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The one-dimensional numerical model developed by Carl R. Goodwin is applied to the Siuslaw estuary. Vertical displacement, horizontal velocity and flow of the water as a function of time and distance from the mouth given by the model are compared with field observations taken under different water mixing conditions in the estuary.

The model is considered adequate under well mixed and partially mixed conditions, and inadequate under strongly stratified conditions.

Estimations of deviations between model predictions and field observations are presented.

Nomograms are constructed from model predictions of amplification factors, high water time lags, maximum flood velocities,

maximum ebb velocities, low water time lags, maximum flood flows, maximum ebb flows, high slack water time lags and low slack water time lags, as a function of river flow, ocean tidal range and river mile for a range of 0 to 6000 cubic feet per second (0 to 170 cubic meters per second) of river flow, and 1 to 11 feet (0.30 to 3.35 meters) of ocean tidal range. These nomograms are considered adequate for predictive purposes during well mixed and partially mixed conditions of the estuary waters.

One-Dimensional Numerical Model Test and Predictions for the Siuslaw Estuary

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

ONE-DIMENSIONAL NUMERICAL MODEL TEST AND PREDICTIONS FOR THE SIUSLAW ESTUARY

I. INTRODUCTION

Background on Tidal Prediction Models

Tidal propagation problems in rivers, coastal areas and seas are usually examined by either physical modeling or by analytical methods.

Physical models, like those built by the U.S. Army Corps of Engineers Waterways Experiment Station (Ippen and Harleman, 13), are useful for predicting the probable effects of proposed engineering works on tidal flows. However, the inherent costs in time and money restrict their use only to the solution of major problems.

Analytical approaches can be classified, according to Harleman and Lee (12) as: harmonic methods, methods of characteristics, and finite difference methods. Several hundreds of studies have been carried out in which analytical methods have been used to examine tidal propagation problems in estuaries.

In the harmonic method, the differential equations of continuity and momentum are linearized by neglecting the advective terms and assuming the friction term has a linear expression. In addition, it is assumed that the geometrical variation of the channel area is an algebraic function of the distance from the mouth. This last assumption makes difficult the applicability of this method to irregularly shaped estuaries. The solution appears to be as the propagation of a superposition of sinusoidal waves representing the almost periodical and continuous character of the tidal motion.

In the method of characteristics, tidal motion is considered as a propagation of a succession of small disturbances from an initial state, with the periodic character placed in the background. Infinitely small discontinuities propagate along the so called characteristics defined as lines on an x, t (distance and time) diagram. The course of the characteristics is rather arbitrary and the method is less convenient than others for making computations (Dronkers, 6). The solution is found graphically. This procedure is extremely cumbersome and slow (Harleman and Lee, 12), although now it can be done partly by computer.

In the finite difference method, the momentum and continuity equations are expressed in a finite difference form. The system is solved by an iterative procedure in a high speed digital computer. Non-linearity does not constitute a problem in this method. If we consider a one-dimensional tidal problem, there are two independent variables x and t as a solution domain diagram where the dependent variables velocity and displacement can be defined at any point between the end boundaries.

Two numerical methods are used to solve the grid system: an explicit and an implicit scheme. In the explicit scheme, the equation at each x level includes only one unknown, the solution at any time level being computed one at a time from various known values of the unknown at the prior time level. In the implicit scheme, various unknowns are present in the equation for each x level, and the resulting set of equations for all time levels are solved simultaneously, or by a convergent iterative method.

Both finite difference schemes are applicable to a wide variety of problems. They can be used to reproduce non-linear effects of tidal channels of many irregular shapes, and accept rather complicated boundary conditions. Many computer programs have been developed for this method.

Examples of use of the harmonic method are Evangelisti (7) and Ippen (14).

An example of the use of the method of characteristics is Liggett and Woolhiser (18).

Examples of use of the explicit finite difference method are Hansen (11), Otter and Day (28), and Harleman and Lee (12).

Examples of use of the implicit finite difference method are Lai (17), Dronkers (6), and Goodwin (10).

Siuslaw Estuary Description and Background Field Studies

The Siuslaw River rises in the Coast Range near Cottage Grove, Oregon, flows westward along a winding 108-mile (174-kilometer) course in the Mid-Coast basin of Oregon, and discharges into the Pacific Ocean at latitude 44° 01' N, about 160 miles (257 kilometers) south of the mouth of the Columbia River and 485 miles (780 kilometers) north of San Francisco Bay.

Tidewater in the estuary extends from the mouth to river mile 22.5 (kilometer 36.2) (24) near the city of Mapleton. Upstream of this point the river flows over a rocky bed in a series of rapids and pools; downstream the river begins to meander across a 1,000-foot (305-meter)-wide flood plain which gradually widens to about 5,000 feet (1,524 meters) just 2 miles (3.2 kilometers) above the city of Florence (located on river mile 5.0 or kilometer 8.0) whence it flows across a relatively level coastal strand to the mouth (32) (Figure 1).

Industrial and commercial incomes in the Siuslaw Basin are derived primarily from the forests. The estuary is used for log storage, towing and barging (29). Commercial fishing, mainly for shad and crab, is quite limited (29), although Giger (8) mentioned that this estuary supports the world's largest searun cutthroat fishery. At present there is no evidence of a significant increase in human interference with the estuary, although recreation and tourism activities are growing in importance (32).

Several physical alterations have been planned and constructed by the U.S. Army Corps of Engineers: a 300 foot (91.4 meter)-wide, 18 foot (5.5 meter)-deep, 3000 foot (914.4 meter)-long entrance channel stabilized by two rubblemound jetties, followed by a 200 foot (61.0 meter)-wide, 16 foot (4.9 meter)-deep channel extending to Florence (river mile 5.0 or kilometer 8.0), followed by a 150 foot (45.7 meter)-wide, 12 foot (3.7 meter)-deep channel to Cushman (river mile 8.0 or kilometer 12.9), followed by a 100 foot (30.5 meter)-wide, 10 foot (3.1 meter)-deep channel to Mapleton (river mile 20.5 or kilometer 33.0) (32). A new modification has been proposed which consists of extending the 150 foot (45.7 meter)-wide, 12 foot (3.7 meter)-deep channel from Cushman to river mile 16.5 (kilometer 26.6). Dredging would be required in two shoal areas at river mile 14.0 (kilometer 22.5) and 15.7 (kilometer 25.3) (32). With this new channel an average of 7 to 8 hours of delay time would be eliminated from barge trips downstream. However, it has been stated (32) that the environmental impact would include: the destruction of the benthic community in twelve subaqueous acres (five square hectometers); change in summer distribution of cutthroat trout and salmon as a consequence of a moderation in the upper estuary temperature related to the increase in saltwater intrusion; and blocking of the movement of the fish upriver until the fall season.

Physical data for the Siuslaw river are available from many sources; Pearcy et al. (29) provide a broad summary of much of the known physical, chemical and biological information, and a list of references on the subject.

Normal flow of the river has been estimated as 3, 150 cubic feet per second (89.2 cubic meter per second) (1). The U.S. Geological Survey operates a gaging station at river mile 23.7 (kilometer 38.1) (head of the estuary); three years of records in the period 1967-1970 show extreme flows of 70 cubic feet per second (2.0 cubic meter per second) and 32, 300 cubic feet per second (914.6 cubic meter per second) (33).

Surface areas of 2, 245 acres (9.09 square kilometers) at mean high water and 1, 489 acres (6.03 square kilometers) at mean low water have been estimated by the Oregon Division of State Lands (25); Johnson (15) gives a value of 1, 458 acres (5.90 square kilometers) at high water; Marriage (20) gives a value of 1, 589 acres (6.43 square kilometers) at an unspecified tidal stage; and finally Utt (35) computes values of 1, 312 acres (5.31 square kilometers) and 1, 270 acres (5.14 square kilometers) at mean tide level from the data given by O'Brien (23) and Johnson (15) respectively (definitions of tidal terms like "mean high water", "mean low water" and "high water" are given in the Appendix).

The tidal prism has been estimated as 4.81×10^{8} cubic feet (13.6×10^{6} cubic meters) at diurnal range by O'Brien (23), and as 2.76×10^{8} cubic feet (7.82×10^{6} cubic meters) at mean tide range and 3.66 x 10^8 cubic feet (10.4 x 10^6 cubic meters) at diurnal range by Johnson (16).

A mean tide range of 5.2 feet (1.58 meters), a mean diurnal range of 6.9 feet (2.10 meters), and an extreme range of 11.0 feet (3.35 meters) at the mouth; a mean tide range of 5.0 feet (1.52 meters) and a mean diurnal range of 6.6 feet (2.01 meters) at Florence have been reported (34), (26), (32).

Between the mouth and the head of the estuary there are approximately 44 tributaries (27). The North Fork of the Siuslaw River is the major tributary with a length of 25.8 miles (41.5 kilometers), it enters the Siuslaw at river mile 6.3 (kilometer 10.1) (27).

The flow of Siuslaw River responds quickly to changes in runoff and precipitation with an annual pattern of high flows during the wet winter months and low flows during the dry summer and early fall months (32).

Burt and McAllister (2) measured salinity in the Siuslaw river during October 1957 and January, March and July 1958. Data showed a considerable seasonal variation in the upstream limit of bottom salinity, i.e. from river mile 17.3 (kilometer 27.8) on October 7 to river mile 4.4 (kilometer 7.1) on January 28. Based on the observed salinity change from top to bottom, Burt and McAllister (3) classified the estuary as a stratified system in January and May, a partly-mixed system in March and a well mixed system in October.

Giger (8) measured salinity during August 1967 and February-March 1968 and found that in winter the wedge of seawater extended only a few miles upstream on both high and low tide, transition from fresh to salt water taking place in a short distance. In summer salt-water influence reached throughout the estuary at high tide and nearly so at low tide, transition being considerably more gradual than in winter. Stratification is not evident at high tide due to the low flow of fresh water.

Utt (35) measured maximum and minimum tidal water displacements on January, April, August and November 1973 for 14 days on each period, and at 4 different locations: river miles 2.0, 8.0, 16.0, and 22.0 (kilometers: 3.2, 12.9, 25.8, and 35.4); and also measured ebb and flood velocities on January 31, August 2, August 3, and November 19 of the same year at two different locations: river miles 4.5 and 8.0 (kilometers 7.2 and 12.9) (for these four days the tidal range at the mouth was approximately 6.0 feet or 1.8 meters). Based on his measurements he concluded that:

a) tidal ranges measured near the entrance are in good agreement with those predicted by NOAA;

b) amplification factors (ratio of the tidal range at a given point to the tidal range at the entrance) vary with the tidal range for low riverflow summer conditions;

c) maximum ebb and flood surface velocities along the river occur at the same locations;

d) surface velocity patterns are those of a fluvial channel, i.e. maximum velocities at mid-channel and concave banks, and reduced velocities in broad sections;

e) maximum velocities occur 3 hours after maximum tidal height at a given location, indicating that the tidal movement progresses as an intermediate wave (between a progressive and a standing) more close to a weakly damped standing wave, with damping dependent on riverflow;

f) mixing conditions in the estuary depend strongly on river flow: for low freshwater inflow (May and August) the system is well mixed, with increasing freshwater inflow (January) the system becomes partial mixed, and finally for high freshwater inflow (November) the system is stratified.

NOAA (22) measured tidal water displacements daily on August, September, October and November 1974 at 5 different locations: river miles 0.0, 5.0, 14.7, and 20.5 (kilometers: 0.0, 8.0, 13.2, 23.7 and 33.0).

No physical model has been built for the Siuslaw estuary (29).

Until the present time it seems that no attempt has been made to apply an analytical model to Siuslaw estuary.

Goodwin's One-Dimensional Numerical Model

As Goodwin explains in his thesis work (10), this one-dimensional, implicit, finite-difference numerical model is based on a simplified version of the equation of motion and the continuity equation as given by Dronkers (5) and obtained through the following assumptions:

- one-dimensional motion
- homogeneous fluid
- negligible wind forces
- negligible Coriolis force
- no tributary inflow along the estuary
- flow to and from the storage areas has no inertial effect on the motion in the main channel
- water particle velocities are less than the critical for hydraulic jumps
- channel bottom is horizontal in each river segment
- the Chezy friction relationship (equation 3, page 20) is adequate.

The equations, following Dronkers (5), are:

$$\frac{\partial H}{\partial x} + \frac{1}{gAC}\frac{\partial Q}{\partial t} - \frac{BT\,Q}{gAC^2}\frac{\partial H}{\partial t} + \frac{BC}{C^2AC^3}\left|Q\right| Q = 0 \qquad (1)$$

$$\frac{\partial Q}{\partial x} + BT\frac{\partial H}{\partial t} = 0 \quad \text{or} \quad Q + AS\frac{\partial H}{\partial t} = 0 \qquad (2)$$

where:

H = instantaneous difference in height between actual water level and mean sea level

Q = instantaneous discharge through a cross section

x = distance from the mouth of the estuary

AS = total surface area of a channel segment

AC = cross sectional area of the conveyance channel

BT = total surface width of the river channel

BC = surface width of the conveyance channel

C = Chezy friction coefficient

g = gravitational acceleration

t = time

To perform the numerical integration of these partial differential equations for a given estuary, we need first to schematize the estuary. By schematization we mean that the estuary is divided into a certain number of segments in which it is assumed that the stream width, depth and bottom slope do not vary over the length of the segment, but only depend on time. Goodwin (10) suggests the following guidelines to perform this schematization:

a) keep physically similar regions together in one segment

b) choose as break-points between segments the controlling cross-sectional areas like shallow or constricting points, ocean or landward limits of a bay.

The following parameters are defined at the segment centroids:

tidal water surface displacement, segment surface area and segment total surface width.

The following parameters are defined at the segment ends: tidal discharge, tidal velocity, channel cross sectional area, channel surface width, channel length between segment centroids, Chezy friction coefficient.

Then, finite-difference approximations for the equations can be written for each estuary segment at each chosen time step. The tidal water surface displacement H, velocity V and discharge Q can be obtained as a solution of this system of equations by an iterative process where the river inflow and the ocean tidal displacement are provided as boundary conditions, and within a predetermined convergence error limit.

Goodwin (10) states that it is reasonable to assume that finite difference approximations to these equations, like those for the wave equation, are unconditionally stable. A stable situation is understood to be one in which the rounding numerical errors generated by the computational procedure in solving the finite-difference equation are not amplified in an unlimited way enough to overshadow the actual solution of the equation.

Input to the model, as programmed for the CDC 3300 computer at Oregon State University requires the following data to be provided:

a) for each estuary segment:

IC conveyance channel cross-sectional area at MSL (ft^2)

SC conveyance channel side slope (adimensional)

ULC upper limit of cross-sectional area at MHHW (ft^2)

LLC lower limit of cross-sectional area at MLLW (ft^2)

B top width of conveyance channel at MSL (ft)

IS intercept at MSL of the linear relation between surface area and vertical water displacement (ft^2)

SS slope of the linear relation between surface area and vertical water displacement (ft)

ULS upper limit of surface area at MHHW (ft^2)

LLS lower limit of surface area at MLLW (ft^2)

L distance between adjacent segment centroids (ft)

CA average value of Chezy friction coefficient at MSL ($ft^{\frac{1}{2}}/sec$)

b) general information as follows:

- number of segments (adimensional)
- time interval increment for computation (degrees of cycle)
- time interval increment for output (degrees of cycle)
- river fresh water inflow (ft^3/sec)
- ocean tidal amplitude (ft)
- ocean offset from MSL (ft)
- error limit for the computed river fresh water inflow with respect to the given value (%)
- error limit for the computed ocean tidal amplitude with respect to

the given value (%)

- number of iterations limit (adimensional)

The computer model output gives the following information:

- tidal water surface displacement H for each segment centroid at the time interval increments chosen for output, in feet.
- water velocity V and flow Q for each segment end point at one-half of a computation time interval before the displacement H time output, in feet/sec and $feet^3/sec$ respectively.
- a summary table containing:
  a) maximum and minimum displacements and their times of occurrence for each segment centroid
  b) maximum and minimum velocities and flows and their times of occurrence for each segment end point
  c) slack water (no flow) time occurrences for each segment end point
  d) amplification factors (tidal range at a given point divided by ocean tidal range) for each segment centroid

The model was applied by Goodwin (10) to Yaquina, Alsea and Siletz estuaries, and the output information compared with hydraulic data collected by Goodwin, Emmett and Glenne (9) under summer conditions (well-mixed system). Predicted peak values for displacement and velocity agree in general with the measured ones within 0.2 feet (6 centimeters) and 0.5 feet/second (15 centimeters/second) respectively; observed values being higher. Times of occurrence agree within 6.0 degrees of tidal cycle (12 minutes).

Purpose of this Thesis

This work intends to satisfy two main objectives:

a) determine how well Goodwin's one-dimensional model simulates the real hydraulic behavior of Siuslaw estuary under well-mixed, partially-mixed and stratified conditions, with an estimation of the deviations between model predictions and field observations.

b) develop nomograms to be used as a predictive tool for the hydraulic behavior of the estuary under all river flow and ocean tidal range conditions covered within the limits of model applicability.

SI-unit equivalents are given for the British-unit numerical expressions and graph scales whenever it is possible in this study. In some other cases, like nomogram scales and tables, conversion factors are given.

II. MODEL APPLICATION

Estuary Schematization

The Siuslaw estuary was divided into four segments according to the guidelines explained in the last chapter. The first segment (A) corresponds to the relatively level coastal strand running from the mouth to Florence. The second segment (B) corresponds to the broad and shallow embayment where the North Fork Siuslaw River discharges. The third segment (C) occupies the region where the estuary flow is partially divided by Duncan Inlet. And finally, the fourth segment (D) corresponds to the upper part of the estuary close to the head characterized as being a single channel with no major tributaries. These four segments can be seen graphically on Figure 1. Location of segment centroids and end points is given on Table 1.

Table 1. Segment Centroids and End Points Location

Segment	Distance from Estuary Mouth (miles)* End Point	Centroid
A	1.0	2.75
B	4.5	6.25
C	8.0	11.20
D	14.4	18.45

* 1 mile = 1.609 kilometers

Geometrical Data Input

Next we have a list of geometrical parameters characterizing the estuary segments, their source and how they were obtained. Numerical values obtained are given in Table 2.

IC conveyance channel cross-sectional area at MSL: total cross-sectional areas at different locations were obtained from soundings on Corps of Engineers charts #SL I 199, 197, 189, 198, 182 and Coast and Geodetical Survey chart #6023 reduced to MSL with the datum given on those charts. For the upper segment (D), soundings were made by us in one location. To obtain the conveyance channel cross-sectional area a trapezoid with equal side slopes was adjusted to each cross section. This is one of the main sources of error of this procedure, irregularly shaped cross-sections should be neglected, and indeed, a careful adjustment of the trapezoidal channel is a matter of experience (Dronkers) (5), final values being obtained only after the calibration procedure. For examples on regular and irregular cross-sections and trapezoidal fitting see Figure 2.

SC conveyance channel side slope: directly measured on the trapezoidal cross-sections already obtained.

ULC and LLC upper limit and lower limit of cross-sectional area: obtained in the same way as IC.

B top width of conveyance channel at MSL: directly measured on the trapezoidal cross-sections already obtained.

IS intercept at MSL of the linear relation between surface area and vertical water displacement: surface area at MLLW and MHHW were obtained by a planimetric measurement on a Map of the Siuslaw River published by the Oregon Division of State Lands and a U.S. Geological Survey Map of Mapleton. The values obtained were plotted against water displacement (see Figure 3), a linear relation assumed, and the required intercept graphically obtained.

SS slope of the linear relation between surface area and vertical water displacement: directly obtained from the graph already done.

ULS and LLS upper limit and lower limit of surface area: measured on the same maps already mentioned for the raw data of IS determination.

L distance between adjacent segment centroids: determined by the schematization process.

CA average value of Chezy friction coefficient at MSL: this determination is the second main source of error in the process, and the final values can be obtained only after the calibration of the model. Friction coefficients are not directly measurable, and indirect methods of determination are difficult due to the

Table 2. Siuslaw Estuary Segments Geometrical Data

Segment	IC feet^2	SC	ULC feet^2	LLC feet^2	B feet	IS feet^2 x10^7	SS feet x10^5	ULS feet^2 x10^7	LLS feet^2 x10^7	L feet	CA feet$^{\frac{1}{2}}$/sec
A	14,610	7.6	17,440	11,785	830	2.30	9.24	2.61	2.00	18,480	90
B	12,970	13.4	15,765	9,570	1,050	2.44	18.11	2.88	1.74	18,480	85
C	7,550	4.4	9,063	6,510	427	1.88	3.58	2.00	1.78	26,136	90
D	6,300	3.7	8,030	5,570	420	1.34	1.67	1.41	1.31	38,280	85

SI-units conversion factors: 1 foot = 30.5 centimeters

$1 \text{ foot}^2 = 929 \text{ cm}^2$

$1 \text{ foot}^{\frac{1}{2}}/\text{sec} = 5.5 \text{ cm}^{\frac{1}{2}}/\text{sec}$

inherent unsteadiness of the tidal flow.

