield equation identified on figure 61 and used to compute the sediment loads given in table 15 is:

$$Q_s = 1750 A^{-0.24} \text{ (Metric Units)}$$

Or

$$Q_s = 2.925 A^{-0.24} \text{ (English Units)}$$

Summary. - The sediment load equations given in table 13 and the size gradation presented in table 14 represent sediment inflow to be used with the STARS or STAB models. The equation for Kanab Creek was adjusted by a factor of 2.11 which relates to the difference in drainage area between the sampling location and the confluence with the Colorado River (see figure 60).

The sediment loads given in table 15 for ungaged areas are to be used in the long term analysis by the STARS or STAB models on the Colorado River in Grand Canyon.

#### SONAR PATTERNS OF RIVER BED

Bed material maps of the river channel bottom were developed by Wilson (1987). These maps provide a nearly continuous chart of surface bed material for 225 miles of the Colorado River below Lees Ferry. The maps were developed from information collected in 1984 including side-scan sonar charts, depth profile charts, low flow aerial photographs, and bed material samples. The maps divide the channel bottom into two major categories: transportable material (sands and gravels) and immovable material ("boulders and bedrock"). The transportable material is further divided by bed form; classified as either "sediment wave" or "smooth bottom" patterns.

<u>Bed Material Type</u>	<u>Symbol</u>
Boulders and Bedrock	B
Smooth Bottom	S
Sediment Waves	SW

As a first approximation, the "S" material is assumed to be coarser than the SW material. Bed material samples collected at and between the sampling stations indicate that, in general, the SW pattern can be represented as sand and the "S" material can be represented as a sand and gravel mixture.

In classifying the material on the bottom at each river cross section the low level aerial photographs taken in October 1984 were extremely valuable. Each channel bottom map represented a short reach of river (usually one mile or less in length) and the percentage of the area for the three types of material was provided on each map. There were some gaps in the maps provided by Wilson (1987) which were filled in by studying the 1984 aerial photographs. Most of the gaps were at rapids where the bottom material was assigned as "B" while some gaps were assumed as extension of material either upstream or downstream. The surface area for the materials identified by Wilson (1987) and filled in for any gaps is listed in table 23.

## BED MATERIAL FOR STARS INPUT

The percentages of areal coverage in S, SW, or B bed material types at each cross section were taken from the data provided by Wilson (1987). These percentages were used to help distribute the various bed material types at each section. A check was made to determine if the areas of the three different types of material being used in the STARS model were similar to those shown in table 23. This check is needed because the model subdivides the channel width at each section into three streamtubes with only one bed material type used in each tube, based on the majority rule (Orvis and Randle, 1987). The channel width at each cross section is subdivided by the user according to bed material type. The model subdivides the channel by streamtubes of equal discharge. The majority of bed material in each streamtube is used for that entire tube. The bed material areas used in the model were computed by multiplying the downstream tube width by the distance between cross sections. Minor changes were made in the areal distribution given to the model until the computed areas matched to within 10 percent of the areas given in table 23. This was done for reaches of river, about 20 miles in length, in order to refine the technique.

The bed material size gradation for the S and SW varied by reach and was determined by averaging all of the bed material samples collected during the 1983, 1984, and 1985-86 sampling periods within a given reach. In addition to bed material samples at the sampling stations (Pemberton, 1987), the data collected during the September 4 to 10, 1984, raft trip by the Geological Survey were used to derive the size gradations of bed material in table 24. Plots of the bed material size analyses for the S and SW materials, given in table 24, are shown in figures 62, 63, and 64 for all reaches.

## STARS-1983 VERIFICATION

The hydraulic and sediment input data to the STARS model are described in previous sections of this report. The only remaining input data for the STARS model are the upstream boundary and water and temperature hydrographs. The 1983 verification period was approximately from June 1 through December 15, 1983. Daily discharges from the Geological Survey gaging stations on the Colorado River at Lees Ferry and near Grand Canyon, the Paria River at Lees Ferry, Little Colorado River near Cameron, and Kanab Creek were used to develop the inflow hydrographs to reaches 1, 2, 3, and 4. Lees Ferry gage data for the Colorado and Paria Rivers were used as inflow to reach 1. The daily flows at the Grand Canyon gage equaled the combined inflow from the main stem and Little Colorado River for reach 2. The flows at the Grand Canyon gage plus the Kanab Creek gage were used as inflow to reaches 3. Water temperatures for 1983 were taken from measurements at the five sampling stations shown in the report by Pemberton, 1987.



## REACH 1 - LEES FERRY TO ABOVE LITTLE COLORADO RIVER

The daily flow hydrograph developed from Lees Ferry discharges plus Paria River inflow is shown on figure 65. The actual discharge hydrograph was approximated by averaging the discharge for a particular block of days. A minimum of 2 days was given to the peak flow of 91,600 ft<sup>3</sup>/s and 59 days to the period from August 13, 1983 to October 10, 1983. In reach 1 the Paria River joined the Colorado River just upstream from river mile 0.90; therefore, the flow hydrograph (figure 65) reflects discharges from river mile 0.90 to river mile 61.0 (gage above the Little Colorado River). Any side inflow to the river except for the Paria River was omitted in the 1983 verification period.

The sand-load supply was computed for each discharge of the hydrograph at Lees Ferry from the sand-load rating curve given in table 9. The size gradation for sand load at Lees Ferry is shown in table 10. Inflow of sand from the Paria River was computed from the equations in table 13 and the corresponding size distribution is listed in table 14. Sand loads on the Paria River for each block of discharges were first computed on a daily basis then averaged for the given discharge block.

Water temperatures used in reach 1 were taken from measurements at Lees Ferry in 1983 and varied from 50° to 57° F.

## REACH 2 - ABOVE LITTLE COLORADO RIVER TO NEAR GRAND CANYON

The upstream cross section for reach 2 was the sediment sampling station above Little Colorado River at river mile 61.0. Because continuous flow records did not exist at river mile 61.0, the daily flows from the Grand Canyon gage minus inflow from Little Colorado River were used as main stem inflow to reach 2. The Grand Canyon gage was only 26.5 miles downstream from the sampling station above the Little Colorado River. Travel time corrections in this reach were considered insignificant. The 3-day peak discharge into reach 2 was 88,433 ft<sup>3</sup>/s (figure 66). In reach 2 the Little Colorado River joined the Colorado River at river mile 61.65. Figure 66 represents the combined discharge hydrographs of the Colorado River at mile 61.0 and the Little Colorado River.

Sand loads in the Colorado River used as input to reach 2 were computed from the discharge hydrograph and the sand-load rating curve (river mile 61.0) shown in tables 9 and 10. Inflow of sand load from the Little Colorado River was computed on a daily basis from equations in table 13 and then averaged for each block of time with a maximum discharge of 560 ft<sup>3</sup>/s for the 62-day period from August 11, 1983 to October 11, 1983. Size gradation for the Little Colorado River sand load is shown in table 14.

Water temperature for 1983 did not fluctuate significantly so that a temperature of 54° F was used for the entire period.

### REACHES 3 AND 4 - NEAR GRAND CANYON TO ABOVE DIAMOND CREEK

Inflow hydrographs were identical for both reaches 3 and 4 as shown on figure 66. Some inconsistencies in flow records at the National Canyon gage for 1983 supported the use of the more reliable discharges at the Grand Canyon gage as inflow to reach 4. The 3-day average peak discharge was 88,433 ft<sup>3</sup>/s. In reach 3, Kanab Creek joined the river at river mile 143.51 with a maximum discharge of 38 ft<sup>3</sup>/s for the 15-day average during the period December 1 to 15, 1983. All flows for Kanab Creek were adjusted to represent flows at the mouth.

Sand load equations for the Colorado River, used as inflow to both reaches 3 and 4, are presented in table 9. Size gradations for the Colorado River sand load are shown in table 10. Inflow of sand from Kanab Creek was computed on a daily basis from equations in table 13. The maximum quantity was 947 tons for the 13-day period from July 21, 1983 to August 1, 1983. Sand loads computed at the sediment gage were multiplied by a factor of 2.11 to adjust for the contributing area between the gage and the confluence.

Measurements of water temperature for 1983 were consistent with time so a water temperature of 54° F was used for the entire period.

### SUMMARY OF VERIFICATION

Data collected during the 1983 sampling period from approximately June 1, 1983, to December 15, 1983 were used to test the applicability of the STARS model in predicting the sand transport in the Colorado River. Bed material samples were not available prior to the 1983 peak discharge. The bed material size gradation used as input for the 1983 verification study contained the areal coverage of B, S, and SW as presented by Wilson, (1987). The data summarized on tables 23 and 24, and used as input to the STARS model, were collected during or subsequent to the peak discharge in 1983. Measurements of the initial channel geometry were also not available prior to the peak discharge of 1983. Instead, cross section data collected in March 1984 were used to represent the initial channel geometry of June 1, 1983. Thus, the initial conditions input to the STARS model in the verification runs were reflective of post-1983 sampling conditions.

In the case of the 1983 sampling period, the STAB model results are thought to be the most accurate because they only depend upon the Modified Einstein sand-load rating curves and the measured discharges.

### COMPARISON OF STARS AND STAB MODEL RESULTS

Reach 1. - The accumulated sand load passing the downstream end of reach 1, as computed by the STARS and STAB models, is given on table 25. Figure 67 shows how the accumulated sand load varies with time according to both models for the 194-day simulation period from June 1 to December 11, 1983. Also shown is the accumulated sand load derived from the Toffaleti sand-load rating curve.

The STARS model estimated the accumulated sand load for the sampling period to be 1,600,000 tons while the STAB model's estimate is 5,170,000 tons. The STARS model underestimated the accumulated sand load at the sampling station above Little Colorado River by 69 percent when compared with the STAB model results.

The underprediction of sand load at the downstream end of reach 1 might be expected for several possible reasons; such as, errors in initial bed material size gradations, and their areal distribution within the reach and also errors in initial channel geometry.

The STAB model when applied to the discharges for the 194-day period from June 1, 1983 to December 11, 1983, gave the following mass balance of sand loads.

<u>Location</u>	<u>Acre-Feet</u>	<u>Tons</u>
Colorado River at Lees Ferry	1,060	2,230,000
Paria River at Lees Ferry	150	317,000
Colorado River above Little Colorado River	2,450	5,170,000
Net Degradation	-1,240	-2,620,000

Reach 2. - Sand-load outflow from reach 2 as computed by the STARS model for the 1983 discharge hydrograph (table 25) indicates a sand load of 3,800,000 tons assuming the Wilson (1987) bed material as initial conditions. Figure 68 shows how the accumulated sand load varies with time according to both models for the 198-day simulation period from June 1 to December 15, 1983. Also shown is the accumulated sand load derived from the Toffaleti sand-load rating curve. The STARS model underestimated the accumulated sand load at the sampling station near Grand Canyon by 62 percent when compared with the STAB model results. Under prediction might be expected because of several reasons similar to those given for reach 1.

The STAB model applied to the discharges from June 1, 1983 to December 15, 1983, gives the following mass balance of sand loads:

<u>Location</u>	<u>Acre-Feet</u>	<u>Tons</u>
Colorado River Above Little Colorado River	2,460	5,190,000
Little Colorado River near Cameron	713	1,510,000
Colorado River near Grand Canyon	4,680	9,900,000
Net Degradation	-1,510	-3,200,000

Reaches 3 and 4. - The STAB model applied to the discharges from June 1, 1983 to December 15, 1983, gives the following mass balance of sand loads:

## Reach 3

<u>Location</u>	<u>Acre-Feet</u>	<u>Tons</u>
Colorado River near Grand Canyon	4,680	9,900,000
Kanab Creek	5	11,100
Colorado River above National Canyon	4,680	9,900,000
Net Aggradation	5	11,000

## Reach 4

<u>Location</u>	<u>Acre-Feet</u>	<u>Tons</u>
Colorado River above National Canyon	4,680	9,900,000
Colorado River above Diamond Creek	4,680	9,900,000
No Net Change	0	0

This would indicate that nearly all of the sand that scoured from the Colorado River during the 1983 high flows occurred in the reach between Glen Canyon Dam and river mile 87.

STARS - OCTOBER 1985 VERIFICATION

An extensive sampling program was conducted from October 1985 to January 1986. A 2-week period from October 1, 1985 to October 14, 1985, was used to verify the adaptability of the STARS model to the Colorado River during powerplant release at Glen Canyon Dam. Due to time and cost limitations, only the first 2 weeks of the 1985 sampling program were used for verification. The discharge hydrograph of these 2 weeks is representative of the sampling period and should be adequate for verification purposes. The hourly discharge hydrograph for the Colorado River at Lees Ferry (inflow to reach 1) was provided by the Geological Survey. The reach 2 inflow hydrograph above Little Colorado River was computed using the SSARR (Streamflow Synthesis and Reservoir Regulation) model (Lazenby, 1987). Reach 3 inflow hydrograph was taken from the Geological Survey flow records for the gage near Grand Canyon gage. Reach 4 discharges were computed using the SSARR model for the station above National Canyon.

Water temperatures for the 2-week period in October 1985 were taken from the sediment sampling stations and input to the model as follows:

<u>Reach</u>	<u>Temperature</u>
1	52° F
2	52° F
3	54° F
4	54° F

#### REACH 1 - LEES FERRY TO ABOVE LITTLE COLORADO RIVER

The inflow hydrograph to reach 1 was obtained from the SSARR model and is shown on figure 69. The 2-week period (336 hours) was subdivided into blocks of hours in order to define the fluctuating hydrograph but to keep the number of time steps to a minimum. The minimum number of hours in any time step that adequately defined the fluctuating hydrograph was 2 hours. Paria River inflow hydrograph was obtained from daily flow gaging records for the 2-week period. Bed material for the October 1985 period was provided by Wilson (1987) with B, S, and SW bed material types.

Sand loads for the Colorado River at Lees Ferry were computed from the equations in table 9 and the discharge hydrograph (figure 69). Initial size gradations for these sand loads at Lees Ferry are shown in table 10. Inflow of sand from the Paria River was computed from the equations in table 13 and the daily flow records.

#### REACH 2 - ABOVE LITTLE COLORADO RIVER TO NEAR GRAND CANYON

The inflow hydrograph to reach 2 is shown on figure 70. The 2-week hydrograph above Little Colorado River (computed for the SSARR model) was subdivided into blocks of hours to define the fluctuations and to keep the number of time steps to a minimum. The little Colorado River inflow hydrograph was obtained from daily flow records for the 2-week period. Bed material for the 2-week period in 1985-86 was provided by Wilson (1987) with B, S, and SW bed material types.

Sand loads for the Colorado River above Little Colorado River gage were computed using equations in table 9 and the discharge hydrograph (figure 70). Initial size gradation for these sand loads are shown in table 10. Inflow of sand from Little Colorado River was computed from the equations in table 13 and the daily flow records.

#### SUMMARY OF VERIFICATION

Simulation of the 2-week period of October 1985, during powerplant fluctuations, provided a good test for verification of the STARS model. The model's successful prediction of the sand transport at each of the sediment sampling stations proved the model was applicable to the Colorado River.

## SAND-LOAD TRANSPORT COMPARISON

Reach 1. - The results of the predicted sediment outflow from reach 1 by the STARS model are given in table 25 for the 2-week period. Figure 71 shows the accumulated sand load versus time for the STARS and STAB models. In addition, the figure shows the accumulated sand load derived from the Toffaleti sand-load rating curve. The STARS model computed a sand outflow of 14,100 tons compared to the STAB model's results of 11,500 tons. The STARS model predicted 23 percent more transport for the 2-week period than the STAB model. Change in initial bed material size gradation or location within reach 1 could be made to provide closer agreement.

Reach 2. - Sand loads from reach 2 are shown in figure 72 and table 25. The STARS model computed sand output of 13,300 tons compared to a computed sand load by the STAB model of 18,000 tons for the 2-week period in October 1985. The STARS model underpredicted the transport by 26 percent for the 2-week period when compared with the STAB model results. This is a good check on the STARS model and its results could be adjusted to give a closer comparison by changing the initial bed material within reach 2.

## COMPARISON OF FLOW ALTERNATIVES

Verification of the STARS model for the 1983 and 1985 sampling periods described in this report support its use in studying the changes in sediment transport resulting from variable release patterns at Glen Canyon Dam. Since the STARS model both overpredicted and underpredicted the sand-load transport, the initial bed material conditions used in the verification simulations were not changed.

The STARS model was used to simulate sediment transport in the Colorado River under future flow alternatives. Comparison of the river's response to each flow alternative will quantify the relative impacts of the various flow scenarios in terms of volume change in the streambed.

Five future flow alternatives were designed by the project manager. These flow alternatives represent potential operation scenarios of the powerplant at Glen Canyon Dam. Each powerplant operation scenario releases the same volume of water in a 1-year period (8.25 million acre-feet), in accordance with minimum streamflow requirements and the compact and treaty agreements between Western States and Mexico.

In terms of sediment transport, the first two flow alternatives represent the two extreme powerplant operations. Due to time and money constraints only the first two flow alternatives were simulated with the STARS model. The first flow alternative represents conditions of steady flow for a given month. In this case, the powerplant would produce a relatively constant supply of electrical energy. The second flow alternative represents conditions of maximum flow fluctuations. In this case, the powerplant would produce a maximum amount of electrical energy during the peak demand and only a minimum amount

during low demand. The third flow alternative represents a compromise of the first two flow scenarios. The fourth and fifth flow alternatives were developed with the fishery and recreation studies in mind and are combinations of the first three alternatives.

River simulations for flow alternatives one and two were modeled separately for each of the first two reaches. The input data to the STARS model was the same for each flow alternative with the exception of the discharge and sediment hydrographs at the main stem upstream boundary. Except for the boundary conditions, input data to the STARS model for the flow alternatives was the same as that used in the October 1985 simulation.

Initial channel geometry was defined by measured and interpolated cross sections calibrated at steady flows. These cross sections represent conditions after the 1983 flood which are assumed to reflect degradation relative to the preflood period.

Initial streambed material consisted of three separate size gradations which were distributed throughout the reach in three dimensions (longitudinal, lateral, and vertical). These three bed material size gradations basically represent sand, gravel, and bedrock. The actual size gradations used for a particular reach were determined by averaging size gradations of bed material samples collected between sampling gages in 1984 with those samples collected at the sampling gages in 1985. The size gradation for bedrock is not meant to be realistic but is used as a switch in the STARS model. The areal distribution of the bed material types was interpreted from maps provided by the Geological Survey (Wilson, 1987). The sand and gravel bed materials were both assumed to rest on bedrock or a nonerodible material and have an initial thickness of 20 feet. This assumption is considered more accurate than assuming that these alluvial deposits have an infinite thickness and is consistent with the sand depths measured on the Colorado River between Glen Canyon Dam and Lees Ferry, in 1956. This assumption of a 20-foot thickness is not as important for an aggrading channel as it would be for a degrading channel.

Total sand supply at the main stem upstream boundary was computed as a function of the discharge hydrograph using the Modified Einstein sediment-discharge rating curve. The size gradation of the sand load was assumed to be constant with time and was determined from the Toffaleti equation using a mean discharge for the water year. Total sand supply from each tributary (Paria River, Little Colorado River, and Kanab Creek) was varied with time and adjusted to match the annual sand load computed from a flow-duration analysis. For each tributary the actual daily sand loads were determined by using the sand load-discharge rating curve and a daily discharge hydrograph representing an average water year. This daily discharge hydrograph was developed from historical records. Long term mean monthly water volumes were computed for each month. Then the historical records were searched to find mean daily flows for a month where the monthly volume matched the long term mean volume for that month. Thus, 1 year's worth of daily flows were constructed using

historical data from months taken from different years. After applying the sand load-discharge rating curve to each day in the discharge hydrograph, the annual sand load was computed and compared with the load derived from the flow duration analysis. Based upon this comparison, factors were applied to the sand load rating curves so that the annual sand loads from each tributary would match the load computed from flow duration analyses. High water years have large influence on the average annual sediment yield. A factor greater than 1.0 was needed since an average water year will not produce the average annual sand load.

<u>Tributary</u>	<u>Factor</u>
Paria River	2.11
Little Colorado River	1.26
Kanab Creek	4.75

#### FLOW ALTERNATIVE ONE

River simulations for this steady flow alternative were performed on the first two reaches (from the gage at Lees Ferry to the gage above the Little Colorado River mouth and down to the gage near Grand Canyon). One continuous water year was simulated in 24 major time steps with each time step representing approximately half a month. Although discharges from the dam were constant for a month, inflow of water and sediment from tributaries were allowed to vary twice a month. Reach 1 was simulated for 4 years while reach 2 was simulated for 1 year. The 4-year discharge hydrograph representing inflow to reach 1 for flow alternative one is shown on figure 73. The 4-year hydrograph was constructed by repeating the hydrograph of the first year.

Results from the steady flow simulation of reach 1 indicate a net fill at the end of the 4-year period. This would be expected if one assumes that the initial channel geometry and bed material represents scour after a large flood with relatively low discharges following. Figure 74 shows the accumulated sand load at river mile 61. Figure 75 shows the accumulated streambed volume change with time for reach 1. The model results also provide information on how this net volume change is distributed throughout the reach.

In reach 1, the model indicated a net fill of 1,489 acre-feet or 3,145,000 tons (figure 75 and table 26) for the 4-year simulation. The months of December, January, and June experienced a net scour while November, April, and May were in equilibrium and the remaining months of October, February, March, July, August, and September experienced a net fill. The greatest amount of fill occurs in August, September, and October corresponding to the thunderstorm season over the Paria River drainage. If successive water years were modeled, then the annual rates of fill would be expected to decrease with time and the range of volume change in streambed would narrow with each year.

In reach 2, the model indicated a net fill of 638 acre-feet or 1,350,000 tons at the end of 1 year. January and June experienced a net scour while



December, February, and May were in equilibrium and the remaining months of October, November, March, April, July, August, and September experienced a net fill. The greatest amount of fill occurs in August, September, and October corresponding to the thunderstorm season over the Little Colorado River drainage. As in reach 1, modeling of successive water years should show a decrease in the annual fill rates with time.

#### FLOW ALTERNATIVE TWO

Modeling flow alternative two proved to be much more complex than simulations of the steady flow alternative. Simulating 365 days of flow with approximately 4-hour time steps, for the first reach alone, would be time and cost prohibitive. Therefore, modeling 1 or more years of fluctuating flow would require the use of an equivalent discharge. In order to verify the use of an equivalent discharge, fluctuating flows were simulated for 2-week periods during the minimum, mean, and maximum sediment inflow times as follows:

Reach	2-Week Period	Sand Inflow	
		(acre-feet)	(Tons)
1	May 16-29	0.78	1,660
1	August 16-29	93.4	197,000
1	September 1-14	181.	383,000
2	November 16-29	3.28	6,940
2	August 18-31	297.	627,000
2	September 16-29	80.1	169,000

Each simulation used the same initial conditions as previously described. The upstream boundary discharge hydrographs for each reach were obtained from the SSARR model results (Lazenby, 1987). This model determined the attenuated hydrograph at each sampling station based upon powerplant releases from Glen Canyon Dam. An equivalent discharge was determined which would reproduce the pattern of streambed volume change with time and corresponding magnitude.

<u>Reach</u>	<u>2-Week Period</u>	<u>SSARR Mean Discharge (ft<sup>3</sup>/s)</u>	<u>Equivalent Steady Discharge (ft<sup>3</sup>/s)</u>	<u>Percent of Mean Discharge</u>
1	May 16-29	9,500	9,900	104.2
1	August 16-29	16,630	18,000	108.2
1	September 1-14	10,790	11,700	108.4
2	November 16-29	9,625	7,350	76.4
2	August 18-31	16,470	17,840	108.3
2	September 16-2	10,500	7,600	72.4

An equivalent discharge was estimated for the remaining portion of the water year and a 1-year simulation was made using these discharges to represent flow alternative two.

<u>Reach</u>	<u>Month</u>	<u>Equivalent Discharge (ft<sup>3</sup>/s)</u>	<u>Percent of Mean Discharge</u>
1	October	9,600	104.2
1	November	9,800	104.2
1	December	15,100	108.3
1	January	15,700	108.3
1	February	9,900	104.2
1	March	8,600	104.2
1	April	10,500	108.3
1	May	9,900	104.2
1	June	10,600	108.3
1	July	18,400	108.3
1	August	18,000	108.2
1	September	11,700	108.4
2	October	6,810	74.4
2	November	7,140	76.4
2	December	15,000	108.3
2	January	15,700	108.3
2	February	7,030	74.4
2	March	6,140	74.4
2	April	7,180	74.4
2	May	6,560	74.4
2	June	7,250	74.4
2	July	18,400	108.3
2	August	17,800	108.3
2	September	7,340	72.4

Figures 76 through 87 show the discharge hydrographs and accumulated tons of sand transport with time for each of the 2-week periods for both reaches 1 and

2. The discharge hydrographs of flow alternative two for reaches 1 and 2 are shown on figures 73 and 88. These hydrographs were developed from the equivalent discharges and were used in the river simulations.

In reach 1, the model indicated a net fill of 1,324 acre-feet or 2,796,000 tons at the end of 4 years. December, January, and June experienced a net scour while November, April, May, June, and July were in equilibrium and the remaining months of February, March, August, September, and October experienced a net fill. The greatest amount of fill occurs in August, September and October corresponding to the thunderstorm season over the Paria River drainage (figure 75).

In reach 2, the model indicated a net fill of 659 acre-feet or 1,390,000 tons at the end of the first year. January and July experienced a net scour while December and June were in equilibrium and the remaining months of November, February, March, April, May, August, September, and October show a net fill. The greatest amount of fill occurs in August, September, and October corresponding to the thunderstorm season over the Little Colorado River drainage. Figures 88, 89, and 90 show the discharge hydrograph, accumulated tons sand outflow, and accumulated bed volume change, respectively for 1 year in reach 2. For comparative purposes the results for flow alternatives one and two are shown in figures 88 to 90.

#### LONG TERM PROJECTIONS OF POWERPLANT FLOW ALTERNATIVES

Long term changes of sand stored on the streambed of the Colorado River are important to the stability of alluvial sand deposits; especially during high water years. The amount of sand scoured from the river channel during the high water years from 1983 through 1985 was estimated by use of the STAB model. The STAB model determined that 16.2 million tons of sand were removed from the channel between Glen Canyon Dam and the sampling station near Grand Canyon (reaches 0, 1, and 2) during the high flows of 1983, 1984, and 1985. A breakdown by reach and time is shown below:

##### Sand Storage Change (1000 tons)

<u>Time Period</u>	<u>Reach 0</u>	<u>Reach 1</u>	<u>Reach 2</u>	<u>Reach 3</u>	<u>Reach 4</u>
Oct-Dec, 1983	-2240	-2730	-3270	12	0
Jan-Sept, 1984	-814	-2950	-1330	0	0
Water year 1985	-580	-2100	-200	0	0
Total	-3630	-7780	-4800	12	0

Both the STARS and STAB models predicted aggradation of the streambed upstream from the gage near Grand Canyon (river mile 87.37) for all Glen Canyon Dam powerplant flow alternatives. This would be expected if it is assumed that the channel had reached a "quasi-equilibrium" (Leopold, 1969) prior to the 1983 high flows and in the future would try to aggrade the streambed until pre-1983 conditions were established.

The length of time required to resupply sand to the streambed of the Colorado River after a high flow period will vary along the river and will be a function of the quantity of sand supplied by the tributaries. An estimate of the time to reestablish equilibrium can be made assuming an average sediment yield from the tributaries each year and only powerplant releases from Glen Canyon Dam. Both the STARS and STAB models predicted a rate of sand deposition, in tons per year, for the powerplant flow alternatives. The STARS model simulated a 4-year period in reach 1 for flow alternatives one and two (table 26). The comparison of results from the STARS and STAB models, in table 26, shows the advantage the STARS model has in computing changes in annual fill rates with time.

The annual fill rates computed by the STARS model in reach 1 for flow alternatives one and two are plotted on figure 91. The annual fill rate was extrapolated past the fourth year assuming a linearly reduction with time. The slope of the extrapolated line was determined such that the tons of sand under the curve would be equal to the tons of sand in the high flow years of 1983 through 1985 (7,780,000 tons for reach 1). The annual fill rates computed by the STAB model in reach 1 for flow alternatives one, two, and three are plotted on figure 92. The annual fill rates computed by the STAB model were extrapolated the same way. Figures 93 and 94 show the annual fill rates for reach 2 as computed by the STARS and STAB models.

Based on the assumptions previously defined, the estimated number of years to replenish the streambed with sand to the pre-1983 level is presented below:

Flow Alternative	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4
1 (STARS)	-	16	6	-	-
2 (STARS)	-	14	6	-	-
1 (STAB)	infinity	20	7	0	0
2 (STAB)	infinity	17	6	0	0
3 (STAB)	infinity	18	7	0	0

The reason that flow alternative two takes less time to reach equilibrium is because flow alternative two stores the least amount of sediment. The times given are rough approximations and represent only one set of estimates. The actual number to years of reach equilibrium will depend upon the quantity of sand supplied by the tributaries in the years to come.

#### LONG TERM PROJECTIONS OF HIGH WATER YEARS

High water years can scour more sand from the main channel than any powerplant flow alternative. The STAB model was used to evaluate the sand storage changes under various annual release volumes from Glen Canyon Dam. Historical releases from the dam in 1982, 1984, and 1986 were used in the analysis. These water years represent annual water volumes of 8.29, 21.1, and 16.6M acre-feet, respectively. Water year 1982 represents near minimum releases

with powerplant fluctuations. Water year 1984 is the highest on record and represents high steady powerplant releases all year plus releases through the river outlet works in May, June, and July. Water year 1986 represents a high water year with powerplant fluctuations from October 1985 to February 1986 and high steady releases the remainder of the year.

The tributary sand inflow was the same for each year in order to evaluate the change in sand storage with change in annual water volume. This analysis used the mean annual tributary sand load for the Paria River, Little Colorado River, and Kanab Creek. Sand supplied by ungaged tributaries was assumed to be zero. The following are the STAB model results using the sand-load rating curves presented by Pemberton (1987):

Water Volume Million acre-feet	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4
8.29	-47	813	1740	340	14
21.1	-895	-2630	-3000	318	0
16.6	-579	-1330	-8150	357	26

These results assume mean annual tributary sand load and indicate that the larger the water volume the greater the quantity of sand removed. The smallest water year indicated a net fill and the highest water year indicated a large net scour. Figure 95 shows a plot of annual water volume versus sand storage change in the streambed. Interpolation of these results would suggest that the streambed would scour when the annual water volume exceeded 12M acre-feet. All of the powerplant flow alternatives for Glen Canyon Dam were studied assuming an annual release volume of 8.25M acre-feet.

### CONCLUSIONS

The tributaries of the Colorado River in the Grand Canyon are ultimately the only source of sediment to the system, since all of the sediments transported by the upper river are trapped in Lake Powell. The long term average annual sand load from all tributaries in the study reach is estimated at 3.7 million tons per year. The Paria and Little Colorado Rivers together represent 72 percent of this total and both enter the Colorado River in the reach where there is the greatest potential for erosion of the streambed.

The streambed of the Colorado River has a large capacity to store tributary sand during powerplant operations. The quantity of sand removed from the 102-mile reach between Glen Canyon Dam (river mile -15) and the Geological Survey gage near Grand Canyon (river mile 87.37) for the 1983, 1984, and 1985 high flow periods is estimated at 16 million tons. There was relatively little sand removed from the main channel during these high flows downstream from the gage near Grand Canyon.

High flows from Glen Canyon Dam, depending upon their frequency, can be much more important to alluvial sand deposits in the Grand Canyon than powerplant

operations at the dam. The more sand that is stored in the streambed of the Colorado River prior to a high flow event, the greater the potential for deposition of sand at the beaches. For 20 years after the closure of Glen Canyon Dam, in 1963, sand storage was maintained in the streambed of the Colorado River. Alluvial sand deposits in the Grand Canyon began to stabilize in the 1970s, according to Howard and Dolan (1981). During the 1983 high flow event, there was a net loss of sediment from the study reach, but sediment deposition occurred near many separation zones in the Grand Canyon (Schmidt and Graf, 1987). During high flows, sediment previously stored in the streambed is a source of sediment for possible beach deposition. The greater the amount of sand stored in streambed before a high flow event, the greater the potential for beach deposition.

The Colorado River more closely approaches equilibrium with increasing distance downstream from Glen Canyon Dam. This is because the supply of sand to the river increases in the downstream direction due to tributaries and the possible scour of the streambed upstream. The attenuation of flood peaks in the downstream direction reduces the transport capability. In reaches 3 and 4 the supply of sand and the transport capability are nearly equal and the channel is near equilibrium.

The operation of Glen Canyon Dam Powerplant impacts the storage potential of sand along the streambed. The greater the sand-load transport, the less the potential there is to store sand along the streambed. Although all of the flow alternatives have a similar sand storage potential, flow alternative one (steady powerplant releases) has the most potential to store sand in the streambed followed by flow alternative three (moderate release fluctuations), and flow alternative two (maximum release fluctuations) has the least potential to store sand. The farther downstream from Glen Canyon Dam the less difference there is between flow alternatives in terms of sand storage potential or sand-load transport. This is because of increased sand supply and attenuation of peak flows in the downstream direction.

Fluctuating flows may be more beneficial to alluvial sand deposits (beaches and terrestrial habitat) than steady flows during periods of high tributary runoff, usually occurring from July to October. During the thunderstorm period, the tributaries supply sand to the Colorado River which in turn provides a source of sand and nutrients to the recirculating zones. Although sustained high river discharges with higher water surface elevations provide the more beneficial sediment inflow to these recirculating zones, the daily fluctuations of discharge with corresponding high water surface elevations will move sediment originating from the tributaries into the beach areas.

In general, the beaches are most likely to aggrade if the main channel aggrades during powerplant operations coupled with high tributary inflow. The beaches are most likely to degrade if the main channel degrades during high releases coupled with low tributary inflow. Deposition of some beaches may occur during high flows if the main channel scours and is able to supply enough sand to the beaches. However, some beaches will be likely to degrade during high

flow events if the main channel has already experienced degradation from previous high water years.

In the long term, the frequency of high flow events (greater than powerplant releases) should allow enough time for the main channel streambed to reestablish equilibrium. The amount of time to reestablish equilibrium will depend upon the volume of sand removed from the streambed and the subsequent sand load supplied by tributaries. The volume of sand removed from the streambed will, in turn, depend upon the water volume and peak discharge of the high flow event. For example, the total discharge from Glen Canyon Dam for water year 1983 was 17,403,000 acre-feet with a peak discharge of 92,600  $\text{ft}^3/\text{s}$ . If the peak discharge could have been limited to releases of 28,000  $\text{ft}^3/\text{s}$  that year, then the volume of sand removed and time to reestablish equilibrium would have been reduced by roughly one third.

### RECOMMENDATIONS

Since Glen Canyon Dam has experienced high flows as recently as 1986, additional care should be taken to minimize the probability of high flows in the next several years. Possibly the criteria to fill Lake Powell every year on June 1 could be relaxed and more importance given to the reservoir volume target for January 1.

Topographic surveys of alluvial sand deposits or beaches should continue in the future and have a level of detail comparable to those surveys conducted by the Bureau of Reclamation's Durango Projects Office.

At least some sediment sampling at the Colorado River sampling stations above Little Colorado River, near Grand Canyon, and above Diamond Creek are needed to identify any changes in the sand-load rating curves that were developed under this project. By properly sampling at the gages near Grand Canyon and above Diamond Creek, there will not be as much need to collect data at the gage above National Canyon. The frequency of collecting data at the three stations will depend on observations of any high tributary inflows or drastic changes at the beaches.

Future tributary flows will have a large influence on the alluvial sand deposits as well as the amount of sand stored on the streambed. Since the sand supplied by the Paria and Little Colorado Rivers represents the vast majority of sand supplied by all tributaries, the discharge from at least these two rivers should be monitored in the future.

Both the channel geometry and bed material size gradation are subject to change with time. If any river modeling were to be done in the future, new cross sections should be surveyed and bed material data should be collected concurrently. If any new cross sections are surveyed, an effort should be made to obtain some of the cross sections as close to the crest of rapids as possible. Also, water surface elevations at cross section locations where mean sea level elevations are available should be measured.

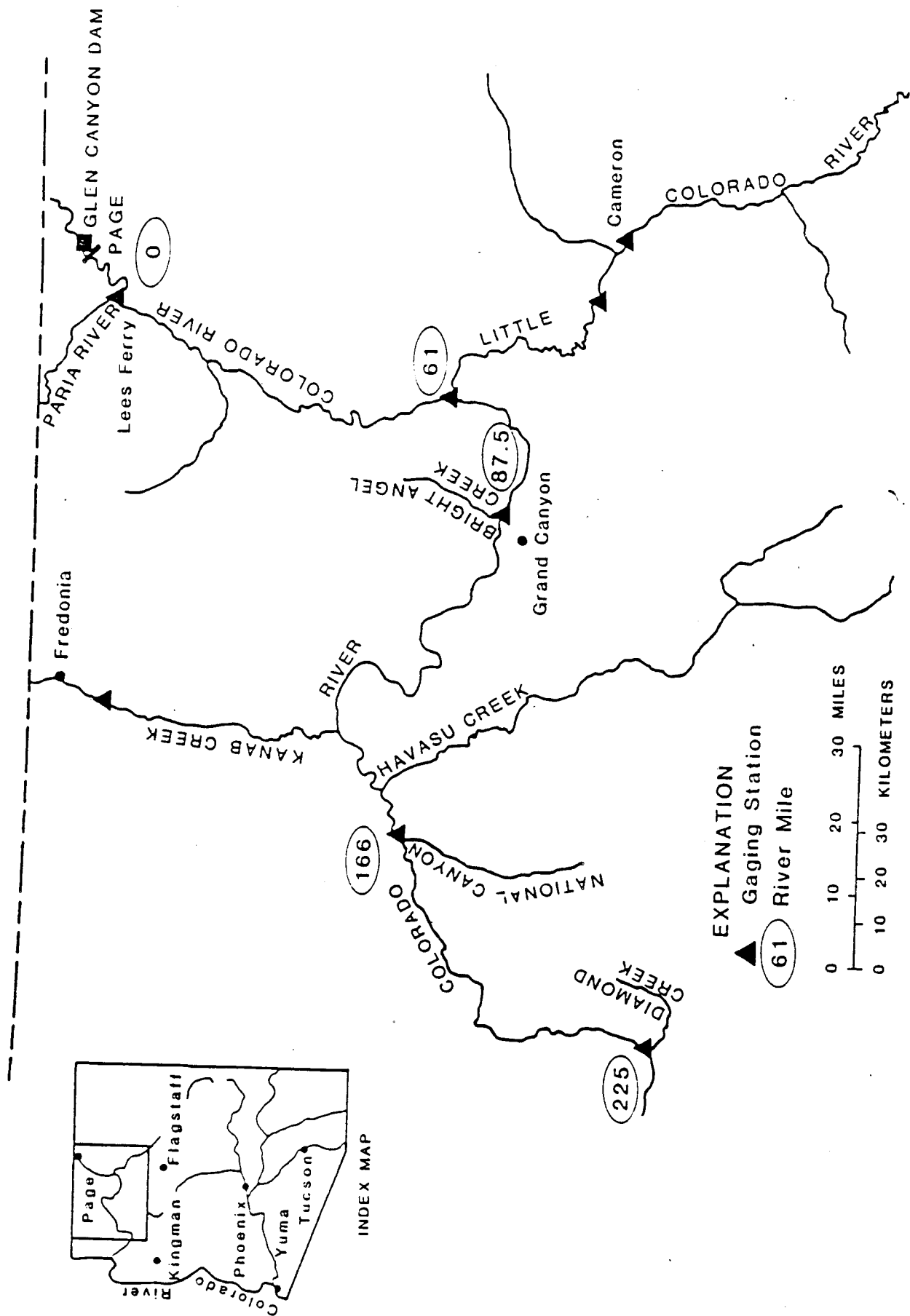
Cross section and bed material data should be collected within the reaches prior to beginning any sediment sampling program at the gaging stations. Verification and calibration for future modeling efforts will require initial channel geometry and bed material size gradations. A model could then be used to simulate sand loads at the gaging stations which can be compared with measured load.

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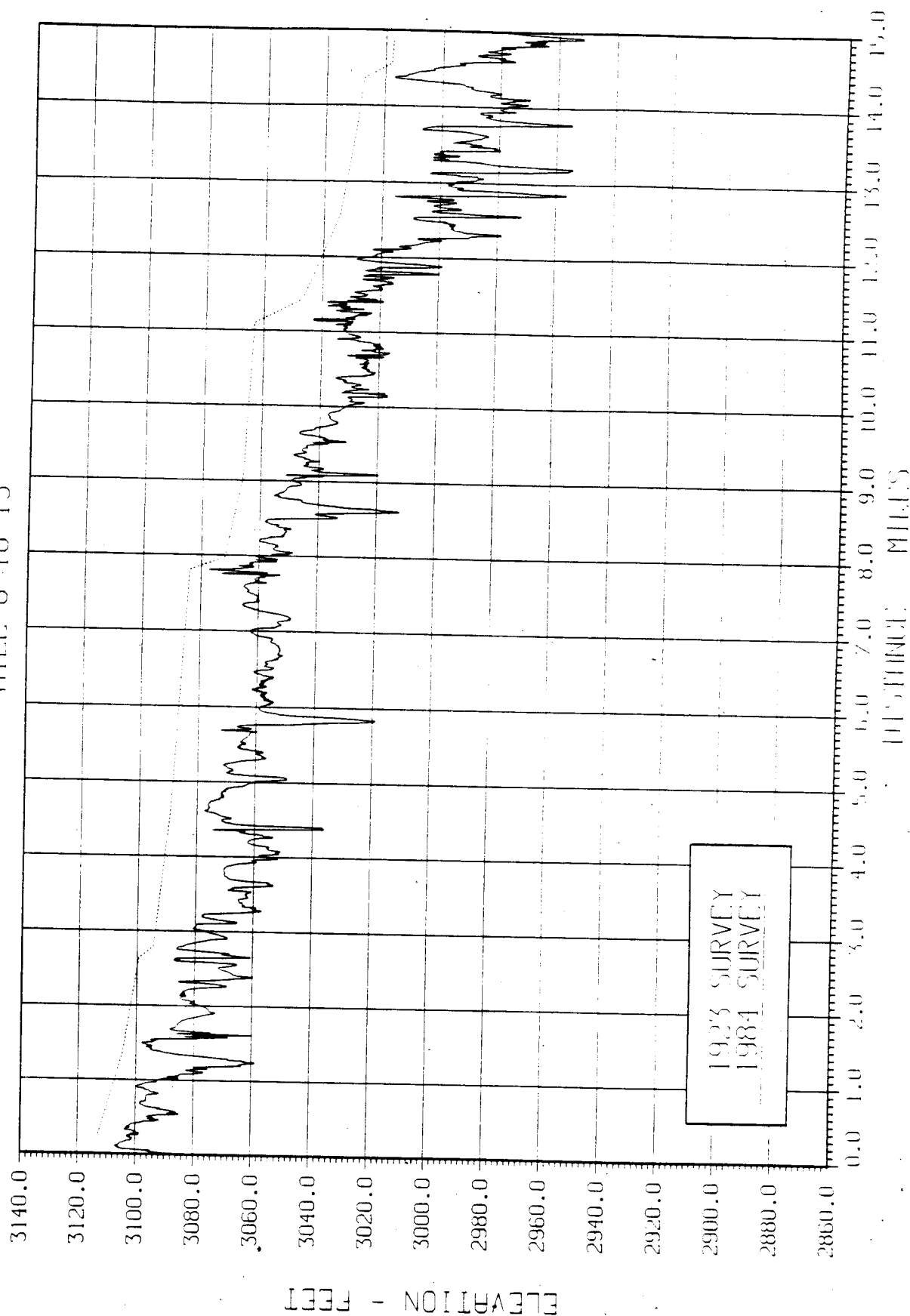


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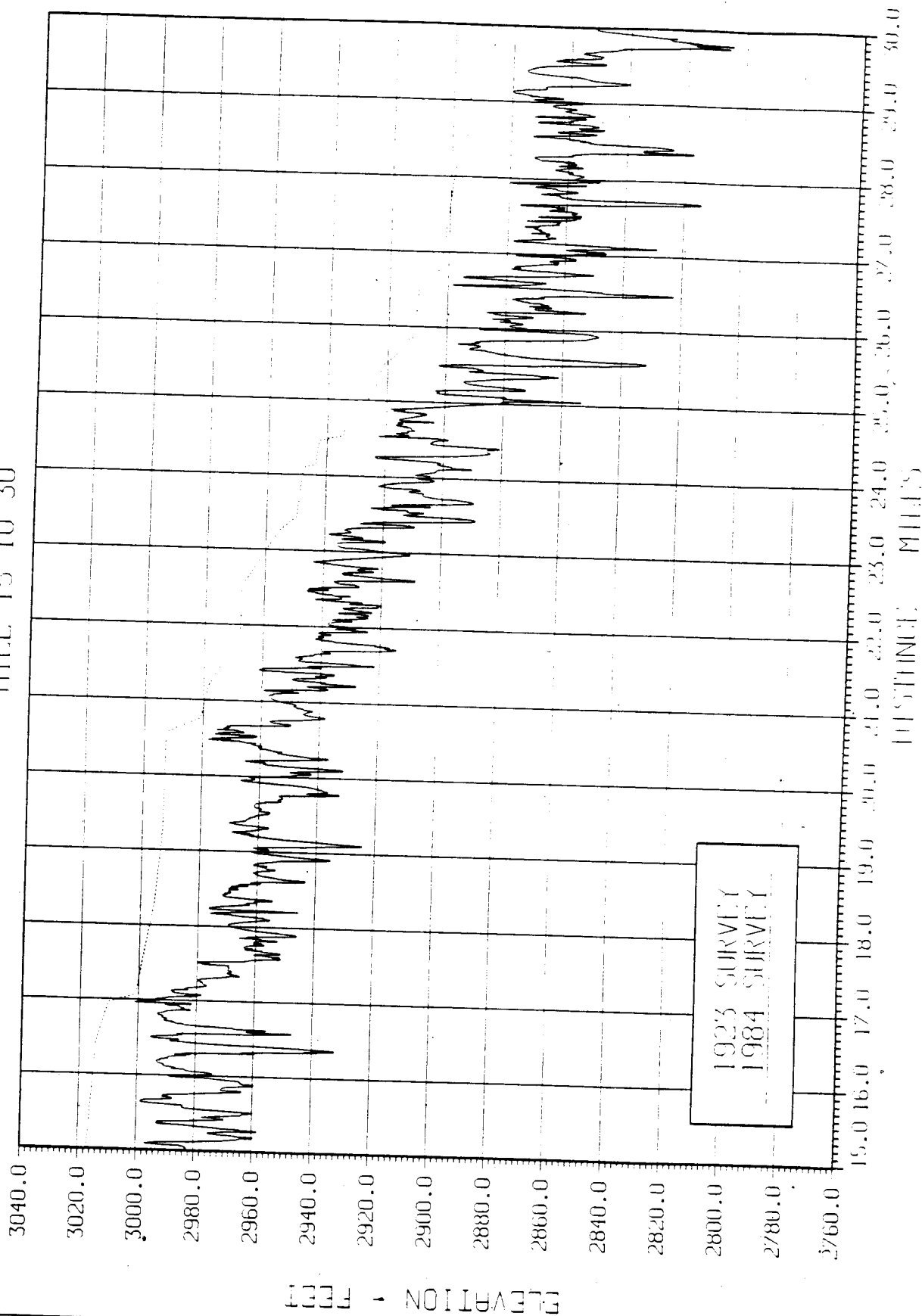


LOCATION MAP  
COLORADO RIVER SEDIMENT TRANSPORT STUDY

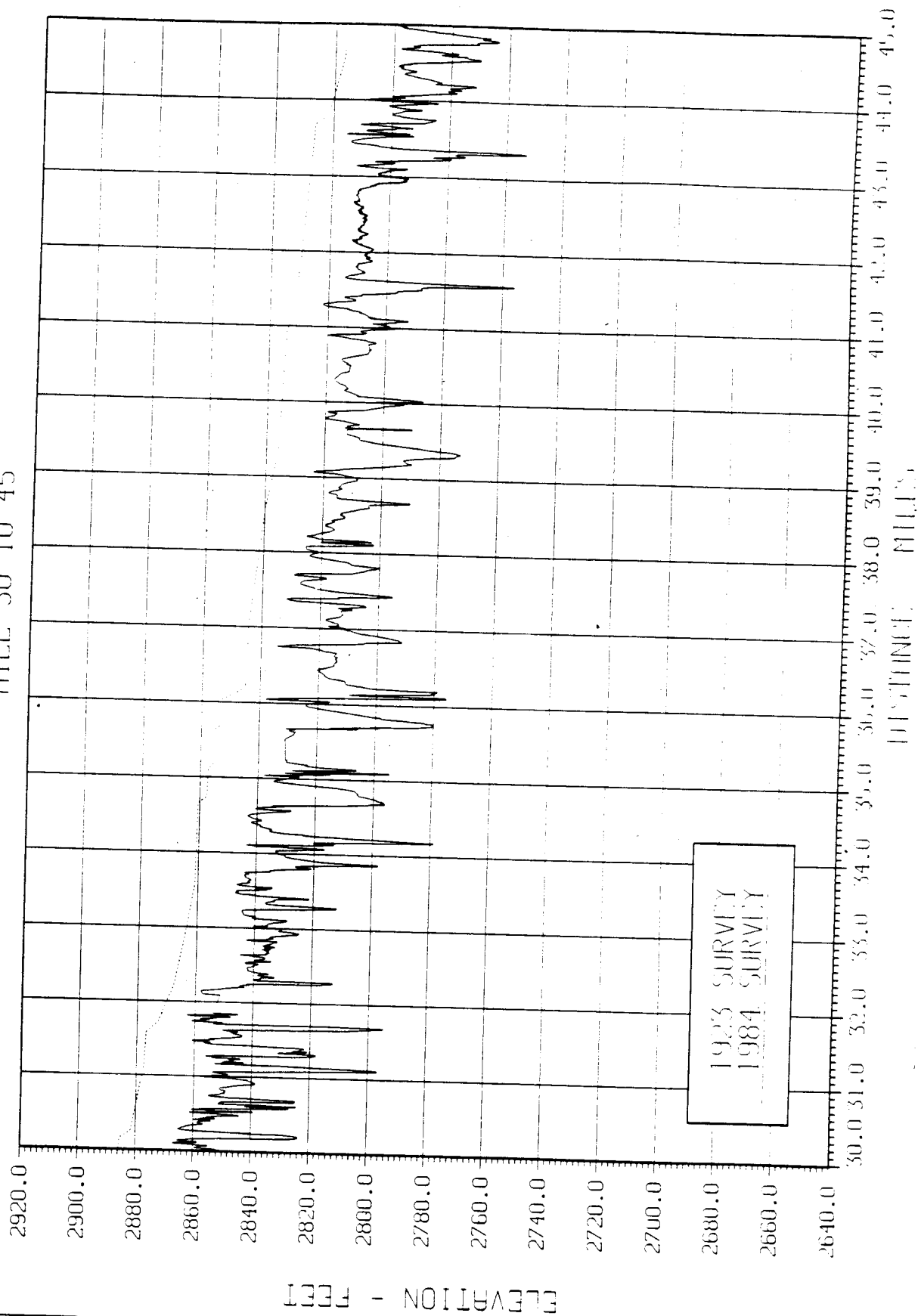
# GRAND CANYON SEDIMENT TRANSPORT STUDY COLORADO RIVER WATER SURFACE AND DEPTH PROFILE MILE 0 TO 15



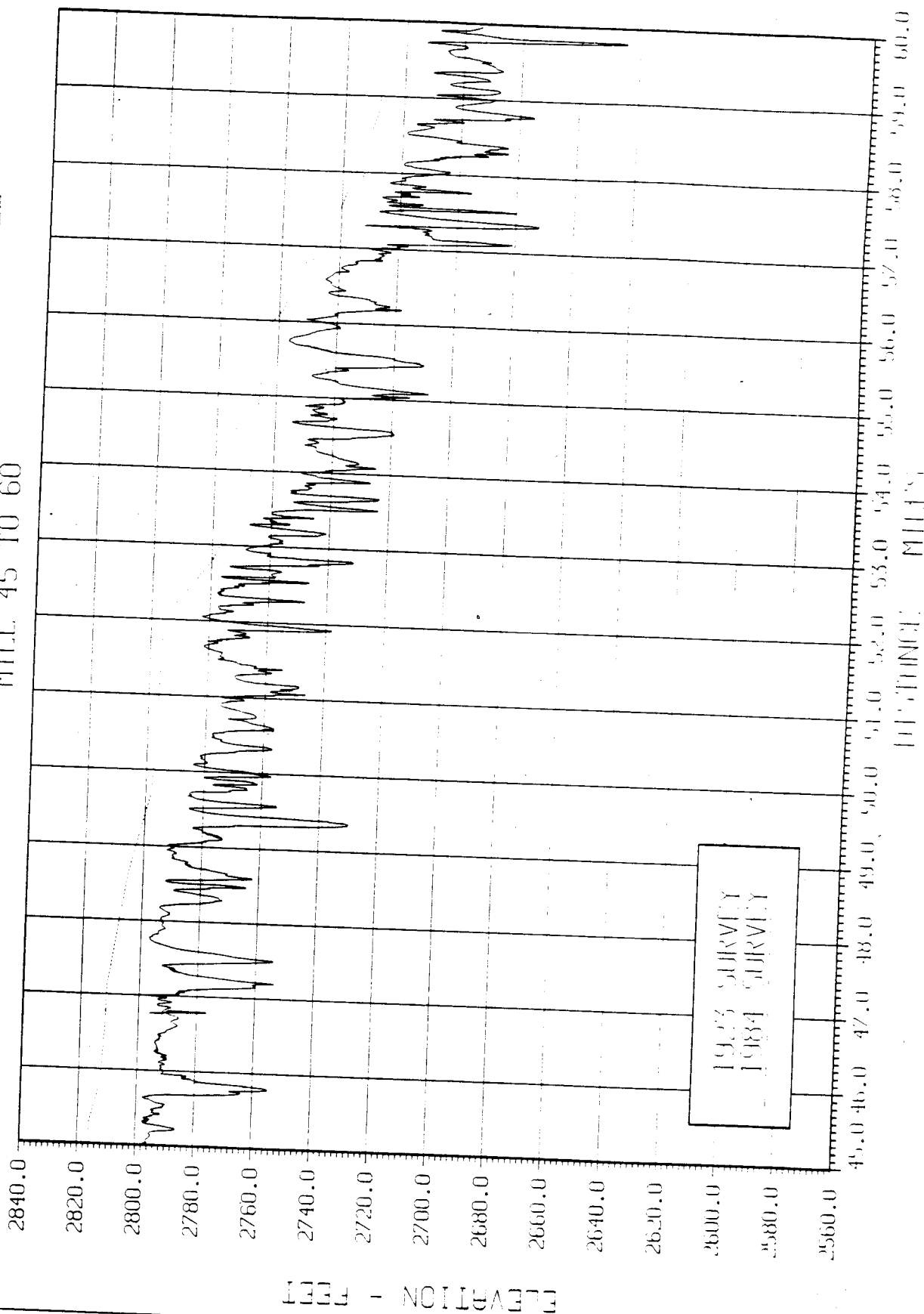
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 MILE 15 TO 30



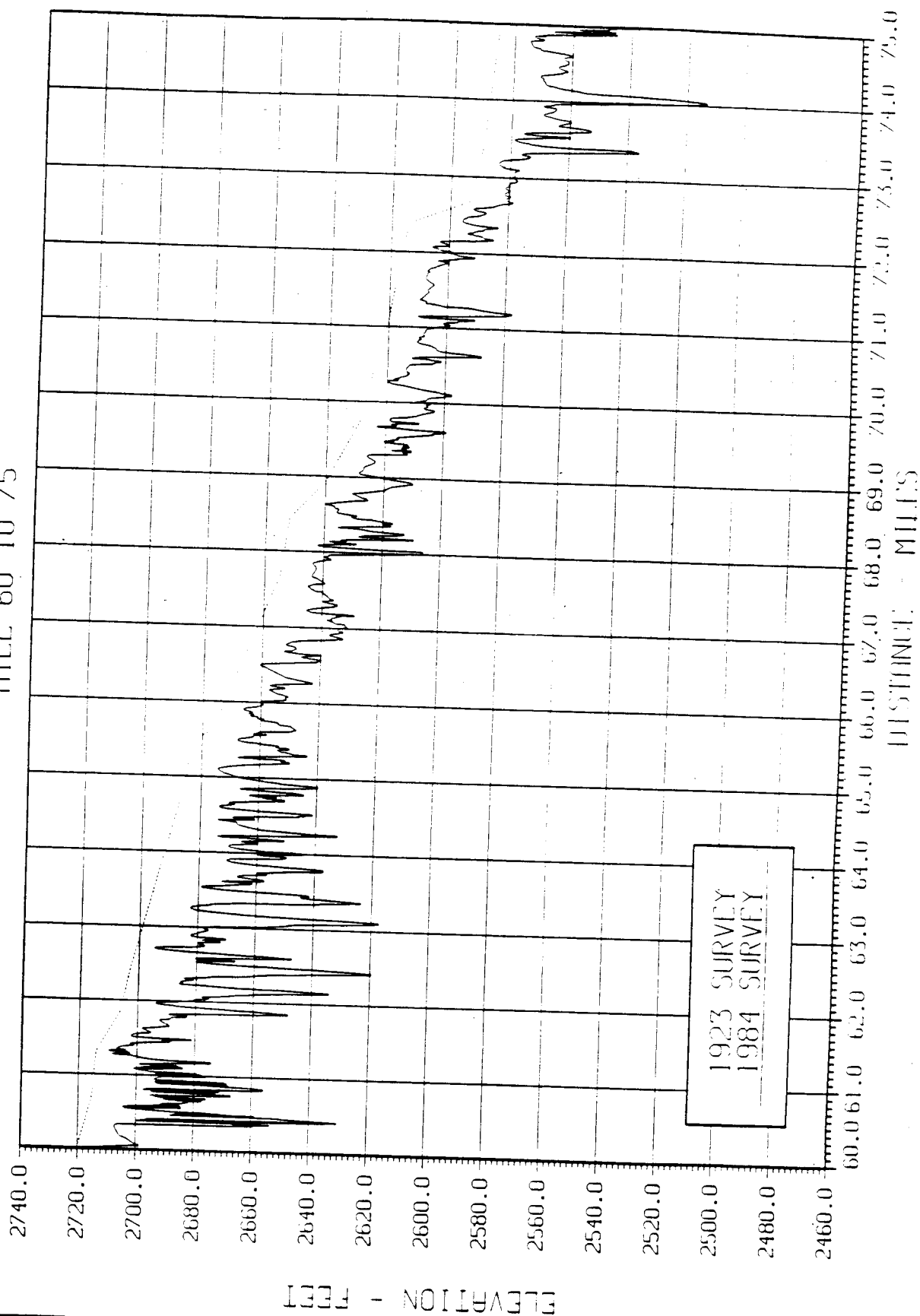
# GRAND CANYON SEDIMENT TRANSPORT STUDY COLORADO RIVER WATER SURFACE AND DEPTH PROFILE MILE 30 TO 45



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER WATER SURFACE AND DEPTH PROFILE  
 MILE 45 TO 60



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER WATER SURFACE AND DEPTH PROFILE  
 MILE 60 TO 75



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER WITH SURFACE AND DEPTH PROFILE  
 MILE 75 TO 90

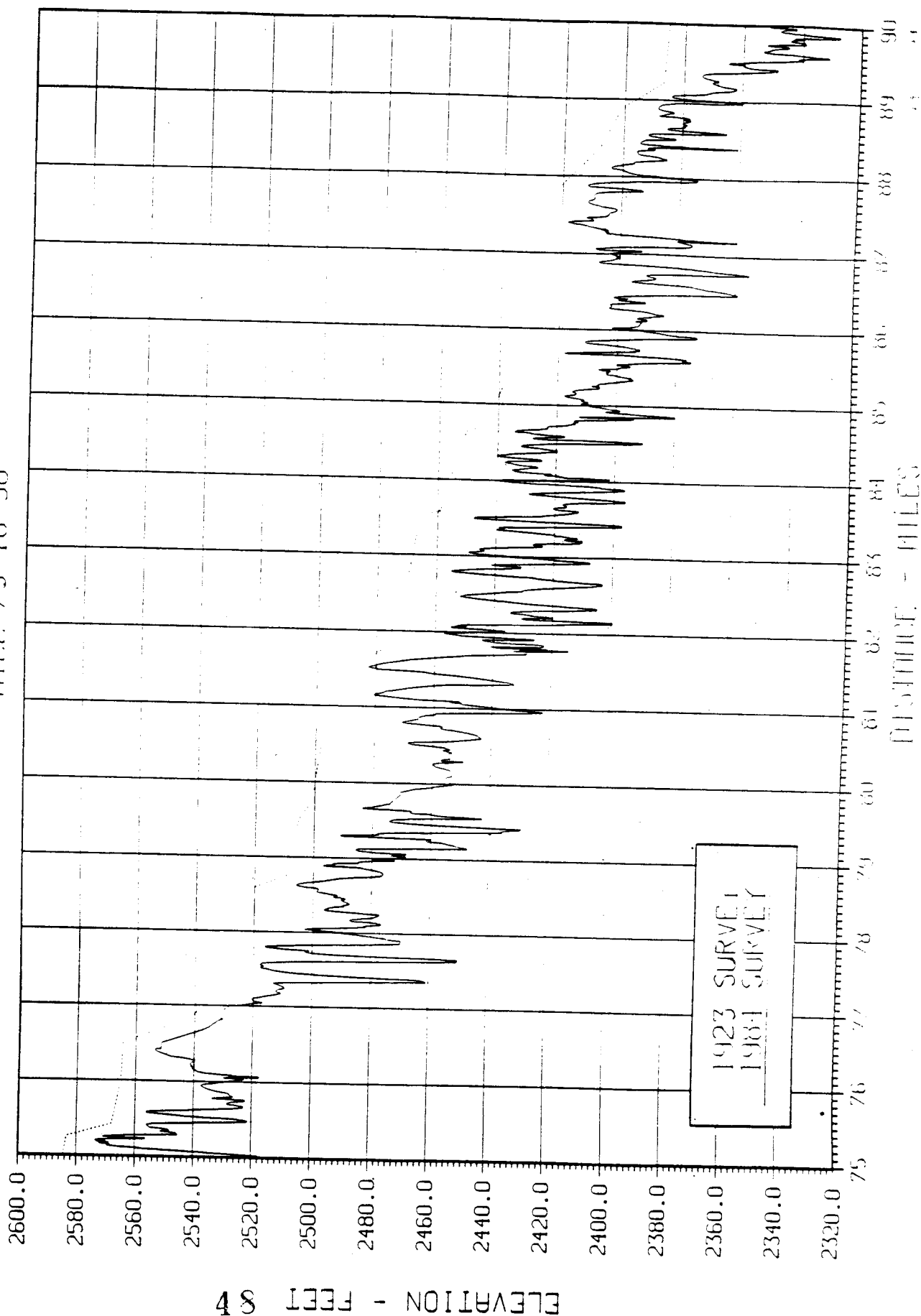
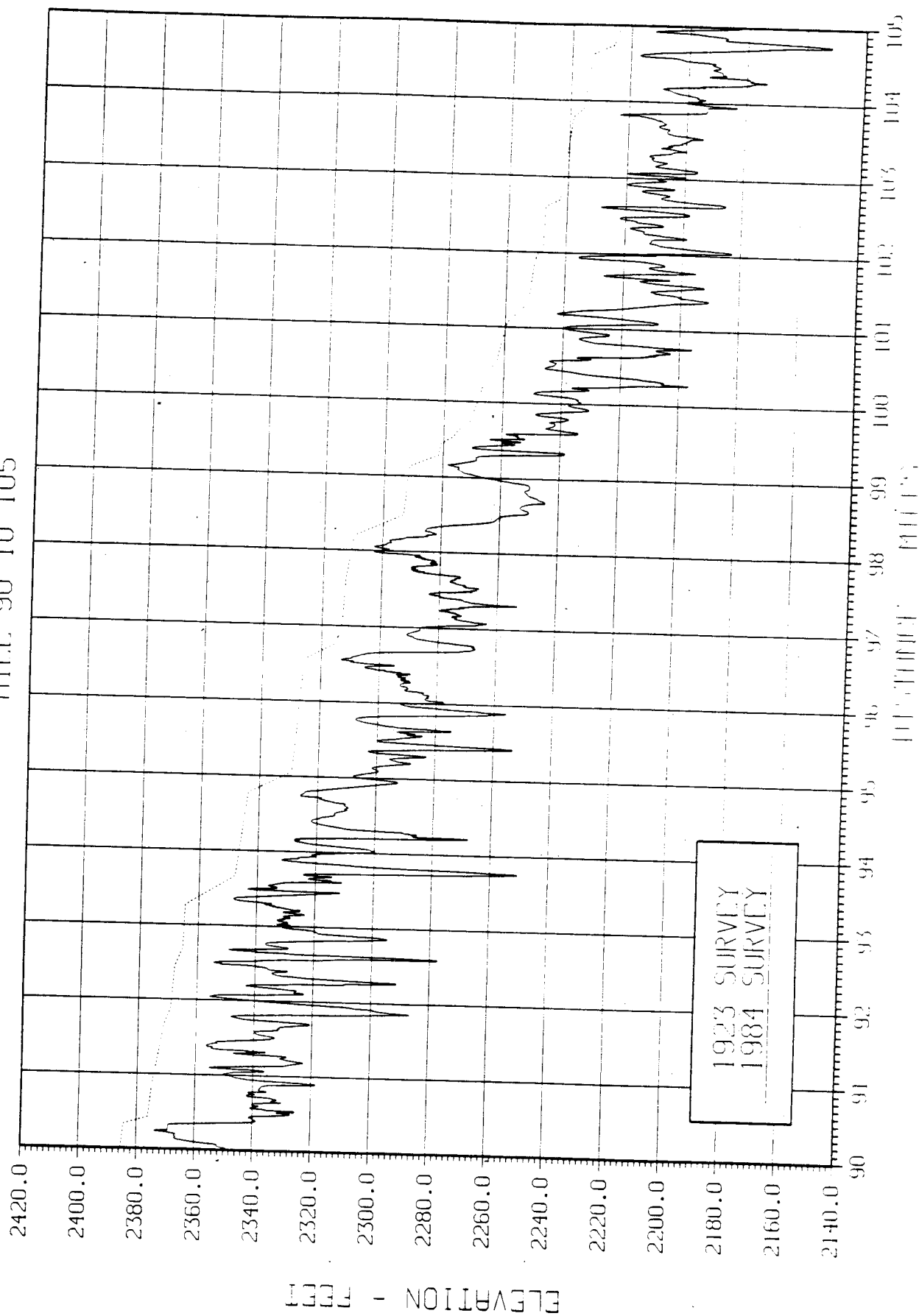


