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CYPRESS CREEK SEDIMENT IMPACT ASSESSMENT, SUMMARY REPORT

Numerical Model Investigation

by

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A sediment impact assessment study was conducted to evaluate channel improvement plans for Cypress Creek near Houston, TX. A one-dimensional numerical model was used to determine potential for scour and deposition with the proposed design. The model study concluded that the proposed channel would have greater sediment transport potential than the existing channel. However, if the channel grass lining is properly maintained, there should be no significant aggradation or degradation problems. A more detailed study was recommended before final design is completed.

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PREFACE

The numerical model investigation of Cypress Creek reported herein was conducted at the US Army Engineer Waterways Experiment Station (WES), at the request of the US Army Engineer District, Galveston (SWG).

This investigation was conducted during the period March-April 1986 in the Hydraulics Laboratory of WES, under the direction of Mr. Frank A. Herrmann, Jr., Chief of the Hydraulics Laboratory, and Mr. Marden B. Boyd, Chief of the Hydraulic Analysis Division (HAD). The project was conducted and the report prepared by Messrs. Ronald R. Copeland and William A. Thomas, Math Modeling Group, HAD.

Mr. Gerald Dunaway, SWG, made many valuable contributions as study coordinator.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

Contents

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
square miles (US statute)	2.589998	square kilometres

CYPRESS CREEK SEDIMENT IMPACT ASSESSMENT

SUMMARY REPORT

Numerical Model Investigation

PART I: INTRODUCTION

1. A feasibility level study was conducted to assess the impact of sedimentation on the channel improvement plans for Cypress Creek, near Houston, TX. A one-dimensional numerical model of the channel was developed to obtain estimates of potential aggradation and degradation. Channel geometry for the existing natural channel was based on 1976-79 survey data. Design geometry called for a grass-lined trapezoidal channel with a low-flow channel and park reaches where one bank remained natural. The model extended from the mouth of Cypress Creek (river mile 0.0) to House Haul Road (river mile 36.75). Roughness coefficients from previous HEC-2 backwater studies were used in this study. The model included three sand size classes: very fine, fine, and medium sand. Sand inflow was calculated at the upstream end of the model assuming an alluvial channel in equilibrium with the inflowing sand discharge. The calculated sediment concentrations were also used as sediment inflow at tributaries. Bed material in the model was based on surface samples collected at three sites in 1986. The numerical model was adjusted so that net change in the existing channel profile was approximately zero for the 2-year frequency peak discharge. Aggradation and degradation quantities were calculated for the design channel assuming both failure and success of the grass lining. These calculations were made for the design hydrograph (10-year frequency with ultimate watershed development) and for an annual-flow-duration hydrograph. The conclusion of this feasibility level study was that the proposed grass-lined channel would have a greater sediment transport potential than the existing channel, but, if properly maintained, should have no significant general degradation or aggradation problems. However, if the grass lining fails, there would be significant scour and deposition. A more detailed sediment study is recommended for the design phase of the project.

The Prototype

2. Cypress Creek is located about 10 miles* north of Houston, in Harris County, TX (Figure 1). The creek is a primary tributary of Spring Creek (Figure 2) and has a drainage area of approximately 320 square miles. The average channel slope is about 2.7 ft per mile. The watershed above the project limit, at US Highway 290 (river mile 33.9), consists largely of prairie land used for rice production and pasture. Through the project reach the watershed is heavily wooded and provides very desirable sites for residential development. Little Cypress Creek, with a drainage area of about 53 square miles, is the major tributary of Cypress Creek with a confluence at river mile 28.5. Several smaller tributaries enter Cypress Creek downstream from Little Cypress Creek. These tributaries carry the runoff for 34 percent of the total drainage area of Cypress Creek.

3. The proposed channel improvement extends from the confluence of Spring and Cypress Creeks to US Highway 290 (Figure 2). It is designed to contain the 10-year-frequency flood that would occur with projected ultimate (2090) watershed development. The design calls for a grass-lined trapezoidal channel with 1 on 3 side slopes. The channel base is 200 ft wide between Spring Creek and Interstate Highway 45 (I-45) (river mile 10.0); 160 ft wide between I-45 and the confluence of Little Cypress Creek; 70 ft wide upstream to river mile 25.6; and then 30 ft wide to US Highway 290. A 20-ft-wide, 2-ft-deep low-flow channel with 1 on 3 side slopes will be constructed everywhere except in the 30-ft-wide reach. There is a riprap-lined constricted reach through the bridges at I-45. At designated cross sections, one bank will be left in its natural condition. Depending on the slope of the natural bank, these sections contract or expand flow. The design channel would generally follow the present stream alignment; however, the cutoff of some existing channel meanders would be unavoidable and the overall channel length downstream from US Highway 290 would be reduced by about 13 percent to 29.4 miles.

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* A table of factors for converting non-SI units of measurement to SI (metric) units is found on page 3.

Purpose of the Numerical Model Study

4. A sediment impact assessment of proposed channel improvement was requested by the US Army Engineer District, Galveston, to accompany the Interim Feasibility Report for Cypress Creek. This impact assessment is a first-level type study, using limited available data, to produce general estimates of the extent and location of sediment problems. Deposition and scour quantities were needed to obtain operation and maintenance costs for the feasibility study.

PART II: MODEL DESCRIPTION

5. The TABS-1 computer program was used to develop the numerical model for this study.* The TABS-1 program produces a one-dimensional model that simulates the response of the riverbed profile to sediment inflow, bed material gradation, and hydraulic parameters. The model simulates a series of steady-state discharge events and their effect on the sediment transport capacity at cross sections and the resulting degradation or aggradation.

Model Geometry

6. The numerical model extends up Cypress Creek from its confluence with Spring Creek (river mile 0.0) to House Haul Road (river mile 36.75). Cross sections for the existing channel were based on 1976-79 field surveys conducted for the Harris County Flood Insurance Study. Some of these surveys included both the channel and overbank. Where survey data were not available, overbank elevations were obtained from 1:24,000 scale US Geological Survey quads. In the TABS-1 numerical model some of these cross sections were modified to account for ineffective and independent flow areas. Cross sections were also modified at bridges to account for the constrictive effect of bridge openings. Weir and pressure flow are not modeled in the TABS-1 program, but these conditions do not occur at the flows tested in this study. Other losses at bridges were accounted for in the TABS-1 model by increasing expansion and contraction coefficients. Cross sections for the design channel were based on the HEC-2 backwater model prepared by the Galveston District.

Histographs

7. Hypothetical hydrographs calculated by the Galveston District were used to develop histographs for the numerical model. (A histograph is a hydrograph simulated by a series of steady-state events of varying durations.)

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* This program is an enhanced version of the widely used HEC-6 program developed by Mr. William A. Thomas, US Army Engineer Waterways Experiment Station.

Using a storm centered over the entire 320-square-mile drainage area, 10-year-frequency hydrographs had been calculated for several locations (Figures 3 and 4). Calculated peak discharges are shown in Table 1. In the numerical model the difference between calculated discharges at the mouth and I-45 were considered local inflow from Lemm Gully, which is downstream from river mile 9.26. The difference between calculated discharges at "I-45" and "downstream from Little Cypress Creek" was equally divided and input into the numerical model at Spring Gully, downstream from river mile 16.56, and Pilot Gully, downstream from river mile 22.15. The calculated difference between "upstream from Little Cypress Creek" and at "US Highway 290" was input into the numerical model at Dry Creek, which is downstream from river mile 33.39. Calculated decreases in discharge due to channel routing were ignored in the numerical simulation. The time scale for the calculated hydrographs at each location was adjusted to account for the effects of flood wave routing. (Numerical calculations follow a Lagrangian coordinate system rather than a Eulerian.) This adjustment is approximate, based on available data; future, more detailed studies should incorporate the combining and routing data from the HEC-1 program.

8. Average annual deposition and scour can be calculated using an annual flow duration hydrograph (Figure 5). This hydrograph was developed from the flow duration curve which includes the effect of major floods during the 35 years of continuous record (1944-79). It represents an annual flood hydrograph based on percent exceedances. The hydrograph developed from historical records represents channel and watershed conditions during the period of record. Tributary flow was accounted for by adjusting the hydrograph based on peak discharge percentages for the 10-year-frequency flood with existing conditions.

Downstream Water-Surface Elevation

9. Normal depth was assumed at the downstream boundary for both the existing and design channels. This assumption neglects possible backwater effects that could occur as a result of high flows on Spring Creek. Previous studies have used the stage exceedance frequency on Spring Creek corresponding to the discharge frequency on Cypress Creek as a downstream water-surface elevation for flood profile calculations. This assumption was considered to

be too extreme for routing a flood hydrograph. The downstream rating curves used in this study are compared with the exceedance frequency values for various flood peaks in Figure 6. The water-surface elevation rating curve used for the design channel is significantly lower than the existing curve. Backwater effects from Spring Creek could result in significant aggradation in the downstream reaches of Cypress Creek. A more detailed study should be made to determine coincident water-surface elevations at the confluence.

Energy Losses

10. Manning's roughness coefficients used in previous backwater studies were incorporated into the TABS-1 numerical model. For the existing channel, roughness coefficients varied between 0.04 and 0.06. Overbank values varied between 0.05 and 0.12. In the design channel the roughness coefficient was 0.035. A composite roughness coefficient of 0.040 was determined for design sections with natural banks. In the riprap-lined portion of the channel a Manning's value of 0.045 was used. Expansion and contraction coefficients of 0.3 and 0.1, respectively, were used throughout the model except at bridge crossings and in the existing channel and at the I-45 contraction in the design channel, where values of 0.5 and 0.3 were used.

