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MODELING OF HYDRODYNAMICS AND SALINITY IN THE ST. LUCIE ESTUARY

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by

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MODELING OF HYDRODYNAMICS AND SALINITY IN THE ST. LUCIE ESTUARY

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EXECUTIVE SUMMARY

Many of Florida's Estuaries, particularly the St. Lucie Estuary on the southeast coast, are adversely affected by altered fresh water inflows. Changes in historical patterns of runoff in the St. Lucie Estuary have been caused by three large flood control canals in the watershed of the estuary, and by increasing water demands. The magnitude of these inflows directly affects the longitudinal distributions of salinity in the estuary which, depending on the season and the amount of rainfall, may become unfavorable to marine species using the estuary during their early development. Although natural runoff cannot always be effectively controlled, supplementary low flow from the largest of the drainage canals (the St. Lucie Canal) during periods of low rainfall and high agricultural demand may enhance environmental conditions for certain species in the estuary.

An estuary computer model was selected, modified, calibrated, verified, and applied to the St. Lucie Estuary. This model simulates hydrodynamics and the movement of salt resulting from mixing of rainfall and fresh water releases from major structures in the watershed. If an initial salinity distribution is known, and daily rainfall is predicted, the model can provide a time history of predicted changes in the salinity distribution that would occur for a certain schedule of releases at a structure, for a period of weeks or months. Thus, the model can be used as a management tool to assist in maintaining the estuary within a desired salinity range.

The estuary model incorporates dynamic equations that include the effects of ocean tide, inflows and outflows, rainfall, evaporation, and ground water seepage. It represents the St. Lucie Estuary with longitudinal increments as short as 1450 feet and time steps of one minute. It was calibrated and verified for ground water seepage during two time periods in 1981; one 23 days long and the other 34 days long. Hydrodynamic characteristics were calibrated over a 58 day period in July and August 1981, and verified using measurements taken during a 65 day, high discharge event from January to May 1983. Salinity simulations were verified with measurements taken by the District during controlled discharge tests in 1977 (29 days), 1978 (49 days), and 1981 (94 days).

The model can be used for other estuaries if rainfall / runoff relationships are known and tide and salinity data are available for calibration and verification. The St. Lucie Estuary model could also be extended to include the Indian River Lagoon between St. Lucie and Ft. Pierce Inlets, to provide a capability for evaluating the effects of regulatory releases in this area.

Section 1. INTRODUCTION

In 1924 a flood control canal was completed from Lake Okeechobee to the South Fork of the St. Lucie Estuary. This canal provided south Florida with one of two major outlets for control of Lake Okeechobee water levels, and supplied agricultural interests with a convenient source of water for irrigation. Since that time, the St. Lucie Estuary has been periodically influenced by releases from the lake that were not necessarily favorable to estuarine habitat or fisheries.

The South Florida Water Management District (SFWMD) began systematic studies of water quality and marine biology in the St. Lucie Estuary in 1975. Controlled release tests from Lake Okeechobee to the estuary were made in 1977, 1978, and 1981 to obtain chemical and biological data associated with discrete discharge levels. Changes in conductivity, temperature, pH, dissolved oxygen, and species distribution caused by the 1977 and 1978 discharges are documented in reports by Haunert & Startzman (1980; 1985).

Measurements from the St. Lucie Estuary have indicated that, at different times, two different kinds of salinity problems might exist: in dry years a lack of adequate fresh water inflow may cause salinity distributions to become too high, while in wet years excess fresh water inflow may cause salinity distributions to fall too low. These distributions often fall outside the tolerance range of marine species that depend on the estuary as habitat during part of their life cycle. In order to quantify the effects of discharges on estuarine salinity, the District adapted an existing computer model to simulate salinity dynamics in the St. Lucie Estuary.

Selection and testing of the model began in 1981 and concluded in 1986. The model simulates the effects of fresh water inflows on hydrodynamics and salinity, which are used to evaluate potential biological impacts on the estuary. This section of the report reviews the major forces at work in an estuary, describes the study area and regulatory releases affecting the St. Lucie Estuary, and shows the sequence of major tasks involved in calibrating and verifying this model.

A. Brief Description of Estuarine Hydrodynamics

It is important at the outset of a modeling project to consider the salient characteristics of the system to be modeled and to determine which variables are probably important in affecting its dynamics. One of the most widely quoted definitions of an estuary is from Cameron and Pritchard (1963):

> "An estuary is a semi-enclosed and coastal body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."

The major variables that are indirectly referenced in this definition, and that affect estuarine hydrodynamics, are sometimes divided into two general groups: internal causes and external causes. The internal causes are the gradients of water temperature and density. The external causes are tidal forces, river discharge, precipitation, evaporation, water transport through the system, wind, atmospheric pressure, and the Coriolis force.

Mixing of fresh water inflows with sea water results principally from the interaction of tidal forces, river discharge, and wind stress on the surface. The amount of fresh water inflow, from whatever source, is very important. The Coriolis force in narrow water bodies, such as the St. Lucie Estuary, is negligible. The local effects of wind can be important, but the overall effect of mild winds is usually small compared to the effects of large fresh water inflows.

Each of the principal causes of estuarine mixing acts over different time and space scales. Tide operates with predictable periodicities and affects the estuary progressively from its mouth to its head. River discharge, because it is a function of weather, is extremely variable and unpredictable in time but is well defined spatially. Wind is highly variable both in time and space, but somewhat predictable by statistical methods over a large area. Estuarine salinity integrates the effects of these variables and is thus a good indicator of antecedent inflow conditions and the present degree of mixing.

Estuaries are normally divided into four classes: salt-wedge, partially mixed, fully mixed, and fjord type. Salt wedge estuaries are characterized by the continuous presence of a tongue of dense, higher salinity water near the bottom, moving with the tide, and an overlying layer of fresh water moving unidirectionally toward the sea. There is little mixing between the layers in these flows. Partially mixed estuaries exhibit vertical density differences causing turbulent vertical exchanges of salt and momentum, resulting in mixing of fresh water downward and saltier water upward. Well mixed or fully mixed estuaries are characterized by a relatively large tidal range, lack of vertical stratification, and possible lateral salinity and velocity gradients. If lateral mixing is relatively large a well-mixed estuary may be sectionally homogeneous, with only longitudinally significant variations in its principal characteristics. The fjord type of estuary is deep and only its surface layer is affected to any appreciable degree by the tide.

B. Description of the Study Area

The St. Lucie Estuary is located on the southeast coast of Florida, in the vicinity of the town of Stuart. It has both a North Fork and a South Fork which join at Stuart, six miles from the coast, and then flow eastward to the Indian River Lagoon and the St. Lucie Inlet. The heads of tide in the North Fork are located 15 miles north of Stuart in Five-Mile Creek, and at a dam on Ten-Mile Creek west of the Florida Turnpike. The heads of tide in the South Fork are about 8 miles south of Stuart in Martin County, in the non-navigable portion of the Old South Fork tributary, and at the St. Lucie Lock and Dam on the St. Lucie Canal (Figure 1.1).

The St. Lucie is a partially mixed estuary. It may develop some salt-wedge estuary characteristics, as evidenced by vertical salinity stratification in SFWMD measurements during large regulatory releases from S-80.

Discharges to the St. Lucie Estuary will vary according to water supply and flood control conditions throughout its drainage basins. Three flood control canals, each draining a different basin, discharge into the St. Lucie Estuary from the west. The northernmost of these is C-24, which is automatically controlled at structure S-49, just west of the Florida Turnpike, and discharges through C-23A into the North Fork. The maximum design discharge of S-49 is 4680 cfs. The second flood control canal is C-23, feeding into the North Fork at Bessey Creek via structures S-97 and S-48. S-97, located 3300 feet west of the Florida Turnpike, is also automatically controlled, with maximum design discharge of 5035 cfs. S-48, located 2-1/2 miles downstream of S-97, is uncontrolled and rated at the same discharge as S-97. The third flood control canal affecting the St. Lucie Estuary is the St. Lucie Canal, C-44, which is used in part to regulate the level of Lake Okeechobee. It discharges into the South Fork at S-80, about 8 miles southwest of Stuart. This structure is basically controlled according to the Lake Okeechobee regulation schedule established by the U. S. Corps of Engineers and the SFWMD. Its day-to-day operation is the responsibility of the SFWMD when the level of Lake Okeechobee is below regulation schedule, and of the COE otherwise. The maximum design discharge of S-80 is 16,900 cfs.

Another structure on C-44 affecting discharges to the St. Lucie Estuary is the Port Mayaca lock and gate, S-308, at the eastern shore of the lake. This structure was first put into operation in August 1977 and accepted for operational control by the District in early 1978. Its basic function is to maintain the lake level by means of discharge to the St. Lucie Canal. Prior to 1978, S-80 was the major eastern outlet for control of Lake Okeechobee water level.

C. Regulatory Discharges to the St. Lucie Estuary

Lake Okeechobee has a surface area of about 695 sq. miles. It is completely surrounded by the Hoover Dike, a 40 ft (mean sea level, MSL) high levee. The Kissimmee River, flowing south from a chain of lakes in and south of the Orlando area, is a major source of water for the lake. Midway along the eastern edge of the lake, the St. Lucie Canal begins at the Port Mayaca (S-308) structure and continues east for about 23 miles to S-80.

The quantity of rainfall in the Kissimmee River watershed directly affects Lake Okeechobee water levels. Other major sources of water to the lake are other tributary inflows, direct rainfall, ground water seepage, backpumping from agricultural canals supplying water to the Everglades Agricultural Areas and the coastal communities of south Florida, and, occasionally, backflow from the St. Lucie and Caloosahatchee canals. The lake is operated on a daily basis according to a schedule that sets the desirable range of maximum lake levels, for a particular season of the year, between 15.5 and 17.5 ft MSL. In the spring, the lake level is brought down in anticipation of the hurricane season, and in the fall it is allowed to rise in anticipation of the dry season. The St. Lucie Canal and the Caloosahatchee River are the principal outlets for regulatory releases from the lake.

The salinity in the St. Lucie Estuary may be described in terms of the longitudinal salinity distribution through the North Fork and the South Fork. The salinity usually decreases steadily upstream from the mouth, although during

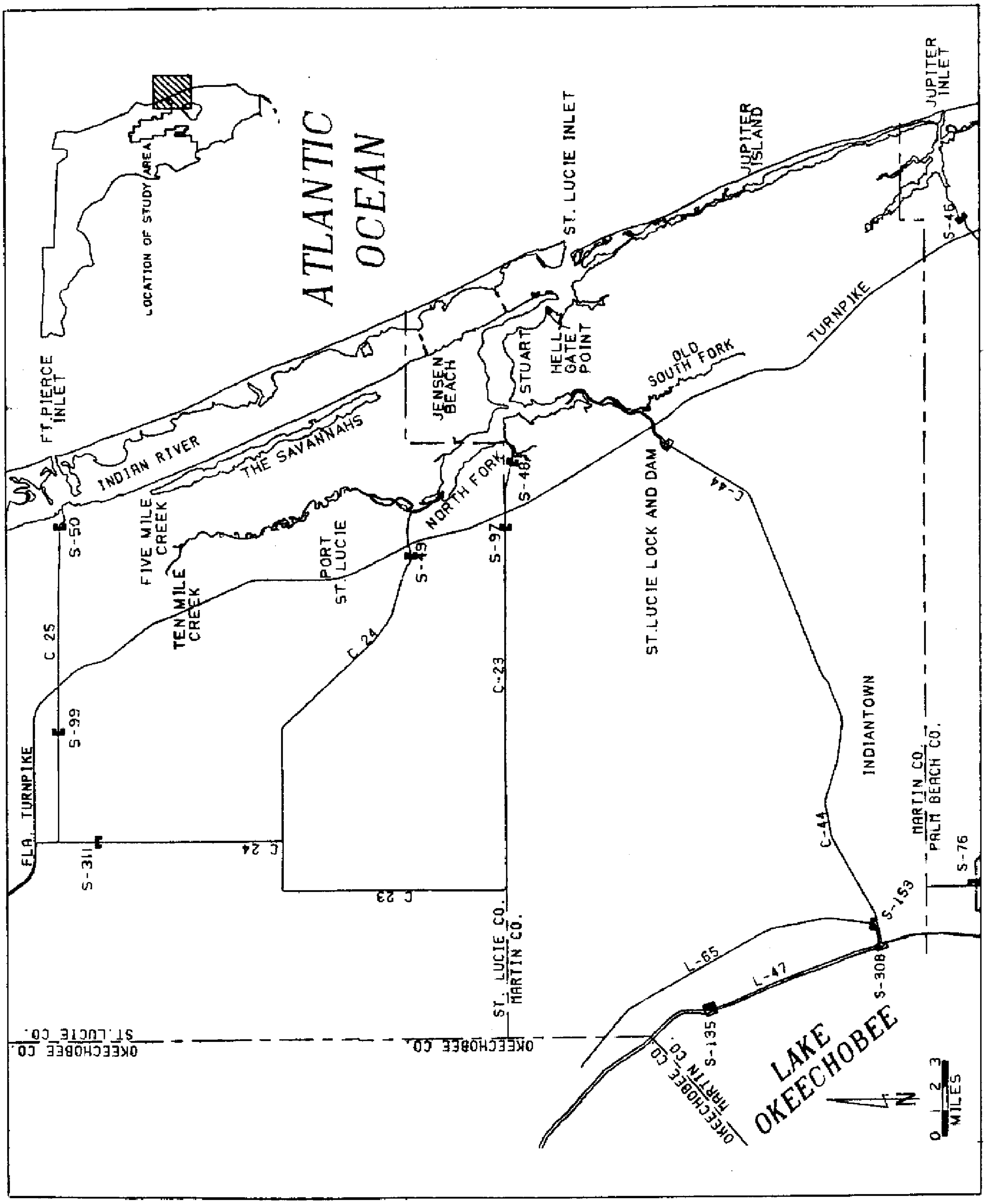


Figure 1.1 Location Map, St. Lucie Estuary, Florida.

substantial discharges the distribution may not follow this pattern. Salinity at the mouth of the river will often be close to oceanic salinity, about 36 parts per thousand (ppt), but can be substantially lower under the influence of large discharges into the North or South Forks.

One of the most important characteristics of the estuary is its effectiveness as a habitat for marine species. Species composition varies seasonally, depending upon the life cycles of different marine organisms. Since species tolerances for salinity vary, it is possible for the salinity distribution to be too high or too low for specific species at certain times of the year. Salinity is sensitive to fresh water discharges caused by man's activities; therefore, it is necessary to understand and respond to the condition and needs of the estuary at all times. It has been shown that large discharges can force salinity well below normal throughout the St. Lucie Estuary, the contiguous Indian River Lagoon, and outside the St. Lucie Inlet. Significant changes in salinity can occur within a day, but the system may require several weeks to a month to approach a salinity equilibrium with a constant inflow.

D. Process of Calibration and Verification of the Model

Calibration and verification of the model were carried out separately for hydrodynamics and salinity. The model was calibrated and verified iteratively using six different periods of historical records. To clarify the overall process, a diagram showing the relationship of each step with references to relevant sections of the report and to the dates of measurements associated with the principal simulations is given in Figure 1.2.

Hydrodynamic calibration began with a 59 node / 58 channel model network using data from July through August 1981 (Section 4.A). Hydrodynamic verification, which was performed with data that included a 9000 cfs regulatory discharge (between January and May 1983), revealed a need to increase the detail of nodal geometry in the lower South Fork. The model network was modified to include 63 nodes and 62 channels.

In preparation for the hydrologic analysis, salt dispersion coefficients were arbitrarily set and a preliminary ground water calibration was run for data in February and March 1981 to establish the order of magnitude of ground water seepage, represented by nodal inflows (Section 5.C). Since data on flow in the North and South Forks were not available, except for measurements in July through September 1981, the model was used to develop daily and total monthly runoff inflows for the time period in which canal discharges were available, 1977 - 1983 (Section 5).

Following the hydrologic analysis, a final ground water calibration was used to produce a new set of salt dispersion coefficients under the assumption that the salinity distribution during a period of negligable runoff would be affected primarily by ground water flow. Next, the hydrodynamic calibration period, July through August 1981, was checked with the new ground water inflows, runoff inflows, and dispersion coefficients (Section 6.A). Hydrodynamics were verified again using data from several contracted sets of measurements taken during the July - September 1981 measurement period (Section 4.A). Finally, ground water inflows were verified for the same period (Section 6.B), and full verification of hydrodynamic characteristics and salinity was shown for the three controlled discharge tests (Section 6.C).

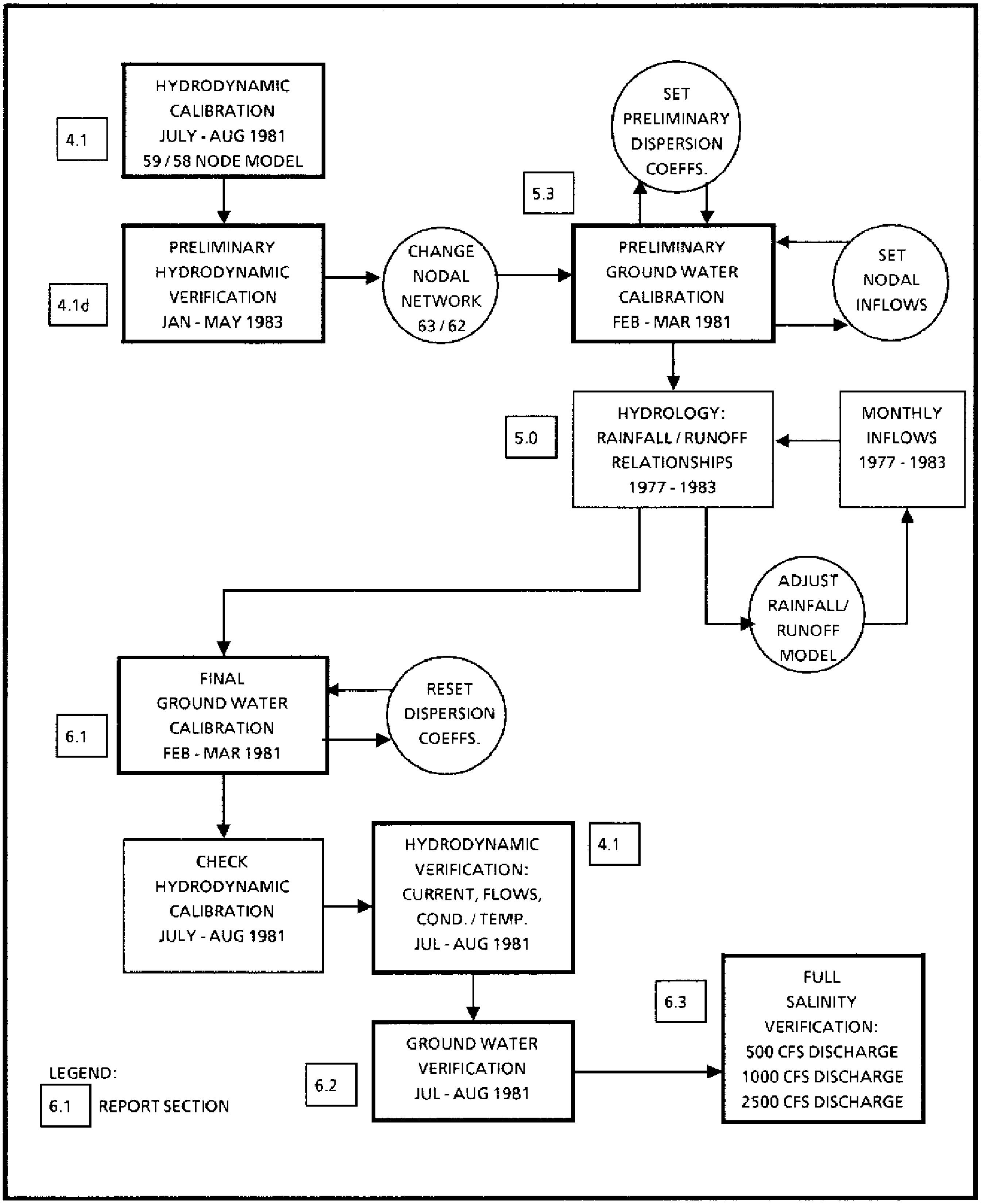


Figure 1.2 Sequence of Calibration and Verification of the St. Lucie Estuary Model.

Section 2. THE ST. LUCIE ESTUARY MODEL

At the outset, the objectives of the estuarine modeling project were to develop a capability to predict salinity throughout an estuary in response to changes in tide, precipitation and evaporation, wind, and discharges from the flood control canals. Primary interest was in the possibility of manipulating low discharges to control longitudinal salinity gradients. Since the effects of low discharges on salinity are generally confined to the area upstream of Hell Gate Point (Figure 3.1), the tidal boundary was established at this location. It was recognized that the effects of high discharges would probably be evaluated after completion of low discharge studies, in which case the tidal boundary would have to be extended through the St. Lucie and Ft. Pierce Inlets.

A. Background

Estuary models are divided into two general categories -- physical and numerical. Physical models are built to a particular scale and use water or some other fluid to produce a scaled flow that can be measured and related back to the prototype. A numerical model, on the other hand, represents the movement of water with the hydrodynamic equations which, if not extensively simplified, must be solved by a computer. Thus, the numerical models can be subdivided into analytic, those with direct solutions, and computational, those that would normally be solved by numerical computer techniques.

Analytic models are available only for estuaries with very simple geometries, i.e., rectangular, circular, or uniformly and gradually changing in width or depth, and simplified forms of the basic fluid dynamics equations. Numerical models, on the other hand, permit irregular geometries and more complex equations to be used. If the equations are tidally averaged, then the movement of water and salt will be averaged accordingly. If, on the other hand, the model can reproduce the changes that occur during the tidal cycle, then it is a fully dynamic model. As the equations become more complex, and as the number of spatial dimensions increases, the description of the details of the estuary also improves; but the model becomes more and more difficult to calibrate and more expensive to operate in terms of computer resources. Also, a numerical estuary model may either be statistical or deterministic. The statistical type is based on statistical relationships between variables, while the deterministic type simulates actual physical processes with the governing equations that describe the hydrodynamics and salinity variations in the prototype estuary.

Several different computational estuary models exist, each having unique strengths and weaknesses. The basic differences between these estuary models are:

- The assumptions or simplifications that have been used in the development of the equations
- Whether the equations have been averaged over a tidal cycle or are fully dynamic
- The dimensionality of the model -- whether it describes one, two, or three spatial dimensions of the estuary.

Usually, the best approach at the outset of a modeling program in an estuary that has not been previously modeled is to first apply a simple dynamic model. This will give useful and realistic results in a relatively short period of time with the least requirement for measurements and the greatest probability for a successful calibration and verification. It will also indicate whether a more complex or detailed approach is necessary.

B. The DYNTRAN Model

The DYNTRAN (DYNamic TRANsport) model is a computer program used for simulating the movement of water and dissolved substances in an estuary. It is an extension of the Dynamic Estuary Model (DEM) which was developed by Water Resources Engineers, Inc. (WRE), in the 1960's for modeling San Francisco Bay. Many versions of the hydrodynamic portion of DEM, called DYNHYD, were developed in the following decade. The version from which DYNTRAN evolved is the model developed by WRE, now a division of Camp Dresser & McKee, Inc., (CDM) for the New York Flood Insurance Study. Salinity calculations were integrated into the hydrodynamic equations of DYNHYD under a contract awarded to CDM by the District and Sarasota County, Florida, in 1982. The program is written in FORTRAN-V for a CDC Cyber computer.

C. Model Selection Criteria

DYNTRAN is a one-dimensional estuary model based on a numeric solution of the dynamic equations. It was selected for the St. Lucie estuarine modeling project because it provided the required predictive capability as well as some additional advantages over other models. Its major advantages are:

- The hydrodynamic portion of DYNTRAN has been successfully applied to many different estuaries since the 1960's.
- It is inexpensive in terms of computer memory usage and time to run a simulation.
- It is inexpensive in terms of data requirements for calibration and verification.
- It has a high probability of a successful calibration and verification, since the one-dimensional equations are relatively simple.
- It can be used to represent two-dimensional (horizontal) flow fields by placing nodes laterally as well as longitudinally.
- A companion water quality model, called DYNQUAL, using the output from the hydrodynamic model (stages and flows) to predict dissolved oxygen and nutrient cycles, is available for DYNTRAN.

The major disadvantage of DYNTRAN, and other one-dimensional estuary models, is that it is not a layered model and, therefore, not capable of accounting for vertical salinity changes and vertical stratification. Since the layered models are considerably more expensive to calibrate, verify, and operate, one of the objectives of the modeling work was to determine whether the one-dimensional approach could provide most, if not all, of the information necessary for management decision-making, before an attempt was made to use the more complex models.

D. Structure of the Model

DYNTRAN is a link-node hydrodynamic model which includes the dynamic mass transport of salt and another substance that can be either conservative or non-conservative (with first-order decay). The model predicts the water surface elevations, mean velocity, flow, salt concentration (salinity), and another constituent concentration as a function of location and time in the estuary. The principal forcing functions included in the model are tide, wind, inflows and outflows, evaporation, and precipitation. The geometry of the estuary is represented by a network of nodes connected by links in a one- or two- dimensional (horizontal) arrangement with up to twenty tidal boundaries, and time-varying inflows/outflows located at up to twenty nodes. Unlike some link-node models, which repeat the same water surface elevations for each tidal cycle, the tide in DYNTRAN can be represented continuously throughout a simulation, leading to more realistic and accurate predictions of conditions in the estuary.

The density of salt is incorporated into the momentum equation through an equation-of-state, which allows the user to simulate estuarine flows affected by density differences. It is also able to simulate dispersion of another substance, either conservative or non-conservative, permitting initial tests of tidal flushing of a dye for studies of the pollutant dispersion mechanism. DYNTRAN is the first version of DEM that contains the salt and constituent mass transport equations coupled to the hydrodynamic equations.

E. Processes and Features of the Model

DYNTRAN simulates estuarine or riverine flow by incorporating the following physical processes:

- Time-varying water surface elevation (tidal and/or non-tidal)
- Time-varying wind (speed and direction, overall)
- Time-varying rainfall and evaporation (overall)
- Energy loss by friction and mixing (magnitude may be different at each node)
- Constant inflow of water (at any node)
- Time-varying inflow of water (at any node, up to 20)
- Time-varying concentration of salt in each time-varying source of inflow
- Time-varying concentration of constituent in each time-varying source
- Salt-density driven flow along predetermined links or channels
- Mass transport of constituent (with optional first order decay).

Other features, not present in some versions of DEM, are included in the model:

- Salt and/or another constituent can be simulated at the same time as the hydrodynamics.
- Dynamic mass transport solution can be obtained at an integer multiple of the hydrodynamic time step.
- X and Y nodal locations can be directly read from input map coordinates
- Water surface area can be a function of depth (at each node)
- Friction or energy loss coefficient can be a function of depth (at each node)
- Concise daily summaries of program variables can be produced

- Line printer plots of nodal elevations can be produced
- The nodal network map can be printed on a line printer
- Statistics can be produced on tidal volume changes and boundary flows during a simulation.

Salinity in the St. Lucie Estuary application of the model proved to be very sensitive to fresh water inflows, which lead to successive testing and refinement of the rainfall/runoff relationships for its drainage basins. Once the runoff was demonstrated to be as accurate as could be expected with available data, the model was calibrated and verified using the measurements from the District's three controlled discharge tests and from a large regulatory discharge in 1983.

The final version of the St. Lucie Estuary model, which is described in this report, can be used to evaluate the effects of low to medium magnitude controlled discharges from Lake Okeechobee into the estuary, in combination with any historical rainfall pattern. The historical rainfall and resulting calculated runoff have been characterized statistically, using data from 1965 through 1983, in terms of "dry", "normal", and "wet" conditions. The salinity distributions predicted by the model have been related to these conditions and used to establish low flow and high flow limits for the estuary.

The present version of the model contains some portions that are specific for the St. Lucie Estuary. It can be readily modified for other estuaries, provided sufficient data are available to establish rainfall/runoff relationships.

F. Function of the Model

The estuary model may use certain external files for running a simulation, some of which are optional depending upon the objectives of the simulation:

- Estuary geometry, the switches and settings needed to set the model for a particular time period, and specifications as to the types of inflows are read from a required model set-up file
- Water surface elevation at the tidal boundary can be read from a file or calculated as needed from harmonic coefficients supplied in the set-up file
- Inflows and outflows can be read directly from the set-up file, input from a separate file, or calculated from values in a rainfall database by the model
- Initial salinity profiles can either be read from the input set-up file or calculated from a historical conductivity/temperature database by the model.

For convenience in analyzing historical rainfall, inflow, and salinity conditions the model is configured to operate with specified dates and times. The user specifies a starting date; then the actual water surface conditions at the tidal boundary, rainfall records, and structure inflows and salinities recorded during that time period are used if available on input files. For simulations at times for which there are no data, a past or future starting month and day can be specified and the corresponding harmonic tidal boundary conditions will be calculated and used for the simulation.

The model produces a printed description of simulation settings and details concerning the management of external files. The user will specify whether the printed output is to be a summary or a detailed listing. Optionally, a separate file containing all nodal elevations and salinities and all channel velocities and flows, at a specified time step (e.g. hourly), can be written for archival purposes or for subsequent plotting by another program.

G. Governing Equations

DYNTRAN is a hydrodynamic and mass transport model. The governing equations for the hydrodynamic model are the one-dimensional momentum equation:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - g\frac{\partial H}{\partial x} - gS_f + gS_w - \frac{gR}{2\rho}\frac{\partial \rho}{\partial x} \quad (2.1)$$

and the continuity equation:

$$A_s\frac{\partial H}{\partial t} = \sum_{i=1}^{k} Q_i + Q_I \quad (2.2)$$

where

u = cross-sectional mean velocity, fps
t = time, sec
x = distance, ft
g = acceleration due to gravity, ft/sec^2
H = water surface elevation above datum plane, ft
S_f = energy gradient (dimensionless)
S_w = wind stress (dimensionless)
R = hydraulic radius, ft
ρ = density, lb_m/ft^3
A_s = surface area at a junction, ft^2
k = number of links into junction

ΣQ = sum of flows to a junction, cfs, and
Q_I = inflow at a junction, cfs.

The energy gradient, S_f uses Manning's equation:

$$S_f = \left(\frac{n}{1.486}\right)^2 \frac{u\,|u|}{R^{4/3}} \qquad (2.3)$$

where n = Manning's friction coefficient, (sec/ft $^{1/3}$).

The wind stress term S_w, projected along a link is:

$$S_w = \frac{k}{d}\,\frac{\rho_a}{g\rho}\,w_s\,|w_s|\cos(\theta + 0.26) \qquad (2.4)$$

where
- k = dimensionless wind coefficient
- d = depth of flow, ft
- ρ_a = air density, lb_m/ft^3
- ρ = water density, lb_m/ft^3
- w_s = wind speed, mph, and
- θ = angle between wind direction and axis of channel (radians)

The governing equation of the mass transport model is:

$$\frac{\partial (Vc_i)}{\partial t} = \sum_{i=1}^{k} Q_i c_i' + \sum_{i=1}^{k} Q_{I_I} c_{I_i} - \sum_{i=1}^{k} A_i E_{L_i} \frac{\partial c_i}{\partial x} - VDc_i \qquad (2.5)$$

where
- V = volume of junction, ft^3
- c_i = concentration of salt or constituent at junction,
- c_i' = concentration in channel
- Q_{I_i} = inflow quantity, ft^3
- c_{I_i} = inflow concentration
- A_i = cross-sectional area of channel, ft^2
- E_{L_i} = longitudinal dispersion coefficient, ft^2/sec
- D = decay coefficient, (1/sec), for constituent only.

The dispersion coefficient, E_L, is calculated from:

$$E_{L_i} = K_{L_i} R_i u_i \qquad (2.6)$$

where
- K_{L_i} = longitudinal dispersion coefficient, channel i (dimensionless).
- R_i = hydraulic radius of channel i, ft.

The concentration of salt, c, in parts per thousand, is converted to density for inclusion in the momentum equation (1), by an equation-of-state:

$$\rho = 0.9995 + 0.000756\,c \qquad (2.7)$$

H. Model Boundary Conditions

DYNTRAN requires both hydrodynamic and mass transport boundary conditions. For the hydrodynamic part of the model, both inflow and tidal boundary conditions must be specified. River discharges and other inflows are treated as inflows to a given junction. The inflows can be specified either to be at a constant rate, or in the form of a hydrograph with different flow rates given at specific times. The flow rate between given times, if unsteady, is linearly interpolated within the model.

Tidal boundary conditions can either be read directly from a file containing measured values, calculated by a separate program using astronomic tidal coefficients, or calculated in DYNTRAN using a least squares fit to measured high and low water surface elevations, which produces sinusoidal and cosinusoidal components that are combined as follows:

$$H_T = A_1 + A_2 sin(\omega t) + A_3 sin(2\omega t) + A_4 sin(3\omega t)$$

$$+ A_5 cos(\omega t) + A_6 cos(2\omega t) + A_7 cos(3wt) \qquad (2.8)$$

where
- H_T = total water surface elevation at time t, ft
- ω = frequency of a diurnal tidal day consisting of two high and two low tides
  = $2/T'$, hrs^{-1}, and
- T' = analysis period, hrs.

In Equation 2.8 the tidal period T' is the period of the analysis, which is not the same as the period of a tidal harmonic. For an estuary with predominantly semi-diurnal tide the analysis period, T', is 24.84 hours, while for an estuary with predominantly diurnal tide T' is set to 49.68 hours.

For the mass transport model, lateral inflow concentrations corresponding to the times and locations of water inflow may be specified. At the tidal boundaries the salinity boundary condition is calculated in two different ways, depending on whether the tide is in ebb or flood. During ebb tide the boundary salinity is calculated from upstream values. During flood tide the boundary concentration, c_b, is arbitrarily increased to within five percent of the specified receiving water concentration, c_{RW}, after t hours, where t hours is the elapsed time after the time of low slack water and before high slack water:

$$c_b = c_{RW} + (c_{LT} - c_{RW})\,e^{-3t/\tau} \qquad (2.9)$$

where
- c_b = boundary salinity concentration

c_{RW} = receiving water salinity concentration
c_{LT} = boundary low tide salinity concentration
ι = rise time to 5% of c_{RW}, (T)

A constant high tide salinity concentration c_{RW} must be specified for every simulation, and thus the tidal boundary should not be located where the concentration might be significantly affected by inflows to the estuary. The rise time, ι, used in the St. Lucie Estuary model is 6.1 hours.

I. Model Stability Conditions

The hydrodynamic model must obey the usual Courant-Friedrichs-Lewy condition for each channel,

$$\Delta t \leq \frac{\Delta x}{\sqrt{gd}} \tag{2.10}$$

the explicit advection condition in each channel,

$$\Delta t \leq \frac{\Delta x}{|u|} \tag{2.11}$$

and a dispersion condition,

$$\Delta t \leq \frac{\Delta x^2}{4E_L} \tag{2.12}$$

These equations specify the maximum time step, Δt, that can be used in the model. The time step must be made smaller as channel length, Δx, is decreased or as channel depth d, velocity u, or the dispersion coefficient E_L is increased.

J. Junctions and Channels

The actual volume of water in an estuary is defined by the irregularities of the shoreline, the topography of the bed, and artificial boundaries drawn across tributaries. To represent this water volume in a link-node model, it is necessary to subdivide (discretize) it into two different, superimposed sets of small, contiguous subvolumes. Each of the subvolumes is represented in the model by a rectangular domain with uniform length, width and depth. One of these two sets of volumes, the "junctions", permits branches, inflow or outflow locations, and significant stage measurement points to be properly oriented in the model according to the geography of the estuary. The other set of volumes, "channels", represent mean flow characteristics between the volumes in the first set.

Each of the subvolumes in the "junctions" or "nodal" set of volumes is expressed in terms of a surface area and a mean depth. The center of mass of one of these subvolumes is called a "junction" or a "node." The sum of the subvolumes in this set must be equal to the total volume of the estuary. It is assumed that the characteristics of each of these volumes are uniform, and therefore that water, salt, and/or a constituent introduced into a nodal subvolume at a certain time step will be uniformly distributed and mixed within that junction by the following time step. The conditions at a nodal subvolume are represented by a water surface elevation (stage) and a salinity and/or constituent concentration at each time step. The nodal surface areas and depths for the 63 node / 62 channel St. Lucie Estuary model are summarized in Table 2.1 and in Figures 2.1 and 2.2.

Each subvolume in the "channels" set of volumes is expressed in terms of a length along the direction of mean flow and a cross-sectional area (expressed in terms of a mean width and a mean depth). This length is the actual distance between the two nodes that the subvolume connects, and the subvolume is called a "channel" or "link". It is assumed that the characteristics of each of the channel volumes are uniform and, therefore, that the movement of water within that volume is uniform and unidirectional at any given time. Conditions in a channel subvolume are represented by a mean velocity and corresponding mean flow at each time step during a model run. However, the navigation channel depth in an estuary is usually significantly different from the cross-sectional mean depth, and the tide will therefore travel faster along the channel than along the banks of the estuary. To allow adjustments for the occurrence of the tide, the sum of the subvolumes in this set may be different than the total estuary volume. The channel lengths, widths, and hydraulic radii for the 63 node / 62 channel St. Lucie Estuary model are summarized in Table 2.1 and in Figures 2.3 through 2.5.

The connectivity or numbering of the nodal network, the numbers of the upper and lower nodes for each channel, is also summarized in Table 2.1.

K. Summary of the Geometry of the St. Lucie Estuary

The maintained navigation depth of the Okeechobee Waterway in the St. Lucie Estuary is approximately 10 ft and the measured maximum depth is 22.4 ft between Roosevelt and Florida East Coast Railroad Bridges. The model uses a total nodal surface area of 3.1×10^8 ft^2, total nodal volume (sum of surface areas multiplied by depths) of 2.44×10^9 ft^3, and mean nodal depth (weighted by surface area) of 7.9 ft. The total channel volume is 2.18 x

Table 2.1 Geometry of the 63 Node / 62 Channel St. Lucie Estuary Model.

NODE NUMBR	SURF AREA 1000 FT²	DEPTH FT	CHAN NUMBR	UPPR NODE	LOWR NODE	LENGTH FT	WIDTH FT	DEPTH FT	MANNINGS n
1	2330	12.7	1	1	2	2064	2950	8.7	.025
2	6620	9.0	2	2	3	1907	3750	7.6	.025
3	7992	8.5	3	3	4	2047	4305	7.7	.025
4	7229	9.0	4	4	5	2367	2468	8.4	.025
5	5741	8.7	5	5	6	1909	2910	7.4	.025
6	5300	8.4	6	6	7	2023	2470	7.8	.025
7	7500	8.1	7	7	8	1950	5331	6.8	.025
8	11432	7.2	8	8	9	2051	6123	6.2	.025
9	12812	6.7	9	9	10	2013	6400	5.9	.025
10	12575	6.5	10	10	11	1904	6539	5.7	.025
11	11980	6.0	11	11	12	1938	5709	5.3	.025
12	11733	6.1	12	12	13	2083	6029	5.6	.025
13	12350	6.1	13	13	14	2138	5675	5.4	.025
14	10882	7.5	14	14	15	1784	5570	8.2	.025
15	6532	11.0	15	15	16	1888	2170	11.7	.025
16	8252	11.0	16	16	17	2184	2750	11.7	.025
17	5614	11.2	17	17	18	1845	2748	8.5	.025
18	5846	8.7	18	18	19	2092	3230	7.2	.025
19	7144	7.6	19	19	20	2240	3381	6.5	.025
20	8719	7.2	20	20	21	1917	4628	6.6	.025
21	9341	7.1	21	21	22	2447	3962	6.3	.025
22	10047	7.2	22	22	23	2360	4339	6.8	.025
23	9176	7.5	23	23	24	1996	4064	6.8	.025
24	7871	7.8	24	24	25	1994	3883	7.2	.025
25	8029	7.7	25	25	26	2030	4107	6.7	.025
26	8409	7.0	26	26	27	2082	4077	5.9	.025
27	8119	6.2	27	27	28	2074	3777	5.1	.025
28	6656	5.5	28	28	29	1928	970	4.6	.025
29	1604	5.1	29	29	30	1928	680	4.7	.025
30	1951	5.0	30	30	31	1765	1498	4.3	.025
31	3170	3.0	31	28	32	2128	1568	5.1	.025
32	1385	9.4	32	32	33	1750	308	11.7	.025
33	540	13.0	33	33	34	1753	308	11.7	.025
34	566	13.0	34	34	35	1923	308	11.7	.025
35	585	13.0	35	35	36	1875	308	11.7	.025
36	1185	11.3	36	36	37	1613	200	7.2	.025
37	383	8.0	37	37	38	2211	200	7.2	.025
38	477	8.0	38	38	39	2556	200	7.2	.025
39	4125	7.6	39	39	40	8200	200	11.3	.025
40	2835	14.0	40	40	41	19600	160	13.5	.025
41	5087	13.0	41	41	42	30340	80	9.9	.025
42	3185	10.5	42	36	43	3000	1040	5.9	.025
43	1428	10.0	43	43	44	1450	200	12.2	.025
44	629	12.0	44	44	45	5400	150	9.0	.025
45	405	9.0	45	36	46	9098	141	11.7	.025
46	642	13.0	46	20	47	5774	760	7.2	.025
47	2027	9.5	47	47	48	2112	169	8.6	.025
48	1785	9.5	48	16	49	2375	2936	8.4	.025
49	4912	10.5	49	49	50	1961	4576	7.4	.025
50	4864	9.2	50	50	51	2491	2807	7.2	.025
51	2886	9.0	51	51	52	2394	2097	6.4	.025
52	7727	8.0	52	52	53	2041	845	2.9	.025
53	2107	3.0	53	53	54	1934	1286	3.0	.025
54	4598	3.0	54	52	55	1737	1593	8.0	.025
55	2752	8.0	55	55	56	1986	1377	6.6	.025
56	1464	15.0	56	56	57	5859	385	7.1	.025
57	1464	14.0	57	57	58	5860	385	13.0	.025
58	2327	13.0	58	58	59	5860	385	11.0	.025
59	1788	10.0	59	59	60	4842	250	8.0	.025
60	1229	7.0	60	60	61	4842	250	6.0	.025
61	370	4.0	61	59	62	3000	200	6.0	.025
62	750	6.0	62	62	63	15000	150	6.0	.025
63	975	6.0							

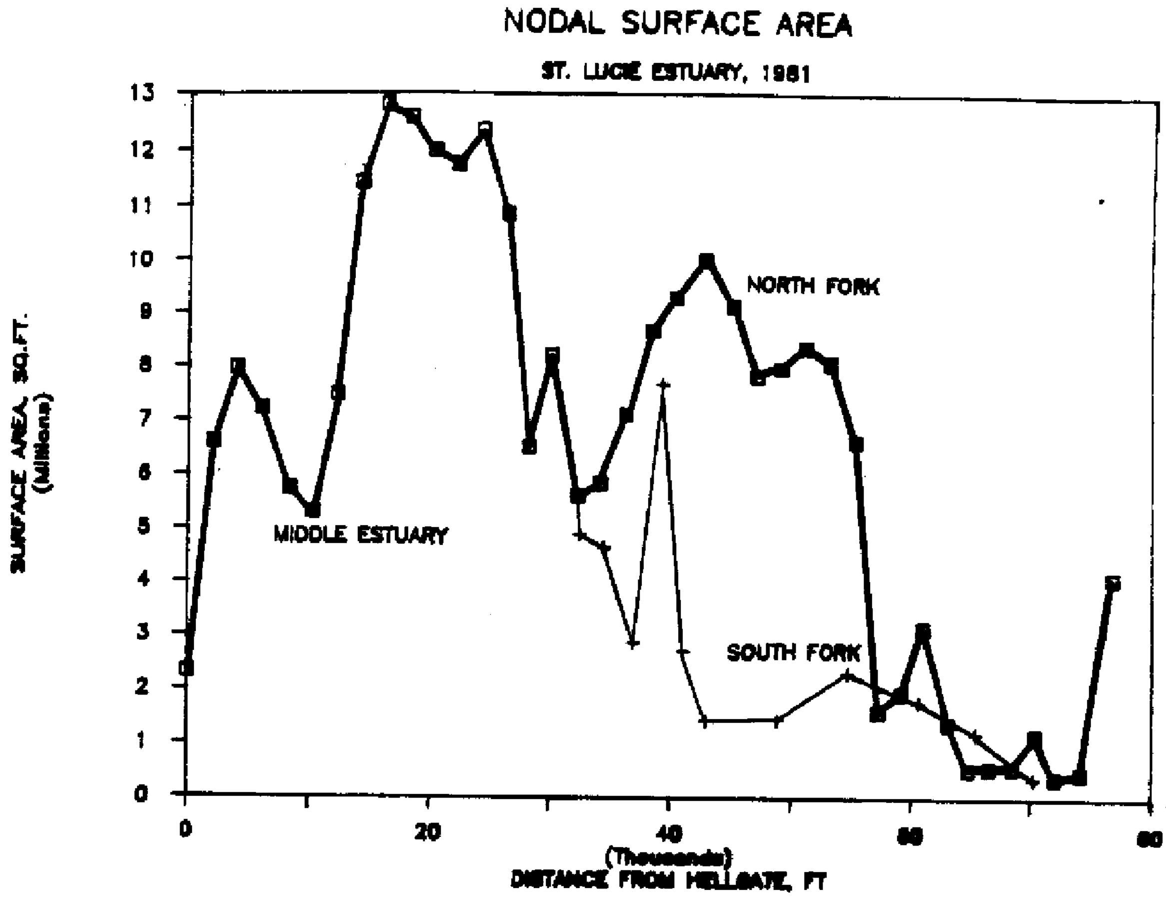


Figure 2.1 Nodal Surface Areas in the 63 Node / 62 Channel St. Lucie Estuary Model.

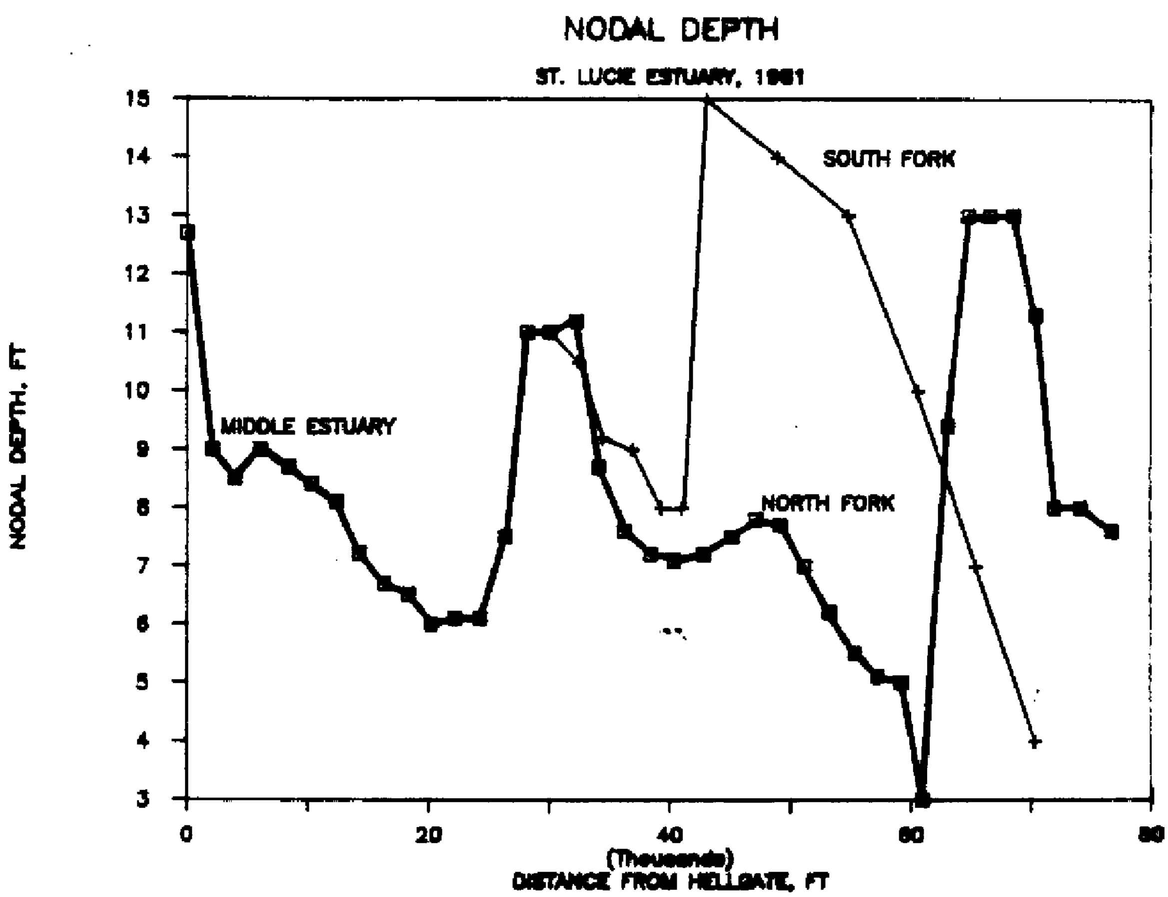


Figure 2.2 Nodal Depths in the 63 Node / 62 Channel St. Lucie Estuary Model.

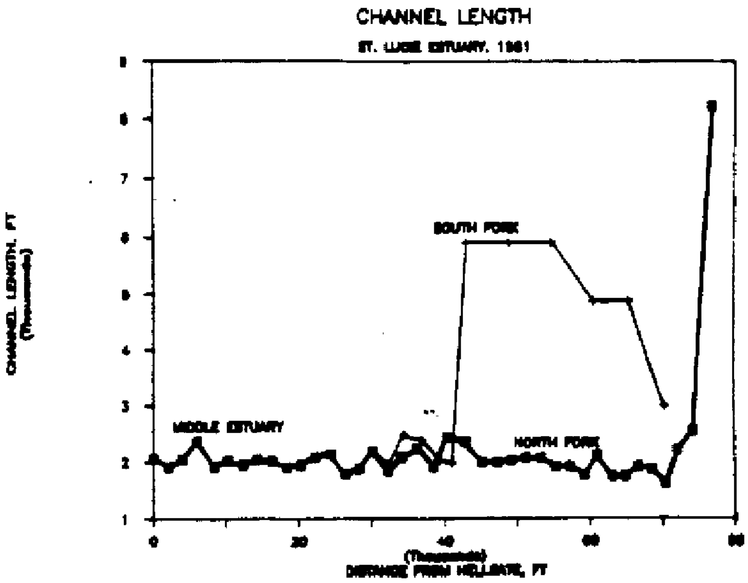


Figure 2.3 Channel Lengths in the 63 Node / 62 Channel St. Lucie Estuary Model.

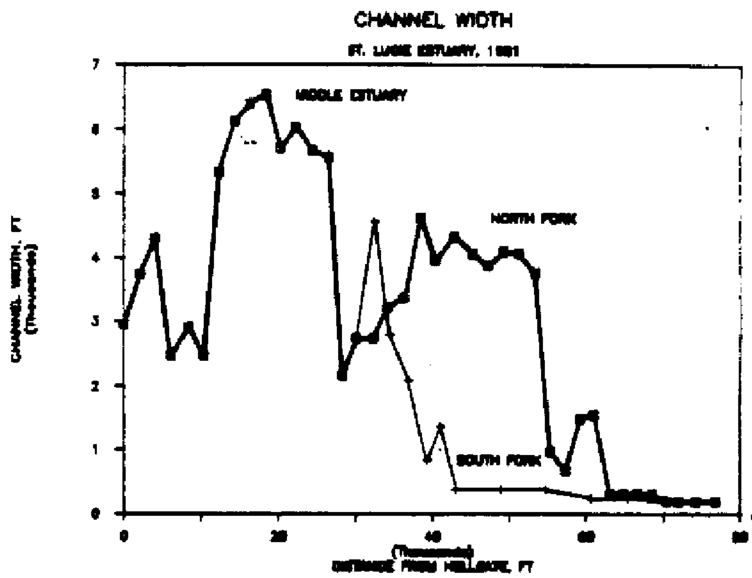


Figure 2.4 Channel Widths in the 63 Node / 62 Channel St. Lucie Estuary Model.

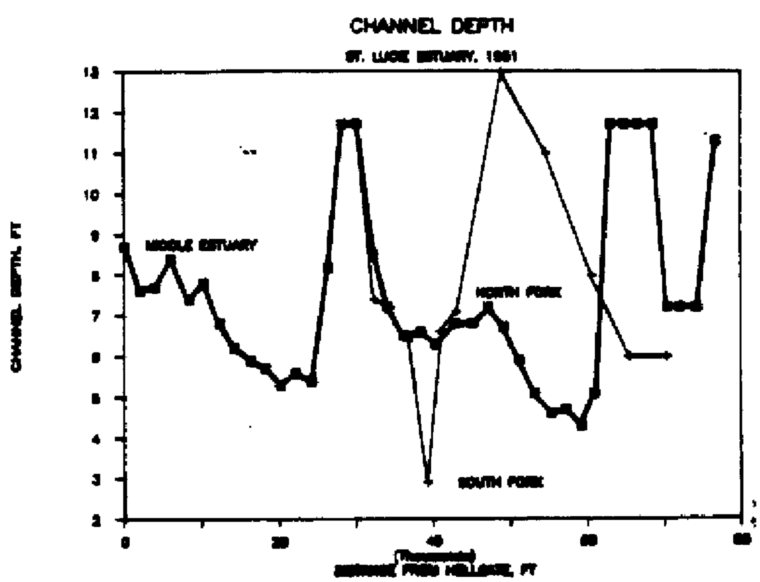


Figure 2.5 Channel Hydraulic Radii in the 63 Node / 62 Channel St. Lucie Estuary Model.

10^9 ft^3 and mean channel depth (weighted by channel length) is 8.6 ft.

L. Model Output

The model prints either a brief summary of results or various detailed outputs. All simulations start with echos of the simulation setup and the input files. The brief summary output then simply tracks the hourly cycles, printing the hourly rainfall and inflows but no data on calculated water surface elevation, flow, or salinity.

The detailed output, on the other hand, first provides hourly data of total mass of the two constituents and estuary volumes. The maximum and minimum volumes, their times of occurrence, and intertidal volumes are also printed. This is followed by a summary of the flows at the tidal boundaries. This summary includes the times of flow reversals and the net ebb and flood tide volumes at each boundary. This hourly time history of the heads (water surface elevations), and the maximum and minimum values and their time of occurrence for all nodes within the system, are printed out next. The program also provides an option to print the elevations at specified nodes on a line printer. The hourly time history of the velocity and flow rates, the daily averaged velocity and flow rates, and the net daily flow volume for each channel in the system are also optionally printed. When mass-transport is simulated, the time histories of salt and/or the second constituent for all nodes within the system follow.

In addition to the printed output, the model can write the nodal stages and salinities and the channel flows and velocities to a file. This file can subsequently be read and selectively plotted by several different District programs written specifically for the DYNTRAN output files.

Section 3. FIELD MEASUREMENTS AND ANALYSIS

A. Estuary Depths

Depths in the St. Lucie Estuary and St. Lucie Inlet have been published previously on nautical charts prepared by the U. S. Coast & Geodetic Survey (C&GS), National Ocean Service (NOS/NOAA), and the U. S. Army Corps of Engineers (COE). Since the most recent complete survey of the estuary had been conducted in 1963, the SFWMD carried out a bathymetric survey in the St. Lucie Estuary and the North and South Forks of the River in 1981 and 1982 to obtain a more detailed and current set of depth measurements. The results of this survey are documented in SFWMD Technical Publication 86-4 (Morris, 1986).

B. Water Surface Elevations and Tides

The ocean tide is the principal force driving the hydrodynamics of the St. Lucie Estuary. The tide at the mouth of the St. Lucie River is a composite of the ocean tide at the St. Lucie Inlet to the east and the ocean tide at Ft. Pierce Inlet to the north, as influenced by inlet geometry, bottom topography, and shoreline variations of the Indian River Lagoon between the two inlets.

The water surface elevation above a tidal datum, or reference plane, at a certain location in the estuary is the sum of the tidal height and additional non-tidal effects, of which the principal components are:

- Fresh water discharges, which add to the water surface elevation
- Wind, which pushes the water surface down in one location and up in another, and as a result can cause the surface flow to be different in magnitude and direction from the bottom flow
- Atmospheric pressure, which depresses the water surface as it increases.

The residual water surface elevation at a particular location, the difference between the total water surface elevation and the tidal height, is directly related to the net non-tidal flow at that location.

The model requires water surface elevation boundary conditions for a simulation. Therefore, it is necessary to know or estimate *a priori* the water surface elevation at the tidal boundary for the entire period of the simulation. For a simulation of historical conditions, measurements of water surface elevation at the boundary during the period of interest are used. For simulations of periods without direct tidal boundary data, the total water surface elevation is unknown and only tidal elevations can be predicted. Pure tidal boundary conditions are correct when there is no fresh water inflow, no wind or only light wind, and no unusual barometric pressure, or when the tidal boundary is established far enough offshore that the water surface elevation can be assumed to be caused by the open-ocean tides alone.

Initially, tidal measurements were limited to upstream of the mouth of the St. Lucie River. The Indian River Lagoon and the two inlets were omitted from the model, and either measured water surface elevations or predicted tides were used for the estuary boundary conditions near Hell Gate Point, north of the river mouth. It was assumed that pure tidal boundary conditions would be sufficient for predictions of the effects of fresh water flow on estuarine salinity during a period of time in which measurements were unavailable.

In 1981, tidal data for the St. Lucie River Estuary were available from National Ocean Service (NOS, a branch of NOAA) and from General Development Corporation (GDC). However, the applicable portions of the NOS data cover only a limited period of time in the 1970's, and GDC data cover only one station (Kellstadt Bridge) in the North Fork. Consequently, the District established a comprehensive network of water level recorders throughout the estuary to obtain data necessary for calibration and verification of the model.

The available NOS water level stations applicable to the St. Lucie Estuary model, for the period prior to June 1981, are summarized in Table 3.1. The period of record for Sewall Point station is July 1969 through October 1973, but the periods of record of the other four stations range from only 5 to 15 months. All of the latter were installed from July through November, 1972. The Sewall Point station is the only one of the five which has been leveled to the NGVD net and updated to the 1960 - 1978 tidal epoch, as of June 1986 (NOS, 1985, 1986). Various water surface datums and statistics for this station are summarized in Table 3.2.

During June to August 1981, SFWMD installed nine water level recorders between Hell Gate, Kellstadt Bridge in the North Fork, and Harbor Drive in the South Fork (Table 3.3 and Figure 3.1). Three additional recorders were installed in October and

Table 3.1 National Ocean Service (NOS/NOAA) Tide Stations, St. Lucie River Estuary.

NOS NUMBER	TIDE STATION NAME	LATITUDE	LONGITUDE	INSTALLATION DATE	REMOVAL DATE	EPOCH
8722334	North Fork, St. Lucie R.	27°14.6N	80°18.8W	72/07/11	73/01/15	60-78
8722357	Stuart, St. Lucie R.	27°12.0N	80°15.5W	69/06/17	70/09/21	41-59
8722366	Seminole Shores, FL	27°11.0N	80° 9.5W	72/09/27	73/04/05	41-59
8722371	Sewall Point, St. Lucie R.	27°10.5N	80°11.3W	69/05/13	73/11/06	60-78
8722376	South Fork, St. Lucie R.	27° 9.9N	80°15.3W	72/07/11	72/11/30	---

November 1981 and July 1982. These Leupold-Stevens Model 7001, float type, punched paper tape digital recorders were set at a recording interval of 15 minutes, and the data were collected and processed bi-weekly. All times were corrected to Eastern Standard Time, and by April 1982 the recording time interval on most of the recorders had been changed from 15 minutes to one hour. An estimated accuracy of leveling of water level recorders in the St. Lucie Estuary is 0.048 ft (Morris, 1986, p.4). The overall accuracy of water level measurements, calculated by combining leveling accuracy with an accuracy of ±0.5 inch in measurements of distance to water at the gage, and an accuracy of ±0.05 ft for the recorder itself, is estimated to be ±0.08 ft.

Harmonic analysis of tides is a mathematical procedure that has been used since the late nineteenth century to describe the tidal characteristics of a waterbody, and to compare the tidal characteristics of

Table 3.2 Measured Levels at NOS/NOAA Tide Station Sewall Point, St. Lucie River Estuary.

	DEPTH (MLW)
HIGHEST OBSERVED WATER LEVEL (69/10/31)	3.19 FT
MEAN HIGH WATER (MHW)	0.90 FT
MEAN TIDE LEVEL (MTL)	0.45 FT
MATIONAL GEODETIC VERTICAL DATUM - 1929 (NGVD)	0.21 FT
MEAN LOW WATER (MLW)	0.00 FT
LOWEST OBSERVED WATER LEVEL (70/04/24)	-0.96 FT
MEAN TIDE RANGE (FROM TIDE TABLES)	0.90 FT
SPRING TIDE RANGE (FROM TIDE TABLES)	1.10 FT

Note: all above depths are referred to MLW.
The NGVD reference is based on adjustment of 1970 and NOS levels of 1969.
Ref: N.O.S., Tidal Bench Marks, Florida Station 872 2371, Sewall Point, June 2 1983, pg. 3.

Table 3.3 St. Lucie Estuary Water Level Measurement Stations Maintained by SFWMD.

STATION NAME	STATE PLANE E/W	STATE PLANE N/S	LATITUDE	LONGITUDE	INSTALLATION DATE TIME	REMOVAL DATE TIME
KELLSTADT BRIDGE	720250	1068600	27°16'19.2N	80°19'19.1W	81/07/02-1300	PRESENT
SANDPIPER BAY	722801	1058110	27°14'35.2N	80°18'51.5W	81/06/15-1600	82/08/06-0915
BRITT CREEK	731450	1054199	27°14'56.0N	80°17'15.9W	81/07/01-1015	82/08/06-0915
ROOSEVELT BRIDGE	740300	1045530	27°12'29.6N	80°15'38.5W	81/07/01-1515	82/10/11-0100
A1A BRIDGE	757340	1042250	27°11'56.1N	80°12'30.0W	81/08/27-0930	83/05/05-1000
HELLGATE	760230	1035520	27°10'49.3N	80°11'58.4W	81/06/10-1545	PRESENT
BESSEY CREEK	729235	1042875	27°12' 4.0N	80°17'41.2W	81/06/16-1530	82/08/06-1415
PALM CITY BRIDGE	740250	1032910	27°10'24.7N	80°15'39.8W	81/07/01-1200	83/06/21-1100
HARBOR DRIVE	739825	1014476	27°07'22.1N	80°15'45.7W	81/07/08-1030	PRESENT
CARDINAL TRAIL	743840	1008250	27°06'20.2N	80°15' 1.7W	81/11/04-1530	83/06/14-0800
FLA. OCEAN. SOC.	750625	1042425	27°11'58.3N	80°13'44.3W	81/10/08-1515	82/02/01-0830
CABANA POINT	742109	1032156	27°10'17.1N	80°15'19.3W	82/07/20-1030	PRESENT

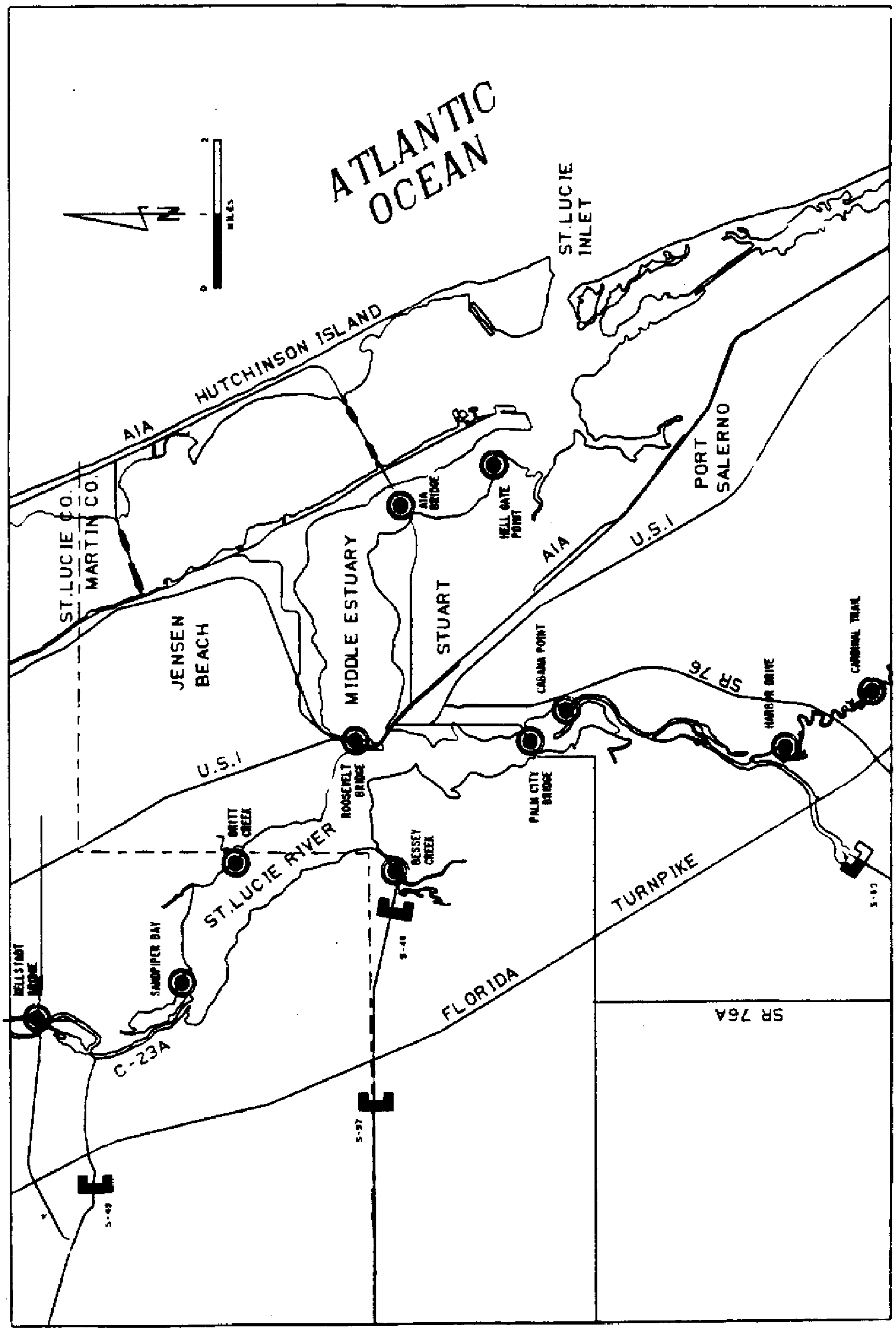


Figure 3.1 Location Map for Water Level Recorders, St. Lucie Estuary.

one waterbody with another. It is based on the fact that the principal tide-producing forces are developed by the mutual gravitational attraction of the earth, the sun, and the moon. Since the positions of the sun and moon relative to the earth can be predicted with great precision, the tidal water surface elevations developed in large bodies of water by the sun and moon can be accurately predicted using the harmonic coefficients obtained from measured water levels at a given location. The analysis produces an amplitude and phase angle for each of the twenty-five most significant solar and lunar components of the tide-generating force. In order to perform a harmonic analysis for a particular location in an estuary, it is necessary to have at least 15 days, and preferably 29 or more days, of measured water surface elevations. Each of the St. Lucie tidal data periods used for the St. Lucie Estuary harmonic analyses were nine to fifteen months in length.

In the spring of 1982 a tidal harmonic analysis was performed on the water level data from the eleven stations then installed in the St. Lucie Estuary; a later analysis was performed on available data from April 1982 to July 1983. These analyses were conducted under District contracts with the Oceanography & Ocean Engineering Department (O&OE), Florida Institute of Technology (FIT) (O&OE, FIT, 1981; 1984). Astronomic constituents calculated by these analyses can be used in a number of different ways:

- To reconstruct (or "fill") the tidal water surface elevation for either the same time period, or for other time periods outside the original data collection period, so that there are no missing data points
- To fill water surface elevation data missing at one station using measured data at another station
- To determine the non-tidal, or residual, water surface elevation at any time during the period of measurement at any measurement station.

The reconstruction of the water surface elevation at a station is useful because it fills gaps in the data, and thus provides a continuous record for use as a boundary condition for the model. Such a reconstruction adds an assumed non-tidal water surface elevation to the calculated tidal elevation, matching the total calculated elevations to the measured elevations at the beginning and end of each data gap.

For convenience in handling the tidal data on the computer, all data sets were filled as necessary and combined into three-month quarters for each station as summarized in Table 3.4. This table shows the file name for each quarter, the number of the set of tidal harmonics used for the analysis of the quarter, the start and stop dates and times, and the Julian equivalents of the start and stop dates referenced to the beginning of the twentieth century. The first quarter extends from July 1 through October 1, 1981, and the others are numbered consecutively thereafter. Those files with "F" after the station name contain one or more filled gaps, in which missing data have been replaced by tidal heights plus a constant or gradually varying additional, non-tidal water surface elevation to match the elevation at each end of the missing data.

C. Structure Discharges

The largest of the St. Lucie Estuary drainage canals is C-44, which is part of the Okeechobee Waterway and extends from S-308 at Port Mayaca to S-80, the St. Lucie Lock and Dam in the South Fork of the St. Lucie River. The other two canals discharging to the St. Lucie Estuary, as described in Section 1.B, are C-23, which is gaged upstream at S-97 and discharges at S-48, and C-24 discharging at S-49. The locations of these canals and structures are shown in Figure 3.2.

S-80 is a gated spillway with seven taintor gates at the dam and two sets of sector gates at the lock. It is designed for a maximum discharge of 16,900 cfs and is regulated manually according to a schedule established by the COE and the District. The mean daily discharge at the structure is calculated by the U.S. Geological Survey (USGS) from water level records provided by the COE, and published in the annual Water Resources Data for Florida (Station 02277000, USGS, Vol 2A. South Florida Surface Water). Lockage and leakage at S-80 result in average daily discharges of between 12 and 20 cfs.

Since C-44 is connected to Lake Okeechobee, the magnitude and direction of discharge in the canal is dependent upon the stage in Lake Okeechobee and at Port Mayaca (S-308), the stage at S-80, the distribution of rainfall in the C-44 basin, and the amount of withdrawal from the canal by agricultural users. Since these functions are not now included in the estuary model, simulations were confined to the use of historical discharges, calculated C-44 basin runoff, or specified discharges at S-80.

S-97, on C-23, is a gated spillway with two automatic lift gates. It is located about 2.5 miles west of S-48, and its primary functions are to maintain upstream water levels and provide flood control. S-49, on C-24, is also a gated spillway with two automatically controlled lift gates. Its primary functions are to maintain upstream water levels, provide flood control, and act as a barrier against salt

Table 3.4 SFWMD Water Level Data Files, St. Lucie Estuary

FILE NAME	SET	START DATE	INCREMENT MIN	STOP DATE
KELLSTADT BRIDGE (North Fork, St. Lucie R.)				
* KELQ1	1	07/02/81-1300	(15)	09/30/81-2345
KELFQ2	1	10/01/81-0000	(15)	12/31/81-2345
KELQ3	1	01/01/82-0000	(15)	03/31/82-2345
KELQ4	2	04/01/82-0000	(60)	07/01/82-0000
KELQ5	2	07/01/82-0000	(60)	10/01/82-0000
KELQ6	2	10/01/82-0000	(60)	01/01/83-0000
KELQ7	2	01/01/83-0000	(60)	04/01/83-0000
KELQ8	2	04/01/83-0000	(60)	07/01/83-0000
SANDPIPER BAY (North Fork, St. Lucie R.)				
* SANQ1	1	06/15/81-1600	(15)	10/01/81-0000
SANFQ2	1	10/01/81-0000	(15)	12/31/81-2345
SANFQ3	1	01/01/82-0000	(15)	03/31/82-2345
SANFQ4	1	04/01/82-0000	(60)	07/01/82-0000
* SANQ5	1	07/01/82-0000	(60)	08/06/82-0900
BRITT CREEK (North Fork, St. Lucie R.)				
* BRIFQ3	2	03/09/82-1300	(60)	04/01/82-0000
BRIQ4	2	04/01/82-0000	(60)	07/01/82-0000
BRIQ5	2	07/01/82-0000	(60)	08/06/82-0900
ROOSEVELT BRIDGE (St. Lucie R.)				
* ROOQ1	1	07/15/81-1515	(15)	09/30/81-2345
ROOQ2	1	10/01/81-0000	(15)	12/31/81-2345
ROOFQ3	1	01/01/82-0000	(15)	03/31/82-2345
ROOQ4	2	04/01/82-0000	(60)	07/01/82-0000
ROOFQ5	2	07/01/82-0000	(60)	10/01/82-0000
* ROOFQ6	2	10/01/82-0000	(60)	10/11/82-0100
A1A ST. LUCIE BRIDGE (St. Lucie R.)				
* A1SFQ1	1	07/01/81-1400	(15)	10/01/81-0000
A1SFQ2	1	10/01/81-0000	(15)	12/31/81-2345
A1SQ3	1	01/01/82-0000	(15)	03/31/82-2345
A1SQ4	2	04/01/82-0000	(60)	07/01/82-0000
* A1SFQ5	2	07/01/82-0000	(60)	09/17/82-0900
HELLGATE (Mouth, St. Lucie R.)				
HELQ1	1	07/01/81-0000	(15)	10/01/81-0000
HELFQ2	1	10/01/81-0000	(15)	12/31/81-2345
HELFQ3	1	01/01/82-0000	(15)	03/31/82-2345
HELQ4	2	04/01/82-0000	(15)	07/01/82-0000
HELFQ5	2	07/01/82-0000	(60)	10/01/82-0000
HELFQ6	2	10/01/82-0000	(60)	01/01/83-0000
HELQ7	2	01/01/83-0000	(60)	04/01/83-0000
* HELQ8	2	04/01/83-0000	(60)	05/23/83-1000
# HELQ8Z	2	04/01/83-0000	(60)	07/01/83-1000
BESSEY CREEK (North Fork, St. Lucie R.)				
* BESQ3	2	03/11/82-1400	(60)	04/01/82-0000
BESQ4	2	04/01/82-0000	(60)	07/01/82-0000
* BESQ5	2	07/01/82-0000	(60)	08/06/82-1400
PALM CITY BRIDGE (South Fork, St. Lucie R.)				
* PALFQ1	1	07/01/81-1200	(15)	09/30/81-2345
PALFQ2	1	10/01/81-0000	(15)	12/31/81-2345
PALQ3	1	01/01/82-0000	(15)	03/31/82-2345
* PALQ4	2	04/01/82-0000	(15)	05/04/82-1500
HARBOR DRIVE (South Fork, St. Lucie R.)				
* HARQ3	1	03/04/82-1300	(60)	04/01/82-0000
HARQ4	2	04/01/82-0000	(60)	07/01/82-0000
HARQ5	2	07/01/82-0000	(60)	10/01/82-0000
HARQ6	2	10/01/82-0000	(60)	01/01/83-0000
HARFQ7	2	01/01/83-0000	(60)	04/01/83-0000
HARQ8	2	04/01/83-0000	(60)	07/01/83-0000
CARDINAL TRAIL (Old South Fork, St. Lucie R.)				
* CARFQ3	2	03/09/82-1400	(60)	04/01/82-0000
CARFQ4	2	04/01/82-0000	(60)	07/01/82-0000
CARFQ5	2	07/01/82-0000	(60)	10/01/82-0000
* CARFQ6	2	10/01/82-0000	(60)	11/28/82-1000
CABANA POINT (South Fork, St. Lucie R.)				
* CABQ5	2	07/20/82-1100	(60)	09/30/82-2300
CABQ6	2	10/01/82-0000	(60)	12/31/82-2300
CABQ7	2	01/01/83-0000	(60)	04/01/83-0000
* CABQ8	2	04/01/83-0000	(60)	05/05/83-1800
# CABQ8Z	2	04/01/83-0000	(60)	07/01/83-0000

Notes:
1. SET NUMBER IS TIDAL ANALYSIS SET
2. NOTATION FOR THE FILE NAME:
   * = NOT AN ENTIRE QUARTER
   # = MORE THAN ONE QUARTER
   THREE LETTER STATION NAME
   F = SOME DATA FILLED USING TIDAL COEFFICIENTS
   Qn = QUARTER NUMBER n
   Z = SPECIAL FILE (SAME AS #)

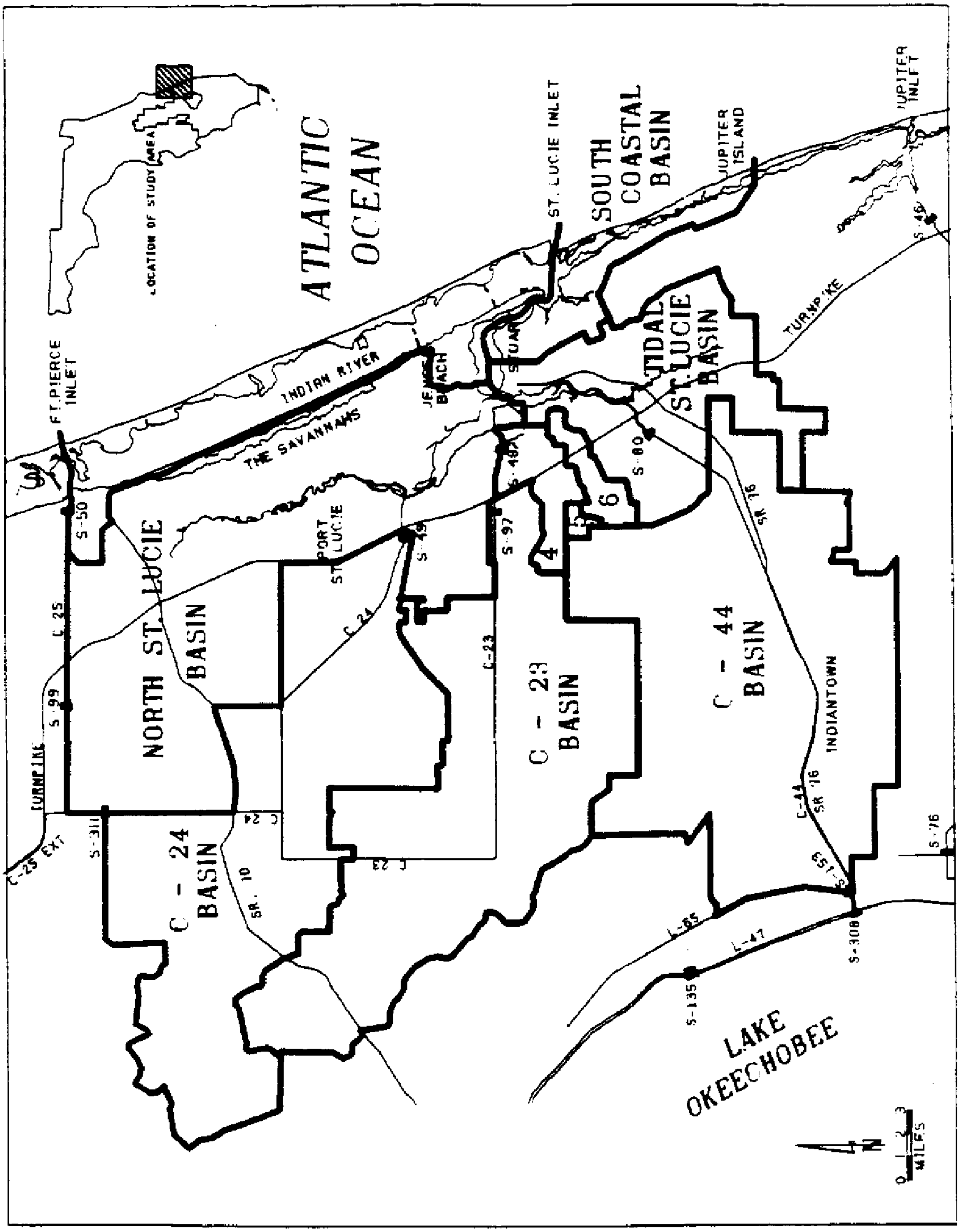


Figure 3.2 Rainfall Basin Map, St. Lucie Estuary.

water intrusion. The design maximum discharges of S-97 and S-49 are 5035 and 4680 cfs, respectively. Daily discharge records for S-97 and S-49 are calculated and maintained by the SFWMD. In 1984 the S-97 and S-49 stage records were re-digitized for the years 1977-1983, discharges were recalculated, and the resulting data were used in all subsequent St. Lucie Estuary simulations.

The Port Mayaca structure (S-308) is a gated spillway with four vertical lift gates and a lock with two sets of sector gates. Together with S-77 at the Caloosahatchee outlet, these spillways are designed to pass the standard project flood (125% of the volume from a 100-yr rainfall) from Lake Okeechobee without exceeding lake flood design stage, while restricting downstream flood stages and channel velocities to non-damaging levels. S-308 is operated by the COE to maintain a tailwater stage of 14.5 ft, if water is available. Its maximum design discharge is 17,000 cfs.

D. Calibration and Verification of Velocity and Flow

Calibration and verification of estuary models is often accomplished with measurements of water surface elevation because these data are relatively easy and inexpensive to collect. However, elevations are affected by forces other than the tide that are difficult to quantify, such as discharges and wind, and therefore it is difficult to achieve an exact calibration with water surface elevation measurements alone unless reliable simultaneous measurements of discharge and wind are also available. Another variable sometimes used for calibration is total flow through a section, but measurement of flow is normally accomplished with many simultaneous point velocity measurements, which are manpower intensive and therefore cannot be conducted over a long period of time. A third variable, which is relatively simple to measure, is the current velocity at one or more locations over some period of time. However, the flow in an estuary is usually not uniform over time and a single point will not ordinarily exist in the channel where the measured current is consistently representative of the cross-sectional mean current over the entire tidal period.

The District decided to evaluate the usefulness of both velocity and flow measurements for hydrodynamic calibration and verification as part of the overall estuary modeling program. These measurements were considered to be necessary because water level comparisons only provide indirect indications of correct flow volumes. It was known, however, that it was not realistic to expect the flow and velocity comparisons to be as close as would be obtained with water levels.

E. CSA Mid-Channel Current Measurements

Velocity measurements for hydrodynamic verification were taken by Continental Shelf Associates, Inc., (CSA) of Jupiter, Florida, under a contract with the District from July to September 1981 (CSA, 1981). Velocity measurement stations were established off Pendarvis Point in the wide part of the North Fork, north of Palm City Bridge, and east of Roosevelt Bridge, as shown in Figure 3.3. Two Endeco Type 105 film-recording current meters were deployed at each station, one at approximately 0.2 ft mean low water (MLW) depth and one at 0.8 MLW depth. Instruments were checked on a weekly basis. Current velocity is a function of the rate of revolution of the ducted impeller, which has a threshold of 2.57 cm/s (.08 fps), accuracy of $\pm 3\%$ full scale, and records at 15 minute intervals. Current direction is sensed by a magnetic compass. The data were processed from the film by Environmental Devices Corp., Marion, Mass., as part of the CSA contract, and supplied to the District on magnetic tape.

Comparisons of velocities computed by the model with these measurements are discussed in Section 4.B, Hydrodynamic Verification.

F. USGS Total Flow Measurements

Since direct measurements of flow in the North and South Forks were not available from the District, a contract was awarded to the USGS for measurement of flow at the four bridges (Figure 3.3) on the St. Lucie Estuary from July 2 to August 27, 1981 (USGS, 1982). The method required installation of a current meter at a point representative of the mean current through the bridge, in the navigation channel. The current meter was a Marsh McBirney electromagnetic sensor, which sampled and recorded at 15 minute intervals. Point velocities at approximately fifty foot stations across the bridges, but clear of bridge supports, at depth intervals of one foot over 13 hours (to span one tidal cycle) were measured with Price current meters suspended by bridge cranes, for calibration of the mean velocity recorder. This calibration, and a similar verification, were conducted by USGS twice during the measurement period (in July and September 1981). A set of two rating curves for each bridge were developed from the current measurements and stage recordings, one relating stage to cross-sectional area and one relating the recorded velocity to calculated mean velocity for the cross-section. The total flow was then calculated at hourly intervals by multiplying mean velocity by the cross-sectional area.

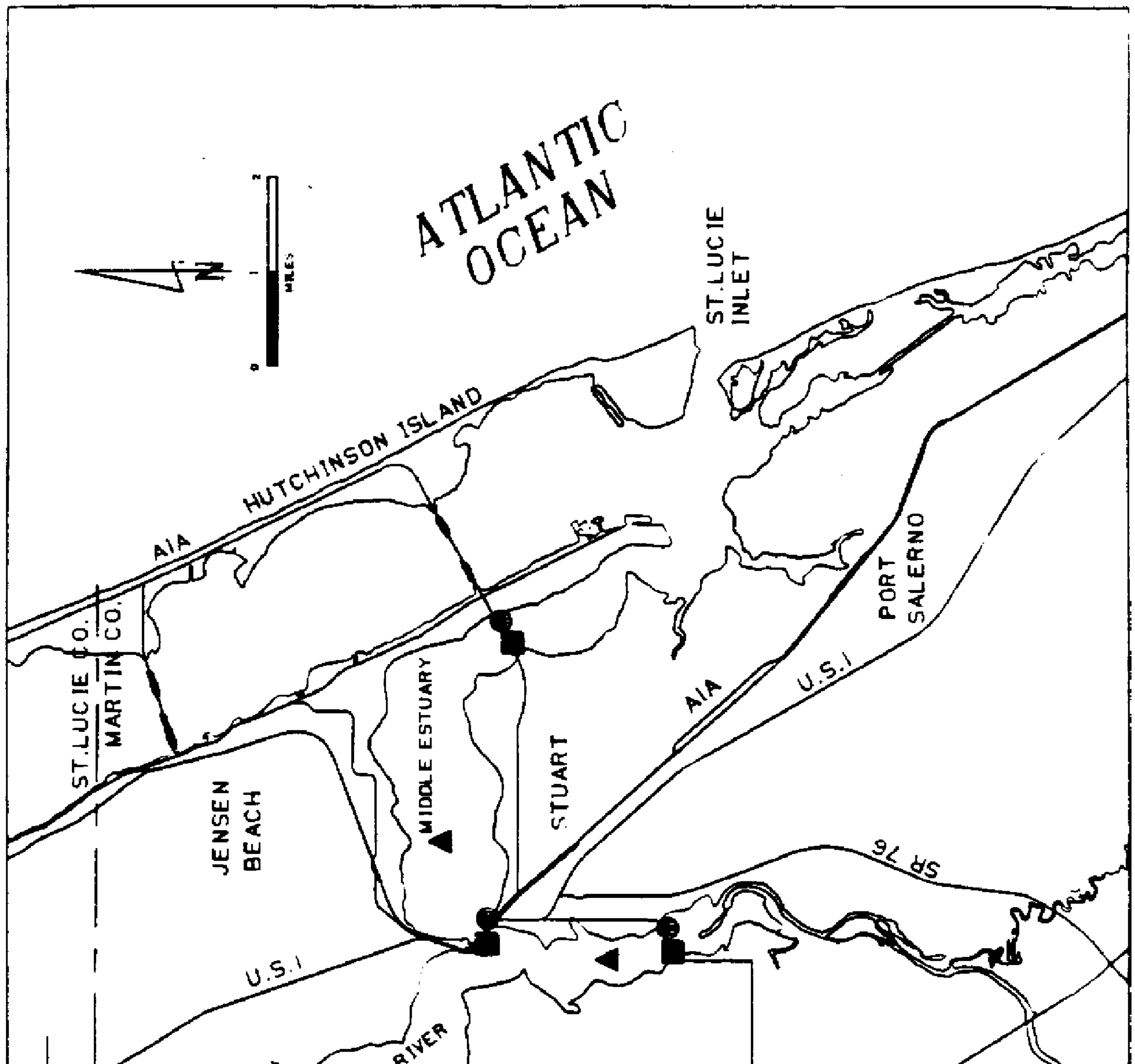


Figure 3.3 Location Map for CSA Velocity and USGS Flow Measurements, St. Lucie Estuary.