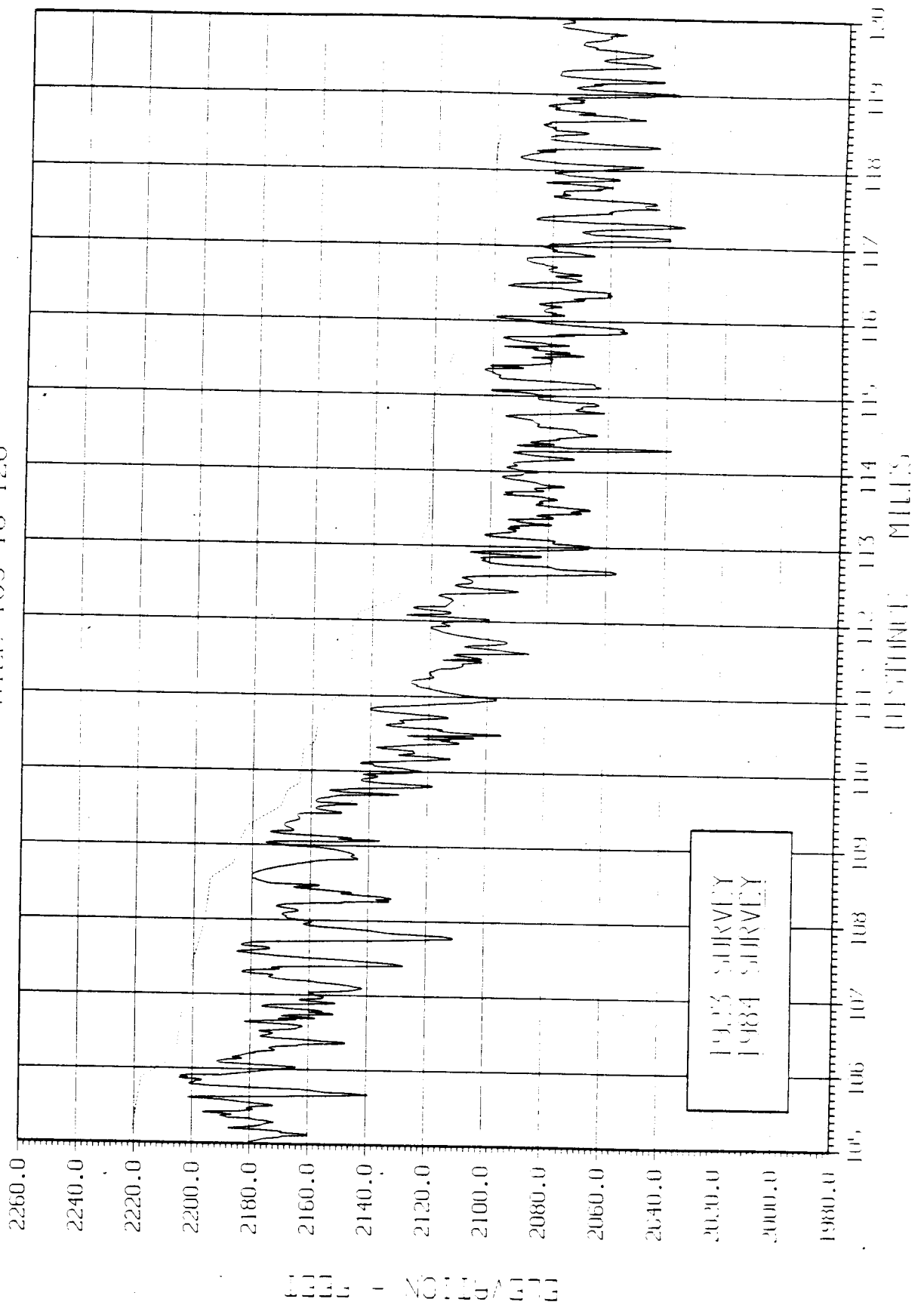
Figure 7



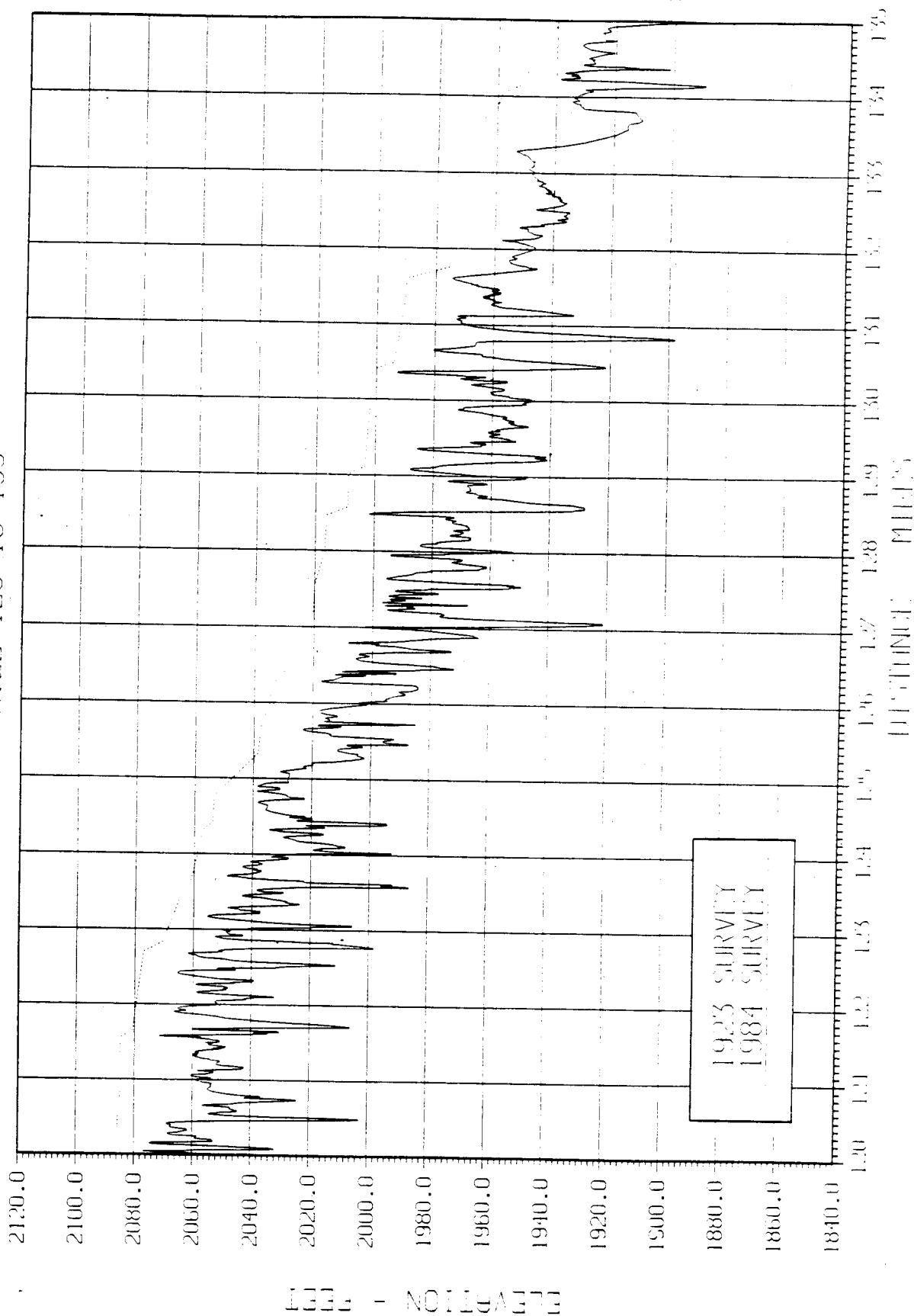
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 MILE 90 TO 105



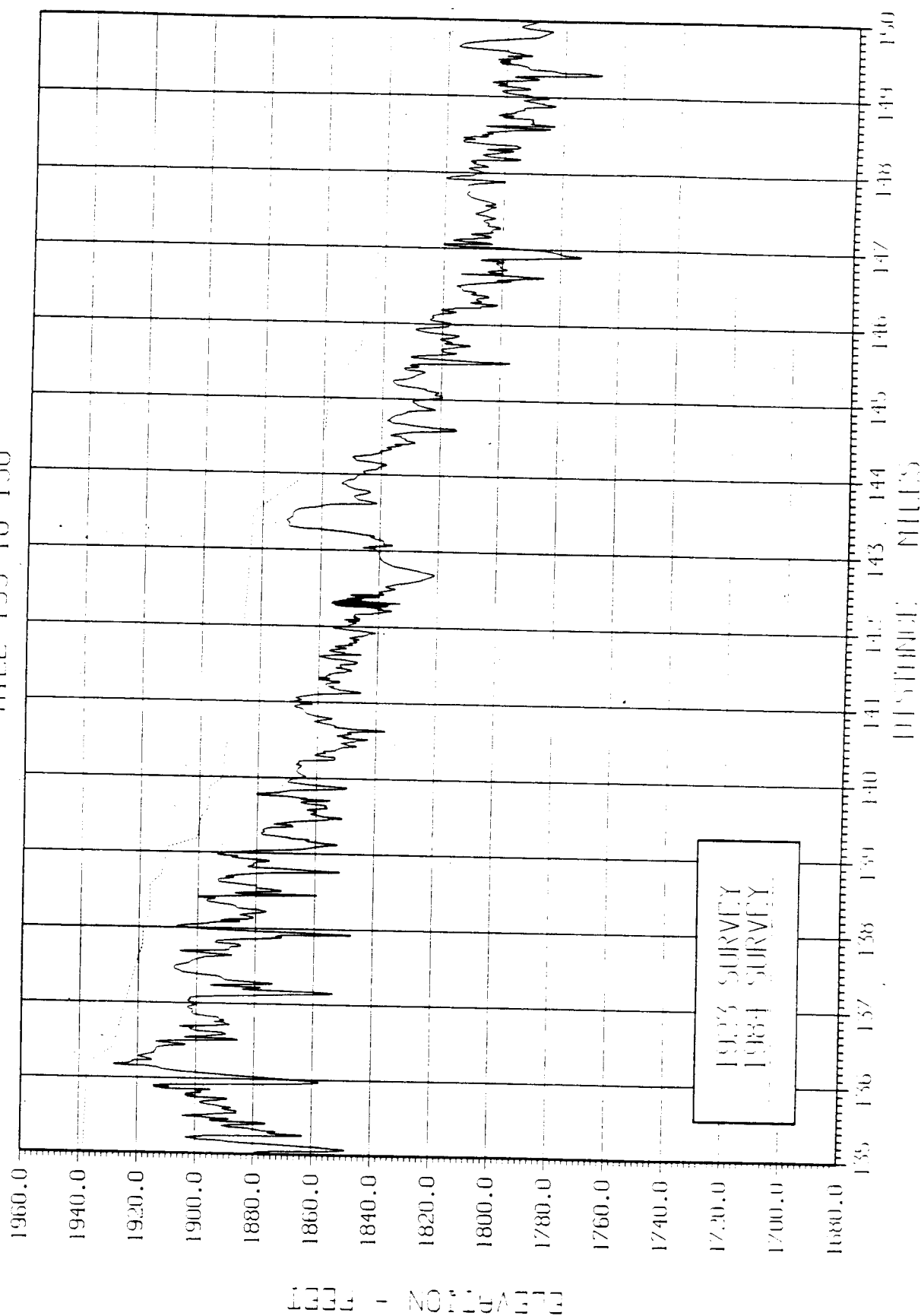
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 MILE 105 TO 120



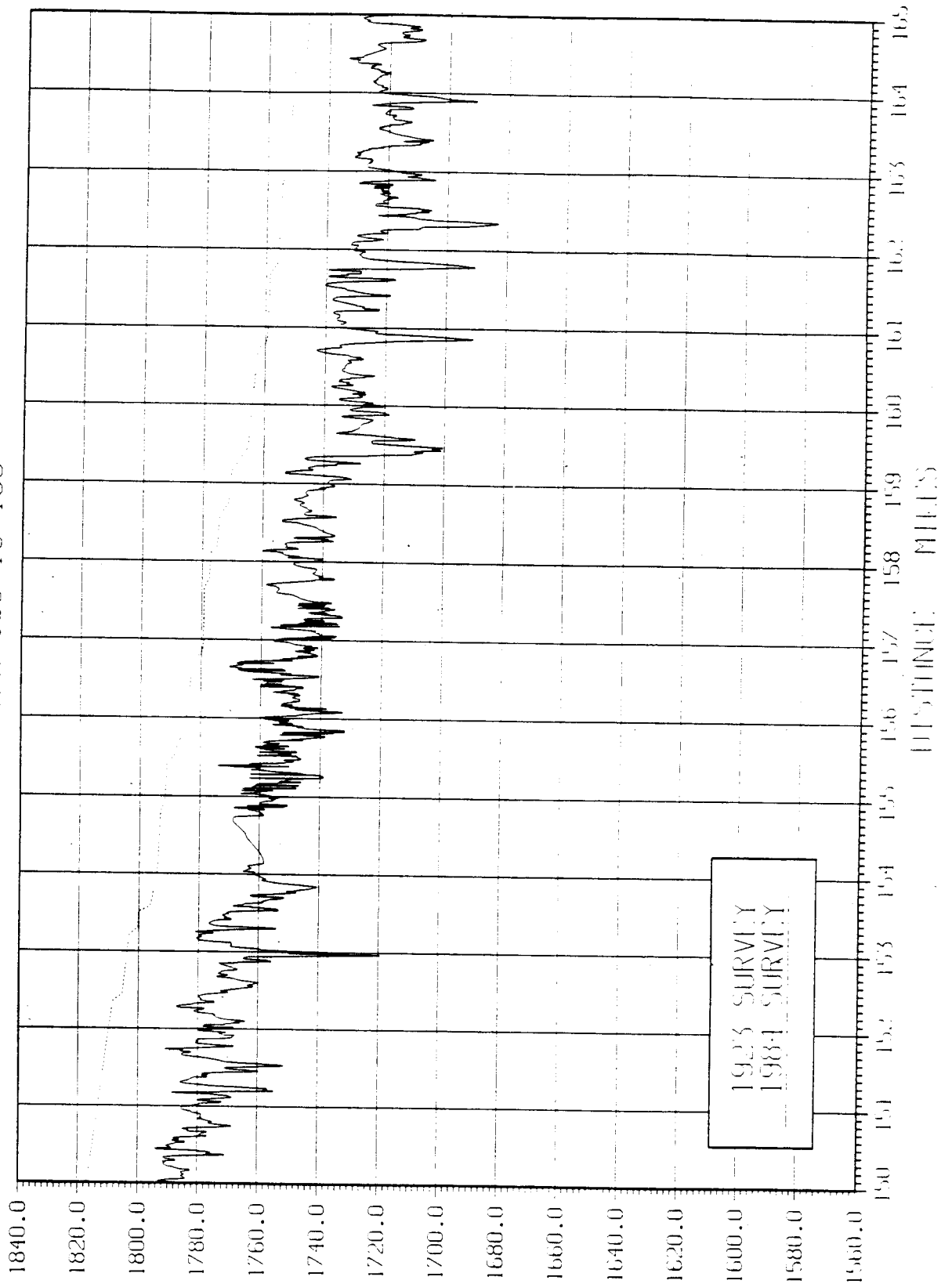
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 MILE 120 TO 135



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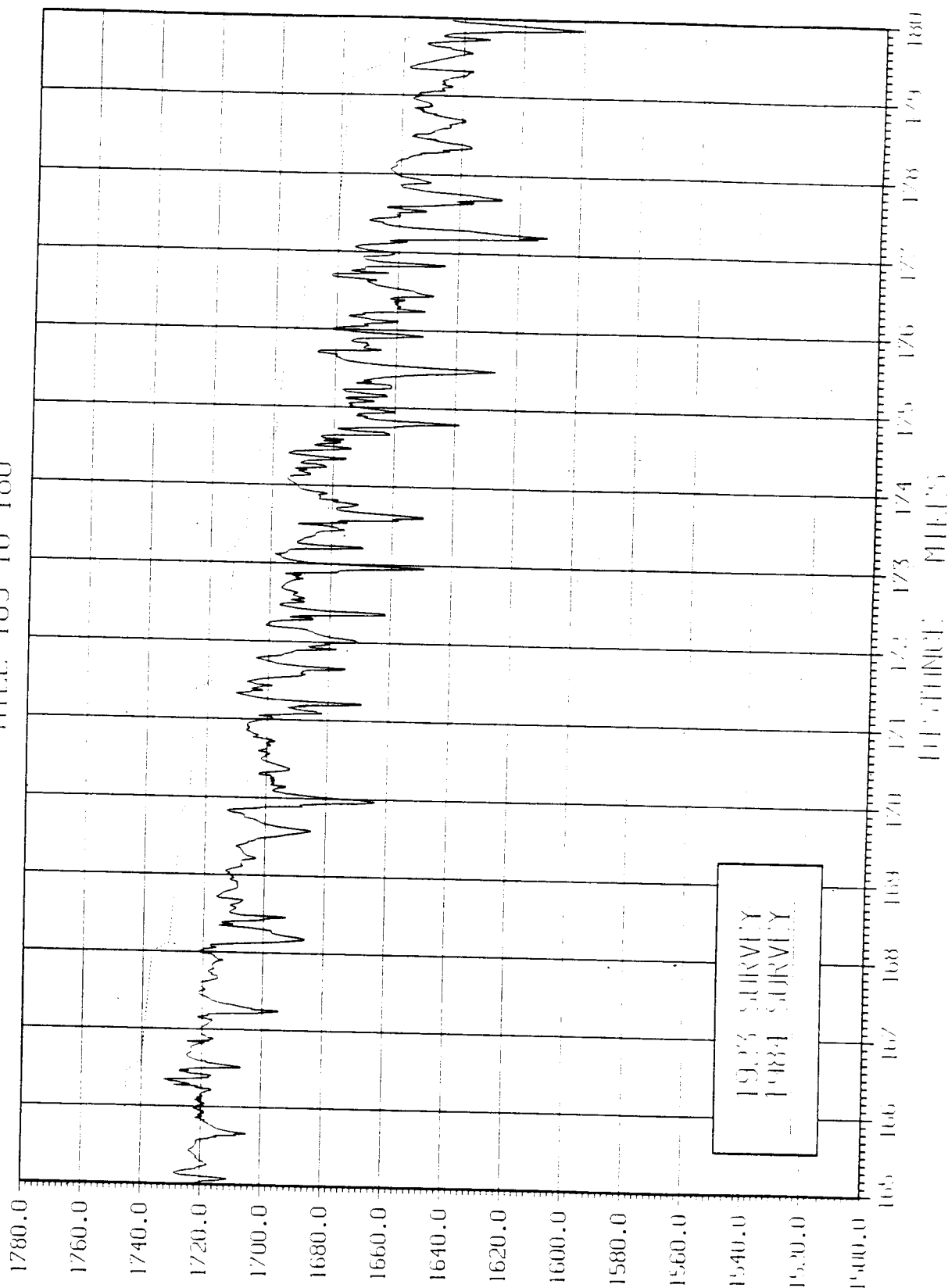


GRAND CANYON SEDIMENT TRANSPORT STUDY  
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 MILE 150 TO 165



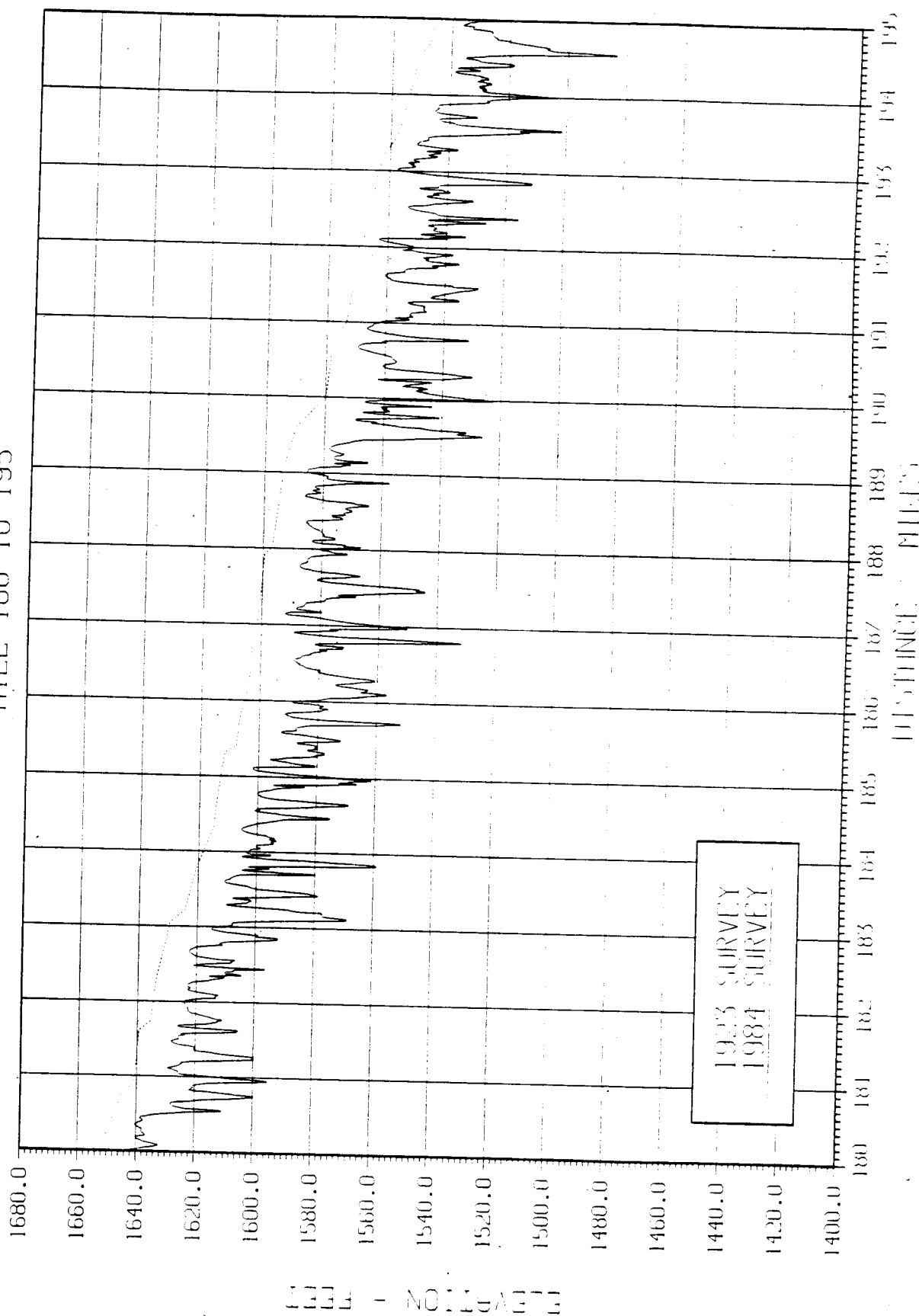
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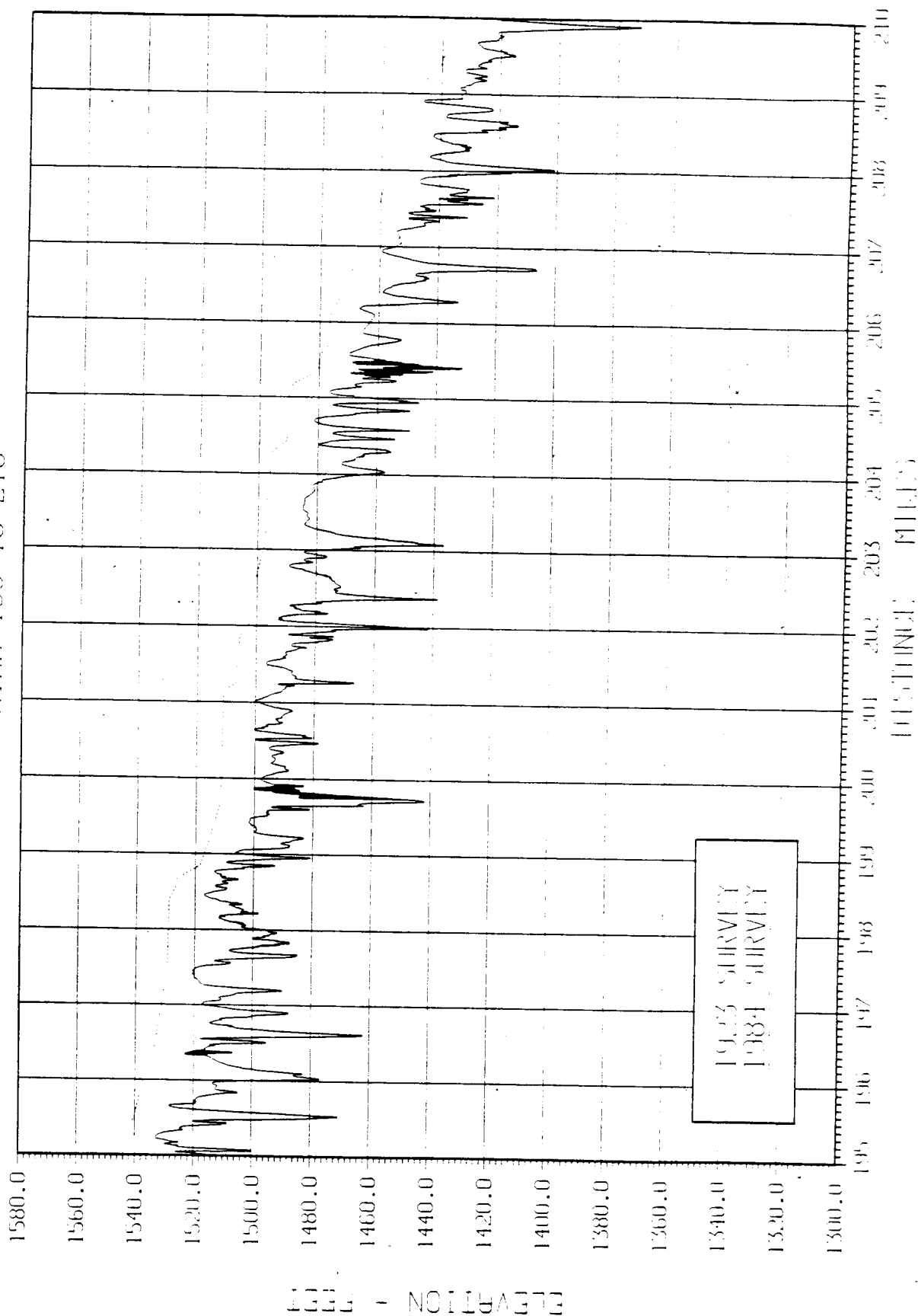


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 MILE 180 TO 195

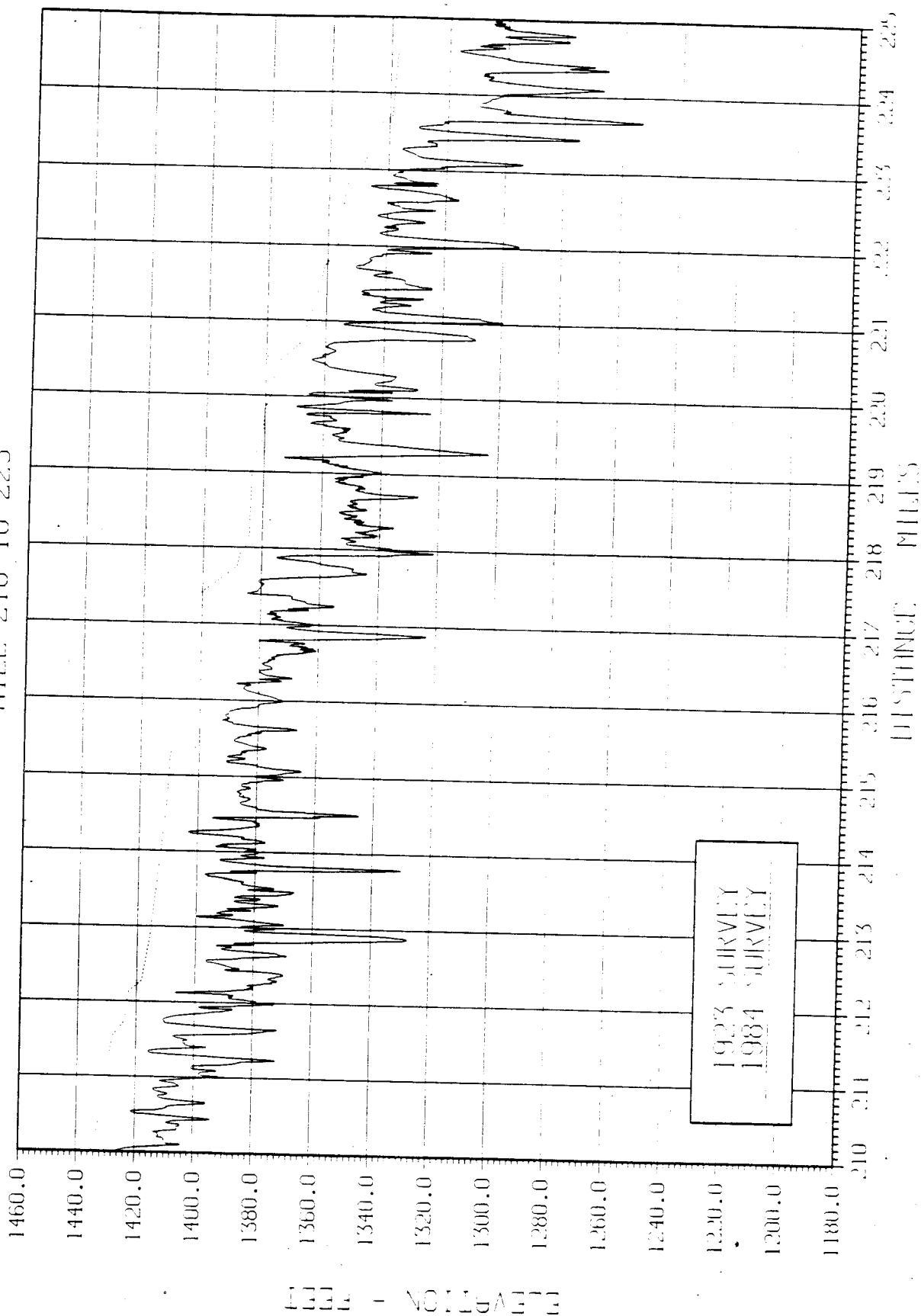


# GRAND CANYON SEDIMENT TRANSPORT STUDY COLORADO RIVER WATER SURFACE AND DEPTH PROFILE MILE 195 TO 210

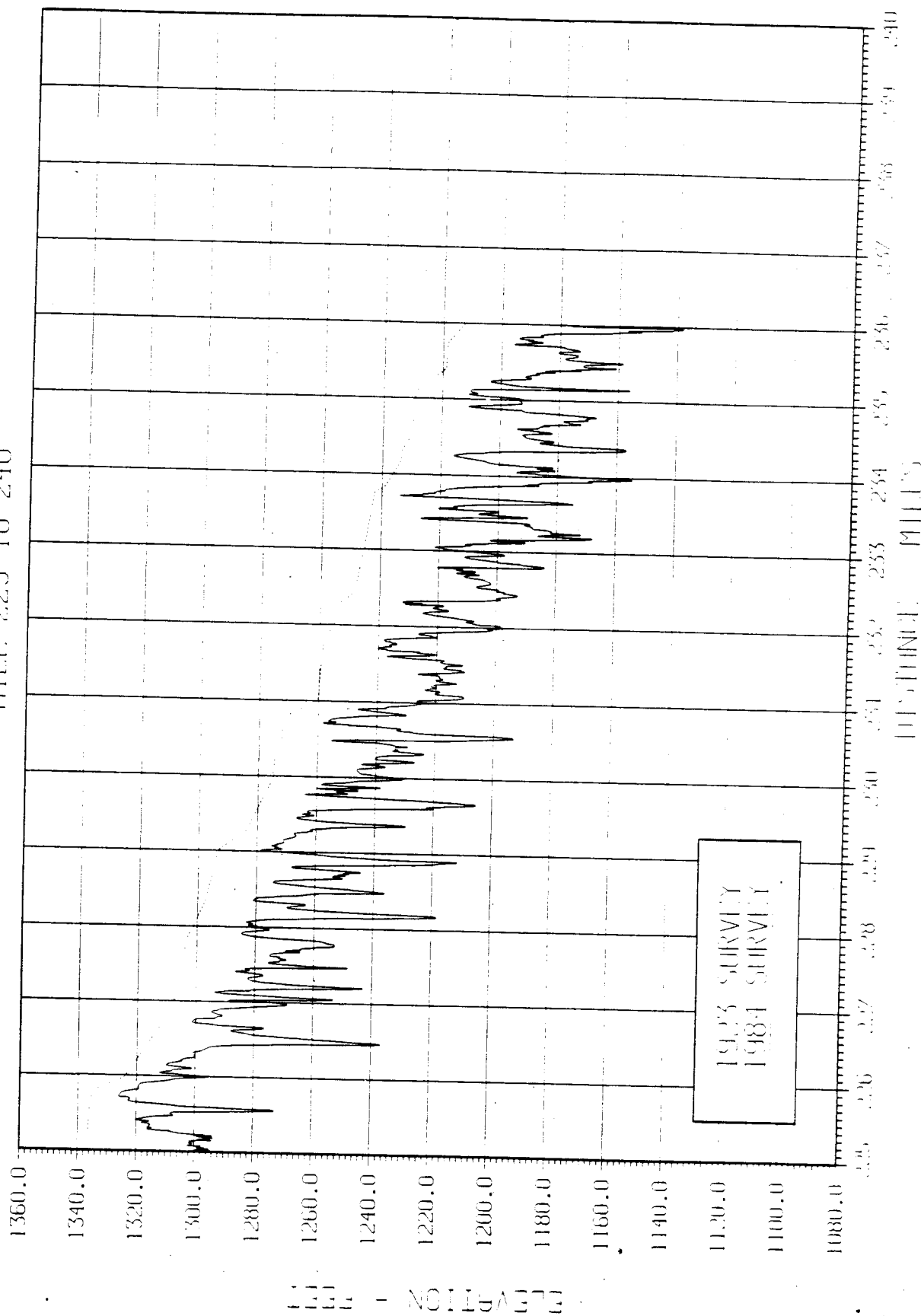




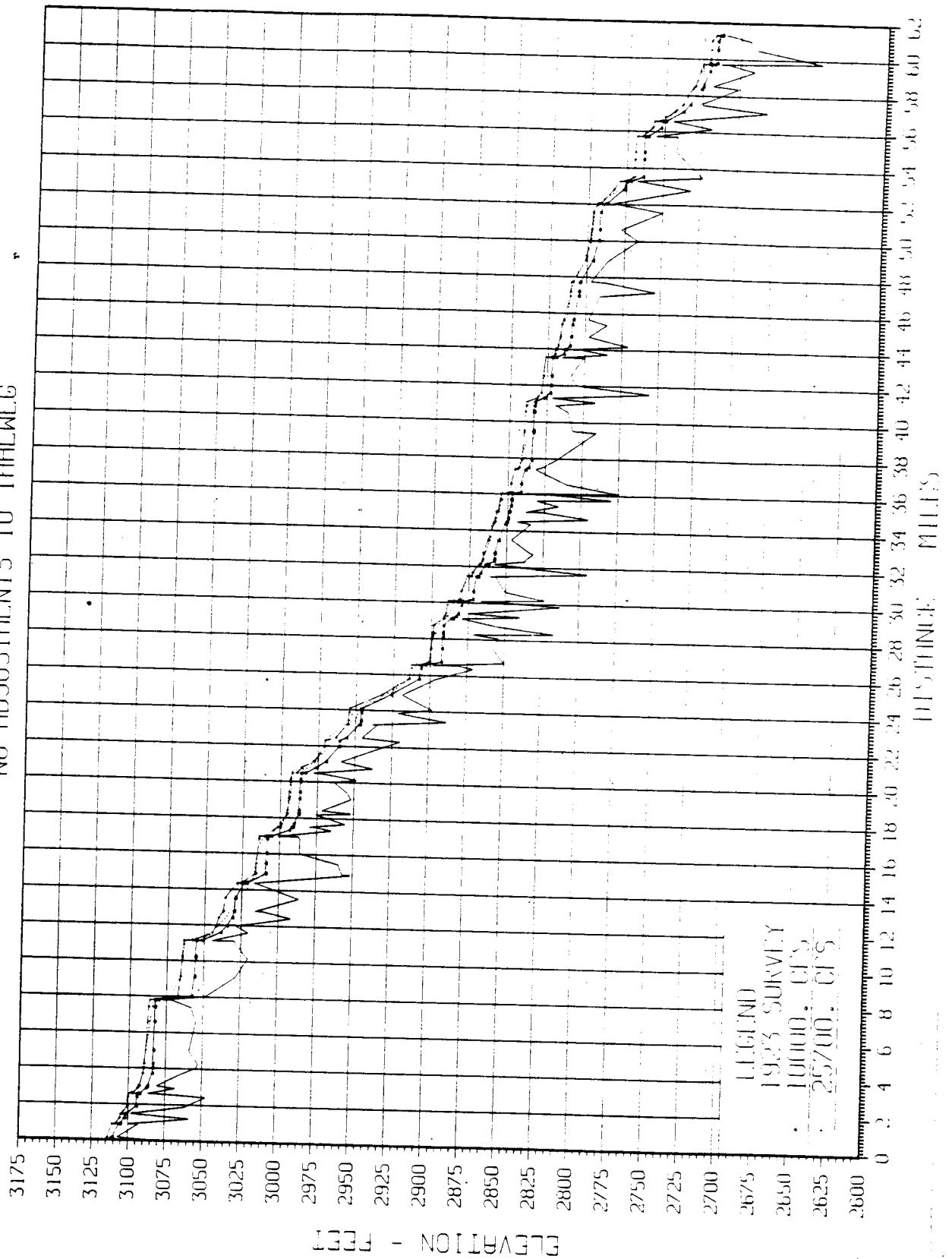
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 COLORADO RIVER WATER SURFACE AND DEPTH PROFILE  
 MILE 210 TO 225



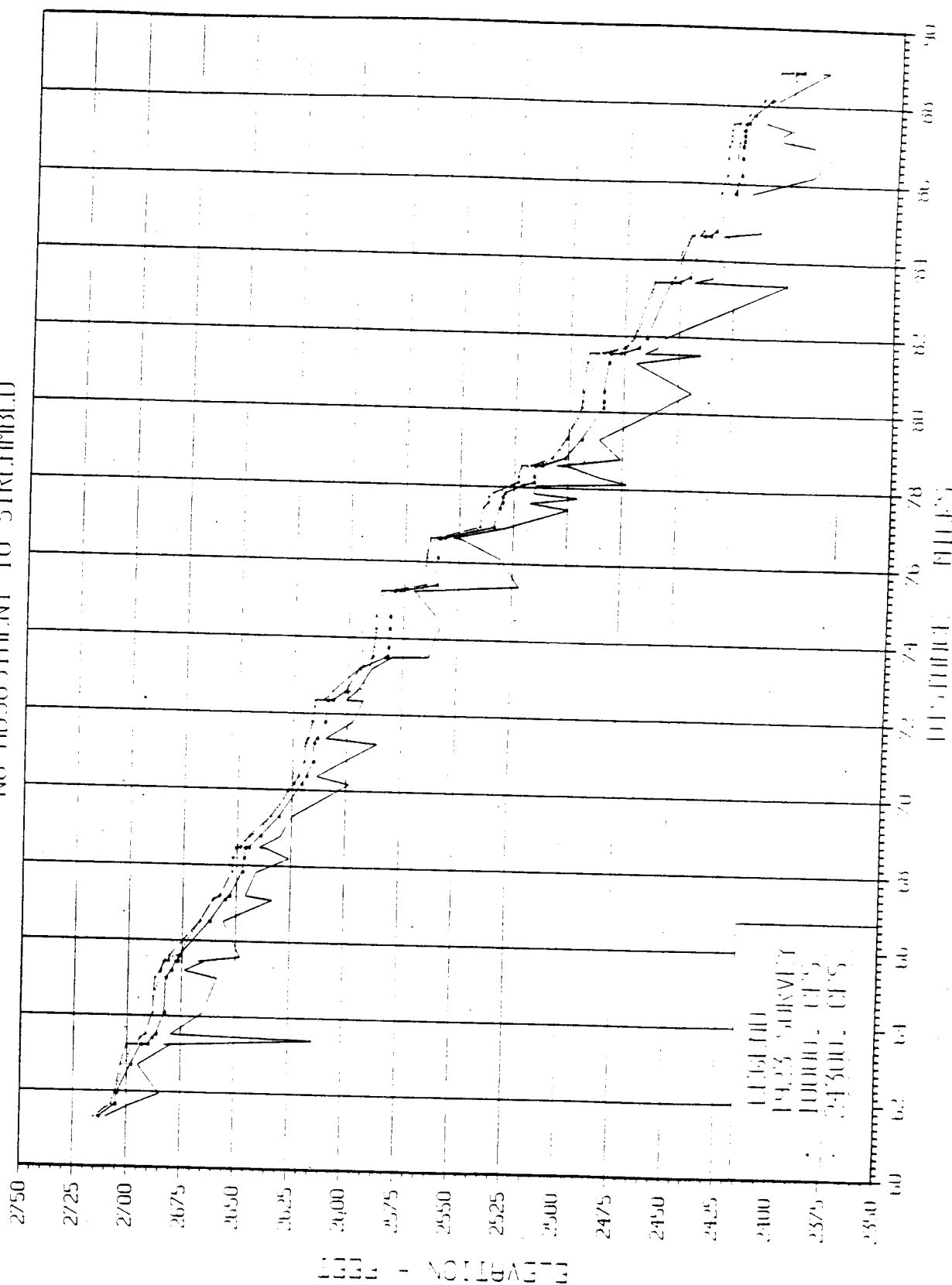
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER WATER SURFACE AND DEPTH PROFILE  
 MILE 225 TO 240



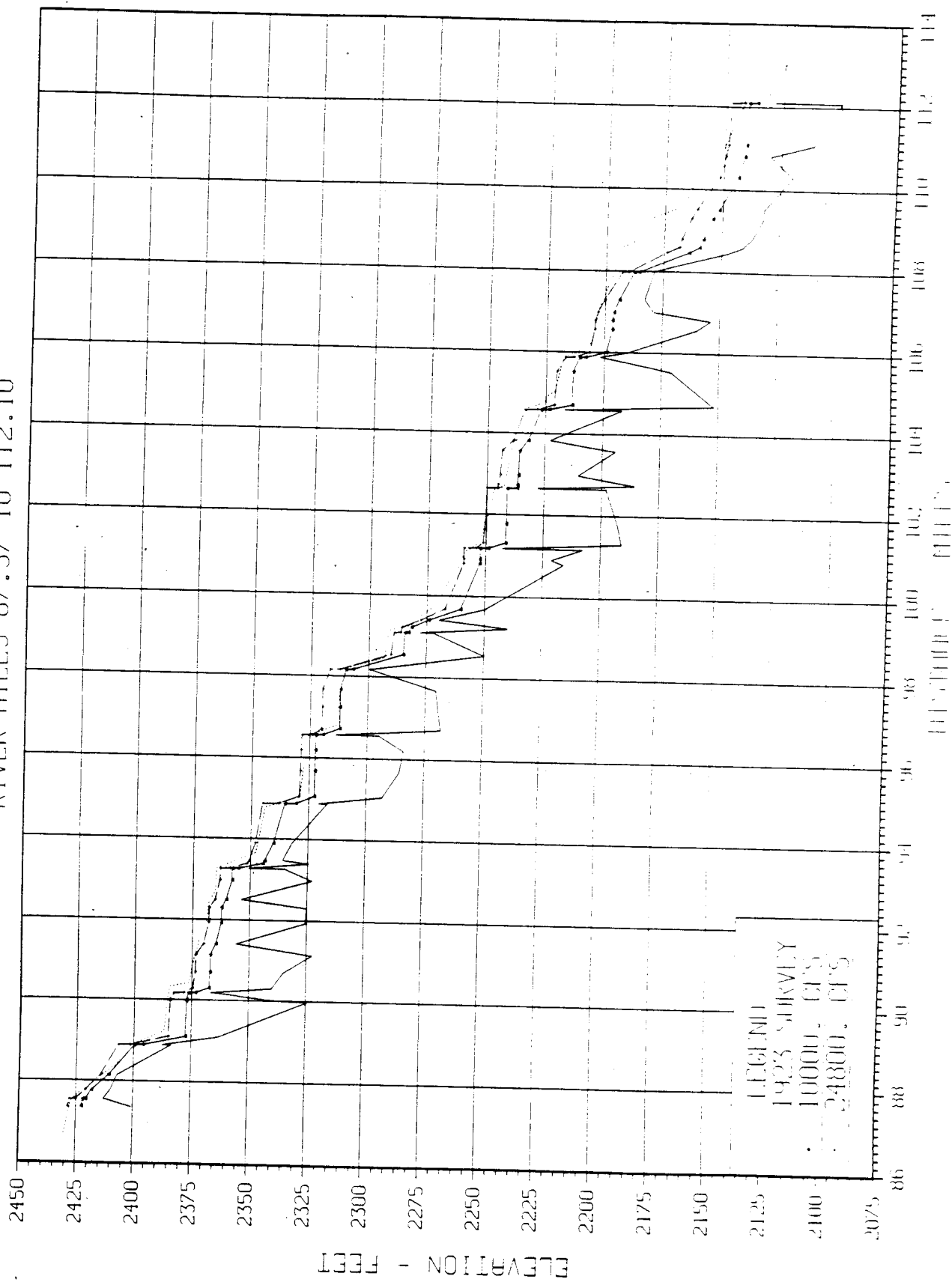
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM LEES FERRY TO ABOVE THE MOUTH OF LITTLE COLORADO RIVER  
 NO ADJUSTMENTS TO THALWEG



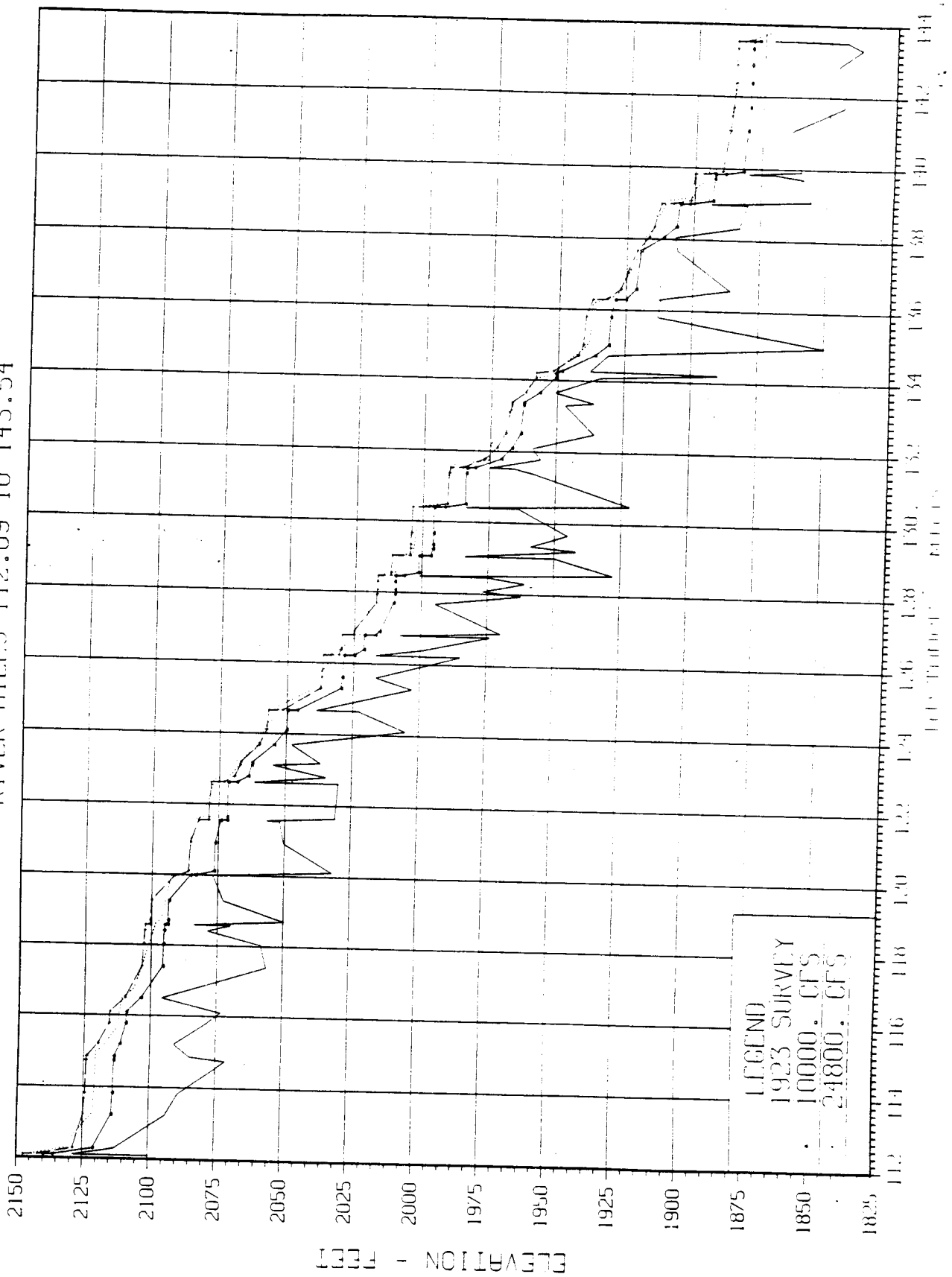
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON  
 NO ADJUSTMENT TO STREAMBED



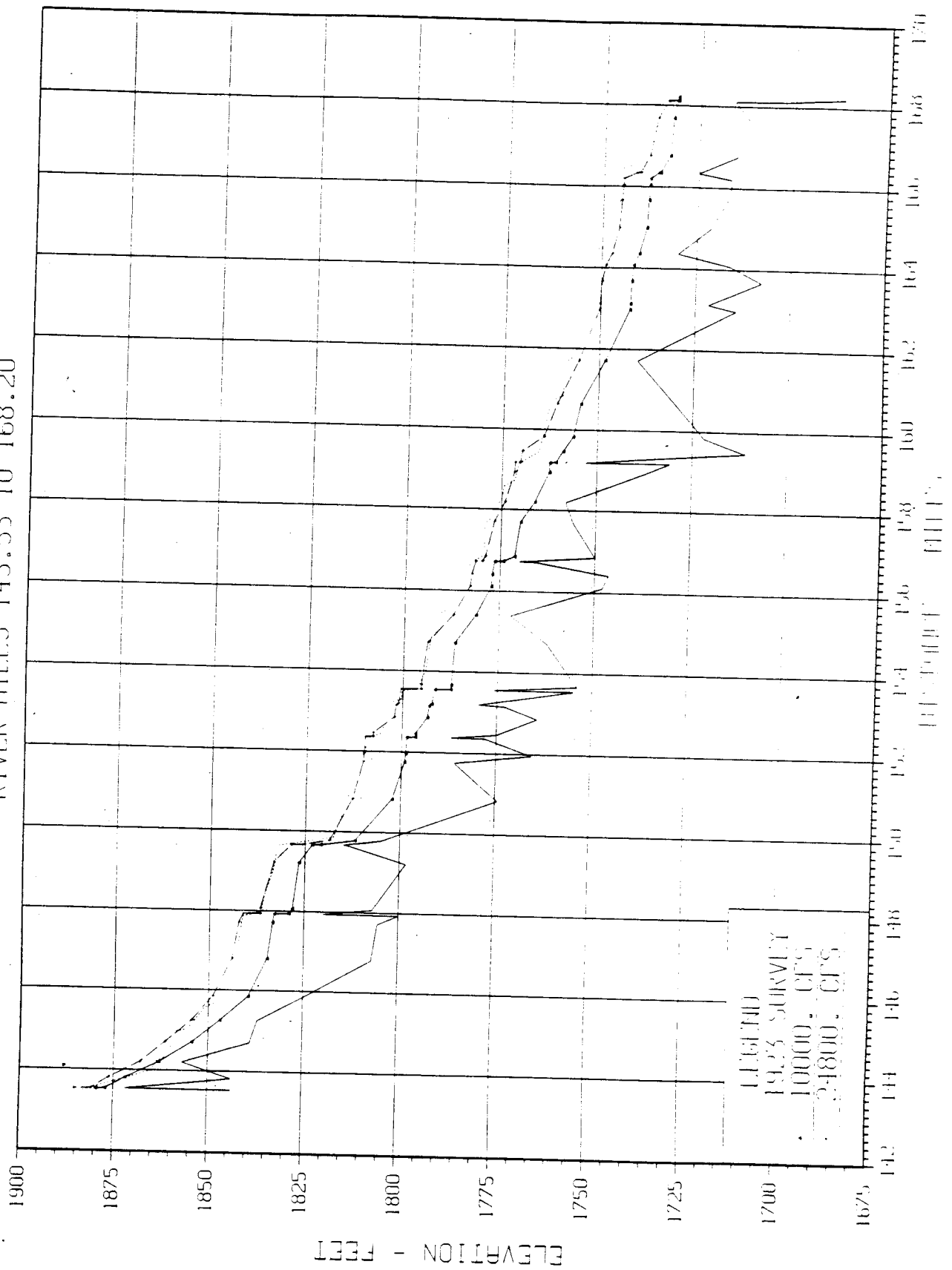
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 87.37 TO 112.10



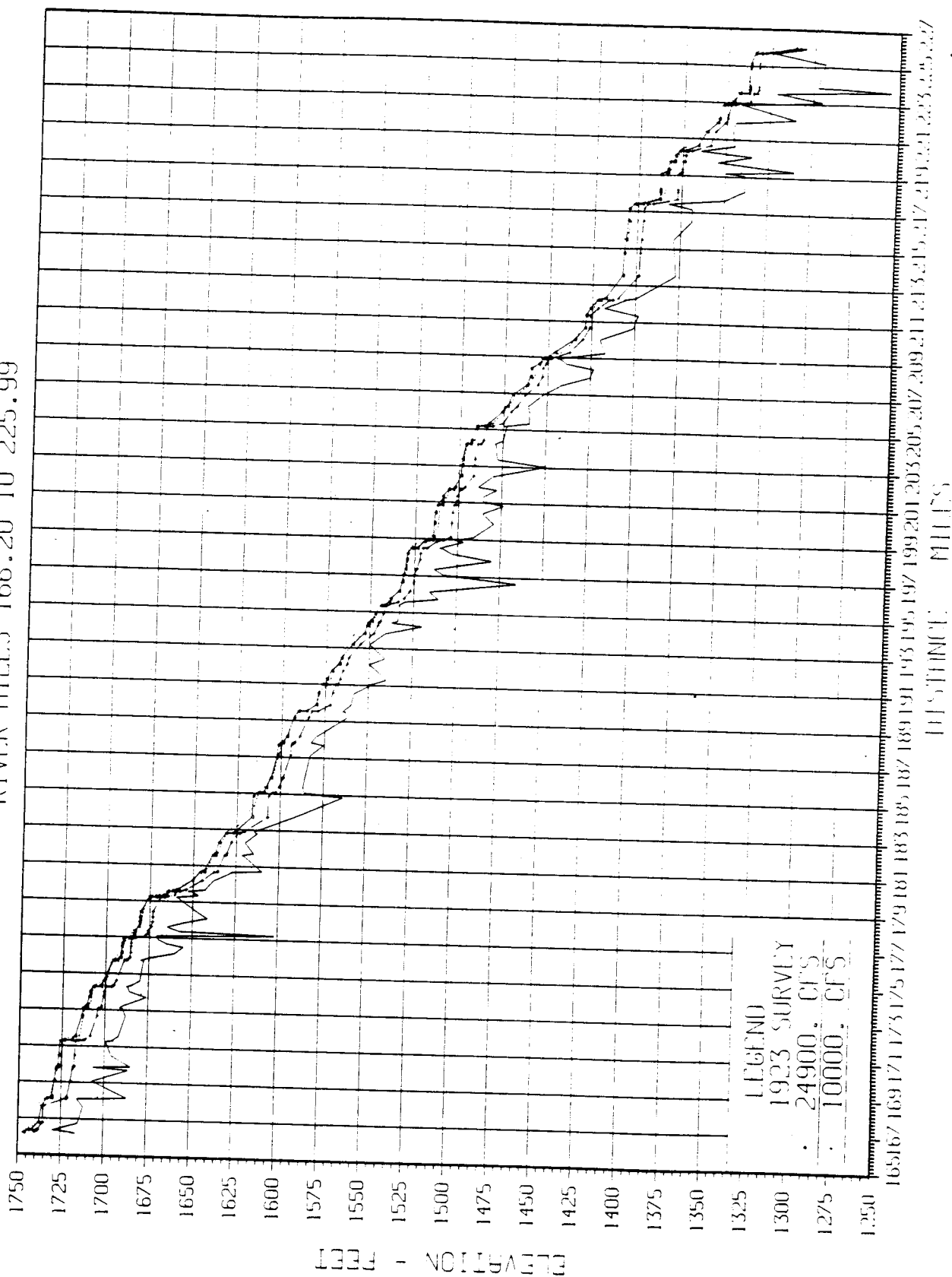
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILE'S 112.09 TO 143.54



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 143.53 TO 168.20

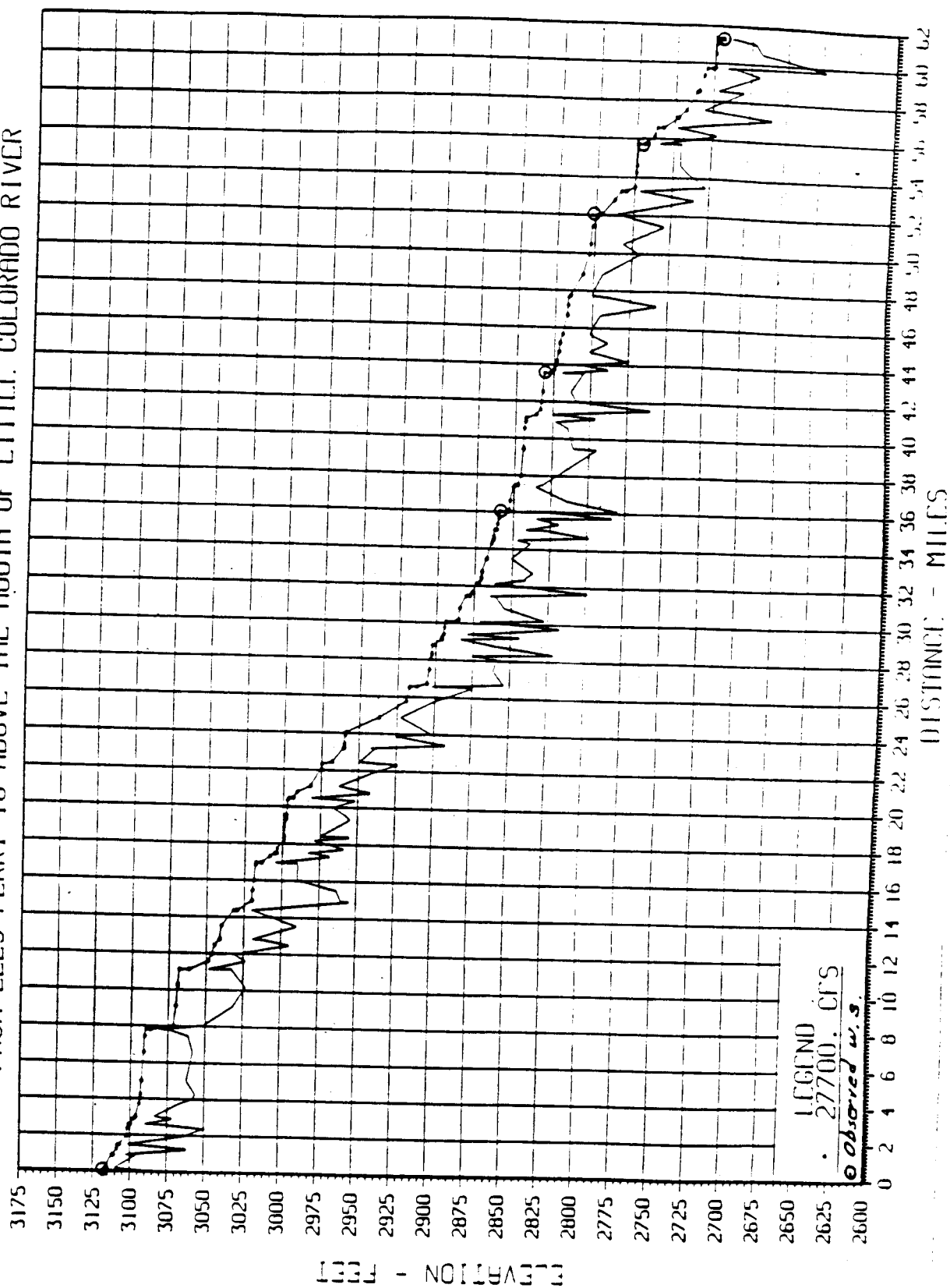


GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 225.99

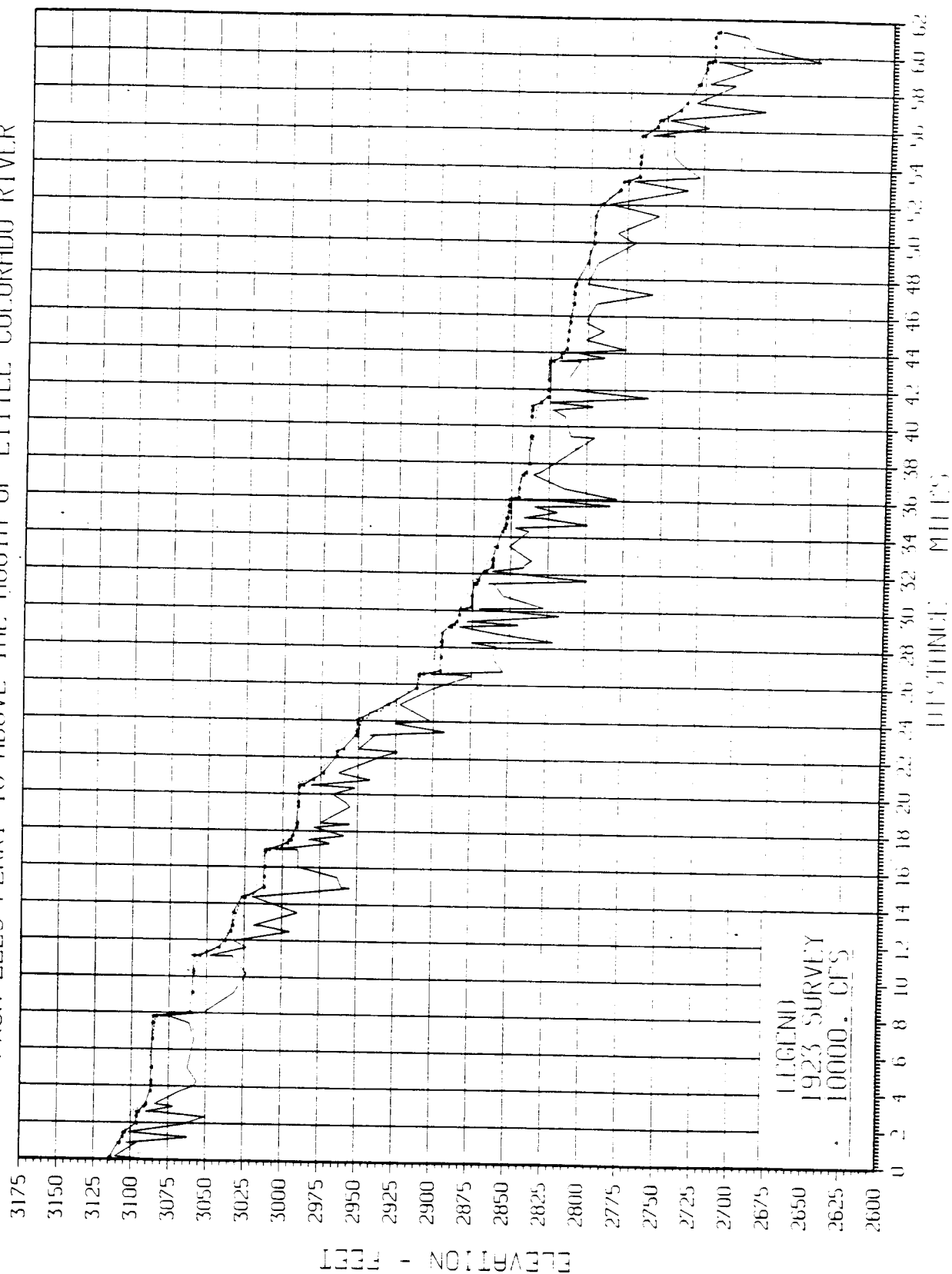




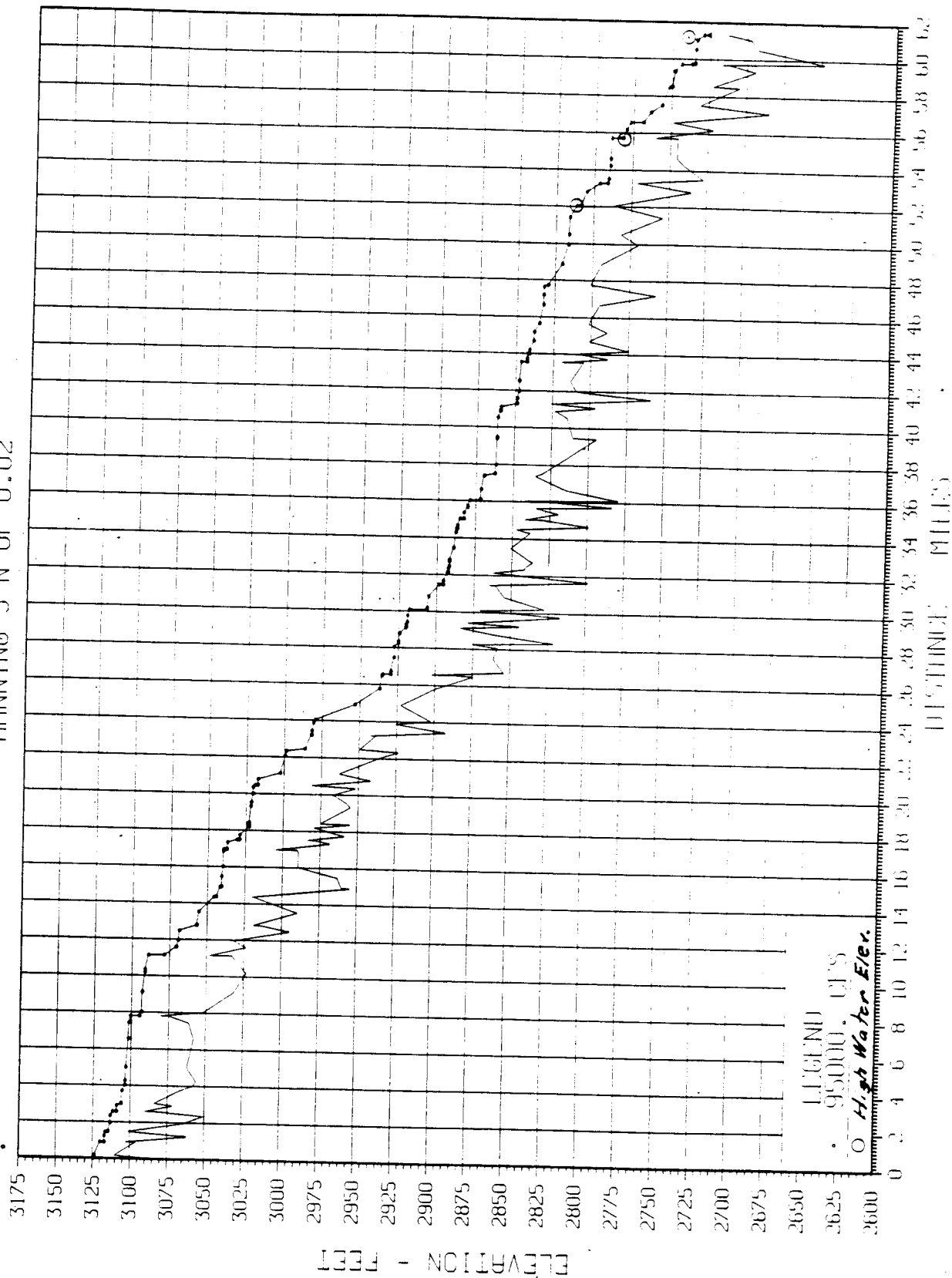
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM LEES FERRY TO ABOVE THE MOUTH OF LITTLE COLORADO RIVER