Bed Material

11. Surface bed material samples were collected at three locations in the study reach (Figure 7). At each site, samples were collected near the thalweg and on top of a bar deposit. An average gradation was obtained at each site. The bed material consisted primarily of very fine to medium sand with the medium grain size decreasing in a downstream direction. An initial estimate of variation in the bed material gradation throughout the study reach was based on the three bed material samples. During the model adjustment phase of the study the initial gradation was coarsened downstream from river mile 20.

12. Soil borings indicate that portions of the channel bottom may be in clay stratum. Several of the borings taken adjacent to the creek show clay layers at or below the thalweg, but there is insufficient evidence to conclude that there is an extensive clay stratum underlying the entire study reach.

The top elevations of clay layers in boring samples are compared with the existing channel thalweg in Figure 8. In the numerical model of the existing channel, cross sections near known clay layers were considered nonerodible. Benefits from possible clay stratum were not considered in the model of the design channel.

Sediment Inflow

13. Sediment inflow into the numerical model was calculated assuming equilibrium transport conditions at the first five cross sections at the upstream end of the model. Sediment transport for each size class was determined using calculated hydraulic parameters, the measured bed material gradation, and the Toffaletti transport function. Due to the absence of cross section of bed material data for any of the tributaries, the same sediment inflow rating curve was used at each tributary inflow point.

14. Suspended sediment measurements were made at the stream gage downstream from I-45 between 1976 and 1979. However, particle size distributions of the samples were not available. Measurements taken between 1965 and 1974 in Spring Creek had an average sand percentage of 37 percent. Nearby Caney Creek had an average sand percentage of 25 percent; and the West Fork San Jacinto River suspended sediment load was 48 percent sand. Typically, sand percentages are higher at higher discharges, but data were not available to determine if this condition occurs on Cypress Creek or any of the nearby streams. The adopted sediment inflow rating curve is compared with the measured suspended data (sand, silt, and clay) at I-45 in Figure 9. Also shown are estimated measured sand loads assuming 37 percent sand.

PART III: MODEL ADJUSTMENT

15. The numerical model of the existing channel was adjusted until the net accumulated aggradation and degradation were balanced with the existing 2-year-frequency peak flow. This amounts to assuming channel equilibrium with the dominate discharge, which is reasonable in cases where historical information is lacking. With the initial bed material gradation (which was extrapolated and interpolated from three field measurements), the model showed a significant degradation trend downstream from river mile 20. Localized scour and deposition occurred as the channel expanded or contracted. The calculated general degradation trend was attributed to decreases in bed material size in the downstream direction. The bed material was coarsened downstream from river mile 20 and the calculated net volume change in the channel for the 2-year-frequency flood peak ceased to show general degradation and became essentially zero. Net degradation, accumulated from the mouth, is plotted in Figure 10. Negative values on this plot represent net deposition; a positive slope indicates a degradation zone; and a negative slope indicates an aggradation zone.

16. Required model adjustment was achieved by coarsening the bed material, but there are other factors which may be responsible for the degradation trend shown initially with the model:

- a. The channel is not in equilibrium and actually is degrading.
- b. Bank erosion is supplying significant quantities of very fine sand to the stream.
- c. The channel is underlain by a clay stratum and is essentially non-erodible.

Data were not available to evaluate these other alternatives. If, in fact, the bed material gradation does not coarsen as assumed in the model adjustment, then quantities presented in this impact assessment may be significantly underestimated.

PART IV: STUDY RESULTS

Base Test

17. The 10-year-frequency hydrograph, with existing channel and watershed conditions, was used to determine response of the existing channel for a flood event. This was used as a base test for the design channel analysis. Localized deposition and scour occurred as the channel expanded and contracted. There was a slight general degradation trend with a net scour of 5,000 cy yd. Accumulated degradation from the mouth of Cypress Creek is shown in Figure 11.

Sediment Inflow Sensitivity

18. The base condition was used to evaluate the sensitivity of the model to sediment inflow. Initial calculated sediment inflow was doubled and halved and inserted into the model at the upstream boundary and at the tributaries. Results (Figure 12) indicate that inflowing load is a significant factor in determining aggradation or degradation trends in Cypress Creek.

Design Channel

19. Scour and deposition potential in the design channel was calculated for a 10-year-frequency flood with ultimate watershed development and for the average annual flow-duration hydrograph. Average sediment inflow and the adjusted bed material gradation were used in the analysis. The 10-year-frequency flood with ultimate watershed development has a peak about 2.5 times that of the 10-year-frequency flood with existing watershed and channel conditions. Thus, in addition to the reduced channel roughness and the increase in channel slope, the improved channel will have larger discharges contributing to a significant increase in channel velocities and sediment transport potential. Assuming that the grass lining did not fail resulted in all sediment inflow passing through the channel. There was also no calculated general aggradation, local deposition, or erosion using the 2-year-frequency peak flow or when sediment was doubled. Assuming failure of the grass lining,

about 120,000 cu yd of deposition and 340,000 cu yd of scour were calculated in the project reach. This results in a net degradation of about 220,000 cu yd. Accumulated degradation and bed change through the project reach are shown in Figures 13 and 14, respectively. Average annual deposition and scour of 132,000 cu yd and 189,000 cu yd, respectively, for a net degradation of about 57,000 cu yd was calculated (Figure 15).

Velocities

20. Calculated average velocities at some locations in the design channel with the ultimate 10-year-peak discharge are very close or slightly higher than currently recommended for grass lining. Design guidance in EM 1110-2-1601 "Hydraulic Design of Flood Control Channels" suggests maximum permissible mean velocities of 6.0 fps and 5.0 fps for Bermuda grass and Kentucky bluegrass, respectively, in grass-lined channels underlain with sandy silt material. Calculated velocities for the ultimate project design flood (10-year-frequency) ranged between 7.0 and 5.4 fps in the 200-ft-wide section; and 6.0 and 4.1 fps in the 30-ft-wide section. Calculated velocities are mean velocities; greater than mean velocities will occur on the outside of channel bends of in areas where eddies concentrate flow such as confluences or expansions. Velocities would also be greater for higher frequency events.

PART V: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

21. The project design channel has a greater sediment transport potential than the existing channel, but, if properly maintained, should have no significant general degradation or aggradation problems. Based on the stated assumptions related to bed material gradation and sediment inflow, the numerical model indicated no trend for aggradation with either the ultimate 10-year hydrograph or the existing 2-year frequency peak flows. However, if the grass lining failed, there would be significant scour and deposition, with a net degradation trend. A potential of about 225,000 cu yd net degradation was calculated for the 10-year-flood. Calculated average annual deposition and scour totals were 132,000 and 189,000 cu yd, respectively, with a net degradation of 57,000 cu yd. Due to this high potential for channel unraveling, the low-flow channel should be protected with riprap or some other erosion-resistant lining. Consideration should be given to enlarging the low-flow channel to allow the grass on the channel invert sufficient dry exposure to develop a strong stand of grass. The one-dimensional numerical model does not consider sediment deposition in slack-water areas such as the inside of channel bends or in eddies downstream from a confluence. Some deposition can be expected in these areas. In addition, sediment material that moves along the bed will not move as fast as the water and can be expected to leave a thin layer of material behind as floods recede. These local deposits are not considered to be significant with respect to determining operation and maintenance costs.

Recommendations

22. A more detailed sediment study is recommended during the design phase of the study. Much more confidence in deposition potential will be attained with more accurate definition of sediment inflow from the tributaries. The extent of scour potential, in case of failure of the grass lining, can be better assessed with a more accurate definition of the bed material. Data requirements for this level study are:

a. Cross-section data on the major tributaries and Spring Creek.

b. Bed material gradations sufficient to define the longitudinal variation throughout the study reach, in the tributaries, and Spring Creek.

c. Suspended sediment measurements with particle size distribution at least one gage location, preferably at two.

d. Definition of reaches where the design invert will be protected by a clay stratum.

e. Identification at existing or potential bank erosion areas on Cypress Creek and on major tributaries.

f. Determination of coincident water-surface elevations at the confluence of Spring and Cypress Creeks.

23. It is recommended that the data collection program commence immediately, especially the suspended sediment measurement program, which is dependent on high runoff for success. Several measurements should be collected during any major runoff event. These data are necessary to conduct an appropriate level sediment study for a channel improvement design in sandy material.

24. A design level sediment study will provide a better picture of how the channel improvement will affect the system. A more accurate evaluation of deposition potential due to tributary inflow and the possible effects of changes in sediment yield or improvement of tributary channels can be obtained. Channel response to failure of the grass lining at discharges greater than the design can be evaluated. Channel response during construction and during the period before the grass is actually established should be evaluated. The effect on Spring Creek of changing sediment loads from Cypress Creek also needs to be addressed. Design alternatives, such as grade control structures, could also be evaluated.