These calculated hourly total flow values were compared with the simulated total flow values to determine how well the model was able to reproduce measured prototype flows.

One week of typical computed flows from the model are described and compared with the measured total flows from the USGS rating curves in Section 4.B, Hydrodynamic Verification.

G. SFWMD Salinity Measurements

Prior to 1981, a Hydrolab Model 6 Surveyor conductivity/temperature/depth (CTD) instrument was used for salinity measurements in the St. Lucie Estuary. In June 1981 the District began using a Hydrolab CTD/pH/dissolved oxygen data logger (Model 4041). In the latter instrument, temperature is measured by a thermistor with calibrated accuracy ±0.2 °C, and conductivity is measured by means of a four electrode sensor with accuracy ±1.0% of selected range (2k, 20k, or 200k). Conductivity is the ability of seawater to conduct an electric current and usually varies over a range of 1 to 50 mmho/cm in estuaries.

Hydrolab measurements were taken by SFWMD at the eight transects shown in Figure 3.4 from June 15, 1977 through May 23, 1984. Three stations were used on each transect and designated as S, C, and X. Measurements were taken as near low slack tide as possible, at half meter intervals in depth at each station on each transect, by following the tide upstream from Hell Gate. Intervals between data sets typically vary from several days to several weeks.

Conductivity, C, in mmho/cm at 25 °C, may be converted to salinity, S, using the conversion equations 3.1a through 3.1c (Hydrolab Corp., 1981, Figure 1, p. 19): For conductivity below 16:

$$S = C \times 0.5625 \qquad (3.1a)$$

for conductivity between 16 and 42:

$$S = (C - 16.0) \times 0.6923 + 9.0 \qquad (3.1b)$$

and for conductivity greater than 42:

$$S = (C - 42.0) \times 0.7222 + 27.0 \qquad (3.1c)$$

These conductivity data are used to establish the initial salinity gradients for the simulations, and for comparisons of simulation results with measured trends in the estuary.

H. CSA Conductivity and Temperature Measurements

In conjunction with velocity measurements, CSA was contracted to obtain conductivity and temperature measurements at Kellstadt, Palm City, and A1A Bridges over the same period as the USGS flow measurements (Figure 3.3) (CSA, 1982). The resulting data spanned the period July 15 to August 12 1981. These measurements were taken at two depths, approximately 0.2 and 0.8 of MLW depth, using thermistors and 5-electrode conductivity sensors, at 15 minute intervals. The accuracy of the temperature measurement is ±0.1 °C and resolution is 0.01 °C; the accuracy of the temperature-corrected conductivity sensors is ±2% full scale and resolution is 0.1% full scale. These instruments were checked and recalibrated as necessary once each week by the contractor, according to accepted standard procedure for these types of instruments.

One week of typical computed salinities are discussed and compared with the calculated salinity from the CSA measurements in Section 4.B, Hydrodynamic Verification.

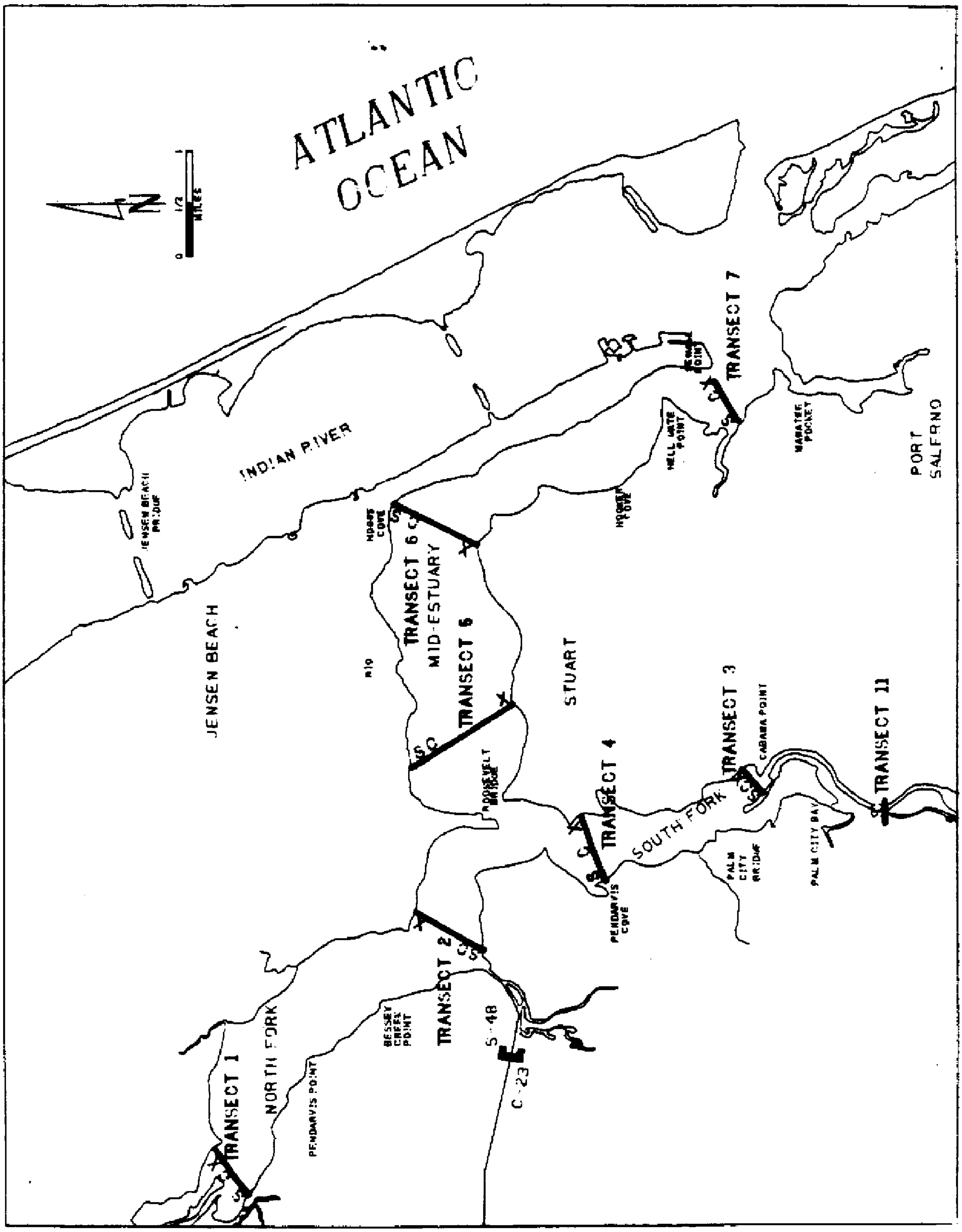


Figure 3.4 Location Map for SFWMD Salinity Transects, St. Lucie Estuary.

Section 4. HYDRODYNAMIC CALIBRATION AND VERIFICATION

When an estuary model is calibrated, it is adjusted so that the computed water surface elevations, flows, and salinities match the measured values as closely as is practical. Verification is the process of checking the calibration against a different set of data than that used for the calibration. The objective of calibration and verification is to demonstrate that the model is able to adequately reproduce measurements, both spatially and temporally. Ideally, calibration and verification should span the full range of conditions that will be used in predictions by the model, so that the model will always be interpolating within the calibrated and verified range, rather than extrapolating outside that range.

Calibration and verification of the DYNTRAN model was performed first on hydrodynamics without salinity, since the salinity depends on correct hydrodynamics while hydrodynamics are only affected to a small degree by salinity. The hydrodynamic calibration was performed with the initial SFWMD water surface elevation measurements in the St. Lucie Estuary, beginning July 1 when water level recorders were first installed and extending to August 27, 1981. The hydrodynamic verification was made with flow data by the USGS and channel velocity measurements by CSA, as described in Section 3, and District water level measurements in the South Fork during the March 1983 high discharge event.

A. Hydrodynamic Calibration

Estuary hydrodynamics depend primarily on model geometry, tidal boundary water surface elevations, and friction (energy loss) coefficients, and to a lesser extent on inflows and outflows, wind effects, and atmospheric pressure effects. For the hydrodynamic calibration and verification simulations in the St. Lucie Estuary, inflows were included but winds and atmospheric pressure were not considered.

Initial discretization of the estuary resulted in a network of 30 nodes which was successively expanded, as preliminary calibration results were obtained, to a final network of 63 nodes and 62 channels (Figure 4.1). Nodes were added to accomodate all of the measurement sites for water surface elevations, velocities, flows, and salinities, as well as to provide the necessary detail for verifying the hydrodynamics of the March 1983 high discharge in the South Fork. The minimum channel length in the model is 1450 ft (channel 43) which, with a depth of 12.2 ft, limits the time step to a maximum of 73 seconds according to the Courant/Friedrichs/Lewy stability criterion (equation 2.10). The time step was set at 60 seconds. Since the speed of the tidal wave determines the time at which water level peaks occur, channel depths were adjusted as necessary to achieve the best phase match of the tides at each measurement station. Wherever a channel depth was changed from its initial value, the associated channel width was adjusted to maintain the correct volume in that section of the model.

Tidal boundary conditions for these simulations consist of the measured water surface elevation at Hell Gate. Proceeding upstream from Hell Gate, attenuation of tidal amplitudes is caused principally by the channel geometry and to a small degree by the energy or friction loss coefficients, which can be set differently for each node. It was found that changes in the Manning's coefficient n (the energy loss or friction coefficients, equation 2.3) over its normal estuarine range of about .010 to .050 resulted in relatively small changes in the amplitude of the calculated water surface elevations. A uniform Manning's n of .025 was found to be adequate for calibration of the model.

A period of relatively low tributary inflow, wind effect, and atmosperic pressure changes was selected for the hydrodynamic calibration. Typically, the hydrodynamic calibration for an estuary needs to be run for only several tidal cycles. The hydrodynamic calibration for the St. Lucie Estuary, however, runs from July 1 to August 27, 1981, to check the hydrodynamics for the entire period of the salinity calibration. The average of daily precipitation in the five basins and at Stuart during this period is plotted in Figure 4.2. The sum of the major inflows from the three basins with canals, inflows from the North and South Fork, direct rainfall, and groundwater seepage (evaluated in Section 5) is shown in Figure 4.3.

Comparisons of the accuracy of the water surface elevation fit were made over the entire simulation and at each historical station, since the simulation spanned a period of 58 days. Comparisons from the hydrodynamic calibration at Kellstadt, Roosevelt, and Palm City Bridges are shown in Figures 4.4 through 4.6 . Full sets of weekly time plots for these stations are included in Appendix A. These comparisons indicate that the amplitude and phase (the time of high and low water) are well represented in the model.

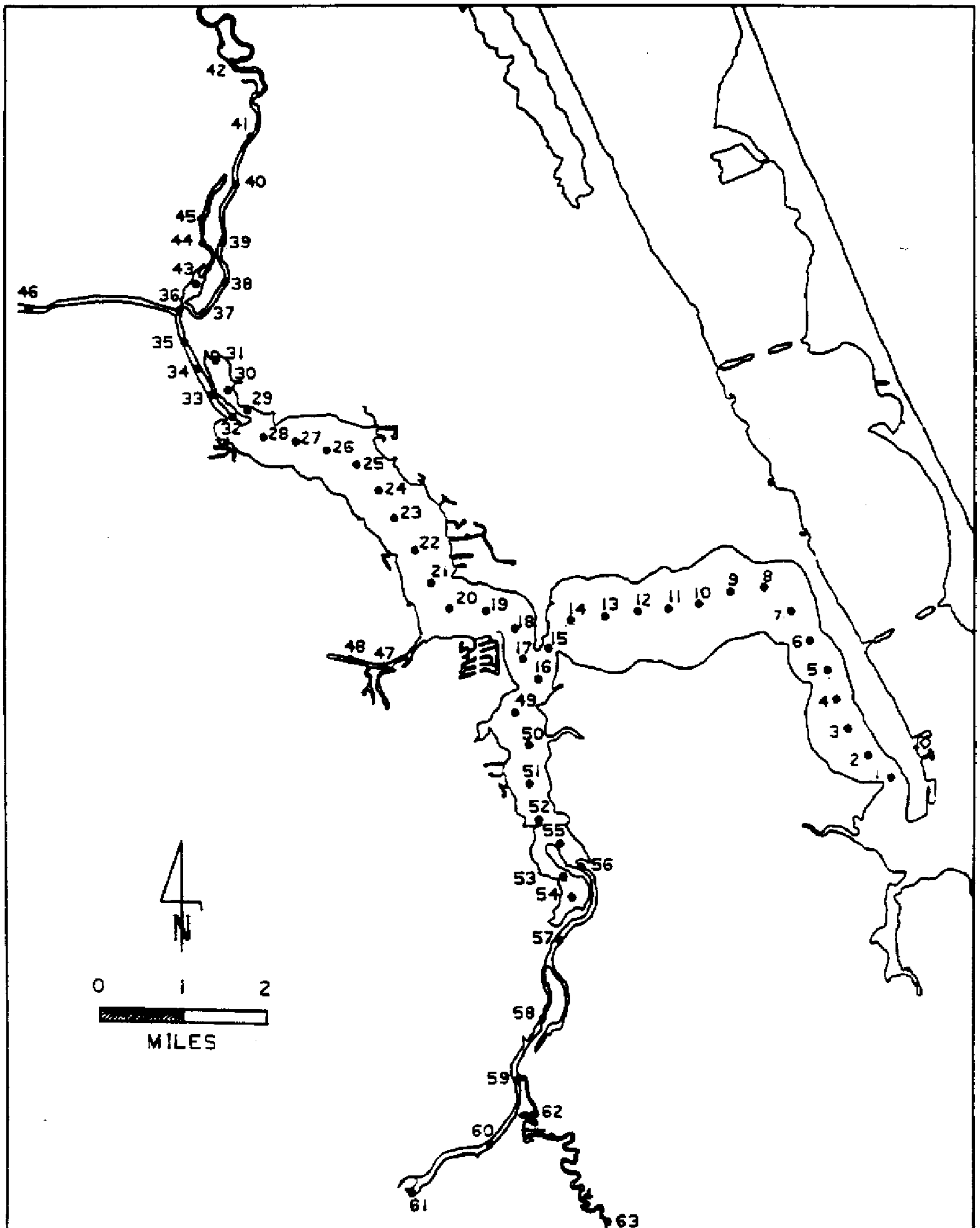


Figure 4.1 St. Lucie Estuary Model Nodal Network, 63 Nodes / 62 Channels.

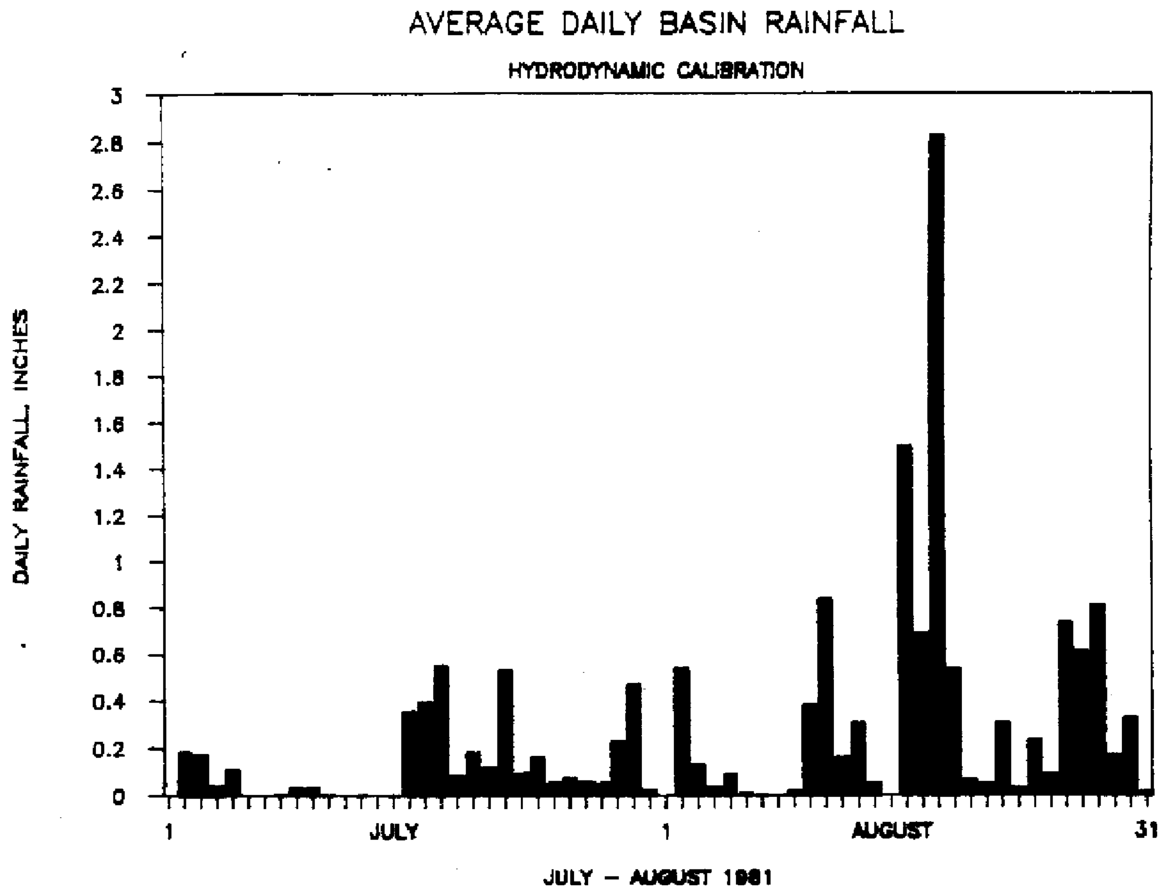


Figure 4.2 Basin Average Rainfall, Hydrodynamic Calibration.

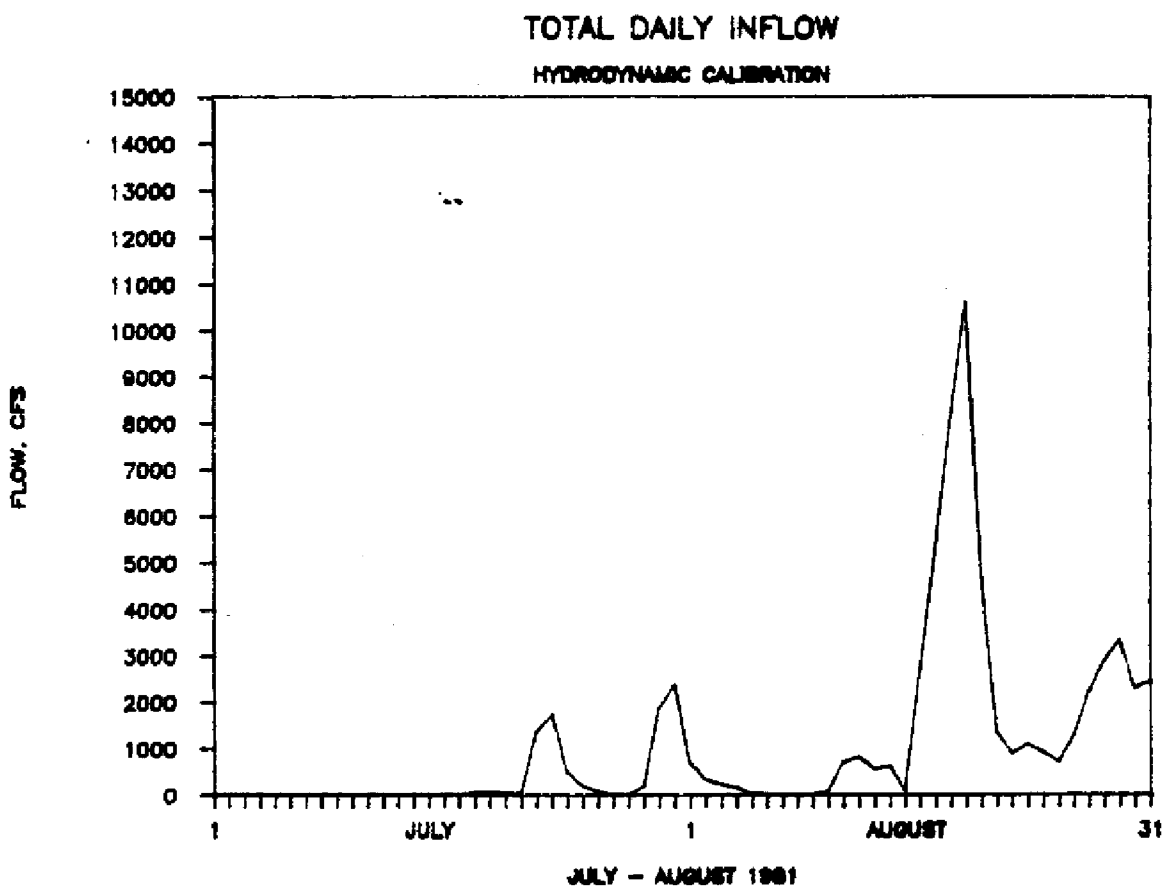


Figure 4.3 Sum of Major Inflows during Hydrodynamic Calibration.

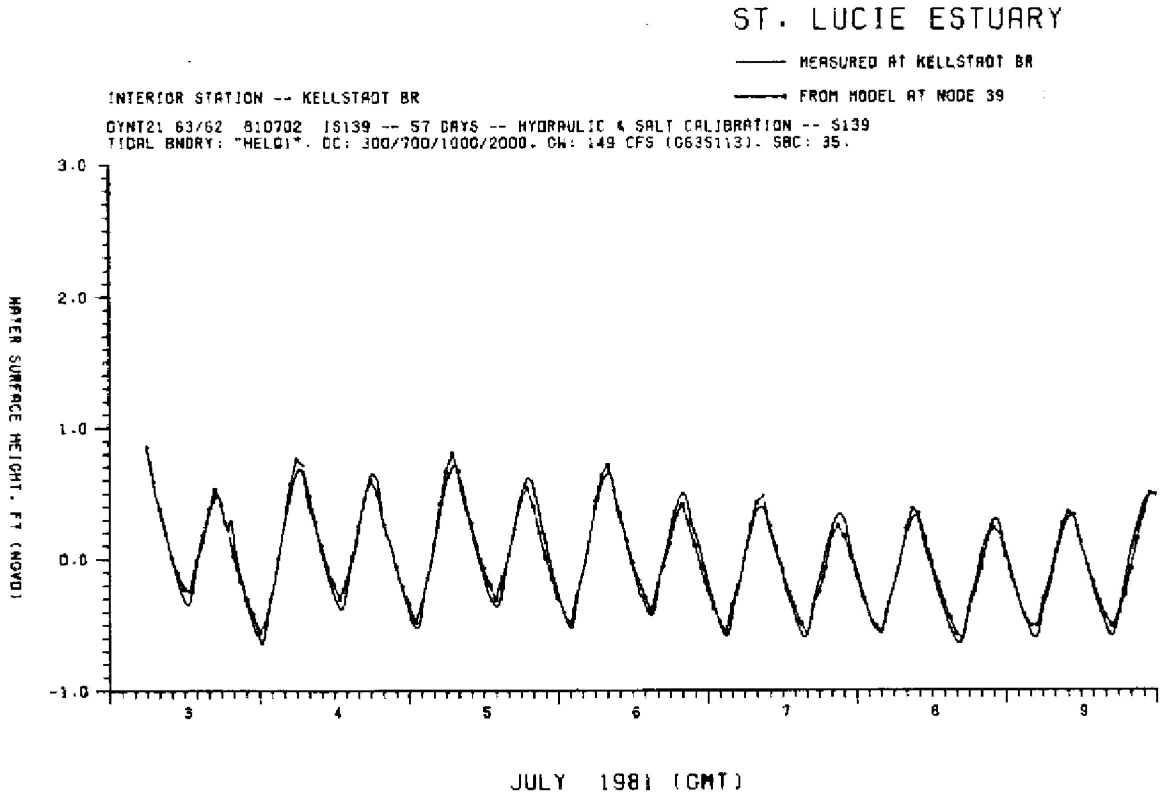


Figure 4.4 Water Surface Elevation Comparison, Kellstadt Bridge.

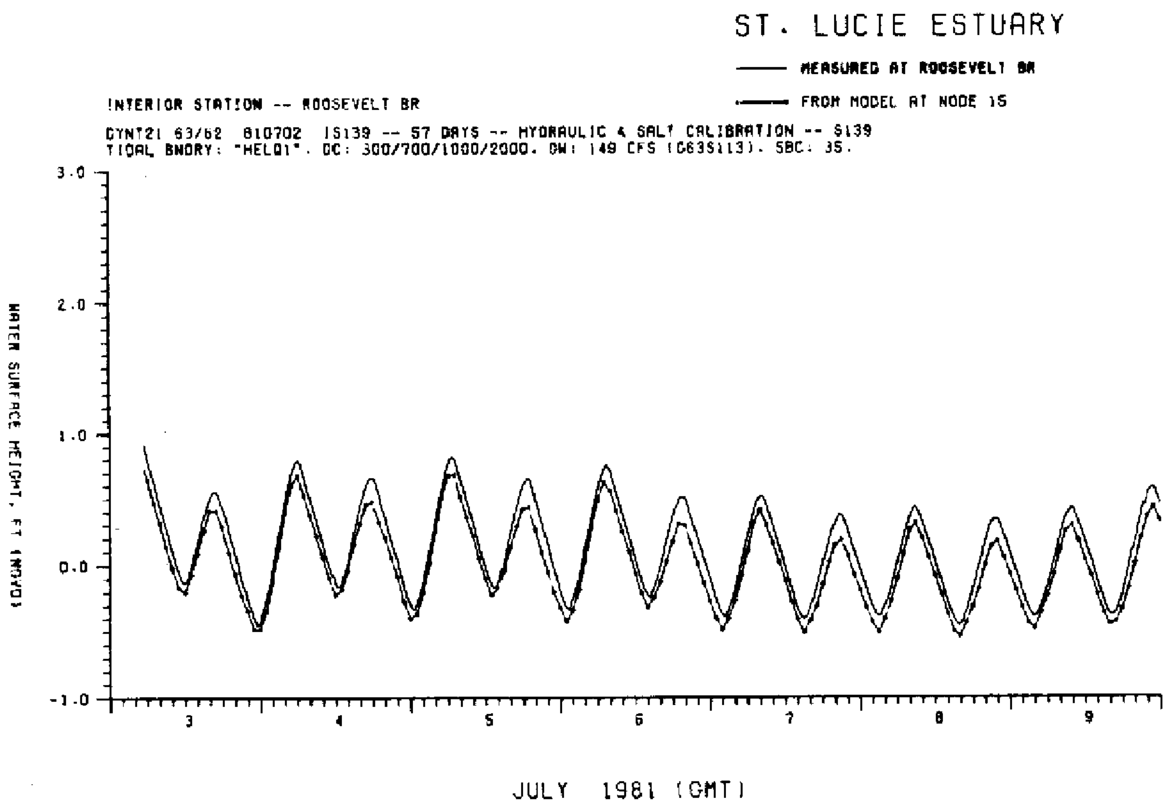


Figure 4.5 Water Surface Elevation Comparison, Roosevelt Bridge.

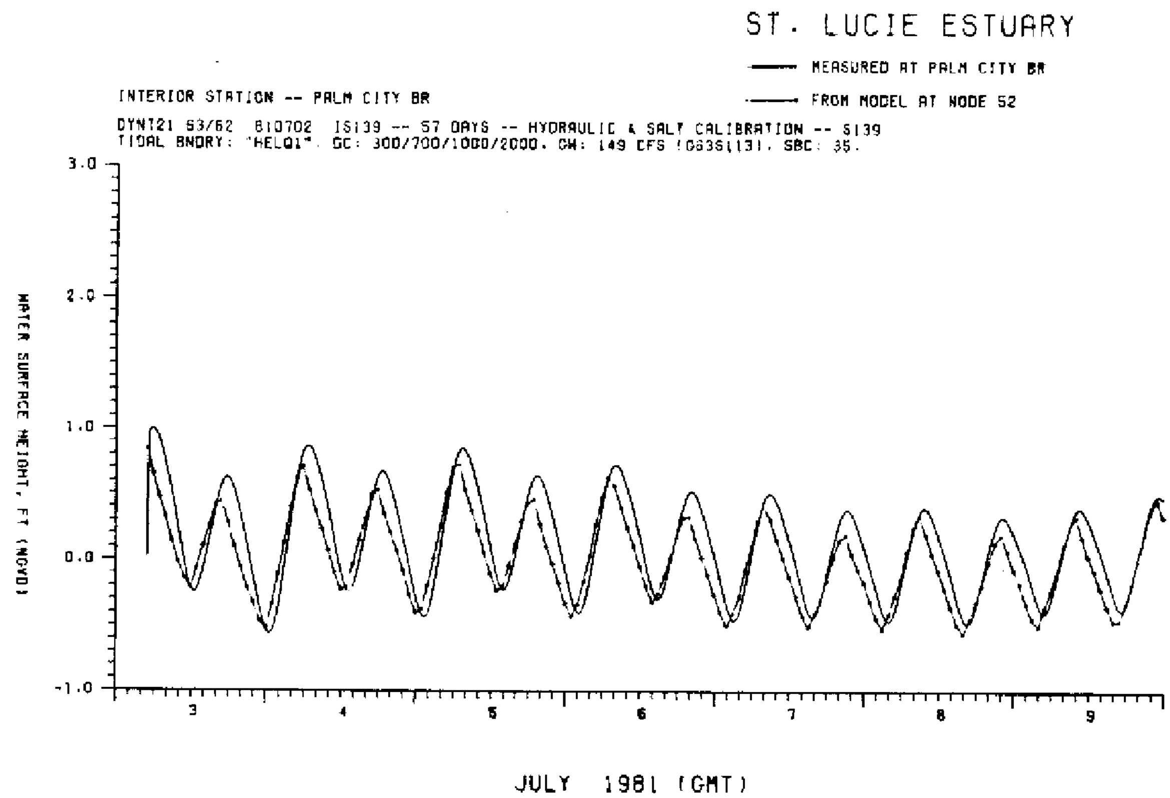


Figure 4.6 Water Surface Elevation Comparison, Palm City Bridge.

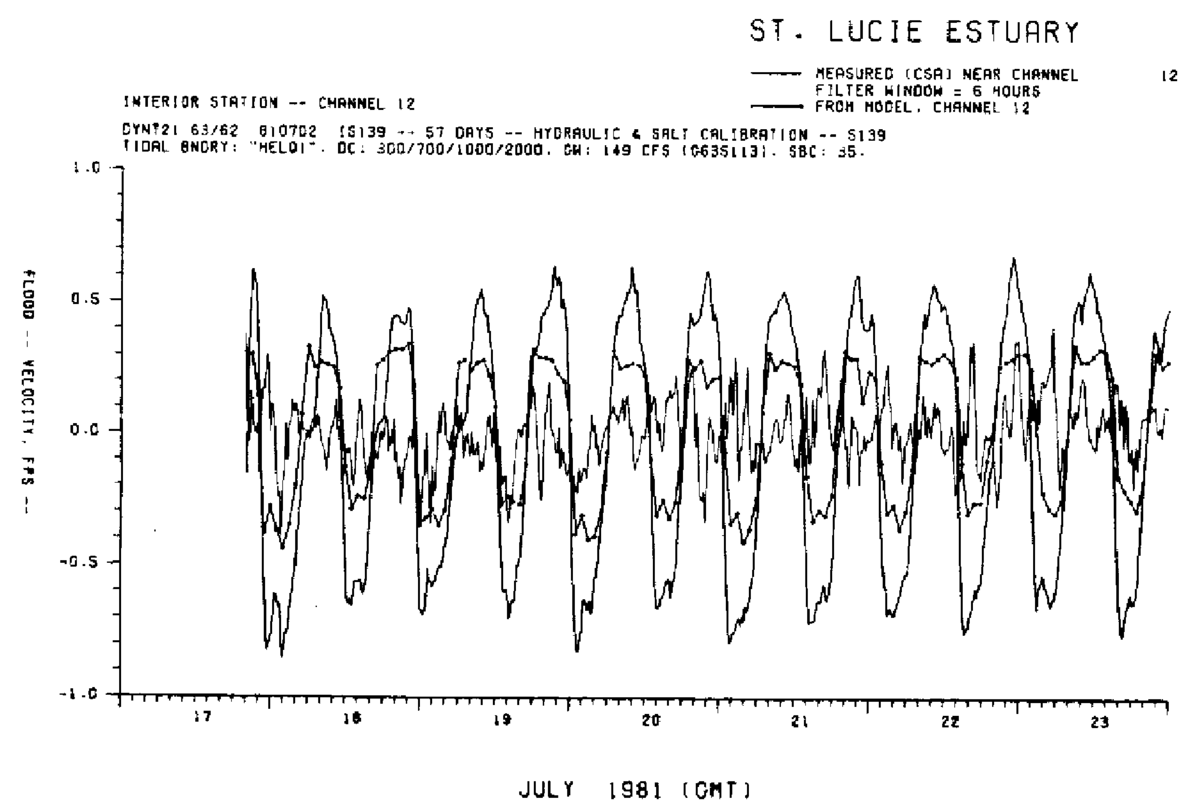


Figure 4.7 Comparison of Typical Velocities, Simulated vs. Measured.

B. Hydrodynamic Verification

1. Mid-Channel Current Measurements

Comparisons of one week of typical computed velocities from the CSA measurements with the corresponding simulated cross-sectional mean velocities are shown in Figure 4.7. These measurements were taken at two depths, approximately 0.2 and 0.8 of total depth at mean low water, east of Roosevelt Bridge at Channel 12 in the model. The raw data, in units of speed (fps) and direction (degrees, magnetic north) at 15-minute intervals, have been resolved to one vector in the direction of the channel in the model. It is apparent that the measured and computed values are in phase, and that the order of magnitude of the computed values is the same as the mean of the measured values. Thus, the velocity calibration is considered to be acceptable.

2. Total Flow Measurements

Comparisons of typical computed flows from the model with the corresponding total flows calculated from the USGS rating curves at Roosevelt Bridge are shown in Figure 4.8. The calculated flow at Roosevelt Bridge from July 15 to 21 averages about 10% less than the measured flow at the peaks and occurs on the average about 30 minutes earlier. These results are reasonably good, considering that this technique is based on point velocity measurements between bridge piers and is not a proven method for tidal flow regimes. In general, the phase of the simulated flows for all four bridges slightly leads the phase of the measured flows, the maximum deviation being two hours. The average time difference is about one hour, but there are several days in the record in which the change in simulated flow direction occurs at the same time as the calculated flows. If the large peaks are ignored, the order of magnitude of the calculated flows is comparable to that of the simulated flows for most of the period of record at all bridges.

In comparing the total flows calculated at the bridges from the U.S.G.S. rating curves with the flows developed from the rainfall/runoff relationships (Section 5) in the model, it is evident that flows calculated from rating curves could be very useful in model calibration. Unfortunately, it is expensive to maintain the current sensor in this system and the total flow measurements in the St. Lucie Estuary were terminated before this evaluation had been made.

3. Conductivity and Temperature Measurements

Comparisons of one week of typical computed salinities from the CSA measurements at the A1A Bridge are compared with simulated salinities in Figure 4.9. The magnitudes of measurements and simulated salinities are comparable, but the computed salinities in this comparison are 2 to 3 ppt higher than the measured values. This difference could be caused by the high tide salinity boundary condition, which must be set at a constant representative value for the entire simulation.

4. 9000 cfs Regulatory Release

A large regulatory release occurring at the beginning of March 1983 provided an ideal set of data for hydrodynamic verification of the model. The inflow at structure S-80 exceeded 9000 cfs, and remained in the 6000 to 7000 cfs range for over one and a half months (Figure 4.10). The corresponding sum of calculated average daily rainfall in the five drainage basins plus direct rainfall at Stuart is shown in Figure 4.11, and the total daily inflow is in Figure 4.12. Measurements of water surface elevation by the District at Cabana Point and Harbor Drive provided a set of water level data for comparison.

Measured water surface elevation at Hell Gate was used for the tidal boundary condition. As the verification progressed with a 59 node 58 channel model, it was evident that the initial South Fork model geometry was inadequate. Nodes and channels were added, and depths in the South Fork near S-80 were adjusted as necessary to reproduce measured water surface elevations in the South Fork. The final version of the model uses a 63 node / 62 channel network. After this verification, the hydrodynamic calibration (July 3 to August 27, 1981) was rerun with the same 63 node network, Manning's n values, and other parameters, with similar results (see Appendix A).

Comparisons of simulated water levels with measured water levels at the beginning of the high discharge simulation are given in Figures 4.13 (Cabana Point in the Okeechobee Waterway) and 4.14 (Harbor Drive in the Old South Fork). The dotted line represents the computed levels, while the solid line follows the hourly measurements. It has been noted (Section 3.B) that the estimated accuracy of water level measurements is ±0.08 ft. The full set of comparisons for Cabana Point and Harbor Drive are included in Appendix D.

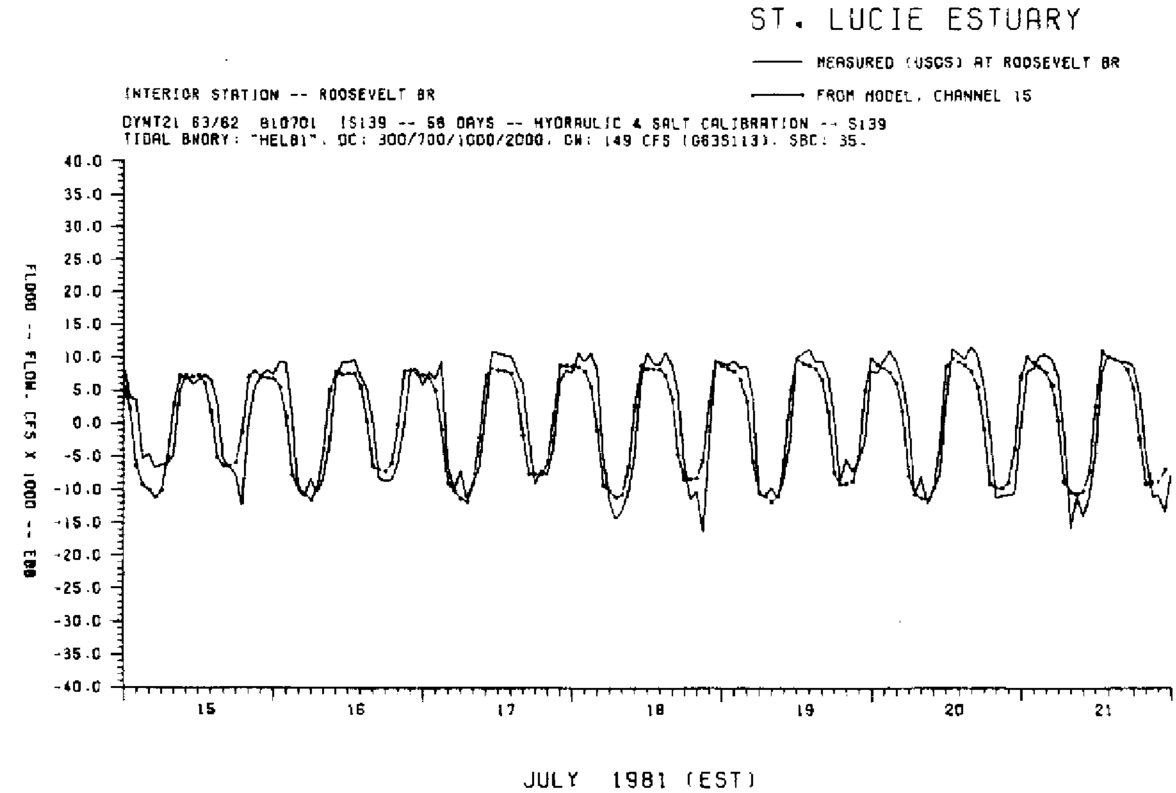


Figure 4.8 Comparison of Typical Flow Measurements, Simulated vs Measured.

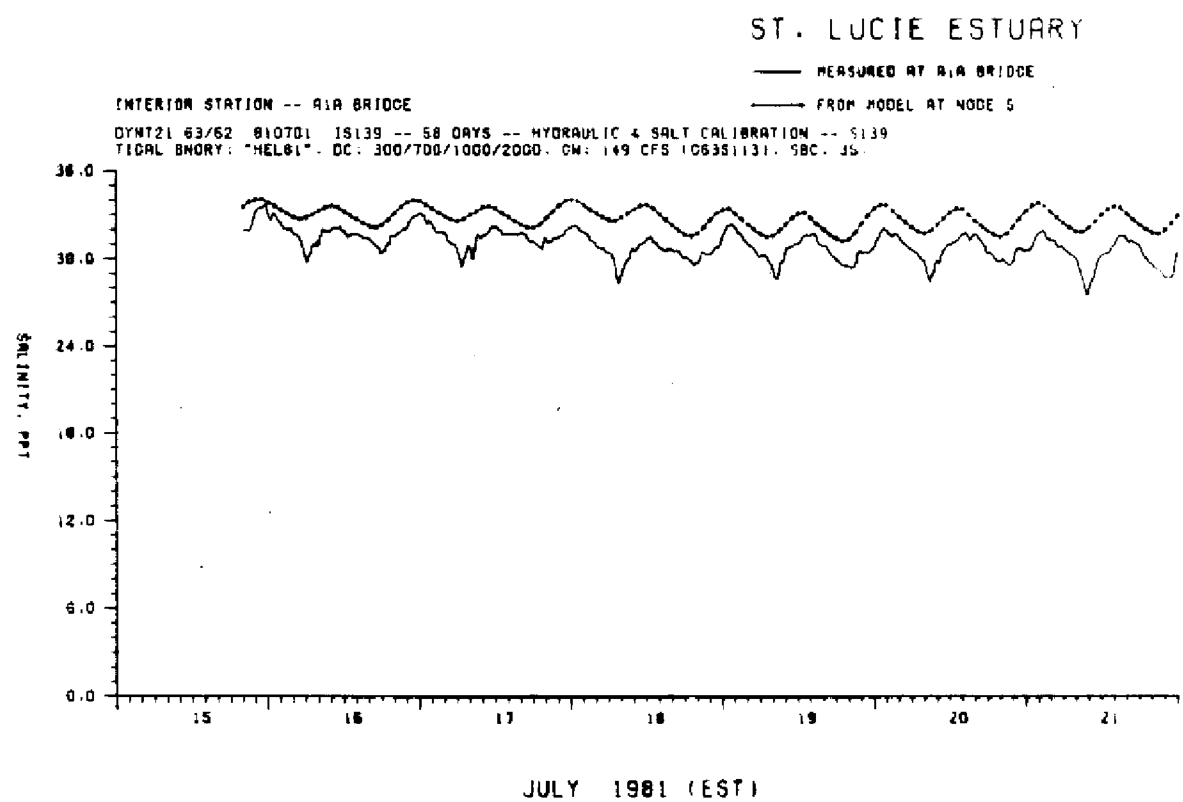


Figure 4.9 Comparison of Typical Salinity Measurements, Simulated vs Measured.

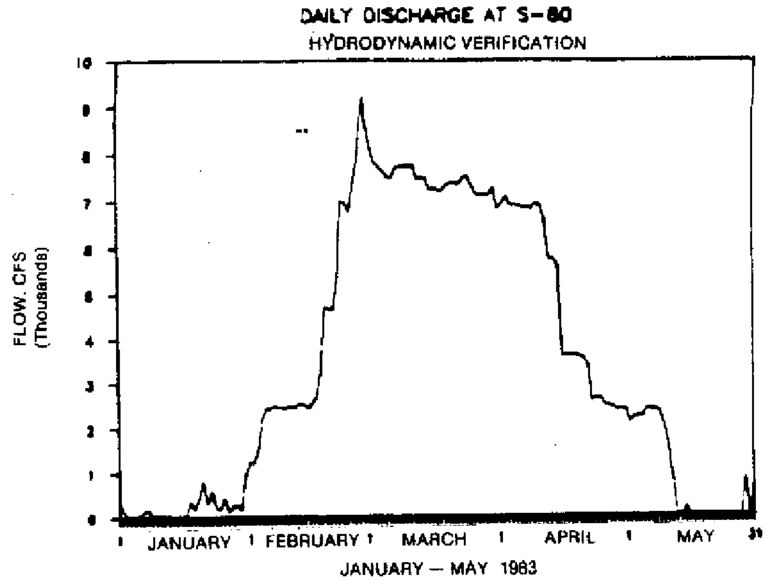


Figure 4.10 Discharge at Structure S-80, Hydrodynamic Verification.

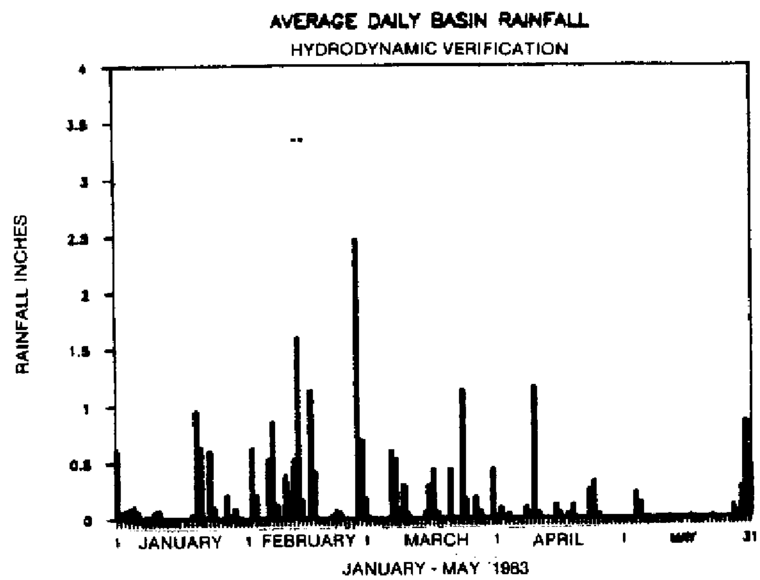


Figure 4.11 Basin Average Rainfall, Hydrodynamic Verification.

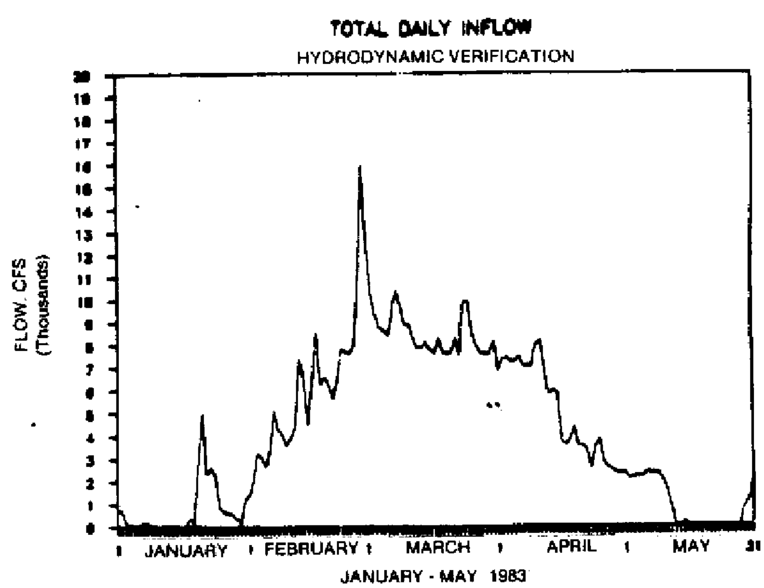


Figure 4.12 Total Daily Inflow, Hydrodynamic Verification.

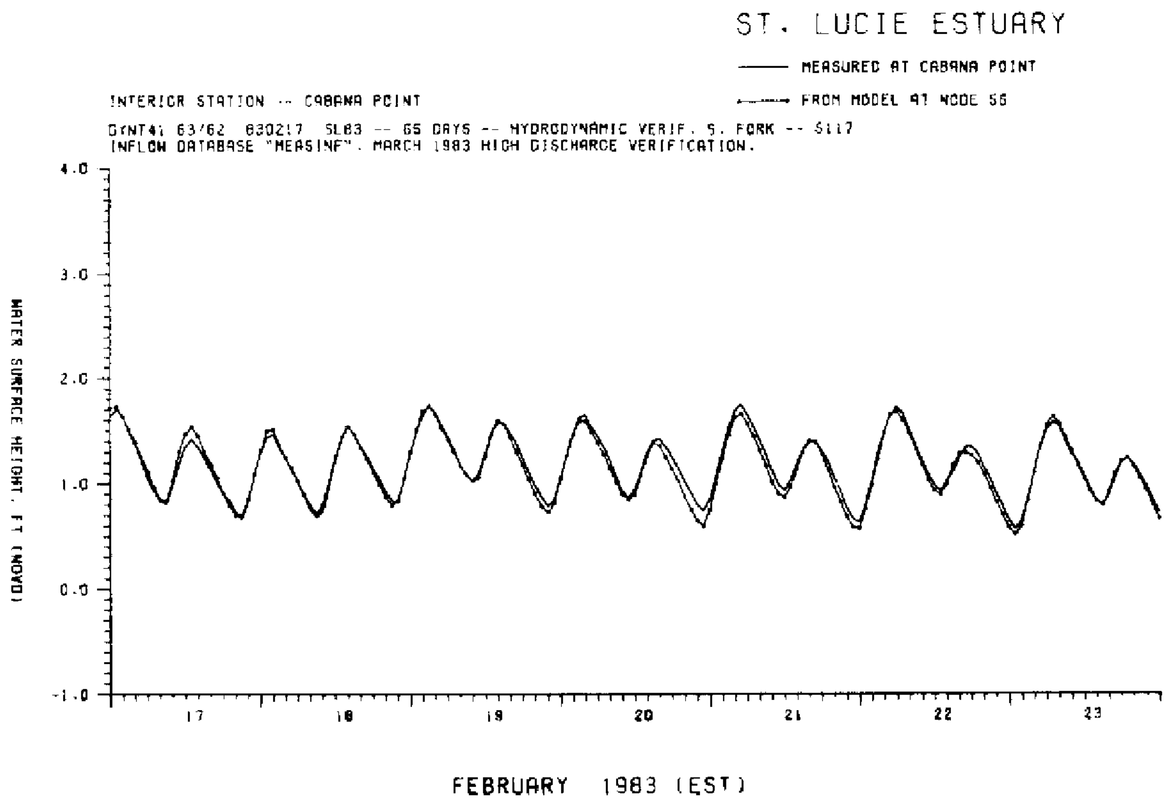


Figure 4.13 Comparison of Initial Water Surface Elevations at Cabana Point.

The calculated water levels at Cabana Point, where the South Fork narrows south of Palm City Bridge, are almost identical to the measured water levels until March 2, the day after the maximum discharge. The simulated water level peaks then average about 0.1 to 0.2 ft (the order of magnitude of measurement accuracy) below the measured water levels, but maintain the correct phase or timing with respect to the occurence of tidal highs and lows. From March 17 until March 30 the simulated water levels ranged from -0.1 to -0.3 ft relative to the measured values. By the end of the first week in April the computed high peaks were consistently low by about 0.2 ft, and as much as 0.5 ft. By April 16, when the regulatory discharge had decreased to about 3500 cfs, the calculated values were essentially the same as the measured values. These results indicate that the water surface calculated in the model is capable of accurately following water levels caused by discharges at least as large as 3500 cfs. Comparisons of the computed and measured water levels at Cabana Point (worst case conditions, April 1 - 7, 1983) during the high discharge are shown in Figure 4.15.

At Harbor Drive in the Old South Fork, the measured water surface elevation was about 0.1 to 0.2 ft below the measured values at the high peak, and 0.2 to 0.3 ft below at the low peaks. On February 17 the measured water surface levels were substantially increasing when the recorder ceased operating. It was restored on the same day, but the calibration was lost (page D-12, Appendix D).

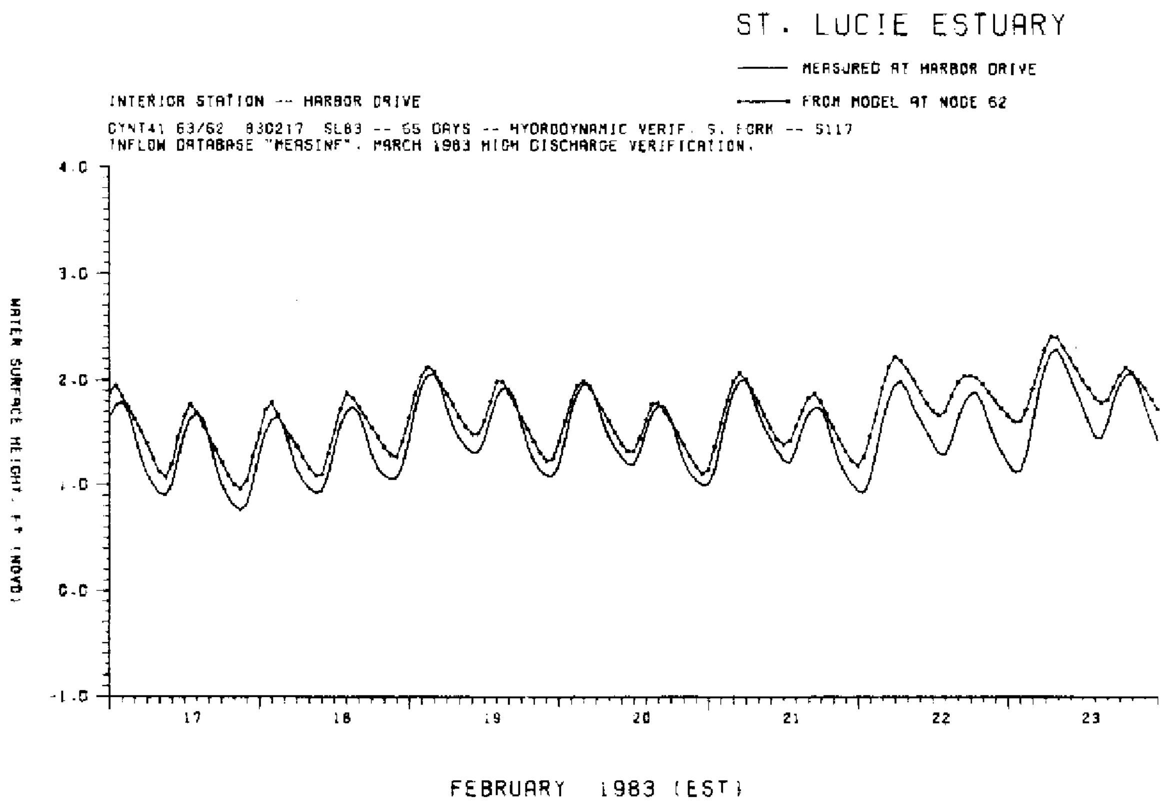


Figure 4.14 Comparison of Initial Water Surface Elevations at Harbor Drive.

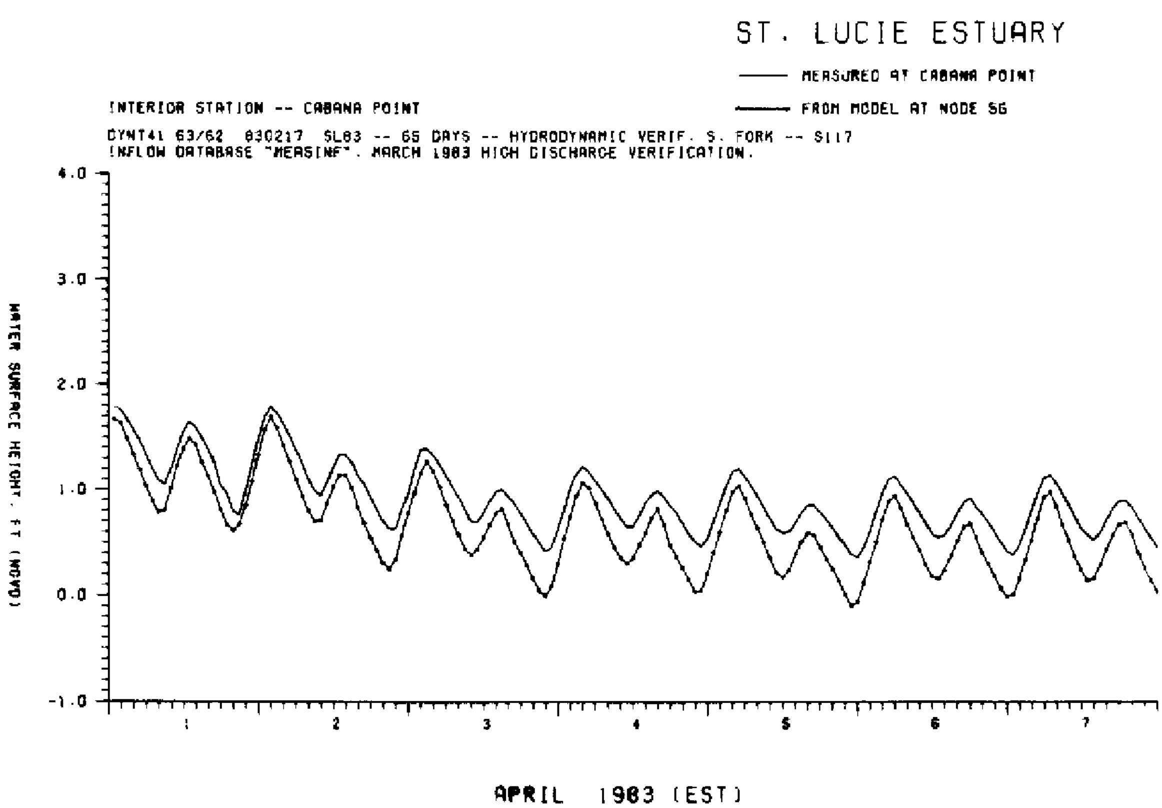


Figure 4.15 Comparison (Worst Case) of Water Surface Elevations at Cabana Point.

Section 5 HYDROLOGIC DATA AND ANALYSIS

The volume of runoff flowing into the St. Lucie Estuary as a result of precipitation is dependent upon a number of variables that are not predictable, to any degree of certainty, over periods of weeks or months. These variables include the areal extent and intensity of storms, the antecedent moisture conditions in each basin, and climatic conditions affecting temperature, evapotranspiration, and winds. The topographic characteristics of each basin add additional complexity to the problem of specifying the path that rainfall will follow to the ground water system and to the St. Lucie Estuary. The hydrologic analysis for the St. Lucie Estuary does not attempt to deal with these uncertainties; instead, the analysis focuses on finding a reasonable set of relationships linking the excess rainfall, or runoff, to the measured rainfall in the five drainage basins so the model can be driven directly by rainfall events and can produce realistic simulations of the monthly averaged effects of rainfall on salinity.

It will be noted that the rainfall/runoff analysis used for the St. Lucie Estuary model is somewhat unusual, in that it begins with physical relationships and evolves into curve-fitting to develop the basin inflows. This technique is justified by the fact that the purpose of the analysis was to develop daily runoff quantities for modeling mean salinity gradients in the estuary, the effects of which will then be compared to the effects of monthly mean S-80 discharges for dry, normal, and wet conditions. Therefore, the analysis was oriented toward finding rainfall/runoff relationships which will produce inflow values that will have reasonable monthly means. Frequency analyses of rainfall were confined to periods of one month only; when predictive (dry, normal, or wet) simulations were necessary for periods longer than one month each month of rainfall was separately selected.

All simulations, whether for calibration, verification, or predictions, are driven by historical daily rainfall data, which are used to calculate the inflows for each simulation. In all cases, therefore, the estuary is subjected to realistic daily rainfall patterns, the net result of which is an average inflow over the month that matches the desired monthly average value.

The simulations described in this report were all run for calibration or verification of historical conditions, and therefore used measured inflows from the three drainage canals whenever available. The daily inflows calculated for the two ungaged tributaries are based on calibration parameters determined from data for the gaged flood control canals. For days on which discharge data were not available for a basin, inflows were calculated using the rainfall/run-off relationship for that basin.

In the future, after a more rigorous rainfall/runoff analysis for Martin and St. Lucie Counties has been completed, it will be worthwhile to use these inputs with the model to obtain updated daily simulations of salinity fluctuations in the estuary. It is doubtful, however, that significantly improved evaluations of monthly mean salinity effects would be achieved by more accurate daily inflow values, since salinity may require several weeks to respond completely to inflows and the effects of individual inflows are averaged spatially and temporally in the estuary.

A. Rainfall and Evaporation in the St. Lucie Watershed

Five drainage basins deliver rainfall excess to the St. Lucie Estuary. From north to south these are the North Fork basin, C-24 basin, C-23 basin, C-44 basin, and the South Fork or Tidal St. Lucie basin (Figure 3.2). The land use and land cover for each of these basins are summarized in Table 5.1. This table shows that the five basins, except for the North St. Lucie, are relatively undeveloped and all quite similar in their hydrological characteristics, which justifies the use of rainfall/runoff relationships for the North and South St. Lucie basins that were developed from data for basins C-23 and C-24.

The North Fork, originating at the confluence of Five- and Ten-Mile Creeks in St. Lucie County, and the South Fork in Martin County are the two major tributaries of the St. Lucie Estuary. The flow in the North Fork has not been gaged since 1965 when the USGS maintained a discharge station at White City, which is about 1.7 miles south of the junction of the two creeks. No records have been located for flow measurements in the Old South Fork.

Precipitation data from twenty-one SFWMD rainfall stations in the two counties were used to develop the rainfall/runoff relationships for the St. Lucie Estuary model. These stations are located as shown in Figure 5.1. Table 5.2 gives the period of record, the county, the frequency of data processing (daily or breakpoint), and the basin in which each rainfall station is located.

Rainfall/runoff and frequency relationships for the St. Lucie Estuary were calculated from the values of

Table 5.1 Land Use and Land Cover Inventory, St. Lucie Estuary Drainage Basins, in acres (1974).

BASIN NAME:	C-23 BASIN		C-24 BASIN		C-44 BASIN		NORTH ST. LUCIE		SOUTH ST. LUCIE	
	SURFACE AREA	%	SURFACE AREA	%	SURFACE AREA	%	SURFACE AREA	%	SURFACE AREA	%
Agriculture	66118	62	65094	61	73535	61	47822	40	22564	50
Barren Land	226	0	750	1	130	0	371	0	0	0
Forrested Uplands	14838	14	18962	18	9848	8	21697	18	9883	22
Rangeland	281	0	704	1	738	1	466	0	17	0
Urban and built-up land	1361	2	5069	5	2845	2	33198	28	6328	14
Water	281	0	857	0	8071	7	368	0	1668	4
Wetlands	23580	22	15783	15	26246	22	16544	14	4346	10
TOTALS	106685		106535		121413		120466		44806	
Percent of Total Basin Area	21.0		21.0		24.0		23.8		8.8	
Percent undeveloped		98.7		95.2		97.7		72.4		85.9

Ref: SFWMD, "Summary Status Report, Upper East Coast. Water Use and Supply Development Plan," October 1980, pg. 28.

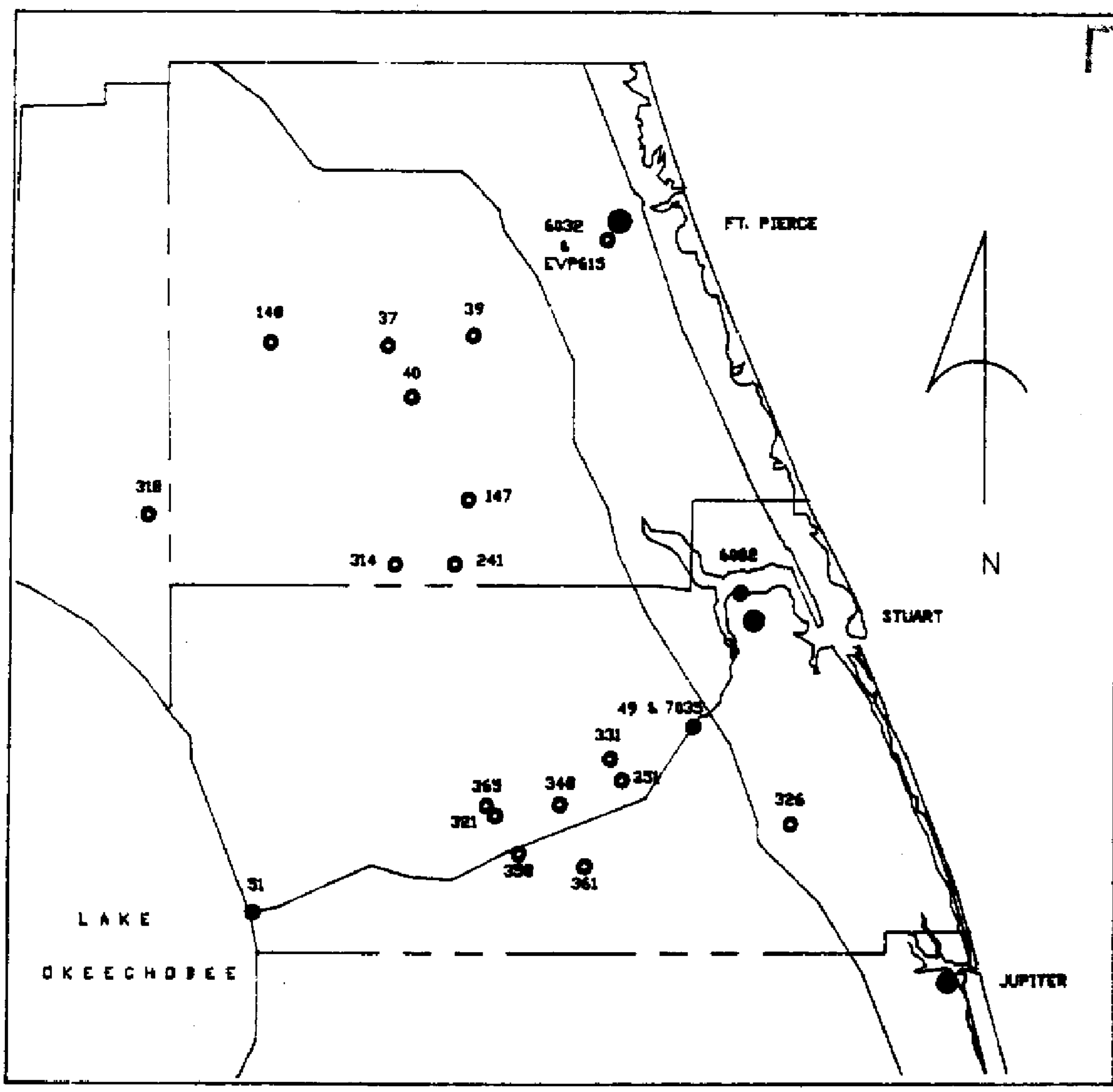


Figure 5.1 Precipitation Station Map, St. Lucie Estuary.

Table 5.2. Rainfall Stations used for Frequency Analyses in the St. Lucie Estuary Basins.

MRF #	USED IN UEC[1]	CTY	PERIOD OF RECORD		DAILY or BRKPNT	C-23	C-24	C-44	N.FK.	S.FK	STU
37	*	S	65/01	83/12	D		*				
39	*	S	60/10	83/12	D				*		
40	*	S	71/05	83/12	B	*	*				
49	*	M	58/01	83/12	D	*		*		*	
51		M	61/05	83/12	D			*			
147		S	70/09	79/04	B	*	*				
148	*	S	70/09	83/12	B		*				
241		S	79/05	83/12	B	*					
314		S	81/05	83/12	D	*					
318		O	81/01	83/12	B	*					
321		M	81/10	83/12	D			*			
326		M	82/06	83/12	D					*	
331		M	82/08	83/01	D			*			
348		M	82/12	83/12	D			*			
351		M	82/12	83/12	D			*			
358		M	82/01	83/12	D			*			
361		M	82/01	83/12	D			*			
365		M	81/01	83/12	D			*			
6032		S	01/01	83/12	D				*		
6082	*	M	36/01	83/12	D	*				*	*
7035		M	40/04	83/12	D			*		*	
TOTALS	5					7	4	10	2	4	1

(The columns C-23 through STU are headed "BASIN NAME".)

UEC = Upper East Coast Planning Area
CTY = county: S = ST. LUCIE; M = MARTIN; P = PALM BEACH; O = OKEECHOBEE
Data Type: DLY = daily; BRKPNT = breakpoint

Ref 1: "Summary of 1983 Hydrologic Conditions," Water Resources Div. and Operations Div., South Florida Water Management District, May 1984., p. 31.

average daily precipitation for each basin. The basin averages from 1965-1983 were obtained by averaging the daily precipitation values, using equal weights, for all stations that had no missing data for that particular day. Precipitation data are available beginning in 1965 for all five basins, but discharge data before 1977 for the three drainage canals have not been verified; therefore, the rainfall/runoff analysis was limited to the period 1977-1983. In cases where no data were available for any stations in a particular basin for a month, monthly total precipitationwas determined by statistical regressions from the totals for the same month in the 1965-1983 period for other basins. In addition, the total monthly precipitation at the city of Stuart was used to obtain values for direct rainfall on the St. Lucie Estuary, which is a separate input to the estuary model.

Monthly precipitation minimums, maximums, and means for the five basins and Stuart are compared in Table 5.3. Monthly evaporation for the St. Lucie Estuary was obtained from SFWMD evaporation station EVP615 near Ft. Pierce. These values, as summarized in Table 5.4, are used in all simulations in the St. Lucie Estuary model.

Data were not available to adequately quantify the spatial variation of the major components of the hydrologic cycle in the St. Lucie basins. Only daily rainfall data were available for existing stations in the five basins, and daily discharge data for the three major drainage canals. It was assumed that structure discharges for the regulated basins provide reasonable estimates for runoff into the estuary from a basin, because the canals collect and transport a large amount of the overland flow resulting from rainfall excess. However, it is recognized that ground water seepage, evaporation, and agricultural withdrawals also influence the rainfall/runoff relationships for the St. Lucie Estuary drainage basins. Since data suitable for quantifying seepage and withdrawals were not available, the analyses were based on the assumption that the canal discharges would account for all rainfall reaching the estuary via direct runoff. Consequently, surface runoff from areas not flowing into the canal systems or into the North and South Fork was ignored.

Table 5.3 Minimum, Maximum, and Mean Rainfall for St. Lucie Basins, (inches)

Basin C-23, 1936 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.22	.17	.02	.00	.53	2.60	1.31	.61	2.08	.87	.15	.08	38.23
MAX	9.69	9.80	15.79	8.27	10.33	15.34	11.05	13.96	19.13	18.81	6.25	9.12	82.78
MEAN	2.21	2.50	3.06	2.66	4.85	6.87	6.27	5.88	8.13	6.74	2.25	2.40	53.51

Basin C-24, 1965 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.27	.06	.25	.25	.00	2.81	3.46	3.30	1.43	.32	.21	.00	35.14
MAX	5.04	7.13	9.70	7.49	13.48	13.98	10.34	12.43	19.48	11.18	5.18	4.80	73.27
MEAN	1.90	2.51	2.78	1.96	5.07	6.59	6.53	5.89	6.82	4.52	1.91	1.72	47.79

Basin C-44, 1940 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.15	.17	.00	.01	.47	1.20	2.09	2.43	.47	1.03	.08	.00	31.66
MAX	8.64	9.51	14.46	8.25	12.61	15.82	12.73	12.98	22.67	13.77	7.80	7.39	71.46
MEAN	2.00	2.44	2.87	2.81	5.18	7.52	6.47	6.30	7.89	6.03	2.00	2.17	53.22

North Fork Basin, 1901 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.19	.00	.19	.00	.42	.69	1.37	1.09	.75	.00	.09	.08	32.05
MAX	9.36	10.19	9.83	11.16	12.97	16.14	12.74	14.57	17.05	19.31	10.65	8.37	77.76
MEAN	2.40	2.62	2.97	3.07	4.48	6.04	5.78	5.66	7.91	6.93	2.85	2.13	53.12

South Fork Basin, 1936 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.22	.17	.01	.00	.44	2.45	1.31	.61	1.88	.82	.10	.04	39.07
MAX	9.44	11.69	14.88	8.27	13.80	15.21	12.31	13.53	20.02	18.81	13.14	8.77	84.18
MEAN	2.15	2.62	3.05	2.83	5.20	7.12	6.29	6.12	8.07	6.97	2.60	2.45	55.61

City of Stuart, 1936 THROUGH 1983

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
MIN	.16	.17	.02	.00	.33	1.89	1.13	.61	2.18	.89	.15	.12	38.02
MAX	10.66	13.47	18.12	8.27	13.50	15.48	13.12	15.11	18.45	18.81	12.71	10.06	87.79
MEAN	2.37	2.74	3.27	2.69	5.01	6.76	6.28	5.52	7.99	6.93	2.73	2.61	54.36

Note: Values in the "TOTAL" column are the minimums, maximums, and means of the total yearly precipitation (the sum of the monthly precipitation from January to December) for all years in the period of record.

Table 5.4 Average Monthly Evaporation in the St. Lucie Basins, 1969-1984

JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3.48	4.13	6.04	6.88	7.64	7.64	7.17	6.48	5.50	5.07	4.33	3.86

Ref: Data, in inches/month, are from Ft. Pierce Station (EVP615)

To calculate the runoff resulting from a given amount of rainfall, the following additional assumptions were made:

- The average of the daily precipitation measurements at all available rain gages in a given basin is representative of the total rainfall for that day in that basin. Over a month, the distribution of rainfall in the basin is randomly distributed.
- All of the basin average daily rainfall reaches the estuary directly by means of the drainage canal for that basin, except for a prescribed initial amount that percolates into the aquifer or is stored or lost by evaporation. This initial amount, as a fraction of the first inch of rainfall, is assumed to be the same for all basins. This assumption is crude, as it does not take into account land use, soil types, antecedent conditions, and other hydrological factors commonly used in quantifying

runoff, but is justified by the similarity of land use characteristics in the basins.

- For basins without drainage canals (the North and South Fork), the direct runoff will be proportional to the runoff from basin C-23 adjusted by the ratio of the surface area of the basin to that of C-23.

B. Use of Rainfall Data, St. Lucie Estuary Model

Direct rainfall and basin runoff are specified separately, and used differently, in the model. Daily rainfall at the Stuart raingage is used for direct rainfall on the estuary, and average rainfall in each basin is used to develop runoff from the basins. Daily rainfall values for Stuart and each of the drainage basins are read from the rainfall data file by the model for the current day. Direct rainfall is then uniformly distributed over the surface area of the estuary for each time step between specified starting and ending times for the day, which for the simulations described in this report is the period between 1300 and 1700.

Daily basin runoff for each designated inflow node, on the other hand, is assumed to occur at noon, In the model a different five-day unit hydrograph is defined for each inflow node in units of cfs per day for each of the successive five days covered by the unit hydrograph. This one-day resolution in the rainfall data would not be adequate for accurately reproducing the hourly (intertidal) effects of runoff on estuarine salinity, but does provide adequate resolution for determining the effects of regulatory discharges over a period of several days. Total daily runoff at noon for each inflow node is then calculated by multiplying the total daily rainfall in the associated basin by the ordinate (cfs) of each successive day of the five-day unit hydrograph. Finally, the runoff for each time step in the model is interpolated between the two successive noon runoff values. Also, it is assumed that successive hydrographs can be added by linear superposition, a standard method for combination.

C. Preliminary Calibration of Ground Water Seepage

A preliminary calibration of the constant residual fresh water inflow to the estuary was needed for the hydrologic analysis. Also, a preliminary set of dispersion coefficients were required for simulation runs. For convenience, the preliminary constant inflow simulations have been labeled "ground water seepage" tests, since ground water is the primary physical parameter that might account for a relatively constant, background flow of fresh water into the estuary. Also for convenience, these simulations were combined with preliminary tests for quantification of dispersion coefficients, although in reality the salt dispersion coefficients are dependent upon tidal velocity gradients and not upon the rate of seepage of fresh water into the estuary.

An attempt was made to locate data on ground water seepage into the estuary. From values for transmissivity in the shallow aquifer and ground water table elevations, it was estimated that the ground water seepage was between 0.01 and 0.1 cfs per mile of shoreline. However, this range of ground water seepage was too small to have any significant effect on estuarine salinity when used in preliminary model runs. The cross-sectional averages of District salinity measurements show that during some months in which there is little or no rainfall, there is some dilution of the salinity in the estuary from its oceanic average value of about 36 parts per thousand (ppt), and that the mean salinity generally decreases with increasing distance upstream. This can either be interpreted as evidence of significant ground water inflow to the estuary, or that the flushing time of the estuary is very long.

The preliminary ground water calibration was run over the period February 18 to March 11, 1981. This period was selected because it was the period with least rainfall bounded by complete salinity samples throughout the estuary. The tidal boundary condition for the salinity calibration was derived from tidal harmonics for Hell Gate, since no measurements of water level were available for that period. The model was initialized at low slack tide with the measured salinity gradient for February 18. High tide salinity was set at 35 ppt at the tidal boundary, determined from the average of the cross-sectional mean salinities measured at Transect 7 for the simulation period. Salt dispersion coefficients used in other estuaries were reviewed, and values of 200 ft^2/sec at all nodes except in the lower South Fork, where 600 ft^2/sec were used, were found to provide simulation results that compared well with measurements.

A total ground water inflow of 149 cfs was found to balance the observed salinity gradients over the simulation period. The spatial distribution of these inflow values in the estuary is given in Figure 5.2. For all subsequent simulations of salinity in the St. Lucie Estuary, it has been assumed that ground water seepage is constant, spatially distributed according to the values used in this dry period simulation, and always flowing into the estuary. This constant inflow distribution was verified after the rainfall/runoff relationships had been calculated, as described in Section 6.B, Ground Water Seepage Verification.

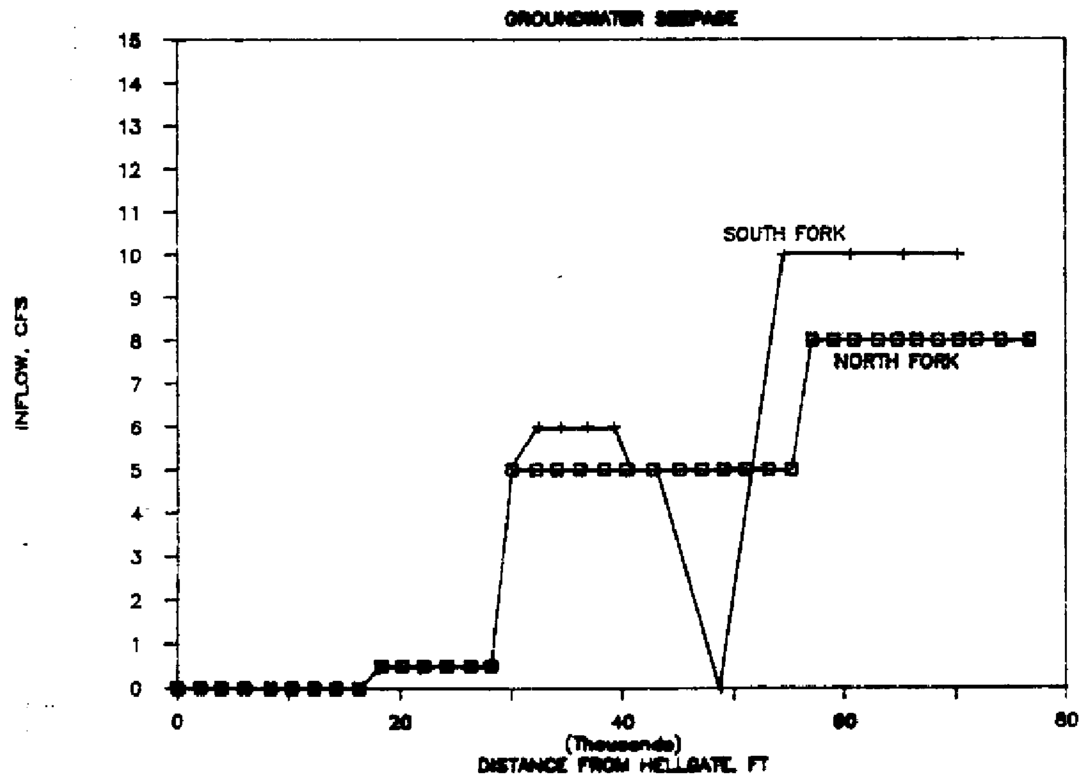


Figure 5.2 Constant Nodal Inflows Representing Ground Water Seepage.

D. Rainfall/Runoff Relationships

A detailed hydrologic analysis of the St. Lucie Estuary basins was not available for the model, since adequate data on the spatial distribution of rainfall, runoff, tributary inflow, overland flow, infiltration, evaporation, and other significant factors in the hydrologic cycle were not available. Therefore, the analysis began with a comparison of daily average basin rainfall and structure discharge data for isolated storms in the C-23, C-24, and C-44 basins, in an attempt to find a reasonably consistent statistical relationship.

The three resulting linear regressions are shown in Figures 5.3 through 5.5 and summarized in Table 5.5. A suitable dimensionless unit hydrograph, originally developed by the COE for the Kissimmee River Project, and fairly typical for south Florida (COE, 1984), was selected to be used with these rainfall/runoff regressions to develop five-day hydrographs for each of the three drainage basins. A rainfall loss equation, or loss function (Figure 5.6), was added to permit the abstraction of an initial amount of rainfall dependent on the cumulative daily rainfall over the past five days. This function is similar to the loss function documented in the HEC-1 Flood Hydrograph user's manual (COE, 1981, pp. 16-17). The line labeled "C-23" in Figure 5.6 fits the regression parameters for isolated storms in the C-23 basin.

When the runoff calculated with linear rainfall/runoff regressions and unit hydrographs was tested against historical rainfall over the period 1977-1983, using the rainfall loss function labeled "C-23" in Figure 5.6, it was found that the calculated values of runoff were significantly smaller than the measured discharges. These results were expected, since the unit hydrographs were developed from data for isolated storms which occurred for the most part during relatively dry periods. At these times agricultural withdrawals from the canals are greater, and more rainfall infiltrates into the ground water system, which together result in substantially smaller discharges from the canals. The lack of adequate detailed hydrologic data could also partially explain this mismatch. It was concluded that modifications to the rainfall/runoff relationships were needed to fit the runoff hydrographs more closely to the measured discharges.

In order to calibrate the COE/Kissimmee unit hydrograph for each of the St. Lucie basins, it was necessary to depart from a physical approach and investigate the statistical characteristics of the available data. The ordinates of the C-23 and C-24 unit hydrographs, multiplied successively by the integers 3 through 6, were designated "3X" through "6X" and compared. The rainfall loss at zero cumulative rainfall was arbitrarily set at 0.5 inch, and the loss rate was set at 5.0 inches/day, as shown in Figure 5.6.

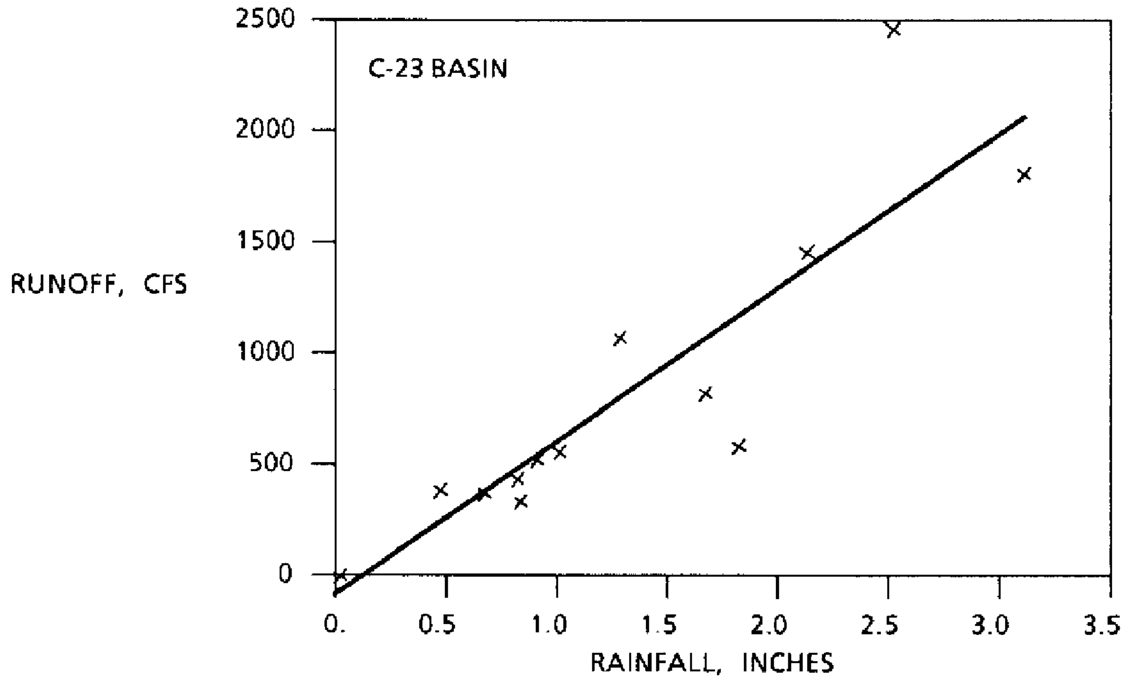


Fig. 5.3 Isolated Storm Rainfall Events used to develop Rainfall/Runoff Relationship for C-23.

Using the 3X, 4X, 5X and 6X hydrographs, the daily inflows to the estuary from the three basins were calculated using daily rainfall, and summed over each month from 1977 to 1983. The measured discharges and calculated runoff values were averaged over each month, and the resulting monthly average runoff values were then compared against the monthly average discharges for the three basins, with the exception that for the months in which regulatory releases occurred from structure S-80, calculated discharges from S-80 were substituted for the measured values. It was found that a 6X multiplier hydrograph provided the best low flow (runoff resulting from low to moderate precipitation) characteristics for both the C-23 and C-24 basins, but for higher values of monthly precipitation the calculated runoff with the 6X multiplier was too large. For these higher rainfall amounts the 4X multiplier provided the best overall fit for the C-23 and C-24 basins. It is most likely that this behavior is due to a larger than desired rainfall loss coefficient, as well as to the fact that many of the hydrologic variables are missing from the rainfall/runoff relationships. It was decided, however, that additional work to determine the optimum rainfall loss coefficient would not justify further delay in the hydrologic analysis.

