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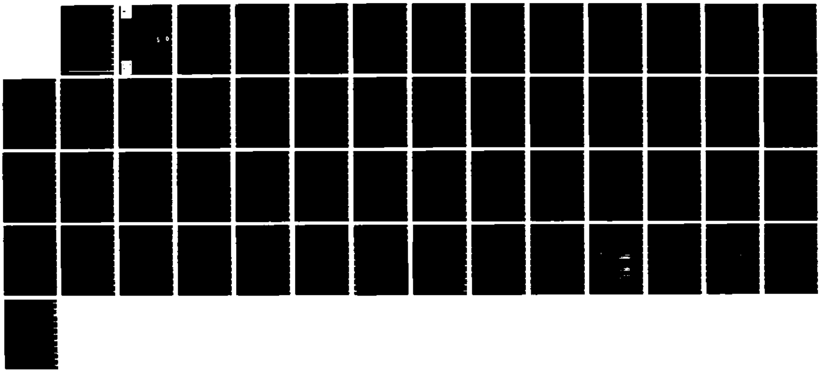

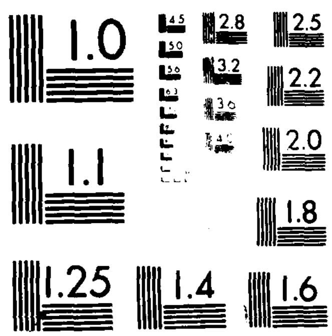


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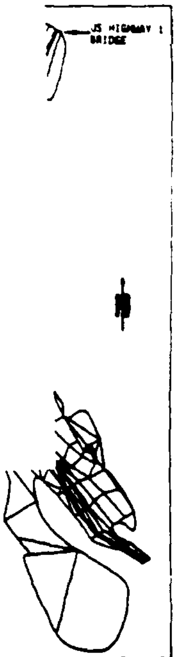

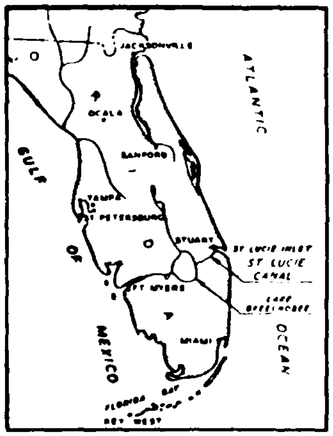


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MISCELLANEOUS PAPER HL-86-4

# ST. LUCIE CANAL AND ESTUARY SEDIMENTATION STUDY

## Mathematical Model Investigation

by

David T. Williams, John J. Ingram, William A. Thomas

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The St. Lucie Canal was constructed for flood control and other purposes in 1948. The canal connects Lake Okeechobee to the South Fork, St. Lucie River, just upstream from the St. Lucie Estuary. Following the project's construction, the canal widened and local interest reported shoaling and turbidity in the South Fork of the St. Lucie Estuary.

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20. ABSTRACT (Continued).

The objectives of this numerical model study were to: (a) identify the major sources of sediment causing shoaling in the South Fork, St. Lucie Estuary, (b) determine the water discharge threshold at which substantial quantities of sand begin to move in the canal, (c) forecast the expected value of future shoaling rates in the South Fork, St. Lucie Estuary, (d) determine if an overgate release of water would produce less turbidity than the present undergate release, and (e) assess the adequacy of existing field data and recommend modifications to the data collection program as necessary. To meet these objectives, numerical models of the systems were developed. The computer code "HEC-6, Scour and Deposition in Rivers and Reservoirs," was used for the canal study area and four numerical models of the estuary were developed. Two of the estuary models analyzed shoaling and scour using field survey data. A two-dimensional hydrodynamic model was developed to investigate water current patterns. The fourth model, an HEC-6 model of the area downstream of the St. Lucie lock, was used to forecast future quantities of sand discharge into the estuary and enable a prediction of future shoaling conditions.

The laterally averaged, two-dimensional model, LARM, was used to study the relative effect of overgate versus undergate releases on the vertical distribution of velocity in addressing the turbidity question.


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# PREFACE

The sedimentation study of the St. Lucie Canal and Estuary, documented by this report, was performed for the US Army Engineer District, Jacksonville.

The study was conducted in the Hydraulics Laboratory of the US Army Engineer Waterways Experiment Station (WES) during the period September 1979 to September 1984 under the direction of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs of the Hydraulics Laboratory, and Mr. M. B. Boyd, Chief of the Hydraulic Analysis Division. The work was performed and the report was written by Messrs. D. T. Williams, J. J. Ingram, and W. A. Thomas of the Hydraulic Analysis Division. This report was edited by Mrs. Beth F. Burris, Publications and Graphic Arts Division.

During publication of this report, COL Dwayne G. Lee, CE, was Commander and Director. Dr. Robert W. Whalin was 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 |
|---|---|---|
| acre-feet | 1,233.489 | cubic metres |
| cubic feet | 0.02831685 | cubic metres |
| cubic yards | 0.7645549 | cubic metres |
| Fahrenheit degrees | * | Celsius degrees or Kelvins |
| feet | 0.3048 | metres |
| miles (US statute) | 1.609347 | kilometres |
| pounds (mass) per cubic foot | 16.01846 | kilograms per cubic metre |
| pound-second per square foot | 47,881.0 | centipoises |
| tons (2,000 pounds, mass) | 907.1847 | kilograms |
| yards | 0.9144 | metres |

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

# ST. LUCIE CANAL AND ESTUARY SEDIMENTATION STUDY

## Mathematical Model Investigation

## PART I: INTRODUCTION

### Location Description

1. The St. Lucie Canal, a part of the central and south Florida project, was constructed for "flood control and other purposes" in 1948.* The canal connects Lake Okeechobee to the South Fork, St. Lucie River, just upstream from the estuary (Figure 1), following the alignment of an existing "box-cut ditch" that had been constructed by local interests in the early 1900's.

2. The St. Lucie Canal is one of three outlets from Lake Okeechobee. Agricultural canals and the Caloosahatchee River are the first and second priority outlets, respectively, in the flood release schedule. However, the agricultural canals are usually flowing at capacity and the Caloosahatchee River, flowing into the Gulf of Mexico, has a substantial drainage area; thus the St. Lucie Canal is the only firm flood regulation outlet in the system.

3. The canal is intersected by numerous smaller, lateral canals that supply irrigation water and provide drainage for adjoining agriculture land; but the only major tributary is the South Fork of the St. Lucie River. The South Fork joins the canal approximately 3 miles** downstream from St. Lucie Lock, which is near the entrance to the estuary.

4. The St. Lucie is also a link in the inland navigation system providing an 8-ft navigation depth. When the canal was enlarged in 1948, the lock at Port Mayaca was removed and water levels in the canal fluctuated with Lake Okeechobee. In 1978, a new lock and dam structure went into operation at Port Mayaca, and the normal operating level in the canal became 14 ft NGVD (National Geodetic Vertical Datum).

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* US Army Engineer District, Jacksonville. 979 (Jan). "St. Lucie Canal Bank Stabilization Problem Identification," Central and Southern Florida Project, letter report, Jacksonville, Fla.

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

## Problem Description and Study Objectives

5. Sedimentation problems became evident early as the canal widened and local interest reported shoaling and turbidity in the South Fork of the St. Lucie Estuary. The US Army Engineer District, Jacksonville (SAJ), studied the problem in 1954 (USAED, Jacksonville, 1979*), and again during the 1970's. Subsequently, SAJ initiated this study to evaluate the behavior of the canal-estuary system by using numerical modeling. The objectives were to:

a. Identify the major sources of sediment causing shoaling in the South Fork, St. Lucie Estuary.

b. Determine the water discharge threshold at which substantial quantities of sand begin to move in the canal.

c. Forecast the expected value of future shoaling rates in the South Fork, St. Lucie Estuary.

d. Determine if an overgate release of water would produce less turbidity than the present undergate release.

e. Assess the adequacy of existing field data and recommend modifications to the data collection program as necessary.

6. The hypothesis advanced by local interests is that waves from boats erode the banks which provides a sediment source for the flows to move out of the canal. Deposition occurs upon reaching the estuary. This study addressed that hypothesis.

## Characteristics and Recent History

7. Land adjacent to the canal is primarily agricultural. Commercial and industrial development is minimal except in the Palm City-Stuart areas.

8. Seven possible sediment sources were suspected: Lake Okeechobee, canal banks, canal bed, lateral inflows feeding storm-water runoff into the canal, South Fork of the St. Lucie River, the bed of the estuary, and local drainage into the estuary.

9. This study assumes storm-water runoff due to gravity is the primary energy source moving sediment into the major shoaling area, the vicinity of Palm City. The tides range from 1.77 ft at lower low water to 5.97 ft at high water with a daily range of about 0.8 ft. Although present, wind waves are

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* Op. cit., page 4.

small and, therefore, are expected to exert minimal influence on the suspension of the bed sediments and no influence on the movement of sediments in suspension. Data were not available to properly address stratification or density currents.

10. The annual water yield at St. Lucie Lock is shown in Table 1 for the period 1954 to 1983, and the accumulated volume curve for water yield is shown in Figure 2. The lower annual yields from 1978 to the present reflect a regulation schedule to increase the flood pool elevation in Lake Okeechobee rather than a long-term change in the flood-control outlets of the system.

11. Figure 3 shows the flow duration curve developed from St. Lucie Lock and Dam records, 1953-1976. The maximum discharge of 11,500 cfs was recorded 26 March 1970, and the discharge exceeded 1,000 cfs 20 percent of the time. This characteristic is significant because the system is either turned off or on and the low to intermediate flows, characteristics of natural rivers, are missing. Consequently, the methods for analyzing sedimentation problems in natural streams were modified for this system.

12. Sedimentation characteristics, like hydrologic characteristics, include both volumes and rates of sediment movement. Other pertinent sedimentation characteristics are suspended sediment concentrations, the composition and size analysis of suspended concentrations, the composition and size analysis of bed and bank sediments, the sources of sediment and their distribution in the study area, and any geologic controls (e.g., bedrock) or man-made controls along the water courses.

13. Periodic suspended sediment samples have been taken and analyzed at various locations along the canal. An approach used in natural rivers to obtain sediment yield is to plot water-sediment load data on log-log paper and determine a sediment load rate corresponding to each water discharge. When applied to the St. Lucie Lock and Dam data set (Figure 4), the regression curve was too steep to give a reliable answer. Therefore sediment yield calculations would require a daily total load station, i.e., the yield is determined by summing each daily load instead of combining the load curve with a flow duration curve to obtain an annual sediment yield.

14. Since the samples were taken over a long period of time, they are grouped into 5-year intervals in an attempt to highlight any trends that might exist. The results for Port Mayaca are shown in Table 2.

15. The standard deviations of the concentrations are too large to use

these mean values to estimate a time interval sediment load. There may have been a trend toward lower concentrations since the early years of the project, but the class interval approach is not conclusive. The percentage of volatile solids has been nearly constant during the life of the project. Some sand has been detected in the samples, but the quantities are highly variable and small which suggests they may have come from a local source such as construction activities along the canal.

16. Portions of the canal banks are vegetated, but the banks are very sandy and exposed, with near vertical buffs of 10 to 15 ft in height for the most part.

17. Downstream from the St. Lucie Lock, banks are lined with mangroves. However, most of the small islands in the vicinity of Palm City Bridge are submerged during high tide. The bed sediments are sands and no mud flats were located.

18. No gage, discharge, or sediment records are available for the lateral canals on the South Fork of the St. Lucie River. A qualitative assessment, made during a site reconnaissance trip, revealed no extensive deltas or maintenance operations that would point to a major lateral sediment source.

19. Dredging has been performed in the systems; however, much of it was in the mouth of the estuary, near the Intracoastal Waterway (IWW) Crossing, which is downstream from this area. The Jacksonville District supplied the dredging quantities in Table 3. Between 1954 and 1959 dredging was limited to the vicinity of the Intracoastal Waterway. In 1960, of the 22,900 total yards dredged, 20,000 yd were removed in the vicinity of the Palm City Bridge and the canal downstream of the St. Lucie Lock. In 1961 and 1969, all material was dredged from the canal near the St. Lucie Lock; otherwise, dredging has been located near the IWW.

20. Bedrock was observed frequently between Port Mayaca and canal sta 200. The bedrock elevation ranged from +8 ft NGVD near Port Mayaca to -1 ft at sta 220. Only two other bedrock outcrops were observed in the remaining distance to Indiantown (canal sta 570), and no bedrock was noted in the boring logs between Indiantown and St. Lucie Lock. The borings were presented in the 1948 construction drawings.

21. The significant fluvial indicators are planform, bottom slope, and cross-section width and depth. Planform refers to width and meander patterns. Aerial photographs are the most useful data source for analyzing planform

changes. The objective is to compare bank caving locations with meander pattern development. Due to the absence of sequential aerial photographs, taken periodically to highlight changes with time, the planform characteristics remain undefined.

22. Detailed surveys of 1949, 1954, and 1976 provide very useful information on width, depth, and bottom slope. Figure 5 shows width profiles for a water-surface elevation of 14.0 ft NGVD. Examination of the cross sections revealed that the geometries at sta 0 and 1000 did not extend up to elevation 14 ft NGVD for the 1949 survey; therefore they were excluded from the 1949 to 1954 analysis but were included in the 1954-1976 analysis. In the 1976 survey, sta 1250 was not at the exact location of other surveys and therefore was also excluded from the analysis. The 1949 width increased from 210 ft near Port Mayaca to 285 ft at canal sta 1050, which is near the approach to St. Lucie Lock and Dam. By the 1954 survey, the width had generally increased along that entire distance. The average increase was 8.6 ft or 1.72 ft/yr. By the 1976 survey, the average width had increased another 37.6 ft, an annual rate of 1.71 ft/yr. As before, the increase was almost uniform along the entire 23 miles. This indicates that the canal is not adjusting its width to some new regime condition because if it were, the width would not have increased uniformly as the canal attempted to adjust its nonuniform initial width to a uniform regime width.

23. The canal has become shallower (Figure 6). In 1949, the width/depth ratio at Indiantown was 16.5, and had increased to 18.7 by 1954; by 1976, the value was 28.4. A continued increase will lead to planform problems that might require local bank stabilization and this problem could possibly extend a considerable distance from Indiantown in both directions.

24. Whereas the change in width does not correlate with distance, the average bed elevation profiles (Figure 6) exhibit some interesting features. The 1949 survey has a relatively steep slope (0.000085) from Port Mayaca (sta 0) to sta 650, which is near Indiantown Bridge. The 1954 survey shows a slight tendency to a flatter slope in this area and the 1976 survey shows an actual decrease to 0.000023. From sta 650 to the St. Lucie Lock (sta 1250), the 1949 and 1954 survey has a slope of almost zero but the 1976 survey has a slope of 0.00002. At sta 650, which is at the pivot point of the slope changes, most of the deposition occurs, which indicates either the canal is trying to steepen the slope to carry the sediment load or significant

deposition from local sediment inflows is near this point, and the latter seems to be the most likely.

25. Another possible influence on the change in bed profile is the density of lateral canals. Most of these occur upstream from Indiantown, suggesting that these canals may supply sediment to the St. Lucie in addition to that coming from the banks.

26. Because the canal is controlled, the relationship between stage, discharge, and velocity is parametric. Hydraulic transients can be expected following each gate operation. A substantial drawdown at St. Lucie Lock is required to pass the larger discharges. Hydraulic roughness in the canal is a complex relationship and exerts a substantial influence on numerical model performance.