Table 1

Calculated Peak Discharges, cfs

Location	2-Year Frequency Existing Conditions	10-Year Frequency Existing Conditions	10-Year Frequency Future Conditions
Mouth	3,650	10,900	22,700
Interstate Highway 45	3,650	10,700	23,000
Below Little Cypress Creek	3,570	10,100	13,600
Above Little Cypress Creek	3,190	8,040	6,030
At US Highway 290	3,240	7,580	6,020

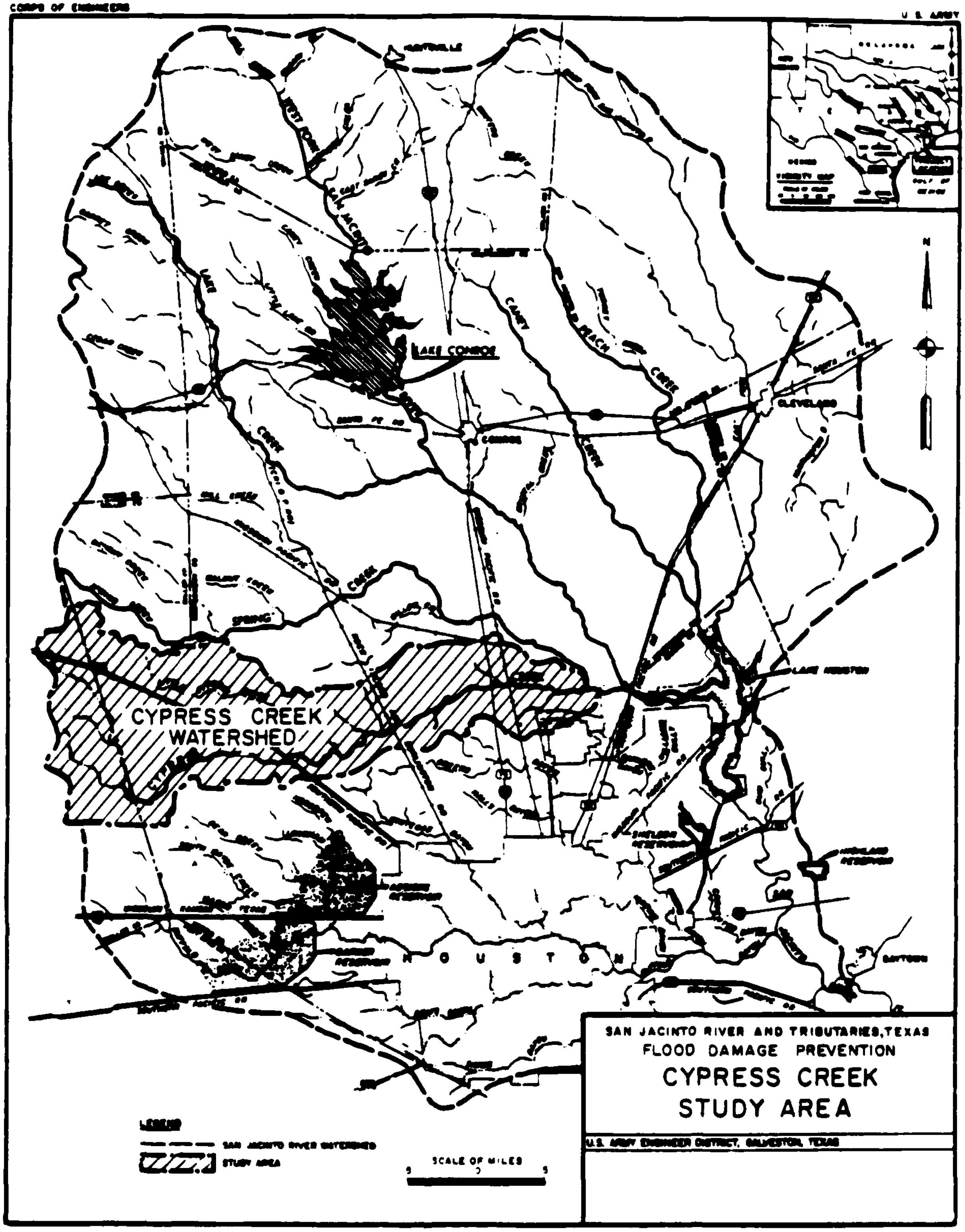

Figure 1. Location map

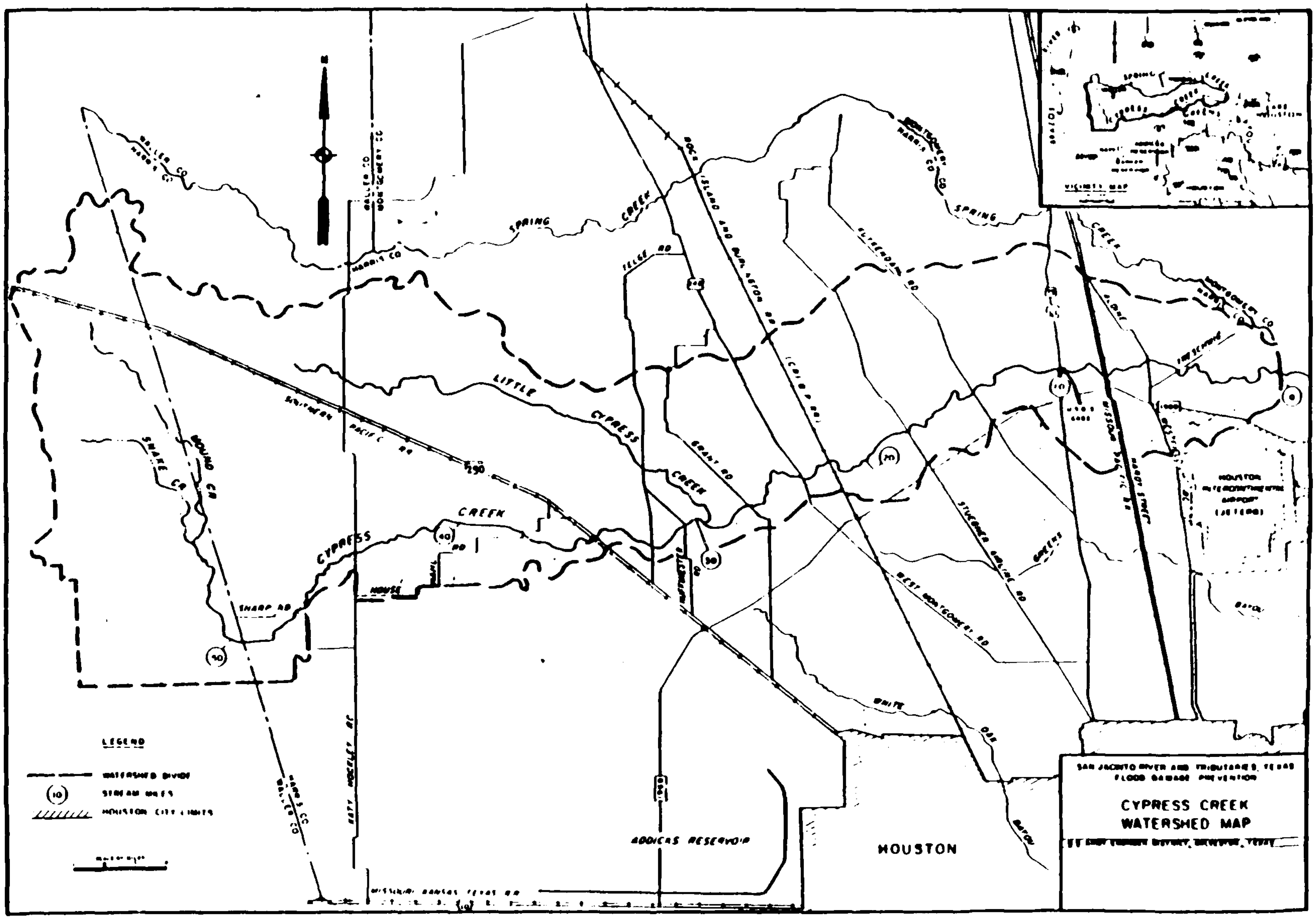

Figure 2. Watershed map

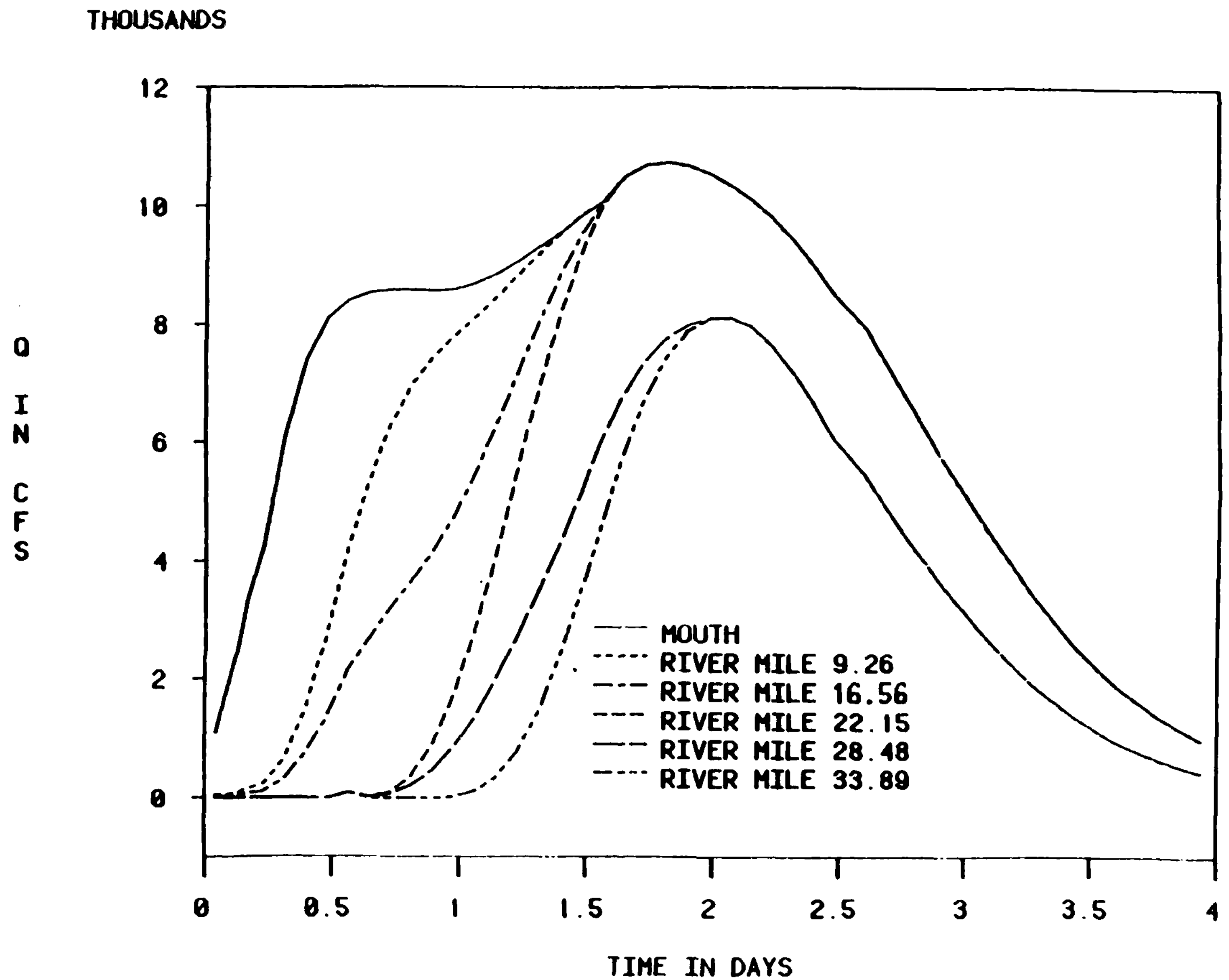

Figure 3. Ten-year hydrograph - existing conditions

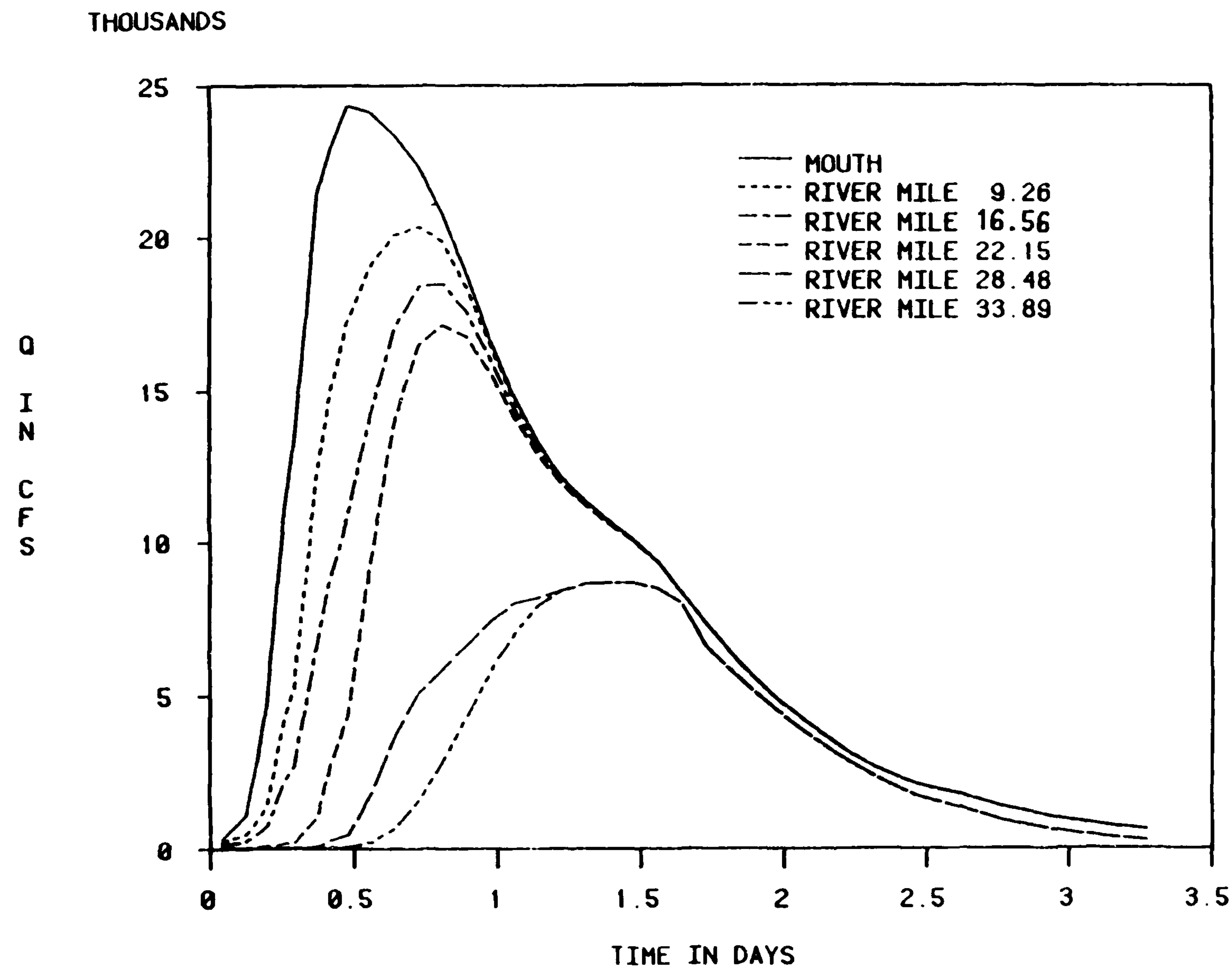