If we accept the Chezy relationship as adequate to describe frictional effects in the tidal flows:

$$v^2 = C^2 RS \tag{3}$$

where v is the velocity of the water, C is the Chezy friction coefficient, R is the hydraulic radius, and S is the bottom slope of the channel; then the Chezy friction coefficient can be obtained from the Manning equation:

$$C = (1.486/n)\, y^{1/6} \tag{4}$$

where n is the Manning roughness coefficient and y is the depth. The Manning coefficient will depend on size, density and shape of bottom roughness, suspended sediment and depth. For a major stream of regular section, values of n given by Chow (4) cover a range from 0.025 to 0.060. This would imply that for the average depths of Siuslaw estuary segments we should have a Chezy coefficient ranging from 42.0 to 101.0 feet$^{\frac{1}{2}}$/sec (23.2 to 55.8 meters$^{\frac{1}{2}}$/sec). Values given by different authors for estuaries in Denmark, Netherlands and Norway range from 45.0 to 127.0 feet$^{\frac{1}{2}}$/sec (24.8 to 70.1 meters$^{\frac{1}{2}}$/sec). Goodwin (10) used values from 85 to 90 feet$^{\frac{1}{2}}$/sec (46.9 to 49.7 meters$^{\frac{1}{2}}$/sec) for the Yaquina, Alsea and Siletz models. These values proved to be the best for the Siuslaw estuary model calibration perhaps because similar physical conditions exist on the bottom of all Oregon estuaries.

Computational Purpose Data Input

Time increment for computation was set as 10.0 degrees of tidal cycle (approximately 20.0 minutes).

Time increment for output was set as 30.0 degrees of tidal cycle (approximately 1.0 hours).

Error limit for the evaluated river inflow and the evaluated ocean tidal amplitude were set as 1%.

Limit of the number of iterations was set as 100.

Selection of Dates for Model Application

As the purpose of this work is to compare model predictions with field observations under well-mixed, partial mixed and stratified conditions, dates were selected to run the model when such field observations were available. Mixing conditions for the estuary in those days were estimated by the flow ratio value, although this is only an approximate criterion because mixing conditions depend also on the width and depth of the estuary. According to Pritchard (30), if we define flow ratio as ratio of fresh water flow per tidal cycle to the tidal prism, then:

flow ratio less than 0.1 means well mixed condition flow ratio in between 0.2 and 0.5 means partial mixed condition flow ratio greater than 1.0 means stratified condition.

For the Siuslaw estuary, if we assume that the total surface area = 1300 acres = 5.663×10^7 feet^2 = 5.26 kilometers^2 (close to O'Brien and Johnson values as computed by Utt (35)), then:

flow ratio = fresh water flow per tidal cycle/tidal prism

$$\text{flow ratio} = \frac{\text{fresh water flow} \times (44,640 \text{ sec})}{\text{tidal range} \times (5.663 \times 10^7 \text{ feet}^2)}$$

$$\text{flow ratio} = \frac{\text{fresh water flow}}{\text{tidal range}} \times 7.88 \times 10^{-4} \qquad (5)$$

where, fresh water flow is expressed in feet^3/sec and tidal range in feet; or,

$$\text{flow ratio} = \frac{\text{fresh water flow}}{\text{tidal range}} \times 8.49 \times 10^{-3} \qquad (5.1)$$

where, fresh water flow is expressed in meters^3/sec and tidal range in meters.

In a first instance, field data were available only from Utt (35). These included displacement, velocity and flow measurements for August 2, August 3 and November 19, 1973; flow ratios evaluated in accordance with the last expressions show for these three days that the estuary was well mixed, well mixed and partially stratified, respectively. Field data including displacement, velocity and flow were also available from our own measurements for July 24, 1974 under well mixed conditions. In addition, to complete our set of testing dates, two additional days were chosen for partially mixed and stratified conditions from Utt's data: February 5 and November 16, 1973. In this case only displacement information was available for these two days. Finally, ten days with the lowest flow ratio values were chosen for well mixed conditions from NOAA's (22) data: Sept. 17, Sept. 22, Sept. 27, Sept. 29, Sept. $29\frac{1}{2}$, Sept. 30, Oct. 1, Oct. 9, Oct. 10, and Oct. 11, 1974. Again, in this last case only displacement information was available.

Flow ratios evaluated with the last expressions for the sixteen days are given on Table 3.

Hydraulic Data Input

Fresh water flow and ocean tidal range for the sixteen days selected for testing the model are given on Table 3. Fresh water flows were obtained from U.S. Geological Survey records for Mapleton gauge station. Ocean tidal ranges were obtained from NOAA Tide Tables (34).

After the model was tested, the program was run again 30 times for a set of values ranging from 1.0 to 11.0 feet (0.30 to 3.35 meters) of tidal range and 100 to 6,000 feet^3/sec (3 to 170 meters^3/sec) of river flow to simulate hypothetical conditions and construct families of curves or nomograms for prediction purposes.

Table 3. Hydraulic Input Data

Date	Fresh Water Flow (ft^3/sec)	Ocean Tidal Range (feet)	Ocean Offset (feet)	Flow Ratio
Aug. 2, 1973	82	6.50	-0.51	0.009
Aug. 3, 1973	79	5.10	-0.31	0.012
July 24, 1974	213	5.40	-0.34	0.031
Nov. 19, 1973	4700	5.80	-0.14	0.638
Feb. 5, 1973	1880	4.50	0.64	0.329
Nov. 16, 1973	23600	3.20	0.76	5.811
Sept. 17, 1974	98	6.40	0.10	0.012
Sept. 22, 1974	87	6.10	-0.77	0.011
Sept. 27, 1974	83	5.40	-0.44	0.012
Sept. 29, 1974	91	5.20	-0.14	0.014
Sept. 29½, 1974	86	5.20	-0.14	0.013
Sept. 30, 1974	81	5.90	-0.32	0.011
Oct. 1, 1974	91	6.40	-0.44	0.011
Oct. 9, 1974	108	6.30	-0.74	0.013
Oct. 10, 1974	108	6.10	-0.62	0.014
Oct. 11, 1974	108	6.10	-0.42	0.014

SI-units conversion factors: 1 foot = 0.305 meters
1 $foot^3$/sec = 0.0283 m^3/sec

Model Output

The model was run for August 3 hydraulic conditions and the friction and geometrical parameters adjusted until an average agreement within 0.2 feet (6.1 centimeters) for peak displacement values and within 7 degrees (14 minutes) for their times of occurrence with respect to the field data was reached. Hydraulic conditions on August 3 correspond to a well-mixed system.

After this calibration was done, the model was run with the purpose of testing it under well mixed, partially mixed and stratified conditions for August 2, 1973, July 24, 1974, November 19, February 5 and November 16, 1973.

Computer print-outs containing the model output data for all these cases are included in the Appendix. Some of these data were plotted for the purpose of comparison with the field data and can be seen in Figures 8 to 33.

In addition, the model was run for the well mixed conditions of Sept. 17, Sept. 22, Sept. 27, Sept. 29, Sept. 29½, Sept. 30, Oct. 1, Oct. 9, Oct. 10, and Oct. 11, 1974. Some of these data were also plotted for the purpose of comparison with the field data and can be seen in Figures 34 to 53. Explanations and analysis of these results are given on Chapter IV.

Print-outs for the future hypothetical simulation runs are not given, but some of the parametric families of curves obtained are shown in Figures 54 to 60, and the correspondent Nomograms in Figures 61 to 69.

III. FIELD OBSERVATIONS

Criteria Determinant on Data Choice

The main purpose in collecting data for this study was to have a set of field data as complete as possible for all the estuary segments, under the different mixing conditions, to be compared with the model output.

The only information available on displacement, velocity and flow measured along Siuslaw estuary were:

a) NOAA displacement predictions for river mouth and Florence (mile 5.0 or kilometer 8.0), already tested as acceptable by Utt (35).

b) flow discharge in the head of the estuary (river mile 23.7 or kilometer 38.1) measured by the U.S. Geological Survey.

c) displacement at river mile 2.0, 8.0, 16.0, 22.0 (kilometers 3.2, 12.9, 25.7, 35.4), and velocity and flow at river mile 4.5 and 8.0 (kilometers 7.2 and 12.9), measured by Utt (35).

d) displacement at river mile 0.0, 5.0, 8.2, 14.7 and 20.5 (kilometers 0.0, 8.0, 13.2, 23.7, and 33.0) measured by NOAA (22).

Data from a) and b) are given daily, while velocities from c) are given for just four days of 1973 and displacements for four 14 days periods, and displacements from d) are given daily for four summer and fall months of 1974.

Available time and funds were too limited to perform a complete program of field measurements. We restricted ourselves to gathering data to complete only the set of data corresponding to well-mixed (summer) conditions. These data were considered as the most important because they should provide the best fit to the one-dimensional model. Data provided by Utt under well-mixed conditions, include velocities and flows just for August 2 and August 3, 1973. Hydraulic boundary conditions for those two days were: ocean tidal range of 6.50 and 5.10 feet (1.98 and 1.55 meters) respectively, and fresh water flow of 82 and 79 $feet^3$/sec (2.3 and 2.2 $meters^3$/sec) respectively. We looked for a summer day during 1974 with similar conditions to those on August 2 and 3, 1973. July 24 with ocean tidal range 5.40 feet (1.64 meters) and fresh water flow of 213 $feet^3$/sec (6.0 $meters^3$/sec) was selected. The data collected on that date should be reasonably compatible with Utt's data for the two summer days just mentioned.

Utt's velocity measurement locations coincide with the velocity prediction sites given by the model (end points of segments). Utt's and NOAA's displacement measurements locations do not coincide with the displacement prediction sites given by the model (segment centroids) but differ in no more than 2.0 miles (3.2 kilometers) so that reasonable comparisons can be established.

There was a complete lack of field data for the following locations:

- end point of segment A (river mile 1.0 or kilometer 1.6): velocity
- centroid of segment C (river mile 11.20 or kilometer 18.0): displacement
- end point of segment D (river mile 14.4 or kilometer 23.2): velocity

In summary then, our purpose was to make those three missing measurements on July 24, 1974.

Location of all the available field observations and model prediction sites are shown on Figure 1.

Data Collection and Treatment

No attempt was made to measure velocities on river mile 1.0 (kilometer 1.6) due to the rough wave and wind conditions prevalent at that place and our lack of experience in maneuvering a small boat under such conditions.

Tidal displacements were measured on July 24 during 12 hours at river mile 11.20 (kilometer 18.0) with a NOAA Nitrogen Bubbler type liquid-level gauge (ACCO-Bristol model #1G3X628-15). The record was read to the nearest 0.05 feet (1.5 centimeters) and to the nearest 5 minutes. The tidal displacement curve obtained is given on Figure 13.

Velocities were measured on July 24 during 7 hours at river mile 14.4 (kilometer 23.2) for flooding and ebbing tides in an attempt to measure maximum values of velocity and flow. These measurements were made from a small boat with a cup-type Price current meter on 3 positions of the cross-section, at 4 depths for each position. A complete circuit of measurements required 20 minutes and 4 circuits were completed for each ebbing and flooding tide. Soundings on 5 positions of the cross section were made simultaneously with the velocity measurements to determine the cross-sectional areas for the flow evaluations. Location of the velocity measurement positions was determined with a sextant.

Velocity measurements were integrated graphically to obtain an average representative value for the cross-section, for each circuit of measurements.

Final data points obtained for velocities and flows are plotted on Figures 18 and 19 respectively.

IV. RESULTS

Model Testing

Table 4 shows a summary of all the comparisons made between model and field data in this work, indicating location, date and variable. The positions of the sites are shown on Figure 1.

The absolute degree of fitness of the model cannot be exactly obtained because of the difference in location between observation points and points assumed in the model.

Also it can be observed that there are just a few cases of comparison for stratified conditions. This implies a limitation in our conclusions for such conditions.

Also it can be seen from Table 4 that the results of this study are based upon comparisons for just fifteen days so that we should be careful in generalizing or extrapolating our conclusions.

Figures 8 to 30 and 35 to 53 show the comparison of tidal displacement, their phase, velocity and flow, at successive locations along the estuary, for all the cases treated. Some of these data were rearranged and shown in a different way on Figures 31 to 33.

From all these figures we may conclude:

- for well mixed conditions peak values of displacement agree in average within 0.3 feet (19.1 centimeters) (with one exception), times of occurrence within 7 degrees (14 minutes) (with one exception),

Table 4. Summary of Model vs. Field Comparisons.

Date:		River Miles: Height	Height	Veloc. & Flow	Height	Veloc. & Flow	Height	Veloc. & Flow	Height
Aug. 2, 1973 well mixed	model	0.0	2.75	4.5	6.25	8.0			18.45
	field	0.0	2.00	4.5	5.0 & 8.0	8.0			16.00
July 24, 1974 well mixed	model	0.0					11.20	14.4	
	field	0.0					11.20	14.4	
Nov. 19, 1973 par. mix. -stra.	model			4.5	6.25	8.0			18.45
	field			4.5	5.0 & 8.0	8.0			16.00
Feb. 5, 1973 partial mixed	model		2.75		6.25				18.45
	field		2.00		5.0 & 8.0				16.00
Nov. 16, 1973 stratified	model				6.25				18.45
	field				5.0 & 8.0				16.00
10 days from Sept. 17, 1974 to Oct. 11, 1974 well mixed	model	0.0			6.25				18.45
	field	0.0			5.0 & 8.0				14.7 & 20.50

SI-unit conversion factor: 1 mile = 1.609 kilometers peak velocities within 0.4 feet/second (0.12 meters/sec), and peak flows within 3×10^3 $feet^3$/sec (85 $meters^3$/sec) (with one exception). These differences are of the order of magnitude of the accuracy of the field data, and thus the model can be considered as adequate.

- for partially mixed conditions peak values of displacement agree in average within 0.3 feet (9.1 centimeters), times of occurrence within 8 degrees (16 minutes), peak velocities within 0.4 feet/second (0.12 meters/sec), and peak flows within 4×10^3 $feet^3$/sec (113 $meters^3$/sec); and the model can be considered as still acceptable.
- for stratified conditions peak values of displacement agree in average within 0.8 feet (24.4 centimeters), times of occurrence within 17 degrees (34 minutes); no velocity and flow field data were available for this case. Thus, the model cannot be considered acceptable under stratified conditions.

In summary, the model results compare well with the field data for well mixed and partially mixed conditions, but not for stratified conditions.

Some other conclusions that can be inferred from the figures are the following:

- the model fails to fit with the field data for the second half of the tidal cycle (see figures 8 and 12) due to its incapacity to generate a sinusoidal tidal wave of variable amplitude like that of the mixed type of tides prevalent on the Oregon coast.

- variation of tidal range with distance upstream (Fig. 31) shows in general a "nonchoked" or amplifying condition for the estuary, except at Florence (mile 5.0 or kilometer 8.0) where attenuation is observed, under all mixing conditions.
- in most of the cases, velocities and flows given by the model are lower or equal in modulus than the measured ones. This may be due to the fact that the model neglects the inflow of tributaries.
- the model gives peak velocities occurrence approximately 3 hours after peak displacements at a given location (i.e. for river mile 8.0 or kilometer 12.9). This is consistent with Utt's (35) statement that this takes place and is an indication that the tidal movement progresses as an intermediate wave (between a progressive and a standing wave).

Model Predictions

Conditions of model applicability, already established, can be expressed approximately in an analytic way as a function of fresh water river inflow (F) and ocean tidal range (R). According to expressions (5) or (5.1), page 22 if we consider that the well mixed or partially mixed conditions correspond to a flow ratio less or equal than 0.5, our model applicability condition will be given by:

$$F \leq 600\ R \qquad (6)$$

(approximated to the nearest hundred)

where F is given in $feet^3/sec$ and R in feet; or

$$F \leq 60\,R \qquad (6.1)$$

(approximated to the nearest ten units)

where F is given in $meters^3/sec$ and R in meters.

As the extreme tidal range in the Oregon coast is 11.0 feet (3.35 feet), the model was run 30 times for a set of different couples of values of R and F within 1.0 and 11.0 feet (0.30 and 3.35 meters) and 100 and 6,000 $feet^3/sec$ (3 and 170 $meters^3/sec$) respectively, to cover the complete field of applicability of the model.

From the computer output, families of parametric curves for the following variables were obtained as a function of fresh water river flow, ocean tidal range and river mile: amplification factor (ratio of the tidal range at a point to the tidal range at mouth), high water time lag, low water time lag, maximum flood velocity, maximum ebb velocity, maximum flood flow, maximum ebb flow, high slack water time lag, low slack water time lag. Families of curves for low water time lag and maximum ebb velocity are shown on figures 54 to 60. The rest of the curves are not shown but they look quite similar to figures 54 to 60.

Most of these curves look like and were reduced to straight lines by a least square method. Finally, these families of straight lines, with slopes and intercepts dependent in an irregular way on the ocean tidal range and river mile, were grouped and represented as nomograms for each variable according to the instructions to build nomograms for equations of the type:

$$f_3 (z) = f_1 (y) \pm f_4 (x) f_2 (y) \qquad (7)$$

given by Lipka (19) and Mavis (21).

These nomograms, shown in figures 61 to 69, constitute a useful tool to provide predictions for present and future conditions in the estuary, although special care should be taken to avoid extrapolating the reading of the scales outside the range of validity of the model, given by expressions (6) or (6.1).

In most of the cases, SI-unit equivalent scales or conversion factors are given in the nomograms; although British-unit scales are always present, as most instrumentation currently used in the U.S.A. reads out in these units.

As an example of the adequacy of these nomogram predictions, the curve of amplification factor values for river flow = 100 feet^3/sec (2.8 meters^3/sec) and river mile 18.45 (kilometer 29.7) was drawn together with 25 values that had been measured by Utt (35) in July and August 1973 at river mile 16.1 (kilometer 25.9) and for river flows of approximately 100 feet^3/sec (2.8 meters^3/sec), see figure 70. The predicted values fit the measured ones adequately.

From the amplification factors nomogram (Fig. 61) we observe that in general tides with small ranges experience more amplification than tides with large ranges. The latter are in general attenuated. Also it can be seen that increasing fresh water flow results in decreasing amplification factors, sometimes less than 1.0 for a given tidal range. This means that the estuary becomes "choked" for high river flow or high tidal range values, in agreement with conditions observed by Utt in his field study of the Siuslaw estuary (35), and by Goodwin, Emmet and Glenne on the Siletz, Alsea and Yaquina estuaries (9). A likely reason for this could be that the estuary water dynamics are dominated by inertial effects under low river flows and by frictional effects under high river flows.

A general analysis of the nomograms shows that:

- amplification factors increase with decreasing tidal range and decreasing river flow.
- high water time lags increase with increasing tidal range and increasing river flow.
- low water time lags increase with increasing tidal range and increasing river flow.
- maximum flood velocities increase with increasing tidal range and decreasing river flow.
- maximum ebb velocities increase with increasing tidal range and increasing river flow.
- maximum flood flows increase with increasing tidal range and

decreasing river flow.

- maximum ebb flows increase with increasing tidal range and increasing river flow.
- high slack water time lags increase with increasing tidal range and decreasing river flow.
- low slack water time lags increase with increasing tidal range for high values of the tidal range and decreasing tidal range for low values of the tidal range, and also increases with increasing river flow.

Instructions for the use of the Nomograms

To find the appropriate value of a requested variable proceed as follows: construct a straight line between a selected value of the river flow scale and a selected value of the ocean tidal range scale correspondent to a chosen river mile. This straight line will intersect the third scale (at the right) at the appropriate value of the requested variable.

Example: To find the amplification factor which corresponds to a river flow of 4600 $feet^3/sec$ (132 met^3/s) and ocean tidal range of 7.0 feet (2.1 meters) at river mile 11.20 (kilometer 18.0): the straight line constructed between the value 4600 of the river flow scale and the value 7.0 of the ocean tidal range scale correspondent to river mile 11.20 intersects the amplification factor scale (at the right) at the required value .990, as shown on Figure 61.