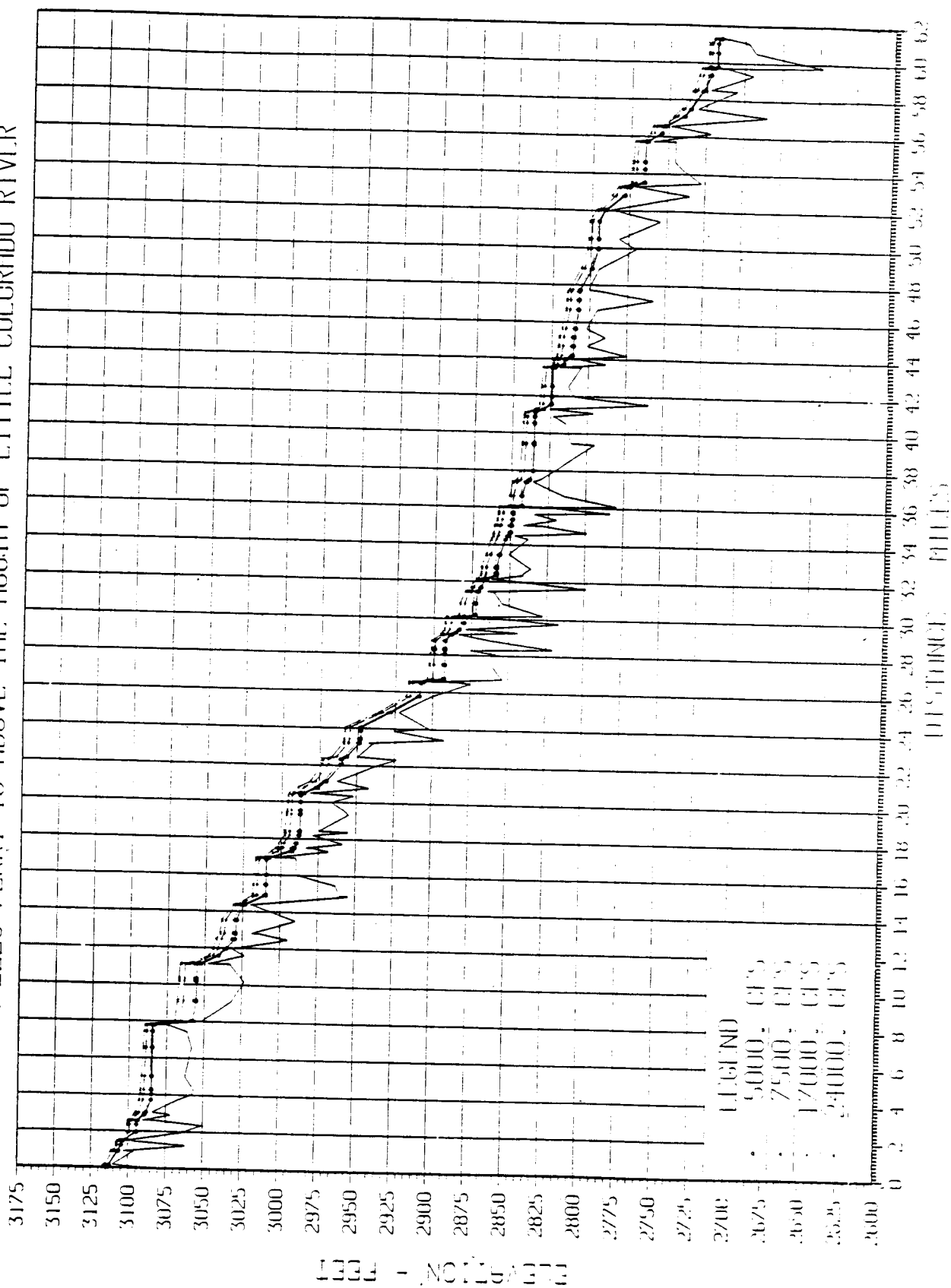
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 COLORADO RIVER, ARIZONA  
 FROM LEES FERRY TO ABOVE THE MOUTH OF LITTLE COLORADO RIVER



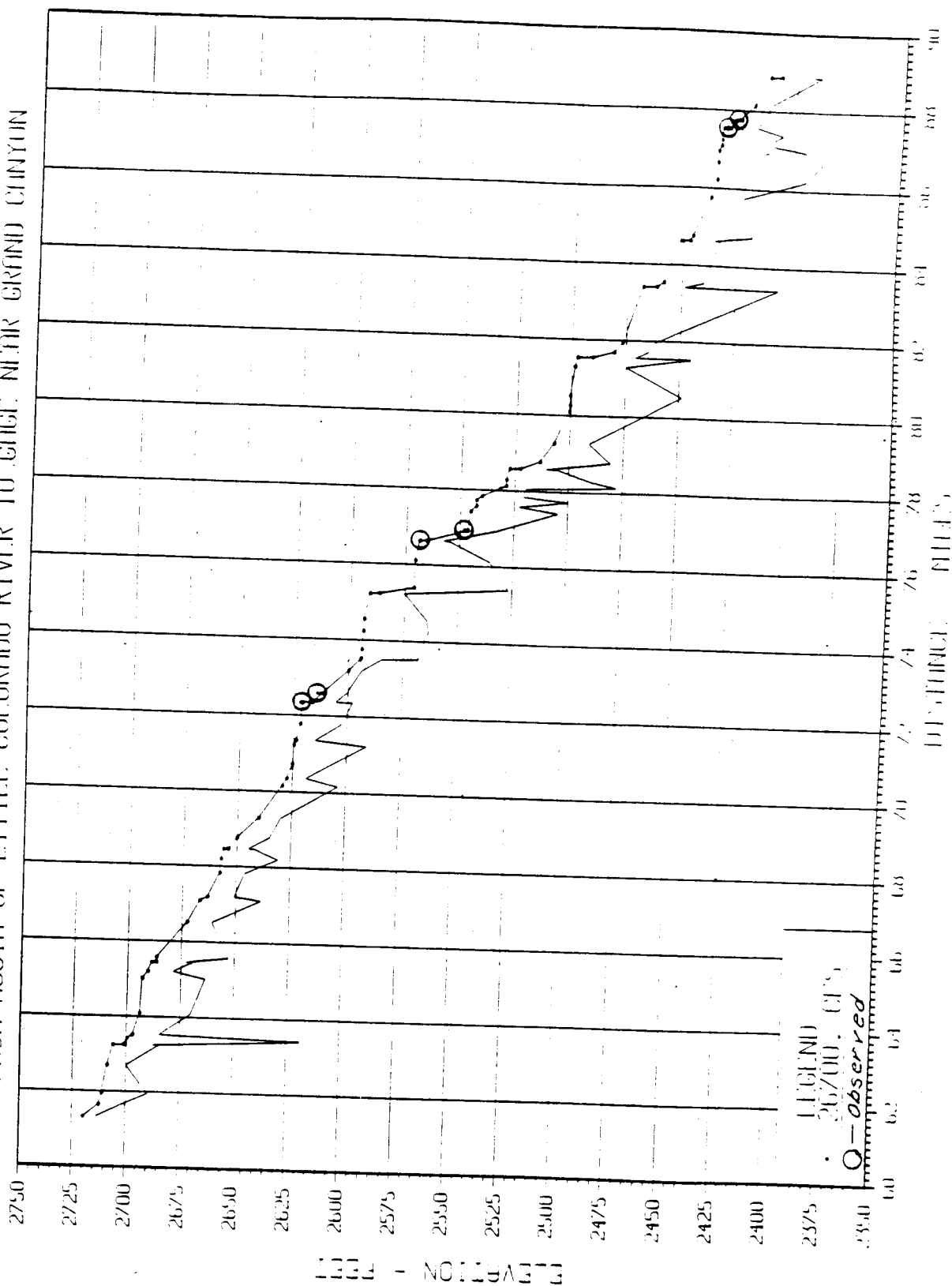
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM LEES FERRY TO ABOVE THE MOUTH OF LITTLE COLORADO RIVER  
 MANNING'S N OF 0.02



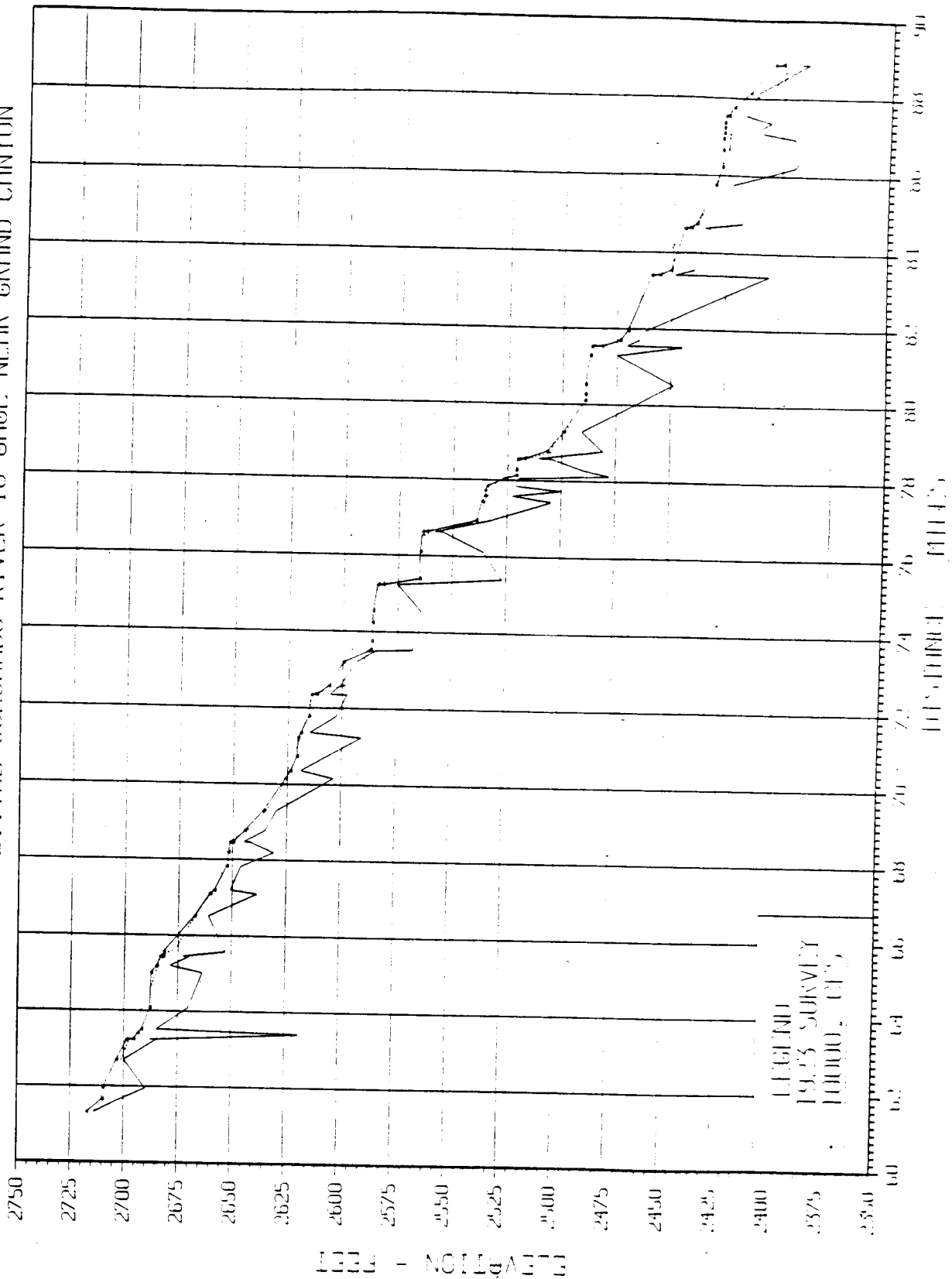
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM LEE'S FERRY TO ABOVE THE MOUTH OF LITTLE COLORADO RIVER



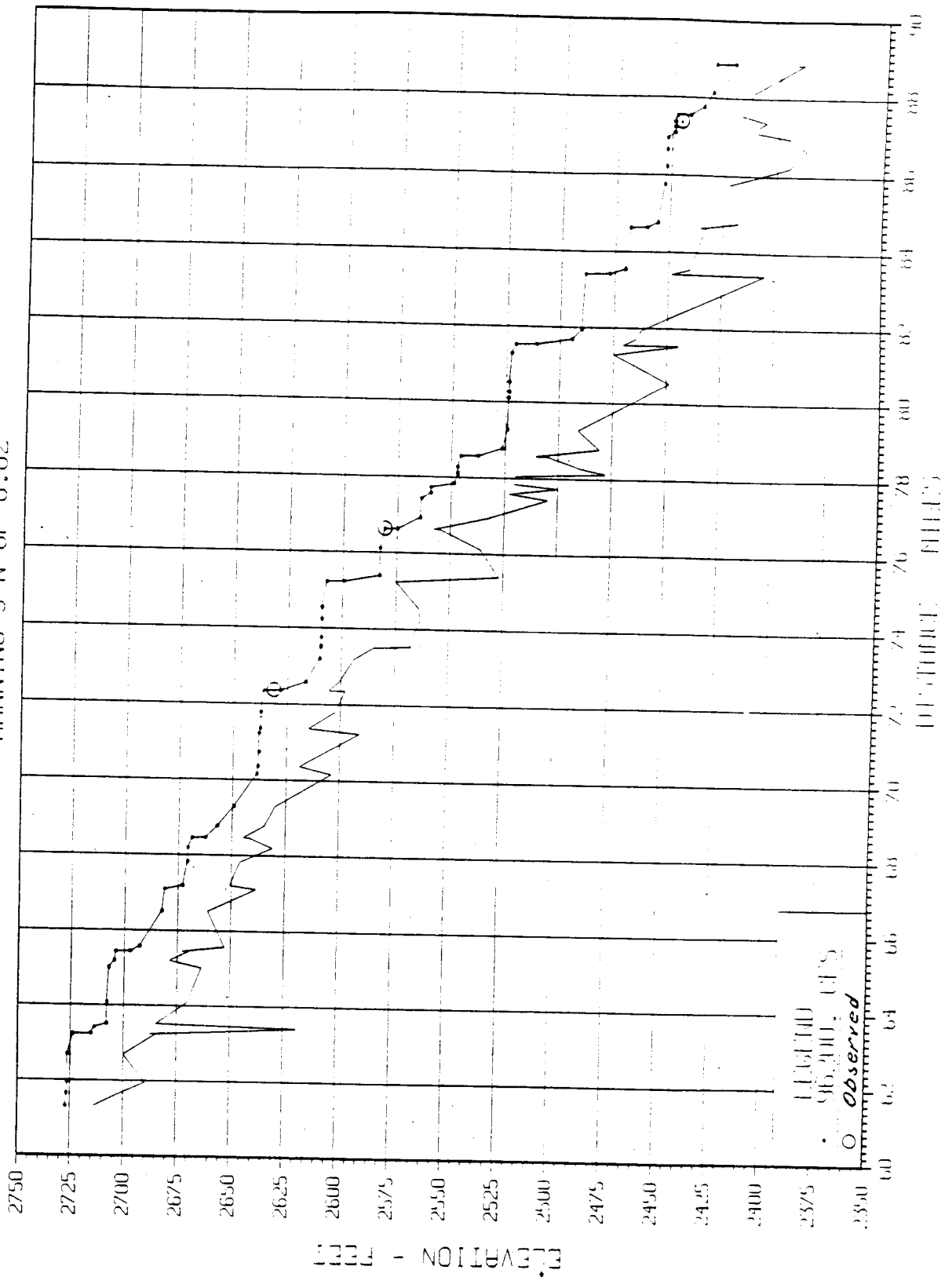
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON



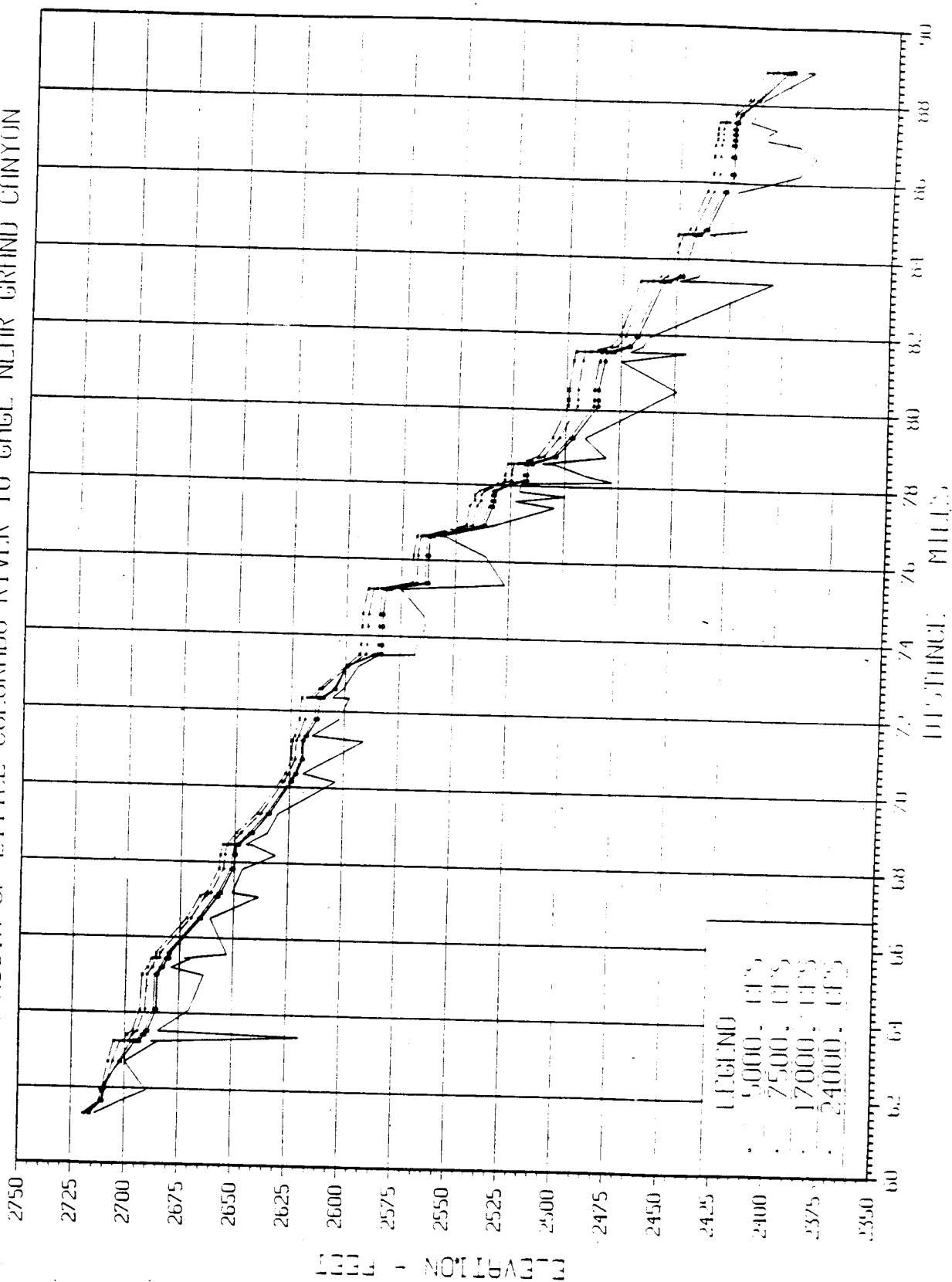
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON  
 MANNING S N OF 0.02

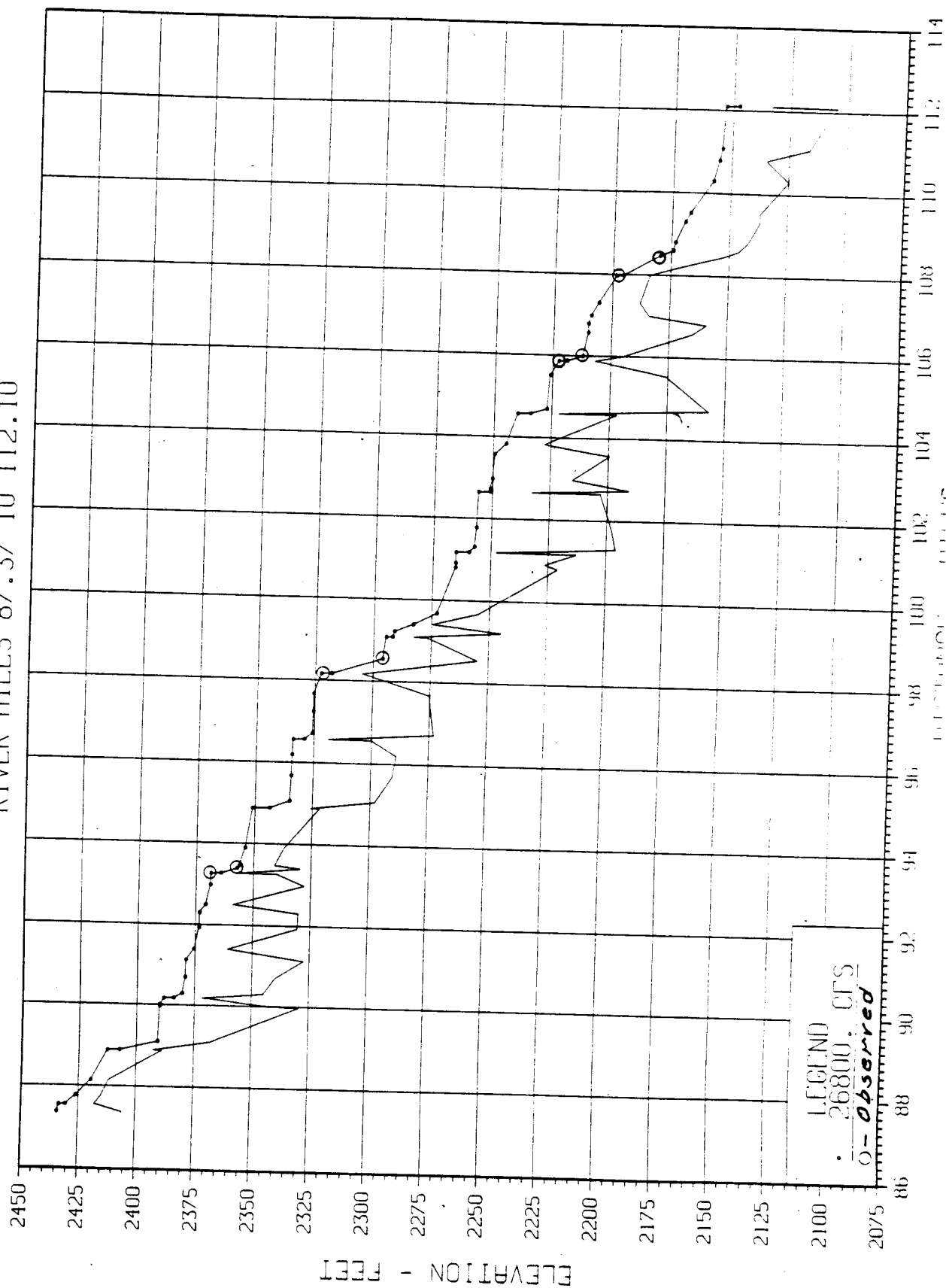


GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON

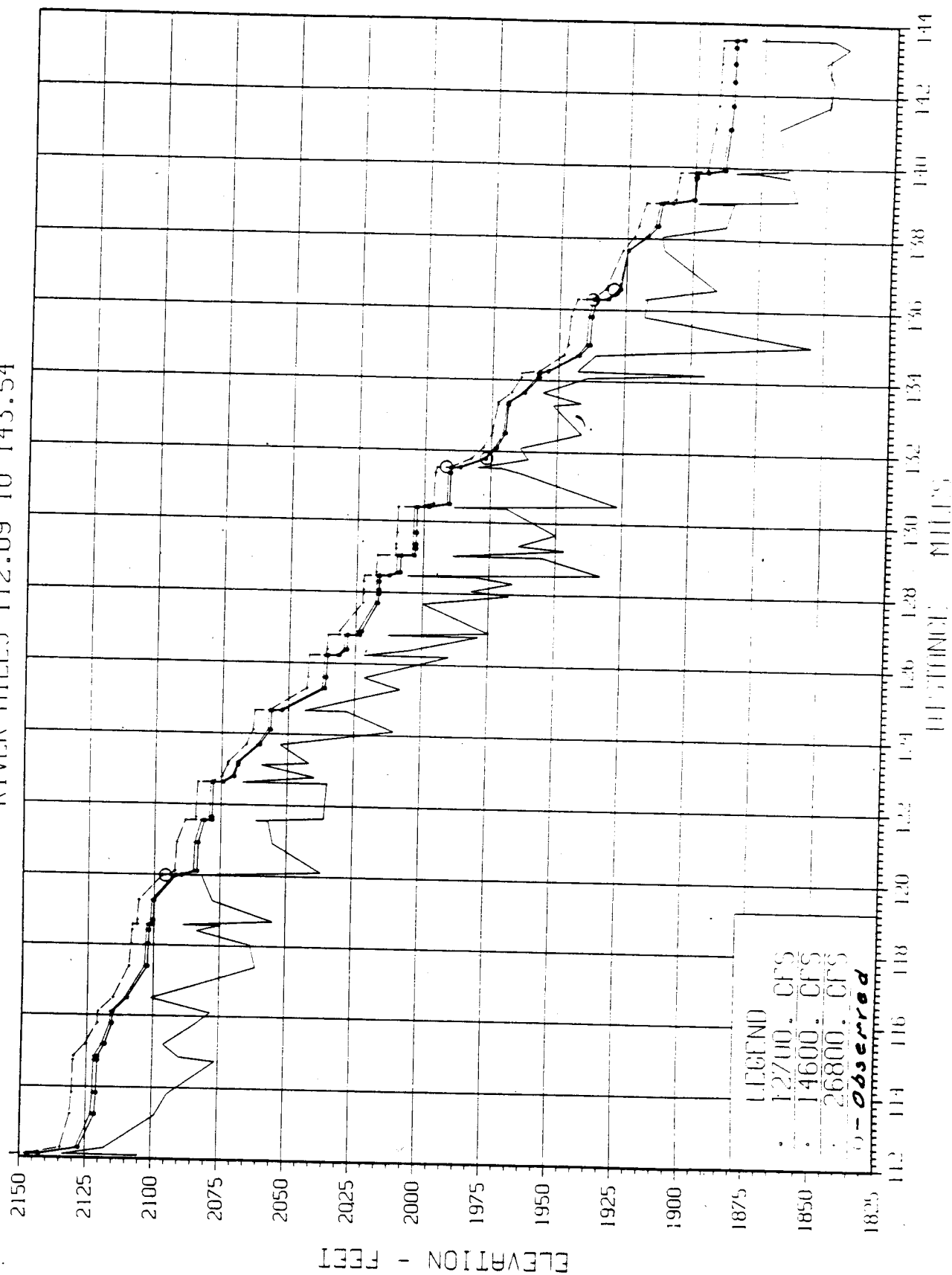




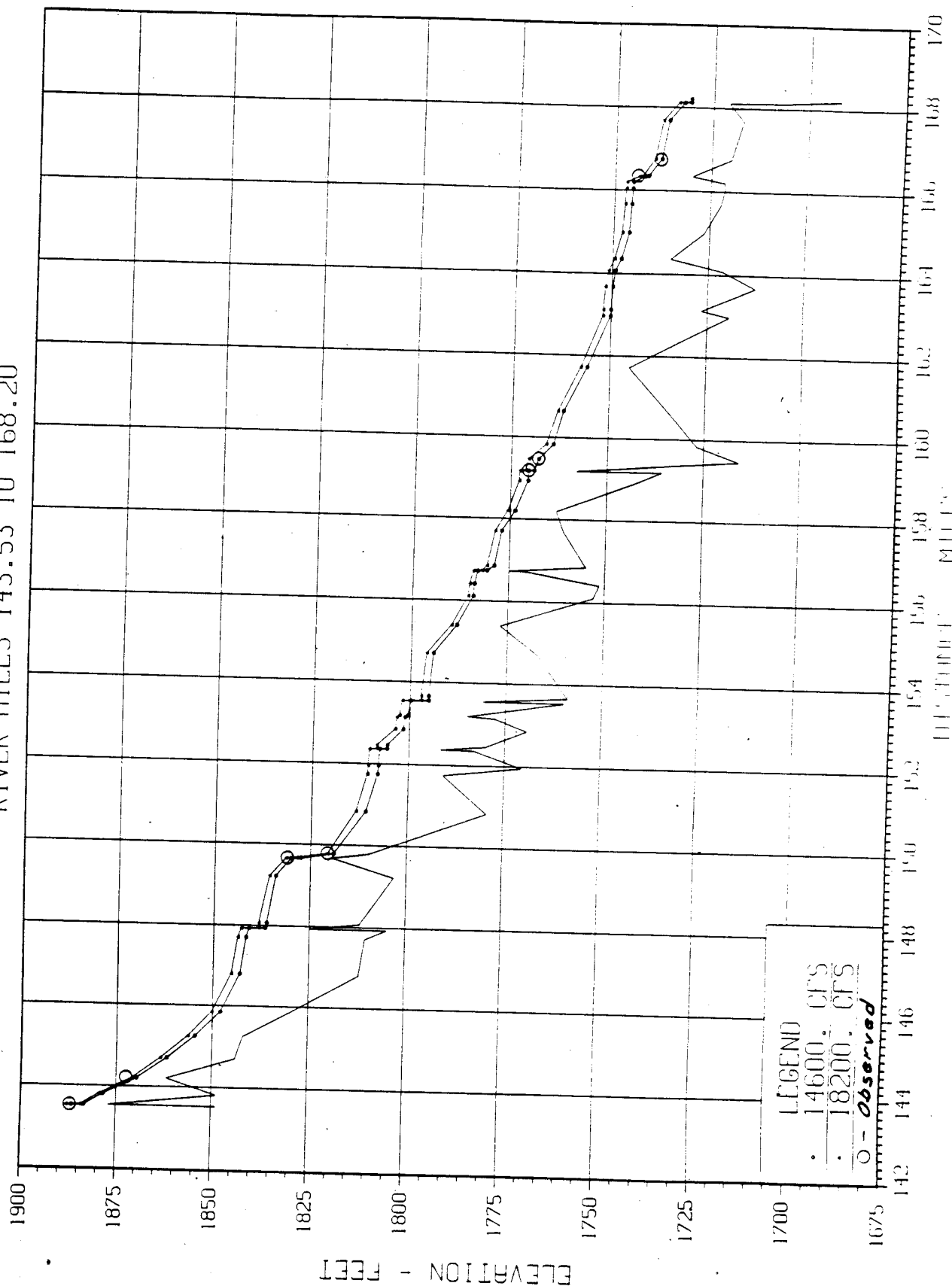
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 87.37 TO 112.10



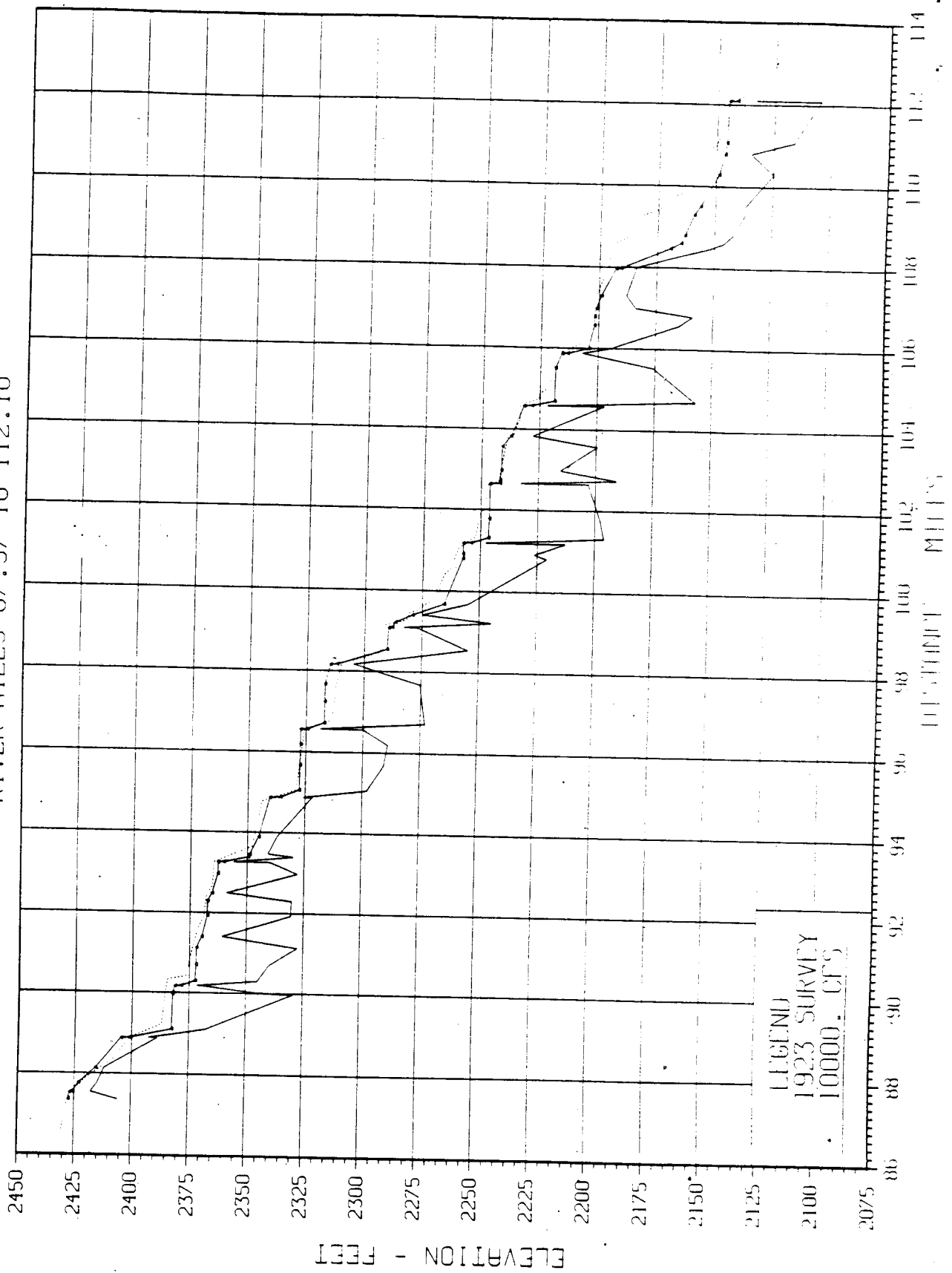
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 112.09 TO 143.54



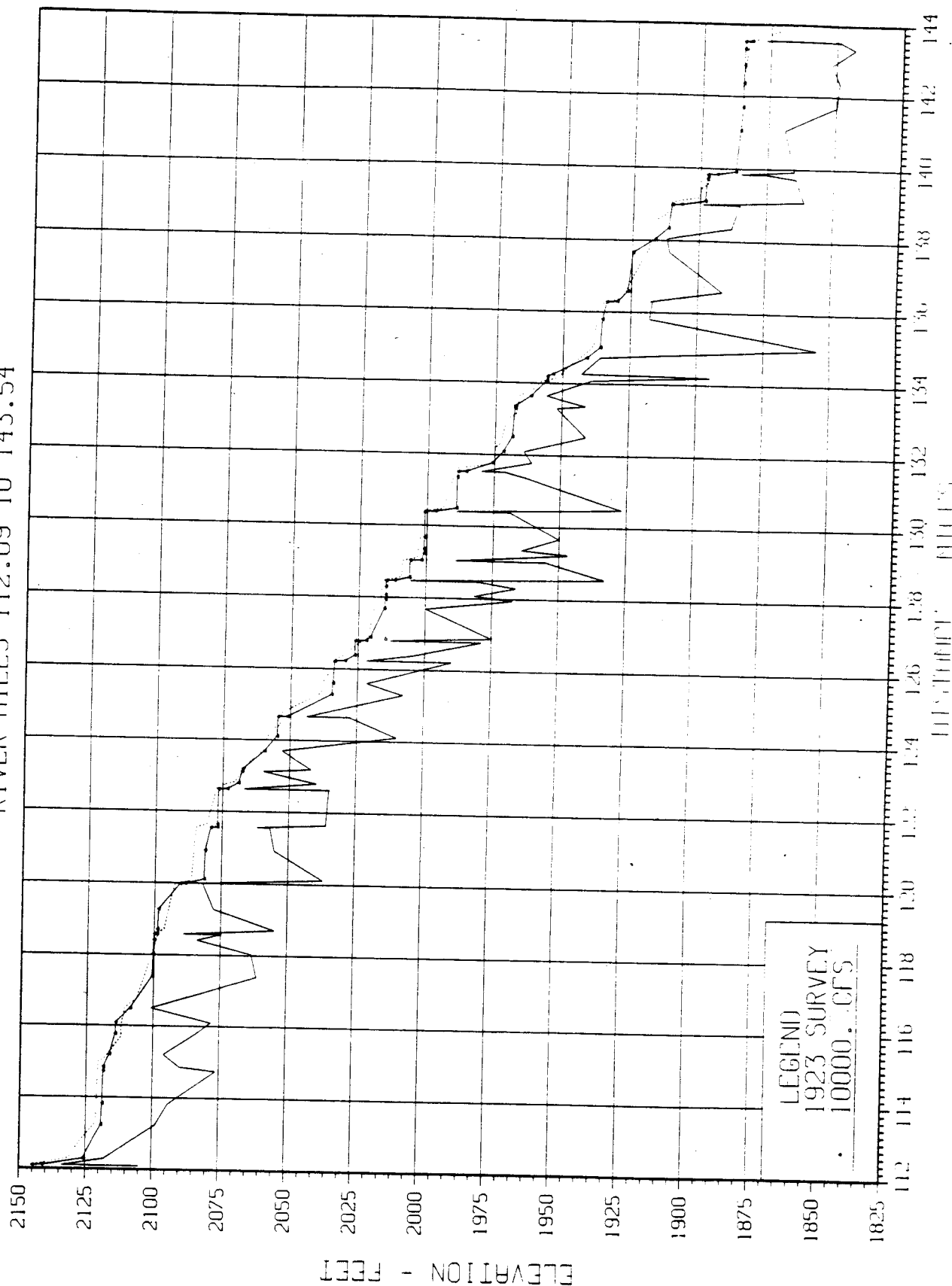
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 143.53 TO 168.20



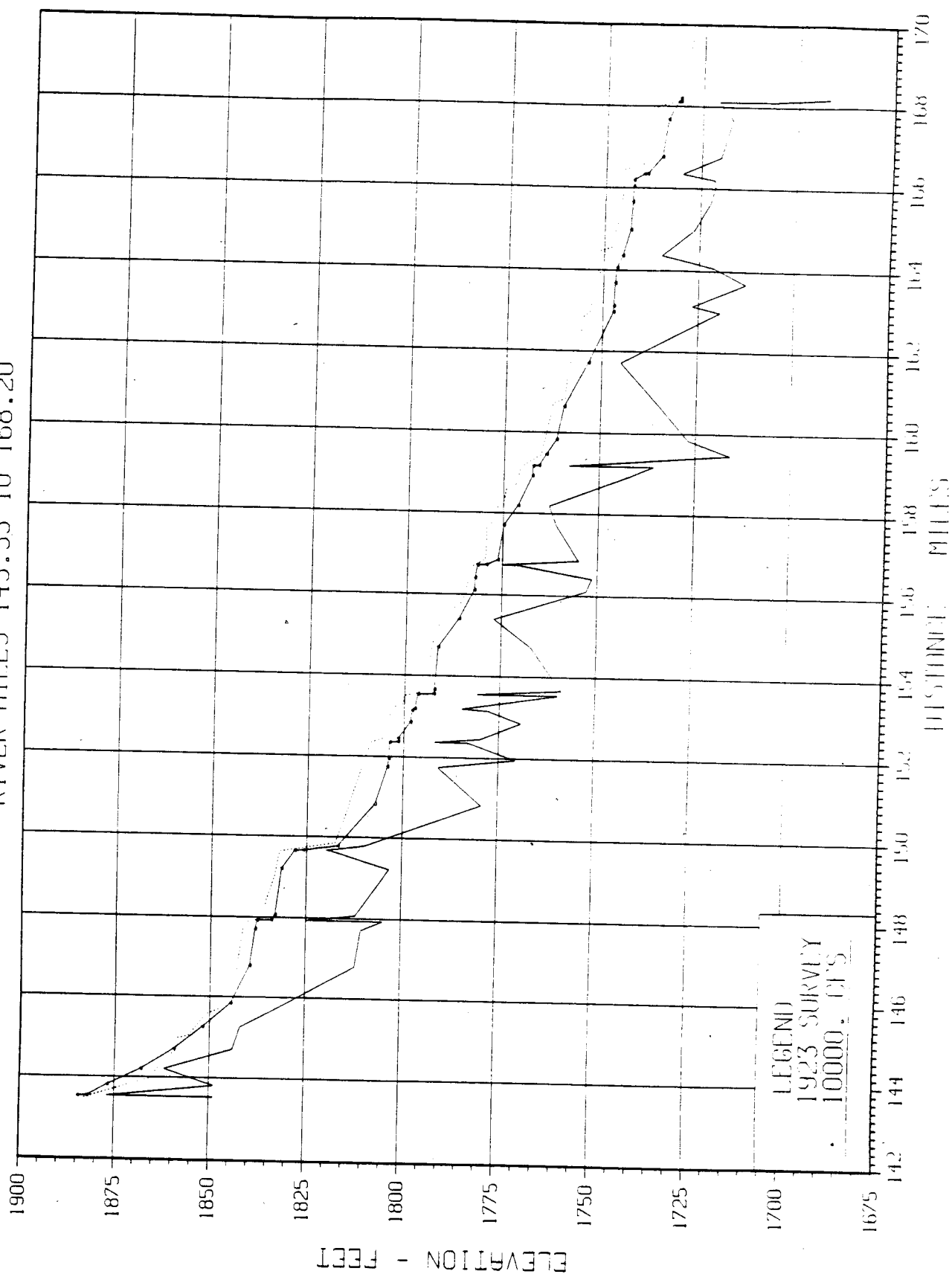
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 87.37 TO 112.10



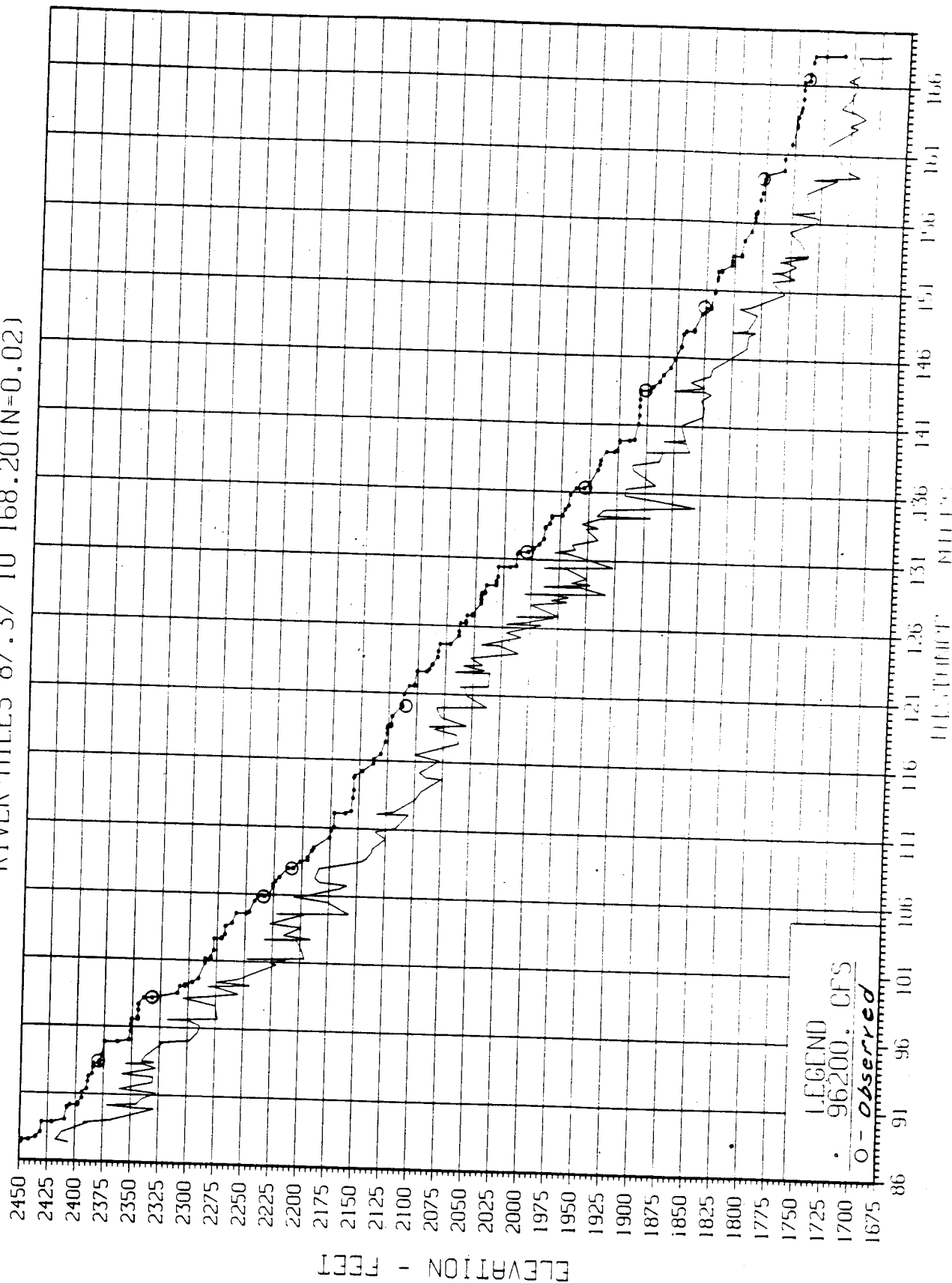
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 112.09 TO 143.54



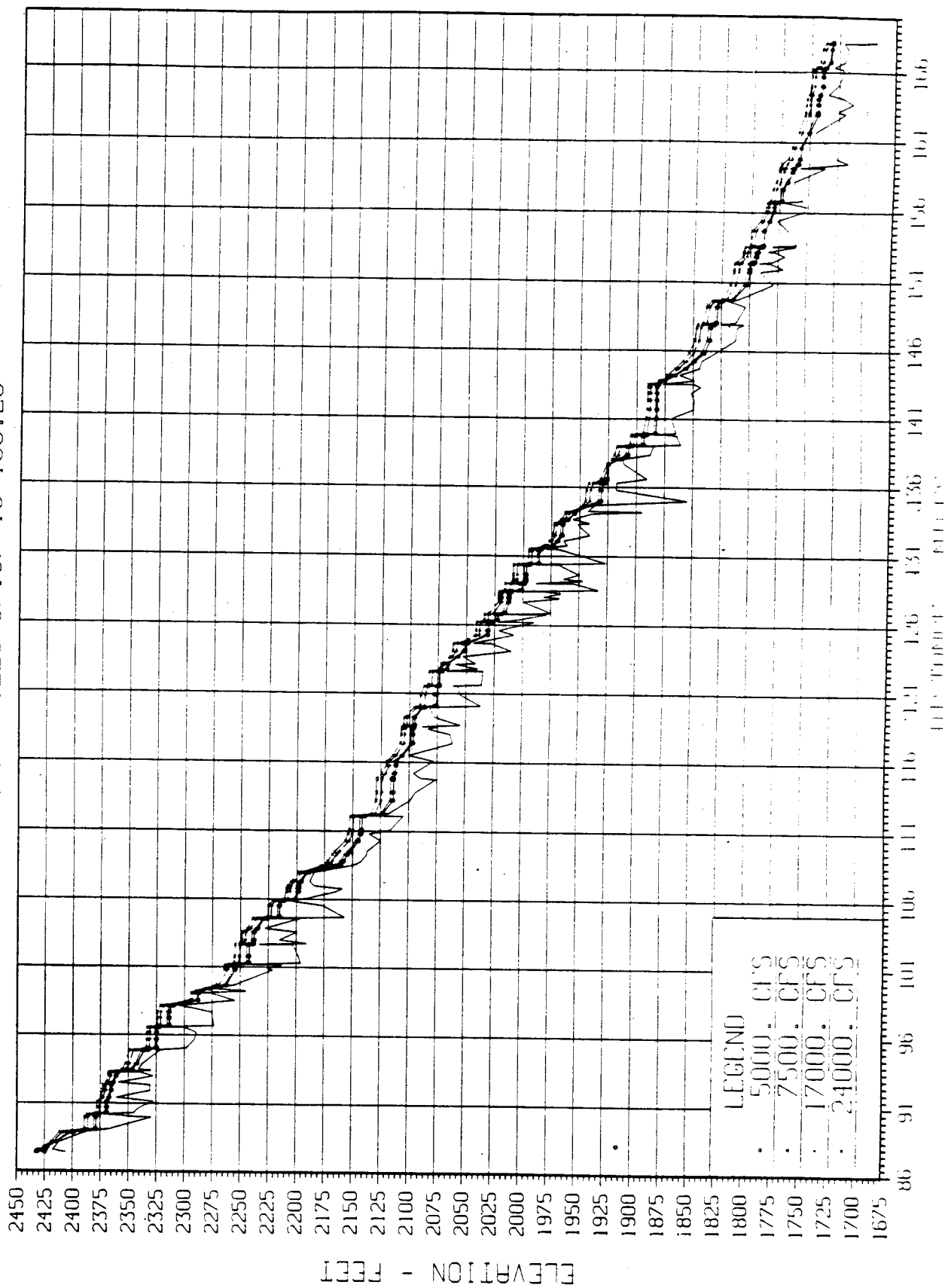
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 143.53 TO 168.20



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 87.37 TO 168.20 (N=0.02)

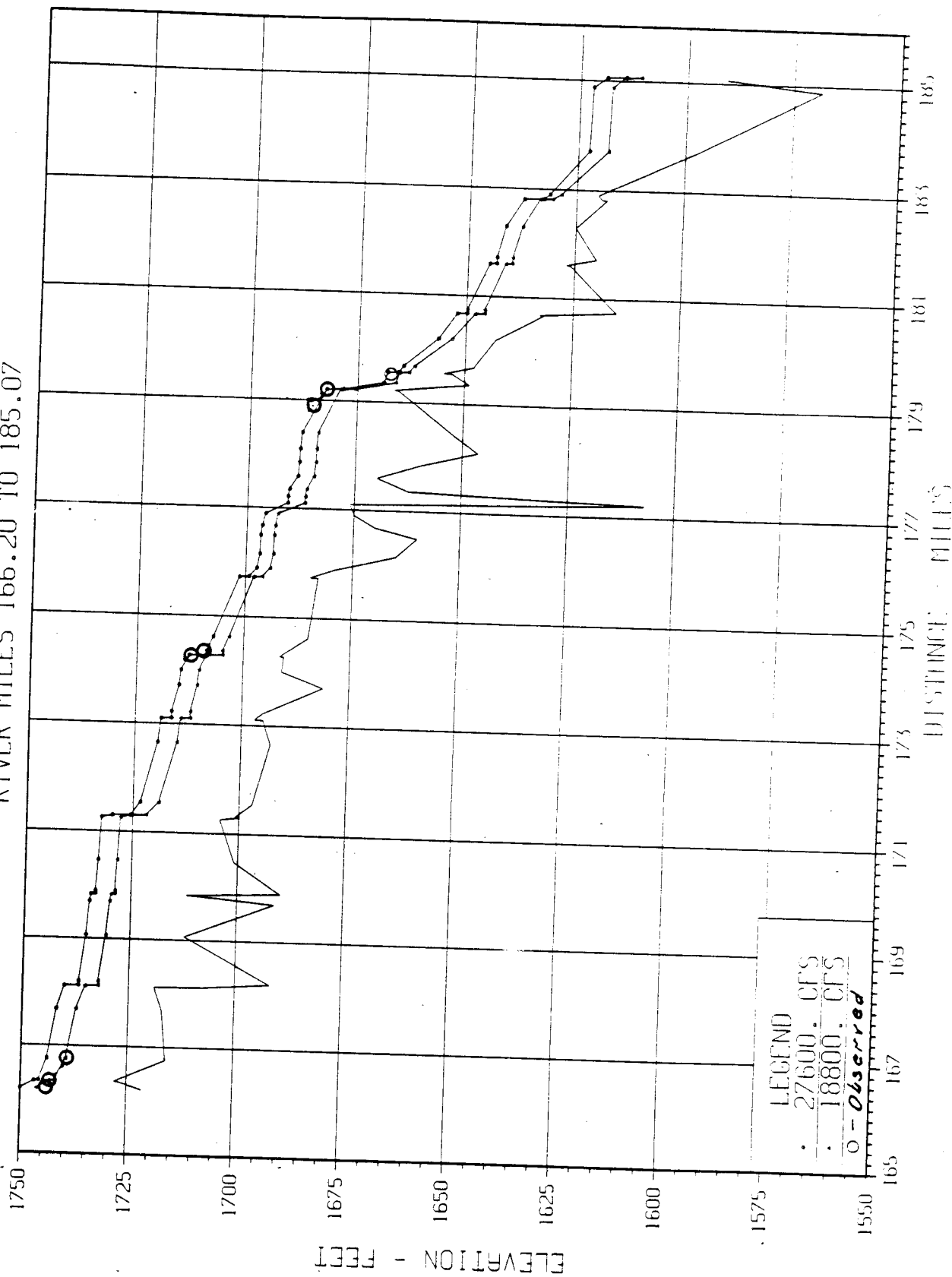


GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 GAGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON  
 RIVER MILES 87.37 TO 168.20





GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 185.07



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 185.07

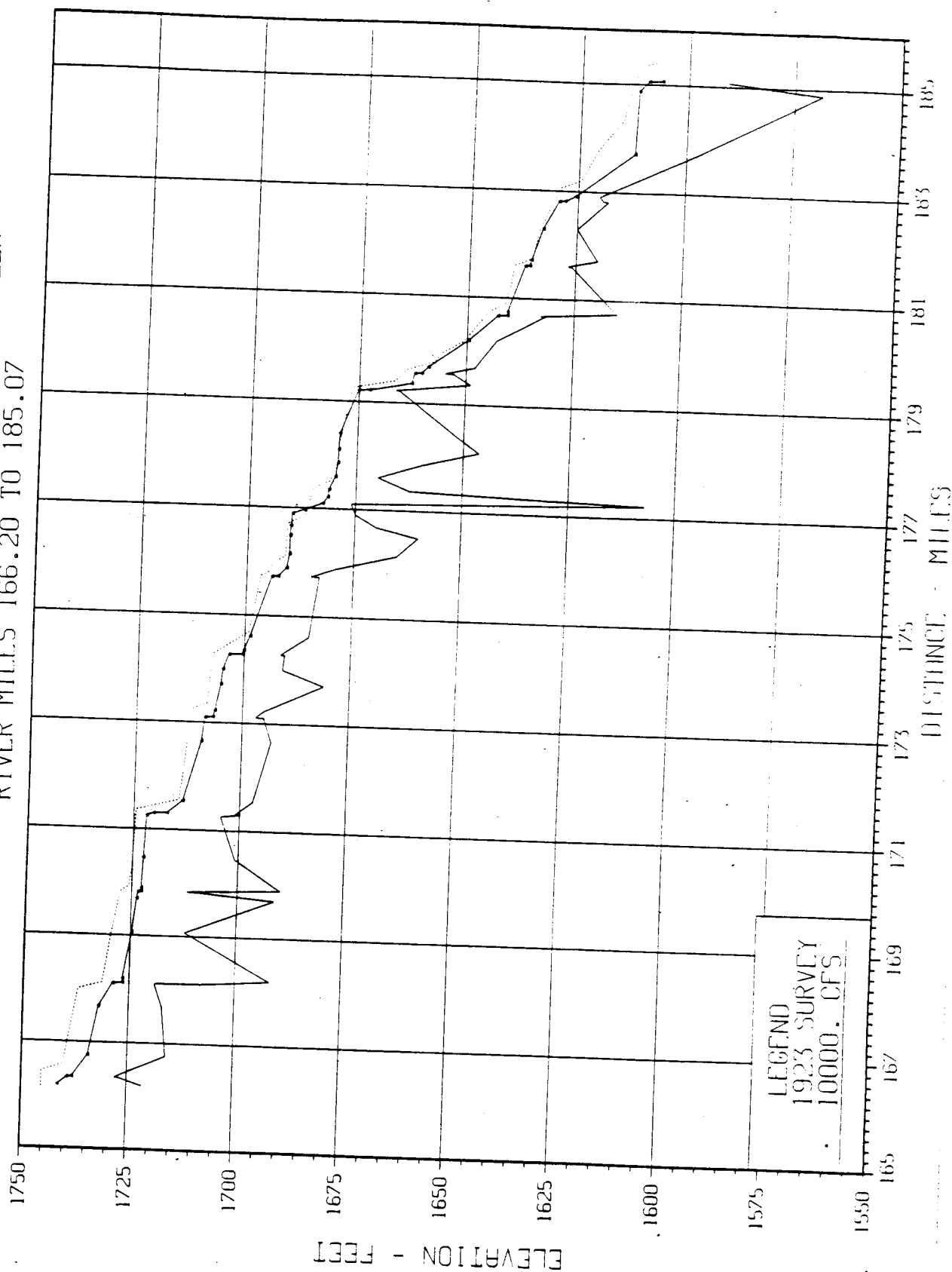
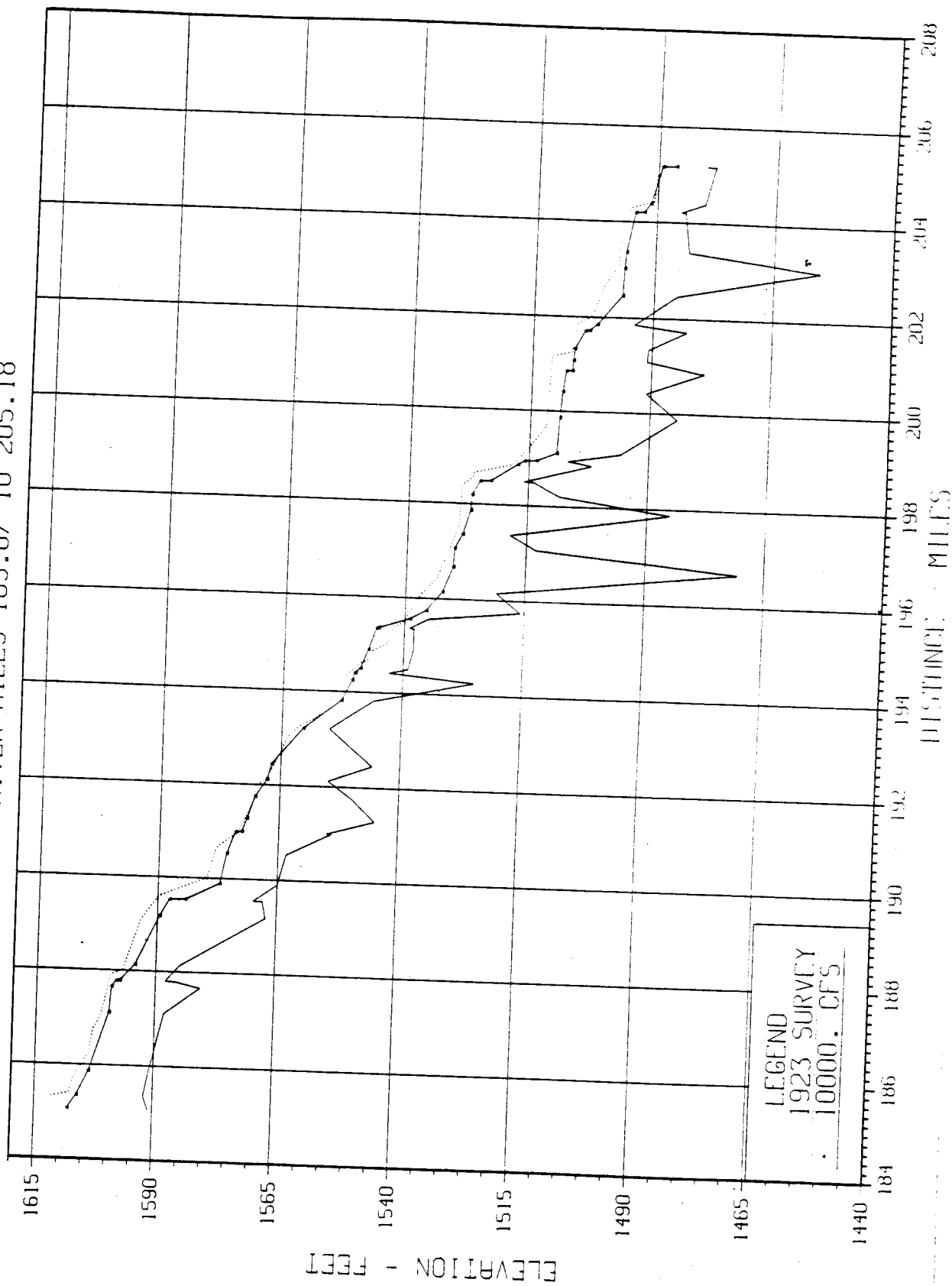
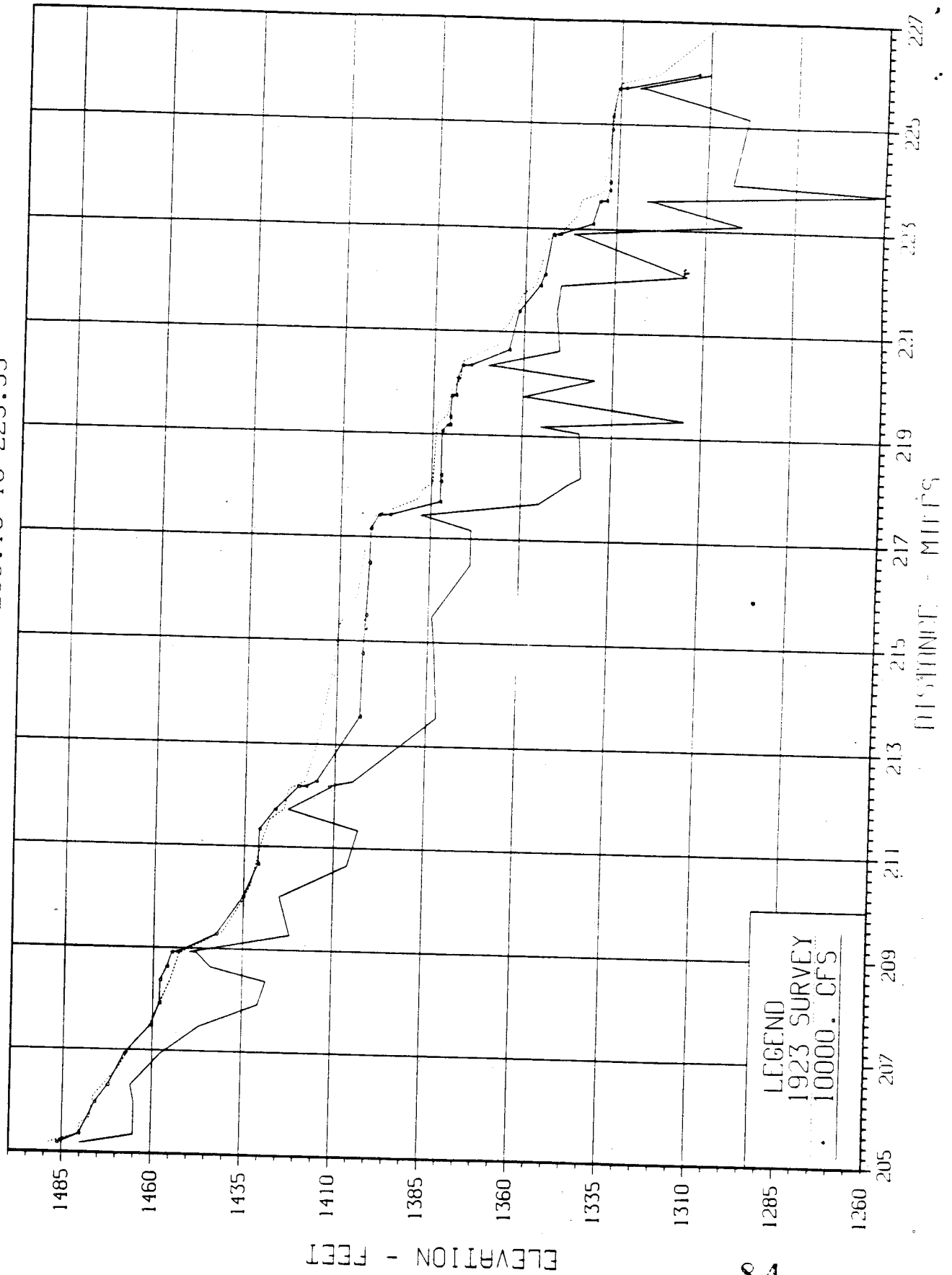