Figure 4. Ten-year hydrograph - ultimate conditions

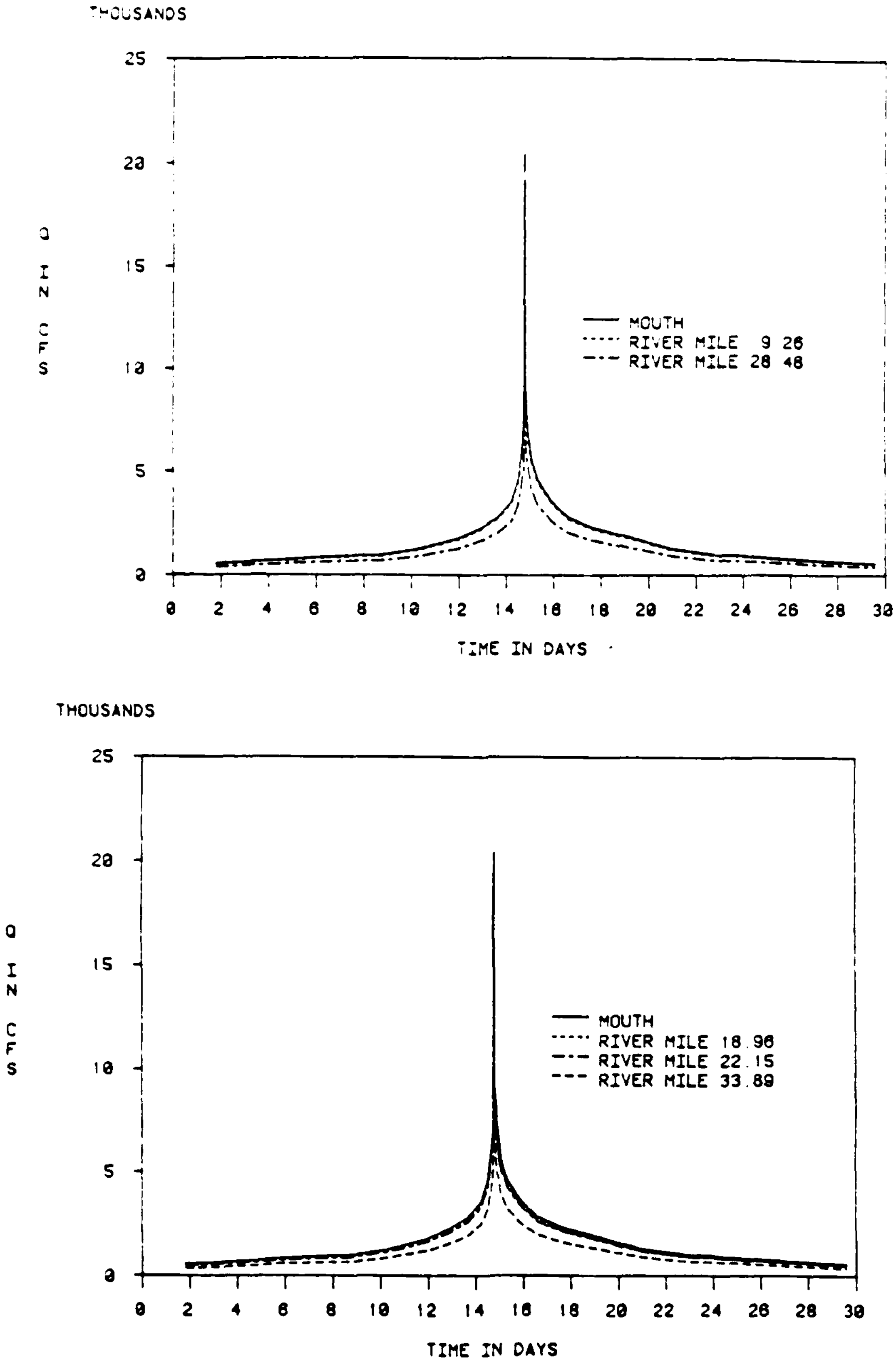

Figure 5. Annual flow duration hydrographs

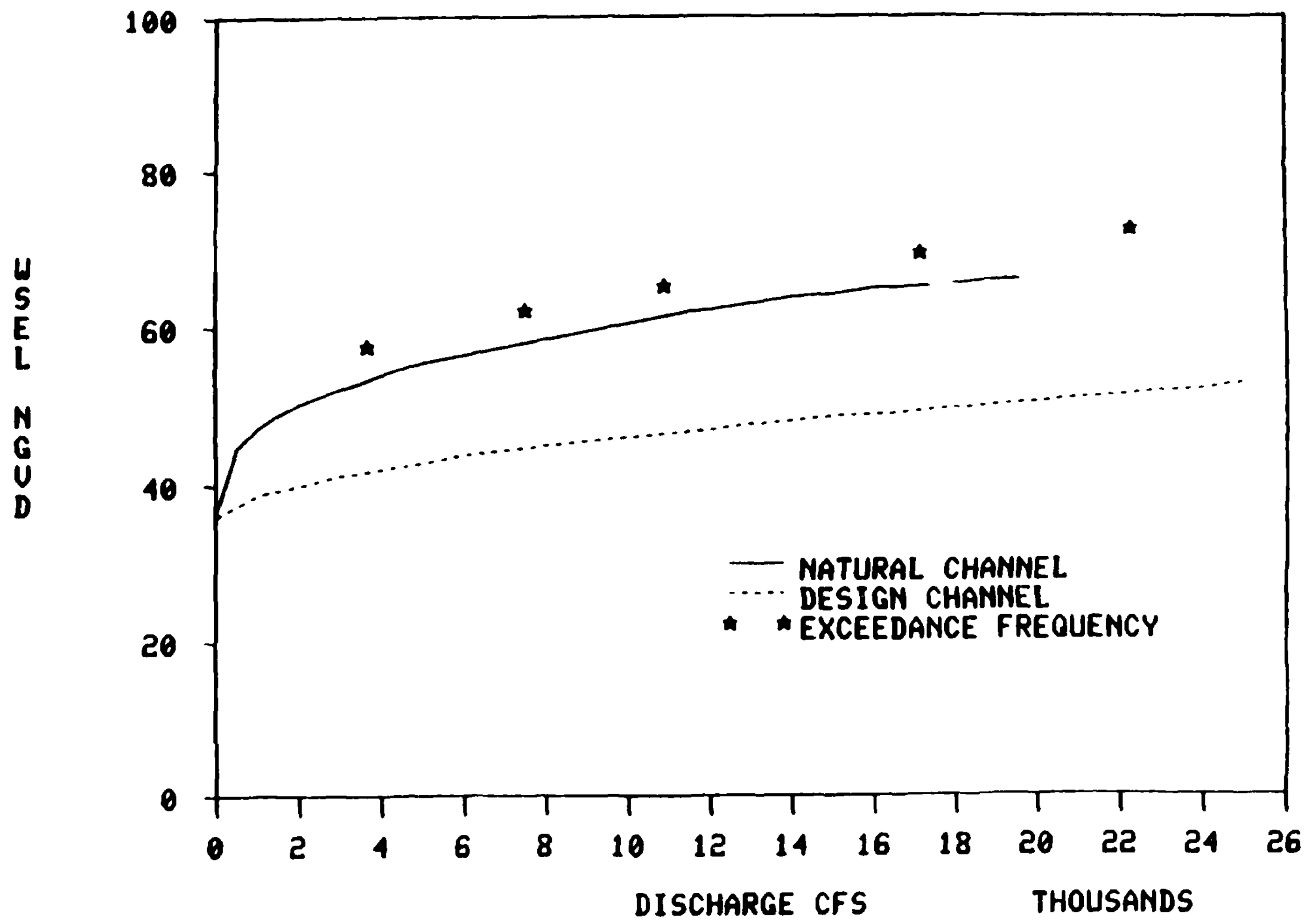

Figure 6. Cypress Creek downstream rating curve

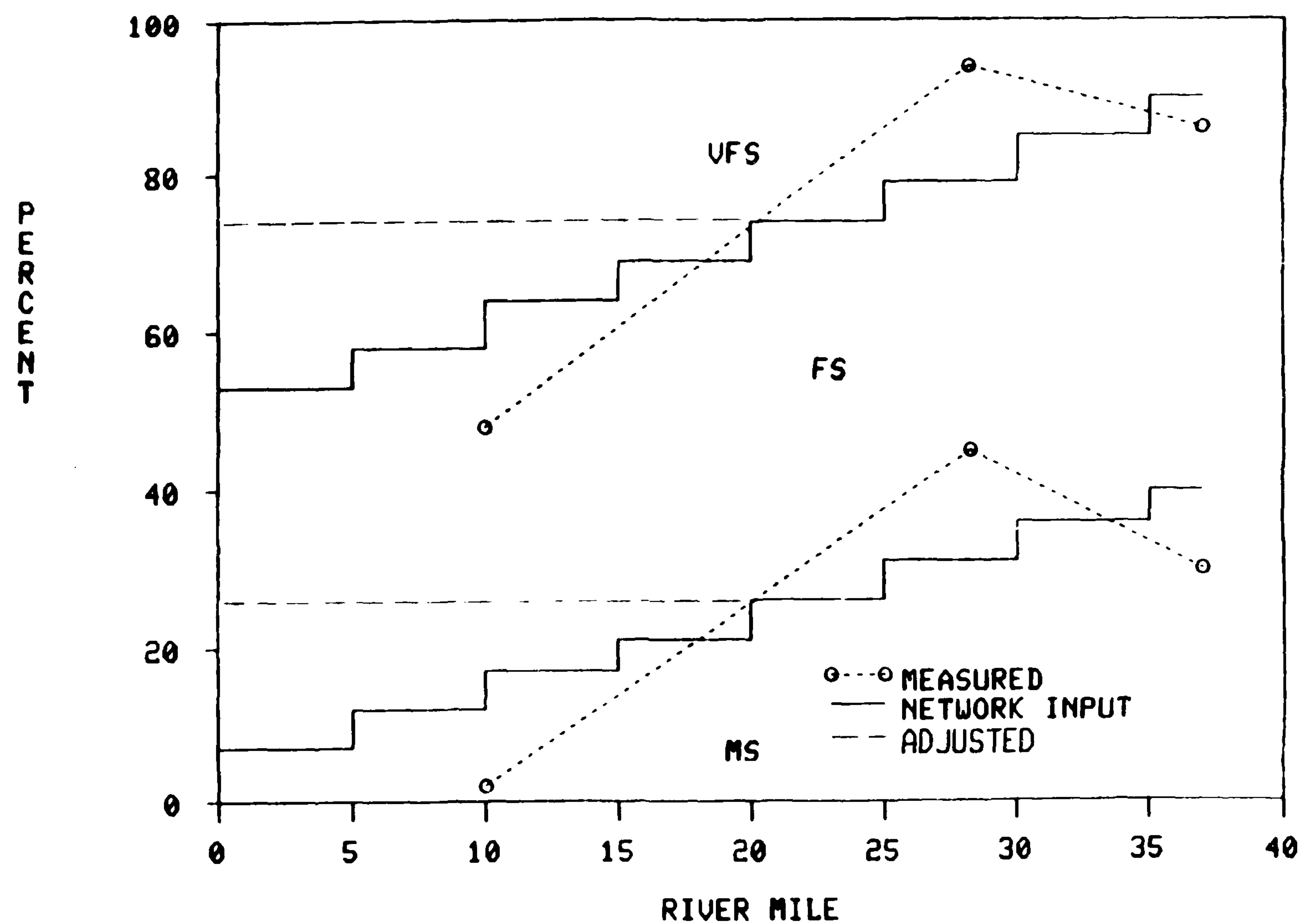

Figure 7. Cypress Creek bed material gradation