V. SUMMARY, CONCLUSIONS AND COMMENTS

Summary

Goodwin's one-dimensional hydraulic model was verified for the Siuslaw estuary. Results are acceptable under well mixed and partially mixed conditions, determined according to the flow ratio criterion, and agree with the measured values within 0.3 feet (9.1 centimeters) for peak displacements, within 7 to 8 degrees (14 to 16 minutes) for their time of occurrence, within 0.4 feet/sec (0.12 meters/sec) for peak velocities, and 3 to 4 x 10^3 $feet^3$/sec (85 to 113 $meters^3$/sec) for peak flows. The model seems to be inadequate for stratified conditions, although the data used for comparison in this case were rather scarce.

A mathematical expression for the river flow and tidal range to be satisfied under well mixed or partially mixed conditions was derived, according to the flow ratio criterion.

Nomograms were constructed, for prediction purposes, of amplification factors, high water time lags, low water time lags, maximum flood velocities, maximum ebb velocities, maximum flood flows, maximum ebb flows, high slack water time lags, low slack water time lags as a function of fresh water flow, ocean tidal range and river mile, to be used under the range of validity of the model. The kind of qualitative dependence of these variables was found from visual observation of the nomograms.

The model predicts amplification in the estuary for small tidal ranges and/or small freshwater flow, and attenuation for the opposite conditions, according to field observations and as explained by the relative influence of inertial or frictional effects.

The model shows a delay between peak velocities and peak displacement occurrence at a given place of approximately 90 degrees (3 hours) indicating that tidal movement progresses as an intermediate wave, in accordance with field observations.

Most of the velocities and flows predicted are lower than or equal to the measured ones as a consequence of assuming negligible tributary inflow, or for some other unknown reason.

The model is unable to generate a sinusoidal tidal wave of variable amplitude, and hence cannot predict well for the second half of a mixed type tidal cycle, typical of the Oregon coast.

Conclusions and Comments

This is a very simple model, and easy to apply for estuaries where not very much information is available, the flow is one-dimensional, and the cost of physical modeling could not be justified.

The main difficulties arising in the model application came from the Chezy friction coefficient determination and the conveyance channel cross-section determinations. These determinations are very subjective and much experience is needed to make them. It is recommended for future applications of the model to make the calibration with Chezy friction coefficient values previously given by other authors for estuaries of the same region with similar physical conditions on the bottom. With respect to the conveyance channel cross-sectional area determination, it is advisable to make many total cross-section determinations close to the section of interest, and then select the most regularly trapezoidal-shaped as representative, neglecting the irregularly shaped ones. From this study and the study already done by Goodwin (10) with his model in the Yaquina, Alsea and Siletz estuaries, it appears that conveyance channel cross-sectional areas are about 65% to 100% of the actual total cross-sectional areas.

The results show that if the assumptions inherent in the basic equations are not violated too greatly the model adequately simulates the tidal hydraulic aspects of the estuary.

As far as this work is concerned, the value of the results is limited by the fact that comparisons were made for only fifteen days, and in some cases, like the stratified one, with incomplete field data.

A future effort should be directed to obtain more field data to use for comparisons, in particular for partially mixed and stratified conditions; also, to redefine the Chezy friction coefficient and the conveyance channel cross-sections in a less subjective way. The latter problem was the main source of error in this work.

Another future effort could be directed to modify the model so that a mixed type tidal wave could be generated. Additional suggested modifications of the model would include: addition of a new term to the equations representing inflow due to rainfall runoff, and addition of a new equation to treat water quality parameters like salinity, temperature or oxygen.

FIGURES

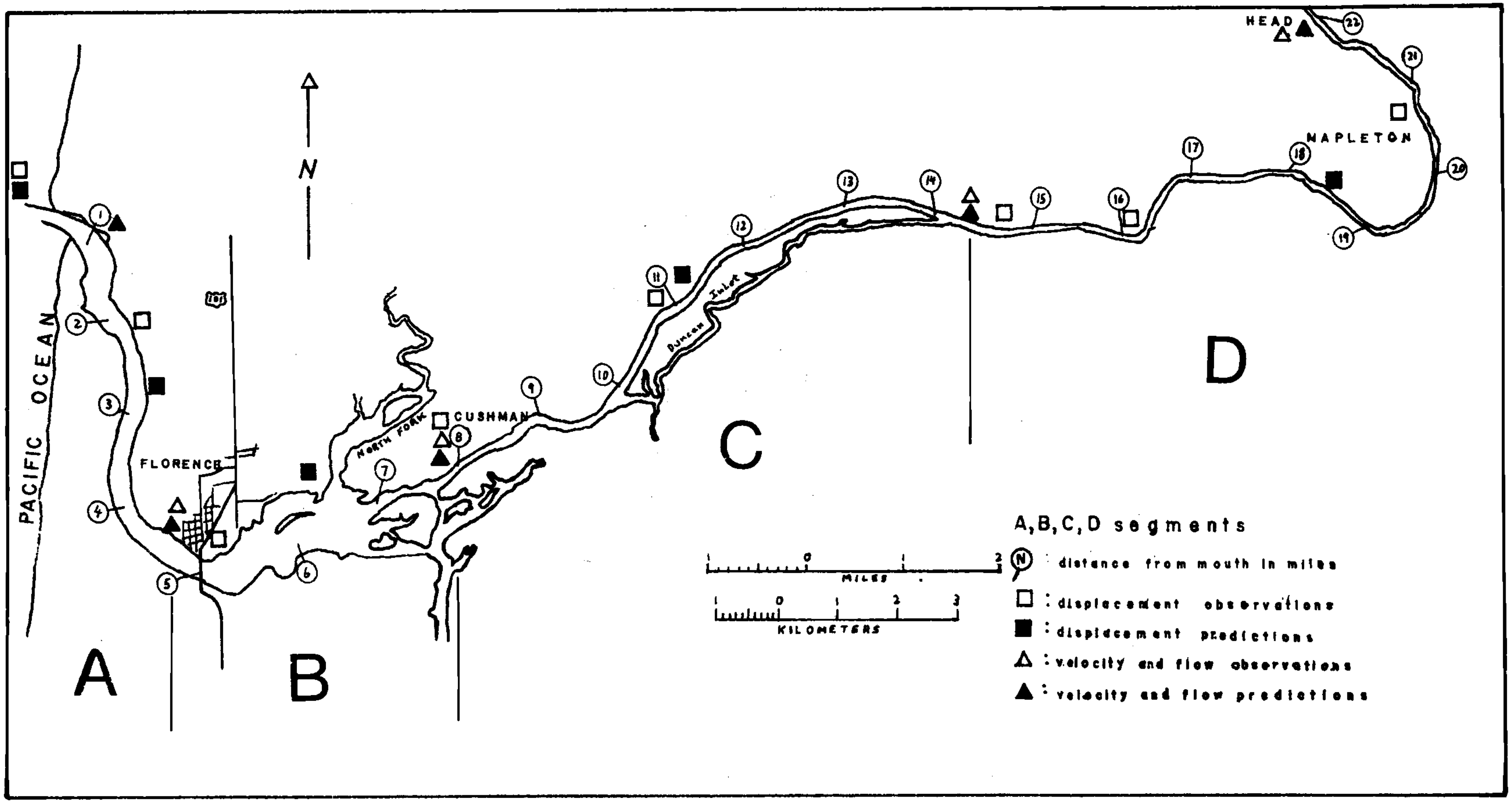

Figure 1. Siuslaw estuary map.

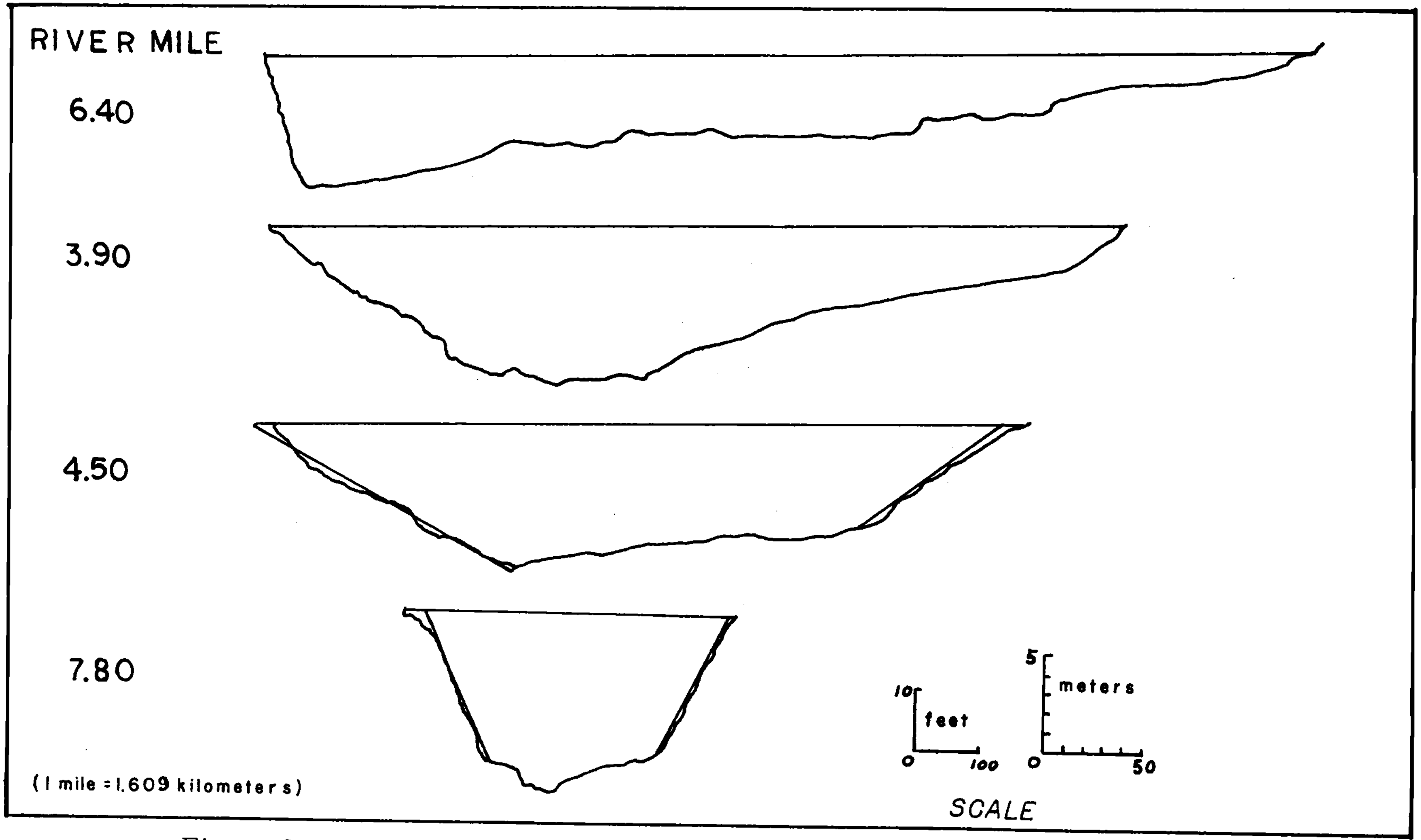

Figure 2. Irregular and regular cross-sections and trapezoidal fitting.

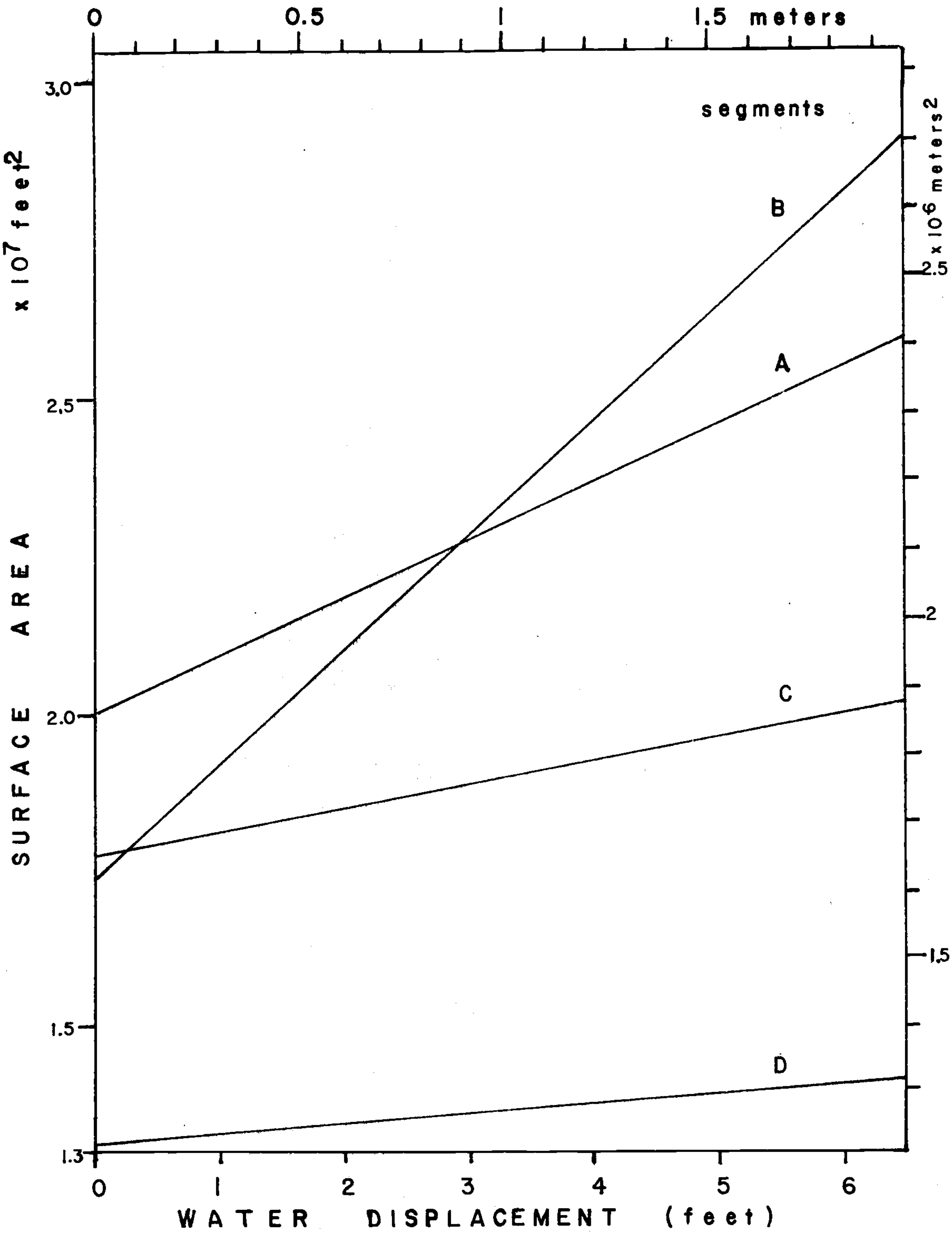

Figure 3. Surface area vs. water displacement.

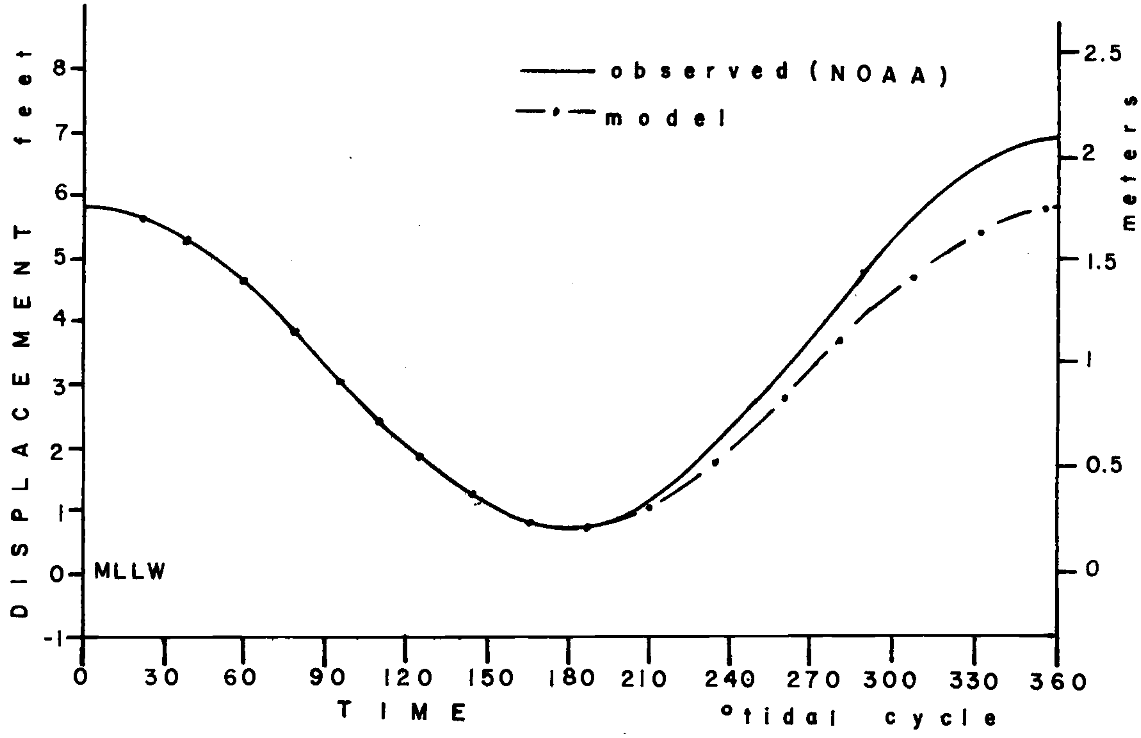

Figure 4. Displacement, August 3, river mile 0.

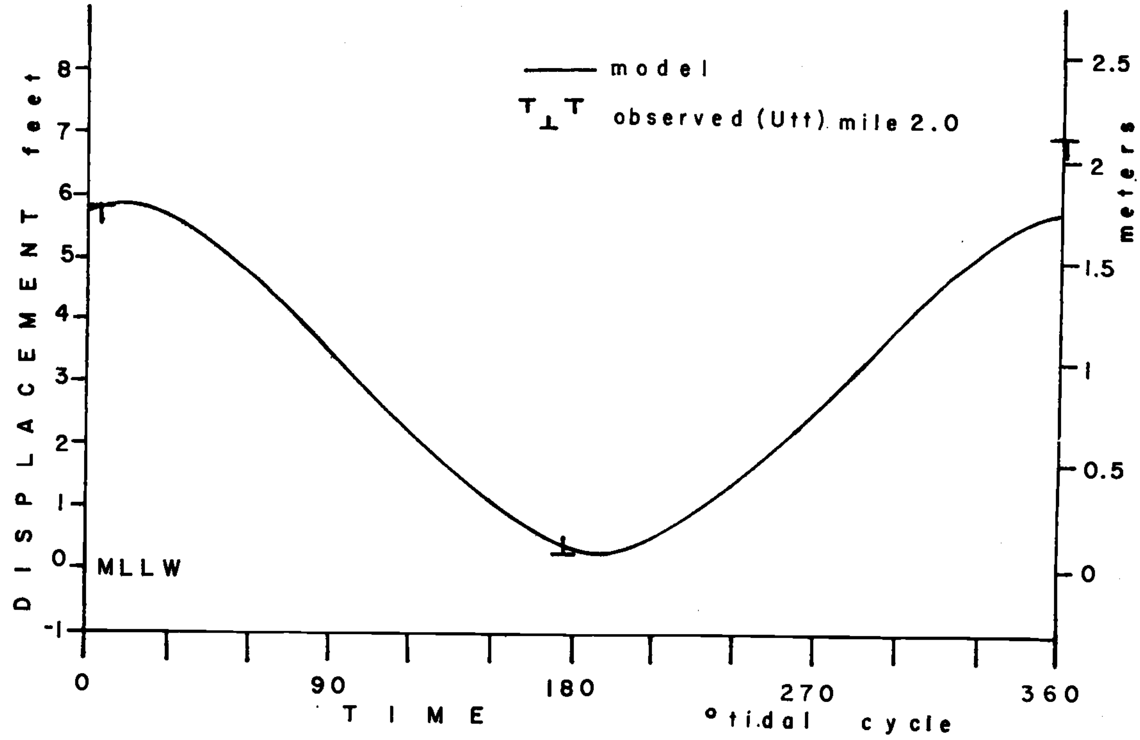

Figure 5. Displacement, August 3, river mile 2.75.