A "low-flow cutoff value" was introduced into the rainfall/runoff relationships in order to define the inflow magnitude at which the 4X or 6X multiplier should be used. Various low flow cutoff values were tested for both the C-23 and the C-24 basins, and a 700 cfs cutoff provided the best fit over the period 1977 to 1983. Thus, if the average total inflow to the estuary over a month was greater than 700 cfs, the runoff calculated with the 4X multiplier was substituted for the runoff calculated with the 6X multiplier.

The monthly mean calculated inflows, using the 4X and 6X multipliers and the 700 cfs cutoff, are compared with the measured discharges for the C-23, C-24 and C-44 basins for the period 1977 to 1983 in Figures 5.7 through 5.9. Several peaks are purposely omitted from the plots in order to more clearly show the details of the low flow comparisons. The gaps in measured discharges at S-80 (C-44 basin) are due to omission of all months with regulatory releases. The periods in which small amounts of measured inflows and large amounts of calculated inflows occur are representative of the diversion of rainfall to agricultural uses or to Lake Okeechobee from the estuary.

The C-23 hydrograph was next modified for use on the C-44, North Fork, and South Fork basins. The daily ordinates of the C-23 unit hydrograph were multiplied by the ratio of the surface area of each basin to the surface area of the C-23 basin.

To develop a set of the best assumed values of total inflow into the estuary for 1977 through 1983, for purposes of comparison with calculated inflows for the entire estuary, the measured discharges for basins C-23 and C-24 were summed on a daily basis with calculated C-44, North Fork and South Fork inflows (using the area-weighted, integer-multiplied, lowflow

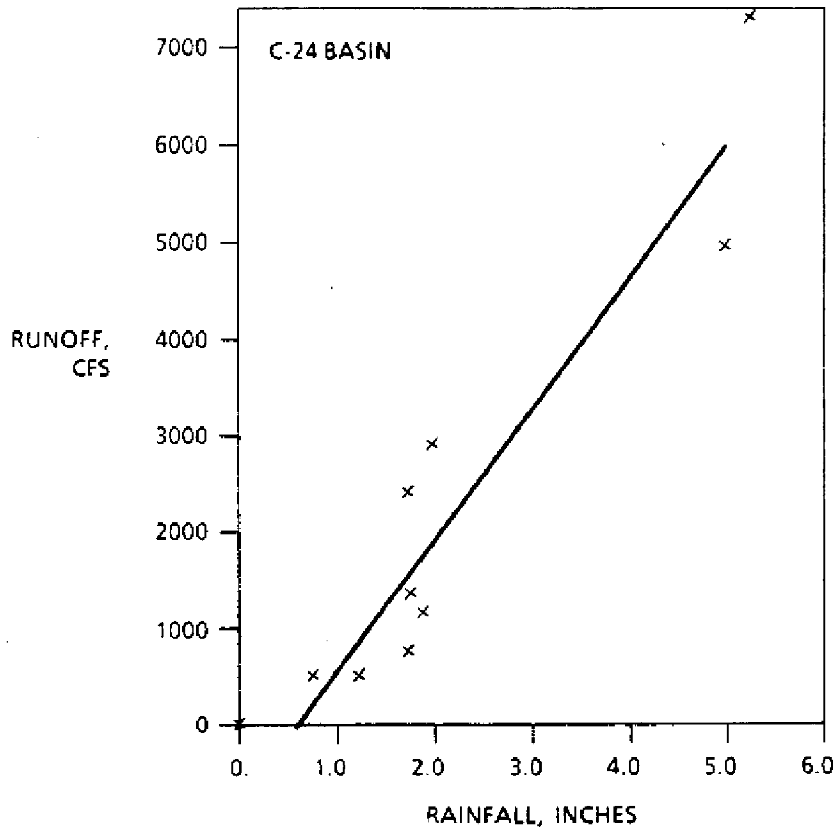


Figure 5.4 Isolated Storm Rainfall Events Used To Develop Rainfall/Runoff Relationship, Basin C-24.

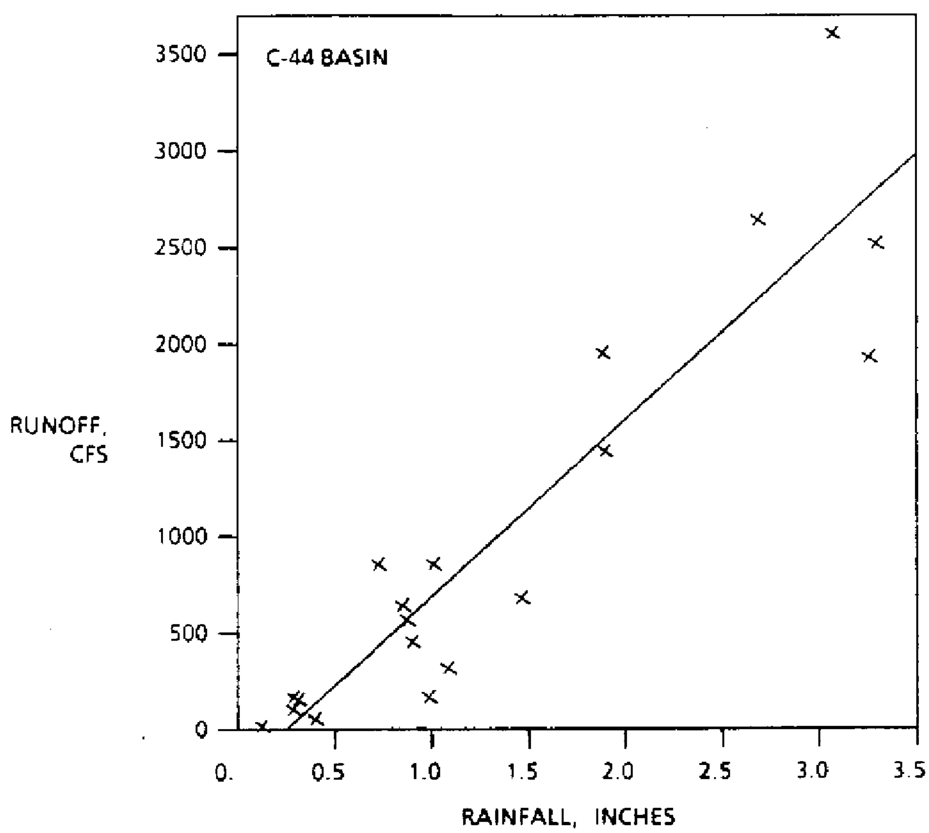


Figure 5.5 Isolated Storm Rainfall Events Used To Develop Rainfall/Runoff Relationship, Basin C-44.

Table 5.5 Regression Line Parameters for Rainfall/Runoff Relationships in Three St. Lucie Estuary Basins.

BASIN	INTERCEPT (CFS)	SLOPE (CFS/INCH)	VARIANCE R^2	APPROXIMATE RUNOFF FOR FIRST INCH (CFS)
C-23	- 80.81	687.98	.88	607.
C-24	-644.84	1321.74	.88	680.
C-44	-207.27	908.62	.84	700.

cutoff C-23 hydrograph), rainfall at Stuart, evaporation, and constant ground water seepage. These daily values are called "measured total inflow". Either the 4X or the 6X multipliers were used for all basins, depending on the particular month and year, as indicated by previous comparisons for the C-23 and C-24 basins. Also, discharges from S-80 during periods of regulatory discharges were omitted. Total inflows were calculated both with and without C-44 inflow, in order to account for the possibility of flow either toward S-80 or toward Lake Okeechobee in C-44. Thus, ranges of daily and monthly "total natural inflows", rather than single values, have been obtained for the St. Lucie simulations. Comparisons between the measured and calculated "total natural inflow" from 1977 to 1983, with and without basin C-44, using the 4X and 6X hydrographs for all basins, modified loss rate, the 700 cfs cutoff, and exclusion of S-80 regulatory releases, are given in Figures 5.10 and 5.11. The means and variances of the differences between the monthly total calculated inflows and the monthly total measured discharges are summarized in Table 5.6.

The daily values of inflow from the five St. Lucie Estuary drainage basins, and their monthly totals, are as close as can be estimated from existing data. If a comprehensive hydrologic analysis of these basins is conducted in the future, and a basin routing model operating on an hourly or daily time step is developed, it would be possible to incorporate such a model and to obtain significantly improved estimates of the daily fluctuations in fresh water inflow to the estuary.

E. Dry/Normal/Wet Rainfall

The principal application of the St. Lucie Estuary model is for predicting and comparing the effects of different combinations of inflows on estuarine salinity. To organize an approach to this problem, available rainfall patterns had to be generalized. This was accomplished by investigating the statistics of the monthly basin total rainfall for each of the five drainage basins and the City of Stuart, which for convenience will hereafter be referred to as the six basins.

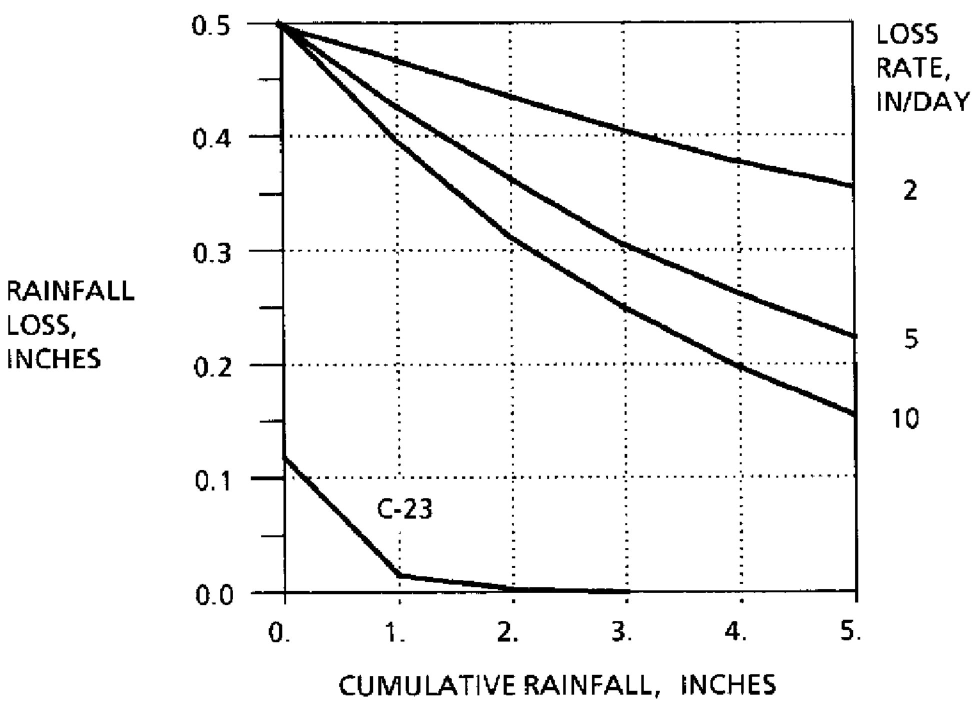


Figure 5.6 Rainfall Loss Rate Function.

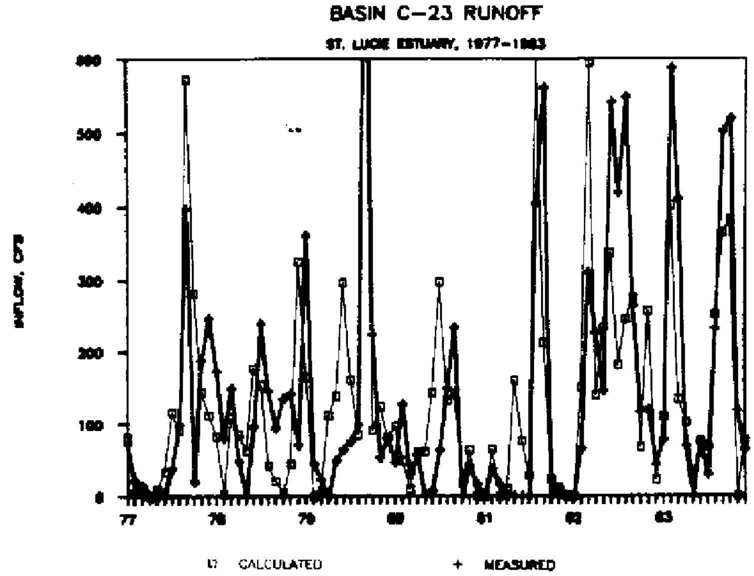


Figure 5.7 Comparison of Monthly Calculated Inflows and Measured Discharges, C-23 Basin.

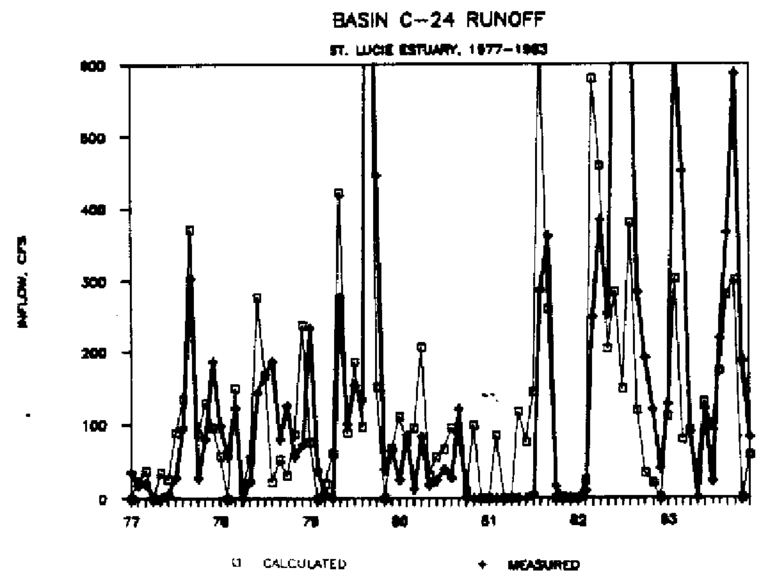


Figure 5.8 Comparison of Monthly Calculated Inflows and Measured Discharges, C-24 Basin.

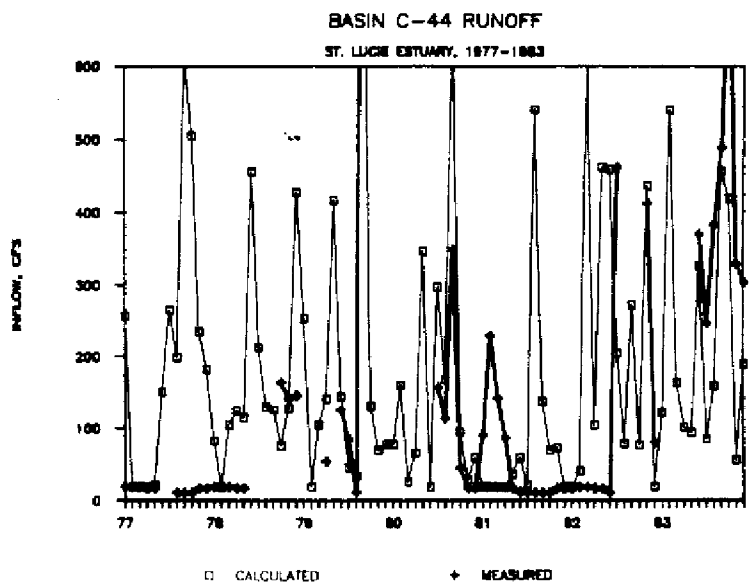


Figure 5.9 Comparison of Monthly Calculated Inflows and Measured Discharges, C-44 Basin.

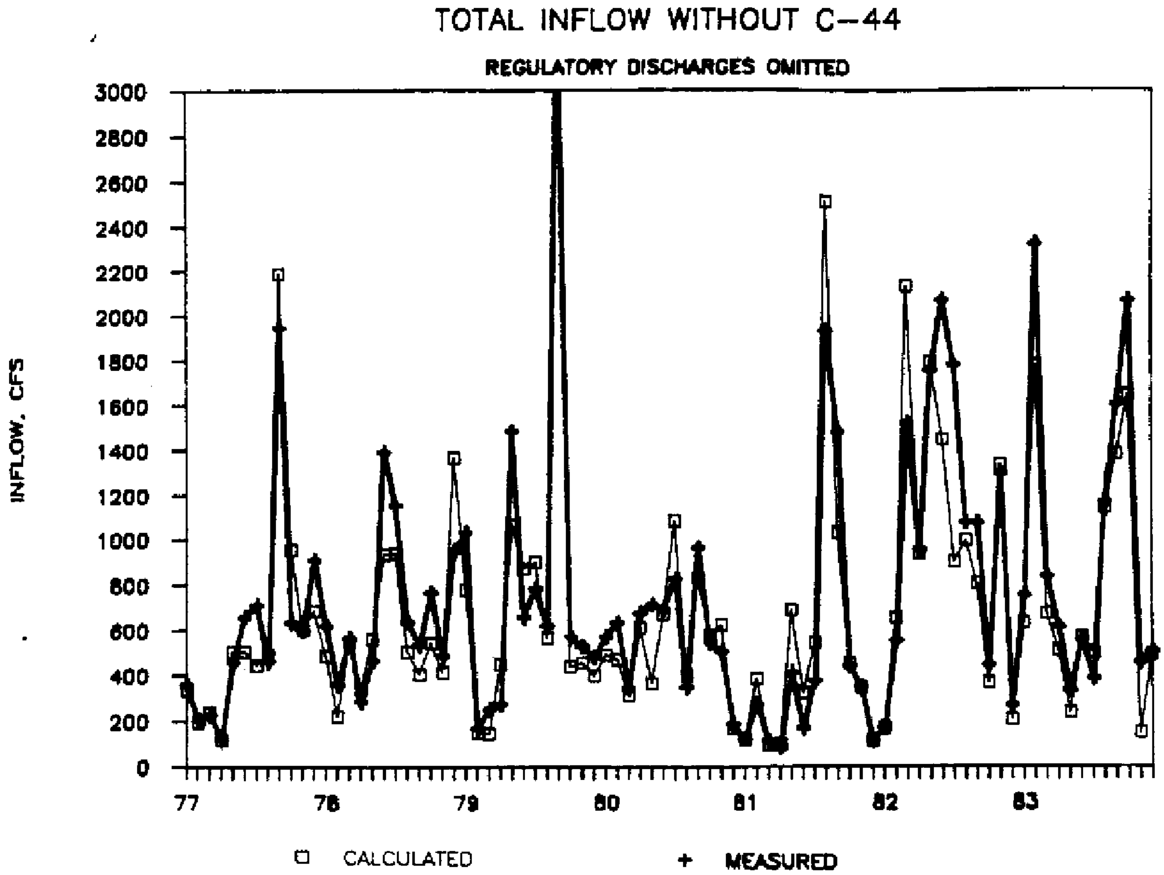


Figure 5.10 Comparison of Calculated and Measured Total Inflow Without C-44 Discharges.

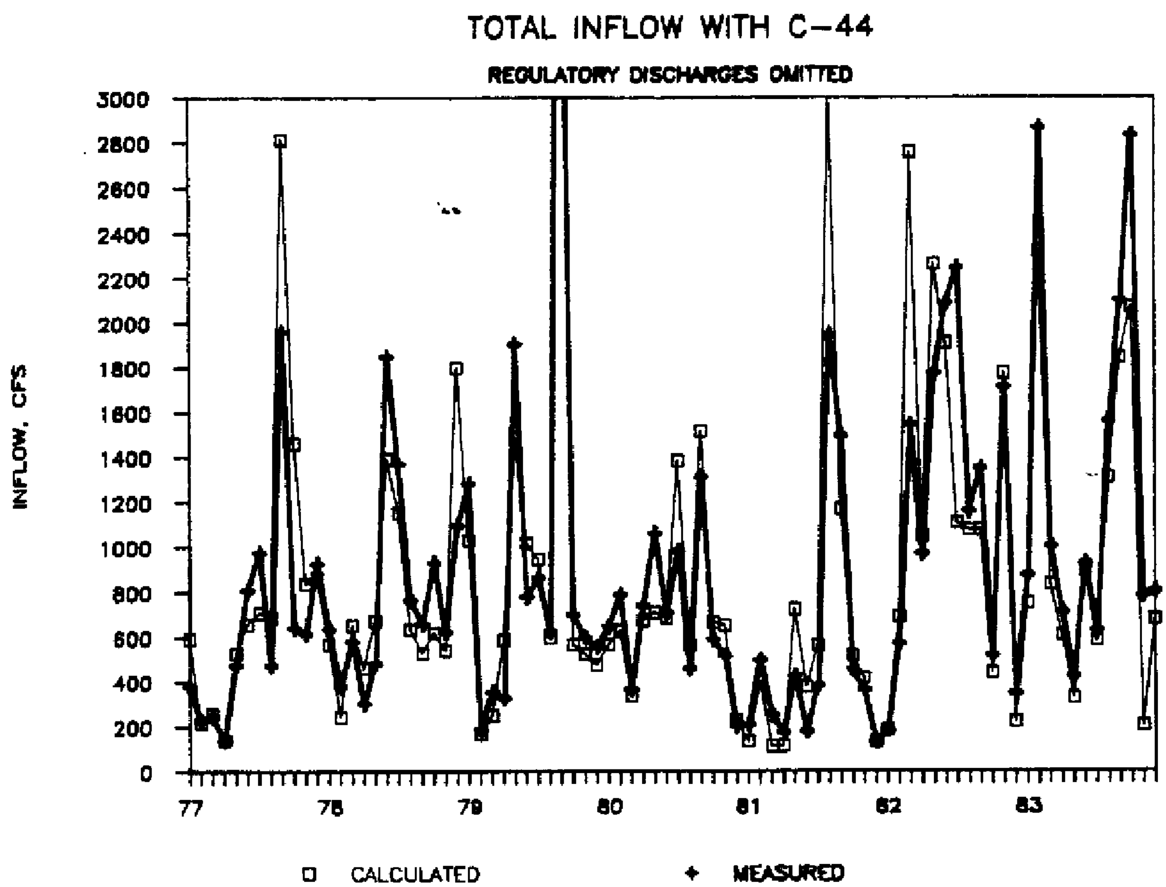


Figure 5.11 Comparison of Calculated Inflows and Measured Total Inflow With C-44 Discharges.

Table 5.6 Means and Variances for Differences between Calculated Inflows and Measured Discharges, cfs, for Basins C-23 and C-24 for Various Multipliers and Low Flow Cutoff Values.

		CALCULATED INFLOW MINUS MEASURED DISCHARGE MEAN MONTHLY FLOW, CFS			
LOW FLOW CUTOFF CFS	HYDROGRAPH MULTIPLIER	....BASIN C-23....		....BASIN C-24....	
		Δ FLOW CFS	VARIANCE	Δ FLOW CFS	VARIANCE
600	4	-12.0	73.2	-16.4	50.3
	5	-11.9	59.5	-10.6	45.6
	6	-12.0	61.7	- 7.6	50.6
700	4	-11.8	73.4	-18.6	52.3
	5	- 4.8	75.3	- 7.6	53.3
	6	- 5.7	61.2	+ 1.6	54.3
800	4	-10.6	75.4	-13.0	58.5
	5	- 5.8	77.5	-11.6	55.1
	6	+ 3.8	79.0	+ 1.3	57.5

The monthly total rainfall in a basin provides an indication of the total possible inflow into the estuary from that basin, but does not provide any information on the intensity and frequency of storms during the month. The monthly totals were used to compare the variability of rainfall over the common nineteen year period of record (1965 - 1983) for the St. Lucie basins. The results of these statistical analyses are used to indicate which months of daily rainfall values are representative of dry, normal, or wet conditions; the simulations in these months actually use natural daily pulses of rainfall, which cause realistic salinity fluctuations in the estuary.

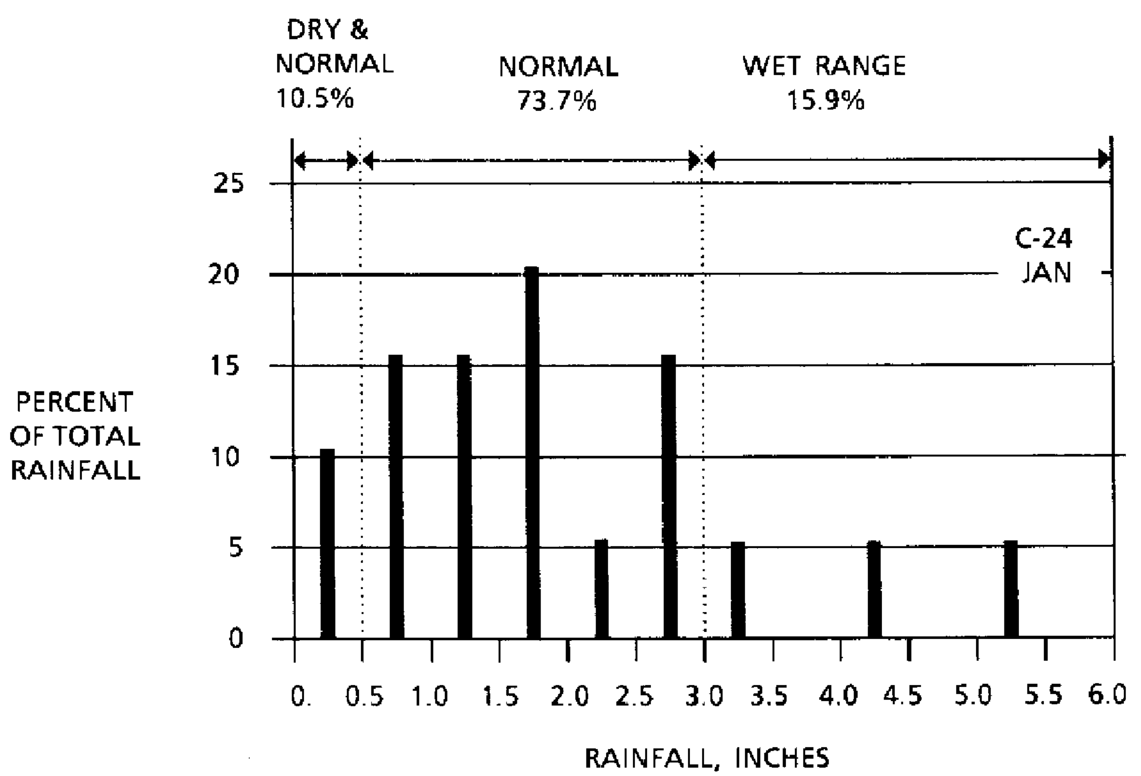


Fig. 5.12 Example of Frequency Analysis showing Division of January Precipitation in the C-24 Basin into "Dry", "Normal", and "Wet" Intervals.

Table 5.7. Summary of Minimum, Maximum, and Mean Precipitation, Representative Values ("REP"), and RepresentativeYears, for Precipitation between 1965 - 1983 in Basin C-24.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
RANGE OF PRECIPITATION												
MIN	.27	.06	.25	.25	.00	2.81	3.46	3.30	1.43	.32	.21	.00
MAX	5.04	7.13	9.70	7.49	13.48	13.98	10.34	12.43	19.48	11.18	5.18	4.80
DRY MONTHS												
MIN	.27	.06	.25	.25	.00	2.81	3.46	3.30	1.43	.32	.21	.00
MAX	.33	.06	.34	.37	.00	2.81	3.46	3.30	1.43	.32	.21	.00
AVE	.30	.06	.30	.29	.00	2.81	3.46	3.30	1.43	.32	.21	.00
REP	.33	.06	.34	.25	.00	2.81	3.46	3.30	1.43	.32	.21	.00
REP YR	1981	1979	1977	1981	1965	1981	1976	1968	1972	1976	1973	1968
NORMAL MONTHS												
MIN	.51	.68	.62	.59	.77	3.40	4.48	3.50	3.03	1.21	.54	.16
MAX	2.84	2.79	4.12	2.45	6.97	7.96	6.33	6.03	6.71	4.94	2.57	2.93
AVE	1.65	2.01	1.94	1.48	3.62	5.36	5.14	5.11	5.05	2.84	1.69	1.41
REP	1.67	2.16	2.12	1.52	3.45	5.40	5.03	5.00	5.23	2.55	1.77	1.54
REP YR	1974	1981	1966	1983	1971	1976	1981	1973	1971	1972	1979	1967
WET MONTHS												
MIN	3.24	5.20	7.05	3.17	8.23	9.15	6.51	6.58	7.13	6.29	3.76	3.30
MAX	5.04	7.13	9.70	7.49	13.48	13.98	10.34	12.43	19.48	11.18	5.18	4.80
AVE	4.11	5.86	8.09	4.67	9.85	10.56	7.95	8.45	9.71	7.77	4.47	3.88
REP	4.06	5.25	7.53	4.41	10.44	10.40	7.81	9.29	8.66	7.31	3.76	3.53
REP YR	1979	1965	1970	1966	1976	1966	1973	1982	1965	1970	1977	1977

The total rainfall in each basin for each month was ranked from lowest to highest. The frequencies of occurrence within each interval in each month were then arranged into a set of monthly histograms, divided into dry, normal, and wet intervals. It was found that the monthly total rainfall values in the histograms for most months could be divided into:

- A dry interval, consisting of the lower 10 to 20 percent of total monthly rainfall
- A wet interval, containing the upper 10 to 15 percent of the total monthly rainfall
- A normal interval, containing all intermediate values.

The frequency distributions in almost all cases had three distinct groups that could be subjectively identified with the three degrees of rainfall. A typical frequency distribution, subdivided into dry, normal, and wet categories, is shown in Figure 5.12.

The mean of the values in each category in each monthly histogram was calculated and tabulated for each basin. Then, each histogram was searched for the value of total monthly rainfall that most closely approximated the mean in each category. These closest, or "representative" values (labeled "REP") were tabulated with the associated representative year. As a result, it was possible to identify the months in the rainfall data base that most closely represented the statistically determined mean dry, normal, and wet rainfall in each month in each basin. This categorization of the precipitation records for the C-24 basin from 1965 to 1983 is summarized in Table 5.7.

The representative months of daily rainfall in each category were extracted from the rainfall database and rearranged month by month and basin by basin into a "dry/normal/wet" database, so that a simulation could be conveniently run in a particular month and rainfall category. For a particular month in a certain category, the daily values for each of the basins in the recombined file usually came from different years, since the representative months in a given dry, normal, or wet category for the six basins did not usually all occur in the same years. Thus, a simulation in the dry, normal, or wet category is not necessarily representative of any historical combination of rainfall in the six basins, but does meet the statistical criteria developed for each of the basins if simulations are limited to one-month periods.

F. Probability of Dry/Normal/Wet Rainfall

Although nineteen years of record is short for a probability analysis, a cumulative probability of exceedence for rainfall can be estimated from this data assuming that each set of monthly total values represents a statistically valid random sample. Then, the cumulative probability of exceedence of each value in a given month and a given basin is given by:

$$P_e = 1 - \frac{r_n}{N+1} \times 100 \qquad (5.1)$$

where:

Table 5.8 Range of Probability of Exceedence of Precipitation for Dry, Normal, and Wet Months, St. Lucie Estuary Basins, 1965-1983.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
						DRY MONTHS						
MIN	92.5	93.2	91.8	88.3	95.0	95.0	95.0	95.0	95.0	95.0	95.0	94.9
MAX	97.9	98.7	98.8	98.8	98.8	98.7	98.0	98.7	98.7	98.7	98.7	98.1
						NORMAL MONTHS						
MIN	54.3	51.9	48.7	47.3	47.1	55.5	55.6	51.7	56.4	49.6	50.0	49.2
MAX	56.2	62.4	60.9	64.5	67.7	64.6	68.9	68.0	67.0	65.0	59.0	54.9
						WET MONTHS						
MIN	6.2	5.2	5.9	8.9	6.2	8.6	6.3	7.8	9.0	5.7	6.1	4.6
MAX	10.4	8.5	9.2	10.8	13.9	11.5	19.1	12.6	13.3	14.2	9.0	9.3

P_e = cumulative probability of exceedence (percent)

r_n = rank of data point n

N = number of months in the data set (in this case, 19)

The results of this analysis provide a probability that a certain value of total monthly rainfall will be exceeded for each month in each basin. For these probabilities to be useful to management, it is necessary to combine the results calculated for each of thesix basins for the estuary as a whole. This is accomplished by tabulating the ranges of probability in terms of the lowest and highest probabilities calculated for all of the six basins in each month, as in Table 5.8. From this table, for example, it can be seen that the probability that January rainfall will exceed the definition of dry conditions for the estuary is between 92.5 and 97.9%.

Section 6. SALINITY CALIBRATION AND VERIFICATION

Spatial and temporal variations in density have significant influences on the stratification, mixing, and movement of water masses in estuaries. Density depends on temperature, salinity, and pressure, but in estuaries, only the temperature and salinity are necessary for determining density since pressure effects on density are negligible in shallow water. Two unknown sets of variables primarily influence the salinity calculated by the model; spatial distribution of dispersion coefficients and spatial distribution of constant nodal inflows used to represent ground water seepage.

Since it is difficult to obtain reliable runoff values, salinity can best be calibrated under conditions of no runoff. The objective of the salinity calibration was to develop a reasonable set of values for each of the two unknown variables mentioned above under conditions of no inflow to the estuary. The dispersion coefficients are the principal adjustment for the rate at which salt spreads or is dispersed through the estuary, and are related physically to the magnitudes of local velocity gradients, secondary currents, and other factors affecting mixing in the estuary. A higher dispersion coefficient implies that larger velocity gradients and a higher level of mixing exist in the system, and that the magnitude of the dispersion is greater on both flood and ebb flow. In the model the rate of dispersion in each channel is calculated from the channel dispersion coefficient and mean velocity at each time step.

The initial evaluation of ground water seepage, previously described in Section 5.C, was preliminary because the rainfall/runoff relationships had not yet been derived. The simulation used an earlier St. Lucie Estuary model, the 59 node / 58 channel version. The preliminary ground water seepage calibration had used dispersion coefficients of 200 ft^2/sec for the North Fork and Middle Estuary nodes, and 800 ft^2/sec for the South Fork nodes. For the final salinity calibrations, the ground water seepage was reevaluated after the rainfall/runoff relationship had been determined, providing new values for the nodal dispersion coefficients. Salinity verification consisted in checking the ability of the model to reproduce the 500, 1000, and 2500 cfs controlled discharge tests conducted by the District in 1981, 1977, and 1978 respectively (Haunert & Startzman, 1980, 1985).

During the preliminary ground water calibration it was found that large increases in the dispersion coefficient were required to produce relatively small increases in salinity. The theoretical range of the dispersion coefficient can be calculated from measured salinity gradients using a simplified version of the mass transport equation (2.5), in which the time dependent term is set to zero, and inflow, outflow, and decay terms are disregarded:

$$u \frac{\partial c}{\partial x} = \frac{1}{A} \frac{\partial}{\partial x} \left[A E_L \frac{\partial c}{\partial x} \right] \tag{6.1}$$

where:

u = cross-sectional mean velocity, (L/T)
c = concentration of salt, ppt
x = longitudinal distance, (L)
A = cross-sectional area, (L^2)
E_L = longitudinal dispersion coefficient, (L^2/T)

When it is assumed that the cross-sectional area A is constant, and that the order of magnitude of the cross-sectional mean velocity is 1 fps, equation 6.1 can be further simplified. The calculated dispersion coefficients for the data measured on February 18 through March 11 1981 are found to range from 8691 to over 20,000 ft^2/sec using this equation. However, from equation 2.12, there is a limit for salt dispersion coefficients -- to meet stability criteria in any link in the nodal network the maximum dispersion coefficient is directly proportional to the square of the channel length. For the shortest link in the model, which is 1450 ft long, and with a 60 sec time step, the maximum permissable dispersion coefficient is 8700 ft^2/sec.

A. Final Ground Water Seepage Calibration

The final ground water calibration was run over the same period as the preliminary ground water calibration, February 18 through March 11, 1981. Rainfall during this period was one of the smallest that occurred in the period of record for District salinity measurements, and full beginning and ending measured salinity profiles were available on these dates. In the first 2 1/2 weeks prior to February 18 a small amount of precipitation (0.7 inch maximum) was recorded, as shown in the plot of the overall average of daily basin average rainfall in the five basins and at Stuart (Figure 6.1), but following that event there was no significant additional rainfall.

Discharge at Structure S-80 decreased from 500 to about 150 cfs on February 8 and remained steady for the remainder of the simulation (Figure 6.2). Total inflow to the estuary during this period, the sum of direct rainfall, runoff, evaporation, and constant ground water seepage, is shown in Figure 6.3. Ground water seepage in the model is represented by the

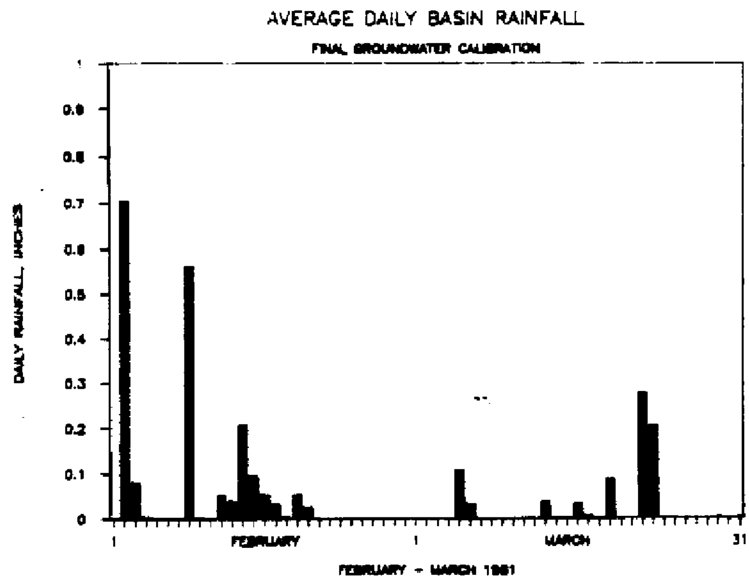


Figure 6.1 Basin Average Rainfall, Salinity Calibration.

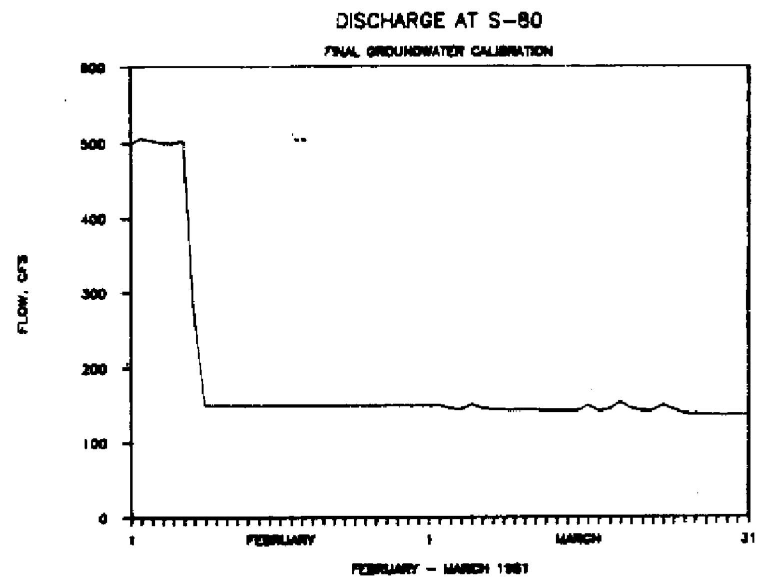


Figure 6.2 S-80 Discharge, Salinity Calbration.

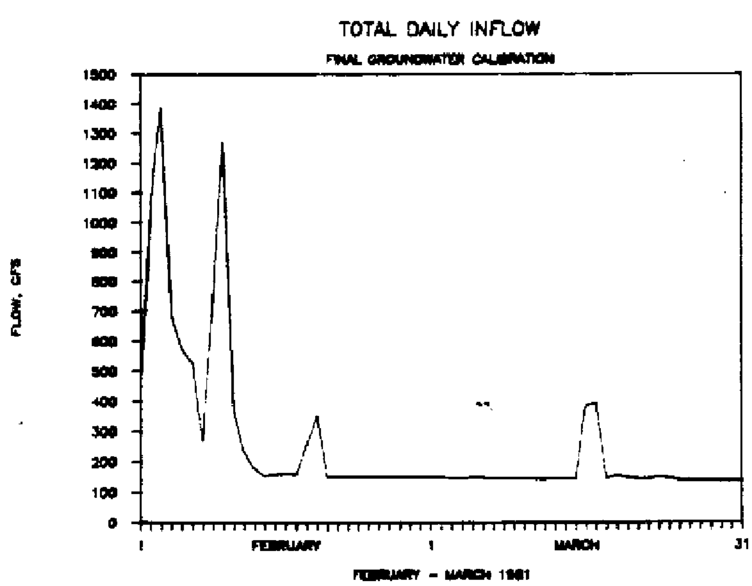


Figure 6.3 Total Daily Inflow, Salinity Calibration.

calibrated set of steady nodal inflows (Figure 5.2). Inflows from each basin are calculated daily from basin rainfall during the simulation.

The tidal boundary condition for the salinity calibration was derived from tidal harmonics for Hell Gate, since no measurements of water level were available for this period. The model was initialized at low slack tide with the measured salinity gradient for February 18 (Figure 6.5). High tide salinity was set at 35 ppt at the tidal boundary, determined from the average of the cross-sectional mean salinities measured at Transect 7 for the simulation period. Different sets of salinity dispersion coefficients between 100 and 3000 ft²/sec were tested.

After several similar runs were completed, it was concluded that the set of salt dispersion coefficients providing the best fit to measured data was 300 ft²/s from Hell Gate to Transect 2 (channels 1 - 19), 1000 ft²/s in the upper North Fork (channels 20 - 40), 700 ft²/sec in North Fork tributaries and the upper South Fork (channels 41 - 56), and 2000 ft²/sec in the lower South Fork (channels 57 - 62), as shown in Figure 6.4. Higher values for the dispersion coefficients in the North Fork (2000 ft²/sec) and the South Fork (3000 ft²/sec) were tried in another test, but the improvement was minimal and these higher values resulted in instabilities in subsequent verification runs.

The calculated salinity gradients on March 11 are compared with the measured values in Figure 6.6. The calculated values at low slack current nearest midday are represented by circles, and the previous or subsequent high slack current salinity gradient is represented by triangles. Low slack current occurs approximately one hour after low tide at Hell Gate. The measured cross-sectional average salinity at each station is designated by the center asterisk, the minimum value on the cross section is represented by the lower of the three asterisks, and the maximum value is represented by the upper asterisk. In cases where there are only two asterisks (some 1977 measurements used in the salinity verification), not enough data were collected to justify calculating a cross-sectional mean. All calculated values of salinity were within the range of measured values except for the salinities at Transects 1 and 2 and S-80, each of which were 1 ppt below the minimum measured value.

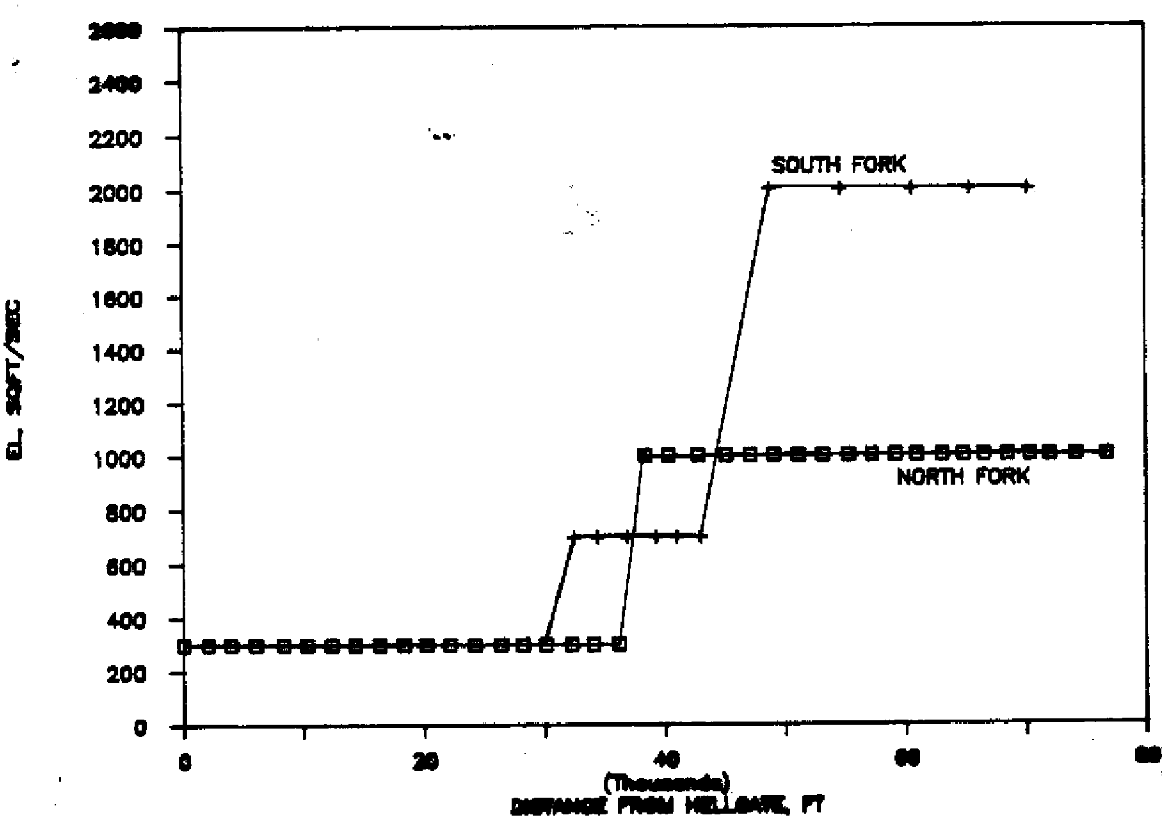


Figure 6.4 Salt Dispersion Coefficient Distribution.

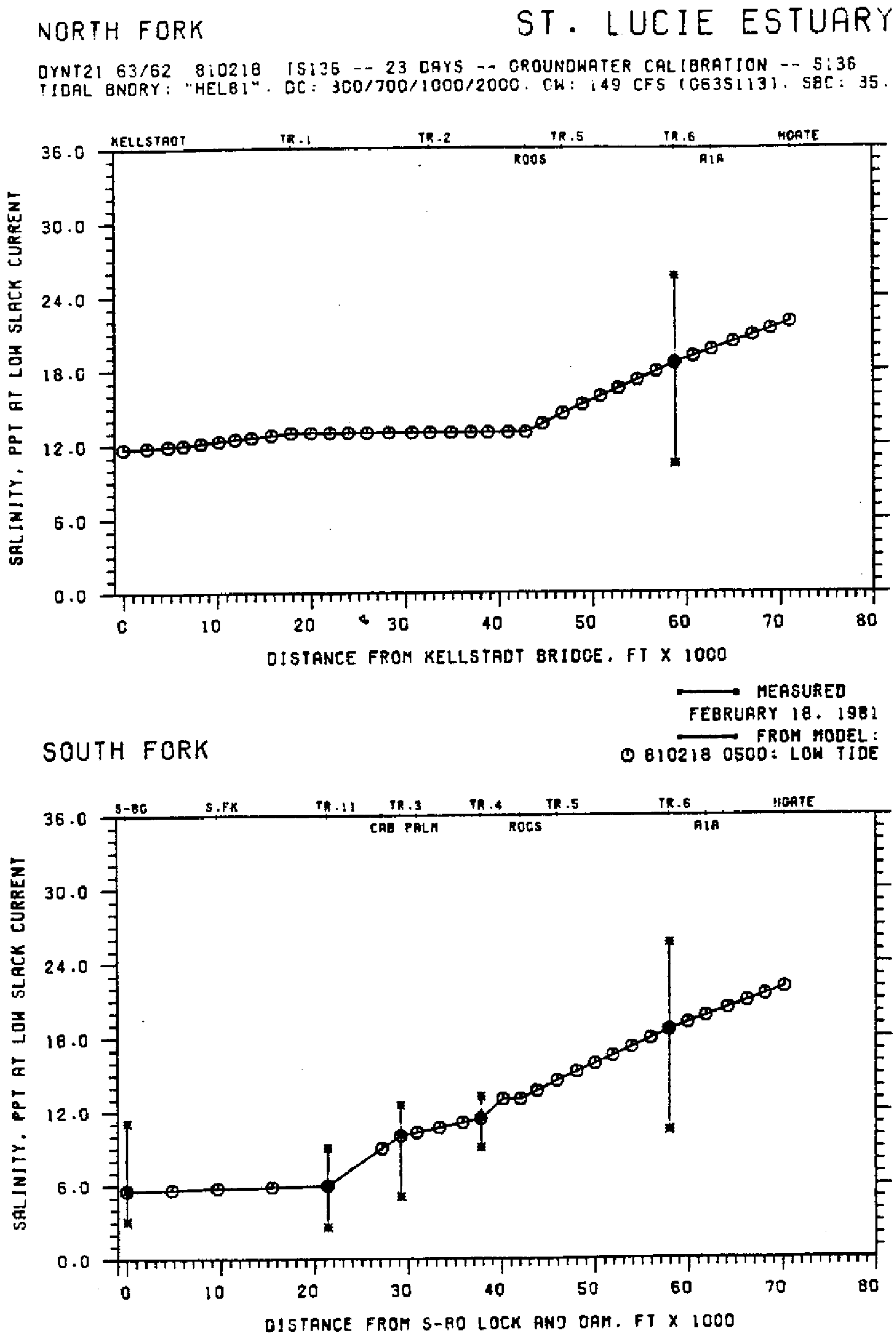


Figure 6.5 Initial Salinity Gradients, Salinity Calibration.

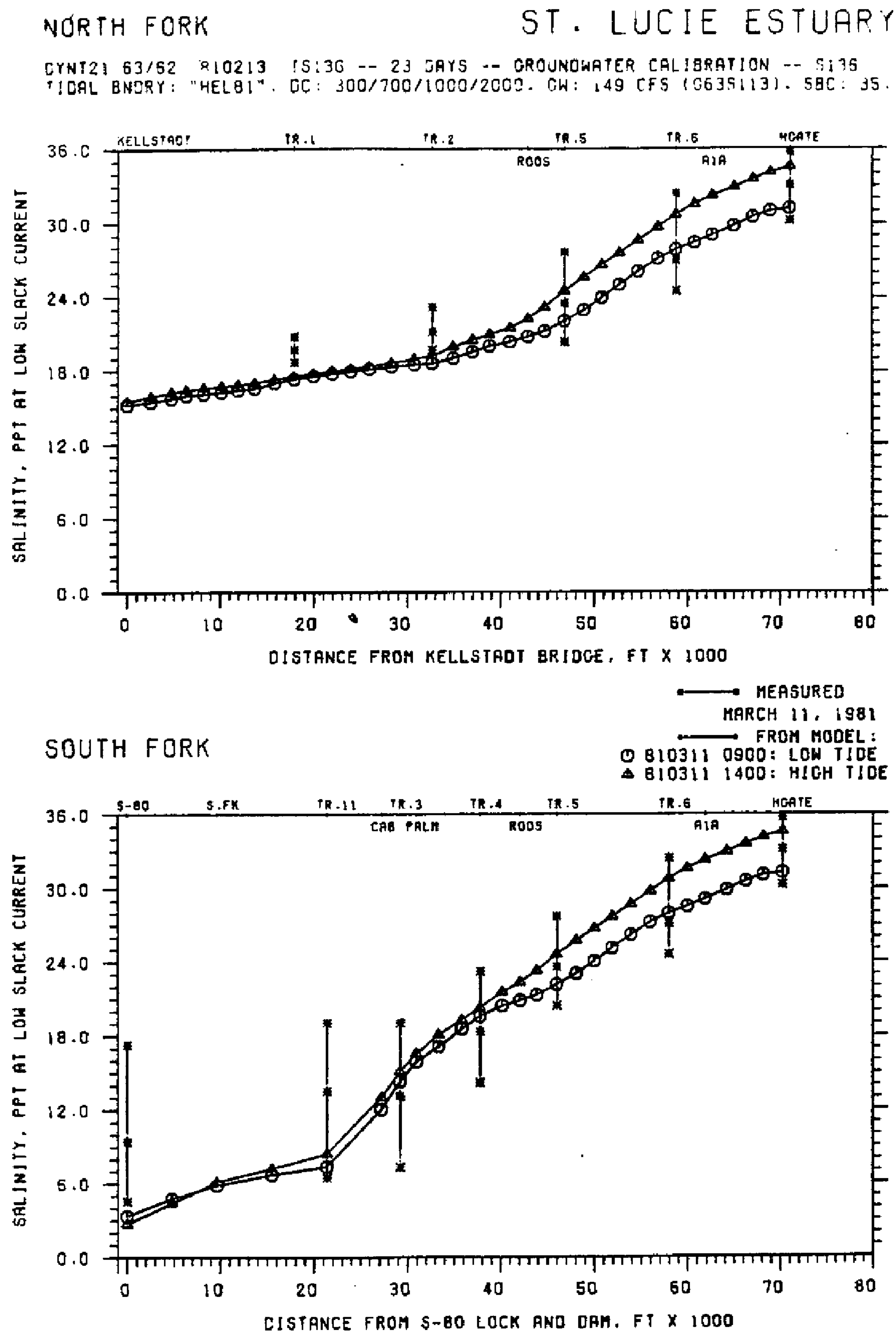


Figure 6.6 Salinity Gradients at end of Salinity Calibration.

B. Ground Water Seepage Verification

The ground water seepage verification was run during the period July 15 - August 27, 1981. The average basin rainfall in the six basins from June through August is shown in Figure 6.7. The inflow from S-80 was constant at 12 cfs, lockage and leakage. The total inflow to the estuary from direct rainfall, runoff, evaporation, and ground water seepage is given in Figure 6.8. These inflow plots provide an indication of the magnitude of inflow to the estuary just before and during the ground water calibration. There were only a few days of insignificant flows (700 cfs) at the beginning of June, some relatively small, short-lived flows during the second two weeks in July (about 2000 cfs), and some significant (over 10,000 cfs) total inflows in the middle and end of August. The constant nodal inflow distribution is the same as described in Section 4, and inflows are calculated daily from basin rainfall as described in Section 5.

The simulation began on July 15, 1981, with the initial salinity gradient in Figure 6.9, and ended on August 27, 1981. The tidal boundary condition for the salinity calibration was calculated from tidal harmonics for Hell Gate and high tide boundary salinity was set at 35 ppt, calculated from the average of the cross-sectional mean measured salinities at Transect 7 over the simulation period. The salt dispersion coefficients found to give the best fit to measured gradients in the February through March test were used in this simulation.

Figure 6.10 gives a comparison of the calculated and measured salinity gradients on July 15, 1981. The first salinity profiles after the beginning of the run were taken on July 23. A summary of the differences between the calculated and measured salinity gradients after 8 days of simulation is given in Table 6.1. In this table, the space is left blank if the computed value falls between the lowest and highest measured salinity on the transect. Otherwise, the differences between the computed and the nearest measured values are expressed to the nearest integer, in parts per thousand (ppt), and entered in the table. Values are not tabulated for the tidal boundary, Hell Gate, because the high tide boundary salinity had to be set as a constant for the entire simulation. The calibration is within the measured salinity range at all stations in the North and South Forks except south of Cabana Point at Transect 11, where the computed salinity was 2 ppt below the measured value, and at S-80, where it was 7 ppt below the measurement.

On the last day of the simulation, August 27, the salinity was within the measured range at all stations except Transects 2 and 3, where it was only 1 ppt lower than the minimum measured values (Table 6.1).

Table 6.1 Comparison of Low Slack Water Salinity in the Hydrodynamic Calibration / Salinity Verification, Calculated Low Tide Salinity Minus Nearest Measured Salinity, ppt.

(Simulation S-139 -- see plots in Appendix C).

		NORTH FORK				SOUTH FORK			
DATE 1981	Rmrks	TR-1	TR-2	TR-5	TR-6	S-80	TR-11	TR-3	TR-4
July 15	initial								
July 23					+1	-7	-2		
Aug 27			-1	------	------		-1	-1	

Notes to Tables 6.1 through 6.4:

1. TR is a salinity transect station number (Fig. 3.4); S-80 is St. Lucie Lock and Dam.
2. Values are salinity differences, ppt, simulated referenced to measured.
3. ------ no measured values.
4. blank or "all wr" : within measured range over the cross-section.

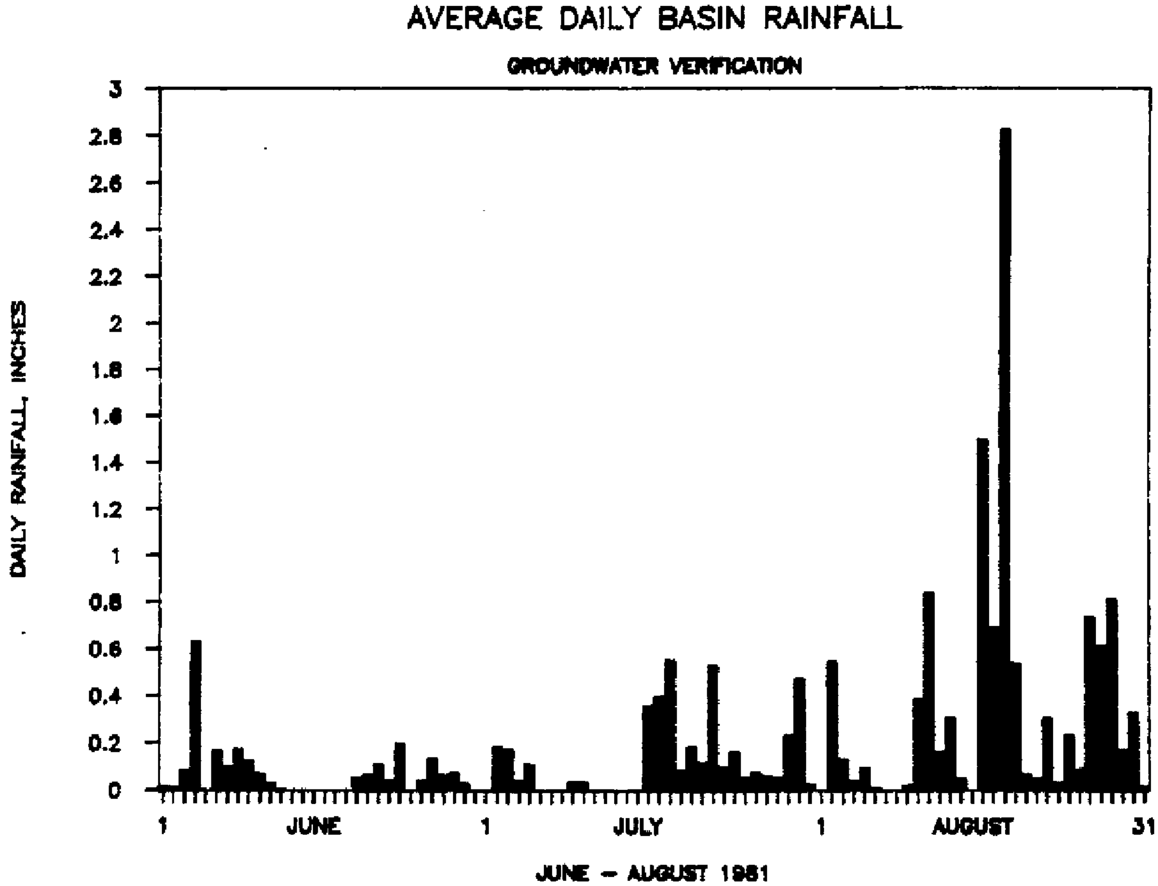


Figure 6.7 Basin Average Rainfall for Ground Water Verification.

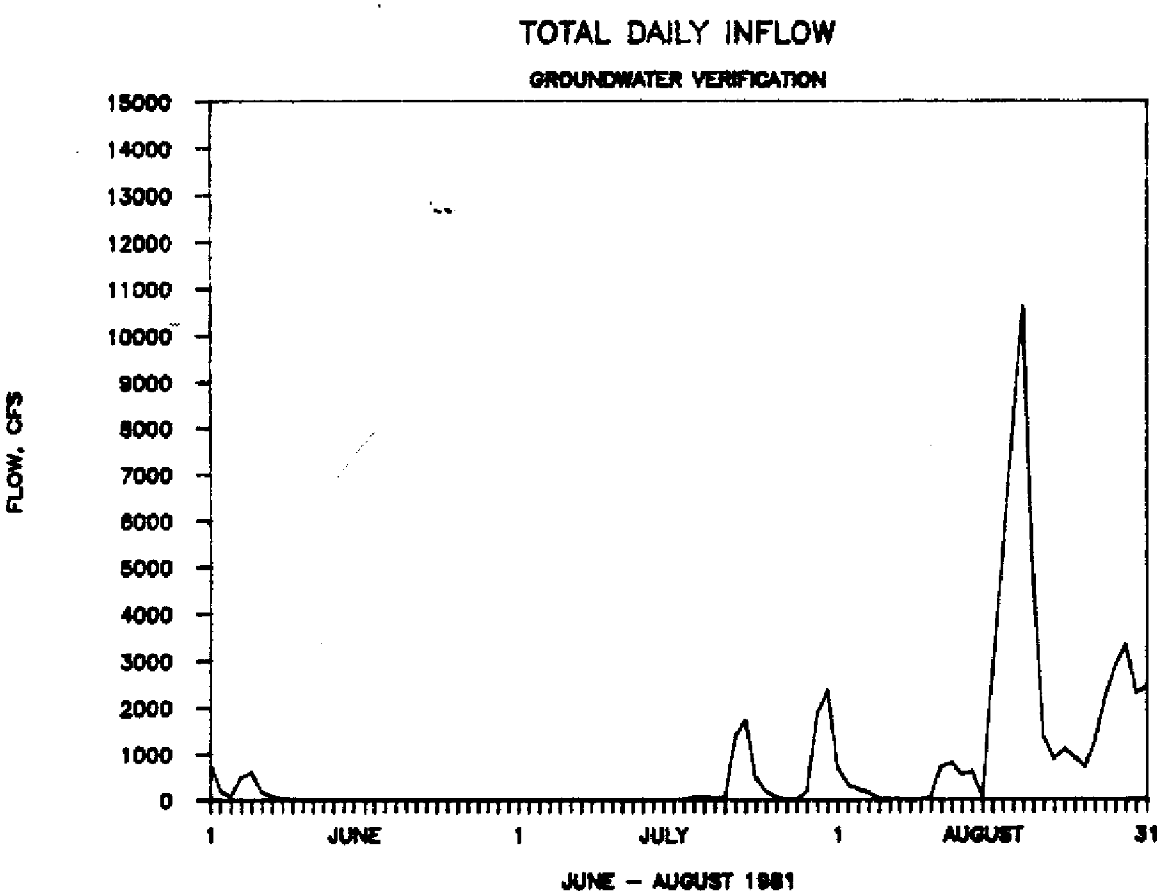


Figure 6.8 Total Inflow for Ground Water Verification.

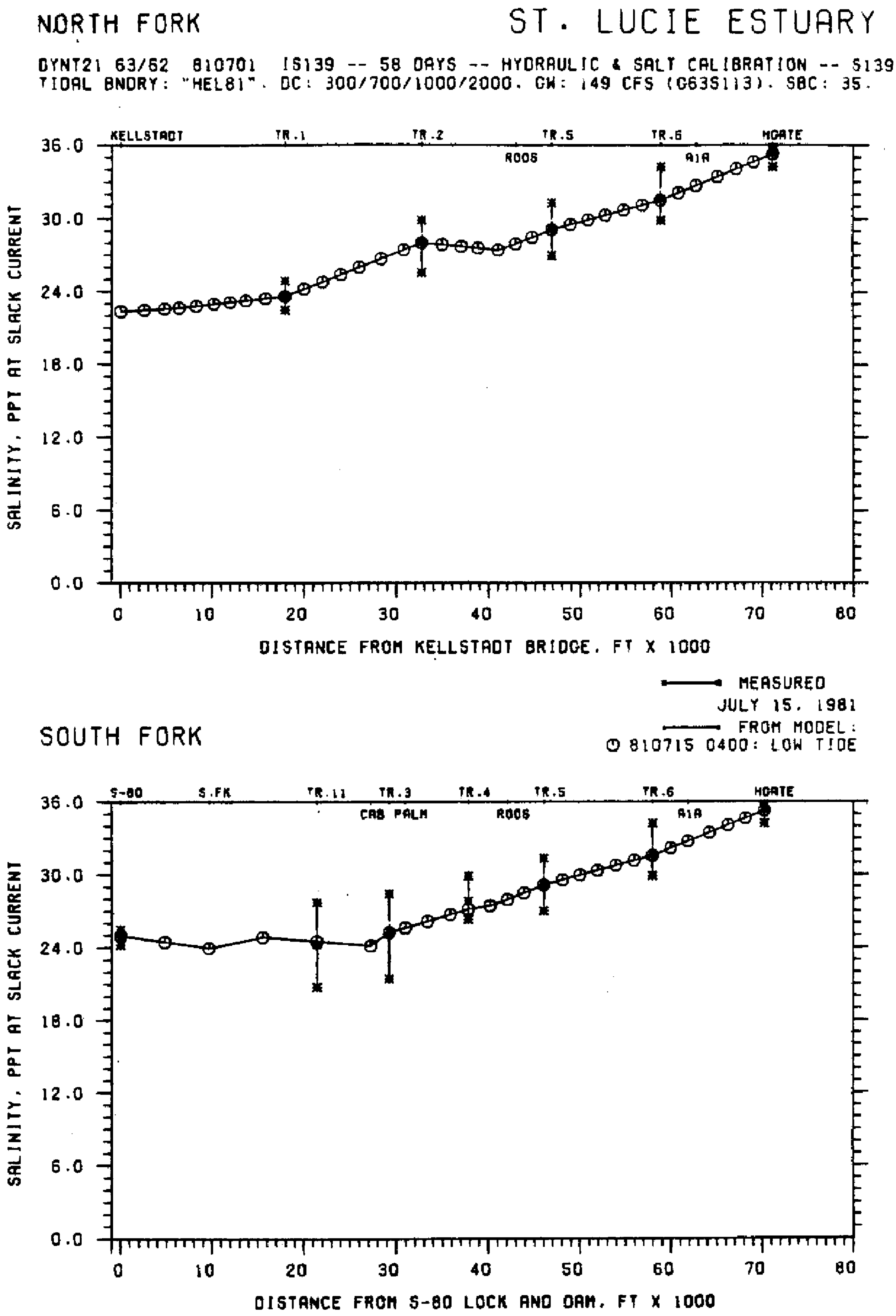


Figure 6.9 Initial Salinity Gradients, Ground Water Verification.

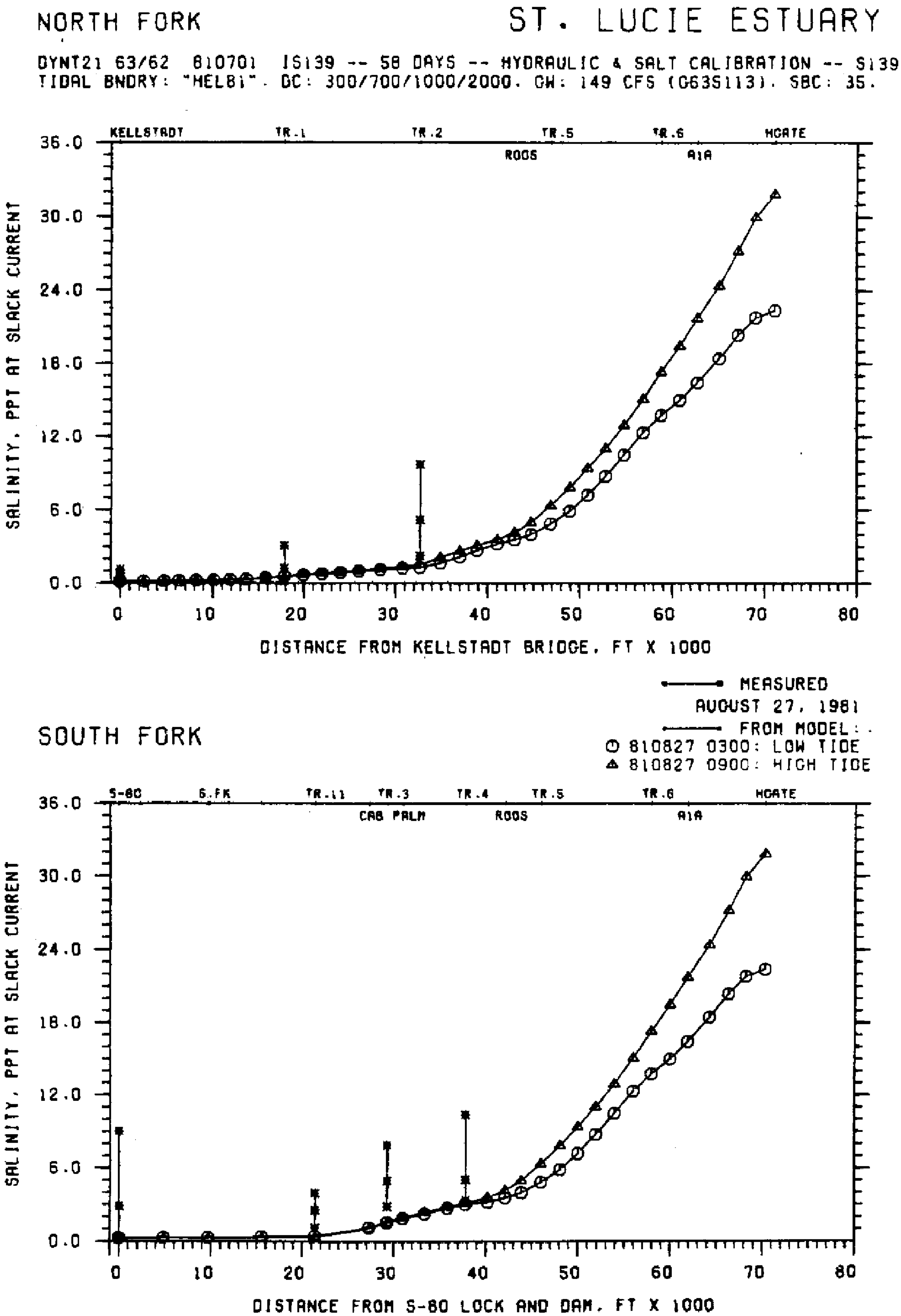


Figure 6.10 Final Salinity Gradients, Ground Water Verification.

C. Salinity Verification

Verification provides a check on the settings determined during the calibration of the model. Three different salinity verification periods were used, corresponding to three controlled discharge tests conducted by SFWMD in 1977, 1978, and 1981. The purpose of three verifications, instead of one as is common, was to check the model over the widest possible range of rainfall conditions.

1. 500 cfs Controlled Discharge

The 500 cfs controlled discharge simulation began January 21 1981 and continued until April 24 1981, a total of 94 days. Average basin rainfall during this period was relatively small (Figure 6.11). The 500 cfs discharge at S-80 occurred from January 27 to February 7, followed by a 150 cfs controlled discharge from February 8 to April 19 (Figure 6.12). The calculated total inflow to the estuary from January through April is given in Figure 6.13. Tidal boundary conditions were calculated using harmonic coefficients, since no water surface elevation data were available during this period.

Salinity profiles measured on January 21 (Figure 6.14) were used to determine realistic initial salinity gradients for the North and South Forks. From the twelve sets of measured salinity gradients during the period, a high tide salinity boundary condition of 33 ppt was selected as representative of the period. The ground water seepage rates and dispersion coefficients determined during calibration were not changed, and inflows were calculated from rainfall.

The computed salinity gradients obtained on the last day of the simulation, April 24, are compared with the measurements for that day in Figure 6.15. The results are summarized in Table 6.2, and the full set of plots for each day of measurement are found in Appendix E.

The effect of the 500 cfs discharge was experienced quickly in the South Fork. Salinity south of Roosevelt Bridge declined rapidly to January 30, then at a slower rate until February 5. By February 10 salinity was rising again in the South Fork, and fluctuated ±3 ppt between February 18 and April 24. In the North Fork the discharge effects first appear on February 2 in the vicinity of Roosevelt Bridge, then salinities decline at a moderate rate until February 10. From this date to April 14 the North Fork salinity steadily increases. It can be seen that, in this case, the estuary begins to respond quickly to significant inflows and changes steadily as the inflow persists.

2. 1000 cfs Controlled Discharge

The 1000 cfs controlled discharge simulation lasted 29 days, beginning on June 15, 1977 and continuing until July 13, 1977. Average basin rainfall during this period is plotted in Figure 6.16. The S-80 discharge, which began 5 days after the start of the simulation on June 20, is shown in Figure 6.17. Total calculated inflow during this period is plotted in Figure 6.18. Tidal boundary conditions were calculated using harmonic coefficients, initial salinity gradients (Figure 6.19) were set to correspond with the salinities measured on June 15, and a high tide salinity boundary condition of 31 ppt was used. The

Table 6.2 Comparison of Low Slack Water Salinity in the 500 CFS Verification, Calculated Low Tide Salinity Minus Nearest Measured Salinity, ppt.

(Simulation S-140 -- see plots in Appendix E).

		NORTH FORK				SOUTH FORK			
DATE 1981	Rmrks	TR-1	TR-2	TR-5	TR-6	S-80	TR-11	TR-3	TR-4
Jan 21	initial								
Jan 28	all wr								
Jan 30		-3				-1	-1		
Feb 2		------	------		+4	-2	-4		
Feb 5	all wr								
Feb 10		------	------			-2	-1		
Feb 18		------	------	------	+3	-2			+3
Mar 11		-2	-1			-2			
Mar 19	all wr	------	------	------		------	------		
Mar 27		------	------			-2			
Apr 10	all wr								
Apr 24						-2			

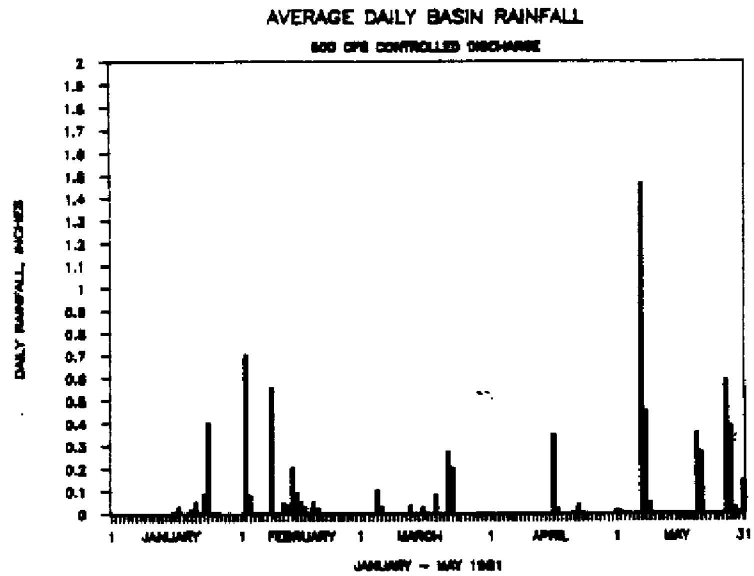


Figure 6.11 Basin Average Rainfall, 500 CFS Controlled Discharge.

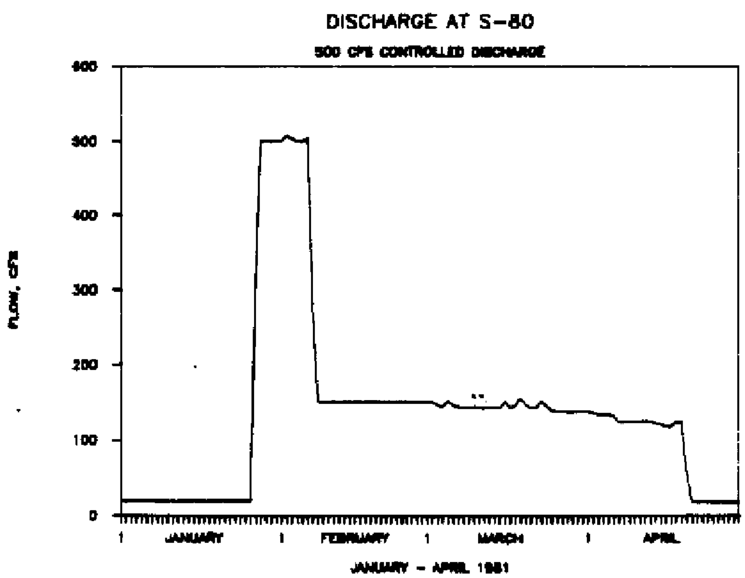


Figure 6.12 S-80 Structure Discharge, 500 CFS Controlled Discharge.

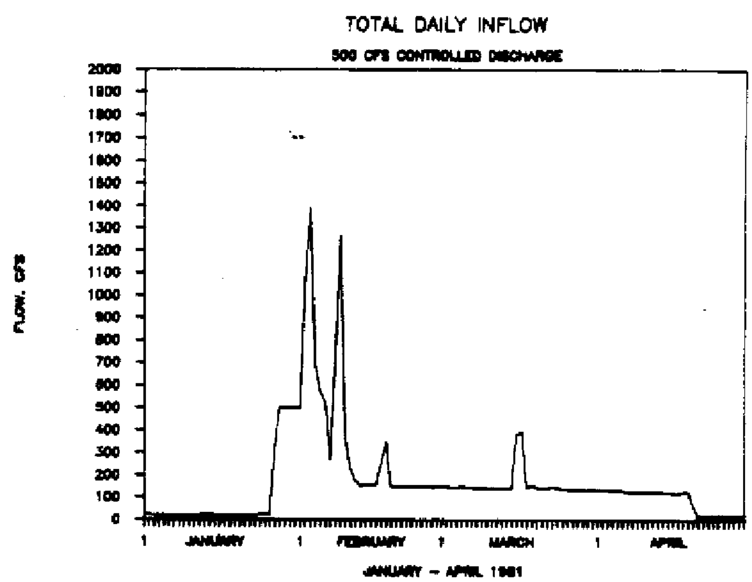


Figure 6.13 Total Inflow During the 500 CFS Controlled Discharge.

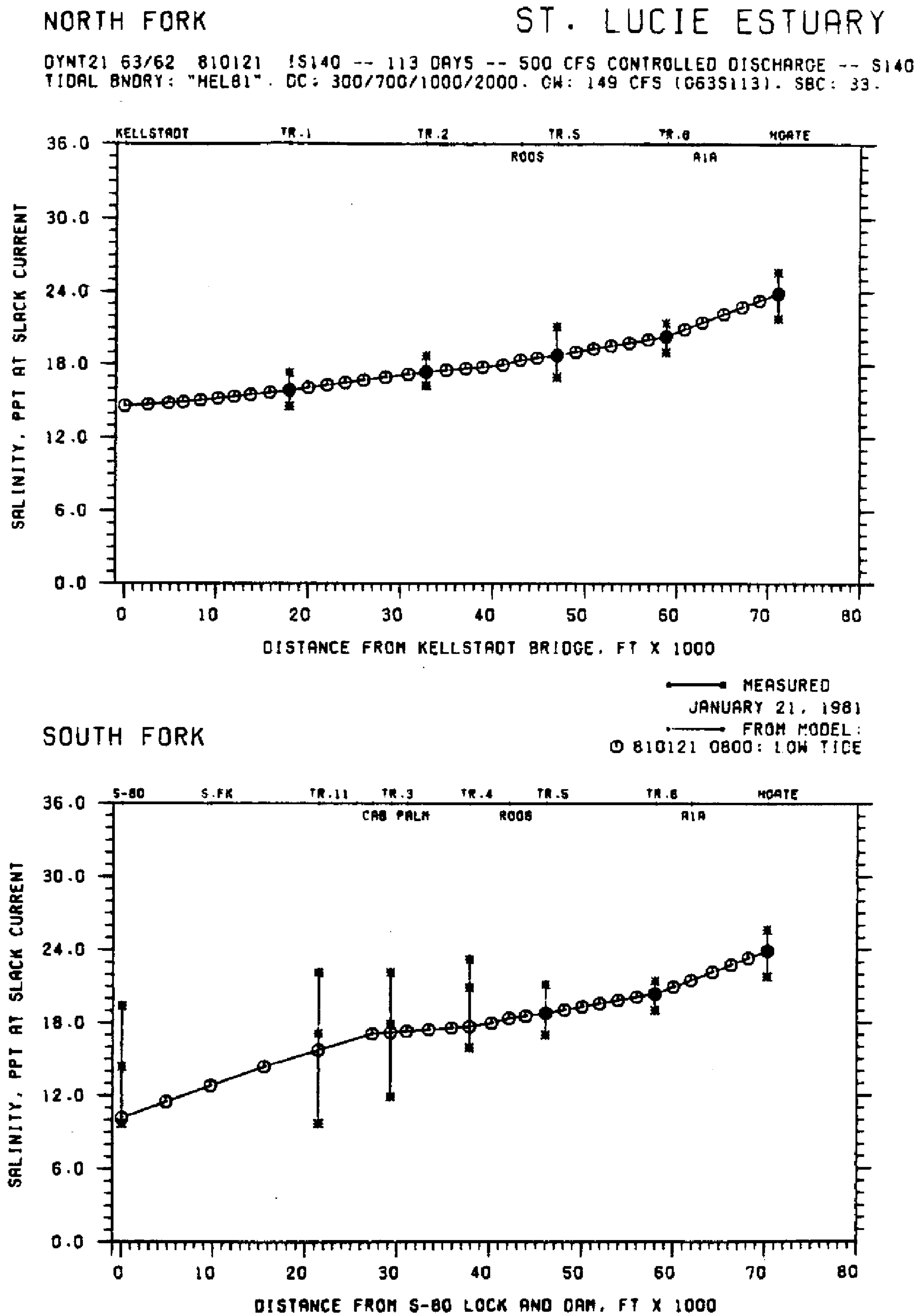


Figure 6.14 500 CFS Test Salinity Gradients, Initial Conditions.

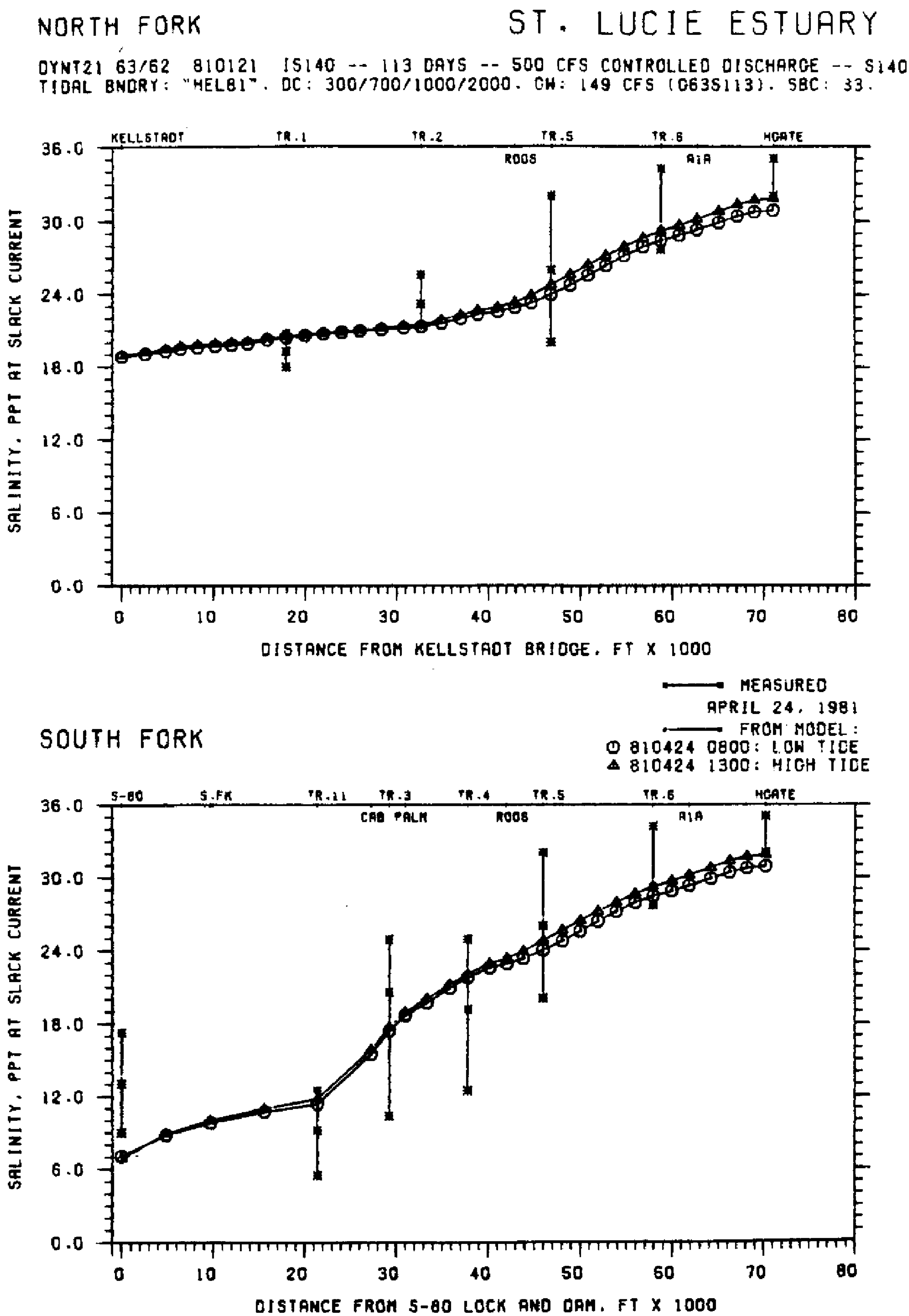


Figure 6.15 500 CFS Test Salinity Gradients, Last Day.

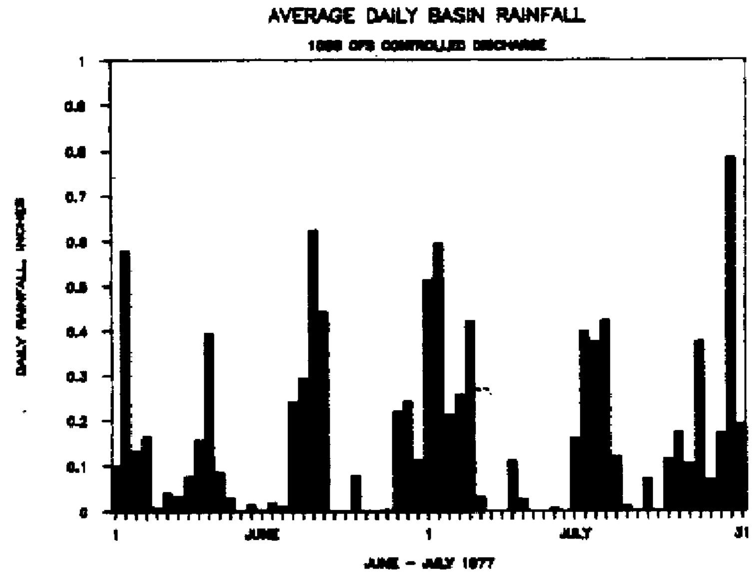


Figure 6.16 Basin Average Rainfall, 1000 CFS Controlled Discharge.