Figure 41

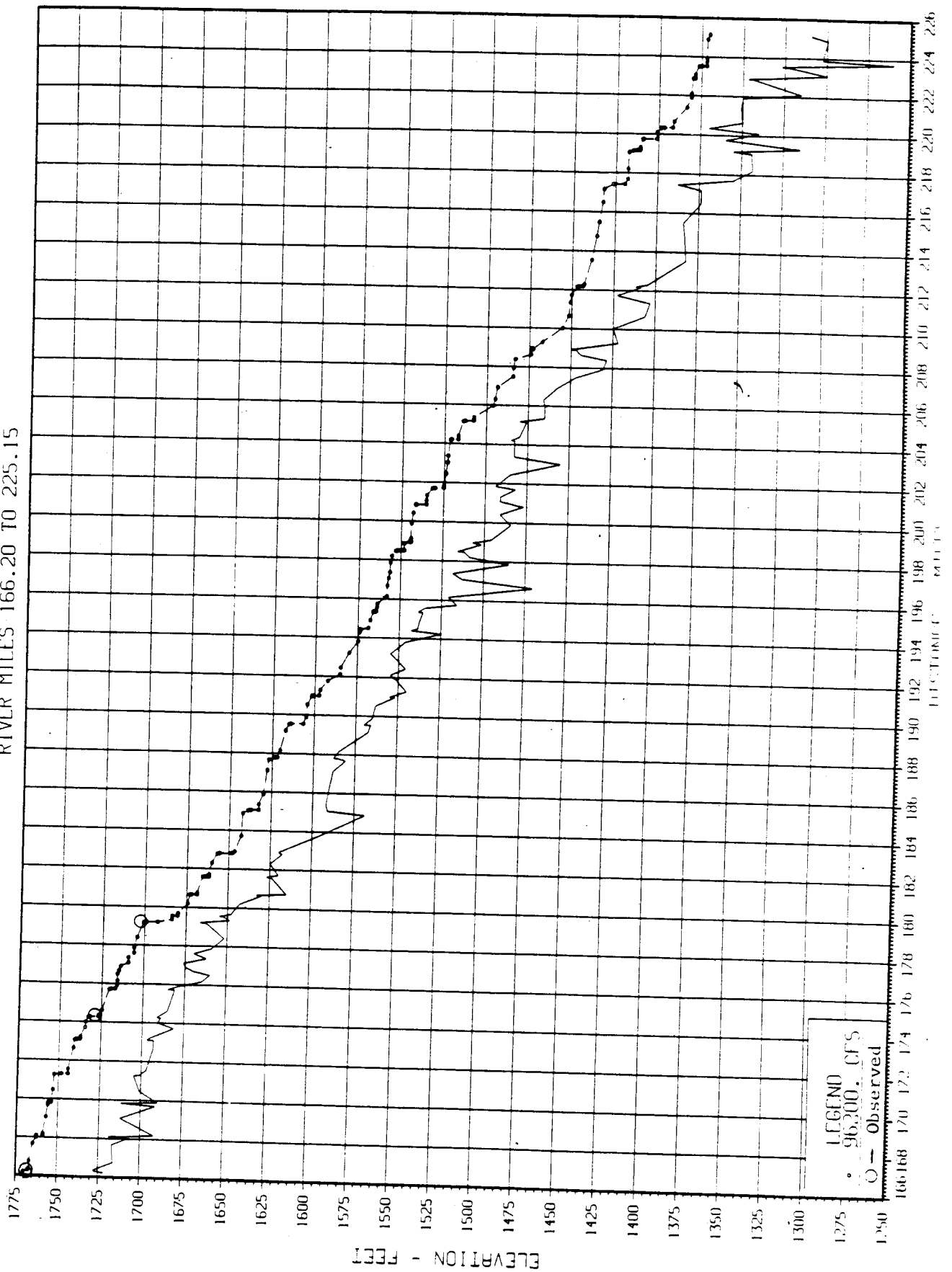
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 185.07 TO 205.18



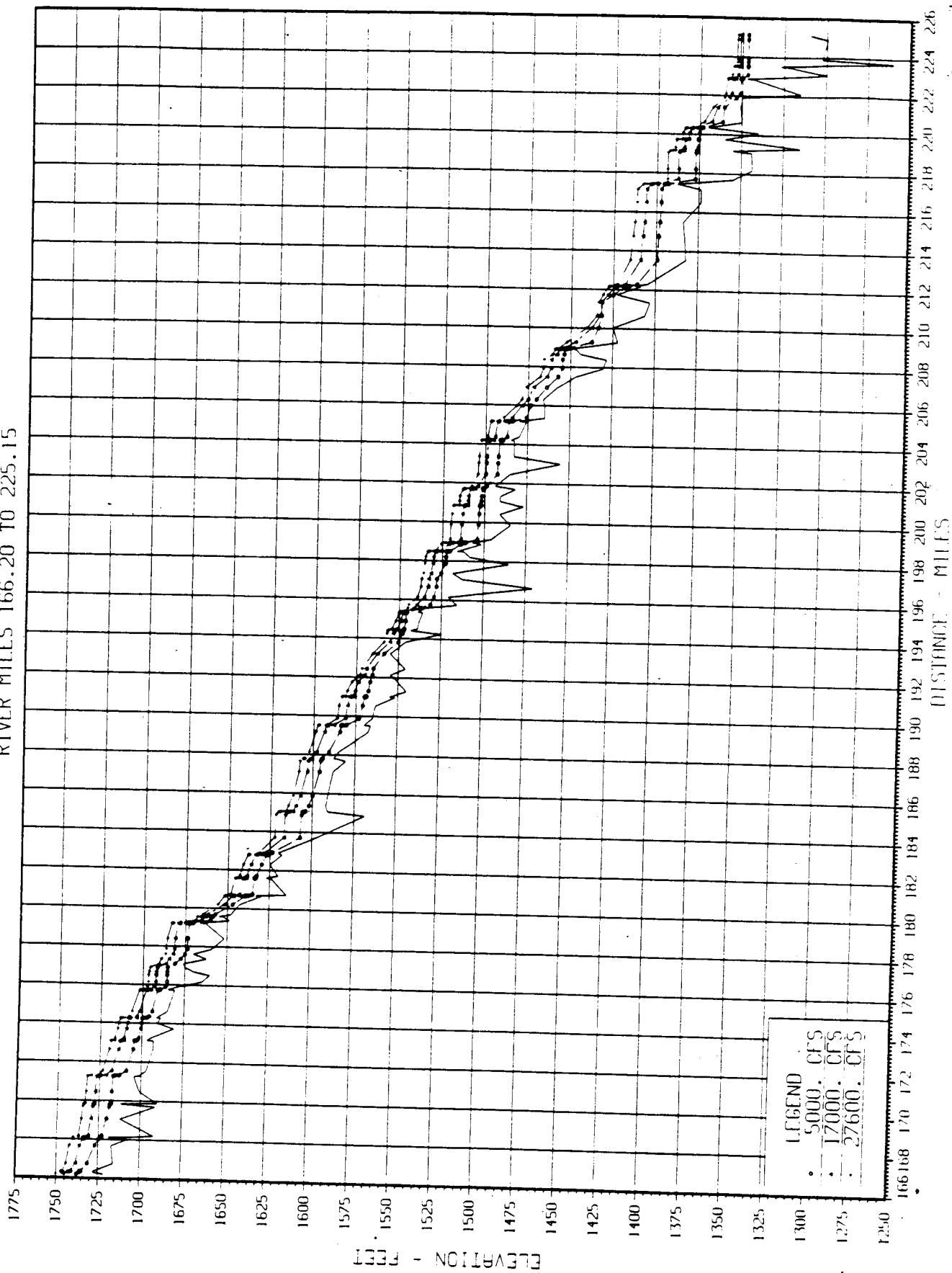
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 205.18 TO 225.99



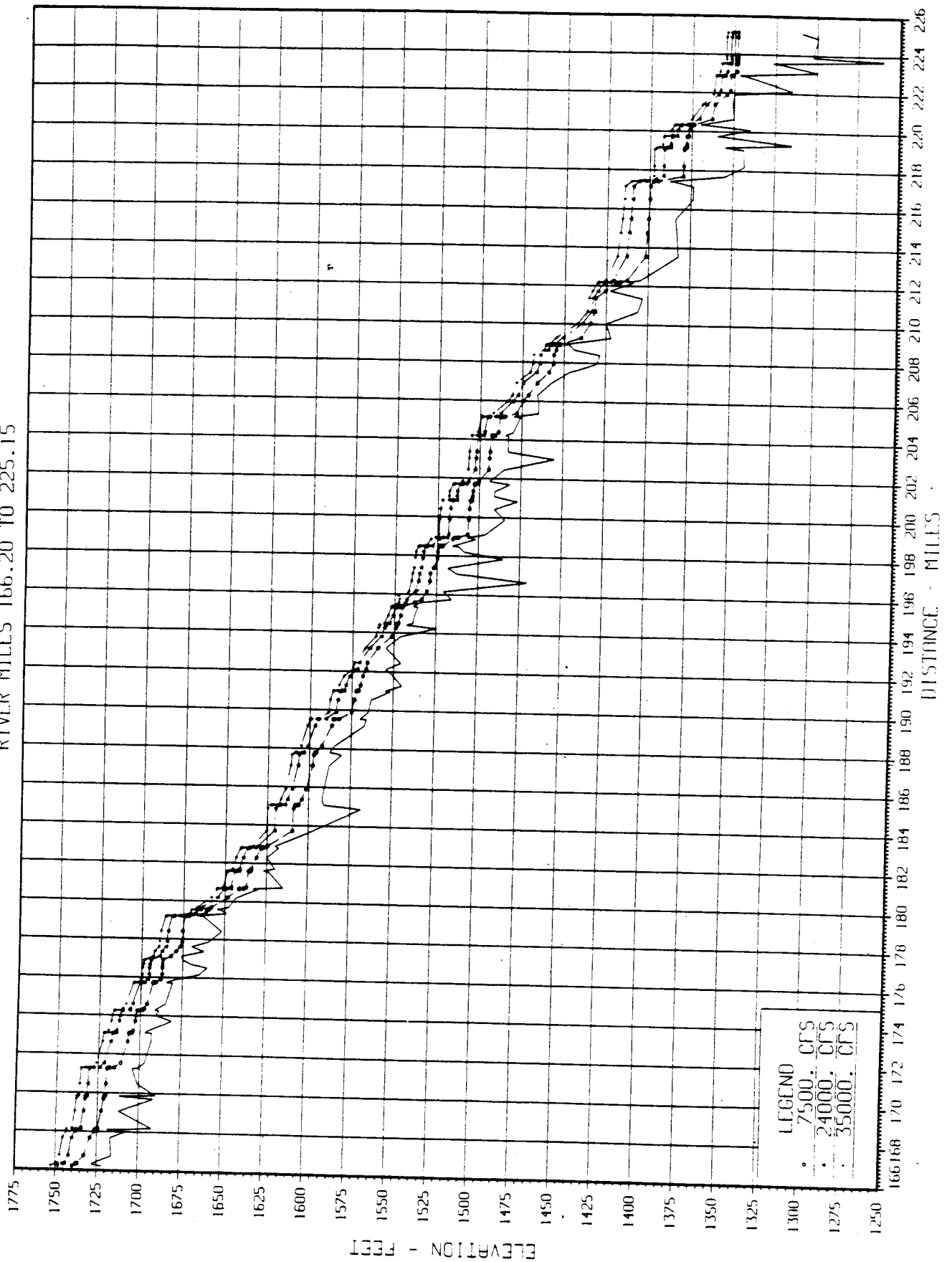
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 225.15



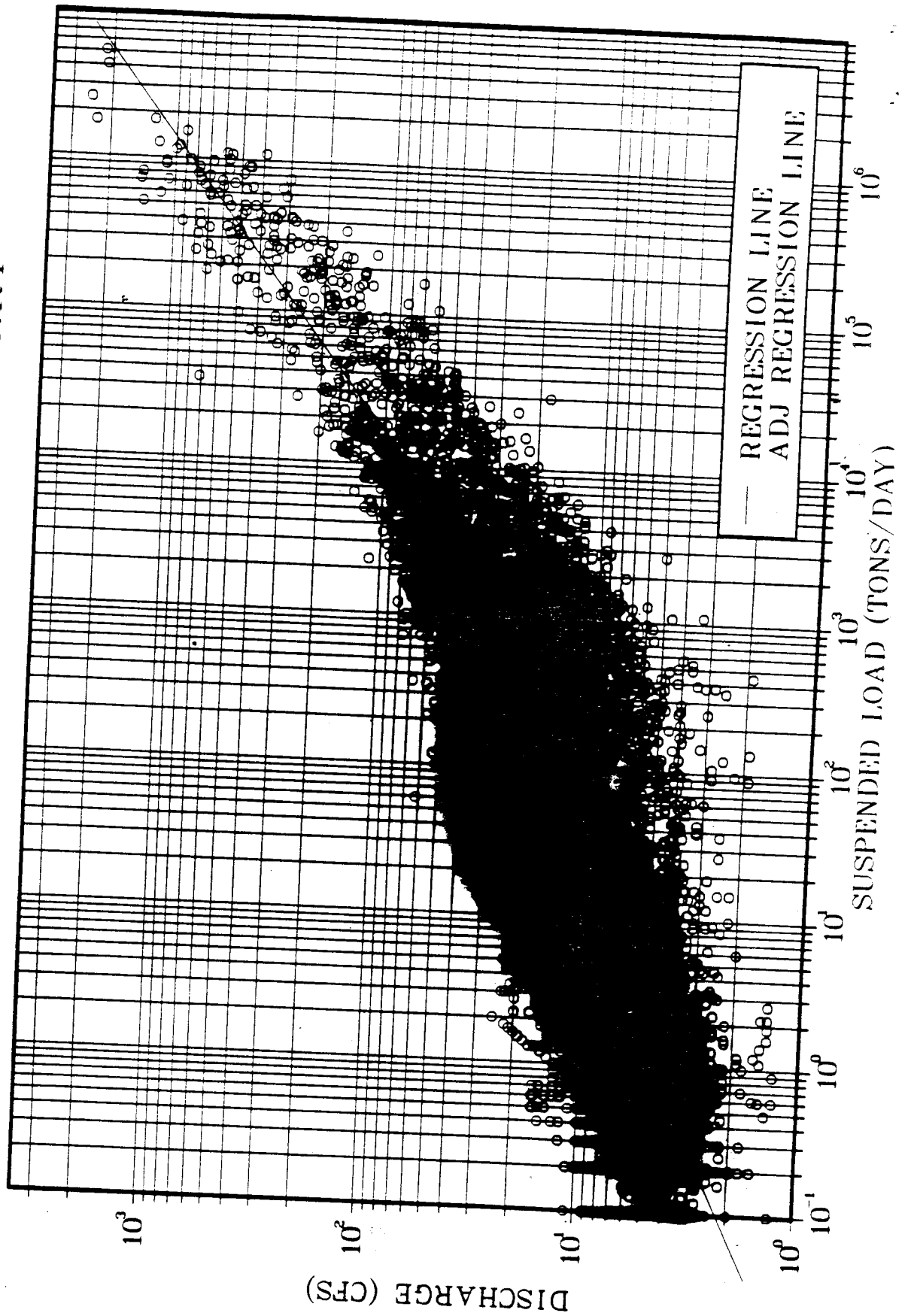
GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 225.15



GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 225.15

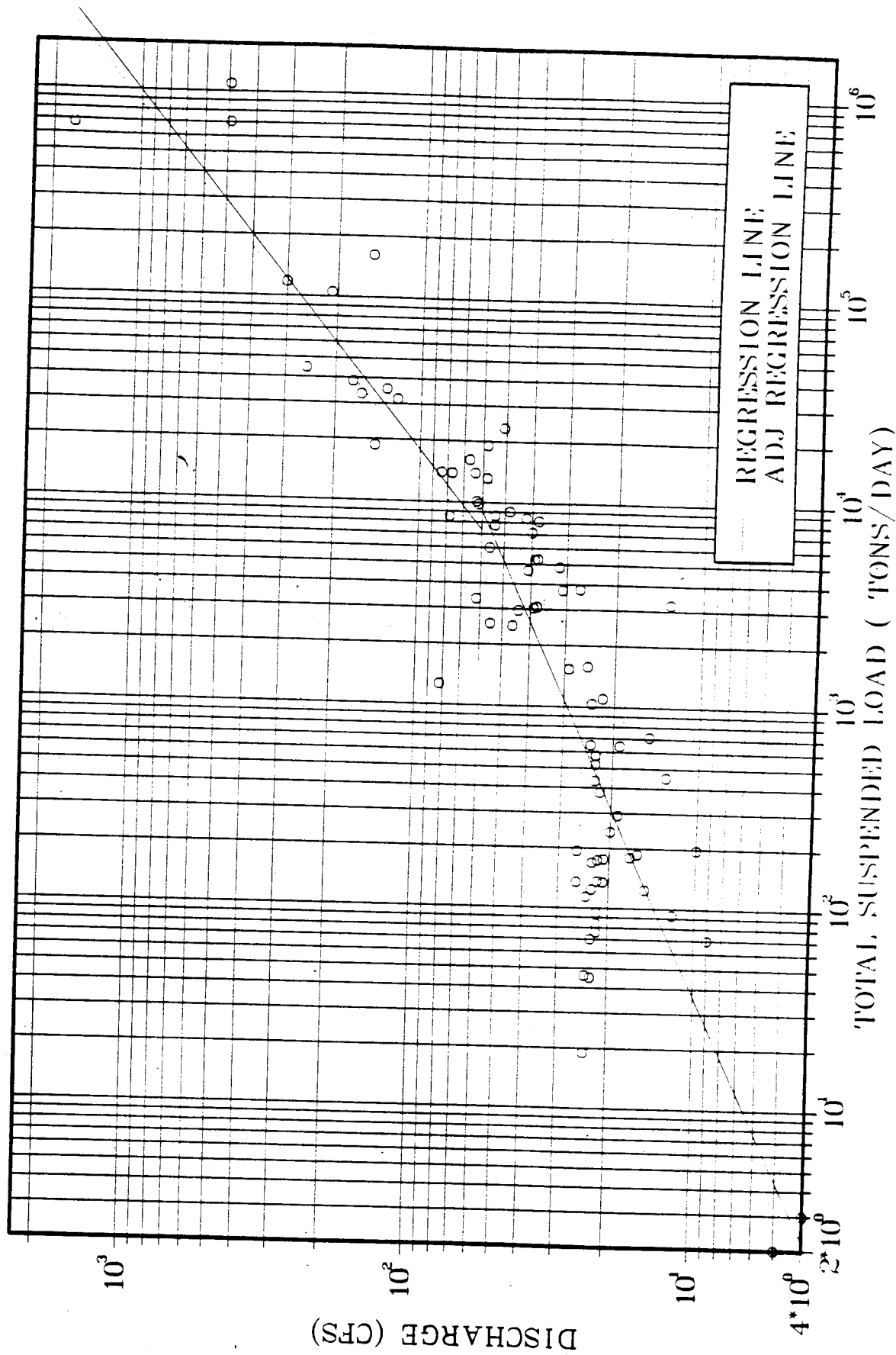


# PARIA RIVER AT LEES FERRY





# PARIA RIVER AT LEES FERRY



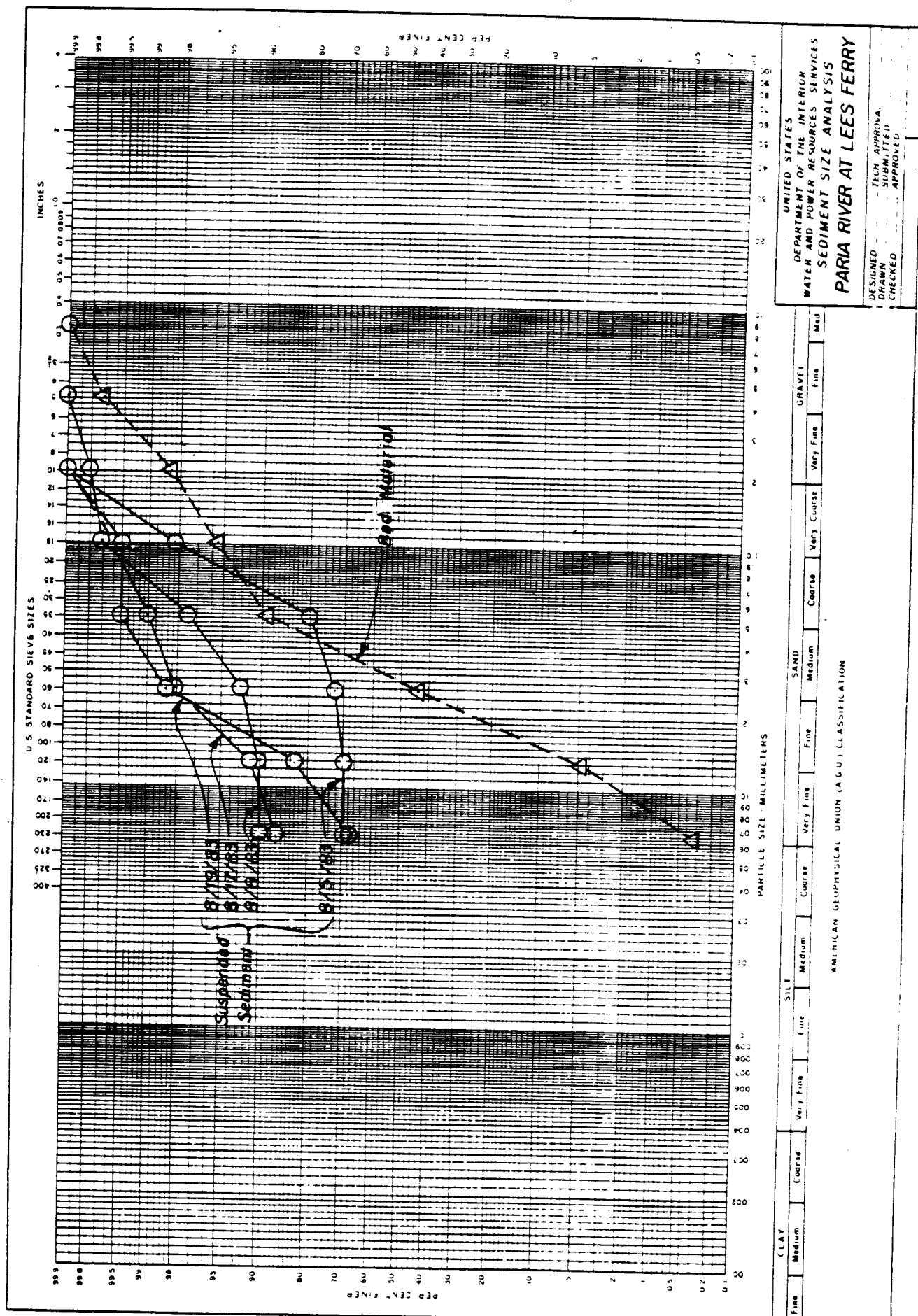
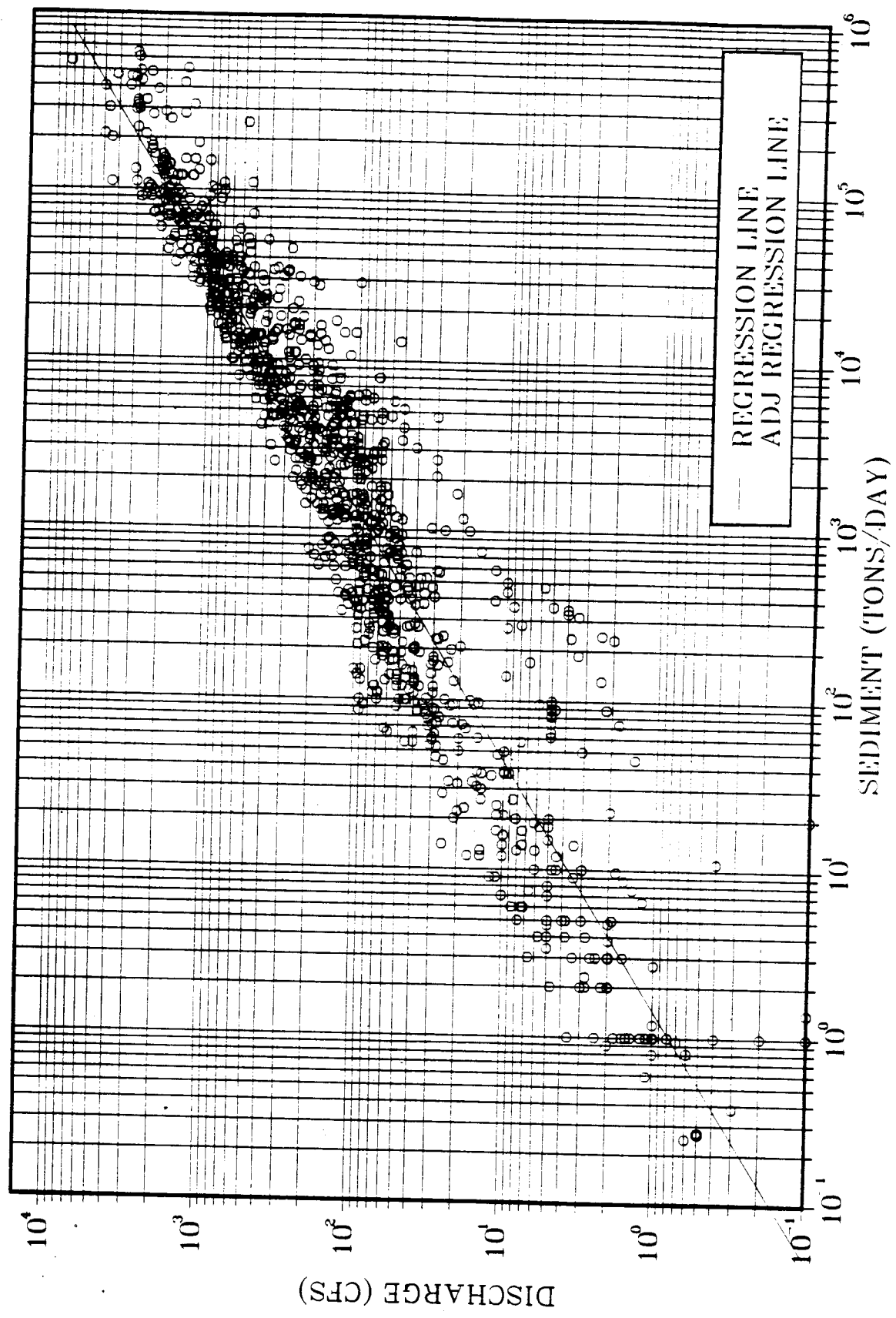


Figure 49

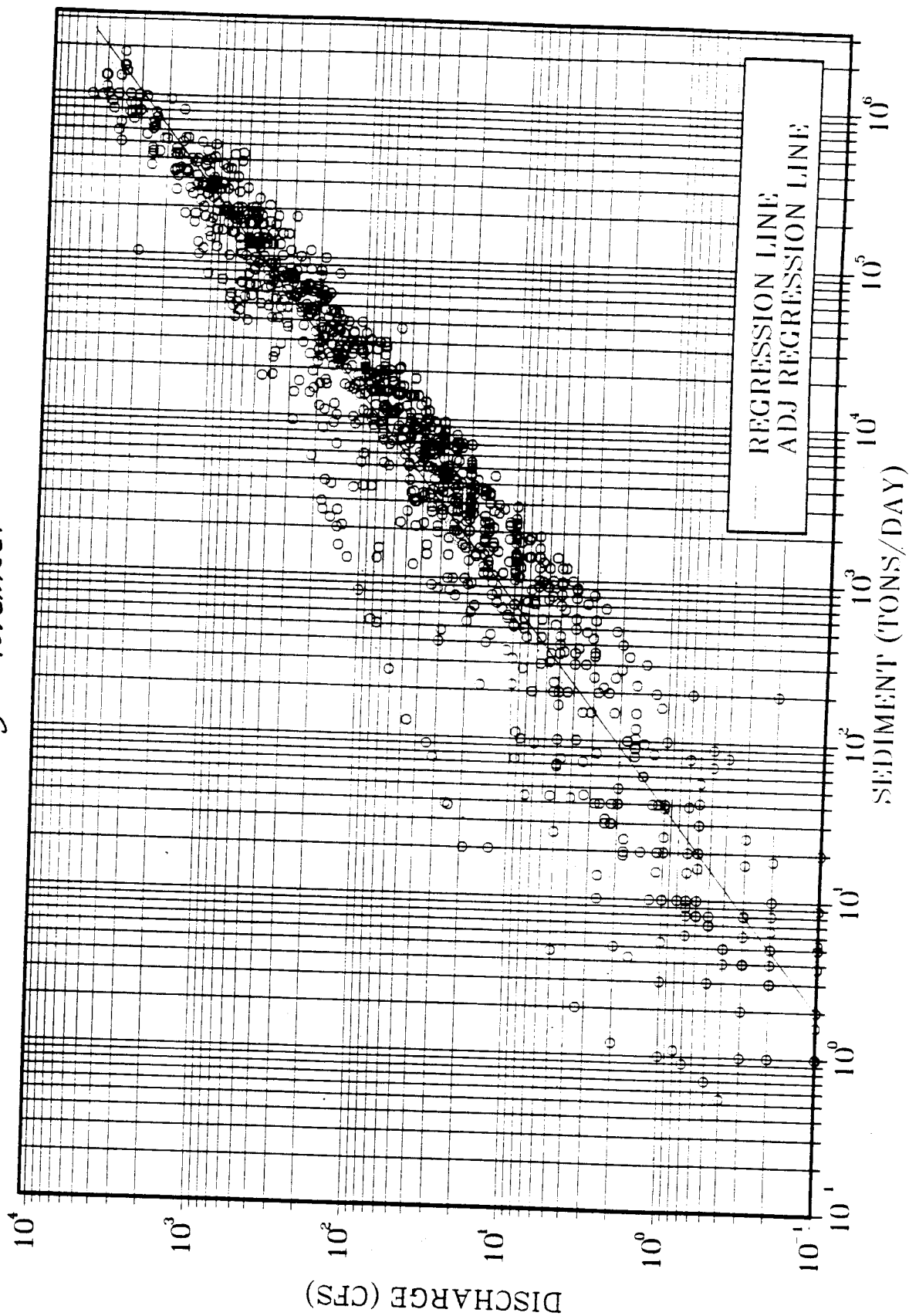


LITTLE COLORADO NEAR CAMERON, ARIZONA  
*December through May*

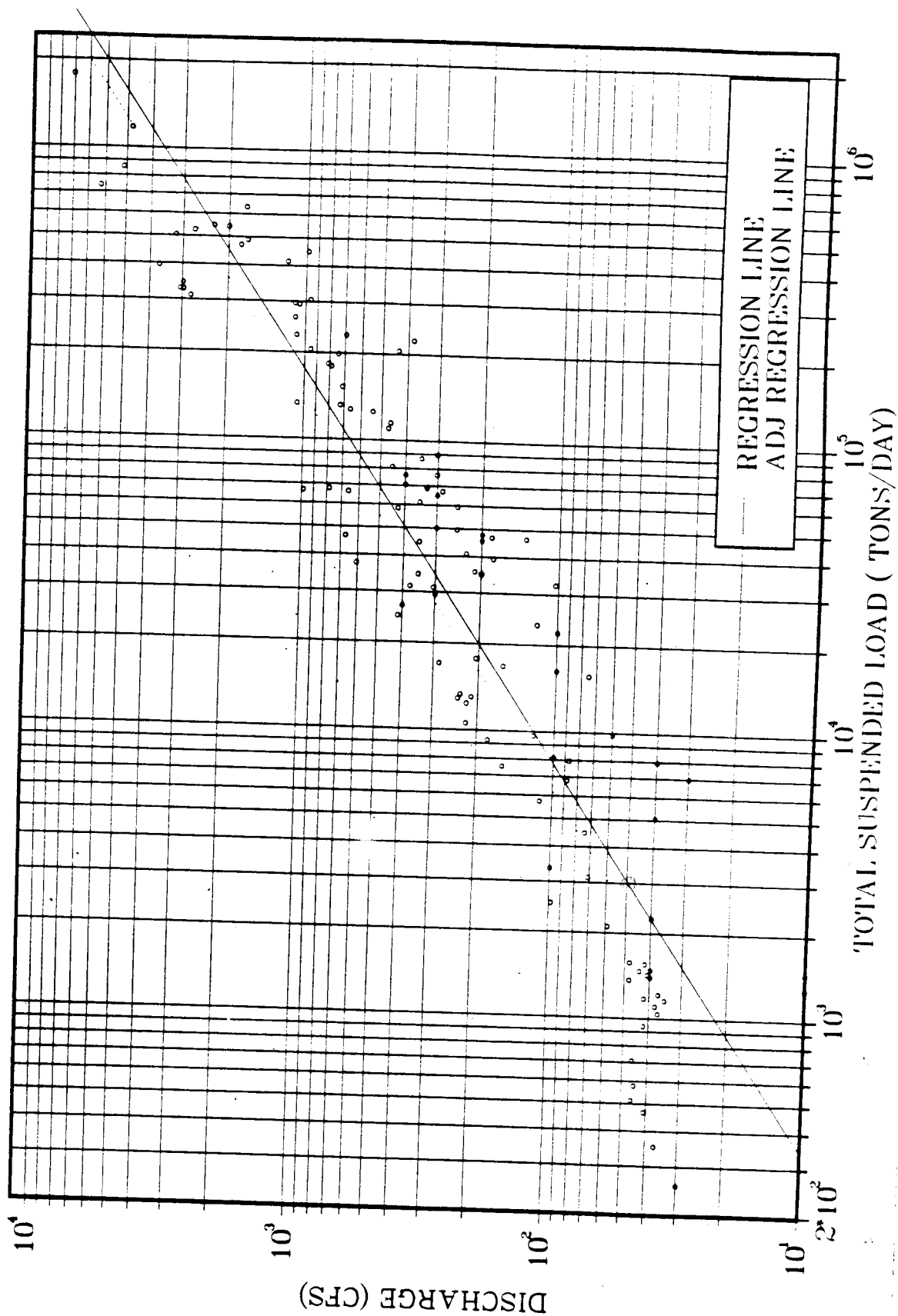


# LITTLE COLORADO NEAR CAMERON, ARIZONA

*June through November*



# LITTLE COLORADO RIVER AT CAMERON, ARIZONA



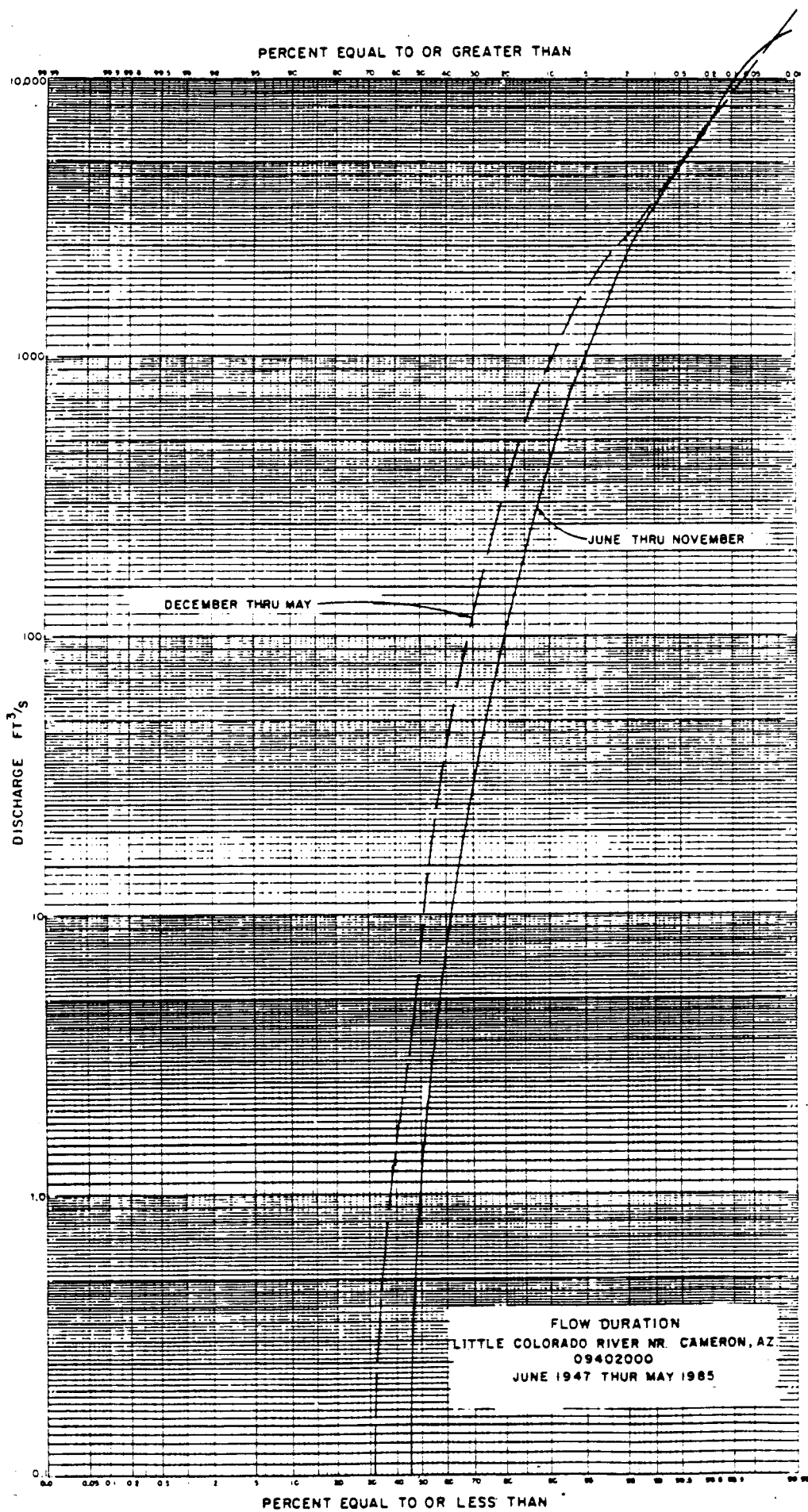
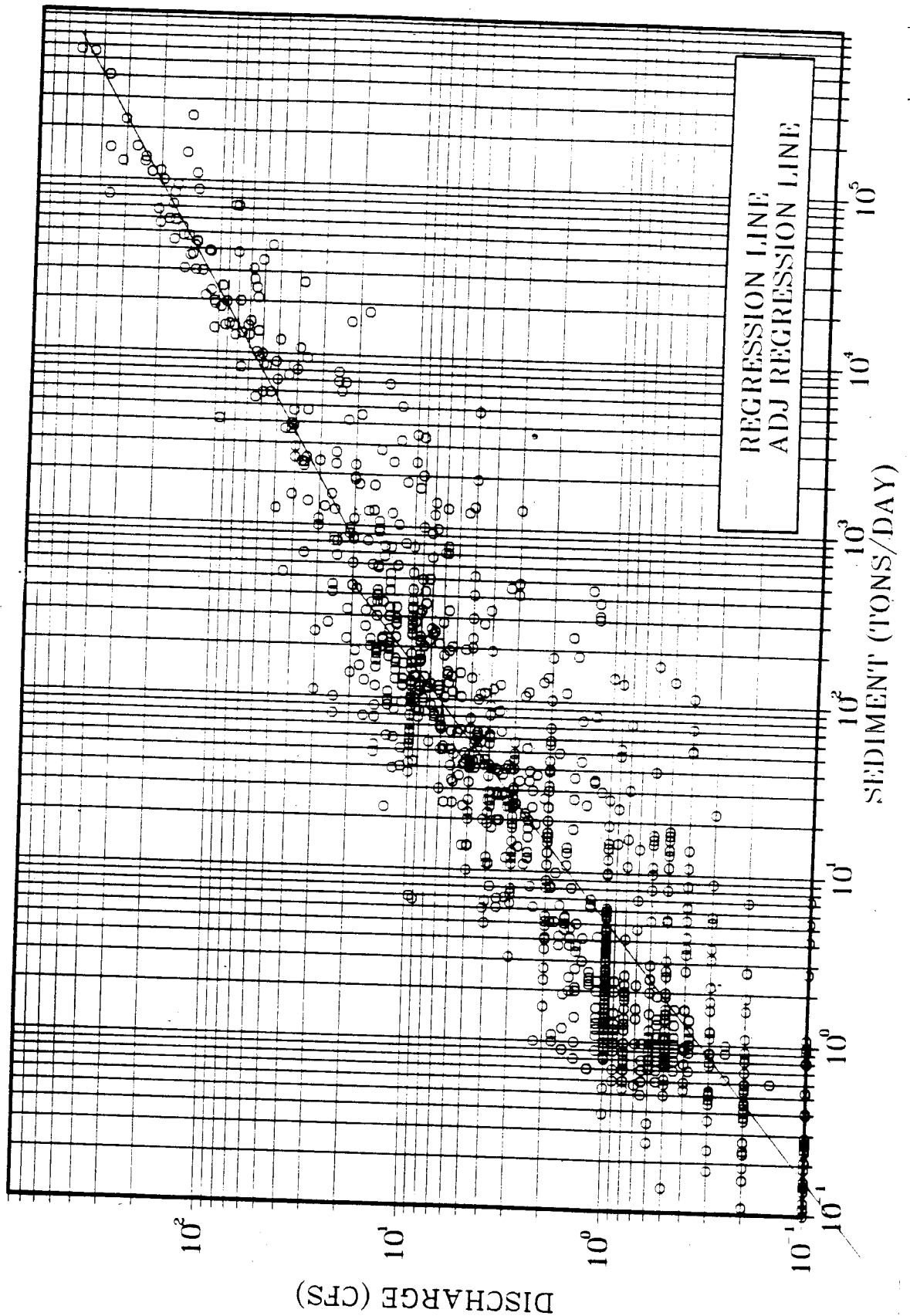


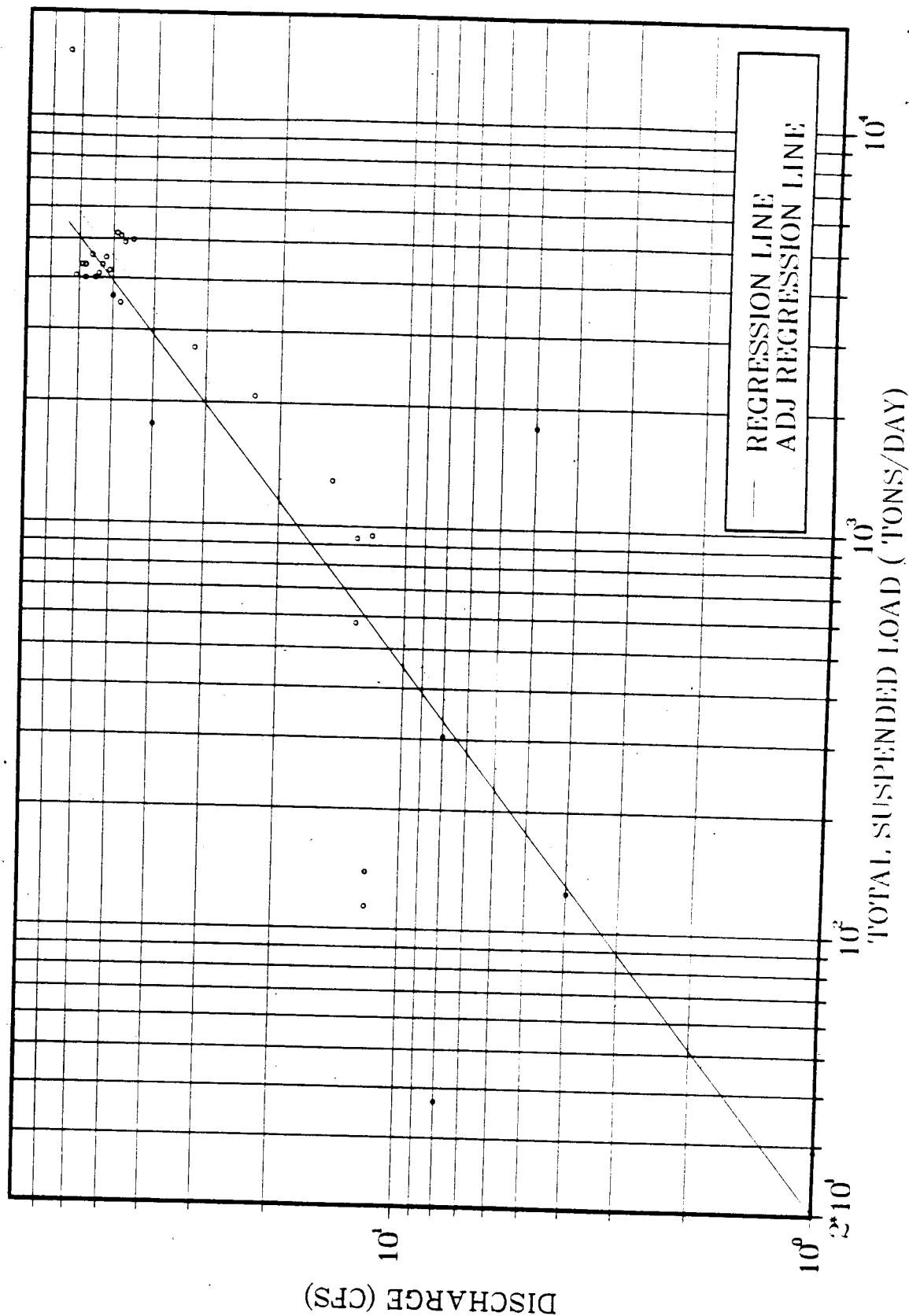
Figure 54

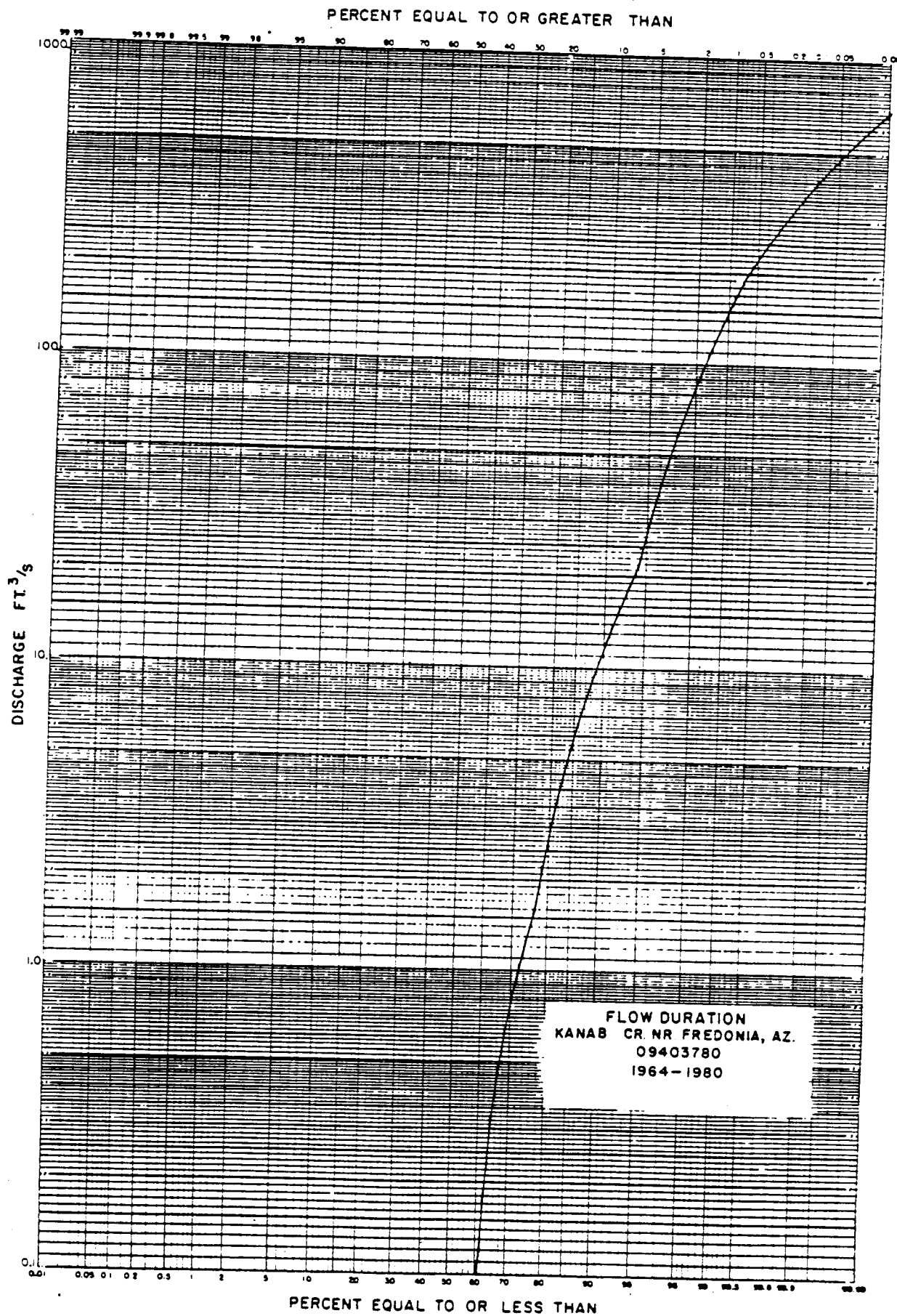
# KANAB CREEK NEAR FREDONIA, ARIZONA



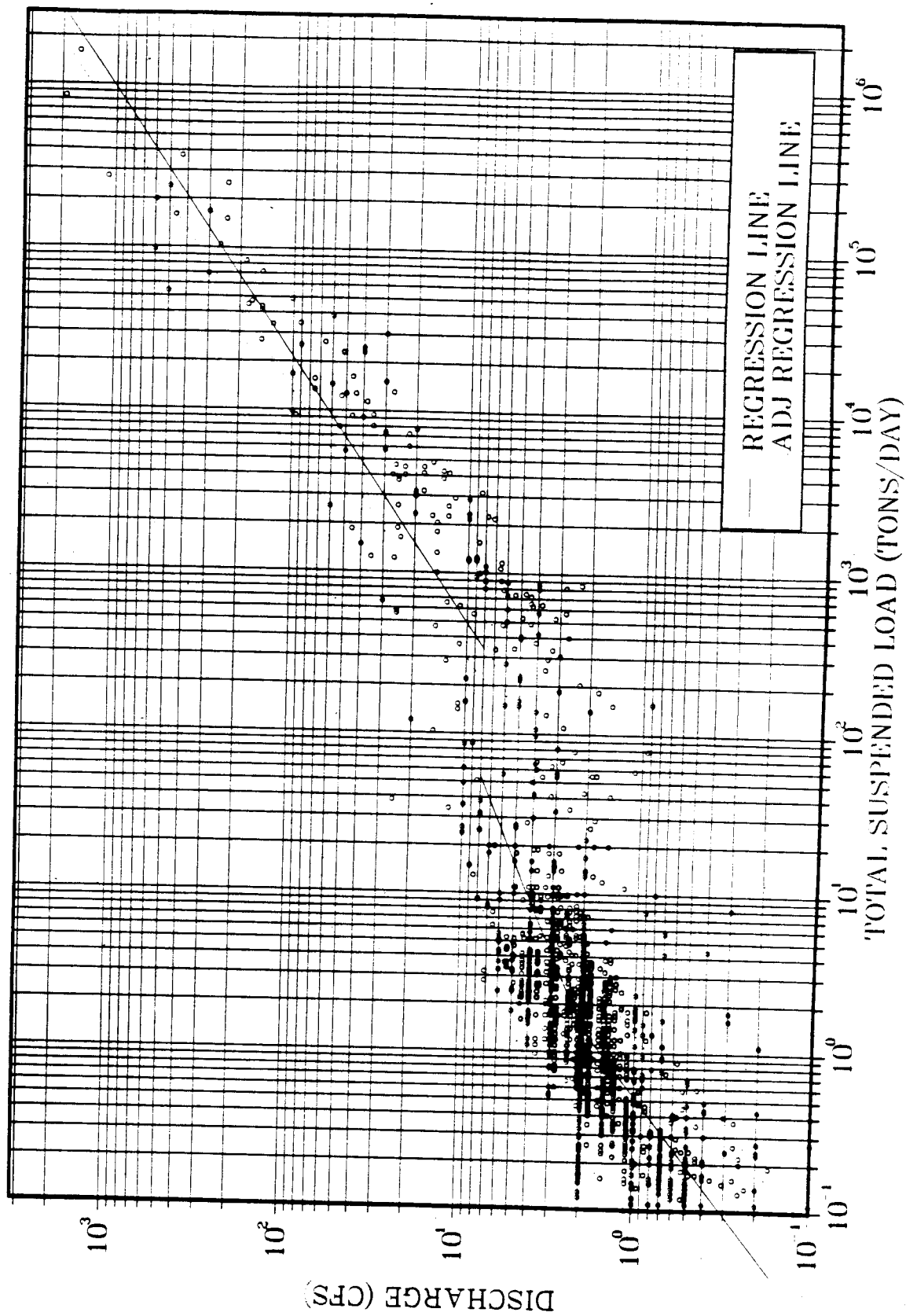


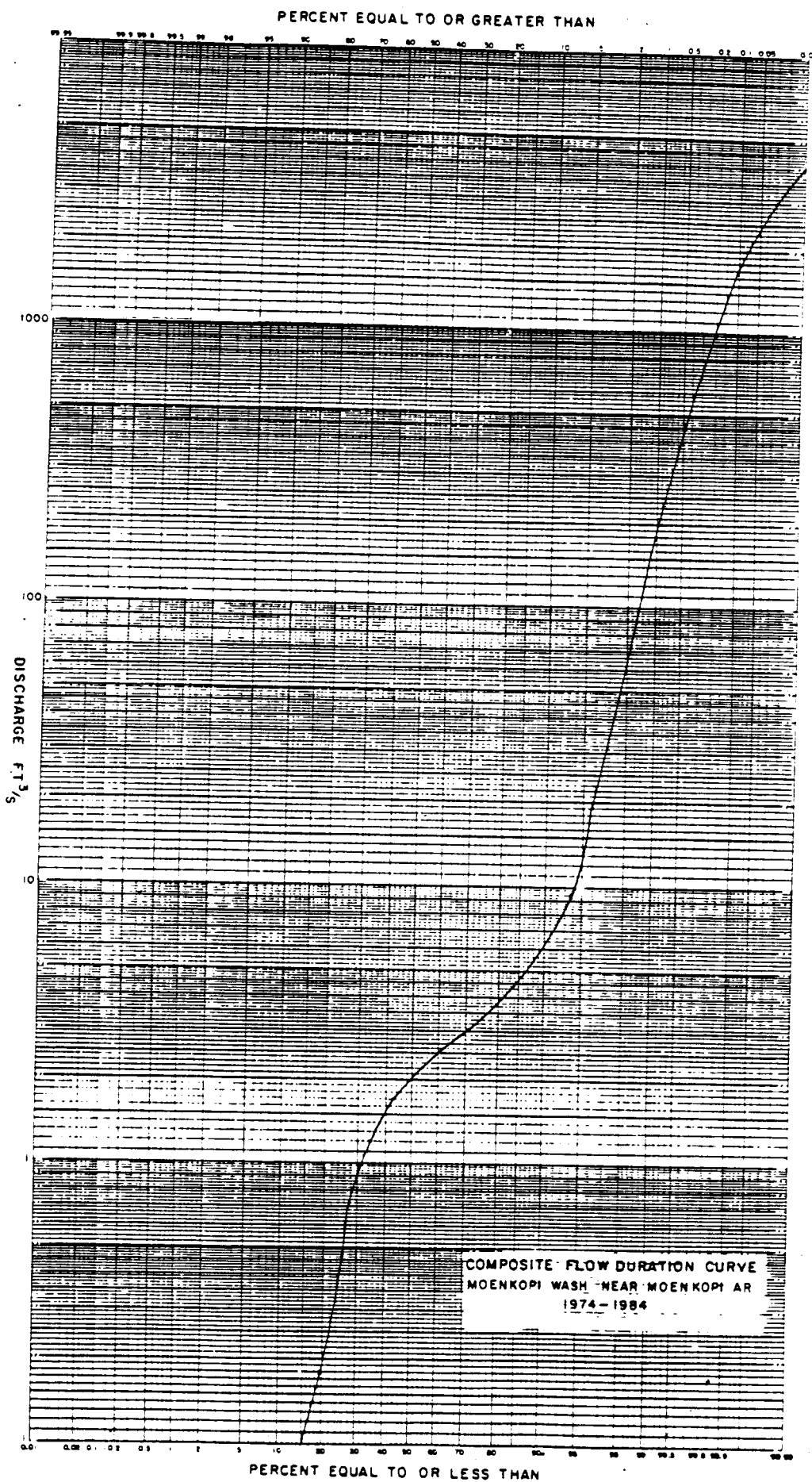
# KANAB CREEK NEAR FREDONIA, ARIZONA

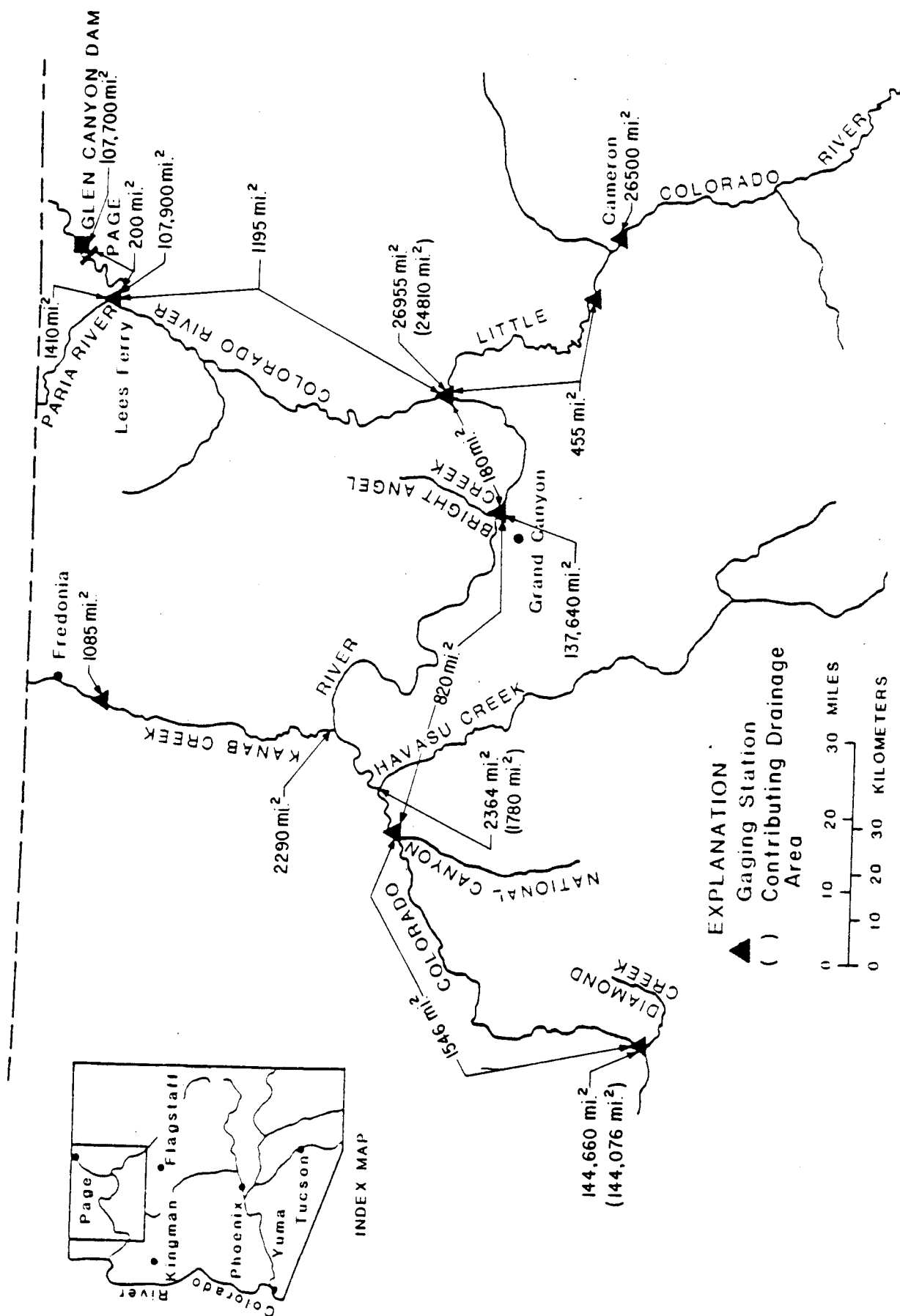




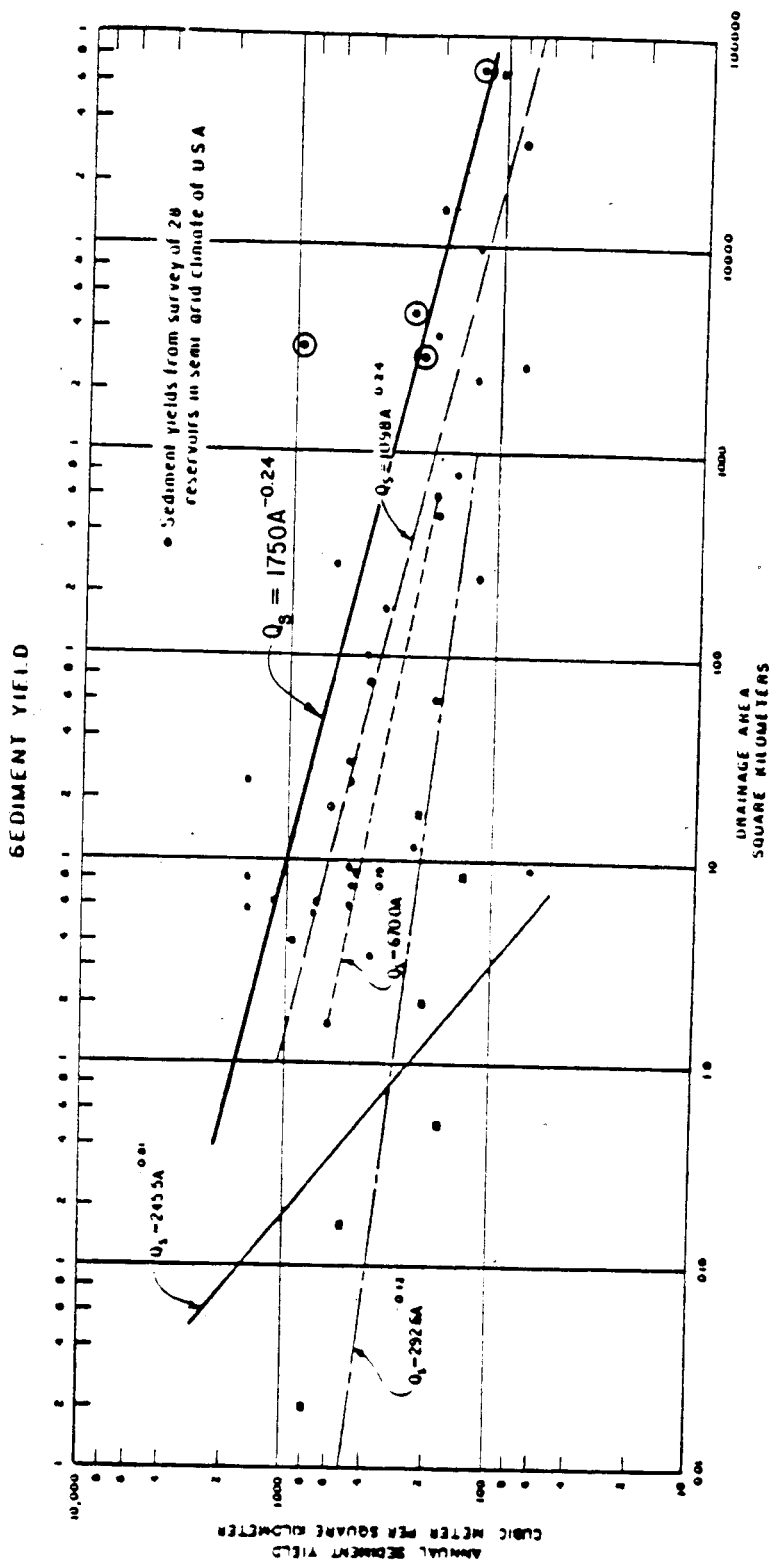
# MOENKOPI WASH NEAR MOENKOPI, ARIZ.







