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VIMS THREE-DIMENSIONAL
HYDRODYNAMIC-EUTROPHICATION MODEL (HEM-3D):
APPLICATION OF THE HYDRODYNAMIC MODEL TO THE YORK RIVER SYSTEM

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The authors are indebted to Dr. John M. Hamrick, developer of the Environmental Fluid Dynamics Code (EFDC) which provides the hydrodynamic base code of the VIMS three dimensional Hydrodynamic-Eutrophication Model (HEM-3D). We owe special thanks to Drs. Carl T. Friedrichs, David A. Evans, Jerome P.-Y. Maa, ZhaoqingYang and Mr. William Stockhausen for providing critical comments and many helpful suggestions during the long process of model calibration and verification for the York River system (York, Mattaponi and Pamunkey Rivers) in Virginia. Messrs. Steven Snyder and Sam Wilson provided invaluable assistance through their participation in the field program which collected the observational data used in this project and Ms. Nancy Wilson provided assistance in data processing and archiving.

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I. Introduction

Ia. Design features of the HEM-3D model

The Environmental Fluid Dynamics Code (EFDC; Hamrick, 1992) constitutes the hydrodynamic portion of the VIMS three dimensional Hydrodynamic-Eutrophication Model (HEM-3D). EFDC was developed and refined at the Virginia Institute of Marine Science (VIMS) over the period 1988-1995 by Associate Professor John M. Hamrick. It is a multi-parameter finite difference model representing estuarine flow and material transport in three dimensions. Whereas EFDC resembles the widely used Blumberg-Mellor model (Blumberg and Mellor, 1987) in both the physics and the computational scheme, it has some unique features which are noteworthy. The code is written in standard FORTRAN 77 and is highly portable to UNIX or DOS platforms. It is computationally efficient due to the programmer's avoidance of logical operators, and it economizes on required storage by storing only active water cell variables in memory. This code was written to be highly vectorizable, anticipating upcoming developments in parallel processing. Due to a well-designed user interface, the internal source code remains the same from application to application. The HEM-3D model can be quickly converted to a 2D model either horizontally or vertically for preliminary testing. The model's most unique features include the mass conservative scheme which it uses for drying and wetting in shallow areas. It also incorporates vegetation resistance formulations (Hamrick,1994). The most valuable feature is the model's ability to couple with both water quality and sediment transport models.

The HEM-3D model uses a stretched (i.e., "sigma") vertical coordinate system and a curvilinear-orthogonal horizontal coordinate system to solve vertically hydrostatic, free surface, variable density, and turbulent-averaged equations of motion. This solution is coupled with a solution of the transport equations for turbulent kinetic energy, turbulent length scale, salinity and temperature. A staggered grid provides the framework for the spatial finite differencing (second order accurate) used by the numerical scheme to solve the equations of motion. Integration over time involves an internal-external mode splitting procedure separating "the internal shear or baroclinic mode from the external free surface gravity wave or barotropic mode" (Hamrick, 1995).

Ib. Structure of the HEM-3D Model.

The HEM-3D model is structured to permit the interfacing of four separate model components as shown in figure 1. The fundamental component is a **hydrodynamic model (EFDC)** simulating water surface elevation, current speed and direction, water salinity and temperature over a domain that is primarily three-dimensional (grid cells arranged in three spatial dimensions) but capable of representation in two-dimensions where necessary (e.g., narrow tributaries with channels of one cell width but more than one cell in both the vertical and longitudinal directions). A two-dimensional application can have the added complexity of either a marsh area or a wet-dry littoral margin at points along either side of the channel where lateral flows are handled as storage with no longitudinal transport of momentum. Wind stress and momentum transfer can also be represented as input at the air-water interface with salinity and freshwater discharge handled as input at the appropriate longitudinal boundary. Tidal input can be represented at the downstream open boundary by either a specific time history of water level or a simulated tide based on one or a combination of multiple tidal constituents of known amplitude and phase.

Water quality is simulated through a coupled **eutrophication model** incorporating up to 21 state (scalar) variables in the water column. This model component may also be used to represent specific chemical processes (sediment diagenesis) near the sediment-water interface. A coupled **suspended sediment model** utilizes bottom shear stress criteria to predict cohesive or granular sediment entrainment at the bed along with its turbulent suspension and subsequent transport in the water column. **Other transport models** are currently being coupled with the hydrodynamic model that predict the movement and distribution of a scalar quantity (e.g., mass concentration of marine larvae, toxins or dredged material). These scalars may be modeled as either conservative or non-conservative quantities that are either coupled or de-coupled with the fluid (e.g., sediment particle with finite settling velocity). In HEM-3D, scalar quantities are usually introduced into the model domain as a point source and then followed over a time scale of hours and days.

Ic. Need for a high resolution grid for the York River system

A map of the shoreline of the York River is shown in Figure 2. Due to the elongation of this water body, the ratio of shoreline to surface area is relatively large. For this reason, the distortion of results due to boundary effects introduced by using a coarser (e.g, 500 meter) grid is significant.

Certain detailed features of the shoreline also dictate the need for a higher resolution. For instance, at Gloucester Point, even using the present 250 meter gridlength, the transect under the Coleman Bridge is represented by only three cells. Further upstream, south of West Point, the channel is aligned along the North bank with very shallow regions just to the south. To represent properly the transverse gradient, throughout the lower York, a high resolution is required.

Id. Scope of this report

This report will attempt to provide a detailed document for the full calibration and verification of the HEM-3D model using independent data sets. Effort was directed primarily at demonstrating the ability of the model to reproduce tidal height and velocity, and at the simulation of the spatial, as well as temporal, distribution of salinity. The important feature of the York system whereby salinity is well-mixed on spring tides and stratified on neap tides was also demonstrated.

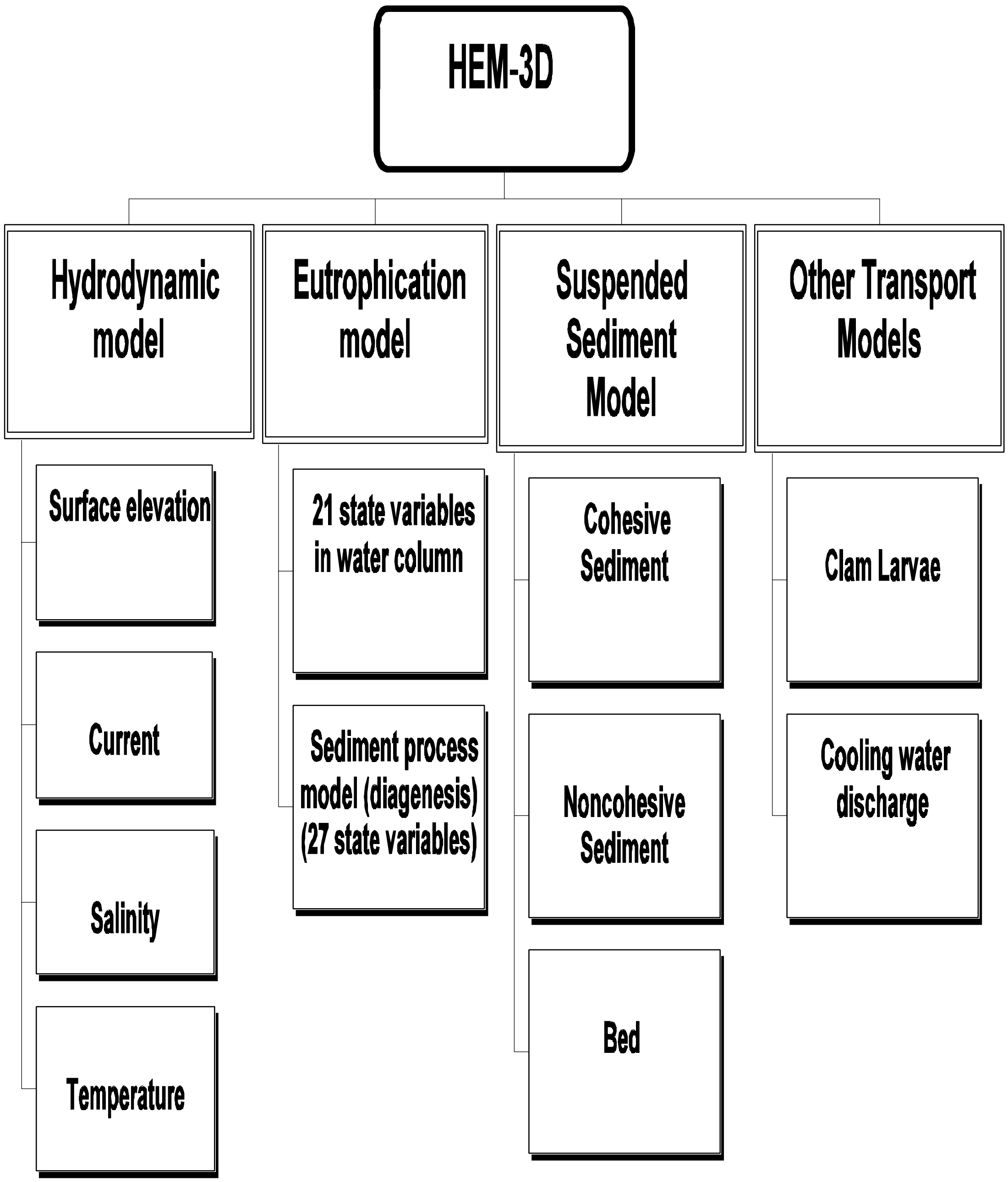


Figure 1. Components of the HEM-3D model.

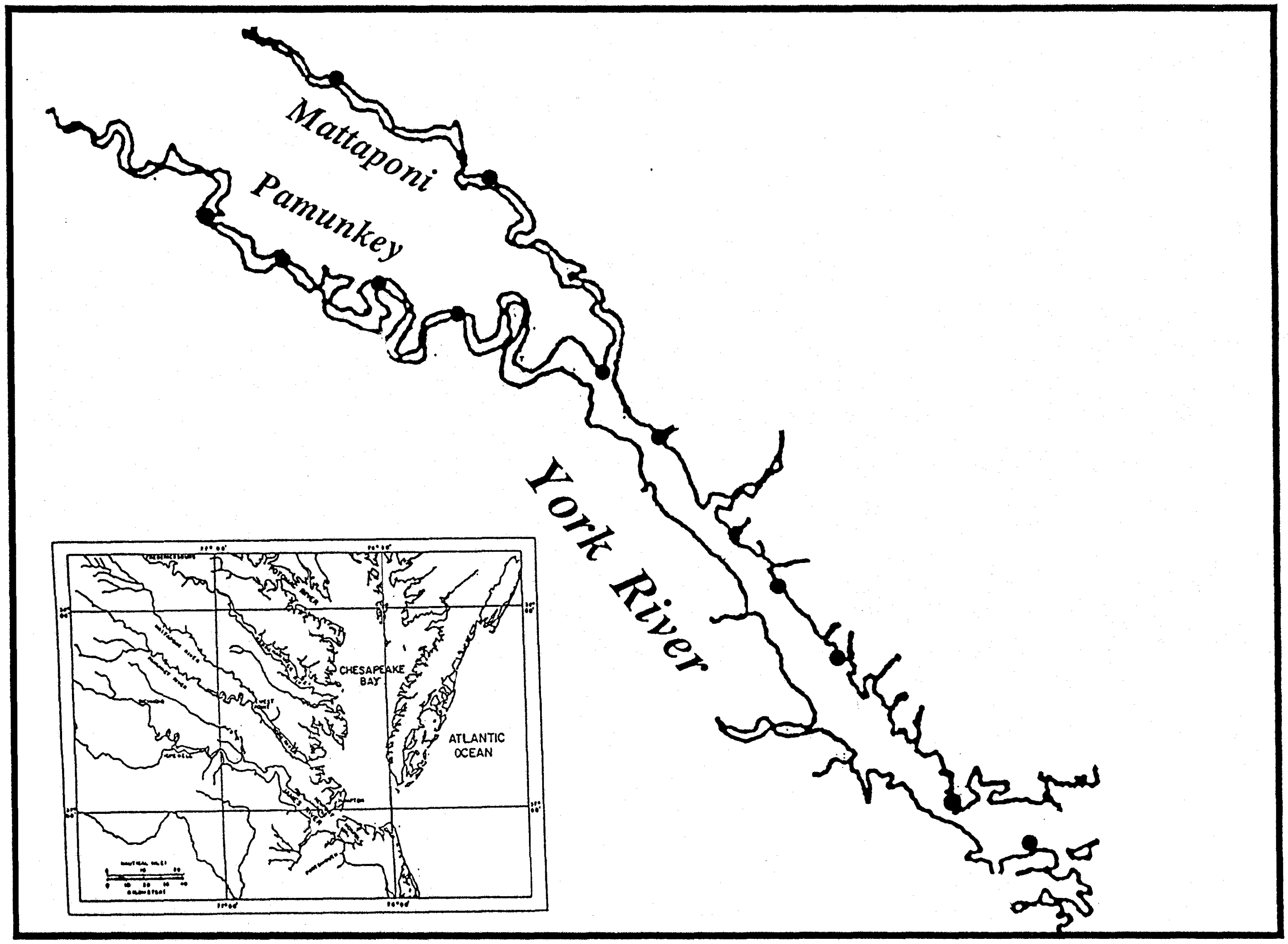


Figure 2. Shoreline of the York, Pamunkey, and Mattaponi Rivers

II. Description of the prototype

IIa. Characteristics of the York River system

The York River system fits the category of a "partially mixed" estuary according to the classification scheme of Pritchard (1952). It is tidally dominated in the sense that the tidal current is of an order of magnitude larger than the residual flow. The propagation of the tide through the York River is unique in that at West Point, the location at which the two major tributaries (the Pamunkey and the Mattaponi) converge, the highly non-linear features of the tidal wave begin to manifest themselves as one moves upstream. These are perhaps best illustrated by the significantly larger contributions of the M4 and M6 overtides at West Point and points upstream (see Appendix B).

One characteristic of the salinity distribution in the York River system is that large portions of the mainstem are relatively well-mixed on spring tides and stratified on neap tides (see Haas, 1977).

IIb. Supporting observational data

IIb1. Tide gauge records - NOAA and VIMS

Tidal elevation has been measured continuously at Gloucester Point for the past sixteen years by a VIMS-NOAA cooperative tide station. For purposes of this study, the eight-year period 1986 - 1993 was selected. Table 1 shows a summary of the tidal constituent variation through these eight one-year periods as computed by the VIMS tidal analysis program HAMELS (Boon and Kiley, 1978).

Additionally, the VIMS Physical Sciences Department has maintained gauges at several locations at various times along the York for periods of up to several months. The locations of VIMS tide gauges are shown in Figure 3 and the summary of available data is presented in Table 2.

The tide range measured by the VIMS Physical Sciences Department was compared to the NOAA Tide Tables at available locations throughout the York River system, as shown in Table 3. Since VIMS measurements are limited to several months duration only, the calculated tidal ranges are normalized with the long-term mean range of 0.73 m at Gloucester Point. In this comparison, one must consider factors which may account for reasonable differences, such as durations of measurements and averaging techniques.

IIb2. Salinity records

There are two types of salinity records: time series data at fixed mooring stations and slack water survey data. Time series of salinities are available from some current meters equipped with conductivity and temperature sensors. Available salinity records of this type are shown in Table 4. Slackwater survey stations for the York mainstem are shown in Figure 4. A list of available dates is shown in Table 5.

IIb3. Velocity records - current meter deployments

Some recent current meter deployments by the VIMS Physical Sciences department are shown in Table 6 for locations shown in Figure 5.

IIc1. Analysis of field observation data

Once the physical dimensions of the geometry (shoreline configuration) and bathymetry of the prototype have been properly represented, it is important to process these data for the model state variables (i.e., tidal height, velocity, and salinity) not only for adequate model boundary condition specification, but also for comparison of model results to field observations.

IIc2. Temporal variations at fixed locations - time series

Most field observation information is from the temporal change of a variable measured at a fixed location, often referred to as a "time series". Some examples of tidal elevation time series at various locations in the York River are shown in Appendix A.

IIc3. Use of HAMELS analysis

The time variation of the water level at a given location can be expressed as the sum of a set of sinusoidally varying terms called the tidal constituents. Tidal constituent amplitudes and phases were determined using the harmonic analysis method of least squares (HAMELS). The principal lunar semi-diurnal constituent, M2, has a period of approximately 12.42 hours and accounts for the basic semi-diurnal effect of the moon on the tide. The amplitude of this constituent accounts for the largest part of the tidal range in the York. The corresponding constituent representing the semi-diurnal effect of the sun is called S2 and has a period of exactly 12 hours. Because of the difference in periods, M2 and S2 tides periodically reinforce and oppose one another through a progressive change in phase. The resultant effect is that the range of the tide varies periodically in time from larger ranges (spring tides) to smaller (neap tides). The period of a spring/neap cycle is 354.86 hours (14.786 days) and can be calculated from the two fundamental M2 and S2 periods.

Additional features of the tidal signature are accounted for by other constituents with various periods which depend upon the relative motions of the earth, moon, and sun. For example, changes in declination of the lunar orbit relative to the equatorial plane of the earth are responsible for observed differences in the heights of sucessive high and/or low waters. Two lunar diurnal tidal constituents, K1 and O1, are needed to account for this monthly variation in diurnal inequality.

Each tidal constituent is characterized by an amplitude and a phase. For a given location the values of these parameters are effectively constant. It is this property that enables tide predictions to be calculated. The tidal constants are estimated by analysis of observed tide records. Originally, HAMELS was developed for the analysis of a time series of 29 days duration (697 hours) of continuous hourly observations. The algorithm was later modified by Hamrick (1991) to treat a time series of arbitrary duration which also could contain some missing observations. However, it should be noted that a sequence of at least 29 days in length is commonly used to resolve the major constituents because M2 and S2 complete one cycle in lunar phases in that time. The application of HAMELS is briefly described in Appendix B.

Characterization of the water level variation in terms of the amplitude and phase of the significant tidal constituents enables more detailed checks to be made between observation and model predictions beyond comparison of mean ranges and high/low water time lags. In the York River system, seven constituents account for almost all the observed tidal variation due to deterministic astronomical causes. The model is excited with a tidal signal of seven constituents with amplitude and phase adjusted to produce a tidal variation at Gloucester Point which has amplitudes and phases consistent with those observed at this station. Because of the large amount of data available at Gloucester Point, the tidal constants are known with considerable accuracy. The water level predictions for various stations are then analyzed with HAMELS and the resulting tidal constants compared with those obtained from analysis of actual observations at those stations.

The tidal constants as determined by HAMELS are, like any quantity computed from observational data, estimates of the unknown true values of the parameters. Consequently it is important to obtain some idea of how close to the true value an estimate is likely to be either in the form of confidence intervals or standard errors. The HAMELS program does not currently provide these, however, the least squares method is effectively identical to a multiple regression where the tidal constants are related to the regression parameters. The regression procedure in most statistical software packages provide estimates for the standard error in the regression parameters. The tidal records were analysed using the commercial MINITAB® package. The method is illustrated in Appendix C.

Plots of the residuals (observed height minus predicted height) are informative. Normally the difference is attributable to meteorological effects (e.g., wind) and the effect of storm events is identifiable. The general appearance of a residual series is that of a stochastic time series. The estimation of the tidal constants is not seriously affected, although large residuals can result in an over-estimate of the errors in parameters. Occasionally a residual series will show a large sinusoidal component; this is always due to the presence of timing errors in the record. The residual series allows one to locate and correct the error. Re-analysis of the corrected series should no longer show a residual series with the sinusoidal component.

IIc4. Spatial variations at fixed points in time - synoptic data

Often field surveys are designed to measure the change of a parameter spatially (longitudinally, transversely, or through the water column). Two or more gauges (or meters) with simultaneous recordings can provide a measure of this spatial change. The slackwater surveys of the VIMS Physical Sciences Department are designed to collect salinities at various locations (and depths) at essentially the same stage of the tide, allowing a "snapshot" of the change of this parameter longitudinally and through the water column.

IId. Related observational studies

The York River HEM-3D Model provides an opportunity for other investigators to test the impact of various modes of tidal, estuarine and river flow on management and science issues related to the York River. The York River is presently the site of several major ongoing research projects at the Virginia Institute of Marine Science. As of the summer of 1996, two large projects funded by the Navy are examining biological, physical and chemical processes governing material and contaminant flux across the sediment-water interface of the York River. Principal Investigators on these Navy projects include Drs. Schaffner, Wright and Canuel. Two large projects funded by the Commonwealth of Virginia are also presently focused on the York River. The York River Regional Ecosystem project, headed by Dr. Wetzel, integrates chemical, geophysical and biological/ecological information about large-scale ecosystems using the techniques of computer simulation modeling. The York River Contaminant and Sediment Transport Study, headed by Dr. Kuo, aims to observe and model transport of fine sediment and associated contaminants. Many other scientists at VIMS are working on smaller studies of the York River or larger studies of the Chesapeake Bay which include the York River. For example, Dr. Orth oversees a large project that monitors the distribution of submerged aquatic vegetation throughout the Chesapeake Bay and its tributaries. Other examples include: Dr. Hershner's group, which facilitates resource planning for the York River Basin; Dr. Austin, who heads regular finfish surveys of the York River; Dr. Van Montfrans' group, which is studying York River Blue Crab distribution; and Dr. Boon who is examining hydrodynamics and sediment transport in the York.

const.	1986	1987	1988	1989	1990	1991	1992	1993	Vect Avg
M2	0.336 3.86	0.336 3.85	0.335 3.84	0.341 3.81	0.341 3.76	0.343 3.75	0.342 3.79	0.349 3.75	0.340 3.80
S2	0.064 -2.31	0.063 -2.29	0.064 -2.31	0.065 -2.30	0.064 -2.34	0.063 -2.38	0.062 -2.27	0.064 -2.35	0.064 -2.32
N2	0.074 -1.79	0.070 -1.92	0.068 -2.13	0.075 -2.03	0.076 -2.18	0.074 -2.23	0.074 -2.24	0.081 -2.17	0.074 -2.09
K1	0.056 7.59	0.055 7.71	0.056 7.29	0.050 7.06	0.056 7.15	0.052 6.79	0.049 6.92	0.048 6.82	0.053 7.18
M4	0.005 -2.90	0.005 -2.73	0.004 -2.83	0.004 -3.00	0.004 -2.93	0.005 -2.90	0.004 -3.09	0.005 -3.05	0.004 -2.92
O1	0.042 -0.13	0.045 0.22	0.041 0.29	0.041 0.45	0.043 0.78	0.039 0.81	0.039 1.07	0.035 1.28	0.040 0.57
M6	0.004 -1.29	0.004 -1.29	0.004 -1.27	0.004 -1.34	0.004 -1.35	0.004 -1.45	0.004 -1.39	0.004 -1.41	0.004 -1.35

* Amplitudes and phases are based on HAMELS analysis of hourly data. Phases are relative to a time origin arbitrarily set at 0000 hours (midnight) on January 1, 1989.

Table 1. Tidal constituent amplitudes (meters) and phases (hours) for an 8-year period at Gloucester Point, Virginia

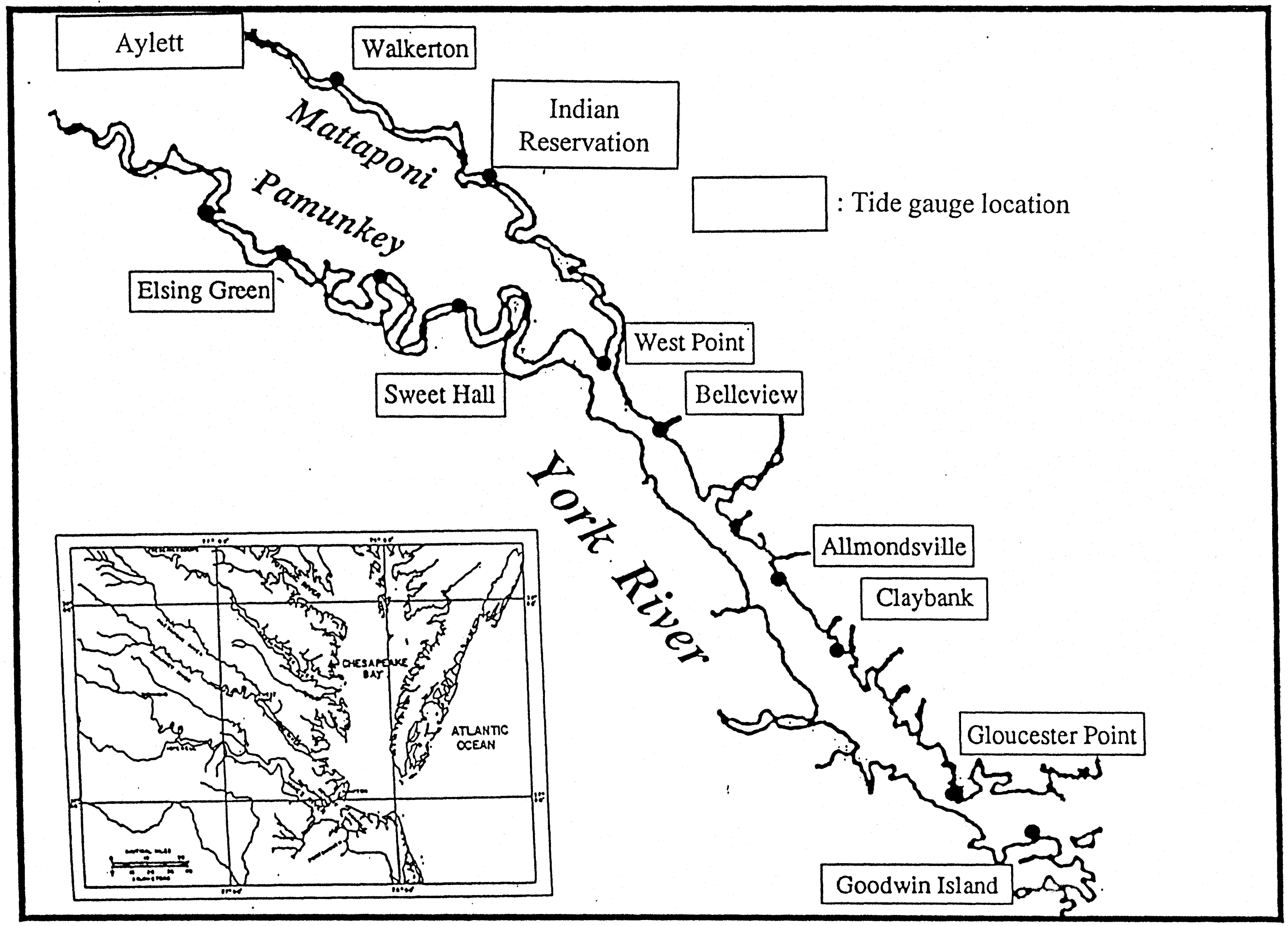


Figure 3. Locations of tidal height measurements used in this study

Location	Start date (time) Model time (hrs) *	End date (time)	No. of obs.
Jenkins Neck	06/01/89 (1000)	09/13/89 (1300)	2500
Goodwin Islands	07/21/93 (1200)	08/29/93 (2300)	949
Claybank	10/27/89 (1100)	01/17/90 (1300)	1971
Allmondsville	06/09/93 (1100)	08/31/93 (0900)	1587
	09/01/93 (0900)	10/18/93 (1000)	1130
Belleview	06/09/93 (0800)	08/31/93 (0900)	1148
	08/31/93 (1000)	10/18/93 (0900)	1152
West Point	07/05/93 (2200)	08/03/93 (2200)	697
	09/01/93 (1000)	10/18/93 (0900)	1128
Sweet Hall (Pam)	05/02/86 (1200)	06/01/86 (1700)	654
	10/13/86 (1100)	11/20/86 (2100)	923
Elsing Green (Pam)	01/11/89 (1400)	04/25/89 (1400)	2497
Indian Reservation (Mat)	10/03/96 (1200)	05/15/97 (0800)	5364
Walkerton (Mat.)	08/01/96 (1000)	03/18/97 (0900)	4862
Aylett (Mat.)	08/01/96 (1500)	03/31/97 (0900)	5489

Table 2. Available observation data for tidal elevations -VIMS Physical Science Department

Station	Distance from the Mouth (km)	NOAA Tide Tables mean range (m)	VIMS gauge data mean range (m)
Quarter Point	0.0	0.70	
Goodwin Islands	1.0		0.67
Gloucester Pt.	10.9	0.73	0.73
Mumford Isl.	13.2	0.76	
Penniman Spit	19.0	0.76	
Cheatham Annex	20.2	0.76	
Claybank	26.6	0.85	0.82
Allmondsville	31.5	0.85	0.79
Roane Point	39.5	0.85	
Belleview	45.0		0.85
West Point	55.4	0.85	0.85
Sweet Hall (Pam)	80.5		0.74
Sweet Hall Landing (Pam)	83.5	0.82	
White House (Pam)	105.1	0.91	
Elsing Green (Pam)	109.		0.91
Northbury (Pam)	118.	1.01	
Wakema (Mat)	80.4	1.04	
Indian Reservation (Mat)	83.0		0.93
Walkerton (Mat)	98.9	1.19	1.01
Aylett (Mat)	114.2		0.38

Table 3. Comparison of predicted mean range from NOAA Tide Tables vs VIMS gauge data.

Location	Station	Depth	Date Range
YR mouth, mid-channel	'0.0'	1.5 m	07/19-08/15/88 08/30-09/14/88
YR mouth, mid-channel	'0.0	6.5 m	07/19-09/14/88
YR mouth, mid-channel	'0.0'	11.5 m	07/19-09/14/88
YR mouth, mid-channel	'0.0'	15.7 m	07/19-08/02/88
Upriver, mid-channel	'3.9'	1.5 m	07/19-09/14/88
Upriver, mid-channel	'3.9'	6.5 m	08/02-09/14/88
Upriver, mid-channel	'3.9'	11.5 m	08/30-09/14/88
Upriver, mid-channel	'3.9'	15.7 m	07/19-08/15/88 08/30-09/14/88
YR mouth, mid-channel	'RB'	1.0 m	07/06-09/01/89
YR mouth, mid-channel	'RB'	6.0 m	07/13-09/02/89
YR mouth, mid-channel	'RB'	11.0 m	07/06-09/06/89
YR mouth, mid-channel	'RB'	16.0 m	07/06-09/06/89
YR mouth, south channel	'TUE'	6.0 m	07/13-09/06/89
YR mouth, south channel	'TUE'	10.0 m	07/06-09/06/89
Claybank		3.7 m	11/09/89-01/10/90
Claybank		5.7 m	11/09/89-01/10/90
Claybank		7.7 m	11/22/89-01/10/90
Allmondsville		1.7 m	11/09/89-12/07/89
Allmondsville		3.7 m	11/09/89-01/09/90
Allmondsville		5.7 m	11/09/89-01/09/90
Allmondsville		7.7 m	11/09/89-01/09/90

Table 4. Available time series data for salinity (1988-89).

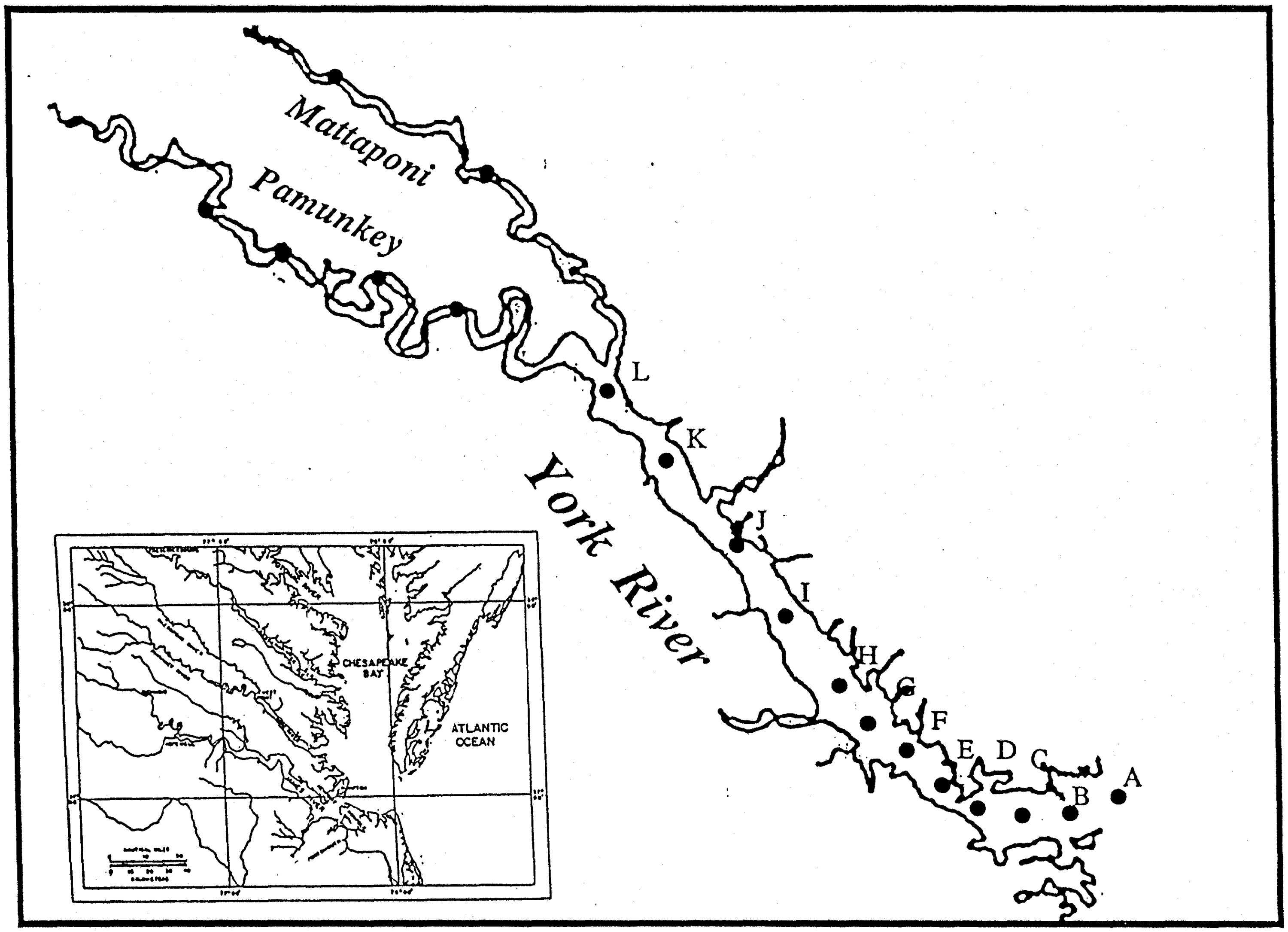


Figure 4. VIMS slackwater survey stations for the York mainstem

Map Key (see Figure 4)	Distance upstream (km)	Total depth (m)	VIMS Slackwater survey sampling dates (1989)									
			5/30	6/12	6/27	7/12	7/20	7/27	8/11	8/29	9/06	9/15
A	0.00	19	x	x	x	x	x	x	x	x	x	x
B	3.90	23	x	x	x	x	x	x	x	x	x	x
C	6.58	17	x	x	x	x	x	x	x	x	x	x
D	8.76	16	x	x	x	x	x	x	x	x	x	x
E	12.09	19	x	x	x	x	x	x	x	x	x	x
F	15.10	19	x	x	x	x	x	x	x		x	x
G	19.21	19	x	x	x	x	x	x	x	x	x	x
H	23.60	12	x	x	x	x	x	x	x	x	x	x
I	29.26	11	x	x	x	x	x	x	x	x	x	x
J	36.95	9	x	x	x	x			x	x	x	x
K	43.00	8	x	x	x	x			x	x	x	x
L	50.47	6	x	x	x	x			x	x	x	x

Table 5. Available observation data for salinty - VIMS slackwater surveys (1989).
Sampling occurred at 1 meter intervals over the total depth.

Location	Depths	Date Range
'0.0'	1.5 m	07/19-09/14/88
'0.0'	6.5 m	07/19-09/14/88
'0.0'	11.5 m	07/19-09/14/88
'0.0'	15.7 m	07/19-09/14/88
'3.9'	1.5 m	07/19-09/14/88
'3.9'	6.5 m	07/19-09/14/88
'3.9'	11.5 m	07/19-09/14/88
'3.9'	15.1 m	07/14-09/14/88
'N2'	1.0 m	07/06-09/07/89
'N2'	7.0 m	07/06-09/07/89
'RB'	1.0 m	07/06-09/07/89
'RB'	6.0 m	07/06-0907/89
'RB'	11.0 m	07/06-09/07/89
'RB'	16.0 m	07/06-09/07/89
'TUE'	1.0 m	07/06-09/07/89
'TUE'	6.0 m	07/06-09/07/89
'TUE'	10.0 m	07/06-09/07/89
Claybank	1.7 m	11/09/89-01/10/90
Claybank	3.7 m	11/09/89-01/10/90
Claybank	5.7 m	11/22/89-01/10/90
Claybank	7.7 m	11/09/89-01/10/90
Allmondsville	1.7 m	11/09/89-12/07/89
Allmondsville	3.7 m	11/09/89-01/09/90
Allmondsville	5.7 m	11/09/89-01/09/90
Allmondsville	7.7 m	11/09/89-01/09/90

Table 6. Available current meter data (1988-1989).

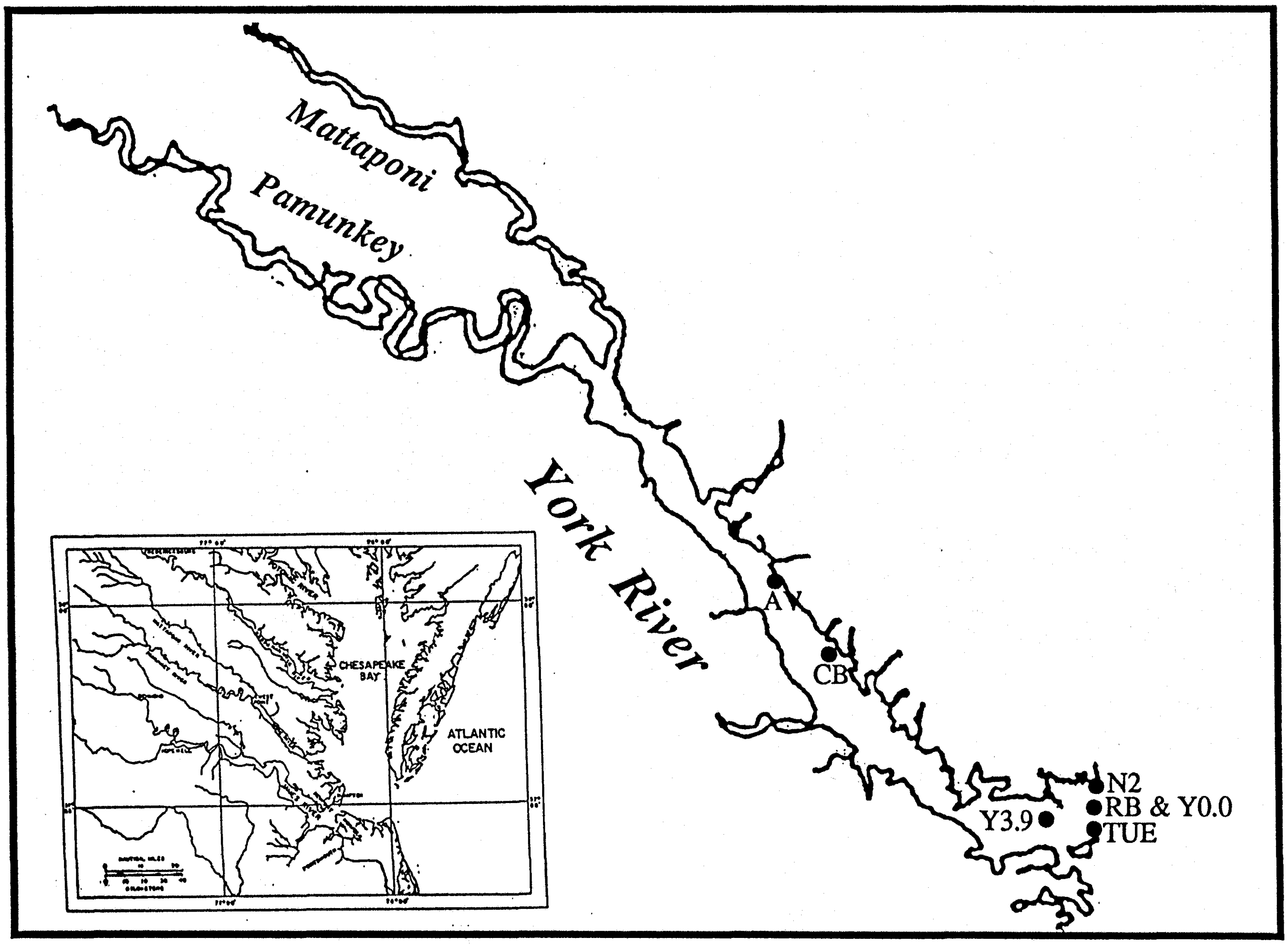


Figure 5. Moored current meter stations (1988-89)

III. Pre-processing of the HEM-3D model

IIIa. Grid selection criteria

Before the model is implemented, decisions must be made about what spatial and temporal scales are desired and feasible, which portions of the prototype need to be represented as fully three-dimensional, and what boundary condition and geometry information are available.