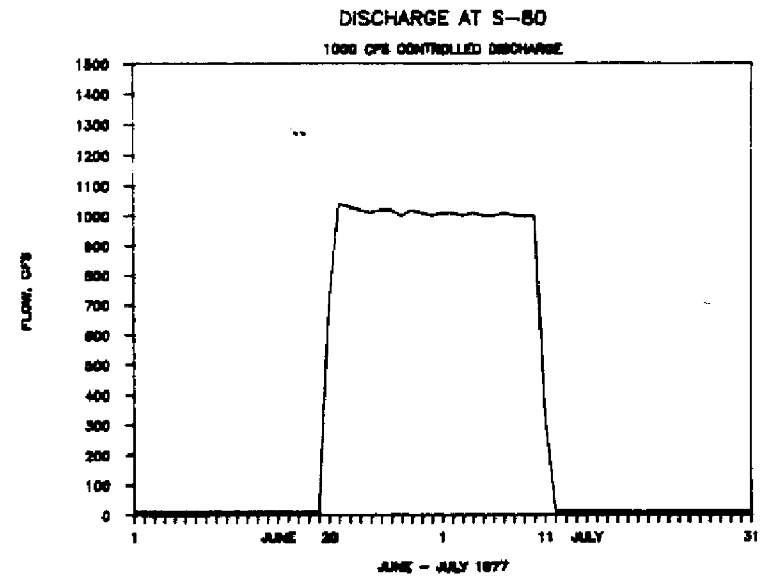


Figure 6.17 S-80 Structure Discharge, 1000 CFS Controlled Discharge.

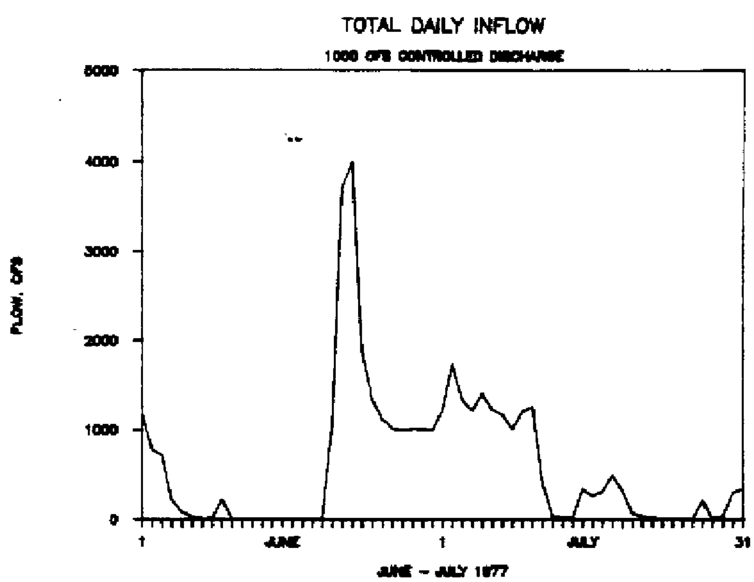


Figure 6.18 Total Inflow During the 1000 CFS Controlled Discharge.

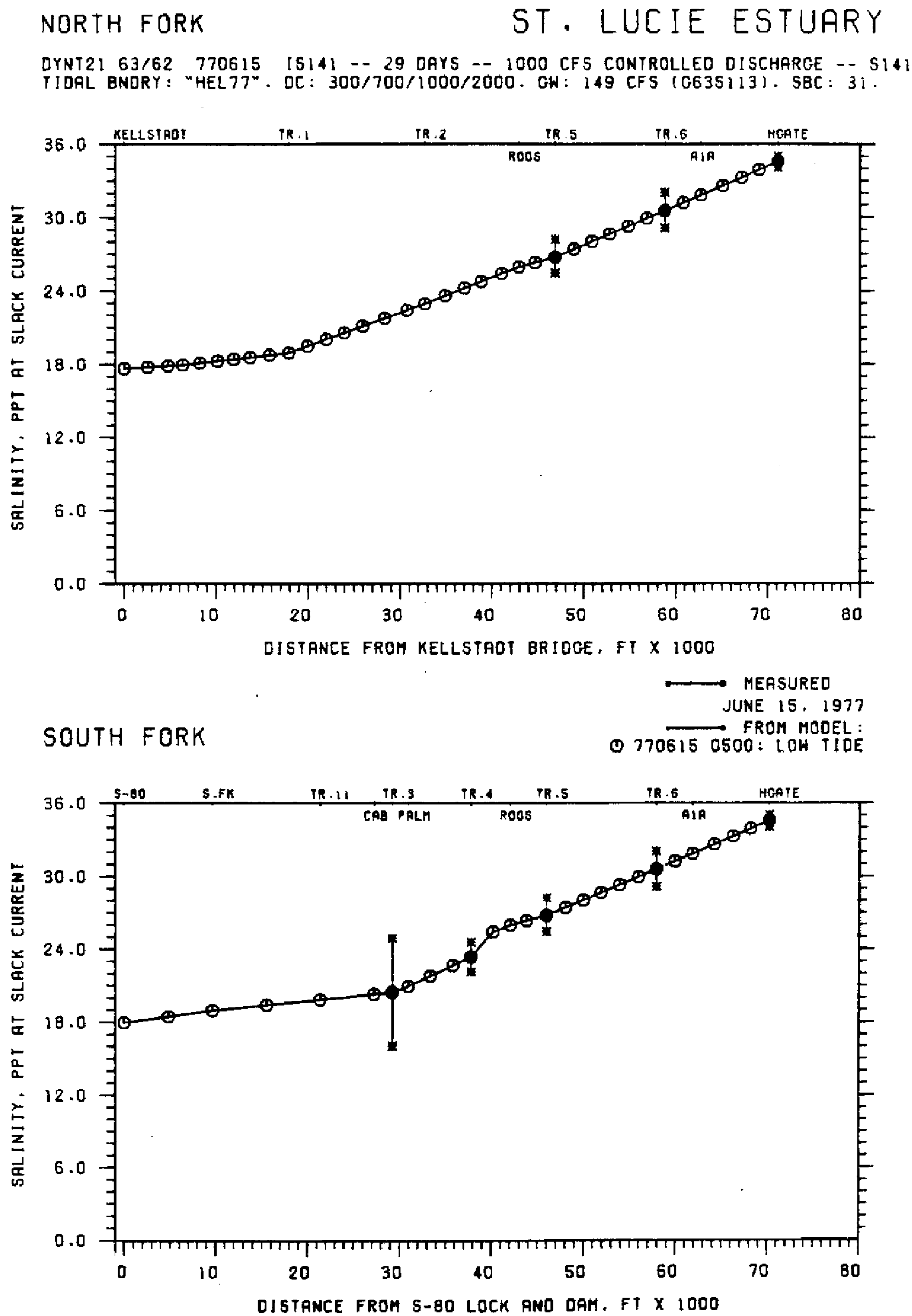


Figure 6.19 1000 CFS Controlled Discharge Salinity Gradients, Initial Conditions.

Table 6.3 Comparison of Low Slack Water Salinity in the 1000 CFS Verification, Calculated Low Tide Salinity Minus Nearest Measured Salinity, ppt.

(Simulation S-141 -- see plots in Appendix F).

DATE 1978	Rmrks	NORTH FORK TR-1	TR-2	TR-5	TR-6	SOUTH FORK S-80	TR-11	TR-3	TR-4
June 15	initial	------	------			------	------	-6	
June 17		+1		-1		------	------		
June 20		+1		-1		------	------	-7	
June 23		-5	-1			------	------		
June 24		-6	-3		-3	------	------		
June 27		-9	-6		-3	------	------		
June 30		-7	-6			------	------		
July 7			-6			------	------		
July 11		-1	-2			------	------		
July 13		-1	-2			------	------		

calibration values of ground water seepage rates and dispersion coefficients were not changed, and inflows were calculated from rainfall as in all other St. Lucie Estuary simulations.

Prior to the start of the controlled discharge, fresh water inflows began to decrease the salinity in the South Fork. Between June 20 and June 23 salinity in both the North Fork and the South Fork declined rapidly. From June 23 salinity declines were steady, but moderate, in the South Fork and there was a decrease east of Transect 1 and an increase to the west of Transect 1 in the North Fork. By July 7 the longitudinal salinity gradients in the North and South Forks had reached equilibrium, as shown by the final plot on July 13 (Figure 6.20). The results are summarized in Table 6.3, and the full set of plots for each day of measurement are included in Appendix F.

3. 2500 cfs Controlled Discharge

The 2500 cfs controlled discharge simulation began on June 15 1978, and continued until August 2 1978. Average basin rainfall during this period is plotted in Figure 6.21, S-80 discharge is shown in Figure 6.22, and total inflow is given in Figure 6.23. Tidal boundary conditions were calculated using harmonic coefficients, initial salinity gradients were set to correspond with the salinities measured on June 15 (Figure 6.24), and a high tide salinity boundary condition of 30 ppt was used. The test used the calibration values of ground water seepage rates and

Table 6.4 Comparison of Low Slack Water Salinity in the 2500 CFS Verification, Calculated Low Tide Salinity Minus Nearest Measured Salinity, ppt.

(Simulation S-142 -- see plots in Appendix G).

DATE 1981	Rmrks	NORTH FORK TR-1	TR-2	TR-5	TR-6	SOUTH FORK S-80	TR-11	TR-3	TR-4
June 15	initial					------			
June 16			-3	-5	-11	------	-2	-1	-3
June 20		------	------			------		+2	
June 22						------		+1	
June 27	all wr					------			
June 29	all wr					------			
July 6	all wr					------			
July 7				-1		------			
July 10	all wr	------	------	------		------			
July 12	all wr					------			
July 20	all wr					------			
July 21	all wr					------			
Aug 1						------			-1
Aug 2			-1	-2		------	-1		-2

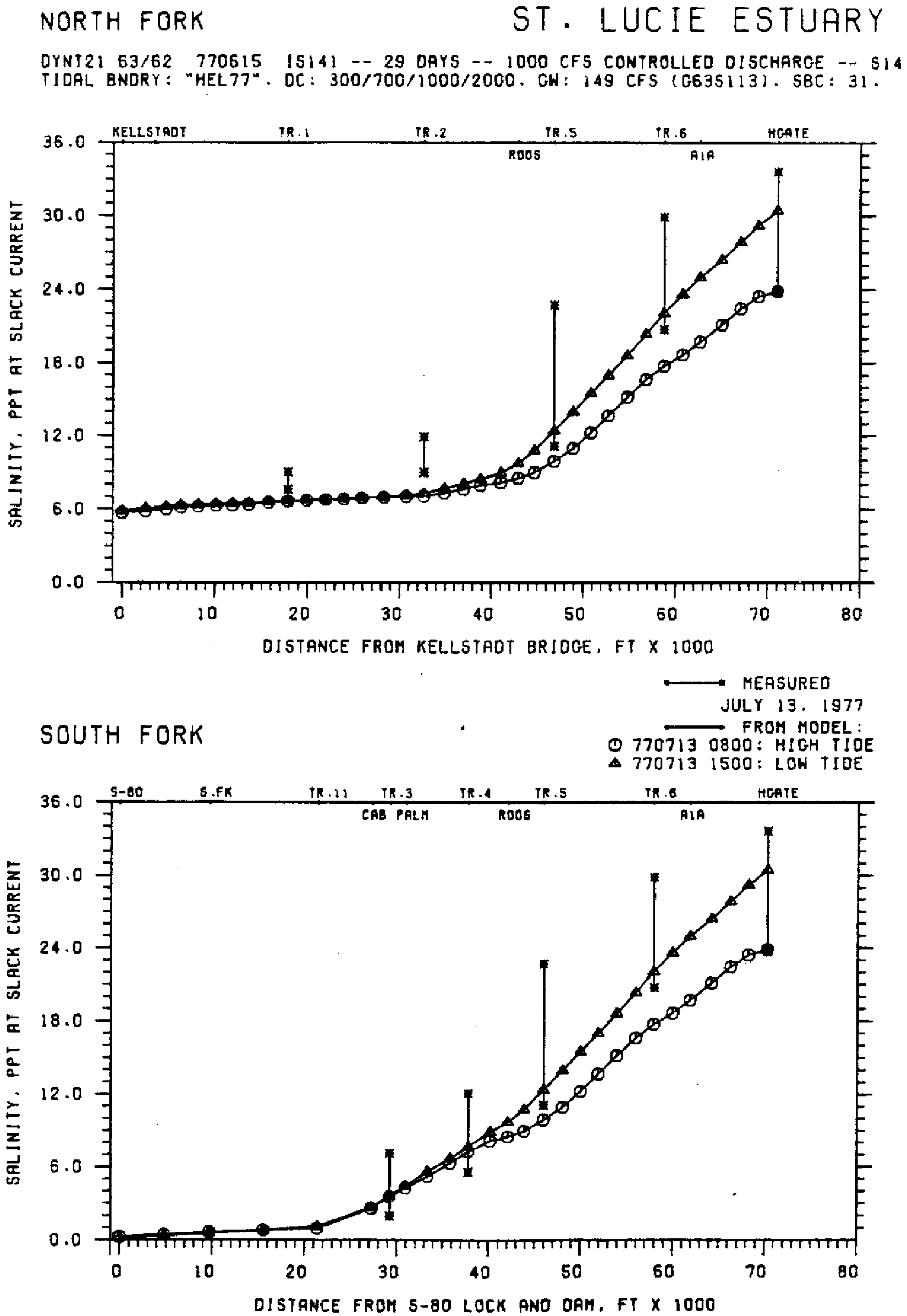


Figure 6.20 1000 CFS Controlled Discharge Salinity Gradients, Last Day.

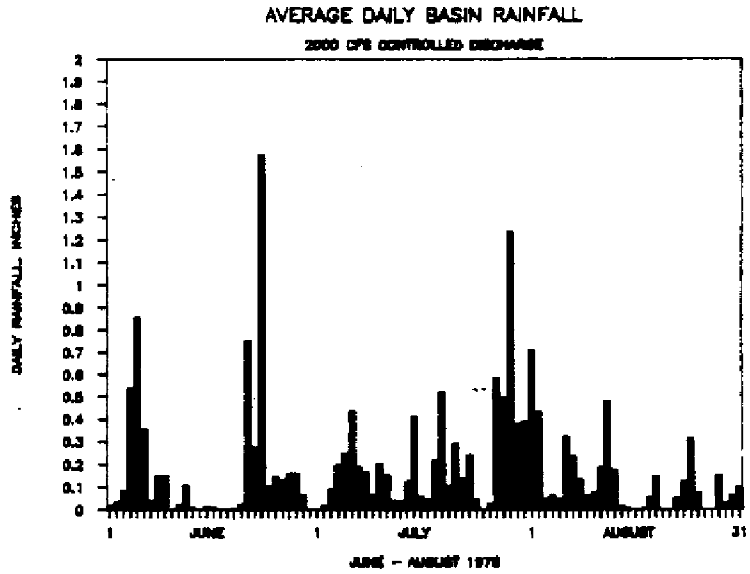


Figure 6.21 Basin Average Rainfall, 2500 CFS Controlled Discharge.

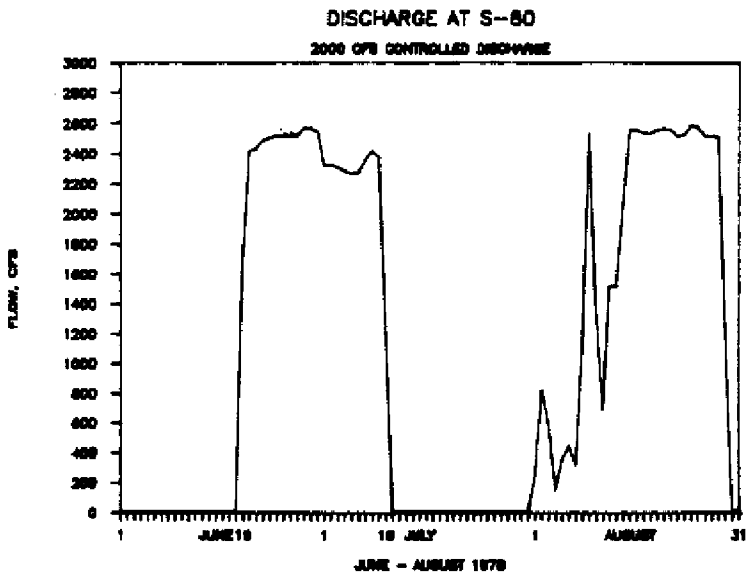


Figure 6.22 S-80 Structure Discharge, 2500 CFS Controlled Discharge.

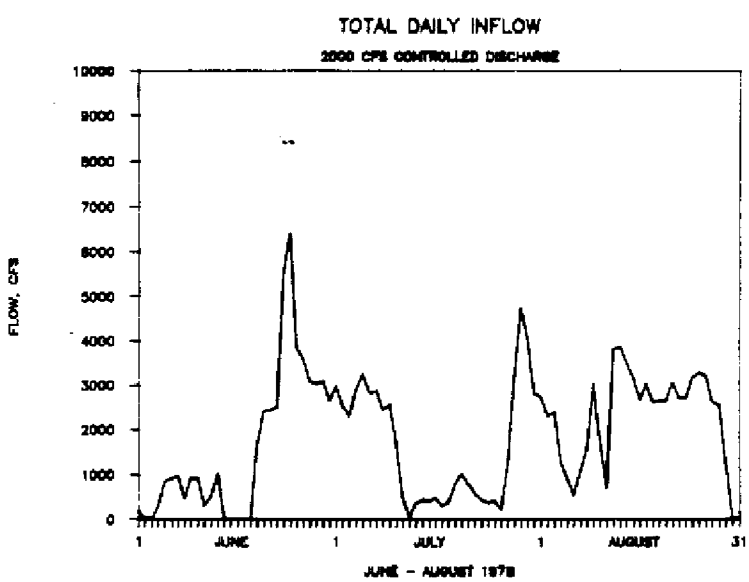


Figure 6.23 Total Inflow During the 2500 CFS Controlled Discharge.

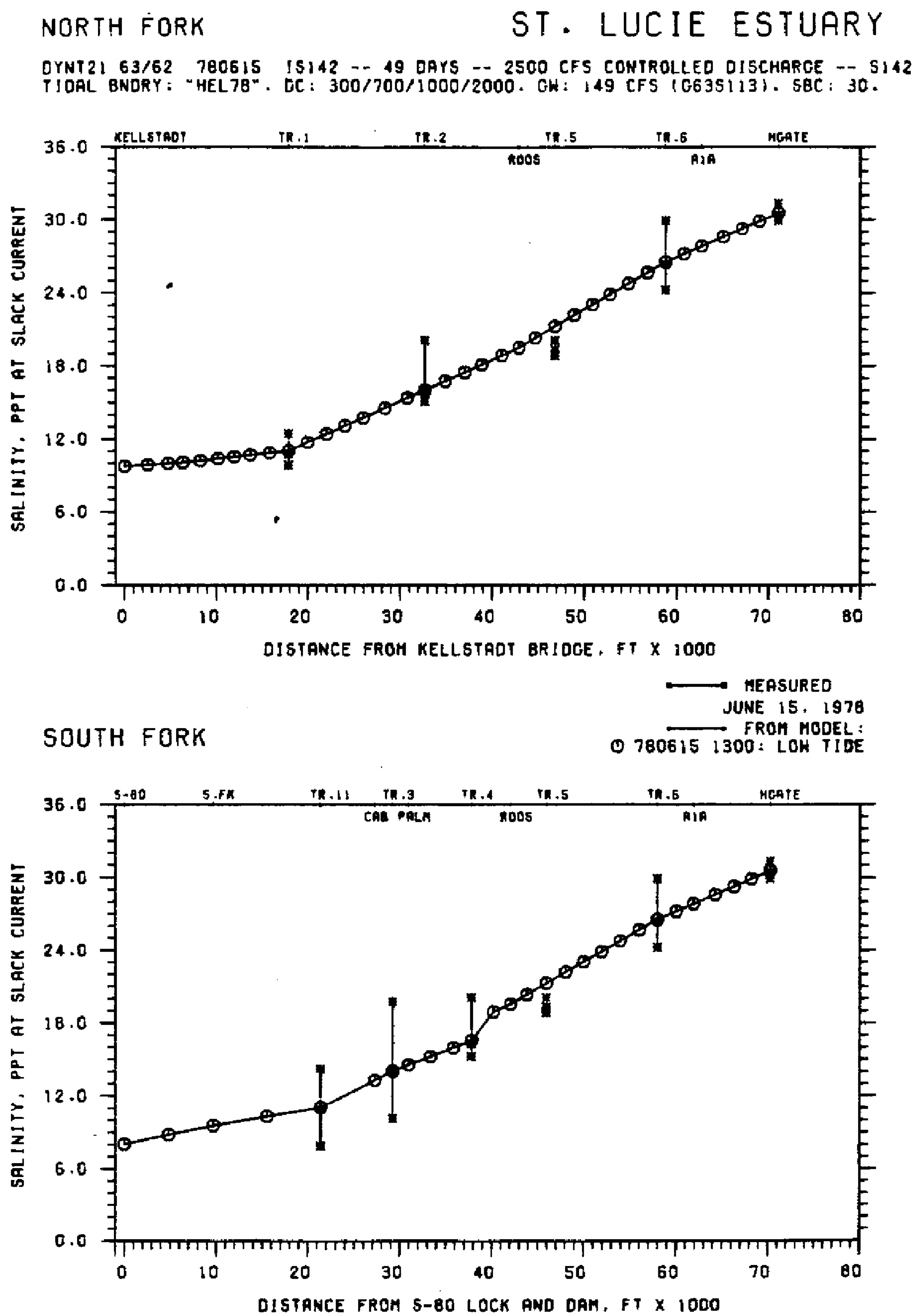


Figure 6.24 2500 CFS Controlled Discharge Salinity Gradients, Initial Conditions.

dispersion coefficients, and inflows were calculated from rainfall.

The 2500 cfs discharge actually occurred in two parts. The first part was a 2400 cfs average release from S-80 between June 19 and July 10, and the second, a more variable discharge averaging about 2000 cfs, occurred from July 31 to August 29. Between June 16 and June 20, both the North and the South Fork salinity declined substantially. The trend continued, at a somewhat slower rate, to about July 6 when a salinity equilibrium was reached. Between July 7 and 20 the salinities began to recover from their low values of about 2 ppt in the lower South Fork, steadily increasing to a new equilibrium on July 20 - 21. Under the influence of the second, approximately 2000 cfs, release the salinity declined again to an apparent equilibrium on August 2.

The results of the simulation are summarized in Table 6.4. The computed salinity gradients obtained on the last day of the simulation are compared with the measurements for that day in Figure 6.25, and the full set of plots for each day of measurement are found in Appendix G.

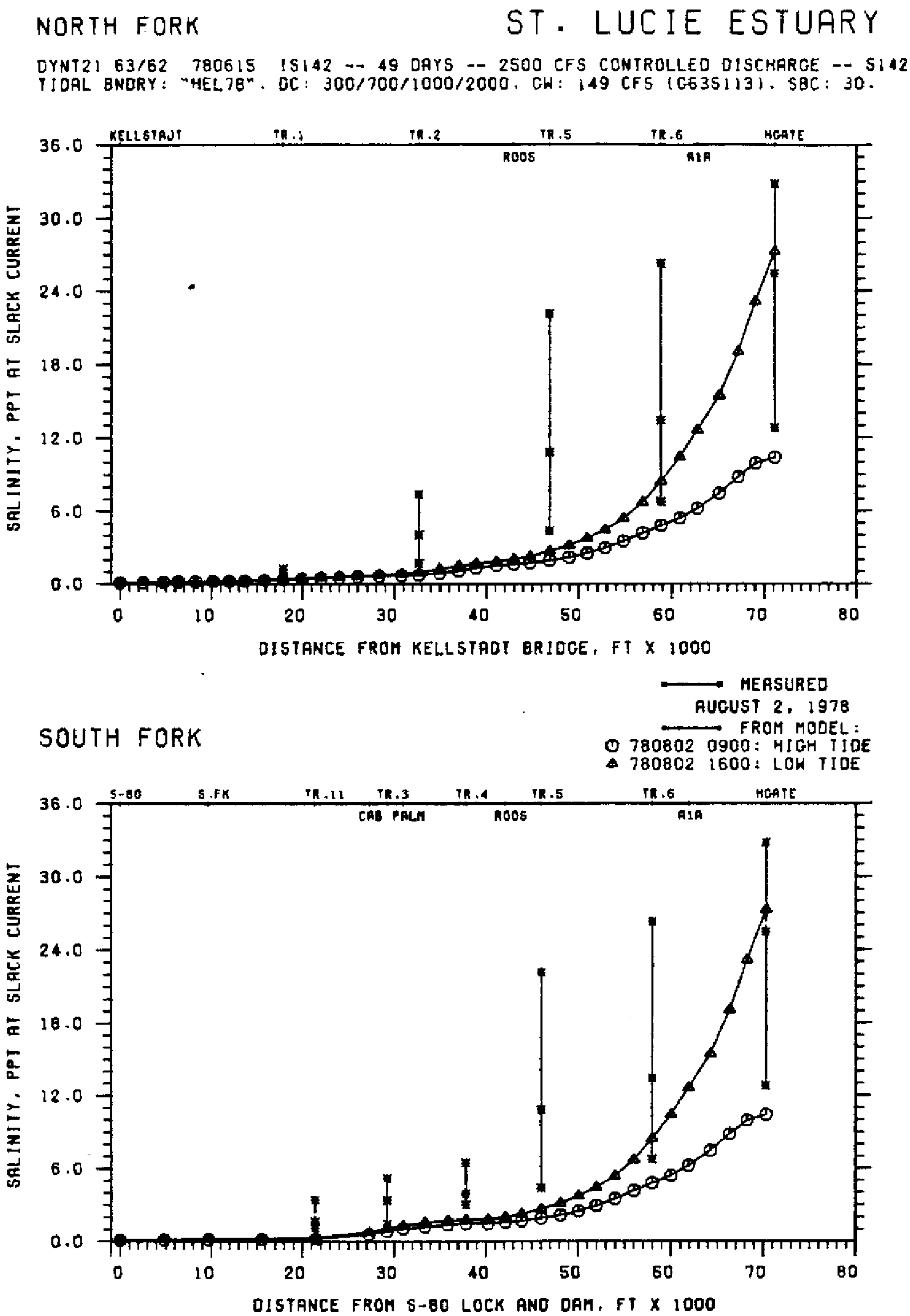


Figure 6.25 2500 CFS Controlled Discharge Salinity Gradients, Last Day.

Section 7 SUMMARY AND CONCLUSIONS

Historical fresh water discharges to the St. Lucie Estuary have been significantly altered by the presence of large flood control canals and changes in land use in the estuary watershed. On occasion these alterations have resulted in salinity changes which have been counterproductive to the maintenance of the estuary as a habitat for marine species.

To be able to quantify the specific effects of fresh water inflows on estuarine salinity, a computer model for simulating hydrodynamics and salinity in the St. Lucie Estuary was selected, modified, and applied. In this model the estuary is represented by a 63 node network, which extends into the North Fork several miles north of Port St. Lucie Boulevard, to the end of the navigable part of the Old South Fork, and to the three structures that discharge to the estuary. An analysis of available data on historic rainfall and measured discharges from District control structures was conducted to provide data on rainfall and runoff for the model. This statistical analysis, which was limited by the lack of measurements of flow in the North and South Forks, and lack of measurements on non-point runoff, nevertheless provides realistic daily runoff pulses and monthly total inflows which are usually the correct order of magnitude. The rainfall / runoff relationships are valid except during periods where rainfall does not result in inflow directly to the estuary, as for example in dry periods when rainfall is used for agricultural withdrawals, or when runoff flows back to Lake Okeechobee. In the calibration and verification simulations, this potential problem was avoided by assuming that measured structure discharges included all runoff that reached the estuary from the respective basins. Runoff in the North and South Forks was calculated from unit hydrographs calibrated on the rainfall / runoff relationships for the basins with structures.

The estuary model was calibrated and verified under conditions varying from no rainfall to periods of high rainfall and an unusually large controlled discharge. Comparisons with salinity gradients measured by the District from 1977 through 1981 over periods from 29 to 94 days long generally showed excellent agreement. It is concluded that the estuary model will provide good predictions of salinity over at least a three month period, during controlled discharges from the S-80 structure up to at least 2500 cfs. The primary limitation of the model is in the rainfall predictions used in a simulation, and the assumption that all rainfall results in runoff to the estuary. It is possible to circumvent this limitation by specifying the discharges to the estuary directly.

At the beginning of the St.Lucie Estuary model study it was not known whether a one-dimensional model would be adequate for evaluating fresh water impacts on the estuary. The calibration and verification runs have shown that the model is adequate for assessing and comparing changes in longitudinal salinity gradients resulting from daily rainfall, with and without specified controlled discharges. Simulations of vertical salinity differences have so far not been needed. Also, considering the present limitations in knowledge of the inflows to the estuary, it is questionable whether more detailed spatial capability in the model could be justified at this time.

This model is a general purpose model, applicable to any Floridian estuary. During the development of the St. Lucie application some parts of the model were modified specifically for that estuary. but these portions will be eliminated, or made general, for the next application.

Since the impacts of fresh water discharges in other estuaries in the District will probably be evaluated in the future, using this or another estuary model, it would be useful to begin the necessary hydrographic measurements and analyses in advance so that results will be ready when estuary model application begins. Also, it can be seen that the success of the calibration and verification of the St. Lucie Estuary model depended to a great degree on the comprehensive set of salinity measurements taken by the Environmental Sciences Division from 1977 through 1981. Similar long term measurements should be initiated several years in advance of the beginning of a model development program in any other estuary.

REFERENCES

Anonymous. 1981a. Velocity, conductivity, and temperature measurements in the St. Lucie Estuary 15 July - 12 August 1981. Unpublished report, Continental Shelf Associates, Inc., Tequesta, FL.

Anonymous. 1981b. Operation and Maintenance Instructions for Model 6 Surveyor. Hydrolab Corp., Austin, TX.

Anonymous. 1981c. HEC-1 Flood Hydrograph Package: User's Manual. Water Resources Support Center, Hydrologic Engineering Center, Davis, CA.

Anonymous. 1982a. Tide data analysis, St. Lucie Estuary, June 1981 - March 1982. Unpublished documents, Oceanography & Ocean Engineering Dept., Florida Institute of Technology, Melbourne, FL.

Anonymous. 1982b. Measurements of velocity and calculations of flow in the St. Lucie Estuary, July - September 1981. Unpublished documents, U. S. Geological Survey.

Anonymous. 1984. Tide data analysis, St. Lucie Estuary, March 1982 - June 1983. Unpublished report, Oceanography & Ocean Engineering Dept., Florida Institute of Technology, Melbourne, FL.

Haunert, D. E., and J. R. Startzman. 1980. Some seasonal fisheries trends and effects of a 1000 cfs fresh water discharge on the fisheries and macro-invertebrates in the St. Lucie Estuary, Florida. Technical Publication 80-3, South Florida Water Management District, West Palm Beach, FL.

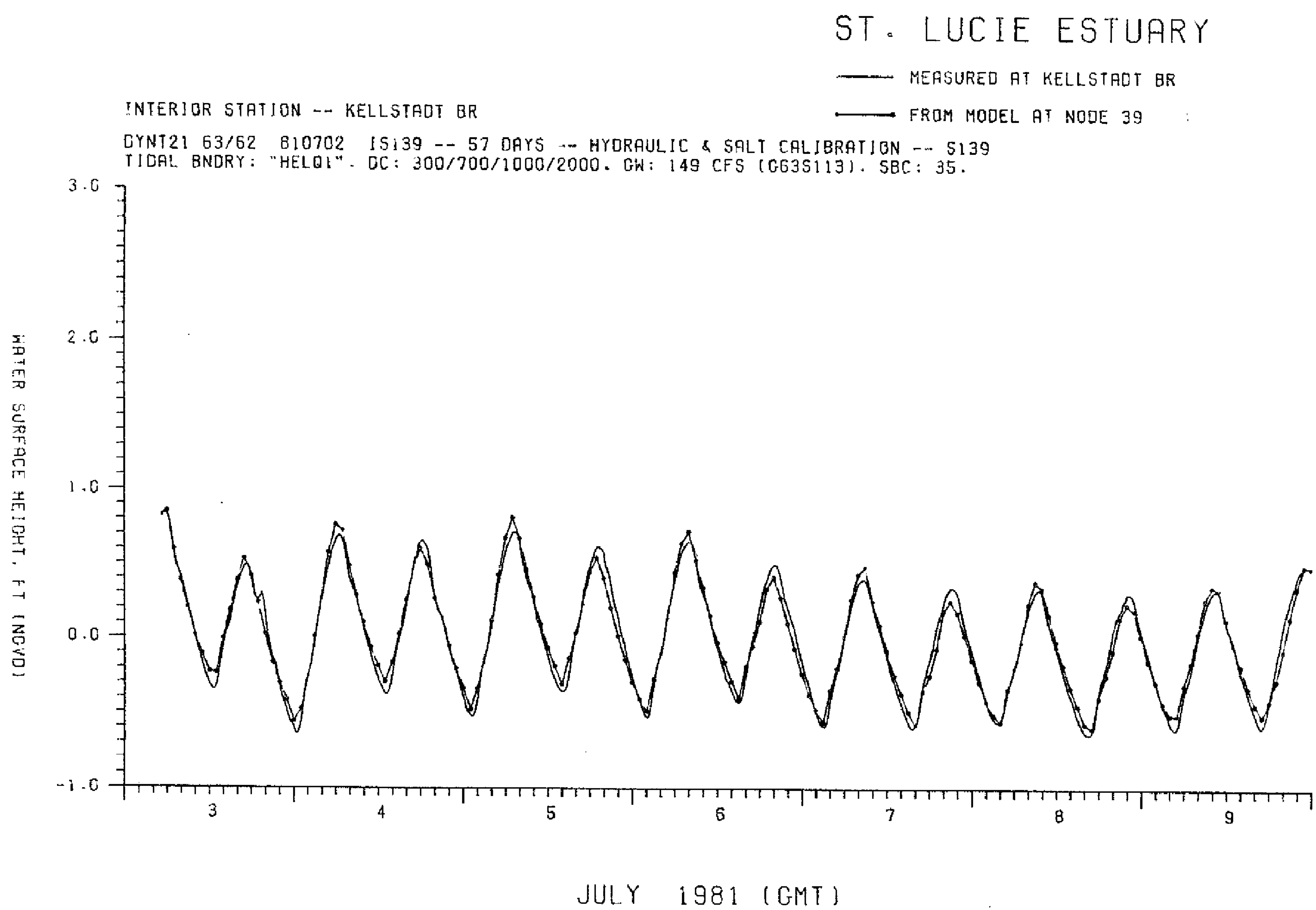
Haunert, D. E., and J. R. Startzman. 1985. Short term effects of a freshwater discharge on the biota of the St. Lucie Estuary, Florida. Technical Publi-cation 85-1, South Florida Water Management District, West Palm Beach, FL.

Morris, Frederick W. 1986. Bathymetry of the St. Lucie Estuary. Technical Publication 86-4, South Florida Water Management District, West Palm Beach, FL.

APPENDIX A

HYDRODYNAMIC CALIBRATION

July 3 through August 27, 1981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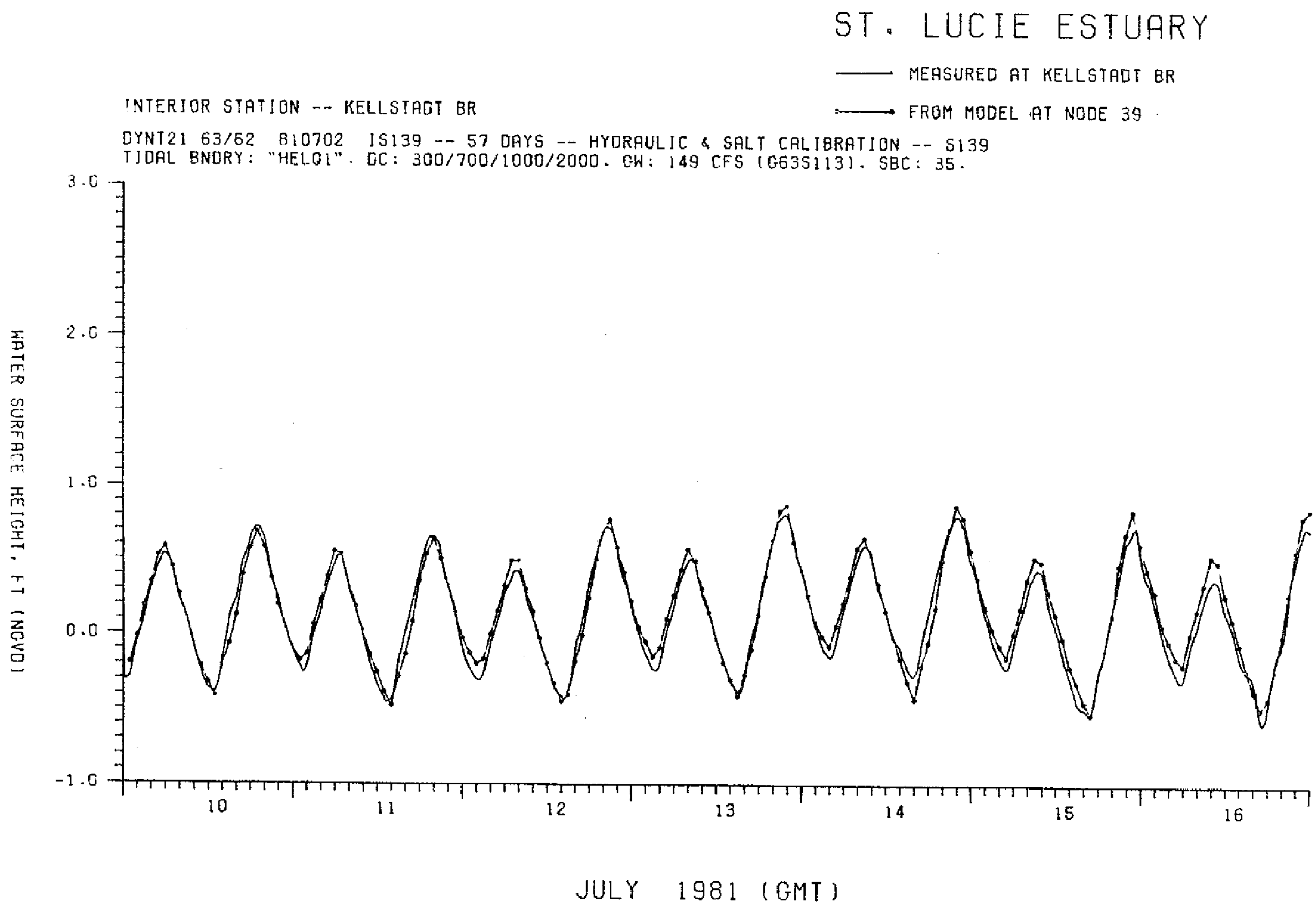
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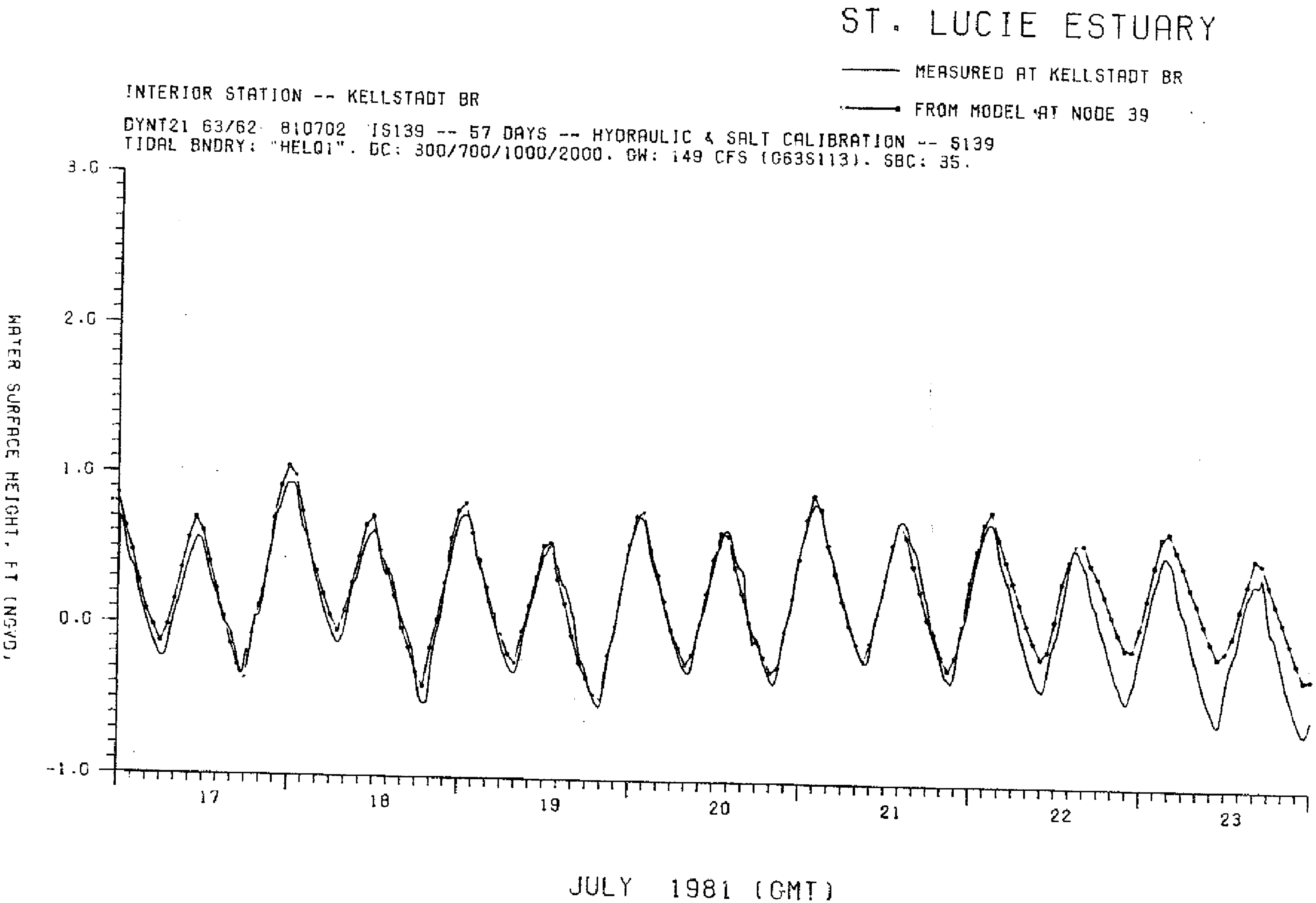
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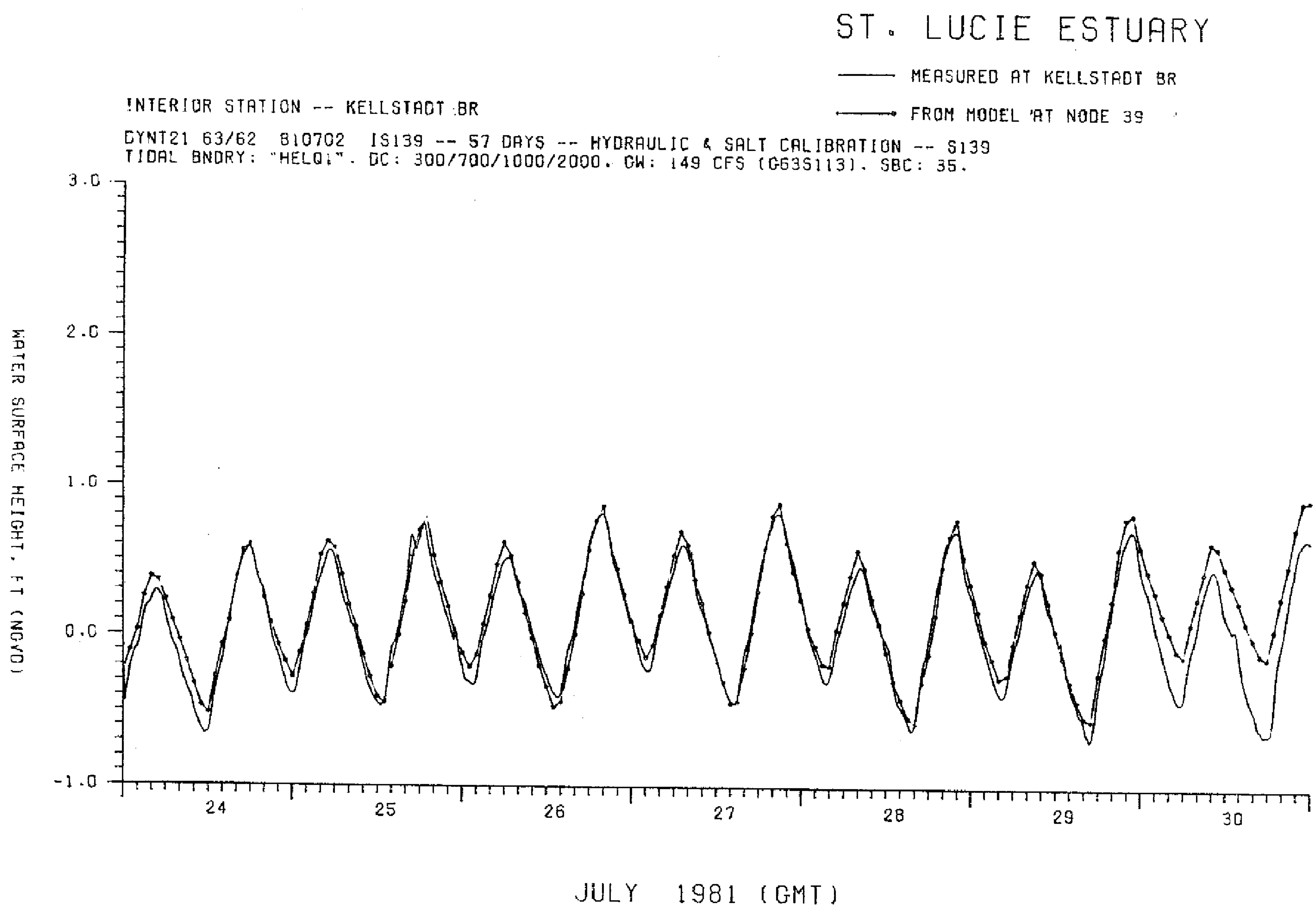
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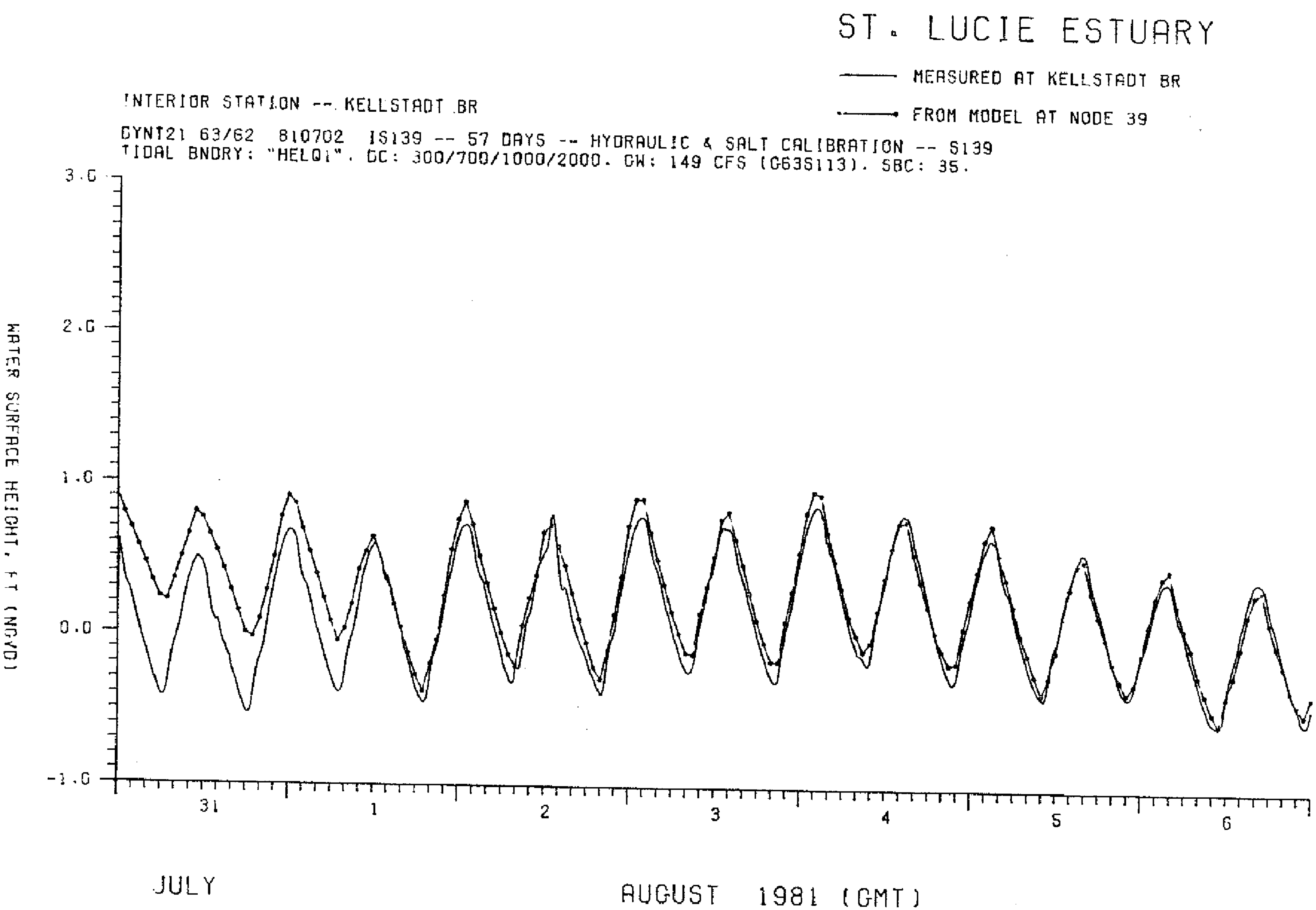

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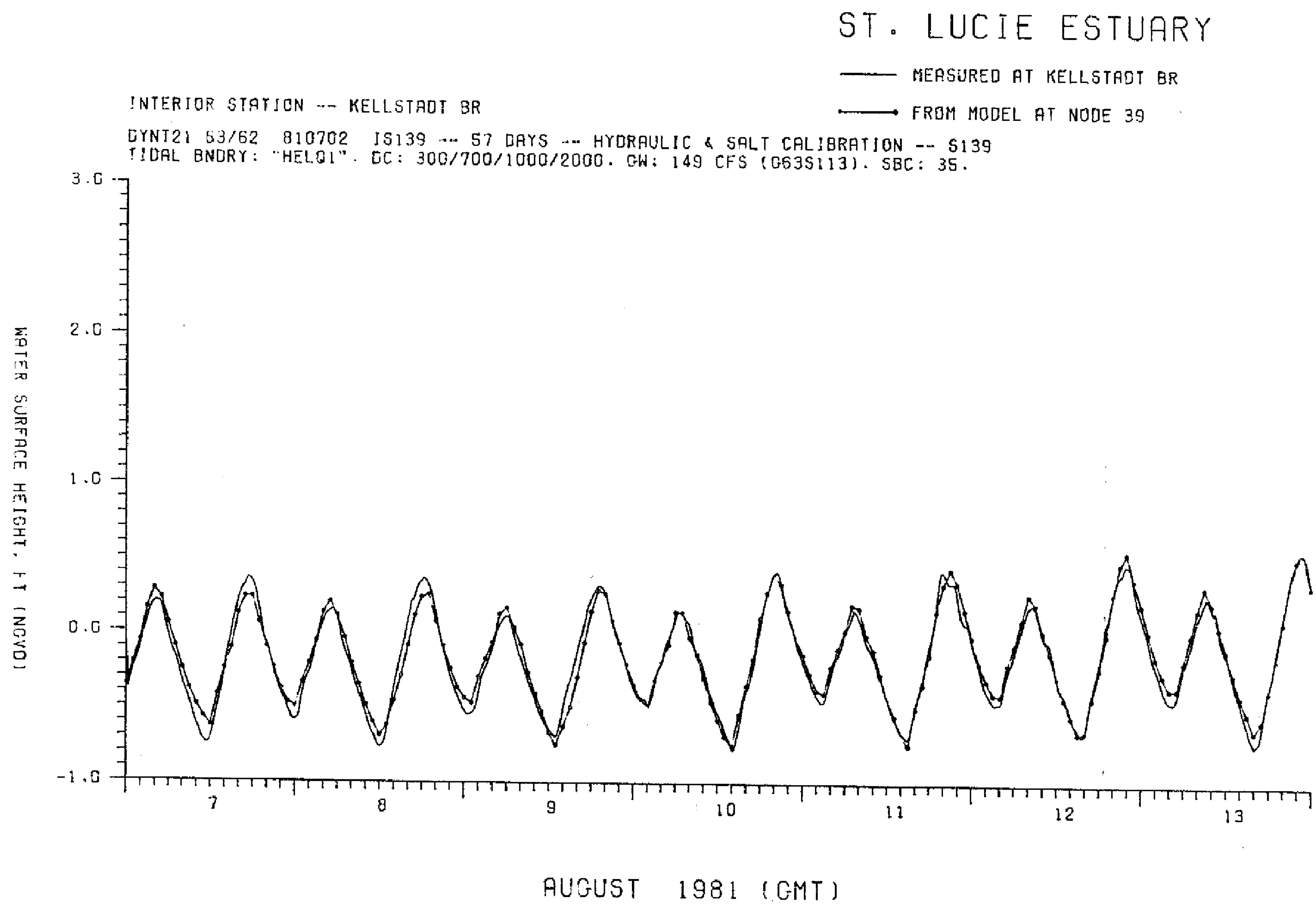
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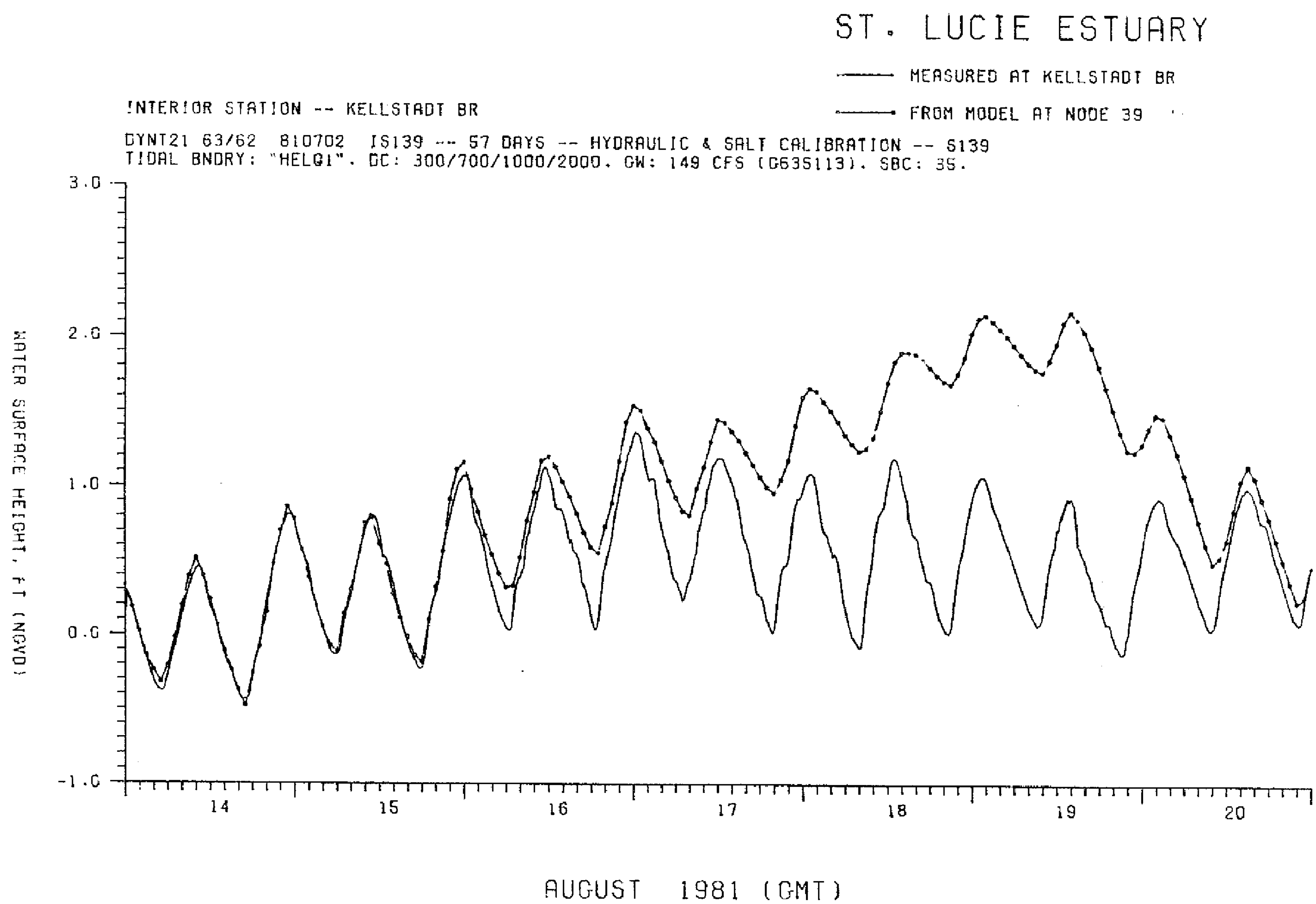
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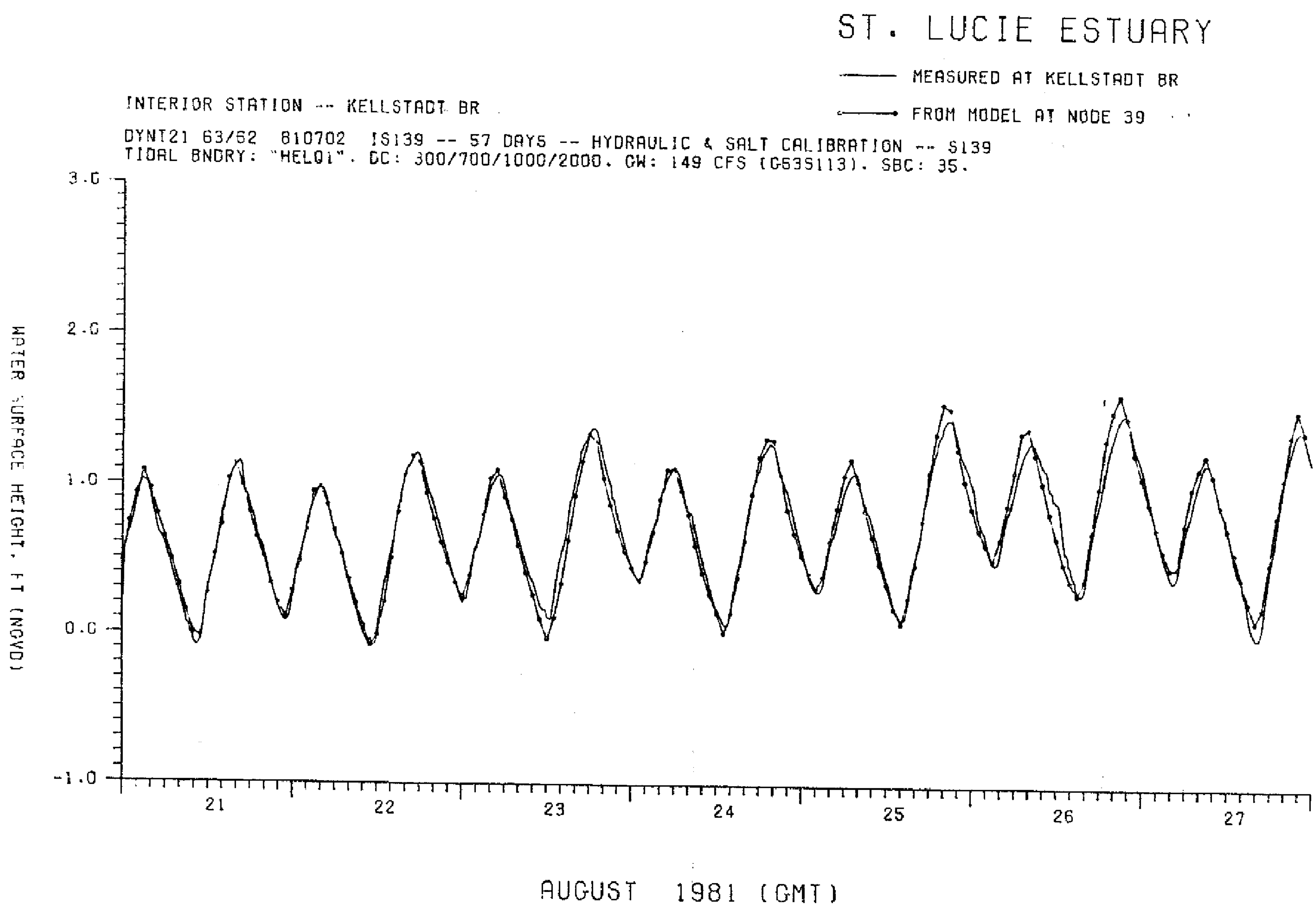
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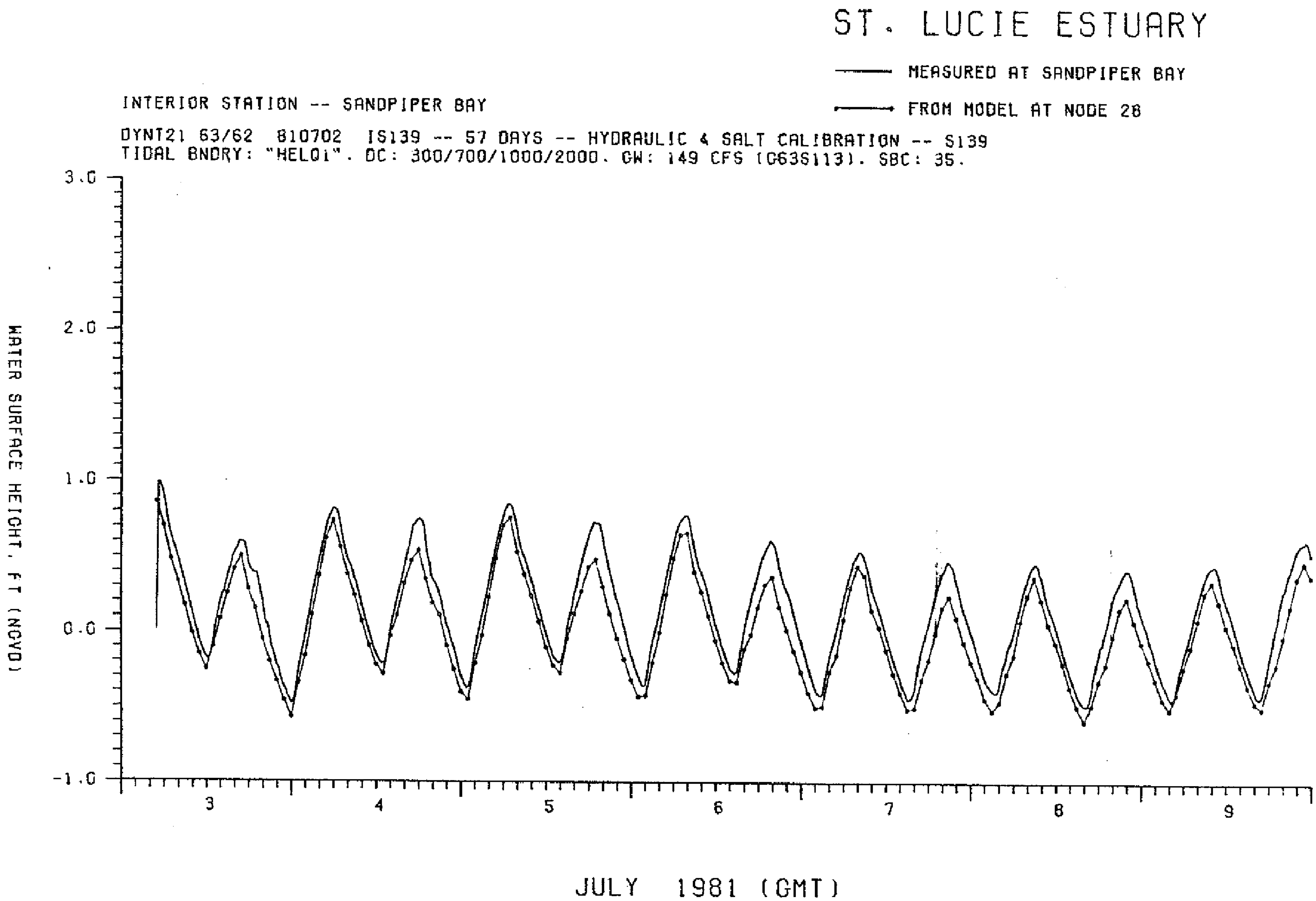

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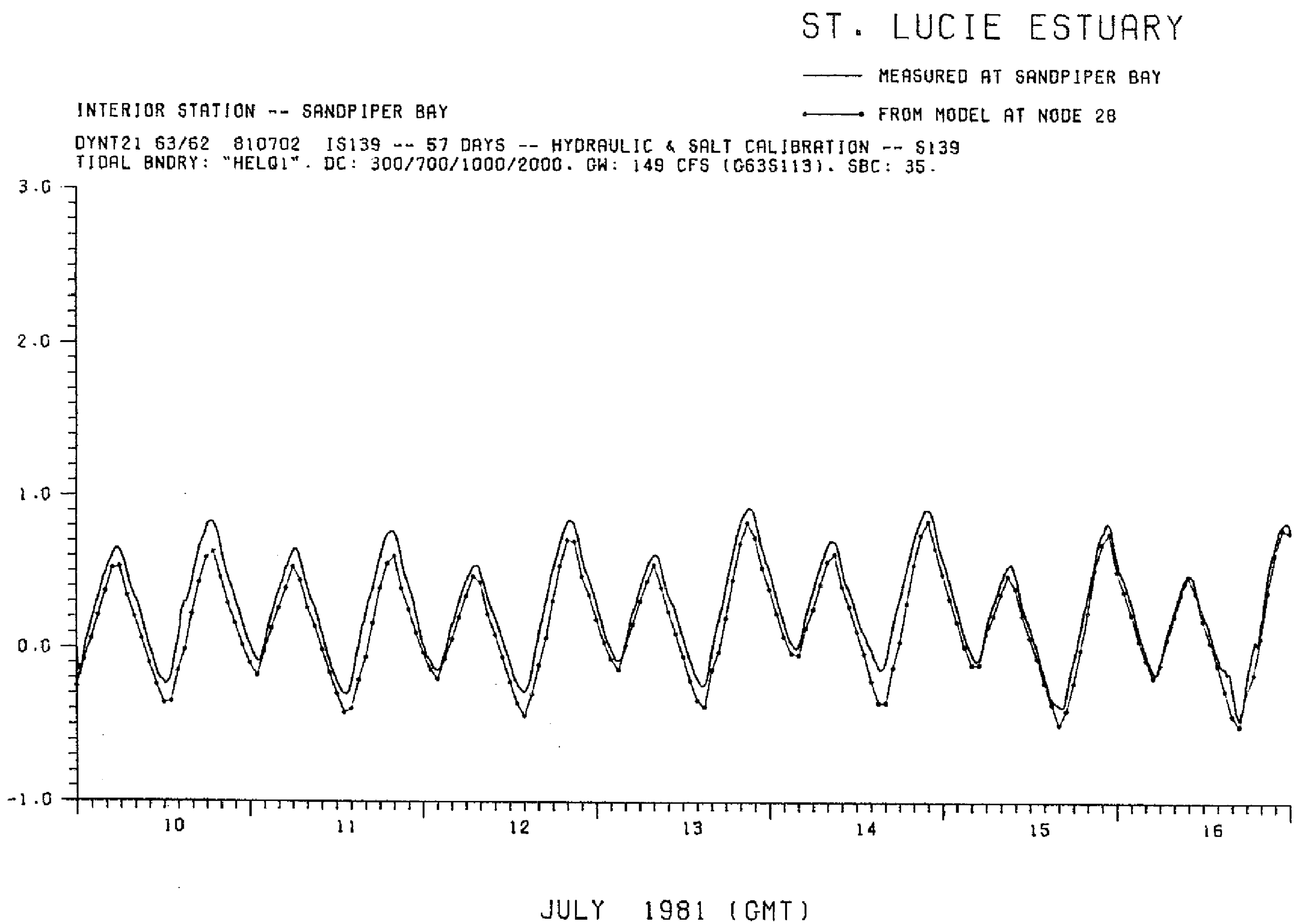
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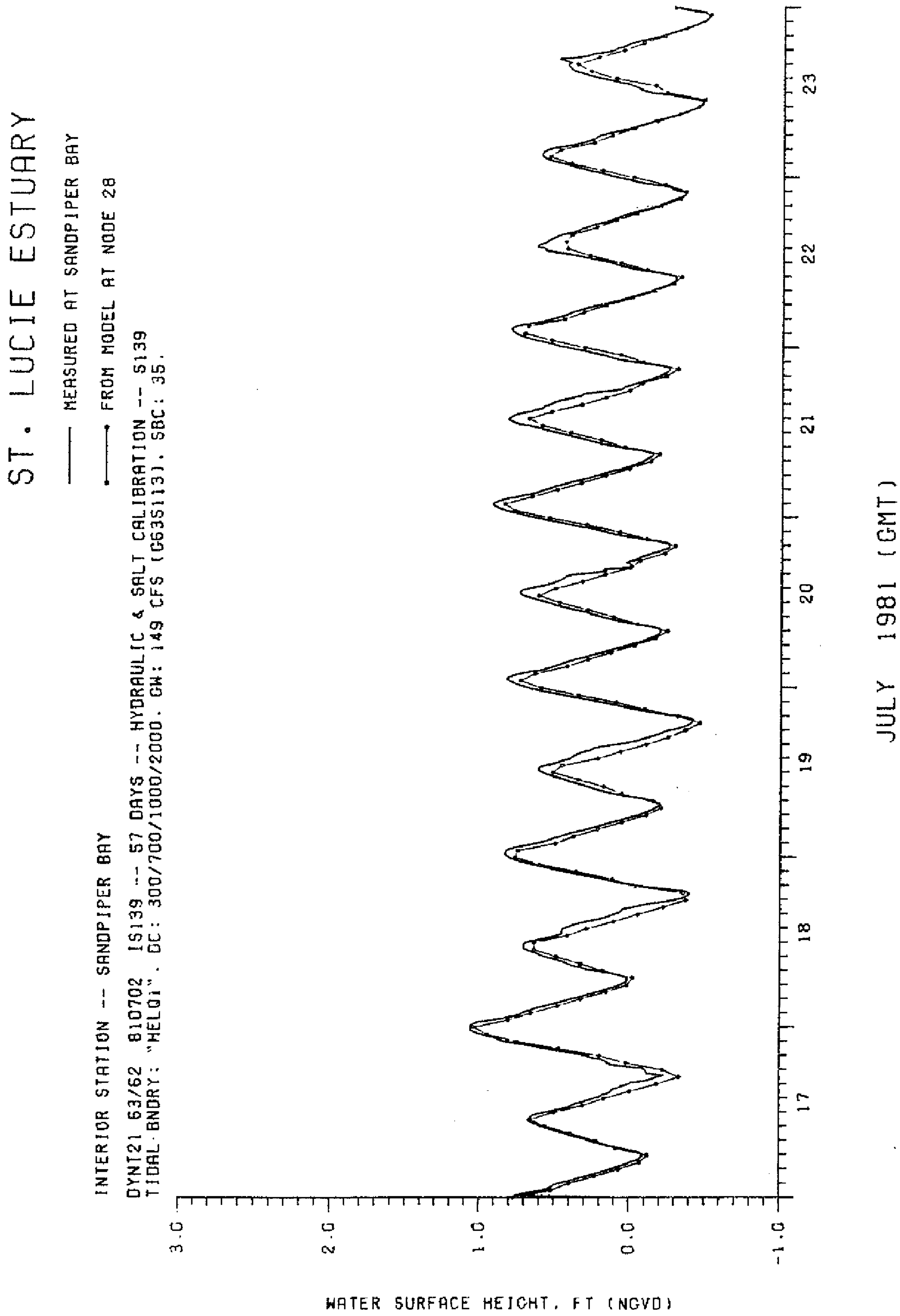
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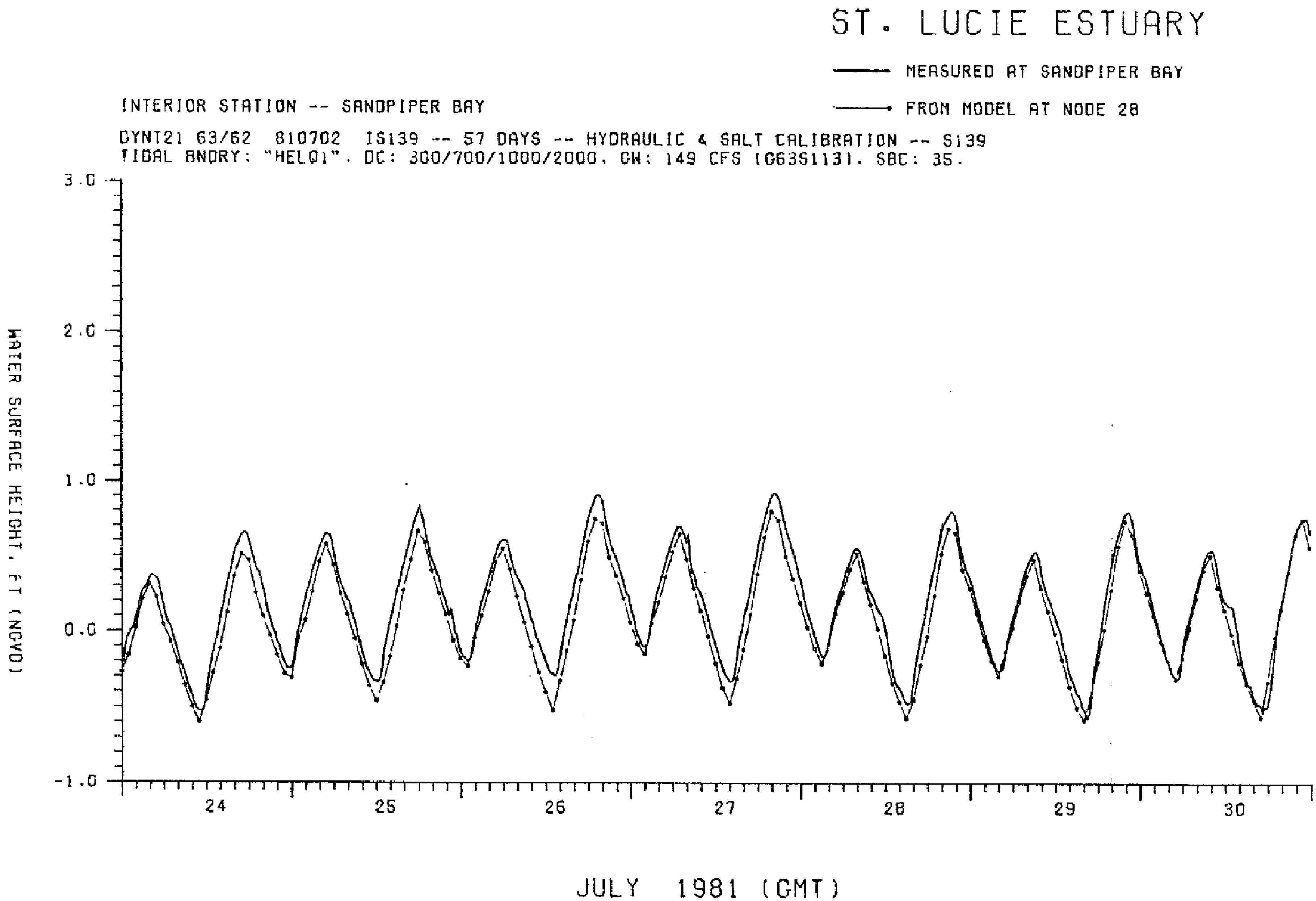
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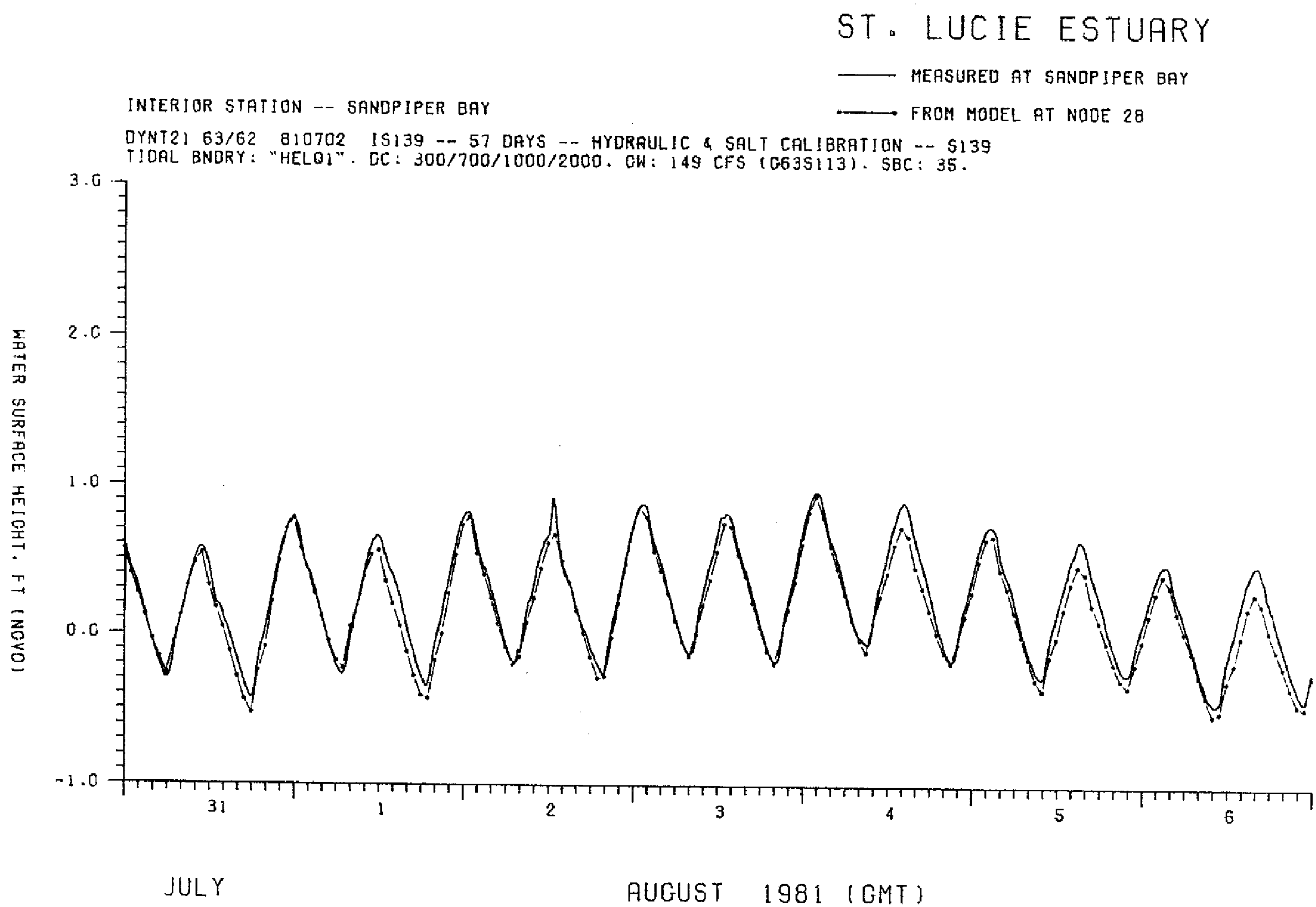
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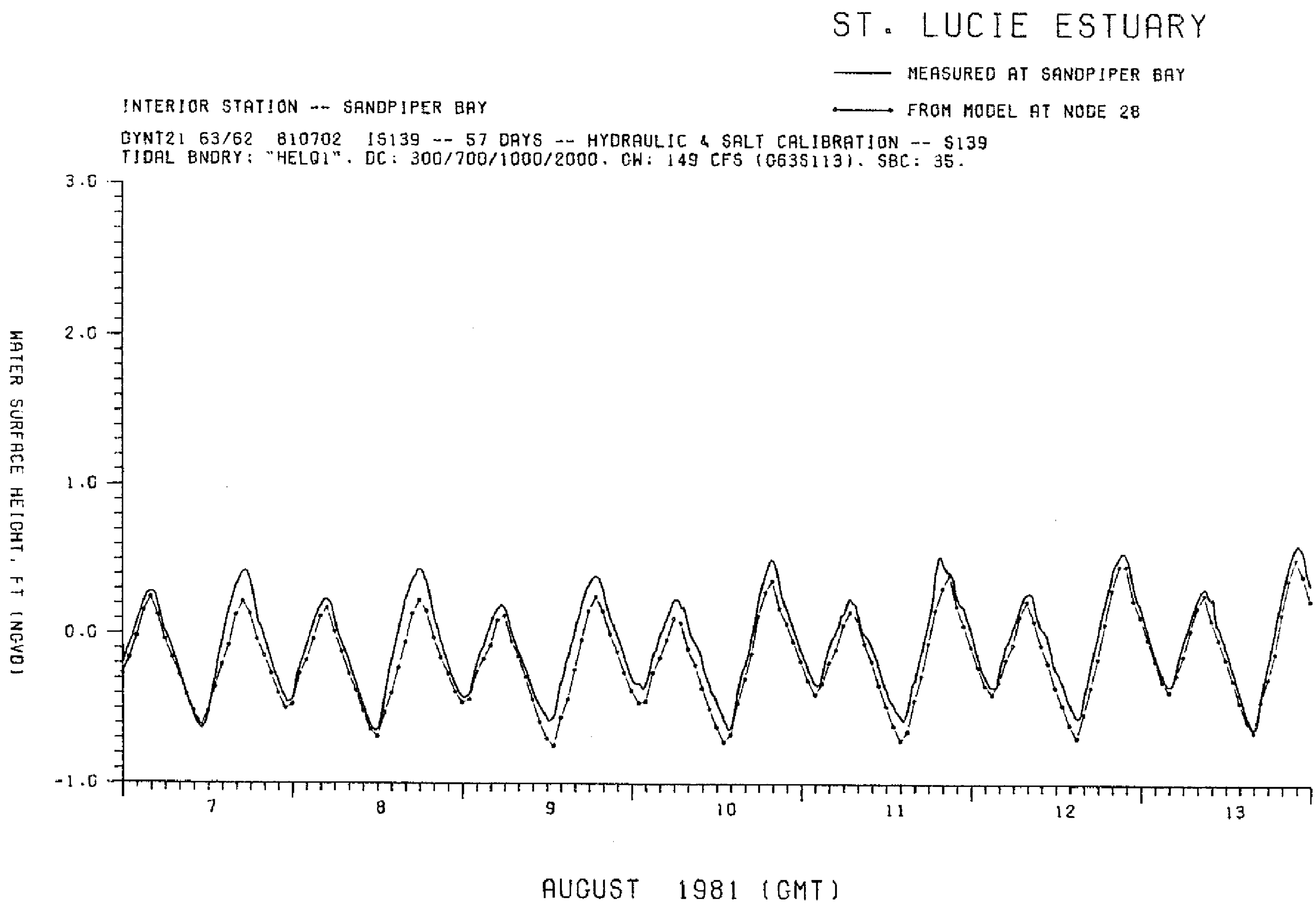
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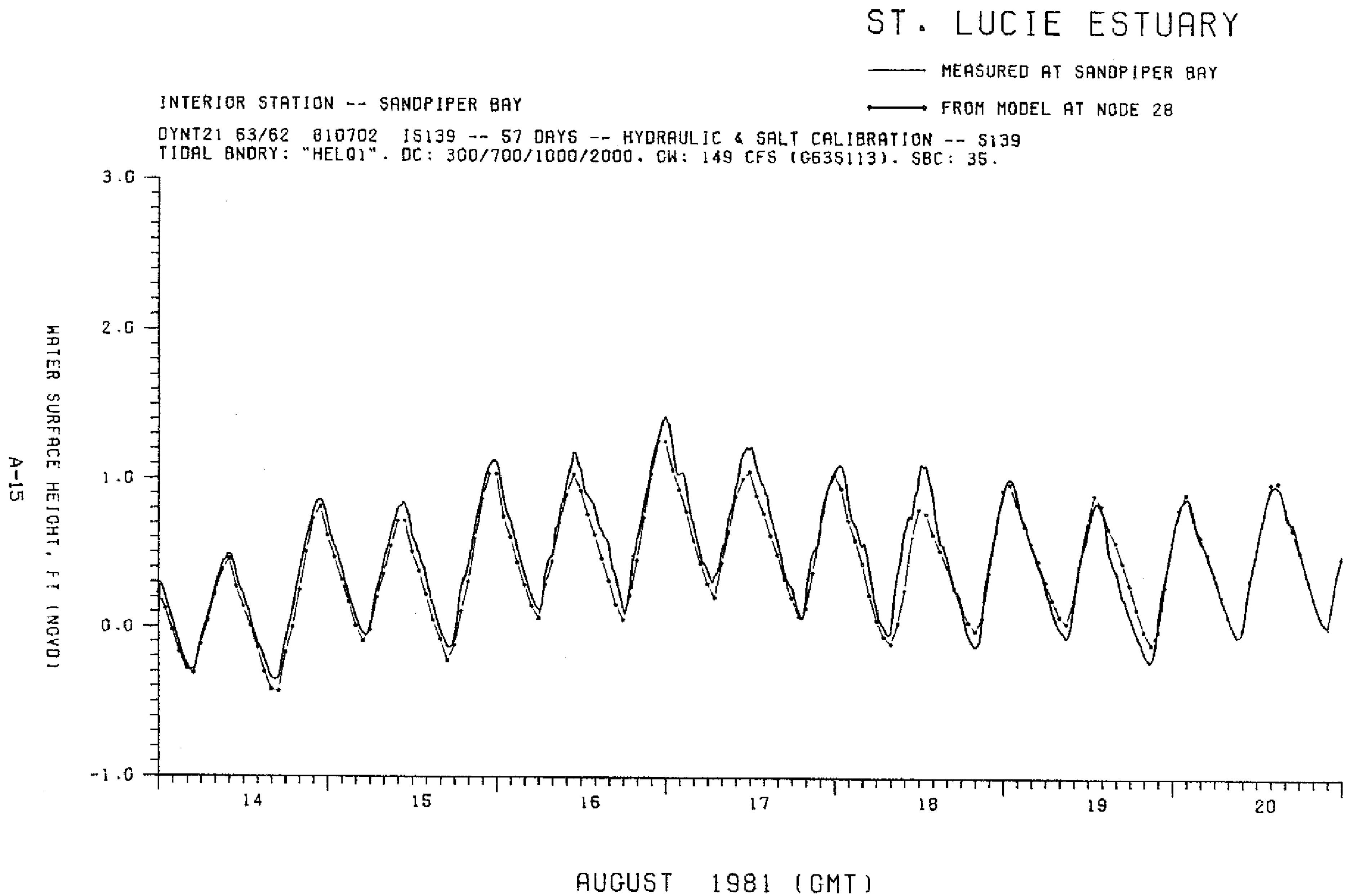
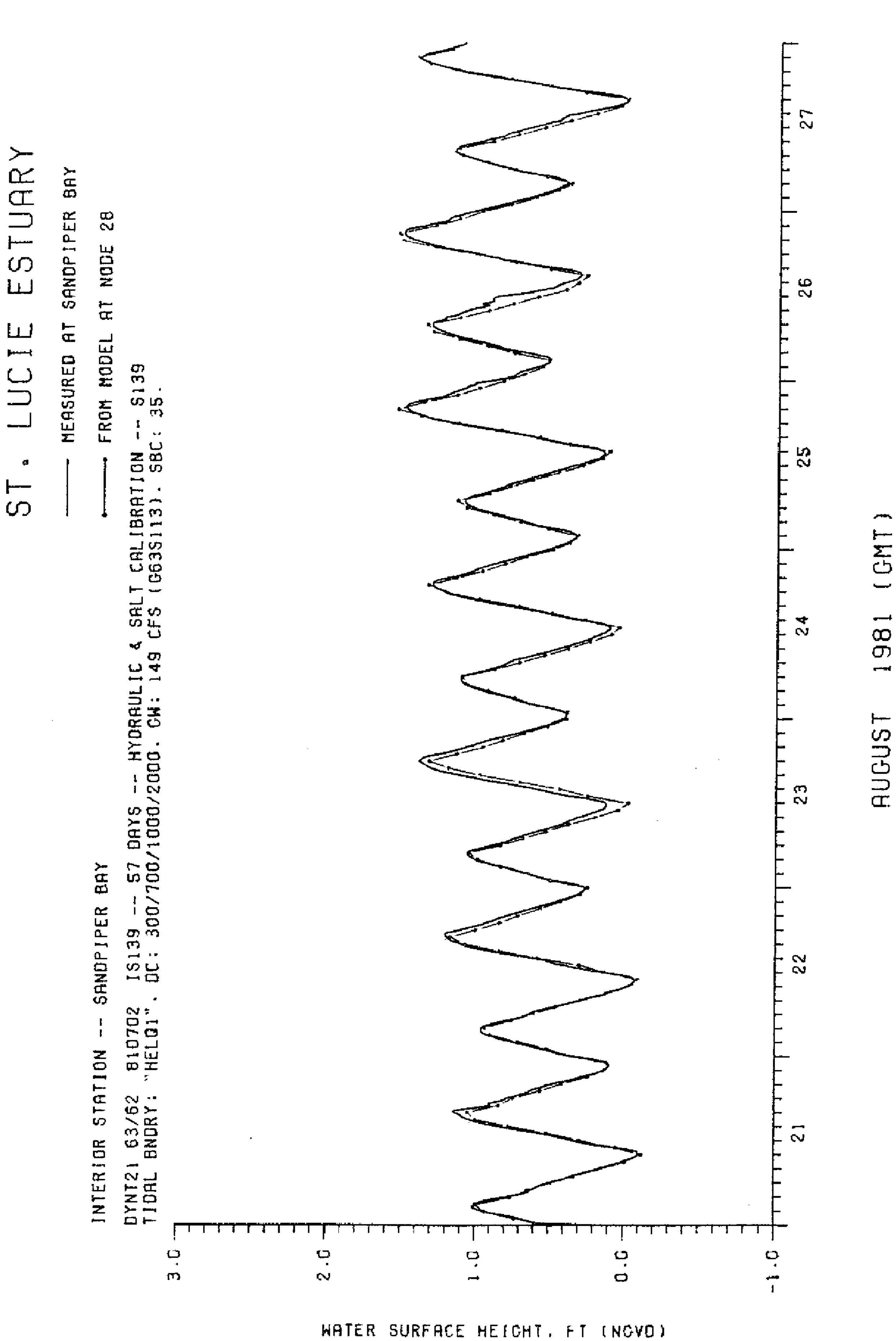
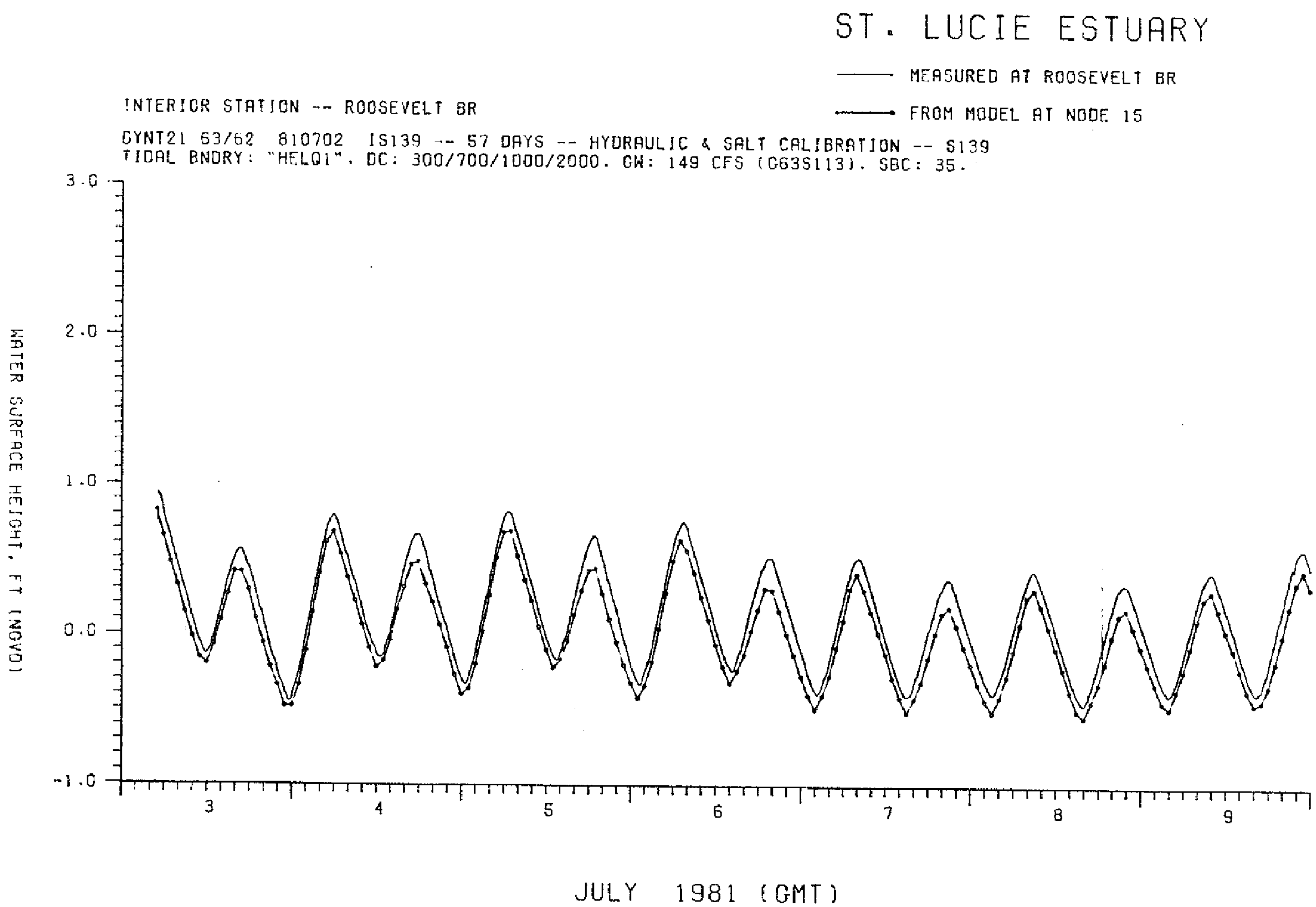
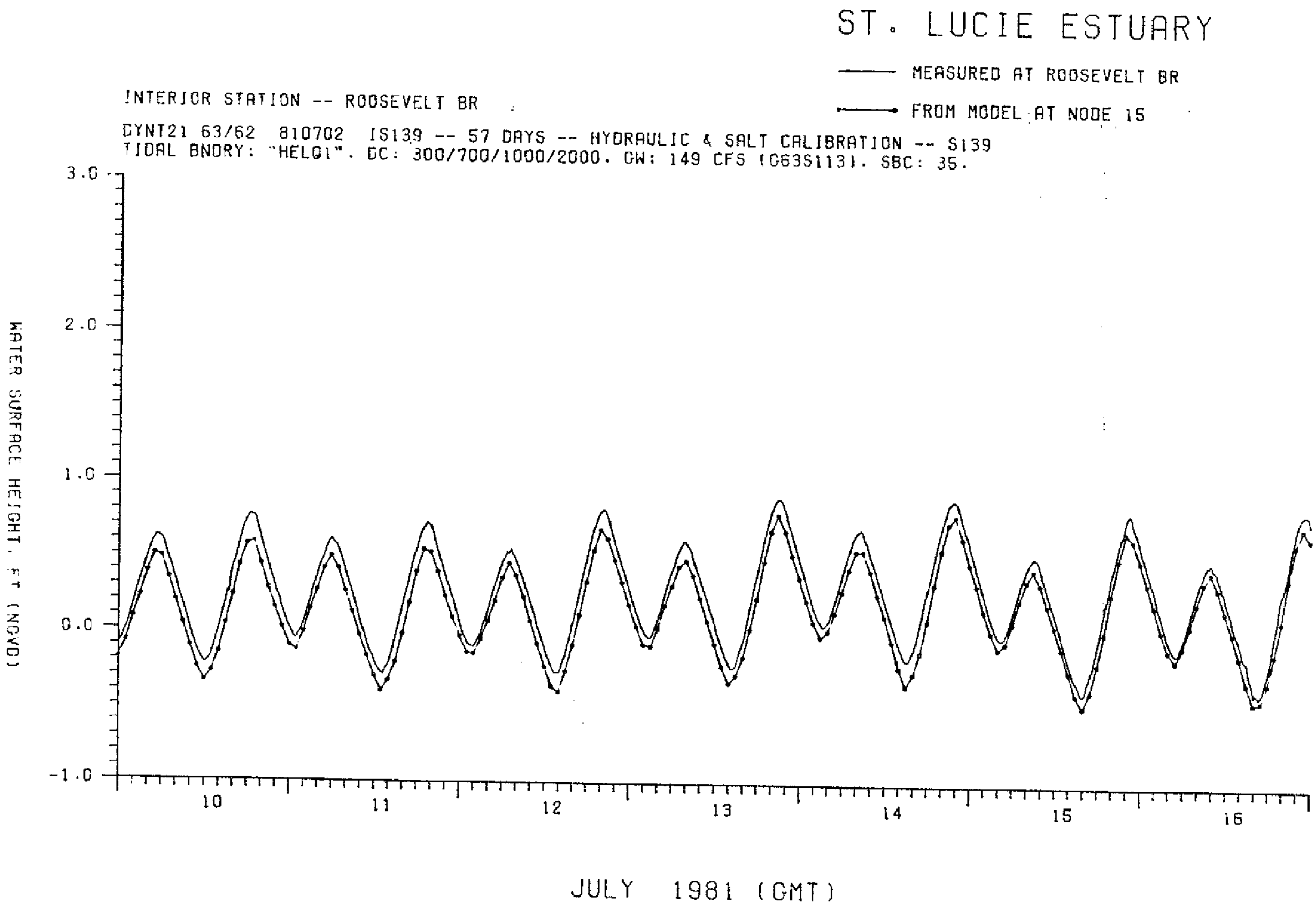
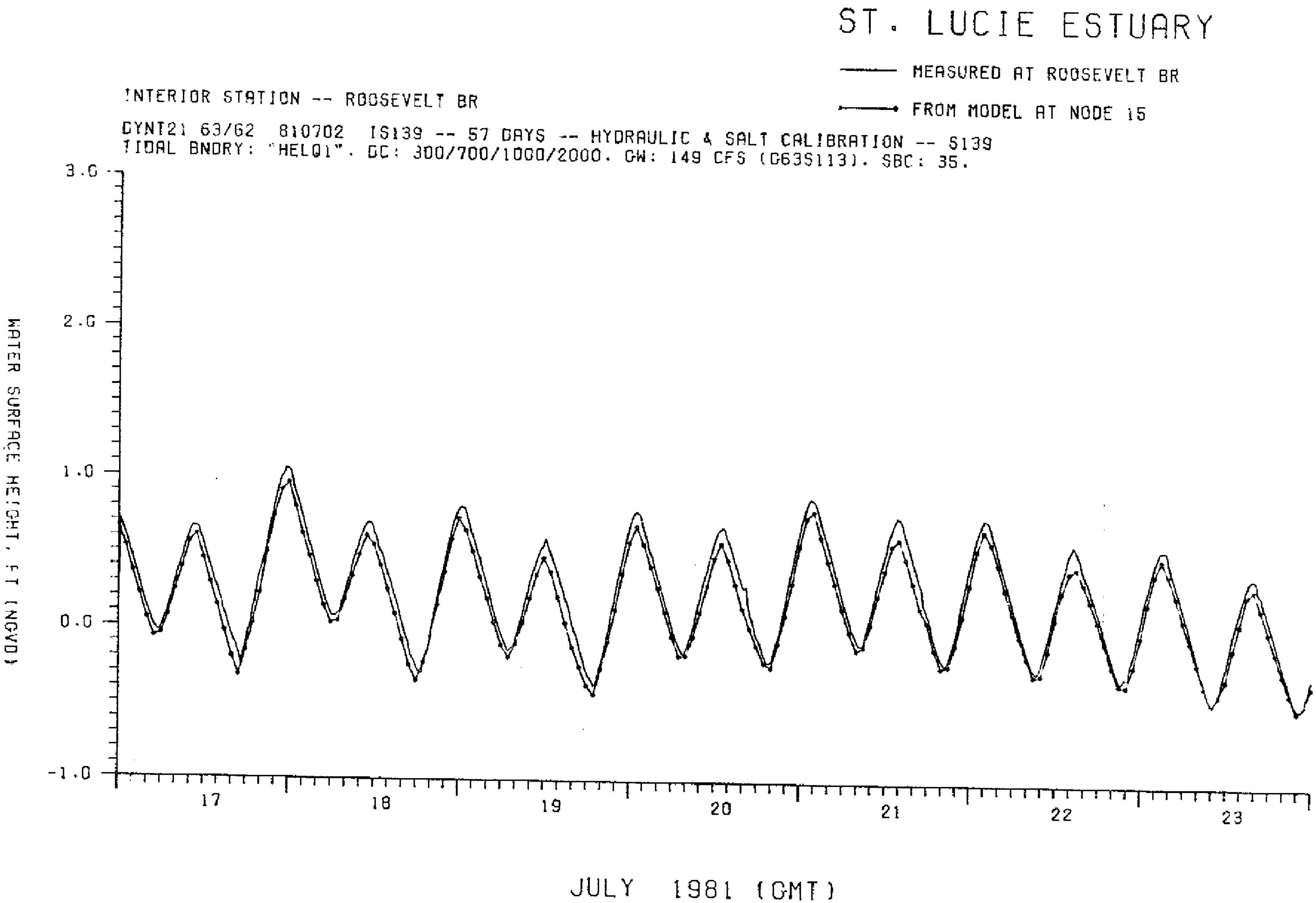
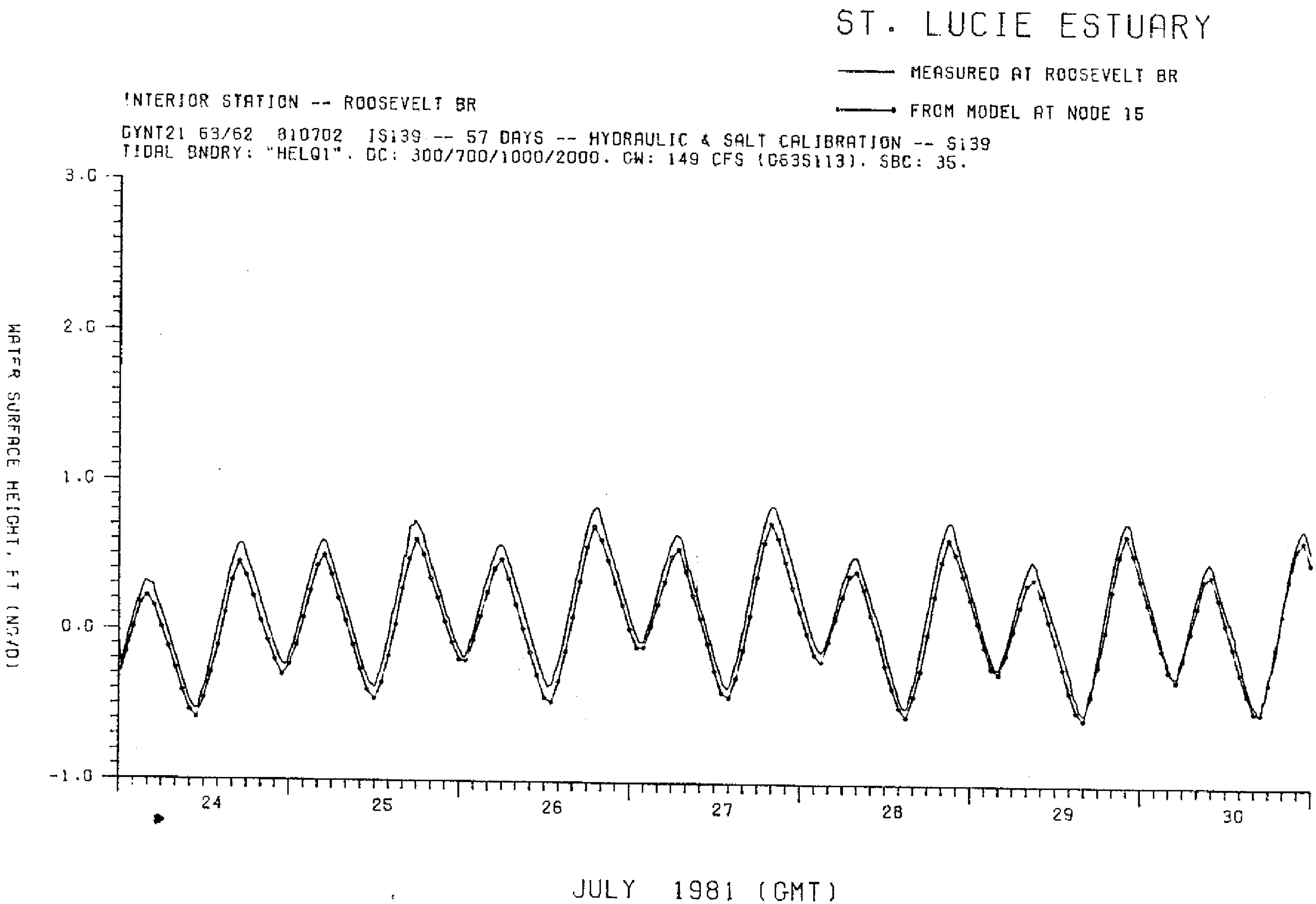