**LOCATION MAP**  
**COLORADO RIVER SEDIMENT TRANSPORT STUDY**  
**DRAINAGE AREAS**



NO DATA POINT SHOWN ON GRAPH  $Q_s = 245.5A^{0.81}$   
 Soil erosion and sedimentation in 73 basins in eastern Wyoming  
 P313 "Studies of Soil Erosion and Sedimentation in Arizona" Edited by Rapp, Barry and Temple

DATA POINTS = 20  $Q_s = 1028A^{0.26}$   $Q_s = 1028A^{0.26}$   
 Sediment yield from reservoir survey data from semi arid climate of US  
 Draft copy 11 Penderton August 24, 1977

DATA POINT = 5  $Q_s = 6700A^{0.18}$   
 5 (station basins in Arizona) P313 "Studies of Soil Erosion and Sedimentation in Arizona" Edited by Rapp, Barry and Temple

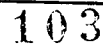
DATA POINT = 6  $Q_s = 292.6A^{0.12}$   
 Average annual sediment yield in 16,000 erosion research techniques  
 P313 "Studies of Soil Erosion and Sedimentation in Arizona" Edited by Rapp, Barry and Temple

• Sediment yields from survey of 28 reservoirs in semi arid climate of USA

$$Q_s = \frac{M^3}{A^2 \cdot Y^2}$$

A - km<sup>2</sup>

Figure 61



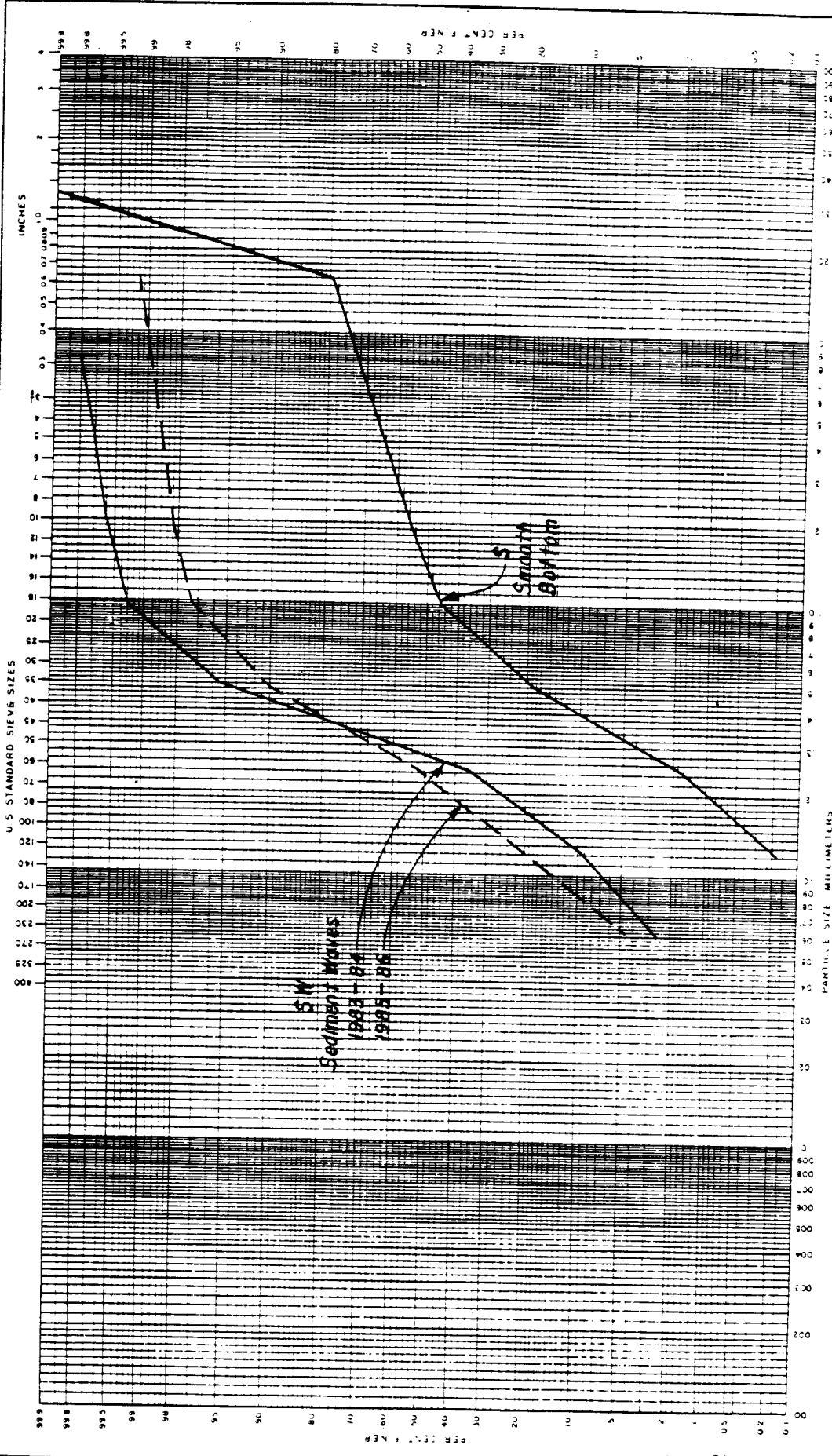


CLAY				SILT				SAND				GRAVEL				
Fine	Medium	Coarse		Very Fine	Fine	Coarse		Very Fine	Fine	Coarse		Very Fine	Fine	Coarse	Very Fine	Med
<p>Reach.2 and Reach 3</p> <p>AMERICAN GEOPHYSICAL UNION (A.G.U.) CLASSIFICATION</p> <p>Material <u>D<sub>50</sub></u></p> <p>SW 1983-84 <u>0.33</u></p> <p>SW 1985-86 <u>0.28</u></p> <p>S <u>1.80</u></p>																



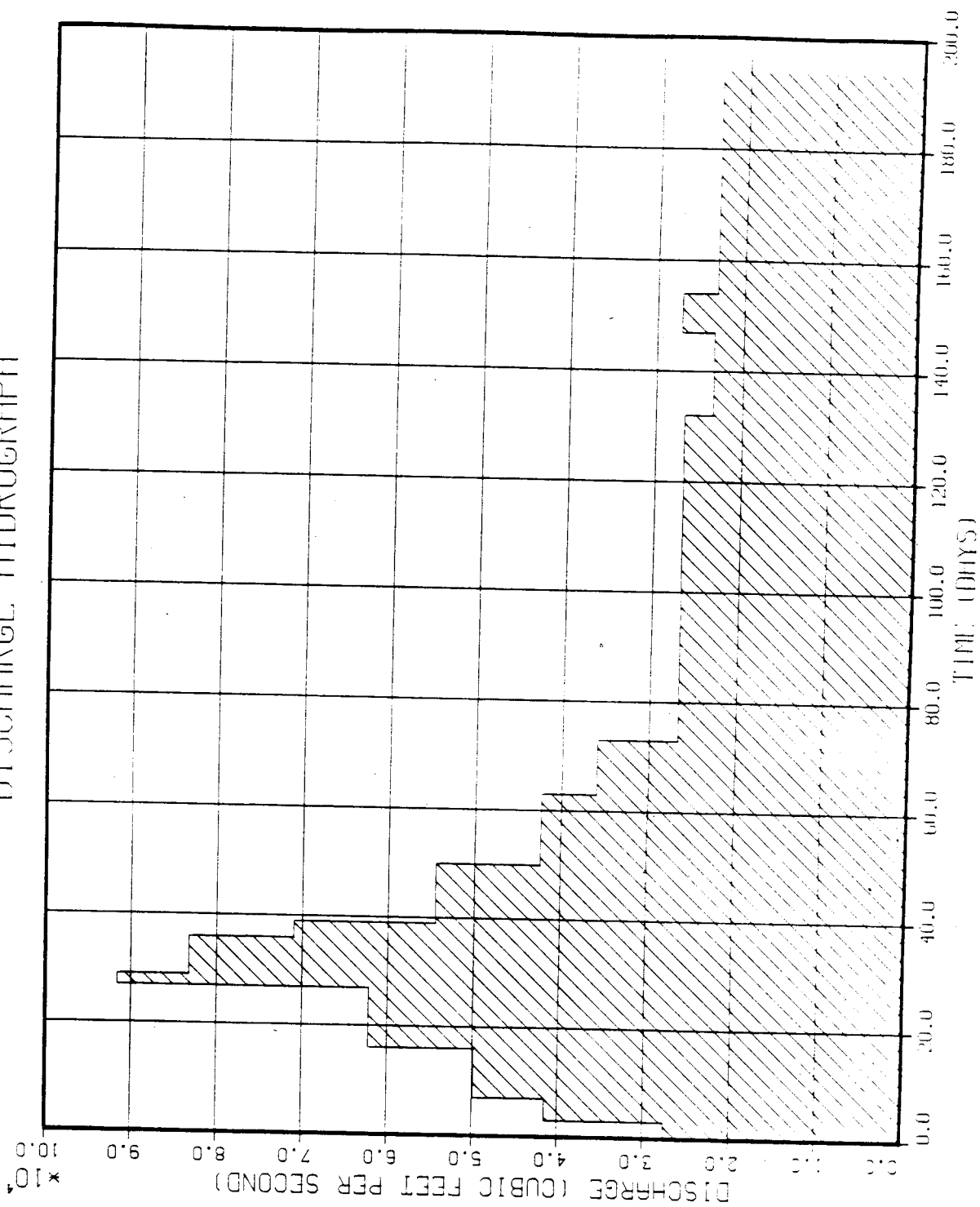
7-1714  
(3-82)

GPO 857-906

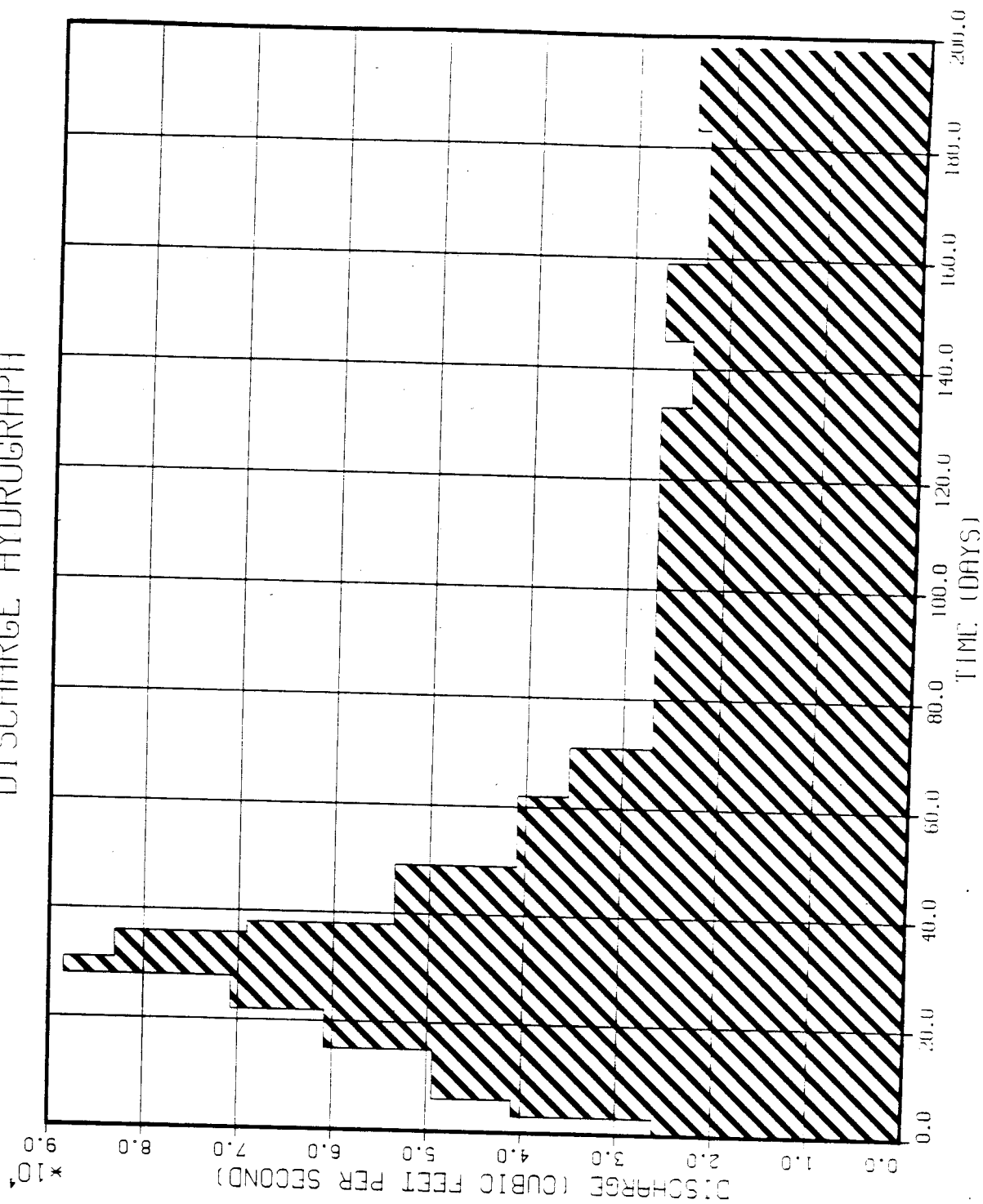


UNITED STATES DEPARTMENT OF THE INTERIOR WATER AND POWER RESOURCES SERVICES SEDIMENT SIZE ANALYSIS									
BED MATERIAL									
DESIGNED: _____									
DRAWN: _____									
CHECKED: _____									
FILM APPROVAL: _____									
SUBMITTED: _____									
APPROVED: _____									
AMERICAN GEOPHYSICAL UNION (AGU) CLASSIFICATION									
Material									
SW 1983-84									
SW 1985-86									
S									
D <sub>50</sub>									
0.28									
0.24									
1.35									
Reach 4									

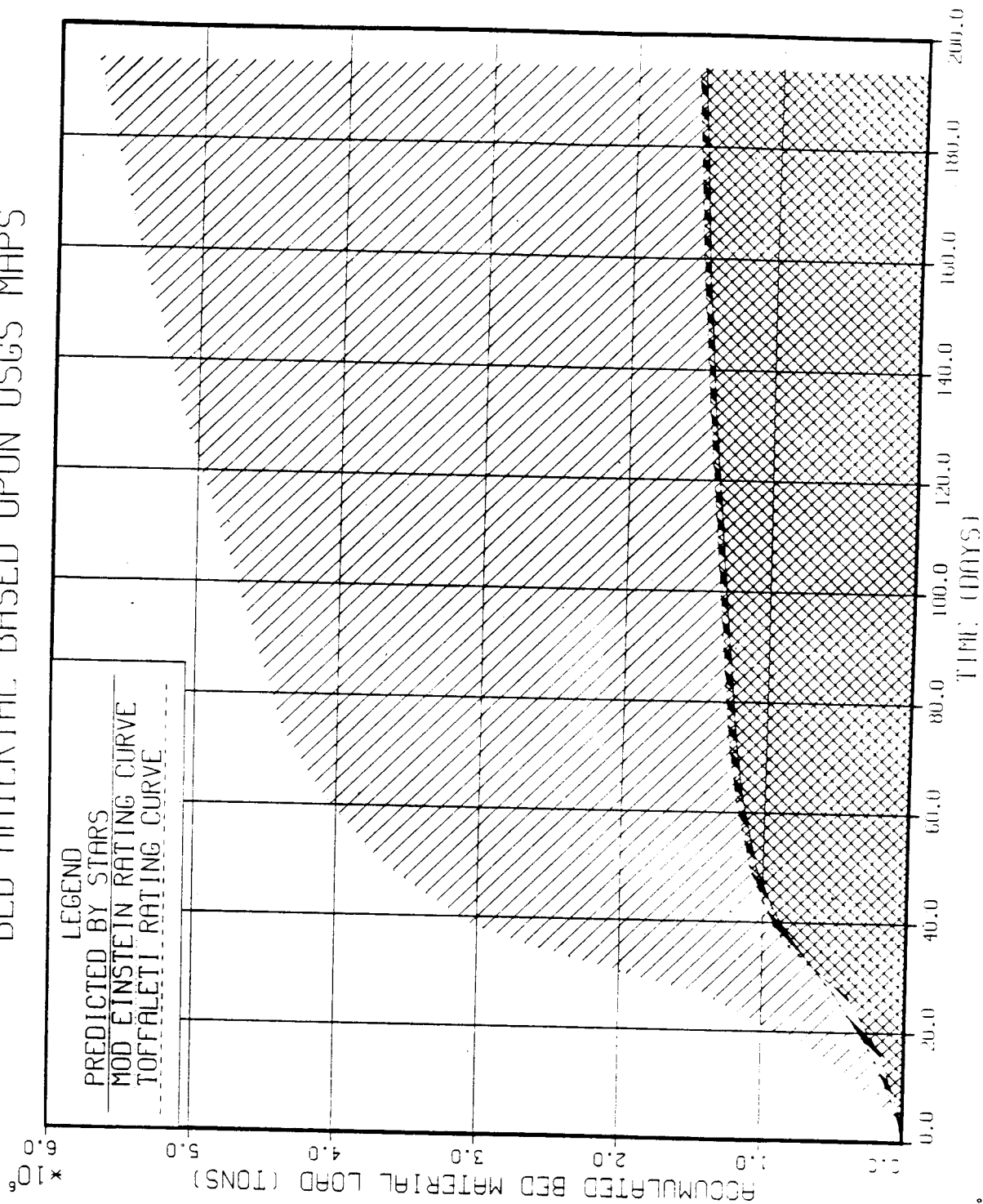
COLORADO RIVER FROM LEES FERRY TO LCR  
 RIVER MILE 61.00  
 DISCHARGE HYDROGRAPH



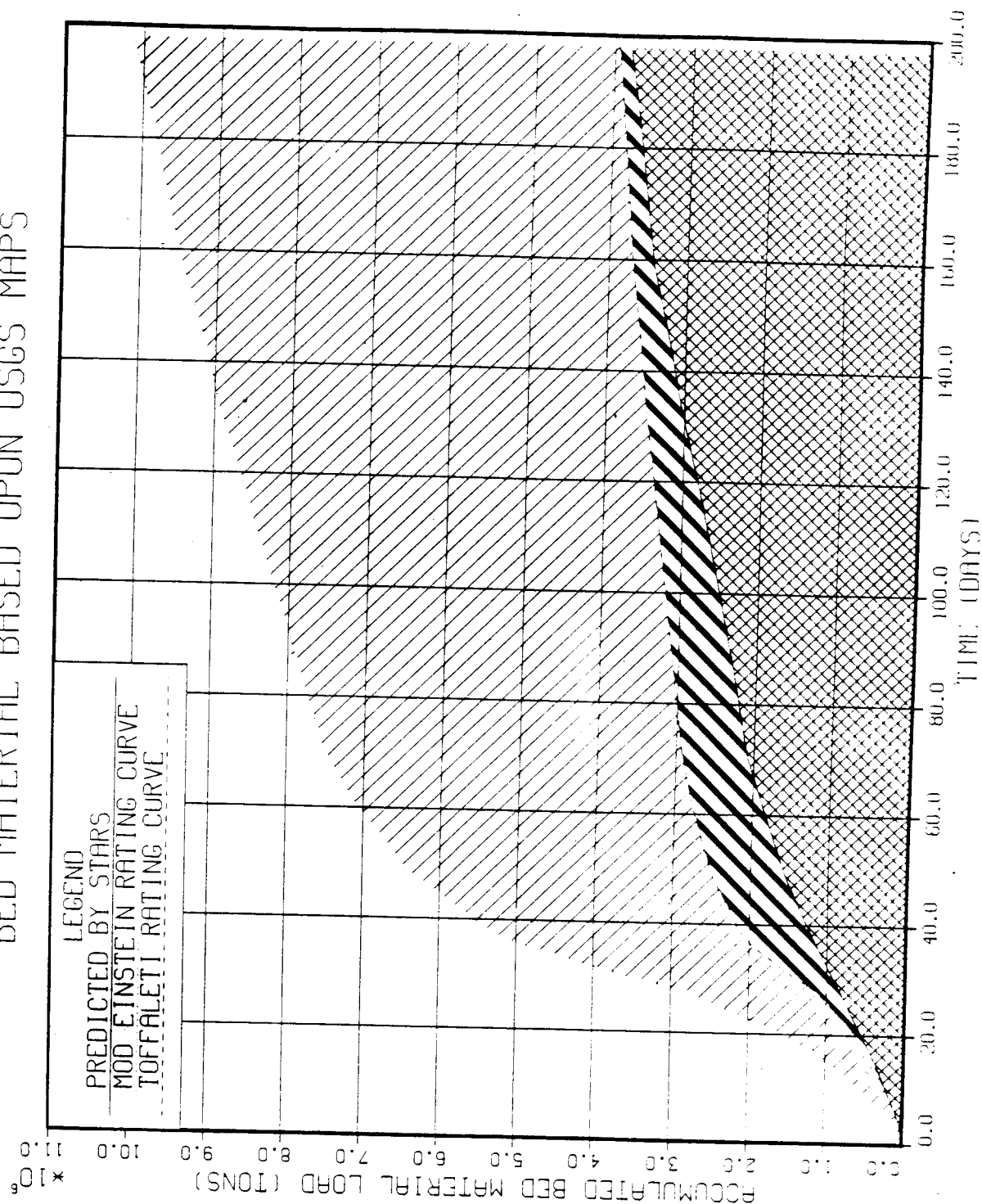
COLORADO RIVER FROM LCR TO GRAND CANYON  
 RIVER MILE 87.37  
 DISCHARGE HYDROGRAPH



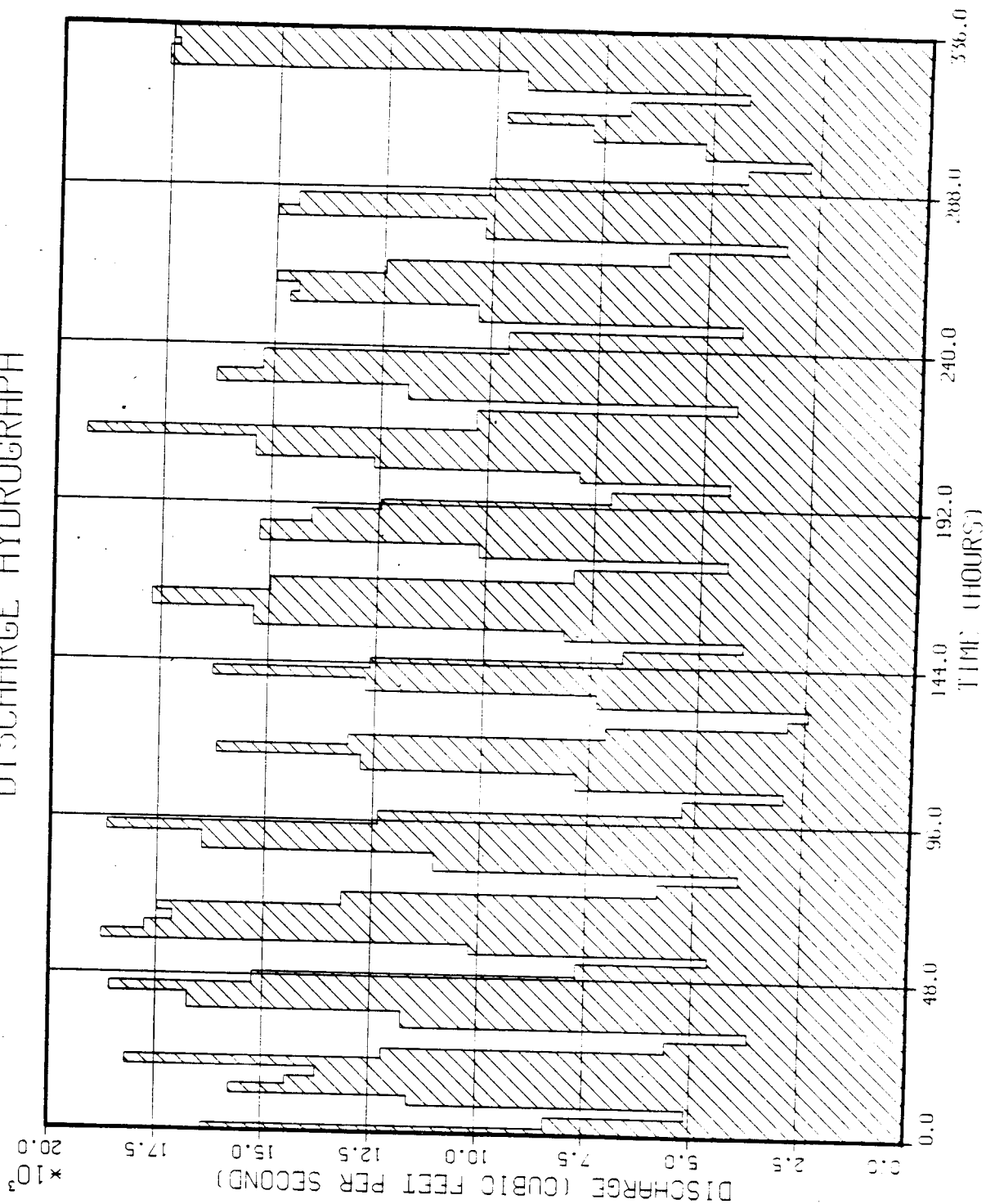
# COLORADO RIVER FROM LEES FERRY TO LCR RIVER MILE 61.00 BED MATERIAL BASED UPON USGS MAPS



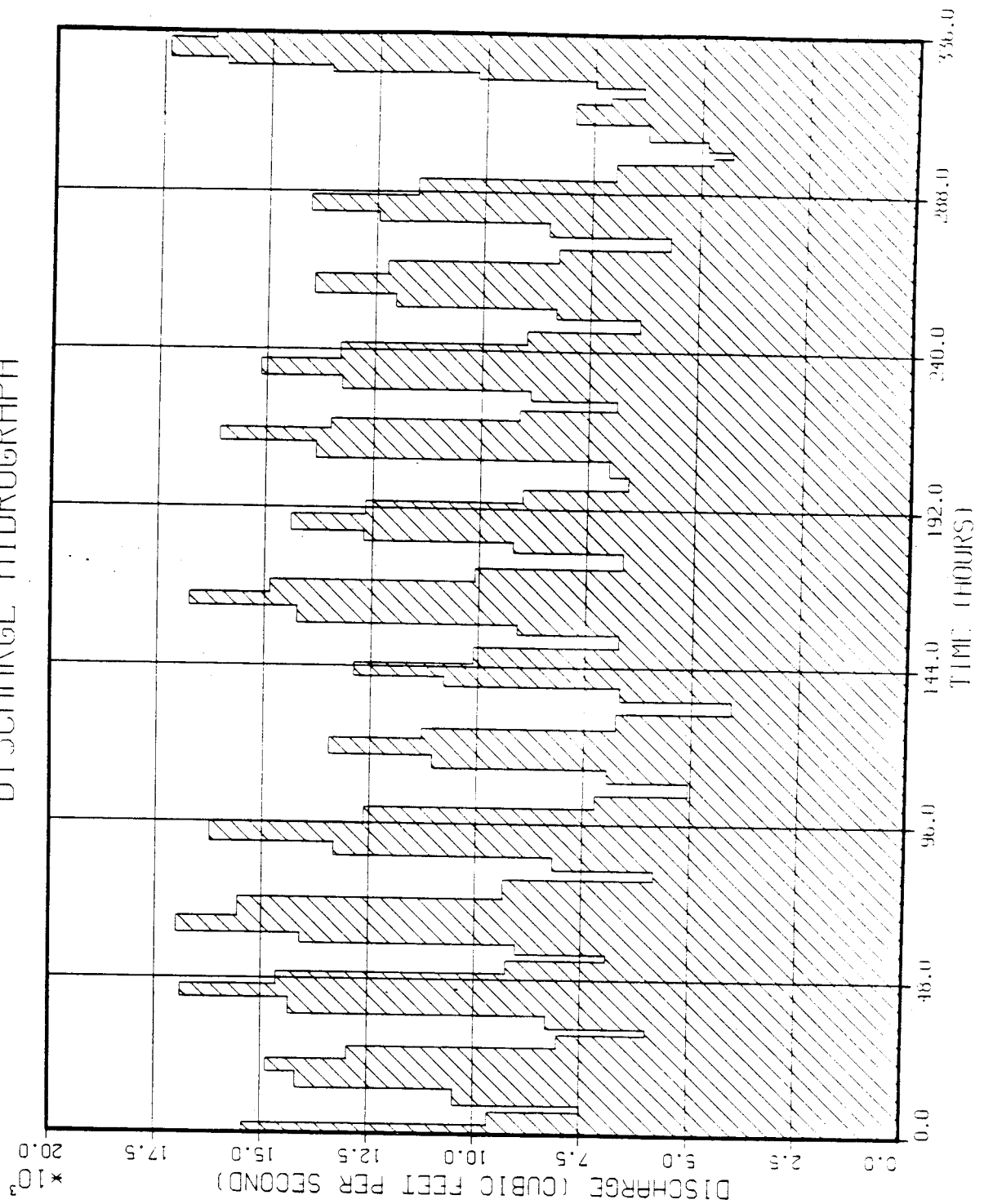
# COLORADO RIVER FROM LCR TO GRAND CANYON RIVER MILE 87.37 BED MATERIAL BASED UPON USGS MAPS



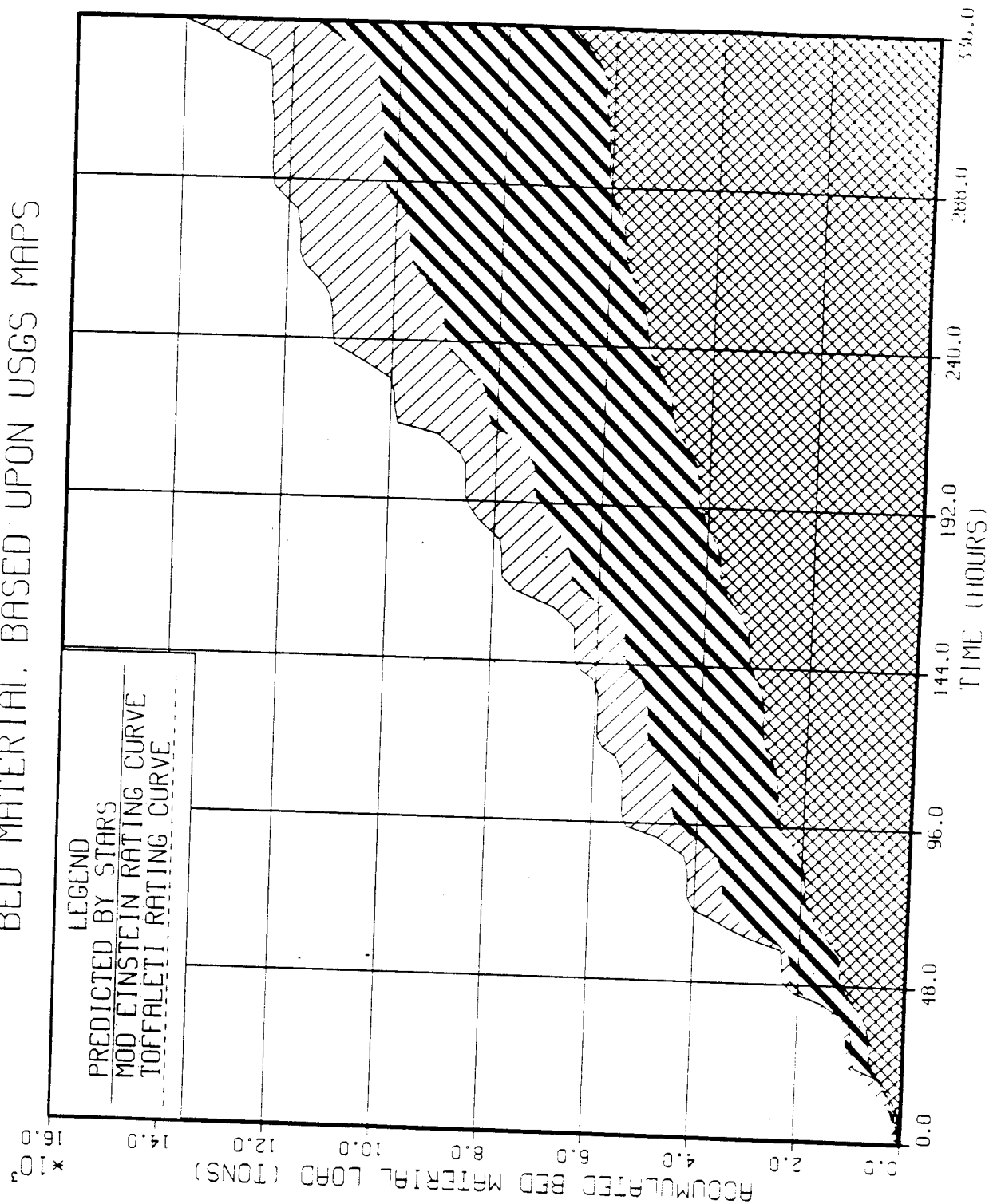
COLORADO RIVER FROM LEES FERRY TO LCR  
 RIVER MILE 61.00  
 DISCHARGE HYDROGRAPH



COLORADO RIVER FROM LCR TO GRAND CANYON  
 RIVER MILE 87.37  
 DISCHARGE HYDROGRAPH

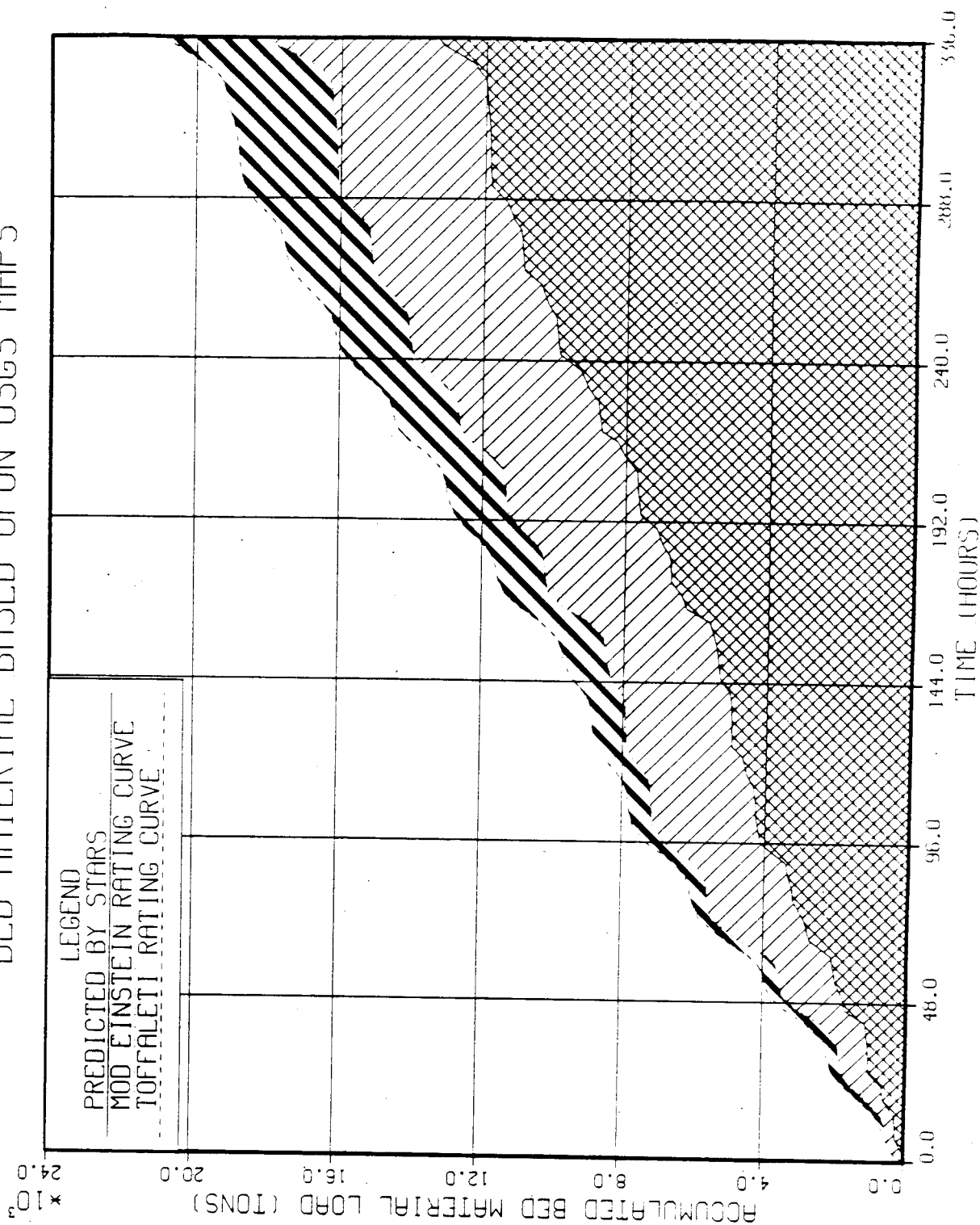


# COLORADO RIVER FROM LEES FERRY TO LCR RIVER MILE 61.00 BED MATERIAL BASED UPON USGS MAPS

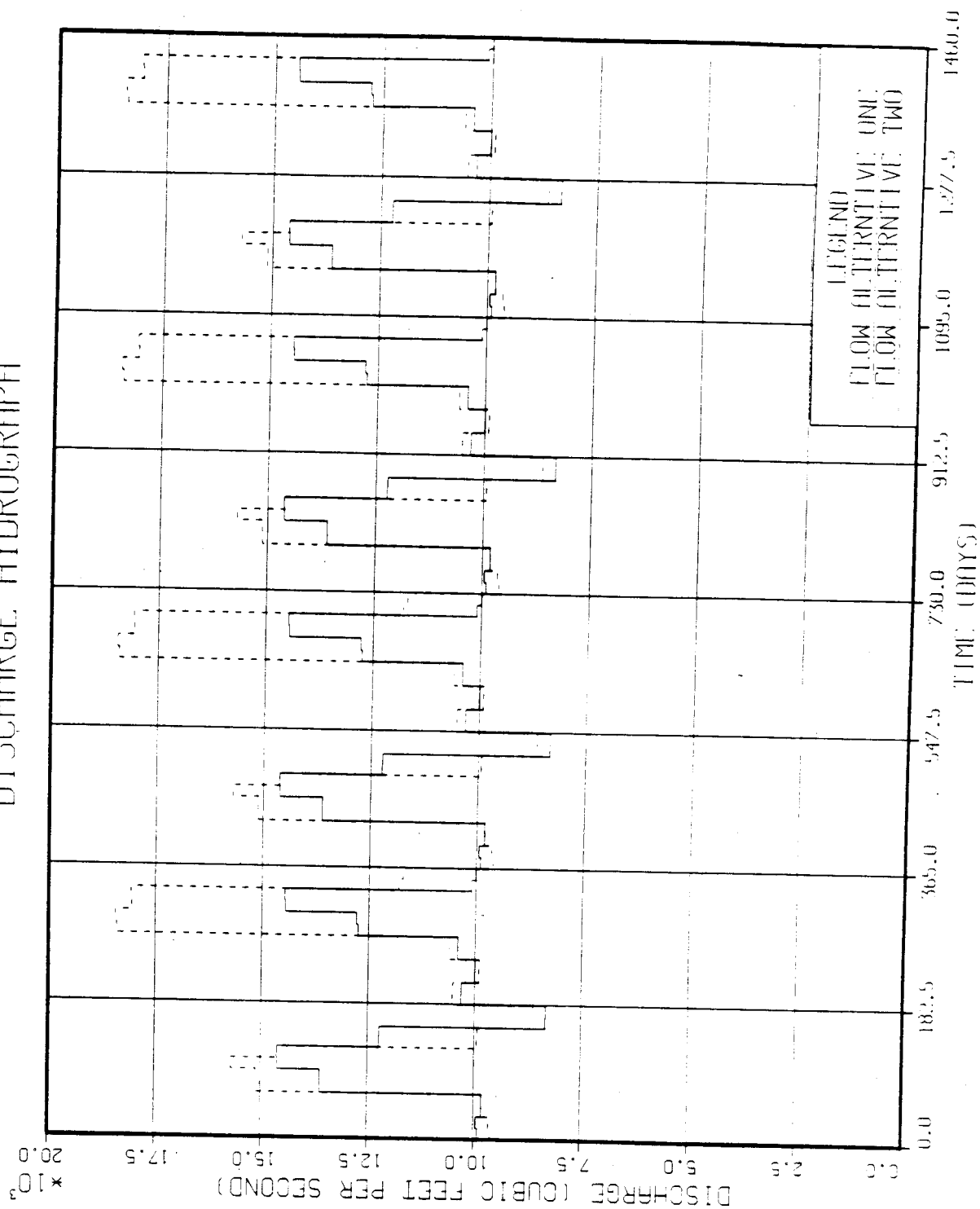




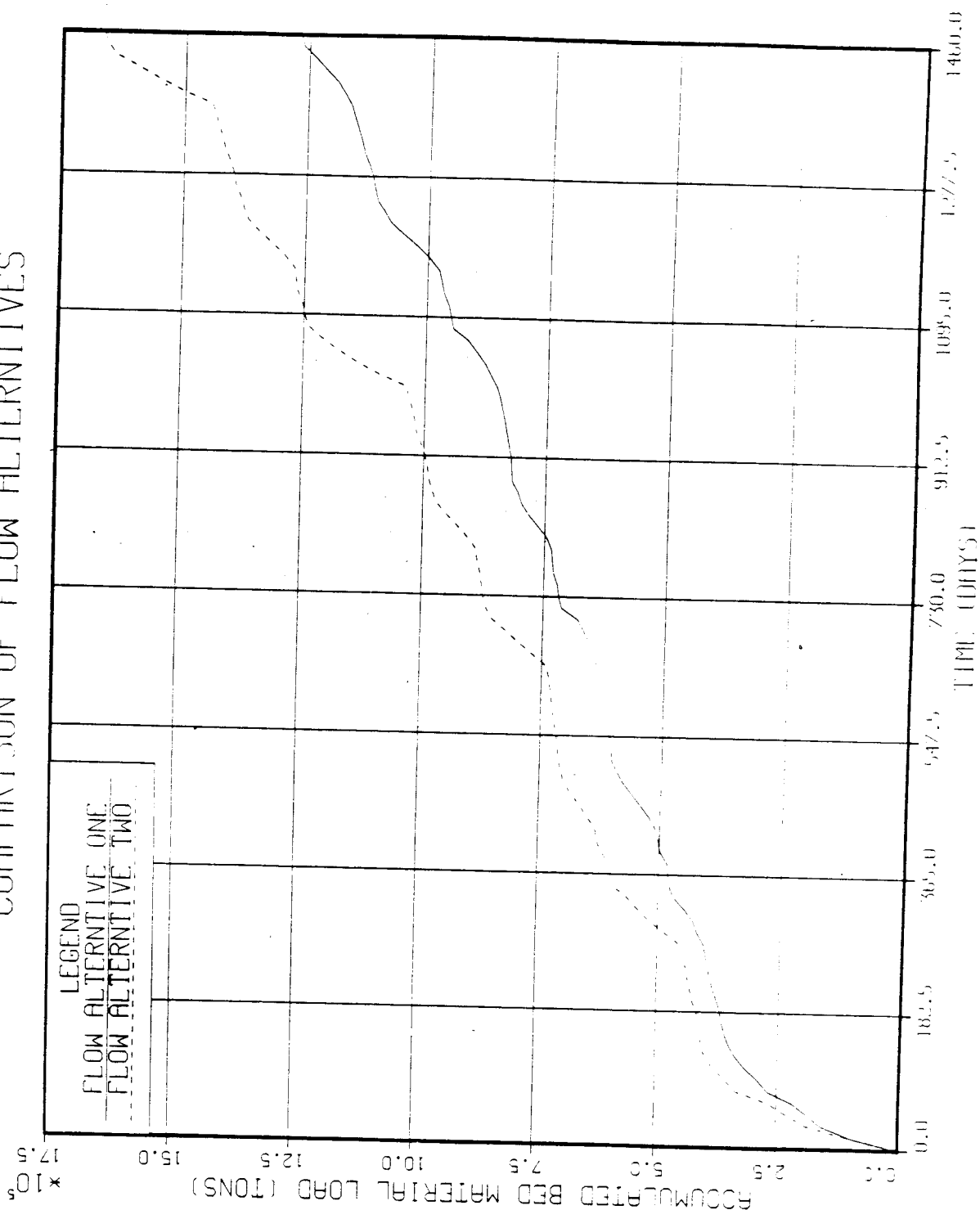
# COLORADO RIVER FROM LCR TO GRAND CANYON RIVER MILE 87.37 BED MATERIAL BASED UPON USGS MAPS

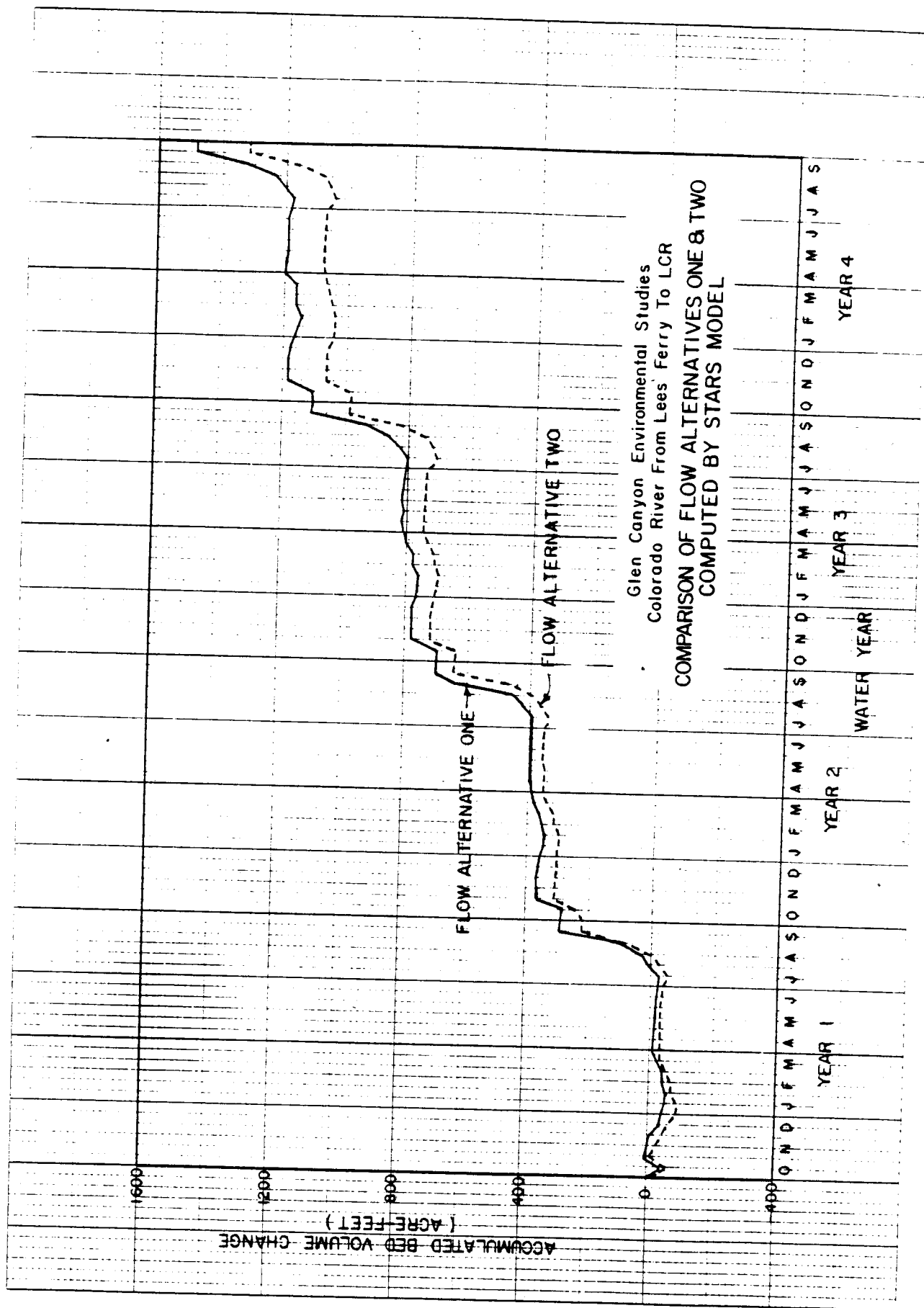


# COLORADO RIVER FROM LEES FERRY TO LCR RIVER MILE 61.00 DISCHARGE HYDROGRAPH



# COLORADO RIVER FROM LEES FERRY TO LCR RIVER MILE 61.00 COMPARISON OF FLOW ALTERNATIVES

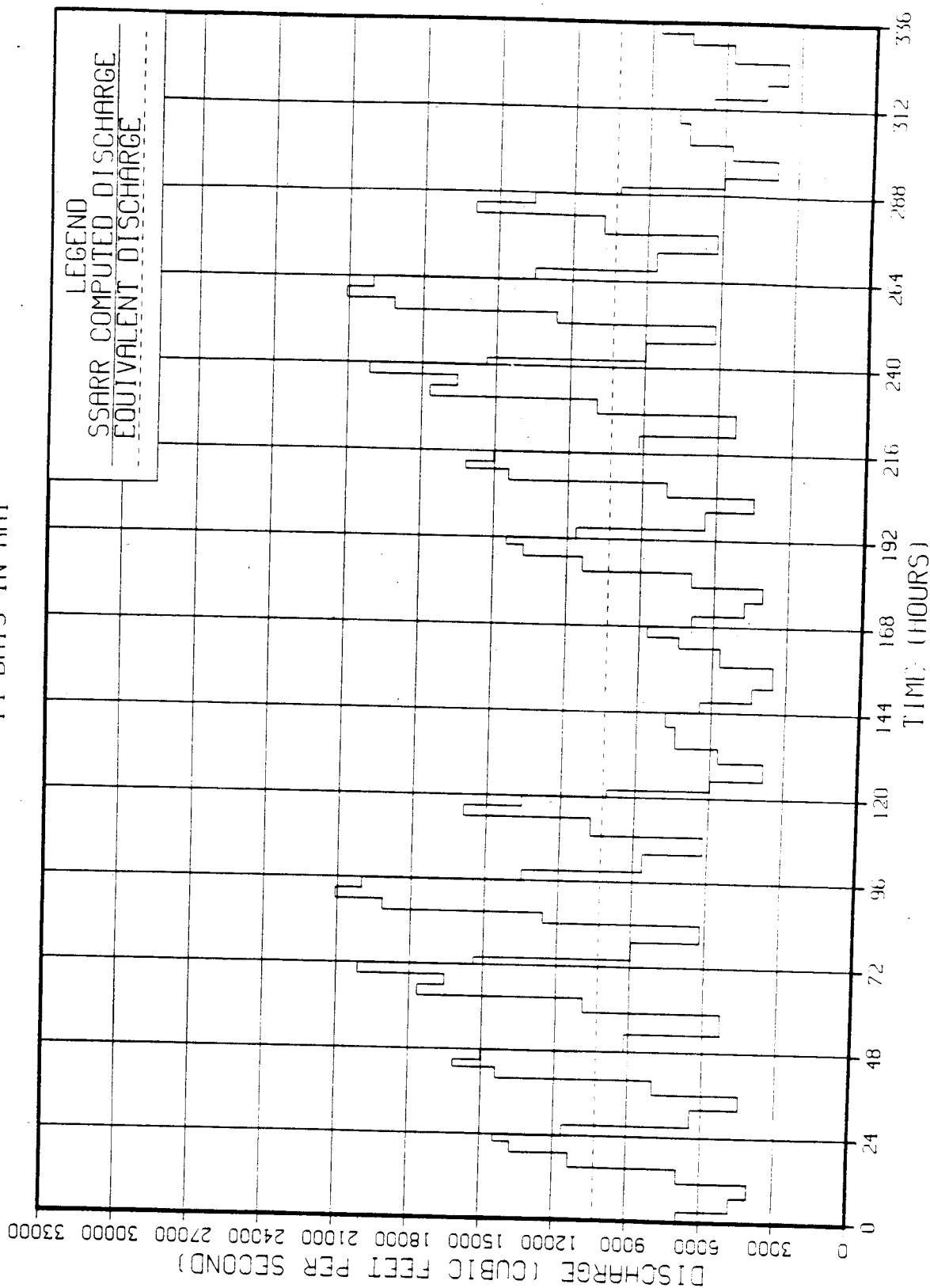




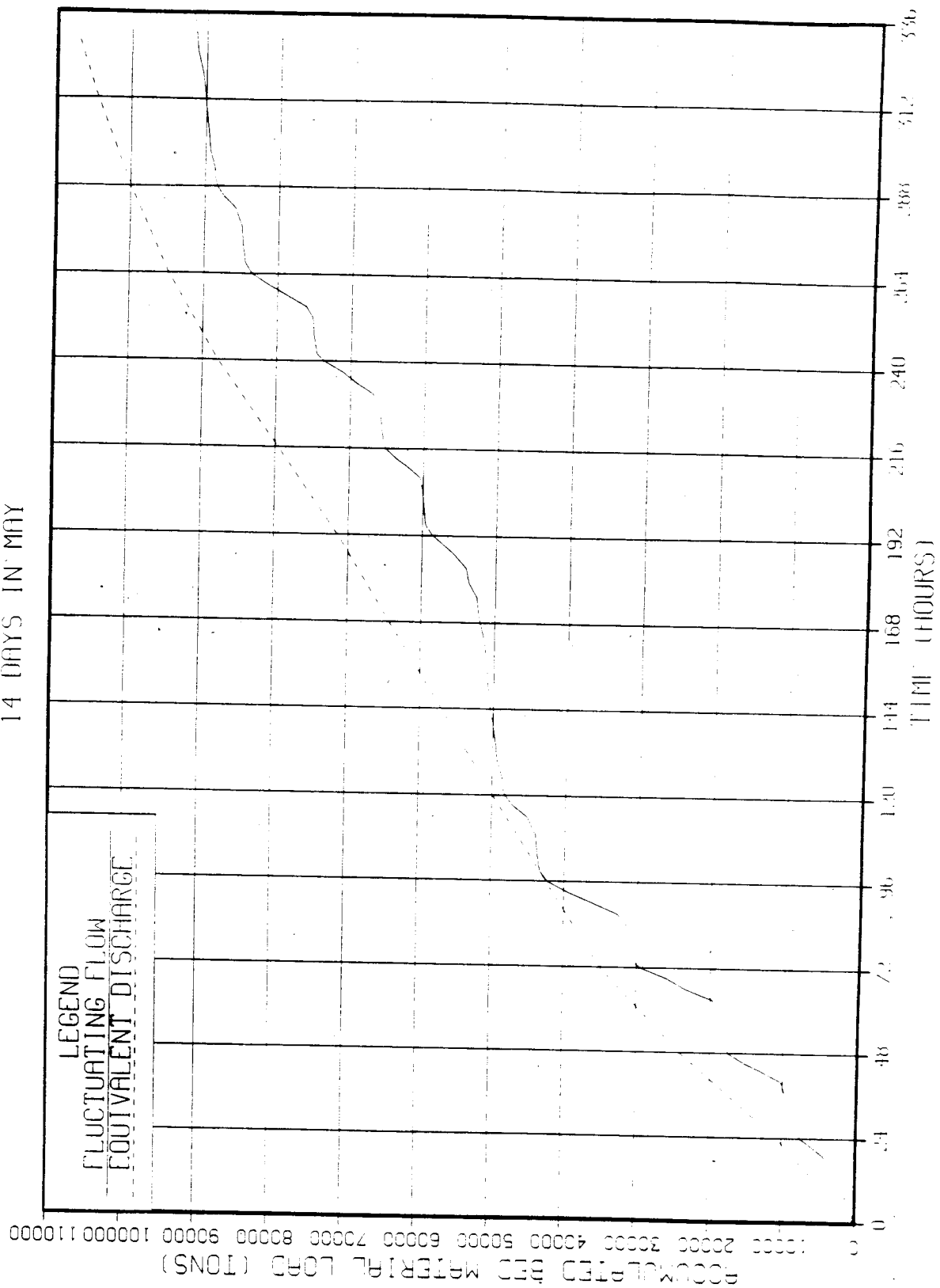
COLORADO RIVER, REACH 1 (RIVER MILE 0 TO 61)

FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN MAY

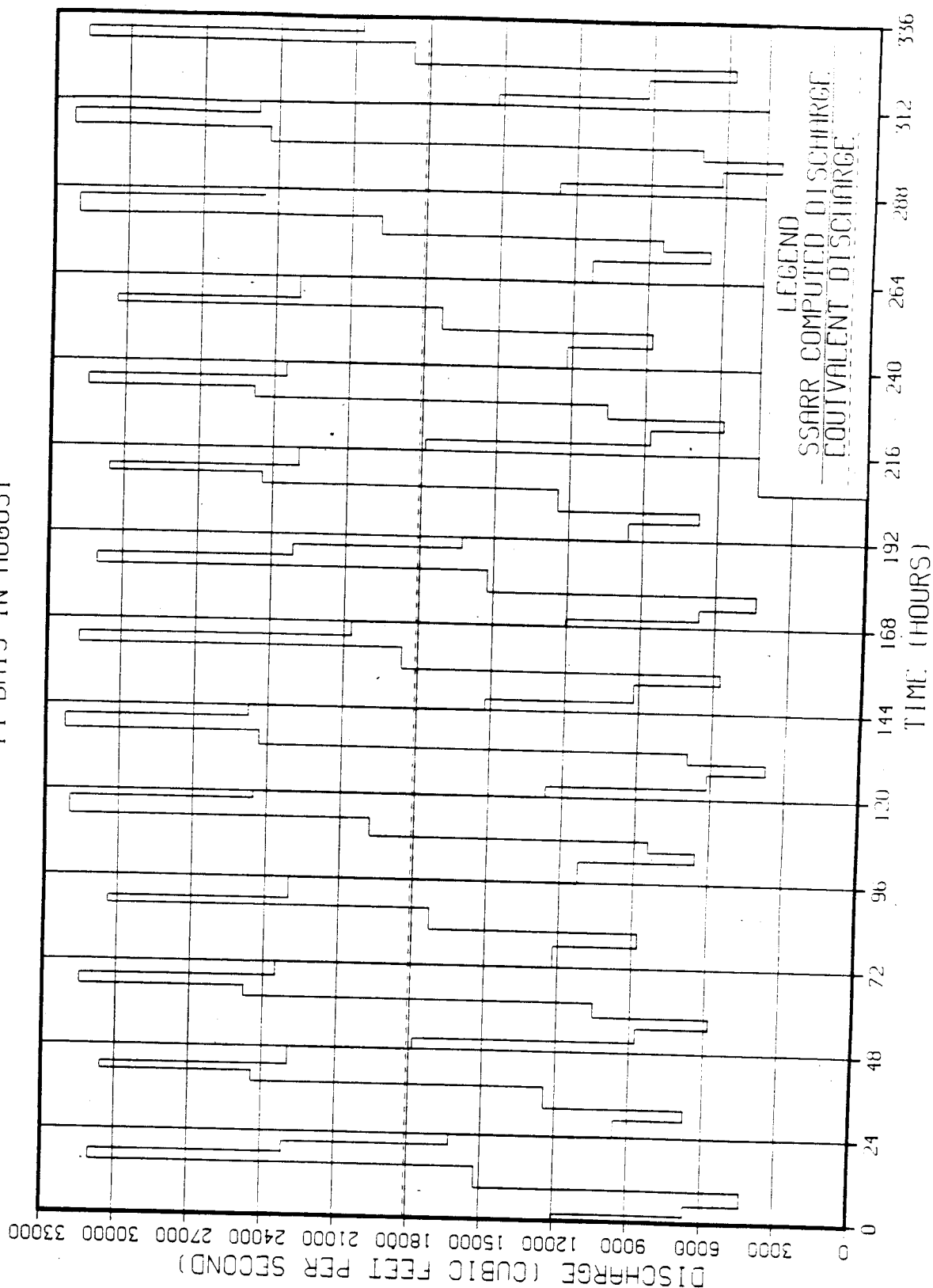


GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 61.00  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)  
 14 DAYS IN MAY

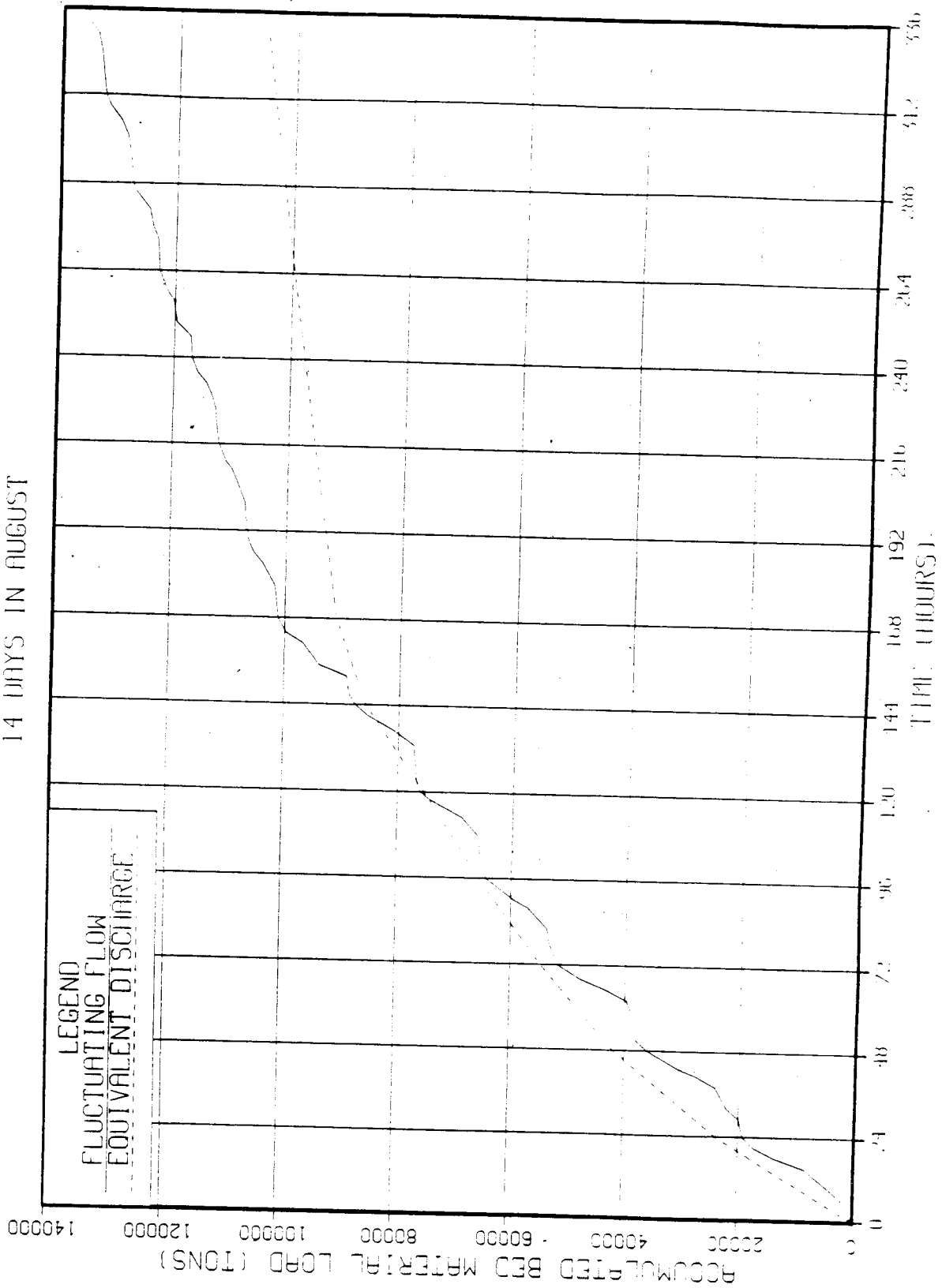


COLORADO RIVER, REACH 1 (RIVER MILE 0 TO 61)  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN AUGUST



GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 61.00  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)  
 14 DAYS IN AUGUST