As an example of the consequences of such decisions we consider choice of spatial resolution. Doubling the resolution in the horizontal requires four times the number of cells, and due to the stability criterion, the timestep must be halved so that the number of timesteps is doubled. As a result, the computational requirements increase eight-fold, as shown in Table 7 below:

Cartesian Portion - Assuming constant iterations/timestep

Gridlength	Approximate # of horizontal cells	Optimal timestep	Tidal Cycles per CPU hour- HP 735
125 m	12000	30 sec	0.125
250 m	3000	60 sec	1
500 m	750	120 sec	8

Table 7. Illustration of limitations to high spatial resolution.

In the present implementation of the VIMS HEM-3D model, it was decided that the 3D portion extend from the York River mouth upstream to West Point, and that a vertical 2D representation was sufficient in the Pamunkey and Mattaponi tributaries.

In the transition area in the vicinity of West Point, where the curvilinear portion is 2D in the horizontal, the grid coordinates produced by the grid generator must be adjusted slightly by aligning the grid as much as possible to ensure orthogonality.

IIIb. Capabilities of the grid generator

The VIMS grid generator code, GEFDC, is a pre-processor system which can generate either Cartesian or curvilinear-orthogonal grids using methods outlined by Mobley and Stewart (1980) and Ryskin and Leal (1983). Also, before the HEM-3D model is executed, bathymetry data digitized from NOAA charts or other sources are processed through an interpolation scheme to generate the depth at each cell location. Enhancements to the pre-processor were developed by Hamrick (1996) and imbedded into the HEM-3D main program. These include the use of triangle half-cells, each using one of four possible orientations, to provide a better fit of the grid to the prototype shoreline.

IIIc. Grid generation

IIIc1. Cartesian portion (York mainstem)

The two fundamental types of grids used in numerical modeling, curvilinear and Cartesian, are both represented in the York River application. The VIMS grid generation code processes both types, depending on input file designations. The model grid is actually composed of two merged "sub-grids", one of each type.

The Cartesian portion, from the river mouth to West Point, is shown in Figure 6. The corresponding grid generation input file is shown in Appendix D, page D-4. A resolution gridlength of 250 m was selected for the Cartesian portion. A small FORTRAN program (‘gengrid.f’) used to specify the Cartesian grid origin and generate I,J,X,Y data (where I,J are the grid cell indices in the east and north directions respectively, and X,Y are the Universal Transverse Mercator (UTM) projection coordinates) is shown on page D-3.

IIIc2. Curvilinear portion (tributaries)

The curvilinear portion, used from the convergence of the tributaries at West Point to the respective "head of tide" locations of both tributaries, is shown in Figure 7, with its input file on page D-5. To construct this portion of the grid, it was necessary to digitize the shoreline boundary surrounding this portion at discreet spatial intervals corresponding to the pre-selected gridlengths.

IIIc3. Merged Cartesian-curvilinear grid

The merged grid is shown in Figure 8 and the input file required for the fully merged grid shown on page D-6. One important step in the grid merger is to concatenate the I,J,X,Y output from the two sub-grids (i.e., 'gridext.out') to form the input file for the merged grid ('gridext.inp'). At this point, the model bathymetry is generated through interpolation. This is done by simply setting parameter ISIDEP to 1 in Card 11 of the input file (see page D-6), and providing the proper X,Y,Z data in file 'depthdat.inp'.

IIId. Depth interpolation

A depth interpolator residing in the grid generator program was used at the time of sub-grid merger to convert existing soundings data into depths at the derived cell locations. This interpolator uses an inverse distance squared weighting to derive model cell depths from soundings data.

Due to the scarcity of soundings data for the York (2460 points) relative to the chosen resolution for this application (3310 cells in the horizontal), a decision was made to enhance these soundings data by adding contour values digitized from the NOAA charts at 6, 12, 18, 24, 30 and 36 foot contour intervals.

Preliminary attempts at calibration caused concern over the lack of agreement between cross-sectional areas reported by Hyer et. al (1971) and those derived from the depth interpolator in the tributaries (i.e., the 2D portion). A test using hydraulic depths derived by matching model cross-sectional area with measured transect data (and interpolated areas at model cell locations in between) caused a pronounced improvement in agreement between tidal range model prediction and observations in the region upstream. It was concluded that the grid generator's depth interpolator scheme is not appropriate for the 2D portion of the model.

IIIe. Grid generation output needed as hydrodynamic input

The grid generator produces two files which are required input to the hydrodynamic portion of HEM-3D. These are as follows:

1) ‘dxdy.out’ - cell dimensions, other parameters - rename to ‘dxdy.inp’ for HEM-3D

2) ‘lxly.out’ - cell locations, orthogonality - rename to ‘lxly.inp’ for HEM-3D

IIIf. Treatment of the marsh areas

The disjoint cells grouped in the rectangle shown to the southwest of West Point on page D-1 represent the 'marsh cells'. For the HEM-3D model, these are simply used for water storage in the 2D section. Although mass exchange is allowed between marsh and channel, no exchange occurs between adjacent marsh cells.

A survey of the Pamunkey and Mattaponi revealed 13 marsh areas varying in size from

0.25 to 1.5 square kilometers. These were measured for area and given an identification number. Each channel cell in the model's 2D portion was assigned either 0, 1, or 2 marsh ID's depending on whether the cell had no marshes on either side, one on either the left or the right, or marshes on both sides. Each marsh area was distributed among the channel cells sharing it, and an appropriate area for each "marsh cell" was thereby assigned. Mapping of the channel cells to the 200 marsh cells is performed in HEM-3D input file ‘modchan.inp’.

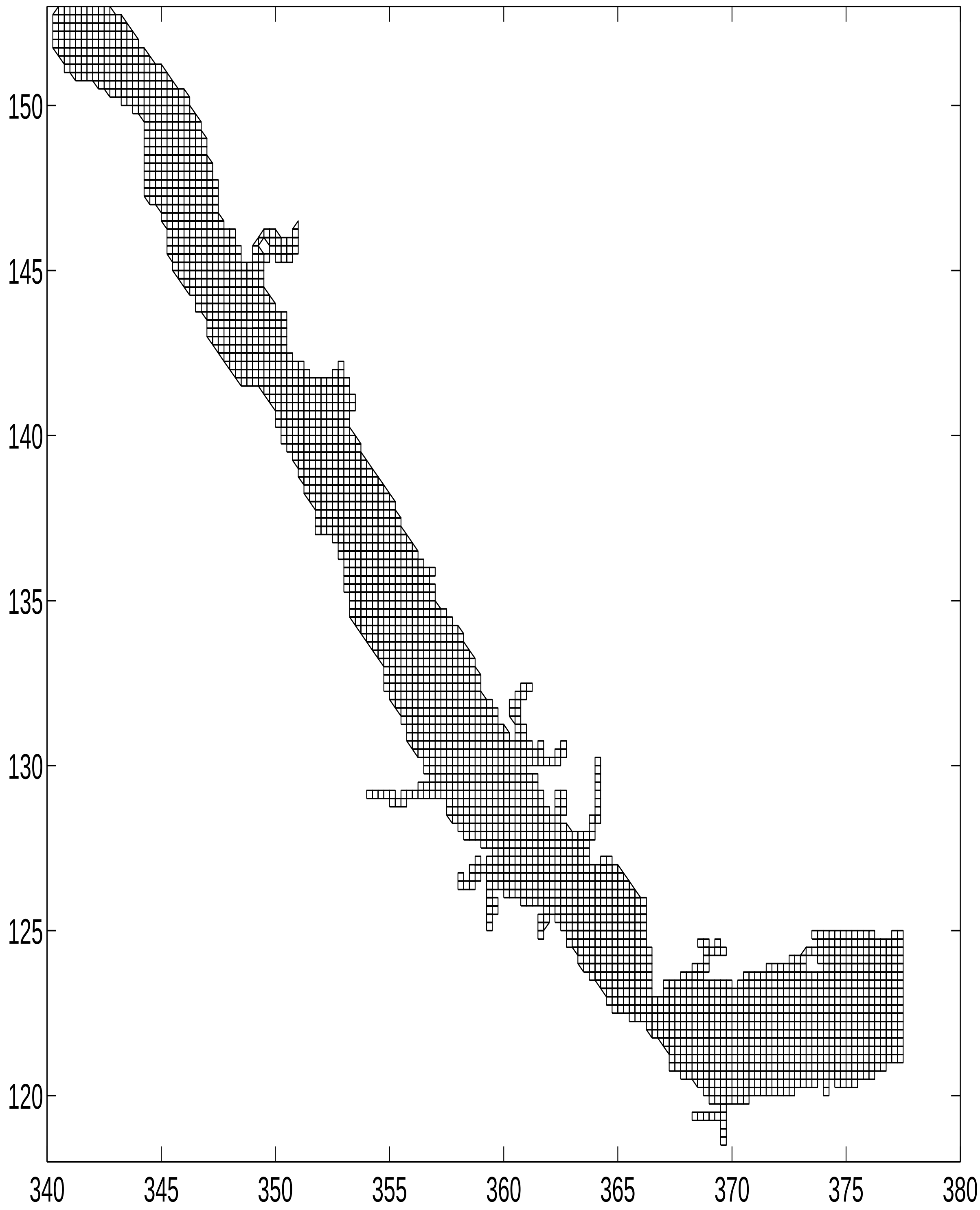


Figure 6. The Cartesian portion of the York River grid. The square grids are 250 meters on a side.

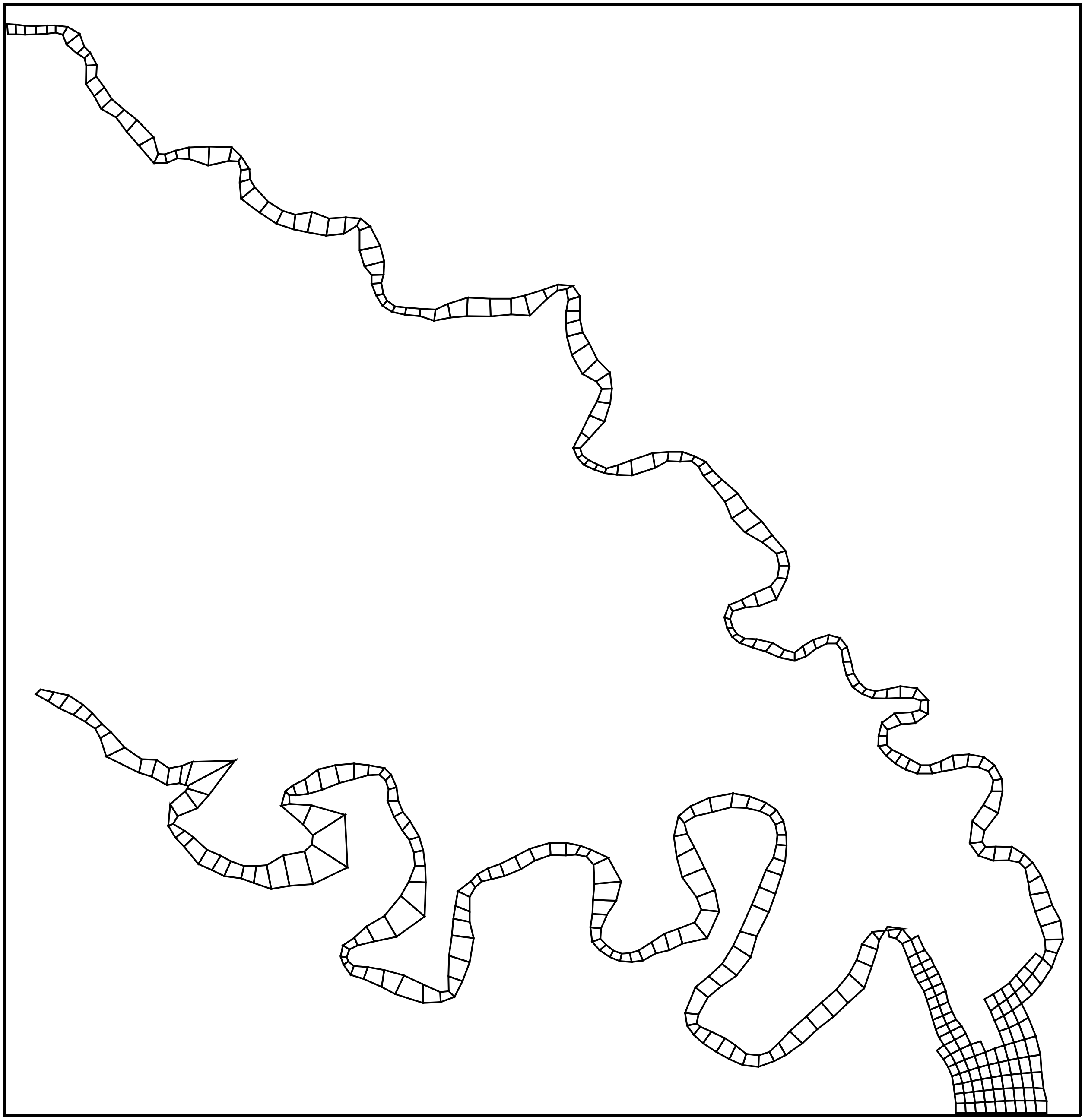


Figure 7.   The curvilinear portion of the York River grid.

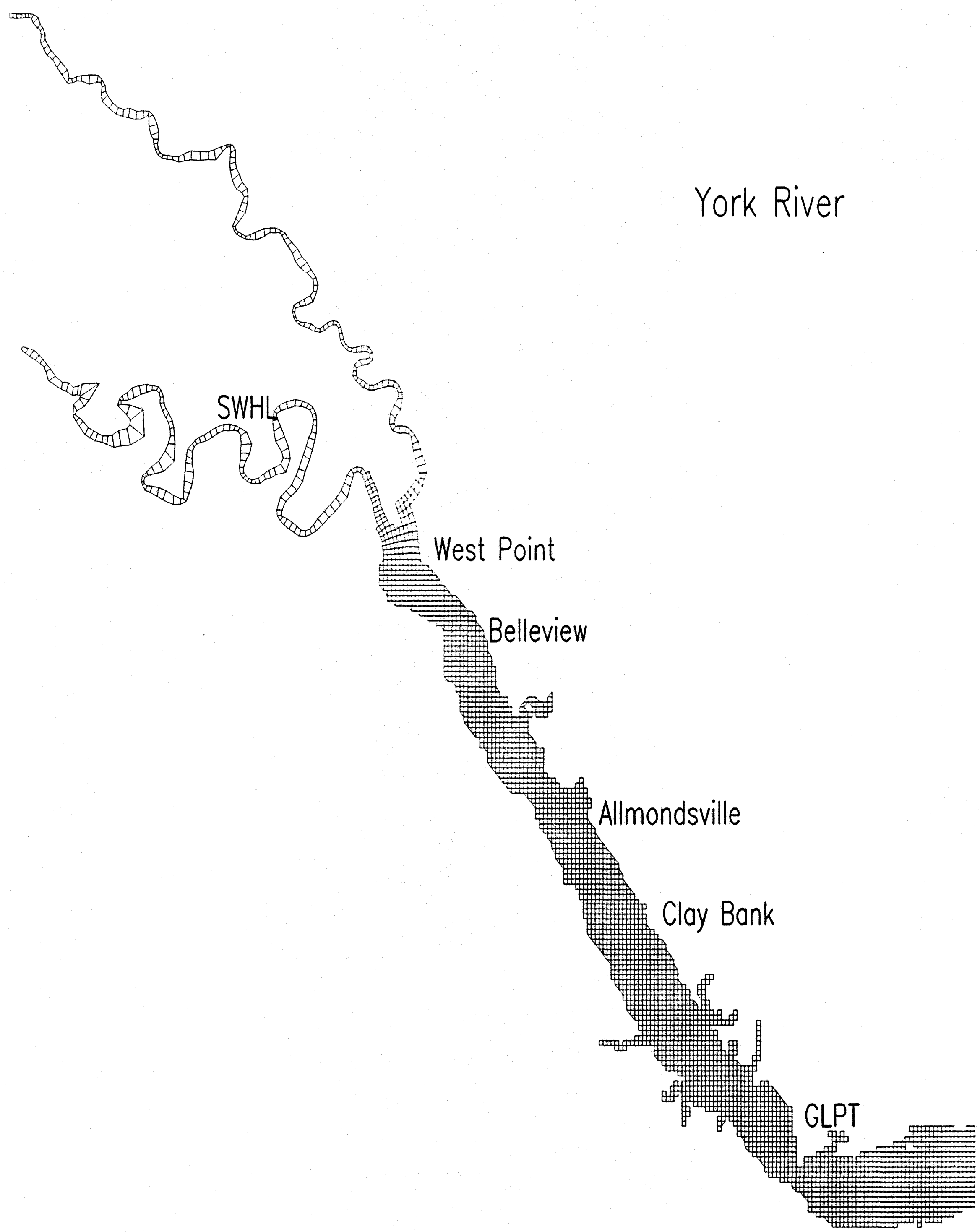


Figure 8. The merged Cartesian-curvilinear grid for the York River system.

IV. Execution of the HEM-3D model

IVa. Setup needed to run the model

Application of the HEM-3D model to a specific prototype and grid representation is all managed through a series of input files, the required ones of which are listed below:

filename	type	comments
efdc.f	model source	no changes required
efdc.com	common block declarations	no changes required
efdc.par	parameter input	array size specification
efdc	executable	machine specific
cell.inp	input	grid cell types
dxdy.inp	input	cell dimensions, local friction specification
lxly.inp	input	cell loc's in UTM
salt.inp	input	salinity initialization
modchan.inp	input	mapping of marshes
aser.inp *	input	atmospheric (wind)
txser.inp *	input	toxicity
gwater.inp *	input	groundwater

* optional files

Table 8. Files required to run the HEM-3D model code.

Partial listings of the main input files for this application are shown in Appendix E. Formation of a machine-specific executable file for a particular application requires customizing the ‘efdc.par’ file, (shown on page E-9), to specify a sufficient dimension for the grid indices, the number of vertical layers, the boundary complexity, and the output capability needed. Two application-invariant files are required at the time of formation of the executable - the model source code file (‘efdc.f’) and the common block declarations file (‘efdc.com’). Once the executable file has been formed, the main input is read from file 'efdc.inp'. A complete description of user designated input can be found in Hamrick (1996).

IVb. Boundary condition specification

The boundary condition specification required depends on the type of application at hand. For example, when one is performing a ‘verification run’, explicit boundary condition specification is a decided advantage. For this reason, the model is capable of reading separate input files for time series specifications of tidal height as well as salinity at the seaward boundary and freshwater discharges at upstream locations.

However, to perform the tidal calibration (see section Va2), it was necessary only to specify constituent amplitudes and phases, and a constant salinity at the York River mouth and averaged freshwater discharges at the heads of the two tributaries. The last were obtained by taking averages over a multi-year period at two gauging stations, Hanover on the Pamunkey and Beaulahville on the Mattaponi. These input values are shown on Card 18 of the main input file (‘efdc.inp’, see Appendix E, page E-3).

IVc. "Spinup" of the model

When the model is first activated, an initial flow field of velocity, tidal height, and salinity values is required. A simple way to provide this is to set all velocities and tidal heights to zero and allow the specified boundary conditions to force the system until an equilibrium condition is reached. This is referred to as a "cold start", and "spinup" refers to a period of simulation before the model reaches equilibrium.

It should be noted that, when performing a cold start, sharp transitions of state variable specifications (both temporal and spatial) should be avoided. For instance, starting the tide height specification driving the model at the seaward boundary normally requires starting the function at zero value, so as not to produce unreasonable gradients. A cold start is specified by setting the first integer flag (i.e.,ISRESTI) of Card 2 of the main input file to 0 to specify this option (see page E-1). The cold start can require a long simulation before reaching equilibrium, depending on the complexity of the boundary condition specification. In the present application, 6 to 10 tidal cycles are required for the 'M2 only' specification, whereas for the full 7 constituents, it may take 20 to 30 cycles). If a change is major, such as a change to the cell designator field or the depth field, a cold start is necessary.

A faster way to reach an equilibrium condition is often possible by "restarting" the model, continuing from a previous run by using the velocity and tidal height values at the end of the previous run to initialize the flow field. If the change is minor (e.g., local bottom roughness increase), a restart file is simpler. Also, a restart file is useful for short runs used to change the specifications for output.

V. Validation of the HEM-3D model

Va. Calibration

When the HEM-3D model is fully equipped with the proper bathymetry, geometry and other output data from the preprocessor, further parameters remain to be specified (e.g, bottom friction values). For this reason, it is prudent to simplify the input conditions of the model until it generates results which do not diverge greatly from reality. For example, it is important to match the overall characteristics of tidal propagation (i.e., mean range and phase lag) before proceeding to a more refined calibration.

Va1. Order of parameters to calibrate

The first parameter to calibrate is the bottom roughness which is adjusted first globally and then, if necessary, locally so as to reproduce the propagation of the tide, both for the range as the wave proceeds upriver, as well as for the high and low tide phase difference relative to some station whose tidal features are well-established. For this application, phase lags relative to Gloucester Pt. were compared.

Traditionally, most modeling efforts start with the calibration of a single sinusoidal tidal constituent, namely the mean tide range forced at the dominant semi-diurnal frequency. The advantage in this is faster convergence to equilibrium, enabling faster turn-around as preliminary tests are made. After the value for bottom roughness is roughly calibrated, it may be refined with a model simulation of a multi-constituent tide.

After the bottom roughness is well-calibrated, the turbulent diffusion coefficient is the next parameter to be determined. This can be accomplished by comparing salinity time series data and synoptic spatial distributions.

Va2. Tidal calibration

The preliminary model calibration involves adjustments of parameters to simulate properly the tidal propagation in terms of mean tide. The bottom roughness heights were adjusted to minimize the differences between the model results and prototype values. The model was forced at the river mouth with a single constituent M2 tide and mean freshwater discharges at the upstream boundaries. The amplitude of this M2 tide was adjusted such that the model range at Gloucester Pt. matched the longterm observed range (i.e., 0.73 m). Adjustment of model bottom friction is straightforward. If the model wave were to propagate too rapidly with too high a range, the model friction (i.e., roughness height) needed increasing. The final bottom roughness heights selected were 0.075 cm for the York mainstem and 0.06 cm for the tributaries above West Point. The computed mean tide ranges and times of high and low tides are compared with prototype values in Figures 9 and 10. It is noted in Figure 9 that there is a significant difference in the tidal range between the NOAA Tide Tables and VIMS 1996-1997 measurements in the Mattaponi River. Since the Gloucester Point tide data used to normalize the 1996-1997 Mattaponi River station data are provisionary, the long-term mean range data of the NOAA Tide Tables were emphasized for model calibration.

The preliminary tidal calibration was confirmed by model simulation of a multiple constituent tide, and bottom roughness heights were refined if necessary. The ability of the model to predict phase relationships between constituents depends on the proper specification of phase lags at the open boundary. The Gloucester Point 8-year record of hourly observed tidal heights processed yields a high degree of confidence as to the amplitudes and phases of each constituent based on a low yearly variation (see Table 1), and therefore these values were used to determine phase relationships of various tidal constituents at the river mouth. Another depiction of the longitudinal change in tidal constituent amplitudes and phases is shown by plotting each as vectors, as shown in Fig. 11.

Va3. Salinity calibration

The methodology of calibrating the salinity evolved from a determination to demonstrate the capability of HEM-3D to simulate the following important features of the prototype:

1) accurate tracking of the estuarine-wide longitudinal salinity distribution and how it is affected by various physical influences (e.g., discharge, wind, withdrawal, or tidal mixing).

2) the spring-neap cycle of the stratification-destratification phenomena (mixing strongest on spring tide, weakest on neap tide). This is vital in that it governs the supply of nutrients to the surface where sunlight is abundant.

3) effects of an “event”, either heavy discharge upriver or unusual boundary conditions at the mouth.

For this reason, the calibration effort involved not only the traditional comparison of historical time series, but also spatial comparisons showing the predicted salinity distribution both against depth and distance upstream. The first comparison that proved beneficial was to plot the HEM-3D salinity averaged over the 8 layers used in this calibration against the VIMS slackwater data averaged over the number of samples taken vertically at each station, as shown in Figures 12-13. In this fashion the model feature of replicating the extent of salinity intrusion could be adjusted.

Salinity calibration of the model involved adjustment to 2 parameters. The first parameter is a coefficient for the specified horizontal diffusivity, which was found to be 0.05 from the mouth to Gloucester Pt. and 0.01 upriver from Gloucester Point. Adjustments to this parameter were made by comparing contours of the salinity regime for the York mainstem for both VIMS slackwater surveys and HEM-3D predictions on 7 separate dates in the summer of 1989, as shown in Figures 14-17. The second parameter is a lag period (about 3 hours) from the beginning of flood at the downstream boundary to the point in time at which the specified salinity is attained at this location (see card 6, main input file, 174 timesteps). Model results appeared to be much less sensitive to this lag period than to the aforementioned horizontal diffusivity.

Vb. Verification procedures

Verification of the model entails the simulation of a specified historical period whereby model results can be shown to agree adequately with field observations without adjustment of any parameters as determined in the calibration procedure as described in the previous section. An important aspect here is the use of datasets independent of those used in the calibration process.

Vb1. Selection of simulation periods for verification

The periods selected for verification of the HEM-3D model are constrained by availability of suitable field observation data, both within the prototype and at the landward and seaward boundaries. Whereas many tide gauge deployments have been made (see Table 2), seldom have current meters been deployed during these periods. Additionally, one needs a continuous specification of both observed hourly tidal heights at the mouth as well as daily USGS discharge records upstream at the heads of both tributaries - (see section Vb3).

The periods selected for the York HEM-3D verification effort include:

1) 1986	Tidal gauge at Sweet Hall
2) June - Sept 1993	Tidal gauges at Belleview and West Pt.
3) Dec 1989 - Jan 1990	Tidal heights measured at Claybank
	2 moorings at Claybank, Allmondsville (velocity & salinity)

Vb2. Specification of initial conditions

It is important that the residual effects of an inaccurate initial spatial distribution be eliminated for each state variable (tidal elevation, velocity, or salinity) prior to comparing model results to field data. For this reason, it is often advantageous to “restart” the model with a set of values from a prior run which are not totally unrealistic. Phase problems with tidal elevation or velocity may disrupt a run, but this will manifest quickly and not delay machine scheduling. Adjustments to these variables seem to be absorbed within 6-10 tidal cycles, whereas salinity can require much longer to overcome a poor initial condition. For this reason, the “spinup” period (the period during which the model must be run with the correctly specified boundary conditions (see next section) prior to the comparison of its results with field observations) depends upon the quality of the initial conditions specified.

Vb3. Specification of boundary conditions

Whereas the tidal calibration runs use longterm averages of discharge upriver and specification of tidal constituents as well as average salinity at the mouth, the verification runs were made with real time specifications as follows:

1) daily discharge values provided by the USGS at the 2 stream gauges upriver (Hanover on the Pamunkey and Beaulahville on the Mattaponi)
2) hourly tidal height specification at the mouth
3) bi-weekly (or more frequent) salinity profile at the mouth
4) daily mean wind data from the VIMS Ferry Pier

These data are easily downloaded from the VIMS WEB site and then require proper formatting to serve as HEM-3D input files ‘pser.inp’ (tidal height specification), ‘qser.inp’ (discharge specification), and ‘aser.inp’ (atmospheric, e.g. wind, specification) in the manner illustrated in Appendix E.

Vb4. Techniques for replacement of missing portions of boundary condition data

In two separate instances, when a period was selected for simulation by a verification run, it was found that boundary condition data was missing. This section describes simple techniques to replace missing portions of boundary conditions, thus preserving these periods as usable for verifications runs.

In one case, it was found that the Mattaponi gauge at Beaulahville was inoperable for 1988-89 due to a land dispute. This was unfortunate as VIMS has excellent slackwater survey data for that period. A method of replacing the missing data was devised by examining long term data at the Bowling Green gauge (further upriver) and looking at the correlation between discharges at these 2 Mattaponi gauges. Looking at a full decade of data (1978-1987), it was found that the correlation was maximized by lagging the recorded values at the upriver Bowling Green gauge by 1 day. It was then found that a higher correlation existed by using only the May 1 - September 30 season corresponding to the slackwater surveys, as shown in Figure 18a. In this fashion we were able to reconstruct closely the Beaulahville gauge record, as shown for 1990 in Figure 18b.

In another case, it was shown that the continuous Gloucester Pt. tidal height specification could be used to drive the model at the river mouth by advancing this record by 15 minutes, a difference determined by correlating the Jenkins Neck gauge record (06/89-09/89) against the Gloucester Pt. record, as shown in Figure 19.

Vb5. Comparison of surface elevation, current, and salinity

Comparisons of time series of VIMS field observations to HEM-3D predicted values are shown for surface elevation in Figure 20, current velocity in Figure 21-24, and for salinity in Figure 25.

To provide a quantitative assessment of the HEM-3D predictive capability, each time series comparison underwent a simple statistical treatment to determine a mean difference, mean absolute difference, and a root-mean-square difference as shown in Table 10. In this fashion, one could also determine tendencies of the model to under-predict or over-predict.

		M2		S2		N2		K1		M4		01		M6	
		A	P	A	P	A	P	A	P`	A	P	A	P	A	P
Goodwin Isl.:	measured	0.317	3.5	0.056	-2.3	0.079	-2.0	0.052	7.1	0.011	2.7	0.036	0.9	0.003	1.9
	modeled	0.321	3.7	0.061	-2.8	0.070	-2.4	0.052	7.4	0.008	2.2	0.039	0.7	0.004	0.5
Gloucester Pt.:	measured	0.340	3.8	0.064	-2.3	0.074	-2.1	0.053	7.2	0.004	-2.9	0.040	0.6	0.004	-1.4
	modeled	0.340	3.8	0.065	-2.7	0.074	-2.3	0.053	7.4	0.005	-3.0	0.039	0.7	0.004	-3.5
Claybank:	measured	0.366	4.7	0.066	-1.9	0.084	-1.7	0.062	8.0	0.006	-2.5	0.040	0.7	0.004	-0.6
	modeled	0.383	4.4	0.067	-2.0	0.076	-1.6	0.055	8.1	0.010	-2.7	0.042	1.3	0.005	-3.2
Allmondsville:	measured	0.385	4.3	0.063	-1.7	0.053	-3.0	0.055	6.9	0.006	-3.1	0.035	1.9	0.004	-0.8
	modeled	0.389	4.6	0.067	-1.8	0.076	-1.4	0.055	8.2	0.010	-2.3	0.042	1.5	0.005	-3.0
Belleview :	measured	0.384	5.3	0.081	-0.8	0.097	-0.4	0.046	9.1	0.021	-2.4	0.031	2.9	0.004	-1.9
	modeled	0.386	5.3	0.061	-1.1	0.069	-0.6	0.054	9.0	0.028	-2.1	0.044	2.3	0.013	2.3
West Point :	measured	0.398	5.7	0.070	-0.5	0.087	9.5	0.057	9.5	0.036	-2.2	0.036	3.4	0.008	-1.7
	modeled	0.369	5.7	0.055	-0.6	0.064	9.5	0.053	9.5	0.044	-2.0	0.044	2.7	0.018	-2.0
Sweet Hall:	measured	0.303	-4.3	0.057	1.2	0.056	3.0	0.050	-11.8	0.020	-0.3	0.042	6.1	0.012	0.6
	modeled	0.315	-4.9	0.040	1.2	0.056	3.0	0.049	-12.5	0.020	-0.3	0.043	4.7	0.020	3.3
Elsing Green:	measured	0.396	-3.2	0.052	3.6	0.052	3.4	0.056	-11.0	0.037	1.6	0.047	6.4	0.015	1.3
	modeled	0.401	-3.8	0.051	2.5	0.062	3.1	0.054	-11.5	0.028	1.1	0.046	5.7	0.021	0.5
Indian Res.:	measured	0.429	-5.7	0.075	1.0	0.067	0.6	0.052	11.4	0.038	-2.6	0.026	1.5	0.018	-1.1
	modeled	0.463	-5.7	0.067	0.6	0.079	1.1	0.057	10.4	0.016	-0.2	0.047	3.6	0.023	-0.8
Walkerton :	measured	0.467	-4.1	0.067	2.5	0.102	2.3	0.043	-11.2	0.048	0.9	0.034	5.5	0.026	0.6
	modeled	0.494	-4.9	0.080	1.6	0.105	2.0	0.072	-12.9	0.059	0.5	0.059	4.5	0.015	0.6

Note: A = amplitude (m) and P = phase (hours) relative to 0000 hrs (midnight) 01/01/89

Table 9. Comparison of observed versus predicted amplitudes and phases for the 7-constituent boundary forcing.

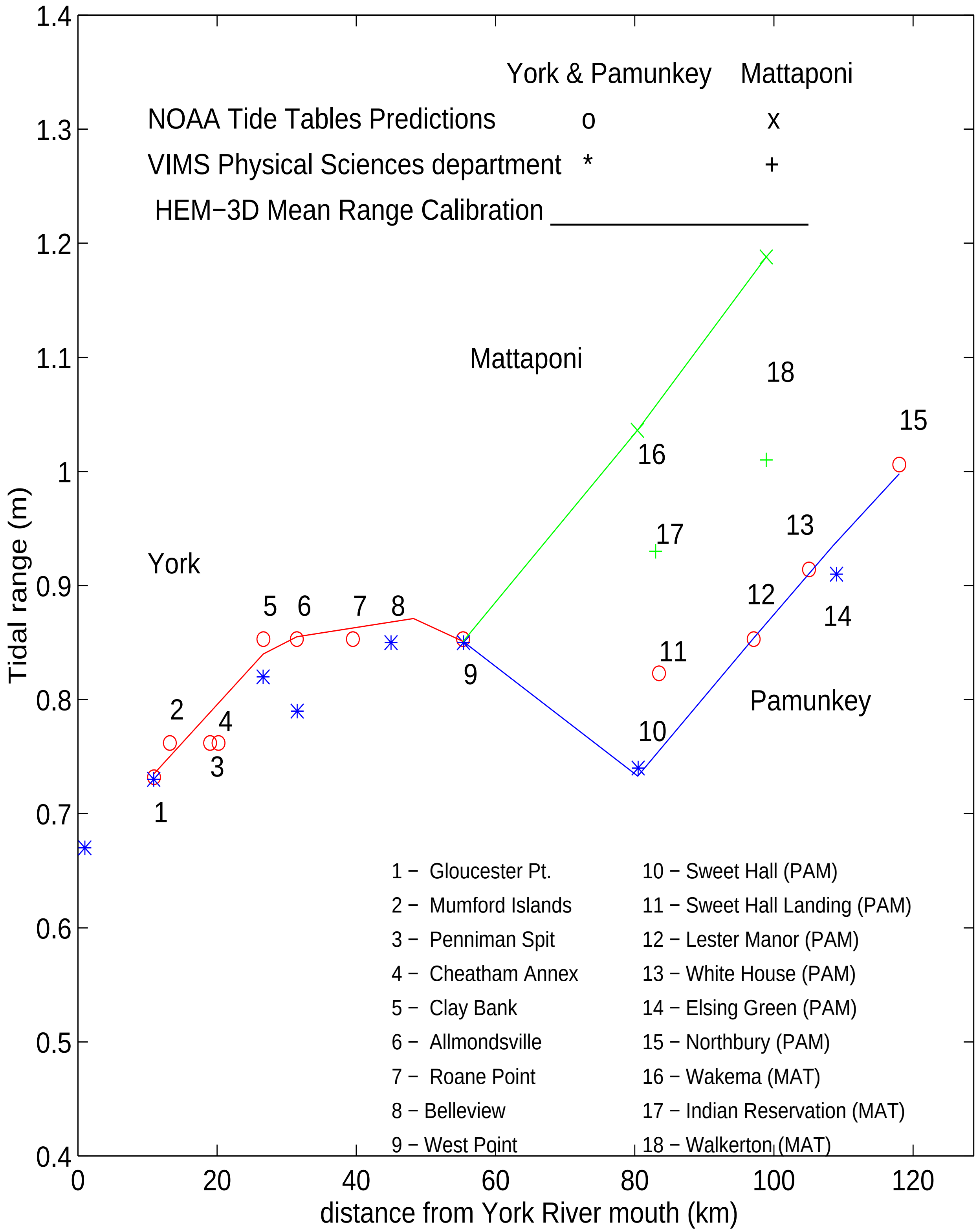
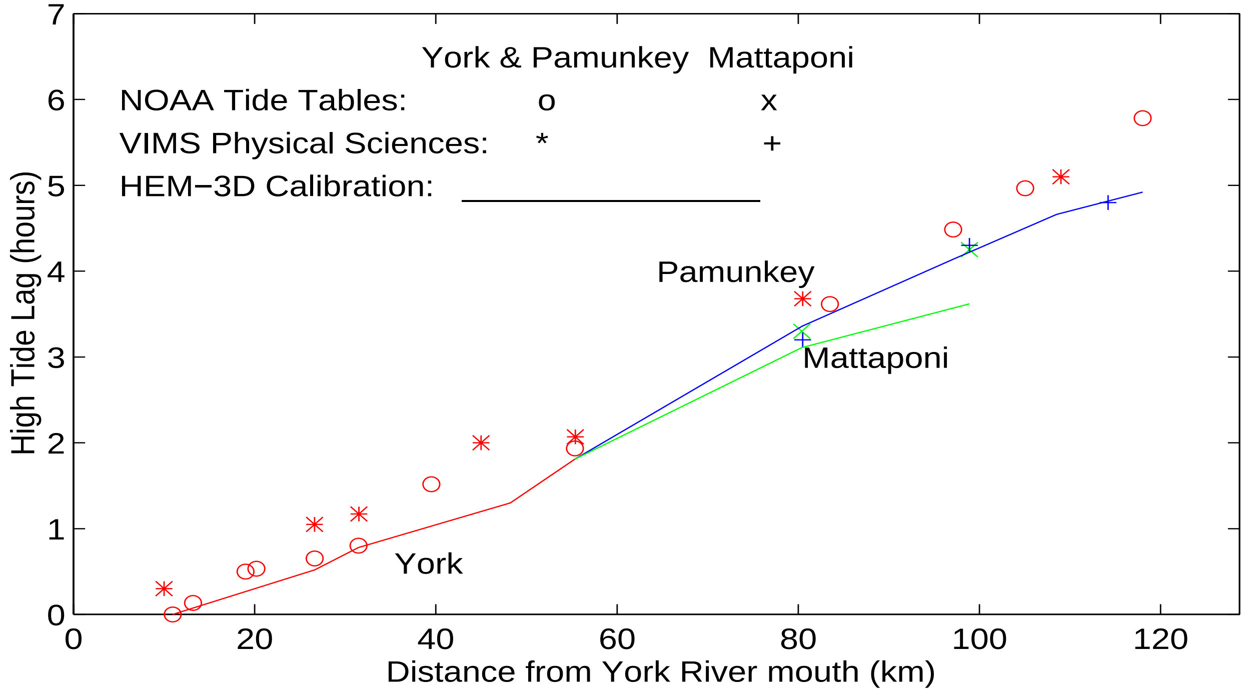


Figure 9. Comparison of tide range from HEM-3D model output, VIMS gauge data, and NOAA Tide Table data at available York River stations. Model forced with mean tide only.