ST. LUCIE ESTUARY
MEASURED AT SANDPIPER BAY
FROM MODEL AT NODE 28
INTERIOR STATION -- SANDPIPER BAY
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. CW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
14
15
16
17
18
19
20
AUGUST 1981 (GMT)

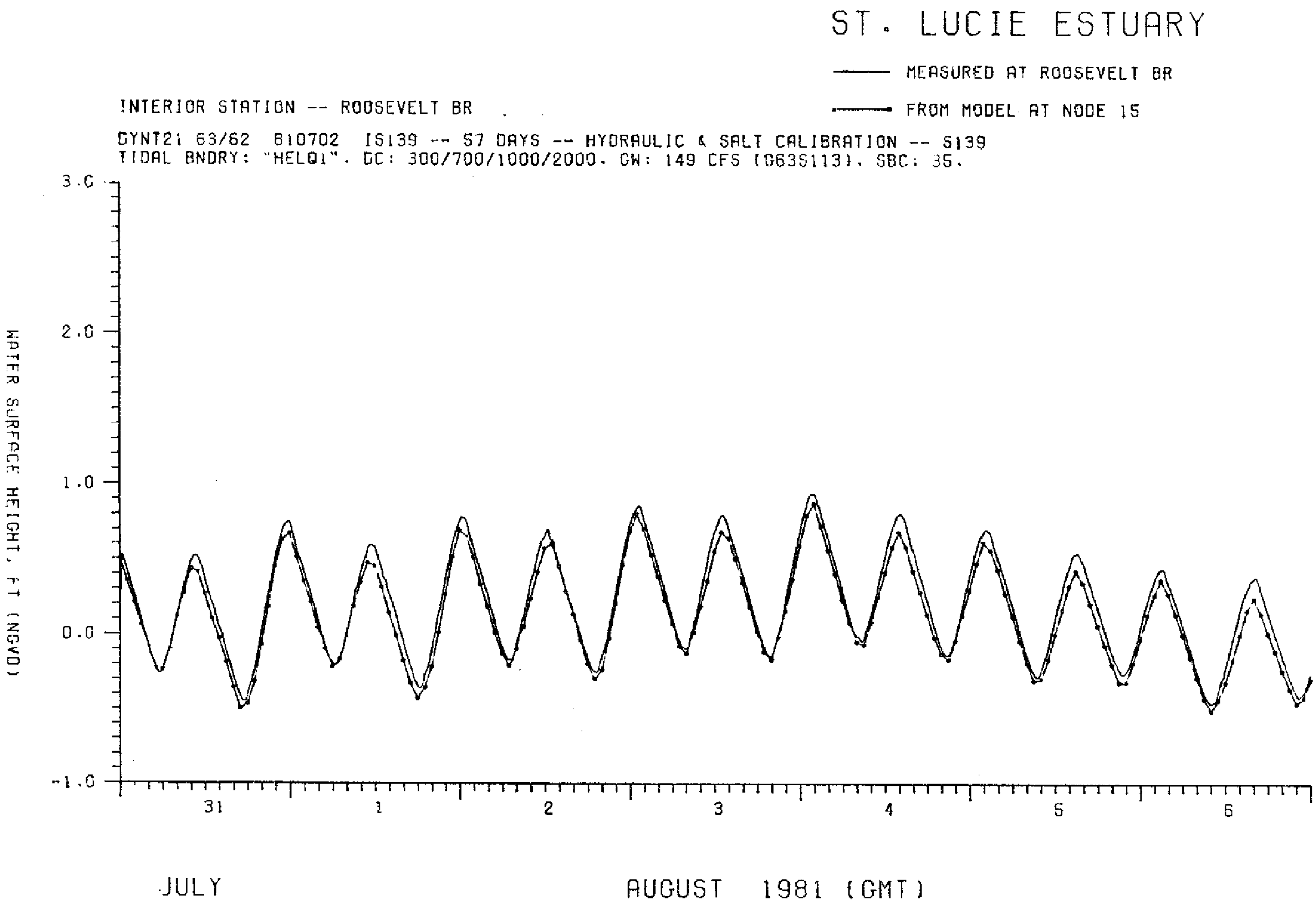

ST. LUCIE ESTUARY
MEASURED AT SANDPIPER BAY
FROM MODEL AT NODE 28
INTERIOR STATION -- SANDPIPER BAY
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. CW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
21
22
23
24
25
26
27
AUGUST 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
3
4
5
6
7
8
9
JULY 1981 (GMT)

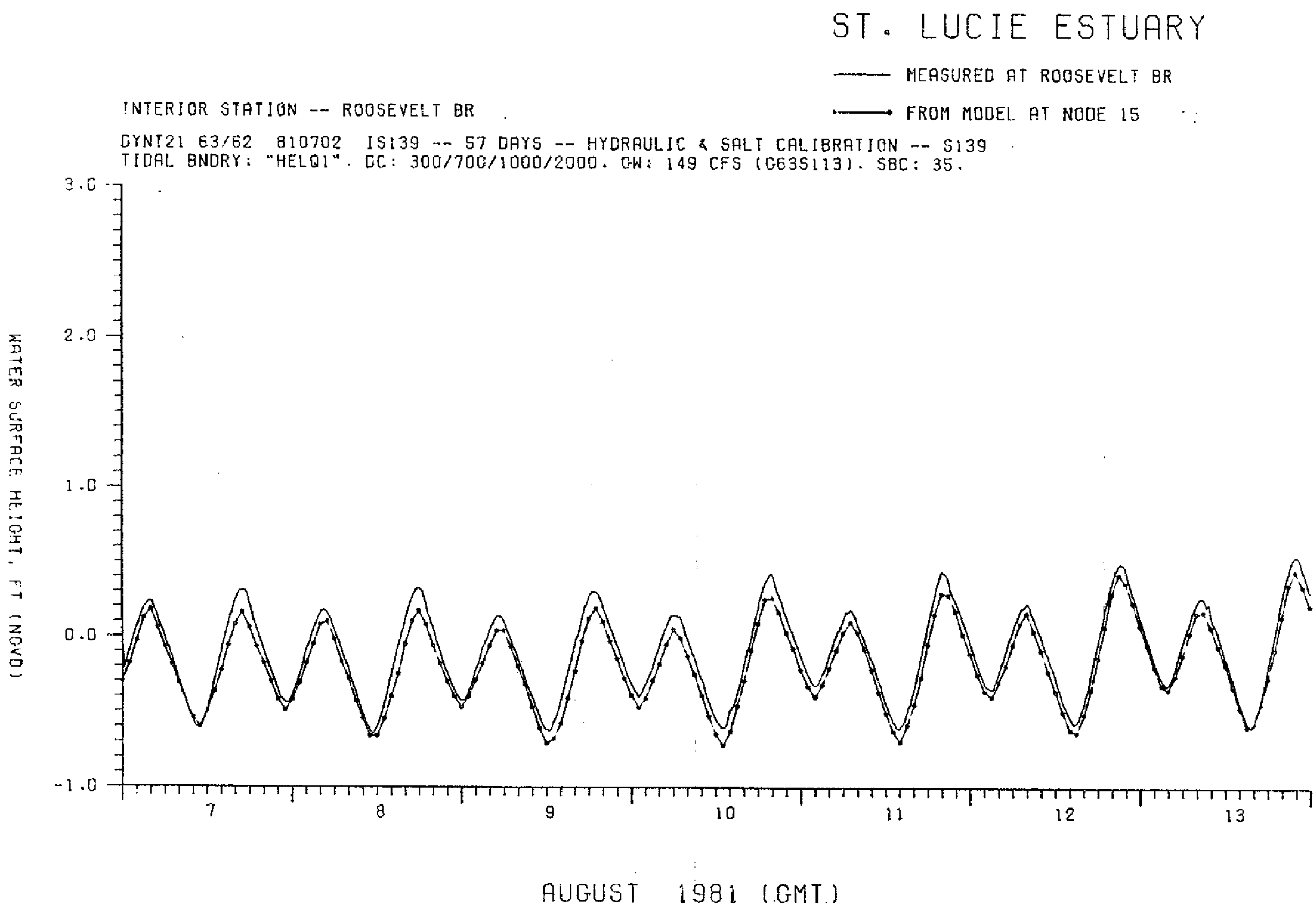

ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELG1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
10
11
12
13
14
15
16
JULY 1981 (GMT)

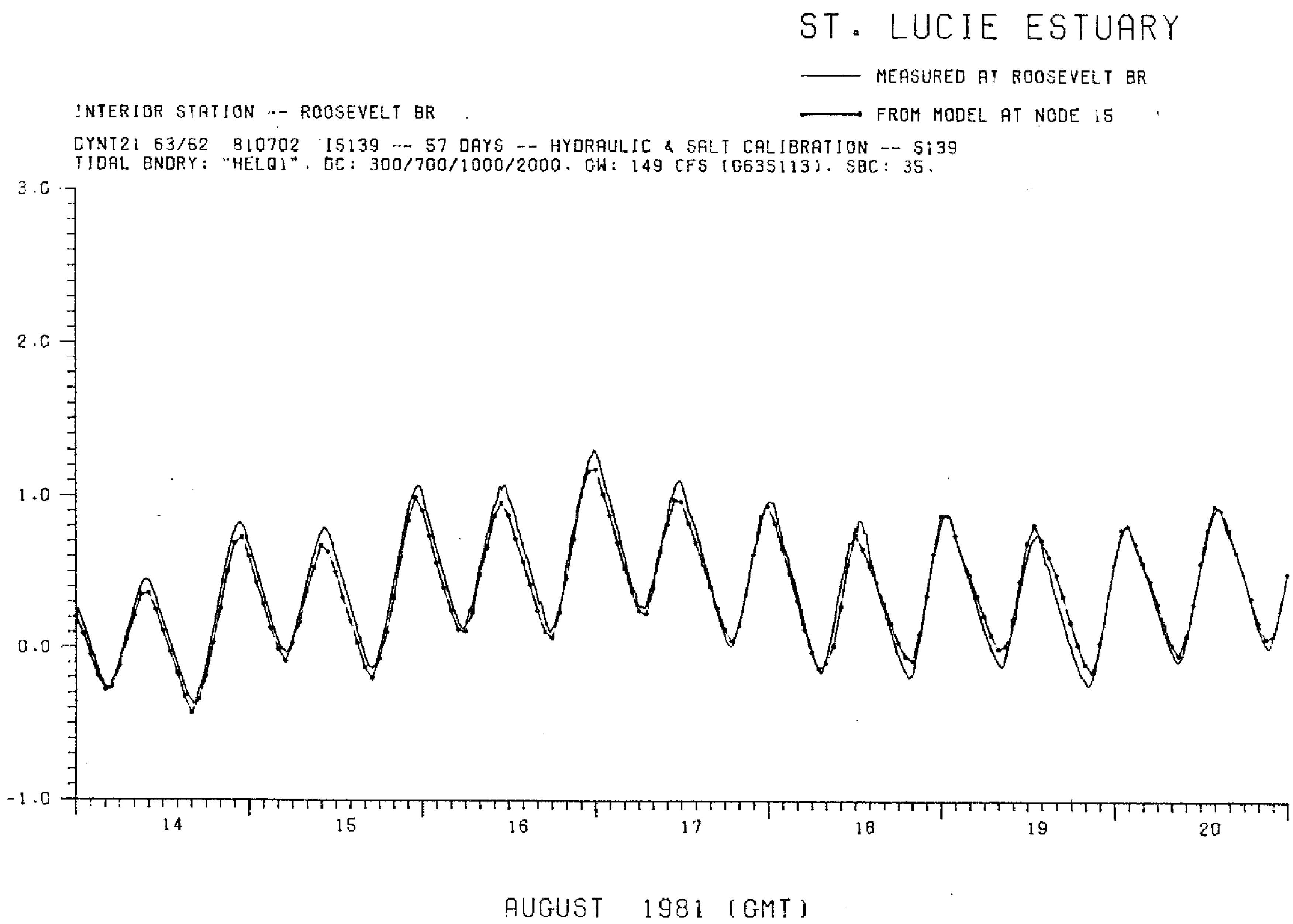

ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
17
18
19
20
21
22
23
JULY 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
24
25
26
27
28
29
30
JULY 1981 (GMT)

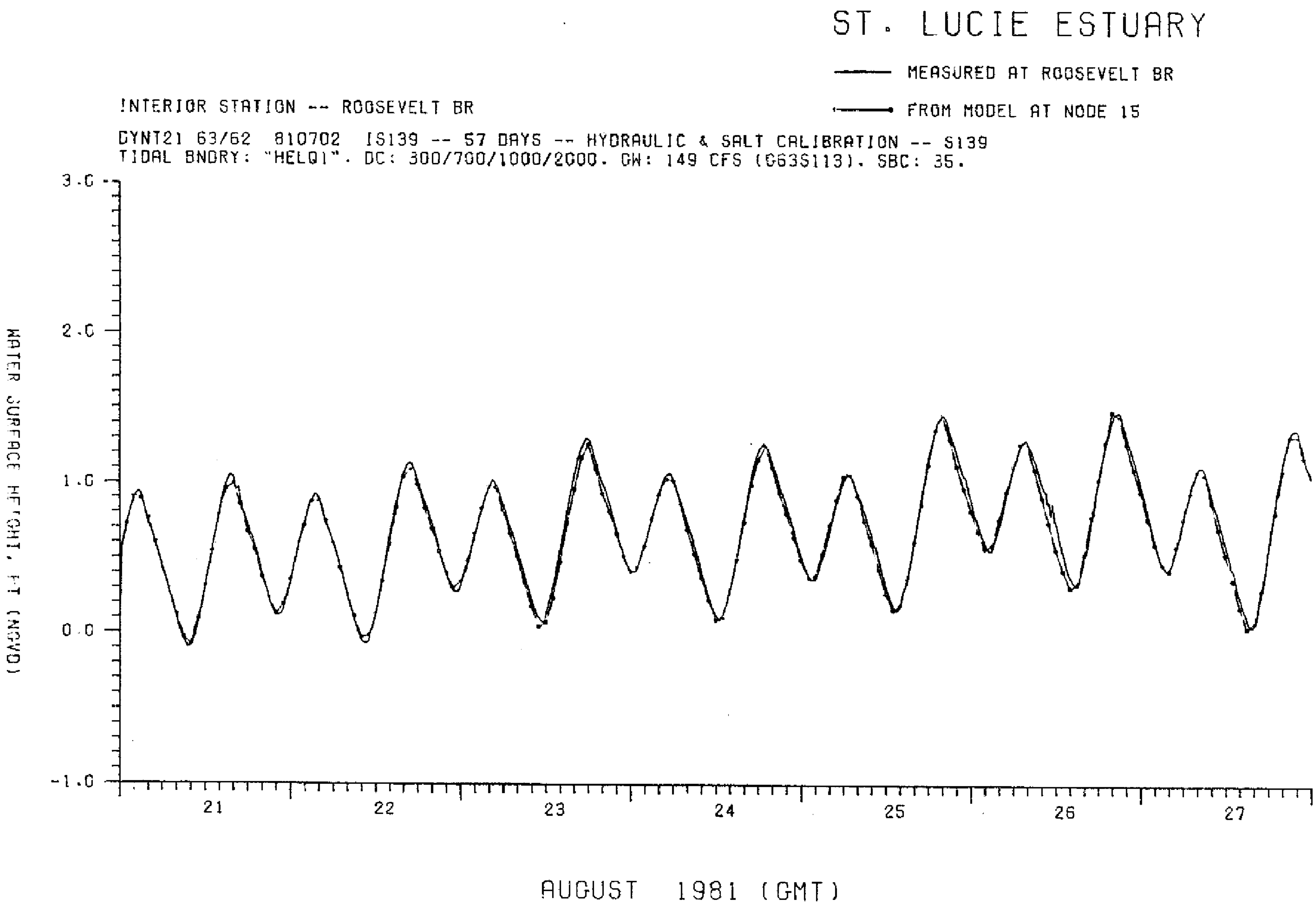


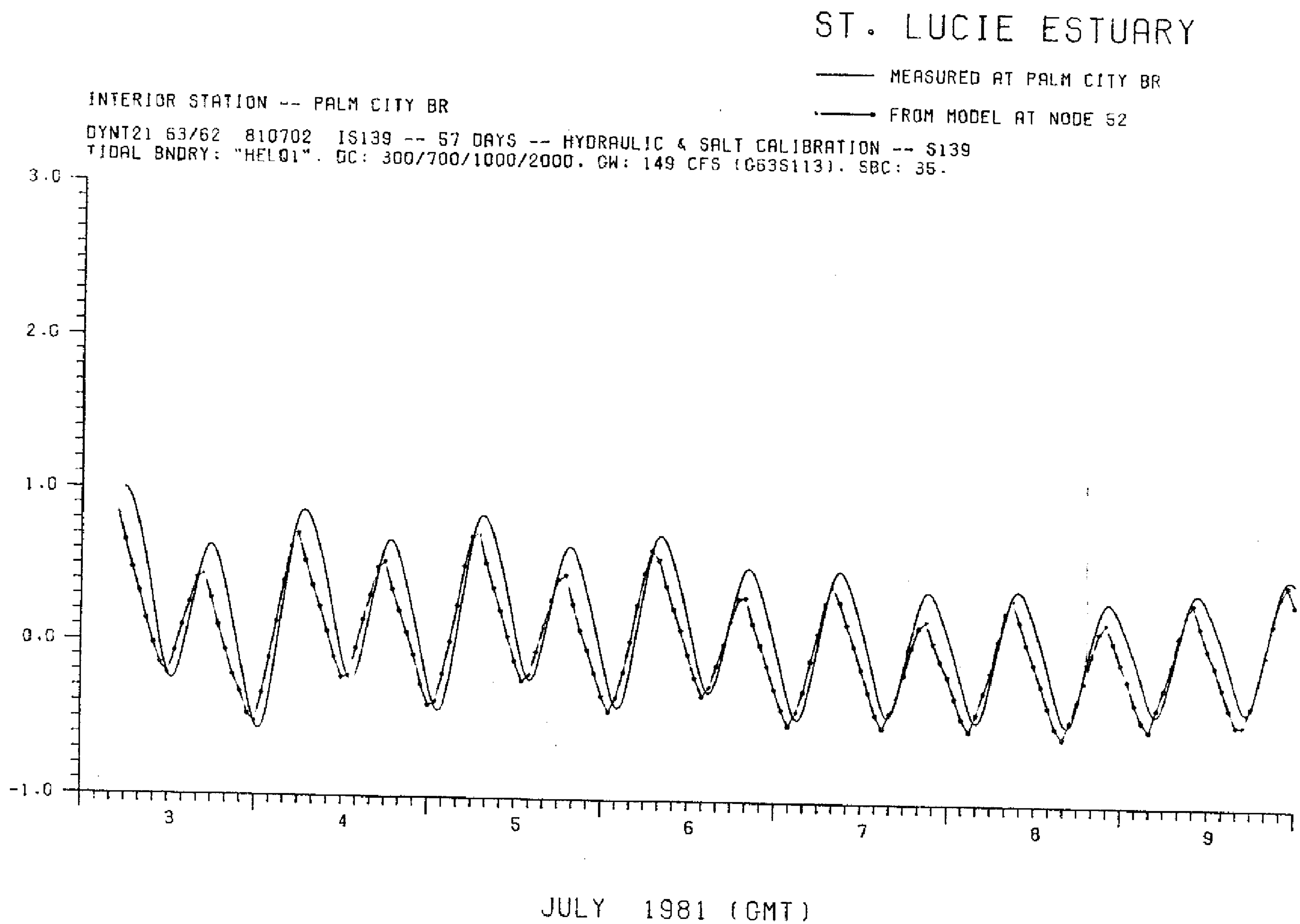
ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
31
1
2
3
4
5
6
JULY
AUGUST 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (C63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
7
8
9
10
11
12
13
AUGUST 1981 (GMT)

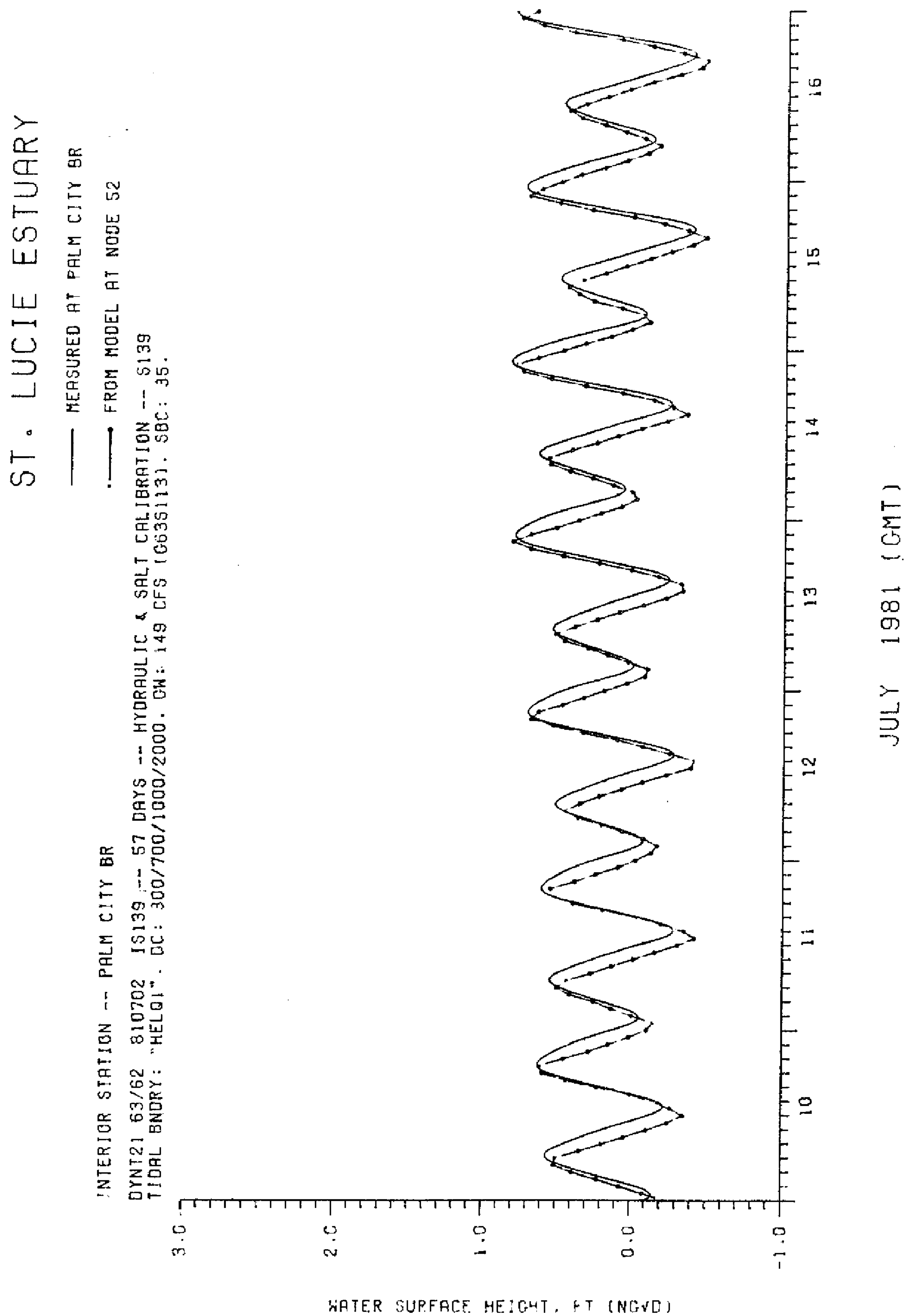


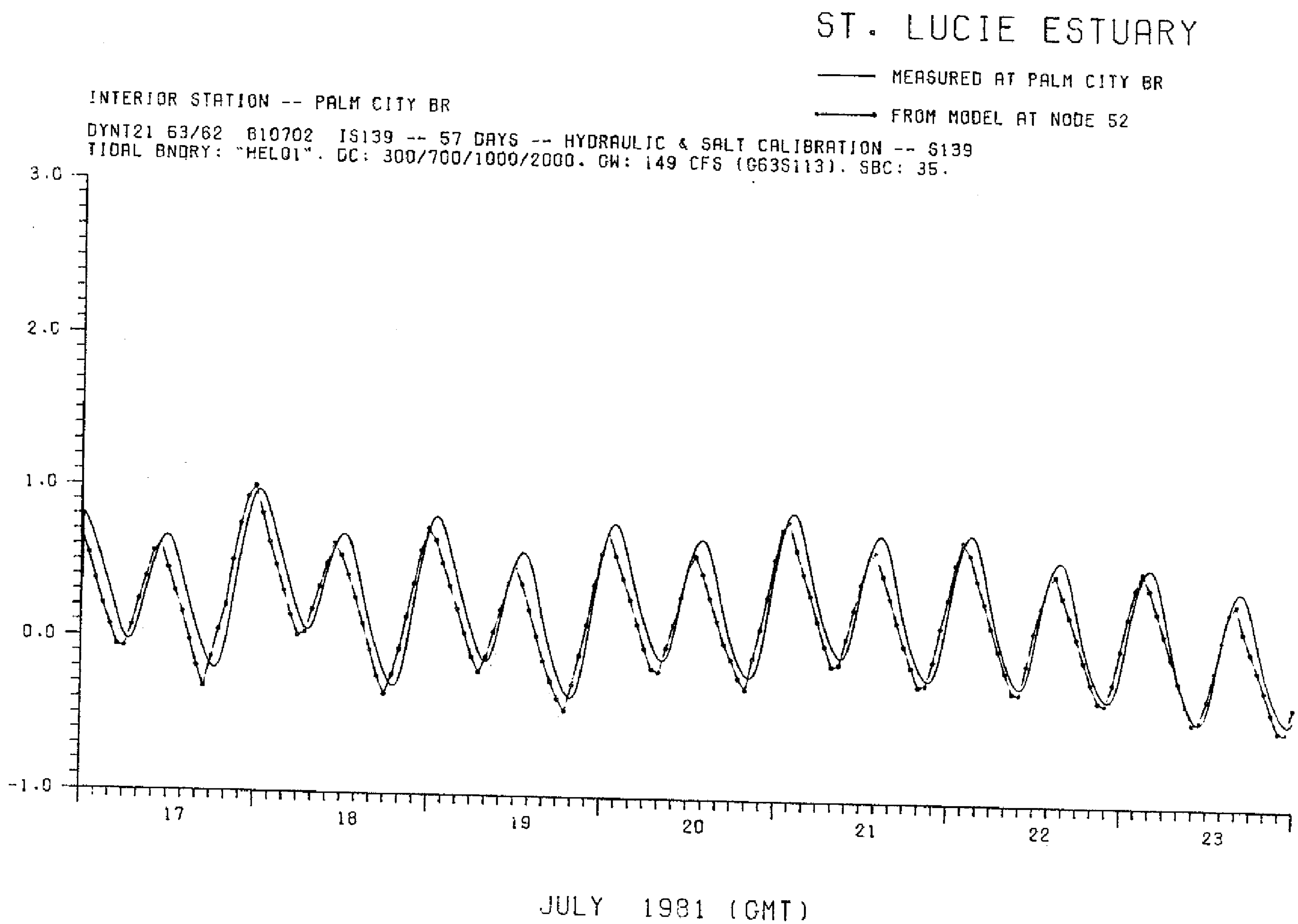
ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
CYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
14
15
16
17
18
19
20
AUGUST 1981 (GMT)

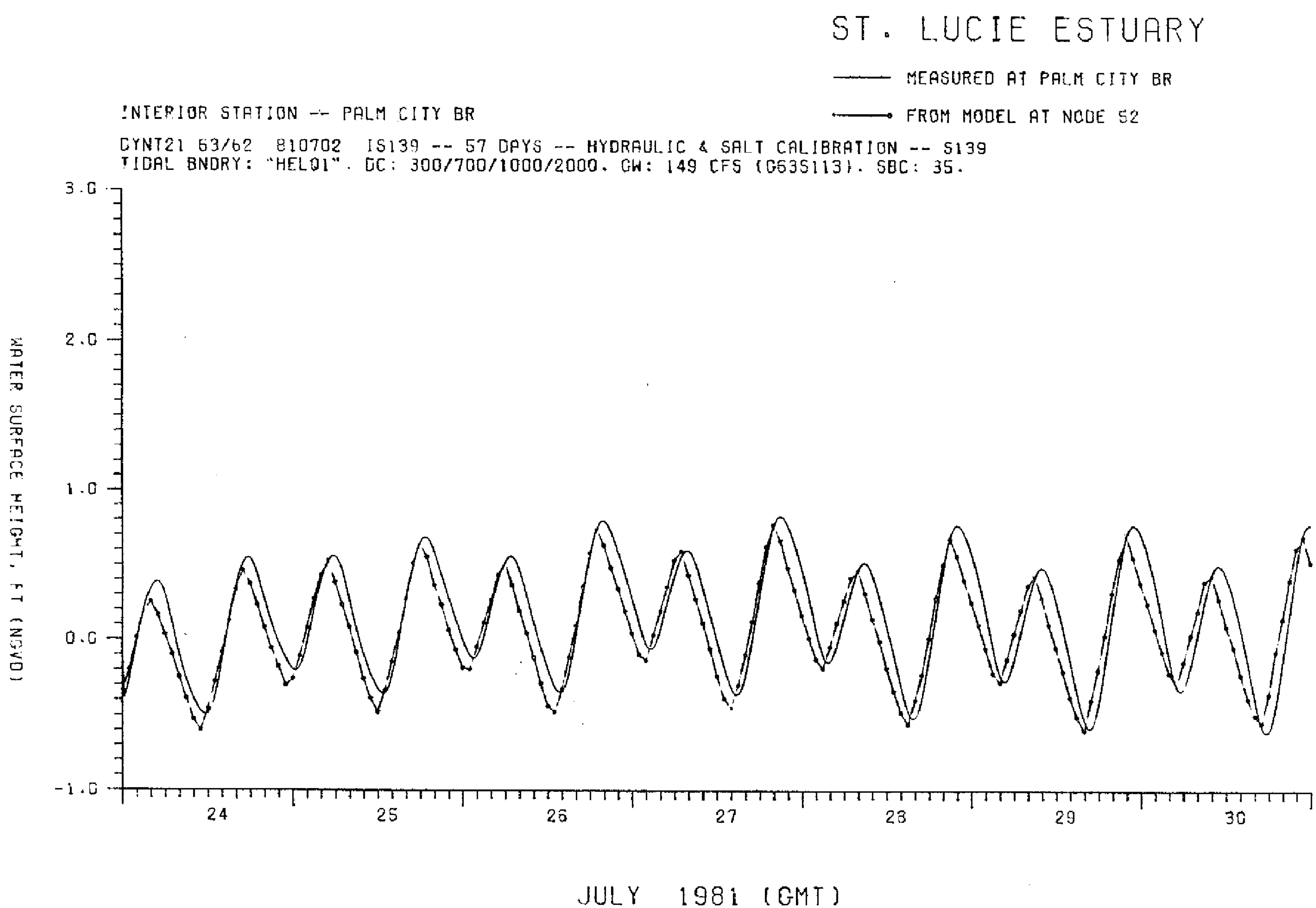

ST. LUCIE ESTUARY
MEASURED AT ROOSEVELT BR
FROM MODEL AT NODE 15
INTERIOR STATION -- ROOSEVELT BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
21
22
23
24
25
26
27
AUGUST 1981 (GMT)

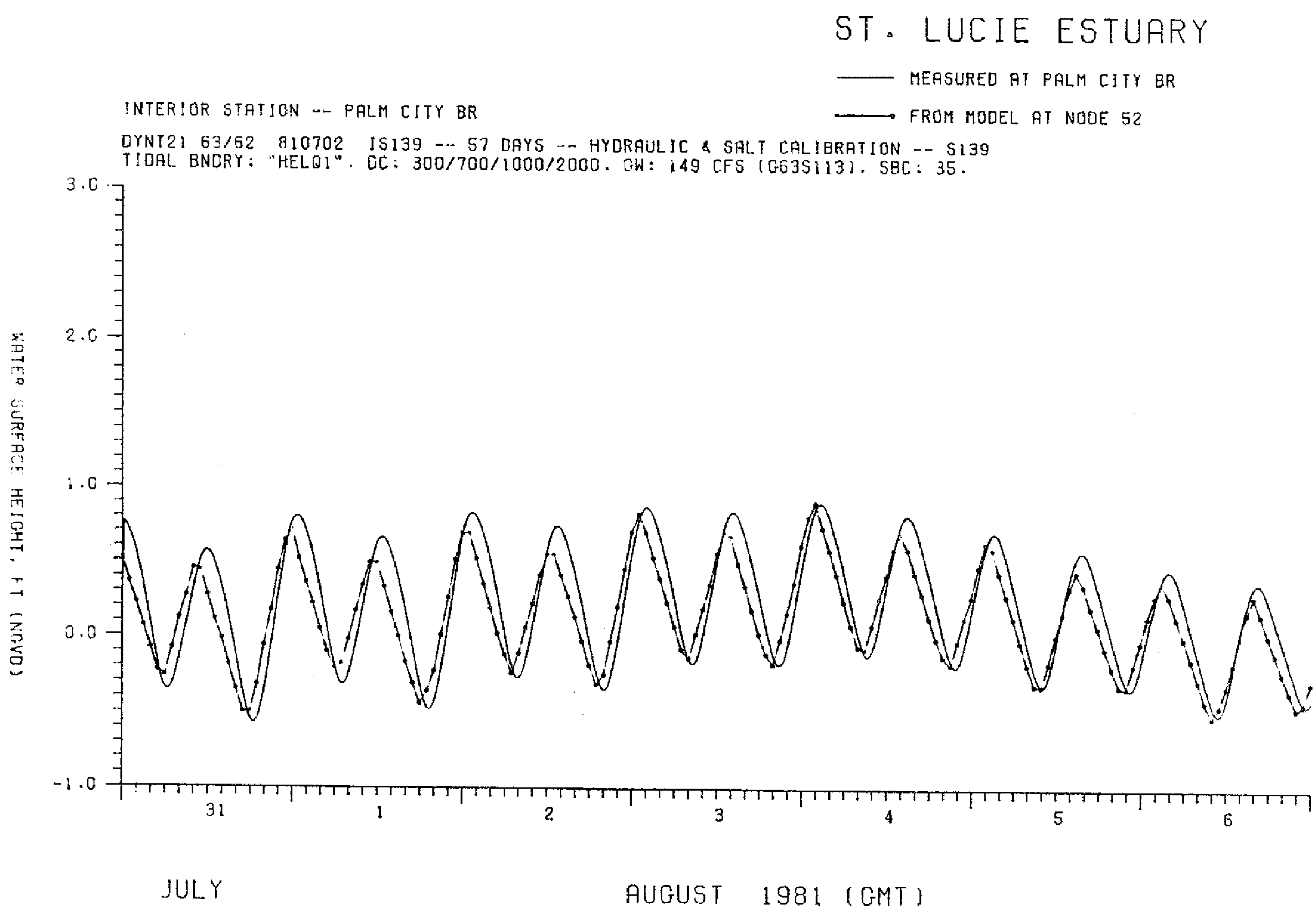


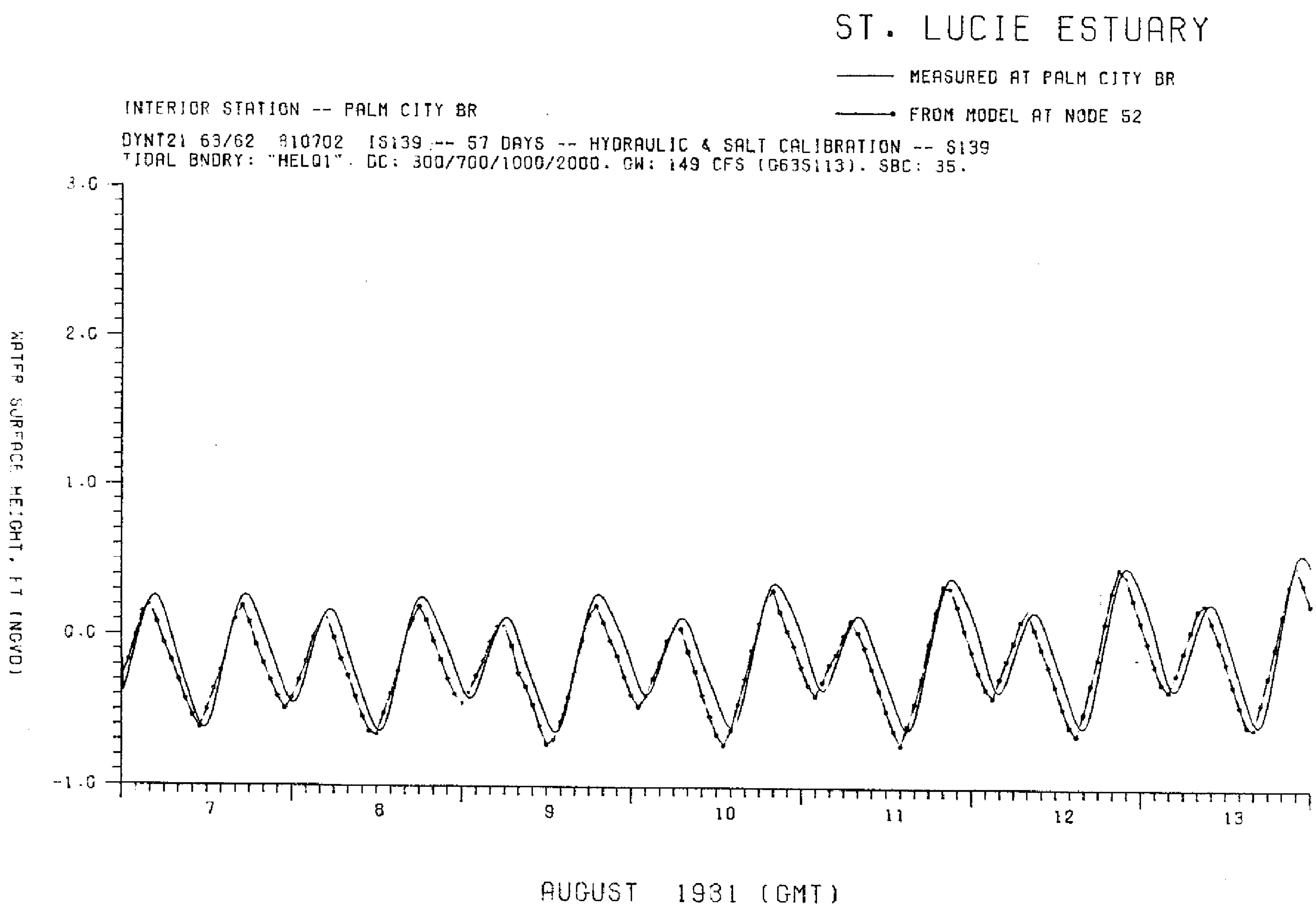
ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL01". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
3
4
5
6
7
8
9
JULY 1981 (GMT)

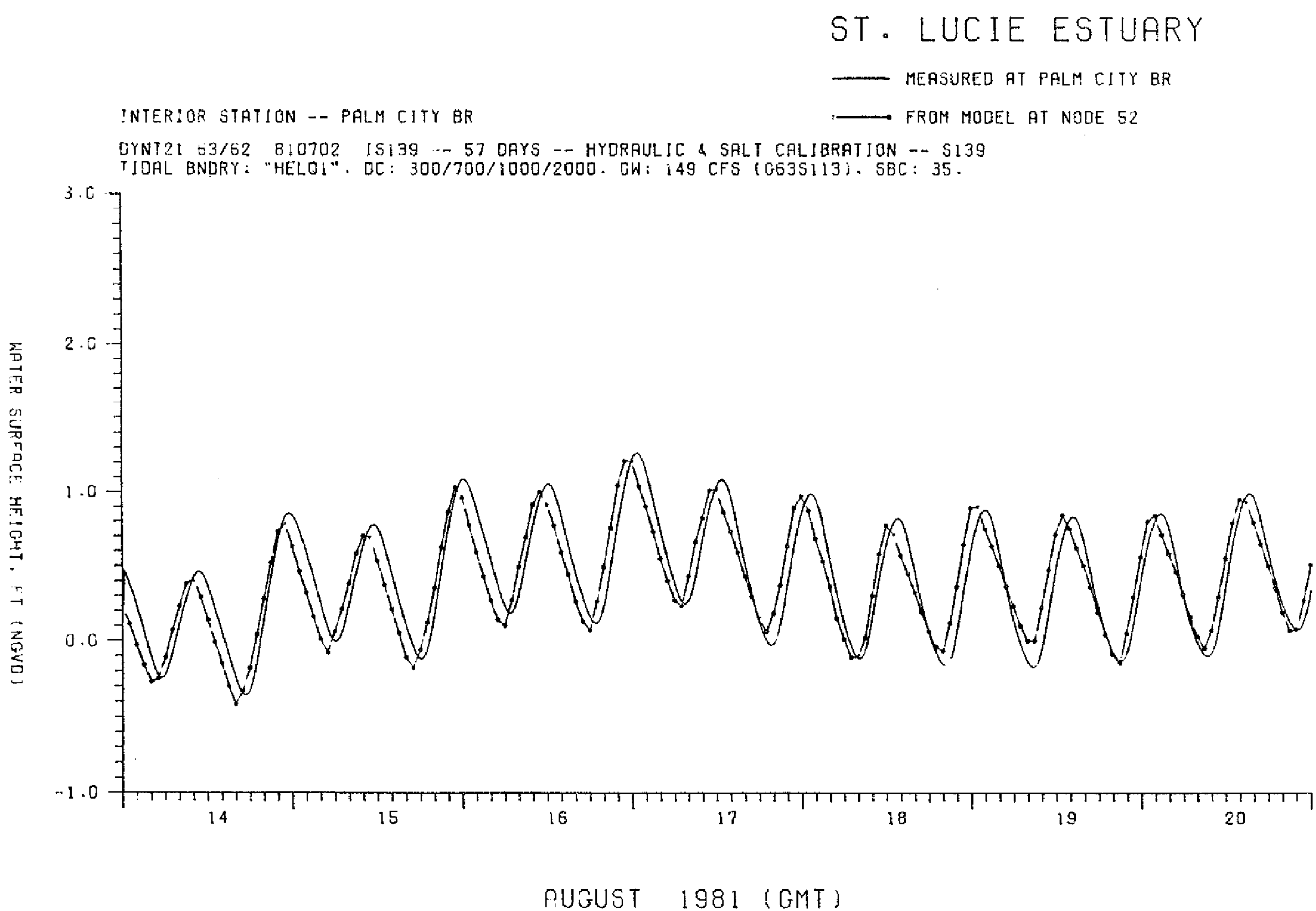

ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQI". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
10
11
12
13
14
15
16
JULY 1981 (GMT)

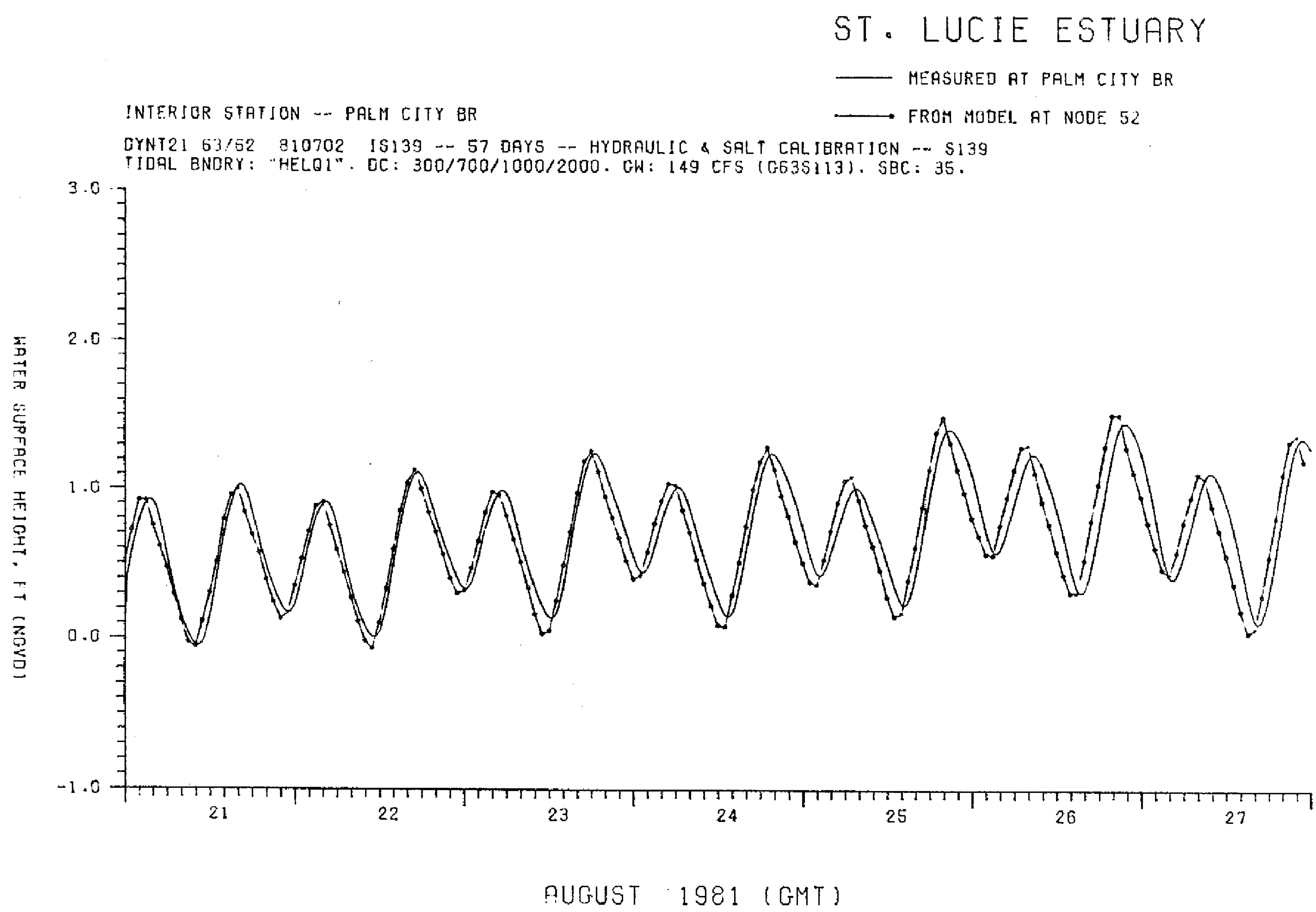

ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL01". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
17
18
19
20
21
22
23
JULY 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
CYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL01". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
24
25
26
27
28
29
30
JULY 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
31
1
2
3
4
5
6
JULY
AUGUST 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
7
8
9
10
11
12
13
AUGUST 1931 (GMT)


ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL01". DC: 300/700/1000/2000. GW: 149 CFS (063S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
14
15
16
17
18
19
20
AUGUST 1981 (GMT)


ST. LUCIE ESTUARY
MEASURED AT PALM CITY BR
FROM MODEL AT NODE 52
INTERIOR STATION -- PALM CITY BR
DYNT21 63/62 810702 IS139 -- 57 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HELQ1". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
21
22
23
24
25
26
27
AUGUST 1981 (GMT)

APPENDIX B

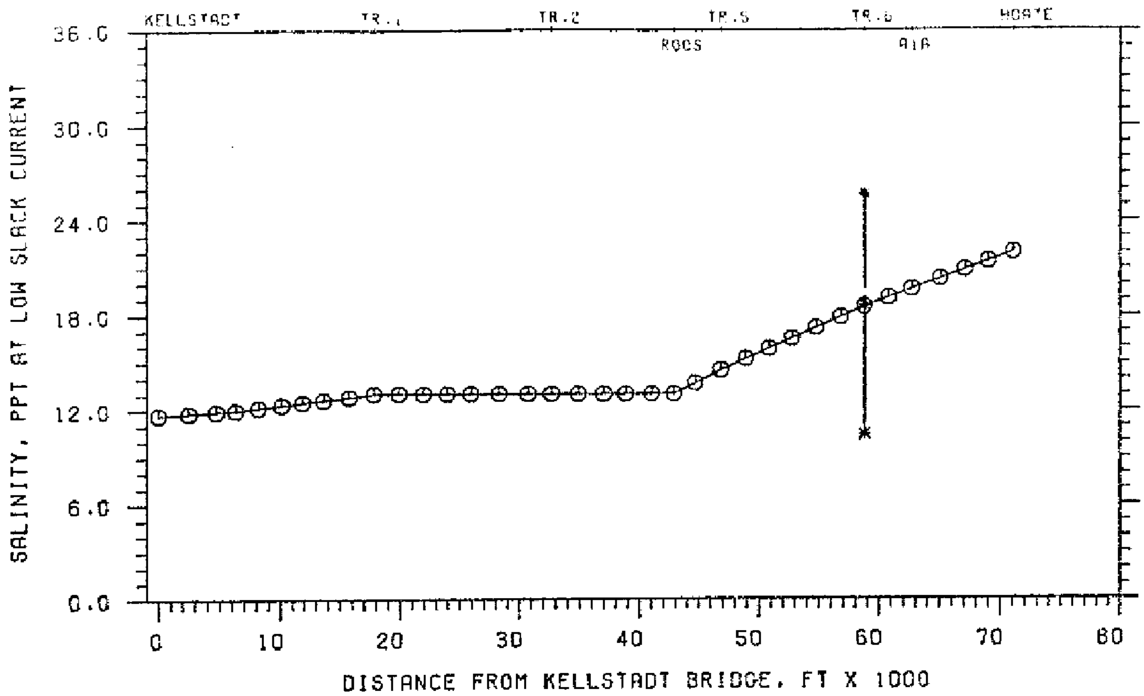
GROUND WATER CALIBRATION

February 18 through March 11, 1981

NORTH FORK

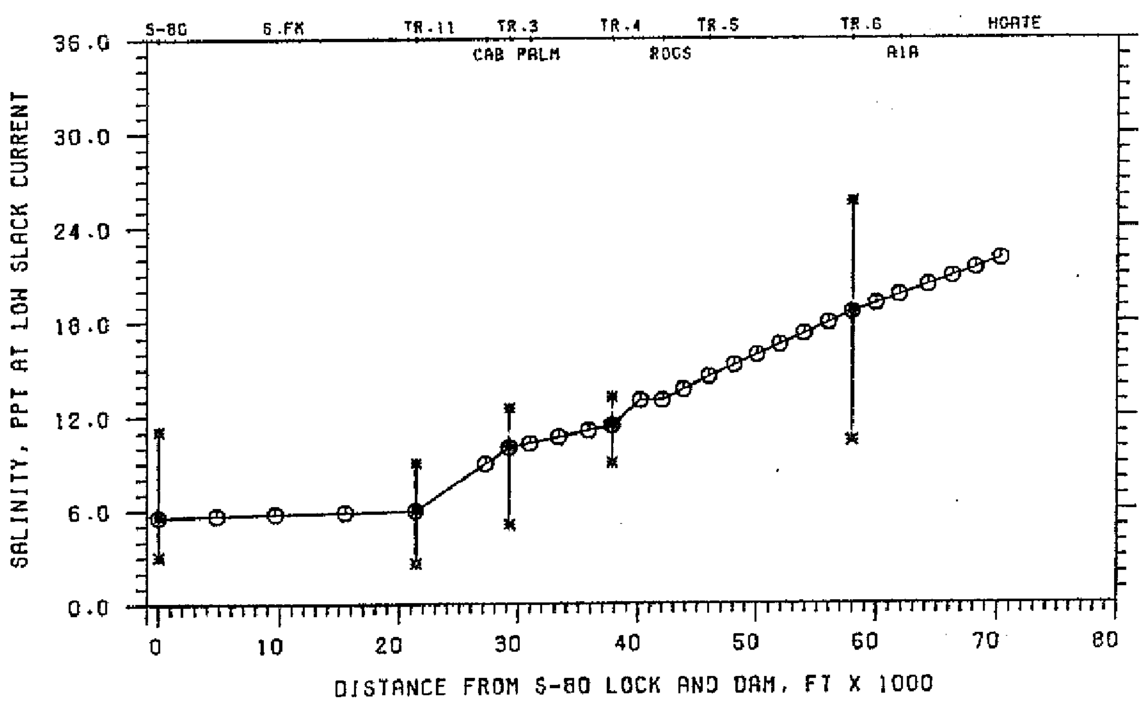
ST. LUCIE ESTUARY

DYNT21 62/62 810218 TS136 -- 23 DAYS -- GROUNDWATER CALIBRATION -- S136
TIDAL BNDRY: "HEL81", GC: 300/700/1000/2000, CW: 149 CFS (G635113), SBC: 35.



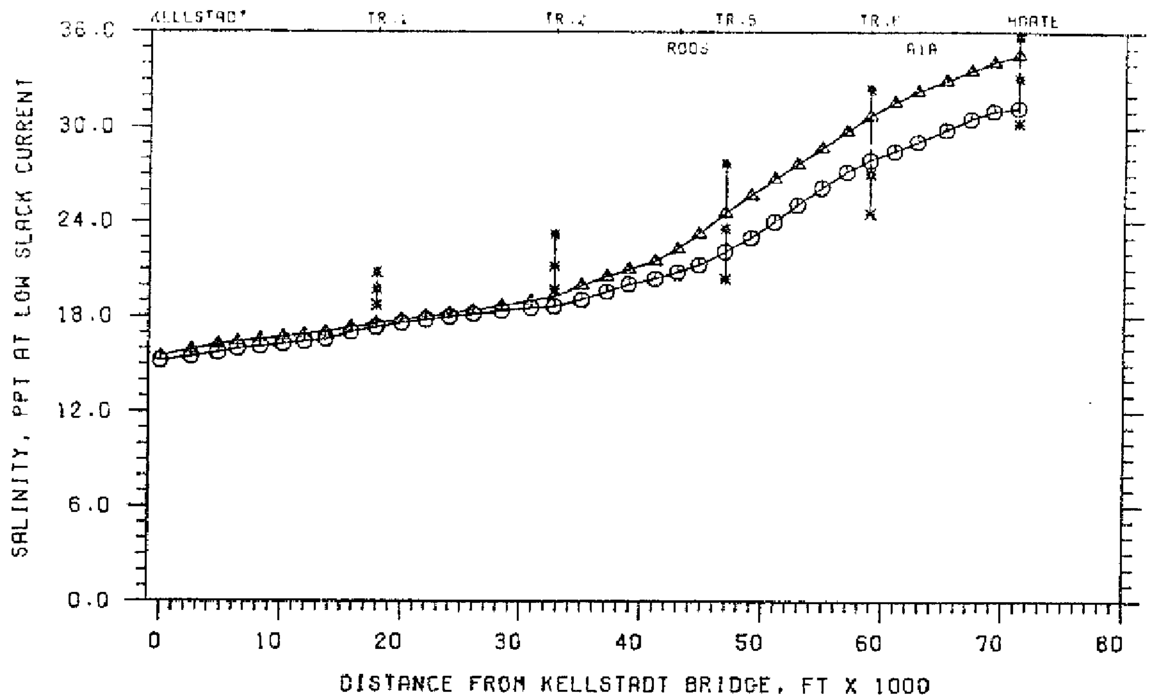
MEASURED
FEBRUARY 18, 1981
FROM MODEL:
810218 0500: LOW TIDE

SOUTH FORK



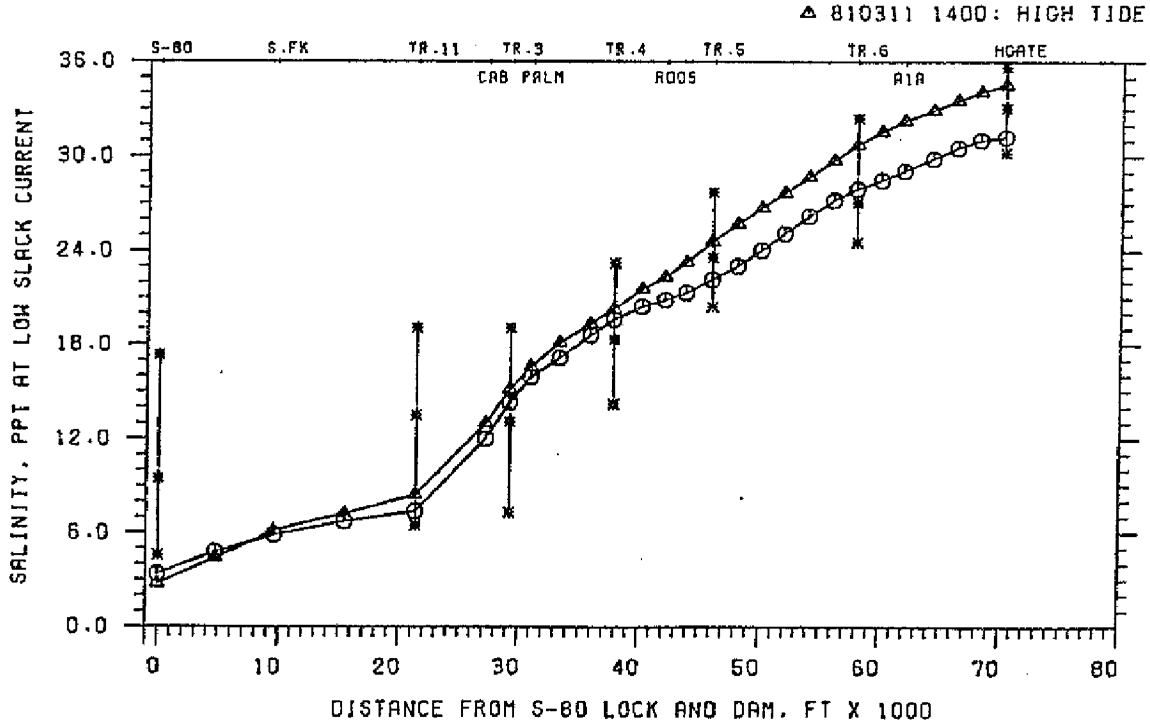
NORTH FORK ST. LUCIE ESTUARY

SYNT21 63/62 810213 1:136 -- 21 DAYS -- GROUNDWATER CALIBRATION -- S136
TIDAL BNDRY: HEL81', CC, 300/700/1000/2000, FW: 149 CFS (96/9,13), SBC, 35,



MEASURED
MARCH 11, 1981
FROM MODEL:
810311 0900: LOW TIDE
810311 1400: HIGH TIDE

SOUTH FORK



APPENDIX C

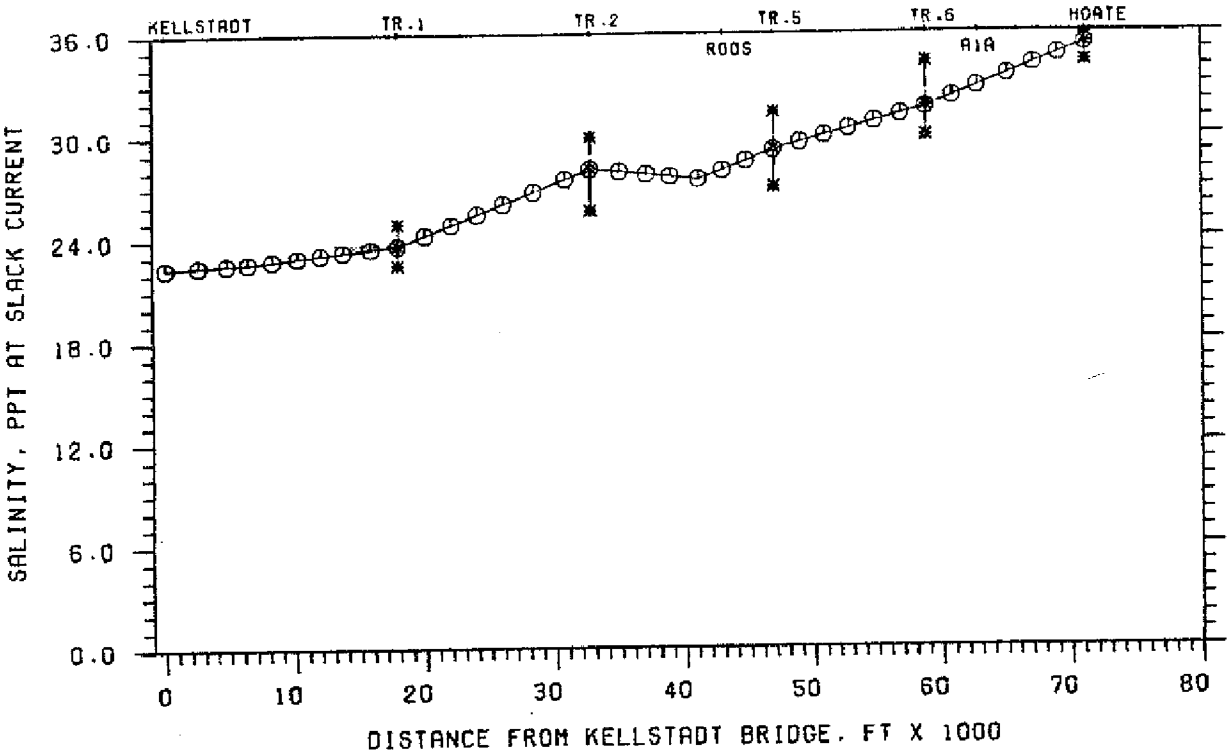
HYDRODYNAMIC AND SALT CALIBRATION

July 15 through August 27, 1981

ST. LUCIE ESTUARY

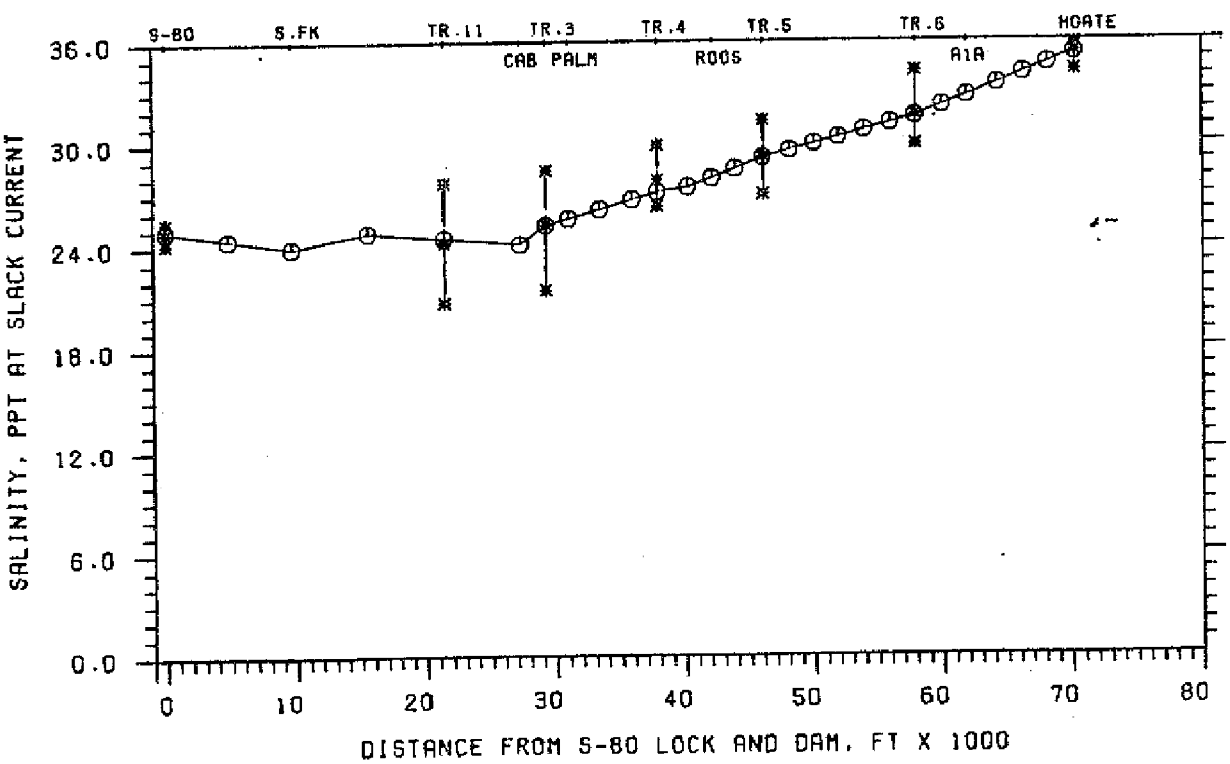
NORTH FORK

GYNT21 63/62 810701 IS139 -- 58 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.



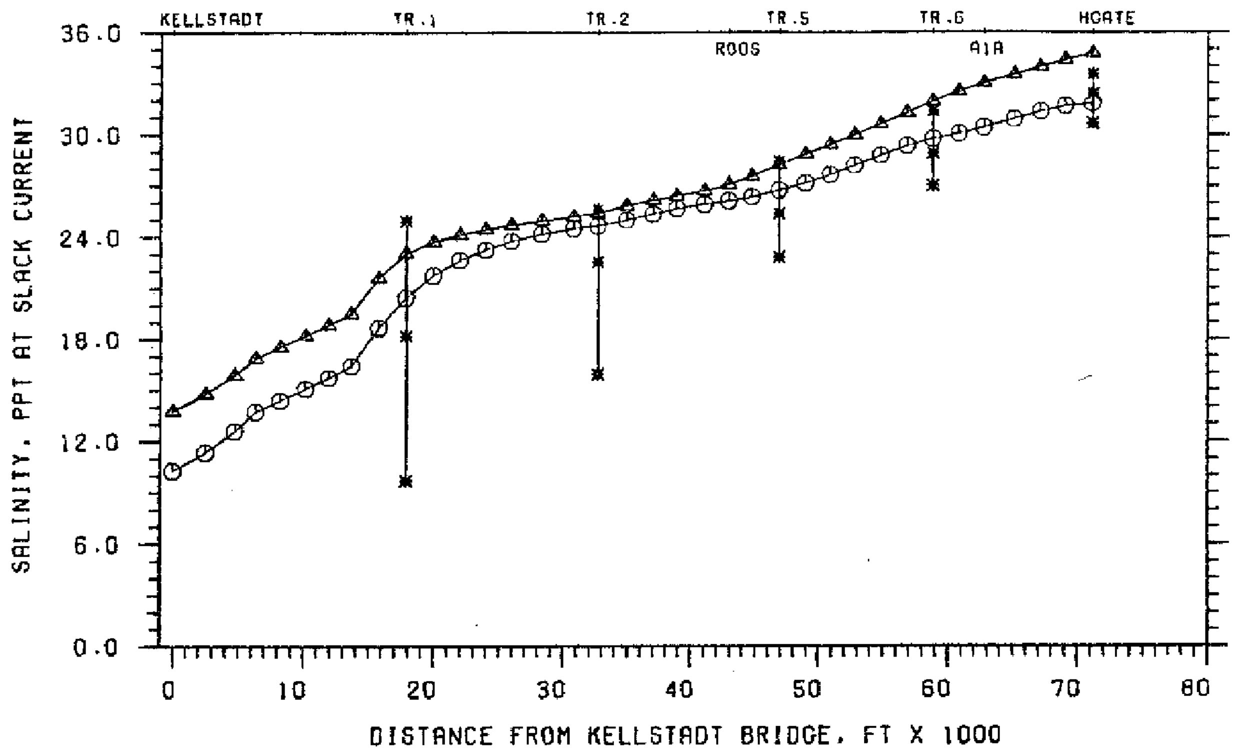
MEASURED
JULY 15, 1981
FROM MODEL:
810715 0400: LOW TIDE

SOUTH FORK



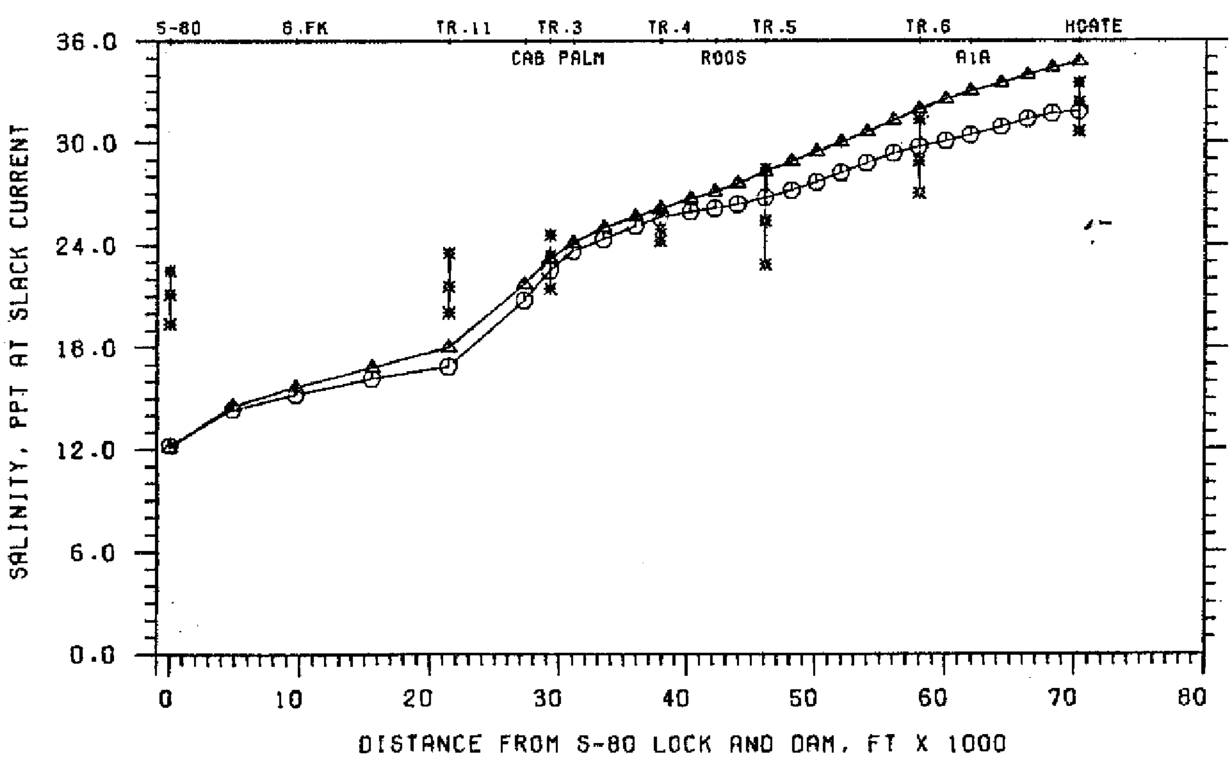
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 810701 (S139 -- 58 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 35.