## Approach

27. Numerical models of the systems were developed to analyze prototype data by simulating the system response. The hydrograph between the 1949 and 1954 cross-section surveys was used to calibrate a numerical model of the canal for the computer code "HEC-6, Scour and Deposition in Rivers and Reservoirs." The hydrograph and surveys between 1954 and 1976 were used to verify the canal model.

28. Four numerical models of the estuary were developed. Two of these analyzed shoaling and scour using the 1954 and 1976 field surveys. In the first, an average-end-area approach was used as well as a spatial data management approach. In the second, the entire South Fork of the St. Lucie Estuary was gridded with 50-ft square cells.

29. In addition to the above volume analyses, a two-dimensional (2-D) hydrodynamic model of the South Fork was developed to investigate water current patterns. Field data were not available to calibrate the model, but results can be interpreted qualitatively.

30. The fourth numerical model was an HEC-6 model of the area downstream from St. Lucie Lock. This model used the results of the canal model to determine the inflowing sand load. The objective of this model was to forecast the future quantities of sand discharge into the estuary and enable a prediction of future shoaling conditions.

## PART II: SEDIMENTATION IN THE CANAL

### Model Development

31. The canal is relatively straight and appears as if it would act like a river; however, due to the controlled discharges at St. Lucie Lock and Dam, this canal contains some characteristics of a reservoir. The computer code "HEC-6 Scour and Deposition in Rivers and Reservoirs" was used for the numerical model simulations.

32. Cross sections from the 1949, 1954, and 1976 surveys were provided at 1,000-ft intervals by SAJ. They were digitized and processed into the required HEC-2/HEC-6 geometry format at 5,000-ft intervals. A sand bed was prescribed by allowing the program to default to a 10-ft-deep sand layer below the canal bottom except at locations identified to have bedrock, then the sand bed was fixed at that elevation. The model was extended 1,500 ft into Lake Okeechobee using the 1948 construction drawings for geometry.

33. The important sediment parameters are grain size, grain specific gravity, unit weight of deposited material, sources of sediment, rate of sediment discharge from each source, and particle size distribution of sediment load and bed material.

34. The bed gradations obtained in 1977 and 1983 were used in the model. Only those gradations deemed representative of the surrounding area were used. In order to get bed gradations at cross sections where no gradations were available, a plot of bed gradation versus channel distance was constructed. The bed gradation at any cross section can then be obtained by linear interpolation of the gradation at the channel distance corresponding to the cross section. Some gradations were adjusted or excluded if they did not seem to conform to trends shown by nearby gradations. This was done only after careful examinations of the gradation revealed that it was not consistent with the hydraulics. The adopted bed gradations are shown in Figure 7. Silt and clay were excluded from these computations because shoaling in the South Fork of the estuary as well as sediment problems along the canal involves only sand sizes.

35. The specific gravity was assumed to be 2.65, and the bulk density of deposits was assumed to be 93 $lb/ft^3$, dry weight.

36. Of the seven sources of sediment identified in the section

"Characteristics and Recent History," four are connected directly to the canal. The banks are an obvious source; however, the computer codes used do not simulate bank erosion. Sediment from the canals and Lake Okeechobee must be input to the program. The program computes aggradation and degradation of the streambed, and from those results considerable information can be inferred about lateral inflow. The quantity of sediment derived from bank caving, after adjustments for sizes less than 0.0625 mm and bulking of 12.5 percent, was added to the bed of the canal so the HEC-6 code could account for that source in the simulation.

37. The lateral canals were tested for two conditions: no sand contributions and estimated contribution to the St. Lucie Canal. However, their contribution was evaluated upon examination of the computer simulation results and used in the verification of the model.

38. Daily stages and water discharges at the St. Lucie Lock were assembled by SAJ and water temperature data were obtained from the United States Geological Survey's Water Supply Papers.

39. The mean daily water discharges and stages at St. Lucie Lock were graphically converted into a histogram for the period 1949 to 1954. The 22 years of record from 1954 to 1976 were coded as mean daily flows and stages and converted into a histogram using the computer program, Sediment Weighted Histogram Generator (SWHG). The resulting hydrologic data contained 160 discharge events representing the 22-year period.

40. Water temperatures was available for water year 1966 at St. Lucie Lock. Values ranged from 56° F in February to 86° F in August. Monthly averages were converted into seasonal averages of 72°, 65°, 78°, and 83° F for the four quarters of the water year beginning in the October-December quarter.

## Model Calibration

41. Hydraulic calibration of HEC-6 consisted of executing the model in the fixed-bed mode and adjusting Manning's n values to match observed energy losses between St. Lucie Lock and Port Mayaca gages for various discharges.

42. Because of the 23-mile distance between Port Mayaca and St. Lucie Lock, any discharge or elevation changes at either locations would not influence the water-surface elevations at the other location for several hours. Because of this phenomenon, only those discharges remaining relatively constant

for a 24-hr period were used in the calibration. The calibrated n-values ranged from 0.0265 to 0.022 and did not exhibit a significant correlation with discharge. Therefore an average value of 0.025 was used in the model. The maximum error generated by using the average rather than 0.022 or 0.0265 was only 5.8 percent in the water-surface elevation and 8.0 percent in sediment transport rate using an extreme discharge of 8,000 cfs.

43. The scatter in hydraulic roughness plus the lack of a correlation with discharge makes the selection of a sediment transport function very difficult. The standard functions in HEC-6, Toffaleti, DuBoys and Stream Power (Yang), were tested using the 1949 to 1954 hydrology. The Toffaleti function was determined to be the best transport function for this system.

44. Three comparisons were made during these tests: (a) the computed rate of sand discharge was compared with observed values; (b) the annual volumes computed by each method were compared with estimated losses and sources from the canal; and (c) the canal bed profile computed by each method was compared with the 1954 survey profile.

45. The sources of sediment in these comparisons are the canal bed and banks. The volume of sediment supplied by bank caving was computed and the equivalent depth change, after 12.5 percent expansion, was added to the canal bed elevation. The comparisons were made by simulating the 1949 to 1954 flows and stages and comparing the resulting bed elevation changes with the prototype changes determined from the 1949 and 1954 surveys (Figure 8). Note that the computed bed elevations between sta 500 and 700 are considerably below the 1954 survey, which indicates a source of sediment not modeled.

46. To reconstitute the prototype profile, local inflow points were identified and grouped into five representative local inflow points. These were inserted in the model at sta 200, 500, 550, 600, and 700. The local sediment discharges from these inflow points were determined by adjusting the local inflowing sediment concentration until the canal bed elevations at the end of the 1949-1954 simulation were reasonably similar to the 1954 survey. The annual rate of local sediment inflow was set to vary linearly with the annual water yield.

47. Figure 9 shows the results of the 1949-1954 calibration simulation with local sediment inflows. Some of the differences between the observed and computed elevations can be attributed to the lumping of the 15 prototype local inflow points into 5 model local inflow points.

48. The prototype showed a bed elevation increase at sta 0 to 50 for which Lake Okeechobee is the only inflow point. However, the absence of sand in the lake bed deposits near the canal and simulation results eliminate that body as a significant sand source. Construction activities and the initial adjustment of the canal cross section probably account for that bed change.

49. The simulation of the various sources for the 1949 to 1954 time period resulted in a net sand deposition of 67,000 cu yd. Table 4 gives a breakdown of the sources. The analysis of the 1949 and 1954 surveys showed a total channel deposition of 1,162,000 cu yd in that time period. Of that amount, 981,000 cu yd can be attributed to bank caving, leaving 181,000 cu yd coming from other sources. The difference between the model results of 67,000 cu yd and prototype results of 181,000 cu yd is reasonable because an increase of only +11 percent in the total bank caving estimate would show a net deposition the same as the model. This 11 percent difference could be from errors in estimating the bulking factor, survey accuracy, sampling and analysis errors in the determination of percentage of material >0.0625 mm, and projection of the 1949 survey cross-sectional profiles to coincide with the 1954 survey. Another possible source of error is the assumption of a linear relationship of canal water yield to local sediment inflow yield.

## Model Verification

50. The hydrograph from 1954 through 1976 was simulated to determine sand yield and change in bed profile elevations. At the beginning, the adjusted volume of bank caving, as described in the calibration section, was added to the 1954 surveyed cross sections. Bedrock controls were prescribed between canal sta 100 and 200 as in the calibration. Lateral local inflows were initially set to zero.

51. The resulting bed profile (Figure 10), is lower than the original prototype bed in a few locations which again suggests that the canal banks are not the only source of sand entering the canal. Canal sta 500 tends to control the movement of sediment which suggests that either the two lateral canals near Indiantown Bridge, canal sta 575, may contribute significant amounts of sand or perhaps local construction has created a source of sediment at that point.

52. Significant deposition also occurs at sta 300 to 400 and near

sta 750. At these locations the "no local inflow model" underpredicted the deposition which again suggests significant sand contribution from the lateral inflow points located there. To simulate these inflows, the calibrated local sand inflows were added to the verification model.

53. Figure 11 shows the results of the local inflow simulation for the 1954-1976 period. Note that the computed results at sta 300 to 400 and 550 to 750 match much closer to the prototype than without the local inflow contribution. From sta 1000 to 1100, there appears to be local sediment sources which were not modeled. The comparison of the 1949 and 1954 surveys did not show this trend and maps did not reveal any significant local inflow points in this area. It was then judged that this was probably not hydrologically/hydraulically related and therefore was not modeled.

54. Comparison of the 1954 and 1976 surveys showed a total channel deposition of 2,254,000 cu yd of which 2,086,000 cu yd can be attributed to bank caving. This leaves 168,000 cu yd coming from other sources. The model results, as shown in Table 5, indicate a deposition of 278,000 cu yd. Again, the difference between the model and prototype results is reasonable because a decrease in the bank caving estimate of only -9 percent would show a net deposition the same as the model. The difference could be from the factors cited in paragraph 49.

## Threshold of Movement

55. Figures 12 and 13 show the calculated rate of sediment movement as a function of velocity and water-surface elevation for 1954 and 1976, respectively. These curves apply in the canal cross section about a mile upstream from the lock. To read these curves, enter with the anticipated water discharge and water-surface elevation at the lock and read the estimated sand load. These curves do not give the pool elevation that is required to produce a desired discharge. Both discharge and pool elevation must be known.

56. Note the 1976 curves show larger sediment discharges than the 1954 curves. This is reasonable since the slope of the canal bottom has increased. This coupled with shallower depths has increased water velocities and consequently the sediment load. For the sand sizes in this study, a reasonable coefficient for weight to volume conversions is 0.8, i.e. 0.8 × tons = cu yd. This corresponds to a unit weight of 93 $lb/ft^3$ dry weight.

57. These curves relate to shoaling problems, not turbidity. It is not possible to develop such curves for turbidity since fine sediments, organic sediments, and dissolved solids dominate in that case.

## PART III: SEDIMENTATION IN THE SOUTH FORK OF ST. LUCIE ESTUARY

58. Between 1949 and 1954, more than 130,000 cu yd of dredging was required between St. Lucie Lock and Stuart (Figure 14). Between 1954 and 1977, dredging records show 450,000 cu yd removed between St. Lucie Lock and the IWW, but only 150,000 cu yd of this material was between the lock and Stuart. The remaining material was dredged near the IWW which is 7 miles downstream from Stuart. Between the confluence with the North Fork and the dredging at the IWW, depths have maintained themselves without dredging.

59. The North Fork, like the South Fork, is a sand bed estuary. The shoal developing at Head Point, where the North Fork of St. Lucie River enters (Figure 14), resembles that at Palm City where the St. Lucie Canal enters the South Fork; however, the deposits are still below the water surface at low tide.

60. The St. Lucie Estuary is also a sand bed system. Even at the IWW, sandy material was scooped up from the shoals. The fact that dredging has not been required to maintain the channel through this estuary suggests there is a shortage of inflowing sand; that is, sand deposits quickly upon entering the two forks resulting in relatively sand-free water at their confluence. This leads to the hypothesis that sand deposits in the mouth of the estuary are supplied by sediment from Indian River and perhaps the coastal zone. Field data would be required to verify that process.

61. Total dredging between St. Lucie Lock and the IWW was plotted with water yield at the lock (Figure 15). This shows that dredging was required within a few years of significant water yield periods. This could indicate that the St. Lucie Canal is a major sand supply to the estuary system; however, high water yield periods at St. Lucie would coincide with high water yield periods at the South Fork and local inflow points.

62. Only two data points were available for dredging in the South Fork. As additional data become available, this analysis could be extended to illustrate the impact of sediment from the canal on shoaling in the South Fork.

63. The three sediment sources for the South Fork of the estuary are discharges from the canal, contributions from South Fork of St. Lucie River plus lateral drains, and the bed of the estuary. Average bed profiles from 1954 and 1978 surveys are shown in Figure 16. Distances start at St. Lucie Lock and the stationing was measured along the navigation channel alignment to the Highway 1 Bridge at Stuart.

64. Nautical Chart 11428* shows the South Fork of St. Lucie River entering the canal at statute mile 13, i.e., 13 navigation miles from the IWW.

65. At statute mile 12.5, the canal passes through a cutoff; and from statute mile 11.5 to 10, they flow together again. The bed profiles show erosion for 1-1/2 miles downstream of the lock and deposition from there, statute mile 13, through Palm City Bridge. Points of greatest bed change coincide with the South Fork of St. Lucie River and the cutoff. Therefore the St. Lucie Canal, upstream from the lock, has been trapping sand whereas the South Fork of St. Lucie River is adding sand to the system. The amount coming from the South Fork is not measured, however.

66. There was no evidence of substantial contributions from lateral drains entering the estuary. The bed source from the estuary required such extensive investigation that it is reported in the section, "Analysis of Prototype Surveys."

## Analysis of Prototype Surveys

67. When the construction survey for the St. Lucie Canal was made in 1948, only the navigation channel was surveyed in the estuary. However, in 1954 and again in 1978, complete surveys of the estuary and canal were made. In the vicinity of Palm City, navigation channel miles 9 to 12, cross sections were spaced 200 ft apart in 1954 which picked up the many islands forming there. In 1978, the cross sections were spaced 1,000 ft apart.

68. One approach for forecasting future behavior of the estuary is to extrapolate from trends shown by these surveys. Two methods were selected for analyzing scour and fill: Method 1--cross sections were coded into HEC-2 format (i.e., the format required for the Hydrologic Engineering Center's computer program "Water Surface Profiles") and the net volume of scour and fill calculated by the average end area method using computer program GEDA "Geometric Elements from Cross Section Coordinates"; and Method 2--the (x, y, z) coordinates from the cross-section surveys were digitized for both surveys to form a spatial data bank; a 50-ft-square grid cell mesh was interpolated using the WES-LaGarde data management computer codes and the 1978 data bank was

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* US Department of Commerce. 1978 (Aug). Nautical Chart 11428, St. Lucie Inlet to Fort Meyers and Lake Okeechobee, Florida, National Ocean Survey.

subtracted from the 1954 data bank to produce total fill, total scour, and net change for zones 1-4 in the estuary.

69. Results from both methods are shown in Table 6. Two conclusions are: (a) there has been a net loss of sediment from the bed of the South Fork during the 25 years between these surveys; and (b) the quantities differ substantially from Method 1 to Method 2, indicating that more resolution is required in subsequent surveys.