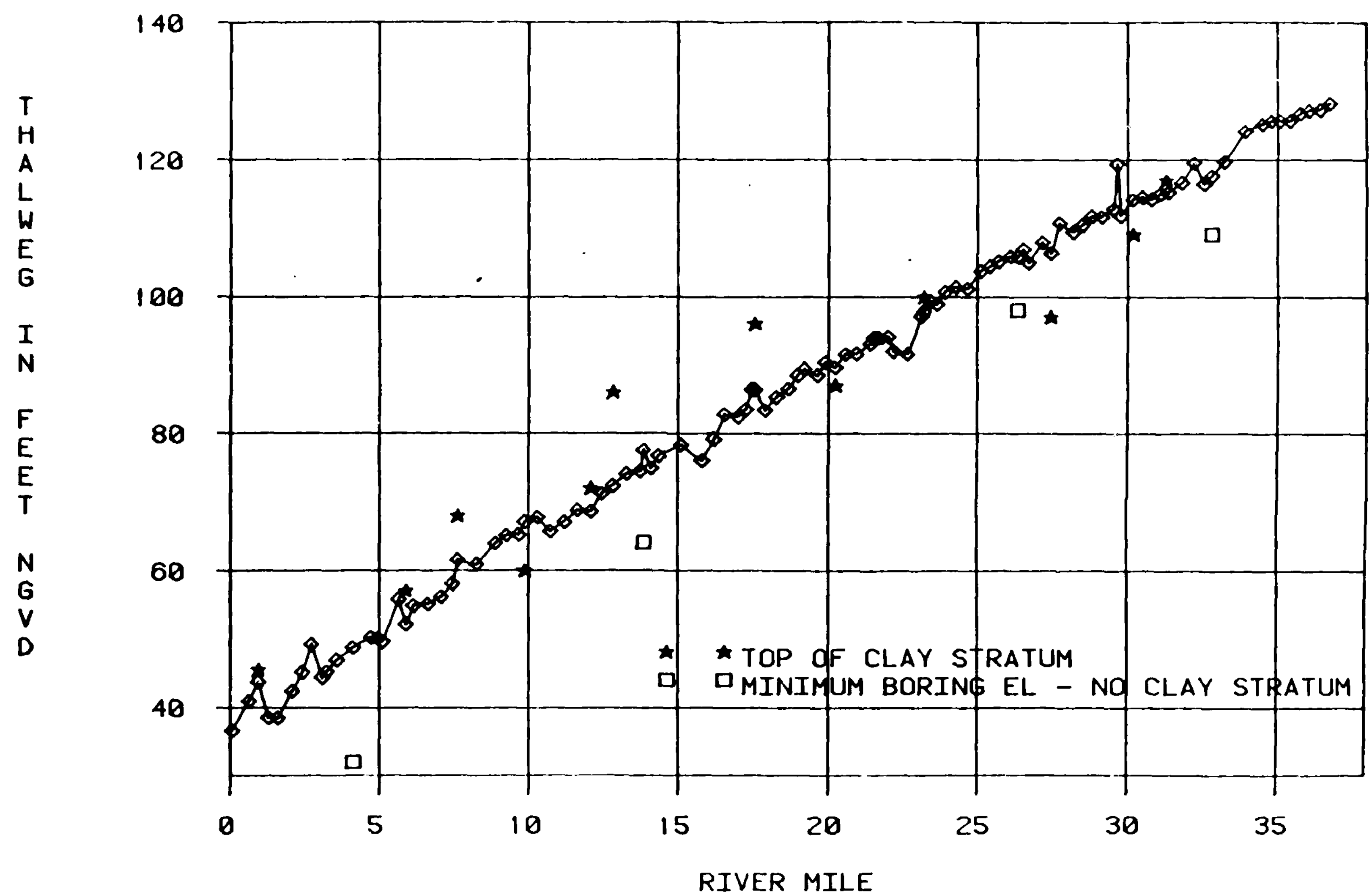

Figure 8. Bed profile showing location of clay stratum

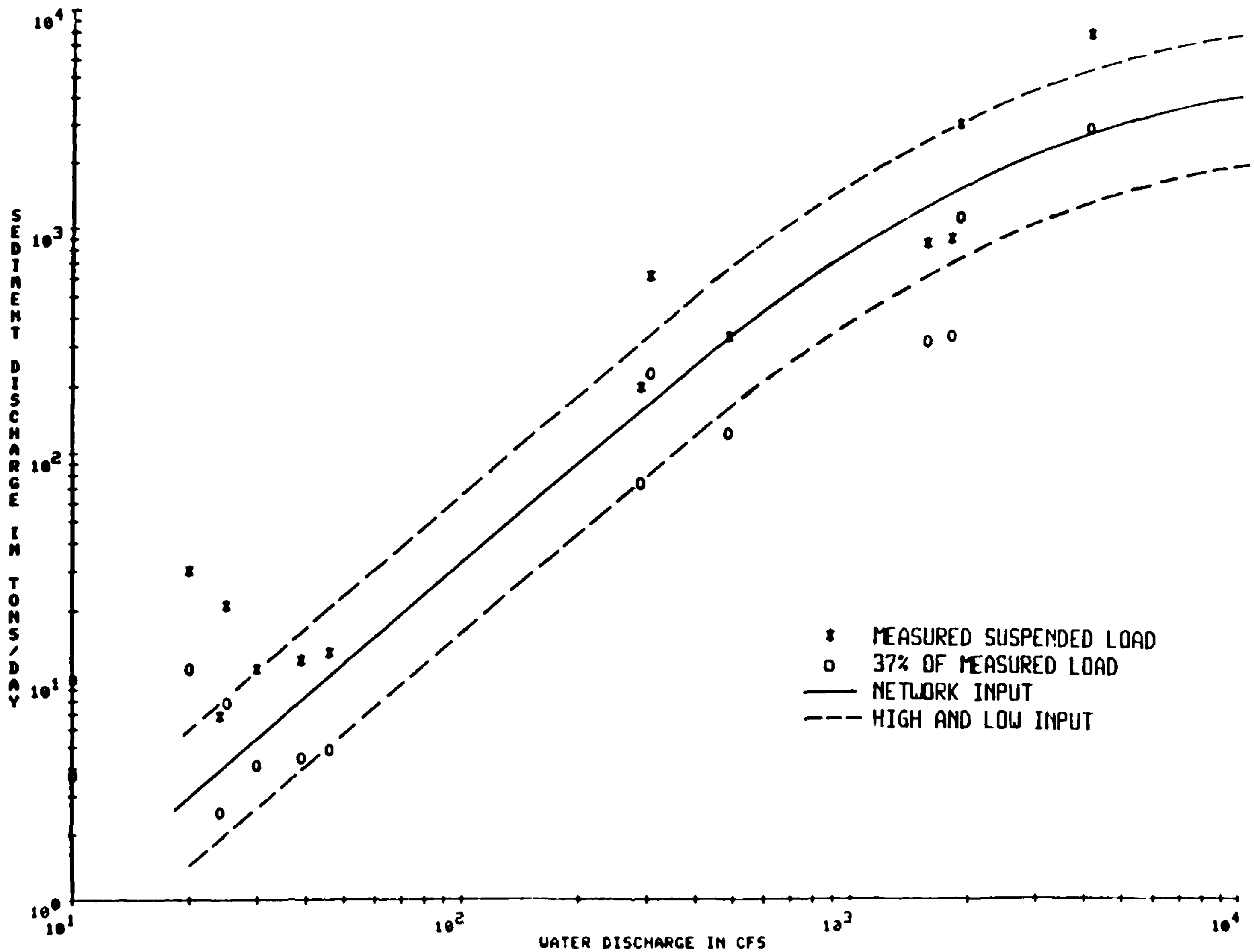

Figure 9. Measured suspended load

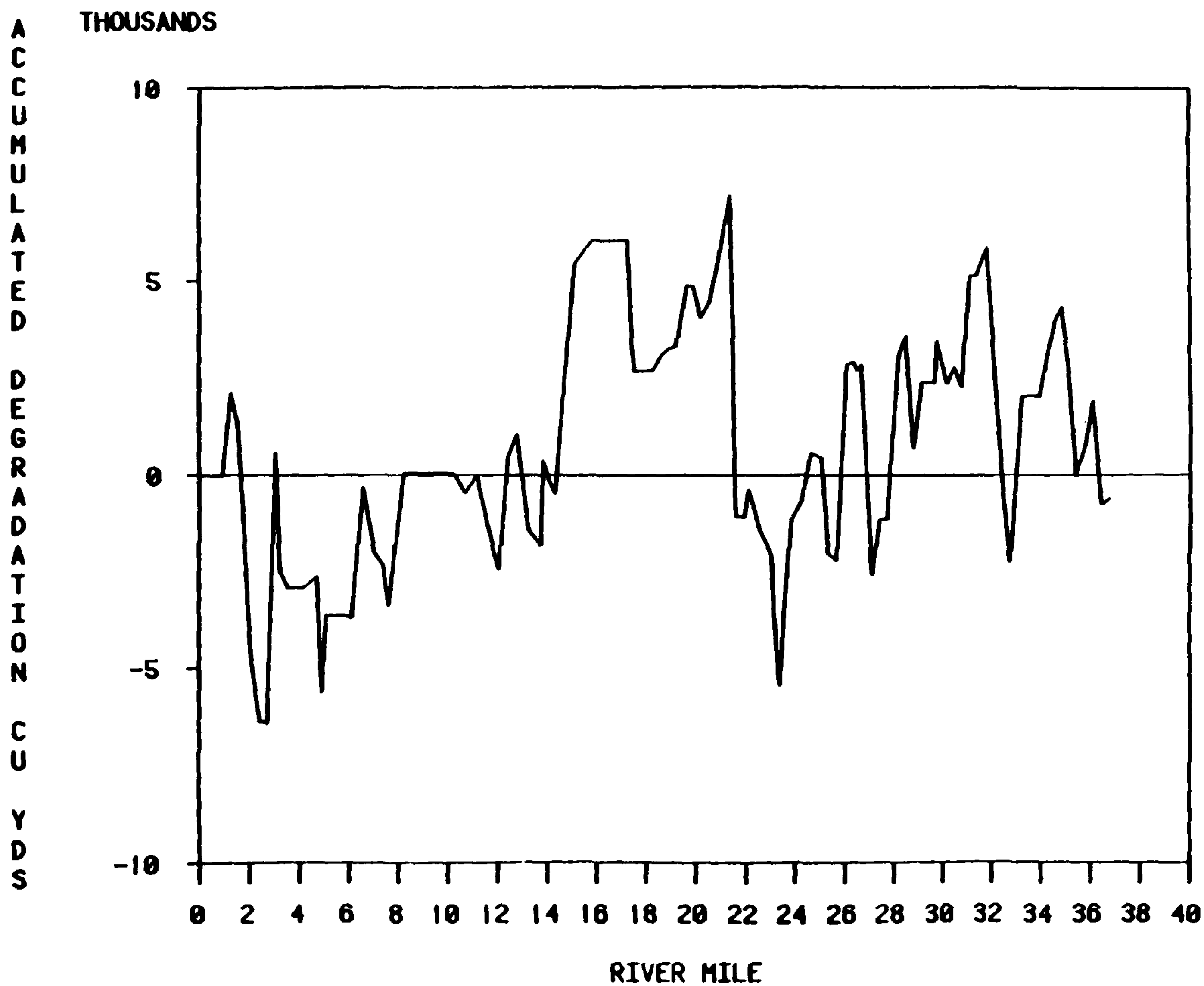

Figure 10. Accumulated degradation for 2-year peak 5-day duration - natural channel