MEASURED
JULY 23, 1981
FROM MODEL:
O 810723 0300: HIGH TIDE
Δ 810723 1000: LOW TIDE

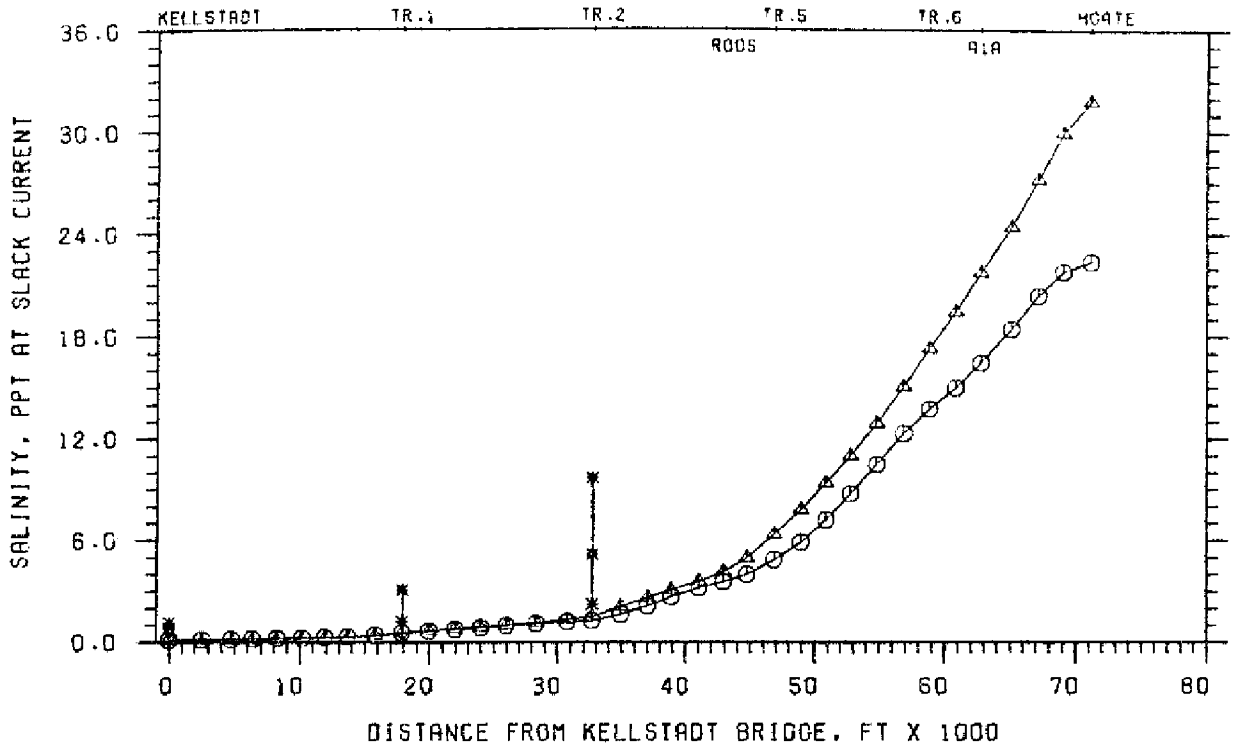
SOUTH FORK



NORTH FORK

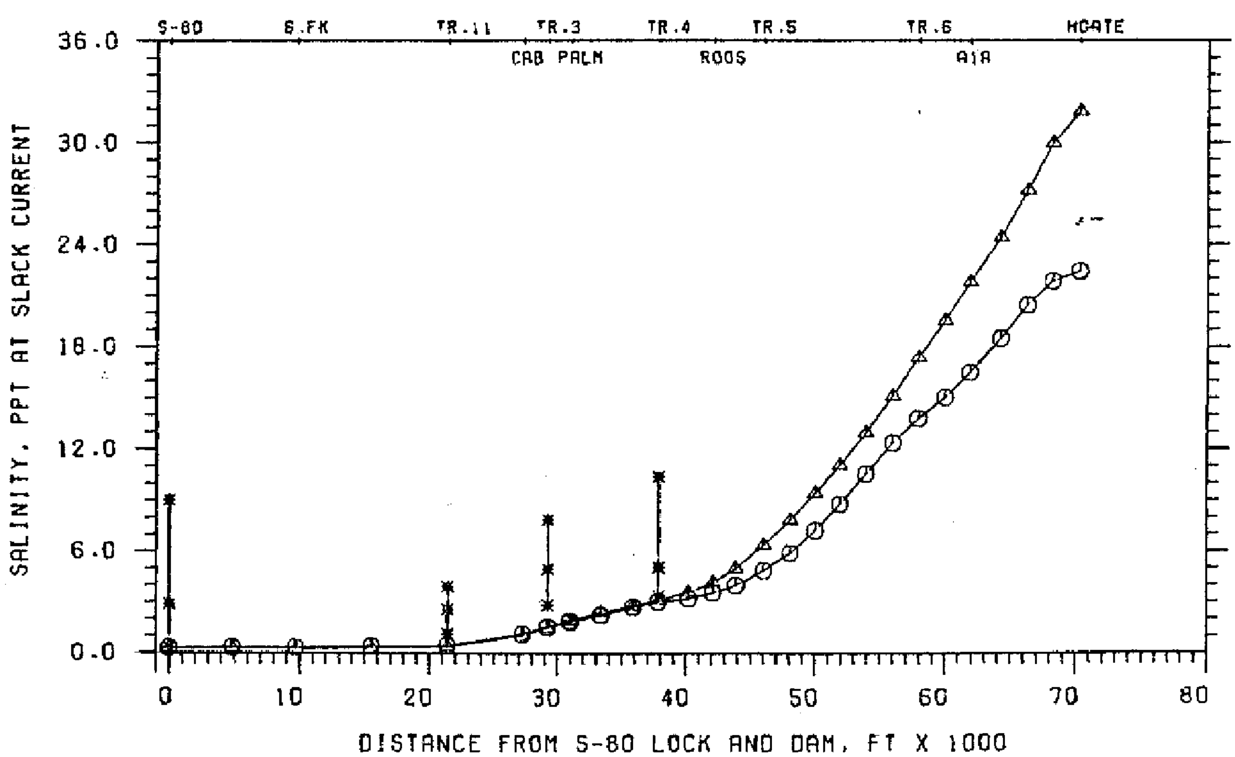
ST. LUCIE ESTUARY

DYNT21 63/62 810701 IS139 -- 58 DAYS -- HYDRAULIC & SALT CALIBRATION -- S139
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. QW: 149 CFS (G63S113). SBC: 35.



MEASURED
AUGUST 27, 1981
FROM MODEL:
O 810827 0300: LOW TIDE
△ 810827 0900: HIGH TIDE

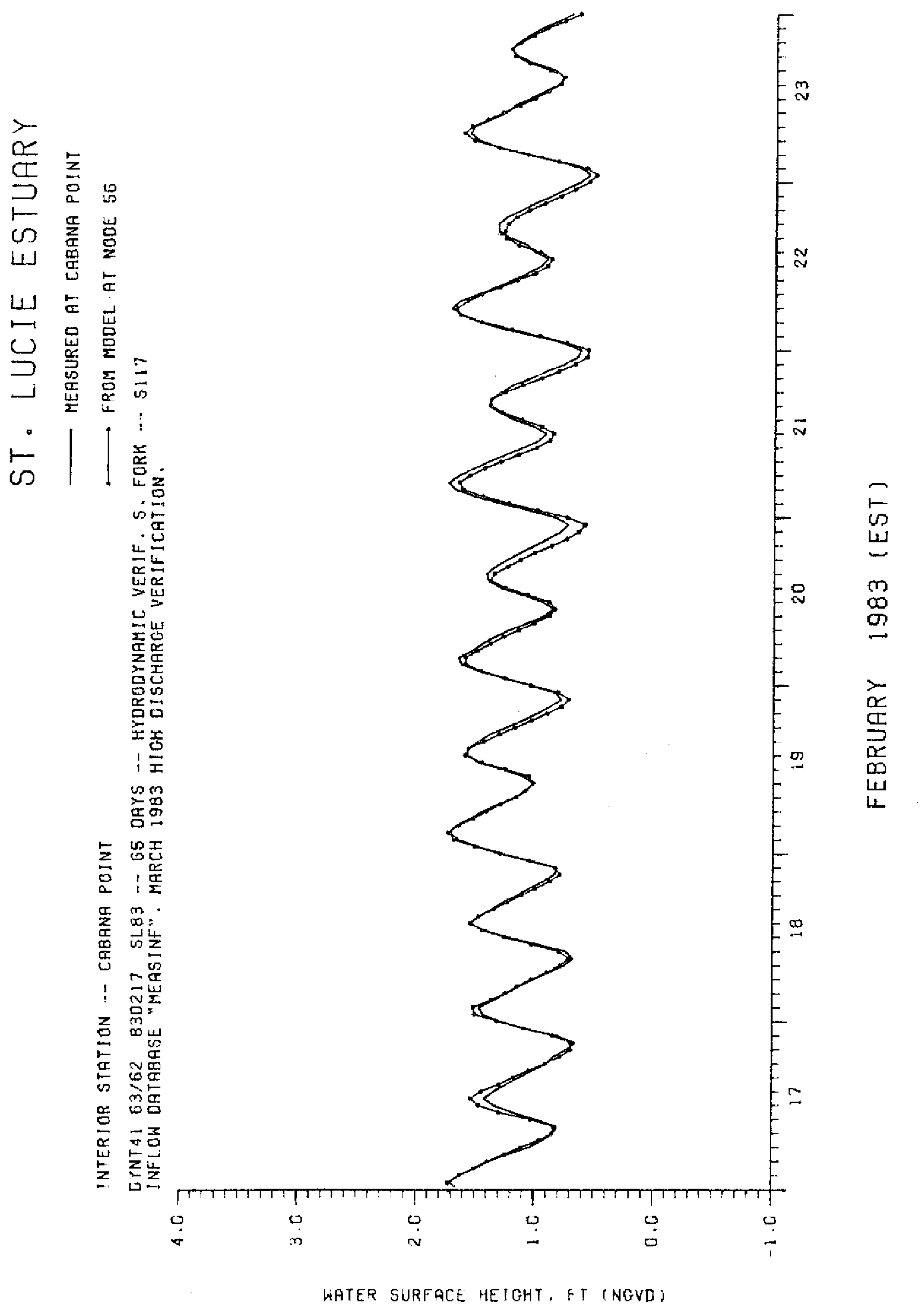
SOUTH FORK



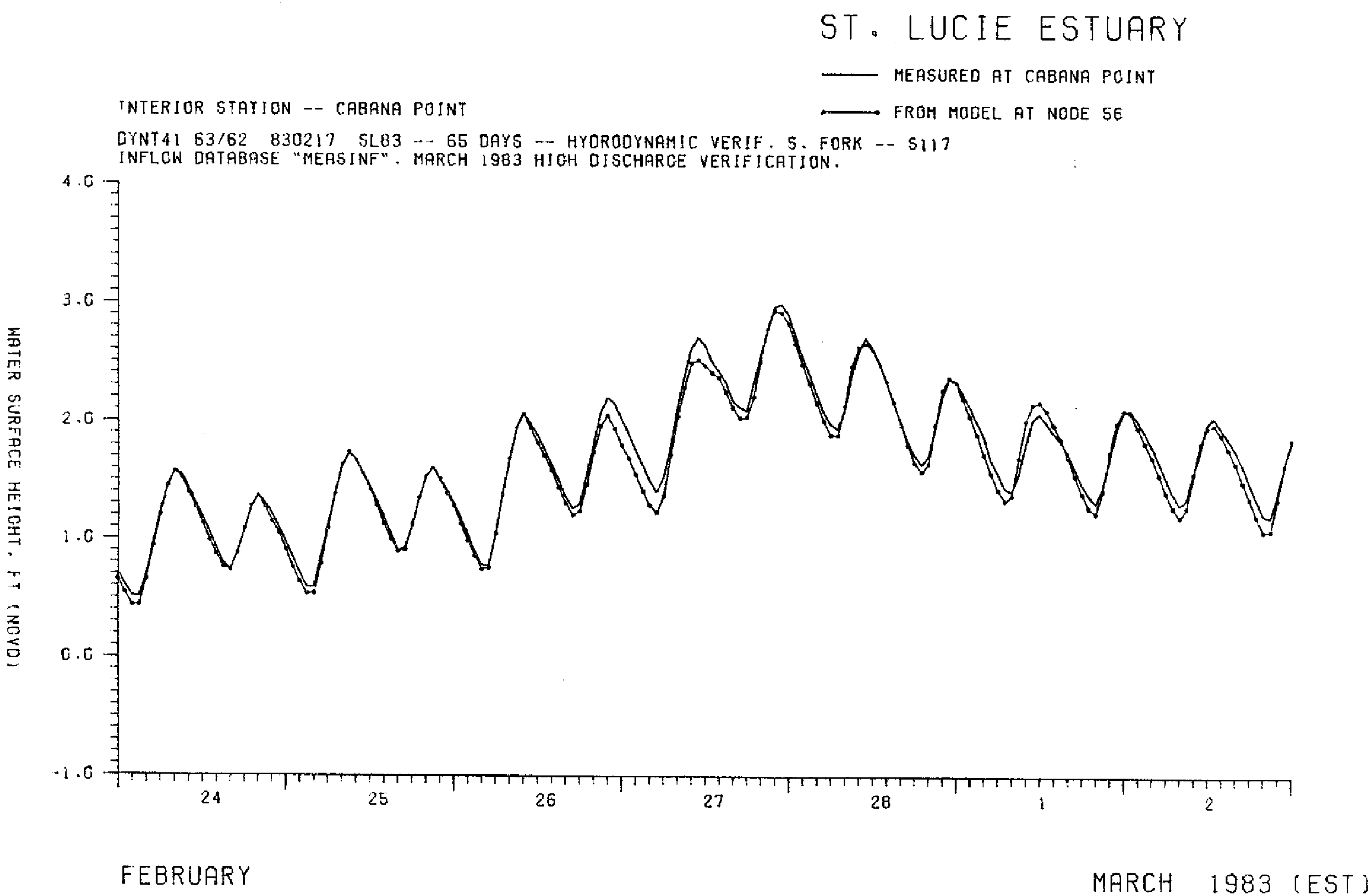
APPENDIX D

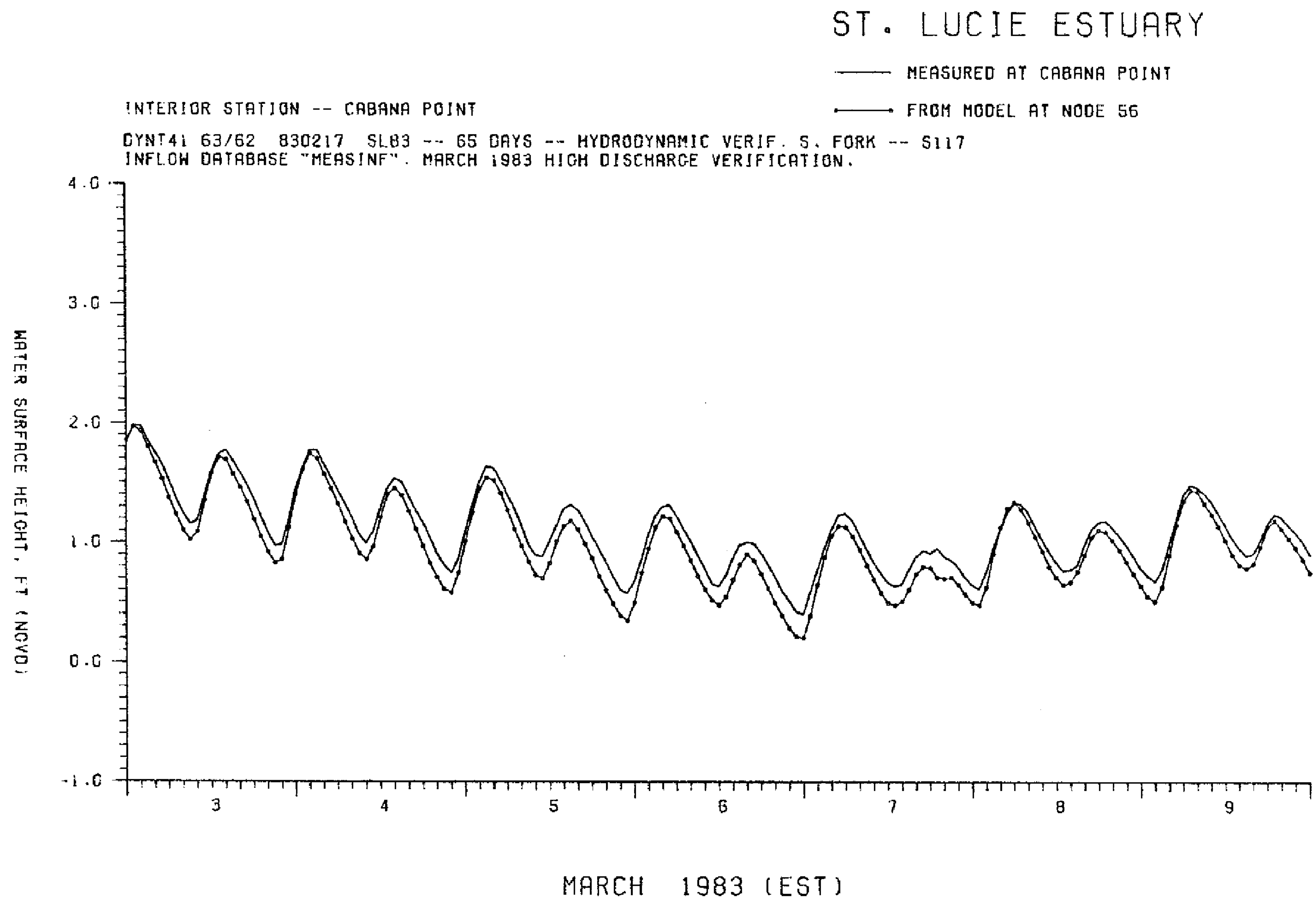
HYDRODYNAMIC VERIFICATION

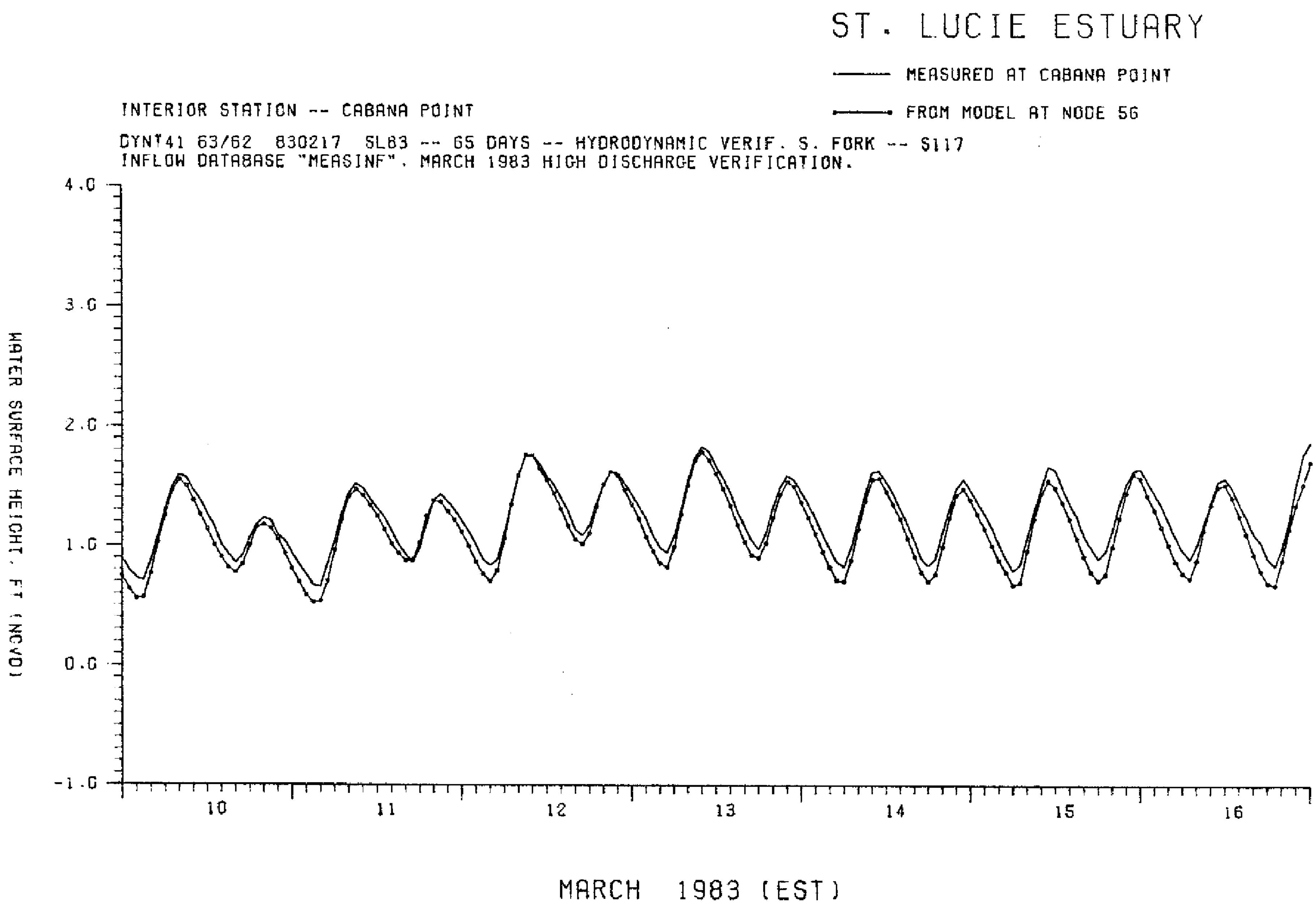
February 17 through April 21, 1983



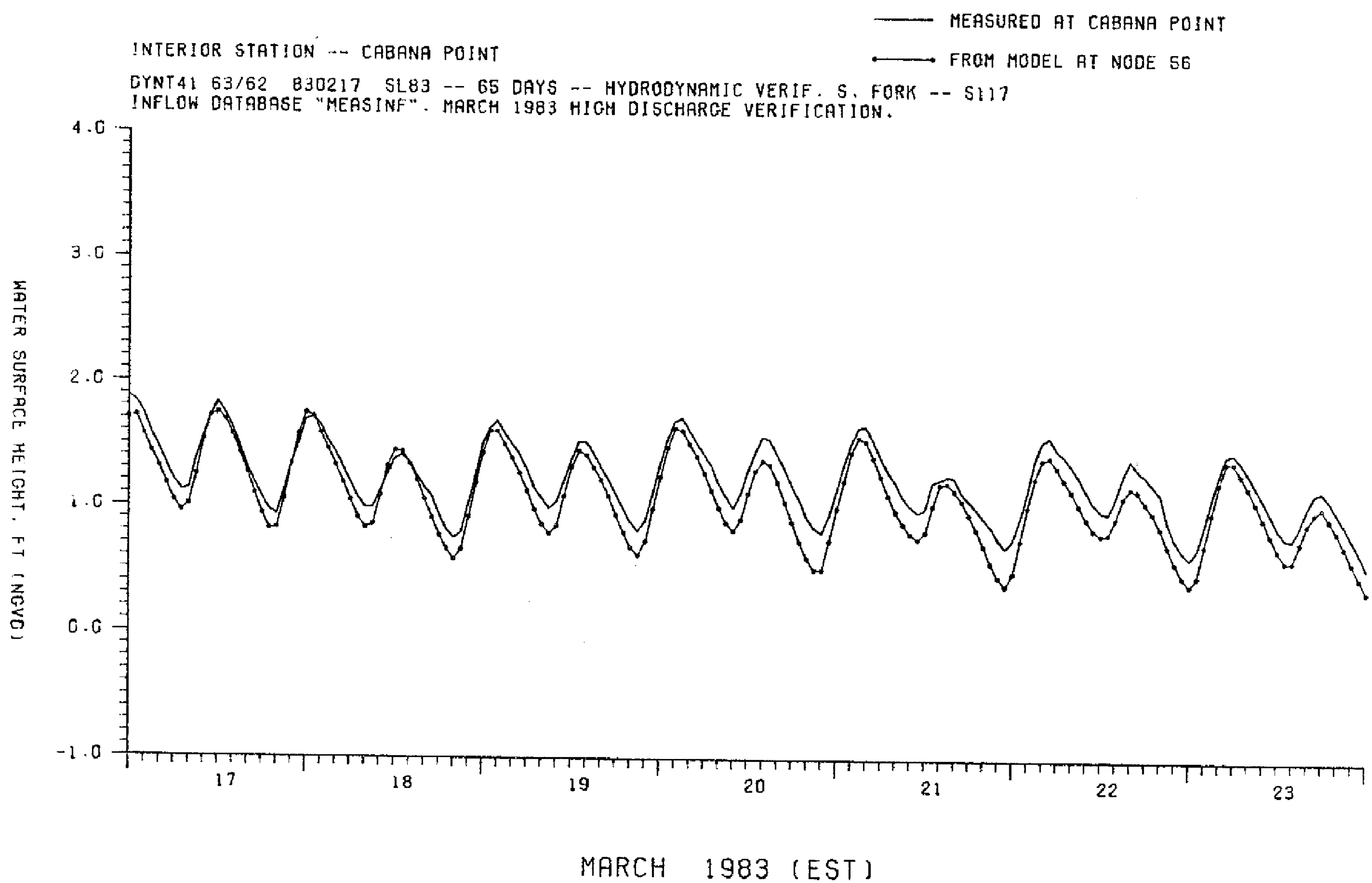
ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
17
18
19
20
21
22
23
FEBRUARY 1983 (EST)
WATER SURFACE HEIGHT, FT (NGVD)

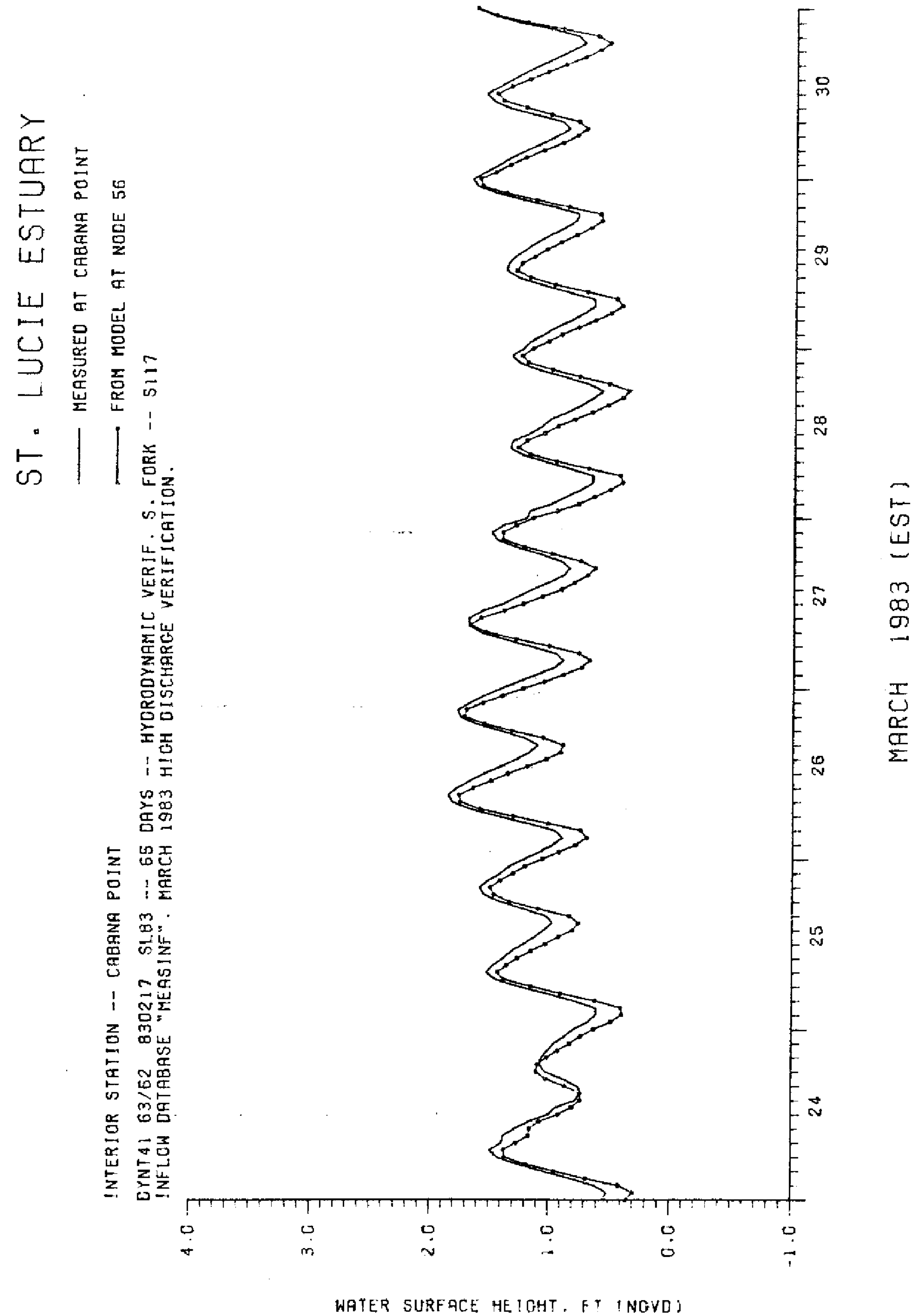

ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
24
25
26
27
28
1
2
FEBRUARY
MARCH 1983 (EST)

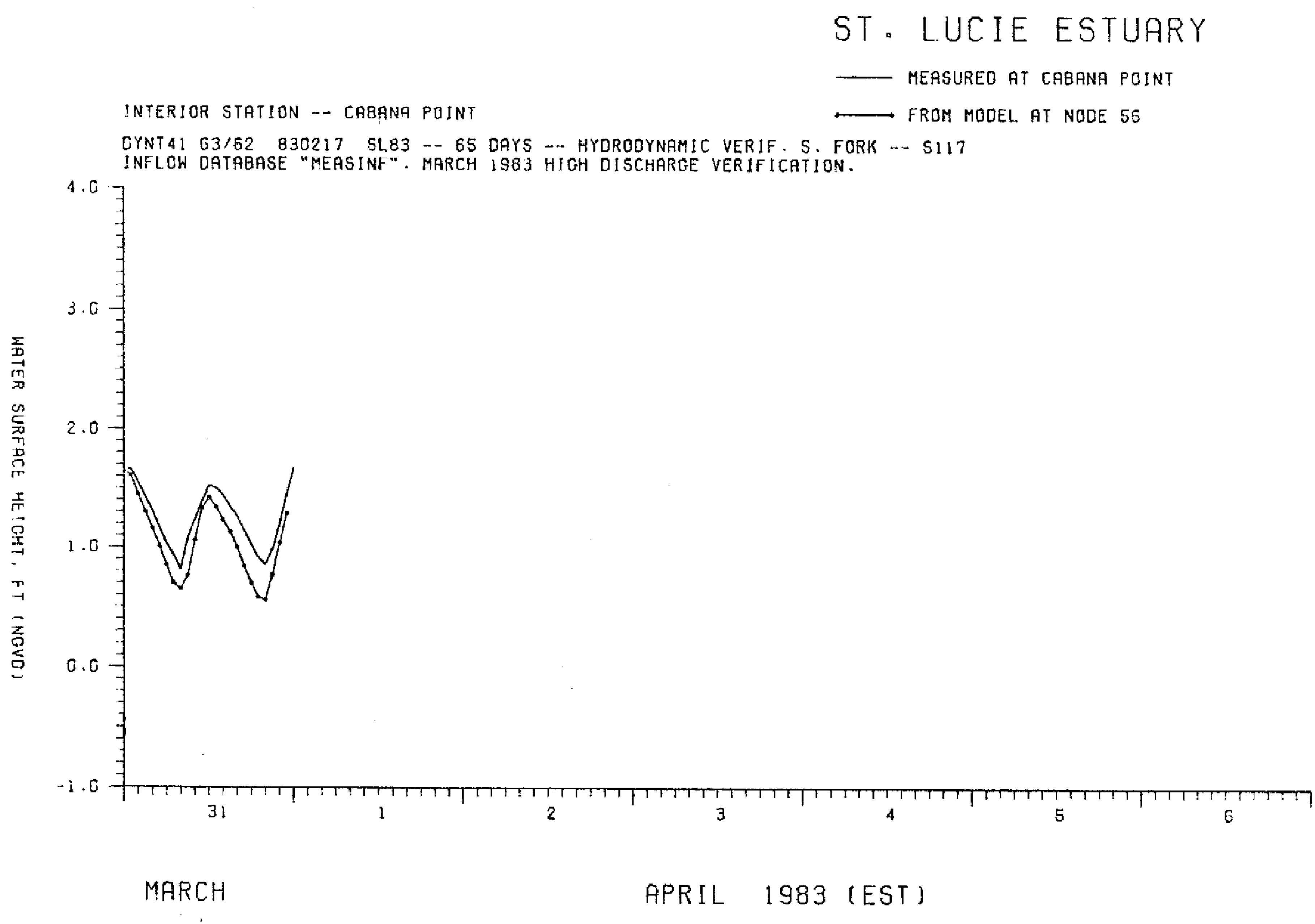

ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
WATER SURFACE HEIGHT, FT (NGVD)
4.0
3.0
2.0
1.0
0.0
-1.0
3
4
5
6
7
8
9
MARCH 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF", MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
10
11
12
13
14
15
16
MARCH 1983 (EST)
WATER SURFACE HEIGHT, FT (NGVD)

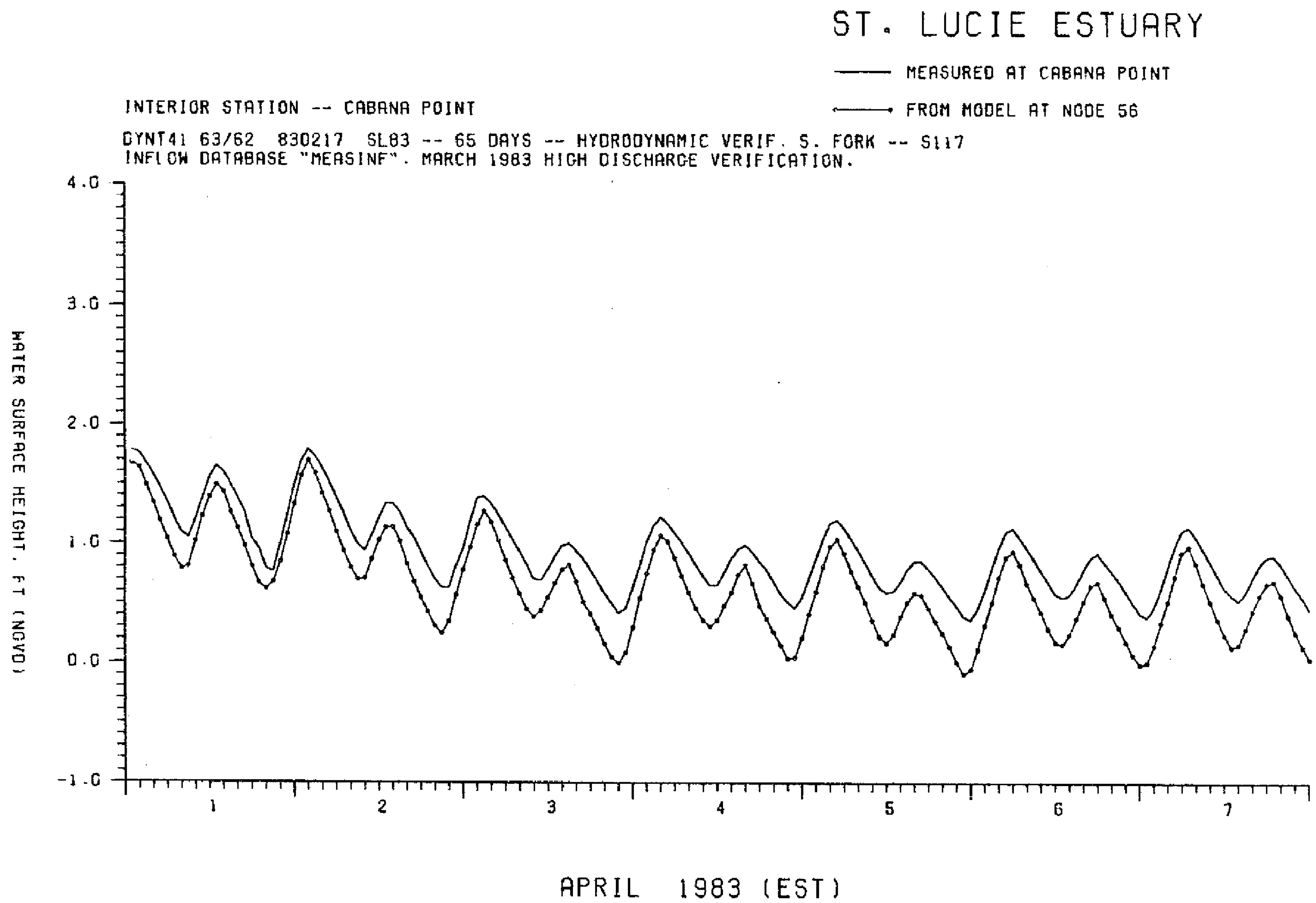
ST. LUCIE ESTUARY

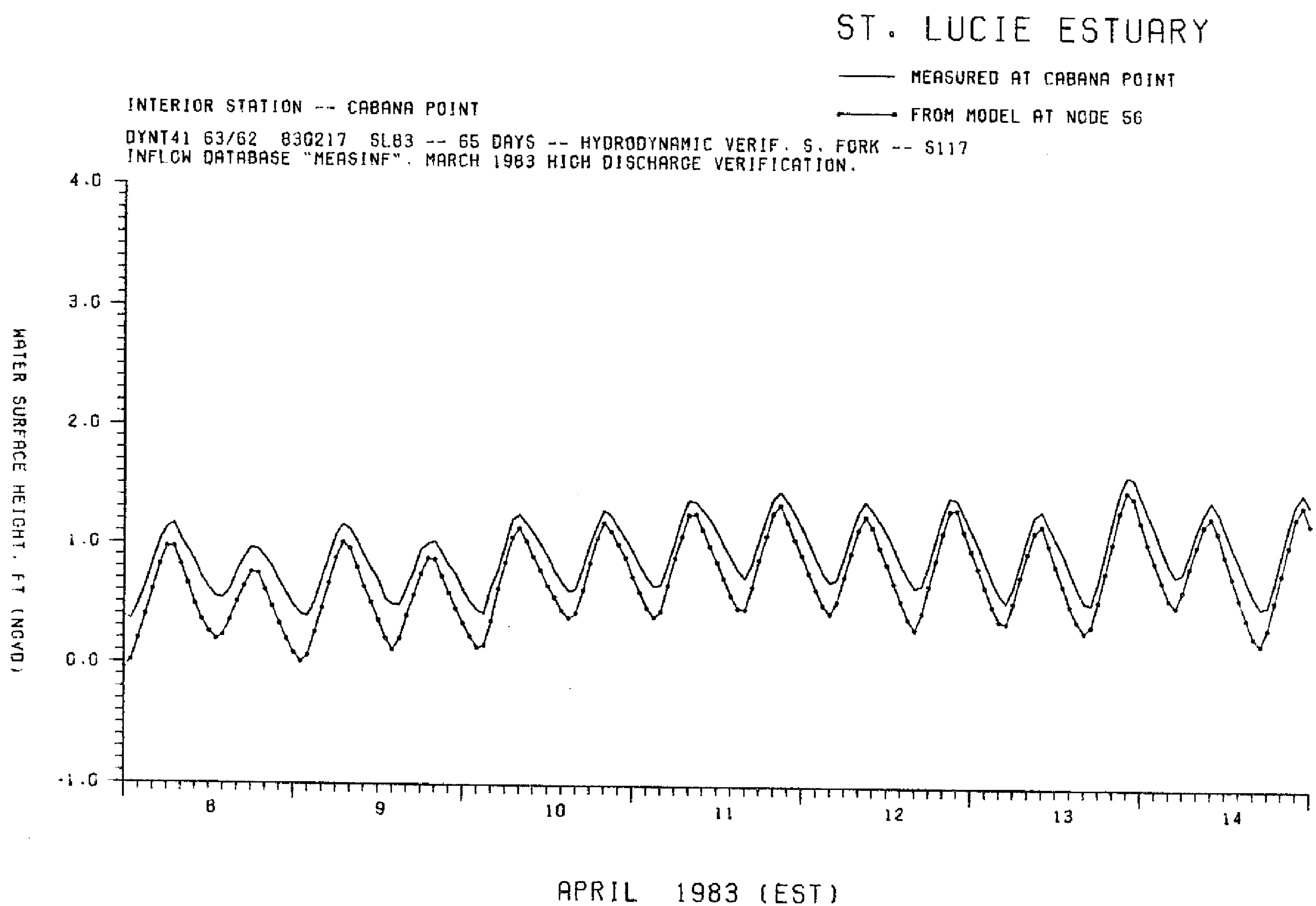


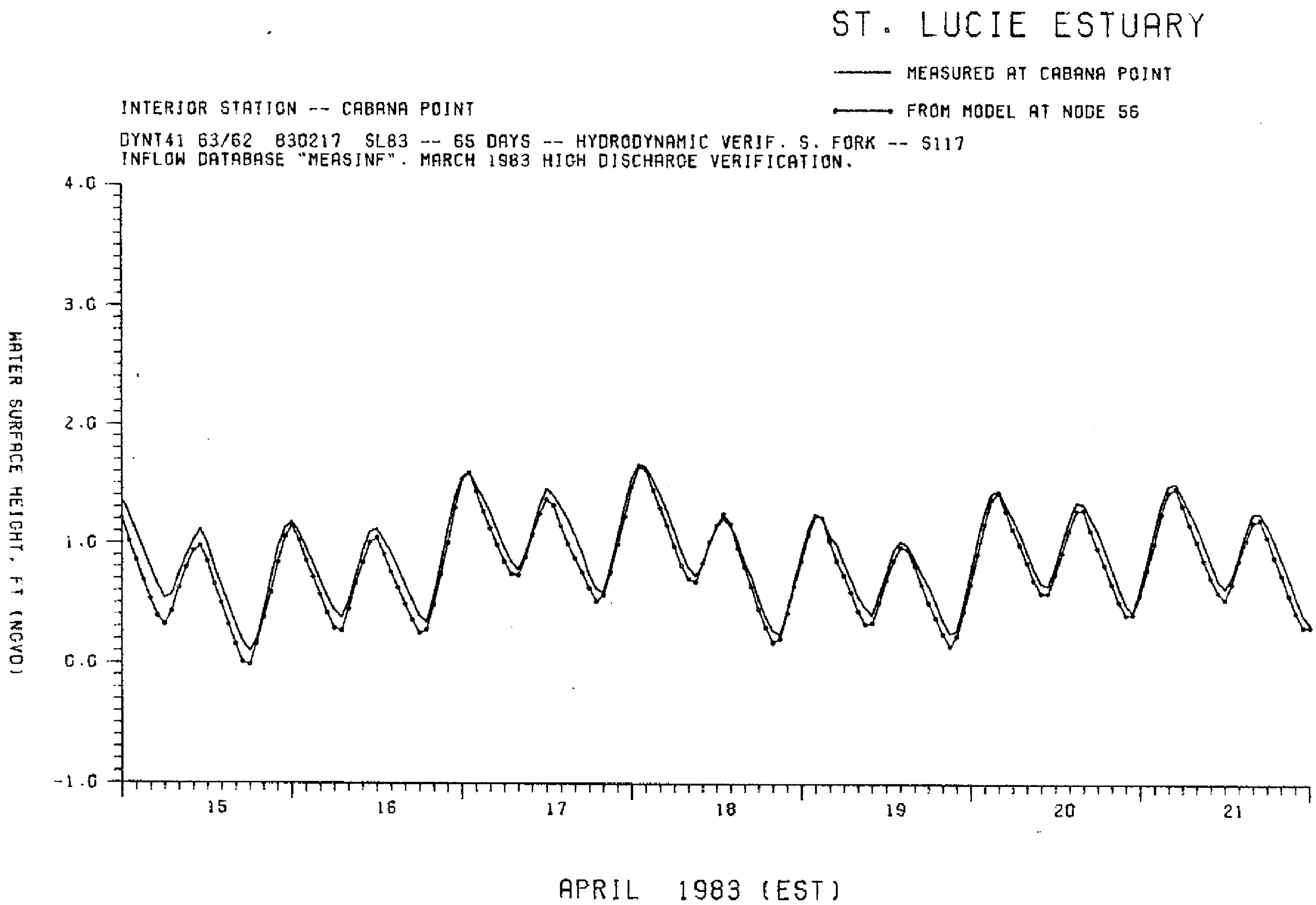

ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
24
25
26
27
28
29
30
MARCH 1983 (EST)
WATER SURFACE HEIGHT, FT (NGVD)

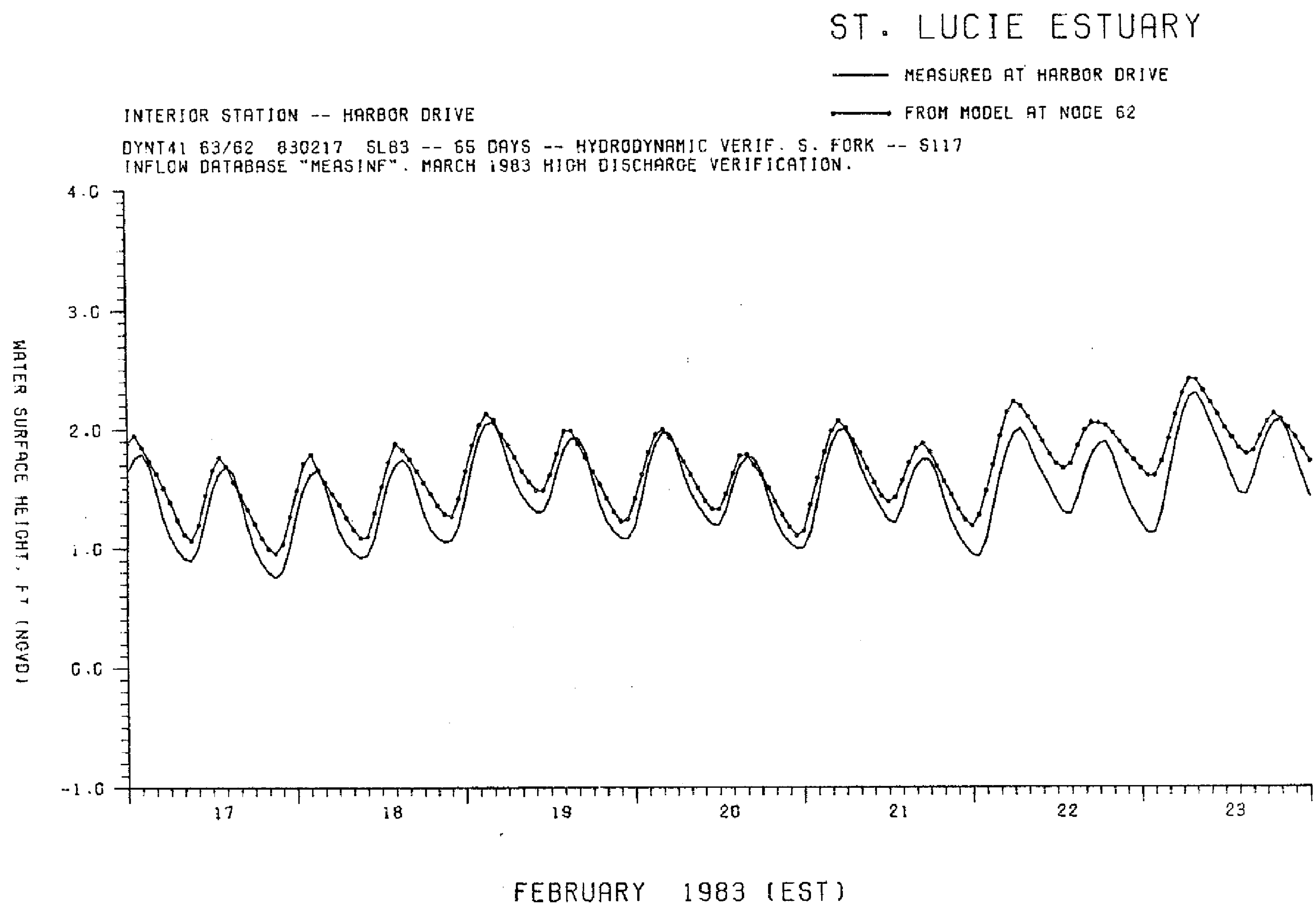


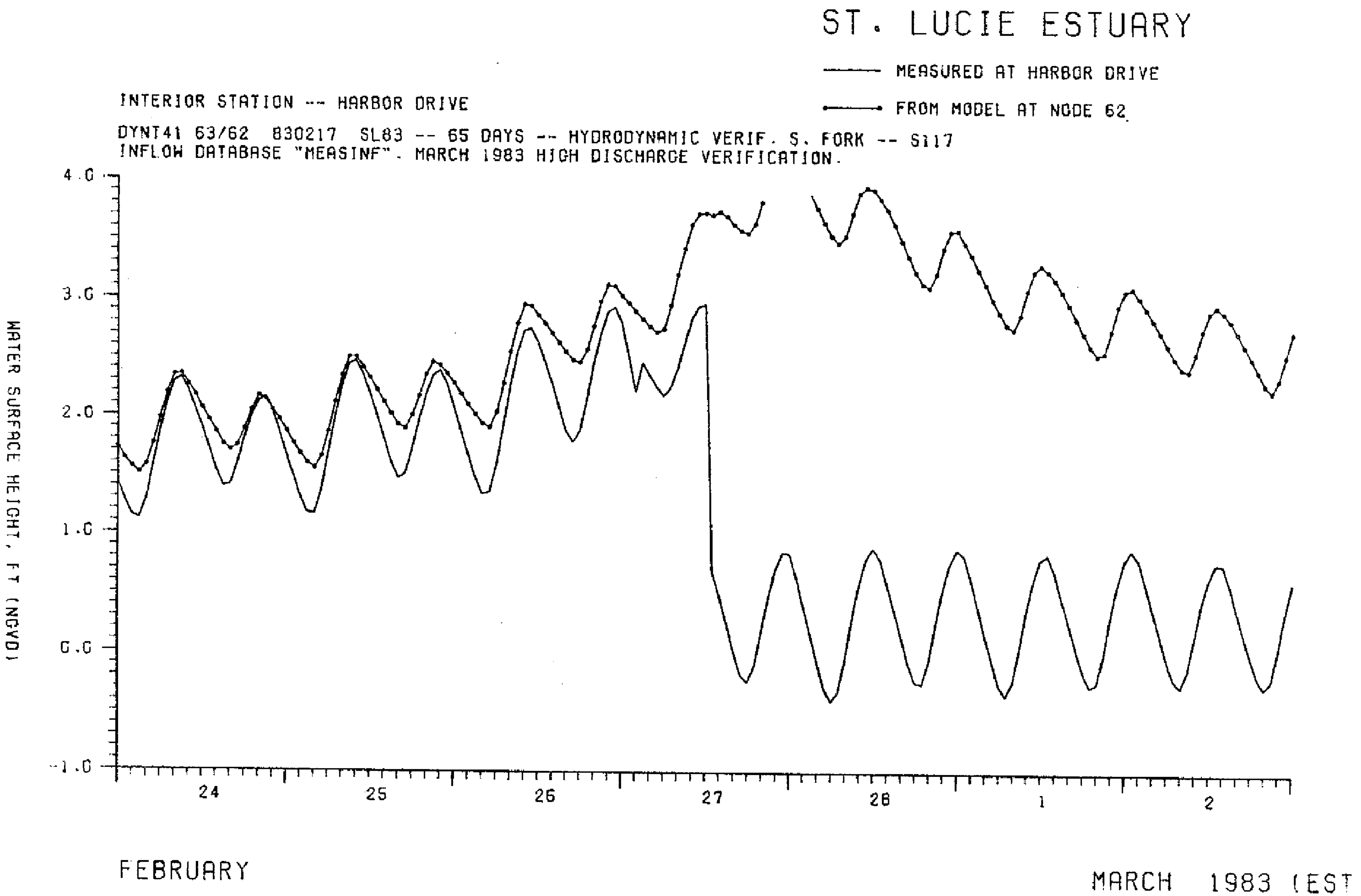
ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
31
1
2
3
4
5
6
MARCH
APRIL 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
1
2
3
4
5
6
7
APRIL 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
8
9
10
11
12
13
14
APRIL 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT CABANA POINT
FROM MODEL AT NODE 56
INTERIOR STATION -- CABANA POINT
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
15
16
17
18
19
20
21
APRIL 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT HARBOR DRIVE
FROM MODEL AT NODE 62
INTERIOR STATION -- HARBOR DRIVE
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
4.0
3.0
2.0
1.0
0.0
-1.0
WATER SURFACE HEIGHT, FT (NGVD)
17
18
19
20
21
22
23
FEBRUARY 1983 (EST)


ST. LUCIE ESTUARY
MEASURED AT HARBOR DRIVE
FROM MODEL AT NODE 62
INTERIOR STATION -- HARBOR DRIVE
DYNT41 63/62 830217 SL83 -- 65 DAYS -- HYDRODYNAMIC VERIF. S. FORK -- S117
INFLOW DATABASE "MEASINF". MARCH 1983 HIGH DISCHARGE VERIFICATION.
WATER SURFACE HEIGHT, FT (NGVD)
4.0
3.0
2.0
1.0
0.0
-1.0
24
25
26
27
28
1
2
FEBRUARY
MARCH 1983 (EST)

APPENDIX E

SALINITY VERIFICATION

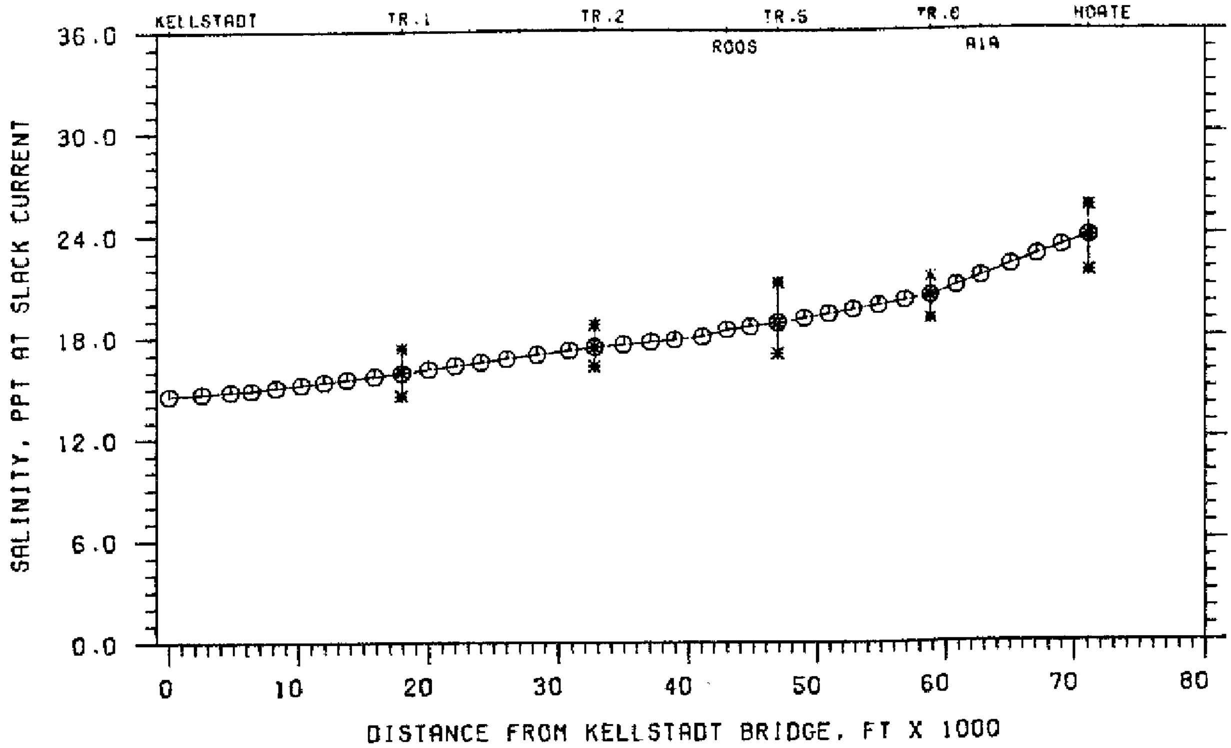
500 CFS CONTROLLED DISCHARGE

January 21 through April 24, 1981

NORTH FORK

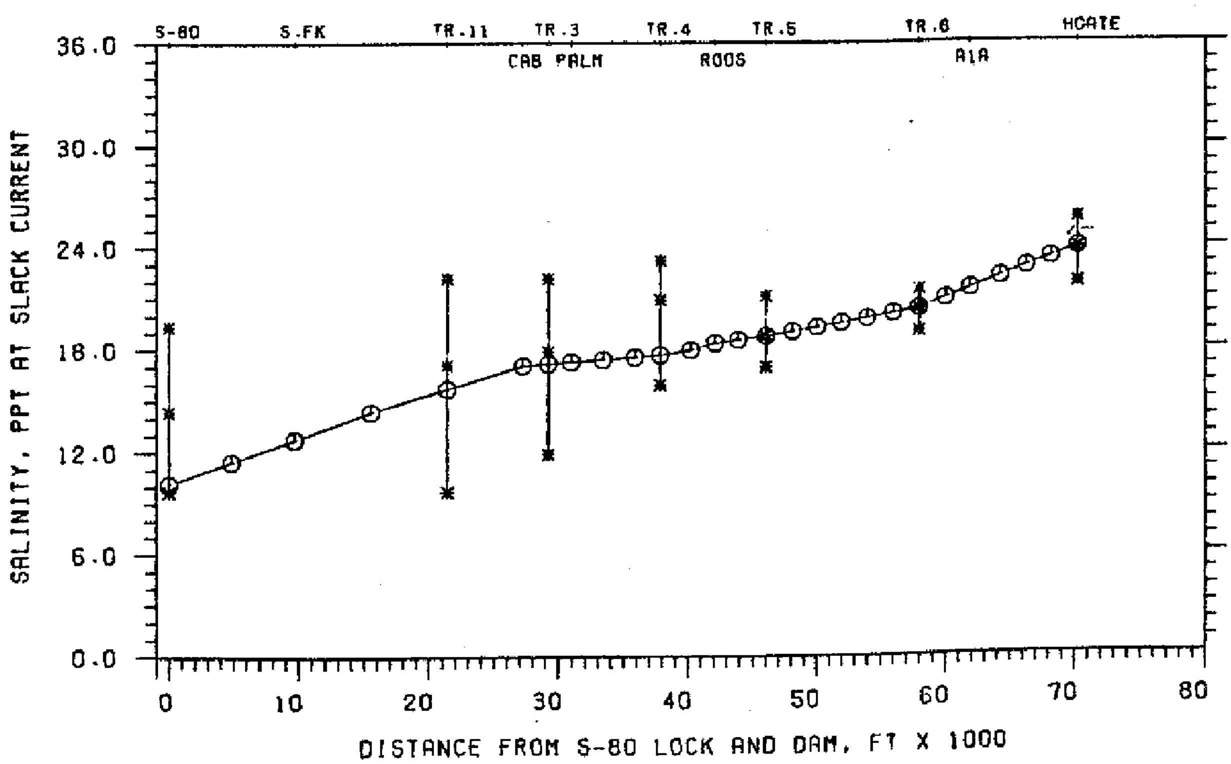
ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. DW: 149 CFS (G63S113). SBC: 33.



MEASURED
JANUARY 21, 1981
FROM MODEL:
810121 0800: LOW TIDE

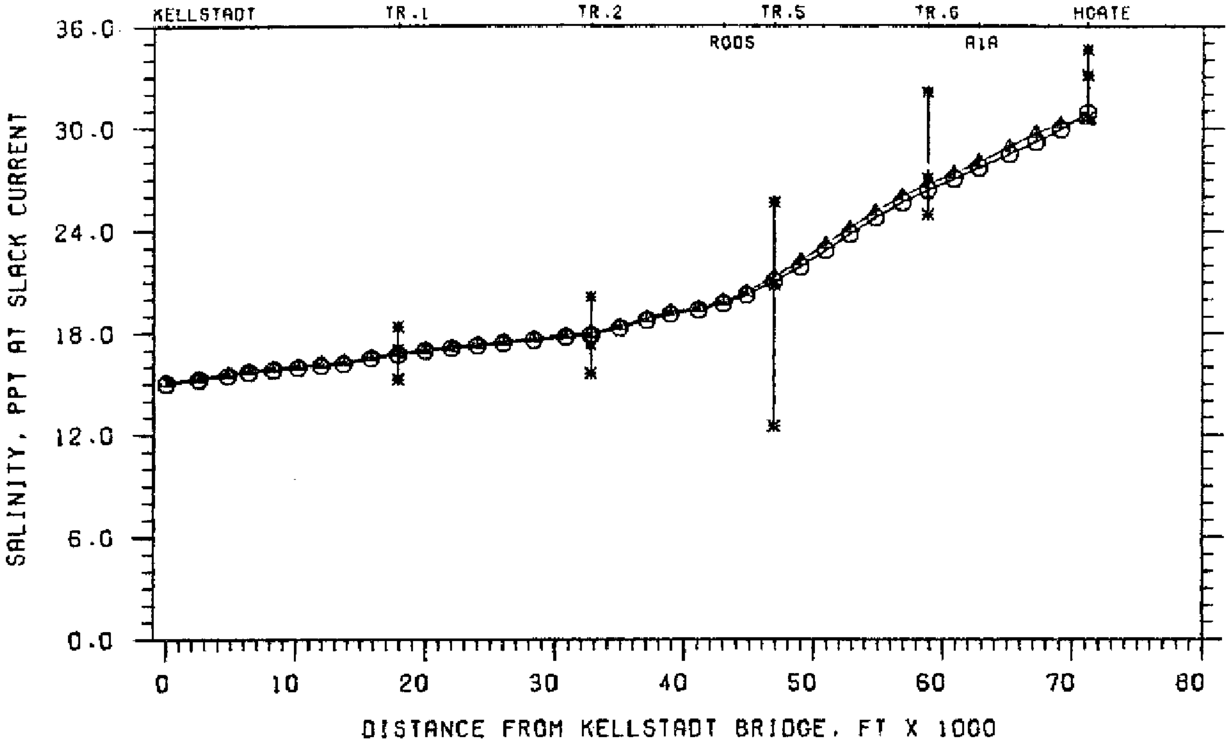
SOUTH FORK



NORTH FORK

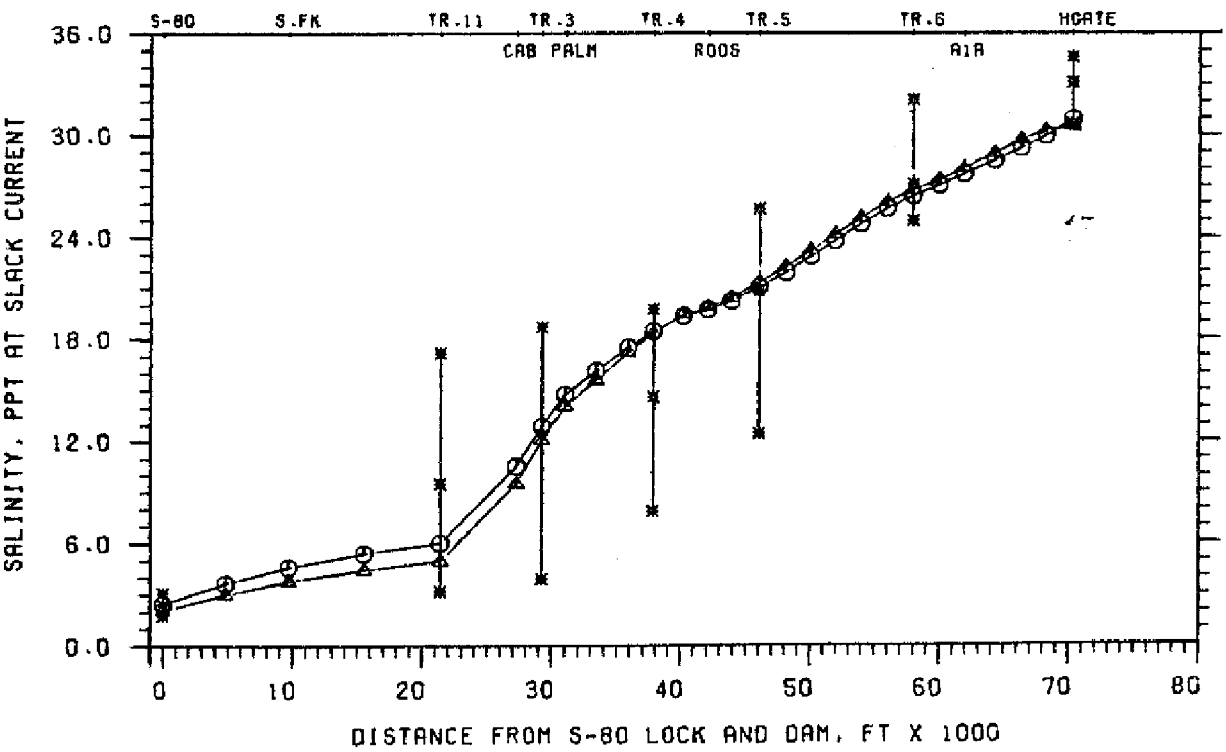
ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. QW: 149 CFS (Q63S113). SBC: 33.



MEASURED
JANUARY 28, 1981
FROM MODEL:
O 810128 1100: LOW TIDE
Δ 810128 1700: HIGH TIDE

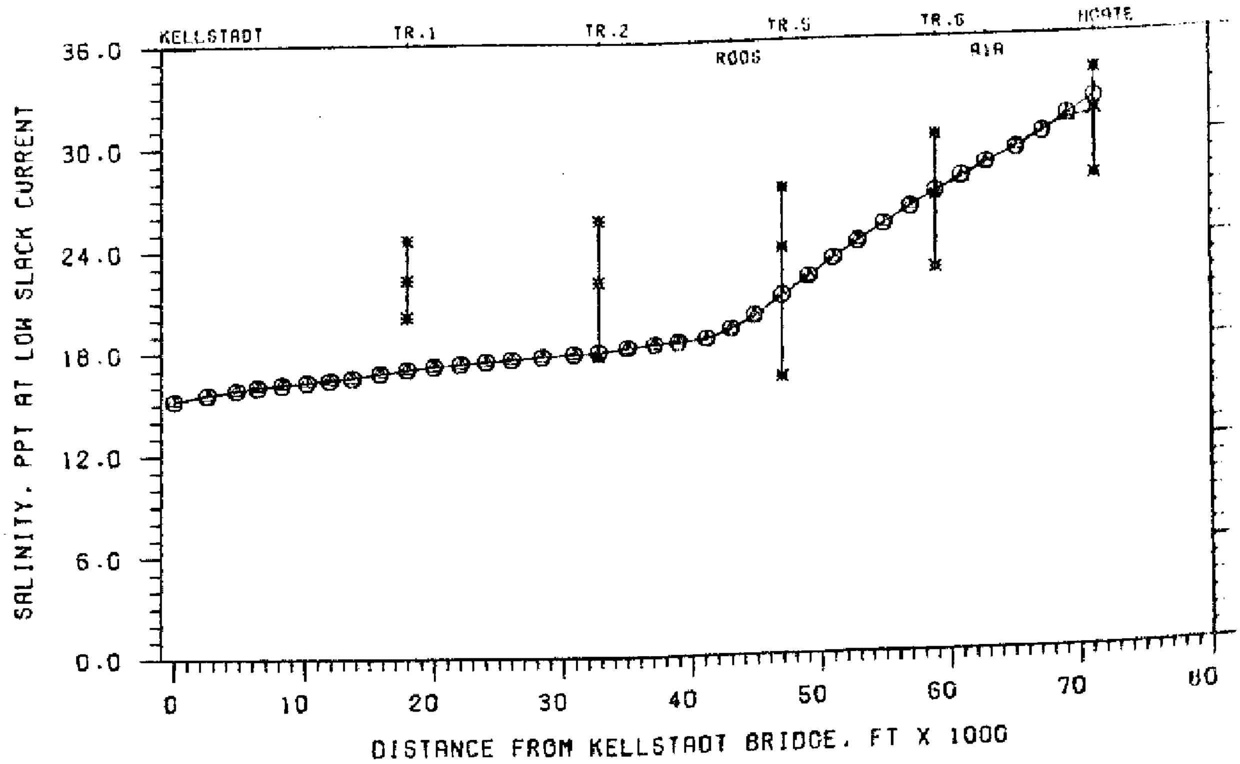
SOUTH FORK



NORTH FORK

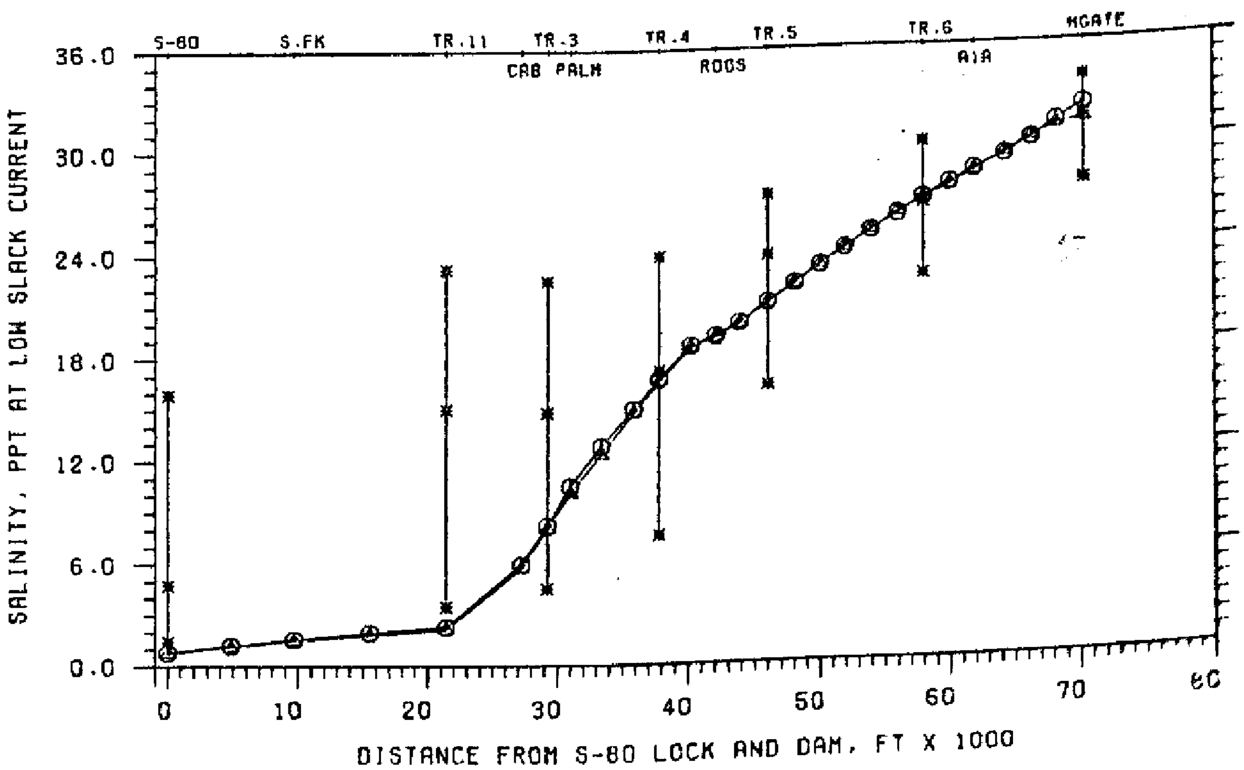
ST. LUCIE ESTUARY

DYNT21 63/62 810121 JS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HELBI". DC: 300/700/1000/2000. CW: 149 CFS (D63S113). SRC. 3.1.



MEASURED
JANUARY 30, 1981
FROM MODEL :
⊕ 810130 1300: LOW TIDE
△ 810130 1700: HIGH TIDE

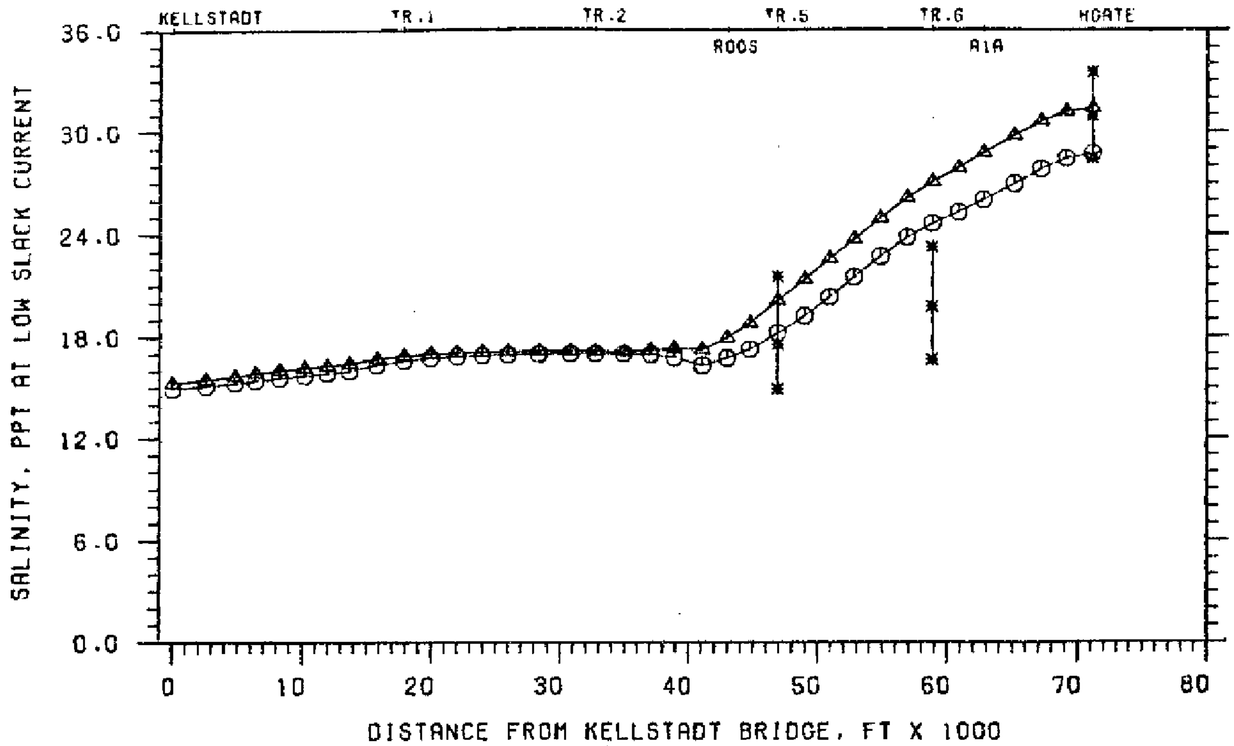
SOUTH FORK



NORTH FORK

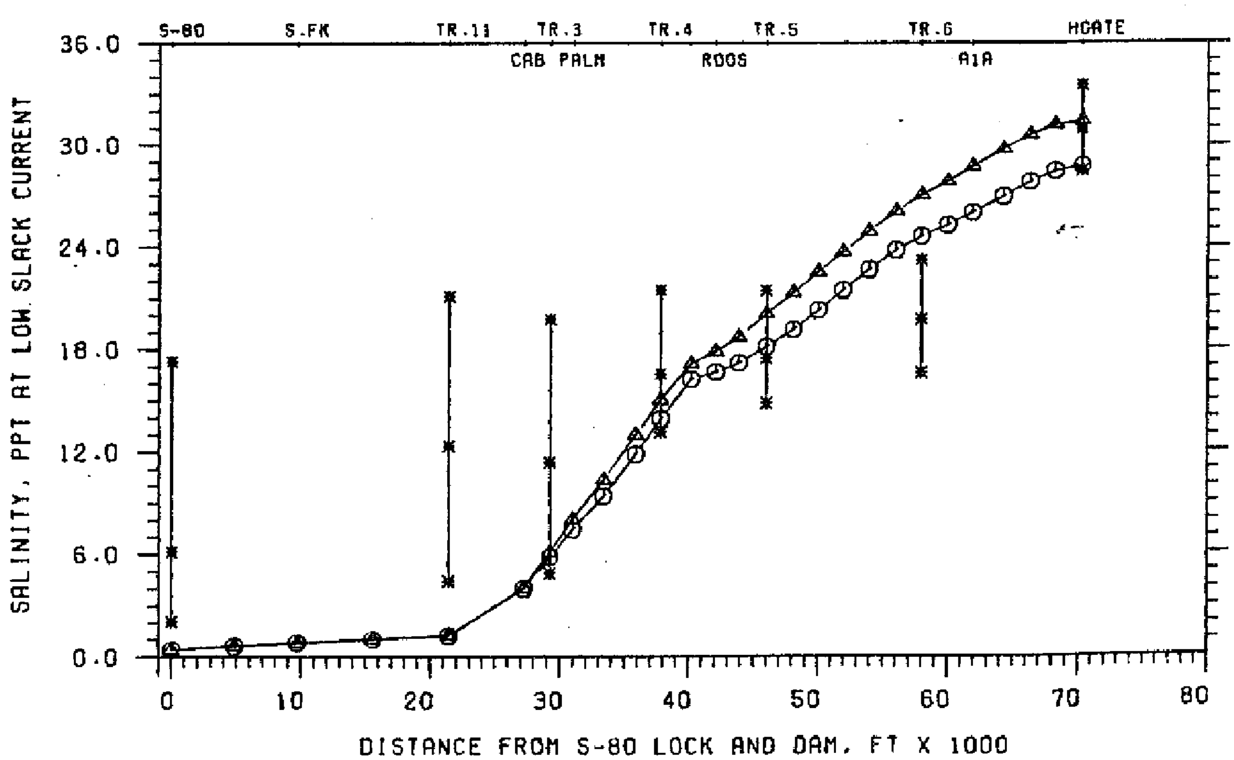
ST. LUCIE ESTUARY

DYNT21 63/62 810121 1S140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. CW: 149 CFS (063S113). SBC: 33.



MEASURED
FEBRUARY 2, 1981
FROM MODEL:
O 810202 0900: HIGH TIDE
Δ 810202 1600: LOW TIDE

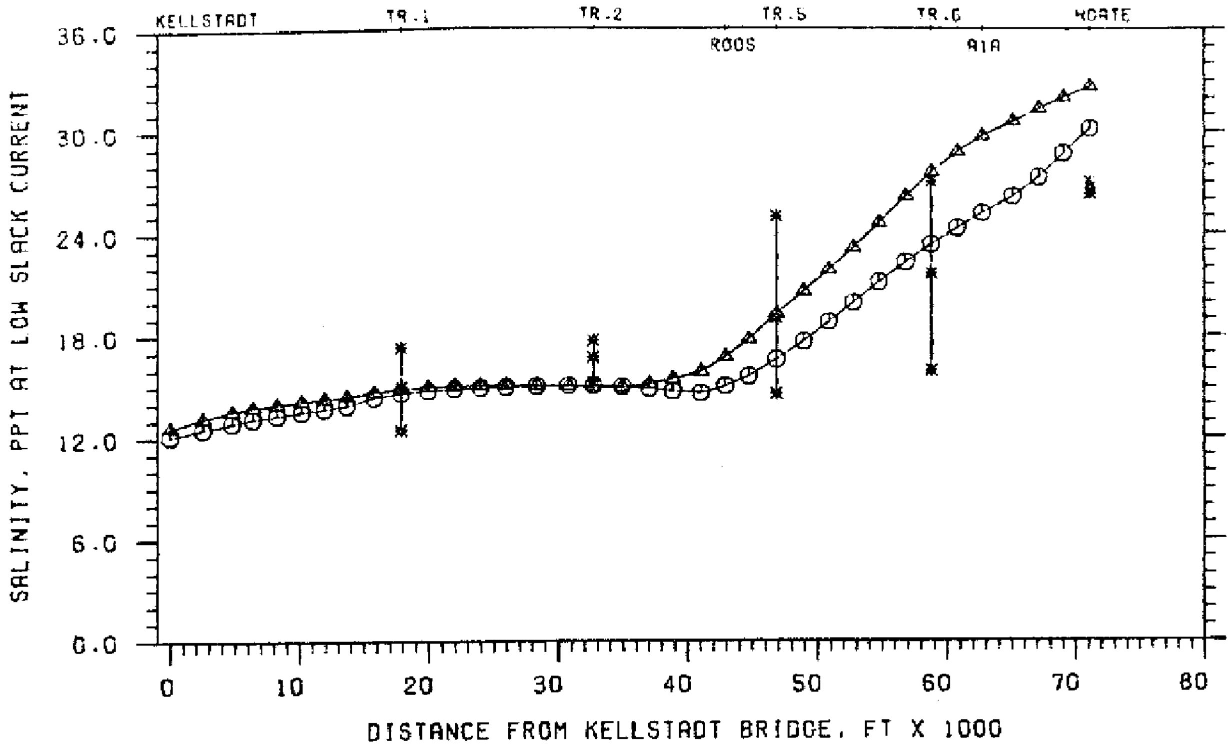
SOUTH FORK



NORTH FORK

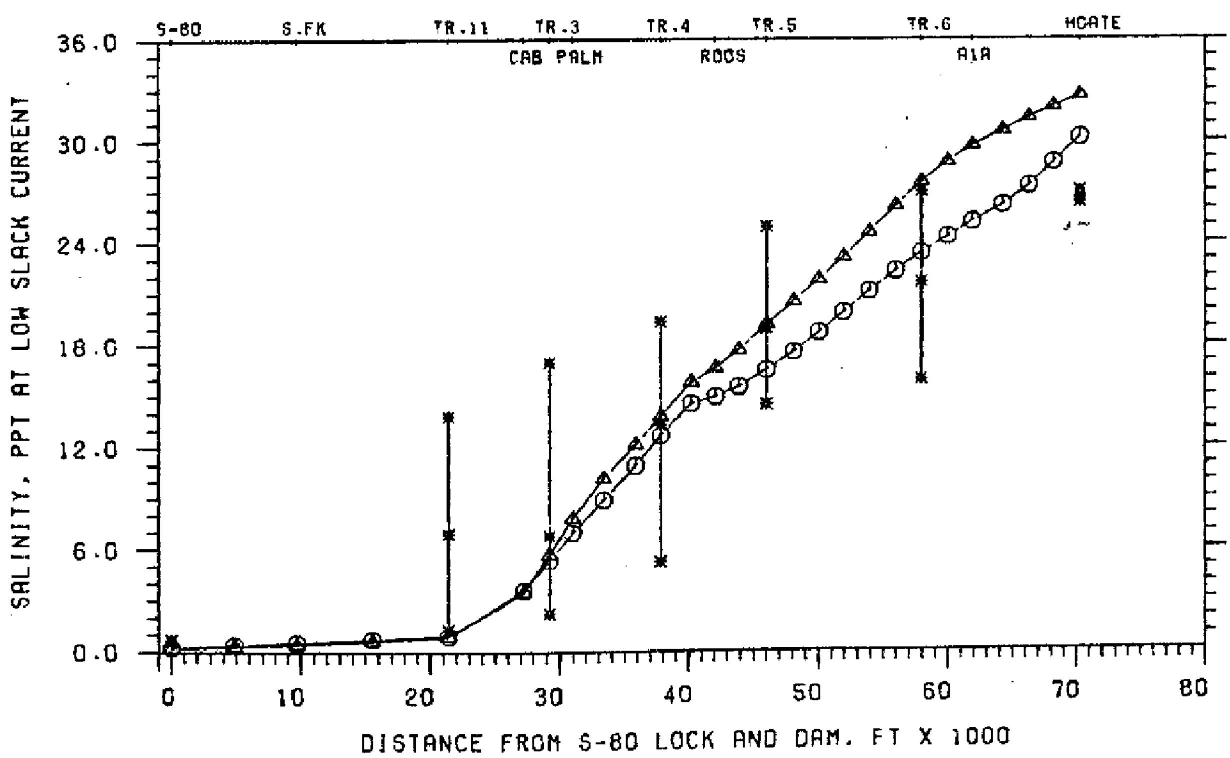
ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (063S113). SBC: 33.