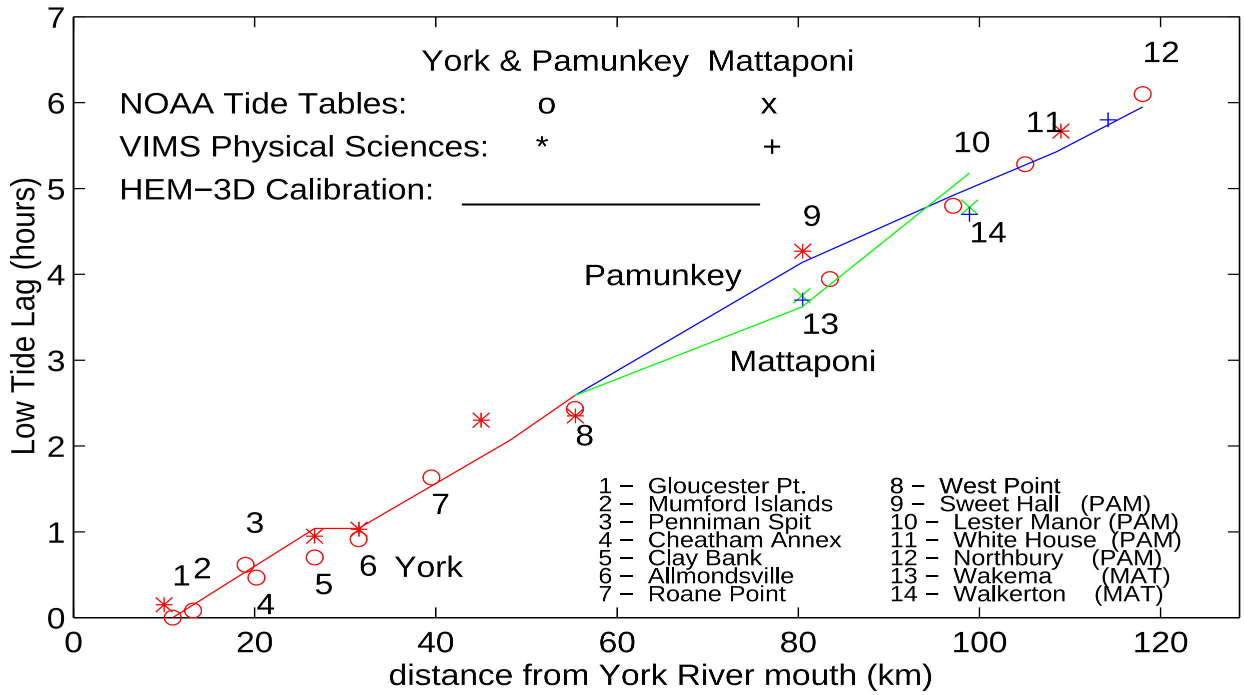


Figure 10. Comparison of high and low tide phase lags relative to Gloucester Pt. from the HEM-3D model output, VIMS gauge data, and NOAA Tide Table data at available York River stations. Model forced with mean tide only.

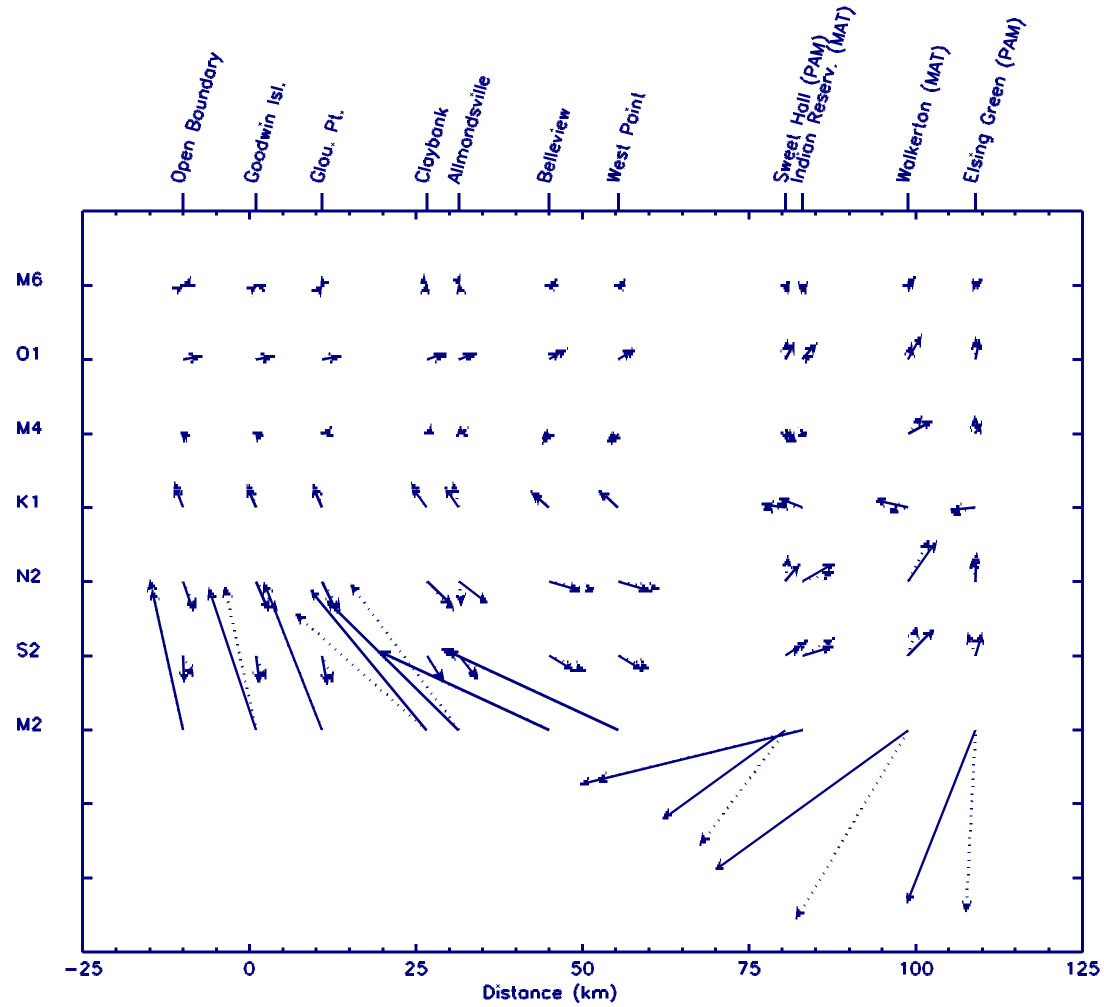


Figure 11. Vector plot of observed versus predicted amplitudes and phases of tidal constituents at selected locations in the York River.

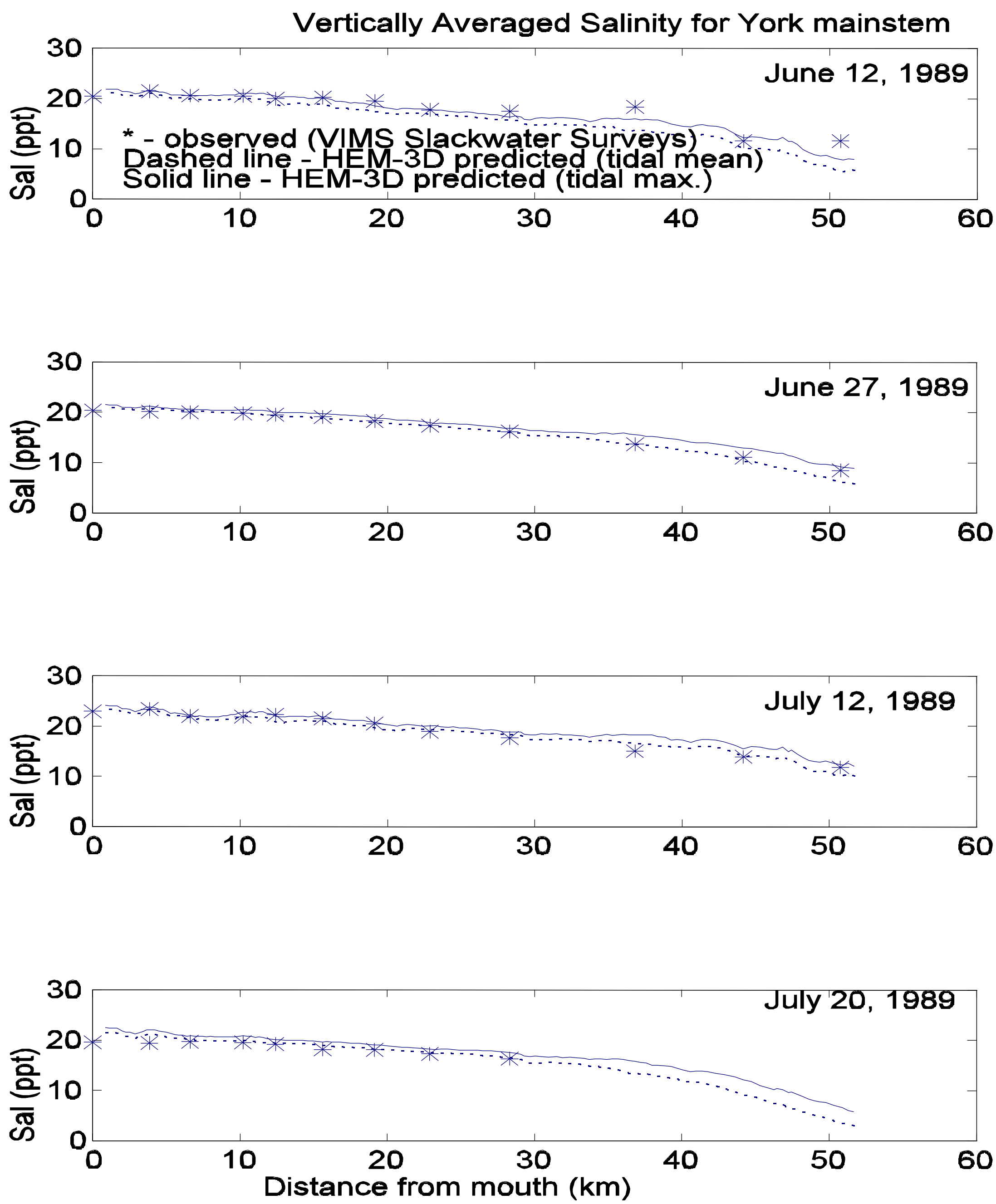


Figure 12. Comparison of vertically averaged salinities from VIMS slackwater surveys and HEM-3D predictions (both tidal mean & tidal maximum) for June 12, June 27, July 12, and July 20, 1989.

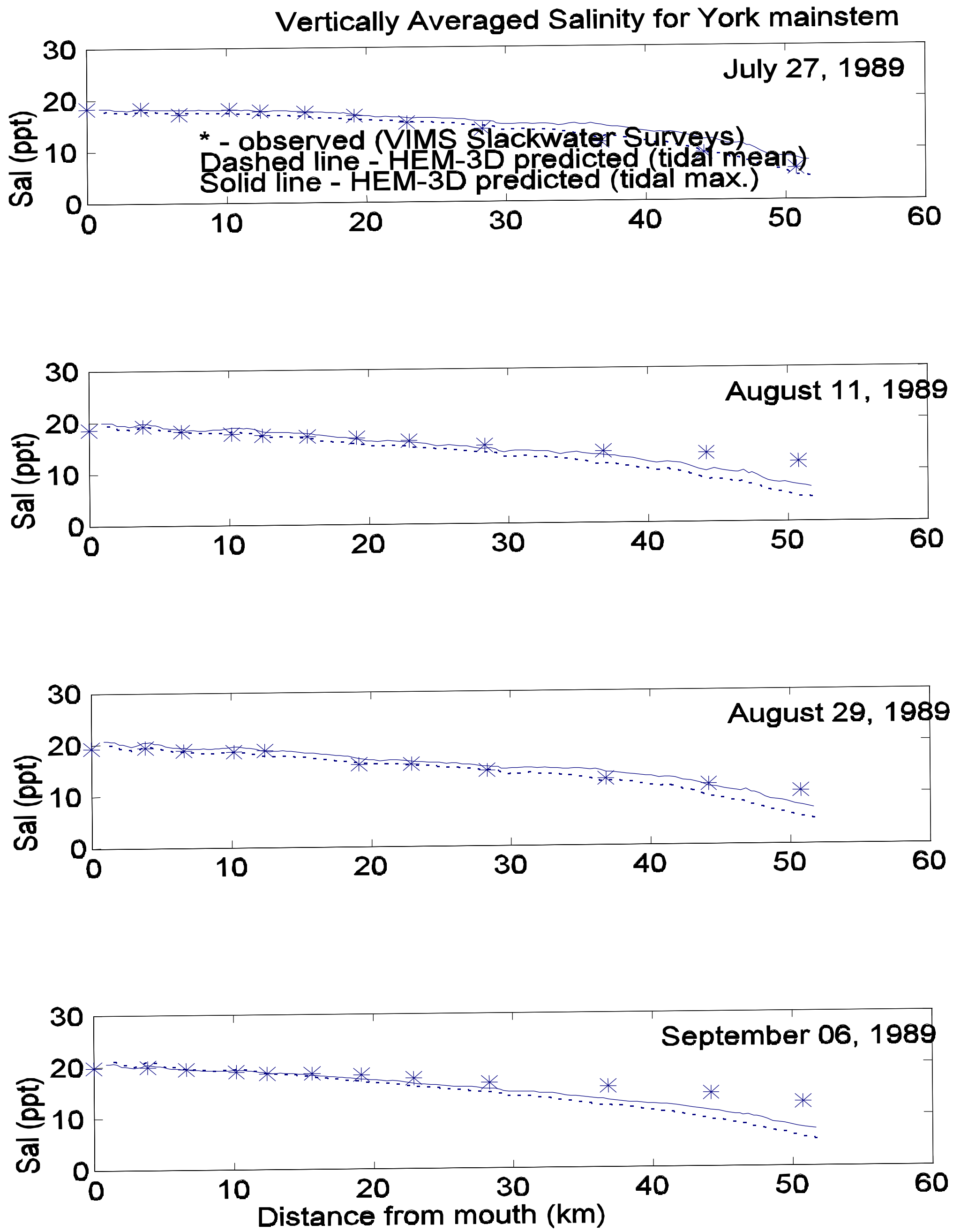


Figure 13. Comparison of vertically averaged salinities from VIMS slackwater surveys and HEM-3D predictions (both tidal mean & tidal maximum) for July 27, August 11, August 29, and September 6, 1989.

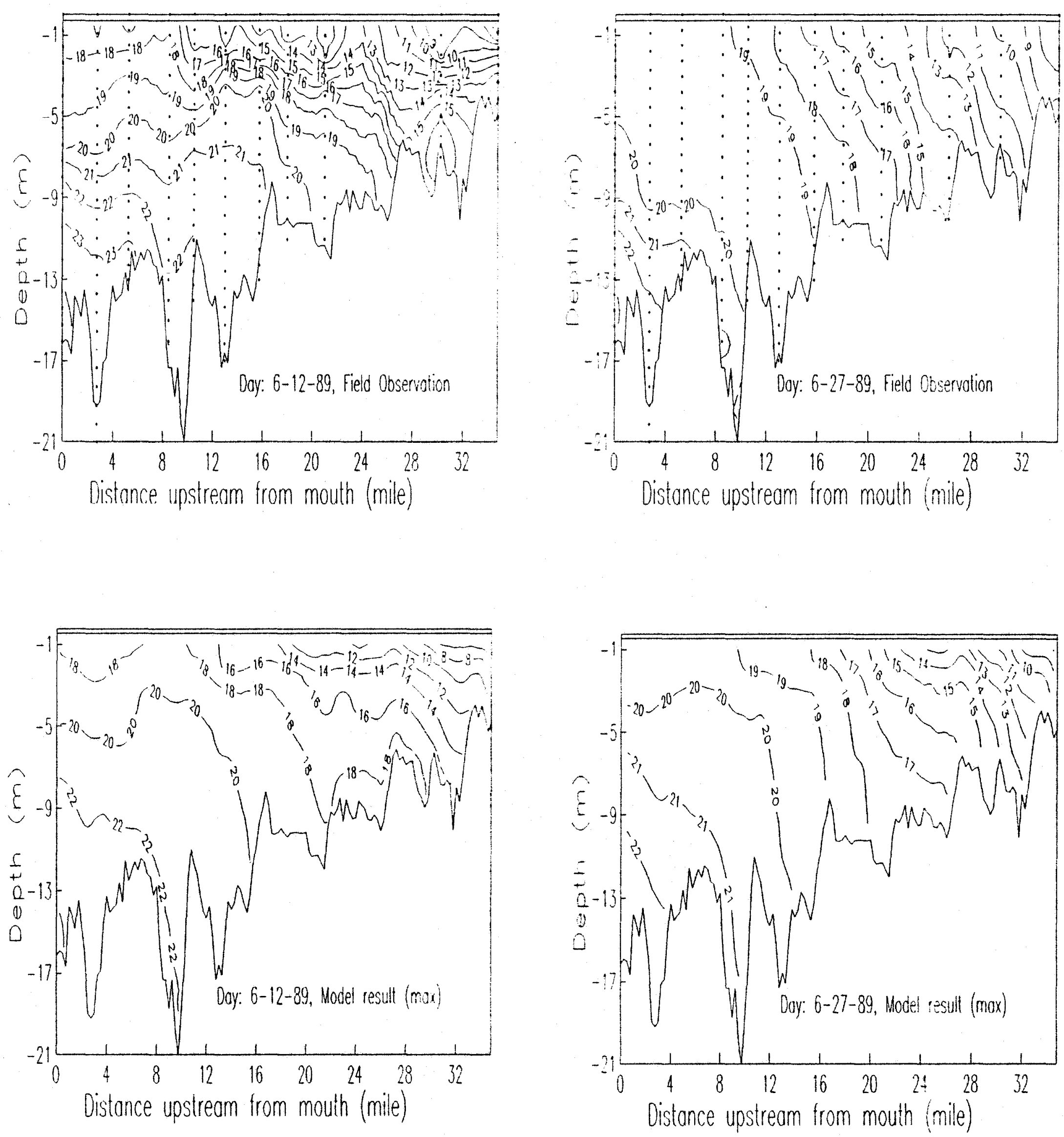


Figure 14. Comparison of salinity profiles for VIMS slackwater surveys and HEM-3D predictions for both June 12 and June 27, 1989.

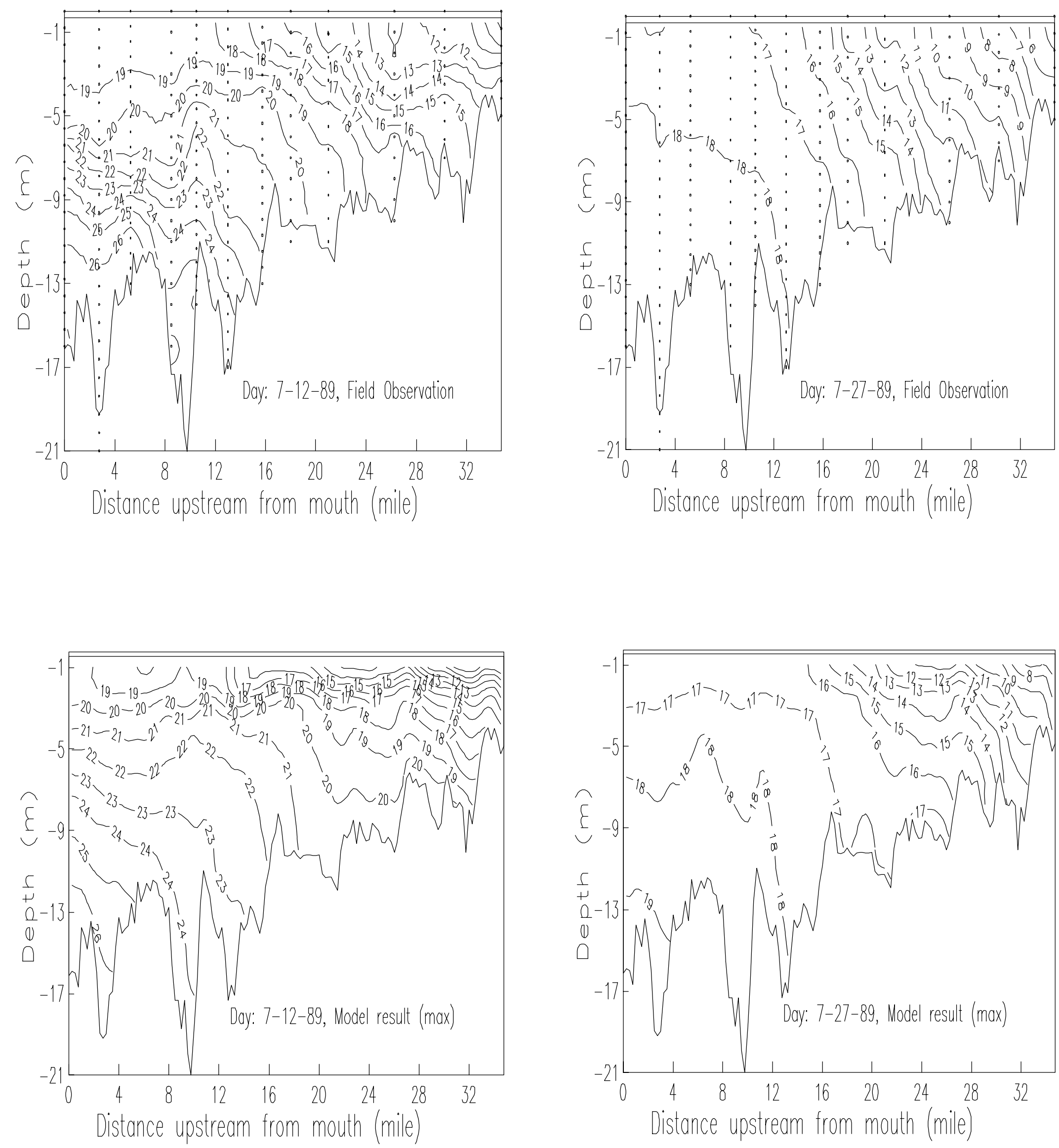


Figure 15. Comparison of salinity profiles for VIMS slackwater surveys and HEM-3D predictions for both July 12 and July 27, 1989.

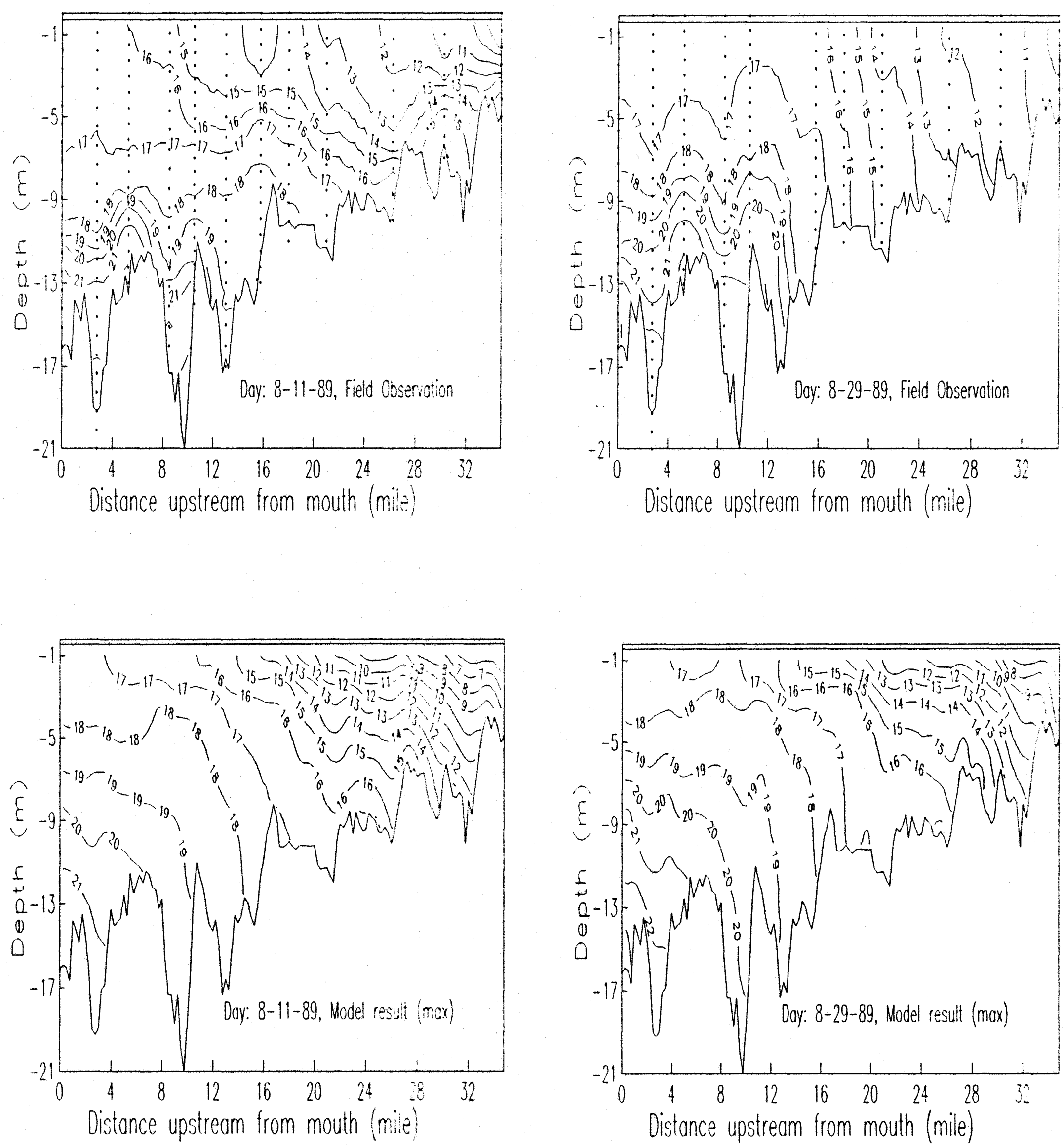


Figure 16. Comparison of salinity profiles for VIMS slackwater surveys and HEM-3D predictions for both August 11 and August 29, 1989.

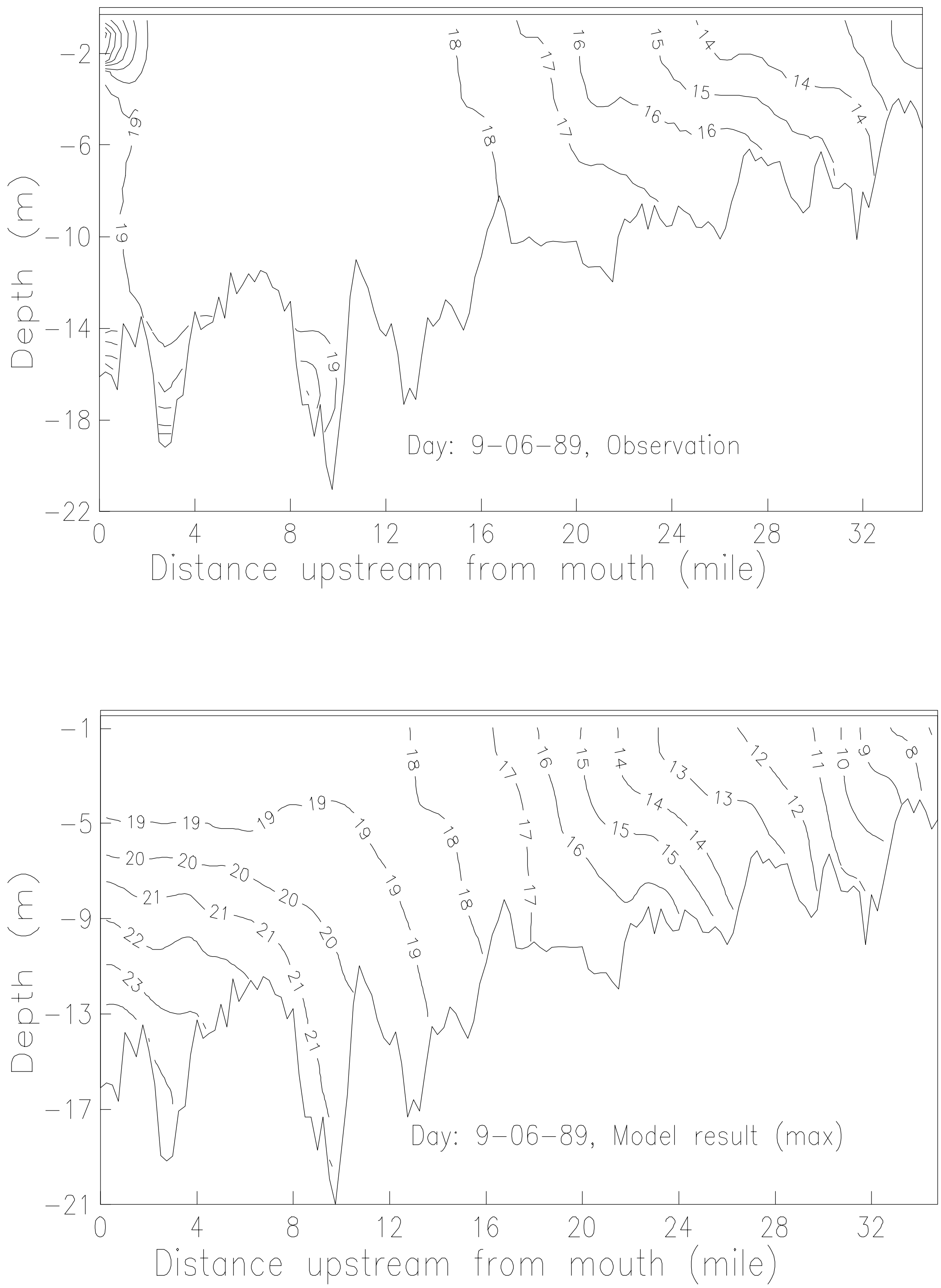
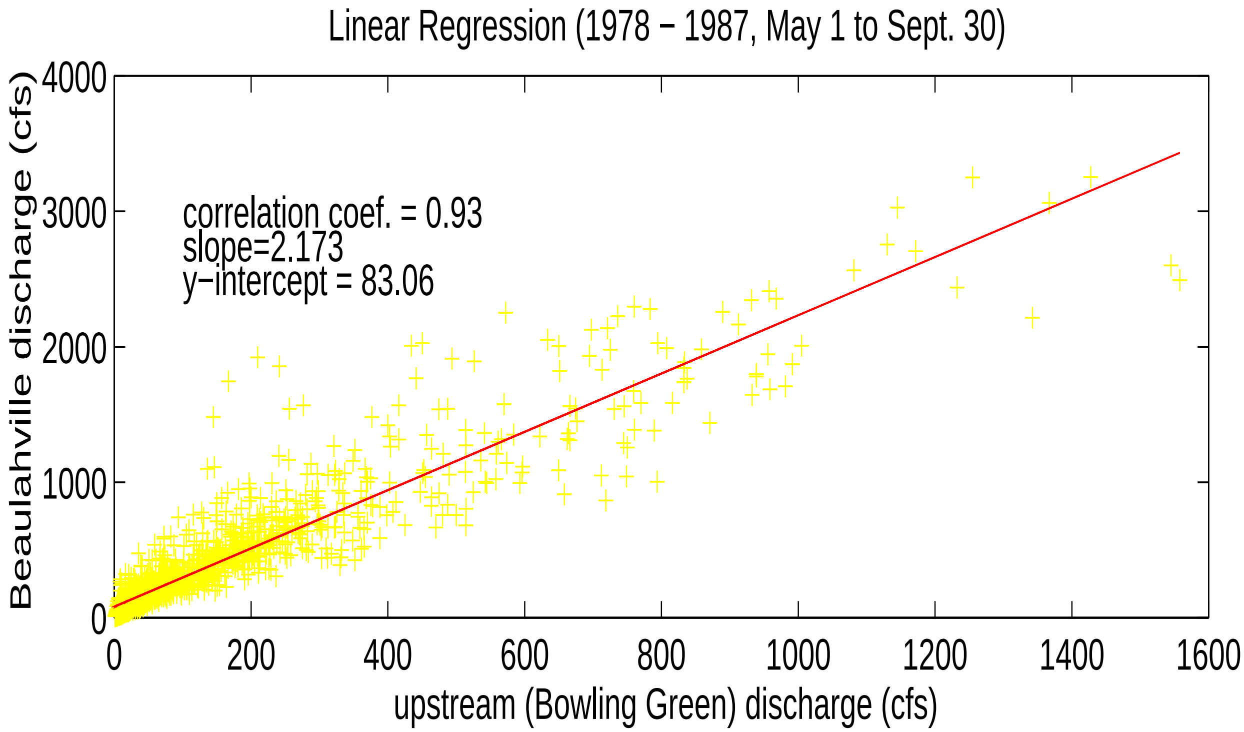


Figure 17. Comparison of salinity profiles for VIMS slackwater surveys and HEM-3D model predictions for September 6, 1989.



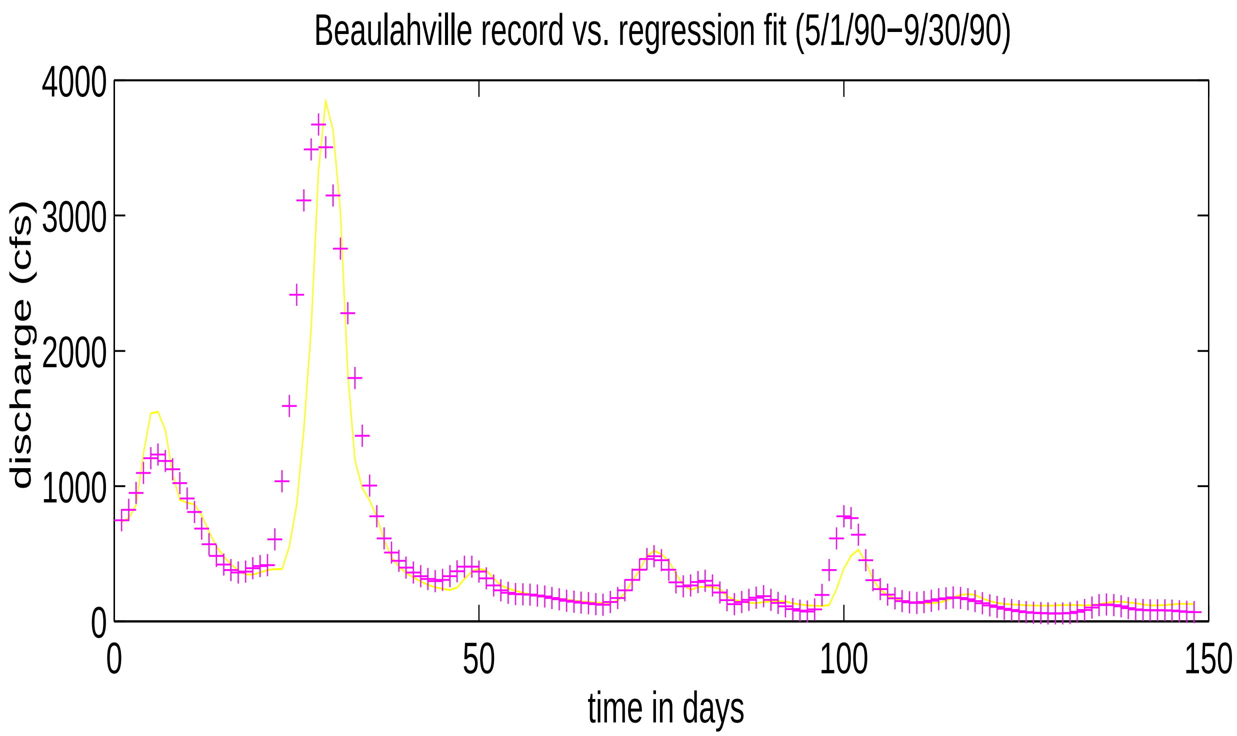


Figure 18a. Regression analysis of discharge from 2 Mattaponi USGS stations: Bowling Green, lagged by 1 day (x-axis) and Beaulahville (y-axis) for daily discharges occurring between May 1 and September 30 for years 1978-1987.

Figure 18b. Regression fit shown plotted against actual gauge data, 05/01/90-09/30/90.

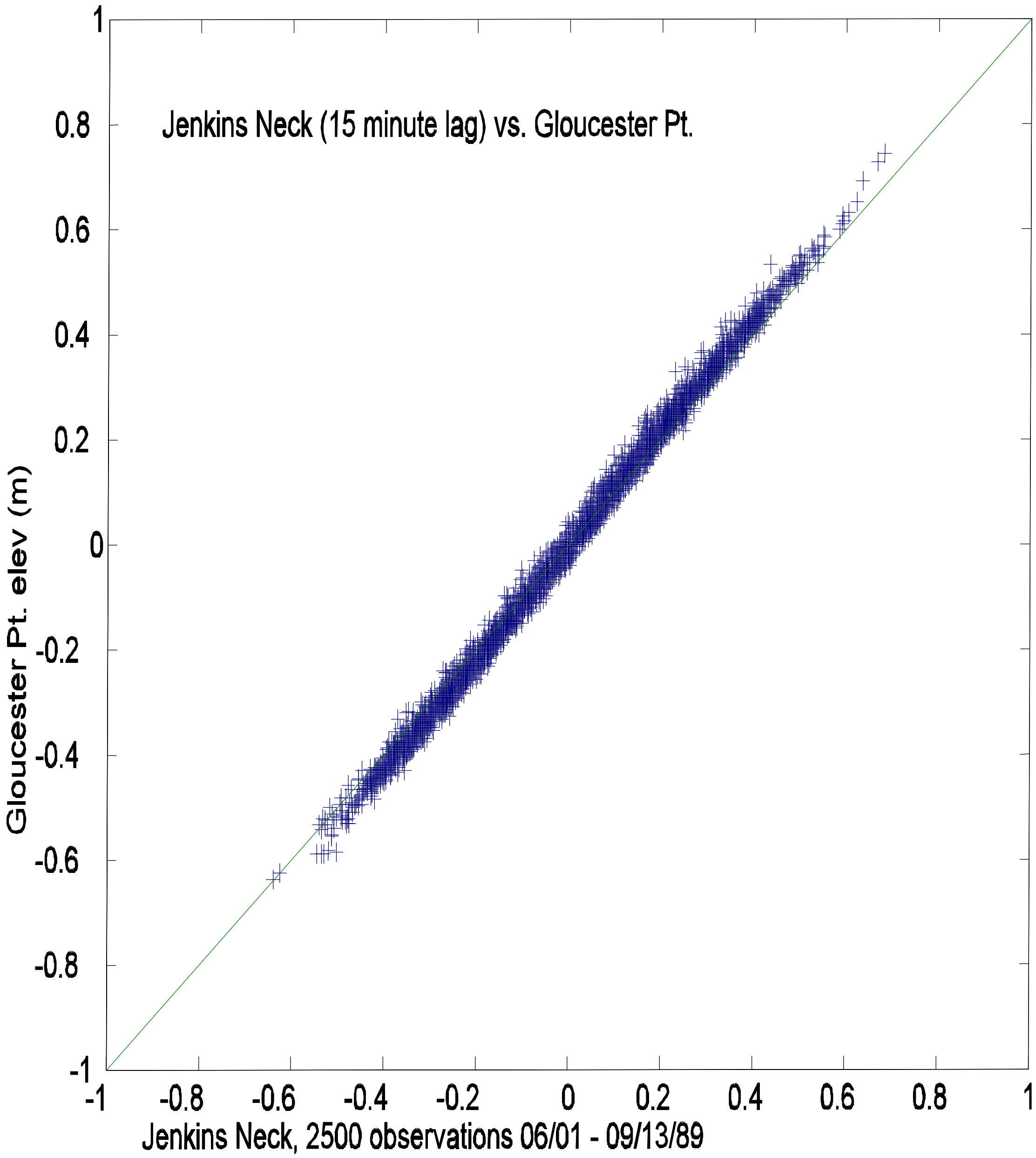


Figure 19. Regression fit of Gloucester Pt. hourly tidal heights (lagged by 15 minutes) plotted against Jenkins Neck (north side of river mouth), 06/01-09/13/89.