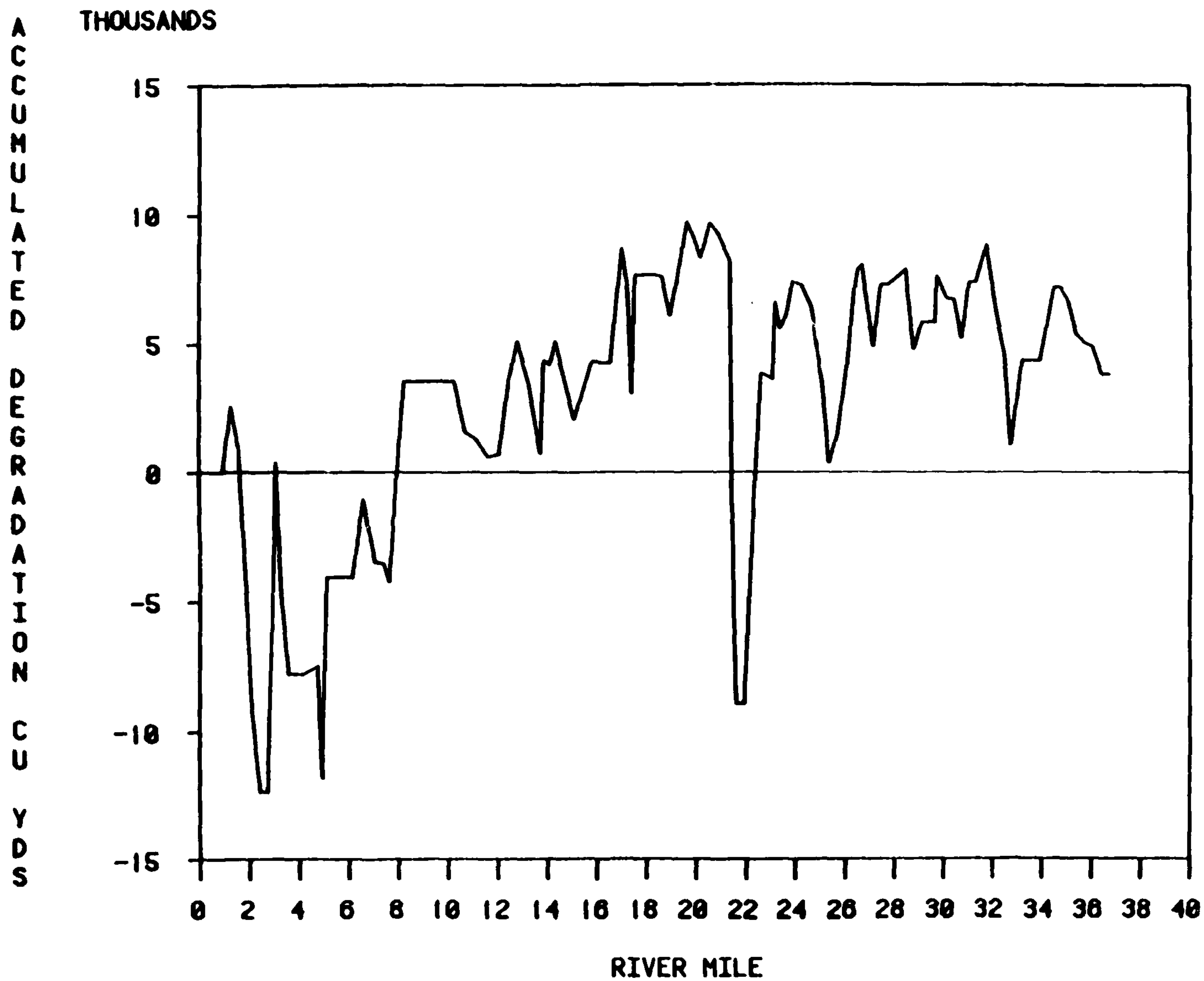

Figure 11. Accumulated degradation for 10-year hydrograph - natural channel

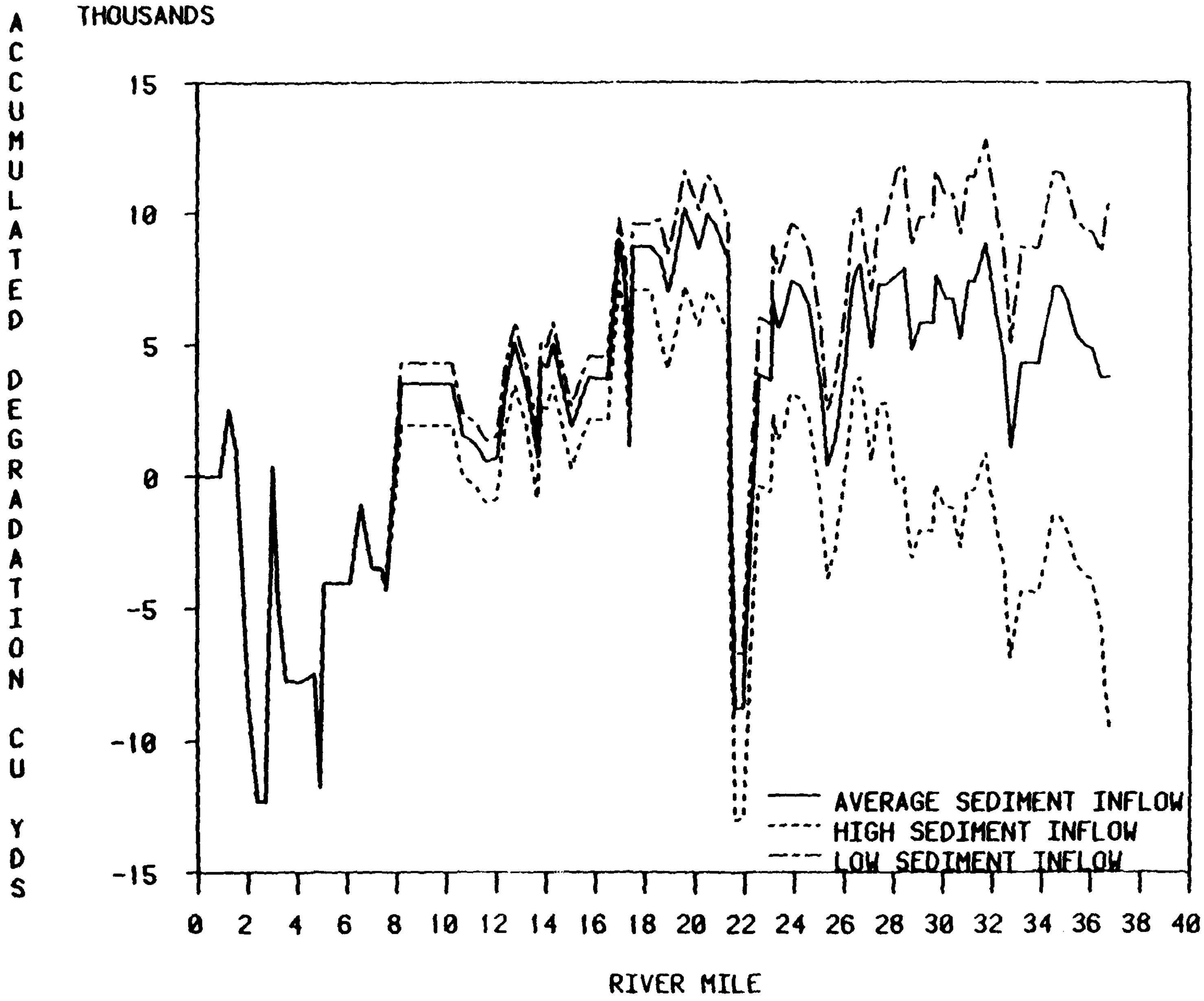

Figure 12. Model sensitivity to sediment inflow

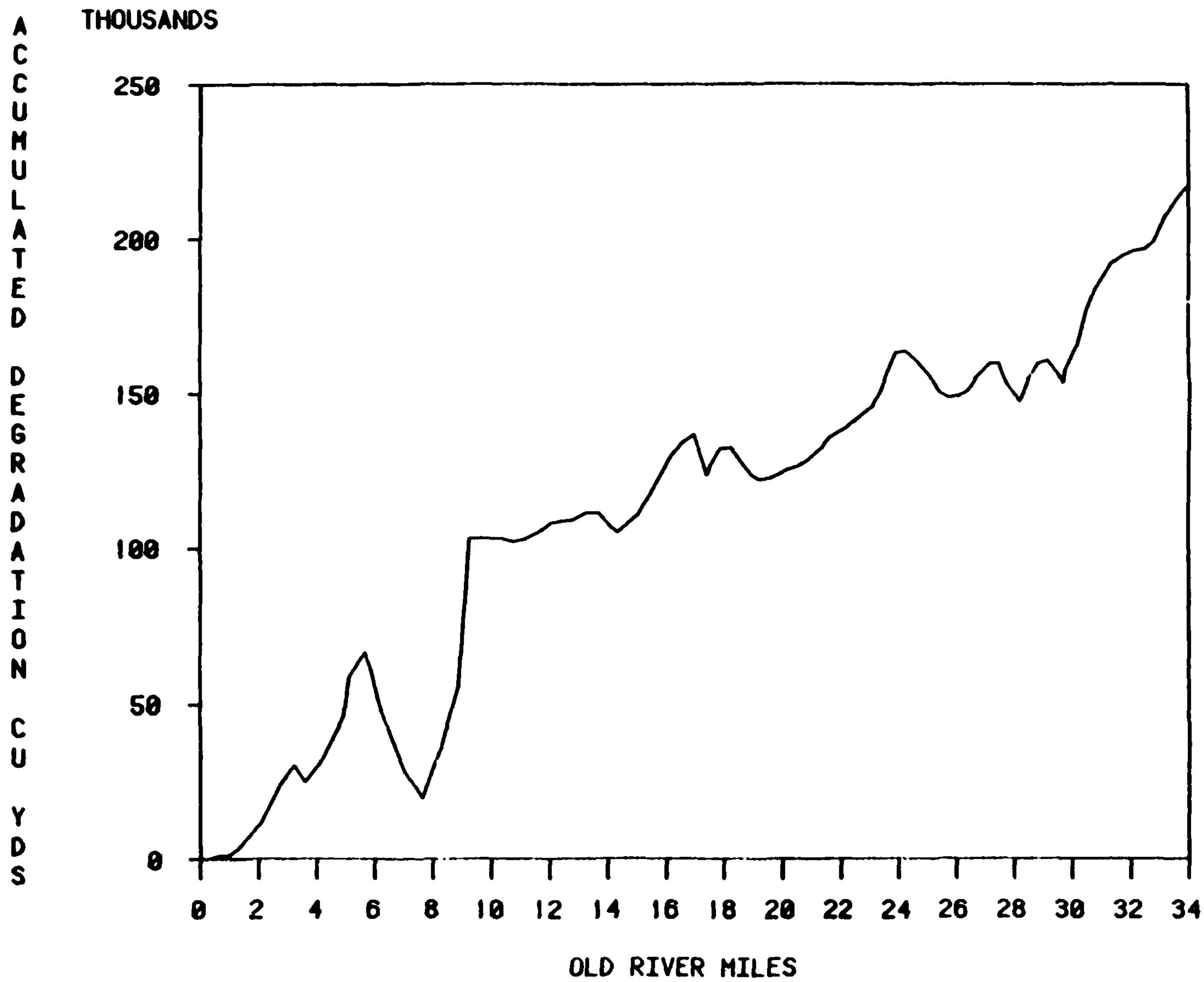