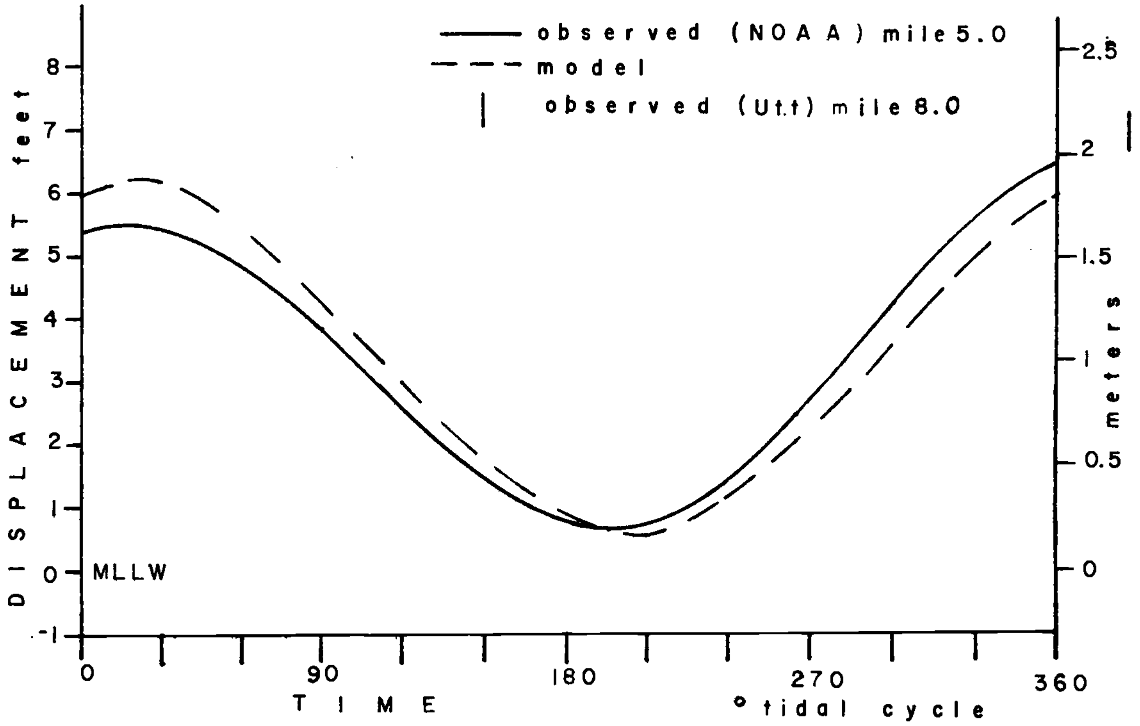

Figure 6. Displacement, August 3, river mile 6.25.

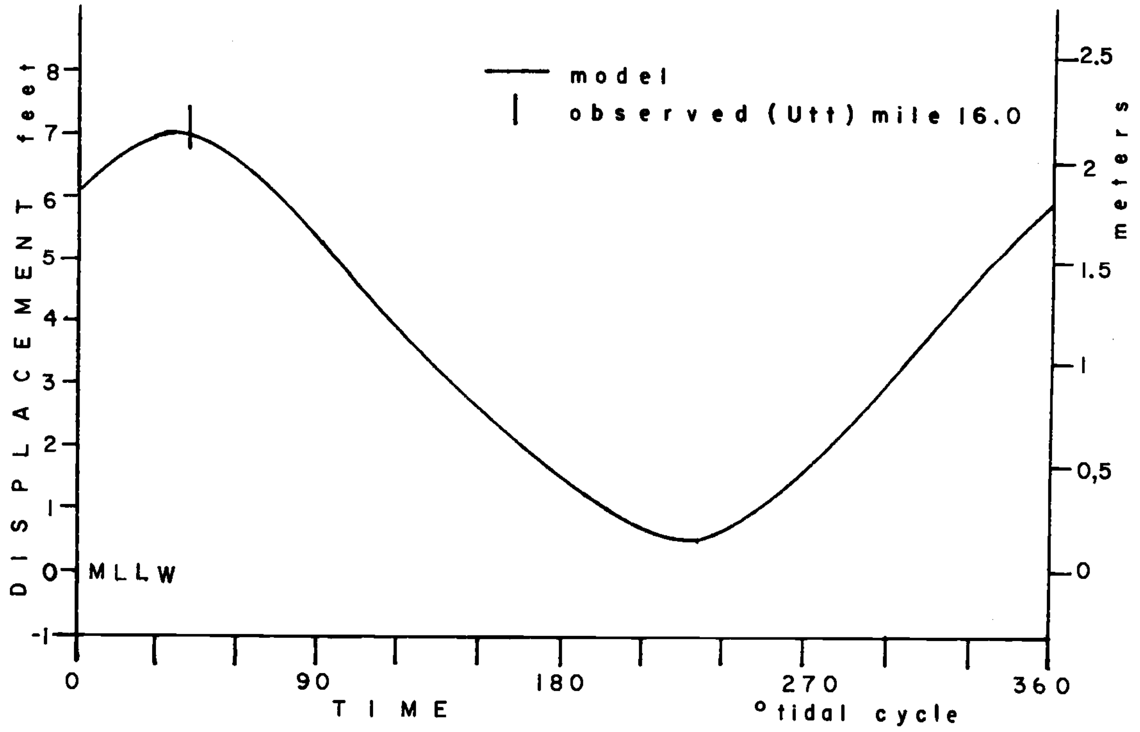

Figure 7. Displacement, August 3, river mile 18.45.

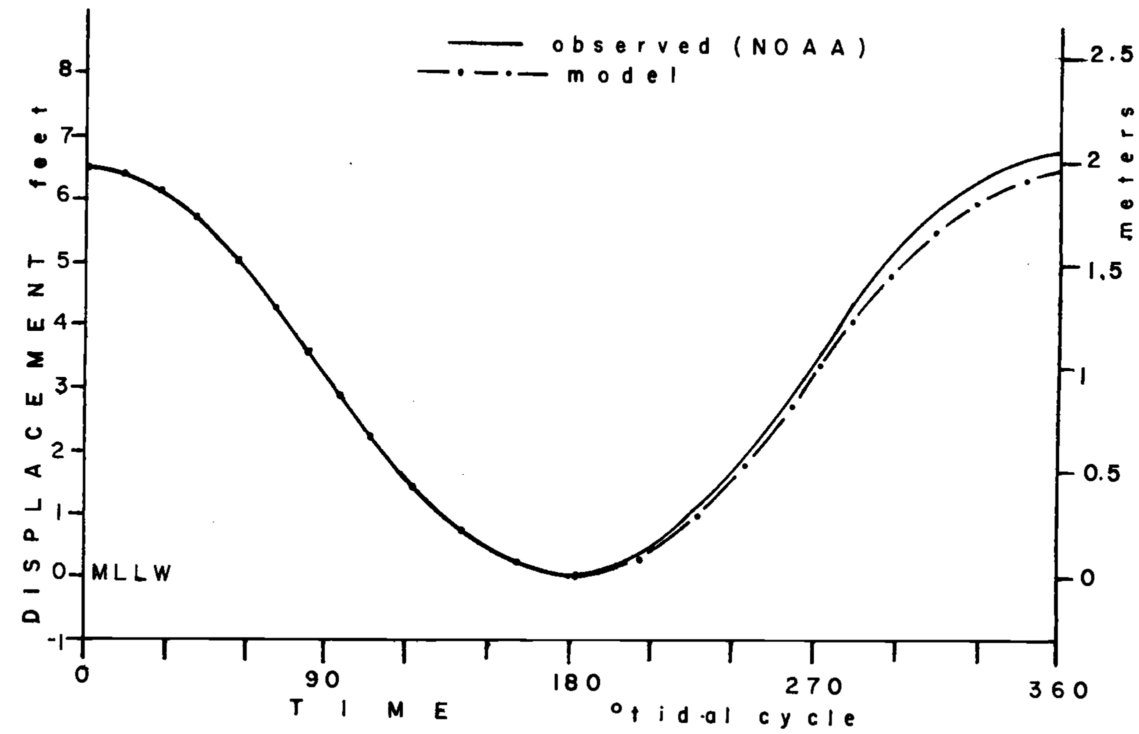

Figure 8. Displacement, August 2, river mile 0.

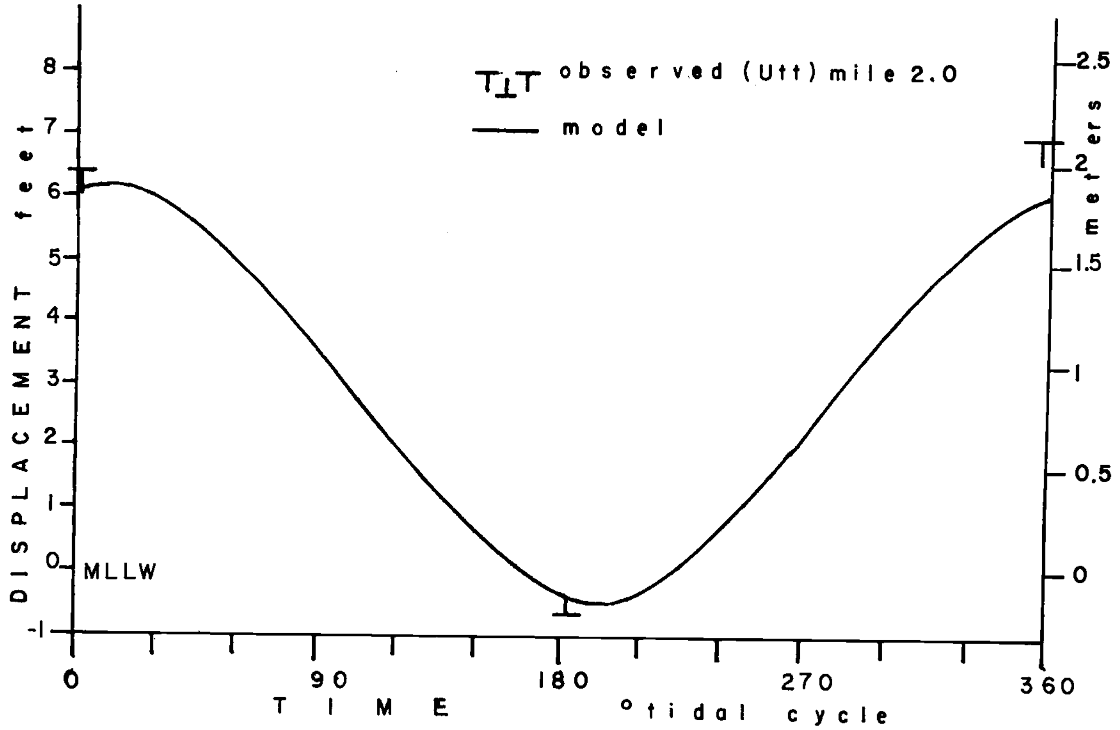

Figure 9. Displacement, August 2, river mile 2.75.

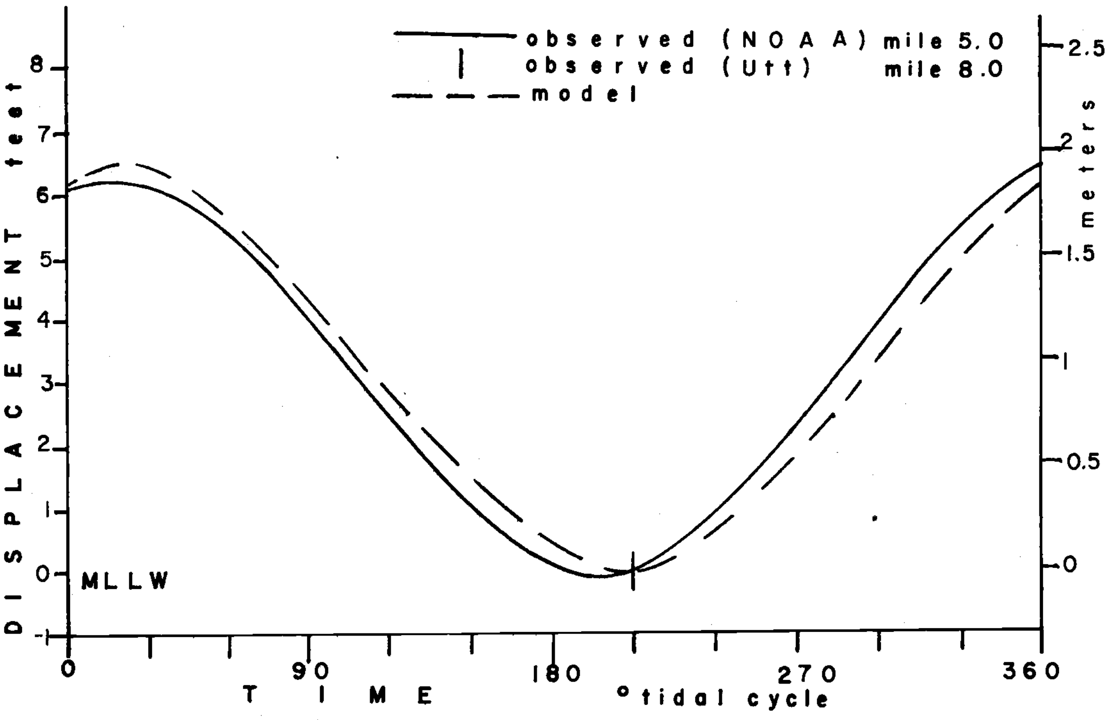

Figure 10. Displacement, August 2, river mile 6.25.

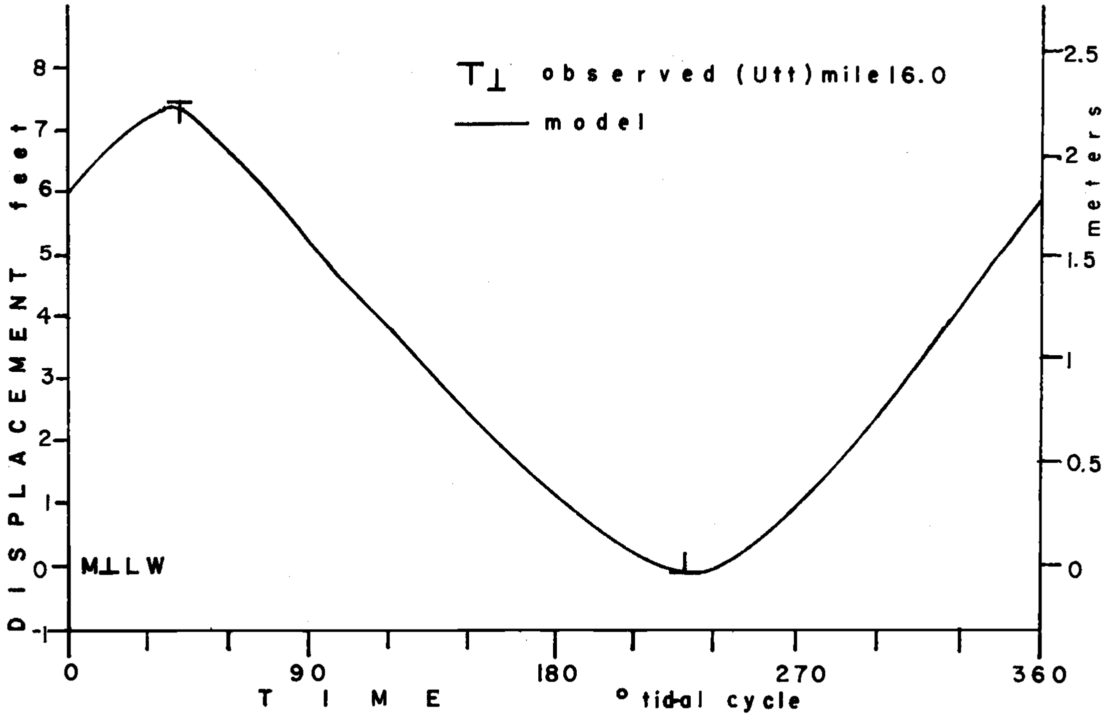

Figure 11. Displacement, August 2, river mile 18.45.

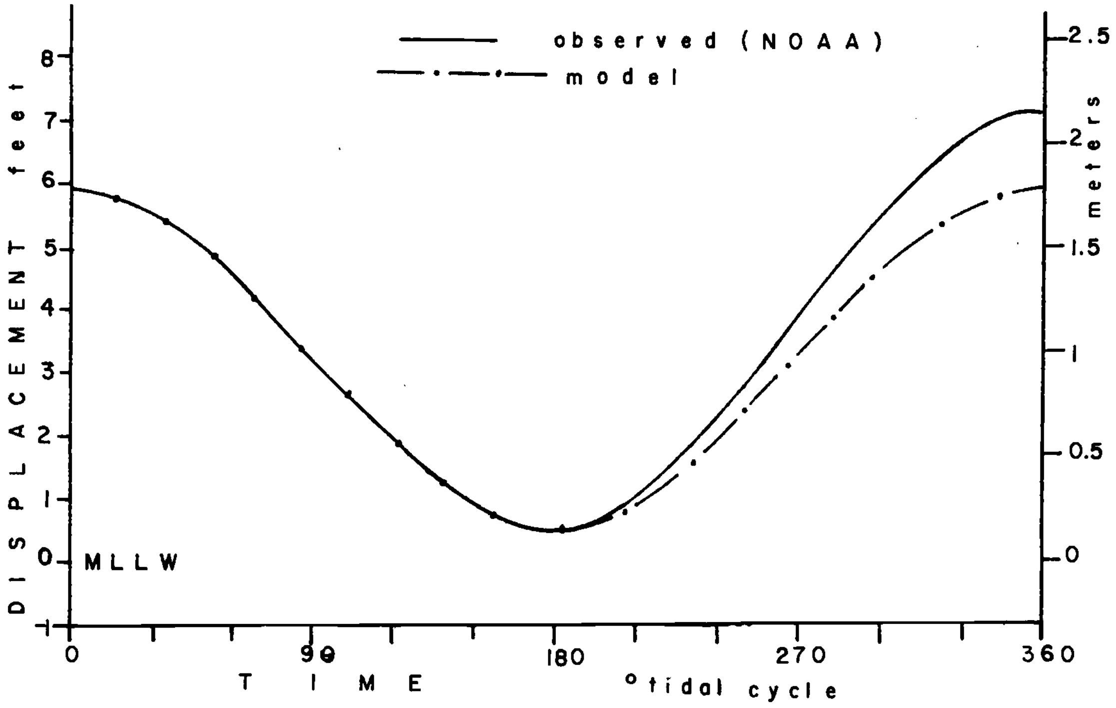

Figure 12. Displacement, July 24, river mile 0.

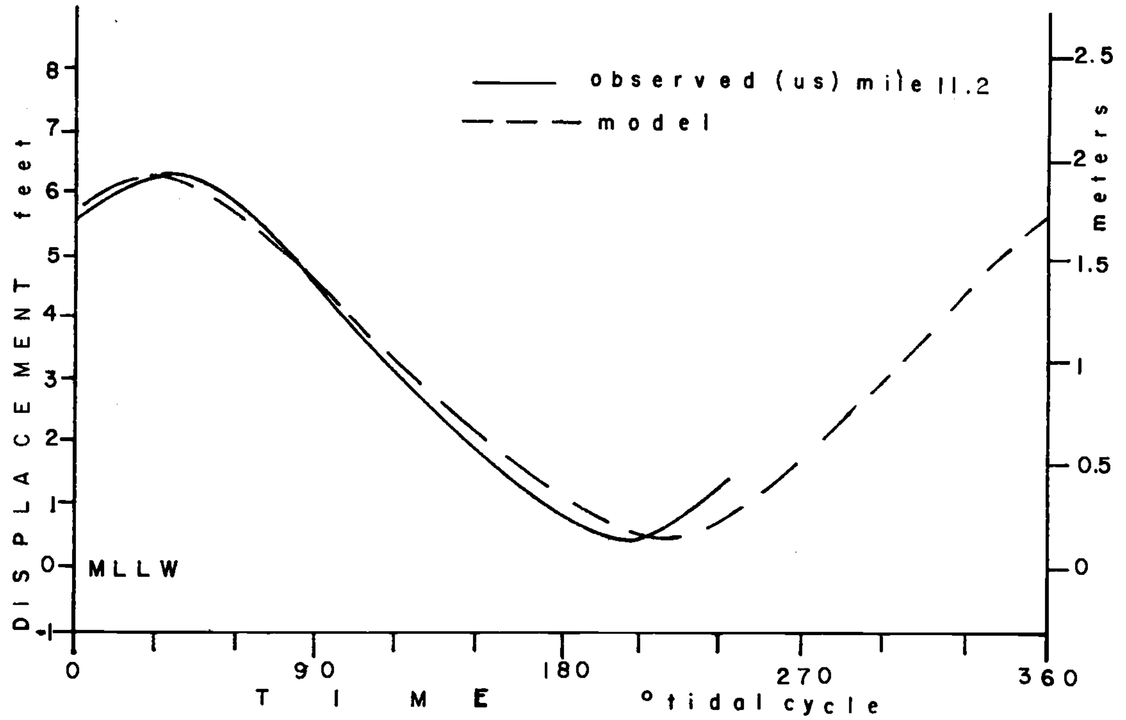

Figure 13. Displacement, July 24, river mile 11.20.