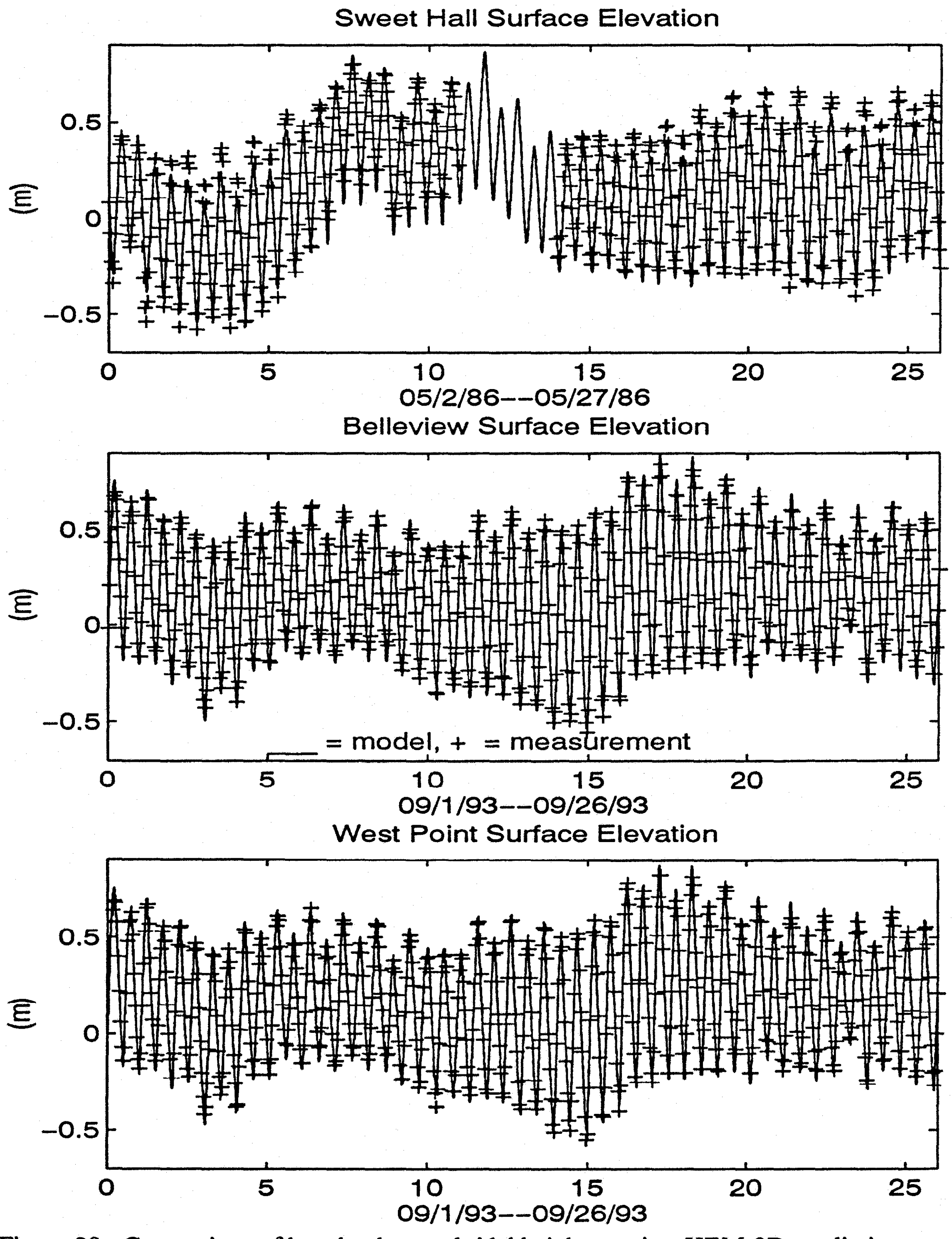


Figure 20. Comparison of hourly observed tidal heights against HEM-3D predictions at:
A) Sweet Hall (Pamunkey), 05/02/86-05/27/86
B) Belleview (York mainstem), 09/01-09/26/93
C) West Point (confluence), 09/01-09/26/93.

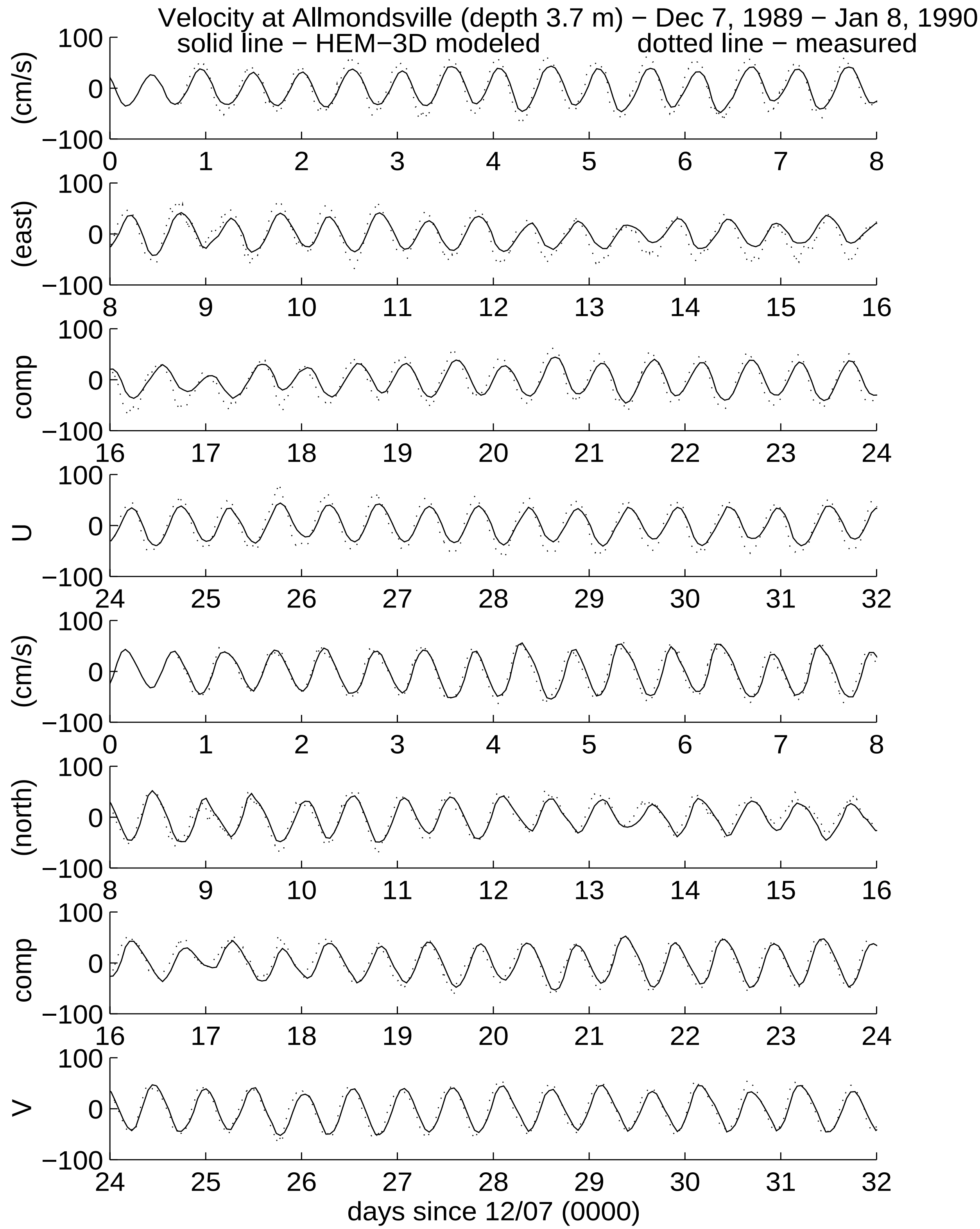


Figure 21. Comparison of observed velocity against HEM-3D predictions at 3.7 meters depth at Allmondsville, 12/07/89-01/08/90.

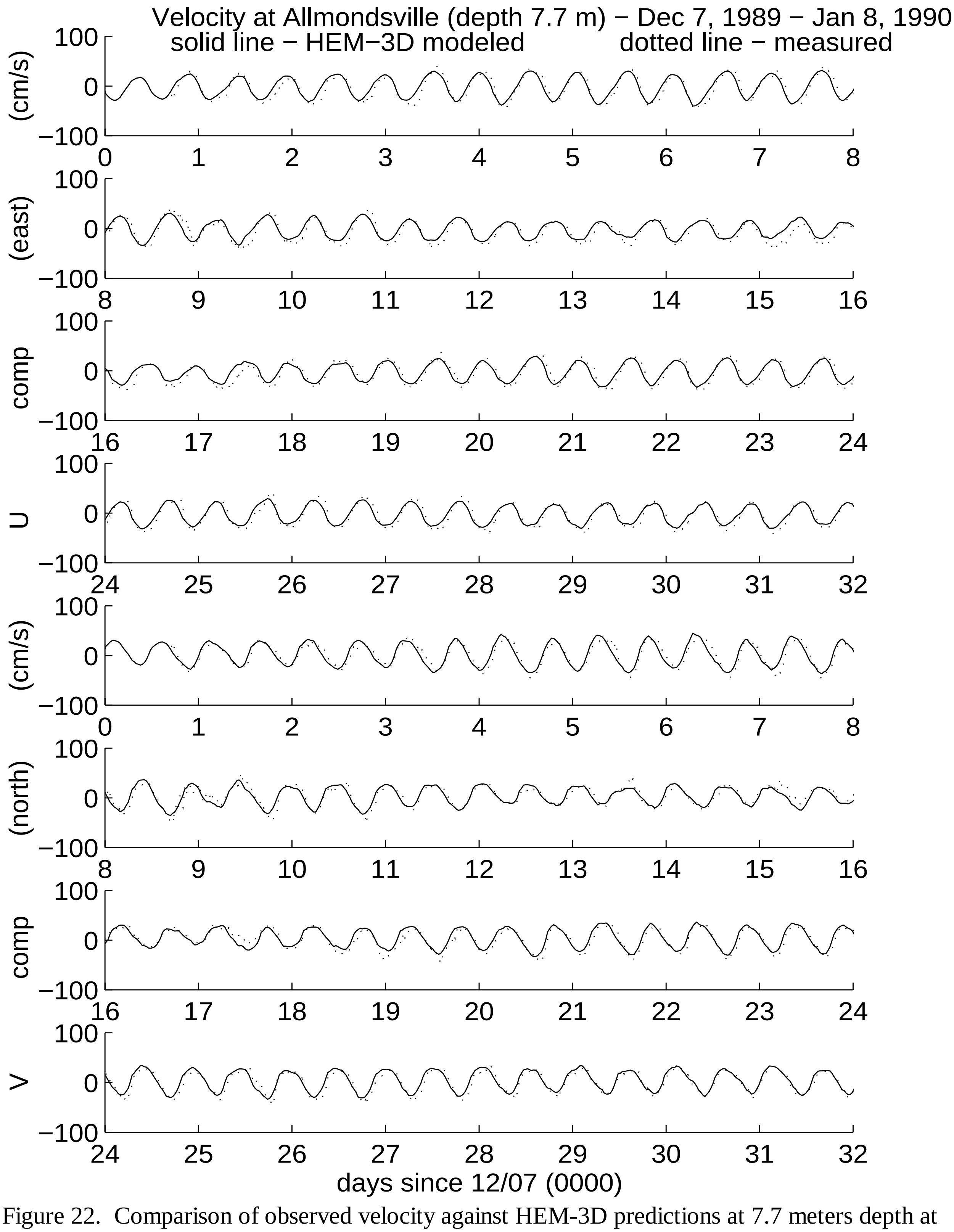


Figure 22. Comparison of observed velocity against HEM-3D predictions at 7.7 meters depth at Allmondsville, 12/07/89-01/08/90.

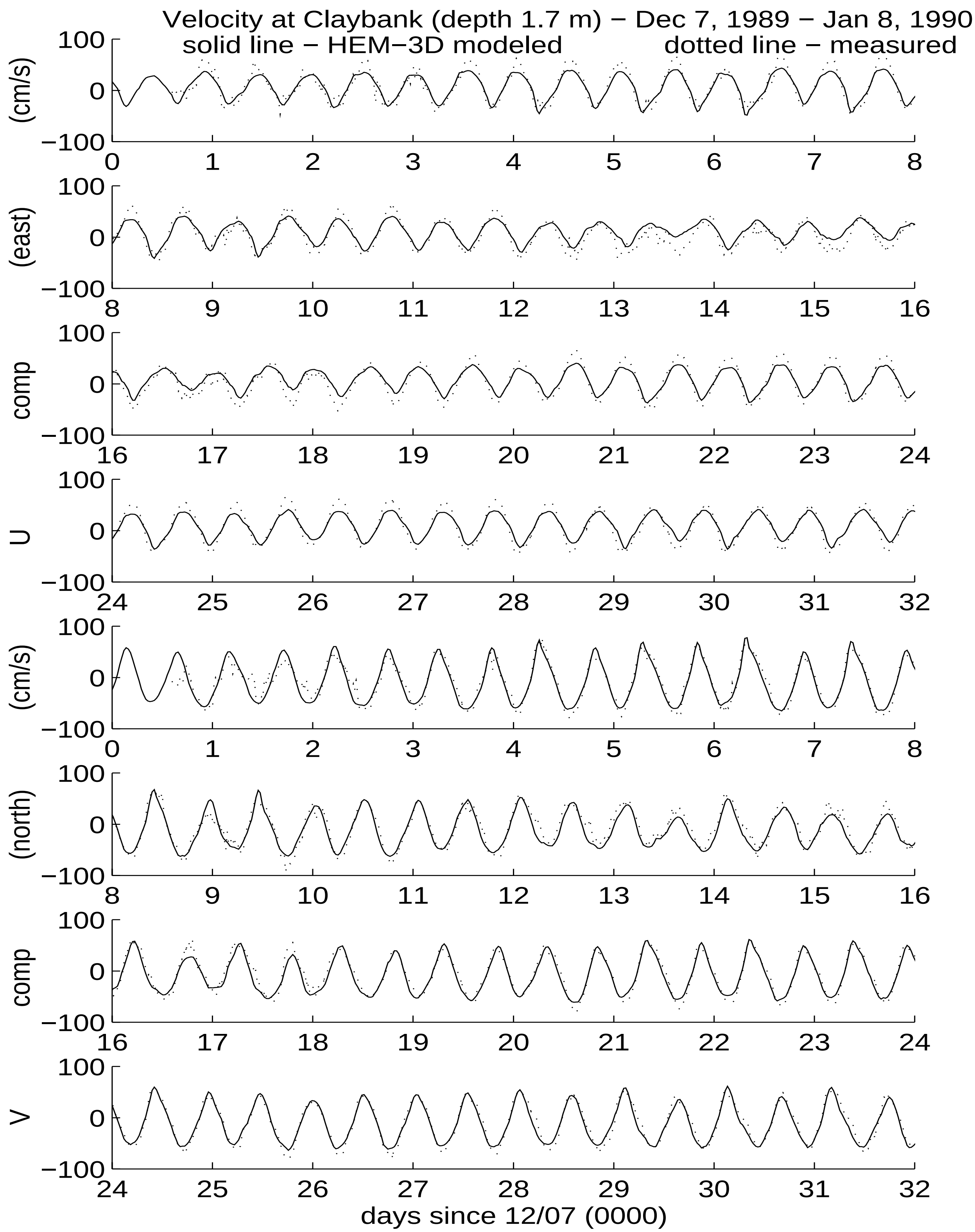


Figure 23. Comparison of observed velocity against HEM-3D predictions at 1.7 meters depth at Claybank, 12/07/89-01/08/90.

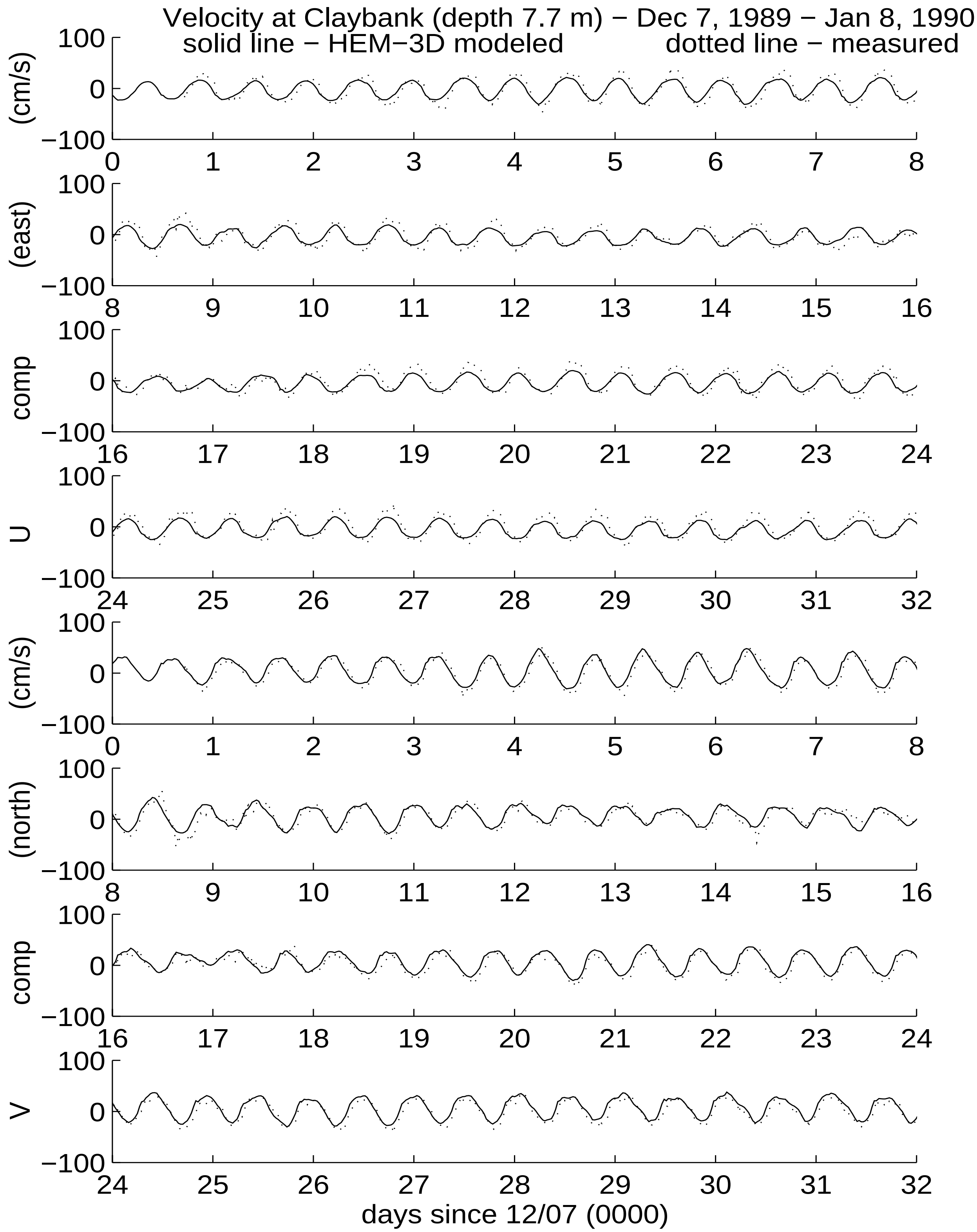


Figure 24. Comparison of observed velocity against HEM-3D predictions at 7.7 meters depth at Claybank, 12/07/89-01/08/90.

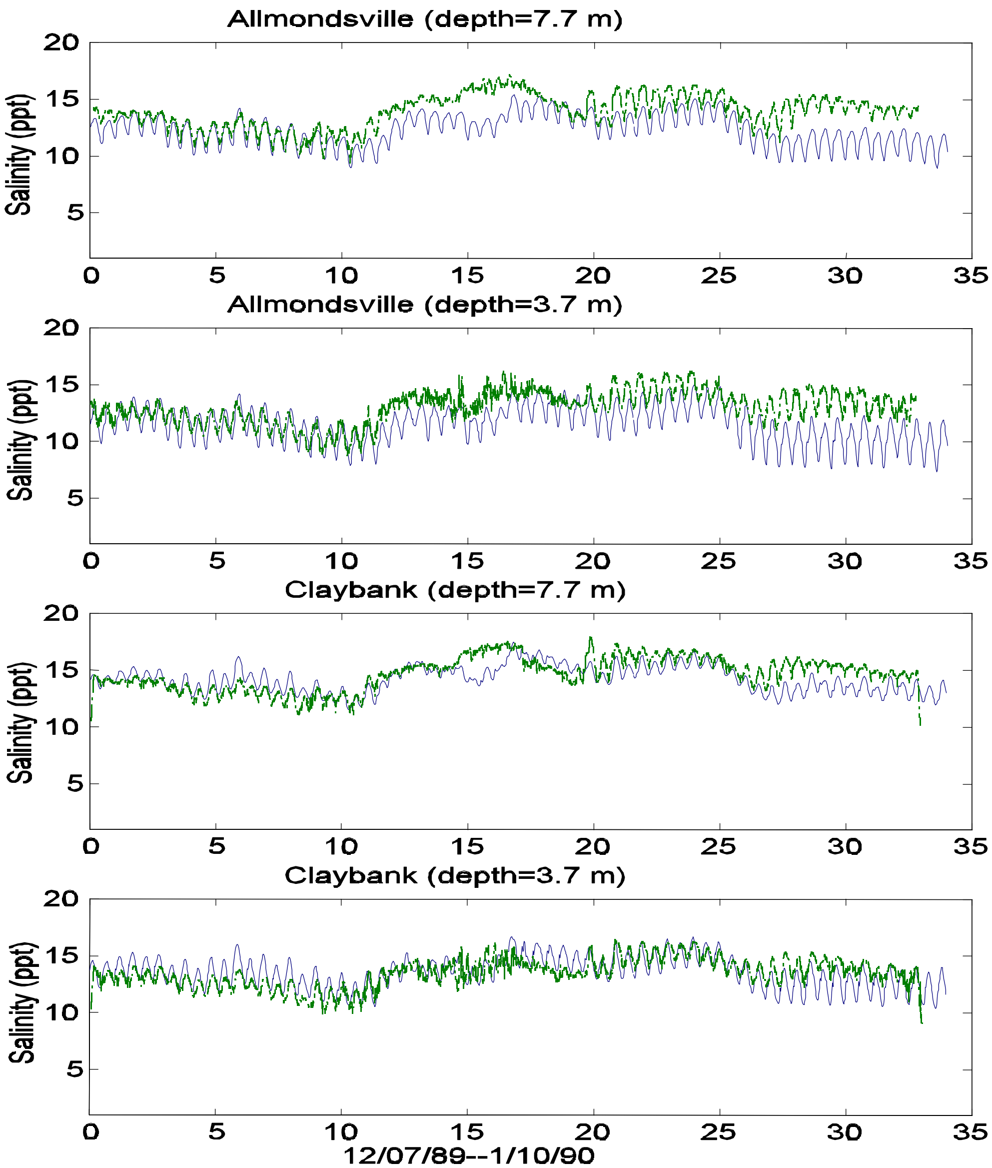


Figure 25. Comparison of observed salinities (dotted line) against HEM-3D predictions at both 3.7 meters depth at both Claybank and Allmondsville, 12/07/89-01/10/90.

Parameter (units)	Station	Depth	Report Figure #	Mean difference	Mean Abs. Diff.	Root mean square Difference
Tidal height (m)	West Point		20	0.0037	0.0370	0.0444
Tidal height (m)	Belleview		20	0.0161	0.0441	0.0489
Tidal height (m)	Sweet Hall		20	0.0309	0.0608	0.0668
Salinity (ppt)	Allmondsville	3.7 m	25	-0.493	0.779	1.012
Salinity (ppt)	Allmondsville	7.7 m	25	0.671	0.949	1.277
Salinity (ppt)	Claybank	3.7 m	25	-0.115	0.671	0.842
Salinity (ppt)	Claybank	7.7 m	25	0.348	0.795	1.024
Velocity (cm/s) East component	Allmondsville	3.7 m	21	2.59	14.07	16.53
Velocity (cm/s) East component	Allmondsville	7.7 m	22	2.63	7.34	9.35
Velocity (cm/s) East component	Claybank	1.7 m	23	2.39	12.46	15.56
Velocity (cm/s) East component	Claybank	7.7 m	24	-3.11	8.99	12.71
Velocity (cm/s) North component	Allmondsville	3.7 m	21	-2.08	9.65	11.86
Velocity (cm/s) North component	Allmondsville	7.7 m	22	1.51	6.36	8.13
Velocity (cm/s) North component	Claybank	1.7 m	23	-1.98	10.53	14.68
Velocity (cm/s) North component	Claybank	7.7 m	24	4.42	7.76	10.18
Resultant (cm/s)	Allmondsville	3.7 m	21	3.24	11.89	14.28
Resultant (cm/s)	Allmondsville	7.7 m	22	0.39	8.76	11.71
Resultant (cm/s)	Claybank	1.7 m	23	2.34	12.54	17.33
Resultant (cm/s)	Claybank	7.7 m	24	-6.52	11.06	15.77

Table 10. Mean, mean absolute, and root-mean-square differences between time series of observed data and HEM-3D predictions.

VI. Summary and Conclusions

The comparison of calibrated HEM-3D model output with observational data for the York River system has shown that the model is capable of simulating basic estuarine state variables (fluctuating water surface elevation, current speed and direction, and salinity) with a relatively high degree of accuracy. For surface elevation, the agreement between predicted and observed values is on the order of two to three centimeters allowing for phase-related differences; i.e., differences in the predicted and observed times of high and low water on the order of several minutes. The predicted and observed time series data of current velocities at given locations follow the same general trend even though their differences in values are much larger than those of surface elevation. Since the observed data are point values while model predicted currents are average values over grid cells, the larger differences are expected. Salinity and salinity gradients are well represented, usually within one to three ppt, although both are sensitive to the relevant boundary conditions, especially fresh-water inflow. Our confidence in the simulated data of the HEM-3D model for the York is consistent with the confidence one normally places in a sampled representation of the system, a representation which commonly includes both systematic and random errors in both sampling and temporal-spatial interpolation.

The use of a three-dimensional estuarine model affords greater objectivity, compared to one- and two-dimensional models, in the simulation and display of scalar and vector quantities. In terms of practical applications such as those involving resource management, properly validated models of this kind afford greater opportunity to convey critical information by visual means.

Computer graphics applications capable of yielding 3D perspective views would seem to be ideal for this purpose but unfortunately most routines that we have tried have failed to live up to our expectations. Instead, we have relied upon innovative graphical representations that utilize two spatial dimensions (i.e., longitudinal-vertical, cross-sectional or plan-view sections or “slices”) and one temporal dimension (time units) through computer animation or “movies”. This approach appears well-suited to management applications because the use of high-resolution, color graphics on personal computers is now widespread and offers rapid, world-wide distribution through the Internet.

An example of the longitudinal-vertical representation of the model-generated salinity field in the York River is shown in figure 26. Note that this figure contains four time-slices aligned with the indicated tidal history at the mouth of the York. Each section is a mid-channel, longitudinal slice, not a lateral average, of the salinity field. Many other representations of scalar and vector quantities are possible. Figure 27 illustrates two time-distance plots of scalar quantities. The color-enhanced contours of the vertical mean salinity (figure 27a), shown from the mouth of the York to West Point, provides an excellent means of visualizing the limit of salt water intrusion as it varies for a specific time history in the upper York. As a companion visual to convey what is lost in vertical averaging of the salinity field (i.e., stratification), the potential energy needed to mix the water column (figure 27b) can be calculated and used as an indicator of the degree of stratification through a section of time and space.

York River Salinity Distribution

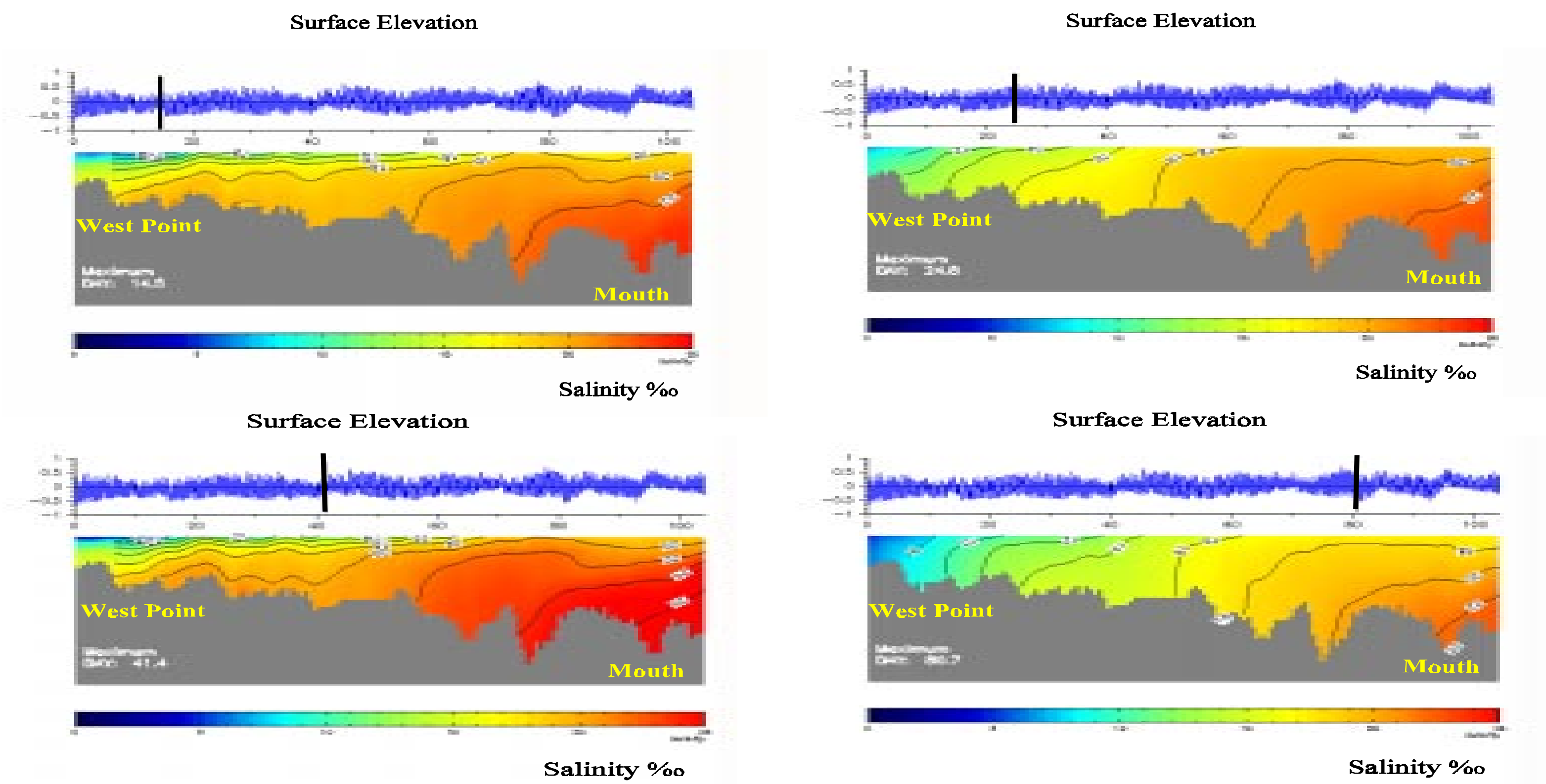


Figure 26. An example of the longitudinal representation of the model-generated salinity field in the York River.

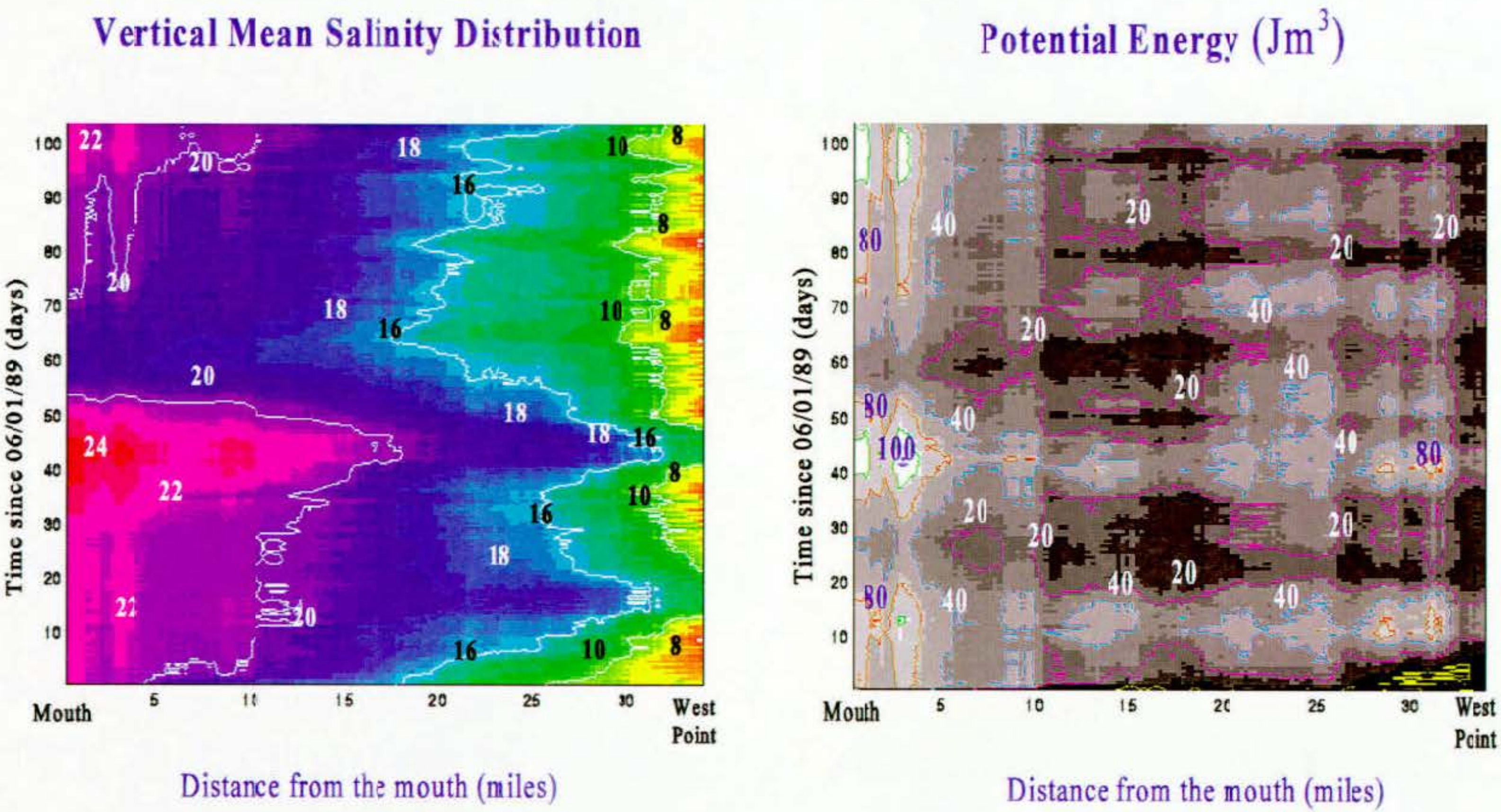


Figure 27. a) Color-enhanced contours of the vertical mean salinity, shown from the mouth of the York to West Point (a means of visualizing the limit of salt water intrusion).
b) The potential energy needed to mix the water column (used as an indicator for the degree of stratification).

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Appendix A. Time series of tidal elevations at Gloucester Point (1986 - 1993) and at locations of VIMS gauge deployments.

Gauge data time series used for model calibration are presented in this appendix.

Hourly tidal heights at Gloucester Point are plotted for 1986 - 1993 against Julian hour since the beginning of the respective year in figs. A.1-A.8. Semidiurnal and spring/neap cycles are evident in all eight figures. Linear segments such as that in fig. A.4 extending from 7690-8100 hours indicate missing data.

Available time series of hourly tidal heights at other stations along the York River system are plotted against Julian hour (since the beginning of the year in which the record begins) in figs. A.9-A.20. Reference datums for these stations are not known. Synoptic tidal heights at Gloucester Point are also plotted for comparison. As in the previous plots, linear segments indicate missing data. In addition, sections where the data go off-scale are indicative of instrument problems.

Lastly, tidal elevations recorded at 3 Mattaponi locations (the Indian Reservation, Walkerton, and Aylett) during the period from August 1996 to May 1997 are plotted in fig. A.21-A.23.

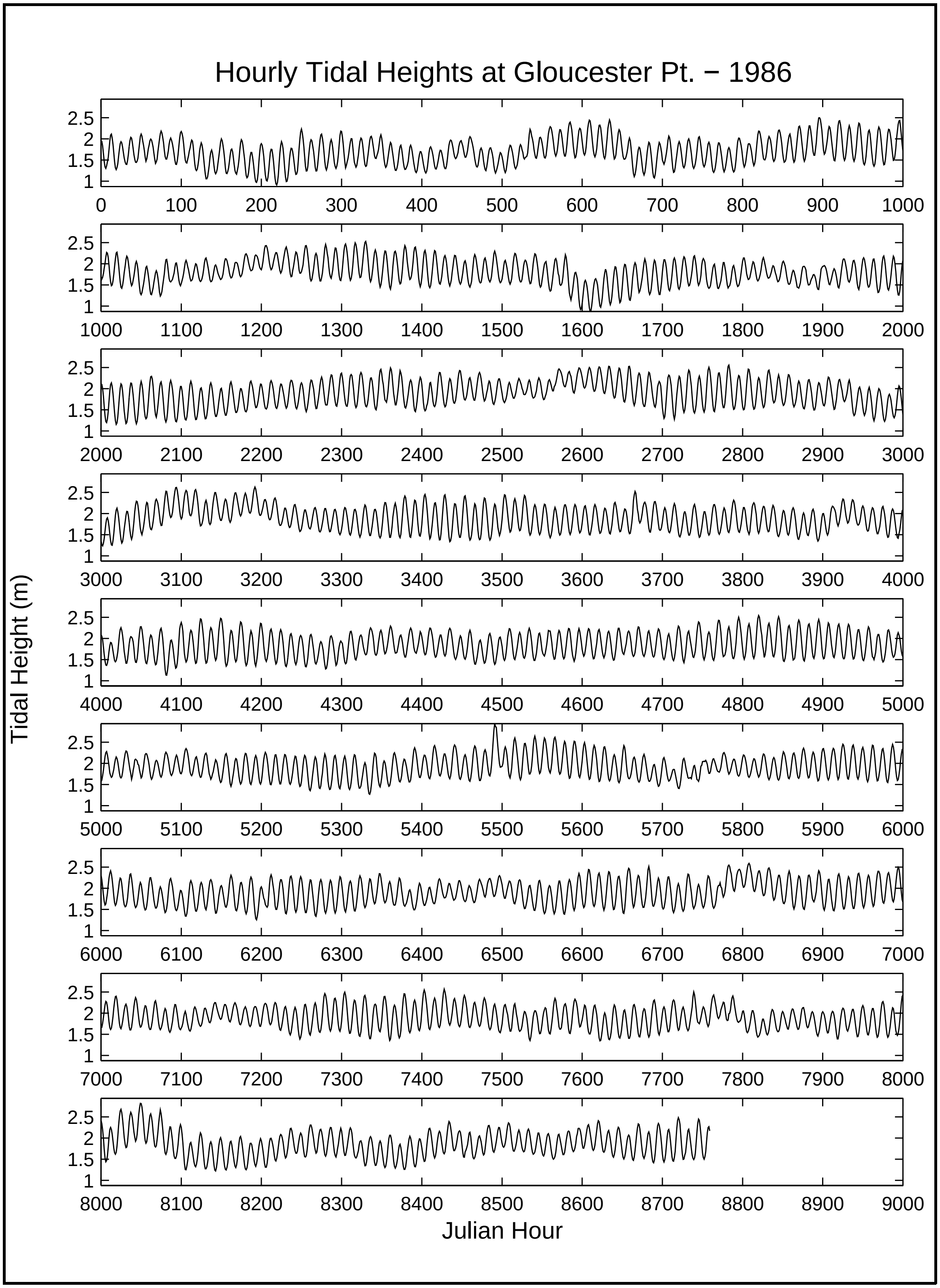


Figure A.1 Hourly surface elevation record from gauge data at Gloucester Point during 1986.