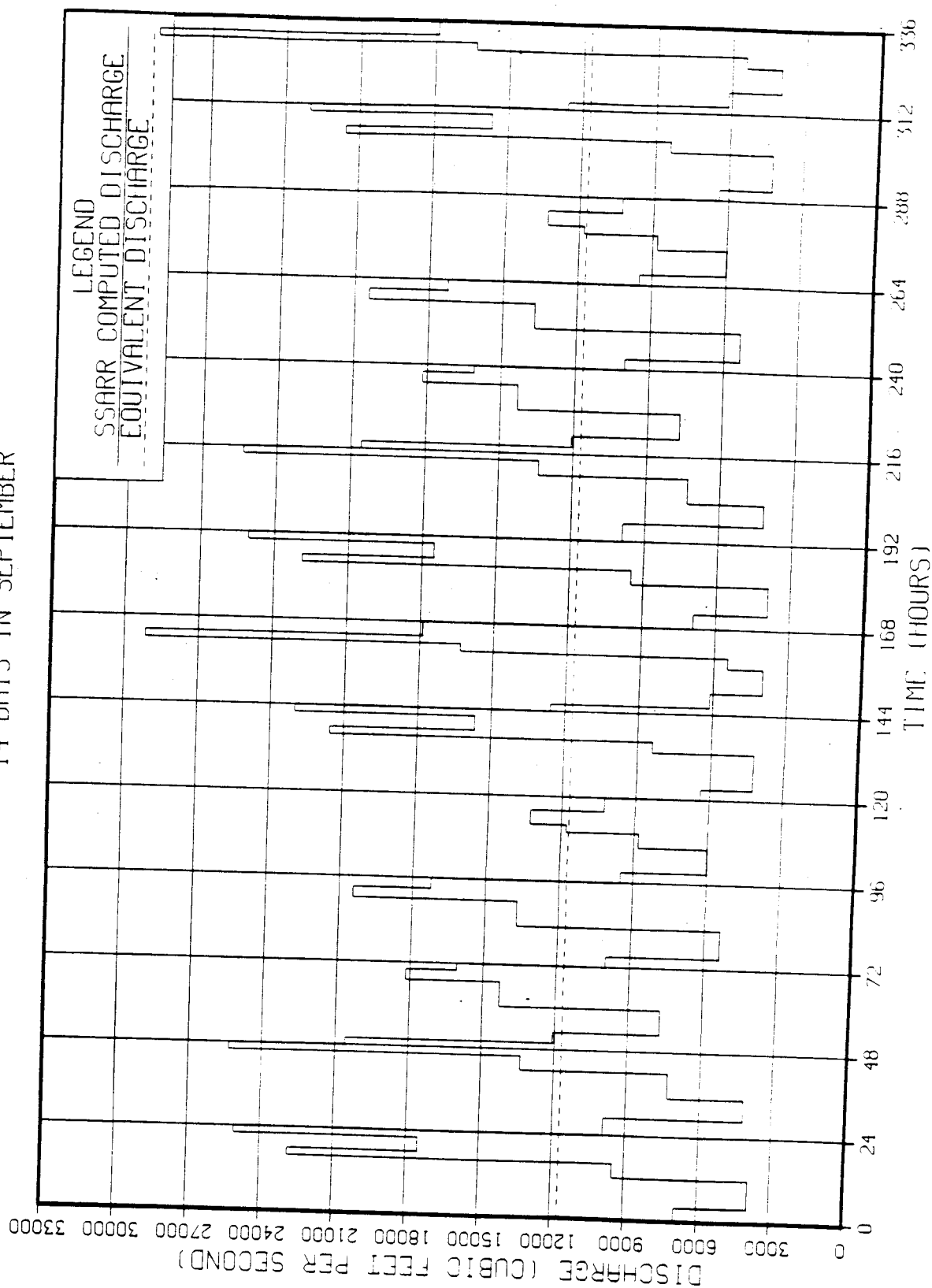




COLORADO RIVER, REACH 1 (RIVER MILE 0 TO 61)

FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN SEPTEMBER



GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 61.00  
 FLOW-ALTERNATIVE TWO (STARS OUTPUT)  
 14 DAYS IN SEPTEMBER

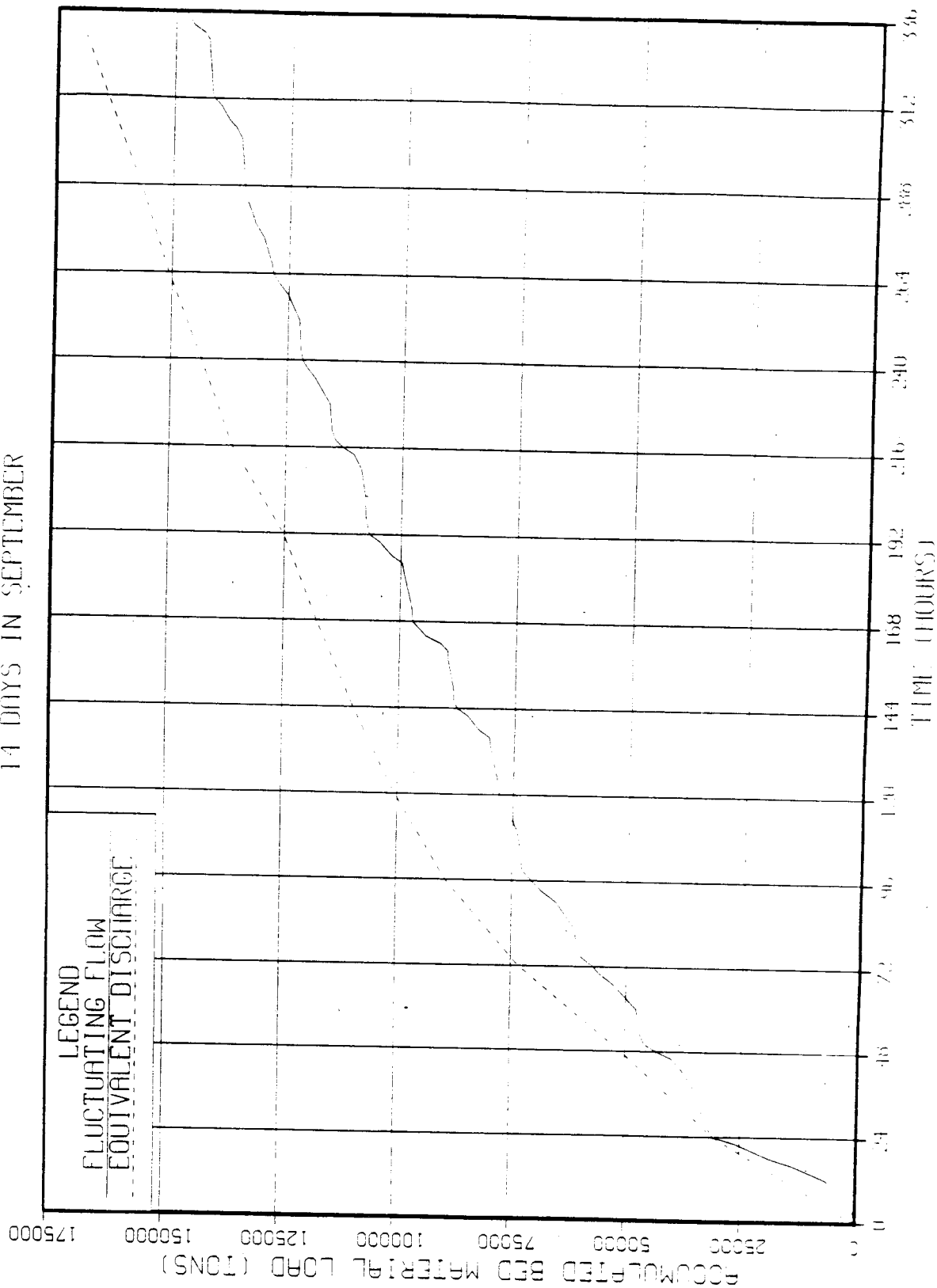
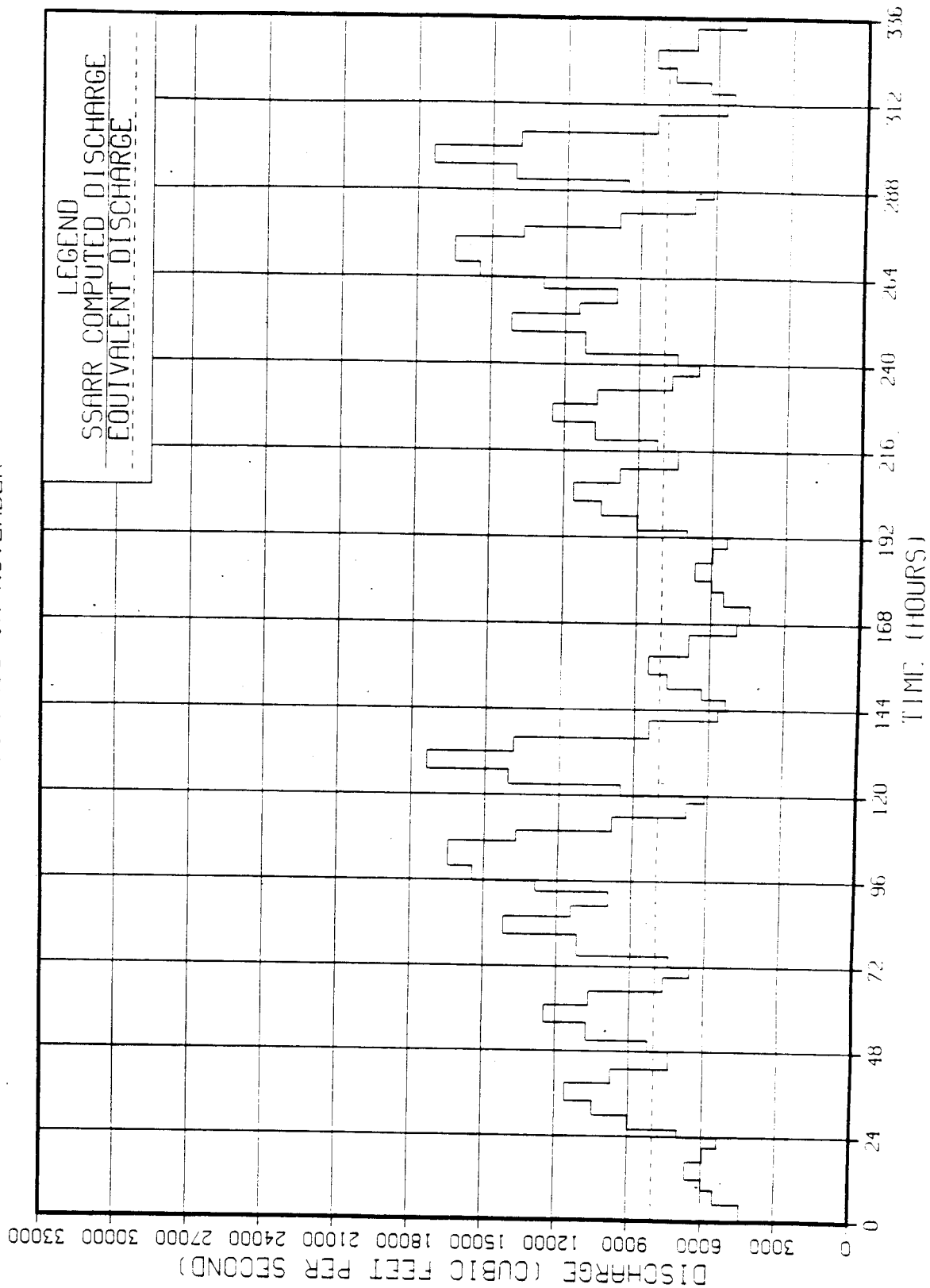


FIGURE 81  
 12.50.25 MON 15 DEC 1986 JOB-RCVC BUREAU OF RECLAMATION DISSEMIN 9.2

# COLORADO RIVER, REACH 2 (RIVER MILE 61 TO 87)

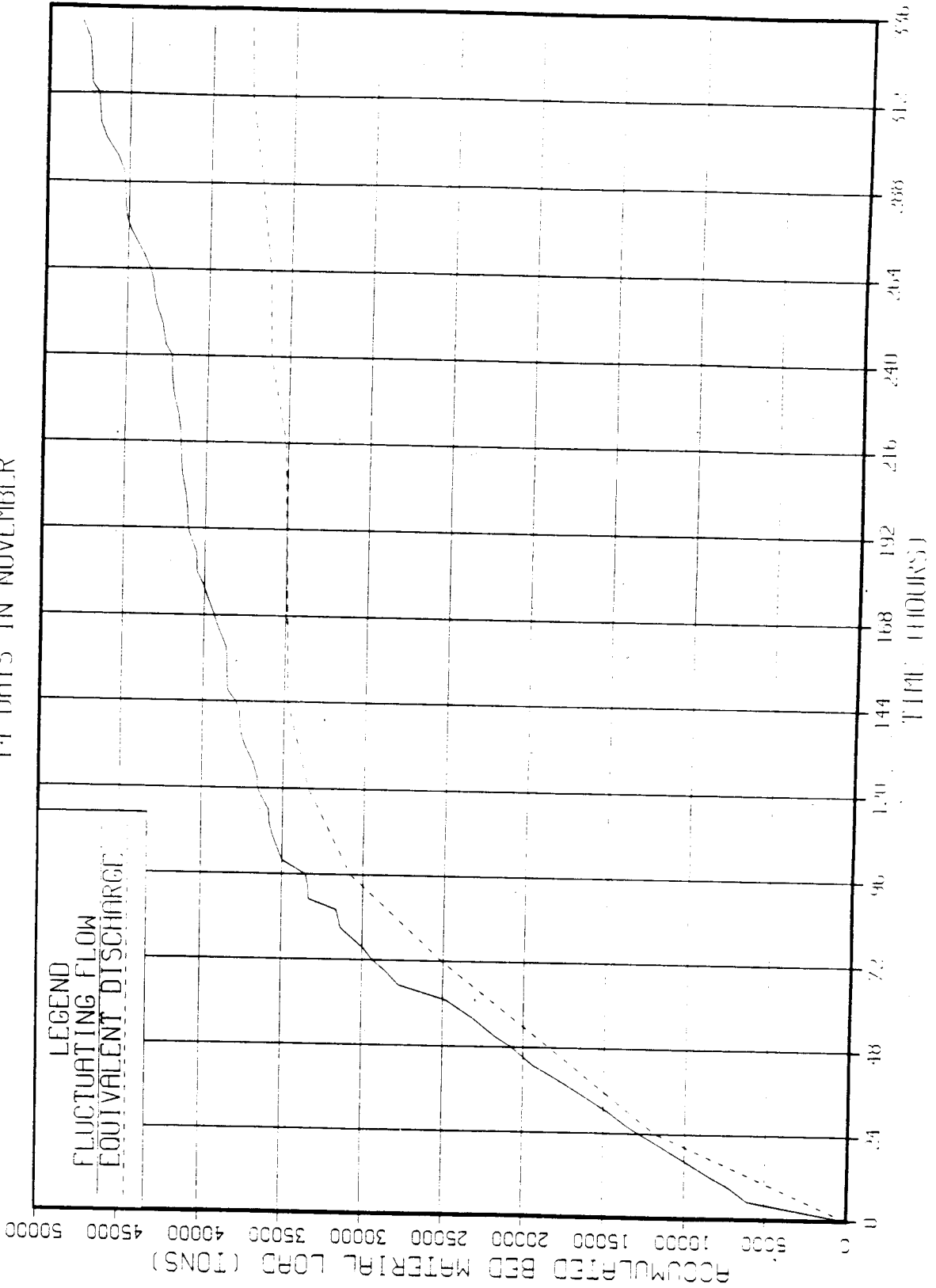
## FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN NOVEMBER



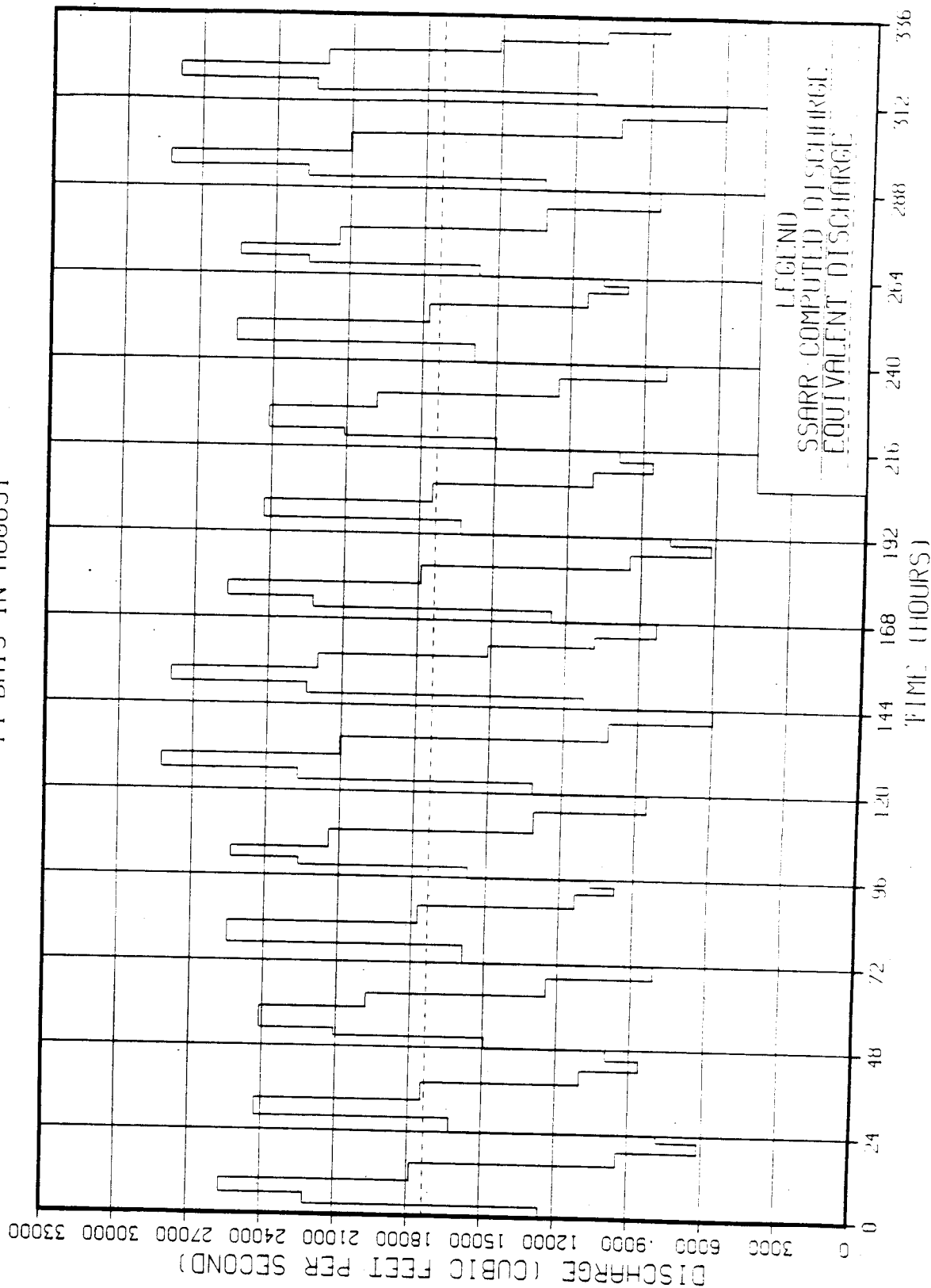
GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 87.37  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN NOVEMBER



COLORADO RIVER, REACH 2 (RIVER MILE 61 TO 87)  
FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN AUGUST



GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 87.37  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)  
 14 DAYS IN AUGUST

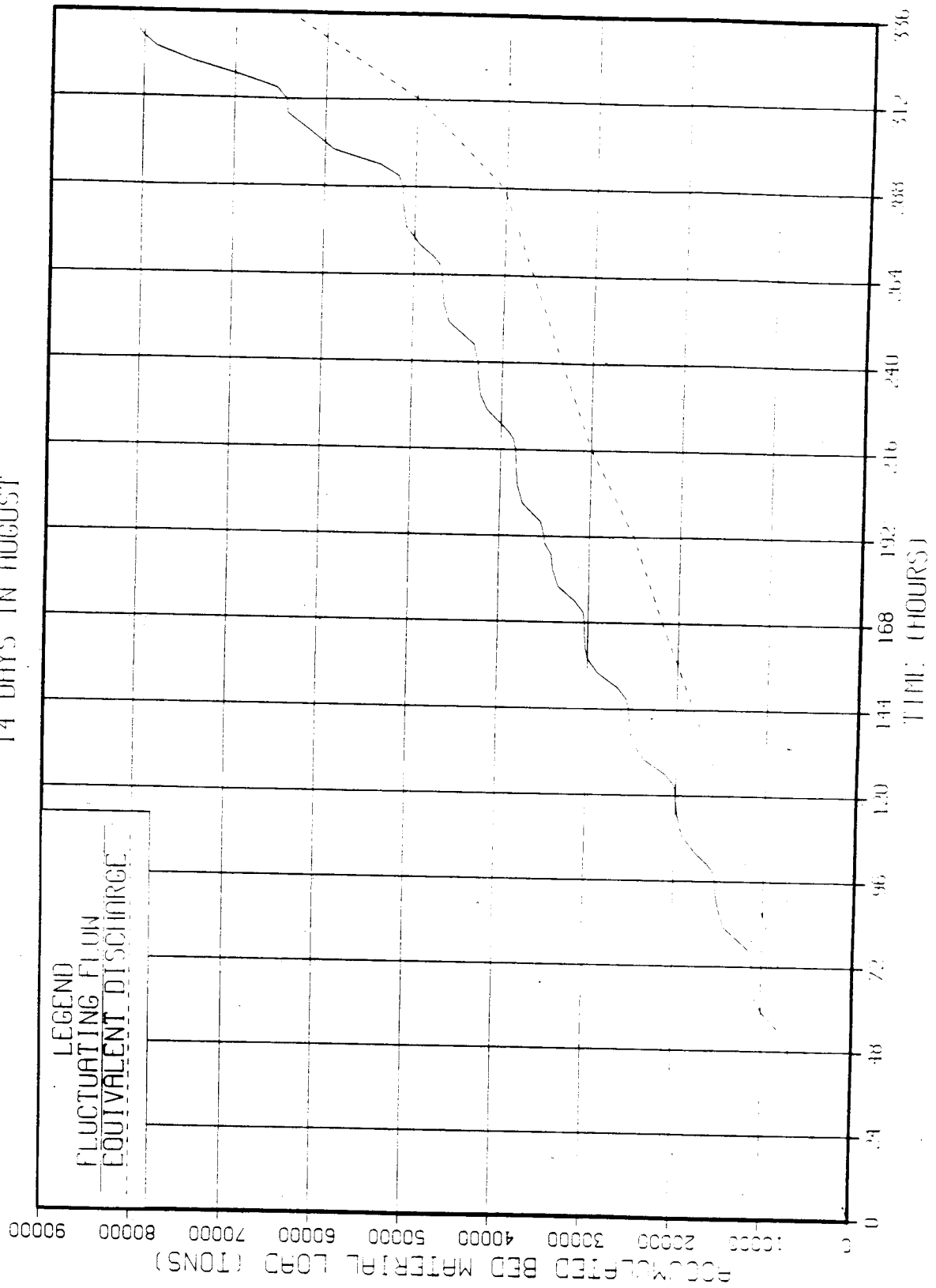
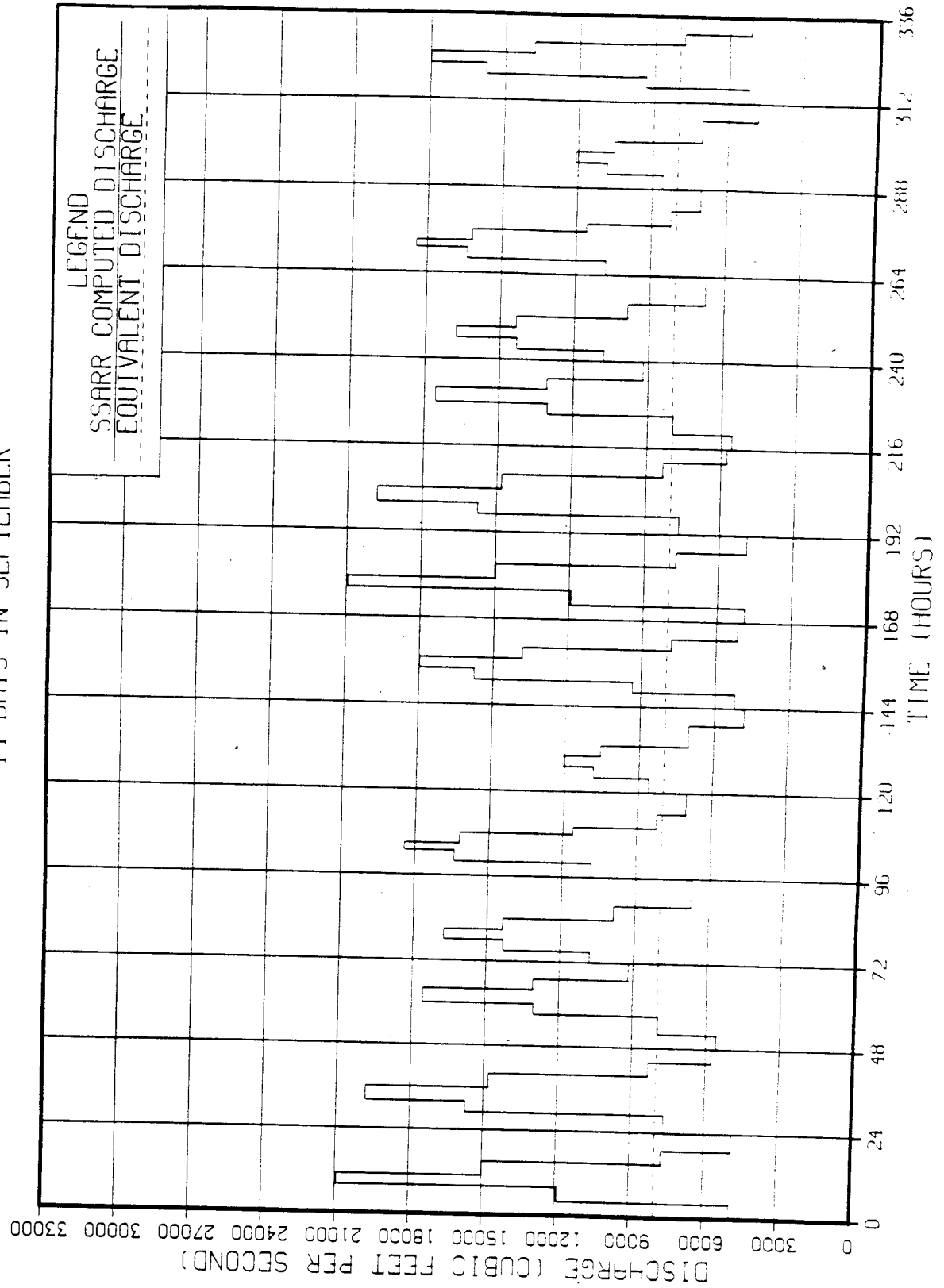


FIGURE 85  
 10-54-02 TUES 23 DEC, 1986 JOB-B-877 BUREAU OF RECLAMATION DISSEMINATION 9.2

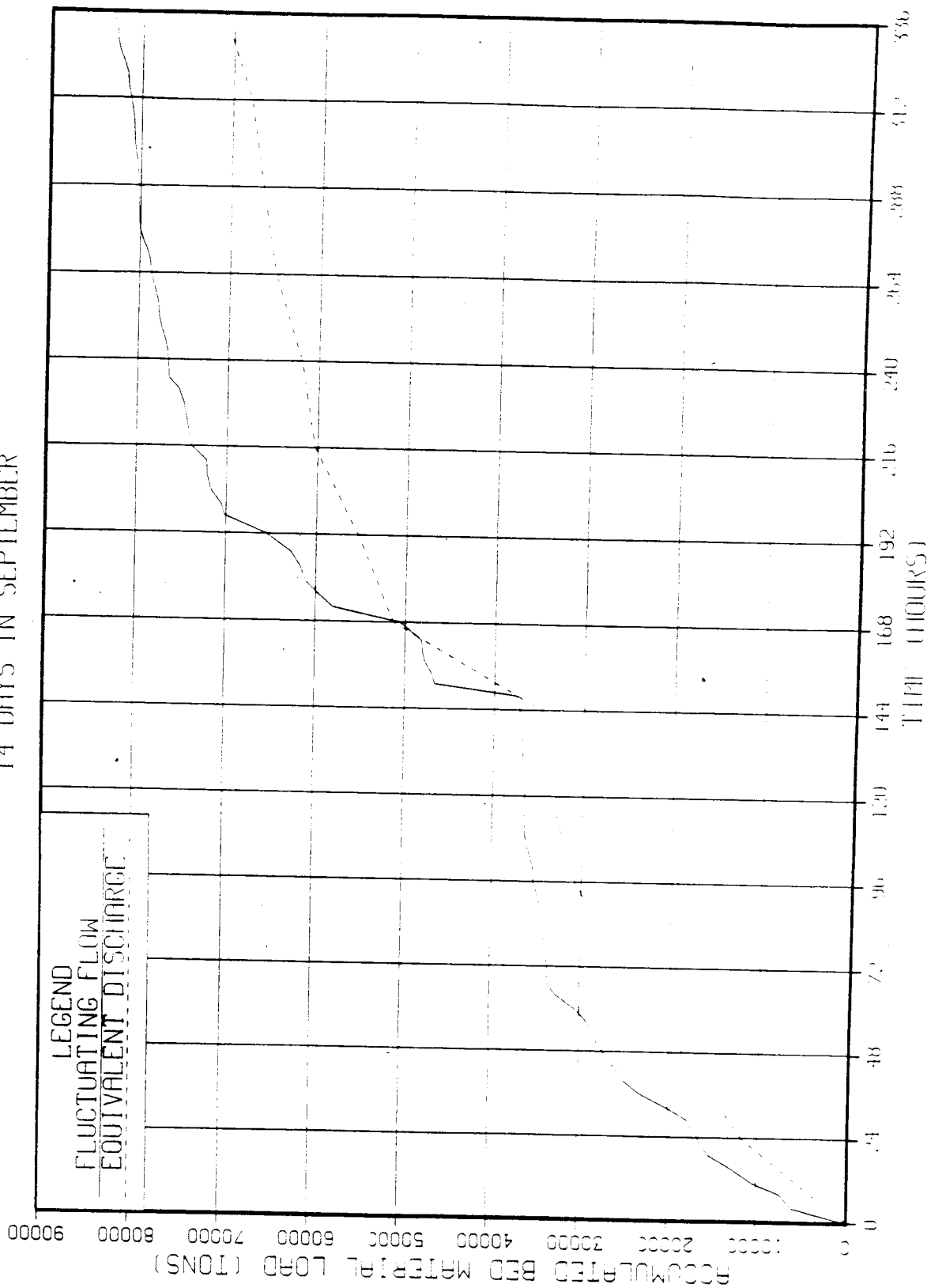
# COLORADO RIVER, REACH 2 (RIVER MILE 61 TO 87)

## FLOW ALTERNATIVE TWO (STARS OUTPUT)

14 DAYS IN SEPTEMBER



GLEN CANYON ENVIRONMENTAL STUDIES  
 COLORADO RIVER AT RIVER MILE 87.37  
 FLOW ALTERNATIVE TWO (STARS OUTPUT)  
 14 DAYS IN SEPTEMBER

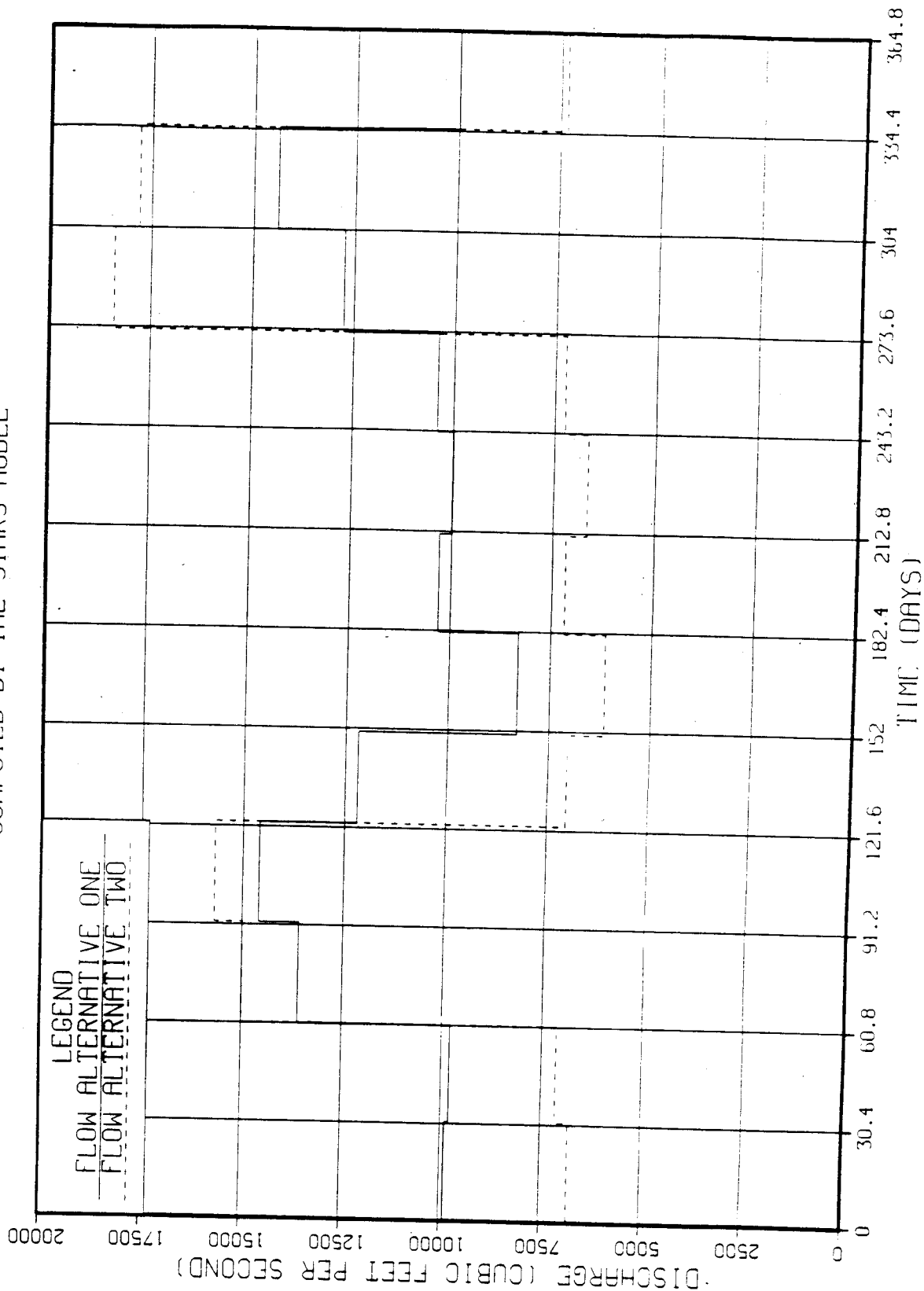




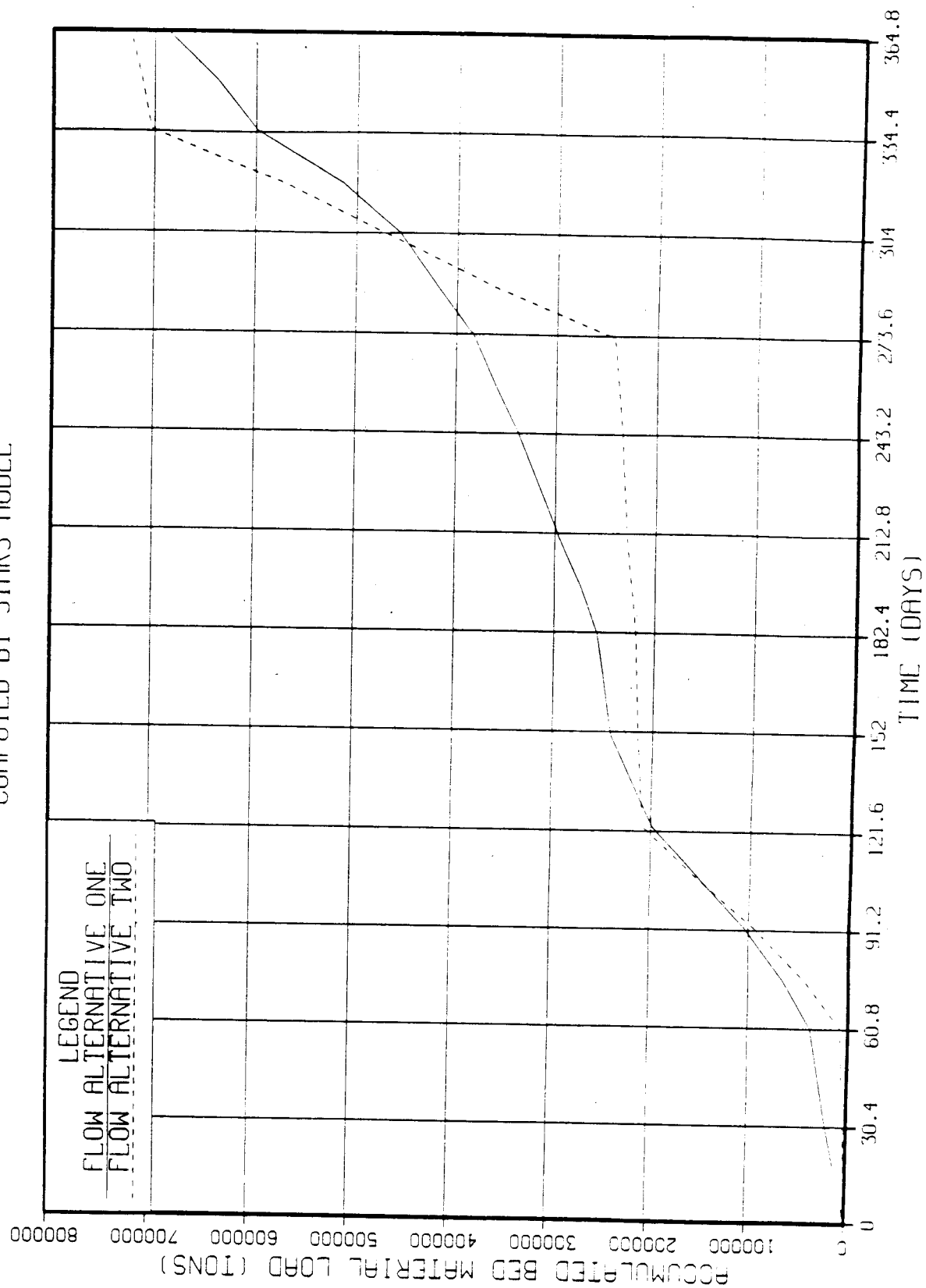
# COLORADO RIVER, REACH 2 (RIVER MILES 61 TO 87 )

## COMPARISON OF FLOW ALTERNATIVES ONE AND TWO

COMPUTED BY THE STARS MODEL



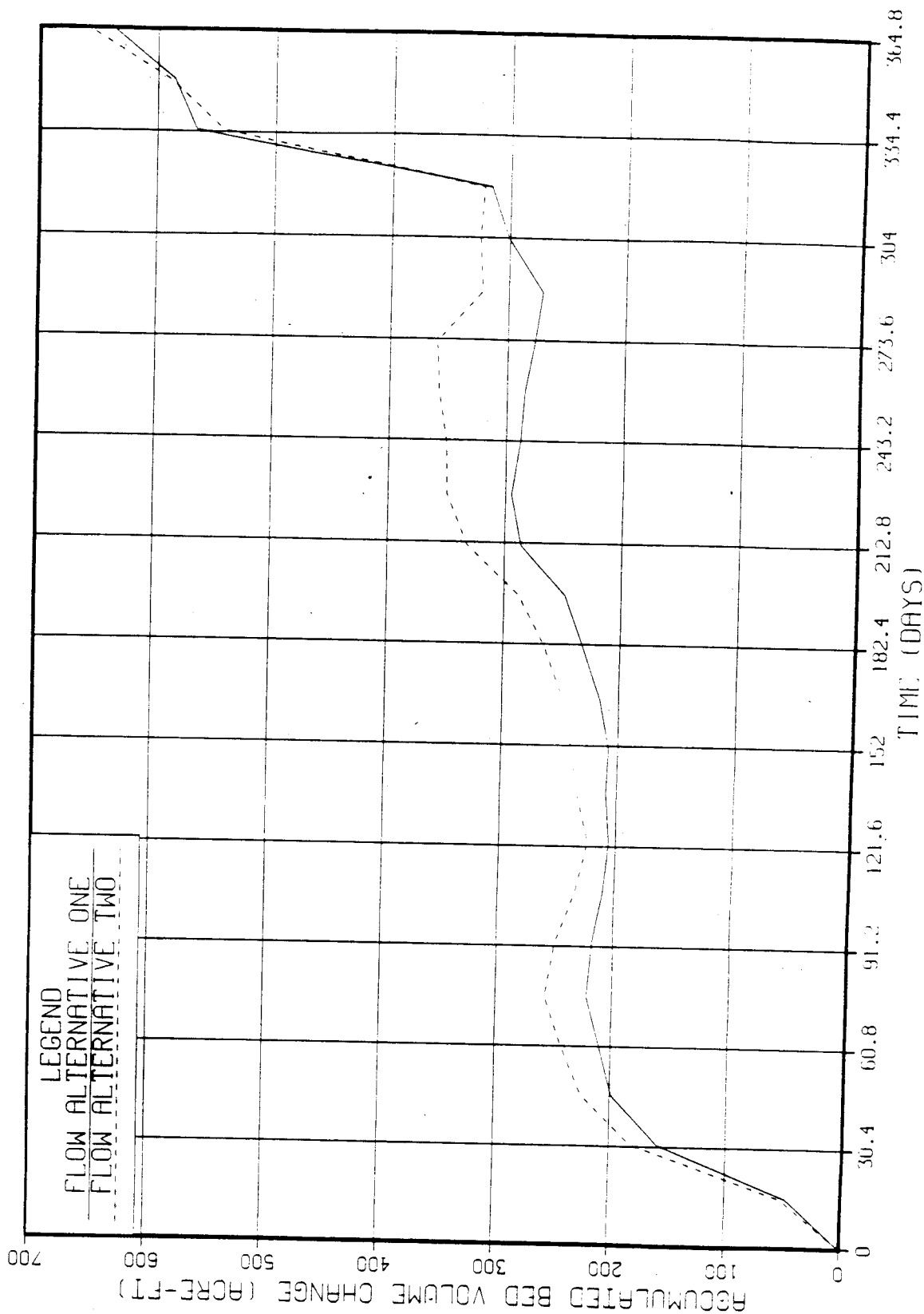
COLORADO RIVER AT RIVER MILE 87.37  
 COMPARISON OF FLOW ALTERNATIVES ONE AND TWO  
 COMPUTED BY STARS MODEL



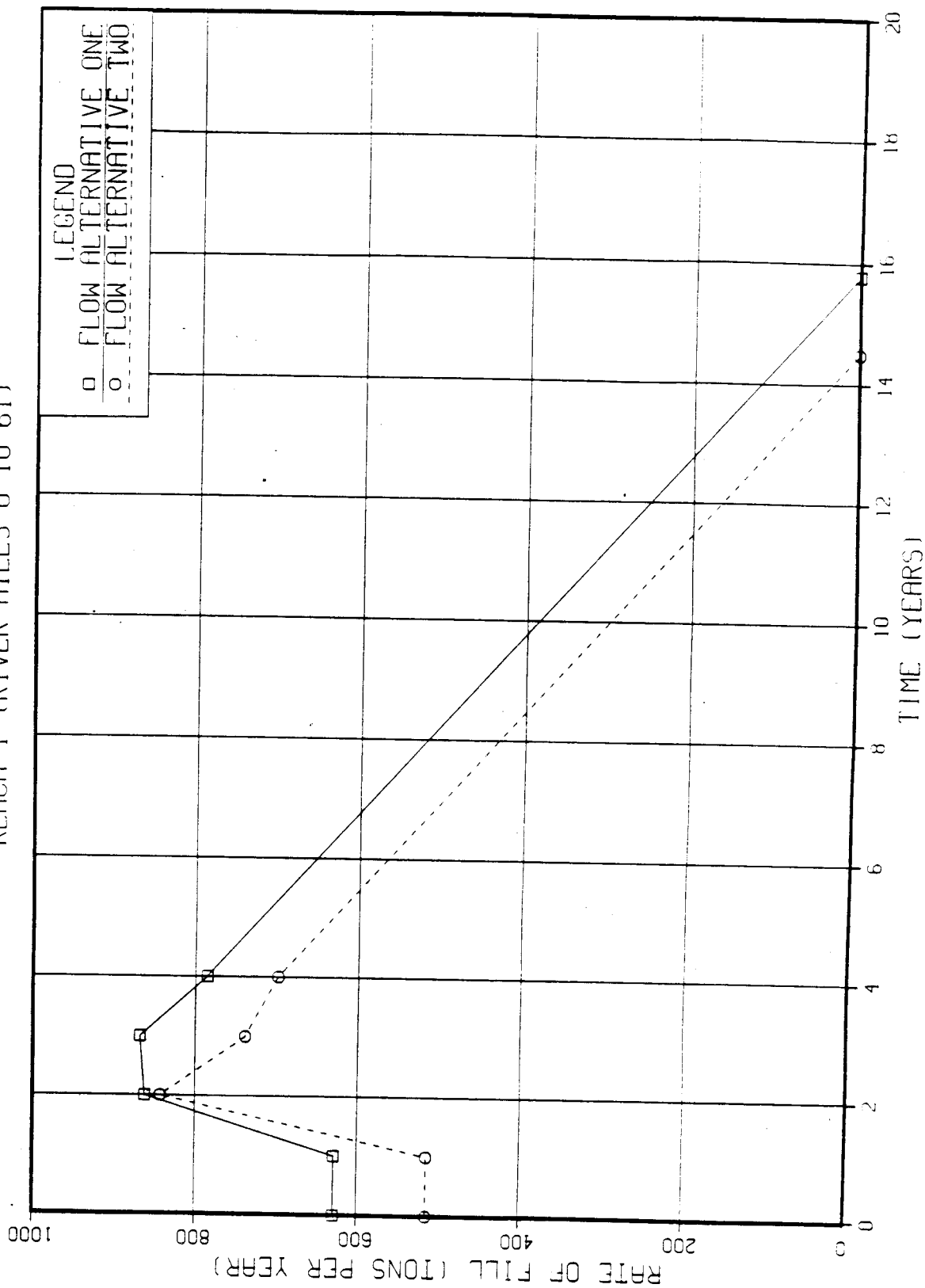
# COLORADO RIVER, REACH 2 (RIVER MILES 61 TO 87)

## COMPARISON OF FLOW ALTERNATIVES ONE AND TWO

COMPUTED BY STARS MODEL

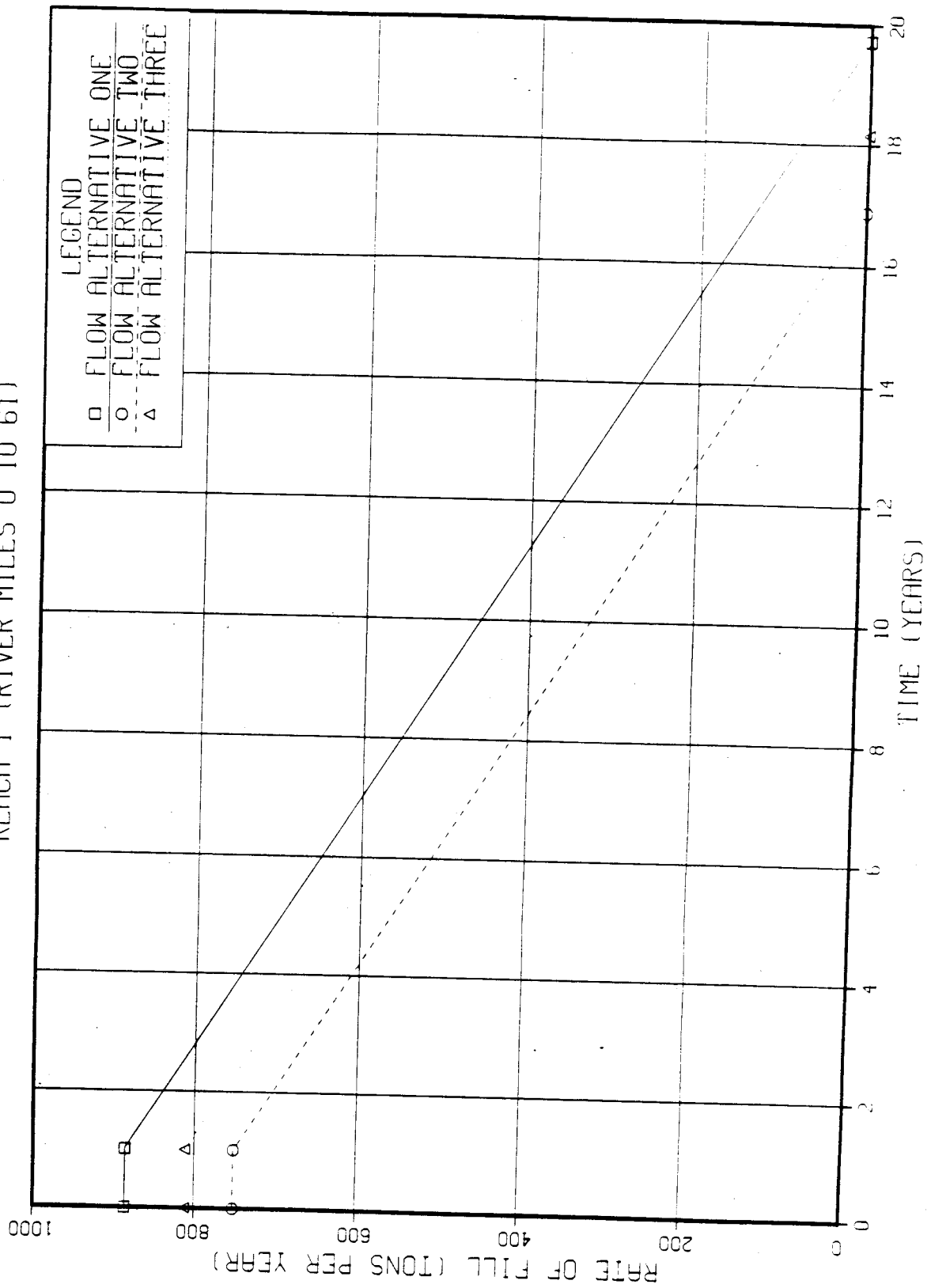


ESTIMATED TIME TO REACH EQUILIBRIUM  
 AFTER THE 1983, 1984, AND 1985 HIGH FLOW PERIOD,  
 BASED UPON EXTRAPOLATION OF STARS MODEL RESULTS  
 REACH 1 (RIVER MILES 0 TO 61)



PLOT 1 15.51.53 FR. 23 JAN. 1987 JOB-ACOV BUREAU OF RECLAMATION DISPLAY 9.2

ESTIMATED TIME TO REACH EQUILIBRIUM  
 AFTER THE 1983, 1984, AND 1985 HIGH FLOW PERIODS  
 BASED UPON EXTRAPOLATION OF STAB MODEL RESULTS  
 REACH 1 (RIVER MILES 0 TO 61)



Plot 1 15.43.31 FR 23 JAN, 1987 JOB-RECD , BUREAU OF RECLAMATION DISPLA 9.2

ESTIMATED TIME TO REACH EQUILIBRIUM  
 AFTER THE 1983, 1984, AND 1985 HIGH FLOW PERIODS  
 BASED UPON EXTRAPOLATION OF STARS MODEL RESULTS  
 REACH 2 (RIVER MILES 61 TO 87)

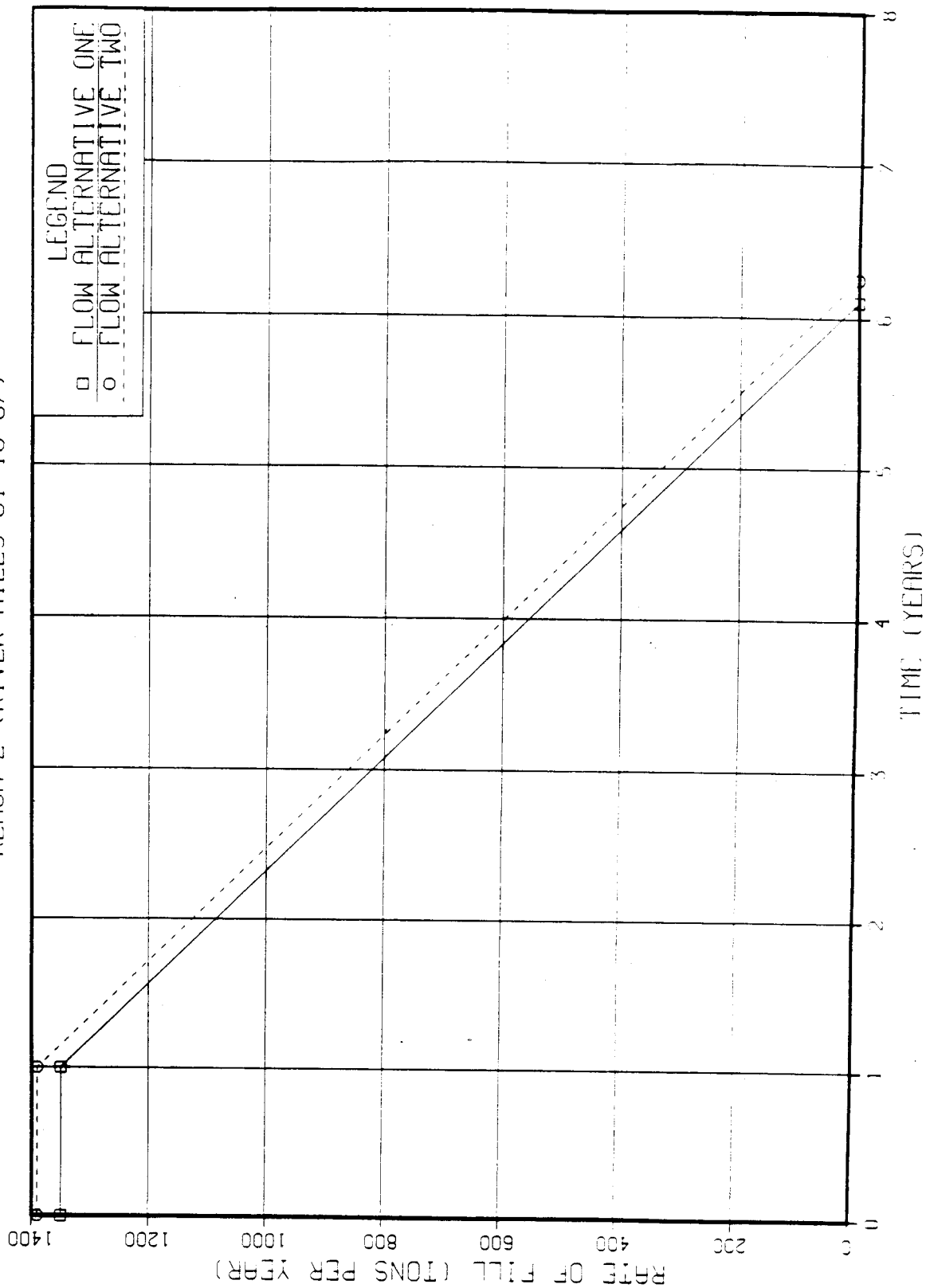
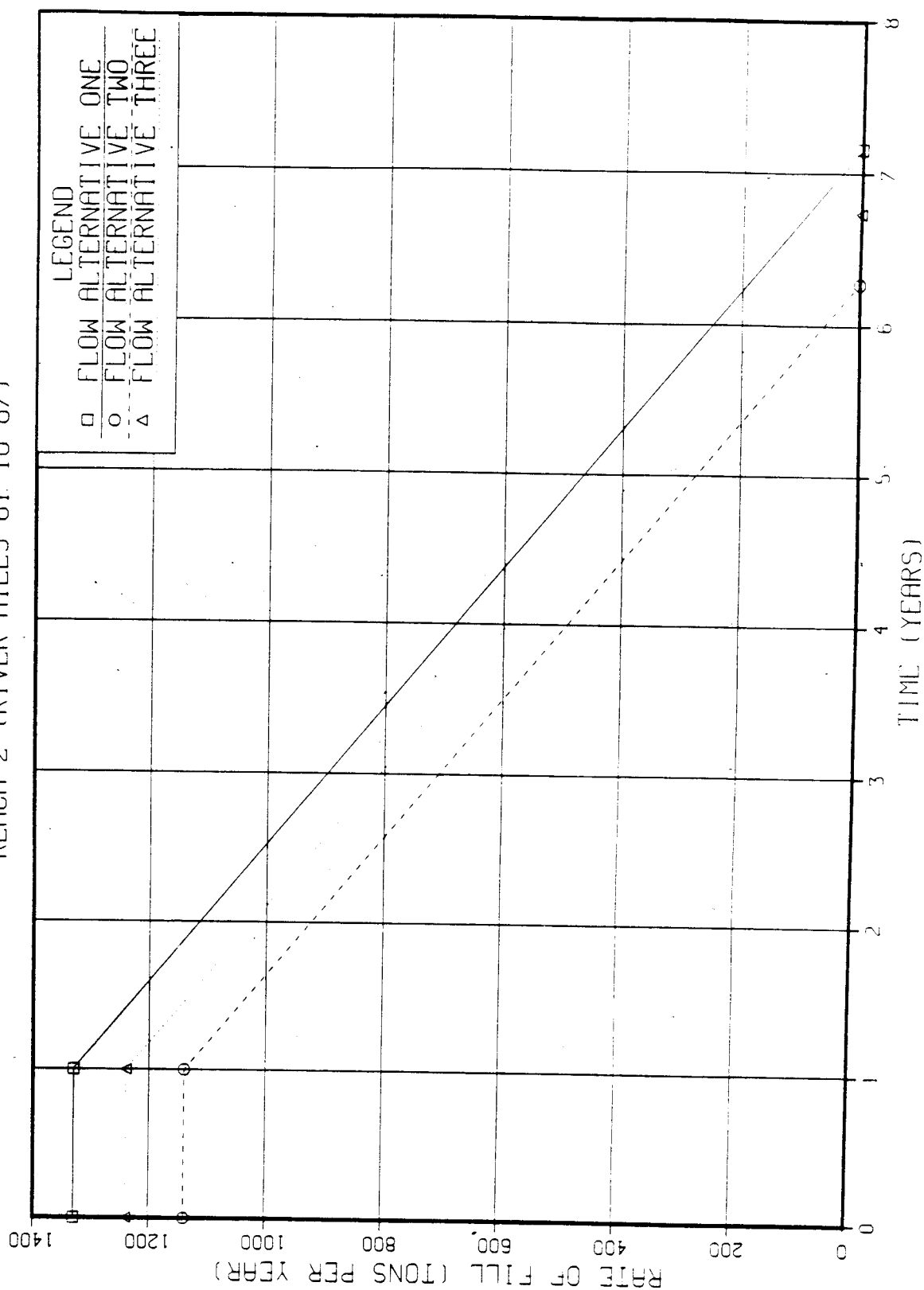


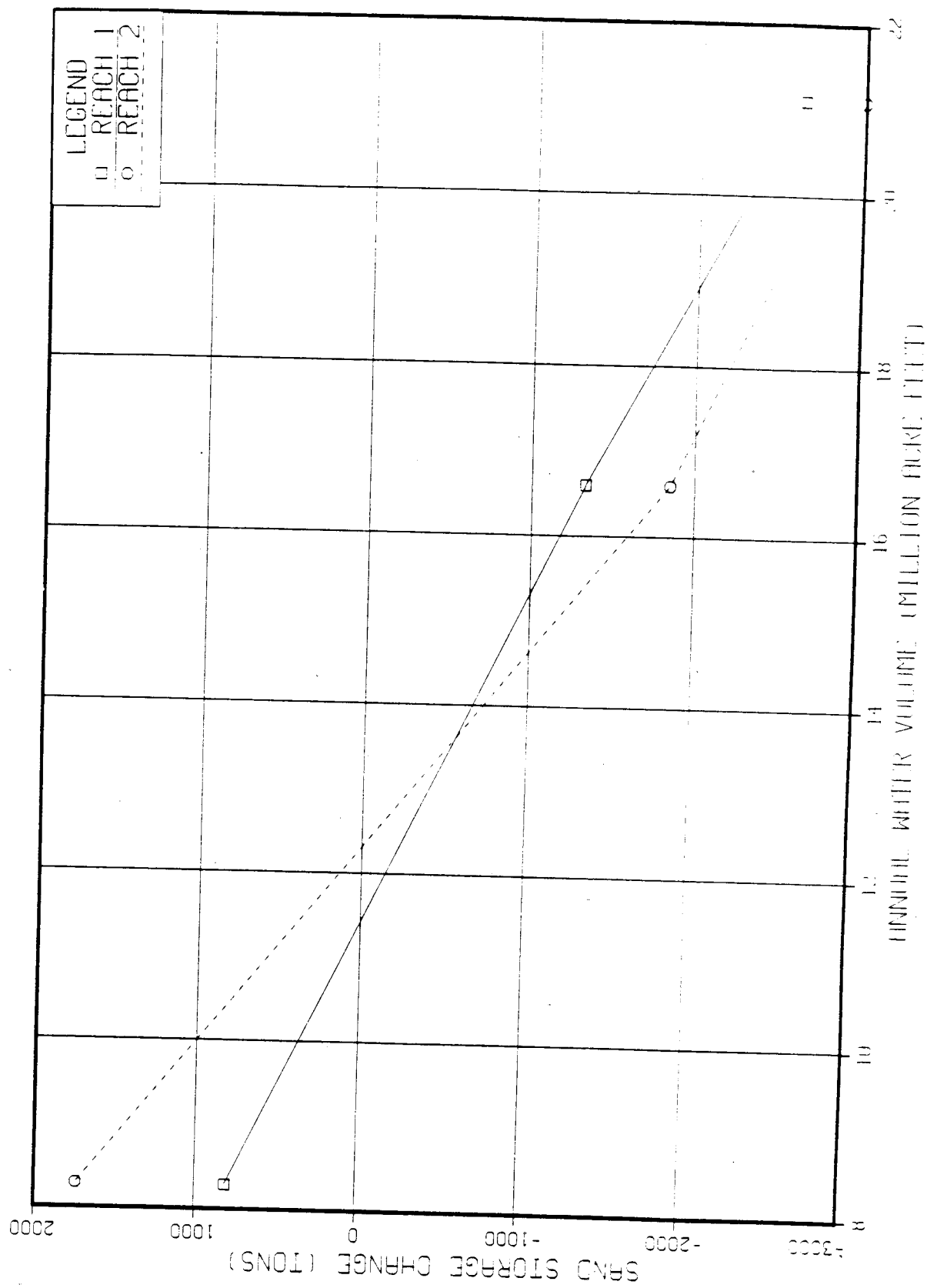
FIGURE 93  
 16.04.05 (FR) 23 JAN, 1987 JOB-REERZ , BUREAU OF RECLAMATION, DISSEMINATION 9.2

ESTIMATED TIME TO REACH EQUILIBRIUM  
 AFTER THE 1983, 1984, AND 1985 HIGH FLOW PERIODS  
 BASED UPON EXTRAPOLATION OF STAB MODEL RESULTS  
 REACH 2 (RIVER MILES 61 TO 87)