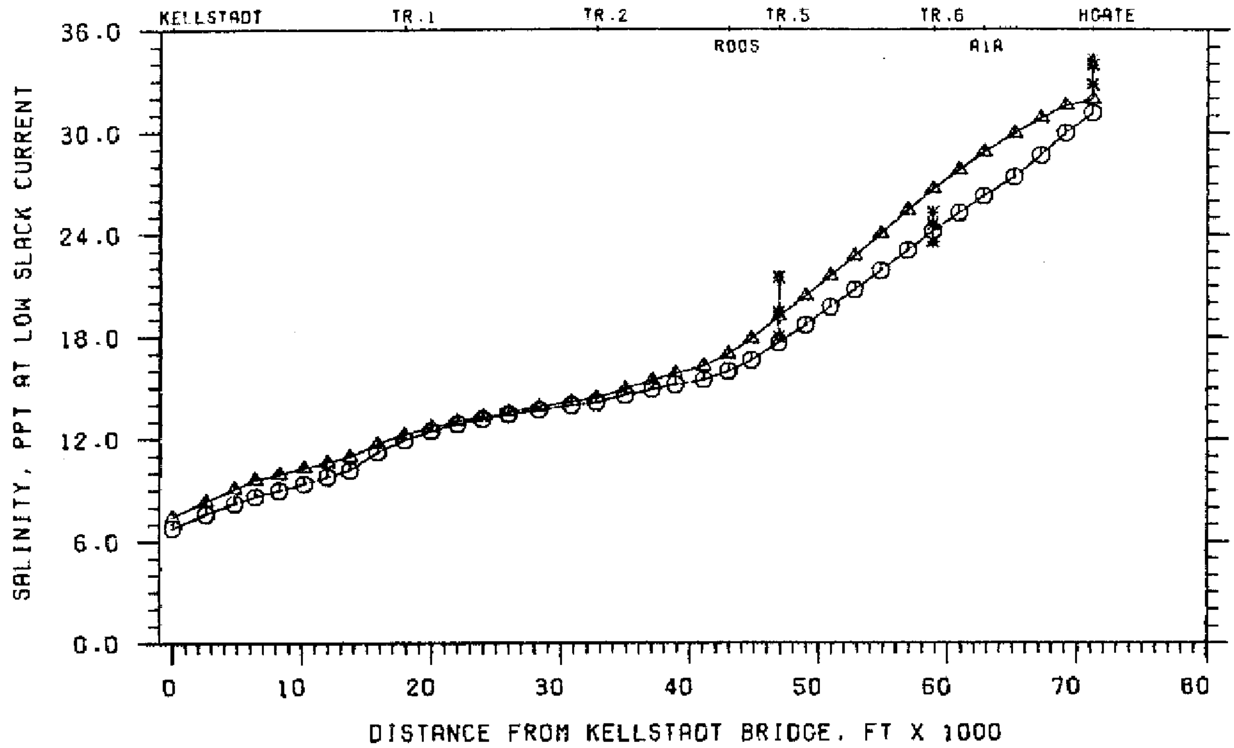
MEASURED
FEBRUARY 5, 1981
FROM MODEL:
⊙ 810205 1100: HIGH TIDE
△ 810205 1800: LOW TIDE

SOUTH FORK



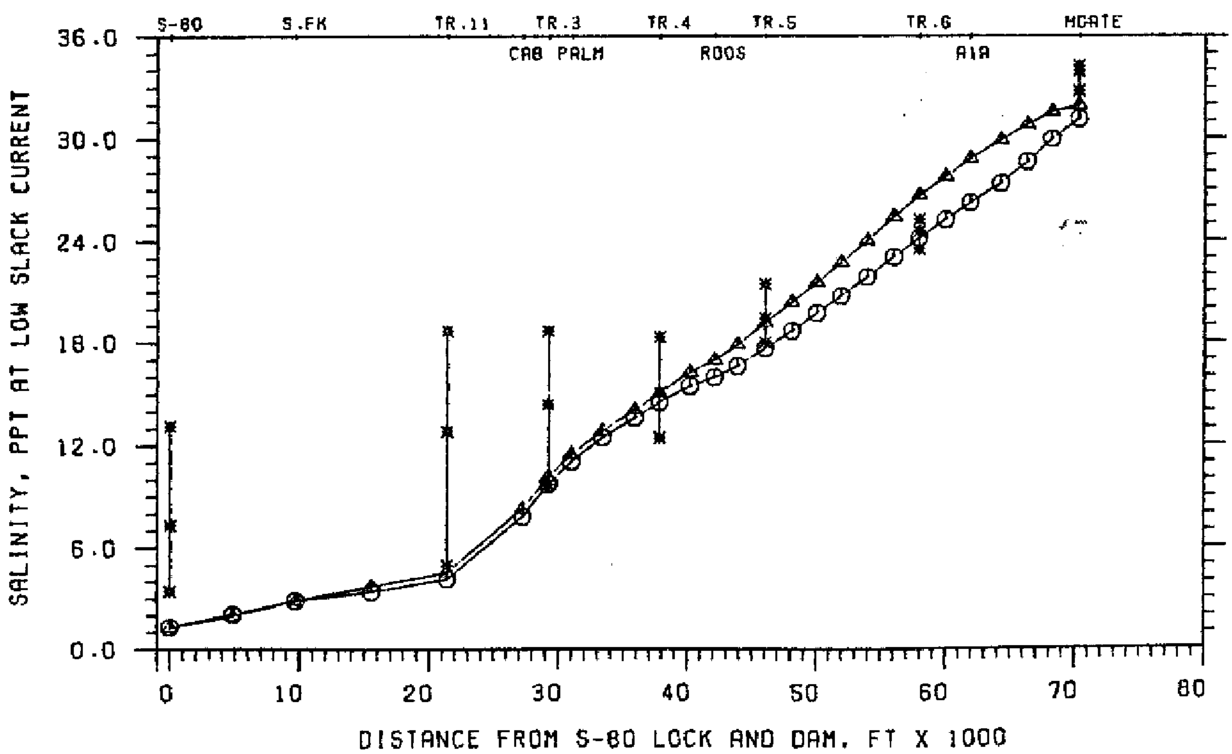
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 33.



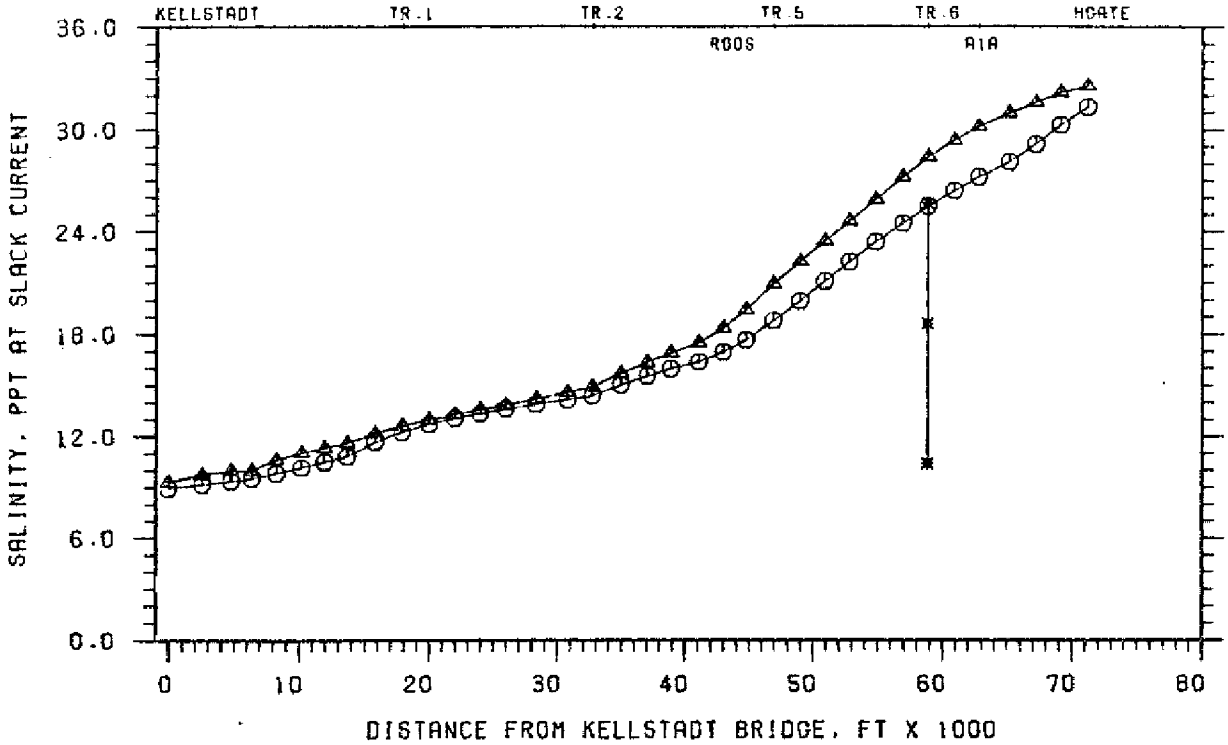
MEASURED
FEBRUARY 10, 1981
FROM MODEL:
○ 810210 0900: LOW TIDE
△ 810210 1400: HIGH TIDE

SOUTH FORK



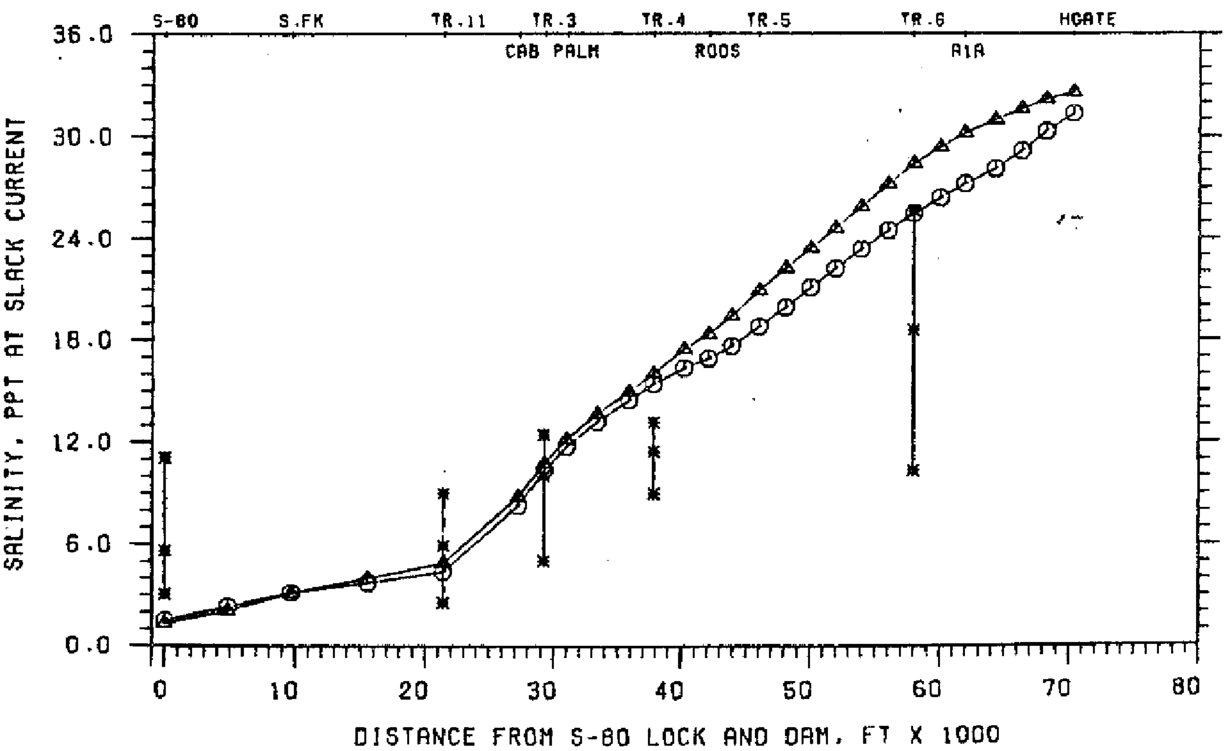
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. OW: 149 CFS (0635113). SBC: 33.



MEASURED
FEBRUARY 18, 1981
FROM MODEL:
O 810218 1100: HIGH TIDE
△ 810218 1700: LOW TIDE

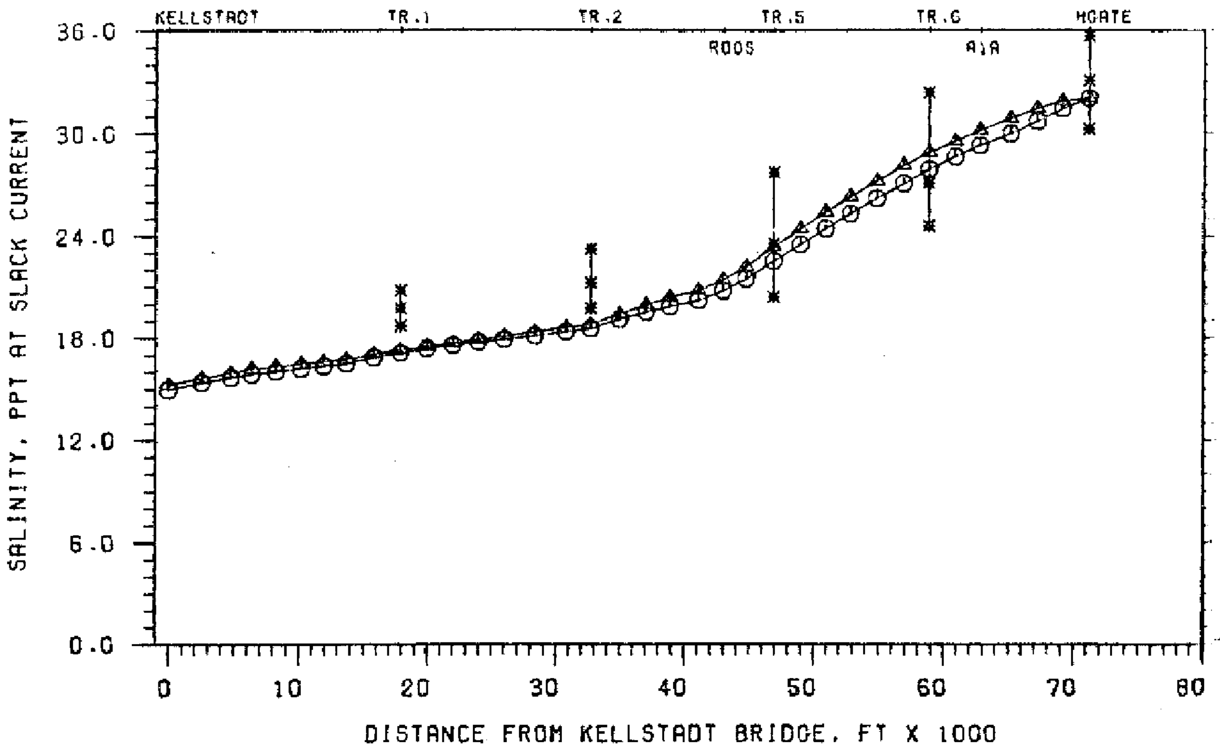
SOUTH FORK



NORTH FORK

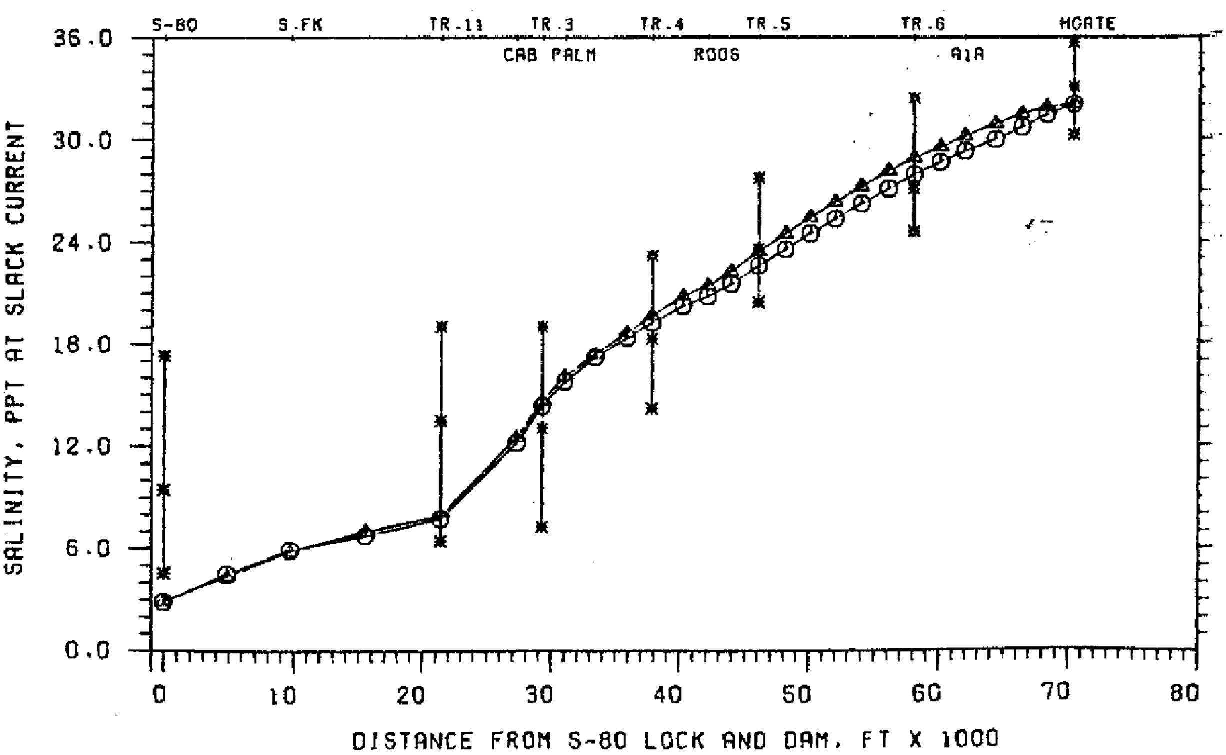
ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. QW: 149 CFS (063S113). SBC: 33.



SOUTH FORK

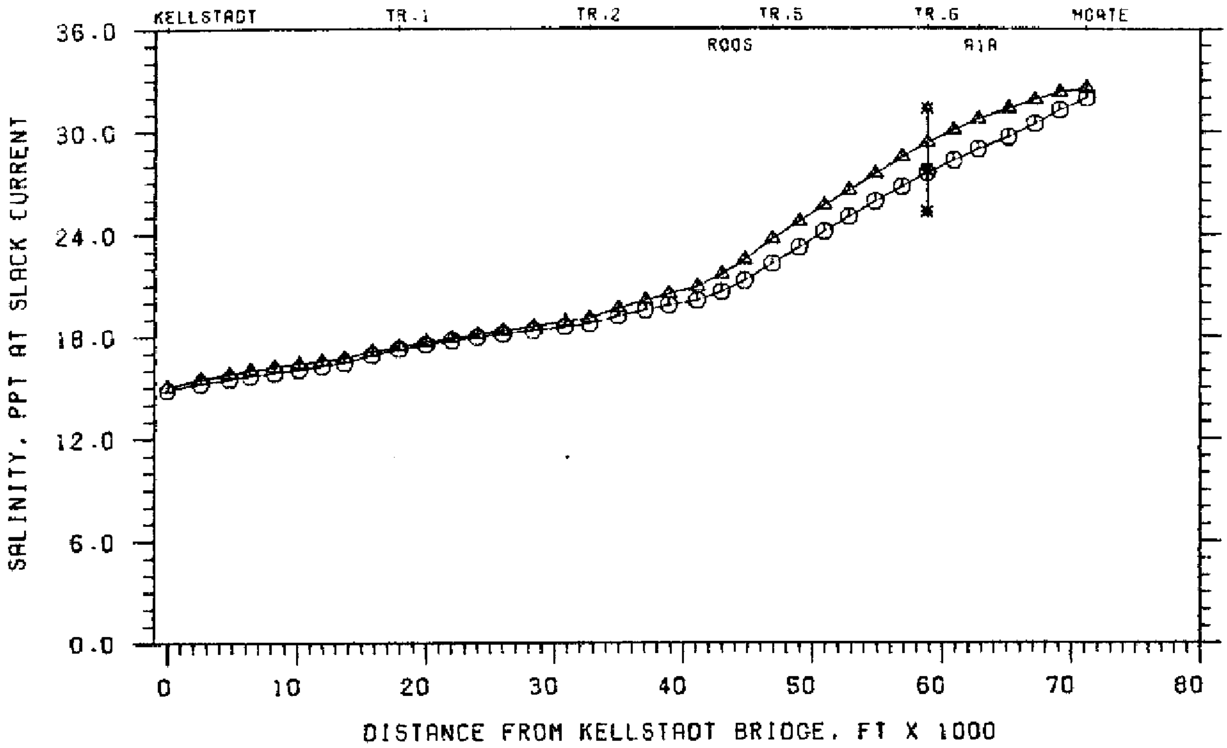
—*— MEASURED
MARCH 11, 1981
——— FROM MODEL:
⊙ 810311 0900: LOW TIDE
△ 810311 1400: HIGH TIDE

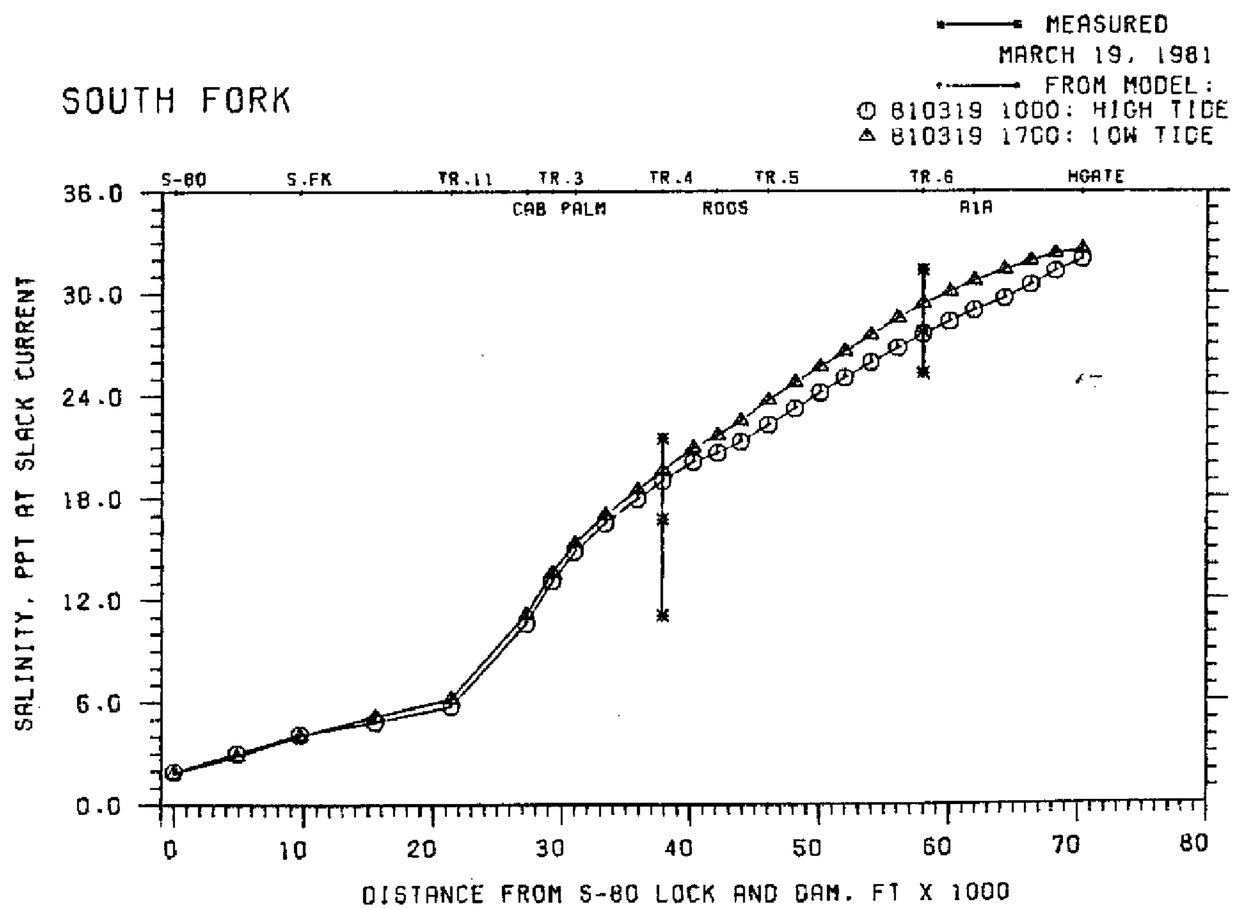


NORTH FORK

ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. CW: 149 CFS (063S113). SBC: 33.

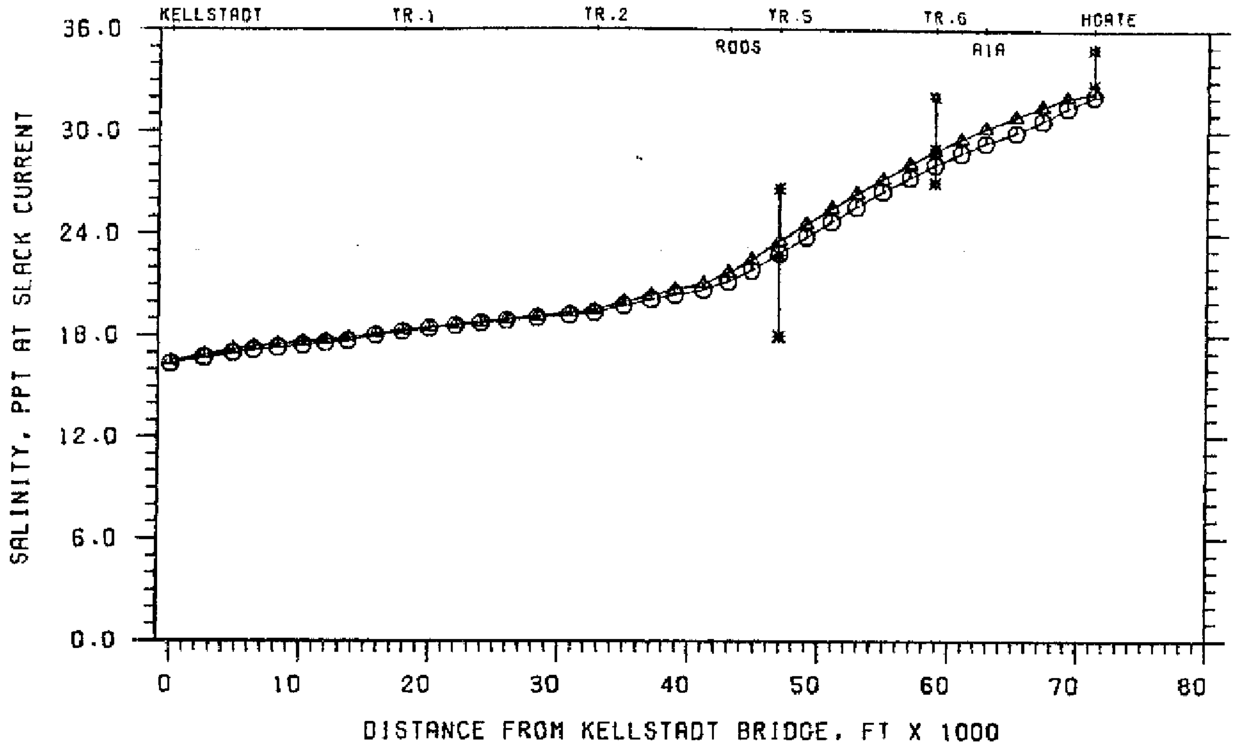




NORTH FORK

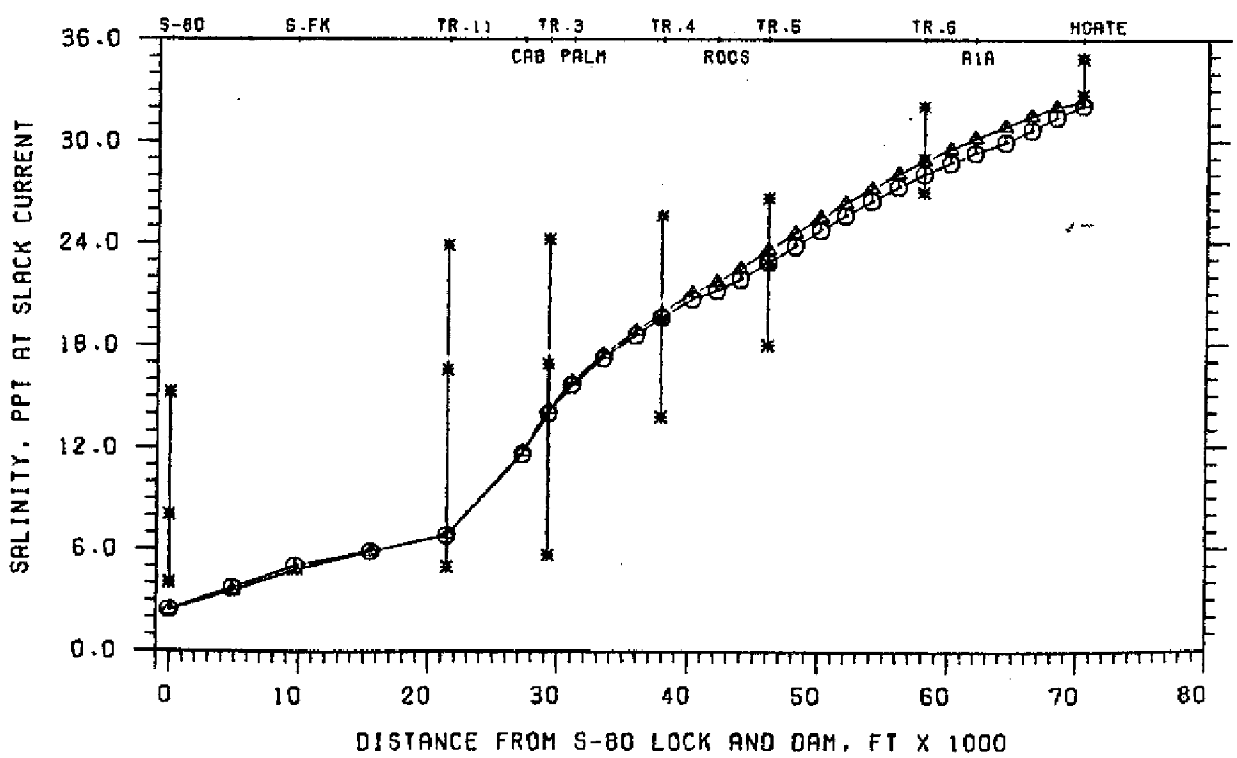
ST. LUCIE ESTUARY

DYNT21 63/62 .810121 [S140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 33.



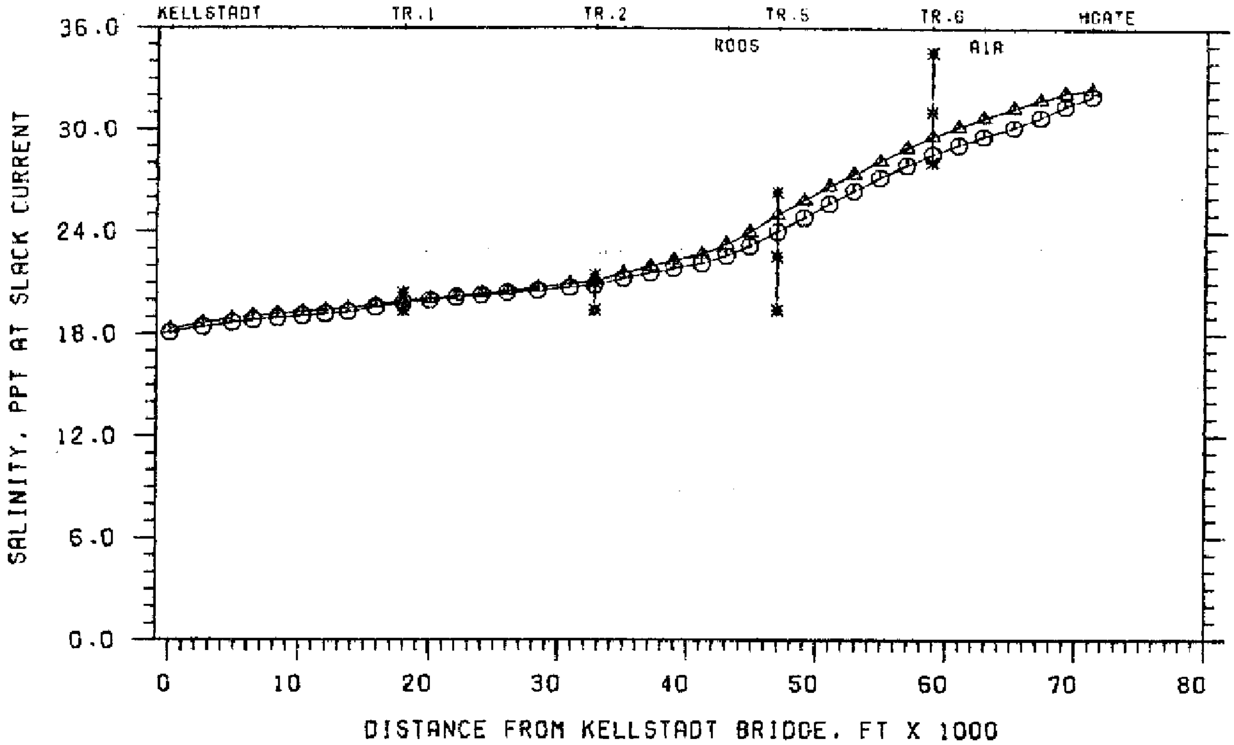
MEASURED
MARCH 27, 1981
FROM MODEL:
⊙ 810327 0900: LOW TIDE
△ 810327 1400: HIGH TIDE

SOUTH FORK



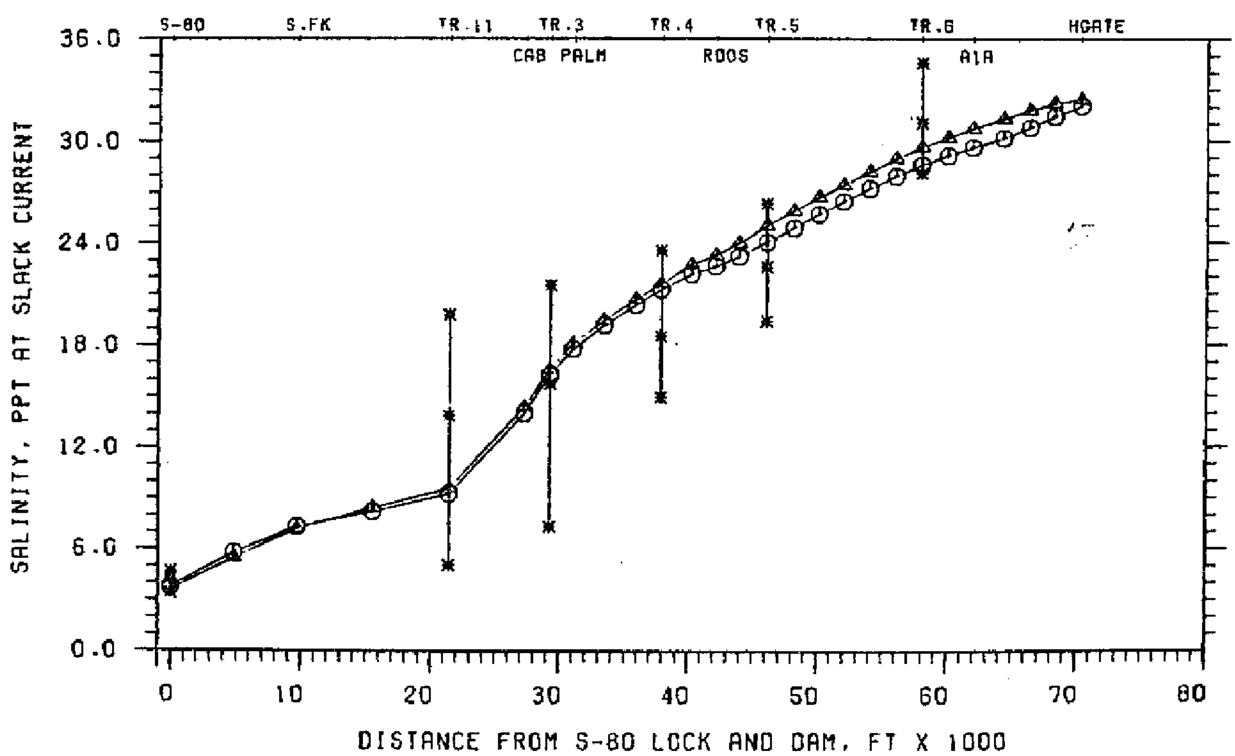
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 810121 !S140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. CW: 149 CFS (063S113). SBC: 33.



MEASURED
APRIL 10, 1981
FROM MODEL:
⊕ 810410 0900: LOW TIDE
△ 810410 1400: HIGH TIDE

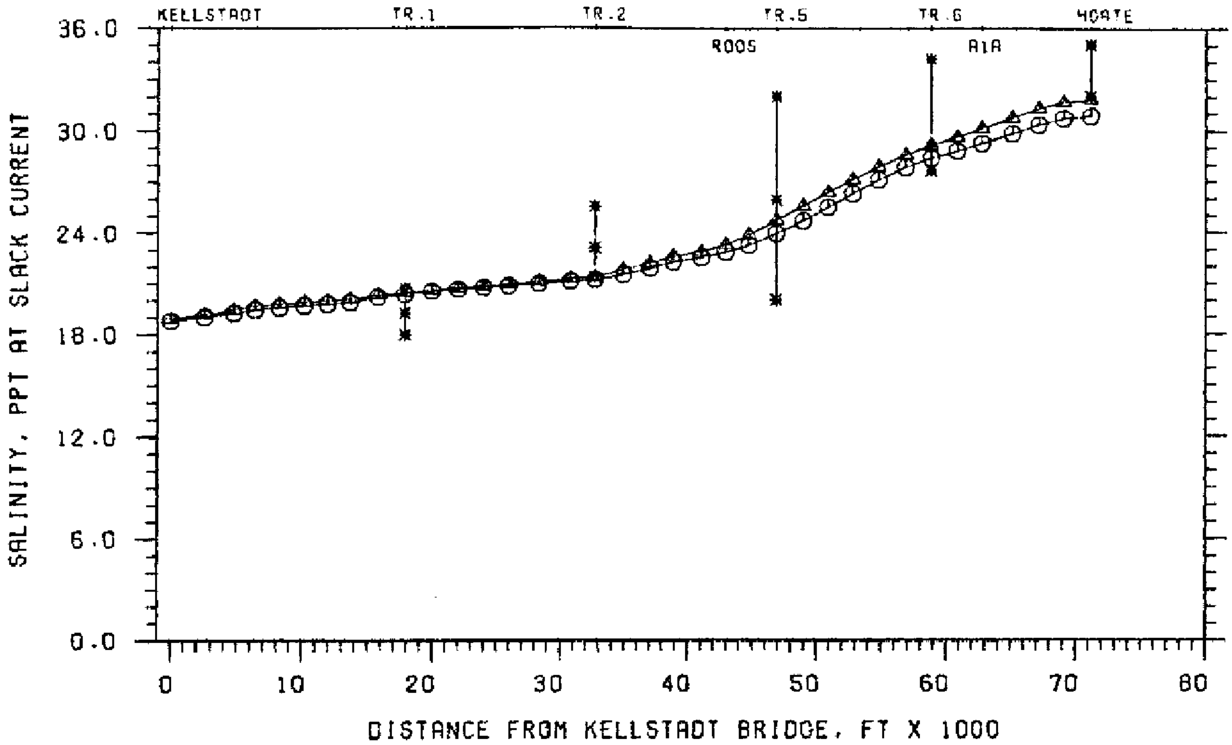
SOUTH FORK



NORTH FORK

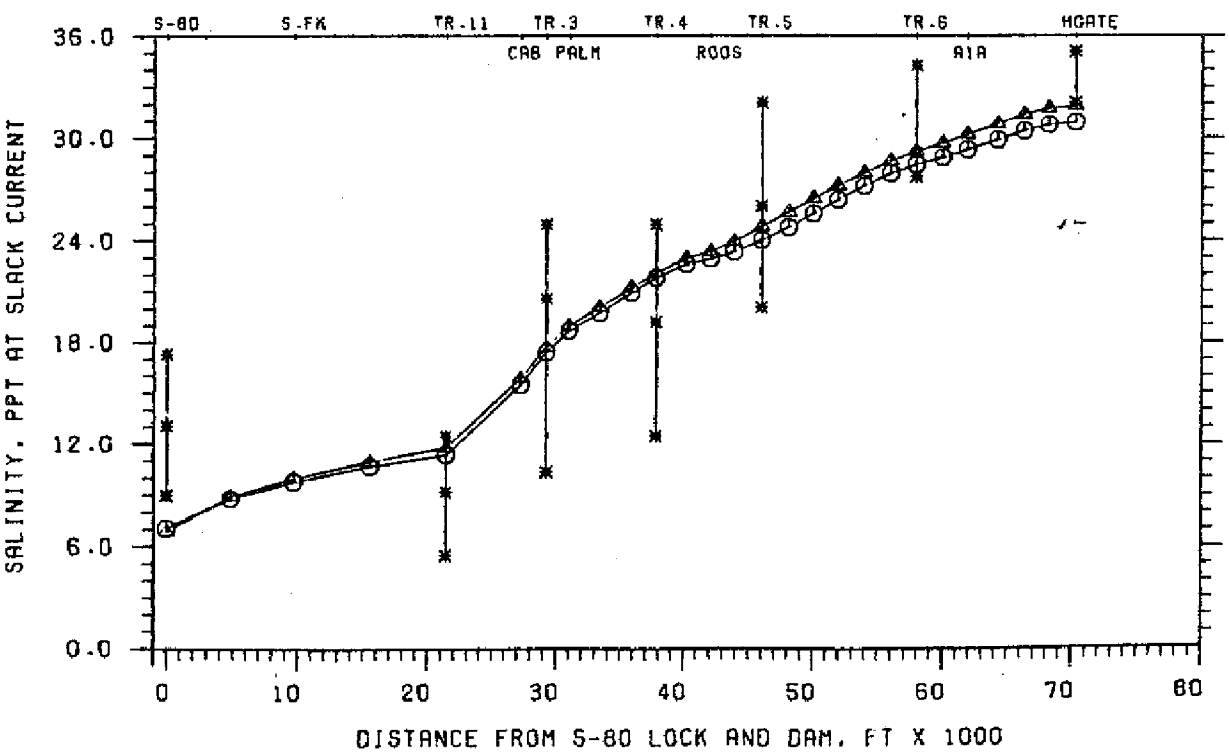
ST. LUCIE ESTUARY

DYNT21 63/62 810121 IS140 -- 113 DAYS -- 500 CFS CONTROLLED DISCHARGE -- S140
TIDAL BNDRY: "HEL81". DC: 300/700/1000/2000. GW: 149 CFS (063S113). SBC: 33.



MEASURED
APRIL 24, 1981
FROM MODEL:
810424 0800: LOW TIDE
810424 1300: HIGH TIDE

SOUTH FORK



APPENDIX F

SALINITY VERIFICATION

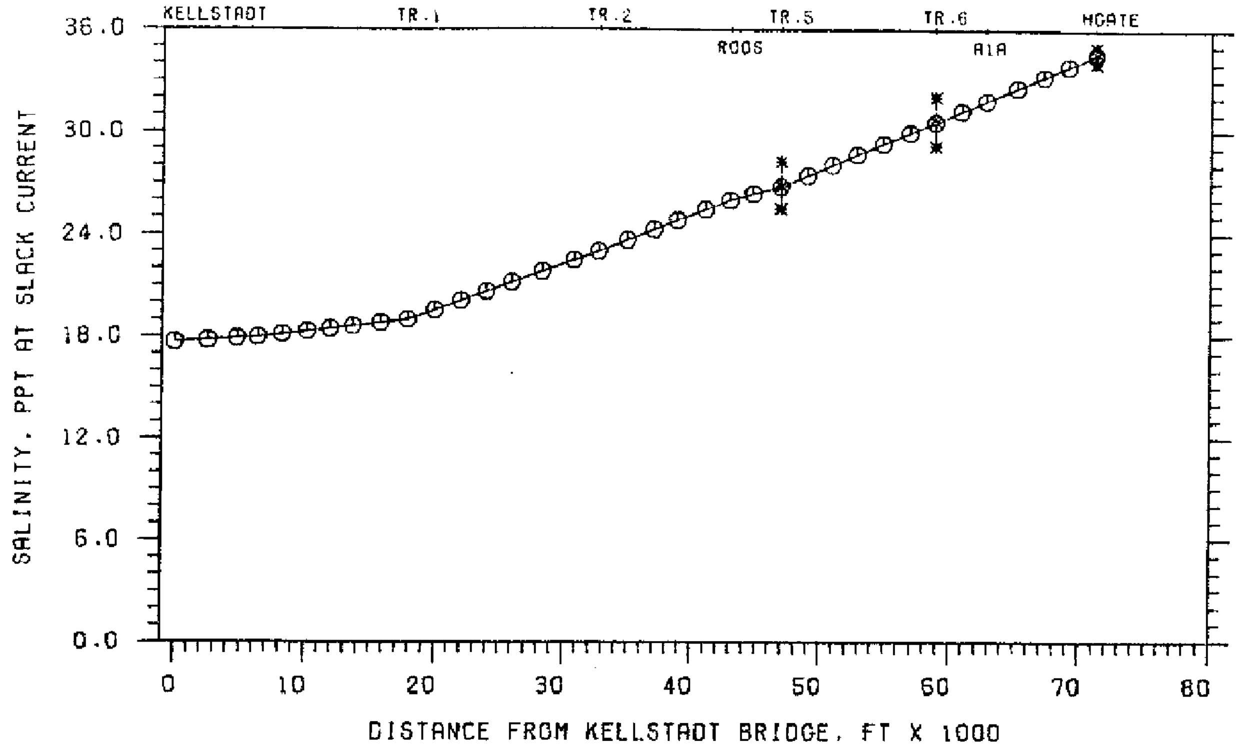
1000 CFS CONTROLLED DISCHARGE

June 15 through July 13, 1977

NORTH FORK

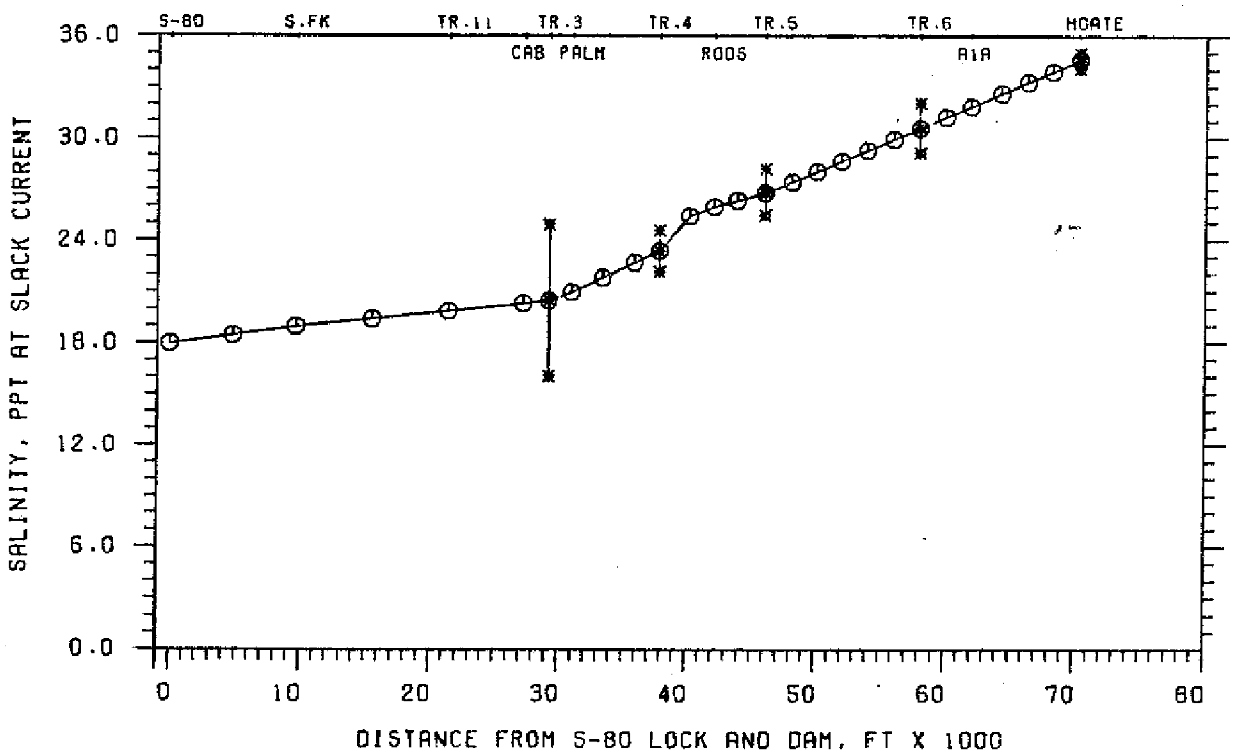
ST. LUCIE ESTUARY

DYNT21 63/62 770615 [S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS (C63S113). SBC: 31.



MEASURED
JUNE 15, 1977
FROM MODEL:
⊕ 770615 0500: LOW TIDE

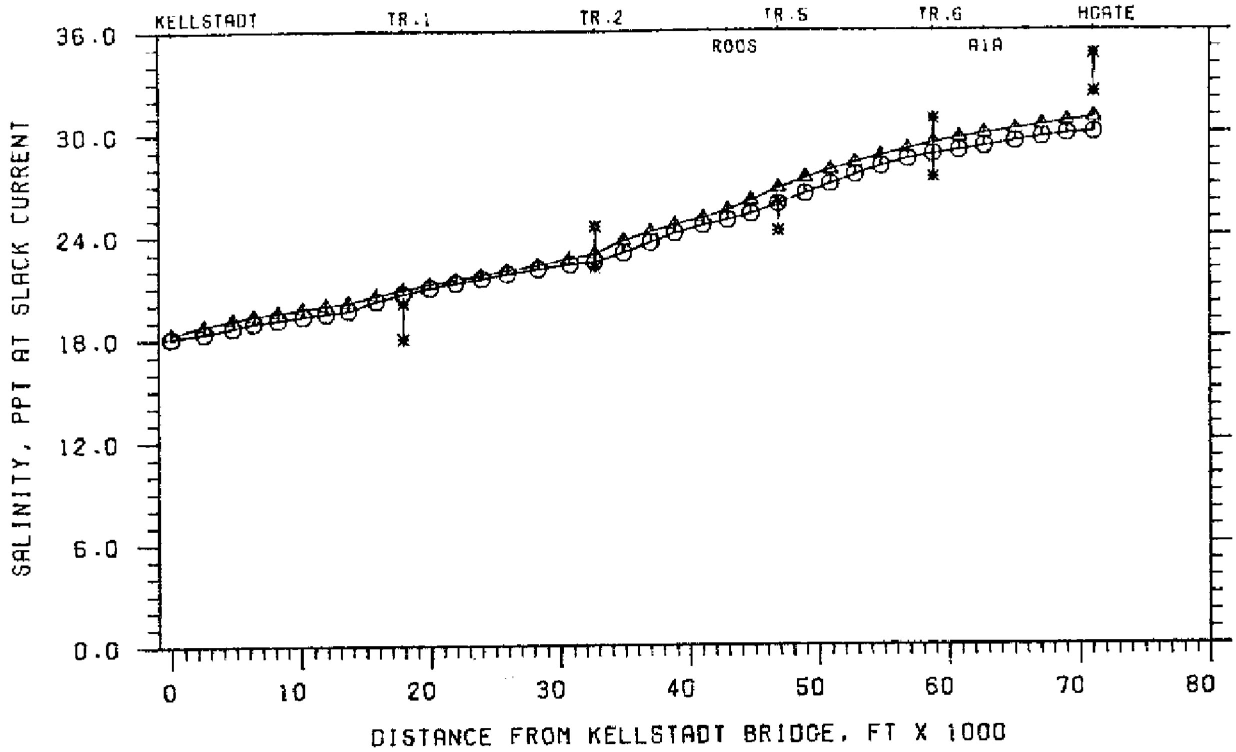
SOUTH FORK



NORTH FORK

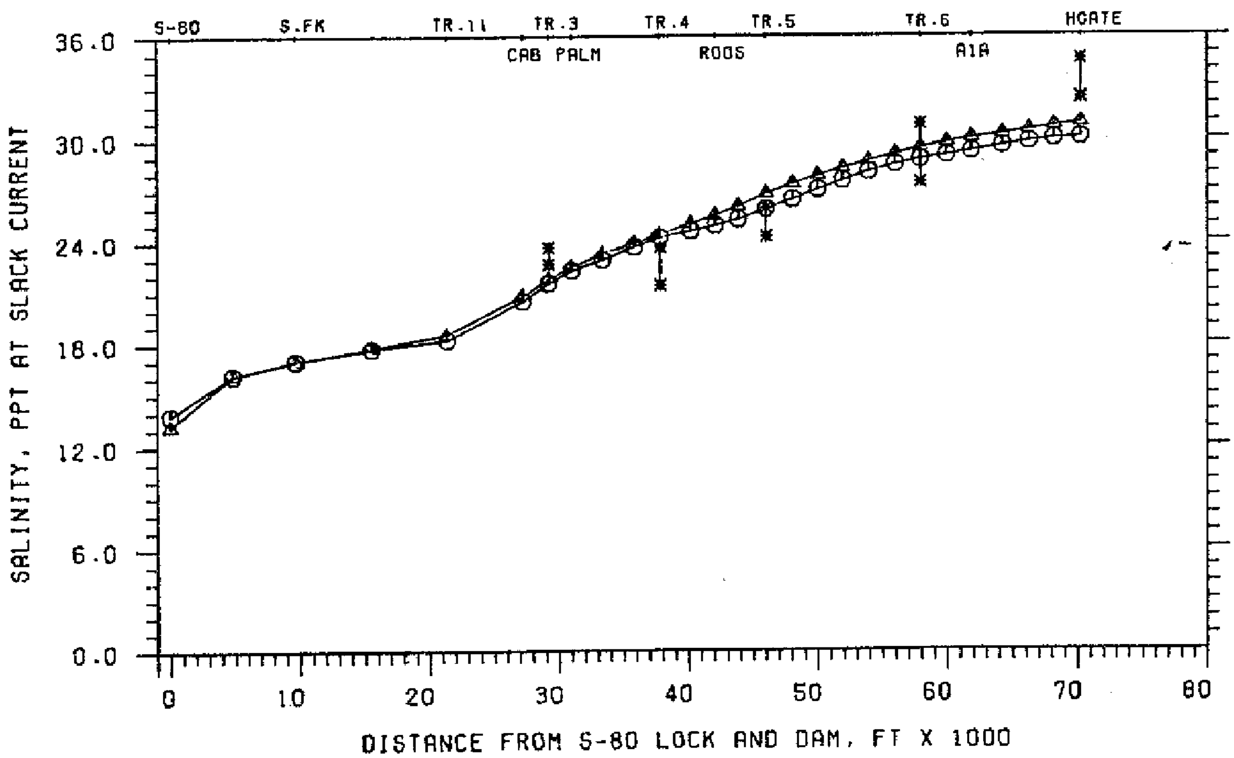
ST. LUCIE ESTUARY

DYNT21 63/62 770615 [S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS [G635113]. SBC: 31.



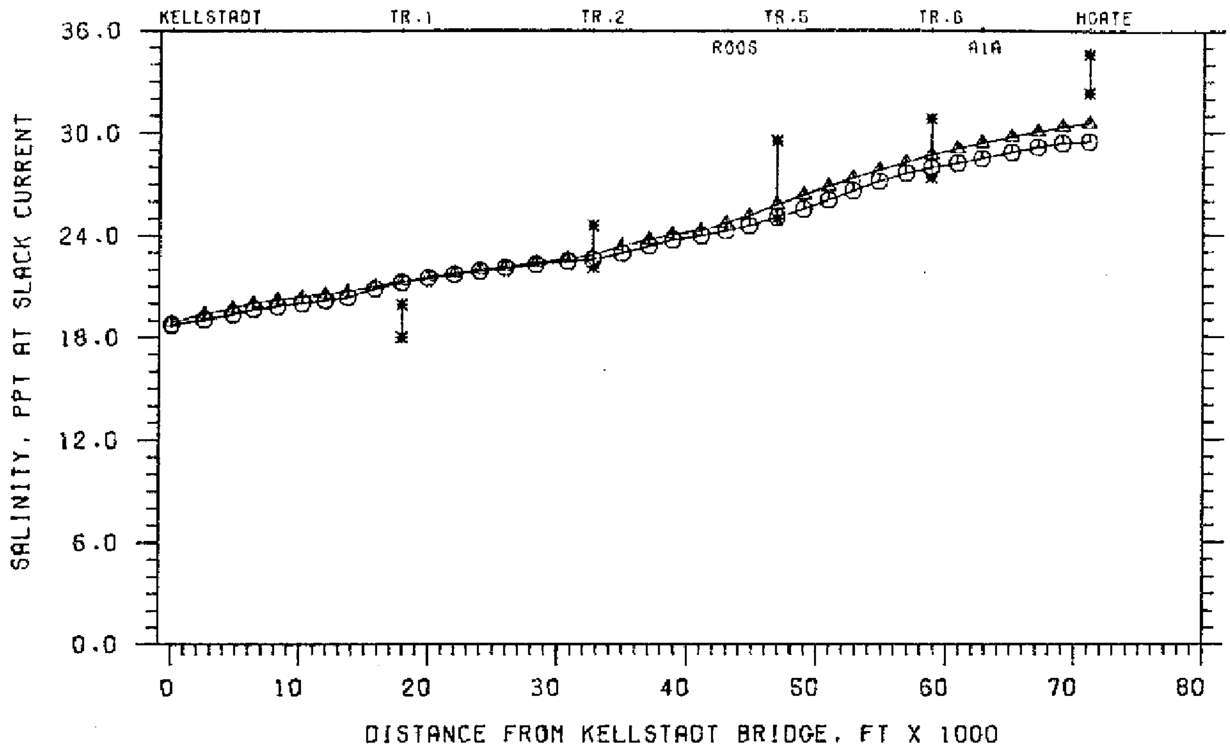
MEASURED
JUNE 17, 1977
FROM MODEL:
⊙ 770617 0600: LOW TIDE
△ 770617 1100: HIGH TIDE

SOUTH FORK



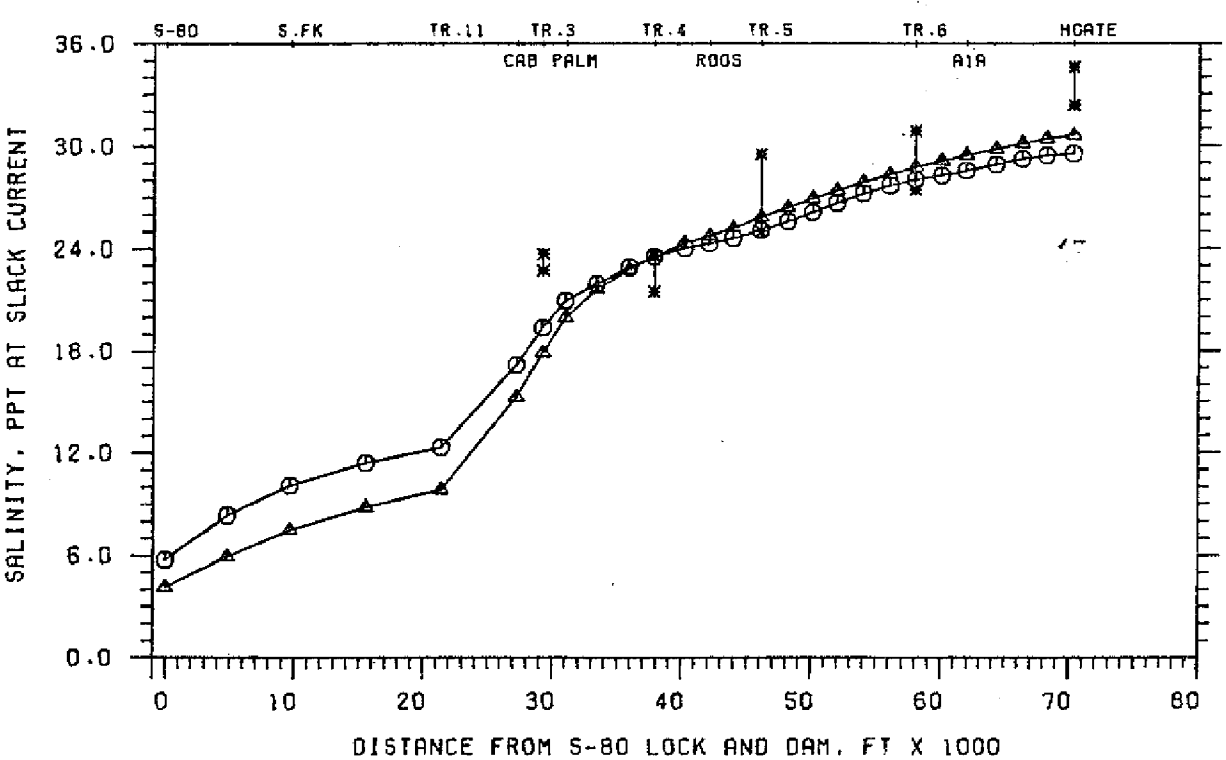
NORTH FORK — ST. LUCIE ESTUARY

DYNT21 63/62 770615 (S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. CW: 149 CFS (G63S113). SBC: 31.



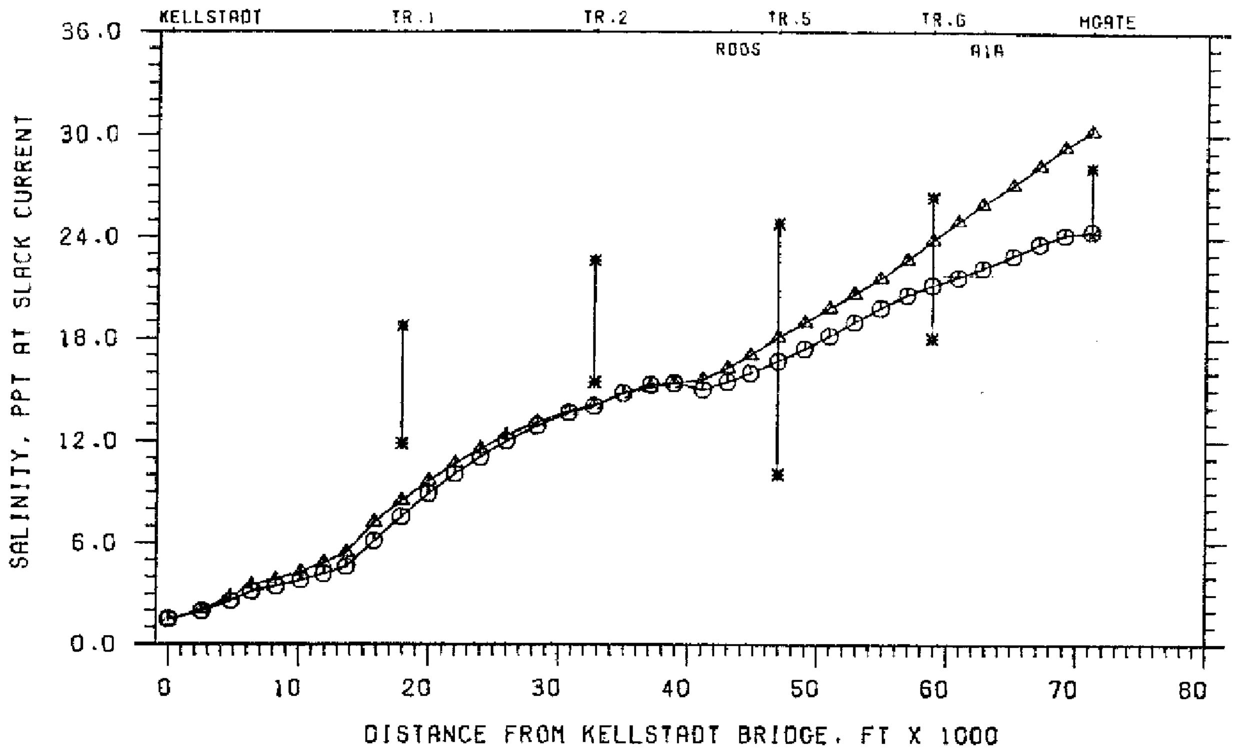
MEASURED
JUNE 20, 1977
FROM MODEL:
770620 0800: LOW TIDE
770620 1400: HIGH TIDE

SOUTH FORK



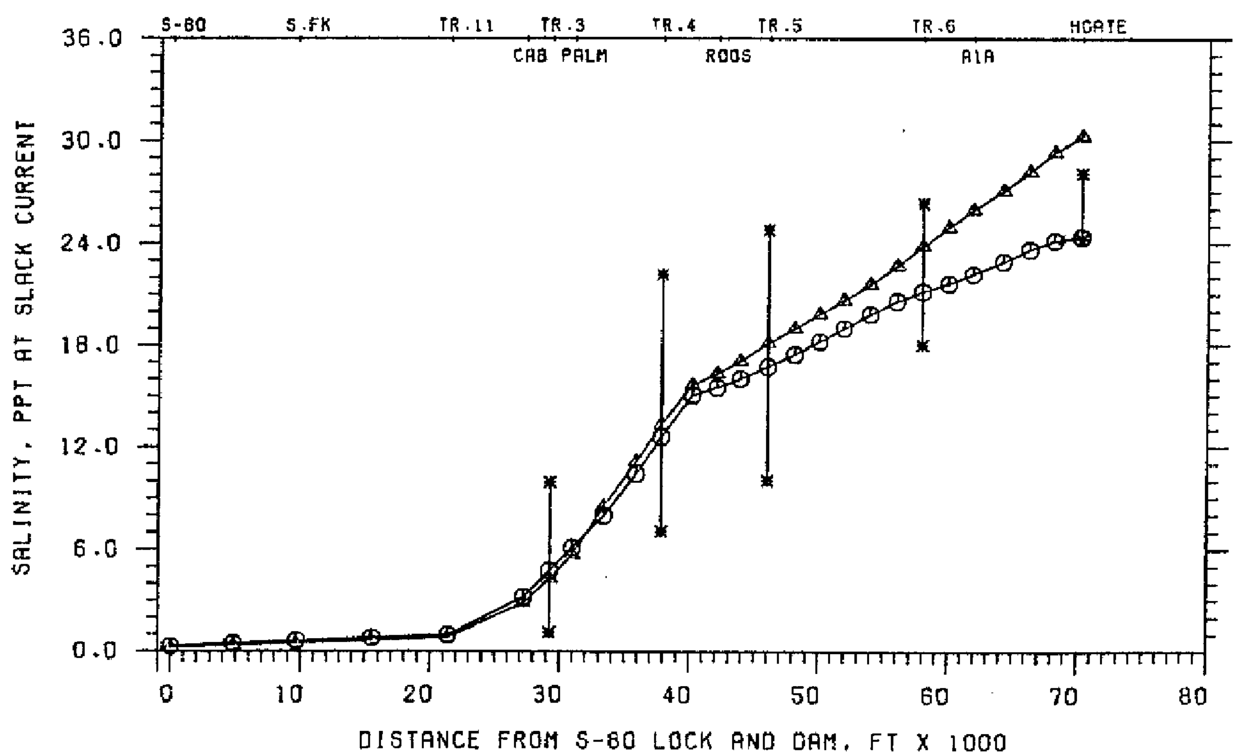
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 770615 IS141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 31.



MEASURED
JUNE 23, 1977
FROM MODEL:
○ 770623 1000: LOW TIDE
△ 770623 1600: HIGH TIDE

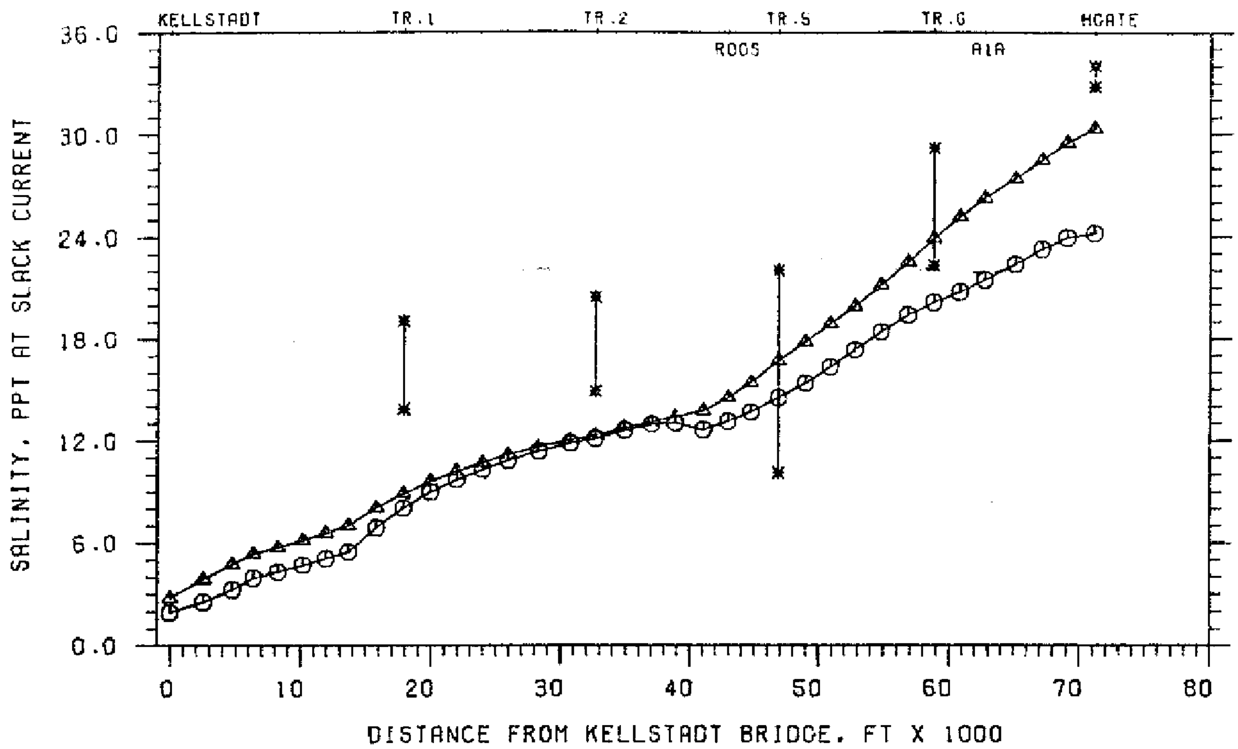
SOUTH FORK



ST. LUCIE ESTUARY

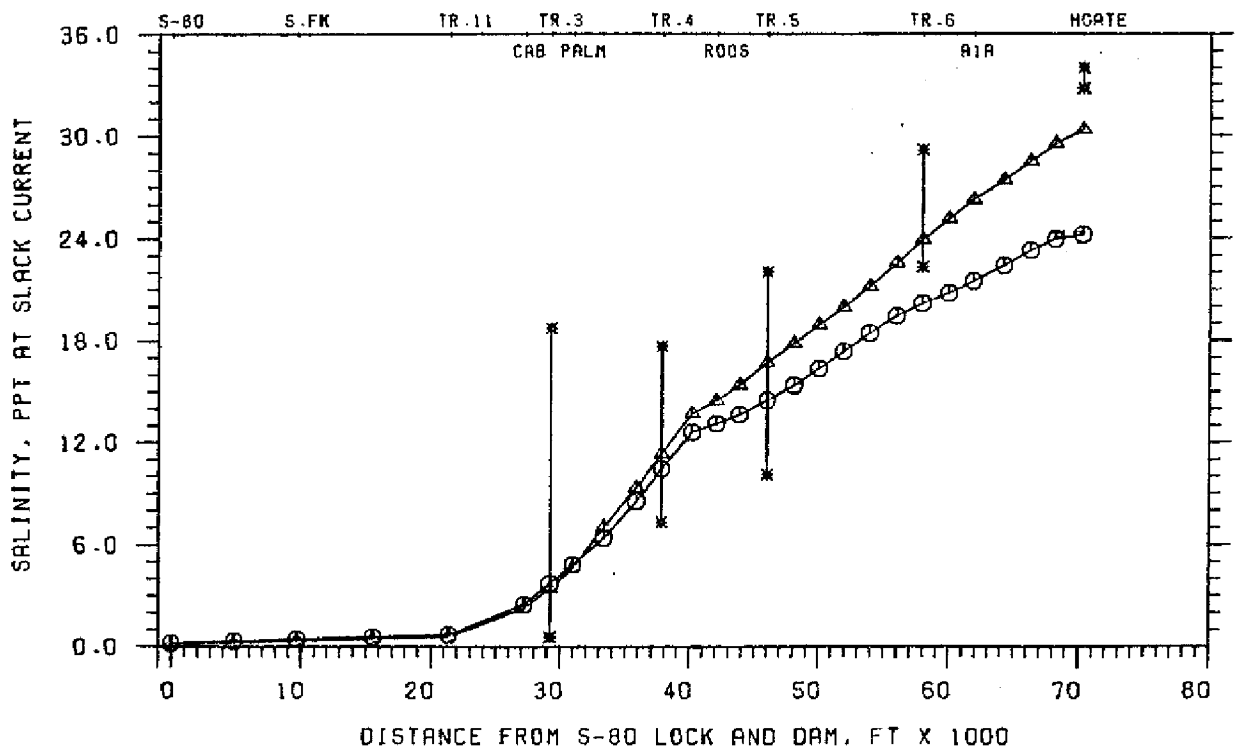
NORTH FORK

DYNT21 63/62 770615 [S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS (G635113). SBC: 31.



MEASURED
JUNE 24, 1977
FROM MODEL:
O 770624 1100: LOW TIDE
△ 770624 1700: HIGH TIDE

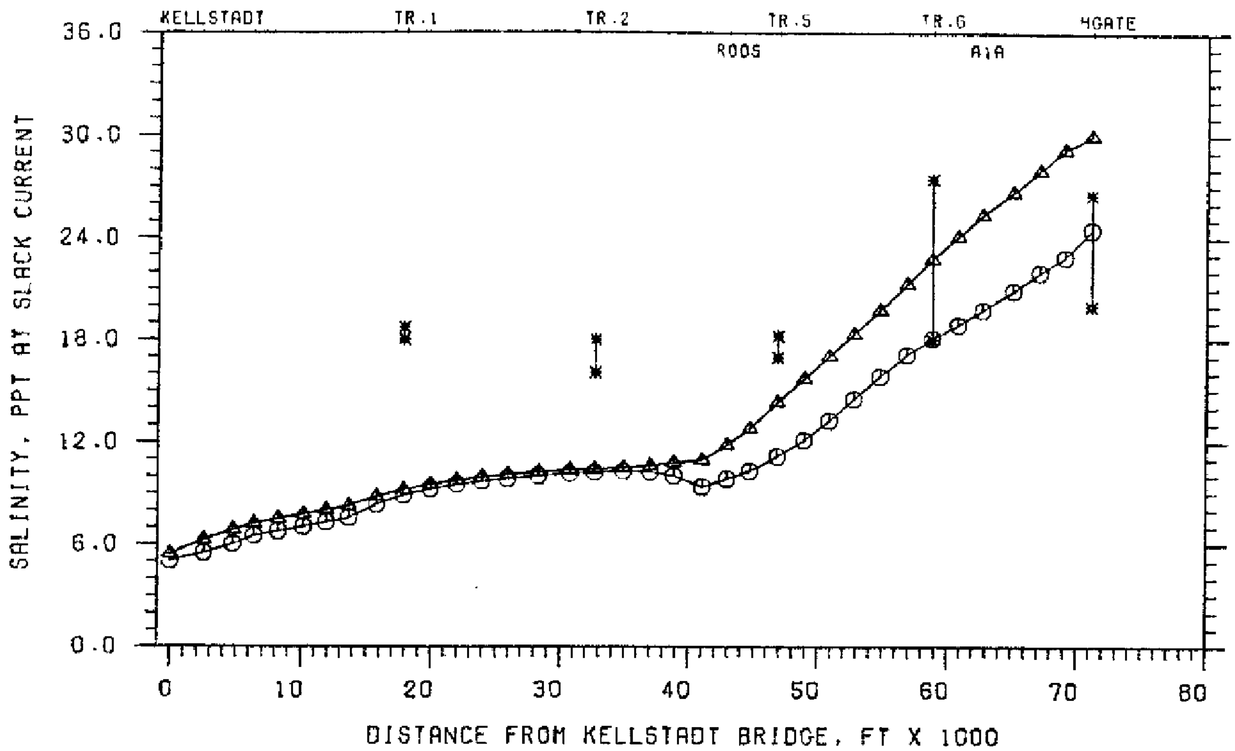
SOUTH FORK



NORTH FORK

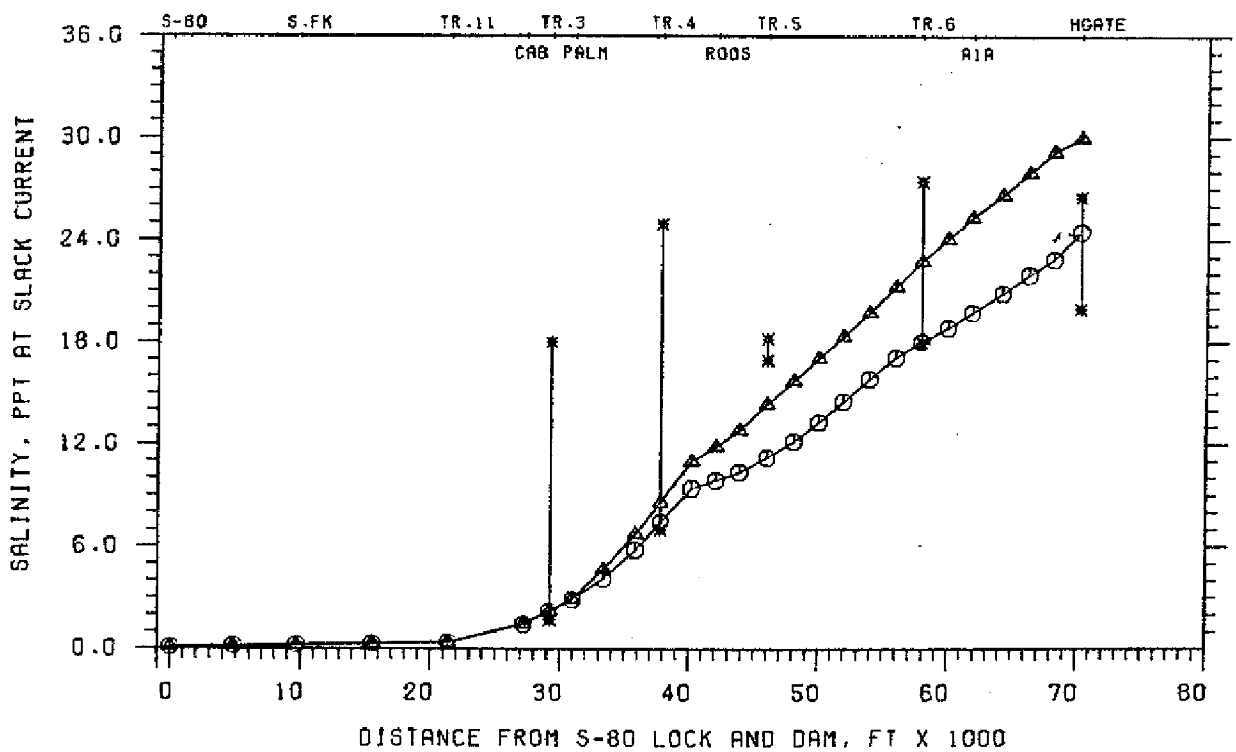
ST. LUCIE ESTUARY

DYNT21 63/62 770615 !S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. DW: 149 CFS (G63S113). SBC: 31.



MEASURED
JUNE 27, 1977
FROM MODEL:
O 770627 0700: HIGH TIDE
△ 770627 1400: LOW TIDE

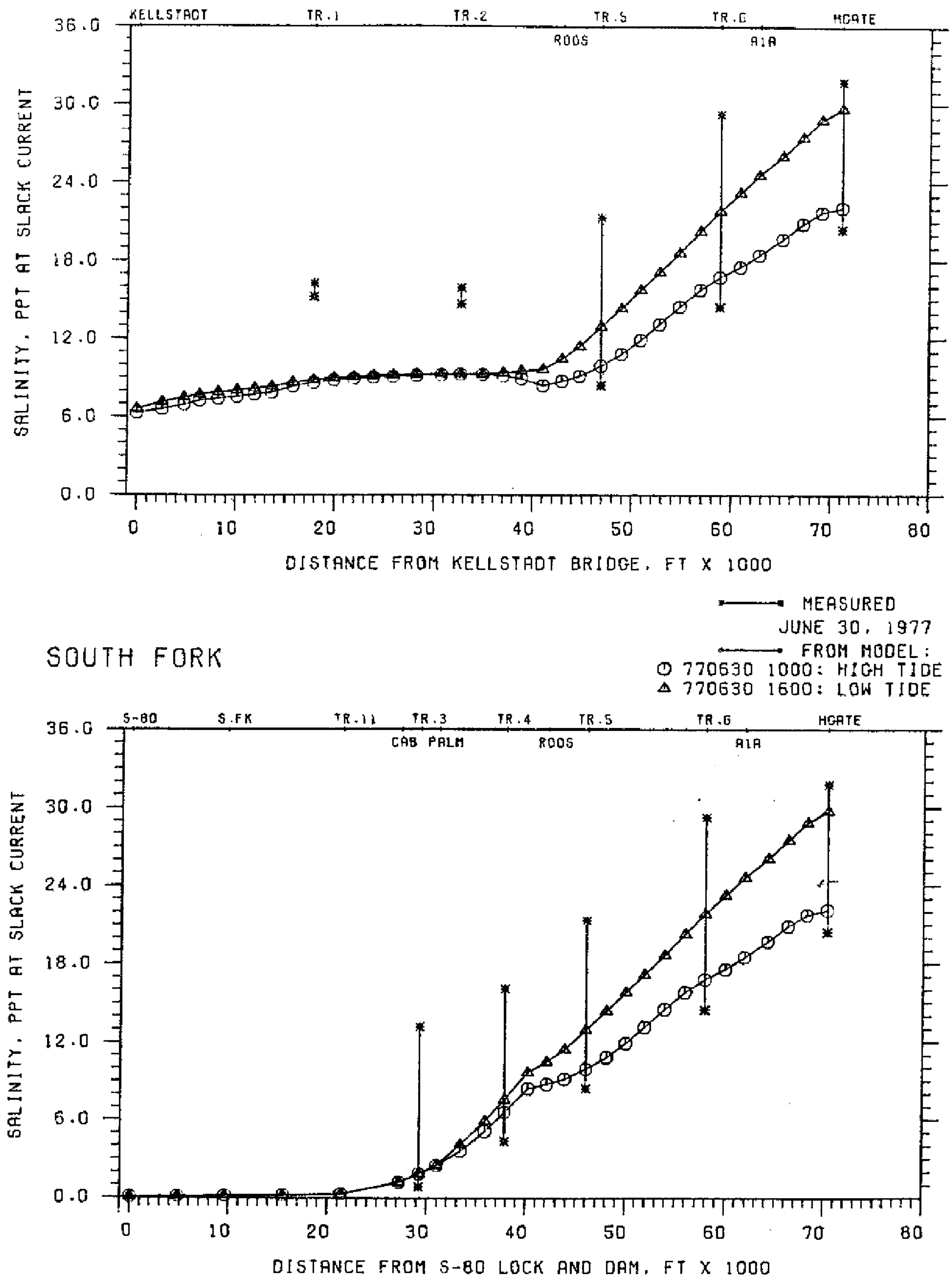
SOUTH FORK



NORTH FORK

ST. LUCIE ESTUARY

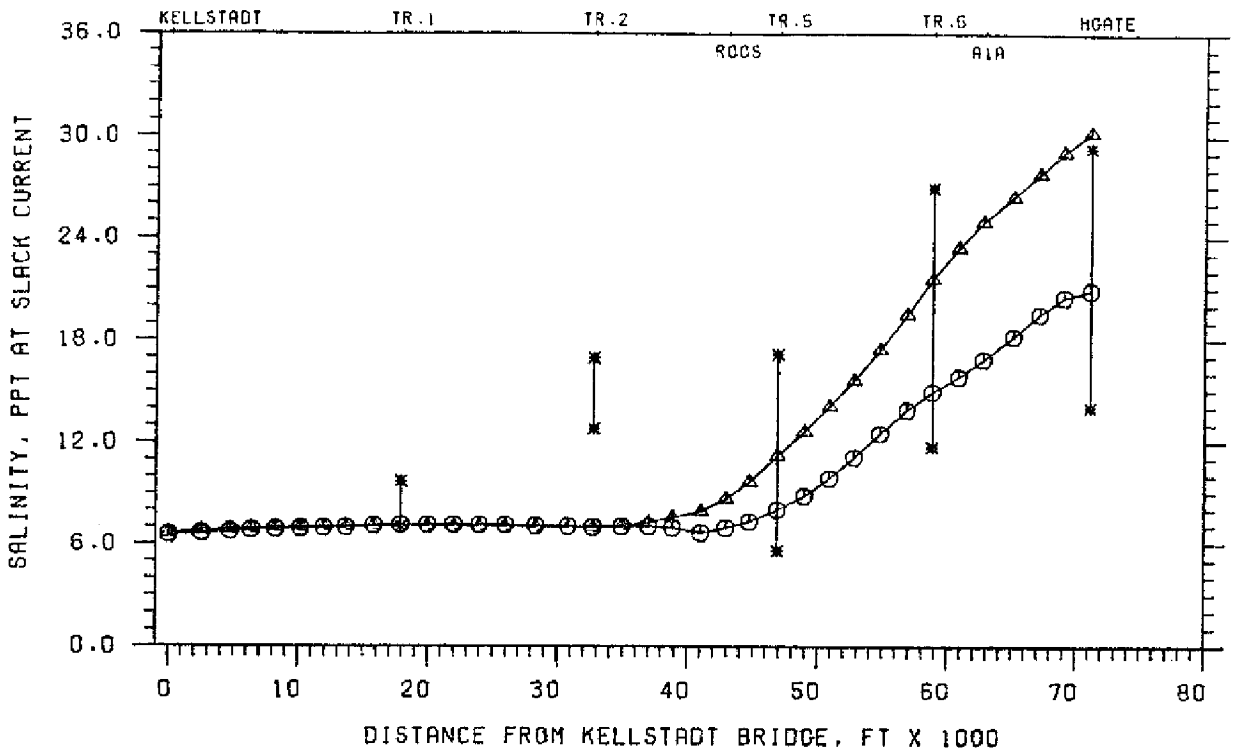
DYNT21 63/62 770615 (S14) -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S14)
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. DW: 149 CFS (G63S113). SBC: 31.