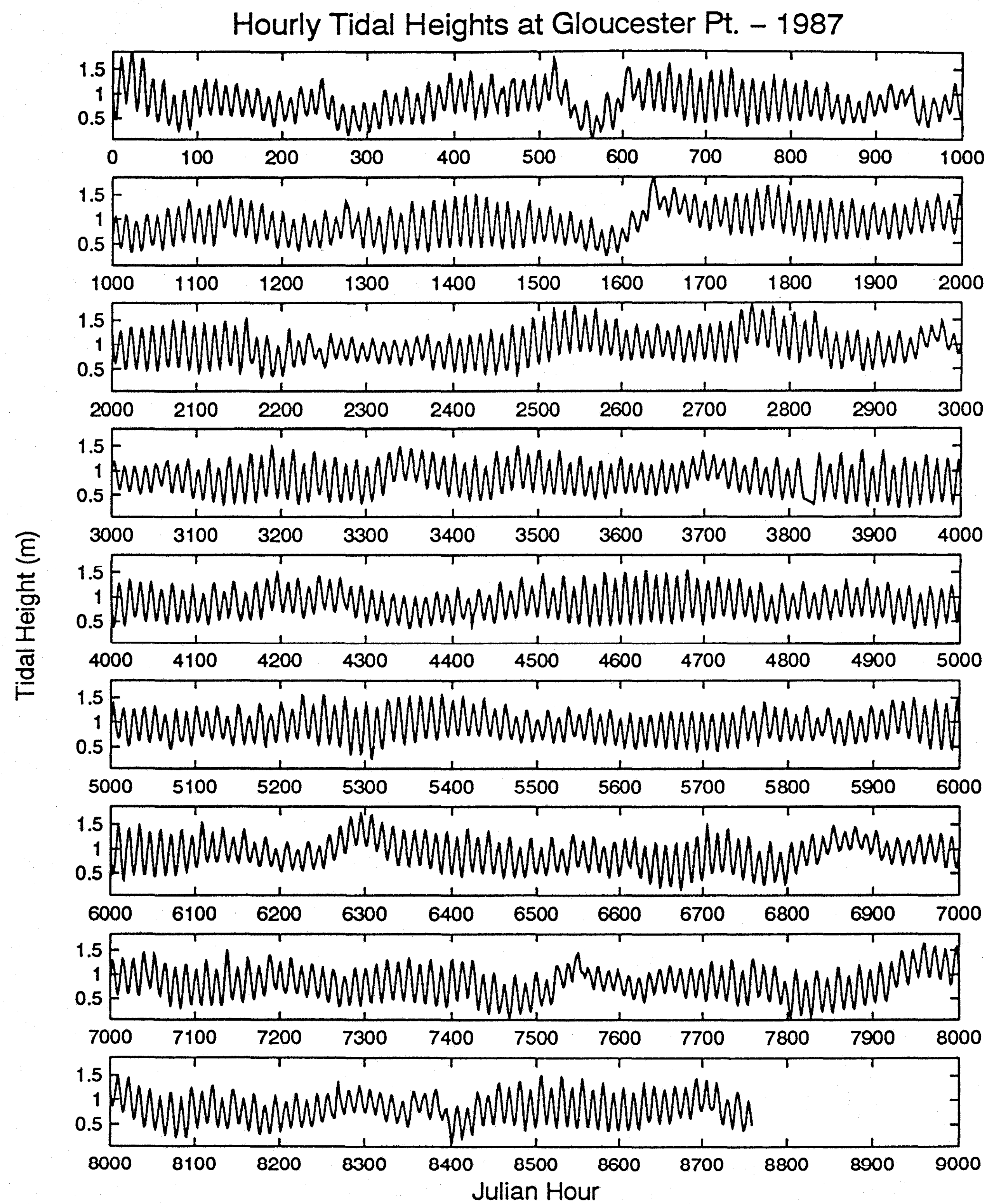


Figure A.2 Hourly surface elevation record from guage data at Gloucester Point during 1987.

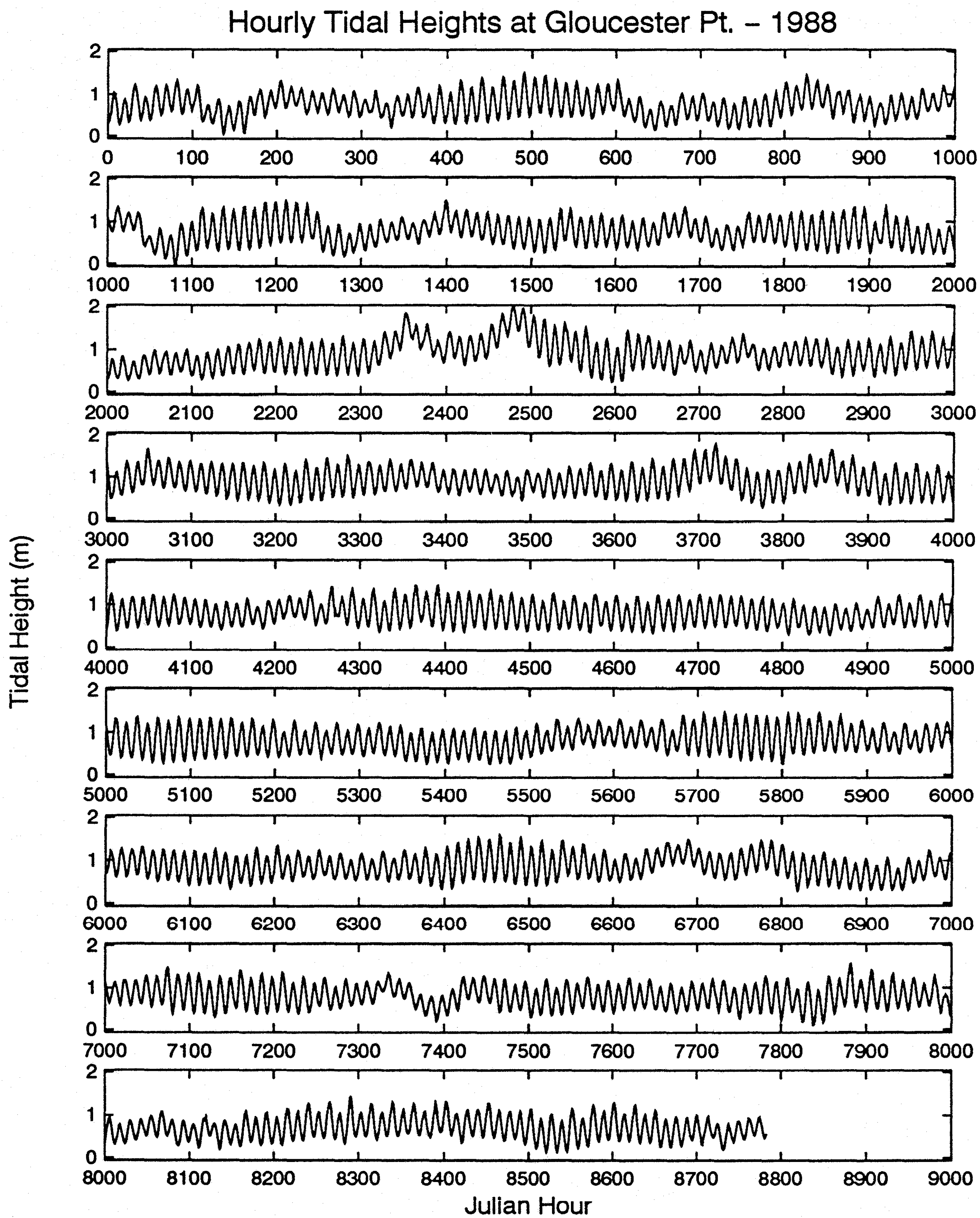


Figure A.3 Hourly surface elevation record from guage data at Gloucester Point during 1988.

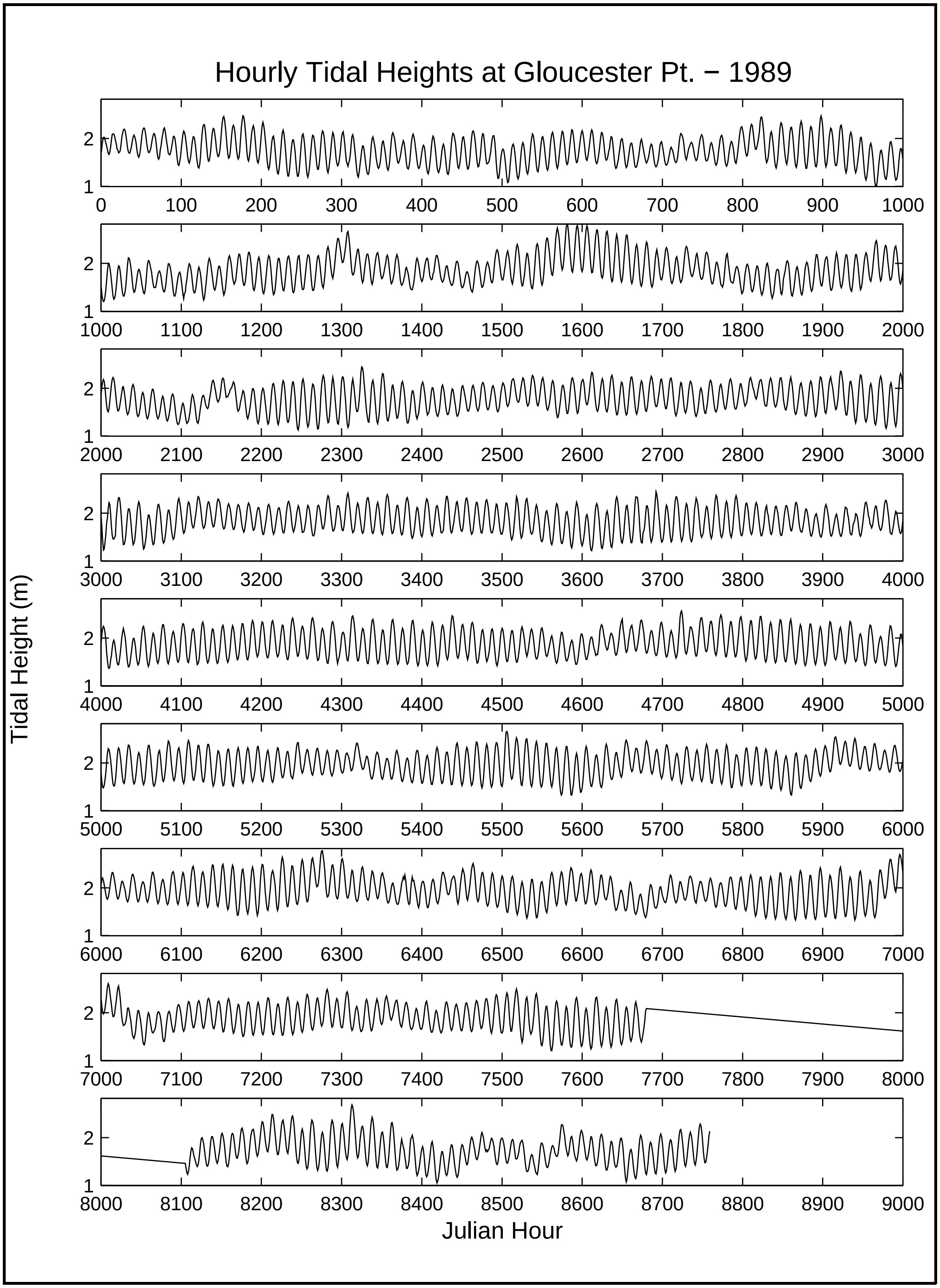


Figure A.4 Hourly surface elevation record from gauge data at Gloucester Point during 1989.

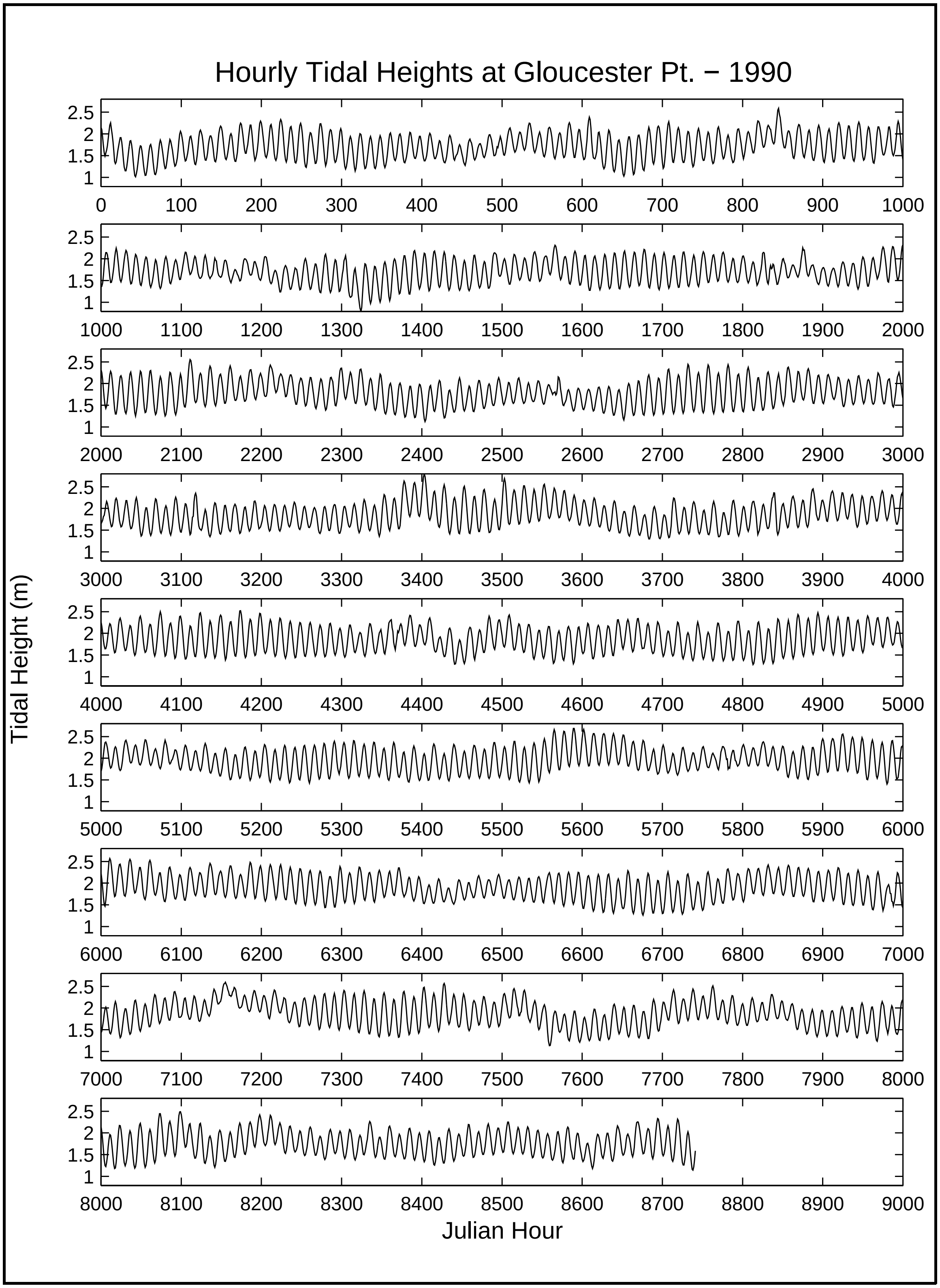


Figure A.5 Hourly surface elevation record from gauge data at Gloucester Point during 1990.

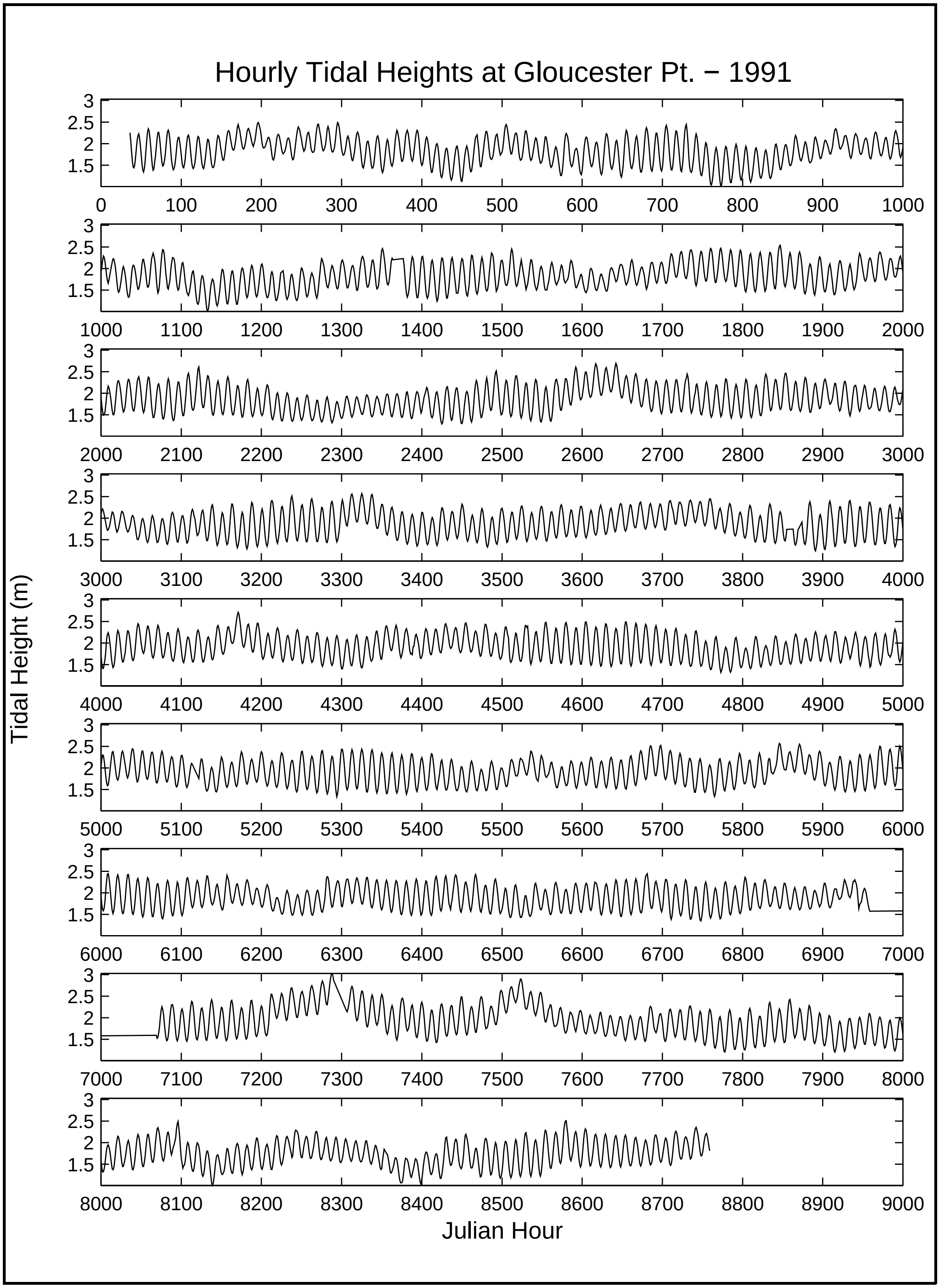


Figure A.6 Hourly surface elevation record from gauge data at Gloucester Point during 1991.

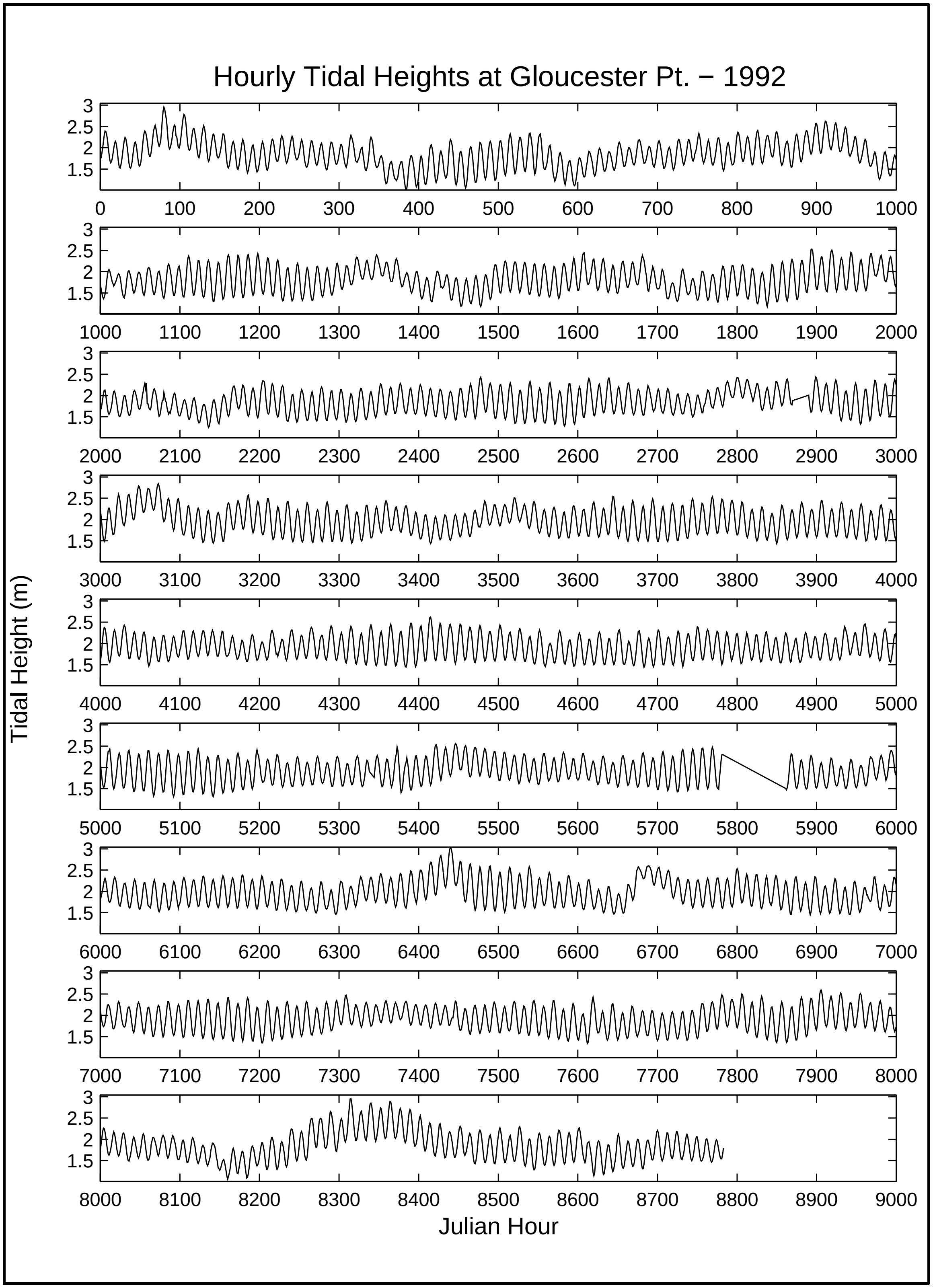


Figure A.7 Hourly surface elevation record from gauge data at Gloucester Point during 1992.

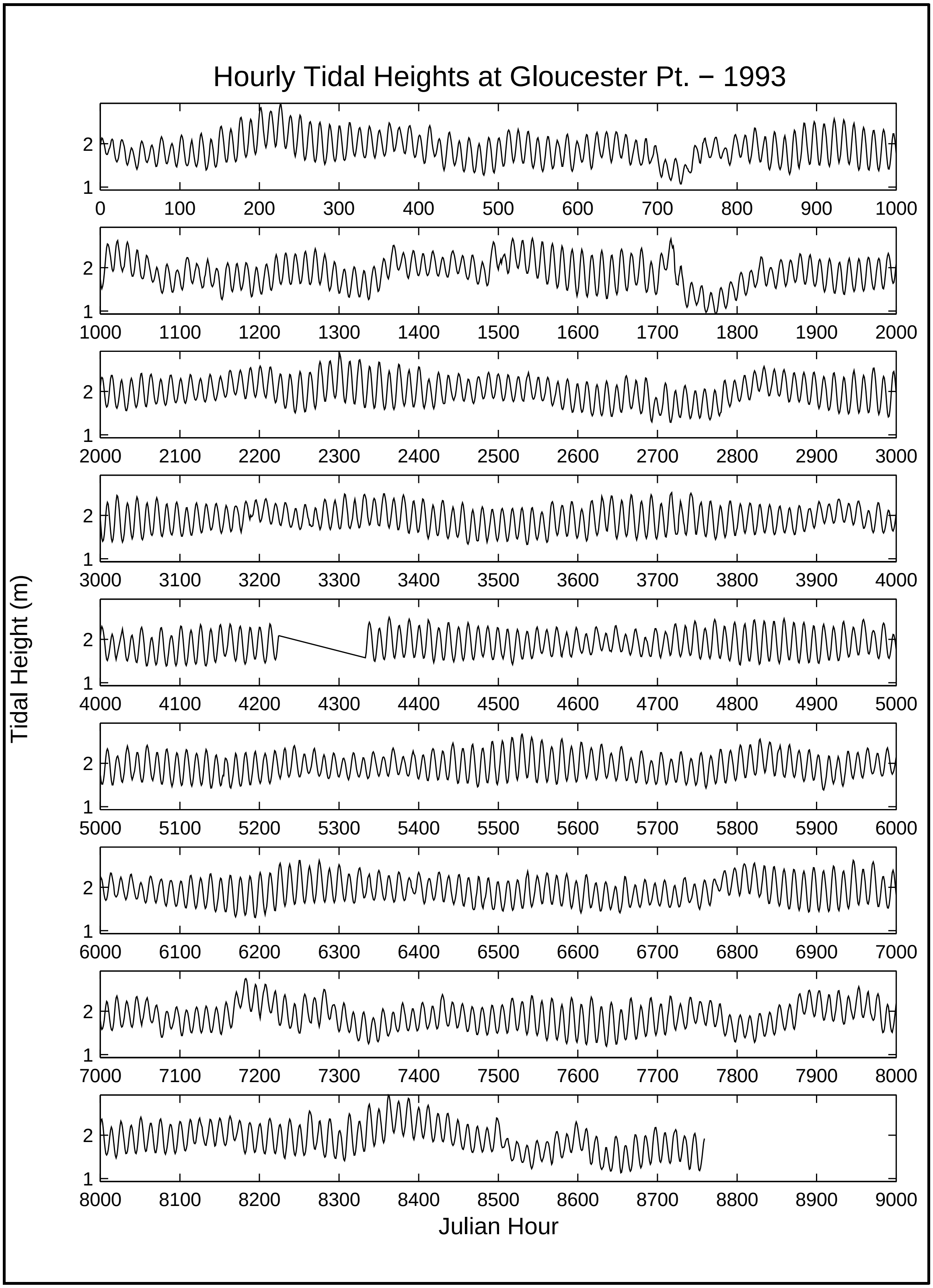


Figure A.8 Hourly surface elevation record from gauge data at Gloucester Point during 1993.

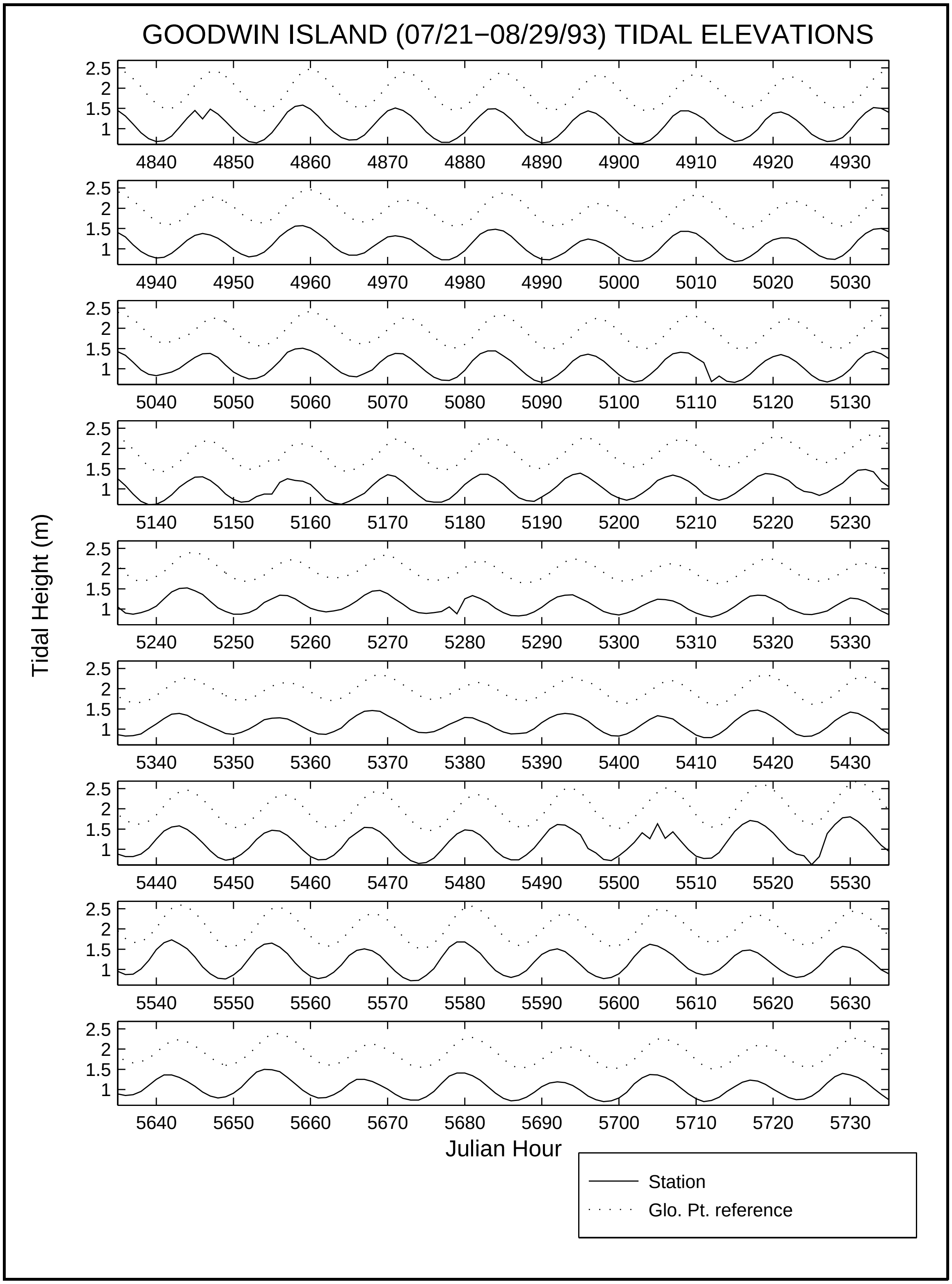


Figure A.9 Comparison of hourly surface elevation records from gauge data (datums unknown) at Goodwin Islands (solid line) and Gloucester Point (dashed line) stations.

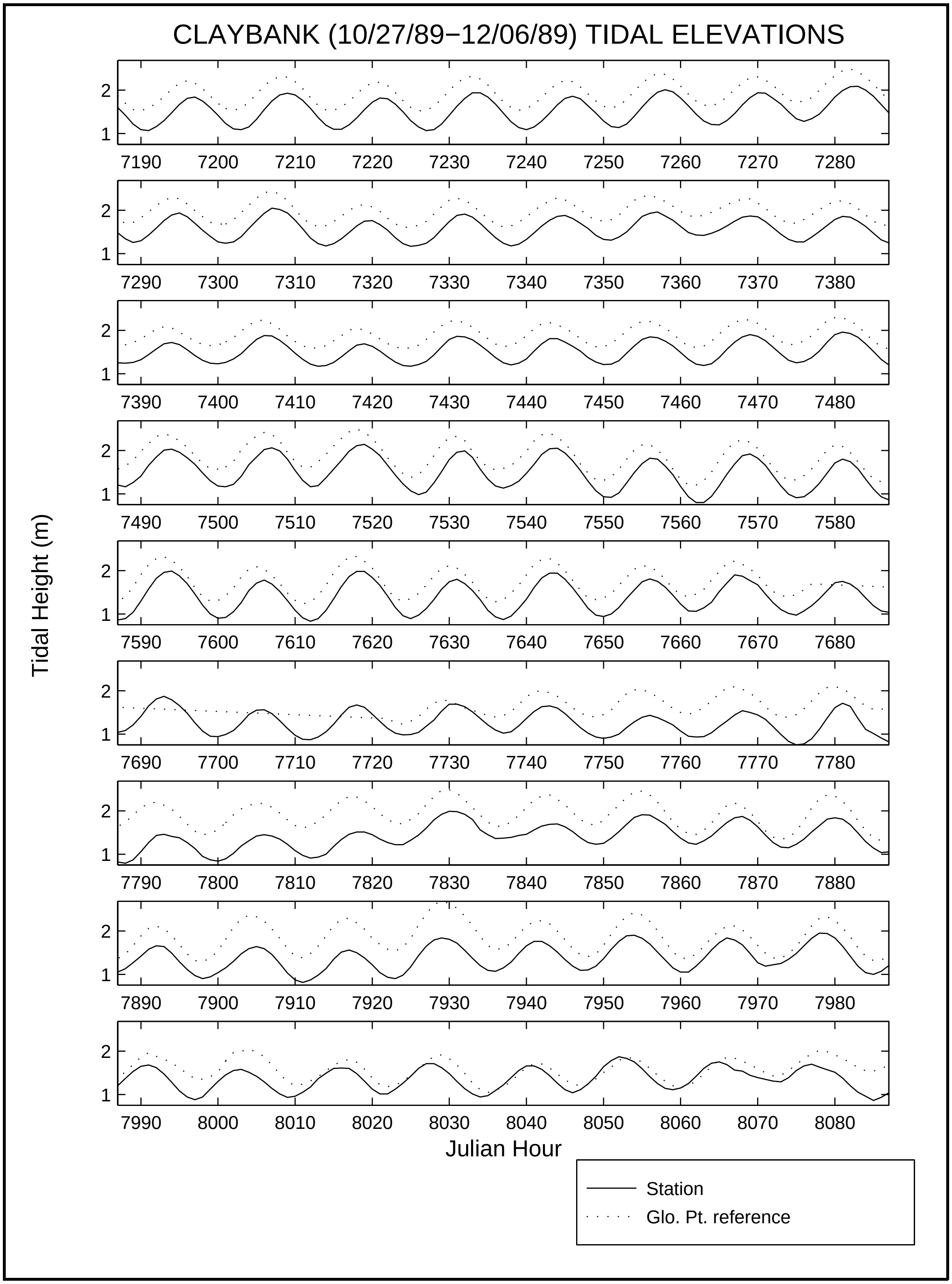


Figure A.10 Comparison of hourly surface elevation records from gauge data (datums unknown) at Clay Bank (solid line) and Gloucester Point (dashed line) stations.

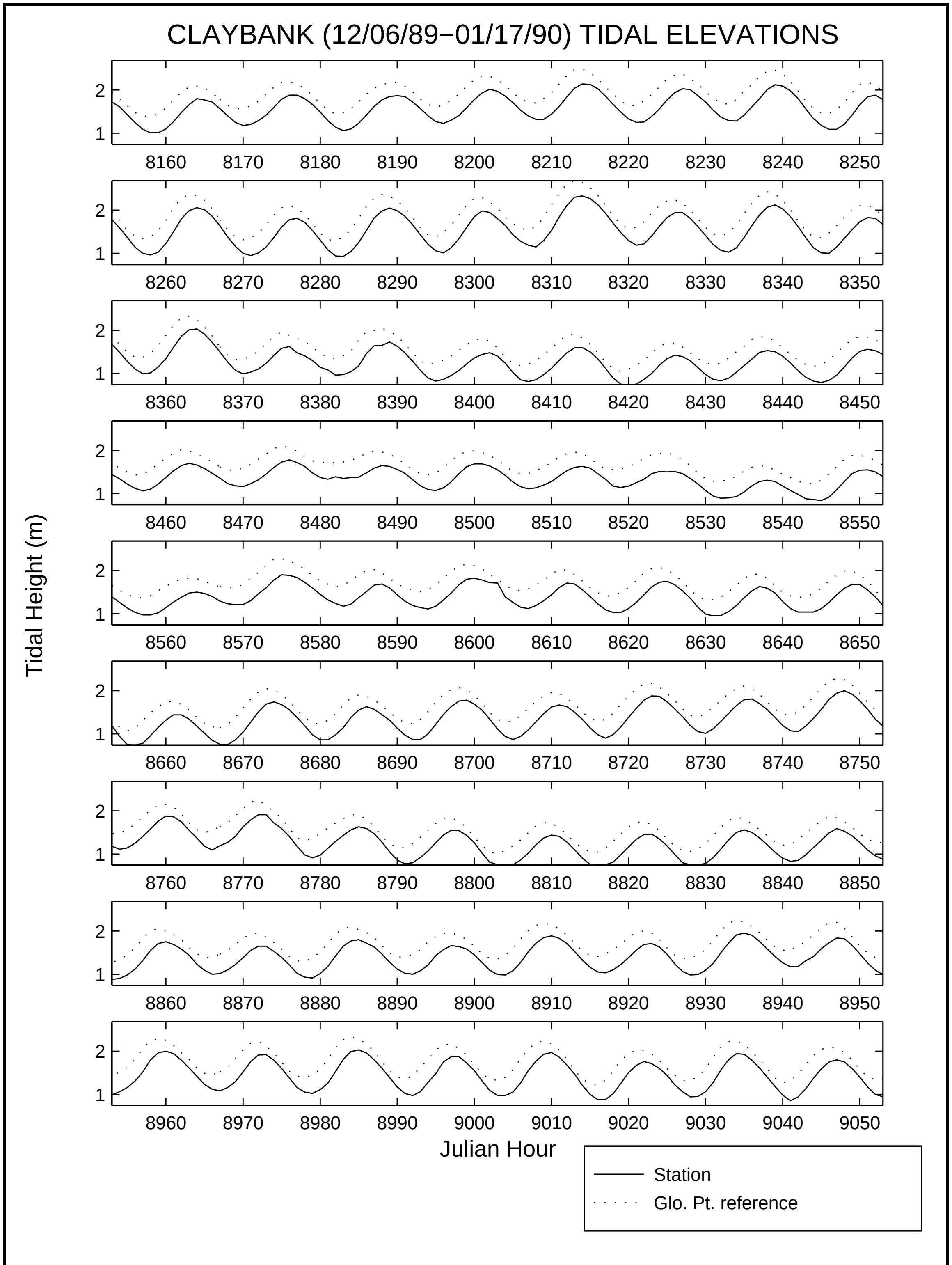


Figure A.11 Comparison of hourly surface elevation records from gauge data (datums unknown) at Clay Bank (solid line) and Gloucester Point (dashed line) stations.

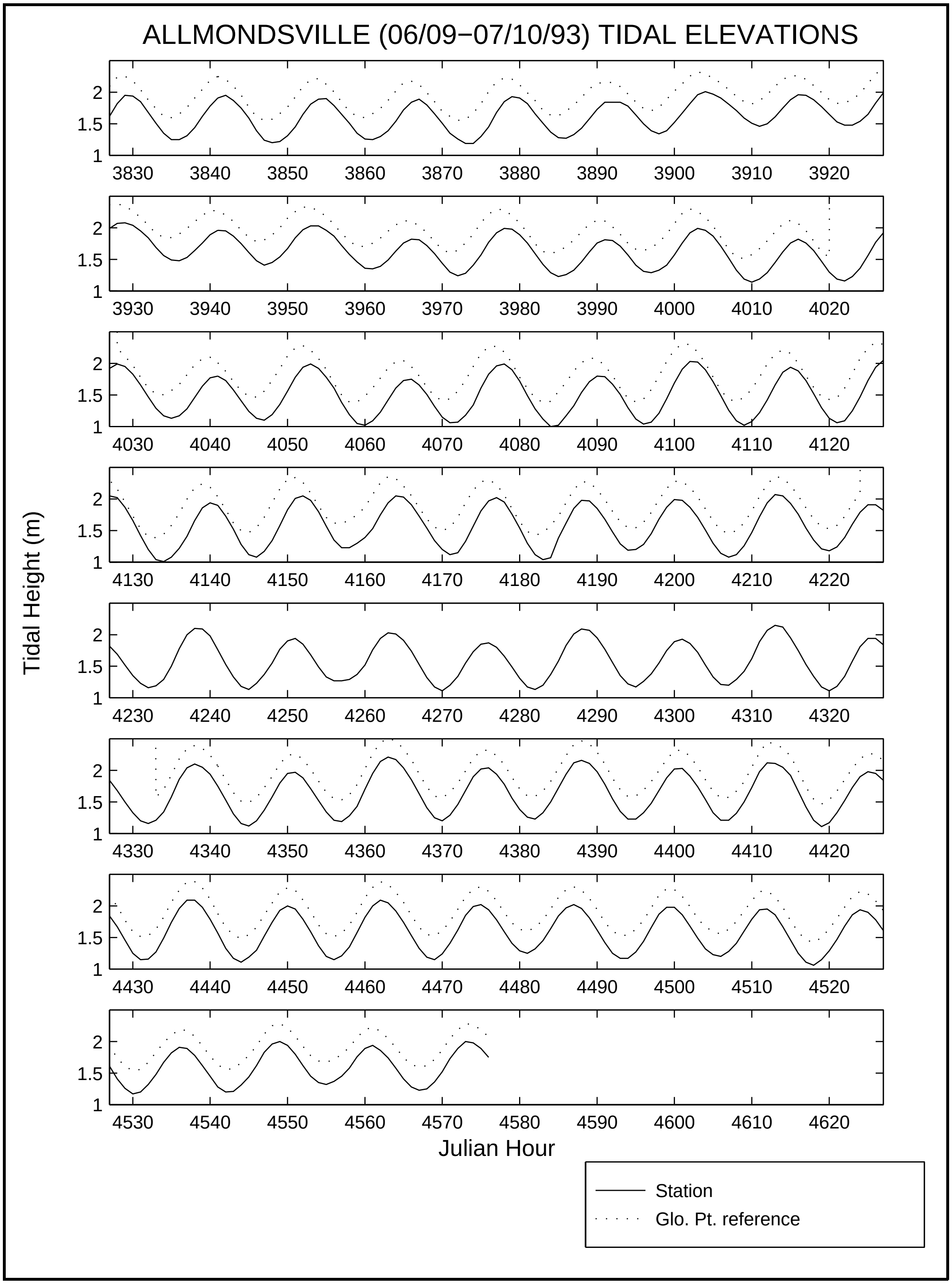


Figure A.12 Comparison of hourly surface elevation records from gauge data (datums unknown) at Allmondsville (solid line) and Gloucester Point (dashed line) stations.