# HIGH WATER VOLUME RELEASES FROM GLEN CANYON DAM

## WATER VOLUME VERSUS SAND STORAGE CHANGE



DISSEPL 10.0

JOB-6595, BUREAU OF RECLAMATION

18:55:43 MON 9 FEB 1987



Table 1  
Colorado River Survey Data  
Lees Ferry to Diamond Creek

Survey	Dates	Mean Daily* Discharge at Lees Ferry (ft <sup>3</sup> /s)	River Mile
REACH 1			
1923 Profile and Strip Topography	Aug 1 Depart @ 9 a.m.	25,200	0.0 to 7.4
	Aug 2	22,700	7.4 to 10.8
	Aug 3	22,700	10.8 to 11.5
	Aug 4	21,500	11.5 to 16.8
	Aug 5	20,800	16.8 to 22.1
	Aug 6	20,800	22.1 to 25.2
	Aug 7	20,400	25.2 to 29.9
	Aug 8	19,000	29.9 to 35.7
	Aug 9 Rained	17,700	35.7 to 43.5
	Aug 10	16,400	Memorial to Pres. Harding
	Aug 11	17,700	43.5 to 51.6
	Aug 12	16,700	51.6 to 55.7
	Aug 13 LCR @ 3 p.m.	22,300	55.7 to 61.4
1984 Depth Profile.	Mar 1	25,200	0.0 to 7.6
	Mar 2	25,800	7.6 to 40.8
	Mar 3	25,800	40.8 to 61.3
	Weighted Mean	25,700	
1984 Cross Sections	Apr 28	28,100	0.0 to 10.3
	Apr 29	28,100	10.3 to 29.8
	Apr 30	25,500	29.8 to 54.6
	May 1	25,200	54.6 to 61.0
REACH 2			
1923 Profile and Strip Topography	Aug 13 After 3 p.m.	24,700	61.3 to 62.6
	Aug 14	28,100	62.6 to 68.9
	Aug 15	31,200	68.9 to 75.4
	Aug 16	32,000	75.4 to 76.6
	Aug 17	28,800	Surveyed Damsite
	Aug 18	30,200	Surveyed Damsite
	Aug 19	33,000	76.6 to 77.0
	Aug 20	33,200	Sunday
	Aug 21	33,400	77.0 to 81.0
	Aug 22	27,900	81.0 to 84.2
	Aug 23	24,800	84.2 to 87.5
	Gage at 1 p.m.		
1984 Depth Profile	Mar 4	24,300	61.3 to 87.1
	Mar 5	24,700	87.1 to 87.5
	Weighted Mean	24,300	
1984 Cross Sections	May 1	25,900	61.9 to 78.3
	May 2	25,600	78.3 to 87.5
REACH 3			
1923 Profile and Strip Topography	Aug 27	17,600	87.5 to 88.5
	Aug 28	16,900	88.5 to 90.8
	Aug 29	15,200	90.8 to 94.3
	Aug 30	15,400	94.3 to 97.6
	Aug 31	23,600	97.6 to 102
	Sep 1	20,400	102 to 107
	Sep 2	27,500	107 to 108
	Sep 3	18,800	Water surface fell 6 feet
	Sep 4	15,100	108 to 110.7

Table 1  
(Continued)

Colorado River Survey Data  
Lees Ferry to Diamond Creek

Survey	Dates	Mean Daily* Discharge at Lees Ferry (ft <sup>3</sup> /s)	River Mile
	Sep 5	13,700	110.7 to 119.5
	Sep 6	12,900	119.5 to 128.5
	Sep 7	12,200	128.5 to 131.5**
	Sep 8	11,600	131.5 to 133.4
	Sep 9 (Sun)	10,800	
	Sep 10	10,600	133.4 to 142.9
	Sep 11	10,500	Kanab Creek
	Sep 12	9,730	142.9 to 149.6
	Sep 13	11,800	149.6 to 156.3
	Sep 14	11,700	
	Sep 15	10,900	156.3 to 164.7
	Sep 16	10,800	164.7 to 166
1984 Depth Profile	Mar 5	24,700	87.5 to 115.8
	Mar 6	24,600	115.8 to 131.8
	Mar 7	24,900	131.8 to 155.7
	Mar 8	24,900	155.7 to 166.2
	Weighted Mean	24,800	
1984 Cross Sections	May 3	25,500	87.5 to 111.1
	May 4	26,200	111.1 to 133.4
	May 5	28,900	133.4 to 166.2
1923 Profile and Strip Topography	Sep 16	10,800	REACH 4 166 to 169.2
	Sep 17	9,380 (Rain)	169.2 to 173.2
	Sep 18	42,800	173.2 to 178.1
	Sep 19	98,500 (16' rise)	Lava Falls
	Sep 20	87,800	Lava Falls
	Sep 21	47,800	Lava Falls
	Sep 22	26,100	178.1 to 185.8
	Sep 23	17,700	185.8 to 188.5
	Sep 24	14,200	188.5 to 193.7
	Sep 25	13,000	193.7 to 197.5
	Sep 26	17,300	197.5 to 203.2
	Sep 27	18,900	203.2 to 207.5
	Sep 28	18,000	----
	Sep 29	15,700	207.5 to 213.0
	Sep 30	14,600	213.0 to 217.9
	Oct 1	14,400	217.9 to 220.5
	Oct 2	14,100 Dia. Cr.	220.5 to 224.4
1984 Depth Profile	Mar 8	24,900	166 to 179.7
	Mar 9	24,900	179.7 to 212.9
	Mar 10	24,900	212.9 to 225.2
	Weighted Mean	24,900	
1984 Cross Sections	May 5	28,900	166 to 167.7
	May 6	32,000	167.7 to 213.6
	May 7	33,200	213.6 to 225.2

\* Discharges below river mile 61 are at Grand Canyon gage  
\*\* Estimated to be at Deubendorff Rapid

Table 2  
 Surveyed Water Surface Elevation By Geological Survey Mapping Service - 1985  
 Colorado River - Lees Ferry to Diamond Creek

Reach 1

Name of Rapids	River Mile	Date	Discharge at Lees Ferry Ft <sup>3</sup> /s	----- Elevations - Feet -----				Channel Distance From Top of Rapids	
				Chiseled Cross	Upstream	Top of Rapids	Bottom of Rapids	Upstream Feet	Downstream Feet
36-Mile	36	Feb. 26	27700	2863.8	2859.8	2859.4		523	*
President Harding	43.7	Feb. 26	27700	2844.8	2831.7	2830.9	2826.7	1113	500
Nankoweap	52	Feb. 26	27700	2811.5	2802.4	2802.1	2787.0	925	3500
Kwagunt	55.8	Mar. 1	27700	2828.5	2771.3	2770.1	2763.2	700	700
Little Colo. River	61.4	Mar. 1	27700	2770.5	2721.7	2721.5	2715.0	750	3652

\* Could not Reach Bottom of Rapid

Reach 2

Name of Rapids	River Mile	Date	Discharge at Grand Canyon Ft <sup>3</sup> /s	----- Elevations - Feet -----				Channel Distance From Top of Rapids	
				Chiseled Cross	Upstream	Top of Rapids	Bottom of Rapids	Upstream Feet	Downstream Feet
Unkar	72.4	Mar. 1	26700	2626.3	2624.3	2623.2	2614.0	660	1080
Hance	76.5	Mar. 1	26700	2608.1	2569.9	2569.0	2548.0	555	1550
Grand Canyon Gage	87.5	Mar. 1	26700	2450.4	2434.0 (Cable)	2432.8	2427.6	863	1950

Table 2  
(Continued)

Reach 3

Name of Rapids	River Mile	Date	Discharge at Grand Canyon Ft <sup>3</sup> /s	----- Elevations - Feet -----				Channel Distance From Top of Rapids	
				Chiseled Cross	Upstream	Top of Rapids	Bottom of Rapids	Upstream Feet	Downstream Feet
Granite	93.3	Feb. 28	26800	2362.5	2368.7	2368.5	2355.8	530	1100
Crystal	98.2	Feb. 28	26900	2359.3	2322.6	2321.6	2296.6	655	2010
Serpentine	105.9	Feb. 28	26900	2230.8	2223.2	2221.7	2212.9	550	700
Bass	108.0	Feb. 27	27200	2251.8	2198.4	2197.9	2180.4	1100	2590
Blacktail	120.0	Feb. 27	26400	2105.3	2096.7	2096.2 2096.9	-----	930 1460	
Deubendorff	131.5	Apr. 2	13200	1995.5	1990.3	1990.1	1976.9	660	1370
Deer Creek	136.3	Apr. 2	14400	2005.9	1937.1	1936.2	1928.7	720	1300
Kanab Creek	143.5	Mar. 26	12200	1889.4	1887.6	1886.5	1872.0	670	3200
Upset	149.7	Mar. 26	17600	1836.8	1831.6	1831.1	1821.0	482	630
159.2 Mile	159.2	Mar. 25	14900	1784.5	1770.3	1770.1	1767.6	294	1480

Reach 4

Name of Rapids	River Mile	Date	Estimate Discharge at Rapids Ft <sup>3</sup> /s	----- Elevations - Feet -----				Channel Distance From Top of Rapids	
				Chiseled Cross	Upstream	Top of Rapids	Bottom of Rapids	Upstream Feet	Downstream Feet
National Canyon	166.4	Mar. 25	18800	1763.5	1743.8	1743.6	1738.8	790	2160
Cove Canyon	174.3	Mar. 6	27600	1724.7	1712.4	1712.3	1708.1	490	1160
Lava Falls	179.2	Mar. 6	27600	1766.5	1684.4	1682.5	1668.1	1410	1336

Table 3  
Computed Water Surface Elevations on Colorado River  
Lees Ferry to Diamond Creek  
24,000 ft<sup>2</sup>/s

REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	WIDTH	TOP	INTERPOLATED AT MILE	USGS GAGE ABOVE	LITTLE CO
52.8	2714.0	2720.43	24000.	35865.	2545.	9.43	409.7		INTERPOLATED AT MILE	61.32	
1689.6	2713.1	2721.15	24000.	50186.	3190.	7.52	412.2		INTERPOLATED AT MILE	61.31	
4171.2	2692.9	2723.66	24000.	196685.	7574.	3.17	340.0		S-61 AT MILE	61.00	
5702.4	2715.0	2723.89	24000.	263926.	9704.	2.47	390.0		S-60 AT MILE	60.53	
8078.4	2700.0	2725.44	24000.	37325.	2155.	11.14	225.8		INTERPOLATED AT MILE	60.24	
8817.6	2717.2	2731.30	24000.	158527.	5869.	4.09	243.7		INTERPOLATED AT MILE	59.79	
8870.4	2712.4	2732.27	24000.	45689.	2355.	10.19	194.0		INTERPOLATED AT MILE	59.65	
8976.0	2711.4	2732.68	24000.	74359.	3313.	7.24	203.1		INTERPOLATED AT MILE	59.64	
10454.4	2694.5	2733.45	24000.	97888.	4171.	5.75	234.7		INTERPOLATED AT MILE	59.62	
14572.8	2722.8	2735.30	24000.	255543.	9139.	2.63	330.0		S-59 AT MILE	59.34	
15470.4	2705.1	2736.50	24000.	64942.	3332.	7.20	276.6		INTERPOLATED AT MILE	58.56	
20697.5	2731.4	2742.45	24000.	165715.	7217.	3.33	360.0		S-57 AT MILE	58.39	
22228.8	2684.9	2746.13	24000.	42971.	2351.	10.21	222.0		INTERPOLATED AT MILE	57.40	
24024.0	2748.8	2756.91	24000.	643105.	15937.	1.51	297.2		INTERPOLATED AT MILE	57.11	
24076.8	2748.4	2760.71	24000.	24000.	1529.	15.69	197.1		INTERPOLATED AT MILE	56.77	
27086.4	2722.2	2762.79	24000.	69546.	3605.	6.66	309.3		INTERPOLATED AT MILE	56.76	
28142.4	2760.4	2768.12	24000.	380723.	11199.	2.14	302.4		INTERPOLATED AT MILE	56.19	
28195.2	2745.2	2772.29	24000.	24000.	1558.	15.41	208.8		INTERPOLATED AT MILE	55.99	
28300.8	2745.2	2772.33	24000.	187194.	7046.	3.41	310.0		INTERPOLATED AT MILE	55.98	
34108.8	2745.2	2772.94	24000.	201903.	7559.	3.18	329.3		INTERPOLATED AT MILE	55.96	
36115.2	2740.2	2773.14	24000.	155867.	7877.	3.05	530.0		S-56 AT MILE	54.86	
39969.6	2727.7	2773.56	24000.	159386.	6392.	3.75	290.0		S-55 AT MILE	54.48	
42504.0	2771.8	2780.46	24000.	400741.	11305.	2.12	275.2		INTERPOLATED AT MILE	53.75	
42609.6	2770.3	2782.80	24000.	26880.	1687.	14.23	210.7		INTERPOLATED AT MILE	53.27	
42715.2	2770.3	2783.07	24000.	46702.	2472.	9.71	219.6		INTERPOLATED AT MILE	53.25	
44880.0	2735.5	2786.58	24000.	47947.	2532.	9.48	220.7		INTERPOLATED AT MILE	53.23	
48364.8	2786.9	2795.12	24000.	518831.	13922.	1.72	312.7		INTERPOLATED AT MILE	52.82	
48417.6	2786.9	2796.81	24000.	29576.	1896.	12.66	245.5		INTERPOLATED AT MILE	52.16	
48523.2	2785.9	2797.40	24000.	47482.	2762.	8.69	295.8		INTERPOLATED AT MILE	52.15	
51480.0	2754.4	2799.91	24000.	62128.	3362.	7.14	312.4		INTERPOLATED AT MILE	52.13	
56496.0	2781.6	2800.67	24000.	224180.	8659.	2.77	348.7		S-54 AT MILE	51.57	
59716.8	2770.0	2801.43	24000.	114665.	5231.	4.59	338.0		S-53 AT MILE	50.62	
65472.0	2789.6	2804.55	24000.	135953.	5894.	4.07	308.5		S-52 AT MILE	50.01	
70857.6	2801.1	2812.12	24000.	61768.	3887.	6.17	419.2		S-51 AT MILE	48.92	
71913.6	2791.1	2814.46	24000.	48674.	2648.	9.06	249.3		INTERPOLATED AT MILE	47.90	
74553.6	2757.8	2814.70	24000.	175809.	10784.	3.07	450.0		S-50 AT MILE	47.70	
75873.6	2794.8	2814.80	24000.	407855.	224.8	2.23	224.8		INTERPOLATED AT MILE	47.20	
82737.6	2802.0	2818.54	24000.	86878.	4284.	5.60	307.9		S-49 AT MILE	46.95	
84268.8	2789.5	2819.73	24000.	77811.	3527.	6.81	227.6		INTERPOLATED AT MILE	45.65	
87753.6	2801.7	2820.46	24000.	176684.	7103.	3.38	339.1		S-48 AT MILE	45.36	
89443.2	2786.0	2821.35	24000.	92264.	4083.	5.88	249.6		INTERPOLATED AT MILE	44.70	
				245444.	8979.	2.67	357.1		INTERPOLATED AT MILE	44.38	

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REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	
90024.0	2775.0	2821.37	24000.	271099.	8823.	2.72	265.9	INTERPOLATED AT MILE 44.27
90393.6	2778.0	2821.39	24000.	281009.	8904.	2.70	264.3	INTERPOLATED AT MILE 44.20
91238.4	2795.0	2821.39	24000.	105411.	4399.	5.46	229.9	INTERPOLATED AT MILE 44.04
91449.6	2812.8	2821.39	24000.	41570.	2548.	9.42	305.2	INTERPOLATED AT MILE 44.00
91502.4	2807.1	2822.53	24000.	96804.	4581.	5.24	323.8	INTERPOLATED AT MILE 43.99
91924.8	2804.0	2822.69	24000.	73118.	4804.	5.00	486.0	INTERPOLATED AT MILE 43.91
92822.4	2788.9	2823.28	24000.	224849.	7366.	3.26	243.3	INTERPOLATED AT MILE 43.74
93825.6	2819.6	2827.25	24000.	24000.	1597.	15.02	222.6	INTERPOLATED AT MILE 43.55
93878.4	2804.8	2831.14	24000.	155691.	5996.	4.00	271.4	INTERPOLATED AT MILE 43.54
93984.0	2803.8	2831.23	24000.	187449.	7018.	3.42	303.7	INTERPOLATED AT MILE 43.52
93916.8	2813.2	2832.03	24000.	129853.	5831.	4.12	367.1	S-47 AT MILE 42.51
102009.6	2809.1	2832.59	24000.	123682.	5113.	4.69	274.2	S-46 AT MILE 42.00
105177.6	2759.8	2833.22	24000.	260320.	8191.	2.93	215.7	INTERPOLATED AT MILE 41.40
105705.6	2826.0	2834.69	24000.	24000.	1510.	15.90	188.9	INTERPOLATED AT MILE 41.30
105811.2	2823.0	2838.89	24000.	79059.	3747.	6.41	265.6	INTERPOLATED AT MILE 41.28
106814.4	2796.5	2839.86	24000.	401633.	11726.	2.05	313.0	INTERPOLATED AT MILE 41.09
107870.4	2823.6	2839.89	24000.	53605.	2596.	9.25	187.8	INTERPOLATED AT MILE 40.89
107923.2	2822.4	2840.48	24000.	70218.	3219.	7.46	209.3	INTERPOLATED AT MILE 40.88
108028.8	2821.4	2840.84	24000.	86948.	3831.	6.26	230.4	INTERPOLATED AT MILE 40.86
109665.6	2814.6	2841.83	24000.	197964.	7711.	3.11	350.0	S-45 AT MILE 40.55
115104.0	2810.8	2842.27	24000.	194032.	7609.	3.15	340.0	S-44 AT MILE 39.52
115579.2	2795.3	2842.35	24000.	264836.	9456.	2.54	310.0	S-43 AT MILE 39.43
123604.8	2821.8	2843.59	24000.	105525.	5094.	4.71	342.6	S-42 AT MILE 37.91
125664.0	2826.0	2844.26	24000.	93266.	4176.	5.75	260.6	INTERPOLATED AT MILE 37.52
126403.2	2835.9	2845.09	24000.	35942.	2154.	11.14	246.0	INTERPOLATED AT MILE 37.38
126456.0	2835.3	2846.15	24000.	51749.	2841.	8.45	272.6	INTERPOLATED AT MILE 37.37
130574.4	2814.3	2850.85	24000.	194960.	6720.	3.57	230.0	S-41 AT MILE 36.59
132792.0	2779.9	2851.06	24000.	278416.	8928.	2.69	247.6	INTERPOLATED AT MILE 36.17
133425.6	2842.2	2852.67	24000.	24000.	1383.	17.36	143.6	INTERPOLATED AT MILE 36.05
133478.4	2830.2	2857.79	24000.	131043.	4841.	4.96	204.0	INTERPOLATED AT MILE 36.04
133584.0	2830.2	2857.89	24000.	138804.	5351.	4.49	240.3	INTERPOLATED AT MILE 36.02
135484.8	2835.1	2858.24	24000.	91565.	3650.	6.57	179.9	INTERPOLATED AT MILE 35.66
136963.2	2819.7	2859.12	24000.	175515.	6500.	3.69	266.1	S-40 AT MILE 35.38
138758.4	2842.0	2859.68	24000.	55186.	2486.	9.65	157.2	INTERPOLATED AT MILE 35.04
138811.2	2830.1	2861.02	24000.	152547.	5324.	4.51	199.4	INTERPOLATED AT MILE 35.03
138916.8	2830.1	2861.09	24000.	155444.	5770.	4.16	240.0	INTERPOLATED AT MILE 35.01
140289.6	2799.3	2861.45	24000.	608126.	15588.	1.54	306.6	INTERPOLATED AT MILE 34.75
141609.6	2847.5	2861.70	24000.	60179.	2940.	8.16	220.6	INTERPOLATED AT MILE 34.50
141662.4	2847.2	2862.07	24000.	72759.	3452.	6.95	245.7	INTERPOLATED AT MILE 34.49
142348.8	2838.3	2862.80	24000.	112911.	4621.	5.19	236.6	S-39 AT MILE 34.36
147048.0	2851.3	2866.01	24000.	57056.	2761.	8.69	202.0	INTERPOLATED AT MILE 33.47
151008.0	2836.1	2869.75	24000.	112633.	4764.	5.04	230.0	S-36 AT MILE 32.72
152539.2	2840.8	2870.07	24000.	113159.	4397.	5.46	199.1	S-34 AT MILE 32.43
153120.0	2841.4	2870.26	24000.	111570.	4675.	5.13	237.3	S-33 AT MILE 32.32
154017.6	2862.4	2871.35	24000.	35384.	2137.	11.23	248.1	INTERPOLATED AT MILE 32.15
154070.4	2862.1	2872.35	24000.	48334.	2722.	8.82	274.9	INTERPOLATED AT MILE 32.14
156921.6	2799.1	2876.51	24000.	511991.	12676.	1.89	217.8	INTERPOLATED AT MILE 31.60

36 MILE C

RFACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	
157608.0	2865.1	2876.56	24000.	24000.	1384.	17.34	140.2	INTERPOLATED AT MILE 31.47
157660.8	2860.7	2880.26	24000.	49952.	2339.	10.26	153.8	INTERPOLATED AT MILE 31.46
157766.4	2859.7	2881.31	24000.	73936.	3234.	7.42	188.1	INTERPOLATED AT MILE 31.44
160987.2	2854.6	2883.19	24000.	136068.	5184.	4.63	229.5	S-32 AT MILE 30.83
164313.6	2827.8	2883.77	24000.	294342.	8655.	2.77	212.3	INTERPOLATED AT MILE 30.20
164841.6	2871.2	2886.14	24000.	24000.	1296.	18.52	112.2	INTERPOLATED AT MILE 30.10
164894.4	2868.2	2891.55	24000.	68469.	2977.	8.06	168.1	INTERPOLATED AT MILE 30.09
165000.0	2867.2	2892.44	24000.	132161.	5234.	4.59	251.3	INTERPOLATED AT MILE 30.07
166056.0	2817.2	2892.81	24000.	377273.	10414.	2.30	210.0	S-31 AT MILE 29.87
168484.8	2879.4	2893.52	24000.	69554.	3394.	7.07	256.9	INTERPOLATED AT MILE 29.41
169593.6	2844.4	2894.20	24000.	98379.	3764.	6.38	148.6	INTERPOLATED AT MILE 29.20
170491.2	2883.8	2895.13	24000.	32816.	1795.	13.37	170.0	INTERPOLATED AT MILE 29.03
170544.0	2883.6	2895.75	24000.	36434.	1929.	12.44	170.8	INTERPOLATED AT MILE 29.02
170649.6	2883.5	2896.76	24000.	42999.	2260.	10.62	195.0	INTERPOLATED AT MILE 29.00
172075.2	2859.7	2900.19	24000.	220612.	7368.	3.26	240.0	S-29 AT MILE 28.73
174028.8	2821.3	2900.41	24000.	674846.	15601.	1.54	244.4	INTERPOLATED AT MILE 28.36
174504.0	2875.9	2900.41	24000.	69208.	2990.	8.03	164.5	INTERPOLATED AT MILE 28.27
175454.4	2858.8	2901.61	24000.	5598.	3644.	4.29	233.9	S-28 AT MILE 28.09
178675.2	2861.3	2902.05	24000.	89102.	3644.	6.59	167.8	S-27 AT MILE 27.48
182582.4	2854.2	2903.45	24000.	257679.	7584.	3.16	192.6	INTERPOLATED AT MILE 26.74
183110.4	2902.6	2913.54	24000.	24000.	1400.	17.14	148.2	INTERPOLATED AT MILE 26.64
183163.2	2885.0	2918.43	24000.	111842.	4344.	5.53	188.9	INTERPOLATED AT MILE 26.63
183268.8	2884.0	2918.68	24000.	149459.	5507.	4.36	219.9	INTERPOLATED AT MILE 26.61
184483.2	2875.2	2918.89	24000.	171429.	6484.	3.70	240.0	S-26 AT MILE 26.38
187651.2	2900.4	2919.83	24000.	69417.	2994.	8.02	172.9	INTERPOLATED AT MILE 25.78
192350.4	2922.8	2935.92	24000.	24380.	1279.	18.76	109.0	INTERPOLATED AT MILE 24.89
196574.4	2902.6	2957.05	24000.	149829.	5293.	4.53	150.0	S-25 AT MILE 24.09
197208.0	2926.3	2957.09	24000.	106785.	4223.	5.68	194.0	INTERPOLATED AT MILE 23.97
200217.6	2892.5	2957.97	24000.	306715.	9030.	2.66	216.7	INTERPOLATED AT MILE 23.40
201748.8	2942.6	2958.56	24000.	42638.	2109.	11.38	159.2	INTERPOLATED AT MILE 23.11
201801.6	2939.2	2960.01	24000.	74084.	3266.	7.35	193.2	INTERPOLATED AT MILE 23.10
201907.2	2938.2	2960.50	24000.	104420.	4365.	5.50	234.8	INTERPOLATED AT MILE 23.08
205392.0	2949.6	2966.75	24000.	27502.	1431.	16.78	113.4	INTERPOLATED AT MILE 22.42
205025.6	2923.9	2973.29	24000.	174443.	6326.	3.79	210.0	S-24 AT MILE 22.30
207715.2	2935.1	2973.50	24000.	199628.	7321.	3.28	280.0	S-23 AT MILE 21.98
213048.0	2963.4	2981.16	24000.	32725.	1506.	15.93	98.0	INTERPOLATED AT MILE 20.97
215424.0	2942.1	2990.02	24000.	287082.	8417.	2.85	221.3	INTERPOLATED AT MILE 20.52
216585.6	2981.7	2991.77	24000.	28317.	1624.	14.78	169.3	INTERPOLATED AT MILE 20.30
216638.4	2976.8	2994.87	24000.	77090.	3344.	7.18	198.5	INTERPOLATED AT MILE 20.29
217483.2	2952.1	2995.78	24000.	172010.	6024.	3.98	208.5	S-22 AT MILE 20.13
221173.2	2957.9	2996.15	24000.	126863.	4875.	4.92	198.9	S-21 AT MILE 19.43
223080.0	2955.1	2996.45	24000.	106783.	4731.	5.07	228.4	S-20 AT MILE 19.07
226512.0	2950.0	2996.95	24000.	142427.	3711.	6.47	80.1	INTERPOLATED AT MILE 18.42
227251.2	2955.5	2997.34	24000.	143758.	5159.	4.65	186.6	S-19A AT MILE 18.28
228412.8	2979.4	2997.51	24000.	46231.	2051.	11.70	123.4	INTERPOLATED AT MILE 18.06
230313.6	2959.2	3001.33	24000.	114050.	4641.	5.17	199.4	S-19 AT MILE 17.70
231316.8	2983.6	3001.33	24000.	35039.	1587.	15.13	99.0	INTERPOLATED AT MILE 17.51

SHINUMO W

25 MILE R

21 MILE R

NORTH CAN

BOULDER N

REDNECK R

RFACH -LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	WIDTH	TOP	
231369.6	2979.4	3003.20	24000.	50780.	2068.	11.60	103.2	INTERPOLATED AT MILE	17.50
231475.2	2979.4	3004.67	24000.	70829.	3036.	7.91	163.5	INTERPOLATED AT MILE	17.48
232267.2	2968.6	3005.75	24000.	164645.	5314.	4.52	170.2	INTERPOLATED AT MILE	17.33
234168.0	3004.9	3013.45	24000.	24000.	1524.	15.75	193.4	INTERPOLATED AT MILE	16.97
234220.8	2990.5	3017.51	24000.	113751.	4511.	5.32	213.3	INTERPOLATED AT MILE	16.96
234326.4	2989.5	3017.71	24000.	144297.	5512.	4.35	244.0	INTERPOLATED AT MILE	16.94
234960.0	2989.4	3017.85	24000.	150780.	5859.	4.10	260.0	S-18 AT MILE	16.82
239184.0	2989.7	3018.55	24000.	113746.	4487.	5.35	208.7	S-17 AT MILE	16.02
242035.2	2963.1	3019.26	24000.	200291.	6424.	3.74	188.3	S-16 AT MILE	15.48
244939.2	2960.2	3019.44	24000.	194814.	6025.	3.98	157.1	S-15 AT MILE	14.93
247896.0	3020.3	3029.04	24000.	25272.	1582.	15.17	196.4	INTERPOLATED AT MILE	14.37
247948.8	3019.3	3031.23	24000.	40134.	2190.	10.96	204.1	INTERPOLATED AT MILE	14.36
252331.2	2989.9	3039.02	24000.	233411.	6884.	3.49	170.0	S-14 AT MILE	13.53
256132.8	3019.4	3040.95	24000.	46460.	2019.	11.89	117.0	INTERPOLATED AT MILE	12.81
256185.6	3014.5	3043.07	24000.	108819.	4053.	5.92	175.5	INTERPOLATED AT MILE	12.80
258086.4	2995.0	3043.74	24000.	180164.	6024.	3.98	180.0	S-13 AT MILE	12.44
262521.6	3023.8	3047.49	24000.	55350.	2809.	8.54	228.7	INTERPOLATED AT MILE	11.97
264950.4	3048.3	3059.14	24000.	114487.	4366.	5.50	199.2	INTERPOLATED AT MILE	11.60
265003.2	3033.1	3062.62	24000.	24000.	1452.	16.52	163.3	INTERPOLATED AT MILE	11.14
265108.8	3033.1	3063.67	24000.	53721.	2630.	9.12	170.2	INTERPOLATED AT MILE	11.13
269544.0	3025.0	3065.00	24000.	91566.	4009.	5.99	214.6	INTERPOLATED AT MILE	11.11
270019.2	3023.4	3065.00	24000.	142897.	5483.	4.38	230.0	S-12 AT MILE	10.27
275503.2	3031.7	3066.10	24000.	127483.	4458.	5.38	154.8	S-11 AT MILE	10.18
281318.4	3051.7	3068.75	24000.	117412.	4933.	4.86	255.5	S-10 AT MILE	9.13
282532.8	3086.4	3094.21	24000.	67127.	3143.	7.64	213.8	INTERPOLATED AT MILE	8.04
282585.6	3075.1	3097.63	24000.	24000.	1697.	14.14	271.2	INTERPOLATED AT MILE	7.81
282691.2	3075.1	3097.73	24000.	144512.	5872.	4.09	302.9	INTERPOLATED AT MILE	7.80
284697.6	3061.4	3098.01	24000.	169763.	6806.	3.53	343.3	INTERPOLATED AT MILE	7.78
289027.2	3058.1	3098.15	24000.	311701.	10807.	2.22	390.0	S-9 AT MILE	7.40
297369.6	3062.4	3098.58	24000.	264207.	8637.	2.78	270.0	S-8 AT MILE	6.58
301276.8	3056.2	3098.80	24000.	204581.	8200.	2.93	350.0	S-7 AT MILE	5.00
302491.2	3057.8	3098.84	24000.	238792.	7431.	3.23	210.0	S-6 AT MILE	4.26
304128.0	3067.4	3099.12	24000.	153709.	6202.	3.87	260.0	S-5 AT MILE	4.03
307171.2	3084.2	3099.82	24000.	228263.	7896.	3.04	290.0	S-4 AT MILE	3.72
308404.8	3072.1	3100.35	24000.	98889.	4571.	5.25	310.9	INTERPOLATED AT MILE	3.04
310041.6	3090.3	3101.65	24000.	101150.	4640.	5.17	311.0	INTERPOLATED AT MILE	3.03
310094.4	3082.2	3103.28	24000.	275864.	9517.	2.52	361.8	INTERPOLATED AT MILE	2.91
310200.0	3082.2	3103.42	24000.	41354.	2274.	10.55	217.8	INTERPOLATED AT MILE	2.60
310939.2	3051.2	3103.56	24000.	125050.	5000.	4.80	251.1	INTERPOLATED AT MILE	2.59
313737.6	3064.6	3103.77	24000.	146044.	6018.	3.99	321.3	INTERPOLATED AT MILE	2.57
315902.4	3098.5	3105.81	24000.	197645.	7281.	3.30	286.2	S-3 AT MILE	2.43
317222.4	3062.2	3107.72	24000.	124140.	5457.	4.40	283.0	S-2 AT MILE	1.90
318964.8	3103.1	3110.28	24000.	52749.	3733.	6.43	580.2	INTERPOLATED AT MILE	1.49
319017.6	3096.3	3111.43	24000.	531112.	14663.	1.64	348.7	INTERPOLATED AT MILE	1.24
322924.8	3103.3	3116.23	24000.	37612.	2525.	9.50	363.4	INTERPOLATED AT MILE	.91
323241.6	3103.3	3117.00	24000.	94546.	4388.	5.47	299.9	INTERPOLATED AT MILE	.90
323769.6	3088.7	3117.12	24000.	53203.	3946.	6.08	696.4	INTERPOLATED AT MILE	.16
				138973.	6702.	3.58	498.3	INTERPOLATED AT MILE	.10
				179455.	7609.	3.15	403.2	S-0 AT MILE	0.00
								USGS GAGE AT LE	



84 4 0  
 RAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 FROM MOUTH OF LITTLE COLORADO RIVER TO GAGE NEAR GRAND CANYON  
 RIVER MILES 61.00 TO 87.37

REACH	THALWEG	SURFACE	CRITICAL	AREA	VELOCITY	TOP	
LENGTH	ELEVATION	DISCHARGE	DISCHARGE			WIDTH	
0	2405.8	2433.38	24000.	6534.	3.67	310.0	MILE 87.37 USGS GAGE NEAR GRAND CAN
1056.0	2410.0	2433.49	24000.	5202.	4.61	251.9	INTERPOLATED AT MILE 87.17
2164.8	2394.7	2433.77	24000.	6437.	3.73	236.9	MILE 86.96
3748.8	2386.6	2433.87	24000.	5696.	4.21	188.2	MILE 86.66
6072.0	2394.2	2434.06	24000.	3348.	7.17	155.8	MILE 86.22
8503.8	2423.0	2436.78	24000.	2159.	11.12	172.8	INTERPOLATED AT MILE 85.76
13728.0	2418.0	2445.18	24000.	2738.	8.77	133.5	INTERPOLATED AT MILE 84.77
14414.4	2436.0	2446.39	24000.	1433.	16.75	152.3	INTERPOLATED AT MILE 84.64
14467.2	2433.0	2450.33	24000.	2862.	8.38	186.7	INTERPOLATED AT MILE 84.63
20169.6	2440.0	2457.52	24000.	2170.	11.06	145.2	INTERPOLATED AT MILE 83.55
20856.0	2449.0	2460.99	24000.	1329.	18.06	126.3	INTERPOLATED AT MILE 83.42
20908.8	2420.0	2466.37	24000.	4140.	5.80	143.8	INTERPOLATED AT MILE 83.41
21014.4	2418.0	2466.66	24000.	5216.	4.60	164.5	INTERPOLATED AT MILE 83.39
28617.6	2462.0	2475.85	24000.	2033.	11.80	165.0	INTERPOLATED AT MILE 81.95
29990.4	2465.0	2479.62	24000.	2735.	8.78	204.8	INTERPOLATED AT MILE 81.69
30782.4	2471.0	2489.45	24000.	1203.	19.96	88.1	INTERPOLATED AT MILE 81.54
30835.2	2445.0	2496.11	24000.	3062.	7.84	118.7	INTERPOLATED AT MILE 81.53
32102.4	2475.0	2497.01	24000.	3245.	7.40	173.3	INTERPOLATED AT MILE 81.29
36115.2	2448.9	2498.94	24000.	5528.	4.34	169.0	MILE 80.53
37488.0	2457.9	2498.96	24000.	3584.	6.70	148.6	MILE 80.27
38332.8	2462.9	2499.17	24000.	3066.	7.83	153.6	MILE 80.11
42715.2	2491.0	2506.06	24000.	1808.	13.28	137.4	INTERPOLATED AT MILE 79.28
45355.2	2481.0	2512.52	24000.	2945.	8.15	127.0	INTERPOLATED AT MILE 78.78
46411.2	2511.0	2522.00	24000.	1360.	17.64	137.2	INTERPOLATED AT MILE 78.58
46464.0	2505.0	2526.62	24000.	2999.	8.00	162.0	INTERPOLATED AT MILE 78.57
47995.2	2489.9	2527.93	24000.	4651.	5.16	141.2	MILE 78.28
48787.2	2478.2	2527.93	24000.	3646.	6.58	151.8	MILE 78.13
50318.4	2521.0	2532.71	24000.	1344.	17.85	131.2	INTERPOLATED AT MILE 77.84
50899.2	2500.7	2540.42	24000.	7017.	3.42	225.2	MILE 77.73
51691.2	2520.0	2540.42	24000.	2653.	9.05	165.1	INTERPOLATED AT MILE 77.58
52483.2	2504.9	2542.05	24000.	5907.	4.06	200.0	MILE 77.43
55123.2	2533.0	2543.93	24000.	52363.	8.22	287.7	INTERPOLATED AT MILE 76.93
56707.2	2558.0	2564.61	24000.	1693.	14.17	288.6	INTERPOLATED AT MILE 76.63
56760.0	2555.0	2567.53	24000.	3460.	6.94	298.4	INTERPOLATED AT MILE 76.62
56865.6	2552.0	2567.98	24000.	4663.	5.15	319.9	INTERPOLATED AT MILE 76.60
59452.8	2535.8	2568.87	24000.	7854.	3.06	352.4	MILE 76.11
63201.6	2527.0	2569.21	24000.	4389.	5.47	203.3	INTERPOLATED AT MILE 75.40
64099.2	2576.0	2585.63	24000.	1455.	16.50	168.1	INTERPOLATED AT MILE 75.23
64152.0	2575.0	2589.67	24000.	3144.	7.63	242.7	INTERPOLATED AT MILE 75.22
64257.6	2573.0	2590.12	24000.	3939.	6.09	259.4	INTERPOLATED AT MILE 75.20
67689.6	2564.3	2591.63	24000.	6572.	3.65	365.0	MILE 74.55
69326.4	2563.4	2591.87	24000.	5406.	4.44	339.4	MILE 74.24
71860.8	2567.3	2592.43	24000.	5471.	4.39	273.0	MILE 73.76
73075.2	2567.9	2592.80	24000.	3130.	7.67	349.4	MILE 73.53
75345.6	2593.2	2600.98	24000.	1964.	12.22	294.7	INTERPOLATED AT MILE 73.10

REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	
78038.4	2601.0	2612.82	24000.	62406.	3390.	7.08	315.3	INTERPOLATED AT MILE 72.59
79252.8	2606.0	2615.76	24000.	28358.	1691.	14.19	189.9	INTERPOLATED AT MILE 72.36
79305.6	2598.0	2618.81	24000.	3939.	3939.	6.09	225.6	INTERPOLATED AT MILE 72.35
73411.2	2596.0	2619.14	24000.	129253.	5240.	4.58	266.7	INTERPOLATED AT MILE 72.33
842262.4	2602.7	2620.18	24000.	79441.	4927.	4.87	511.3	MILE 71.79
84216.0	2615.0	2622.78	24000.	45929.	2966.	8.09	395.8	INTERPOLATED AT MILE 71.42
85219.2	2591.2	2624.97	24000.	152973.	7916.	3.03	470.0	MILE 71.23
87806.4	2607.0	2625.42	24000.	104750.	4994.	4.81	340.0	MILE 70.74
89443.2	2619.0	2627.25	24000.	91452.	2942.	8.16	383.1	INTERPOLATED AT MILE 70.43
90868.8	2603.9	2629.75	24000.	30815.	4498.	5.34	301.8	MILE 70.16
95409.6	2630.0	2639.86	24000.	55871.	1931.	12.43	235.7	INTERPOLATED AT MILE 69.30
98155.2	2635.0	2649.34	24000.	31346.	2795.	8.59	219.8	INTERPOLATED AT MILE 68.78
99792.0	2645.0	2653.74	24000.	72597.	2007.	11.96	256.9	INTERPOLATED AT MILE 68.47
99844.8	2642.0	2655.64	24000.	110041.	3641.	6.59	289.8	INTERPOLATED AT MILE 68.46
99950.4	2639.0	2656.06	24000.	207558.	4986.	4.81	321.4	INTERPOLATED AT MILE 68.44
101217.6	2631.1	2656.58	24000.	93578.	9346.	2.57	545.8	MILE 68.20
103171.2	2646.1	2657.07	24000.	65573.	5542.	4.33	610.8	MILE 67.83
107025.6	2638.7	2659.27	24000.	24398.	3303.	7.27	238.8	MILE 67.10
110088.0	2661.0	2670.42	24000.	103006.	1539.	15.60	191.0	INTERPOLATED AT MILE 66.52
110193.6	2658.0	2674.74	24000.	161862.	4710.	5.10	311.3	INTERPOLATED AT MILE 66.50
110299.2	2656.0	2675.01	24000.	54557.	6927.	3.46	400.0	INTERPOLATED AT MILE 66.48
114417.6	2653.0	2676.64	24000.	24000.	2603.	9.22	169.0	INTERPOLATED AT MILE 65.70
115737.6	2673.0	2683.63	24000.	1453.	1453.	16.51	163.7	INTERPOLATED AT MILE 65.45
115790.4	2670.0	2687.58	24000.	61533.	2975.	8.07	213.1	INTERPOLATED AT MILE 65.44
115896.0	2667.0	2688.44	24000.	122966.	5125.	4.68	276.4	INTERPOLATED AT MILE 65.42
117057.6	2679.0	2689.45	24000.	41911.	2428.	9.89	257.5	INTERPOLATED AT MILE 65.20
118060.8	2663.7	2692.23	24000.	131049.	5993.	4.00	340.0	MILE 65.01
122918.4	2670.1	2693.09	24000.	141328.	6249.	3.84	368.2	MILE 64.09
124977.6	2685.0	2695.64	24000.	37365.	2171.	11.05	230.8	INTERPOLATED AT MILE 63.70
126456.0	2619.0	2700.10	24000.	528728.	19326.	1.24	560.0	MILE 63.42
127248.0	2688.0	2700.47	24000.	24000.	1396.	17.19	143.0	INTERPOLATED AT MILE 63.27
127300.8	2685.0	2705.17	24000.	72687.	3339.	7.19	212.7	INTERPOLATED AT MILE 63.26
127406.4	2681.9	2705.95	24000.	178197.	6972.	3.44	333.0	INTERPOLATED AT MILE 63.24
130257.6	2700.0	2708.11	24000.	56102.	3545.	6.77	450.8	INTERPOLATED AT MILE 62.70
134217.6	2689.9	2712.22	24000.	105667.	4871.	4.93	300.0	MILE 61.95
135801.6	2703.0	2713.27	24000.	60751.	3451.	6.95	354.3	INTERPOLATED AT MILE 61.65
137544.0	2715.0	2720.44	24000.	27426.	2104.	11.40	396.8	INTERPOLATED AT MILE 61.32
137596.9	2713.1	2722.15	24000.	59352.	3603.	6.66	416.2	INTERPOLATED AT MILE 61.31
139233.6	2697.5	2723.91	24000.	200083.	7660.	3.13	340.0	S-61 AT MILE 61.00 USGS GAGE ABOVE

RAND CANYON SEDIMENT TRANSPORT STUDY OLORADO RIVER, ARIZONA AGE NEAR GRAND CANYON TO ABOVE NATIONAL CANYON IVER MILES 87.37 TO 168.20									
REACH	THALWEG	SURFACE	CRITICAL	AREA	VELOCITY	TOP			
LENGTH	ELEVATION	ELEVATION	DISCHARGE			WIDTH	MILE	USGS GAGE	ABOVE NATIONAL
0	1721.5	1748.82	24000.	6791.	3.53	257.9	MILE 166.20		
844.8	1721.3	1748.88	24000.	5853.	4.10	276.8	MILE 166.04		
2798.4	1722.3	1749.20	24000.	6485.	3.70	301.4	MILE 165.67		
6388.8	1726.5	1749.79	24000.	5095.	4.71	280.0	MILE 164.99		
9715.2	1735.0	1751.60	24000.	2776.	8.65	198.5	INTERPOLATED AT MILE 164.36		
11246.4	1721.1	1753.27	24000.	92979.	6.38	173.4	MILE 164.07		
13305.6	1712.7	1754.13	24000.	5297.	4.53	198.9	MILE 163.68		
16262.4	1726.7	1754.63	24000.	4763.	5.04	238.8	MILE 163.12		
17054.4	1719.4	1754.71	24000.	3935.	6.10	206.7	MILE 162.97		
23654.4	1745.0	1759.90	24000.	2631.	9.12	204.5	INTERPOLATED AT MILE 161.72		
29356.8	1734.5	1765.50	24000.	5285.	4.54	243.7	MILE 160.64		
33633.6	1726.9	1768.76	24000.	1897.	12.65	104.6	MILE 159.83		
35534.4	1716.0	1774.24	24000.	38321.	4.64	173.0	INTERPOLATED AT MILE 159.47		
37012.8	1758.0	1774.77	24000.	51931.	9.78	169.4	INTERPOLATED AT MILE 159.19		
37065.6	1736.0	1776.12	24000.	144383.	4.68	184.5	INTERPOLATED AT MILE 159.18		
38332.8	1742.1	1776.27	24000.	4513.	5.32	191.1	MILE 158.94		
42240.0	1763.0	1778.64	24000.	2733.	8.78	196.3	INTERPOLATED AT MILE 158.20		
44880.0	1761.0	1781.44	24000.	57068.	7.01	195.7	INTERPOLATED AT MILE 157.70		
49368.0	1755.0	1783.57	24000.	3426.	6.95	168.6	INTERPOLATED AT MILE 156.85		
50001.6	1775.0	1784.33	24000.	3456.	12.03	229.4	INTERPOLATED AT MILE 156.73		
50054.4	1771.0	1786.16	24000.	1996.	6.87	255.5	INTERPOLATED AT MILE 156.72		
51691.2	1751.4	1787.13	24000.	3492.	5.90	172.5	MILE 156.41		
53275.2	1752.8	1787.50	24000.	4070.	6.37	154.8	MILE 156.11		
57024.0	1777.0	1791.74	24000.	3765.	11.66	165.3	INTERPOLATED AT MILE 155.40		
60667.2	1767.1	1798.36	24000.	2058.	5.40	199.3	MILE 154.71		
66158.4	1759.0	1799.81	24000.	4444.	6.90	165.3	INTERPOLATED AT MILE 153.67		
66739.2	1781.0	1799.81	24000.	3476.	16.97	113.8	INTERPOLATED AT MILE 153.56		SINYALA RA
66792.0	1770.0	1803.48	24000.	1414.	10.29	134.3	INTERPOLATED AT MILE 153.55		
66897.6	1760.0	1804.64	24000.	2332.	7.26	145.6	INTERPOLATED AT MILE 153.53		
68904.0	1777.8	1805.62	24000.	3306.	7.23	160.4	MILE 153.15		
70435.2	1769.4	1806.02	24000.	3321.	12.76	110.0	MILE 152.86		
72547.2	1780.0	1812.00	24000.	1881.	4.86	194.0	INTERPOLATED AT MILE 152.46		
73022.4	1792.0	1812.00	24000.	4937.	11.28	130.2	INTERPOLATED AT MILE 152.37		
73075.2	1790.0	1813.02	24000.	2128.	8.71	147.4	INTERPOLATED AT MILE 152.36		
73180.8	1783.0	1813.68	24000.	2755.	6.51	156.9	INTERPOLATED AT MILE 152.34		
75187.2	1770.7	1814.37	24000.	3686.	5.39	140.0	MILE 151.96		
76560.0	1791.0	1814.62	24000.	4454.	8.05	156.5	INTERPOLATED AT MILE 151.70		
81153.6	1779.4	1817.10	24000.	2981.	6.23	149.0	MILE 150.83		
86644.8	1810.0	1823.16	24000.	3854.	10.44	199.7	INTERPOLATED AT MILE 149.79		
87278.4	1820.0	1830.39	24000.	2298.	16.87	156.3	INTERPOLATED AT MILE 149.67		UPSET RAPI
87331.2	1819.0	1833.24	24000.	1422.	11.80	169.4	INTERPOLATED AT MILE 149.66		
87436.8	1817.0	1834.38	24000.	2034.	9.30	181.5	INTERPOLATED AT MILE 149.64		
89654.4	1803.3	1836.69	24000.	2580.	8.28	155.0	MILE 149.22		
95726.4	1812.0	1840.59	24000.	64607.	6.50	178.6	INTERPOLATED AT MILE 148.07		
96412.8	1825.0	1840.59	24000.	90862.	17.95	112.8	INTERPOLATED AT MILE 147.94		MATKATAMIB
				1337.					

REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	TOP
96465.6	1805.0	1845.73	24000.	78157.	3256.	7.37	150.6	INTERPOLATED AT MILE 147.93
97627.2	1810.5	1846.80	24000.	161444.	5587.	4.30	191.5	MILE 147.71
102432.0	1812.0	1848.47	24000.	56633.	2532.	9.48	138.0	INTERPOLATED AT MILE 146.80
107448.0	1830.0	1853.48	24000.	50251.	2343.	10.24	145.9	INTERPOLATED AT MILE 145.85
110616.0	1842.0	1859.07	24000.	35708.	1823.	13.17	140.3	INTERPOLATED AT MILE 145.25
113520.0	1844.0	1866.07	24000.	66378.	2973.	8.07	178.3	INTERPOLATED AT MILE 144.70
116160.0	1862.0	1872.71	24000.	29271.	1699.	14.12	179.8	INTERPOLATED AT MILE 144.20
118219.2	1849.0	1881.06	24000.	90624.	3739.	6.42	179.5	INTERPOLATED AT MILE 143.81
119644.8	1877.0	1885.68	24000.	24000.	1520.	15.79	192.0	INTERPOLATED AT MILE 143.54 KANAB RAPI
119697.6	1874.0	1889.17	24000.	60377.	2977.	8.06	226.3	INTERPOLATED AT MILE 143.53
119803.2	1849.0	1890.18	24000.	206829.	7244.	3.31	256.8	INTERPOLATED AT MILE 143.51
120806.4	1843.2	1890.23	24000.	188873.	7181.	3.34	258.4	MILE 143.32
123182.4	1851.9	1890.39	24000.	183506.	6652.	3.61	240.0	MILE 142.87
125822.4	1848.8	1890.60	24000.	163504.	5925.	4.05	220.5	MILE 142.37
129360.0	1849.7	1890.98	24000.	119959.	4852.	4.95	210.6	MILE 141.70
132739.2	1868.9	1891.95	24000.	78231.	3669.	6.54	237.0	MILE 141.06
138705.6	1865.0	1894.36	24000.	131284.	5219.	4.60	243.8	INTERPOLATED AT MILE 139.93
139128.0	1885.0	1899.52	24000.	24000.	1371.	17.50	132.2	INTERPOLATED AT MILE 139.85
139180.8	1875.0	1904.78	24000.	91043.	3926.	6.11	205.1	INTERPOLATED AT MILE 139.84
139814.4	1864.2	1904.95	24000.	86630.	4014.	5.98	191.5	MILE 139.72
143008.0	1861.0	1906.06	24000.	158806.	6019.	3.99	234.3	INTERPOLATED AT MILE 139.10
143616.0	1899.0	1912.66	24000.	24000.	1358.	17.67	130.1	INTERPOLATED AT MILE 139.00 FISHTAIL R
143668.8	1897.0	1916.44	24000.	44701.	2195.	10.94	156.6	INTERPOLATED AT MILE 138.99
143774.4	1885.0	1917.85	24000.	79941.	3465.	6.93	179.4	INTERPOLATED AT MILE 138.97
147048.0	1887.9	1919.33	24000.	120183.	4863.	4.94	228.6	MILE 138.35
148632.0	1912.0	1921.33	24000.	38825.	2349.	10.22	272.6	INTERPOLATED AT MILE 138.05
150638.4	1911.0	1926.17	24000.	54664.	2750.	8.73	214.7	INTERPOLATED AT MILE 137.67
156340.8	1891.0	1931.70	24000.	61167.	2595.	9.25	124.1	INTERPOLATED AT MILE 136.59
157872.0	1918.0	1936.87	24000.	24000.	1324.	18.13	112.6	INTERPOLATED AT MILE 136.30 DEER CREEK
157924.8	1917.0	1942.76	24000.	88543.	3636.	6.60	183.1	INTERPOLATED AT MILE 136.29
158030.4	1915.0	1943.12	24000.	115376.	4704.	5.10	230.5	INTERPOLATED AT MILE 136.27
160512.0	1855.0	1943.69	24000.	104502.	4366.	5.50	226.8	INTERPOLATED AT MILE 135.80
164683.2	1936.0	1946.65	24000.	35967.	4197.	5.72	92.4	INTERPOLATED AT MILE 135.01
166214.4	1943.0	1956.68	24000.	24851.	1400.	11.53	219.4	INTERPOLATED AT MILE 134.72
168643.2	1895.0	1962.88	24000.	210558.	6997.	3.43	132.7	INTERPOLATED AT MILE 134.26
168960.0	1939.0	1962.88	24000.	86007.	3733.	6.43	207.5	INTERPOLATED AT MILE 134.20
169593.6	1956.0	1966.75	24000.	34197.	1985.	12.09	210.0	INTERPOLATED AT MILE 134.08
171864.0	1941.4	1972.00	24000.	153364.	6054.	3.96	209.9	INTERPOLATED AT MILE 133.65
173395.2	1952.0	1972.05	24000.	83675.	3722.	6.45	268.1	MILE 133.36
174240.0	1941.0	1973.71	24000.	68239.	2851.	8.42	225.2	INTERPOLATED AT MILE 133.20
177883.2	1964.0	1977.01	24000.	37184.	1979.	12.13	138.2	MILE 132.51
180048.0	1961.0	1981.57	24000.	72534.	3216.	7.46	174.6	INTERPOLATED AT MILE 132.10
181684.8	1980.0	1989.96	24000.	24000.	1446.	16.60	192.3	INTERPOLATED AT MILE 131.79
183057.6	183110.4	1994.47	24000.	100770.	4166.	5.76	162.6	INTERPOLATED AT MILE 131.53 DUBENDORFF
183902.4	1962.9	1994.95	24000.	159246.	5947.	4.04	218.2	INTERPOLATED AT MILE 131.52
188496.0	1927.0	1995.46	24000.	139438.	4591.	5.23	249.5	MILE 131.37
189024.0	1899.0	2002.59	24000.	24000.	1328.	18.08	133.2	INTERPOLATED AT MILE 130.50
189076.8	1984.9	2007.77	24000.	73145.	3155.	7.61	121.4	INTERPOLATED AT MILE 130.40 BEDROCK RA
							177.3	INTERPOLATED AT MILE 130.39

REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	
189182.4	1969.0	2008.67	24000.	207123.	7139.	3.36	248.9	INTERPOLATED AT MILE 130.37
192878.4	1950.2	2008.86	24000.	161586.	5656.	4.24	160.0	MILE 129.67
194568.0	1964.3	2009.16	24000.	177234.	6624.	3.62	249.2	MILE 129.35
195201.6	1947.0	2009.16	24000.	149416.	5155.	4.66	165.7	INTERPOLATED AT MILE 129.23
196204.8	1989.0	2009.16	24000.	25192.	1291.	18.59	95.0	INTERPOLATED AT MILE 129.04
196257.6	1985.0	2014.26	24000.	56204.	2427.	9.89	125.7	INTERPOLATED AT MILE 129.03
196363.2	1955.0	2015.86	24000.	161455.	5460.	4.40	159.7	INTERPOLATED AT MILE 129.01
198739.2	1933.0	2016.25	24000.	276466.	8277.	2.90	199.0	INTERPOLATED AT MILE 128.56
199214.4	2006.0	2016.25	24000.	24284.	1430.	16.78	155.3	INTERPOLATED AT MILE 128.47
199267.2	1980.0	2021.12	24000.	158960.	5637.	4.26	200.5	INTERPOLATED AT MILE 128.46
200112.0	1966.2	2021.37	24000.	286259.	8480.	2.83	209.5	MILE 128.30
201326.4	1982.0	2021.38	24000.	173825.	6180.	3.88	224.9	MILE 128.07
201960.0	1967.5	2021.42	24000.	189025.	6221.	3.86	184.1	MILE 127.95
203280.0	2000.0	2021.57	24000.	35896.	1814.	13.23	130.4	INTERPOLATED AT MILE 127.70
207504.0	1975.0	2029.81	24000.	168345.	6099.	3.93	215.2	INTERPOLATED AT MILE 126.90
208032.0	2013.0	2029.81	24000.	28989.	1541.	15.57	127.2	INTERPOLATED AT MILE 126.80
208084.8	2009.0	2032.31	24000.	48622.	2218.	10.82	134.1	INTERPOLATED AT MILE 126.79
208190.4	1979.0	2034.23	24000.	149320.	5269.	4.55	187.4	INTERPOLATED AT MILE 126.77
210196.8	2005.0	2034.52	24000.	126394.	5008.	4.79	233.0	INTERPOLATED AT MILE 126.39
211041.6	2022.0	2035.43	24000.	24000.	1355.	17.72	129.7	INTERPOLATED AT MILE 126.23
211094.4	2018.0	2040.11	24000.	62189.	2837.	8.46	175.4	INTERPOLATED AT MILE 126.22
211200.0	1990.0	2041.15	24000.	152095.	5706.	4.21	216.5	INTERPOLATED AT MILE 126.20
214315.2	2021.7	2041.72	24000.	116594.	5437.	4.41	357.9	MILE 125.61
215952.0	2008.0	2042.01	24000.	59030.	2748.	8.73	160.9	INTERPOLATED AT MILE 125.30
219278.4	2044.0	2056.30	24000.	24000.	1394.	17.22	142.3	INTERPOLATED AT MILE 124.67
219331.2	2039.8	2060.74	24000.	64139.	2974.	8.07	191.6	INTERPOLATED AT MILE 124.66
219436.8	2028.0	2061.40	24000.	103145.	4285.	5.60	207.1	INTERPOLATED AT MILE 124.64
222182.4	2010.2	2062.24	24000.	258658.	8714.	2.75	273.0	MILE 124.12
224136.0	2053.0	2064.60	24000.	34317.	1938.	12.38	193.3	INTERPOLATED AT MILE 123.75
227092.8	2042.1	2072.44	24000.	99747.	4267.	5.62	203.4	MILE 123.19
227462.4	2060.0	2072.53	24000.	59479.	3170.	7.57	282.1	INTERPOLATED AT MILE 123.12
229152.0	2040.0	2074.30	24000.	146708.	5689.	4.22	246.6	INTERPOLATED AT MILE 122.80
230049.6	2067.0	2077.98	24000.	24000.	1429.	16.79	156.0	INTERPOLATED AT MILE 122.63
230102.4	2063.3	2081.80	24000.	55075.	2646.	9.07	185.8	INTERPOLATED AT MILE 122.62
230208.0	2035.0	2083.04	24000.	156128.	5802.	4.93	215.1	INTERPOLATED AT MILE 122.60
235275.8	2036.0	2083.59	24000.	125624.	4863.	4.14	195.6	INTERPOLATED AT MILE 121.64
235699.2	2062.0	2083.59	24000.	27433.	1488.	16.13	119.8	INTERPOLATED AT MILE 121.56
235752.0	2057.0	2086.23	24000.	41558.	2053.	11.69	135.7	INTERPOLATED AT MILE 121.55
235857.6	2055.0	2088.29	24000.	87117.	3755.	6.39	191.2	INTERPOLATED AT MILE 121.53
239078.4	2055.3	2089.46	24000.	142429.	5145.	4.66	197.1	MILE 120.92
243302.4	2037.0	2090.05	24000.	167628.	6314.	3.86	231.0	INTERPOLATED AT MILE 120.12
243936.0	2082.0	2093.42	24000.	24000.	1417.	16.93	152.2	INTERPOLATED AT MILE 120.00
243988.8	2082.0	2095.96	24000.	34833.	1889.	12.70	169.8	INTERPOLATED AT MILE 119.99
244094.4	2080.0	2097.93	24000.	61438.	2958.	8.11	207.7	INTERPOLATED AT MILE 119.97
247737.6	2077.8	2100.99	24000.	90780.	4238.	5.66	273.7	MILE 119.28
250747.2	2055.0	2101.98	24000.	123159.	4861.	4.94	203.9	INTERPOLATED AT MILE 118.71
251592.0	2089.0	2102.36	24000.	30223.	1721.	13.95	167.7	INTERPOLATED AT MILE 118.55
251644.8	2075.0	2105.10	24000.	74751.	3445.	6.97	200.5	INTERPOLATED AT MILE 118.54
252278.4	2084.0	2105.89	24000.	116239.	5031.	4.77	280.7	MILE 118.42

REACH	THALWEG	SURFACE	CRITICAL	AREA	VELOCITY	WIDTH	TOP
LENGTH	ELEVATION	ELEVATION	DISCHARGE	DISCHARGE			
254337.6	2063.4	2106.25	24000.	4363.	5.50	172.1	MILE 118.03
257664.0	2061.3	2107.00	24000.	5720.	4.20	180.8	MILE 117.40
262416.0	2101.0	2114.00	24000.	1851.	12.96	159.7	INTERPOLATED AT MILE 116.50
264528.0	2078.4	2120.23	24000.	4770.	5.03	178.7	MILE 116.10
266317.6	2084.1	2120.38	24000.	2096.	11.45	100.0	MILE 115.78
269280.0	2096.0	2124.48	24000.	2017.	11.90	108.6	INTERPOLATED AT MILE 115.20
271128.0	2089.9	2128.51	24000.	7052.	3.40	250.0	MILE 114.85
271708.8	2076.4	2128.65	24000.	10380.	2.31	260.0	MILE 114.74
276513.6	2094.1	2129.92	24000.	133216.	4.64	215.0	MILE 113.83
279628.8	2098.8	2129.48	24000.	6713.	3.58	235.0	MILE 113.24
284644.8	2118.0	2133.25	24000.	2381.	10.08	192.0	INTERPOLATED AT MILE 112.29
285648.0	2134.0	2146.59	24000.	1379.	17.41	139.0	INTERPOLATED AT MILE 112.10 WALTENBERG
285700.8	2130.0	2151.06	24000.	2851.	8.42	185.1	INTERPOLATED AT MILE 112.09
285806.4	2105.0	2152.01	24000.	5169.	4.64	215.6	INTERPOLATED AT MILE 112.07
291033.6	2116.3	2153.19	24000.	3377.	7.11	164.7	MILE 111.08
292512.0	2135.0	2154.17	24000.	3501.	6.86	227.8	INTERPOLATED AT MILE 110.80
295152.0	2125.0	2156.49	24000.	1718.	13.97	105.0	INTERPOLATED AT MILE 110.30
299270.4	2137.0	2165.75	24000.	1973.	12.16	130.3	INTERPOLATED AT MILE 109.52
300432.0	2137.0	2168.01	24000.	2101.	11.42	134.4	INTERPOLATED AT MILE 109.30
303072.0	2142.0	2172.02	24000.	2397.	10.01	150.6	INTERPOLATED AT MILE 108.80
304128.0	2146.0	2173.61	24000.	2864.	8.38	152.8	INTERPOLATED AT MILE 108.60
304814.4	2152.0	2173.67	24000.	1784.	13.46	133.4	INTERPOLATED AT MILE 108.47
307401.6	2185.0	2195.40	24000.	1419.	16.56	162.8	INTERPOLATED AT MILE 107.98 BASS RAP
307454.4	2184.0	2198.34	24000.	2161.	11.11	183.4	INTERPOLATED AT MILE 107.97
307560.0	2182.0	2199.50	24000.	2896.	8.29	206.0	INTERPOLATED AT MILE 107.95
310992.0	2188.0	2204.17	24000.	2146.	11.18	170.7	INTERPOLATED AT MILE 107.30
312628.8	2183.9	2207.59	24000.	3089.	7.77	178.5	MILE 106.99
313684.8	2159.1	2208.73	24000.	5381.	4.46	150.0	MILE 106.79
314846.4	2164.9	2208.73	24000.	3771.	6.36	142.7	MILE 106.57
317856.0	2195.0	2210.90	24000.	2493.	9.63	177.2	INTERPOLATED AT MILE 106.00
318489.6	2207.0	2217.91	24000.	1369.	17.53	139.5	INTERPOLATED AT MILE 105.88 SERPENTINE
318542.4	2206.0	2221.38	24000.	2134.	11.25	158.4	INTERPOLATED AT MILE 105.87
318648.0	2203.0	2222.97	24000.	3525.	6.81	203.9	INTERPOLATED AT MILE 105.85
320390.4	2175.8	2223.68	24000.	4106.	5.84	122.6	MILE 105.52
324720.0	2157.0	2224.67	24000.	8083.	2.97	212.6	INTERPOLATED AT MILE 104.70
325353.6	2222.0	2233.41	24000.	1357.	17.69	134.6	INTERPOLATED AT MILE 104.58 RUBY RAPID
325406.4	2218.0	2237.91	24000.	2784.	8.62	167.1	INTERPOLATED AT MILE 104.57
325512.0	2197.0	2239.00	24000.	5957.	4.02	200.0	INTERPOLATED AT MILE 104.55
329313.6	2228.0	2243.41	24000.	1806.	13.29	138.4	INTERPOLATED AT MILE 103.83
330680.4	2199.6	2248.25	24000.	4947.	4.85	160.0	MILE 103.57
333801.6	2215.5	2248.89	24000.	3536.	6.79	151.6	MILE 102.98
335068.8	2191.0	2249.81	24000.	6177.	3.89	197.2	INTERPOLATED AT MILE 102.74
335491.2	2233.0	2249.81	24000.	1468.	16.34	113.3	INTERPOLATED AT MILE 102.66
335544.0	2228.0	2252.48	24000.	2112.	11.37	123.7	INTERPOLATED AT MILE 102.65
335649.6	2203.0	2254.78	24000.	6196.	3.87	199.3	INTERPOLATED AT MILE 102.63
340137.6	2197.8	2255.20	24000.	117994.	5.73	125.0	MILE 101.78
342619.2	2196.0	2255.84	24000.	147369.	4.65	171.7	INTERPOLATED AT MILE 101.31
343305.6	2248.0	2258.81	24000.	1397.	17.18	145.9	INTERPOLATED AT MILE 101.18 SAPPHIRE R
343358.4	2244.0	2263.33	24000.	3245.	7.40	197.6	INTERPOLATED AT MILE 101.17