70. Method 1 was applied to the canal as well as to the estuary and indicated 200,000 cu yd of sediment, averaging 0.7 ft over the entire bed surface, deposited in the canal in 1978. Dredging records showed that 150,000 cu yd had been removed during this period.

71. In the estuary, the cross sections in 1954 were spaced 200 ft apart throughout zones 1 and 2. The 1978 cross sections were 1,000 ft apart, half of the width of the estuary. However, the shoals are small islands spotted here and there, and many of the islands in the 1954 survey lie between the 1978 cross section. Consequently, Method 1, which depends solely upon "representative" cross sections, shows scour through these zones as well as the rest of the South Fork of the estuary.

72. The column "Base Data," Method 2, was computed with no adjustments to the raw data. It is the approach closest to Method 1 and the total bed sediment removed is within 80,000 cu yd of Method 1. Assumptions A and B were attempts to apply judgment to the 1978 data set prior to analysis. Assumption A was "the islands in the 1954 survey are still present although 1978 cross sections do not show them." The computed net shoaling upstream from Palm City Bridge was 188,000 cu yd, 0.75 ft of bed change.

73. Assumption B went a step further: "the islands are still present and have the same elevation as shown in the 1954 survey." A slight increase, 0.05 ft, in the computed shoaling depth resulted.

74. Zone 2 responded in a similar manner. Zones 3-5 consistently showed scour for both methods and all assumptions. The computed bed change was about 1 ft of scour.

75. Neither of these methods included new islands or shoals that might have formed since 1954 and are not shown on the 1978 cross sections. Neither method identified the energy source causing zones 3, 4, and 5 to scour. The destination of scoured material is not evident from this analysis. Reason suggests that zone 5 should be treated separately from the others since it is

in the confluence of the North and South Forks and is, therefore, subjected to turbulent mixing. If eliminated, the resulting bed erosion in the South Fork is -390,000 cu yd. This is of the same order of significance as the sediment discharge from the St. Lucie Canal which indicates that the bed of the estuary should be considered as a significant sediment source in future investigations. Prototype surveys and data collection should be designed accordingly.

## Current Patterns Using RMA-2

76. The objective of this application was to develop current patterns in the South Fork of the estuary coincident with flood releases from St. Lucie Canal.

77. The RMA-2 computer code is a fixed-bed solution of the Reynold's form of the Navier-Stokes equations in two-dimensions.* It was developed for flows that are well mixed in the vertical and contains no accounting for density stratified conditions. Energy sources are gravity, tidal pressure, and surface wind stress; and since all terms are included in the equations, energy is free to change from one form to another (i.e., pressure to kinetic, etc.). Friction and eddy viscosity are the energy loss terms in the code. The solution technique is Galerkin's method of weighted residuals. The head terms used linear shape functions, and quadratic shape functions are used for the velocity terms.

78. The portion of the estuary to be analyzed corresponds to zones 1-5 and is shown in the computation grid (Figure 17). The network consists of 148 elements and 529 nodes. The lack of tidal records in the study area forced a steady-state approach to the problem. However, the tidal information at Stuart for July 1969, October 1969, and July 1970 together with the tidal information shown as the South Fork St. Lucie, August 1972, identified two extremes and the range: lower low water = 1.77 ft NGVD; higher high water = 5.97 ft NGVD, with a daily range of 0.8 ft. The two extremes were used as the downstream boundary elevation in executing RMA-2.

79. Three steady-state water discharges were selected for the upstream

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* W. A. Thomas and W. H. McAnally, Jr. 1985 (Jan). "Open-Channel Flow and Sedimentation, TABS-2; User's Manual for the Generalized Computer Program System," Instruction Report HL-85-1, US Army Engineer Waterways Experiment Station, Vicksburg, Miss.

boundary condition: 2,000, 4,000, and 6,000 cfs; the probabilities for these flows to be equaled or exceeded are 18, 13, and 9 percent, respectively. Energy loss coefficients were assumed. The uniform values applied over the entire grid are 250 lb-sec/ft$^2$ for the eddy viscosity and Manning's roughness coefficient, $n$, of 0.025.

80. The resulting current pattern for $Q = 6,000$ cfs and the lower low water tidal condition, 1.77 ft NGVD, at US Highway 1 Bridge is shown in Figure 18.

81. The length of a vector indicates speed and the direction shows current direction at the base of the vector. The extra large arrowheads show where the velocity exceeds the vector scale. The vector scale diagram is for 0.1 fps.

82. Of particular interest is the current passing around the east side of the island as flow enters the estuary. These values are larger than the values in the navigation channel, up to 1/2 fps, and are probably instrumental in moving sediment in that direction.

83. Another point of interest is the tendency for flow to cross the navigation channel as it passes the Palm City Bridge. The erosion of the bed in zone 3 occurred on the west side which correlates with this current movement.

84. A final point of interest is the uniformity of velocities across the estuary in zone 3. This indicates that a one-dimensional analysis of sediment movement is a reasonable approximation in zone 3.

85. The other combinations of discharge-tidal elevation produced similar patterns with only changes in the magnitude of velocities. To assess the behavior of ebb currents, a discharge of -6,000 cfs was prescribed at the downstream boundary of the grid. (The negative sign indicates a flood tide.) The only surprise was a tendency for currents to concentrate along the western shore in zone 3; additional field data are needed to verify that.

86. The interpretation of these results is primarily qualitative because the model has not been verified. They are presented here to guide any future data collection efforts in the area of the estuary where additional data are needed. Current magnitude and direction at three depths, salinity profiles, and water temperatures are the hydraulic parameters needed. Ranges should extend from bank to bank and provide sufficient measurements for computing the water discharge according to USGS criteria for discharge ranges. Locations should include those shown by letters A-F in Figure 18.

## Sediment Movement Using HEC-6

87. The 1954 survey sections were coded in HEC-6 format, an average bed gradation for each zone was input, and the calibrated St. Lucie Canal model was added to produce a model representing the prototype from Lake Okeechobee to survey station 381 (navigation channel mile 7.6) in the estuary. The 1954 through 1978 discharges were run with an average tidal elevation of 2.70 ft NGVD as the downstream boundary and no attenuation of the water discharge.

88. Results for the canal and zones 1 and 2, as shown in Table 7, are compared with prototype surveys and dredging records. Note that the prototype subtotals are close to the model results except at the canal. The South Fork River, which was not modeled, enters the system in this area; and if prototype subtotal and model results are accurate, the sand yield from the South Fork River can be estimated as shown in the last column of Table 7.

89. A direct comparison of prototype with model is hard to make because of the dredging activities and sand yield of the South Fork River, both of which could not be modeled due to lack of spatial and temporal sand data. The sand yield of 26,000 cu yd (1,000 cu yd/yr) from the South Fork River is a reasonable quantity and makes the model results compatible with prototype surveys and dredging quantities.

90. The model did not calculate the erosion that showed in the prototype surveys in zones 3, 4, and 5. Consequently, one or both of the energy sources that are neglected in HEC-6, i.e., density currents or wind-induced currents, must be active in this area. Zone 5 is in the confluence of the two forks of the estuary and should be excluded from this analysis. However, 390,000 cu yd of bed sediment was eroded from zones 3 and 4 according to best estimates from the prototype data. This is 0.6 ft of erosion if spread uniformly over both zones. It is possible for some of this sediment to have been moved into zone 2 during flood tides. Preliminary estimates of the current pattern were made using RMA-2 by running 6,000 cfs in the upstream direction coincident with the 1.77-ft tide. Current patterns tended to swing into the western side of the estuary in zone 3, which corresponds to the area where erosion was calculated from the prototype surveys.

91. The dilemma, "where did eroded sediment from zones 3 and 4 go?" cannot be definitely resolved. The computed evidence suggests that most of the sand discharged from the canal has settled by the time the flow reaches

Palm City Bridge. Therefore some of the deposits downstream from the bridge may be coming from the downstream direction.

92. If additional field data are taken, the locations should be chosen to resolve the above dilemma in the process. Suspended concentrations, bed samples, and size distributions should be added to the list of field data parameters described earlier for current patterns. The conditions for which additional data are needed must be determined after some samples have been analyzed. Based on this analysis, extreme events of the tide and wind are cases for which data are needed but some additional record of density currents is needed for normal conditions.

93. Results of reconstituting the 1954 to 1978 historic discharges in HEC-6 gave sediment yields as follows. A total of 605,000 cu yd of sand passed the St. Lucie Lock during this time period. Approximately 200,000 cu yd (from survey using Method 1) of this material deposited between the lock and estuary and an additional 20,000 cu yd has been dredged. With an estimate of 21,000 cu yd yield from South Fork River, 406,000 cu yd was delivered to the estuary. Method 2, Assumption B, analysis of the surveys revealed 392,000 cu yd deposited in zones 1 and 2. Also 21,000 cu yd had been dredged from these zones. With 406,000 cu yd entering zone 1, 392,000 cu yd depositing, 21,000 cu yd dredged, and an estimated sand yield of 5,000 cu yd from South Fork River, the resulting yield to zone 3 is -2,000 cu yd, indicating sand movement from zone 3 to zone 2. Method 2, Assumption B, revealed a scour of -390,000 cu yd from the bed in zones 3 and 4. Dredging in those zones was 61,000 cu yd. The resulting yield from the South Fork portion of the estuary is 327,000 cu yd (13,000 cu yd/yr), a reasonable quantity.

## Predicted Future Bed Changes

94. Since the model results in the calibration and verification process were fairly good, the model hydrology was extended to 1983 using data from St. Lucie Lock. The period 1954-1983 was simulated and the model was allowed to continue using the same 1954-1983 hydrology to simulate the time period 1984-2013. Both time periods include an estimated sand contribution from the South Fork River. Since the 1984-2013 simulation does not include dredging, the 1954-1983 simulation was also made with no dredging adjustments, therefore is not truly representative of the 1983 prototype conditions and is just for

comparison purposes. The 1984-2013 simulation is, however, a prediction of the future if no dredging is performed and secondary/tidal currents are insignificant. Results are shown in Table 8.

95. Results of the 1954-1983 simulation are similar to the survey results shown in Table 6 except for zones 3 and 4, which is explained in paragraph 90. The deposition in the area between St. Lucie Lock and zone 1 slightly decreases over time, and zone 1 deposition decreases dramatically as it fills and becomes more efficient in transporting sand. Deposition continues in zone 2 but not as rapid as before. The most deposition occurs in zone 3 which in the previous time period showed no deposition at all. This indicates that the sand is being deposited farther into the estuary as the upper end becomes more efficient in transporting the sand. This accelerated deposition is further compounded by the increase in the sand discharge from St. Lucie Lock as the canal approaches its equilibrium and tends to cease as a sink for the local sediment inflows. Zones 3 and 4 are in areas of energy sources not modeled and the sand deposition in zone 3 in the model may, in the prototype, be redistributed by these energy sources both upstream and downstream (zones 2 and 4) as evidenced by the 1954-1976 prototype analysis.

# PART IV: TURBIDITY CONTROL BY SKIMMING

96. A special study for possibly reducing the turbidity by changing structures for overgate release was conducted using the St. Lucie Canal as a test case. The two-dimensional (vertical) computer code, LARM, by Edinger and Buchak* was applied to develop velocity profiles in the canal. First, the present undergate release schedule was analyzed for a 1,000-cfs discharge. The velocity profiles were analyzed at 1-mile intervals and found to match the classical log velocity law with no vertical components. Near the dam, deviations from the classical log velocity profile were observed but these were local, extending only a short distance from the structure.

97. Consequently, when the release overgate schedule was tested, the velocity profiles did not change from those described above except locally near the structure. Without a general change in the velocity profile, sediment movement will be the same for both types of release schedule; therefore turbidity would not be changed.

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* J. R. Edinger and E. M. Buchak. 1979. "A Hydrodynamic Two-Dimensional Reservoir Model: Development and Test Application to Sutton Reservoir, Elk River, West Virginia," prepared for US Army Engineer Division, Ohio River.

## PART V: CONCLUSIONS

98. This application of numerical modeling is somewhat different from traditional approaches. Usually field data are collected and used to drive the models. In this case the study area is sufficiently large, and the potential sediment sources are sufficiently numerous, diverse, and obscure that an economical field collection program could not be designed without additional insight. One of the results of this model study is such insight. The idea is to use the numerical model, with the available data, to highlight where to collect additional data and at the same time to assess the severity of the sedimentation problems by predicting future deposition. In our judgment, the model prediction of the severity of sedimentation problems in the prototype, given the available field data, is more reliable than the prediction of specific source locations. The results are considered useful; however, the next step should be to confirm the sediment sources identified by the model with field measurements.

99. Of the seven sediment sources suspected for this system, Lake Okeechobee and small tributaries entering the estuary appear to contribute negligible quantities. The canal banks, laterals entering the canal, the bed of the South Fork of St. Lucie Estuary and the South Fork of St. Lucie River are the primary sources.

100. The US Army Engineer District, Jacksonville, has already measured canal bank caving, one obvious source, by cross-section surveys. The model simulation showed that bulk densities of the original bank sediment and of the bed deposits should be measured also. Resulting quantities of scour or deposition are sensitive to that property. Also, suspended sediment and water-discharge measurements of flow from selected laterals would either confirm that the model sources are correct or flag the need for additional work.

101. The three prototype surveys of canal cross sections show no decrease in bank erosion with respect to time. Between 1949 and 1954 the average rate of bank caving was 1.72 ft/yr; between 1954 and 1976 the average was 1.71 ft/yr. Another survey should be taken.

102. The canal is a sink trapping approximately 12,000 cu yd of sediment annually. To minimize flushing it out, the reregulation at St. Lucie Lock could be modified. The water-discharge threshold for sediment movement past St. Lucie Lock depends on both flow and stage at the lock as shown in

Figures 12 and 13. These should also be checked by field measurements.

103. The discharge at which sediment motion begins is being slowly reduced with time as the canal fills with sediment. Having a wider width does not totally compensate for the shallower depth when computing flow velocity.

104. Given the historical hydrology and reregulation but no future bank covering, shoaling in the canal downstream of the lock is expected to continue past year 2013 but at a rate of 88 percent of historical. The rate of shoaling in the estuary upstream from Palm City Bridge is expected to decrease to about 15 percent of the historical rate. Shoaling is expected to continue immediately downstream from the Palm City Bridge but at 60 percent of the historical rate. General shoaling is expected to start between the bridge and the North Fork; the amount of sand leaving the South Fork is expected to increase during this projection period thereby increasing the potential for shoaling in the upper end of the main estuary.

105. The overgate release of water would have negligible effect on turbidity because it affects the velocity profile only in the vicinity of the structure. The turbidity would not be affected unless the shape of the velocity profile were changed over a substantial portion of the canal length.

106. The type of field data being collected is appropriate for a general sediment study of system behavior but the significant bed changes are in fractions of a foot and often produced by local shoals and islands. These need to be included in the cross sections surveyed. Water-velocity magnitudes and directions are needed as well as salinity and turbidity profiles. Suspended sediment concentrations and bed sediment samples should be included along with size fraction analysis and density of deposits.