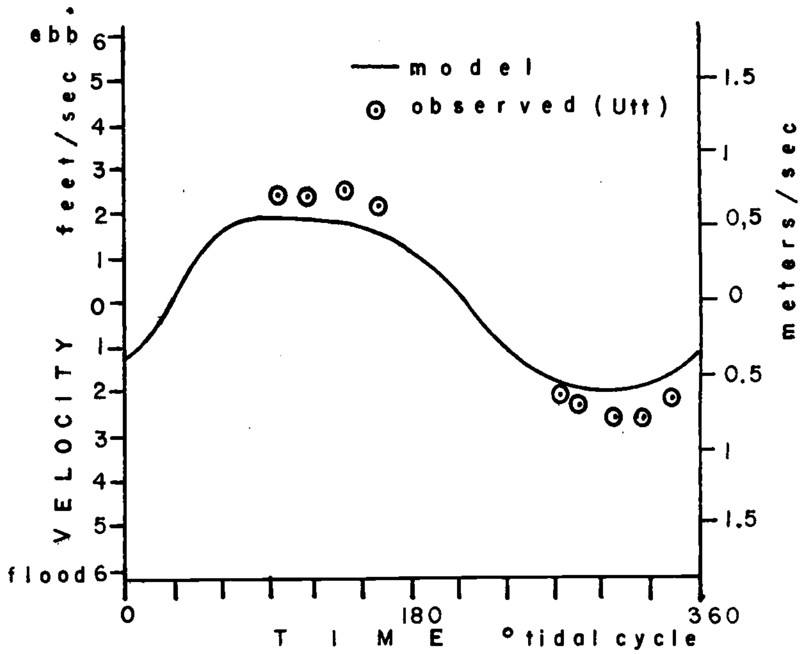

Figure 14. Velocity, August 2, 1973; river mile 4.5.

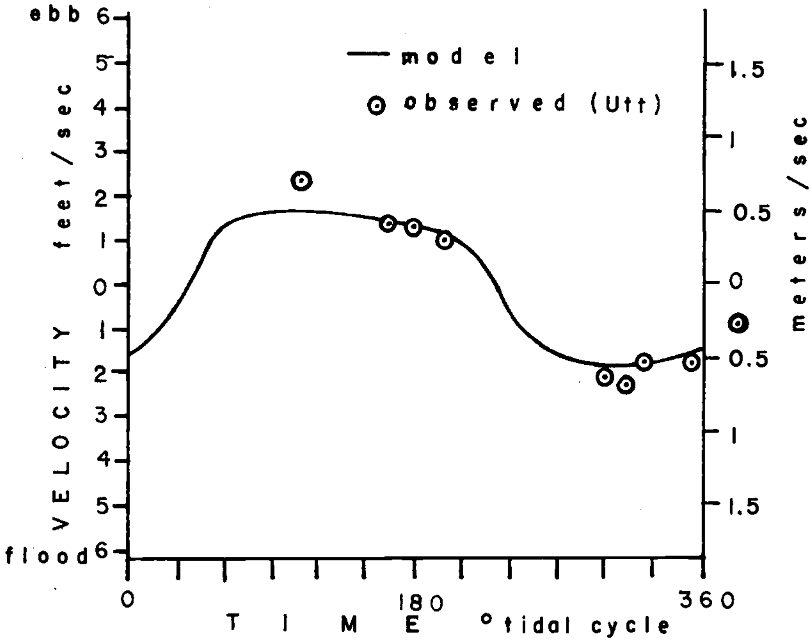

Figure 15. Velocity, August 2, 1973; river mile 8.0.

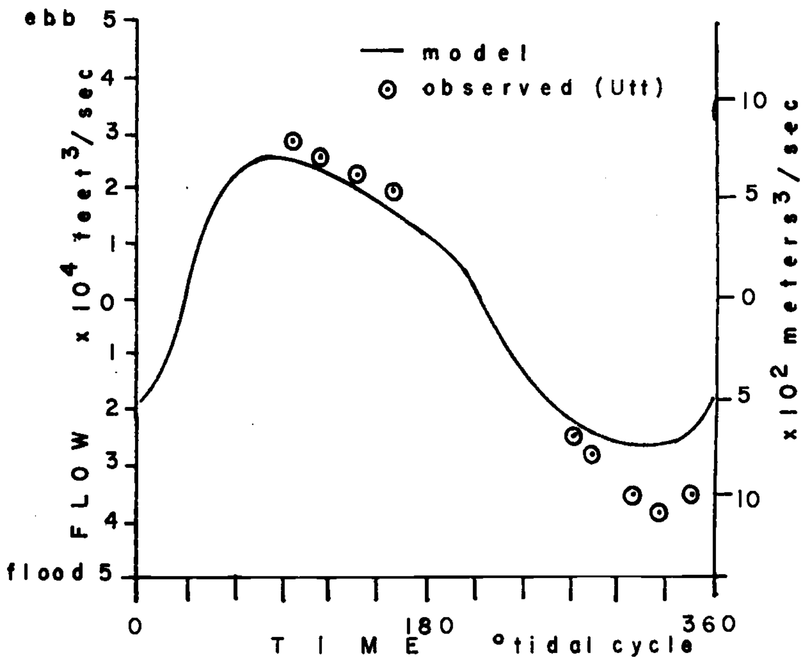

Figure 16. Flow, August 2, 1973; river mile 4.5.

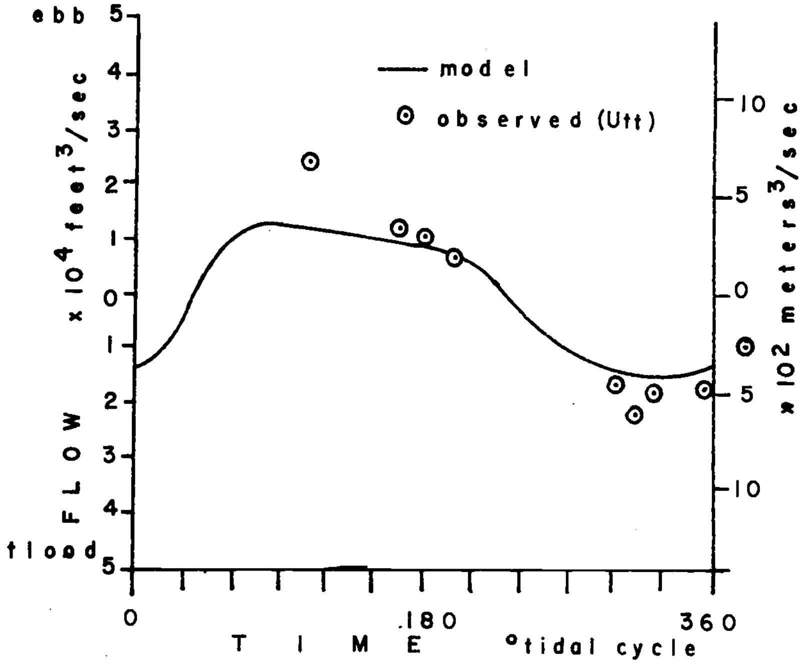

Figure 17. Flow, August 2, 1973; river mile 8.0.

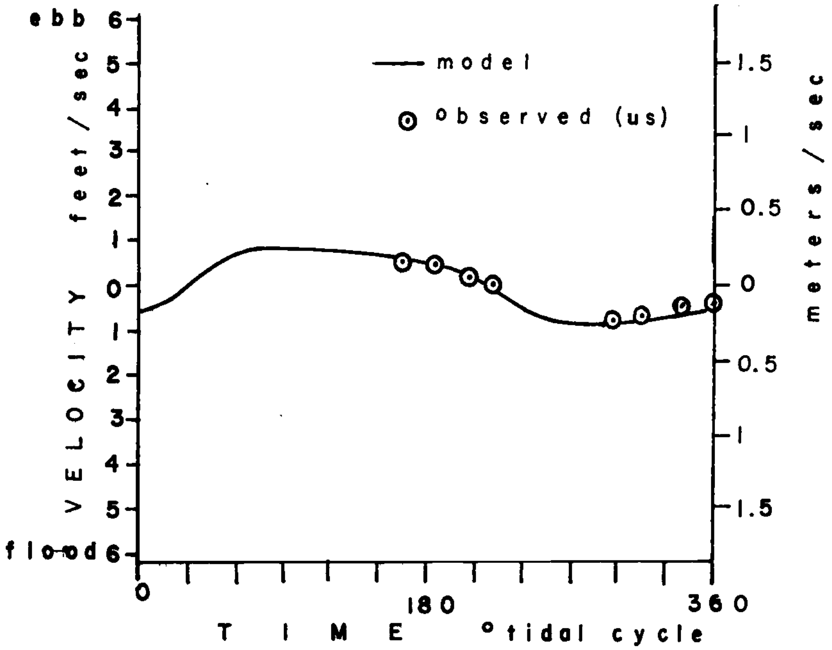

Figure 18. Velocity, July 24, 1974, river mile 14.4.

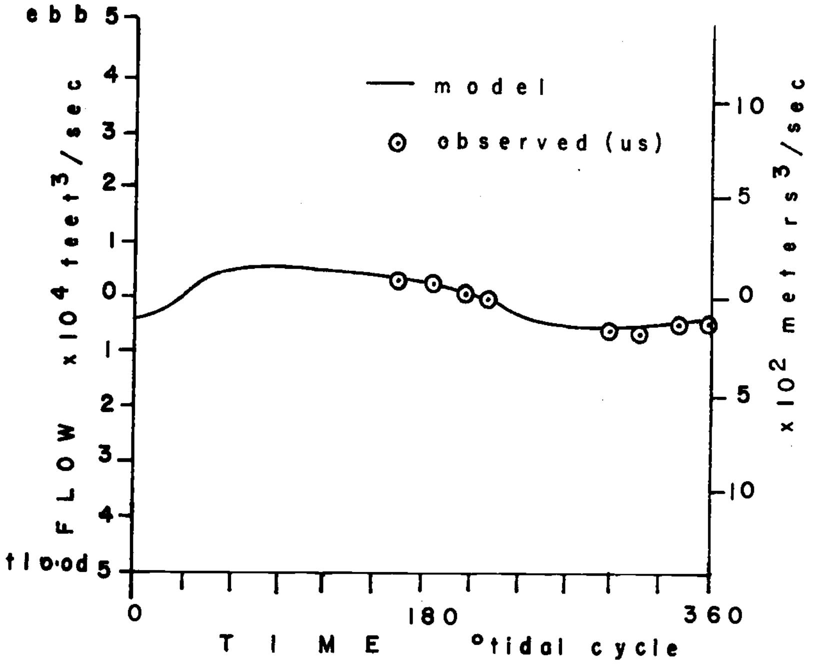

Figure 19. Flow, July 24, 1974, river mile 14.4.

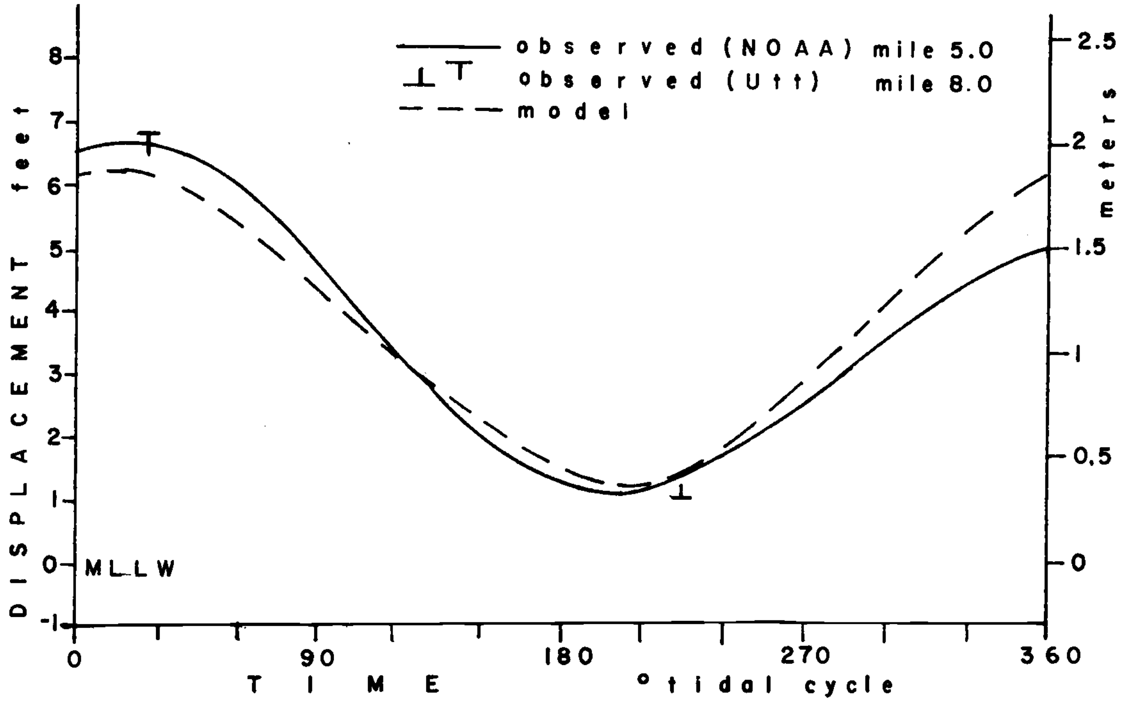

Figure 20. Displacement, November 19, river mile 6.25.

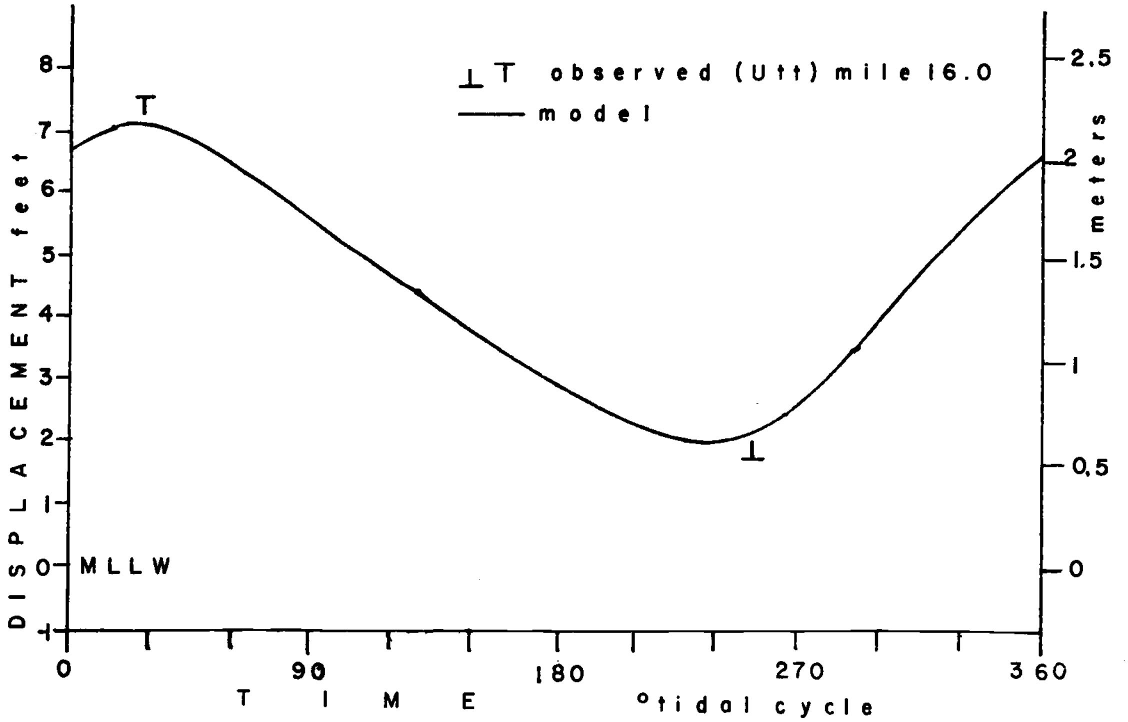

Figure 21. Displacement, November 19, river mile 18.45.

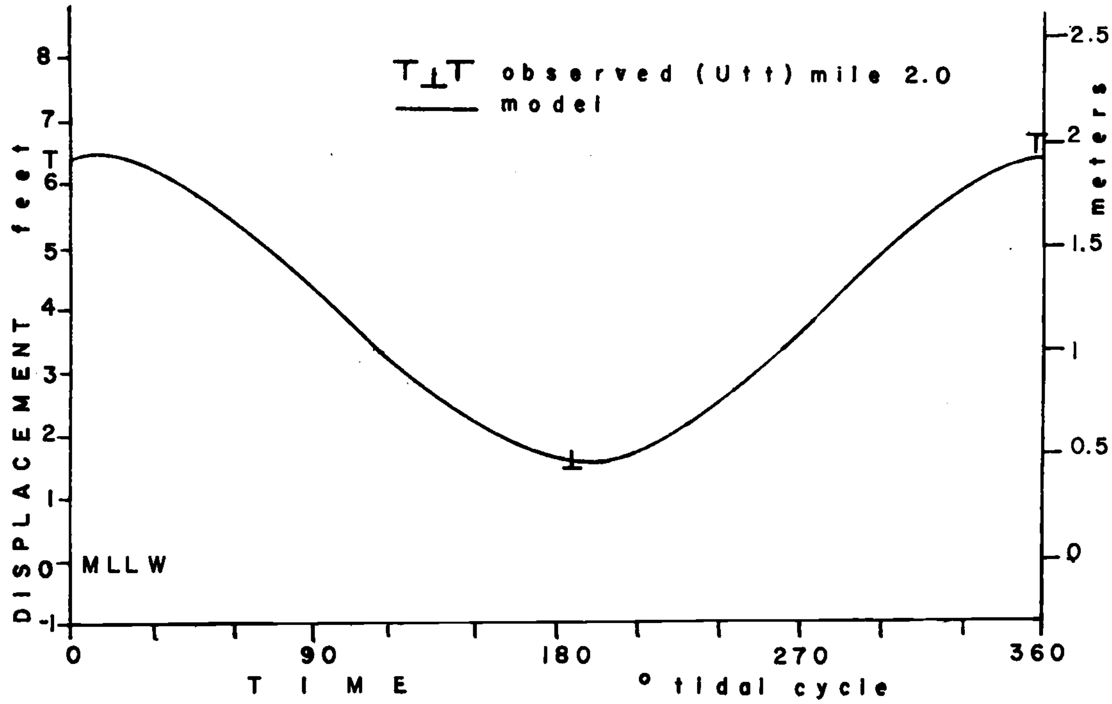

Figure 22. Displacement, February 5, river mile 2.75.

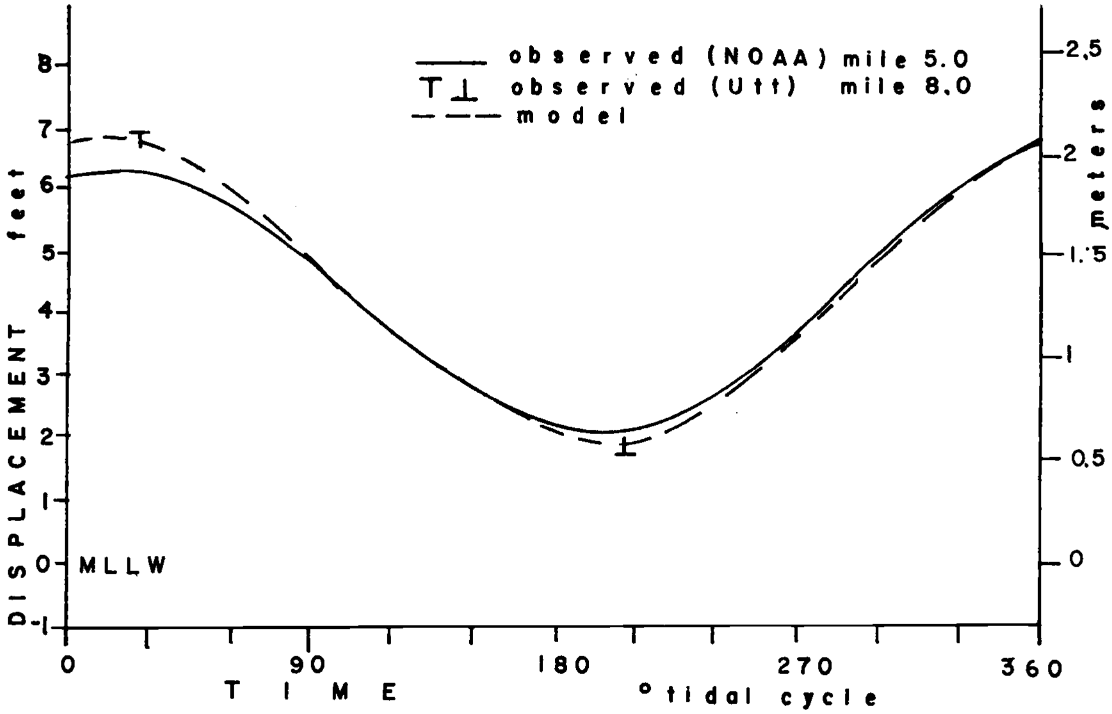

Figure 23. Displacement, February 5, river mile 6.25.