NORTH FORK

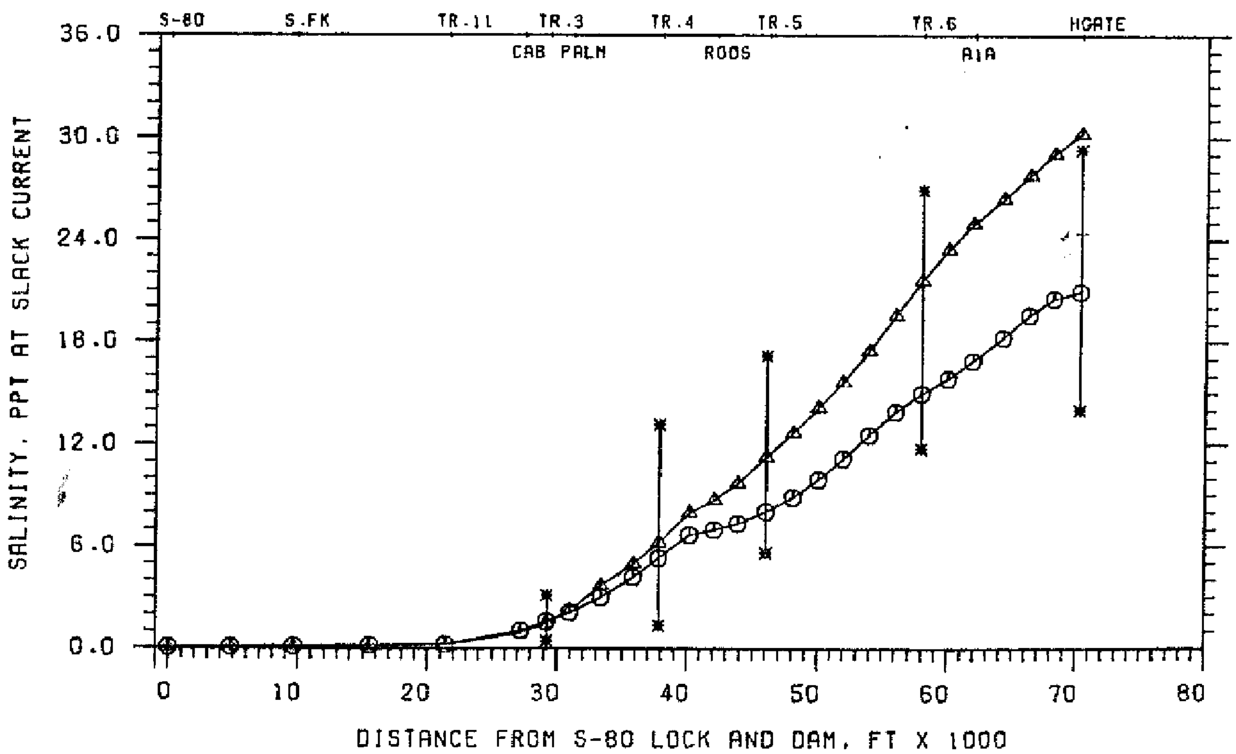
ST. LUCIE ESTUARY

DYNT21 63/62 770615 [S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS (063S113). SBC: 31.



MEASURED
JULY 7, 1977
FROM MODEL:
770707 1000: LOW TIDE
770707 1600: HIGH TIDE

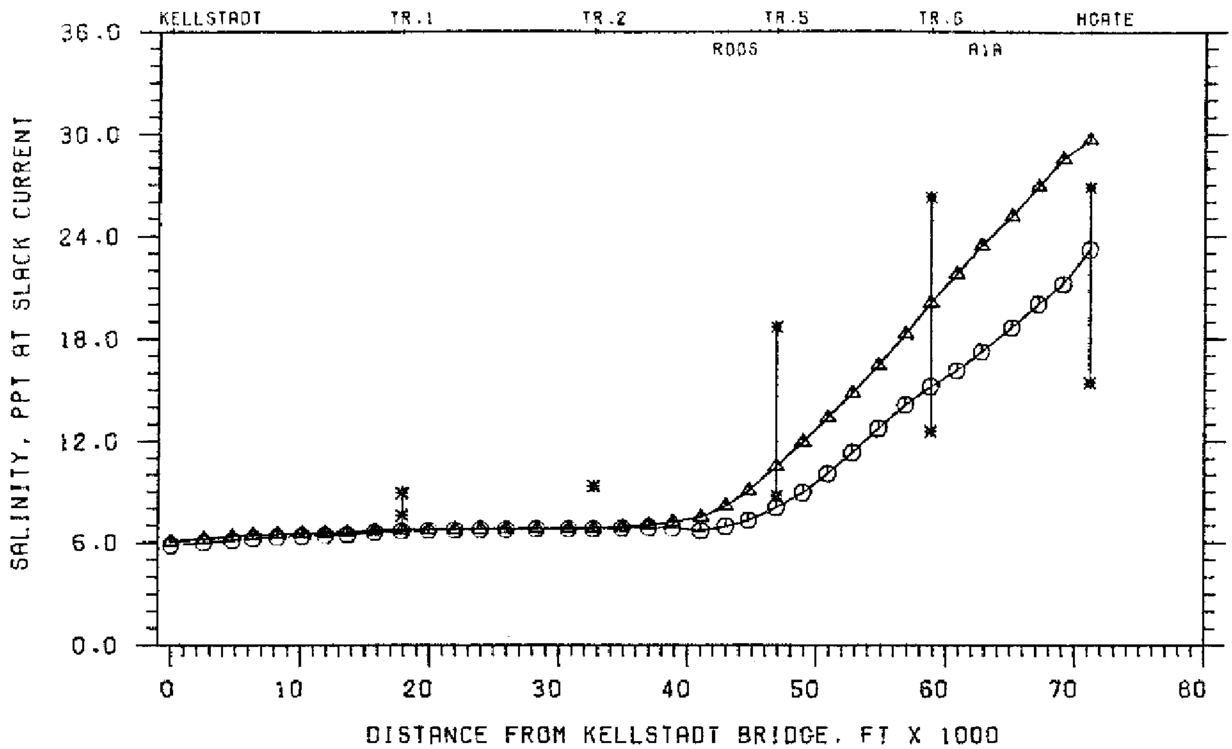
SOUTH FORK



NORTH FORK

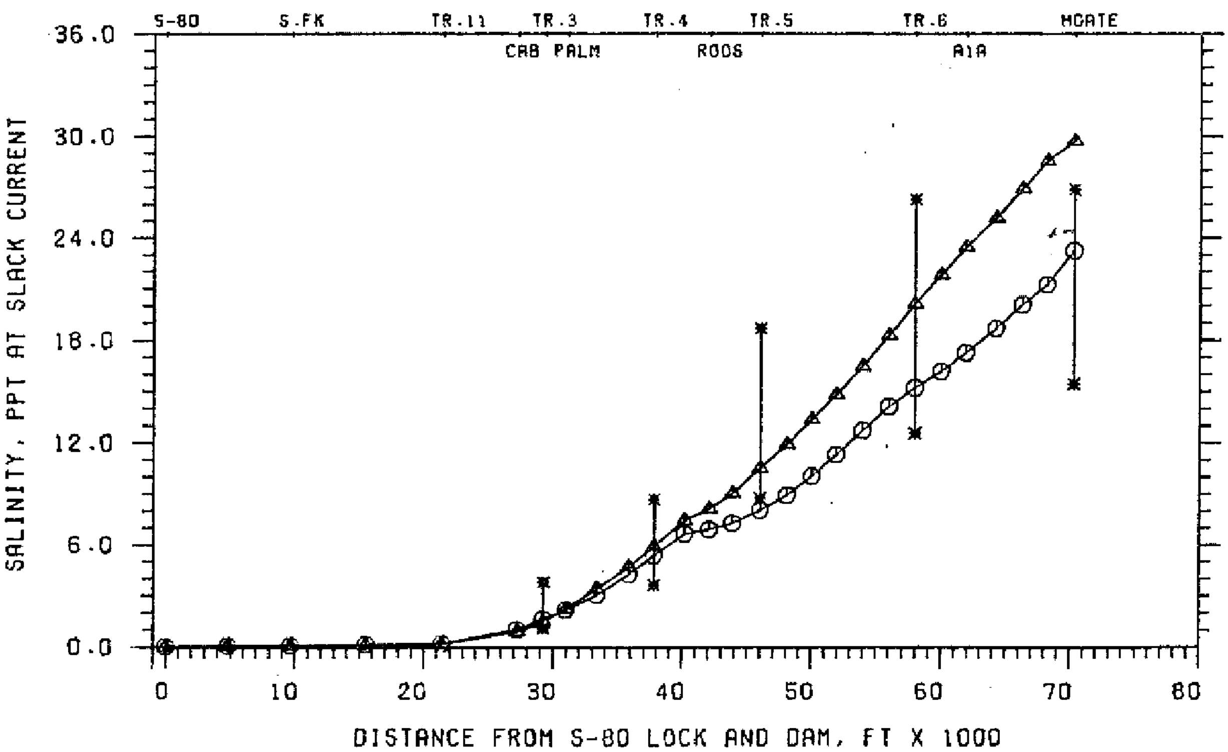
ST. LUCIE ESTUARY

DYNT21 63/62 770615 !S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77". DC: 300/700/1000/2000. GW: 149 CFS (G636113). SBC: 31.



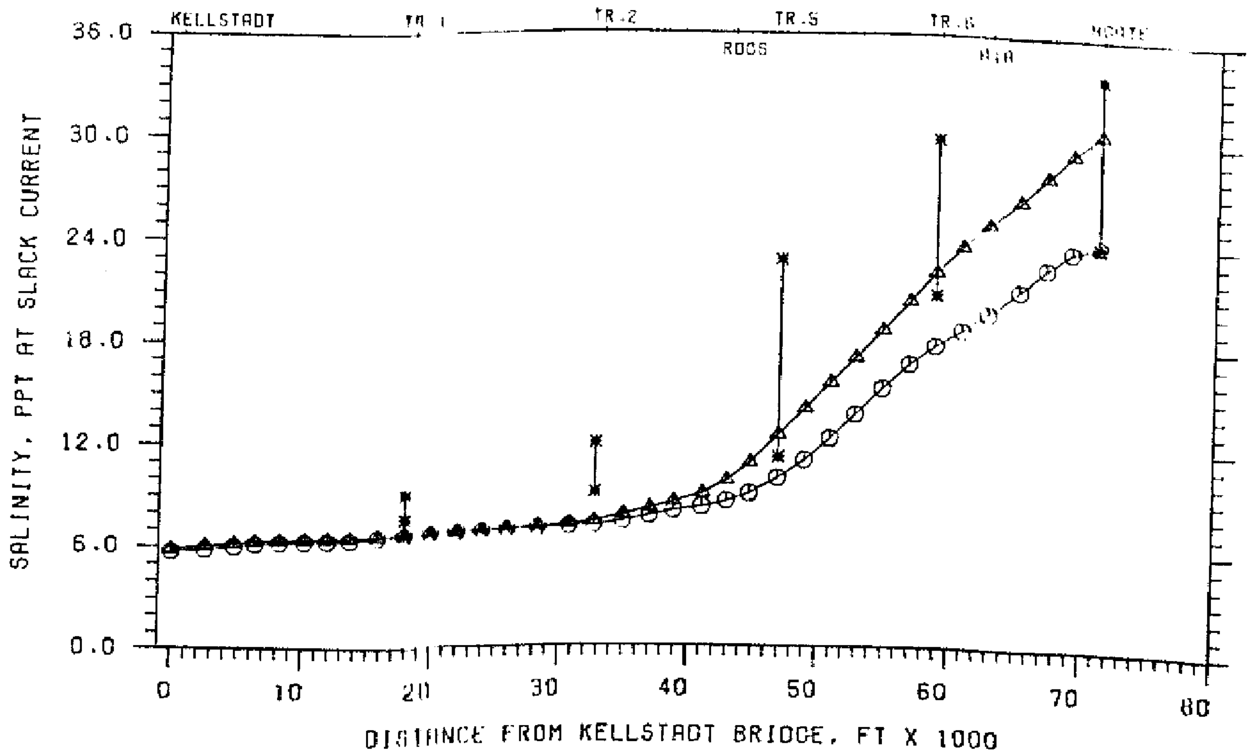
MEASURED
JULY 11, 1977
FROM MODEL:
O 770711 0700: HIGH TIDE
Δ 770711 1400: LOW TIDE

SOUTH FORK



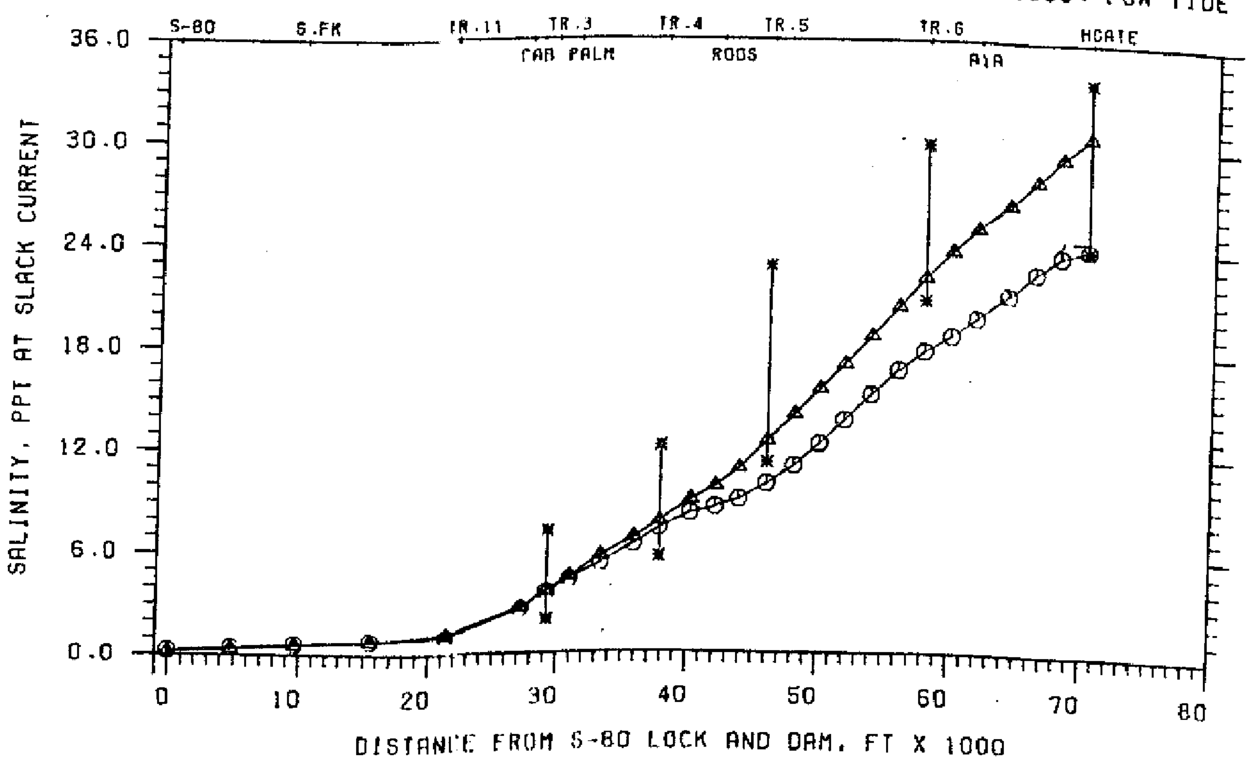
NORTH FORK — ST. LUCIE ESTUARY

DYNT21 63/62 770615 (S141 -- 29 DAYS -- 1000 CFS CONTROLLED DISCHARGE -- S141
TIDAL BNDRY: "HEL77", BC, 300/700/1000/2000. GW: 149 CFS (DG3S113), SBC, 31.



MEASURED
JULY 13, 1977
FROM MODEL:
O 770713 0800: HIGH TIDE
△ 770713 1500: LOW TIDE

SOUTH FORK



APPENDIX G

SALINITY VERIFICATION

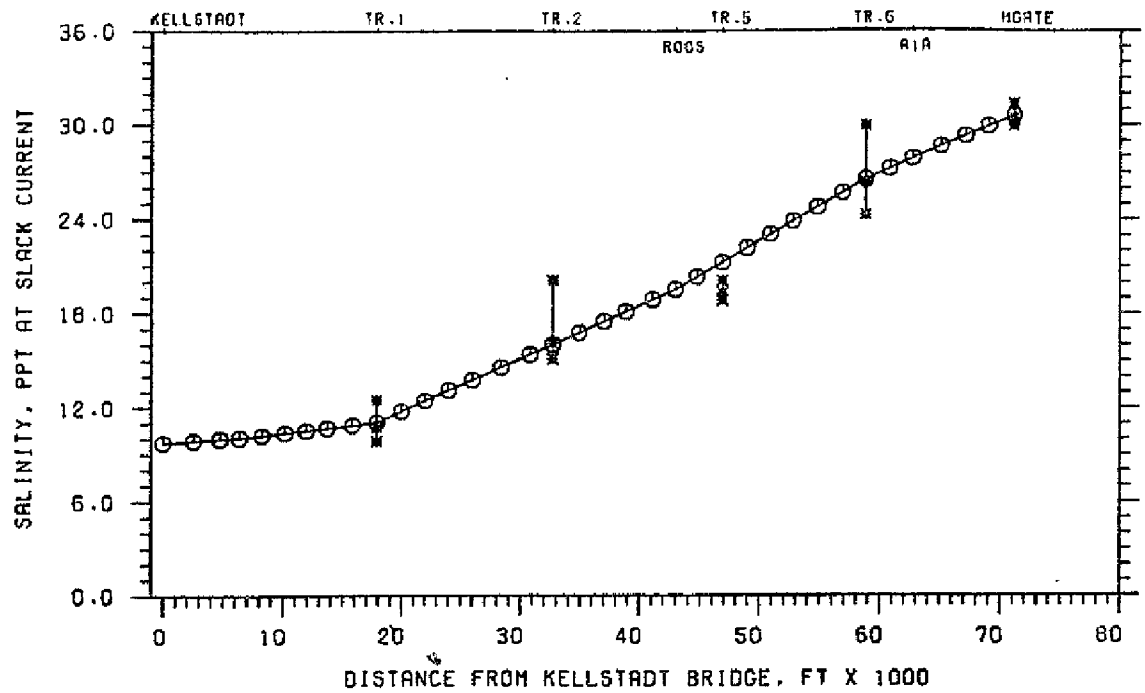
2500 CFS CONTROLLED DISCHARGE

June15 through August 2, 1978

ST. LUCIE ESTUARY

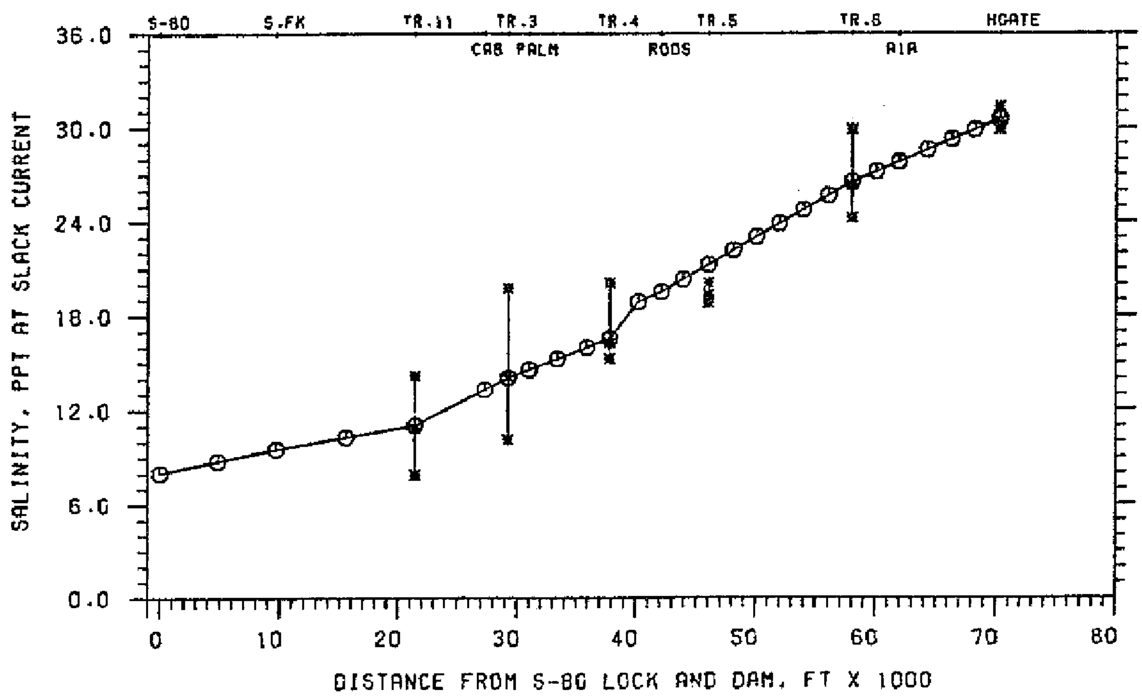
NORTH FORK

DYNT21 63/62 780615 TS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (0635113). SBC: 30.



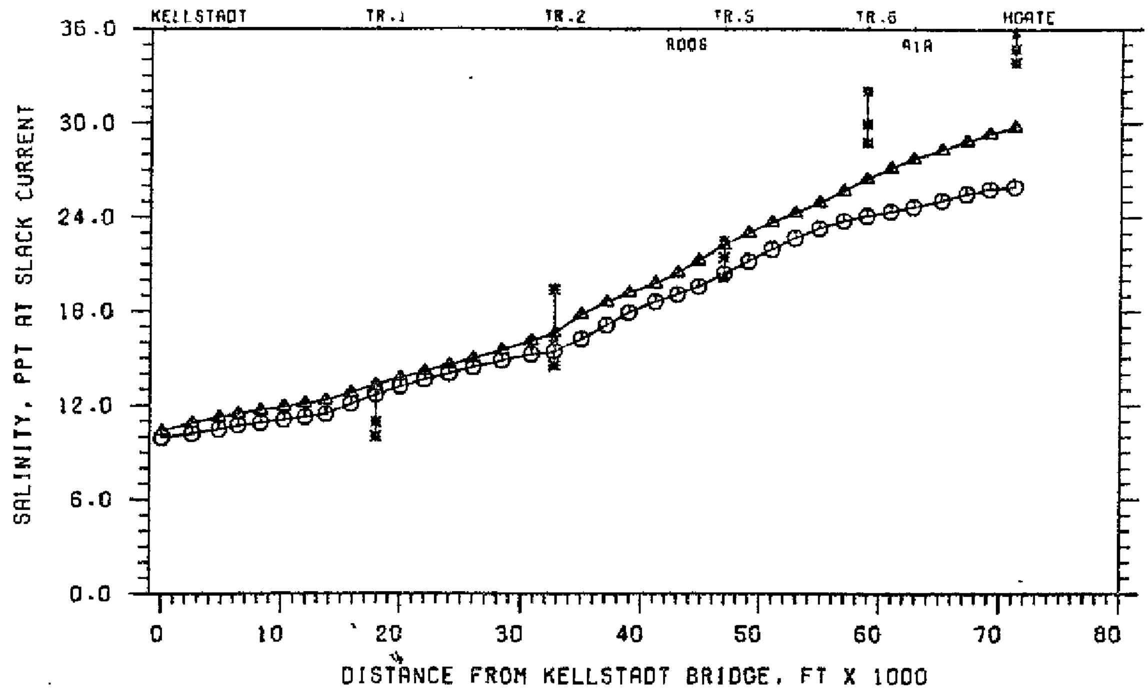
MEASURED
JUNE 15, 1978
FROM MODEL:
780615 1300: LOW TIDE

SOUTH FORK



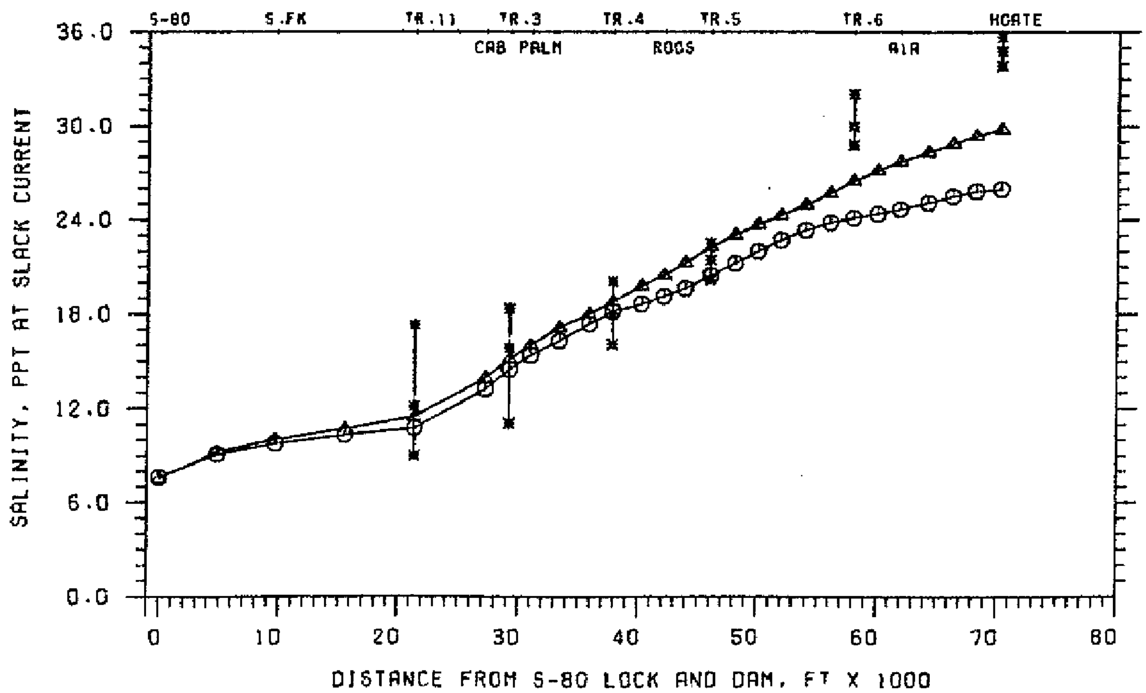
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (GG3S113). SBC: 30.



MEASURED
JUNE 16, 1978
FROM MODEL:
O 780616 1300: LOW TIDE
△ 780616 1900: HIGH TIDE

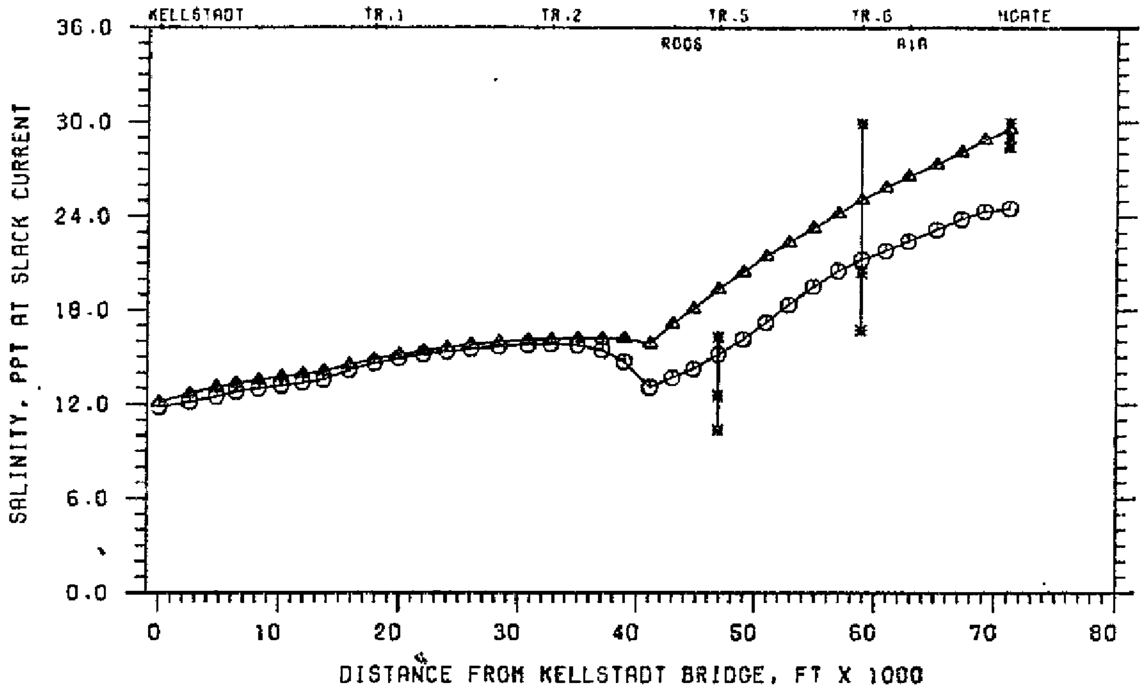
SOUTH FORK



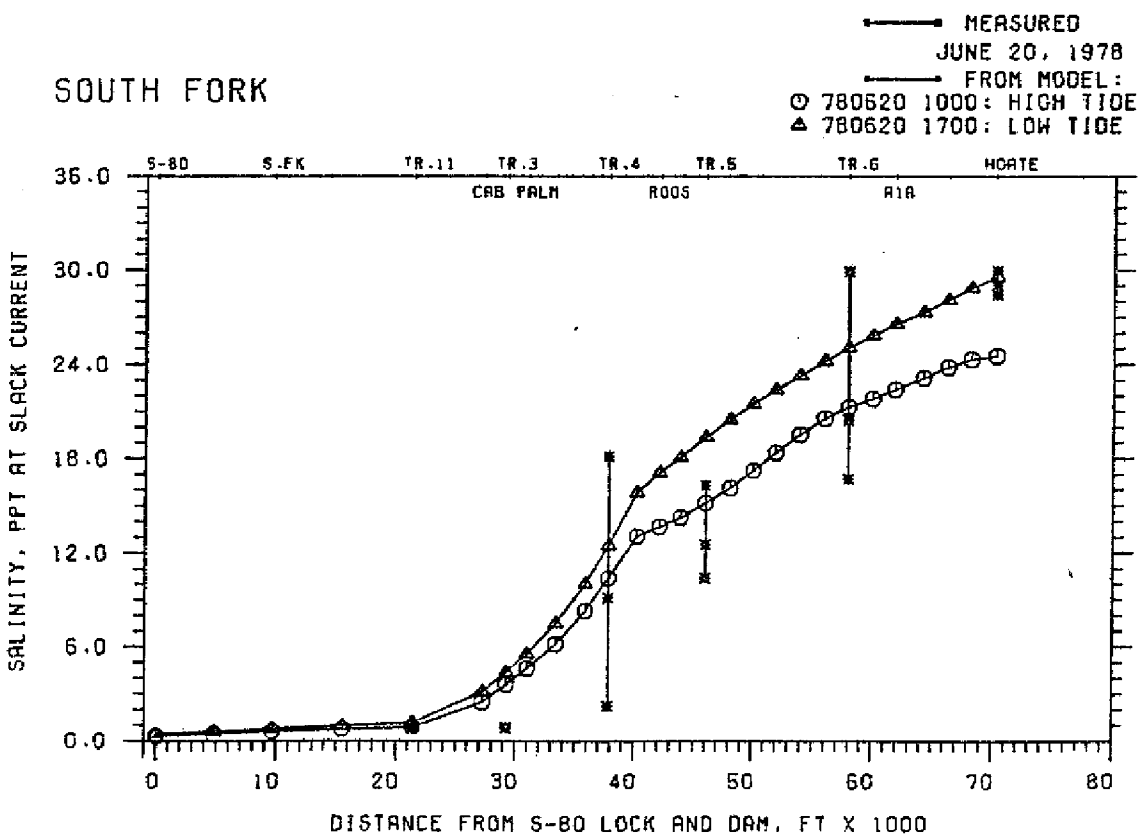
NORTH FORK

ST. LUCIE ESTUARY

DYNT21 63/62 780615 1S142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (063S113). SBC: 30.



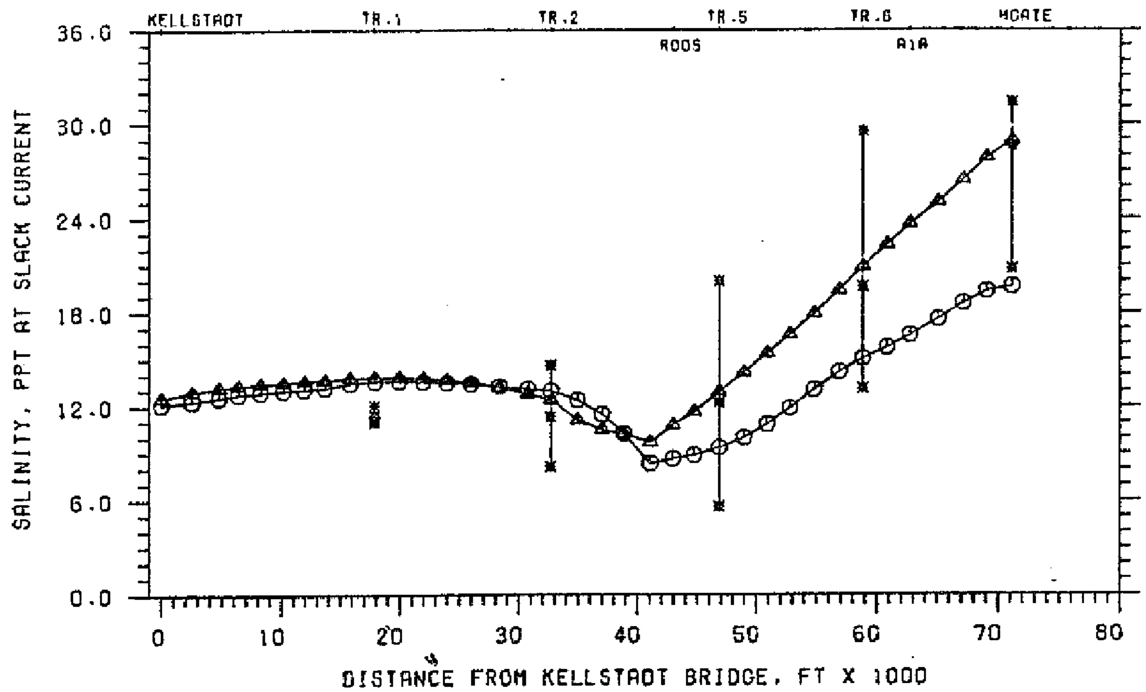
SOUTH FORK



ST. LUCIE ESTUARY

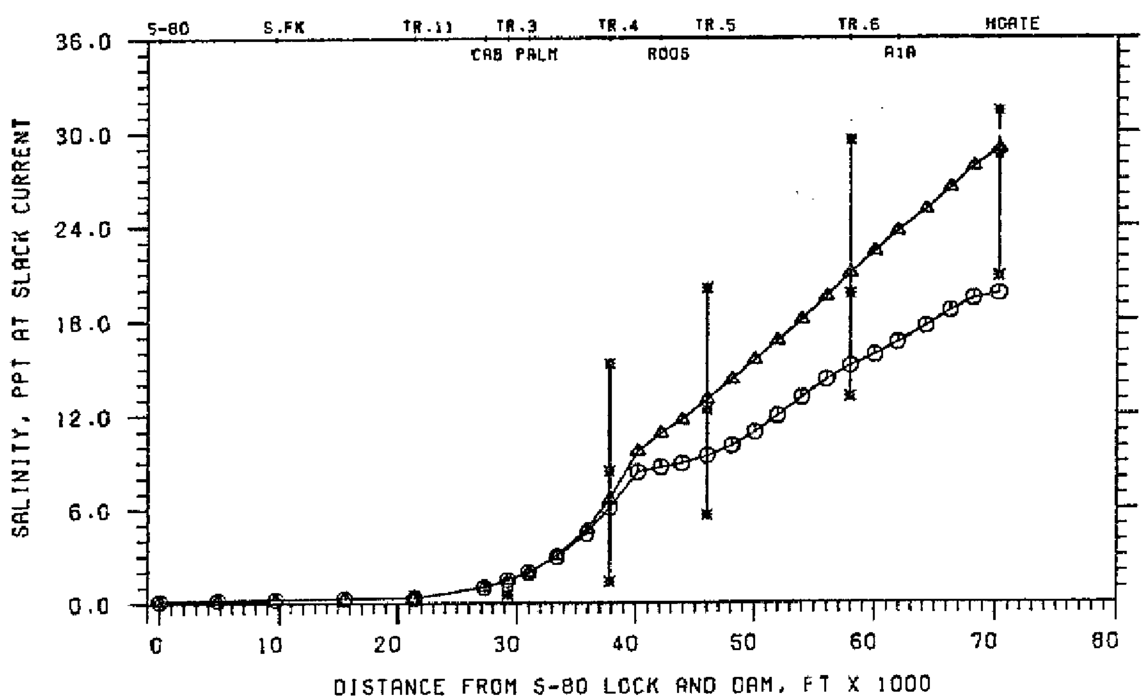
NORTH FORK

DYNT21 63/62 780615 !S142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78", DC: 300/700/1000/2000, CW: 149 CFS (C63S113), SBC: 30.



MEASURED
JUNE 22, 1978
FROM MODEL:
⊕ 780622 1200: HIGH TIDE
△ 780622 1900: LOW TIDE

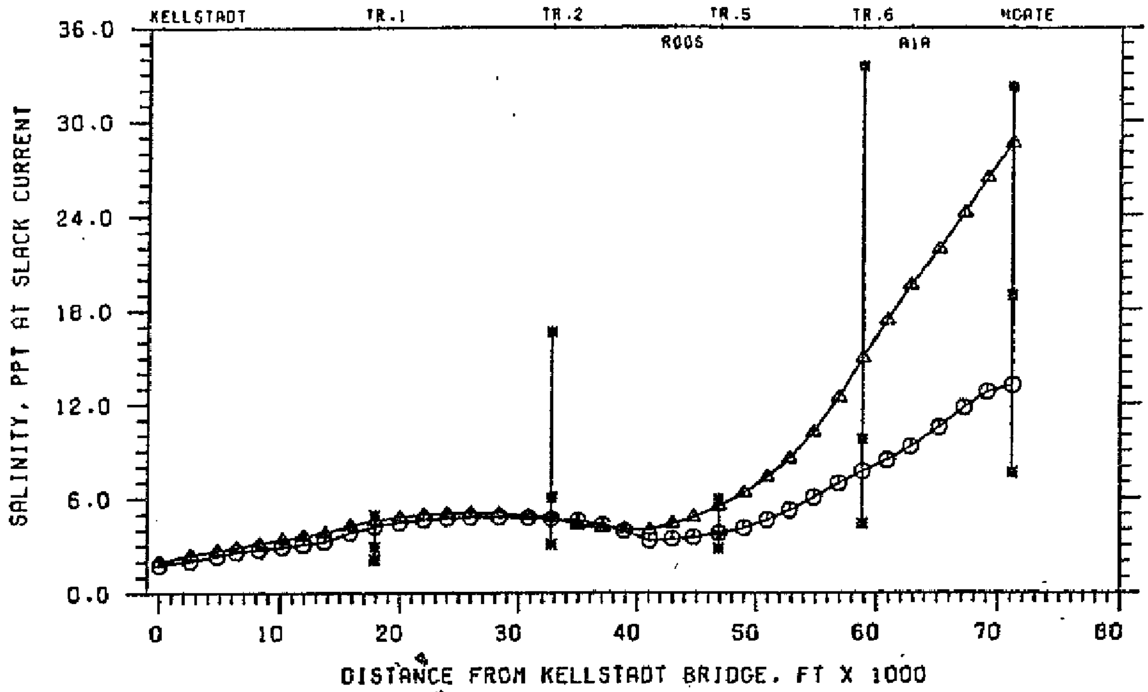
SOUTH FORK



NORTH FORK

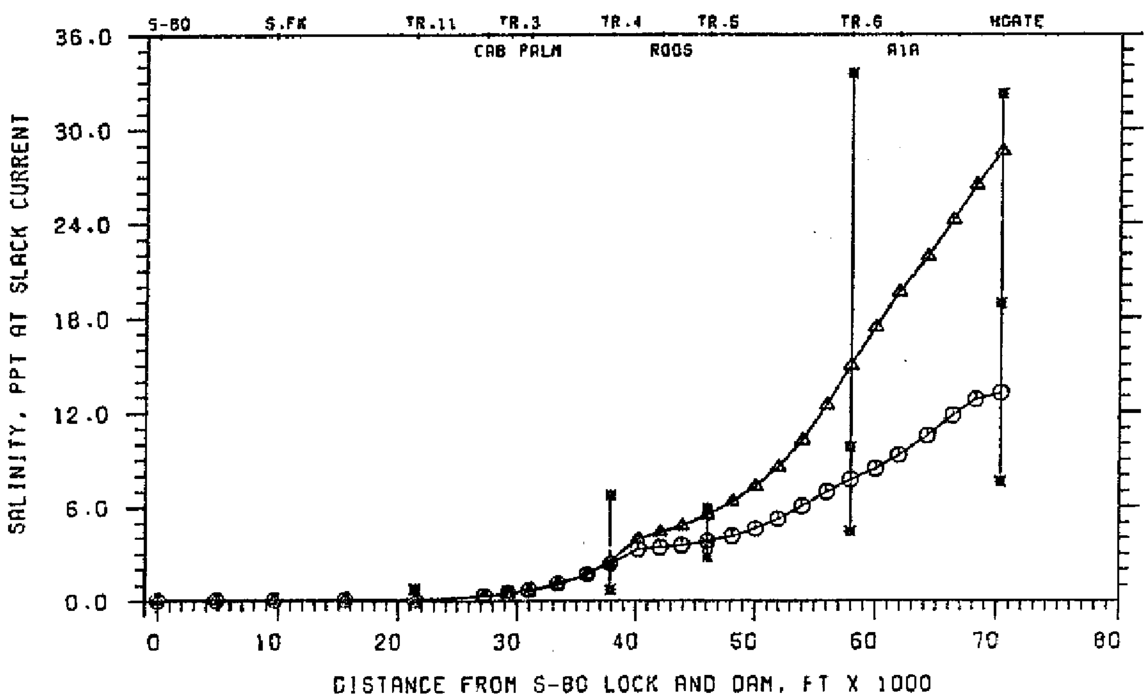
ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. CW: 149 CFS (G63S113). SBC: 30.



MEASURED
JUNE 27, 1978
FROM MODEL:
○ 780627 0400: HIGH TIDE
△ 780627 1100: LOW TIDE

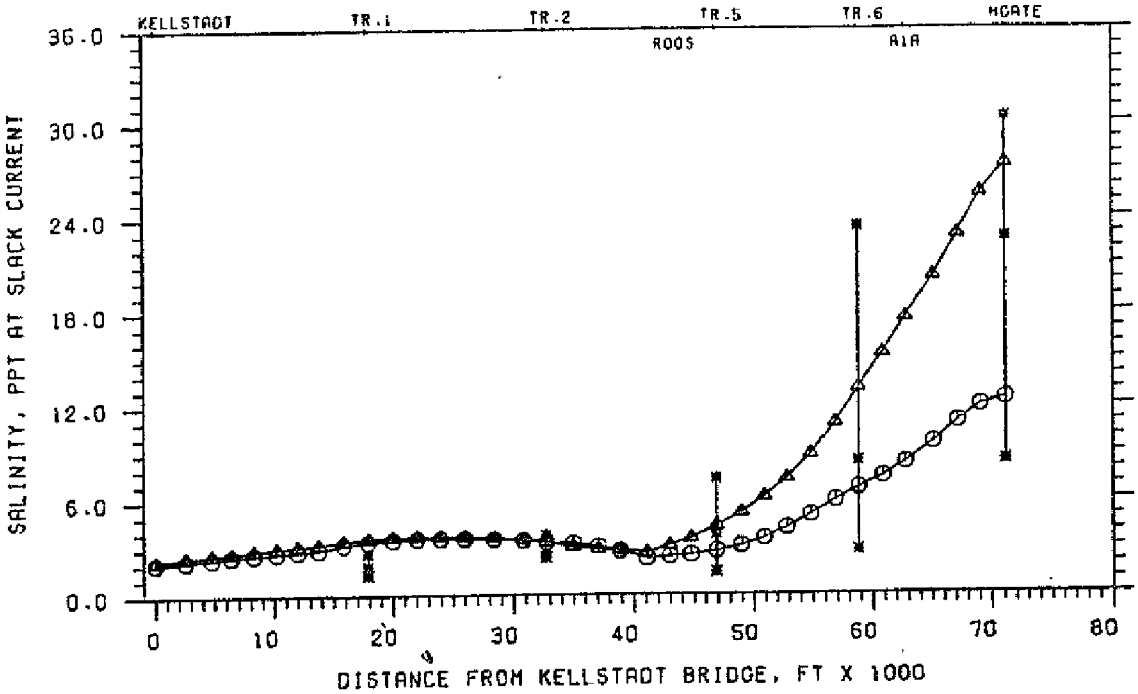
SOUTH FORK



ST. LUCIE ESTUARY

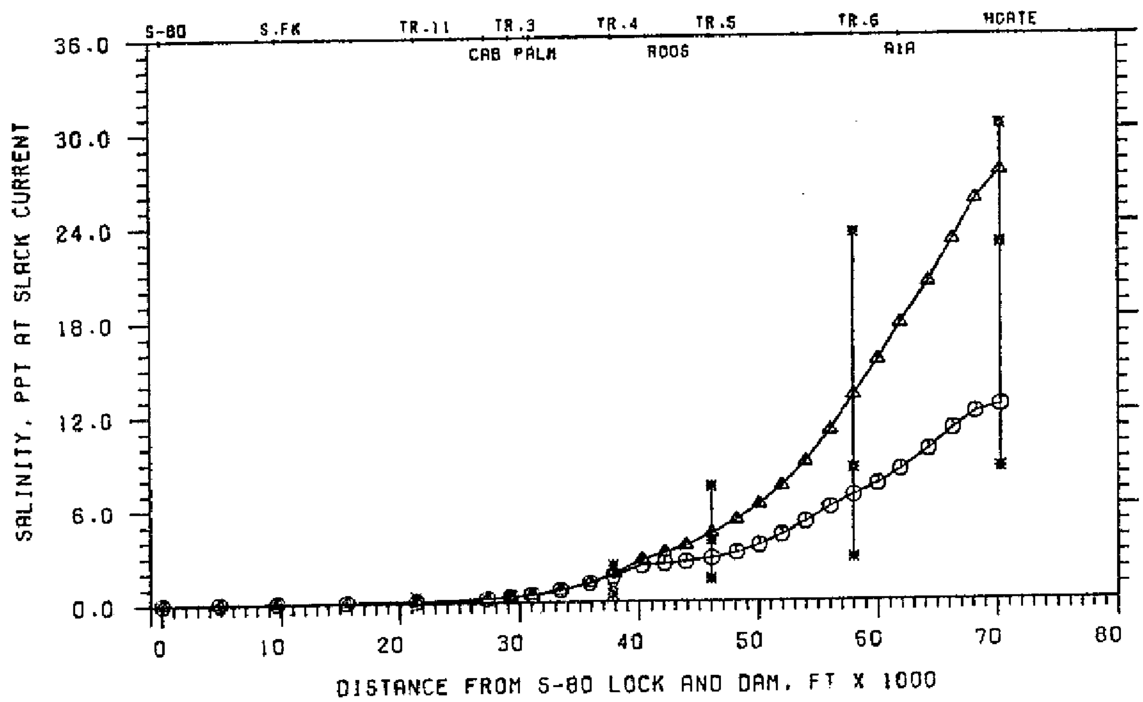
NORTH FORK

DYNT21 63/62 780615 !S142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. CW: 149 CFS (06351131). SBC: 30.



—— MEASURED
JUNE 29, 1978
——— FROM MODEL:
○ 780629 0600: HIGH TIDE
△ 780629 1300: LOW TIDE

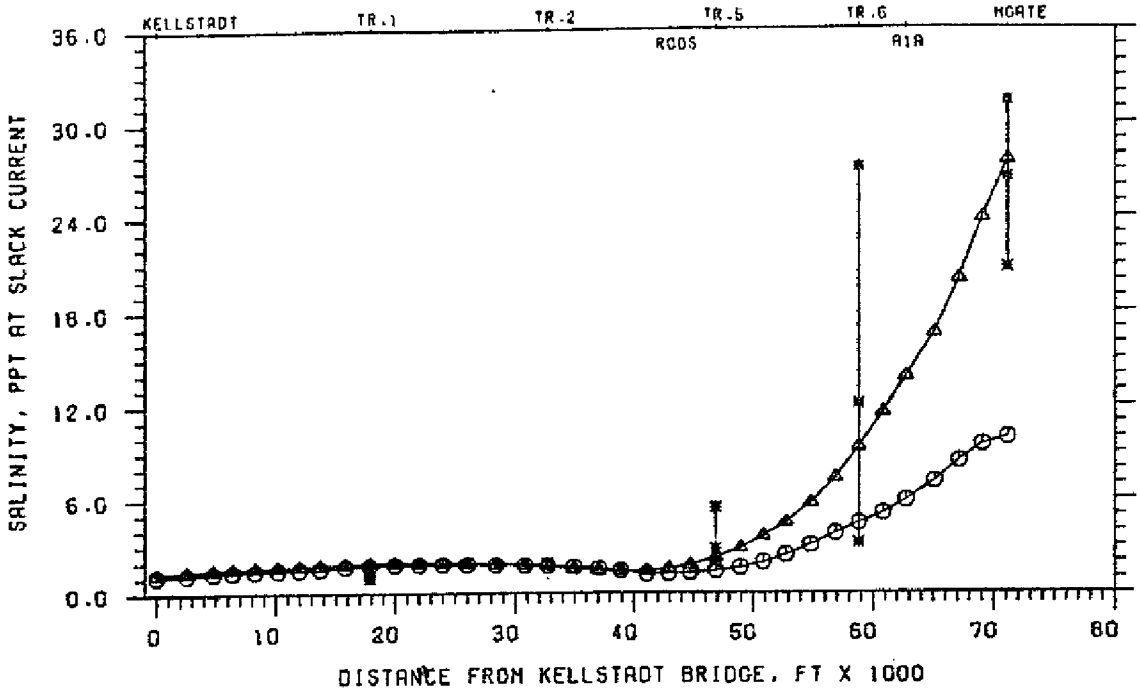
SOUTH FORK



NORTH FORK

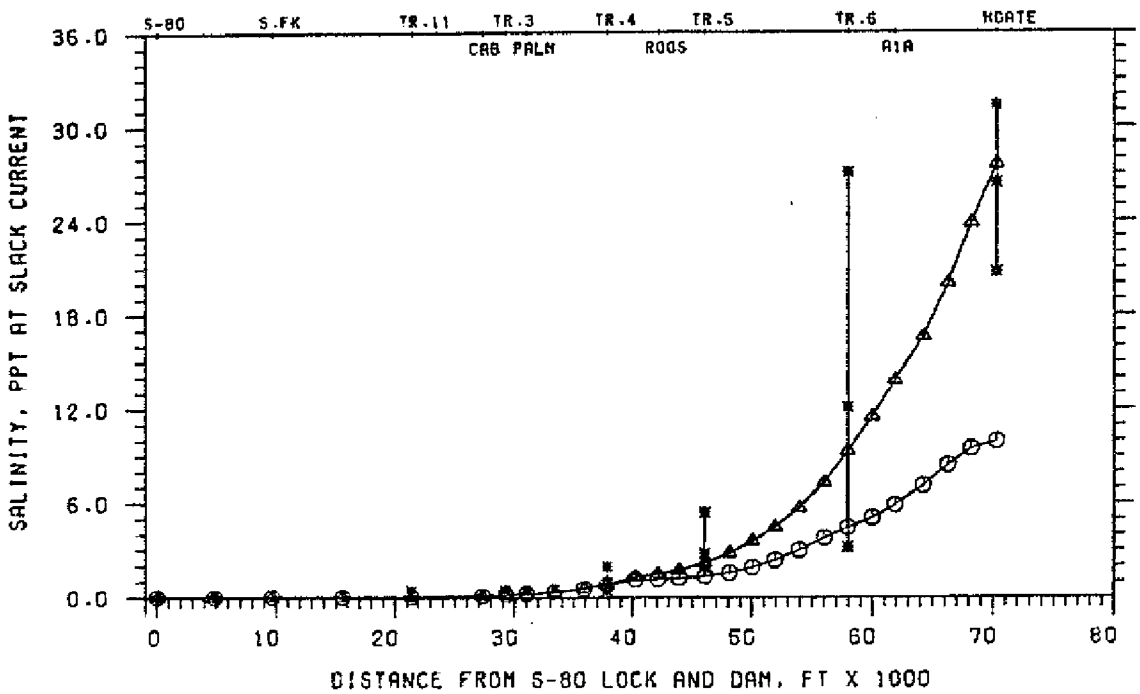
ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. CW: 149 CFS (G63S113). SBC: 30.



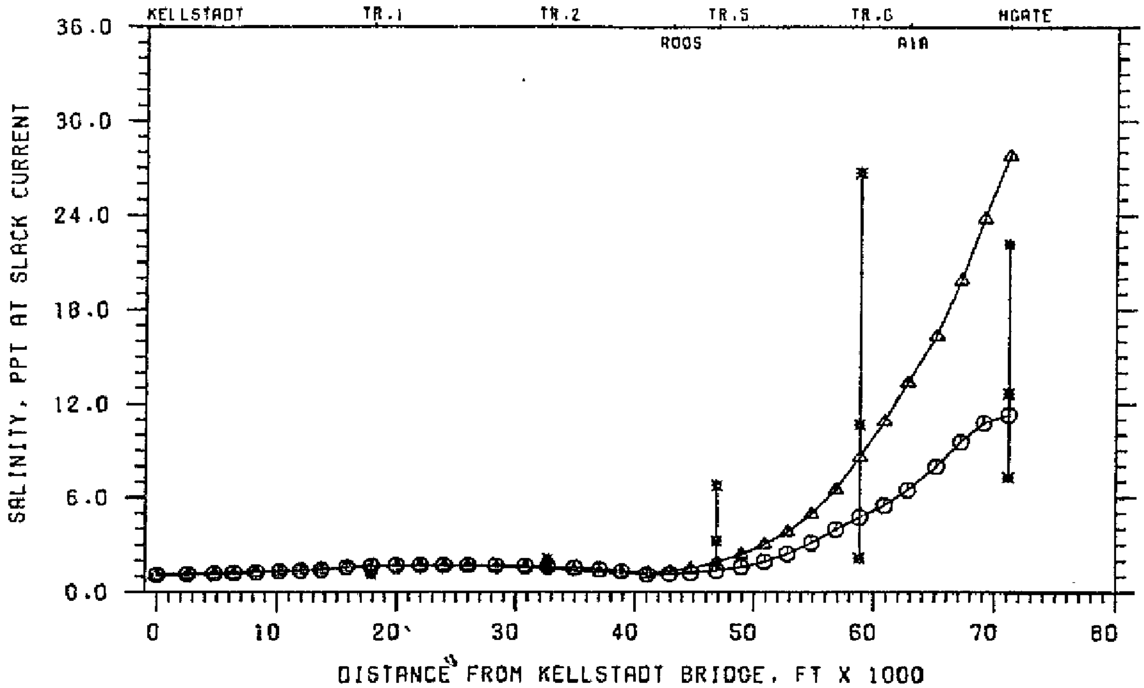
MEASURED
JULY 6, 1978
FROM MODEL:
O 780706 1100: HIGH TIDE
Δ 780706 1800: LOW TIDE

SOUTH FORK



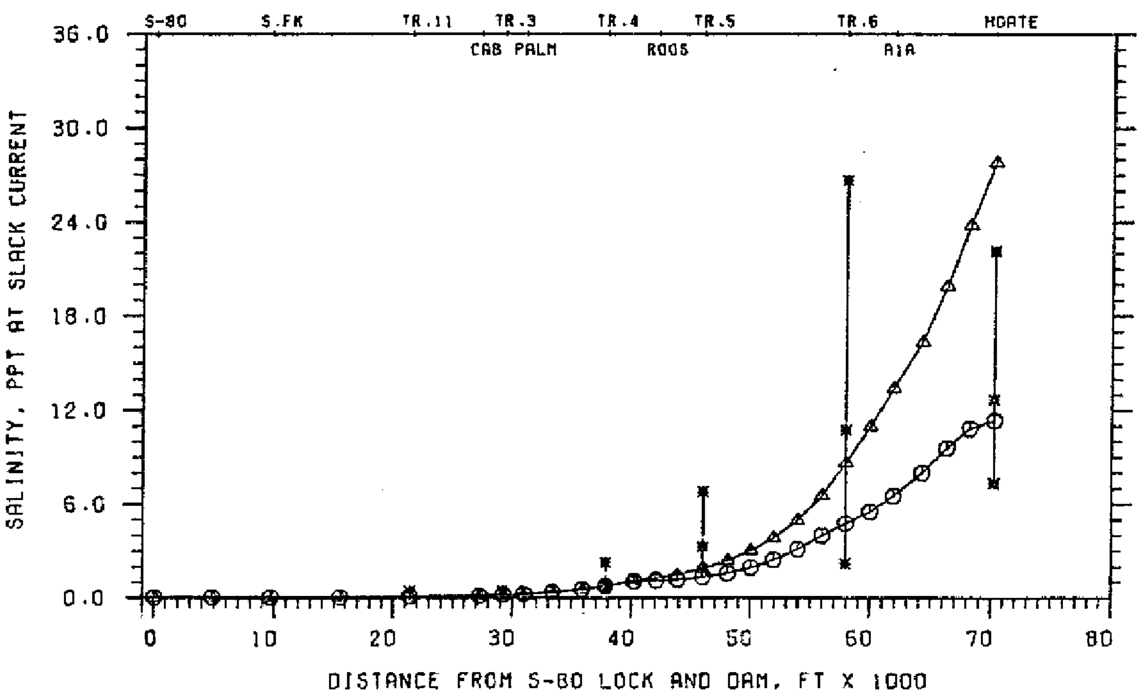
NORTH FORK ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. CH: 149 CFS (C63S113). SBC: 30.



MEASURED
JULY 7, 1978
FROM MODEL:
O 780707 0700: LOW TIDE
Δ 780707 1200: HIGH TIDE

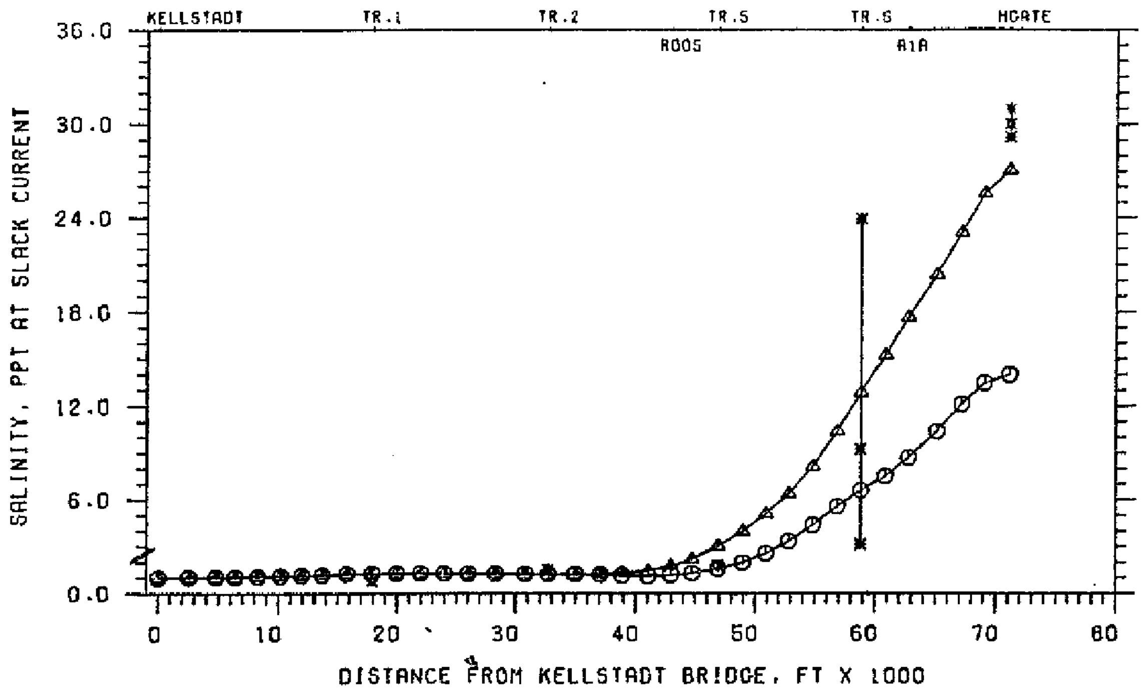
SOUTH FORK



NORTH FORK

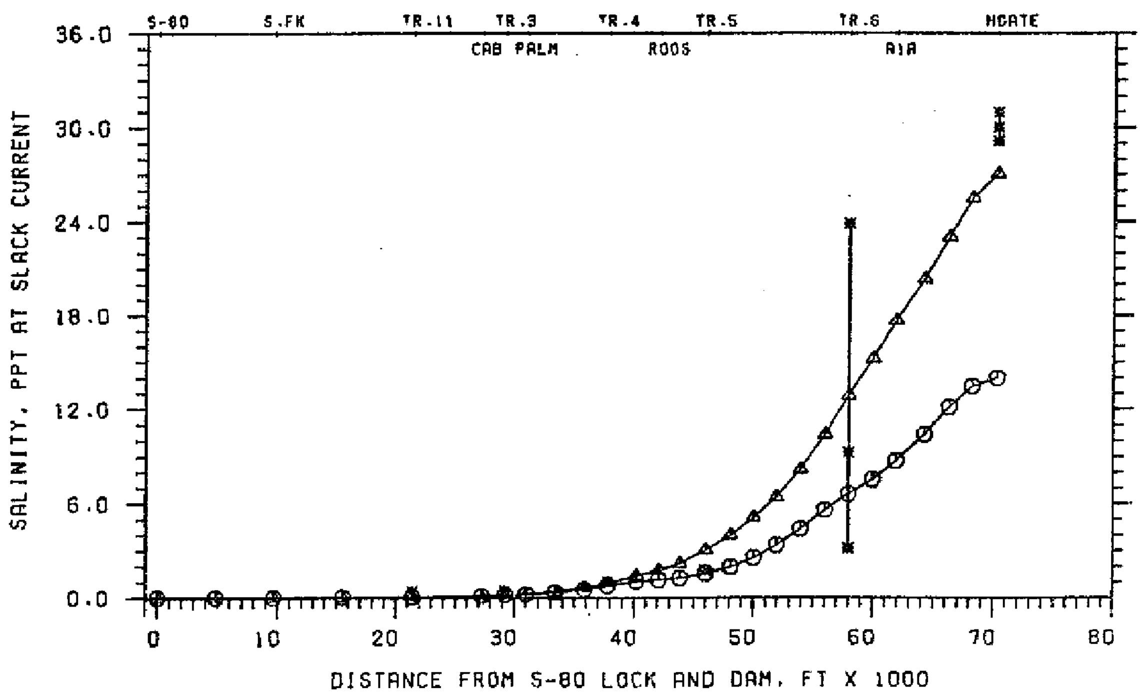
ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 30.



MEASURED
JULY 10, 1978
FROM MODEL:
O 780710 0900: LOW TIDE
△ 780710 1500: HIGH TIDE

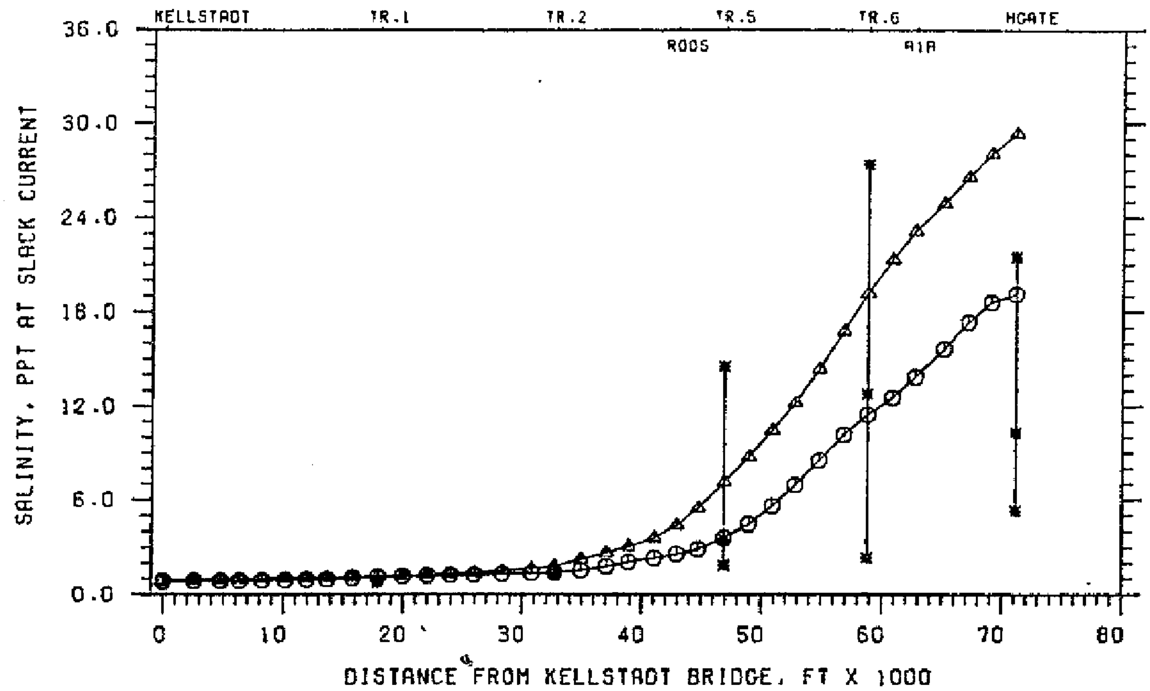
SOUTH FORK



ST. LUCIE ESTUARY

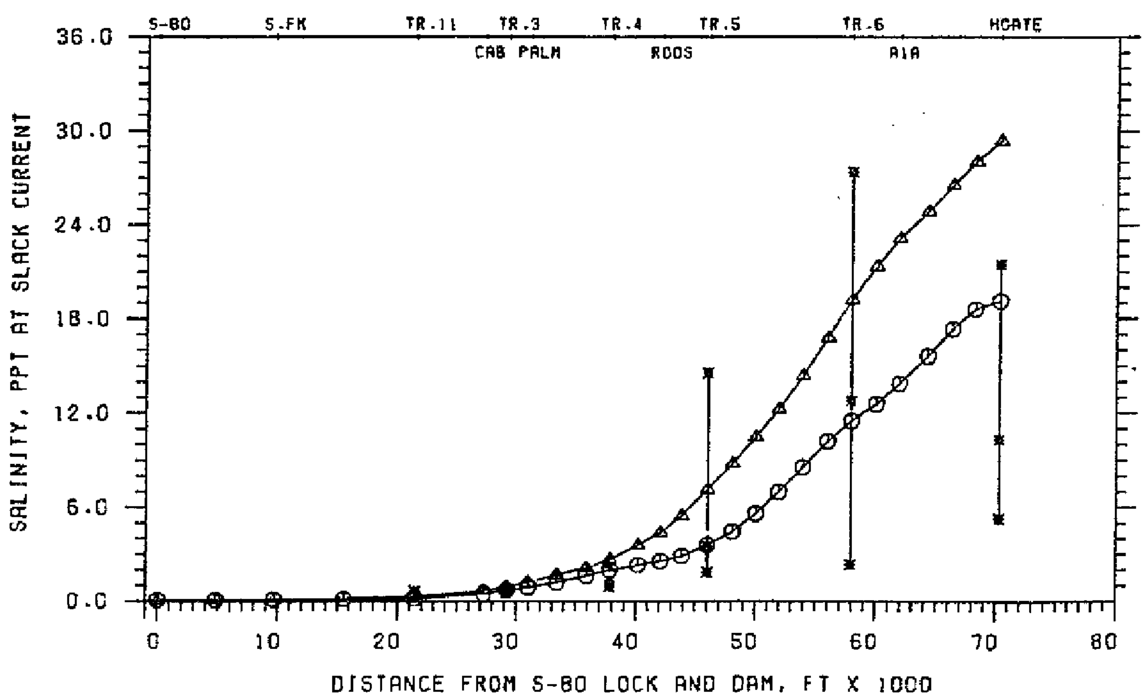
NORTH FORK

DYNT21 63/62 780615 !S142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (G63S113). SBC: 30.



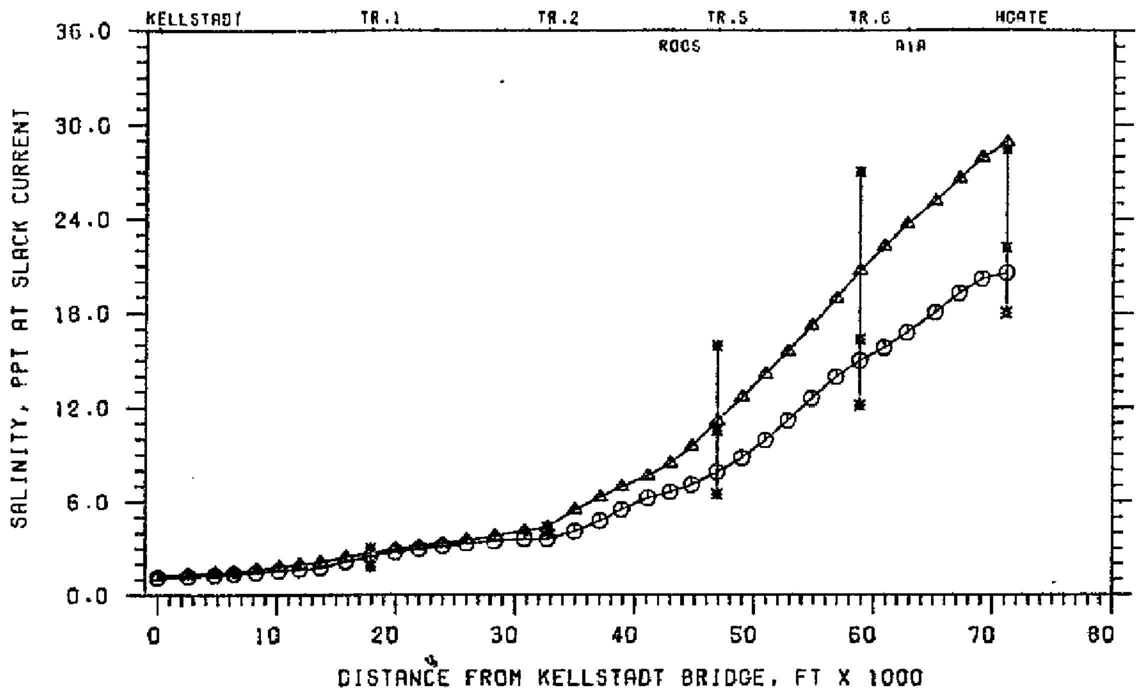
MEASURED
JULY 12, 1978
FROM MODEL:
O 780712 1000: LOW TIDE
Δ 780712 1600: HIGH TIDE

SOUTH FORK



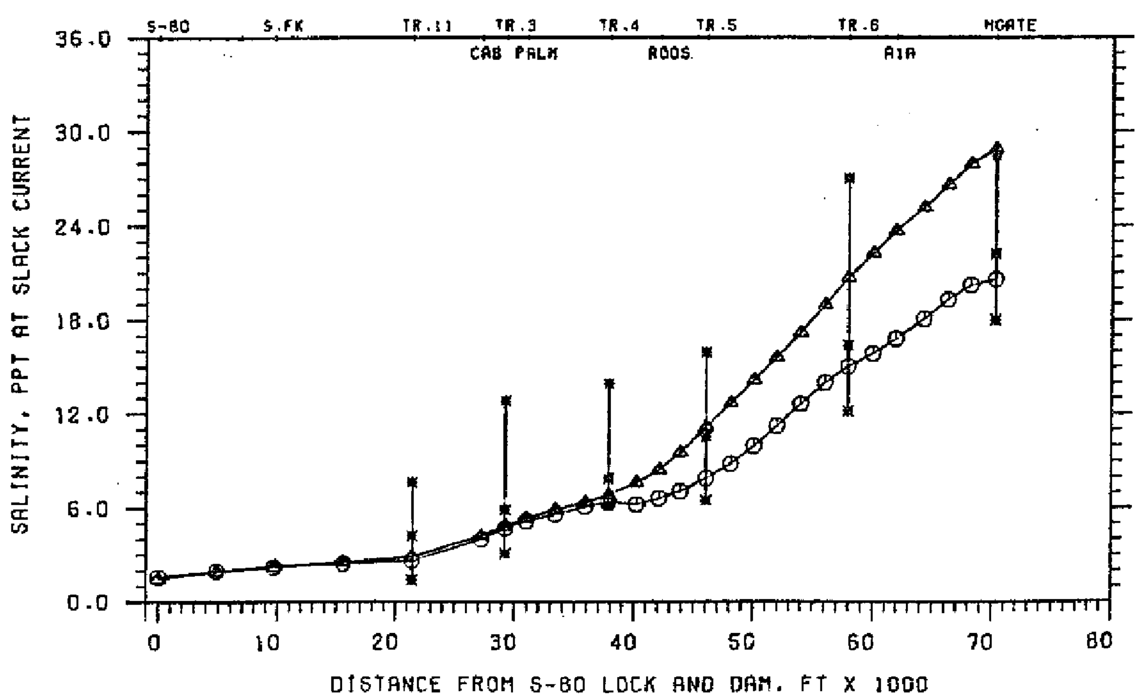
NORTH FORK — ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (0635113). SBC: 30.



MEASURED JULY 20, 1978
FROM MODEL:
O 780720 1100: HIGH TIDE
△ 780720 1700: LOW TIDE

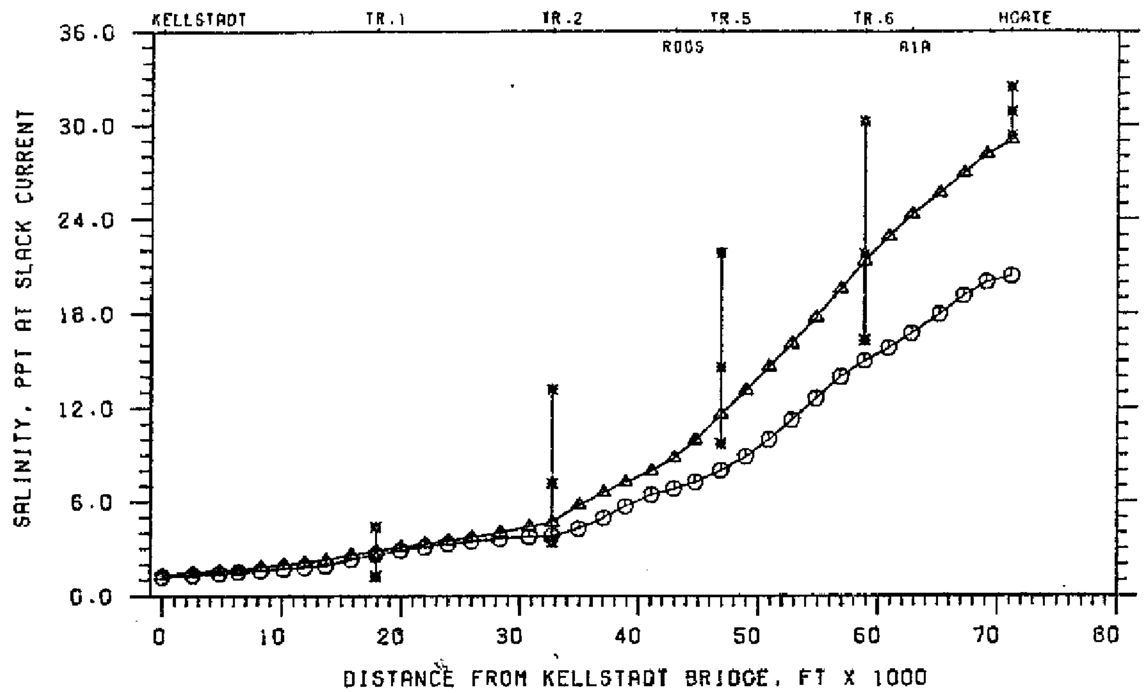
SOUTH FORK



ST. LUCIE ESTUARY

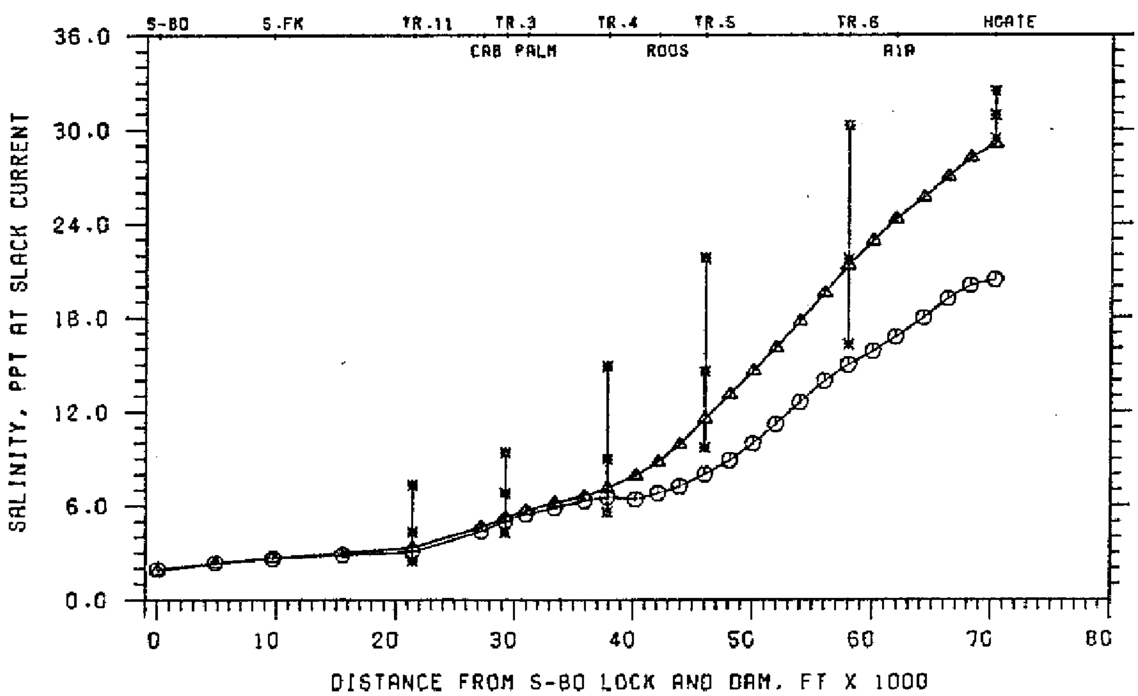
NORTH FORK

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (06351131). SBC: 30.



MEASURED
JULY 21, 1978
FROM MODEL:
○ 780721 1200: HIGH TIDE
△ 780721 1800: LOW TIDE

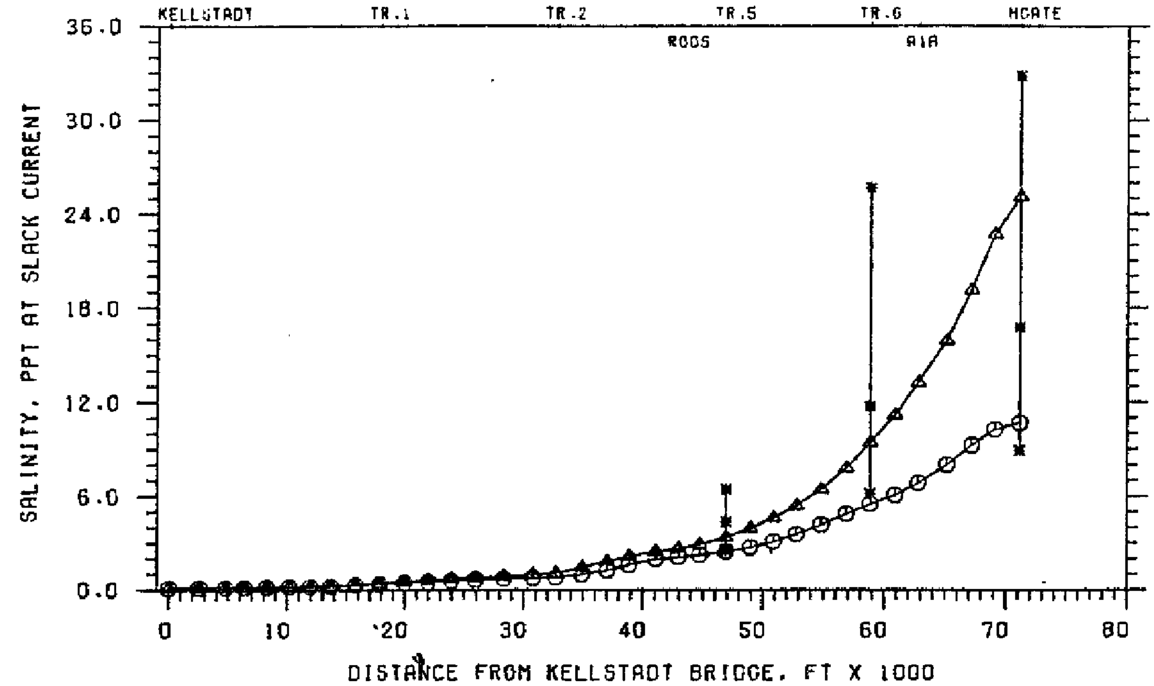
SOUTH FORK



NORTH FORK

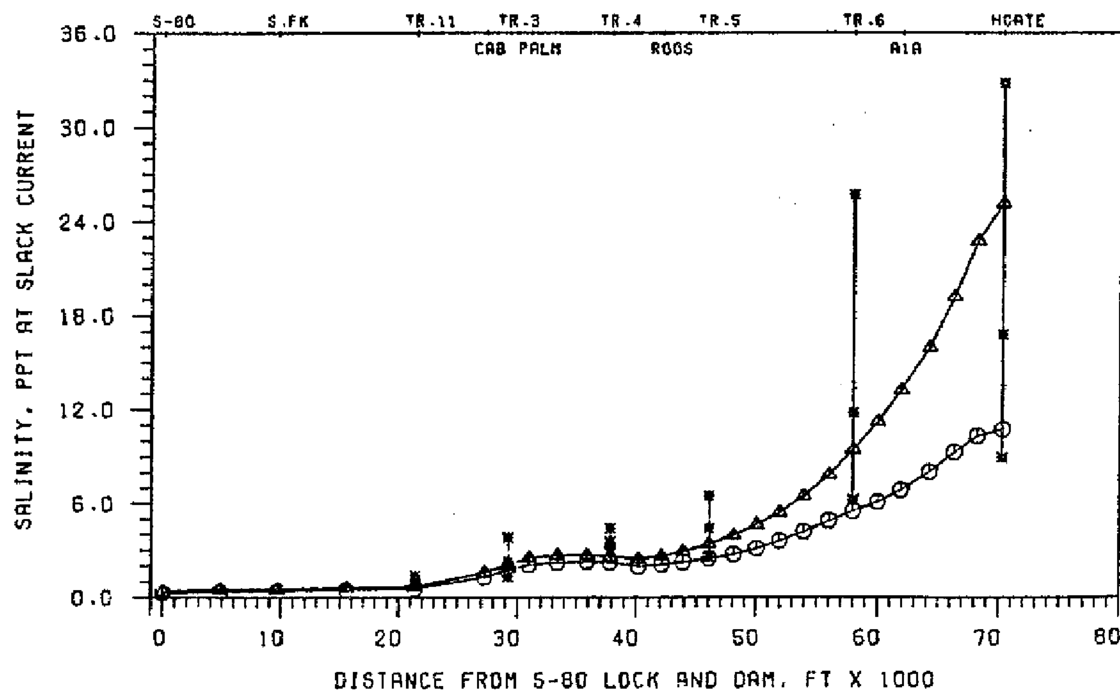
ST. LUCIE ESTUARY

DYNT21 63/62 780615 16142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. GW: 149 CFS (0635113). SBC: 30.



MEASURED
AUGUST 1, 1978
FROM MODEL:
O 780801 0900: HIGH TIDE
△ 780801 1600: LOW TIDE

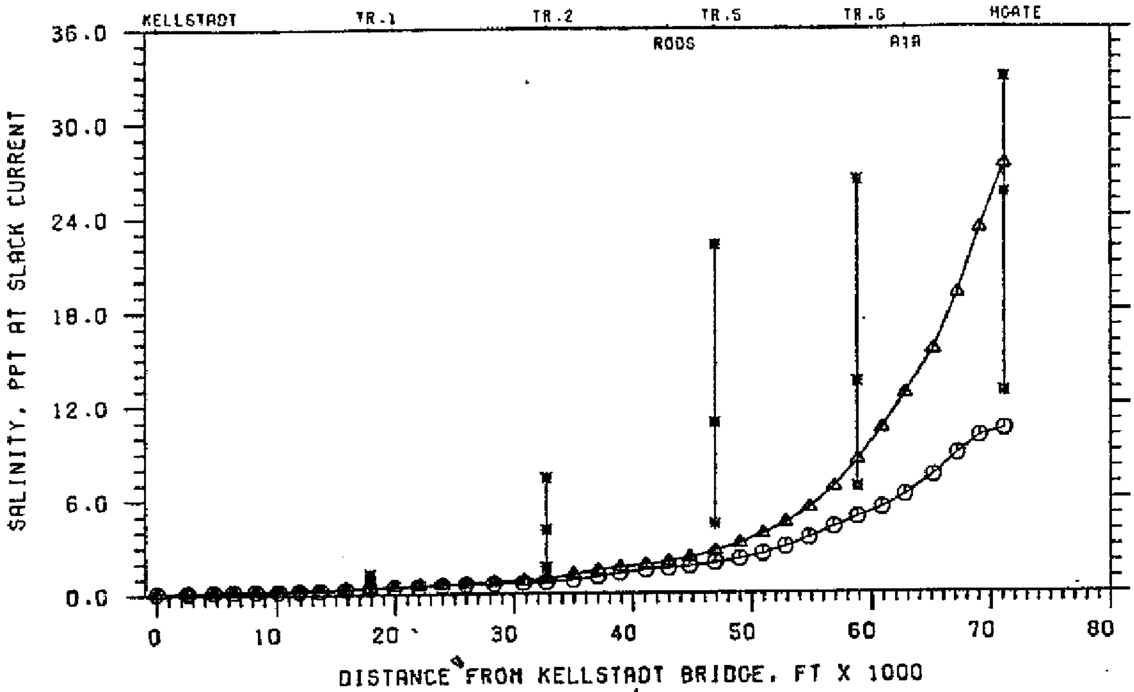
SOUTH FORK



NORTH FORK

ST. LUCIE ESTUARY

DYNT21 63/62 780615 IS142 -- 49 DAYS -- 2500 CFS CONTROLLED DISCHARGE -- S142
TIDAL BNDRY: "HEL78". DC: 300/700/1000/2000. CW: 149 CFS (DG3S113). SRC: 30.



MEASURED
AUGUST 2, 1978
FROM MODEL:
780802 0900: HIGH TIDE
780802 1600: LOW TIDE

SOUTH FORK