Table 1

Water Yield, St. Lucie Lock and Dam

| Calendar Year | Water Yield 1,000 acre-ft | Calendar Year | Water Yield 1,000 acre-ft |
|---|---|---|---|
| 1954 | 1,107 | 1969 | 1,200 |
| 1955 | 3 | 1970 | 1,021 |
| 1956 | -- | 1971 | -- |
| 1957 | 850 | 1972 | -- |
| 1958 | 1,858 | 1973 | -- |
| 1959 | 2,750 | 1974 | 235 |
| 1960 | 3,093 | 1975 | -- |
| 1961 | -- | 1976 | -- |
| 1962 | -- | 1977 | 42 |
| 1963 | -- | 1978 | 212 |
| 1964 | 3 | 1979 | 464 |
| 1965 | 26 | 1980 | 272 |
| 1966 | 3,477 | 1981 | 383 |
| 1967 | -- | 1982 | 191 |
| 1968 | 875 | 1983 | 119 |

Table 2

Suspended Sediment Samples, Port Mayaca

| Time Interval | No. of Samples | Discharge | | Concentration | | Volatile Solids | | Silt Clay | |
|---|---|---|---|---|---|---|---|---|---|
| | | Avg cfs | Standard Deviations | Avg ppm | Standard Deviations | Avg %* | Standard Deviation, % | Avg %* | Standard Deviation, % |
| 1954-1959 | 11 | 5,773 | 1,277 | 141 | 109 | 44 | 12 | 72 | 31 |
| 1960-1964 | 1 | 8,360 | -- | 70 | -- | 32 | -- | 37 | -- |
| 1965-1969 | 7 | 6,018 | 400 | 64 | 60 | 36 | 14 | 50 | 30 |
| 1970-1974 | 2 | 4,895 | 2,510 | 63 | 60 | 36 | 31 | 61 | 28 |

* % is the percent of a sample.

Table 3

Dredging Quantities, Stuart, Florida, to St. Lucie Lock

| Date | Cubic Yards | General Area Dredged |
|---|---|---|
| Sep-Dec 1931 | 188,330* | Between Palm City and Lock 2 |
| Jan 1933 | 17,557* | St. Lucie Canal (7 shoals) |
| Mar-Jun 1934 | 536,991 | St. Lucie River |
| Jun 1938 | 62,593 | St. Lucie River |
| Sep-Oct 1937 | 9,678 | St. Lucie River and Canal |
| Jul-Aug 1938 | 242,183 | Between Lock 2 and Stuart |
| Jun 1940 | 5,767 | Shoal immediately below Lock 2 |
| Nov 1942 | 4,527 | St. Lucie River |
| Jun 1948-Oct 1949 | 3,496,088 | Deepening St. Lucie Canal to -8 ft |
| Nov-Dec 1949 | 97,381 | St. Lucie River |
| Mar-Apr 1950 | 179,652 | St. Lucie Lock to Stuart |
| Feb 1952 | 21,108 | St. Lucie River (near Palm City Bridge) |
| Jan 1953 | 32,012 | St. Lucie Lock to Stuart |
| Dec 1953-Jan 1954 | 93,539 | St. Lucie Lock to IWW |
| Feb-Mar 1955 | 33,035 | St. Lucie Lock to IWW |
| Aug 1959 | 47,903 | St. Lucie Lock to IWW |
| Apr-Jun 1960 | 22,932 | St. Lucie Lock to IWW |
| Feb-May 1961 | 73,904 | St. Lucie Canal |
| Jun-Sep 1963 | 23,814 | St. Lucie Lock to IWW |
| Aug-Sep 1969 | 74,866 | Shoal west and St. Lucie Lock |
| Aug-Sep 1969 | 3,056 | Shoal east and St. Lucie Lock |
| Apr-May 1970 | 38,649 | St. Lucie River at IWW |
| Aug-Dec 1972 | 30,636 | St. Lucie River at IWW |

* New work.

Table 4

Simulation Results of Sand Sources 1949-1954

St. Lucie Canal

| Source | | Sand Yield, cu yd |
|---|---|---|
| Lake Okeechobee | | 2,800 |
| Local Inflows | | |
| Canal Sta | | |
| 250 | 31,700 | |
| 500 | 39,800 | |
| 550 | 71,500 | |
| 600 | 39,800 | |
| 700 | 27,800 | |
| Subtotal | 210,600 | 210,600 |
| Total Sand Inflow | | 213,400 |
| Exiting St. Lucie Lock | | 146,000 |
| Net Deposition | | 67,400 |

Table 5

Simulation Results of Sand Sources 1954-1976

St. Lucie Canal

| Source | | Sand Yield, cu yd |
|---|---|---|
| Lake Okeechobee | | 21,900 |
| Local Inflows | | |
| Canal Sta | | |
| 250 | 130,100 | |
| 500 | 162,700 | |
| 550 | 292,800 | |
| 600 | 162,700 | |
| 700 | 113,900 | |
| Subtotal | 862,200 | 862,200 |
| Total Sand Inflow | | 884,100 |
| Exiting St. Lucie Lock | | 605,200 |
| Net Deposition | | 278,900 |

Table 6

Scour and Fill, St. Lucie Lock to North Fork of St. Lucie Estuary, 1954 and 1978 Surveys

| | Location | | | 1,000 cu yd of Bed Sediment* | | | | Bed Change |
|---|---|---|---|---|---|---|---|---|
| | | 1954 | | | Method 2 | | | Method 2 |
| Description | Zones | Survey Stations "BN Line" | Statute miles | Method 1 | Base Data | Assumption A | Assumption B | Assumption B |
| St. Lucie Lock to Estuary | | 00 to 263+00 | 15.0-10.0 | +200 | — | -- | -- | -- |
| Estuary to Palm City Bridge | 1** | 263 to 295 | 10.0- 9.4 | -50 | +2 | +188 | +211 | 0.82 |
| | 2 | 295 to 310 | 9.4- 9.1 | | +104 | +182 | 181 | 1.32 |
| | 3 | 310 to 339 | 9.1- 8.6 | -800 | -128 | -96 | -97 | -0.36 |
| | 4 | 339 to 379 | 8.6- 7.82 | | -330 | -293 | -293 | -0.72 |
| | 5 | 379 to 381 | 7.82-7.78 | | -375 | -516 | -517 | -2.56 |
| | | | | -650 | -728 | -535 | -514 | |

* Negative values are scour; positive values are fill.
** Zones 1-5 of Figure 16.

Table 7

Sand Budget Analysis 1954-1978

St. Lucie Estuary

| Zone | Sand Deposition, 1,000 cu yd — Prototype: Survey | Prototype: Dredged | Prototype: Subtotal | Model | Estimated from* South Fork River |
|---|---|---|---|---|---|
| St. Lucie Lock to Estuary | 200** | 20 | 220 | 199 | 21 |
| 1 | 211† | 21 | 232 | 230 | 2 |
| 2 | 181† | 0 | 181 | 178 | 3 |
| Total | 592 | 41 | 633 | 607 | 26 |

* Obtained from difference of model results and prototype subtotal.
** Method 1.
† Method 2, Assumption B.

Table 8

Comparison of Computed Sand Volume and Bed Changes

St. Lucie Estuary

| Zone | Surface Area, acres | 1954-1983 Volume Dep 1,000 cu yd | 1954-1983 Bed Change ft | 1984-2013 Volume Dep 1,000 cu yd | 1984-2013 Bed Change ft |
|---|---|---|---|---|---|
| St. Lucie Lock to Estuary | 180 | 212 | 0.73 | 188 | 0.65 |
| 1 | 159 | 209 | 0.82 | 34 | 0.13 |
| 2 | 85 | 228 | 1.66 | 137 | 1.00 |
| 3 | 165 | 0 | 0 | 403 | 1.51 |
| 4 | 252 | 0 | 0 | 0 | 0 |
| Total | 841 | 649 | | 762 | |

Note: Volume of sand exiting St. Lucie Lock is 622,800 cu yd for 1954-1983 and 734,800 cu yd for 1984-2013.

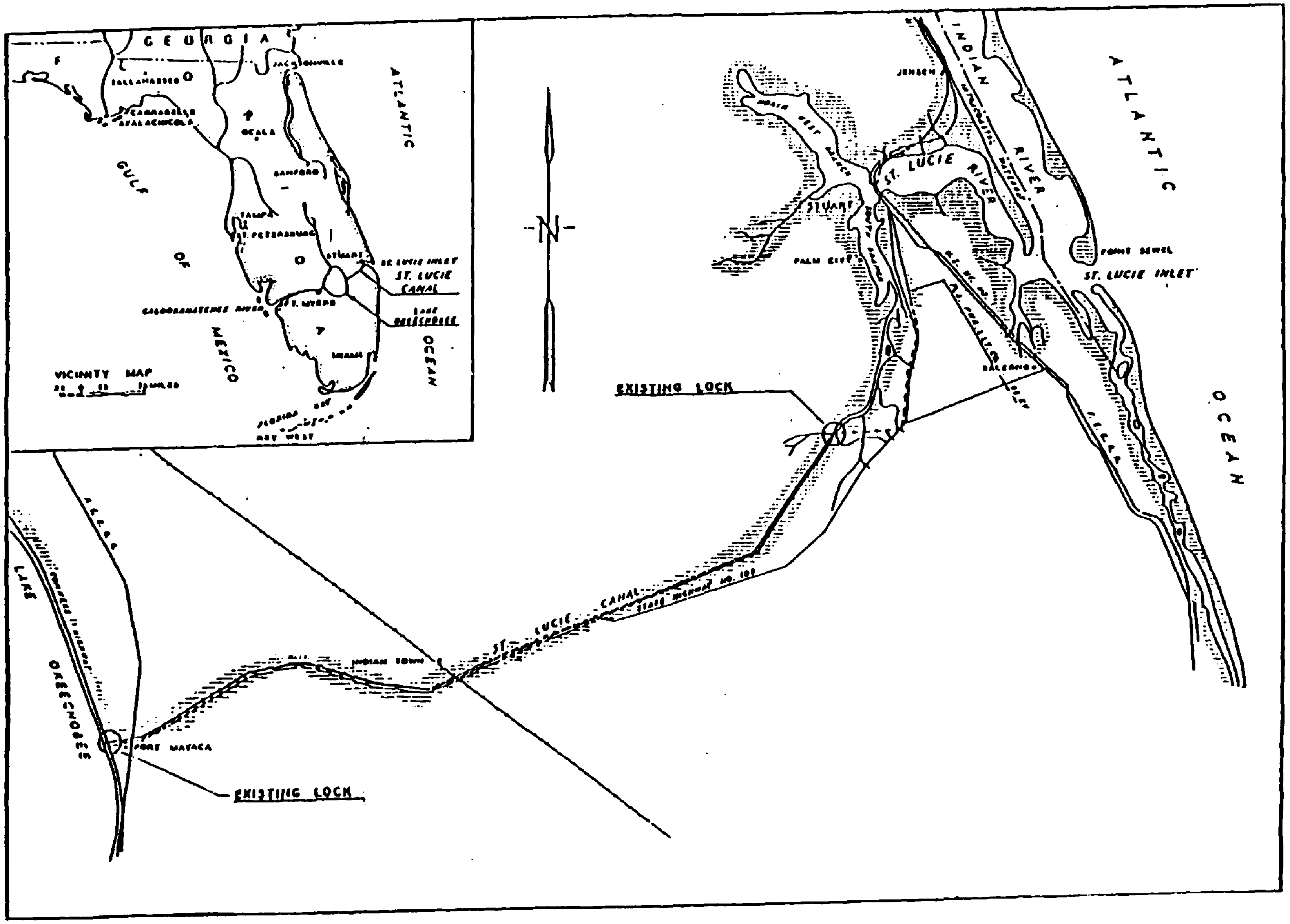


Figure 1. Location map

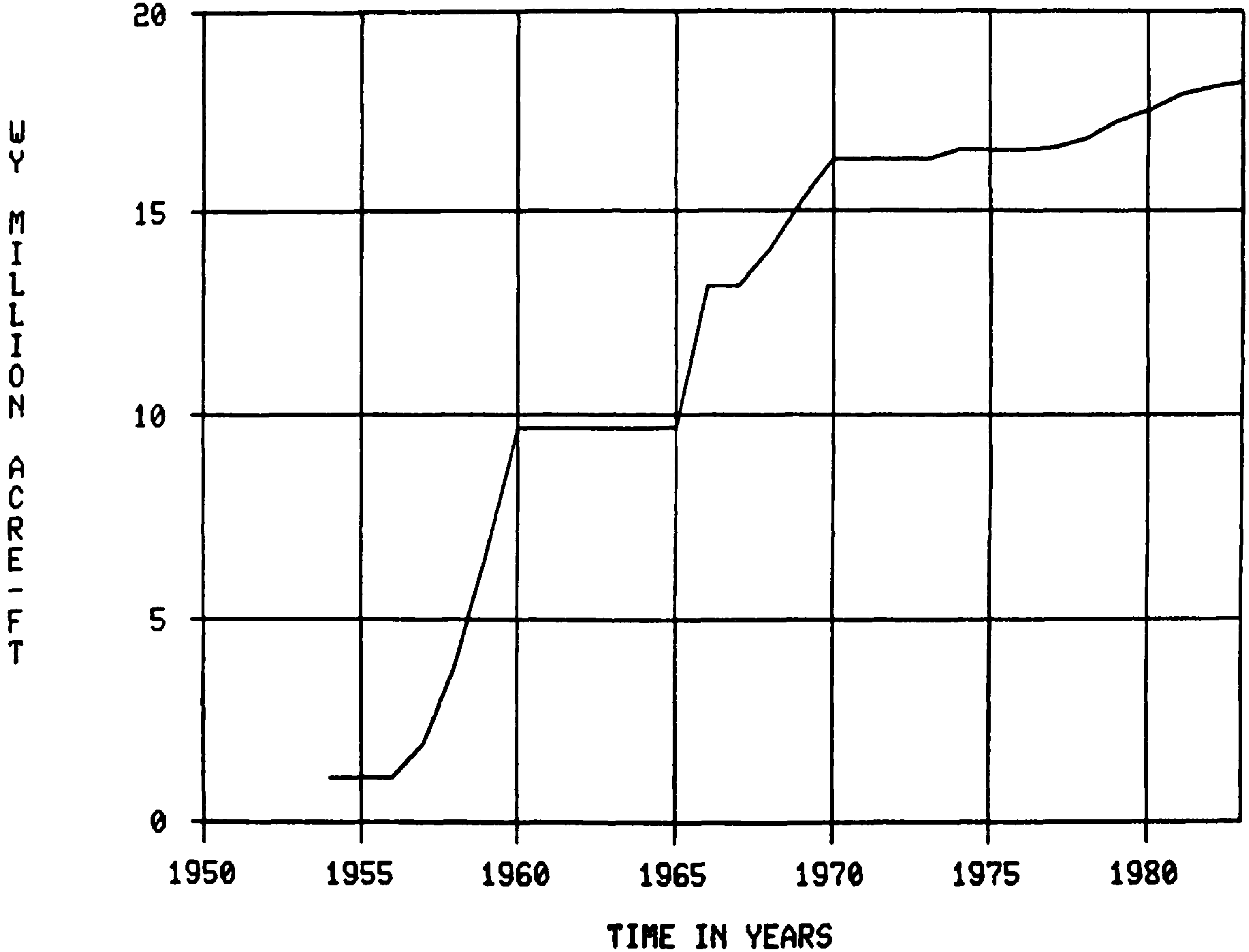


Figure 2. Accumulated water yield (WY)