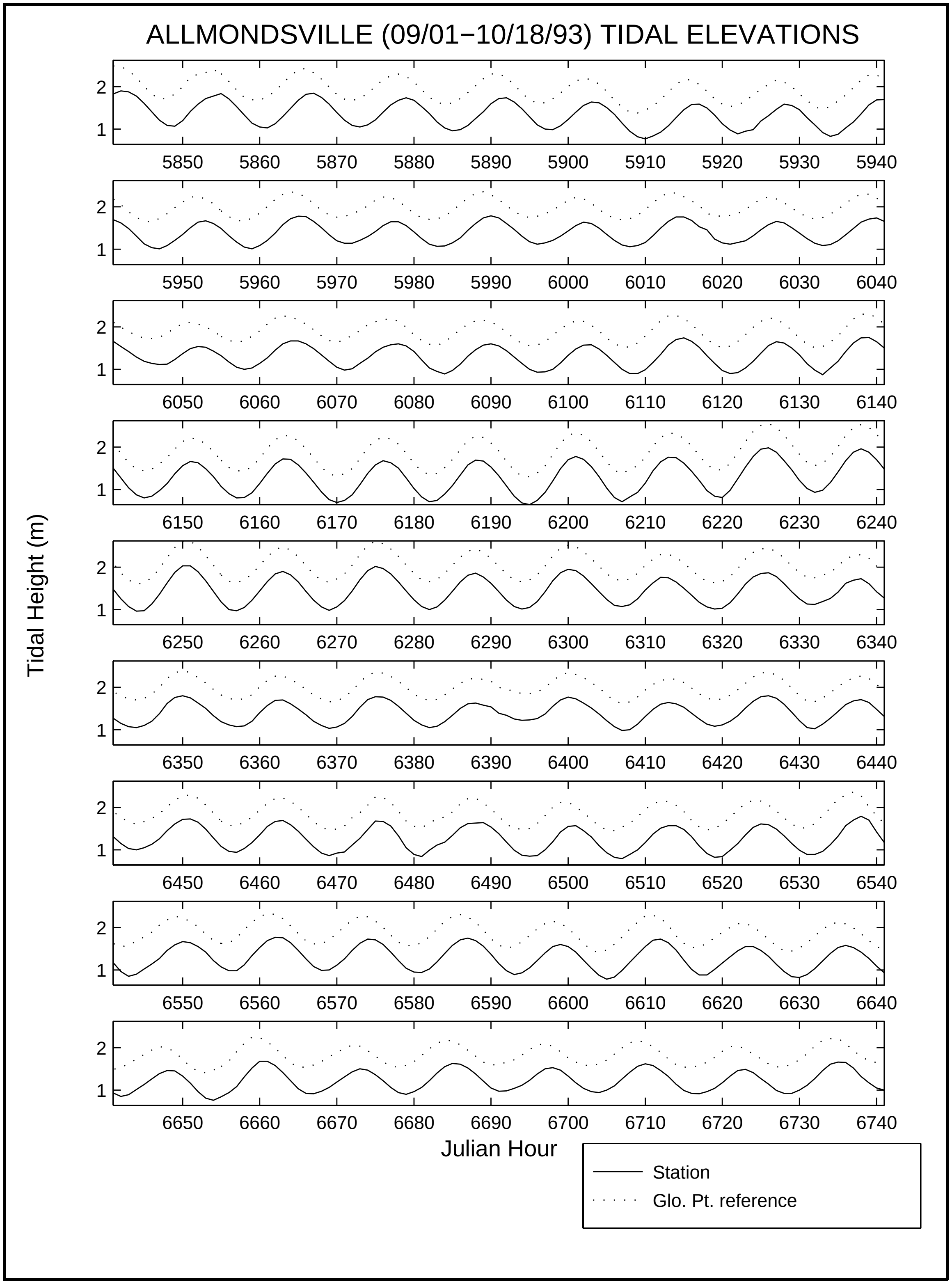


Figure A.13 Comparison of hourly surface elevation records from gauge data (datums unknown) at Allmondsville (solid line) and Gloucester Point (dashed line) stations.

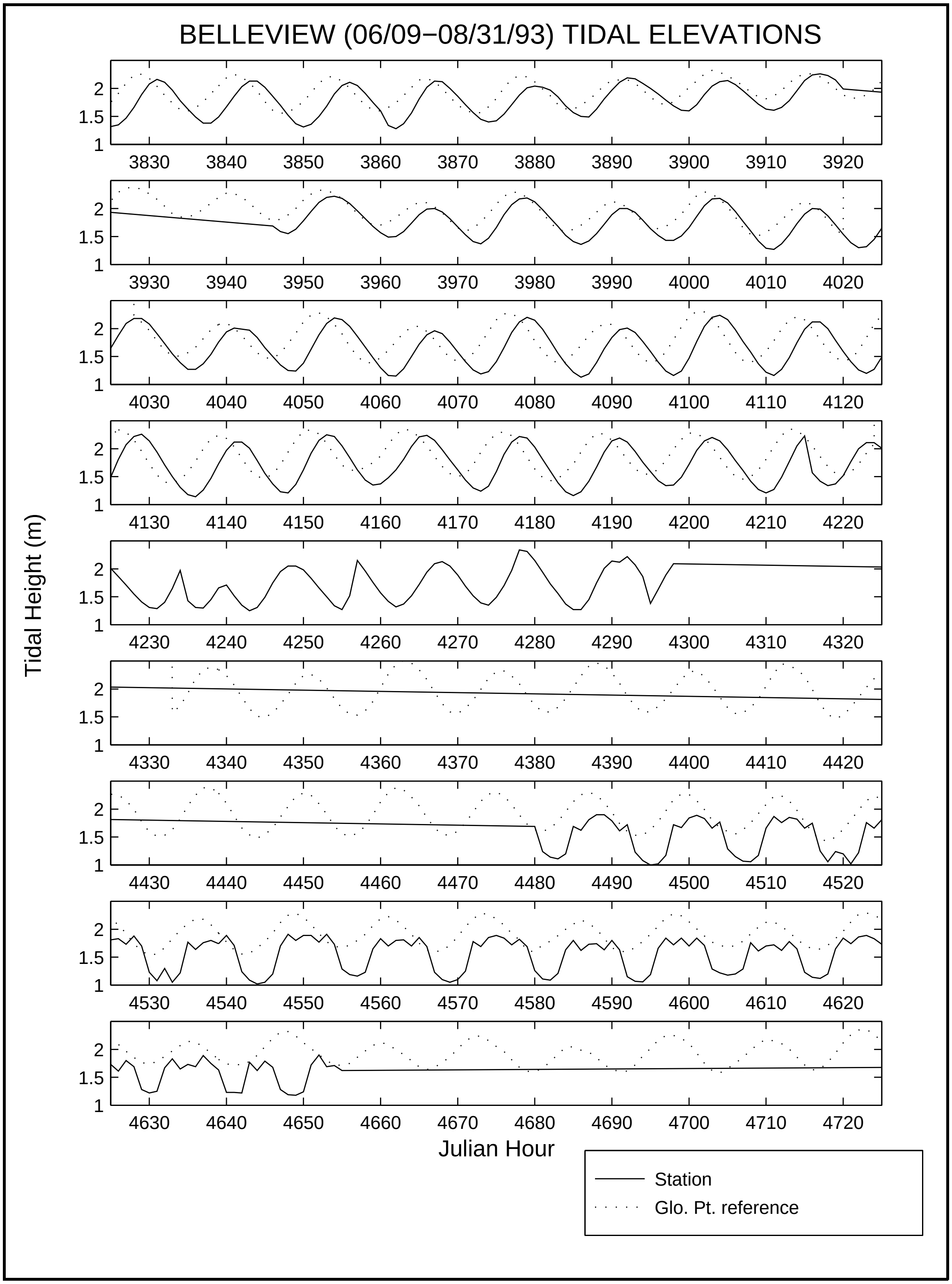


Figure A.14 Comparison of hourly surface elevation records from gauge data (datums unknown) at Belleview (solid line) and Gloucester Point (dashed line) stations.

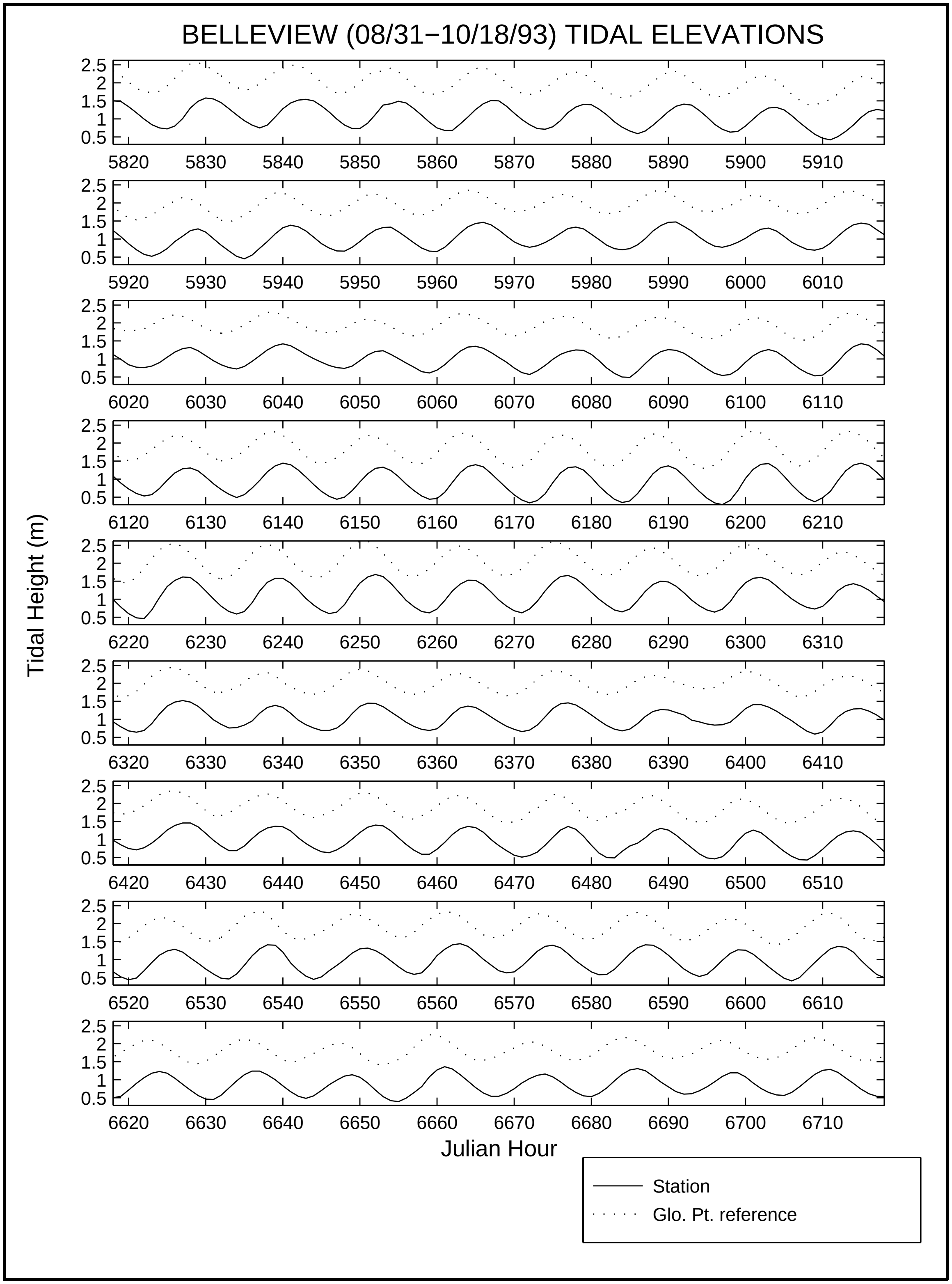


Figure A.15 Comparison of hourly surface elevation records from gauge data (datums unknown) at Belleview (solid line) and Gloucester Point (dashed line) stations.

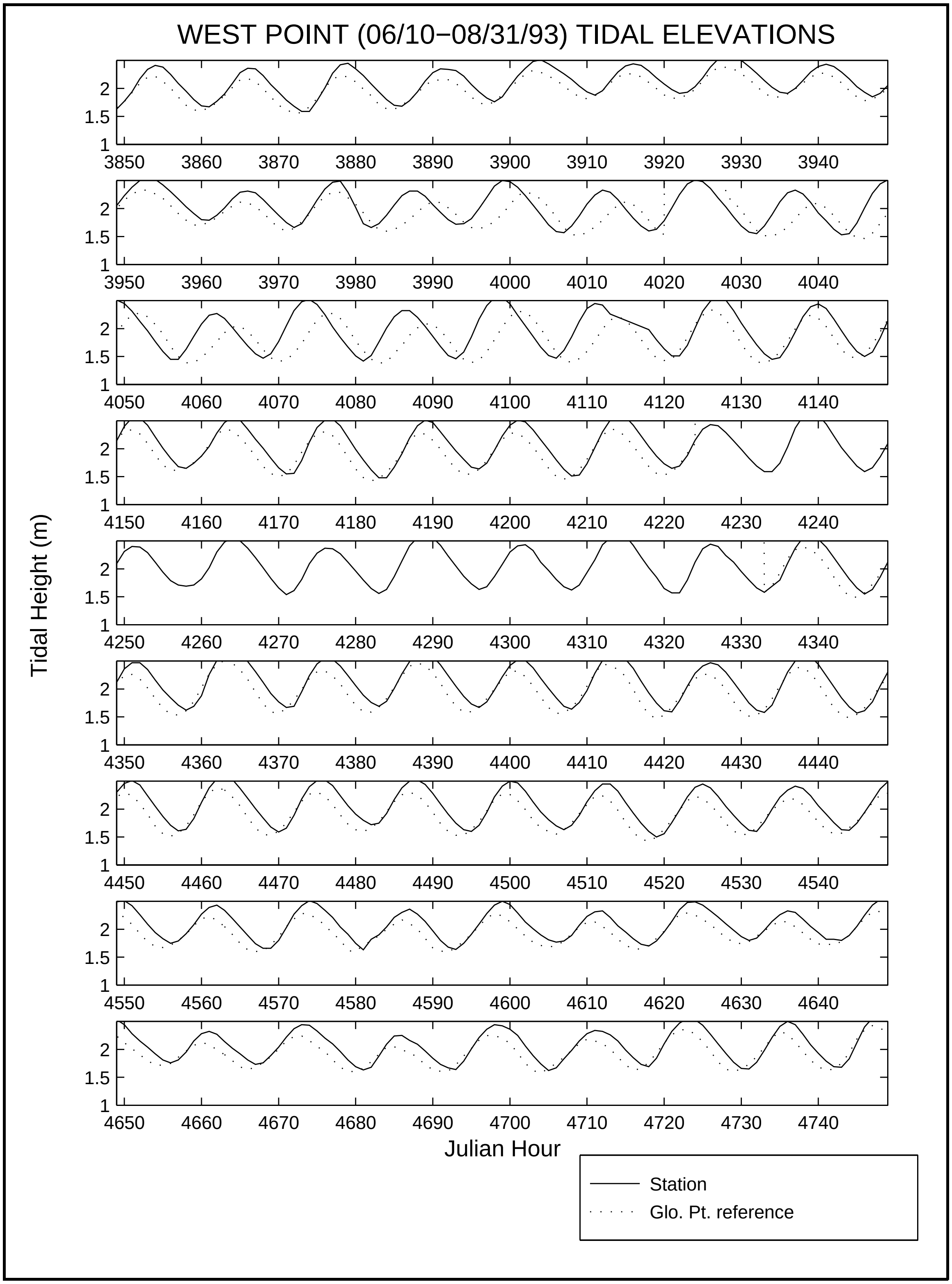


Figure A.16 Comparison of hourly surface elevation records from gauge data (datums unknown) at West Point (solid line) and Gloucester Point (dashed line) stations.

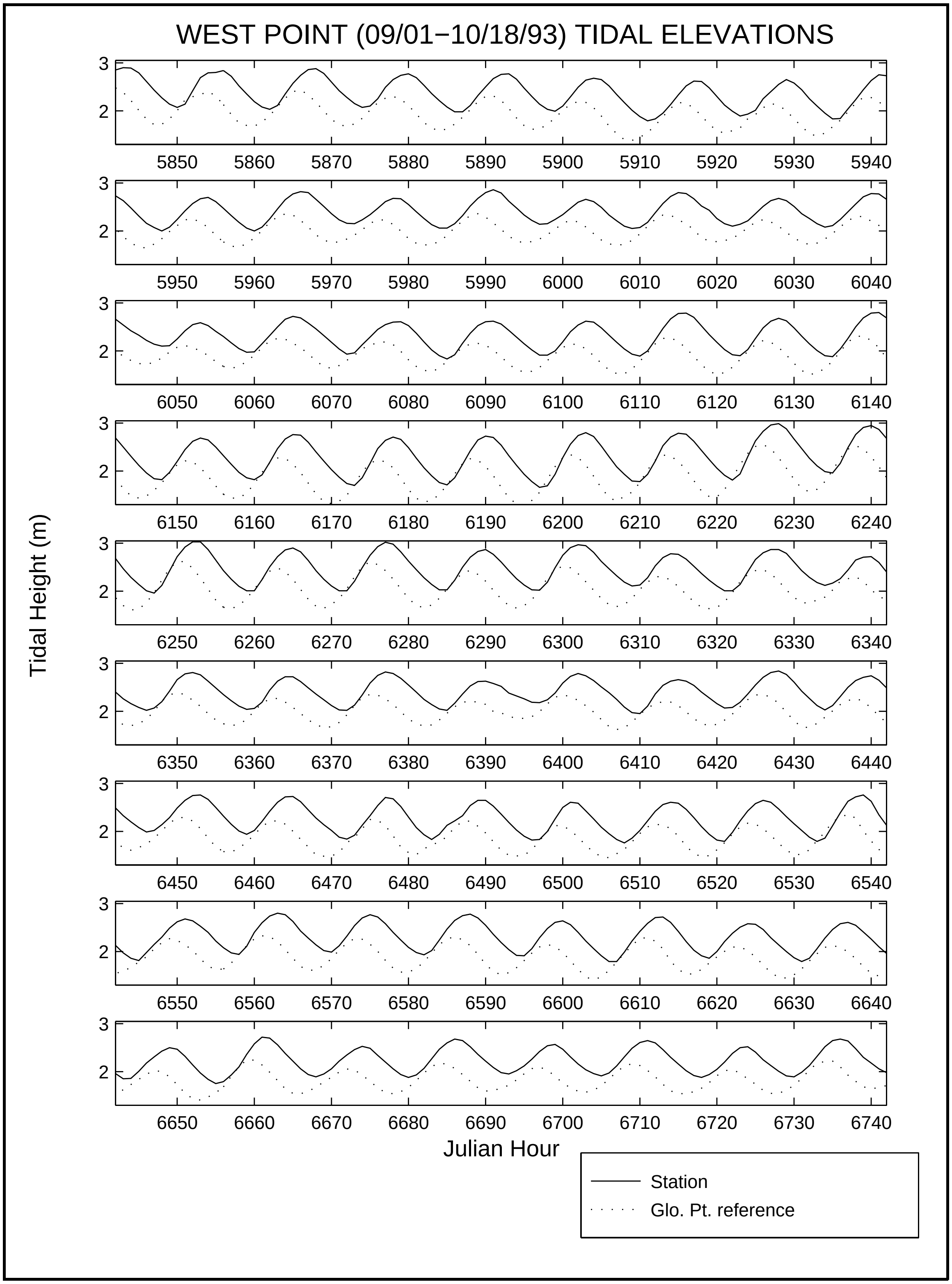


Figure A.17 Comparison of hourly surface elevation records from gauge data (datums unknown) at West Point (solid line) and Gloucester Point (dashed line) stations.

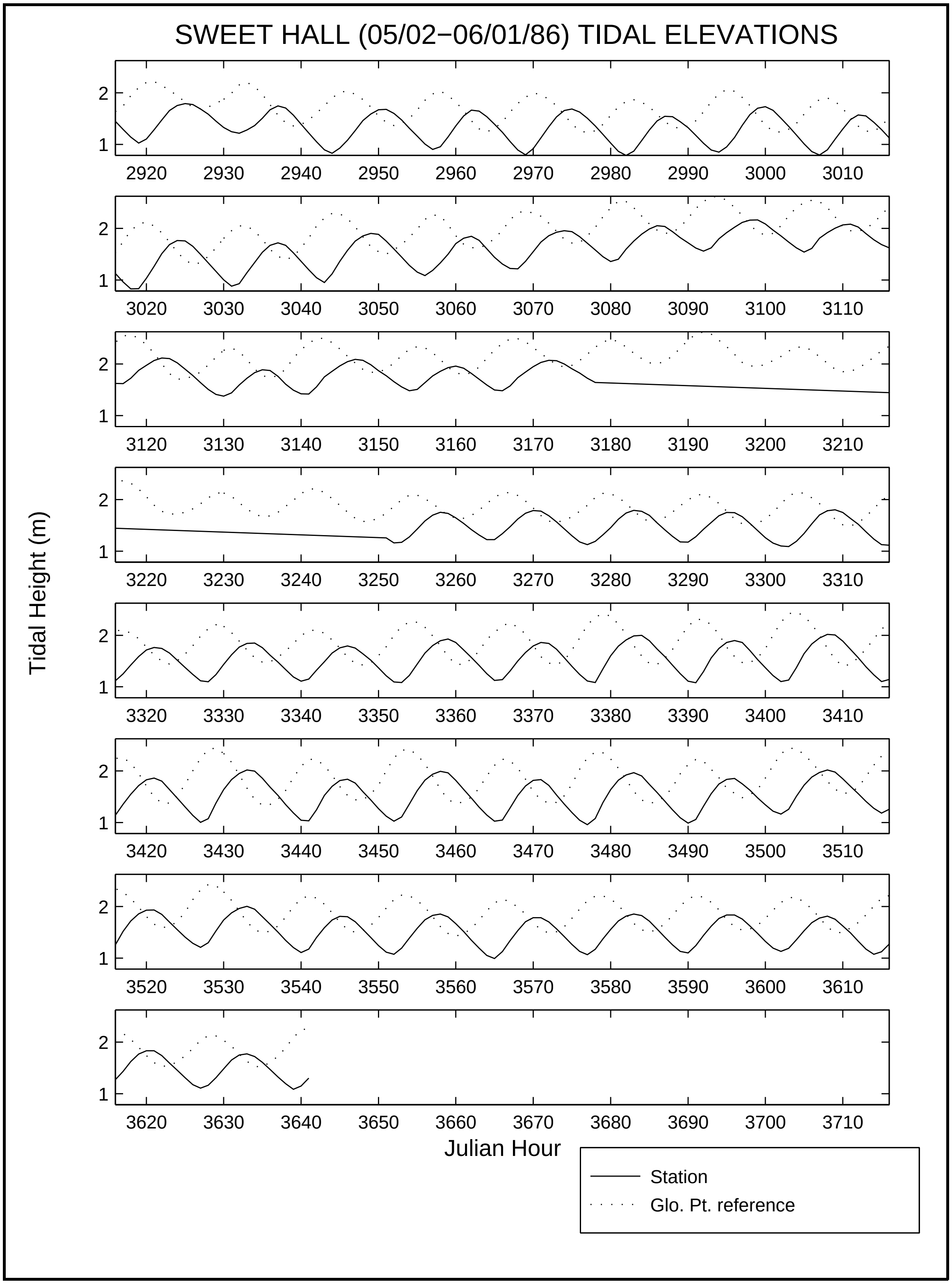


Figure A.18 Comparison of hourly surface elevation records from gauge data (datums unknown) at Sweet Hall (solid line) and Gloucester Point (dashed line) stations.

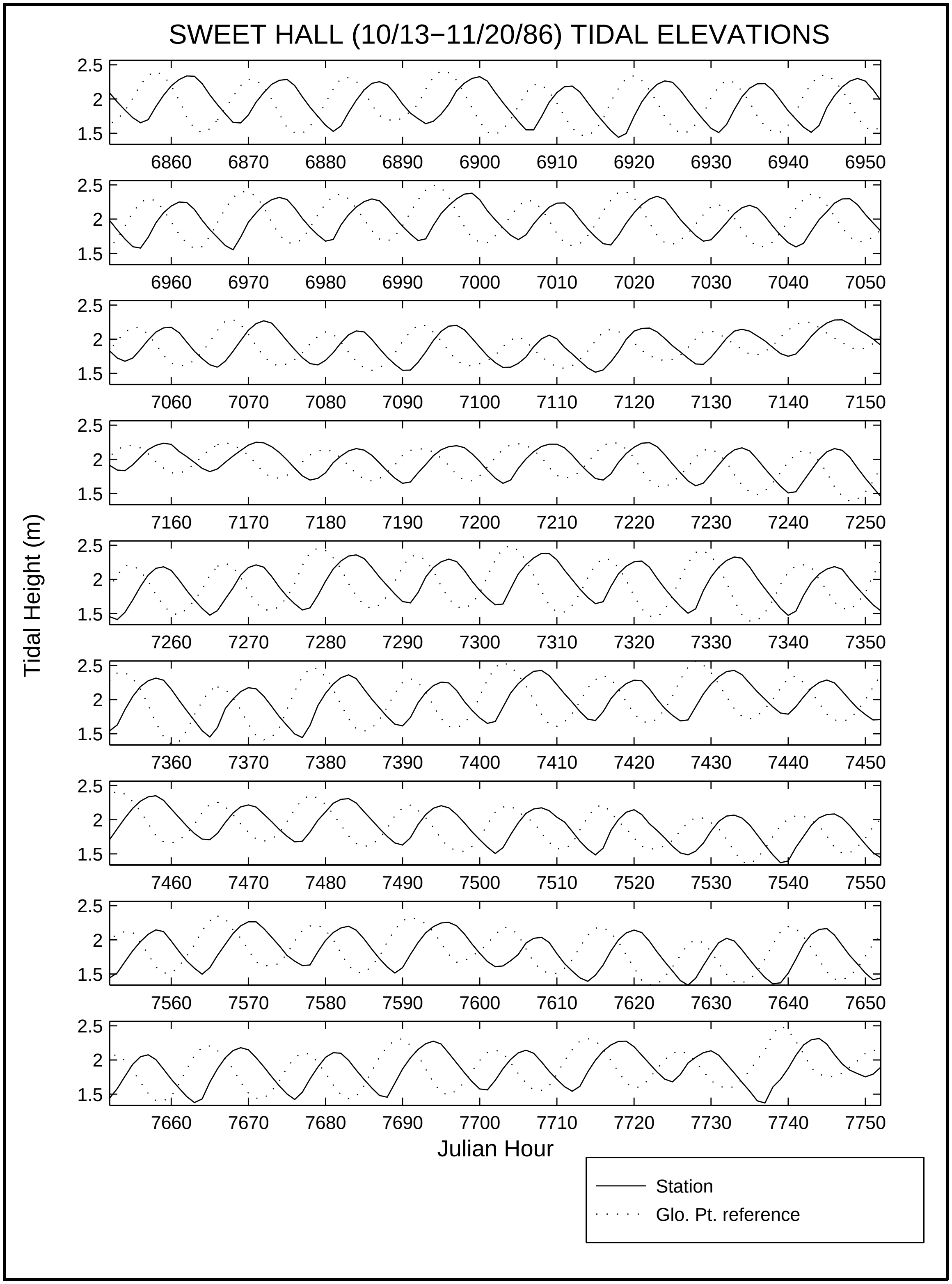


Figure A.19 Comparison of hourly surface elevation records from gauge data (datums unknown) at Sweet Hall (solid line) and Gloucester Point (dashed line) stations.

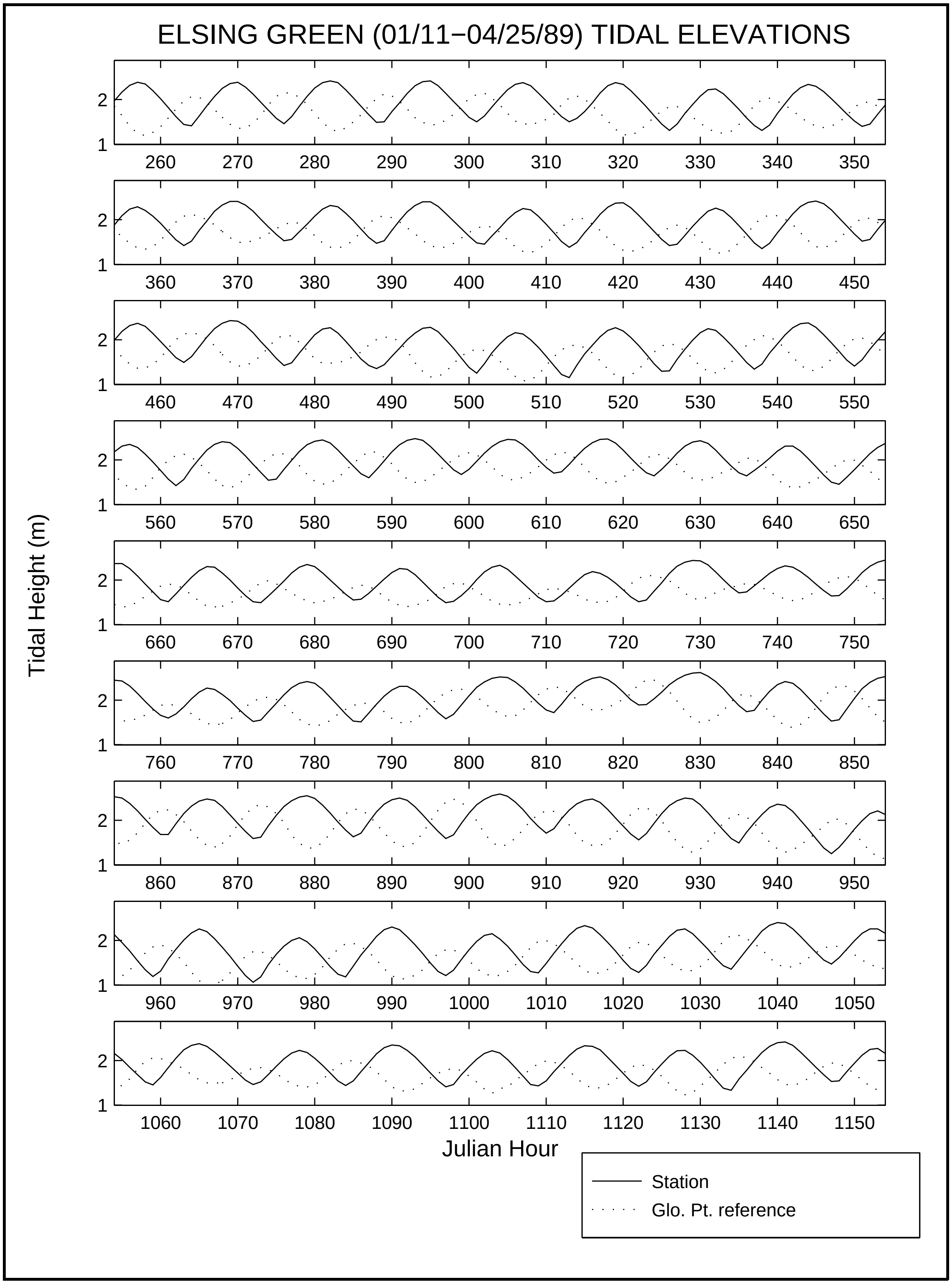


Figure A.20 Comparison of hourly surface elevation records from gauge data (datums unknown) at Elsing Green (solid line) and Gloucester Point (dashed line) stations.

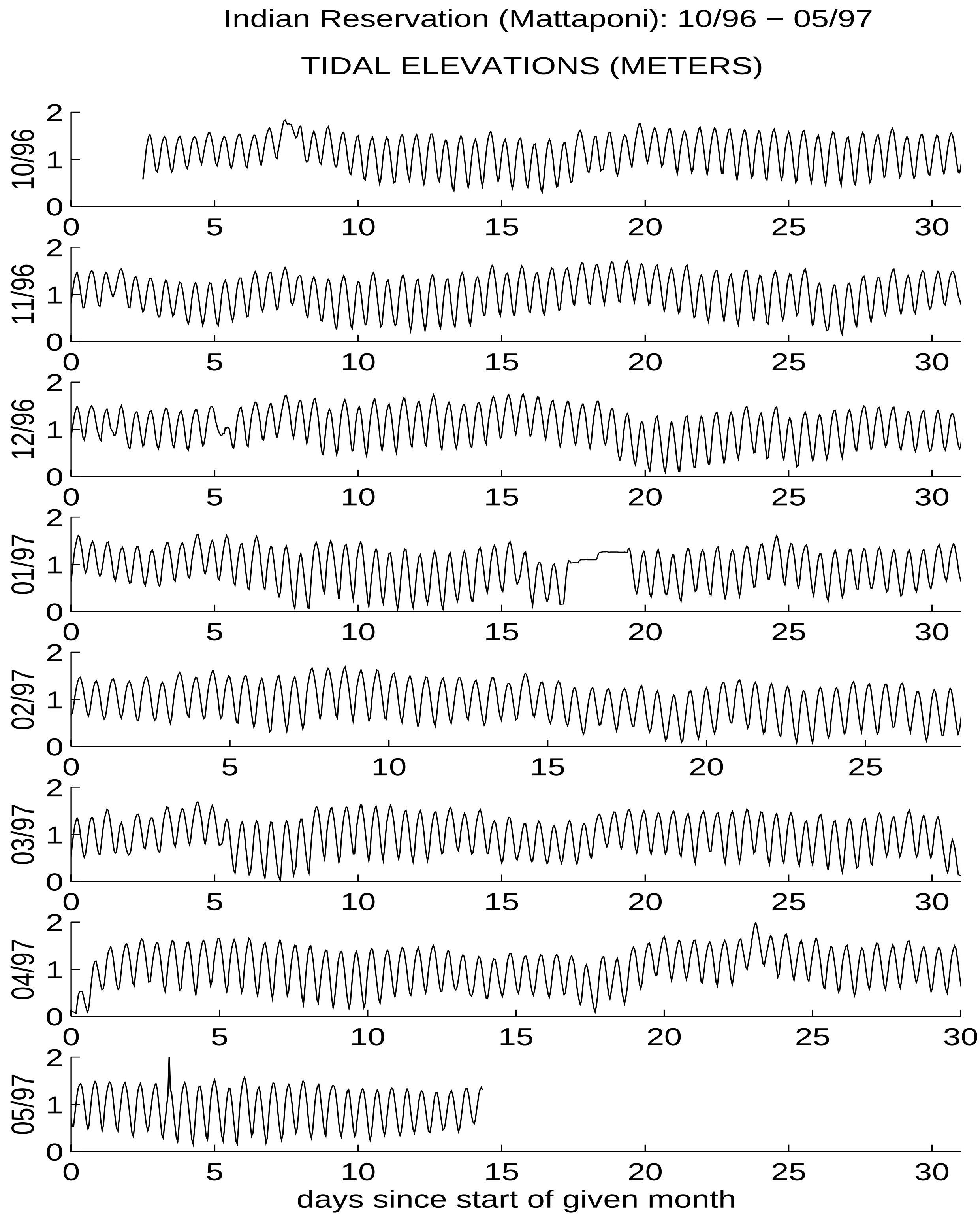


Figure A.21 Surface elevation records from gauge data (datums unknown) at the Indian Reservation. Flat portions of record represent missing data. Note gauge stuck due to ice January 17-20.

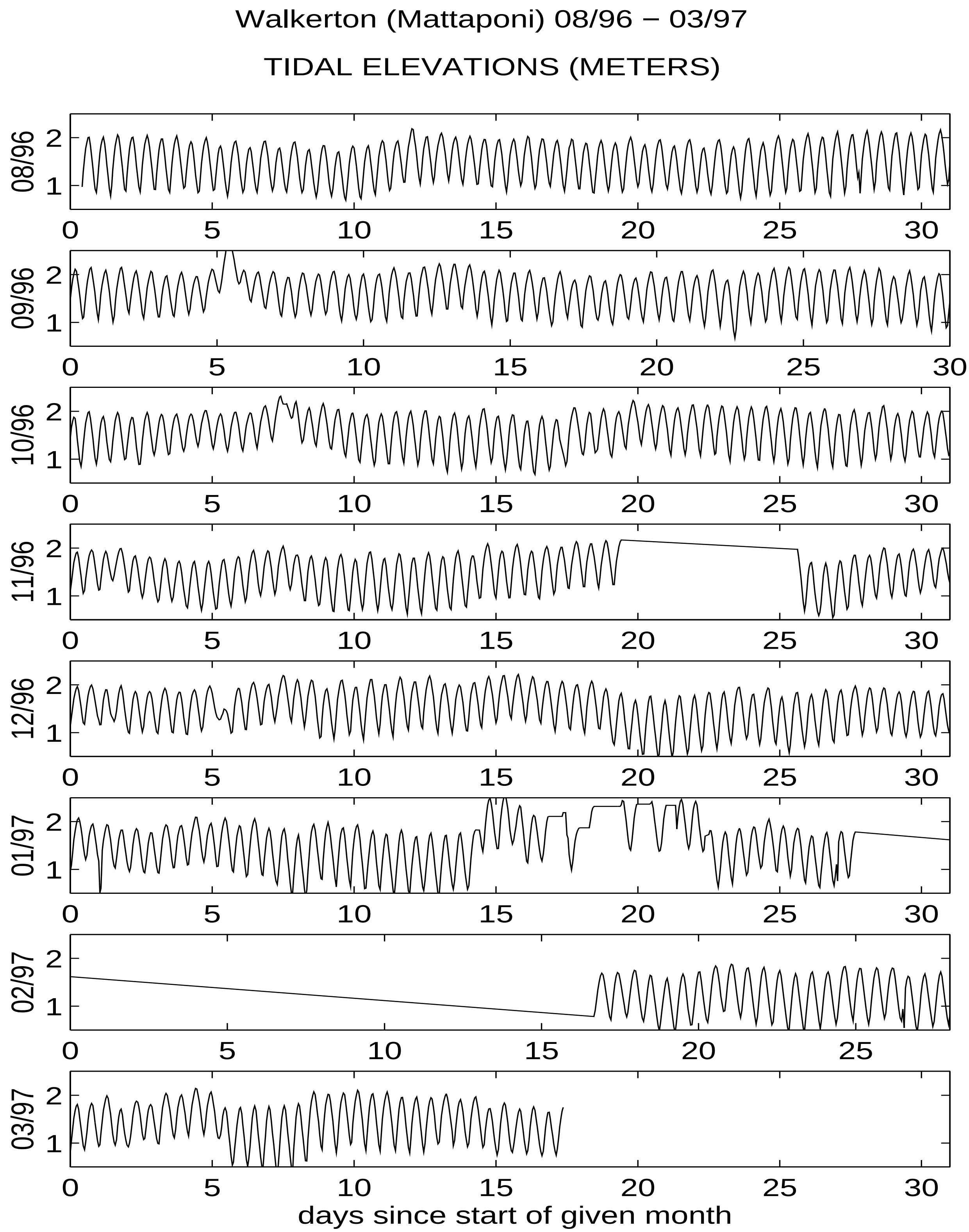


Figure A.22 Surface elevation records from gauge data (datums unknown) at Walkerton. Flat portions of record represent missing data. Note gauge stuck due to ice January 17-21.