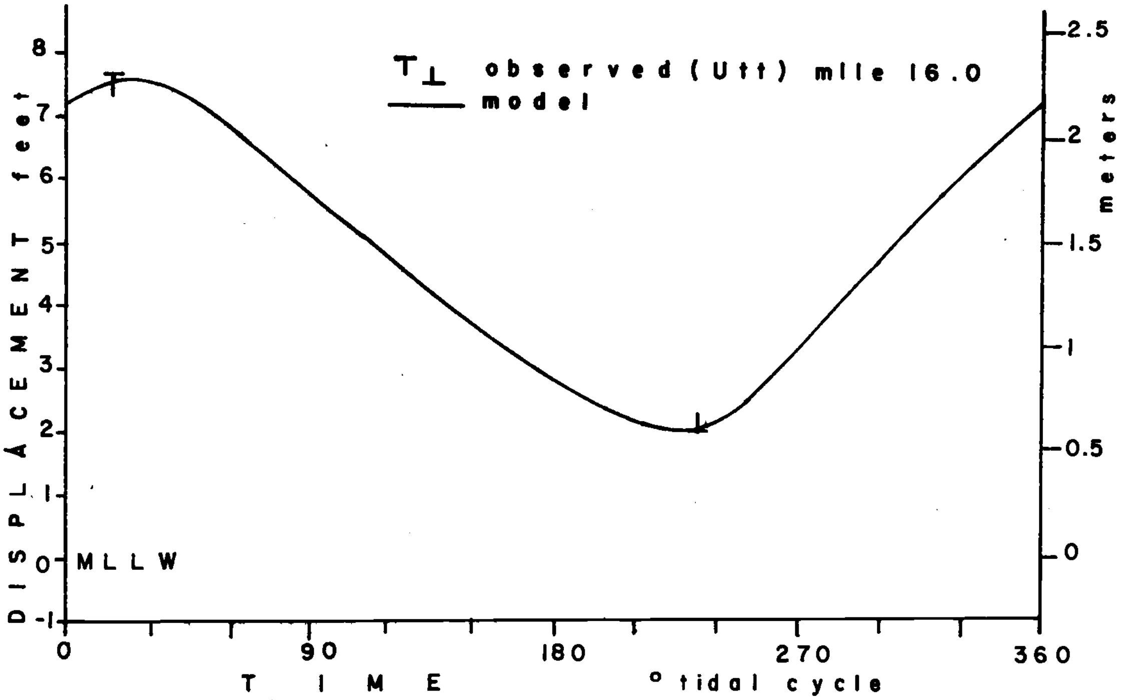

Figure 24. Displacement, February 5, river mile 18.45.

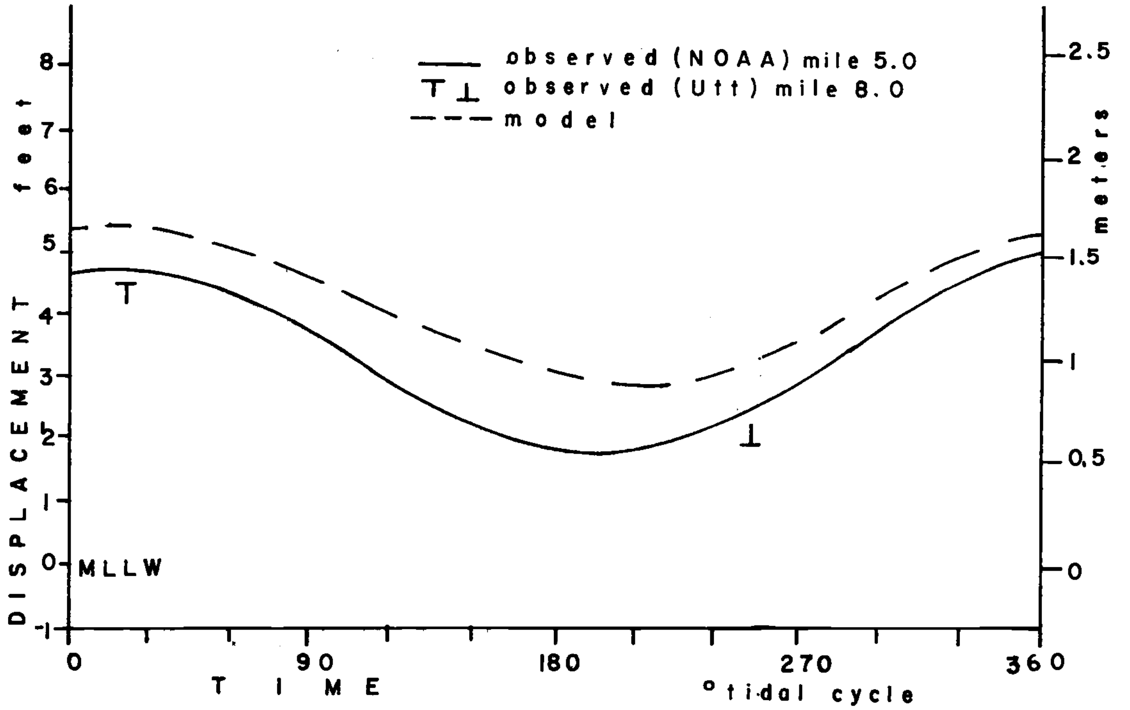

Figure 25. Displacement, November 16, river mile 6.25.

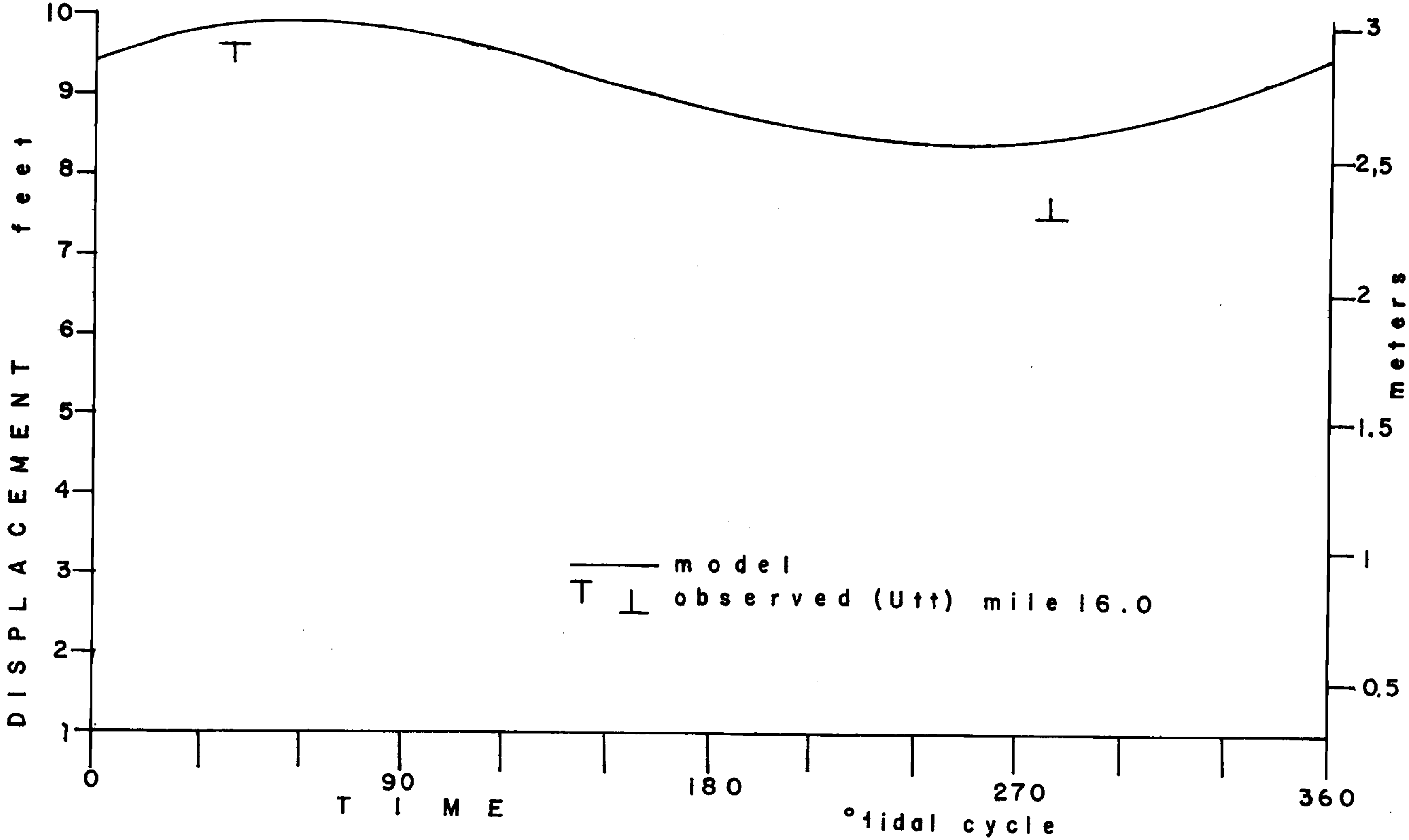

Figure 26. Displacement, November 16, river mile 18.45.

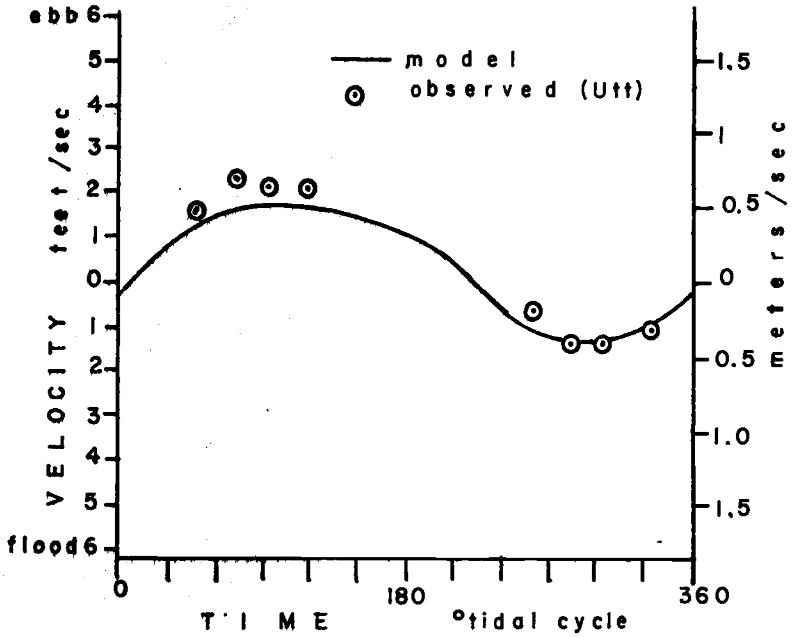

Figure 27. Velocity, November 19, 1973; river mile 4.5.

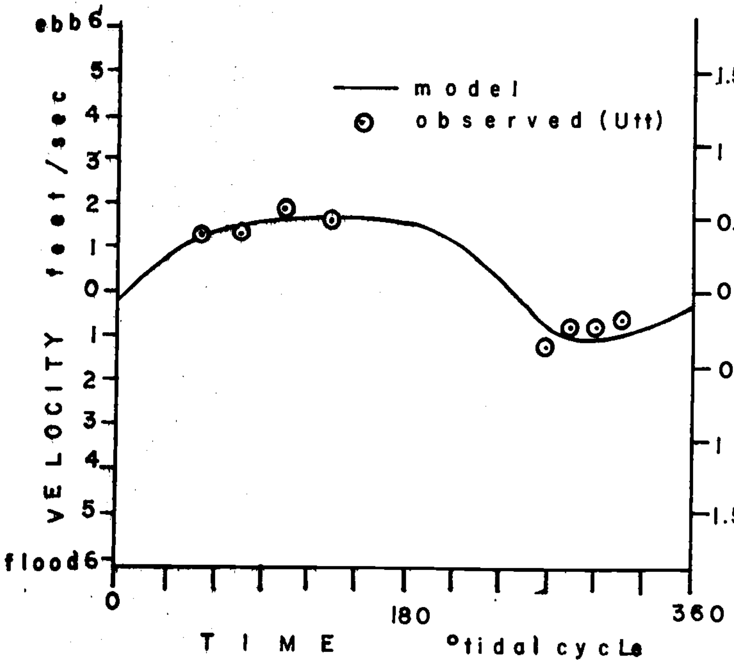

Figure 28. Velocity, November 19, 1973; river mile 8.0.

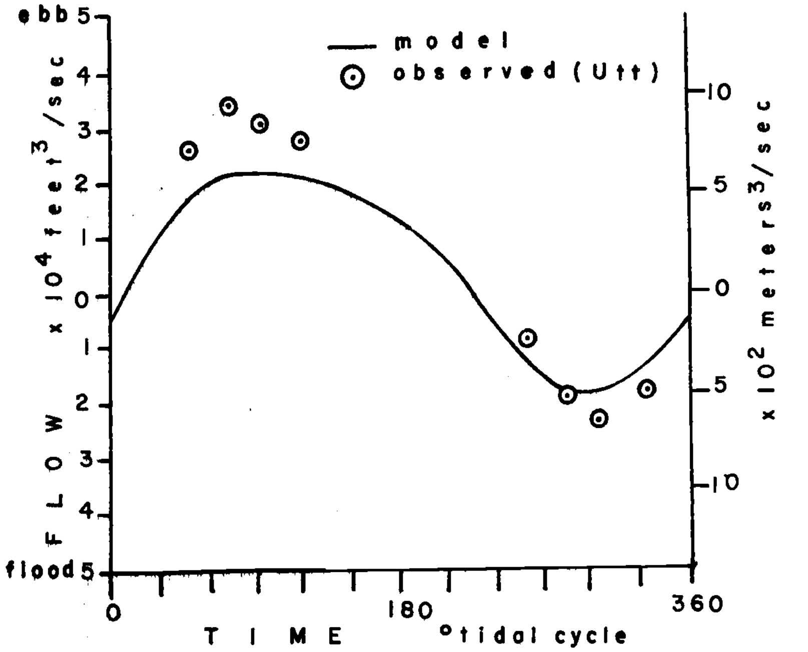

Figure 29. Flow, November 19, 1973; river mile 4.5.

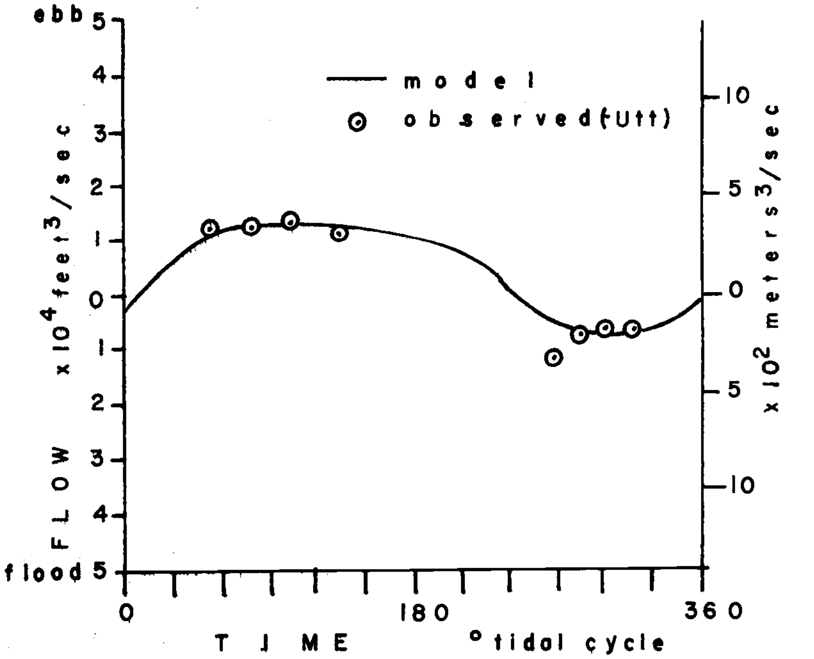

Figure 30. Flow, November 19, 1973; river mile 8.0.

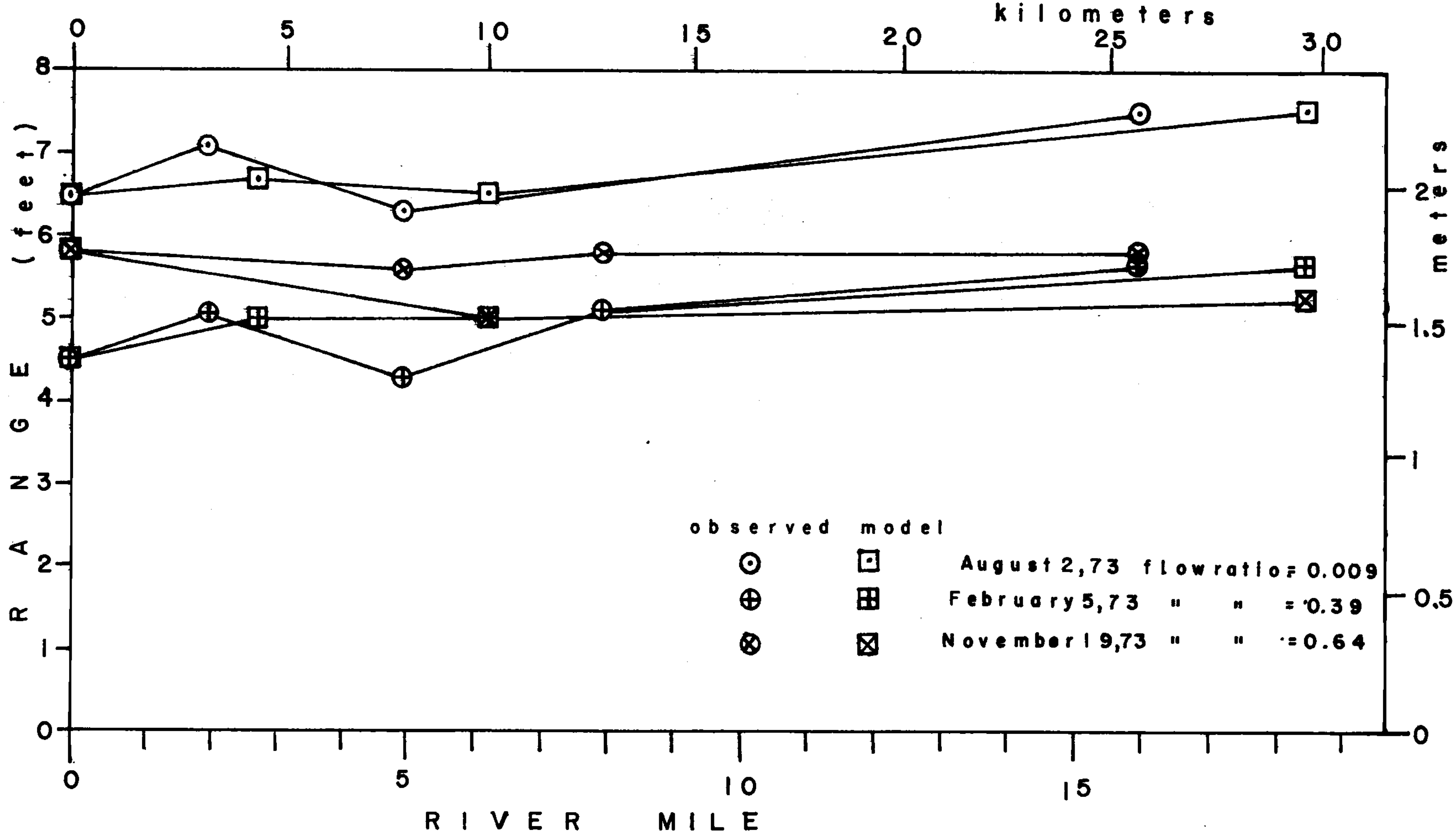

Figure 31. Measured vs. predicted range along river miles.