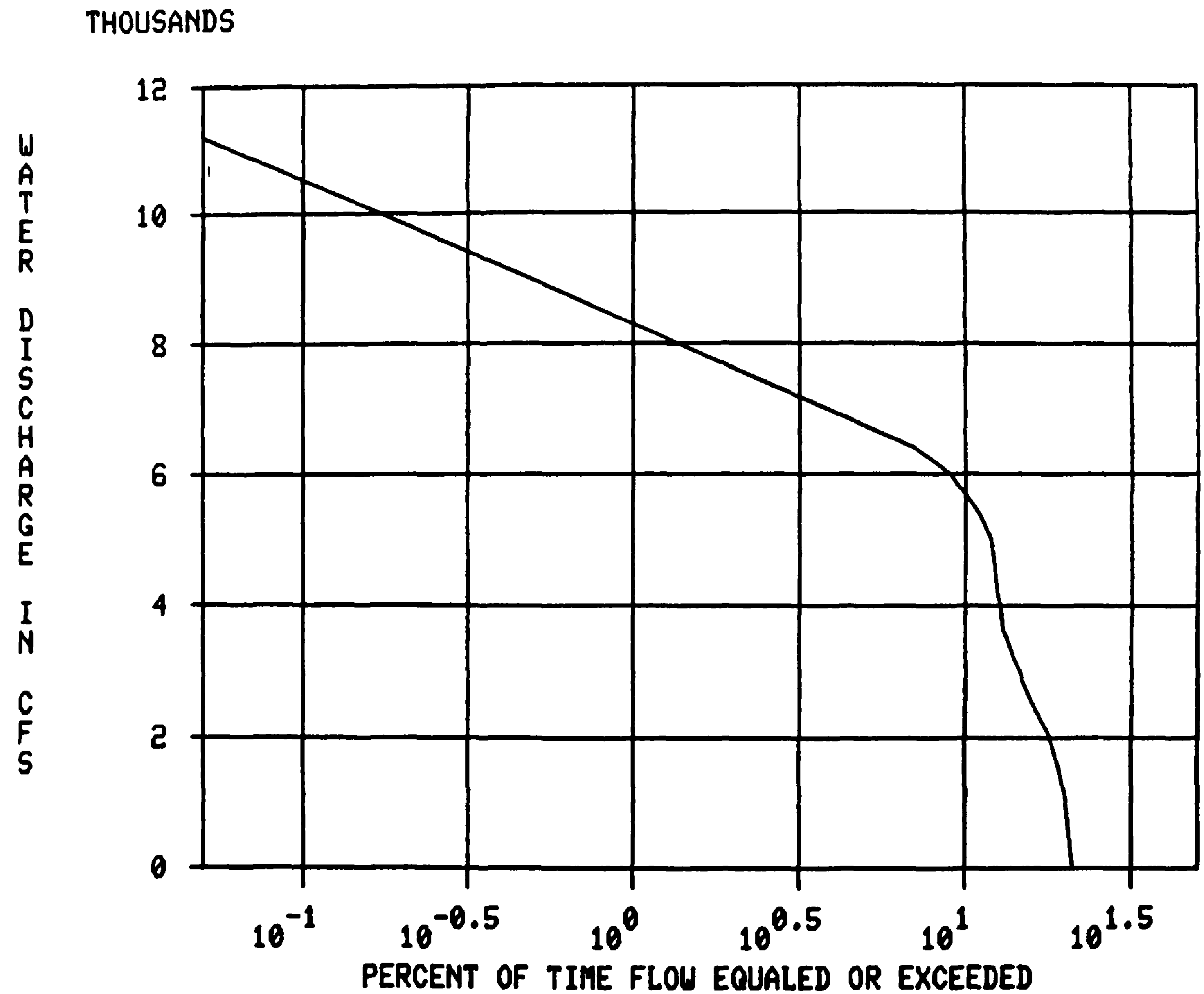


Figure 3. St. Lucie Canal flow duration curve, 1953-1976

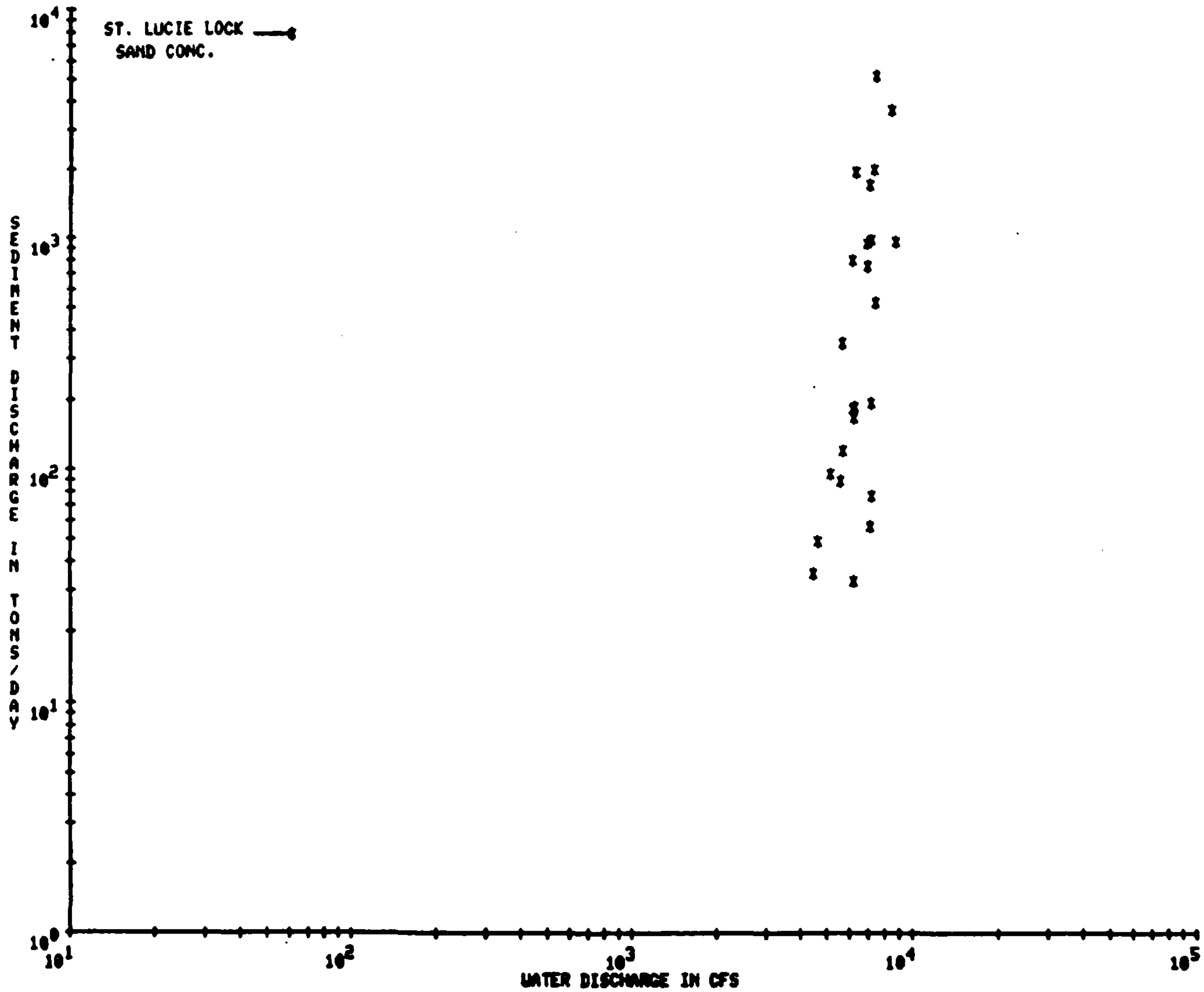


Figure 4. Suspended sediment load, St. Lucie Lock and Dam

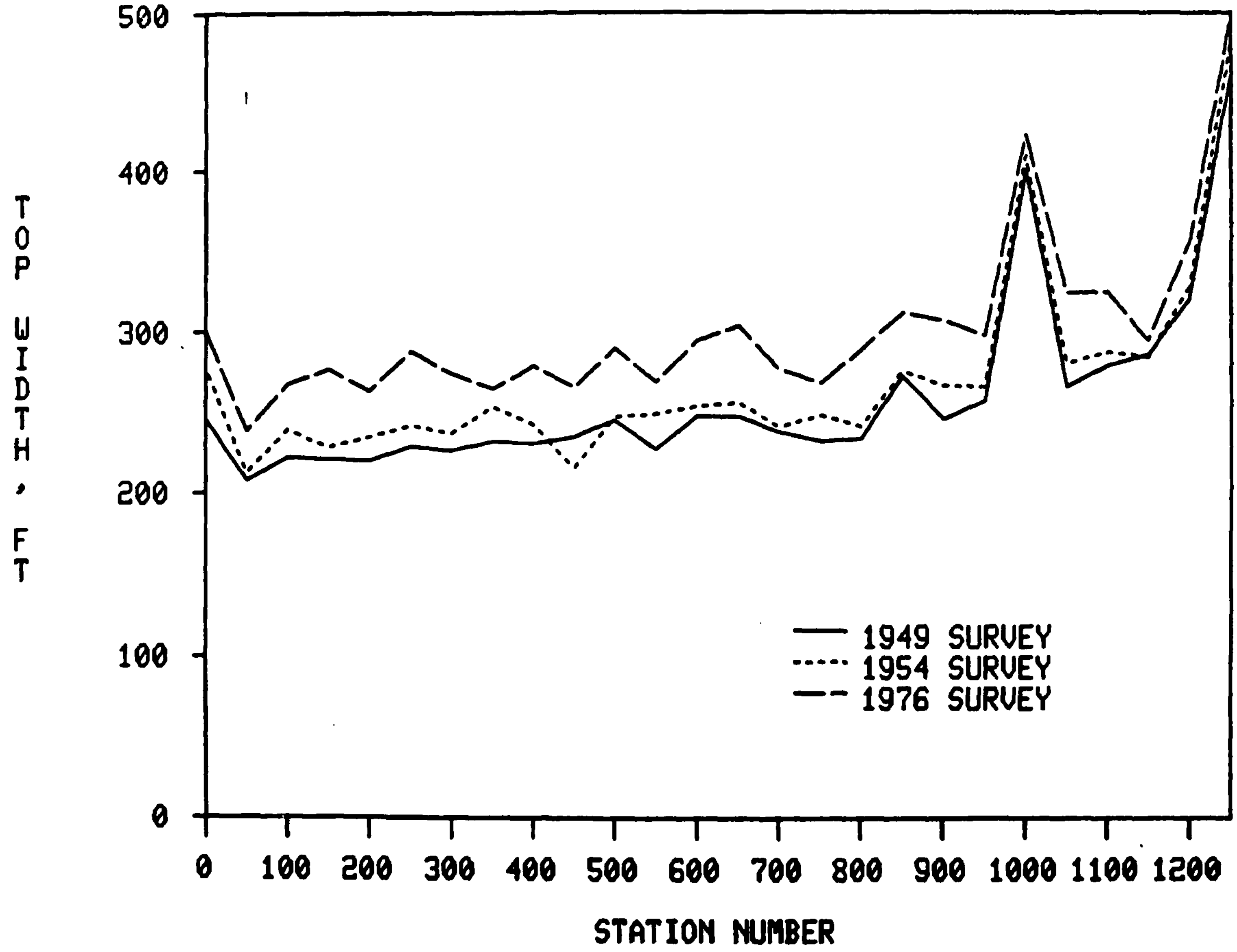


Figure 5. St. Lucie Canal top widths

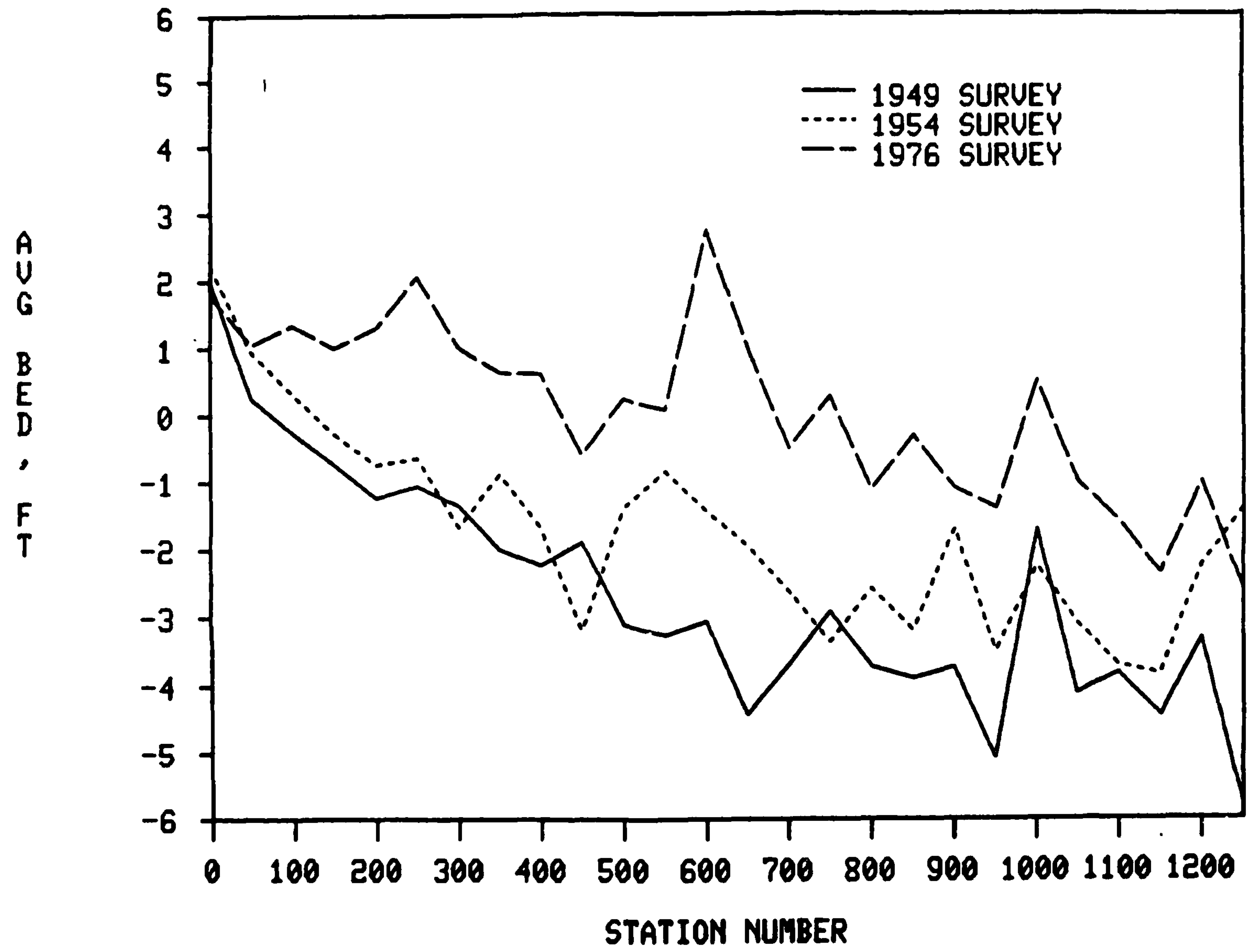


Figure 6. St. Lucie Canal water-surface elevation = 10 ft