REACH LENGTH	THALWEG ELEVATION	SURFACE ELEVATION	DISCHARGE	CRITICAL DISCHARGE	AREA	VELOCITY	WIDTH	TOP
343464.0	2213.0	2264.16	24000.	231969.	7596.	3.16	227.4	INTERPOLATED AT MILE 101.15
344731.2	2226.5	2264.16	24000.	133535.	4935.	4.86	191.0	MILE 100.91
351225.6	2255.0	2272.13	24000.	36331.	1802.	13.32	133.8	INTERPOLATED AT MILE 99.68
352704.0	2275.0	2282.44	24000.	24000.	1604.	14.96	228.1	INTERPOLATED AT MILE 99.40
353654.4	2245.0	2290.30	24000.	173786.	6105.	3.93	209.7	INTERPOLATED AT MILE 99.22
354340.8	2283.0	2291.21	24000.	27701.	1780.	13.48	230.9	INTERPOLATED AT MILE 99.09
354393.6	2277.0	2293.77	24000.	76950.	3562.	6.74	239.6	INTERPOLATED AT MILE 99.08
354499.2	2273.0	2294.17	24000.	113237.	4762.	5.04	260.7	INTERPOLATED AT MILE 99.06
357192.0	2255.0	2294.93	24000.	63600.	2726.	8.80	134.8	INTERPOLATED AT MILE 98.55
359198.4	2305.0	2316.99	24000.	24000.	1359.	17.66	134.0	INTERPOLATED AT MILE 98.17
359251.2	2304.0	2321.30	24000.	53950.	2584.	9.29	181.2	CRYSTAL RA
359356.8	2300.0	2322.26	24000.	91334.	3863.	6.21	211.0	INTERPOLATED AT MILE 98.16
361785.6	2275.4	2323.35	24000.	302735.	9019.	2.66	230.0	INTERPOLATED AT MILE 98.14
364056.0	2274.4	2323.40	24000.	210743.	7058.	3.40	210.0	MILE 97.68
366854.4	2273.0	2323.55	24000.	177736.	6333.	3.79	218.2	MILE 97.25
367646.4	2319.0	2328.51	24000.	24000.	1463.	16.41	171.0	INTERPOLATED AT MILE 96.72
367699.2	2315.0	2332.03	24000.	55305.	2641.	9.09	185.9	INTERPOLATED AT MILE 96.57
367804.8	2300.0	2333.25	24000.	149362.	5556.	4.32	227.3	BOUCHER RA
369652.8	2289.1	2333.51	24000.	189546.	6420.	3.74	206.8	INTERPOLATED AT MILE 96.54
372345.6	2290.7	2333.71	24000.	161557.	5930.	4.05	210.0	MILE 96.19
375619.2	2298.0	2334.10	24000.	222183.	7422.	3.23	250.4	MILE 95.68
376569.6	2326.0	2342.64	24000.	24000.	1226.	19.57	94.2	INTERPOLATED AT MILE 95.06
376622.4	2322.0	2349.22	24000.	86833.	3417.	7.02	158.9	INTERPOLATED AT MILE 94.88
376728.0	2320.0	2349.86	24000.	159179.	5748.	4.18	229.6	INTERPOLATED AT MILE 94.87
381744.0	2337.0	2352.53	24000.	59044.	2829.	8.48	202.1	INTERPOLATED AT MILE 94.85
384384.0	2330.0	2355.19	24000.	159986.	6097.	3.94	277.8	INTERPOLATED AT MILE 93.90
385070.4	2356.0	2363.67	24000.	24000.	1572.	15.27	214.3	INTERPOLATED AT MILE 93.40
385123.2	2352.0	2367.24	24000.	77442.	3659.	6.56	258.7	INTERPOLATED AT MILE 93.27
385228.8	2340.0	2367.84	24000.	204587.	7375.	3.25	299.6	GRANITE RA
386601.6	2328.1	2367.98	24000.	275841.	8796.	2.73	271.5	INTERPOLATED AT MILE 93.24
389136.0	2359.0	2370.00	24000.	470556.	2579.	9.31	245.9	MILE 92.98
390192.0	2330.3	2372.46	24000.	245151.	8122.	2.95	273.4	MILE 92.30
392145.6	2330.6	2372.60	24000.	278906.	10397.	2.31	396.4	MILE 91.93
394944.0	2361.0	2374.76	24000.	192309.	6101.	10.58	198.8	INTERPOLATED AT MILE 91.40
396369.6	2327.7	2378.05	24000.	425556.	3200.	3.93	174.6	MILE 91.13
398640.0	2339.9	2378.19	24000.	74271.	3200.	7.50	152.4	MILE 90.70
400752.0	2345.0	2379.30	24000.	81074.	3400.	7.06	163.6	INTERPOLATED AT MILE 90.30
401395.6	2372.0	2383.27	24000.	24000.	1391.	17.25	144.7	INTERPOLATED AT MILE 90.18
401438.4	2369.0	2387.39	24000.	56891.	2678.	8.96	180.2	HORN CREEK
401541.0	2366.0	2388.19	24000.	86342.	3745.	6.41	210.8	INTERPOLATED AT MILE 90.17
402494.4	2329.6	2388.86	24000.	187355.	5965.	4.02	163.1	INTERPOLATED AT MILE 90.15
407088.0	2368.0	2389.49	24000.	134901.	5446.	4.41	279.0	MILE 89.97
408249.6	2393.0	2406.47	24000.	24000.	1418.	16.92	146.7	INTERPOLATED AT MILE 89.10
408302.4	2389.0	2410.33	24000.	43962.	2523.	9.51	183.2	INTERPOLATED AT MILE 88.87
408408.0	2388.0	2411.55	24000.	93111.	4183.	5.74	250.2	INTERPOLATED AT MILE 88.85
412156.8	2412.0	2419.02	24000.	36578.	2525.	9.50	381.4	INTERPOLATED AT MILE 88.14
414110.4	2415.0	2425.85	24000.	34480.	2040.	11.76	221.5	INTERPOLATED AT MILE 87.77
415272.0	2418.0	2429.96	24000.	31198.	1798.	13.35	183.1	INTERPOLATED AT MILE 87.55
415324.8	2417.0	2432.66	24000.	80736.	3990.	6.02	302.9	INTERPOLATED AT MILE 87.54
416222.4	2405.8	2433.38	24000.	162841.	6533.	3.67	310.0	MILE 87.37 USGS GAGE NEAR GRAND CAN

GRAND CANYON SEDIMENT TRANSPORT STUDY  
 COLORADO RIVER, ARIZONA  
 ABOVE NATIONAL CANYON TO ABOVE DIAMOND CREEK  
 RIVER MILES 166.20 TO 225.15

REACH	THALWEG	SURFACE	CRITICAL DISCHARGE	AREA	VELOCITY	TOP WIDTH	USGS GAGE ABOVE DIAMOND C
LENGTH	ELEVATION	ELEVATION	DISCHARGE	AREA	VELOCITY	TOP WIDTH	
1320.0	1310.0	1351.92	190606.	6370.	3.77	207.9	MILE 225.15
6652.8	1299.6	1352.16	400632.	11104.	2.16	246.0	MILE 224.90
7444.8	1302.7	1352.26	328398.	9214.	2.60	211.0	MILE 223.89
8500.8	1260.0	1352.26	188758.	5701.	4.21	143.0	INTERPOLATED AT MILE 223.74
8553.6	1327.0	1352.26	54317.	2278.	10.54	119.0	INTERPOLATED AT MILE 223.54
8659.2	1323.0	1353.30	79127.	3098.	7.75	143.2	INTERPOLATED AT MILE 223.53
10824.0	1300.0	1353.94	118971.	4405.	5.45	183.8	INTERPOLATED AT MILE 223.51
11880.0	1347.0	1354.65	390128.	10956.	2.19	256.6	INTERPOLATED AT MILE 223.10
11932.8	1346.0	1355.73	36559.	2229.	10.77	263.7	INTERPOLATED AT MILE 222.90
12038.4	1344.0	1357.57	74629.	4000.	6.00	366.6	INTERPOLATED AT MILE 222.89
15998.4	1315.0	1358.63	107044.	5255.	4.57	402.3	INTERPOLATED AT MILE 222.87
17107.2	1350.0	1359.59	451654.	13147.	1.83	343.5	INTERPOLATED AT MILE 222.12
19800.0	1351.0	1366.53	37497.	2190.	10.96	237.7	INTERPOLATED AT MILE 221.91
23760.0	1350.0	1370.99	53253.	2520.	9.52	177.2	INTERPOLATED AT MILE 221.40
25396.8	1370.0	1378.53	150274.	6042.	3.97	308.1	INTERPOLATED AT MILE 220.65
25449.6	1368.0	1381.77	24000.	1494.	16.07	183.3	INTERPOLATED AT MILE 220.34
25555.2	1366.0	1382.55	51666.	2565.	9.36	199.6	INTERPOLATED AT MILE 220.33
26716.8	1340.1	1383.66	73842.	3383.	7.10	222.2	INTERPOLATED AT MILE 220.31
28512.0	1360.0	1384.11	166581.	6943.	3.46	304.8	MILE 220.09
28564.8	1358.0	1387.00	37695.	1812.	13.25	116.9	INTERPOLATED AT MILE 219.75
28670.4	1356.0	1387.31	98732.	3965.	6.05	188.0	INTERPOLATED AT MILE 219.74
30729.6	1315.0	1387.79	135071.	5108.	4.70	217.6	INTERPOLATED AT MILE 219.72
31521.6	1355.0	1387.79	325568.	10201.	2.35	267.2	INTERPOLATED AT MILE 219.33
31574.4	1354.0	1389.19	37185.	1758.	13.65	106.1	INTERPOLATED AT MILE 219.18
31680.0	1352.0	1390.74	47719.	2182.	11.00	120.8	INTERPOLATED AT MILE 219.17
32155.2	1343.9	1391.75	82949.	3401.	7.06	152.9	INTERPOLATED AT MILE 219.15
36643.2	1343.3	1391.87	328397.	10155.	2.36	278.0	MILE 219.06
39336.0	1355.0	1391.92	426547.	11831.	2.03	278.0	MILE 218.21
40761.6	1388.0	1402.32	157934.	5925.	4.05	239.6	INTERPOLATED AT MILE 217.70
40814.4	1387.0	1406.63	24000.	1302.	18.43	115.7	INTERPOLATED AT MILE 217.43
42187.2	1373.6	1409.80	46290.	2192.	10.95	146.5	INTERPOLATED AT MILE 217.42
45672.0	1373.6	1410.05	209538.	7213.	3.33	250.0	MILE 217.16
51004.8	1384.0	1410.98	160222.	5387.	4.45	180.0	MILE 216.50
54859.2	1383.1	1411.89	116839.	4640.	5.17	218.9	MILE 215.49
61248.0	1382.2	1413.28	117904.	4415.	5.44	187.3	MILE 214.76
67900.8	1405.0	1421.14	165481.	5939.	4.04	235.7	MILE 213.55
68428.8	1412.0	1422.85	38036.	1859.	12.91	136.7	INTERPOLATED AT MILE 212.29
68481.6	1411.0	1425.75	26475.	1511.	15.89	153.7	INTERPOLATED AT MILE 212.19
68587.2	1409.0	1426.60	48236.	2386.	10.06	181.4	INTERPOLATED AT MILE 212.18
70857.6	1423.0	1430.11	67899.	3082.	7.79	198.9	INTERPOLATED AT MILE 212.16
72916.8	1403.3	1433.05	50517.	3379.	7.10	484.7	INTERPOLATED AT MILE 211.73
76507.2	1406.2	1433.75	195658.	8294.	2.89	429.8	MILE 211.34
79833.6	1425.0	1439.44	95248.	4349.	5.52	267.6	MILE 210.66
83740.8	1422.0	1450.87	30511.	1693.	14.18	156.9	INTERPOLATED AT MILE 210.03
85641.6	1450.0	1456.76	55492.	2658.	9.03	163.5	INTERPOLATED AT MILE 209.29
85694.4	1448.0	1458.15	30837.	2160.	11.11	338.1	INTERPOLATED AT MILE 208.93
85800.0	1447.0	1458.65	56354.	3279.	7.32	350.6	INTERPOLATED AT MILE 208.92
87172.8	1444.0	1459.89	78578.	4259.	5.63	398.0	INTERPOLATED AT MILE 208.90
88545.6	1428.5	1464.48	35915.	1926.	12.46	163.6	INTERPOLATED AT MILE 208.64
90921.6	1430.6	1464.71	192635.	6973.	3.44	260.0	MILE 208.38
93244.8	1447.0	1466.70	226552.	8518.	2.82	335.0	MILE 207.93
96201.6	1457.8	1474.80	31250.	1807.	13.29	162.8	INTERPOLATED AT MILE 207.49
99475.2	1466.0	1477.65	110811.	5626.	4.27	425.0	MILE 206.93
101217.6	1465.0	1480.75	49858.	2752.	8.72	263.6	INTERPOLATED AT MILE 206.31
			36732.	1921.	12.49	159.2	INTERPOLATED AT MILE 205.98



104491.2	1465.0	1487.95	24000.	135452.	5617.	4.27	296.8	INTERPOLATED AT MILE 205.36
105441.6	1480.0	1490.98	24000.	1429.	16.79	156.0	INTERPOLATED AT MILE 205.18	
105494.4	1478.0	1495.22	24000.	64493	3107.	7.72	220.9	INTERPOLATED AT MILE 205.17
105600.0	1476.0	1495.72	24000.	88452.	3984.	6.02	248.7	INTERPOLATED AT MILE 205.15
109612.8	1480.0	1497.42	24000.	121035.	5498.	4.36	355.7	INTERPOLATED AT MILE 204.39
110563.2	1485.0	1498.00	24000.	31631.	1757.	13.66	165.7	INTERPOLATED AT MILE 204.21
110616.0	1484.0	1500.89	24000.	86161.	4048.	5.93	279.5	INTERPOLATED AT MILE 204.20
110721.6	1483.0	1501.23	24000.	123733.	5530.	4.34	346.3	INTERPOLATED AT MILE 204.18
114998.4	1483.0	1502.25	24000.	133514.	6418.	3.74	433.9	MILE 203.37
116793.6	1455.4	1502.53	24000.	198646.	7366.	3.26	281.0	MILE 203.03
119803.2	1485.2	1502.87	24000.	146122.	6666.	3.60	433.7	MILE 202.46
123024.0	1494.0	1506.85	24000.	36491.	2037.	11.78	195.7	INTERPOLATED AT MILE 201.85
123710.4	1484.0	1508.03	24000.	29122.	1582.	15.17	125.2	INTERPOLATED AT MILE 201.72
123763.2	1483.0	1510.55	24000.	44454.	2254.	10.65	157.5	INTERPOLATED AT MILE 201.71
123868.8	1482.0	1511.69	24000.	64273.	3034.	7.91	182.8	INTERPOLATED AT MILE 201.69
125769.6	1490.8	1513.45	24000.	139277.	6016.	3.99	333.2	MILE 201.33
127089.6	1491.0	1513.65	24000.	103606.	4503.	5.33	257.7	INTERPOLATED AT MILE 201.08
128251.2	1480.0	1513.65	24000.	88311.	1787.	13.43	103.0	INTERPOLATED AT MILE 200.86
128304.0	1479.0	1516.60	24000.	35971.	3756.	6.39	192.4	INTERPOLATED AT MILE 200.85
128409.6	1477.0	1516.80	24000.	98826.	4195.	5.72	204.0	INTERPOLATED AT MILE 200.83
130574.4	1491.0	1517.55	24000.	132081.	5414.	4.43	271.2	INTERPOLATED AT MILE 200.42
133478.4	1484.4	1518.12	24000.	311221.	10990.	2.18	409.8	MILE 199.87
137438.4	1496.0	1518.47	24000.	125899.	5050.	4.75	253.5	INTERPOLATED AT MILE 199.12
138336.0	1507.0	1519.19	24000.	26812.	1460.	16.43	135.4	INTERPOLATED AT MILE 198.95
138388.8	1506.0	1521.90	24000.	43060.	2098.	11.44	153.6	INTERPOLATED AT MILE 198.94
138811.2	1502.0	1524.23	24000.	107277.	4389.	5.47	228.9	INTERPOLATED AT MILE 198.86
140712.0	1516.0	1528.12	24000.	27046.	1478.	16.23	137.5	INTERPOLATED AT MILE 198.50
140764.8	1514.0	1531.38	24000.	53826.	2496.	9.62	165.9	INTERPOLATED AT MILE 198.49
140870.4	1512.0	1532.22	24000.	76992.	3326.	7.22	190.9	INTERPOLATED AT MILE 198.47
142296.0	1508.4	1533.43	24000.	150460.	6159.	3.90	319.5	MILE 198.20
144038.4	1485.3	1533.77	24000.	341734.	11233.	2.14	348.9	MILE 197.87
146678.4	1518.6	1534.52	24000.	74558.	4042.	5.94	354.6	MILE 197.37
148262.4	1513.0	1535.61	24000.	142242.	6238.	3.85	354.0	MILE 197.07
150321.6	1470.7	1536.01	24000.	532911.	13798.	1.74	278.3	MILE 196.68
153120.0	1521.0	1537.99	24000.	38770.	2005.	11.97	160.0	INTERPOLATED AT MILE 196.15
155232.0	1515.9	1542.94	24000.	140555.	5692.	4.22	277.7	MILE 195.75
156182.4	1535.0	1543.84	24000.	40234.	2495.	9.62	304.2	INTERPOLATED AT MILE 195.57
157291.2	1539.0	1547.57	24000.	33414.	2113.	11.36	267.8	INTERPOLATED AT MILE 195.36
157344.0	1538.0	1548.87	24000.	53290.	3014.	7.96	303.5	INTERPOLATED AT MILE 195.35
157449.6	1536.0	1549.43	24000.	75341.	3874.	6.20	321.7	INTERPOLATED AT MILE 195.33
159720.0	1538.0	1551.05	24000.	81604.	4214.	5.70	354.2	INTERPOLATED AT MILE 194.90
161832.0	1539.0	1553.26	24000.	42122.	2226.	10.78	191.3	INTERPOLATED AT MILE 194.50
162307.2	1543.0	1555.45	24000.	77203.	4063.	5.91	357.2	INTERPOLATED AT MILE 194.41
162360.0	1542.0	1555.59	24000.	88285.	4475.	5.36	362.9	INTERPOLATED AT MILE 194.40
163152.0	1525.2	1556.15	24000.	193107.	7528.	3.19	343.4	MILE 194.25
165422.4	1546.0	1557.72	24000.	49883.	2609.	9.20	227.3	INTERPOLATED AT MILE 193.82
168643.2	1555.0	1564.55	24000.	43777.	2619.	9.16	297.8	INTERPOLATED AT MILE 193.21
172656.0	1545.9	1570.91	24000.	165082.	7188.	3.34	389.7	MILE 192.45
174398.4	1555.0	1572.02	24000.	35562.	2025.	11.85	187.2	INTERPOLATED AT MILE 192.12
176299.2	1550.0	1576.44	24000.	51533.	2666.	9.00	191.8	INTERPOLATED AT MILE 191.76
178780.8	1545.0	1578.94	24000.	79275.	3627.	6.62	203.8	INTERPOLATED AT MILE 191.29
180259.2	1555.0	1579.85	24000.	36114.	1954.	12.28	153.4	INTERPOLATED AT MILE 191.01
180312.0	1554.0	1581.71	24000.	59787.	3026.	7.93	206.8	INTERPOLATED AT MILE 191.00
180417.6	1552.0	1582.13	24000.	72993.	3568.	6.73	230.5	INTERPOLATED AT MILE 190.98
182740.8	1563.3	1583.57	24000.	149083.	7203.	3.33	478.8	MILE 190.54
186172.8	1565.0	1584.51	24000.	74713.	3924.	6.12	311.9	INTERPOLATED AT MILE 189.89
188020.8	1570.0	1590.69	24000.	24000.	1394.	17.21	127.6	INTERPOLATED AT MILE 189.54
188073.6	1568.0	1595.13	24000.	49670.	2587.	9.28	190.0	INTERPOLATED AT MILE 189.53
188179.2	1566.0	1595.98	24000.	71456.	3453.	6.95	219.9	INTERPOLATED AT MILE 189.51
189921.6	1567.3	1597.06	24000.	75229.	4188.	5.73	303.3	MILE 189.18
195412.8	1585.0	1601.18	24000.	55877.	2734.	8.78	200.7	INTERPOLATED AT MILE 188.14
197205.0	1588.0	1603.73	24000.	40816.	2076.	11.56	162.9	INTERPOLATED AT MILE 187.80
								WILTMORE R

197260.8	1586.0	1604.78	24000.	56996.	2672.	8.98	179.1	INTERPOLATED AT MILE 187.79
197894.4	1580.7	1606.43	24000.	171002.	6971.	3.44	342.9	MILE 187.67
200798.4	1588.1	1606.85	24000.	142027.	7111.	3.38	517.1	MILE 187.12
207345.6	1591.0	1610.29	24000.	54131.	2834.	8.47	224.2	INTERPOLATED AT MILE 185.88
210091.2	1592.0	1613.02	24000.	69010.	3445.	6.97	248.2	INTERPOLATED AT MILE 185.36
211622.4	1591.0	1614.51	24000.	27581.	3456.	15.83	122.5	INTERPOLATED AT MILE 185.07
211675.2	1590.0	1617.40	24000.	43844.	2230.	10.76	156.7	INTERPOLATED AT MILE 185.06
211780.8	1588.0	1618.59	24000.	64080.	3030.	7.92	182.3	INTERPOLATED AT MILE 185.04
212625.6	1568.7	1620.03	24000.	297219.	10579.	2.27	355.1	MILE 184.88
218750.4	1597.5	1620.51	24000.	154247.	6367.	3.77	338.0	MILE 183.72
223027.2	1620.0	1630.26	24000.	29828.	1740.	13.79	185.4	INTERPOLATED AT MILE 182.91
223502.4	1619.0	1631.97	24000.	25052.	1371.	17.50	125.7	INTERPOLATED AT MILE 182.82
223555.2	1618.0	1635.88	24000.	50371.	2362.	10.16	159.6	INTERPOLATED AT MILE 182.81
223660.8	1618.0	1636.60	24000.	62204.	2845.	8.44	182.4	INTERPOLATED AT MILE 182.79
226248.0	1625.0	1639.32	24000.	66314.	3278.	7.32	251.3	INTERPOLATED AT MILE 182.30
229310.4	1620.0	1641.58	24000.	79667.	3420.	7.02	192.3	INTERPOLATED AT MILE 181.72
229891.2	1627.0	1641.58	24000.	33913.	1750.	13.72	142.5	INTERPOLATED AT MILE 181.61
229944.0	1626.0	1643.29	24000.	50345.	2388.	10.05	164.7	INTERPOLATED AT MILE 181.60
230049.6	1624.0	1644.24	24000.	73187.	3220.	7.45	190.9	INTERPOLATED AT MILE 181.58
234432.0	1615.0	1646.58	24000.	146487.	5395.	4.45	219.4	INTERPOLATED AT MILE 180.75
234801.6	1633.0	1646.58	24000.	29498.	1568.	15.31	136.3	INTERPOLATED AT MILE 180.68
234854.4	1632.0	1649.81	24000.	64309.	2953.	8.13	193.3	INTERPOLATED AT MILE 180.67
234960.0	1630.0	1650.35	24000.	88201.	3793.	6.33	218.0	INTERPOLATED AT MILE 180.65
237336.0	1643.0	1654.68	24000.	32072.	1774.	13.53	169.8	INTERPOLATED AT MILE 180.20
240081.6	1648.0	1663.88	24000.	62459.	2982.	8.05	212.3	INTERPOLATED AT MILE 179.68
240115.2	1655.0	1664.86	24000.	30411.	1795.	13.37	197.2	INTERPOLATED AT MILE 179.56
240768.0	1653.0	1667.11	24000.	62092.	3094.	7.76	241.0	INTERPOLATED AT MILE 179.55
242510.4	1666.5	1677.31	24000.	53862.	2474.	9.70	159.8	INTERPOLATED AT MILE 179.36
242563.2	1665.5	1681.03	24000.	24000.	1394.	17.22	145.6	INTERPOLATED AT MILE 179.22
242568.8	1663.0	1682.00	24000.	48631.	2378.	10.09	177.0	INTERPOLATED AT MILE 179.21
246787.2	1651.9	1684.32	24000.	72732.	3242.	7.40	200.0	INTERPOLATED AT MILE 179.19
249691.2	1659.5	1684.91	24000.	133096.	5119.	4.69	218.3	MILE 178.41
251064.0	1670.0	1685.40	24000.	144699.	6027.	3.98	306.4	MILE 177.86
252331.2	1662.5	1687.76	24000.	51850.	2532.	9.48	188.1	INTERPOLATED AT MILE 177.60
253704.0	1676.0	1689.20	24000.	122707.	5876.	4.08	374.1	MILE 177.36
254760.0	1675.0	1694.46	24000.	31006.	1721.	13.95	161.4	INTERPOLATED AT MILE 177.10
255921.6	1670.0	1695.10	24000.	88646.	3999.	6.00	249.8	INTERPOLATED AT MILE 176.90
256872.0	1660.2	1695.40	24000.	134238.	5393.	4.45	266.3	INTERPOLATED AT MILE 176.68
258667.2	1665.0	1695.48	24000.	201723.	8028.	2.99	359.5	MILE 176.50
260040.0	1679.0	1696.14	24000.	105782.	4280.	5.61	202.9	INTERPOLATED AT MILE 176.16
260884.8	1685.0	1697.97	24000.	44546.	2212.	10.85	164.3	INTERPOLATED AT MILE 175.90
260937.6	1683.0	1700.13	24000.	32338.	1775.	13.52	163.5	INTERPOLATED AT MILE 175.74
261043.2	1681.0	1700.73	24000.	59752.	2865.	8.38	202.3	INTERPOLATED AT MILE 175.73
266798.4	1685.0	1704.93	24000.	83007.	3712.	6.47	228.9	INTERPOLATED AT MILE 175.71
268171.2	1690.0	1706.65	24000.	54755.	2569.	9.34	169.7	INTERPOLATED AT MILE 174.62
268593.6	1691.5	1706.65	24000.	53294.	2602.	9.22	190.4	INTERPOLATED AT MILE 174.36
268646.4	1690.5	1711.13	24000.	25148.	1381.	17.38	122.2	INTERPOLATED AT MILE 174.28
268752.0	1689.0	1711.71	24000.	60150.	2768.	8.67	176.5	INTERPOLATED AT MILE 174.27
270072.0	1690.9	1712.64	24000.	79080.	3454.	6.95	198.8	INTERPOLATED AT MILE 174.25
271550.4	1681.2	1713.05	24000.	105093.	4485.	5.35	248.6	MILE 174.00
274137.6	1695.0	1714.63	24000.	72381.	3403.	7.05	192.8	MILE 173.72
274771.2	1697.0	1714.63	24000.	91491.	4045.	5.93	244.6	INTERPOLATED AT MILE 173.23
274824.0	1695.0	1716.42	24000.	39251.	1959.	12.25	145.7	INTERPOLATED AT MILE 173.11
274929.6	1693.0	1717.16	24000.	69657.	3110.	7.72	187.0	INTERPOLATED AT MILE 173.10
277147.2	1693.1	1717.73	24000.	124386.	5055.	4.75	256.7	INTERPOLATED AT MILE 173.08
283008.0	1697.0	1721.60	24000.	86189.	3943.	6.09	229.8	MILE 172.66
284275.2	1701.0	1724.04	24000.	50984.	2515.	9.54	169.8	INTERPOLATED AT MILE 171.55
284328.0	1700.0	1728.30	24000.	24000.	1346.	17.83	115.3	INTERPOLATED AT MILE 171.31
284539.2	1704.5	1730.61	24000.	43663.	2218.	10.82	156.1	INTERPOLATED AT MILE 171.30
288710.4	1700.9	1731.16	24000.	155468.	6976.	3.44	410.0	MILE 171.26
291720.0	1690.0	1731.64	24000.	124477.	4925.	4.87	225.5	MILE 170.47
				139655.	4960.	4.84	176.5	INTERPOLATED AT MILE 169.90

LAVA FALLS

292036.8	1712.0	1731.64	24000.	62059.	2755.	8.71	166.4	INTERPOLATED AT MILE 169.84
292089.6	1710.0	1732.59	24000.	117164.	4720.	5.08	238.9	INTERPOLATED AT MILE 169.83
292776.0	1691.4	1732.86	24000.	175948.	5869.	4.09	190.8	MILE 169.70
296102.4	1712.3	1733.57	24000.	92643.	4046.	5.93	237.3	MILE 169.07
300696.0	1692.0	1735.07	24000.	103765.	4270.	5.62	195.9	INTERPOLATED AT MILE 168.20
301118.4	1708.0	1735.07	24000.	32342.	1665.	14.42	119.5	INTERPOLATED AT MILE 168.12
301171.2	1719.0	1738.29	24000.	64991.	3108.	7.72	214.0	INTERPOLATED AT MILE 168.11
301276.8	1708.0	1738.29	24000.	58089.	2796.	8.59	175.6	INTERPOLATED AT MILE 168.09
303441.6	1717.1	1740.45	24000.	83215.	3888.	6.17	251.4	MILE 167.68
308299.2	1716.0	1742.37	24000.	204239.	8038.	2.99	381.4	INTERPOLATED AT MILE 166.76
310464.0	1728.0	1744.45	24000.	31500.	1793.	13.39	166.3	INTERPOLATED AT MILE 166.35
310516.8	1727.0	1745.57	24000.	39089.	2123.	11.30	179.1	INTERPOLATED AT MILE 166.34
310622.4	1728.0	1745.76	24000.	38175.	2085.	11.51	179.6	INTERPOLATED AT MILE 166.32
311256.0	1721.5	1748.82	24000.	179938.	6624.	3.62	279.3	MILE 166.20 USGS GAGE ABOVE NATIONAL

Table 4  
Adjustment in Streambed Profile

Reach 1

Cross Section Locations - At or Near Critical Discharge for 25,700 Ft <sup>3</sup> /s	----- Computed Water ----- Surface Elevation Feet		$\Delta h$ Difference in Water Surface Elevation Feet
	10,000 Ft <sup>3</sup> /s	25,700 Ft <sup>3</sup> /s	
River Mile			
59.72	2717.75	2721.70	3.95
56.57*	2749.60	2753.37	3.77
53.29	2772.33	2776.18	3.85
43.55*	2819.52	2822.95	3.43
36.05	2844.16	2849.14	4.98
30.10	2875.59	2882.24	6.65
26.56	2903.61	2907.93	4.32
24.89	2926.55	2932.37	5.82
16.97*	3005.92	3009.97	4.05
14.37*	3021.91	3025.88	3.97
11.14	3051.80	3057.63	5.83
7.81	3050.58	3083.34	2.76
0.0**	3111.20	3114.61	3.41
		Average	4.37
		Use	4 Feet

Reach 2

Cross Section Locations - At or Near Critical Discharge for 24,300 Ft <sup>3</sup> /s	----- Computed Water ----- Surface Elevation Feet		$\Delta h$ Difference in Water Surface Elevation Feet
	10,000 Ft <sup>3</sup> /s	24,300 Ft <sup>3</sup> /s	
River Mile			
84.64	2436.86	2441.30	4.44
83.42	2450.88	2456.08	5.20
81.54	2477.06	2484.58	7.52
78.58	2512.30	2517.09	4.79
78.05	2521.38	2526.26	4.88
76.63	2556.95	2560.03	3.08
75.23	2576.83	2581.23	4.40
72.36	2606.98	2610.88	3.90
63.25	2690.48	2695.56	5.08
		Average	4.81
		Use	5.00 Feet

\* Near critical discharge (Critical Discharge less than 5 percent greater than 25,700 Ft<sup>3</sup>/s)

\*\* Gage at Lees Ferry

Table 4  
(Continued)

Reach 3

Cross Section Locations - At or Near Critical Discharge for 24,800 Ft <sup>3</sup> /s	----- Computed Water ----- Surface Elevation Feet		$\Delta h$ Difference in Water Surface Elevation Feet
	10,000 Ft <sup>3</sup> /s	24,800 Ft <sup>3</sup> /s	
River Mile			
153.56	1787.33	1795.16	7.83
149.67	1820.93	1825.61	4.68
143.54	1877.17	1880.87	3.70
139.85	1888.81	1894.78	5.97
139.00	1902.06	1907.92	5.86
136.30	1925.10	1932.17	7.07
134.26	1948.69	1951.81	3.12
131.53	1980.62	1985.16	4.54
130.40	1991.92	1997.86	5.94
129.04	1996.84	2004.51	7.67
128.47	2006.77	2011.65	4.88
126.23	2024.91	2030.68	5.77
124.67	2046.17	2051.54	5.37
122.63	2068.31	2073.20	4.89
121.56	2071.83	2078.87	7.04
120.00	2083.62	2088.65	5.03
112.10	2136.37	2141.91	5.54
107.28	2185.57	2189.94	4.37
105.88	2208.18	2213.18	5.00
104.58	2223.50	2228.65	5.15
102.66	2236.80	2245.19	8.39
101.18	2249.11	2254.03	4.92
99.10	2274.18	2277.60	3.42
98.17	2306.85	2312.23	5.38
96.57	2319.39	2323.71	4.32
94.88	2330.71	2337.96	7.25
93.27	2355.30	2358.84	3.54
90.18	2373.45	2378.50	5.05
88.88	2396.13	2401.72	5.59
		Average	5.42
		Use	5.0 Feet

Reach 4

Cross Section Locations - At or Near Critical Discharge for 24,900 Ft <sup>3</sup> /s	----- Computed Water ----- Surface Elevation Feet		$\Delta h$ Difference in Water Surface Elevation Feet
	10,000 Ft <sup>3</sup> /s	24,900 Ft <sup>3</sup> /s	
River Mile			
225.70	1328.66	1331.69	3.03
223.54	1333.03	1337.99	4.96
220.34	1369.78	1373.74	3.96
217.43	1391.37	1397.64	6.27
205.18	1481.31	1486.23	4.92
189.54	1579.27	1586.00	6.73
182.82	1623.13	1627.19	4.06
179.22	1667.62	1672.56	4.94
174.28	1695.59	1702.59	7.00
171.31	1712.23	1719.38	7.15
		Average	5.30
		Use	5.0 Feet

Table 5  
Comparison of Computed Water  
Surface Elevations with Surveyed (1985)  
Elevations at Selected Rapids  
Q = 27,700 Ft<sup>3</sup>/s

Reach 1

Location Rapids	River Mile	----- Downstream ----- (Feet)				----- Upstream ----- (Feet)			
		Distance Below Top of Rapid	Computed Elevation	Observed Elevation	Difference	Distance Upstream From Rapid	Computed Elevation	Observed Elevation	Difference
36 Mile Rapid	36.17	634	2852.1	NA	NA				
	36.05					0	2853.7		
	36.04					53	2859.2	2859.4	-0.2
	36.02					158	2859.3		-0.1
President Harding	43.74	1000	2824.6	2826.7	+0.3				
		500	2825.9*		-0.8				
	43.55					0	2828.0		
	43.54					53	2832.2	2830.9	+1.3
Nankoweap	43.52					158	2832.3		
	52.82	3480	2787.8	2787.0	+0.3				
		3040	2788.7*		+1.7				
	52.16					0	2795.9		
Kwagunt	52.15					53	2797.7	2802.1	-4.4
	52.13					158	2798.3		-3.8
	56.19	1060	2764.0	2763.2	-0.5				
		305	2765.9*		+2.7				
Little Colorado River	55.99					0	2768.9		-1.2
	55.98					53	2773.4	2770.1	+3.3
	55.96					158	2773.4		
	NA	3652	NA	2715.0	NA				
Little Colorado River	61.32					0	2721.0		
	61.31					53	2721.7	2721.5	+0.2
	61.00					1700	2724.4		

\* Straight line interpretation between computed elevations

Comparison of Computed Water  
Surface Elevations with Surveyed (1985)  
Elevations at Selected Rapids  
Q = 26,700 Ft<sup>3</sup>/s

Reach 2

Unkar	72.59	1210	2613.2	2614.0	-0.8				
	72.36					0	2616.2		
	72.35					53	2619.6	2623.2	-3.6
	71.79					3010	2621.0		
Hance	76.93	1580	2545.0	2548.0	-3.0				
	76.63					0	2565.1		
	76.62					53	2568.1	2569.0	-0.9
	76.11					2745	2569.6		
Grand Canyon Gage	87.77	1160	2426.30	2427.6	-1.3				
	87.55					0	2430.6		
	87.54					53	2433.6	2432.8	+0.8
	87.37					2110	2434.3		

Table 5  
(Continued)

Comparison of Computed Water  
Surface Elevations with Surveyed (1985)  
Elevations at Selected Rapids  
Q varying from 12,700 to 26,800 Ft<sup>3</sup>/s

Reach 3

Location Rapids	River Mile	Discharge Ft <sup>3</sup> /s	Downstream ----- (Feet)				Upstream ----- (Feet)			
			Distance Below Top of Rapid	Computed Elevation	Observed Elevation	Difference	Distance Upstream From Rapid	Computed Elevation	Observed Elevation	Difference
Granite	93.40	26800	1100	2356.5	2355.8	+0.6				
	93.27						0	2364.2		
	93.26						53	2368.0	2368.5	-0.5
	93.24						158	2368.7	2368.7	0.0
	92.98						1530	2368.8		
Crystal	98.55	26800	2010	2295.8	2296.6	-0.8				
	98.17						0	2317.8		
	98.16						53	2322.4	2321.6	+0.8
	98.14						158	2323.4	2322.6	+0.8
	97.68						2600	2324.5		
Serpentine	106.00	26800	700	2212.0	2212.9	-0.9				
	105.88						0	2218.7		
	105.87						53	2222.3	2221.7	+0.6
	105.85						158	2224.0	2223.2	+0.8
	105.52						1900	2224.7		
Bass	108.47	26800	2590	2175.0	2180.4	-5.4				
	107.98						0	2196.1		
	107.97						53	2199.2	2197.9	+1.3
	107.95						158	2200.4	2198.4	+2.0
	107.30						3600	2205.1		
Blacktail	120.12	26800	630	2091.5	-----					
	120.00						0	2094.2		
	119.99						53	2096.8	2096.2	+0.6
	119.97						158	2098.9	2096.2	+2.7
	-						1460*	2100.1	2096.9	+3.2
Deubendorff	119.28						3750	2102.1		
	131.79	12700	1370	1977.0	1976.9	+0.1				
	131.53						0	1986.6		
	131.52						53	1989.9	1990.1	-0.2
	-						660*	1990.1	1990.3	-0.2
	131.37						850	1990.2		
Deer Creek	136.59	14600	1300	1927.9	1928.7	-0.8				
	136.30						0	1932.6		
	136.29						53	1937.6	1936.2	+1.4
	136.27						158	1937.9	1937.1	+0.7
	135.80						2640	1938.3		
Kanab Creek	144.2	12700	3480	1869.0	1872.0	-1.8				
	-									
	143.81									
	143.54						0	1882.9		
	143.53						53	1885.35	1886.5	-1.2
Upset	143.51						158	1885.9	1887.6	-1.7
	143.32						1160	1886.0		
	149.79	18200	630	1820.6	1821.0	-0.4				
	149.67						0	1828.7		
	149.66						53	1831.3	1831.1	+0.2
	149.64						158	1832.3	1831.6	+0.7
	149.22						2380	1834.4		
159.2 Mile	159.47	14600	1480	1767.9	1767.6	+0.3				
	159.19						0	1769.0		
	159.18						53	1770.4	1770.1	+0.3
	-						294*	1770.4	1770.3	+0.1
	158.94						1320	1770.6		

\* Straight line interpolation between computed elevations

Table 5  
(Continued)

Comparison of Computed Water  
Surface Elevations with Surveyed (1985)  
Elevations at Selected Rapids  
Q = 18,800 or 27,600 Ft<sup>3</sup>/s

Reach 4

Location Rapids	River Mile	Discharge Ft <sup>3</sup> /s	Downstream ----- (Feet)				Upstream ----- (Feet)			
			Distance Below Top of Rapid	Computed Elevation	Observed Elevation	Difference	Distance Upstream From Rapid	Computed Elevation	Observed Elevation	Difference
National Canyon	166.76	18800	2160	1739.5	1738.8	+0.7				
	166.35						0	1742.2		
	166.34						53	1743.4		
	166.32						158	1743.6	1743.6	-0.2
Cove Canyon	166.2	27600	1160*	1706.4	1708.1	-0.9	790	1746.5	1743.8	-0.2
	174.62									
	174.50									
	174.36									
	174.28									
	174.27						0	1708.1		
	174.25						53	1712.6		
	174.00						158	1713.3	1712.3	+0.3
Lava Falls	179.55	27600	1336*	1668.2	1668.1	+0.3				
	179.47									
	179.36									
	179.22									
	179.21									
	178.19						0	1678.3		
	178.41						53	1682.3	1682.5	-0.2
							158	1683.3	1684.4	-1.1
								1685.8		

\* Straight line interpolation between computed elevations



Table 6  
Estimated Discharge At Rapids  
Surveyed by USGS Mapping Service - 1985

Rapids	Miles Below Grand Canyon Gage	Hours Below Grand Canyon Gage @4 mi/hr	Time at Rapids		Time at Grand Canyon Gage	Discharge at Rapids Ft <sup>3</sup> /s	Discharge for Computer Computations (Average Value) Ft <sup>3</sup> /s
			Day	Time			
Reach 3							
Granite	5.9	1.5	2/28	1:15PM	11:45PM	26800	26800
Crystal	10.8	2.7	2/28	11:10AM	8:30AM	26900	26800
Serpentine	18.5	4.6	2/28	8:30AM	3:54AM	26900	26800
Bass	20.6	5.2	2/27	3:45PM	10:30AM	27200	26800
Blacktail	32.6	8.2	2/27	12:05PM	3:53AM	26400	26800
Deubendorff	44.1	11.0	4/2	11:45AM	12:45AM	13200	12700
Kanab Creek	56.1	14.0	3/26	1:15PM	11:15PM (25)	12200	12700
Deer Creek	48.9	12.2	4/2	9:30AM	9:18PM (1)	14400	14600
159.2 Mile	71.8	18.0	3/25	1:30PM	7:30PM (24)	14900	14600
Upset	62.3	15.6	3/26	10:10AM	6:34PM (25)	17600	18200
Reach 4							
National Canyon	79.0	19.7	3/25	10:20AM	2:38PM (24)	18800	18200
Cove Canyon	86.9	21.7	3/6	10:30AM	12:48PM (5)	27600	27600
Lava Falls	91.8	23.0	3/6	1:05PM	2:05PM (5)	27600	27600

Table 7  
Water Surface Elevations at Gages  
Lees Ferry Gage-Feet

Q Ft <sup>3</sup> /s	Rating Curve	Computed	Difference Δh
5,000	3113.17	3113.20	+0.03
7,500	3114.03	3113.85	-0.18
10,000	3114.75	3114.43	-0.32
17,000	3116.18	3115.87	-0.31
24,000	3117.30	3117.15	-0.15
27,700	3117.85	3117.78	-0.07
95,000	3124.16	3125.20	+1.00
95,000*	3124.16	3124.35	-0.19

Cross Section 87.37 at USGS Gage-Feet

Discharge Ft <sup>3</sup> /s	Rating Table	Computed Elevation	Difference Δh
5,000	2424.5	2424.7	+0.2
7,500	2426.2	2426.2	0.0
10,000	2427.6	2427.6	0.0
17,000	2430.7	2430.8	+0.1
24,000	2433.0	2433.4	+0.4
26,700	2433.8	2434.3	+0.5
96,200	2446.8	2449.3	+2.5
96,200*	2446.8	2448.8	+2.0

Above National Canyon Sampling Cableway-Feet

Discharge Ft <sup>3</sup> /s	Rating Table at Gage	Reach 4 Computation	Difference Δh
5,000	1737.6	1737.8	+0.2
7,500	1739.9	1739.6	-0.3
10,000	1741.7	1741.7	0.0
17,000	1745.6	1745.6	0.0
20,800	1747.2	1747.2	0.0
24,000	1748.5	1748.8	+0.3
27,600	1749.7	1750.3	+0.6
35,000	1751.9	1752.8	+0.9
96,200	1763.2	1768.0	+4.8

Above Diamond Creek Sampling Cableway-Feet

Discharge Ft <sup>3</sup> /s	Rating Table at Gage**
5,000	1346.7
7,500	1348.2
10,000	1349.4
17,000	1351.2
24,000	1351.9
27,600	1352.9
35,000	1354.4
96,200	1370.4***

\* n value equals 0.02

\*\* Rating for August to December 1983

\*\*\* Extrapolation of Rating Table

Table 8  
Comparison of High Water Marks

Reach 1  
June 1983 Peak Discharge Equal 95,000 Ft<sup>3</sup>/s

Location	Elevation-Feet		Difference
	Observed	Computed*	
Lees Ferry Gage	3124.2	3124.4	+0.2
Nankoweap Rapids	2814.4	2810.4	-4.0
Kwagunt Rapids	2779.6	2788.0	+8.4

Reach 2  
June 1983 Peak Discharge Equal 96,200 Ft<sup>3</sup>/s

Location	Elevation - Feet		Difference
	Observed	Computed*	
Mouth of Little Colorado River	2739.1	2731.2	-7.9
Unkar Rapids	2631.9	2627.3 2630.8** 2634.4	-1.1
Hance Rapids	2581.2	2579.4	-1.8
Grand Canyon Gage	2446.8	2448.8	+2.0

Reach 3  
June 1983 Peak Discharge Equal 96,200 Ft<sup>3</sup>/s

Location	Elevation - Feet		Difference
	Observed	Computed*	
Granite Rapids (Mile 93.27)	2377.7	2377.1	-0.6
Crystal Rapids (Mile 98.17)	2334.1	2332.7	-1.4
Serpentine Rapids (Mile 105.88)	2233.1	2233.4	+0.3
Bass Rapids (Mile 107.98)	2207.6	2209.1	+1.5
Blacktail Rapids (Mile 120.00)	2107.9	2111.1	+3.2
Deubendorff Rapids (Mile 131.53)	2000.8	2003.7	+2.9
Deer Creek Rapids (Mile 136.30)	1952.9	1954.6	+1.7
Kanab Creek Rapids (Mile 143.54)	1900.2	1897.9	-2.3
Upset Rapids (Mile 149.67)	1852.7	1844.5	-8.2
159.2 Mile Rapids (Mile 159.19)	1800.2	1799.3	-0.9

Table 8  
(Continued)

Reach 4  
June 1983 Peak Discharge Equal 96,200 Ft<sup>3</sup>/s

Location	Elevation - Feet		Difference
	Observed	Computed*	
National Canyon (Mile 166.35)	1764.3	1764.9**	+0.6
Cove Canyon (Mile 174.28)	1726.9	1727.2**	+0.3
Lava Falls (Mile 179.22)	1702.9	1695.5** 1702.3***	-7.4 -0.6

\* n value equals 0.02

\*\* Average value at brink and 53 feet upstream from brink

\*\*\* At section about 4000 feet upstream from brink

Table 9

COLORADO RIVER TRANSPORT STUDY  
SAND LOAD RATING CURVES  
1983 and 1985-86 Data

Location	Discharge Limits		Sand Load Equation - Tons/Day		R Correlation Coefficient
1	0 CFS	to 25,000 CFS	$= 0.21029E-11*Q^{**03.3326}$		--
1	25,000 CFS	to Maximum	$= 0.27301E-14*Q^{**03.9864}$		0.897
3	0 CFS	to 40,000 CFS	$= 0.46047E-10*Q^{**03.2228}$		0.915
3	40,000 CFS	to Maximum	$= 0.57336E-05*Q^{**02.1117}$		--
4, 5&6	0 CFS	to 25,000 CFS	$= 0.31854E-10*Q^{**03.3326}$		0.898
	25,000 CFS	to Maximum	$= 0.10114E-04*Q^{**02.1117}$		0.675

Legend: Location 1 = Colorado River at Lees Ferry  
 Location 3 = Colorado River above Little Colorado River  
 Location 4 = Colorado River near Grand Canyon  
 Location 5 = Colorado River above National Canyon  
 Location 6 = Colorado River above Diamond Creek

Table 10  
Size Gradation  
Total Sand Load at Sampling Station  
Colorado River, Lees Ferry to National Canyon

Sampling Station	Year	Range in Measurements	Range in Discharges	Percent Finer Than (Sieve Size in Millimeters)									
				0.0625	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0
Lees Ferry	1983	13	23170 to 91044	0	13.4	31.7	65.9	86.0	93.8	98.1	99.5	99.9	100
	1985-86	2	14855 to 14876	0	31.1	56.0	83.1	99.3	100.0				
Above Little Colorado River	1983	9	23845 to 57643	0	12.9	47.2	90.8	99.2	100.0				
	1985-86	2	9223 to 9308	0	48.8	78.6	94.5	100.0					
Near Grand Canyon	1983	12	23813 to 83542	0	8.6	33.6	85.0	98.1	99.7	99.9	100.0		
	1985-86	2	8976 to 15612	0	20.0	57.5	89.5	96.8	100.0				
Above National Canyon	1983	10	23027 to 55133	0	13.5	43.0	89.1	99.0	99.9	100.0			
	1985-86	2	9977 to 12543	0	41.6	66.0	86.8	99.4	99.9	100.0			
SCENARIOS													
Lees Ferry	1985-86		Toffaleti	0	56.1	68.7	88.3	98.6	99.9	100.0			
Above Little Colorado River	1985-86		Toffaleti	0	33.9	85.1	99.6	99.8	99.9	100.0			

Table 11  
Modified Einstein Total Load - Parla River at Lees Ferry

Date	Time	Discharge Measurement				Temp. (F)	Susp. Load (C, mg/L)	Bed Material		Susp. Load (t/d)	Total Load (t/d)	%
		Q (ft <sup>3</sup> /s)	Width (feet)	Vel. (ft/s)	Avg. Depth (feet)			D <sub>35</sub> (mm)	D <sub>65</sub> (mm)			
8/5/83	945	200	55	3.28	1.11	75	196,830	.229	.330	106,300	110,450	3.9
8/8/83	1,150	48	34	2.67	0.54	86	96,012	.229	.330	12,470	13,920	11.6
8/17/83	1,736	54	33	3.14	0.52	83	184,481	.229	.330	26,900	28,920	7.5
8/19/83	800	250	48	5.31	0.98	73	150,757	.229	.330	101,800	108,950	7.0
Average												7.5

SEDIMENT LOAD  
PARIA RIVER

Qw.A.D. =	29.55	D.D.x365x1.9835 =	21,400	(AF)/yr.
Qs.A.D. =	10,908	D.D.x365 =	3,981,000	Tons/yr.
<u>7.5</u>	Percent Correction for Bedload =	<u>298,600</u>	Tons/yr.	
	Total Sediment Discharge =	4,279,600	Tons/yr.	

D.D. = Daily Discharge  
A.D. = Annual Discharge  
D.A. = Drainage Area  
    = lbs./cubic foot = 72  
    = Tons/acre foot = 1568



Table 13

## Sand Load Equations for Tributary Inflow

<u>Tributary</u>	<u>Range in Discharge or Season</u>	<u>Equation</u>
Paria River	$Q < 80 \text{ ft}^3/\text{s}$	$Q_s = 0.82521\text{E-}02 * Q^{**3.1342}$
	$Q, 80 \text{ to } 1,100 \text{ ft}^3/\text{s}$	$Q_s = 1.02102 * Q^{**1.8319}$
	$Q > 1,100 \text{ ft}^3/\text{s}$	$Q_s = 387 * Q$
Little Colorado River	Dec to May	$Q_s = 0.2435 * Q^{**1.4777}$
	Jun to Nov	$Q_s = 4.1722 * Q^{**1.2769}$
Kanab Creek	$Q < 20 \text{ ft}^3/\text{s}$	$Q_s = 2.5577 * Q^{**1.5005}$
	$Q, 20 \text{ to } 600 \text{ ft}^3/\text{s}$	$Q_s = 0.2968 * Q^{**2.0711}$
	$Q > 600 \text{ ft}^3/\text{s}$	$Q_s = 258 * Q$

Table 14

Size Gradation  
Total Sand Load From Tributary  
1983 Measurements

<u>Tributary</u>	<u>Percent Finer Than (Sieve Size in Millimeters)</u>					
	<u>0.0625</u>	<u>0.125</u>	<u>0.250</u>	<u>0.500</u>	<u>1.00</u>	<u>2.00</u>
Paria River at Lees Ferry	0	49.2	88.9	97.6	99.5	100.0
Little Colorado River near Cameron	0	37.2	81.3	99.1	100.0	
Kanab Creek near Fredonia	0	59.7	81.9	100.0		

Table 15  
Annual Sediment Inflow for Tributaries

Tributary	Total Sediment Gaged Areas plus Havasu Creek			Sand Load Tons/Year
	mi <sup>2</sup>	(acre-feet) mi <sup>2</sup>	Tons per mi <sup>2</sup>	
Paria River	1,410	1.94	3,035	1,080,000
Little Colorado River	26,500	0.285	447	1,540,000
Kanab Creek	2,290 (at mouth)	0.513	805	318,000
Havasu Creek*	1,780	0.485	760	203,000
			Subtotal = 3,141,000	

Tributary	Total Sediment From Ungaged Areas*			Sand Load Tons/Year
	mi <sup>2</sup>	(acre-feet) mi <sup>2</sup>	Tons per mi <sup>2</sup>	
Dam to Lees Ferry	200	0.820	1,286	38,600
Lees Ferry to Little Colorado River	1,195	0.534	837	150,000
Little Colorado River to Grand Canyon	180	0.841	1,319	35,600
Grand Canyon to National Canyon	820	0.585	917	113,000
Grand Canyon to Diamond Creek	1,546	0.502	787	183,000
			Subtotal = 520,000	
			Total = 3,661,200	

Reaches	Drainage Area	Sand Load Tons/Year	% Ungaged of Total Sand Load
Reach 0 Dam to Lees Ferry	Ungaged	38,600	100
Reach 1 Lees Ferry to Little Colorado River	Paria River	1,080,000	12
Reach 2 Little Colorado River to Grand Canyon	Ungaged	150,000	
	Little Colorado River	1,540,000	
Reach 3 Grand Canyon to National Canyon	Ungaged	35,600	2.2
	Kanab Creek at mouth	318,000	49.8
Reach 4 National Canyon to Diamond Creek	Ungaged	316,000	
	Ungaged	183,000	100
Total Drainage Area	Gaged	2,938,000	
	Ungaged	723,200	19.8

\*Total sediment yield from figure 61 with  $Q_s = 1,750A^{-.24}$  (Metric Units) or  $Q_s = 2.925^{-.24}$  (English Units), unit weight = 72 lbs/ft<sup>3</sup>/s, and sand load equal 15 percent of total sediment yield from average of Little Colorado River and Kanab Creek studies.

Table 16  
Tributary Sediment Yields

Station	Drainage Area (mi <sup>2</sup> )	Sediment Yield			
		Total Sediment		Sand Load	
		(t/mi <sup>2</sup> )	(acre-ft/mi <sup>2</sup> )	(t/mi <sup>2</sup> )	(acre-ft/mi <sup>2</sup> )
Paria River at Lees Ferry	1,410	3,035	1.94	759*	0.484*
Little Colorado River nr. Cameron, AZ	26,500	447	0.285	58**	0.036**
Kanab Creek nr. Fredonia, AZ	1,085	805	0.513	139***	0.089***
Moenkopi Wash nr. Moenkopi, AZ	1,660	965	0.581	125**	0.080**

\* Sand equal 25 percent of total load; with suspended sand equal 19.4 percent of suspended load and bedload (sand size) equal 7.5 percent of suspended load.

\*\* Sand equal 13 percent of total load; with suspended sand equal 10.4 percent of suspended load and bedload (sand size) equal 3 percent of suspended load.

\*\*\* Sand equal 17.3 percent of total load; with suspended sand equal 14.9 percent of suspended load and bedload (sand size) equal 3 percent of suspended load.

Table 17

Modified Einstein Total Load - Little Colorado River Near Cameron

Date	Time	Discharge Measurement				Temp. (F)	Susp. Load (C, mg/L)	Bed Material		Susp. Load (t/d)	Total Load (t/d)	%
		Q (ft <sup>3</sup> /s)	Width (feet)	Vel. (ft/s)	Avg. Depth (feet)			D <sub>35</sub> (mm)	D <sub>65</sub> (mm)			
8/4/83	600	169	55.0	2.91	1.06	68	94,718	.179	.276	43,220	44,746	3.5
8/4/83	1,920	169	55.0	2.91	1.06	76	174,670	.179	.276	79,702	81,826	2.7
11/30/83	1,135	44	28.2	1.40	1.11	37	13,787	.179	.276	1,627	1,651	1.5
Average											2.6	
Use											3.0	

SEDIMENT LOAD

SECTION	PERIOD	RIVER
near Cameron, AZ	(1947-1985) December thru May	Little Colorado River
COMPUTED BY	CHECKED BY	DATE

TOTAL	291.3	18909.6
-------	-------	---------

		<u>Sediment</u>		
A.D.	= $\frac{11,845,000}{1568}$	Tons/yr.	-----	7554 (AF)/yr.
Yield	= $\frac{11,845,000}{1568 (26500)}$	Tons/yr. Tons/(AF) x D.A.	-----	0.285 (AF)/sq. mi.
Concentration	= $\frac{11,500,000 \times 100}{170,200 \times 1361}$	Qs A.D. x 100 Qw A.D. x 1361	-----	4.96 Percent
		<u>Runoff</u>		
Rate	= $\frac{170,200}{26,500}$	Qw A.D. D.A.	-----	6.42 (AF)/sq. mi.

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SEDIMENT LOAD

LITTLE COLORADO RIVER

Qw.A.D. = 178.78 D.O.  $\times \frac{183}{265} = 1.9835 = 64,900$  (AF)/yr.

Qs.A.D. = 43,981.6 D.O.  $\times \frac{183}{265} = 8,050,000$  Tons/yr.

3 Percent Correction for Bedload = \_\_\_\_\_ Tons/yr.

Total Sediment Discharge = \_\_\_\_\_ Tons/yr.

D.D. = Daily Discharge  
A.D. = Annual Discharge  
D.A. = Drainage Area  
      = lbs./cubic foot = 72  
      = Tons/acre foot = 1568

Table 20  
Modified Einstein Total Load - Kanab Creek Near Fredonia

Date	Time	Discharge Measurement			Temp. (F)	Susp. Load (C, mg/L)	Bed Material		Susp. Load (t/d)	Total Load (t/d)	%
		Q (ft <sup>3</sup> /s)	Width (feet)	Vel. (ft/s)			D <sub>35</sub> (mm)	D <sub>65</sub> (mm)			
8/13/83	1830	11	17	1.08	81	11,656	.244	.394	346	347.7	0.5
11/2/83	1121	12	17	1.32	37	3,529	.244	.394	116	121.2	4.5
12/13/83	1600	10	19	1.22	40	16,454	.244	.394	440	454.3	3.2
Average											2.7
Use											3.0



KANAB CREEK

D.D. = Daily Discharge  
A.D. = Annual Discharge  
D.A. = Drainage Area  
      = lbs./cubic foot = 72  
      = Tons/acre foot = 1568

MOENKOPI WASH.

		<u>Sediment</u>		
A.D.	= <u>1,513,575</u>	Tons/yr.	965	(AF)/yr.
	<u>1568</u>	Tons/(AF)		
Yield	= <u>965</u>	Tons/yr.		
	<u>1660</u>	Tons/(AF)x D.A.	.581	(AF)/sq.mi.
Concentration	=	Qs A.D. x 100		
		Qw A.D. x 1361		Percent
<u>Runoff</u>				
Rate	= <u>7486</u>	Qw A.D.		
		D.A.		(AF)/sq.mi.

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Table 23  
Areas of River Bed Patterns  
Colorado River from Lees Ferry to Diamond Creek

<u>Reach</u>	<u>Length Miles</u>	<u>Area on Surface of Streambed (Square-Feet)</u>			<u>Total</u>
		<u>B</u> <u>Boulders</u>	<u>S</u> <u>Smooth Bottom</u>	<u>SW</u> <u>Sediment Wave</u>	
1	61	53,900,000	33,300,000	14,700,000	101,900,000
2	26.5	18,100,000	21,200,000	1,610,000	40,910,000
3	78.5	60,700,000	29,800,000	6,410,000	96,910,000
4	59.5	31,100,000	53,700,000	10,700,000	95,500,000
Total	225	163,800,000	138,000,000	33,420,000	335,220,000

<u>Reach</u>	<u>Length Miles</u>	<u>Area on Surface of Streambed (Percent of Total)</u>		
		<u>B</u> <u>Boulders</u>	<u>S</u> <u>Smooth Bottom</u>	<u>SW</u> <u>Sediment Wave</u>
1	61	52.9%	32.7%	14.4%
2	26.5	44.2%	51.8%	3.9%
3	78.5	62.6%	30.8%	6.6%
4	59.5	32.6%	56.2%	11.2%
Total	225	48.9%	41.2%	10.0%

Table 24

Colorado River Transport Study  
Average Bed Material - Input to STARS by Reaches

Reach	Year of Sampling	Number of Samples	Type of Material	Percent Finer Than (Sieve Size in Millimeters)									
				0.0625	0.125	0.250	0.500	1.00	2.00	4.00	8.00	16.0	32.0
1	1983-84	229	SW-Sediment Waves	0.2	1.7	15.0	82.8	95.7	98.1	98.7	99.5	99.8	100.0
	1985-86	74	SW-Sediment Waves	2.2	11.9	38.0	81.2	95.1	98.0	98.9	99.5	100.0	
	1983-84	74	S-Smooth Bottom	0.0	0.3	1.4	15.7	33.9	49.7	62.2	75.1	83.8	100.0
	1985-86		S-Smooth Bottom					(Same as 1983-84)					
2 & 3	1983-84	223	SW-Sediment Waves	0.6	3.2	23.7	86.3	95.9	97.2	97.7	98.0	98.6	100.0
	1985-86	114	SW-Sediment Waves	2.2	11.5	40.0	87.7	97.8	99.1	99.4	99.8	100.0	
	1983-84	6	S-Smooth Bottom	0.0	0.2	2.0	20.0	39.3	51.6	61.9	70.2	76.3	100.0
	1985-86		S-Smooth Bottom					(Same as 1983-84)					
4	1983-84	260	SW-Sediment Waves	2.8	9.8	36.6	95.3	99.3	99.6	99.7	99.8	100.0	
	1985-86	141	SW-Sediment Waves	4.7	20.0	51.8	90.0	97.2	98.1	98.5	98.9	99.2	100.0
	1983-84	8	S-Smooth Bottom	0.0	0.2	1.8	18.3	45.6	55.9	64.6	72.3	78.6	100.0
	1985-86		S-Smooth Bottom					(Same as 1983-84)					

Note: Reach 1 is average of samples collected at Lees Ferry and Above Little Colorado River sampling stations and special samples taken in reach by USGS from 9/4/84 to 9/10/84.

Reach 2 and 3 is average of samples collected at Grand Canyon and Above National Canyon sampling stations and special samples taken in reach by USGS from 9/4/84 to 9/10/84.

Reach 4 is average of samples collected at Above National Canyon and Above Diamond Creek sampling stations and special samples taken in reach by USGS from 9/4/84 to 9/10/84.

Table 25  
Comparison of the STARS and STAB Modeling Results

<u>Reach</u>	<u>Time Period</u>		<u>Outflow From Reach Computed By</u>		<u>Percent Difference</u>
	<u>From</u>	<u>To</u>	<u>STAB</u>	<u>STARS</u>	
1	June 1, 1983	December 11, 1983	5,170,000	1,600,000	-69.1
2	June 1, 1983	December 15, 1983	9,900,000	3,800,000	-61.6
1	October 1, 1985	October 14, 1985	11,500	14,100	+22.6
2	October 1, 1985	October 14, 1985	18,000	13,300	-26.1

Table 26  
Summary of STARS and STAB Models  
STARS

Flow Alternative	Reach	Annual Sand Change (1000 tons) for Water Year			
		Year 1	Year 2	Year 3	Year 4
1	1	629 (298)	862 (408)	868 (411)	786 (372)
2	1	515 (244)	843 (399)	739 (350)	699 (331)
1	2	1350 (638)			
2	2	1390 (659)			

STAB

Flow Alternative	Annual Sand Change (1000 Tons) for Water Year				
	Reach 0	Reach 1	Reach 2	Reach 3	Reach 4
1	-28	886 (419)	1330 (629)	318 (150)	0
2	-78	753 (356)	1140 (540)	406 (192)	55 (26)
3	-49	812 (384)	1240 (586)	345 (163)	17 (8)

Annual Sand Load (1000 Tons) at  
Sampling Stations  
(STAB)

Flow Alternative	Lees Ferry	Above Little Colorado River	Near Grand Canyon	Above National Canyon	Above Diamond Creek
1	28	220	428	428	428
2	78	403	799	711	656
3	49	315	614	587	570

( ) Values converted to acre-feet at unit weight equal 97 lbs/ft<sup>3</sup> or 2113 tons/acre-feet.