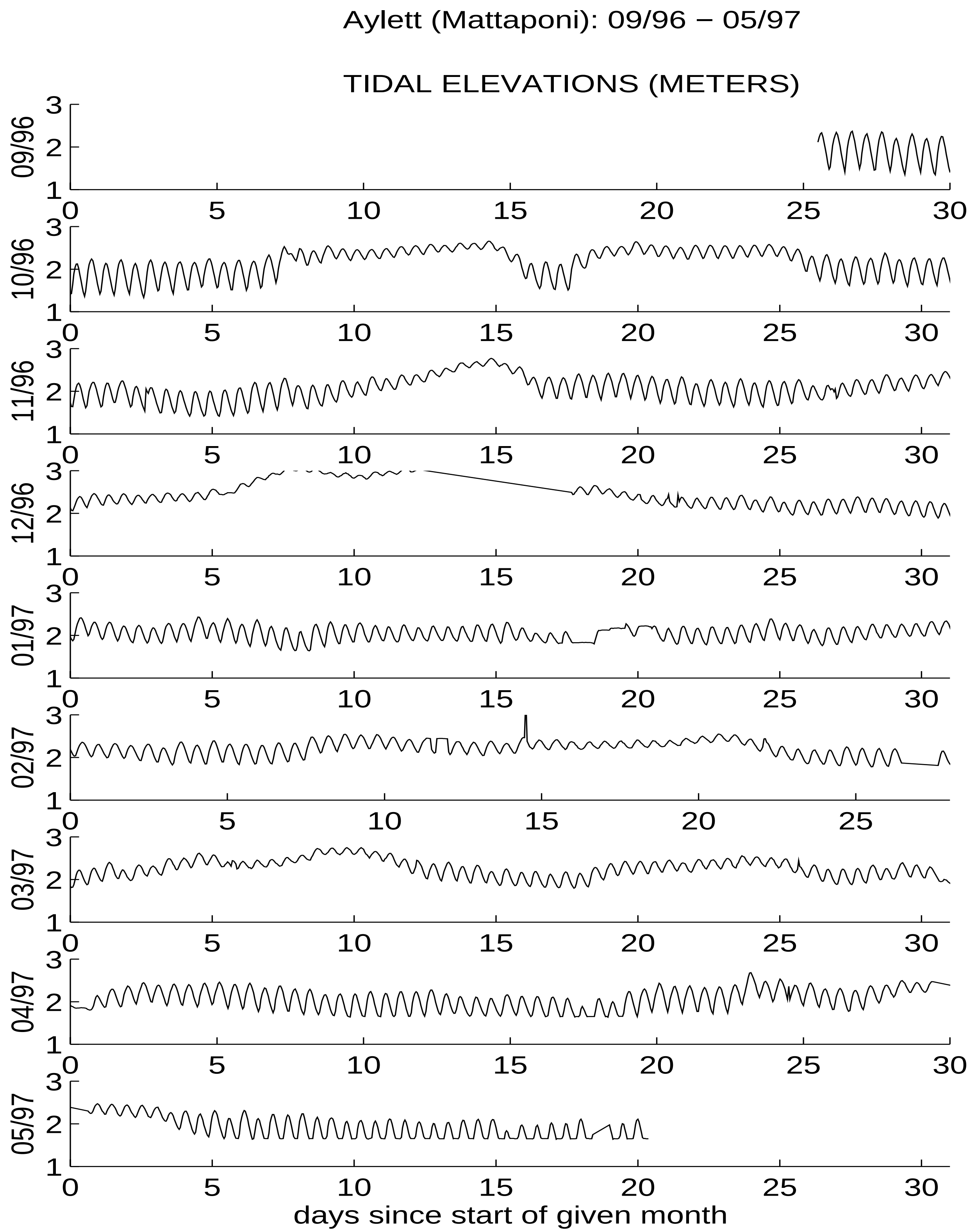


Figure A.23 Surface elevation records from gauge data (datums unknown) at Aylett. Flat portions of record represent missing data. Note gauge stuck due to ice January 18-21.

Appendix B. HAMELS Analyses of Tidal Constituents

As shown in Table 9 (page 40), a key part of the HEM-3D model validation (i.e., “fine-tune” calibration) is comparison of the individual constituents of the tide (both amplitude and phase) for observation data and model output. These amplitudes and phases are determined by a FORTRAN program known as HAMELS. This appendix is intended to illustrate the use of HAMELS in this report.

Works using HAMELS (i.e., Boon and Kiley (1978) and Hamrick (1991)) are described in Section IIc3.

HAMELS analysis for observation data:
Illustrative Example: West Point, July 5, 1993-August 3, 1993

The HAMELS program requires 2 input data files:

1) Input data file # 1 (constituent data) - filename **‘tidcon.dat**’
This is simply the number of constituents, followed by the character names and their periods (in seconds), as shown below:

```
  7
M2    44714.1644
S2    43200.0000
N2    45570.0535
K1    86164.0908
M4    22357.0822
O1    92949.6300
M6    14904.7215
```

2) Input data file # 2 (actual hourly tidal elevations) - filename **‘xxxxxxx.hh’**

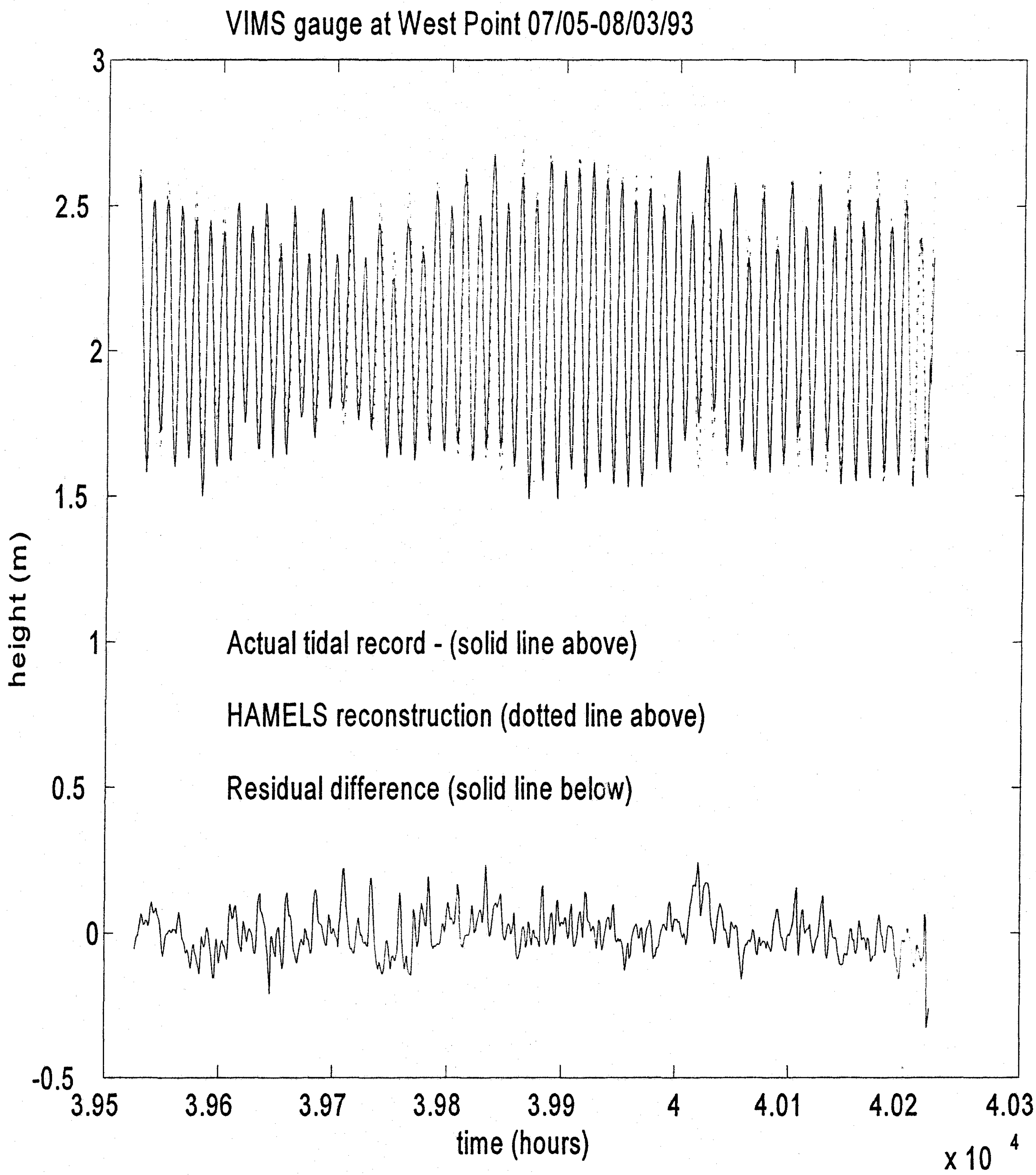
In this file, each date (separate record) is followed by 2 12-field records corresponding to tidal elevations records from midnight (0000 hours) to 2300 hours for that date. Values of ‘-9.99' denote missing observations. Thus, in the following example, the analysis starts at 2200 on July 5 and ends at 2200 on August 3. The HAMELS program expects this file to have a DOS suffix ‘.hh’ (e.g., **‘WESTPT93.HH’**).

```
 HOURLY TIDAL HEIGHTS FOR WEST POINT, 07/05/93-08/03/93
      70593
        -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99
        -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99 -9.99  2.54  2.60
      70693
         2.53  2.37  2.19  2.01  1.84  1.68  1.59  1.66  1.89  2.18  2.40  2.51
         2.52  2.42  2.24  2.06  1.91  1.80  1.72  1.75  1.92  2.17  2.38  2.50
      70793
```

```
  2.52  2.44  2.28  2.09  1.91  1.75  1.63  1.60  1.71  1.94  2.22  2.41
  2.50  2.47  2.32  2.13  1.95  1.81  1.70  1.63  1.71  1.89  2.13  2.33
70893
  2.45  2.45  2.32  2.12  1.93  1.75  1.60  1.50  1.56  1.76  1.98  2.22
  2.39  2.45  2.38  2.23  2.05  1.89  1.74  1.62  1.60  1.77  2.00  2.21
70993
  2.34  2.41  2.37  2.24  2.06  1.91  1.76  1.63  1.62  1.75  1.94  2.15
  2.36  2.49  2.51  2.42  2.26  2.09  1.94  1.83  1.75  1.79  1.92  2.08
71093
  2.27  2.39  2.43  2.34  2.19  2.04  1.89  1.74  1.66  1.66  1.80  2.03
  2.27  2.42  2.51  2.46  2.34  2.21  2.04  1.91  1.75  1.63  1.82  1.90
                              .
                              .
                              .

73093
  1.82  1.70  1.74  1.87  1.96  2.13  2.33  2.43  2.42  2.31  2.11  1.92
  1.77  1.65  1.61  1.73  1.93  2.22  2.44  2.56  2.57  2.48  2.33  2.16
73193
  2.00  1.84  1.72  1.65  1.73  1.91  2.15  2.34  2.43  2.40  2.25  2.07
  1.89  1.73  1.60  1.54  1.64  1.89  2.20  2.43  2.52  2.52  2.40  2.22
80193
  2.03  1.85  1.69  1.57  1.55  1.73  1.97  2.22  2.38  2.45  2.40  2.24
  2.04  1.87  1.71  1.59  1.56  1.76  2.04  2.31  2.47  2.53  2.48  2.34
80293
  2.16  2.01  1.84  1.69  1.58  1.59  1.80  2.05  2.28  2.40  2.43  2.37
  2.23  2.05  1.88  1.72  1.60  1.57  1.75  2.01  2.26  2.44  2.52  2.48
80393
  2.32  2.12  1.93  1.75  1.61  1.53  1.61  1.82  2.08  2.28  2.38  2.39
  2.28  2.10  1.91  1.73  1.61  1.56  1.77  1.96  1.88  2.17  2.32 -9.99
```

The plot shown on the next page compares the actual record with the reconstruction using HAMELS-derived constituent amplitudes and phases. In this manner, one can partially assess the reliability of the analysis.


VIMS gauge at West Point 07/05-08/03/93
height (m)
time (hours)
x 10^4
3
2.5
2
1.5
1
0.5
0
-0.5
3.95
3.96
3.97
3.98
3.99
4
4.01
4.02
4.03
Actual tidal record - (solid line above)
HAMELS reconstruction (dotted line above)
Residual difference (solid line below)

Appendix C. Tidal Constituent Error Analysis

The tidal constituent analysis presented in the previous appendix for the gauge data is subject to error from two primary sources: 1) unmodeled physical phenomena (e.g., storm setup) and 2) instrument noise. Errors in the data introduce uncertainty in the estimates of the tidal constituents. In this appendix we discuss a method for evaluating the size of the uncertainty in estimated tidal constituents. We also present an error analysis based on this method for the tide gauge data.

The tidal constituents are estimated using linear regression on a time series of gauge data. Let y_i be the recorded surface elevation at time t_i for a given station. Then we model the time series $\{y_i\}$ as composed of N tidal constituents using

$$y_i = b_0 + \sum_{k=1}^{k=N} b_{2k-1}\cos\left(\frac{2\pi}{T_k}t_i\right) + b_{2k}\sin\left(\frac{2\pi}{T_k}t_i\right) \qquad \textbf{(C.1)}$$

where b_0 is a constant term and b_{2k}, b_{2k+1} are the in-phase and quadrature components of the tidal constituent with period T_k. We can express eq. C.1 succinctly in matrix form as

$$\boldsymbol{y} = \boldsymbol{X}\boldsymbol{b} \qquad \textbf{(C.2)}$$

where $\boldsymbol{y} = [y_1\ y_2\ \ldots\ y_m]^t$ is the m x 1 column vector of observed surface elevations, $\boldsymbol{b} = [b_0\ b_1\ b_2\ \ldots\ b_{2N}]^t$ is the $2N$+1 x 1 column vector of coefficients to be estimated, and $\boldsymbol{X}$ is the m x $2N$+1 matrix

$$\boldsymbol{X} = \begin{bmatrix} 1 & \cos(\frac{2\pi}{T_1}t_1) & \sin(\frac{2\pi}{T_1}t_1) & \ldots & \cos(\frac{2\pi}{T_N}t_1) & \sin(\frac{2\pi}{T_N}t_1) \\ 1 & \cos(\frac{2\pi}{T_1}t_2) & \sin(\frac{2\pi}{T_1}t_2) & \ldots & \cos(\frac{2\pi}{T_N}t_2) & \sin(\frac{2\pi}{T_N}t_2) \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 1 & \cos(\frac{2\pi}{T_1}t_m) & \sin(\frac{2\pi}{T_1}t_m) & \ldots & \cos(\frac{2\pi}{T_N}t_m) & \sin(\frac{2\pi}{T_N}t_m) \end{bmatrix} \qquad \textbf{(C.3)}$$

The solution to eq. C.2 for the unknown vector of coefficients, $\boldsymbol{b}$, is

$$\hat{\boldsymbol{b}} = \{\boldsymbol{X}^t\boldsymbol{X}\}^{-1}\boldsymbol{X}^t\boldsymbol{y} \qquad \textbf{(C.4)}$$

The covariance matrix associated with the estimated coefficients is

$$\hat{\sigma}^2(\boldsymbol{b}) = \hat{\sigma}^2 \{\boldsymbol{X}^t \boldsymbol{X}\}^{-1} \quad \textbf{(C.5)}$$

where

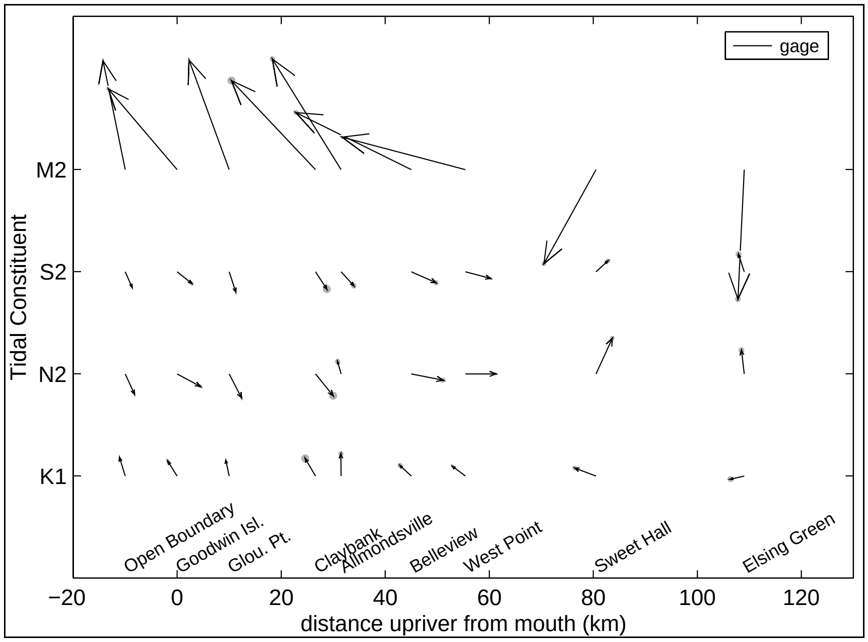
$$\hat{\sigma}^2 = \frac{1}{m - n}(\boldsymbol{y}^t - \boldsymbol{b}^t\boldsymbol{X}^t)\,\boldsymbol{y} \quad \textbf{(C.6)}$$

The α-level confidence interval for the *j*th coefficient is then given by

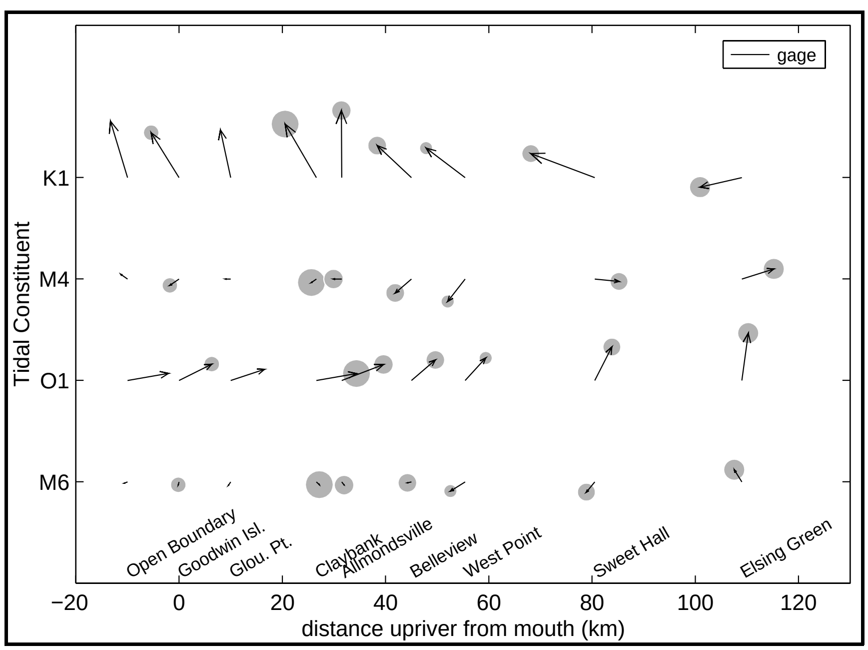
$$b_j \pm t(1 - \alpha/2; m - N)\,\hat{\sigma}(b_j) \quad \textbf{(C.7)}$$

where *t* is student's *t* distribution and $\hat{\sigma}(b_j)$ is the square root of the *j*th component along the diagonal in the covariance matrix (eq. C.5).

As presented in figure C.1, the estimated 95% confidence intervals in the tidal constituents at each station in the York River system are small compared to the largest tidal constituent (M2); however, they are on the order of the smallest constituents (typically O1 or M6). Estimates of the first seven tidal constituents, with accompanying uncertainty, are plotted against distance upriver at each of nine stations. Each constituent is plotted as a vector in the horizontal plane. The in-phase coefficient of the constituent is the x-component and the quadrature coefficient is the y-component of this vector. Using eq. C.7, a 95% confidence "surface" is plotted centered at the tip of each constituent. The normalization used to plot the tidal constituents changes between figs. C.1a and C.1b; the constituents in the latter figure are plotted using a smaller scale to make the detail more apparent.



a).



b).

Figure C.1. The indicated tidal constituents, derived from gauge data, are plotted as Cartesian vectors. The horizontal position of the base of each vector corresponds to the station distance from the river mouth; its vertical position indicates the tidal constituent. 95% confidence intervals for the vector components are indicated by shaded surfaces. Note 1) M2 error too small to see, and 2) the change in vector scale between a) and b) is used to show detail in the smaller components.

Appendix D. Partial listings of required input files for grid generator

This appendix is intended to provide some useful illustration of the sort of input required for forming the grid over which the model runs.

Due to the lengths of the files involved, only partial listings are provided (the full files are available from the authors). For further discussion, the reader is referred to the HEM-3D User's Manual by Hamrick (1996).

D1. Files required for the generation of the grid

In addition to the source (FORTRAN), the files required for a grid are:

a) '**cell.inp'**
b) **'depdat.inp**'
c) **'gridext.inp**'
d) '**gefdc.inp**' (Cartesian portion)
e) **'gefdc.inp**' (Curvilinear portion)
f) '**gefdc.inp**' (merged version)

The **'cell.inp**' file is most important in that it is the geometry, or domain boundary, designator file, and it does this by simply designating cell type within the specified grid matrix. In the following partial listing of 'cell.inp', the first field is the j (or y-direction index), followed by multiple 80-character fields of single integer designations of cell type, whereby column position indicates the i (or x-direction index) of the specified water type. The lines which follow illustrate the mapping around the confluence area of West Point:

```
C cell.inp file, i columns and j rows, for YORK RIVER (revised)
C-------------1---------2---------3---------4---------5---------6---------7---------
8
C
12345678901234567890123456789012345678901234567890123456789012345678901234567890
C
357
00000000000000000000000000000000000000000000000000000000000000000000000000000000
                                  .
                                  .
                                  .
184  00000000000000000000000000000000000000000 9559 000000000000000000000000000000000
183  00000000000000000000000000000000000000000 9559         0000000000000000000000000
182  00000000000000000000000000000000000000000 9559 99999999
181  00000000000000000000000000000000000000000 9559 955555999999999999999999999999999
180  0000000000000000000000000000000000000000 99559 955555555555555555555555555555555
179  0000000000000000000000000000000000000000 955599555999999999999999999999999999999
178  0000000000000000000000000000000000000000 95555995559
177  0000000000000000000000000000000000000000 95555555559 000000000000000000000000000
176  0000000000000000000000000000000000000000 95555555559 000000000000000000000000000
175  0000000000000000000000000000000000000000 95555555559 000000000000000000000000000
174                                  00000000 95555555559 000000000000000000000000000
173  9999999999999999999999999999999 0000000 9955555555599 00000000000000000000000000
172  9595959595959595959595959595959 0000000 955555555551999 000000000000000000000000
171  9999999999999999999999999999999 0000000 9555555555555199 00000000000000000000000
170  9595959595959595959595959595959 0000000 95555555555555199 0000000000000000000000
169  9999999999999999999999999999999 0000000 95555555555555519 0000000000000000000000
```

```
168  9595959595959595959595959595959 0000000 9555555555555555999 00000000000000000000
167  9999999999999999999999999999999 0000000 95555555555555555199 0000000000000000000
166  9595959595959595959595959595959 0000000 9955555555555555551999 00000000000000000
165  9999999999999999999999999999999 00000000 9955555555555555555199 0000000000000000
164  9595959595959595959595959595959 000000000 9955555555555555555199 000000000000000
163  9999999999999999999999999999999 0000000000 99999555555555555551999 0000000000000
162  9595959595959595959595959595959 00000000000    9995555555555555519 0000000000000
161  9999999999999999999999999999999 0000000000000000 999955555555555599 000000000000
160  9595959595959595959595959595959 0000000000000000000 9995555555555199 00000000000
159  9999999999999999999999999999999 000000000000000000000 99355555555519 00000000000
158  9595959595959595959595959595959 0000000000000000000000 99555555555599 0000000000
157  9999999999999999999999999999999 00000000000000000000000 9555555555519 0000000000
156  9595959595959595959595959595959 00000000000000000000000 9555555555559 0000000000
155  9999999999999999999999999999999 00000000000000000000000 95555555555599 000000000
154  9595959595959595959595959595959 00000000000000000000000 95555555555519 000000000
153  9999999999999999999999999999999 00000000000000000000000 95555555555559 000000000
152  9595959595959595959595959595959 00000000000000000000000 955555555555599 00000000
151  9999999999999999999999999999999 00000000000000000000000 955555555555559 00000000
150  9595959595959595959595959595959 00000000000000000000000 955555555555559 00000000
149  9999999999999999999999999999999 00000000000000000000000 935555555555559 00000000
148                                  00000000000000000000000 9993555555555599 0000000
```

The first 4 card images (those with ‘C’ in column 1) are ‘comment cards’ not input by the program. Land cell designators (i.e.,’0') adjacent to the water-land boundaries have been replaced with blank characters to accentuate this illustration. The region of interest begins as the j index (columns 1-3) is decremented from 184 to 148. As a ‘5' designates a water cell, ‘0' designates land, and ‘9' designates land-water interface, one can recognize West Point in the vicinity of j=177 under column 47. The Mattaponi is represented (here in the computational domain) as the single cell eastward extension along the row for j=180. The rectangular array of disjoint water cells from j=172 to j=150 represent marsh storage areas. Cell designator values between 1 and 4 (1 and 3 illustrated here) represent triangular ‘half cells’ allowing for a better fit to the shoreline for the Cartesian portion of the grid.

The file **‘depdat.inp**’ is the input file for bathymetry data used by the model. Note the data is in simple X-Y-Z format with X and Y being UTM (Universal Transverse Mercator) coordinates. The Z field is depth in meters relative to NGVD. These values were extracted from navigation charts by digitization and converted from latitude and longitude coordinates to UTM by a program available from the authors.

For the York River application, the number of depth soundings was 2460. These are interpolated by the grid generator to provide depths at the 3300 cell locations. Eight of the 2460 values are shown below in ‘**depdat.inp**’:

```
316.332  183.338  2.13
316.096  183.465  2.74
315.822  183.416  1.82
315.628  183.420  2.13
315.481  183.546  1.82
315.140  183.642  1.82
315.048  183.866  1.52
314.802  183.905  1.82
```

A grid of cell indices and UTM locations is easily constructed using the following simple FORTRAN routine:

```
      PROGRAM GENGRID
      OPEN(1,FILE='gridext.inp',STATUS='UNKNOWN')
      DO J=1,281
      DO I=1,320
      X=310.+0.25*FLOAT(I-1)
      Y=110.+0.25*FLOAT(J-1)
      WRITE(1,100)I,J,X,Y
      END DO
      END DO
  100 FORMAT(2I5,2(2X,F12.3))
      CLOSE(1)
      STOP
      END
```

The file ‘**gridext.inp’** is required for the formation of a Cartesian grid. This file simply maps the i and j indices into the UTM coordinates. A few lines of this file are shown below:

```
  1    1  310.000000  110.000000
  2    1  310.250000  110.000000
  3    1  310.500000  110.000000
       .
318    1  389.250000  110.000000
319    1  389.500000  110.000000
320    1  389.750000  110.000000
  1    2  310.000000  110.250000
  2    2  310.250000  110.250000
  3    2  310.500000  110.250000
       .
318    2  389.250000  110.250000
319    2  389.500000  110.250000
320    2  389.750000  110.250000
  1    3  310.000000  110.500000
  2    3  310.250000  110.500000
  3    3  310.500000  110.500000
       .
       .
       .
```

The main grid generator input file, '**gefdc.inp**' used for the Cartesian portion is shown below:

```
C1  TITLE
C1  (LIMITED TO 80 CHARACTERS)
     York River (Cartesian portion)
C2  INTEGER INPUT
C2  NTYPE  NBPP   IMIN  IMAX  JMIN  JMAX  IC   JC
    0      0      1     320   1     331  320   331  80
C3  GRAPHICS GRID INFORMATION
C3  ISGG  IGM  JGM  DXCG  DYCG  NWTGG
    1     320  331  250. 250.  1
C4  CARTESIAN AND GRAPHICS GRID COORDINATE DATA
C4  CDLON1  CDLON2  CDLON3  CDLAT1  CDLAT2  CDLAT3
     310   15    -00         110     15      00  15
C5  INTEGER INPUT
C5  ITRXM  ITRHM  ITRKM  ITRGM  NDEPSM  DEPMIN
     100    100    100    100    4000   1.0
C6  REAL INPUT
C6  RPX  RPK  RPH  RSQXM  RSQKM  RSQKIM  RSQHM  RSQHIM  RSQHJM
    1.8  1.8  1.8  1.E-12 1.E-12 1.E-12  1.E-12 1.E-12  1.E-12
C7  COORDINATE SHIFT PARAMETERS
C7  XSHIFT    YSHIFT   HSCALE  RKJDKI  ANGORO
     0.        0.       1000.   1.      15.0
C8  INTERPOLATION SWITCHES
C8  ISIRKI  JSIRKI  ISIHIHJ  JSIHIHJ
     1       0       0        0
C9  NTYPE = 7 SPECIFIED INPUT
C9  IB  IE  JB  JE  N7RLX NXYIT ITN7M IJSMD ISMD JSMD RP7  SERRMAX
C10 NTYPE = 7 SPECIFIED INPUT
C10 X    Y   IN ORDER (IB,JB) (IE,JB) (IE,JE) (IB,JE)
C11 DEPTH INTERPOLATION SWITCHES
C11 ISIDEP NDEPDAT CDEP RADM ISIDPTYP SURFELV ISVEG NVEGDAT NVEGTYP
    1      2460    1    1.2   1        5.0     0     0       0
C12 LAST BOUNDARY POINT INFORMATION
C12 ILT JLT X(ILT,JLT)  Y(ILT,JLT)
    96   115    453.616327     87.400612
C13 BOUNDARY POINT INFORMATION
C13 I   J   X(I,J)  Y(I,J)
```

If the file is curvilinear, the i and j indices are mapped into the UTM coordinates directly the main grid generator input file (see below) and 'gridext.inp**'** is not required.

The file '**gefdc.inp' (curvilinear portion)** is shown below:

```
C1  TITLE
C1  (LIMITED TO 80 CHARACTERS)
      York River (curvilinear portion - june 1996)
C2  INTEGER INPUT
C2   NTYPE  NBPP   IMIN  IMAX  JMIN  JMAX  IC   JC
     5      630    1     320   1     331  320   331
C3  GRAPHICS GRID INFORMATION
C3   ISGG  IGM  JGM  DXCG  DYCG  NWTGG
     0     320 331  1850. 1850.  1
C4  CARTESIAN AND GRAPHICS GRID COORDINATE DATA
C4  CDLON1  CDLON2  CDLON3  CDLAT1  CDLAT2  CDLAT3
      -77.5   1.25    -0.625  36.7    1.0     -0.5
C5  INTEGER INPUT
C5  ITRXM  ITRHM  ITRKM  ITRGM  NDEPSM  DEPMIN
      100    100    100    100    4000   1.0
C6  REAL INPUT
C6  RPX  RPK  RPH  RSQXM  RSQKM  RSQKIM  RSQHM  RSQHIM  RSQHJM
    1.8  1.8  1.8  1.E-12 1.E-12 1.E-12  1.E-12 1.E-12  1.E-12
C7  COORDINATE SHIFT PARAMETERS
C7  XSHIFT    YSHIFT   HSCALE  RKJDKI  ANGORO
     0.        0.       1000.   1.      15.0
C8  INTERPOLATION SWITCHES
C8  ISIRKI  JSIRKI  ISIHIHJ  JSIHIH
     1       0       0        0
C9  NTYPE = 7 SPECIFIED INPUT
C9  IB  IE  JB  JE  N7RLX NXYIT ITN7M IJSMD ISMD JSMD RP7  SERRMAX
C10 NTYPE = 7 SPECIFIED INPUT
C10 X    Y   IN ORDER (IB,JB) (IE,JB) (IE,JE) (IB,JE)
C11 DEPTH INTERPOLATION SWITCHES
C11 ISIDEP NDEPDAT CDEP RADM ISIDPTYP SURFELV ISVEG NVEGDAT NVEGTYP
    0      2460     2.  .5    1        5.0     0     0       0
C12 LAST BOUNDARY POINT INFORMATION
C12 ILT JLT X(ILT,JLT)  Y(ILT,JLT)
   124 173   340.75    153.00
C13 BOUNDARY POINT INFORMATION
C13 I   J   X(I,J)  Y(I,J)
  123  173 340.50 153.00
  123  174 340.50 153.24
  123  175 340.47 153.48
   .    .      .      .
   .    .      .      .
   .    .      .      .
  124  173 340.75 153.00
```

In order to **merge** the 2 grid portions, one must concatenate the outputs of these portions (i.e., 'gridext.out') and rename to 'gridext.inp' using the slightly altered version of the main input file, **'gefdc.inp'**:

```
C1  TITLE
C1  (LIMITED TO 80 CHARACTERS)
  York River (merged Cartesian & curvilinear portions -jan. 1996)
C2  INTEGER INPUT
C2  NTYPE  NBPP   IMIN  IMAX  JMIN  JMAX  IC   JC
    0      0      1     320   1     331  320   331
C3  GRAPHICS GRID INFORMATION
C3  ISGG  IGM  JGM  DXCG  DYCG  NWTGG
    1     320  331  250. 250.  1
C4  CARTESIAN AND GRAPHICS GRID COORDINATE DATA
C4  CDLON1  CDLON2  CDLON3  CDLAT1  CDLAT2  CDLAT3
     310   15    -00         110     15      00  15
C5  INTEGER INPUT
C5  ITRXM  ITRHM  ITRKM  ITRGM  NDEPSM  DEPMIN
     100    100    100    100    4000   1.0
C6  REAL INPUT
C6  RPX  RPK  RPH  RSQXM  RSQKM  RSQKIM  RSQHM  RSQHIM  RSQHJM
    1.8  1.8  1.8  1.E-12 1.E-12 1.E-12  1.E-12 1.E-12  1.E-12
C7  COORDINATE SHIFT PARAMETERS
C7  XSHIFT    YSHIFT   HSCALE  RKJDKI  ANGORO
     0.        0.       1000.   1.      15.0
C8  INTERPOLATION SWITCHES
C8  ISIRKI  JSIRKI  ISIHIHJ  JSIHIHJ
     1       0       0        0
C9  NTYPE = 7 SPECIFIED INPUT
C9  IB  IE  JB  JE  N7RLX NXYIT ITN7M IJSMD ISMD JSMD RP7  SERRMAX
C10 NTYPE = 7 SPECIFIED INPUT
C10 X    Y   IN ORDER (IB,JB) (IE,JB) (IE,JE) (IB,JE)
C11 DEPTH INTERPOLATION SWITCHES
C11 ISIDEP NDEPDAT CDEP RADM ISIDPTYP SURFELV ISVEG NVEGDAT NVEGTYP
    1      6039     2.  .5    1        5.0     0     0       0
C12 LAST BOUNDARY POINT INFORMATION
C12 ILT JLT X(ILT,JLT)  Y(ILT,JLT)
    96   115    453.616327     87.400612
C13 BOUNDARY POINT INFORMATION
C13 I   J   X(I,J)  Y(I,J)
```

Appendix E. Partial listings of required input files for the HEM-3D model run

This appendix is intended to provide some useful illustration of the sort of input required both for making the actual HEM-3D runs.

Due to the lengths of the files involved, only partial listings are provided (the full files are available from the authors). For further discussion, the reader is referred to the HEM-3D User's Manual by Hamrick (1996).