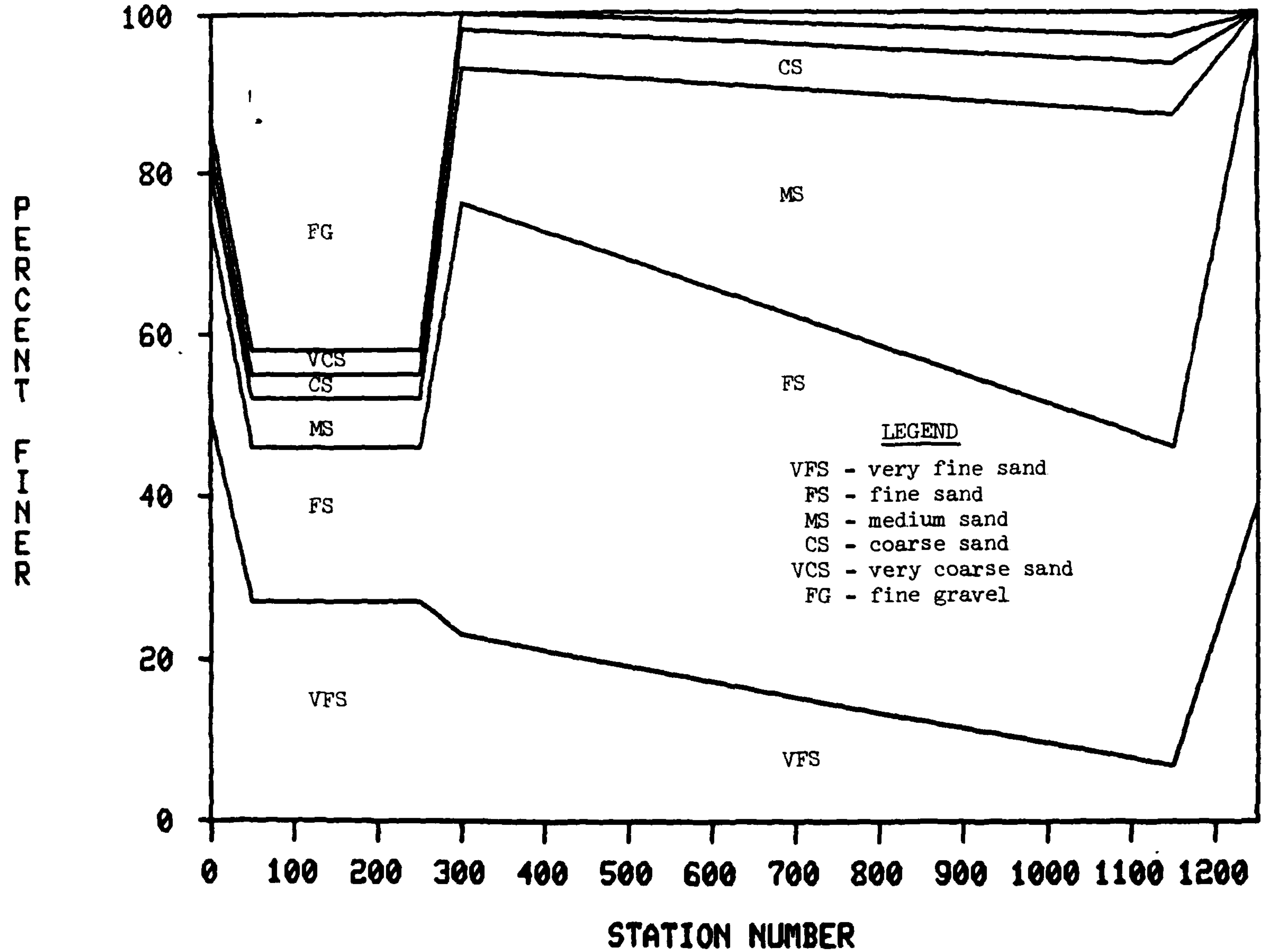


Figure 7. St. Lucie Canal bed gradation profile

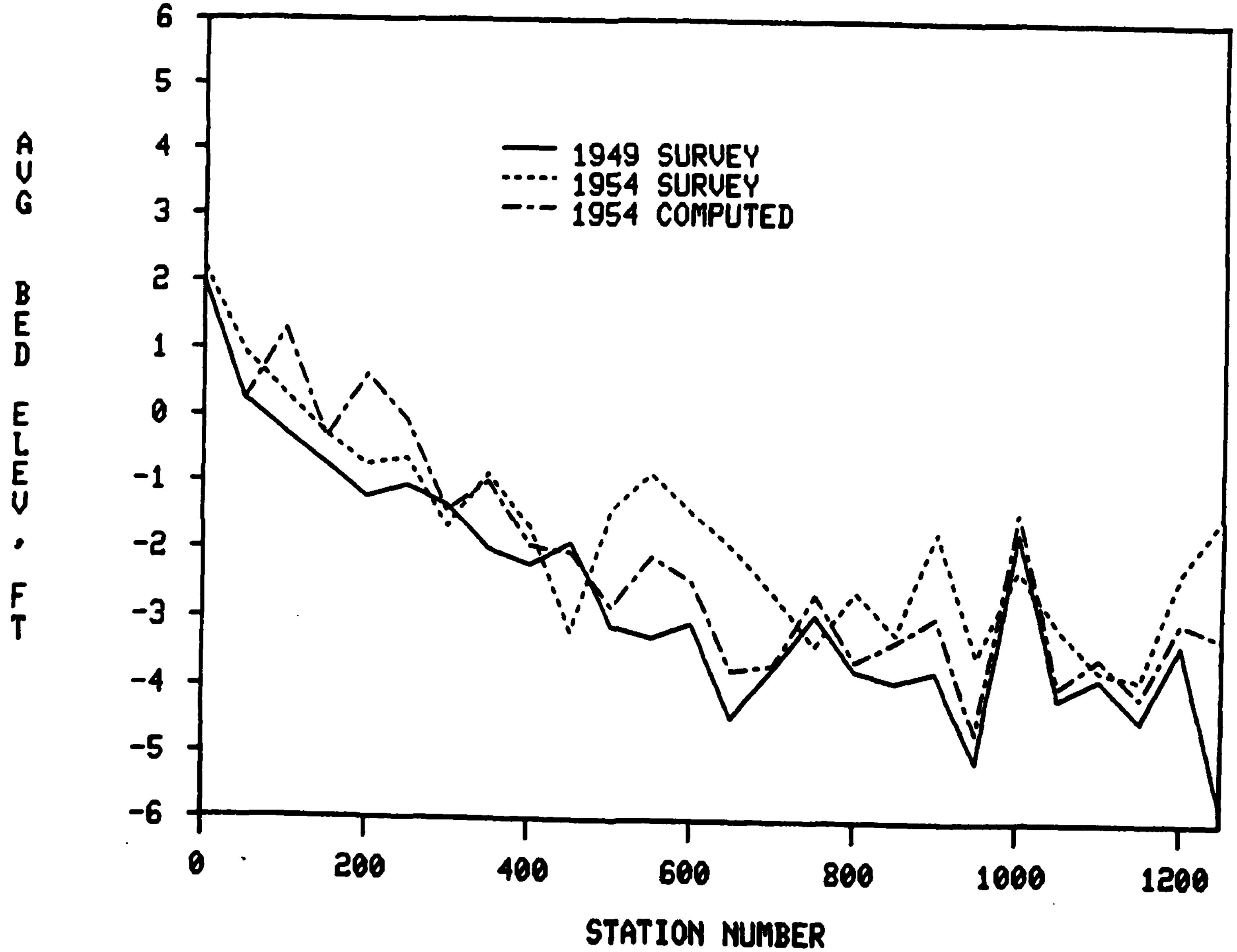

Figure 8. St. Lucie Canal bed elevations without local inflows

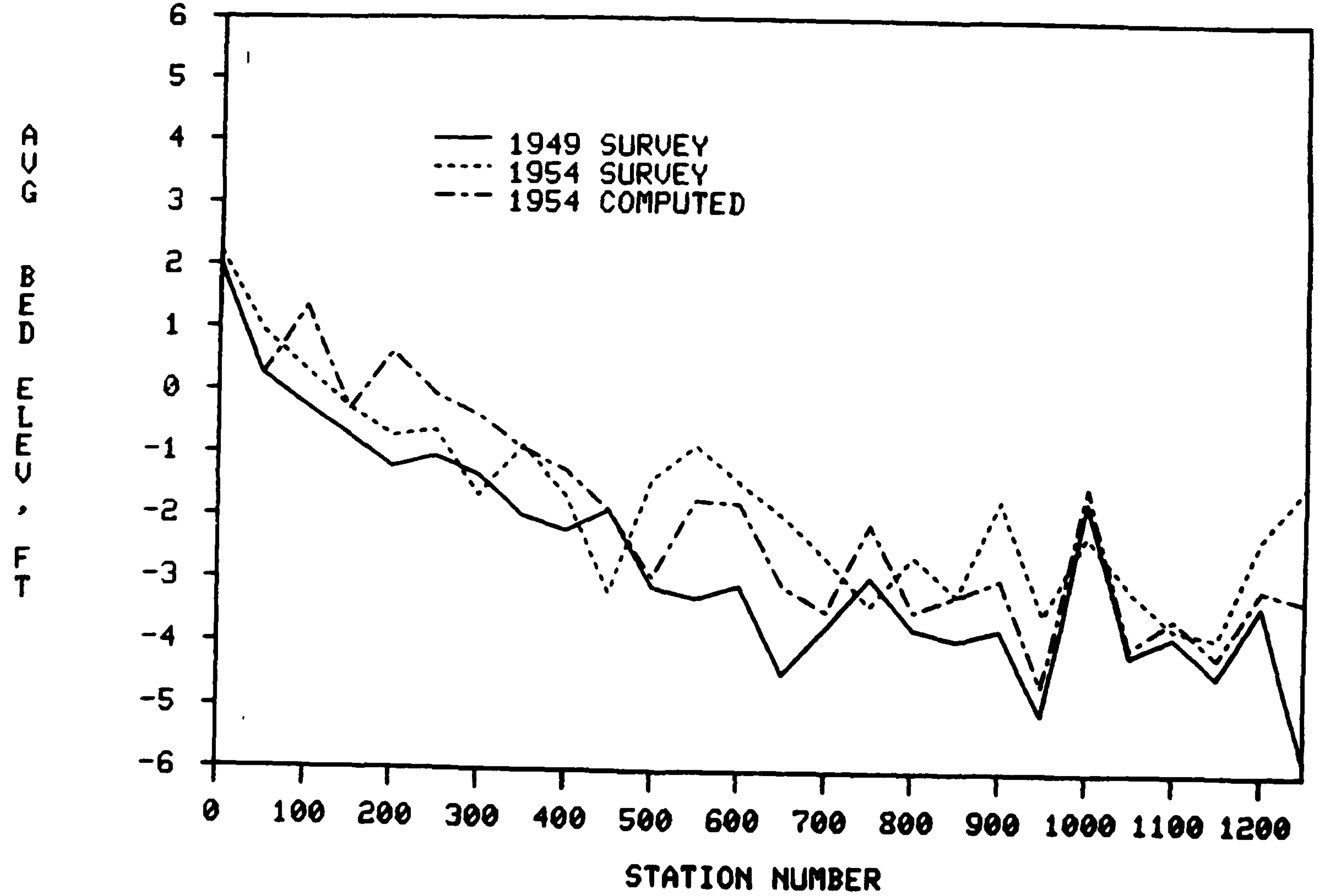


Figure 9. St. Lucie Canal bed elevations with local inflows

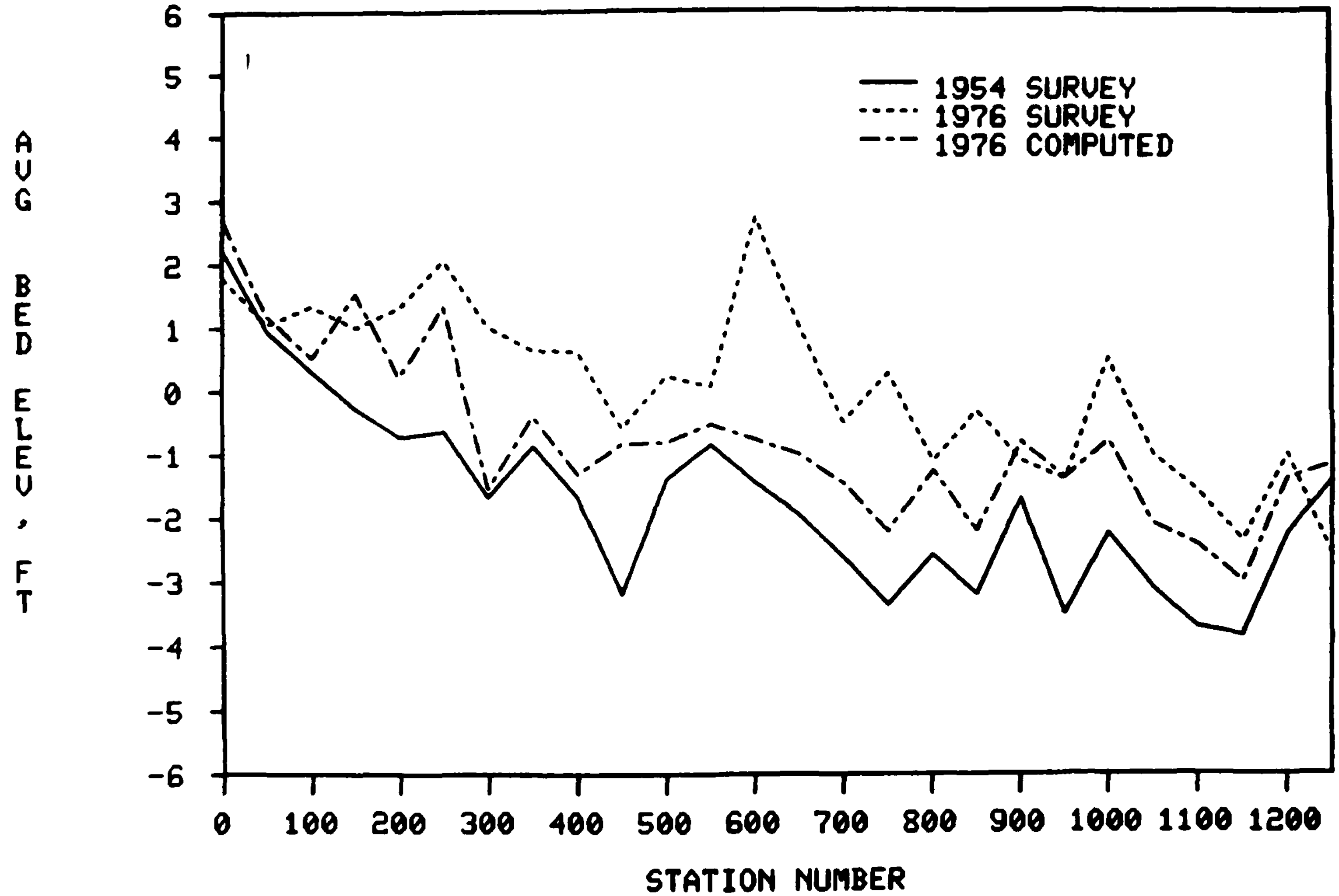


Figure 10. St. Lucie Canal adjusted bed elevations without local inflows