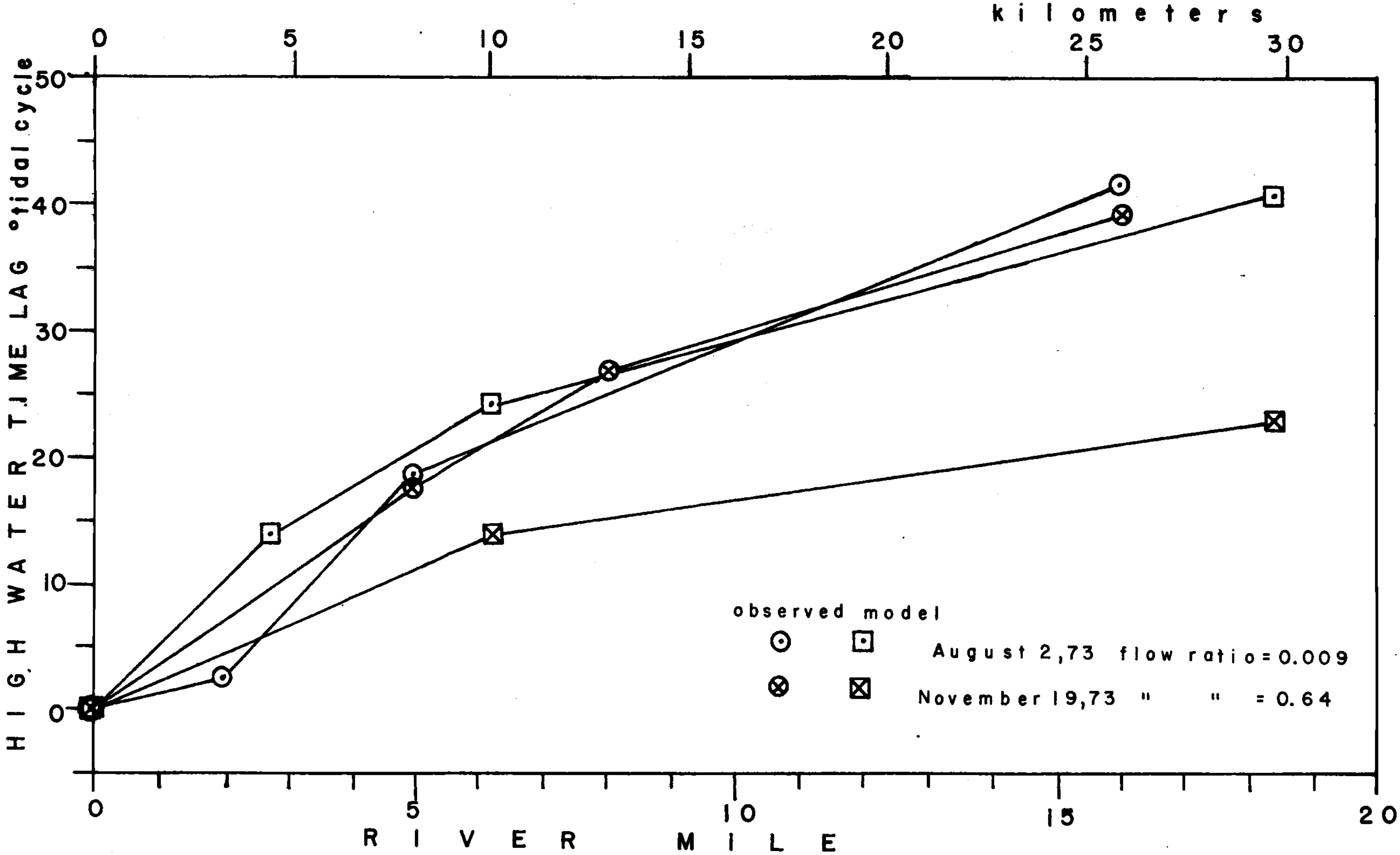

Figure 32. Measured vs. predicted high water time lag along river miles.

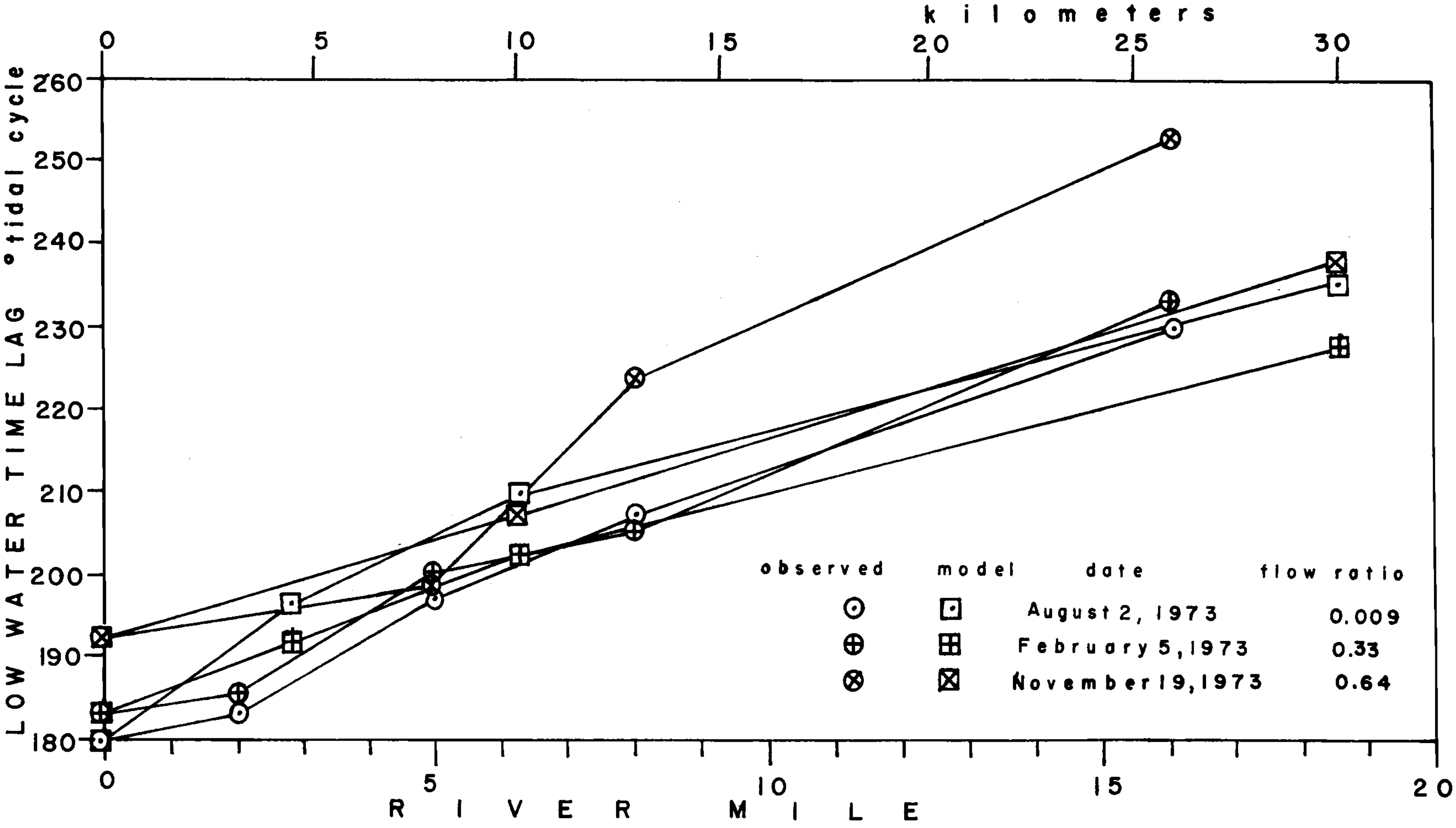

Figure 33. Measured vs. predicted low water time lag along river miles.

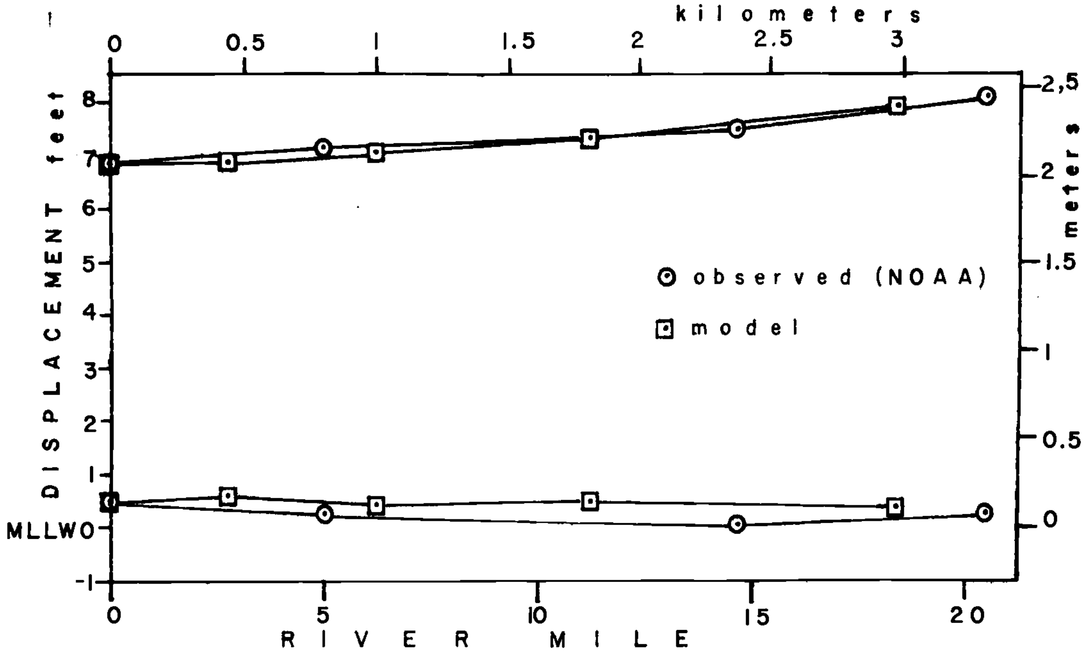

Figure 34. Measured vs. predicted max. and min. water displacement along river miles, Sept. 17, 1974.

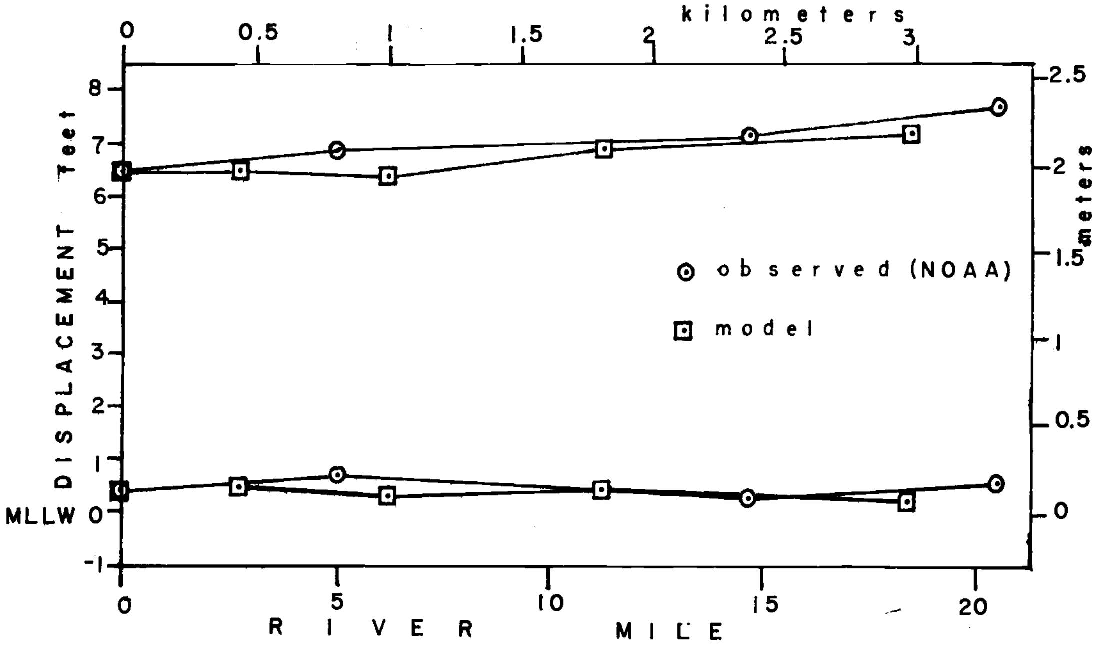

Figure 35. Measured vs. predicted max. and min. water displacement along river miles, Sept. 22, 1974.

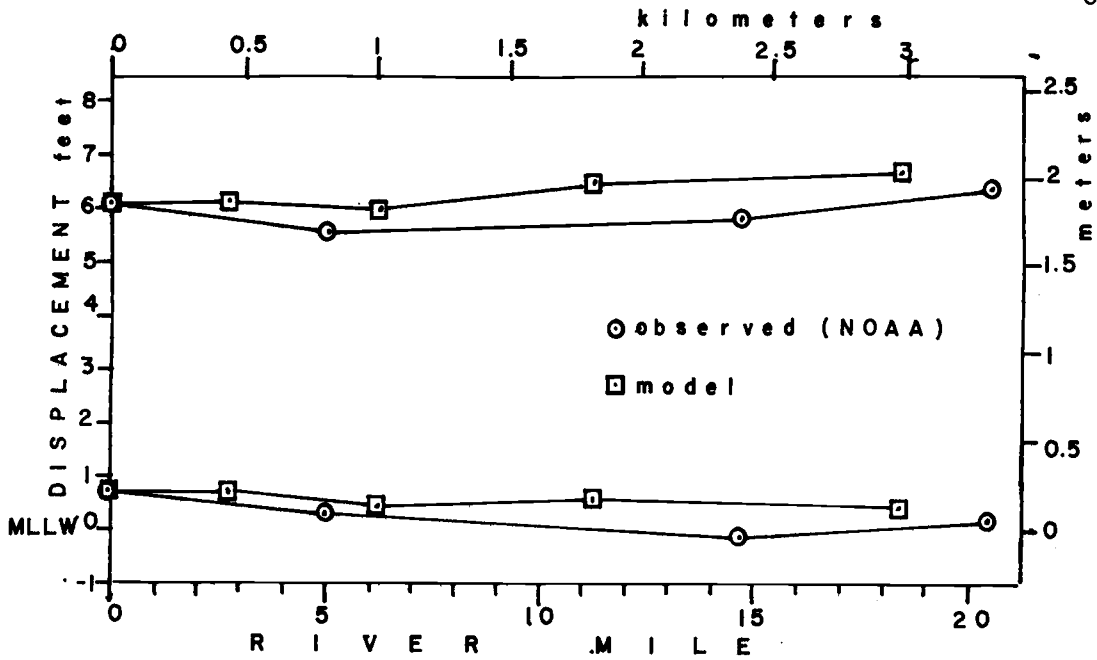

Figure 36. Measured vs. predicted max. and min. water displacement along river miles, Sept. 27, 1974.

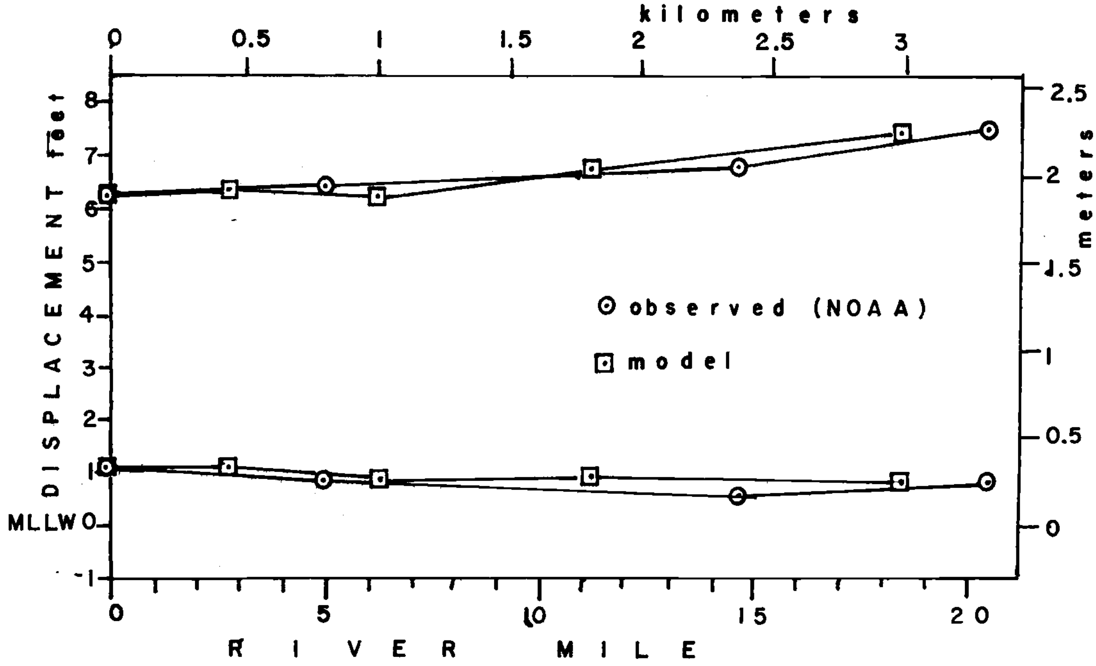

Figure 37. Measured vs. predicted max. and min. water displacement along river miles, Sept. 29, 1974.

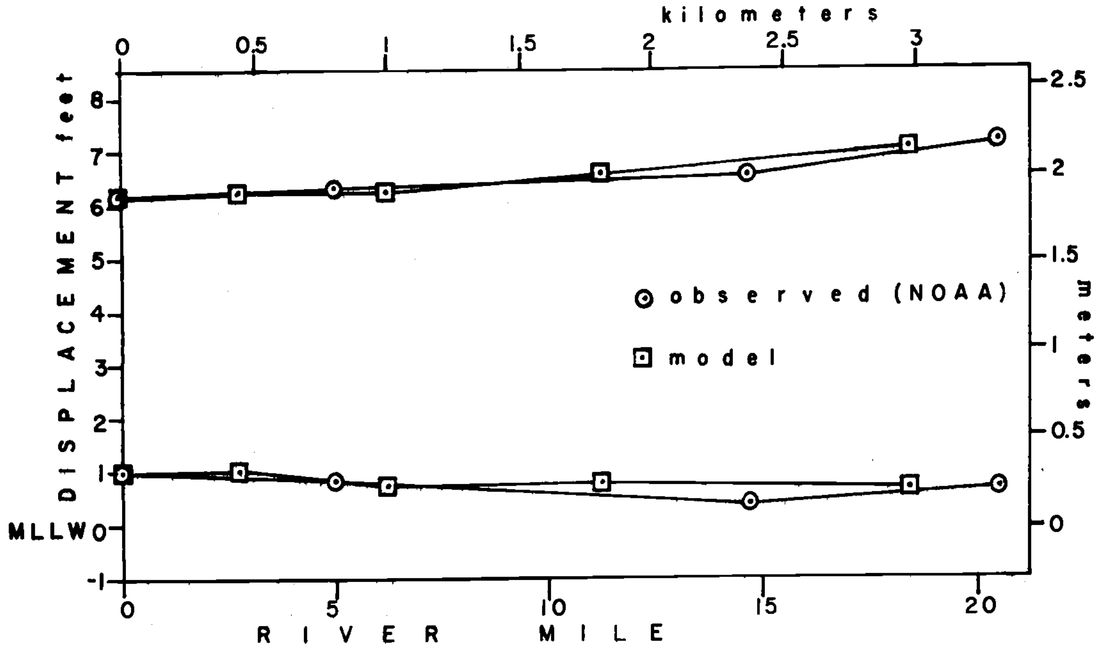

Figure 38. Measured vs. predicted max. and min. water displacement along river miles, Sept. $29\frac{1}{2}$, 1974.