Figure 13. Accumulated degradation for 10-year hydrograph - design channel

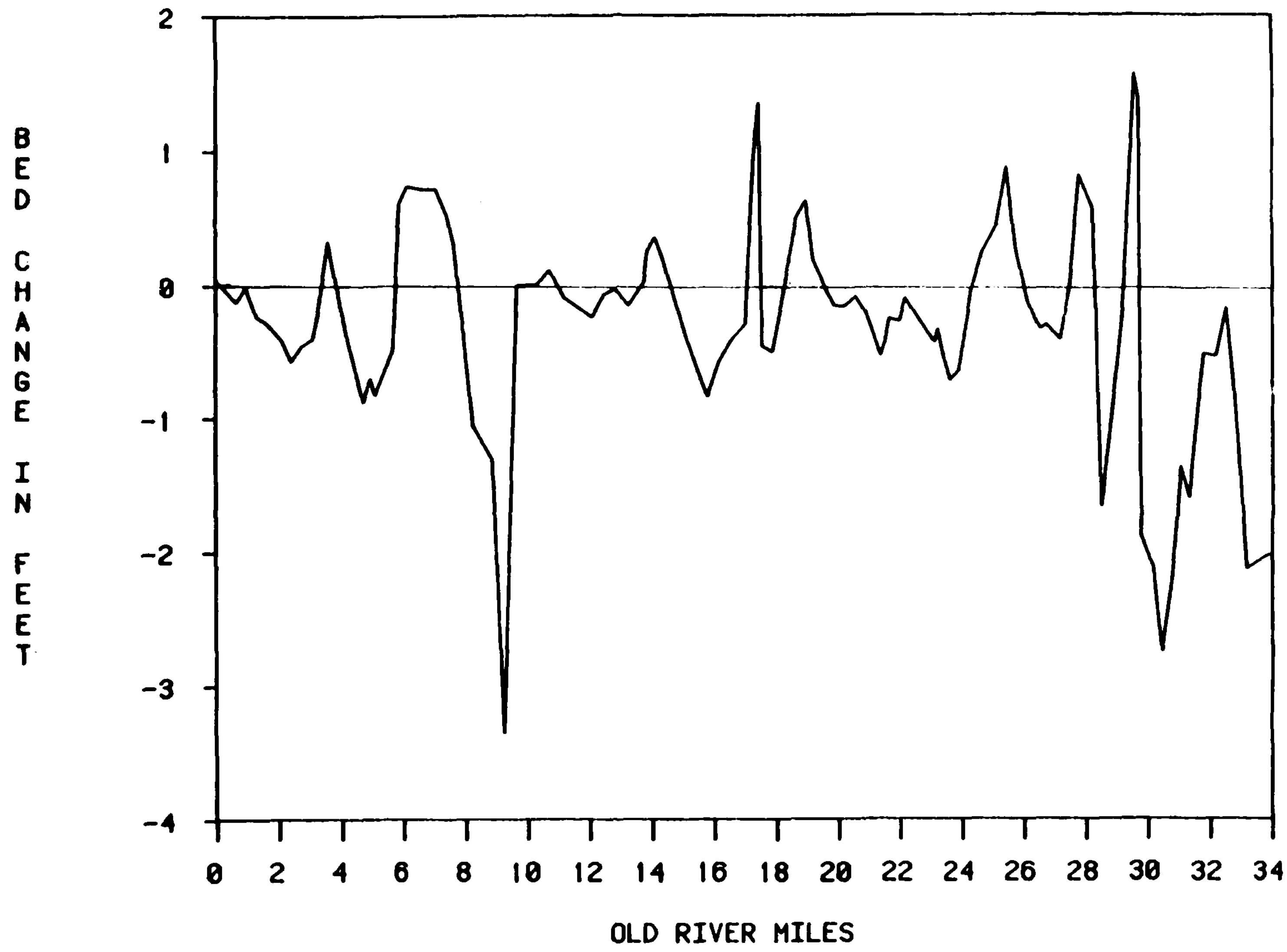

Figure 14. Bed change at end of 10-year hydrograph - design channel

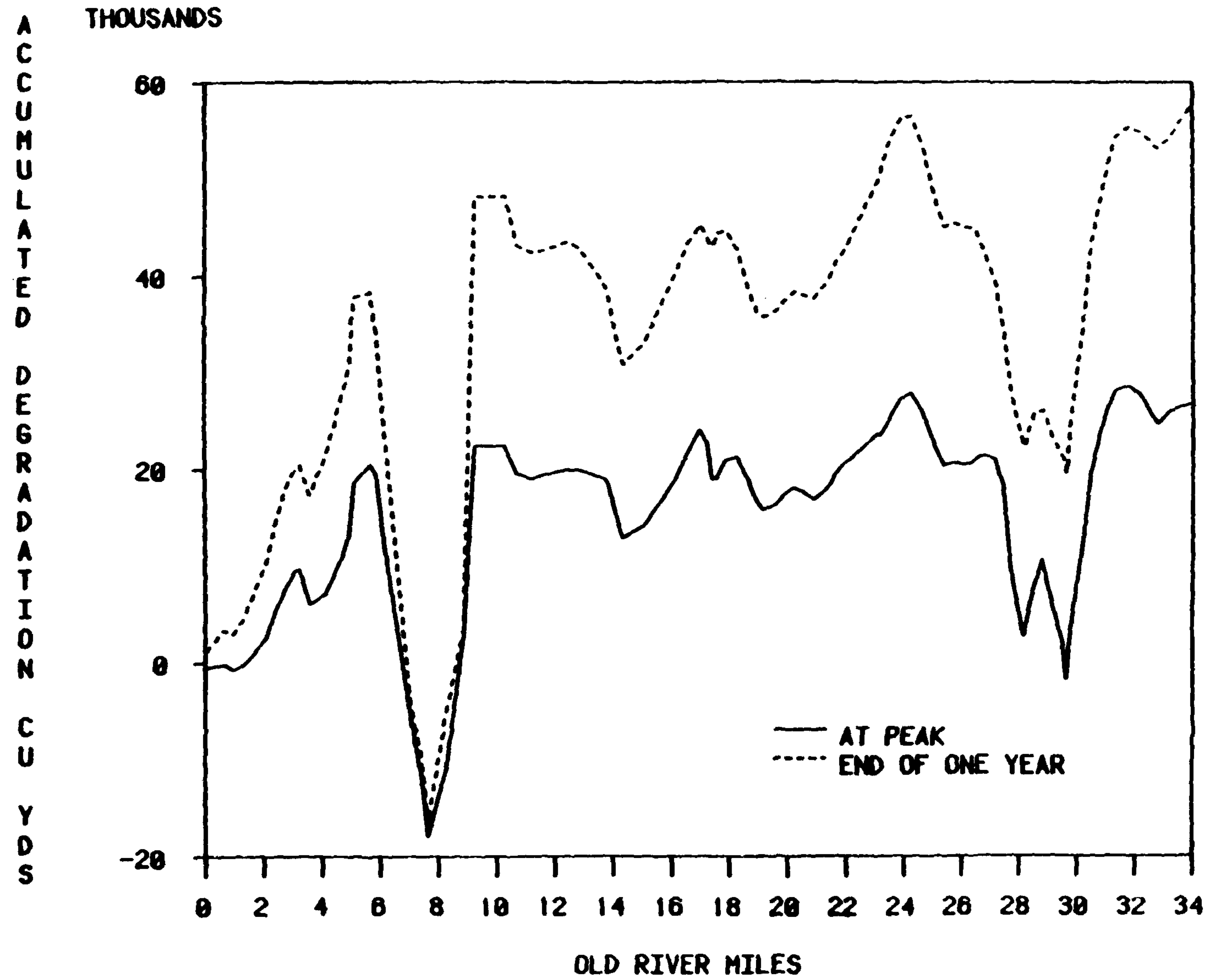

Figure 15. Accumulated degradation - design channel - annual flow duration hydrograph