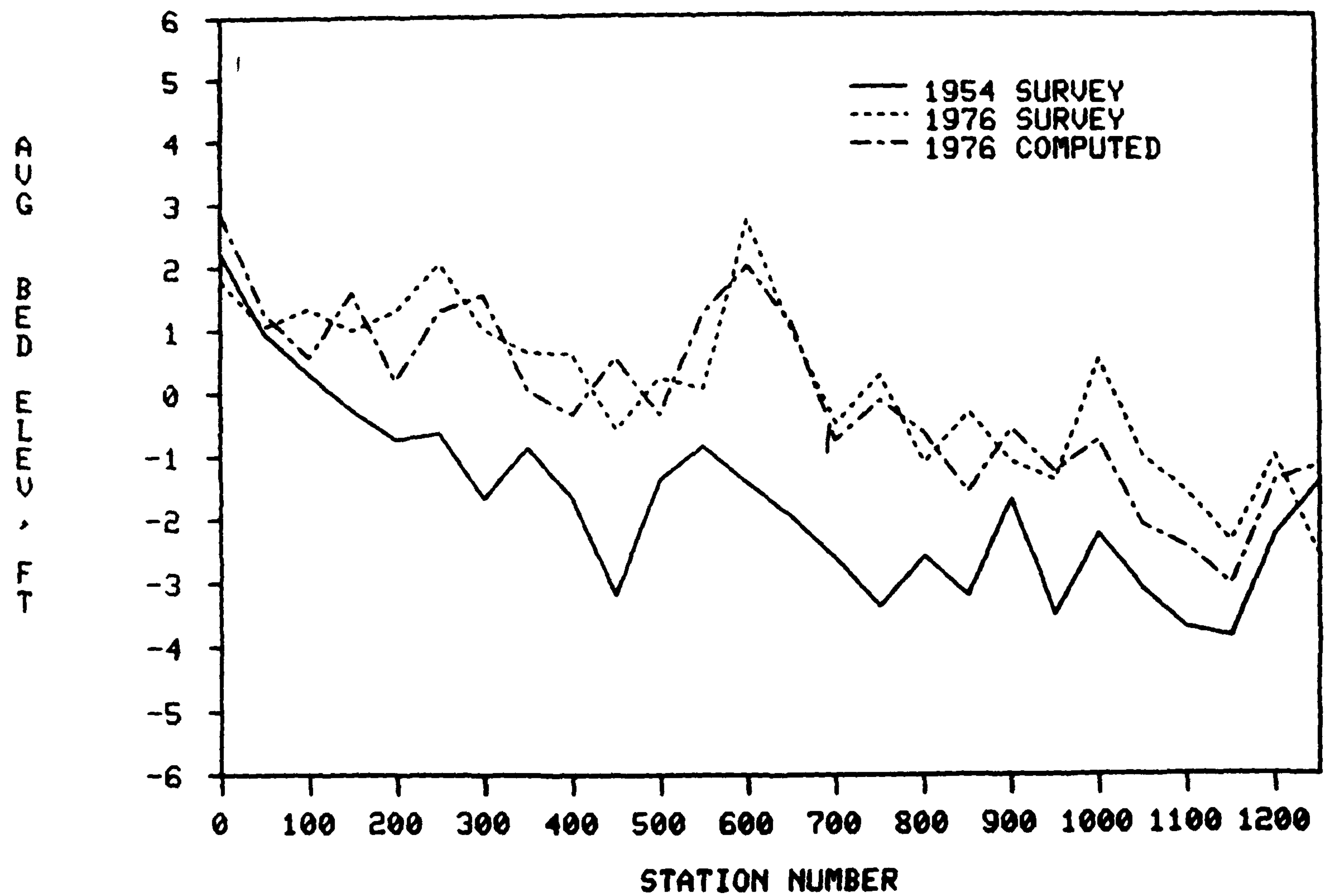


Figure 11. St. Lucie Canal adjusted bed elevations with local inflows

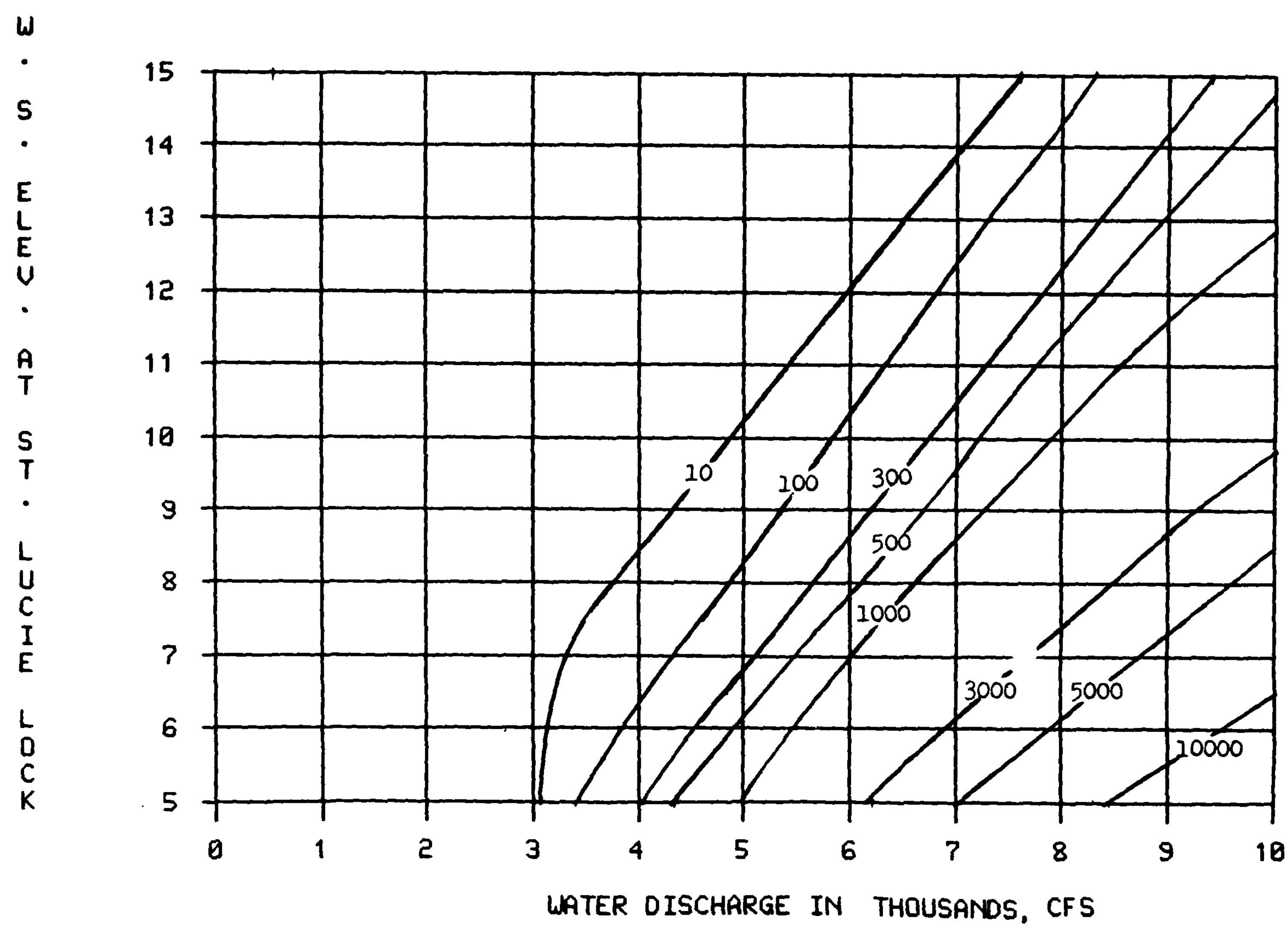


Figure 12. St. Lucie Canal sand load in tons/day at sta 1200 for 1954 cross sections

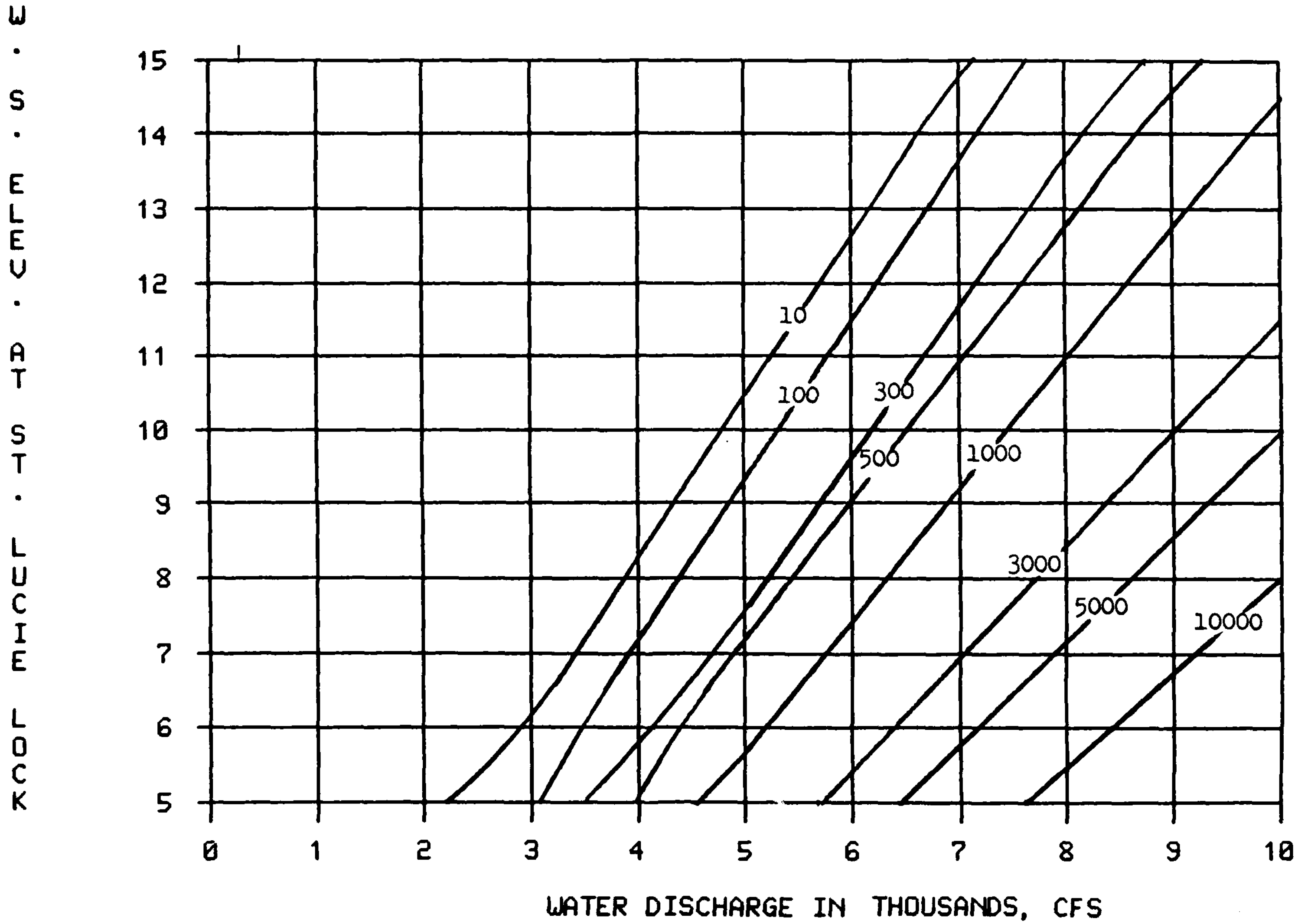


Figure 13. St. Lucie Canal sand load in tons/day at sta 1200 for 1976 cross sections