In addition to the main source (or corresponding executable), there are several files needed by the HEM-3D hydrodynamic portion, for both calibration and verification. For calibration, these include:

a) '**efdc.inp'**
b) '**efdc.com'**
c) **'efdc.par**'
d) '**dxdy.inp**'
e) '**lxly.inp'**
f) **'salt.inp**'
g) '**modchan.inp**'
h) **'gwater.inp**'
i) '**txser.inp'**

Additional files required for verification include:

j) **'qser.inp**'
k)'**pser.inp**'
l) **'aser.inp'**
m) **'sser.inp**'

The main input file, '**efdc.inp**', for the York River calibration is shown below. In order to keep this document to a reasonable length, most in-line comments have been stripped out (see User's Manual):

```
*******************************************************************************
*   WELCOME TO THE ENVIRONMENTAL FLUID DYNAMICS COMPUTER CODE SERIES          *
*   DEVELOPED BY JOHN M. HAMRICK.
*******************************************************************************
C1   TITLE FOR RUN                                                             |
     ' FINAL CALIBRATION' Test horizontal diff. set it=0.020'                  |
-------------------------------------------------------------------------------
C2  RESTART, GENERAL CONTROL AND AND DIAGNOSTIC SWITCHES                       |
C2  ISRESTI ISRESTO ISRESTR ISPAR ISLOG ISDIVEX ISNEGH ISMMC ISBAL ISHP ISHOW |
    0        1       0       0     2     0       1      0     0     0    0
-------------------------------------------------------------------------------
C3   RELAXATION PARAMETERS AND SWITCHES                                        |
C3   RP  RSQM  ITERM IRVEC RPADJ  RSQMADJ  ITRMADJ  ITERHPM ISDRYCK ISDSOLV   |
    1.8 1.E-5   500  2   1.8    1.E-16   1000     1        20       0
-------------------------------------------------------------------------------
C4   LONGTERM MASS TRANSPORT INTEGRATION ONLY SWITCHES                         |
C4   ISLTMT  ISSSMMT ISLTMTS  ISIA  RPIA  RSQMIA   ITRMIA                      |
```

```
     0       0       0        0     1.8   1.E-10   100
-------------------------------------------------------------------------------
C5   MOMENTUM ADVEC AND HORIZ DIFF SWITCHES AND MISC SWITCHES                  |
C5   ISCDMA ISAHMF ISDISP ISWASP ISDRY ISQQ ISRLID ISVEG ISVEGL ISITB ISWAVE  |
     0      2      0      0      11      1    0      0     0      0     0
--------------------------------------------------------------------------------
C6   DISSOLVED AND SUSPENDED CONSTITUENT TRANSPORT SWITCHES                    |
C6   TURB INT=0,SALT=1,TEMP=2,DYEC=3,SEDC=4,SNDC=5,TOXC=6,SFL=7,CWQ=8          |
C6   ISTRAN ISTOPT ISCDCA ISADAC ISFCT ISPLIT ISADAH ISADAV ISCI ISCO          |
     1      0      0      0      0      0      0      0      0    0    !turb 0
     1      1      1      1      0      0      0      0      1    1    !sal  1
     0      0      0      0      0      0      0      0      0    0    !tem  2
     0      0      0      0      0      0      0      0      0    0    !dye  3
     0      1      0      1      1      0      0      0      0    0    !sed  4
     0      0      0      0      0      0      0      0      0    0    !snd  5
     0      0      0      1      1      0      0      0      0    0    !tox  6
     0      0      0      0      0      0      0      0      0    0    !sfl  7
     0      0      0      0      0      0      0      0      0    0    !cwq  8
-------------------------------------------------------------------------------
C7   TIME-RELATED INTEGER PARAMETERS                                           |
 C7   NTC  NTSPTC NLTC NTTC NTCPP NTSTBC NTCNB NTCVB NTSMMT NFLTMT  NDRYSTP   |
     238  720   0    0   1440     8     0     2     720   1       5
-------------------------------------------------------------------------------
C8   TIME-RELATED REAL PARAMETERS                                              |
C8   TCON     TBEGIN  TREF       CORIOLIS   ISCCA   ISCFL                      |
     44714.16 0.00   44714.16     0.0001     0       0
-------------------------------------------------------------------------------
C9  SPACE-RELATED AND SMOOTHING  PARAMETERS                                    |
C9 KC  IC  JC   LC  LVC ISCO NDM LDW ISMASK ISPGNS NSHMX NSBMX   WSMH    WSMB |
   8  320 357 3311 3309 1    1  3309 0      0        0   0   0.0625  0.0625
------------------------------------------------------------------------------
C10  LAYER THICKNESS IN VERTICAL                                               |
C10  LAYER NUMBER    DIMENSIONLESS LAYER THICKNESS                             |
     1                 0.1250
     2                 0.1250
     3                 0.1250
     4                 0.1250
     5                 0.1250
     6                 0.1250
     7                 0.1250
     8                 0.1250
-------------------------------------------------------------------------------
C11  GRID, ROUGHNESS AND DEPTH PARAMETERS                                      |
C11  DX  DY   DXYCVT ZBRADJ ZBRCVRT HMIN HMADJ HCVRT HDRY HWET BELADJ BELCVRT |
     1.  1.   1.     0.0    0.5   0.5    0.4  1.   0.40 0.40  -0.4    1.0
-------------------------------------------------------------------------------
C12  TURBULENT DIFFUSION PARAMETERS                                            |
C12  AHO   AHD     AVO      ABO      AVBCON  ISFAVB                            |
     0.0   0.020    1.E-6    1.E-8    1.0     1
-------------------------------------------------------------------------------
C13  TURBULENCE CLOSURE PARAMETERS                                             |
C13  VKC   CTURB   CTE1   CTE2   CTE3   QQMIN   QQLMIN   DMLMIN                |
     0.4   16.0    1.8    1.33   0.53   1.E-8   1.E-16   1.E-8
-------------------------------------------------------------------------------
C14 PERIODIC FORCING (TIDAL) CONSTITUENT AND HARMONIC ANALYSIS PARAMETERS     |
C14  MTIDE  ISLSHA  MLLSHA   NTCLSHA  ISLSTR   ISHTA                           |
     1      1        16        5        0        1
-------------------------------------------------------------------------------
C15 PERIODIC FORCING (TIDAL) CONSTITUENT SYMBOLS AND PERIODS                   |
C15  SYMBOL    PERIOD                                                          |
     'M2'      44714.16
-------------------------------------------------------------------------------
C16  HARMONIC ANALYSIS LOCATIONS AND SWITCHES                                  |
C16  ILLSHA   JLLSHA    LSHAP  LSHAB  LSHAUE  LSHAU   CLSL                     |
      270      52        1      0      0      0       'OPEN BNDRY'             |
```

```
      248      42        1      0      1      0       'GOODWIN'              |
      227      52        1      0      1      0       'GLOUPT'               |
      186     105        1      0      1      0       'CLAYBA'               |
      173     118        1      0      1      0       'ALLMONV'              |
      145     160        1      0      1      0       'BELLEVW'              |
      129     180        1      0      1      0       'WESTPT'               |
      124     239        1      0      1      0       'SWEETH'               |
      124     283        1      0      1      0       'Lester Manor'         |
      124     322        1      0      1      0       'ELSING GR'            |
      124     327        1      0      1      0       'Northbury'            |
      209     180        1      0      1      0       'Wakema'               |
      277     180        1      0      1      0       'Walkerton'            |
      128     176        1      0      1      0       'mwpt'
      130     176        1      0      1      0       'nwpt'
      126     176        1      0      1      0       'swpt'
--------------------------------------------------------------------------------
C17 SURFACE ELEVATION OR PRESSURE BOUNDARY CONDITION PARAMETERS               |
C17  NPBS NPBW NPBE NPBN  NPFOR  NPSER  PDGINIT                               |
     0    0    16   0     0       1      0.00
--------------------------------------------------------------------------------
C18 PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE BOUNDARY COND. FORCINGS    |
C18  NPFOR  SYMBOL   AMPLITUDE         PHASE                                  |
--------------------------------------------------------------------------------
C19 PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE ON SOUTH OPEN BOUNDARIES   |
C19  IPBS     JPBS   ISPBS    NPFORS  NPSERS                                  |
--------------------------------------------------------------------------------
C20 PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE ON WEST OPEN BOUNDARIES    |
C20 IPBW     JPBW   ISPBW    NPFORW   NPSERW
--------------------------------------------------------------------------------
C21 PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE ON EAST OPEN BOUNDARIES
C21  IPBE     JPBE   ISPBE    NPFORE  NPSERE
      270      45    1        1       1
      270      46    1        1       1
      270      47    1        1       1
      270      48    1        1       1
      270      49    1        1       1
      270      50    1        1       1
      270      51    1        1       1
      270      52    1        1       1
      270      53    1        1       1
      270      54    1        1       1
      270      55    1        1       1
      270      56    1        1       1
      270      57    1        1       1
      270      58    1        1       1
      270      59    1        1       1
      270      60    1        1       1
--------------------------------------------------------------------------------
C22 PERIODIC FORCING (TIDAL) SURF ELEV OR PRESSURE ON NORTH OPEN BOUNDARIES   |
C22 IPBN     JPBN   ISPBN    NPFORN  NPSERN                                   |
--------------------------------------------------------------------------------
C23 VELOCITY, VOLUMN SOURCE/SINK, FLOW CONTROL, AND WITHDRAWAL/RETURN DATA    |
C23 NVBS NUBW NUBE NVBN NQSIJ NQSER NQCTL NQWR  ISDIQ                         |
    0    0    0    0    2     2     0     0     0
--------------------------------------------------------------------------------
C24 VOLUMETRIC SOURCE/SINK LOCATIONS, MAGNITUDES, AND CONCENTRATION SERIES    |
C24 IQS  JQS   QSSE  NQSMUL NQSMFF NQSERQ NS- NT- ND- NSD- NSN- NTX- NSF-     |
    124  352   39.2  0      0      1      0   0   0   0    0    0    0
    277  180   20.5  0      0      2      0   0   0   0    0    0    0
--------------------------------------------------------------------------------
C25 TIME CONSTANT INFLOW CONCENTRATIONS FOR TIME CONSTANT VOLUMETRIC SOURCES  |
C25 SALT   TEMP   DYEC   SEDC  SNDC  TOXC  SFLC                               |
    0.     25.    0.     10.   0.    0.    0.
    0.     25.    0.     10.   0.    0.    0.
--------------------------------------------------------------------------------
```

```
C26 SURFACE ELEV OR PRESSURE DEPENDENT FLOW CONTROL STRUCTURE INFORMATION     |
C26 IQCTLU JQCTLU IQCTLD JQCTLD NQCTYP NQCTLQ NQCMUL NQCMFU NQCMFD IQCAX JQCAX|
-------------------------------------------------------------------------------
C27 FLOW WITHDRAWAL, HEAT OR MATERIAL ADDITION, AND RETURN DATA
C27 IWRU JWRU IWRD JCWRD QWRE NQSERW NSS- NTS- NDS- NSDS- NSNS- NTXS- NSFS-   |
-------------------------------------------------------------------------------
C28 TIME CONSTANT WITHDRAWAL AND RETURN CONCENTRATION RISES                    |
C28   SALTR  TEMPR   DYER   SEDR   SNDR   TOXR   SFLR                         |
-------------------------------------------------------------------------------
C29 SUSPENDED SEDIMENT SOURCE/SINK PARAMETERS                                 |
C29 SEDO SEDBO SDEN  SSG  WSEDO SEDN   SEXP TAUD WRSPO  TAUR  TAUN  TEX SDBLV |
    20.0  0.   0.0   2.5  5.E-5 1.E-5  0.  7.5E-5 0.2  1.E-4 1.E-4  1.  0.
-------------------------------------------------------------------------------
C30A CONCENTRATION PARAMETERS FOR BUOY, EQ TEMP, DYE DECAY AND TOXIC COMTAM    |
C30A  BSC TEMO  HEQT  RKDYE  TOXINIT TOXBINIT  TOXPAR  RKTOX                  |
      1.  25.0  0.0   0.0    0.0     0.0       0.05     0.
-------------------------------------------------------------------------------
C30B CONCENTRATION BOUNDARY CONDITION AND TIME SERIES INFORMATION             |
C30B NCBS NCBW NCBE NCBN NSSER NTSER NDSER NSDSER NSNSER NTXSER NSFSER         |
     0    0    16   0    1     0     0     0      0      0      0
-------------------------------------------------------------------------------
C31  LOCATION OF CONC BC'S ON SOUTH BOUNDARIES                                |
C31 IBBS  JBBS  NTSCRS NSSERS NTSERS NDSERS NSDSERS  NSNSERS NTXSERS NSFSERS  |
-------------------------------------------------------------------------------
C32 TIME CONSTANT BOTTOM CONC ON SOUTH CONC BOUNDARIES                        |
C32 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
-------------------------------------------------------------------------------
C33 TIME CONSTANT SURFACE CONC ON SOUTH CONC BOUNDARIES                       |
C33 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
-------------------------------------------------------------------------------
C34 LOCATION OF CONC BC'S ON WEST BOUNDARIES AND SERIES IDENTIFIERS           |
C34 IBBW  JBBW  NTSCRW NSSERW NTSERW NDSERW NSDSERW  NSNSERW NTXSERW NSFSERW  |
-------------------------------------------------------------------------------
C35 TIME CONSTANT BOTTOM CONC ON WEST CONC BOUNDARIES                         |
C35 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
-------------------------------------------------------------------------------
C36 TIME CONSTANT SURFACE CONC ON WEST CONC BOUNDARIES                        |
C36 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
-------------------------------------------------------------------------------
C37 LOCATION OF CONC BC'S ON EAST BOUNDARIES AND SERIES IDENTIFIERS           |
C37 IBBE  JBBE  NTSCRE NSSERE NTSERE NDSERE NSDSERE  NSNSERE NTXSERE NSFSERE  |
     270   45     74    1      0      0      0        0       0       0
     270   46     74    1      0      0      0        0       0       0
     270   47     74    1      0      0      0        0       0       0
     270   48     74    1      0      0      0        0       0       0
     270   49     74    1      0      0      0        0       0       0
     270   50     74    1      0      0      0        0       0       0
     270   51     74    1      0      0      0        0       0       0
     270   52     74    1      0      0      0        0       0       0
     270   53     74    1      0      0      0        0       0       0
     270   54     74    1      0      0      0        0       0       0
     270   55     74    1      0      0      0        0       0       0
     270   56     74    1      0      0      0        0       0       0
     270   57     74    1      0      0      0        0       0       0
     270   58     74    1      0      0      0        0       0       0
     270   59     74    1      0      0      0        0       0       0
     270   60     74    1      0      0      0        0       0       0
-------------------------------------------------------------------------------
C38 TIME CONSTANT BOTTOM CONC ON EAST CONC BOUNDARIES                          |
C38 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
      0.  25.     0.   0.     0.   0.    0.
      0.  25.     0.   0.     0.   0.    0.
      0.  25.     0.   0.     0.   0.    0.
      0.  25.     0.   0.     0.   0.    0.
      0.  25.     0.   0.     0.   0.    0.
```

```
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
-------------------------------------------------------------------------------
C39 TIME CONSTANT SURFACE CONC ON EAST CONC BOUNDARIES                         |
C39 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                  |
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
      0.  25.     0.   0.    0.   0.    0.
-------------------------------------------------------------------------------
C40 LOCATION OF CONC BC'S ON NORTH BOUNDARIES AND SERIES IDENTIFIERS           |
C40 IBBN  JBBN  NTSCRN NSSERN NTSERN NDSERN NSDSERN  NSNSERN NTXSERN NSFSERN   |
-------------------------------------------------------------------------------
C41 TIME CONSTANT BOTTOM CONC ON NORTH CONC BOUNDARIES                         |
C41  SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                 |
-------------------------------------------------------------------------------
C42 TIME CONSTANT SURFACE CONC ON NORTH CONC BOUNDARIES                        |
C42 SALT  TEMP  DYEC  SEDC   SNDC  TOXC  SFLC                                  |
-------------------------------------------------------------------------------
C43 DRIFTER DATA (FIRST 4 PARAMETER FOR SUB DRIFER, SECOND 6 FOR SUB LAGRES)  |
C43 ISPD NPD NPDRT NWPD ISLRPD ILRPD1 ILRPD2 JLRPD1  JLRPD2  MLRPDRT IPLRPD    |
    0    0   0     0    0      1      1      1       1       12      1
-------------------------------------------------------------------------------
C44  INITIAL DRIFTER POSITIONS                                                 |
C44  RI    RJ   RK
-------------------------------------------------------------------------------
C45 CONSTANTS FOR CARTESION GRID CELL CENTER LONGITUDE AND LATITUDE            |
C45  CDLON1  CDLON2   CDLON3   CDLAT1  CDLAT2   CDLAT3                         |
     0.0     0.      0.        0.      0.       0.
-------------------------------------------------------------------------------
C46  CONTROLS FOR PRINTED OUTPUT                                               |
C46  ISPOP   ISPOU  ISPOV  ISPOS                                               |
     0       0      0      0
-------------------------------------------------------------------------------
C47 CONTROLS FOR HORIZONTAL PLANE SCALAR FIELD CONTOURING                      |
C47 ISSPH   NPSPH   ISRSPH                                                     |
    0       24      1
-------------------------------------------------------------------------------
C48 CONTROLS FOR HORIZONTAL SURFACE ELEVATION OR PRESSURE CONTOURING           |
C48 ISPPH   NPPPH   ISRPPH                                                     |
    0       0       0
-------------------------------------------------------------------------------
C49 CONTROLS FOR HORIZONTAL PLANE VELOCITY VECTOR PLOTTING                     |
C49 ISVPH   NPVPH   ISRVPH                                                     |
```

```
    0       24      0
-------------------------------------------------------------------------------
C50 CONTROLS FOR VERTICAL PLANE SCALAR FIELD CONTOURING                        |
C50 ISECSPV   NPSPV  ISSPV  ISRSPV  ISHPLTV                                    |
     9        12      1      1       0
-------------------------------------------------------------------------------
C51 MORE CONTROLS FOR VERTICAL PLANE SCALAR FIELD CONTOURING                   |
C                                                                              |
      ISECSPV:  SECTION NUMBER                                                 |
      NIJSPV:   NUMBER OF CELLS OR I,J PAIRS IN SECTION                        |
      SEC ID:   CHARACTER FORMAT SECTION TITLE                                 |
C                                                                              |
C51 ISECSPV NIJSPV  SEC ID                                                     |
    1       140     'Horz'
    2       15      'Month'
    3        8      'G. PT'
    4       10      'L-clay'
    5        8      'clay'
    6       10      'U-clay'
    7        8      'L-belv'
    8        8      'Belv'
    9        9      'W-pt'
-------------------------------------------------------------------------------
C52 I,J LOCATIONS FOR VERTICAL PLANE SCALAR FIELD CONTOURING                   |
C                                                                              |
      ISECSPV: SECTION NUMBER                                                  |
      ISPV:    I CELL                                                          |
      JSPV:    J CELL                                                          |
C                                                                              |
C52 ISECSPV ISPV    JSPV                                                       |
    1       127     174
             .
    1       266     50
    2       238     54
             .
    2       238     40
    3       222     67
             .
    3       215     56
    4       205     79
             .
    4       198     66
    5       192     97
             .
    5       185     83
    6       182     110
             .
    6       174     101
    7       172     128
             .
    7       165     116
    8       147     159
             .
    8       140     148
    9       123     175
             .
    9       131     175
-------------------------------------------------------------------------------
C53 CONTROLS FOR VERTICAL PLANE VELOCITY VECTOR PLOTTING                       |
C                                                                              |
      ISECVPV:  N AN INTEGER NUMBER (N.LE.9) OF VERTICAL SECTIONS              |
                  TO WRITE N FILES FOR VELOCITY PLOTTING                       |
      NPVPV:      NUMBER OF WRITES PER REFERENCE TIME PERIOD                   |
      ISVPV:    1 TO ACTIVATE INSTANTANEOUS VELOCITY                           |
      ISRVPV:   1 TO ACTIVATE FOR RESIDUAL VELOCITY                            |
```

```
C                                                                              |
C53 ISECVPV   NPVPV  ISVPV  ISRVPV                                             |
      6        12      1      1
-------------------------------------------------------------------------------
C54 MORE CONTROLS FOR VERTICAL PLANE VELOCITY VECTOR PLOTTING                  |
C                                                                              |
      ISCEVPV:  SECTION NUMBER                                                 |
      NIJVPV:   NUMBER IS CELLS OR I,J PAIRS IN SECTION                        |
      ANGVPV:   CCW POSITIVE ANGLE FROM EAST TO SECTION NORMAL                 |
      SEC ID:   CHARACTER FORMAT SECTION TITLE                                 |
C                                                                              |
C54 ISECVPV   NIJVPV  ANGVPV  SEC ID                                           |
    1       140      -135  'Horz'
    2       15        0    'Month'
    3        8       -45   'G. PT'
    4       10       -40   'L-clay'
    5        8       -30   'clay'
    6       10       -40    'U-clay'
-------------------------------------------------------------------------------
C55 CONTROLS FOR VERTICAL PLANE VELOCITY PLOTTING                              |
C55 ISECVPV IVPV    JVPV                                                       |
    1       127     174
             .
    1       265     50
             .
    1       266     50
    2       238     54
             .
    2       238     40
    3       222     67
             .
    3       215     56
    4       205     79
             .
    4       198     66
    5       192     97
             .
    5       185     83
    6       182     110
             .
    6       174     101
-------------------------------------------------------------------------------
C56 CONTROLS FOR 3D FIELD OUTPUT                                               |
C56 IS3DO ISR3DO NP3DO KPC NWGG I3DMI I3DMA J3DMI J3DMA I3DRW SELVMAX BELVMIN |
    0     0      12     1   0    2     331    2     320    0     0.25 -31.75
-------------------------------------------------------------------------------
C57 SCALES FOR 3D FIELD OUTPUT                                                 |
C57 VARIABLE    IS3D(VARID)  JS3D(VARID)   MAX SCALE VALUE  MIN SCALE VALUE   |
    'U VEL'     1            2                0.5              -0.5
    'V VEL'     1            2                0.5              -0.5
    'W VEL'     0            0                1.0E-3           -1.0E-3
    'SALINITY'  1            2               25.0               0.0
    'TEMP'      0            0               30.0              10.0
    'DYE'       0            0             1000.0               0.0
    'SEDIMENT'  0            0             1000.0               0.0
-------------------------------------------------------------------------------
C58 CONTROLS FOR WRITING TO TIME SERIES FILES                                  |
C58 ISTMSR  MLTMSR  NBTMSR  NSTMSR  NWTMSR  TCTMSR                             |
    1        21        0    9990000    60      3600.
-------------------------------------------------------------------------------
C59 CONTROLS FOR WRITING TO TIME SERIES FILES                                  |
C59 ILTS JLTS  MTSP MTSC MTSA  MTSUE MTSUT MTSU MTSQE MTSQ  CLTS               |
    270   52   1    1    0     1     0     0    0     0    'OPEN BNDRY'
    248   42   1    1    0     1     0     0    0     0    'GOODWIN'
    227   52   1    1    0     1     0     0    0     0    'GLOU PT'
```

```
    203   73   1    1    0     1     0     0    0     0    'GL-CL'
    191   94   1    1    0     1     0     0    0     0    'GL-CL2'
    191   82   1    1    0     1     0     0    0     0    'GL-CL3'
    186  105   1    1    0     1     0     0    0     0    'CLAYBANK'
    173  118   1    1    0     1     0     0    0     0    'ALLMONDSV'
    145  160   1    1    0     1     0     0    0     0    'BELLEVIEW'
    129  180   1    1    0     1     0     0    0     0    'WEST PT'
    124  249   1    1    0     1     0     0    0     0    'SWEET HALL'
    124  294   1    1    0     1     0     0    0     0    'Lester Manor'
    124  325   1    1    0     1     0     0    0     0    'ELSING GREEN'
    124  332   1    1    0     1     0     0    0     0    'Northbury'
    209  180   1    1    0     1     0     0    0     0    'Wakema'
    277  180   1    1    0     1     0     0    0     0    'Walkerton'
    124  199   1    1    0     0     0     1    0     0    'pam chan'
     90  164   1    1    0     1     0     0    0     0    'mwpt'
    124  199   1    1    0     0     0     1    0     0    'pam chan'
     90  164   1    1    0     1     0     0    0     0    'mwpt'
    209  180   1    1    0     1     0     0    0     0    'c-mat'
-------------------------------------------------------------------------------
C60 CONTROLS FOR EXTRACTING INSTANTANEOUS VERTICAL SCALAR FIELD PROFILES      |
C60 ISVSFP  MDVSFP  MLVSFP  TMVSFP  TAVSFP                                    |
      0       0       0      3600.   0.0
-------------------------------------------------------------------------------
C61 SAMPLING DEPTHS FOR EXTRACTING INST VERTICAL SCALAR FIELD PROFILES        |
C61 MMDVSFP  DMVSFP                                                           |
-------------------------------------------------------------------------------
C62 HORIZONTAL SPACE-TIME LOCATIONS FOR SAMPLING                              |
C62 MMLVSFP  TIMVSFP  IVSFP  JVSFP                                            |
*******************************************************************************
*******************************************************************************
*******************************************************************************
```

The file **'efdc.com**' contains common block declarations for the hundreds of arrays required by HEM-3D. Its header lines, along with typical declaration blocks, are shown below:

```
C**********************************************************************C
C
C **  GLOBAL COMMON FILE EFDC.COM
C
C**********************************************************************C
C **  REMOVE COMMENT ON IMPLICIT FOR DOUBLE PRECISION
C     IMPLICIT REAL*8 (A-H,O-Z)
C**********************************************************************C
C
      CHARACTER*20 CCTITLE(100),CLSL(100),CVTITLE(100),CLTMSR(MLTMSRM)
      CHARACTER*5 SYMBOL(MTM)
      CHARACTER*13 FNSAL(MLTMSRM),FNTEM(MLTMSRM),FNDYE(MLTMSRM),
     $             FNSED(MLTMSRM),FNSND(MLTMSRM),FNTOX(MLTMSRM),
     $             FNSFL(MLTMSRM),FNAVV(MLTMSRM),
     $             FNAVB(MLTMSRM),FNSEL(MLTMSRM),
     $             FNUVE(MLTMSRM),FNUVT(MLTMSRM),FNU3D(MLTMSRM),
     $             FNV3D(MLTMSRM),FNQQE(MLTMSRM),FNQ3D(MLTMSRM)
      CHARACTER*2  CNTMSR(MLTMSRM)
C
C**********************************************************************C
C
      COMMON/CHARY/ CCTITLE,CLSL,CVTITLE,SYMBOL,CLTMSR,
     $             FNSAL,FNTEM,FNDYE,
```

```
     $              FNSED,FNSND,FNTOX,FNSFL,FNAVV,
     $              FNAVB,FNSEL,
     $              FNUVE,FNUVT,FNU3D,
     $              FNV3D,FNQQE,FNQ3D,
     $              CNTMSR
C
C**********************************************************************C
      COMMON/A1/  CU1(LCM,KCM),     CU2(LCM,KCM),
     2            UUU(LCM,KCM),     VVV(LCM,KCM),  WWW(LCM,0:KCM),
     3             DU(LCM,KCM),      DV(LCM,KCM),
     4             FX(LCM,KCM),      FY(LCM,KCM),
     5             FBBX(LCM,KCM),    FBBY(LCM,KCM),
     6             CAP(LCM,KCM),    CAM(LCM,KCM), CAS(LCM,KCM),
     7             CAN(LCM,KCM),    CAE(LCM,KCM), CAW(LCM,KCM),
     8             RSDZ(LCM,KCM), BH(LCM,KCM)
C
C**********************************************************************C
```

It should be noted that ‘efdc.com’ does not require change from application to application, since its arrays are dynamically allocated in the parameter file, ‘**efdc.par**’, shown below:

```
C **  EFDC PARAMETER FILE - YORK RIVER  (Mac Sisson)
C **  LAST MODIFIED ON 15 MAY 1996
C
C   IMPLICIT REAL*8 (A-H,O-Z)
    PARAMETER (KSM=7,KCM=8,KGM=8,LCM=3588,ICM=320,JCM=331,
   $     IGM=320,JGM=331,KPCM=1,NWGGM=3587,NTSM=2000,NPDM=10,
   $     NPBSM=2,NPBWM=2,NPBEM=17,NPBNM=2,NGLM=2,
   $     NVBSM=1,NVBNM=1,NUBWM=1,NUBEM=1,LCMW=1,LCGLM=2,
   $     NQSIJM=2,NQSERM=20,NCSERM=20,NQCTLM=2,
   $     NQWRM=2,NPSERM=20,NDQSER=2000,NVEGTPM=20,
   $     NBBSM=2,NBBWM=2,NBBEM=17,NBBNM=2,
   $     MTM=1,MLM=10,MGM=2,NPFORM=12,MLTMSRM=99)
C
C    ICM= MAXIMUM X OR I CELL INDEX TO SPECIFIC GRID IN
C         FILE cell.inp
C    IGM= ICM+1
C    JCM= MAXIMUM Y OR J CELL INDEX TO SPECIFIC GRID IN
C         FILE cell.inp
C    JGM= JCM+1
C    KCM= MAXIMUM NUMBER OF LAYERS, MAX LOOP INDEX KC
C    KGM= KCM
C    KSM= KCM-1
C   KPCM= MAXIMUM NUMBER OF CONSTANT ELEVATION LEVELS FOR
C         THREE DIMENSION GRAPHIC OUTPUT
C    LCM= MAXIMUM NUMBER OF WATER CELLS + 2
C         OR 1 + THE MAX LOOP INDEX LA
C   LCMW= SET TO LCM IF ISWAVE.GE.1 OTHERWISE =2
C  LCGLM= SET TO LCM IF ISLRD.GE.1 OTHERWISE =2
C    MGM= 2*MTM
C    MLM= MAXIMUN NUMBER OF HARMONIC ANALYSIS LOCATION
C    MTM= MAXIMUM NUMBER OF PERIODIC FORCING CONSTITUENTS
C MLTMSRM= MAXIMUM NUMBER OF TIME SERIES SAVE LOCATIONS
C NCHANM= MAXIMUM NUMBER OF SUBGRID SCALE CHANNEL HOST CELLS
C NCSERM= MAXIMUM NUMBER OF CONCENTRATION TIME SERIES FOR
C         ANY CONCENTRATION VARIABLE
C   NGLM= NUMBER OF ISLRD PARTICLE RELEASE TIMES
```

```
C    NBBEM= NPBEM, NBBNM=NBBNM, NBBSM=NBBSM, NBBWM=NBBWM
C   NDQSER= MAXIMUM NUMBER OF TIME POINTS IN THE LONGEST TIME SERIES
C    NPBEM= MAXIMUM NUMBER OF EAST OPEN SURFACE ELEV BOUNDARIES
C    NPBNM= MAXIMUM NUMBER OF EAST OPEN SURFACE ELEV BOUNDARIES
C    NPBSM= MAXIMUM NUMBER OF EAST OPEN SURFACE ELEV BOUNDARIES
C    NPBWM= MAXIMUM NUMBER OF EAST OPEN SURFACE ELEV BOUNDARIES
C     NPDM= MAXIMUM NUMBER OF ISPD TYPE PARTICLE DRIFTERS
C   NPFORM= MAXIMUM NUMBER OF PERIODIC FORCING FUNCTIONS
C   NPSERM= MAXIMUM NUMBER OF SURFACE ELEVATION TIME SERIES
C   NQCTLM= MAXIMUM NUMBER OF FLOW CONTROL STRUCTURES
C   NQSERM= MAXIMUM NUMBER OF FLOW TIME SERIES
C   NQSIJM= MAXIMUM NUMBER OF NQSIJ VOLUMETRIC SOURCE-SINKS
C    NQWRM= MAXIMUM NUMBER OF FLOW WITH-RETURN PAIRS
C     NTSM= MAXIMUM NUMBER OF TIME STEP PER REFERENCE TIME PERIOD
C    NUBEM= 1, NUBWM= 1, NVBNM= 1, NVBSM= 1
C  NVEGTPM= MAXIMUM NUMBER OF VEGETATION TYPE CLASSES
C    NWGGM= NUMBER OF WATER CELLS IN CARTESIAN GRAPHIC OVERLAY
C          GRID, EQUAL TO LCM-2 FOR CARTESIAN GRIDS
```

Two files output by the grid generator ('**dxdy.out**' and '**lxly.out**') are renamed to '**dxdy.inp'** and '**lxly.inp**' and used as input to the hydrodynamic portion. Each devotes a full card image to each horizontal cell in the grid.

File '**dxdy.inp**', shown below, includes for each cell, the i and j indices (fields 1 and 2), the x & y horizontal dimensions (m) (fields 3 and 4), depth and bottom elevation (fields 5 and 6), and bottom roughness and vegetation class (fields 7 and 8):

```
C       dxdy.inp file, in free format across line
       C
C
C
   239    35   .25000E+03   .25000E+03   .12449E+01  -.12449E+01   .15000E-02   .00000E+00
   239    36   .25000E+03   .25000E+03   .12603E+01  -.12603E+01   .15000E-02   .00000E+00
           .
           .
   131   179   .28092E+03   .37393E+03   .44894E+01  -.44894E+01   .15000E-02   .00000E+00
   124   180   .30570E+03   .23271E+03   .46920E+01  -.46920E+01   .14000E-02   .00000E+00
           .
           .
   279   180   .20000E+04   .30000E+02   .20000E+01  -.20000E+01   .14000E-02   .00000E+00
   124   181   .30854E+03   .21068E+03   .43484E+01  -.43484E+01   .12000E-02   .00000E+00
           .
           .
    82   150   .25000E+03   .25000E+03   .05000E+01  -.05000E+01   .12000E-02   .00000E+00
           .
           .
    82   172   .22160E+03   .22160E+03   .05000E+01  -.05000E+01   .12000E-02   .00000E+00
           .
           .
   102   172   .38730E+03   .38730E+03   .05000E+01  -.05000E+01   .12000E-02   .00000E+00
```

The 9 records shown above represent cells which differ greatly. The first 2 records (i.e., i=239) corresponds to cells in the Cartesian portion of the grid, where the constant gridlength is 250 m (fields 3 and 4). The next record represents a curvilinear cell just below West Point, whereas record 4 represents a cell in the Mattaponi tributary. The last 3 records represent marsh cells, whose various horizontal dimensions must conform to the areal estimates of the marshes to which they correspond. Inspection of field 7 shows various bottom friction multipliers used in the calibration effort.

The file '**lxly.inp**' specifies both the horizontal cell center coordinates (UTM) but also the cell orientations (Cartesian or curvilinear). Sample records from '**lxly.inp**' are shown below:

```
 C lxly.inp file, in free format across line
C
C    I     J    XLNUTME       YLTUTMN        CCUE            CCVE          CCUN         CCVN
C
    239      35   0.369625E+03   0.118625E+03   0.100000E+01   0.000000E+00   0.000000E+00
0.100000E+01
    239      36   0.369625E+03   0.118875E+03   0.100000E+01   0.000000E+00   0.000000E+00
0.100000E+01
    239      37   0.369625E+03   0.119125E+03   0.100000E+01   0.000000E+00   0.000000E+00
0.100000E+01
         .
         .
         .
    123     173   0.340621E+03   0.153122E+03   0.999881E+00  -0.313617E-01   0.154468E-01
0.999508E+00
    124     173   0.340866E+03   0.153127E+03   0.999634E+00  -0.716428E-01   0.270465E-01
0.997430E+00
    125     173   0.341114E+03   0.153134E+03   0.999549E+00  -0.850466E-01   0.300370E-01
0.996377E+00
         .
         .
         .
     82    150    .330375E+03    .147375E+03    .100000E+01    .000000E+00    .000000E+00
.100000E+01
     84    150    .330875E+03    .147375E+03    .100000E+01    .000000E+00    .000000E+00
.100000E+01
     86    150    .331375E+03    .147375E+03    .100000E+01    .000000E+00    .000000E+00
.100000E+01
```

The first 3 records represent Cartesian cells and are by definition normal and have center spacing of 250 m, or the gridlength. The next 3 records are for curvilinear cells and have a more irregular spacing. And yet the orientation is nearly orthogonal.

The file '**salt.inp'** is used to initialize the model domain with a pre-determined salinity field. Each cell is represented by a card image with a horizontal cell counter in field 1 and i & j in fields 2 and 3. Salinity for the bottom layer is in field 4, and progressive fields denote salinities moving up the water column:

```
    2 239  35 17.19 17.08 17.08 17.08 17.08 17.08 17.08 17.08
    3 239  36 16.58 16.36 16.36 16.36 16.36 16.36 16.36 16.36
    4 239  37 16.76 16.64 16.64 16.64 16.64 16.64 16.64 16.64
          .
 2020 166 126  9.85  9.44  9.44  9.44  9.44  9.44  9.44  9.44
 2021 167 126  9.70  9.44  9.44  9.44  9.44  9.44  9.44  9.44
 2022 168 126  9.61  9.43  9.43  9.43  9.43  9.43  9.43  9.43
          .
 2834 133 171  7.12  7.10  7.10  7.10  7.10  7.10  7.10  7.10
 2835 134 171  7.11  7.10  7.10  7.10  7.10  7.10  7.10  7.10
          .
 3309 124 351   .00   .00   .00   .00   .00   .00   .00   .00
 3310 124 352   .00   .00   .00   .00   .00   .00   .00   .00
```

The file **'modchan.inp**' handles the mapping of the 'marsh cells' into the tributary portions to which they are attached (see Section IIIf.) In the following example, several header lines are followed by 8 examples of mapping. Note the value '200' on line 9, specifying the number of marsh cells (and consequently also subsequent lines). The first 4 mappings (i.e., those records having a '1' in column 1) map 'host cells' connecting to 'marsh cells' in the y-direction. Here, the 'host cell' at i=135,j=180 connects to the 'marsh cell' located in i=108, j=150. The last 4 mappings (i.e, those records having a '2' in column 1) map 'host cells' to 'marsh cells' in the y-direction:

```
C modchan.inp file, in free format across columns
C # host cells  MDCHHD=1 wet host from chan  MDCHHD2=1 dry ck first
C MDCHH         MDCHHD            MDCHHD2
C max iters     MDCHHQ=1 int Q=0   QCHERR= abs error for flow cms
C MDCITM        MDCHHQ            QCHERR
C type     i host  j host  i uchan  j uchan  i vchan  j vchan
C MDCHTYP  IMDCHH  JMDCHH  IMDCHU   JMDCHU   IMDCHV   JMDCHH
C
    200           1              1
    20           1              0.01
1     135   180   108   150   1     1
1     136   180   110   150   1     1
1     137   180   82    152   1     1
          .
          .
1     211   180   104   160   1     1
2     124   194   1     1     110   162
2     124   195   1     1     82    164
2     124   196   1     1     84    164
          .
2     124   319   1     1     127   319
```

Finally, 2 other input files provide for, respectively, a soil moisture model ('**gwater.inp**') and input of toxicity parameters (**'txser.inp**'). These were not utilized in this application but, due to their brevity, are listed below to complete the input file group:

```
C gwater.inp file, in free format across columns
C   ISGWIE
C     1 for on
C   DAGWZ        RNPOR         RIFTRM
C dep act gw  eff porosity  max infilt rate
C
    0
    0.4          0.3           0.0001
```

```
C  txser.inp file, toxic is nc=6 conc, in free format across line, Pu york
C  repeats ncser(3) times, test case
C
8
C  ISTYP  MCSER(NS,3)  TCCSER(NS,3)  TACSER(NS,3)  RMULADJ(NS,3)  ADDADJ(NS,3)
0
C
C  if istyp.eq.1 then read depth weights and single value of CSER
C
C  (WKQ(K),K=1,KC)
C
C  TCSER(M,NS,3)   CSER(M,NS,3)  !(mcser(ns,3) pairs for ns=3,ncser(3) series)
C
C  else read a value of dser for each layer
C
C  TCSER(M,NS,3)   (CSER(M,K,NS,3),K=1,KC) !(mcser(ns,3) pairs)
```

```
C
    1     6     3600.0     0.     1.    0.
    0.00    0.00   0.00   0.00   0.00   0.00   0.00   1.00
-1000.00000        0.0
   10.99167        0.0
   11.00000        3.702E+7
   11.50000        3.702E+7
   11.50833        0.0
 1000.00000        0.0
   1     6     3600.0     0.     1.    0.
    0.00    0.00   0.00   0.00   0.00   0.00   0.00   1.00
-1000.00000        0.0
   10.99167        0.0
   11.00000        9.856E+6
   11.50000        9.856E+6
   11.50833        0.0
 1000.00000        0.0
```

Examples of verification files (**'qser.inp', 'pser.inp', 'aser.inp'**)

Time series data for freshwater discharge is input to HEM-3D via the file '**qser.inp**'. Below is a short example showing how easy it is to input USGS daily values directly, first for the Pamunkey gauge (June 1, 2, 3 ..... September 25, 26) and then for the Mataponi gauge as well (note corresponding time array in exponential format). Discharges are easily converted from cfs to model input unit cms by specifying the .0283 constant in the header:

```
C qser.inp
C
C
1         118       3600   0.000000       0.283000E-01   0.000000       1
   0.1250   0.1250   0.1250   0.1250   0.1250  0.1250   0.1250   0.1250
          1    472.000    1989.06.01
         25    436.000    1989.06.02
         49    308.000    1989.06.03
                              .
       2785    642.000    1989.09.25
       2809    926.000    1989.09.26
1        118        3600   0.000000       0.283000E-01   0.000000      1
   0.1250  0.1250  0.1250  0.1250  0.1250   0.1250  0.1250  0.1250
  1.0000000e+000  2.6178554e+002
  2.5000000e+001  2.4548842e+002
  4.9000000e+001  3.1773895e+002
                              .
  2.7850000e+003  1.2189693e+003
  2.8090000e+003  1.4134481e+003
```

The file **'pser.inp'** specifies the tidal height time series at the open seaward boundary. Illustrated is the beginning and end of a 2500 hour-long hourly specification starting at 10 a.m. on June 1, 1989:

```
C pser.inp file, in free format across line
C
C MPSER(NS) TCPSER(NS) TAPSER(NS) RMULADJ  ADDADJ
C
C  TPSER(M.NS) PSER(M,NS)
C
    2500    3600      0.      0.81     -1.446
    1.00    1.19                       01JUN89:10
```

```
    2.00    1.03                         01JUN89:11
    3.00    0.94                         01JUN89:12
    4.00    0.95                         01JUN89:13
    5.00    1.09                         01JUN89:14
           .
           .
           .
 2496.00    1.80                         13SEP89:09
 2497.00    1.64                         13SEP89:10
 2498.00    1.46                         13SEP89:11
 2499.00    1.34                         13SEP89:12
 2500.00    1.31                         13SEP89:13
```

Atmospheric input, especially wind speed and direction, is important to the model and is input via file '**aser.inp**'. shown below:

```
C  aser.inp file, in free format across line, repeats naser=1 times, test case
C
8
C  MASER   TCASER   TAASER   WINDSCT  RAINCVT  EVAPCVT
0
C
C  TASER(M) WINDS(M) WINDD(M) PATM(M) TDRY(M) TWET(M) RAIN(M) EVAP(M) SOLSWR(M)
C
183    86400  0      1      1      1      1
-1     2.96   115    0      0      0      0      0      0      1      245
2      2.8    97     0      0      0      0      0      0      2      263
3      1.23   186    0      0      0      0      0      0      3      174
4      4.13   129    0      0      0      0      0      0      4      231
5      2.77   146    0      0      0      0      0      0      5      214
          .
          .
          .
181    5.03   129    0      0      0      0      0      0      28     231
182    3.7    17     0      0      0      0      0      0      29     343
183    3.48   111    0      0      0      0      0      0      30     249
```

Salinity specification at the river mouth is an important part of a verification run. In the following example, file is used to specify salinities at all 8 layers at the elapsed model time hours specified in the first field (i.e., 576, 577, 721, 1105, 1249. 1513, 1728):

```
C
C sser.inp
C
C
0          7        3600   -577.0000       1   0.000000    1
576    22.7  22.0   21.7   20.1  19.9  19.6  19.6  19.0  16.6     1989.11.25
577    22.7  22.0   21.7   20.1  19.9  19.6  19.6  19.0  16.6     1989.11.25
721    23.0  22.7   22.6   22.5  22.4  21.9  21.5  21.1  21.1     1989.12.01
1105   24.0  23.7   23.6   23.5  23.4  22.9  22.5  22.1  22.1     1989.12.17
1249   26.5  26.5   26.2   25.5  25.4  24.9  24.5  24.1  24.1     1989.12.23
1513   25.2  24.7   24.6   24.5  24.4  23.9  23.5  23.4  23.4     1990.01.03
1728   25.4  25.0   24.8   24.2  23.2  23.0  23.6  23.5  23.5     1990.01.11
```