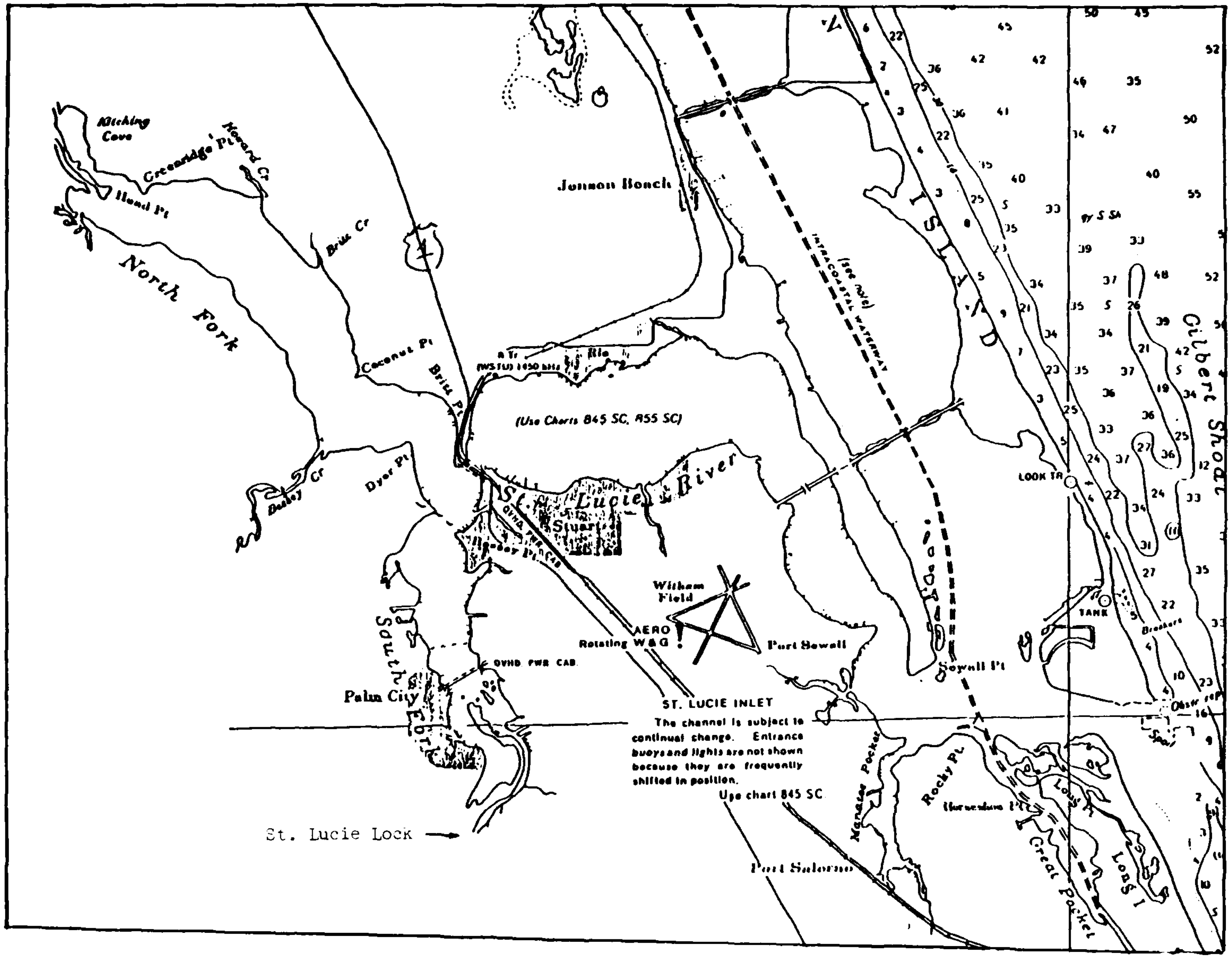


Figure 14. St. Lucie Estuary

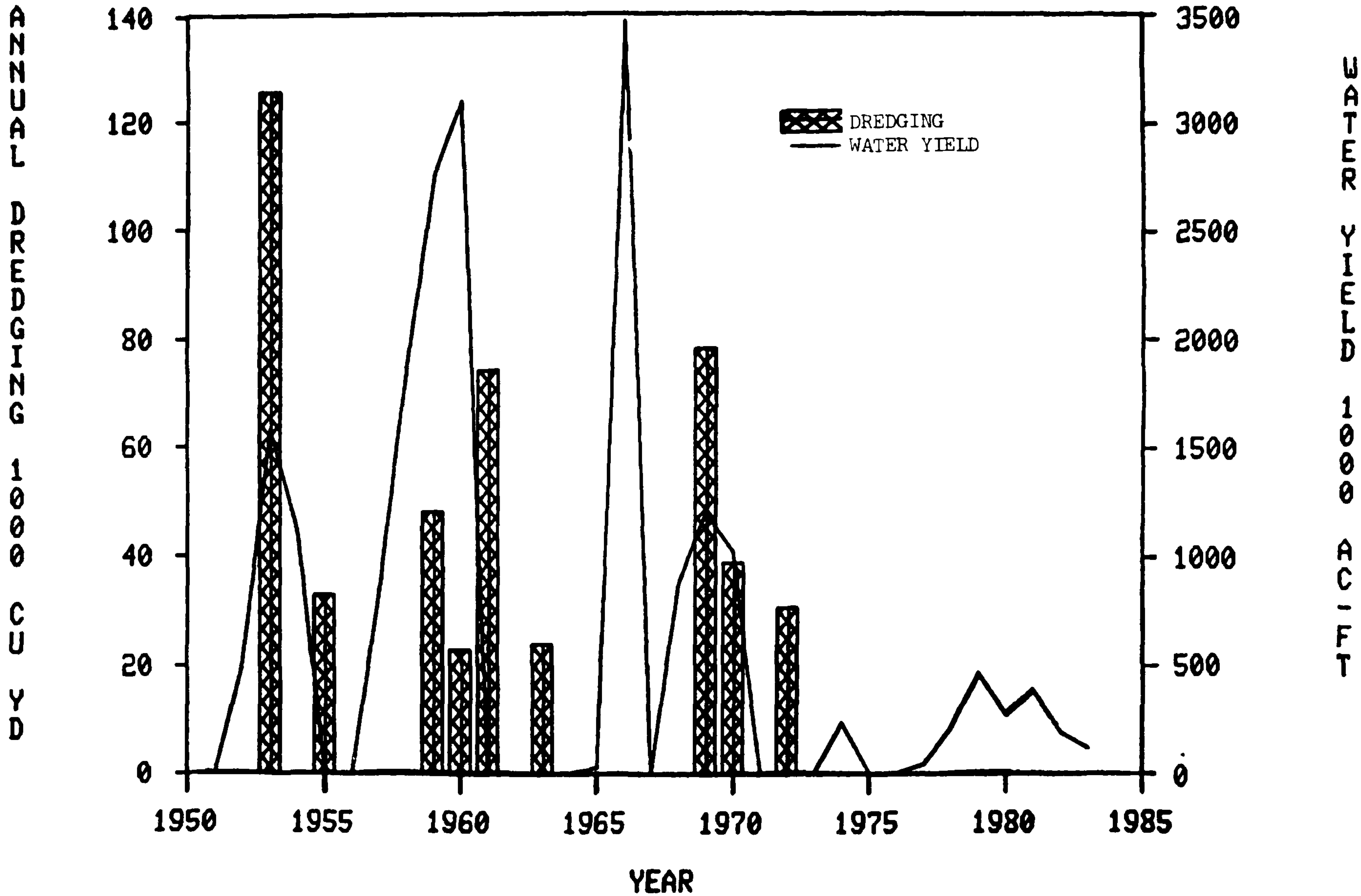


Figure 15. Comparison of water yield and dredging volumes, St. Lucie Canal and Estuary

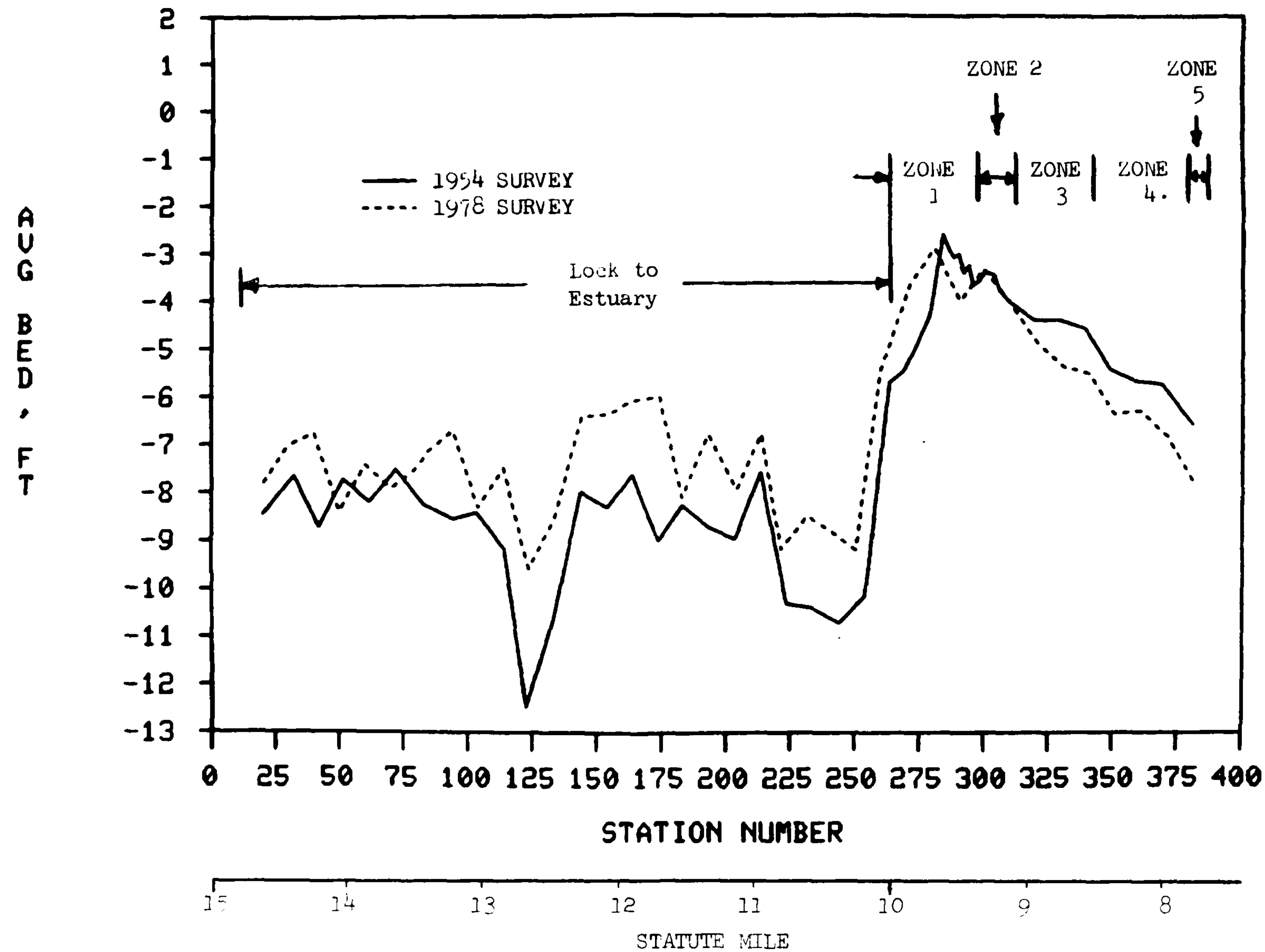


Figure 16. St. Lucie Lock to Estuary 1954 and 1978 surveys

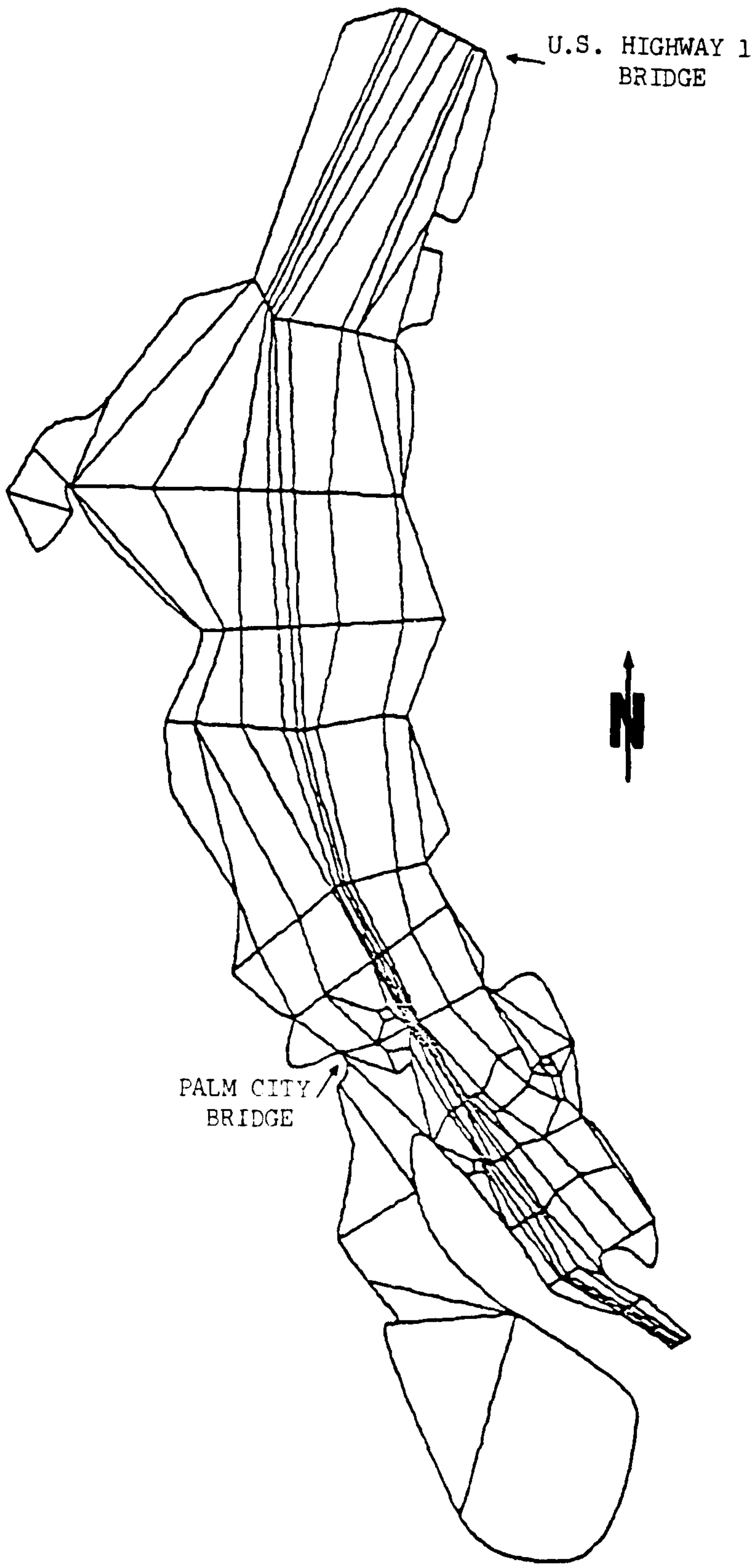


Figure 17. RMA-2 geometric grid of St. Lucie Estuary

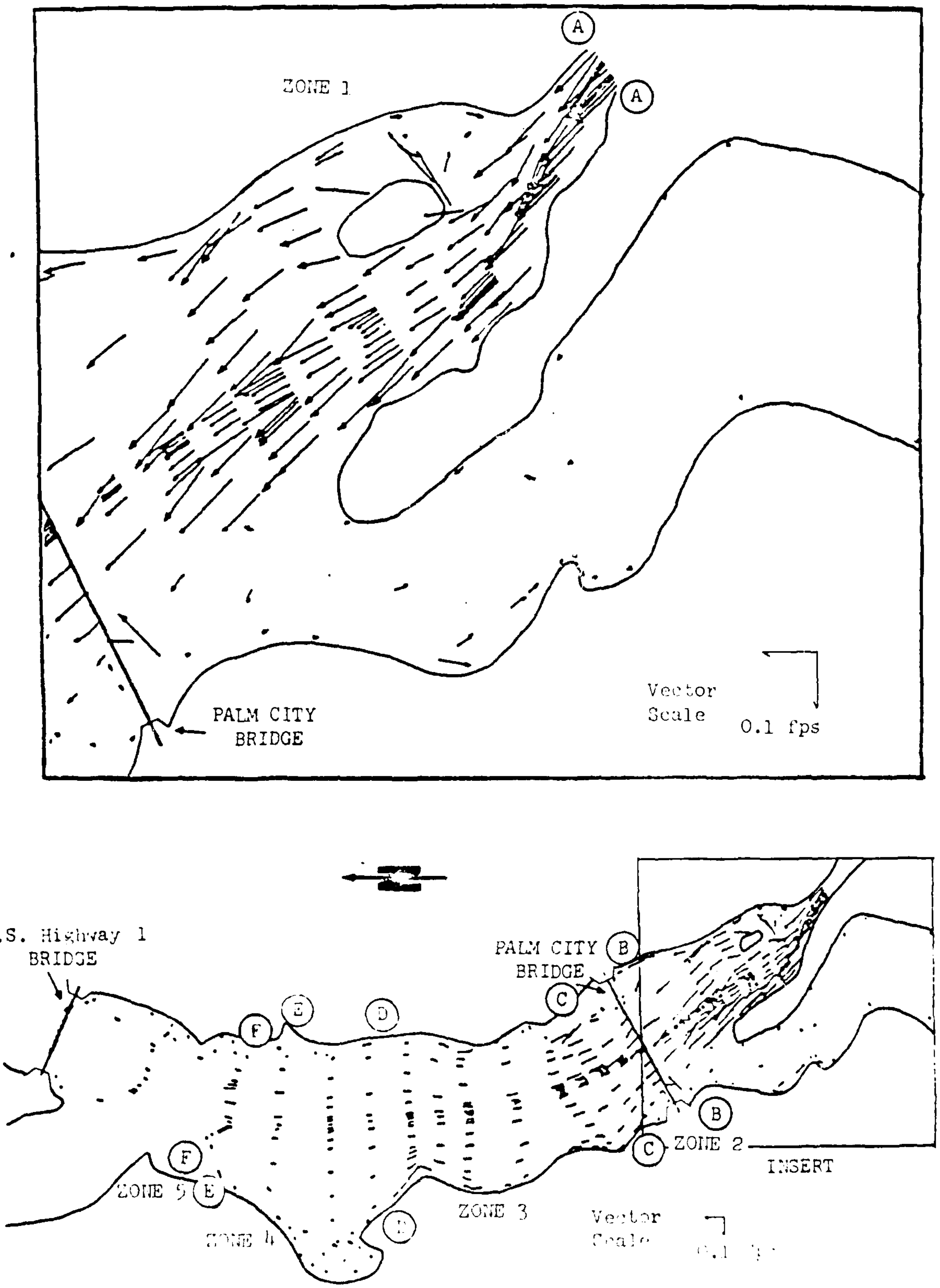


Figure 18. RMA-2 flow velocity vectors of St. Lucie Estuary

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