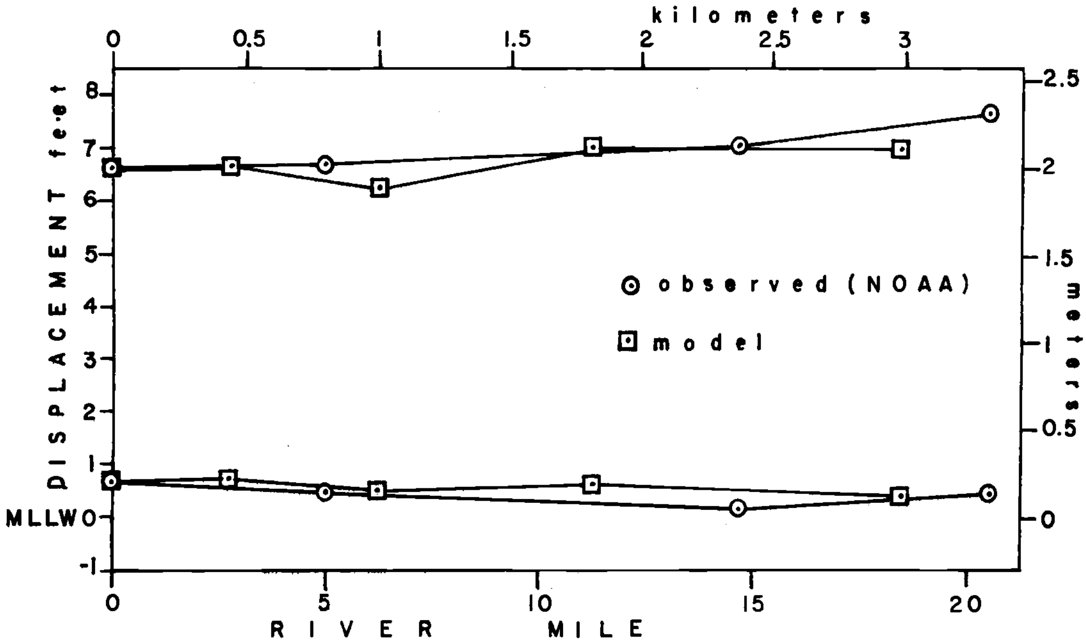

Figure 39. Measured vs. predicted max. and min. water displacement along river miles, Sept. 30, 1974.

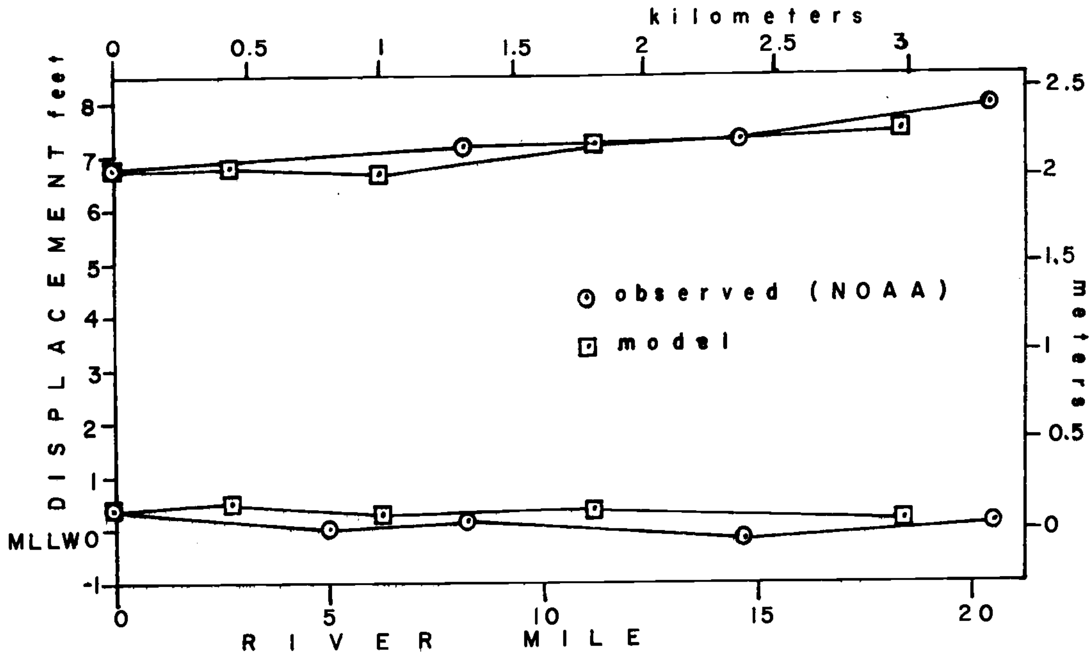

Figure 40. Measured vs. predicted max. and min. water displacement along river miles, Oct. 1, 1974.

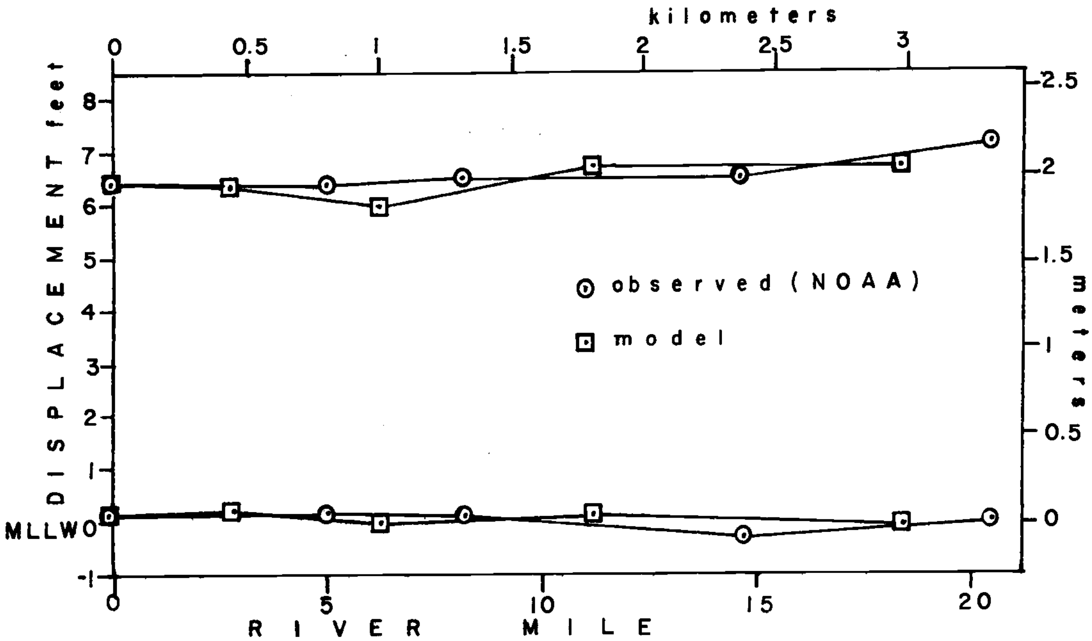

Figure 41. Measured vs. predicted max. and min. water displacement along river miles, Oct. 9, 1974.

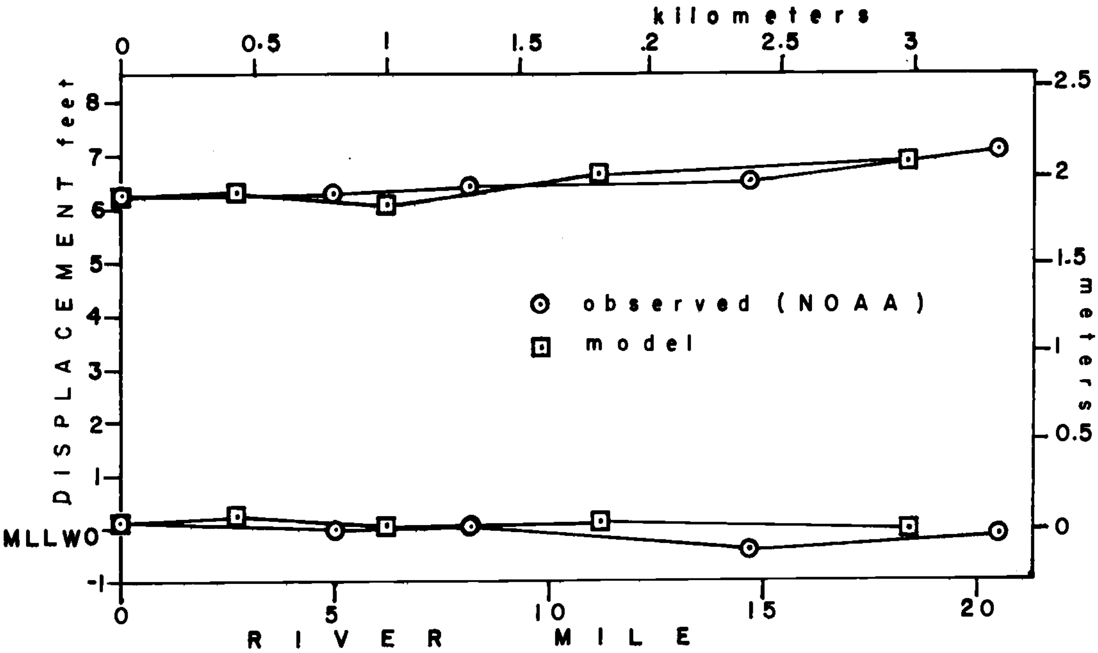

Figure 42. Measured vs. predicted max. and min. water displacement along river miles, Oct. 10, 1974.

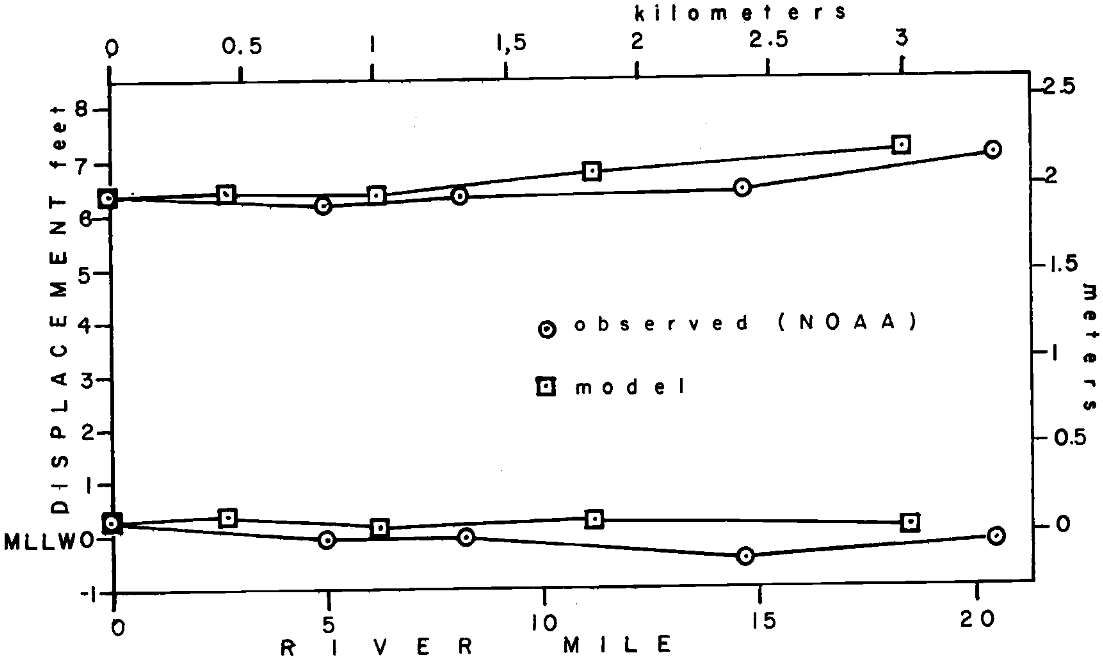

Figure 43. Measured vs. predicted max. and min. water displacement along river miles, Oct. 11, 1974.

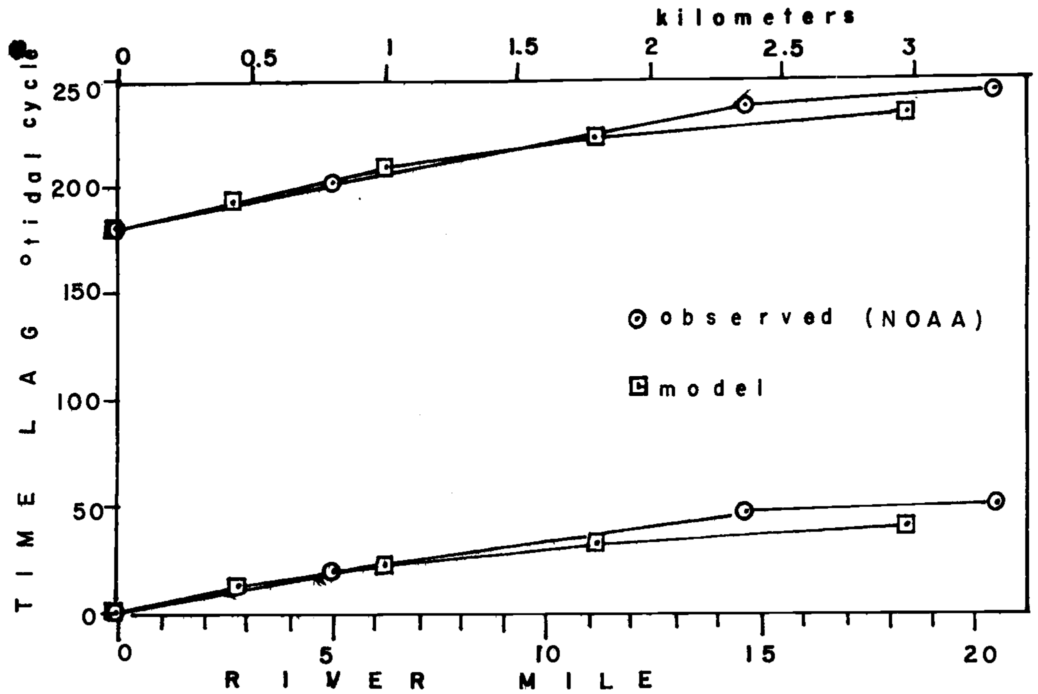

Figure 44. Measured vs. predicted high and low water time lag along river miles, Sept. 17, 1974.

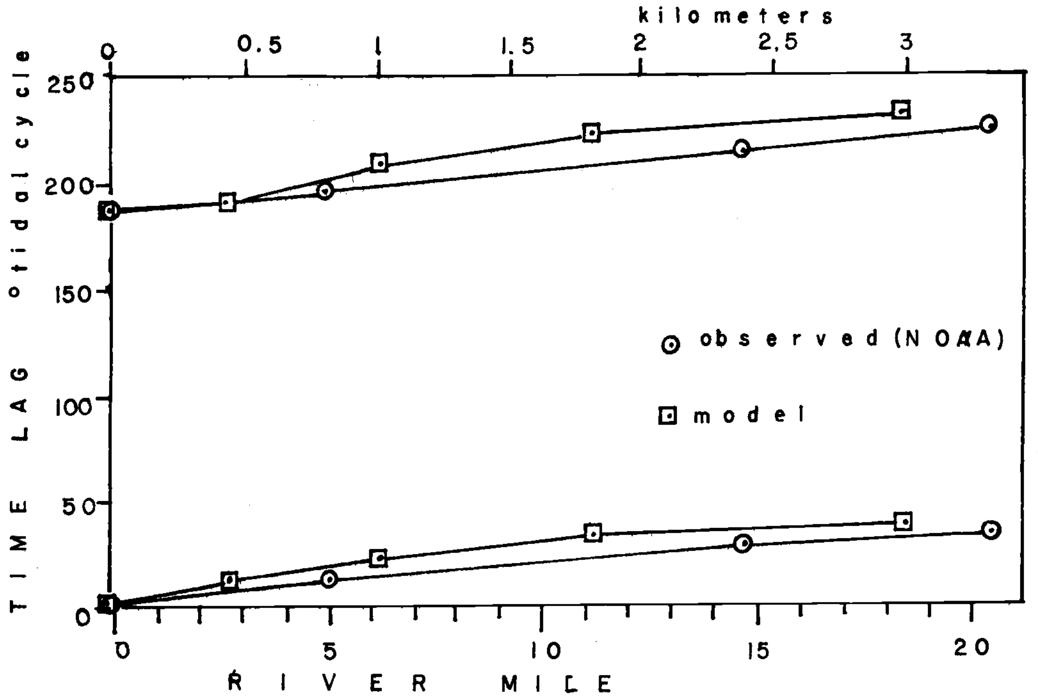

Figure 45. Measured vs. predicted high and low water time lag along river miles, Sept. 22, 1974.

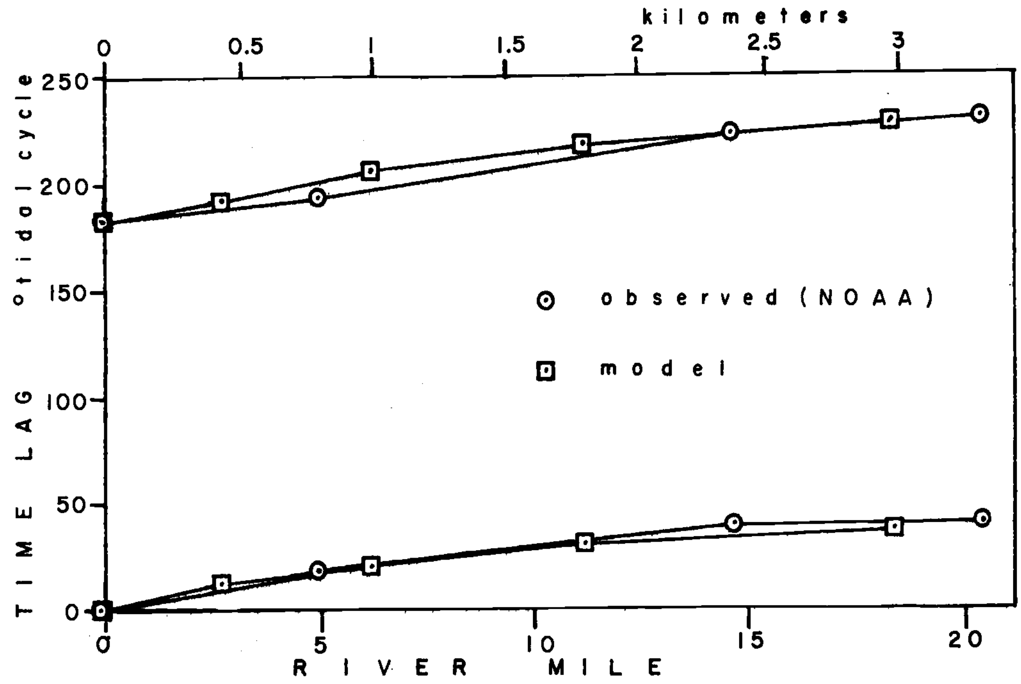

Figure 46. Measured vs. predicted high and low water time lag along river miles, Sept. 27, 1974.

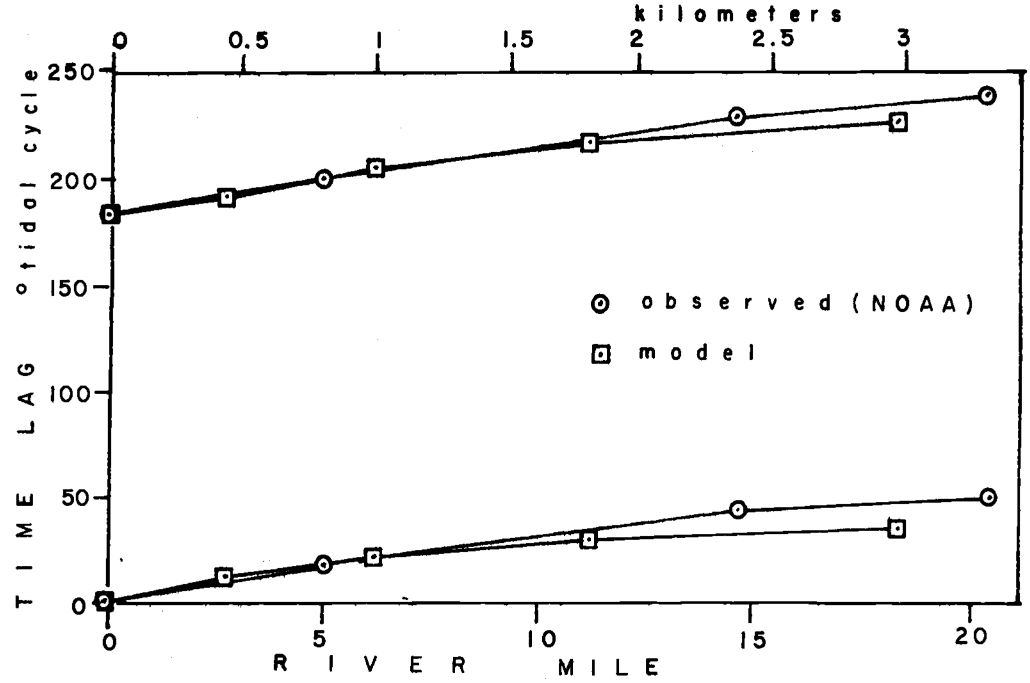

Figure 47. Measured vs. predicted high and low water time lag along river miles, Sept. 29, 1974.

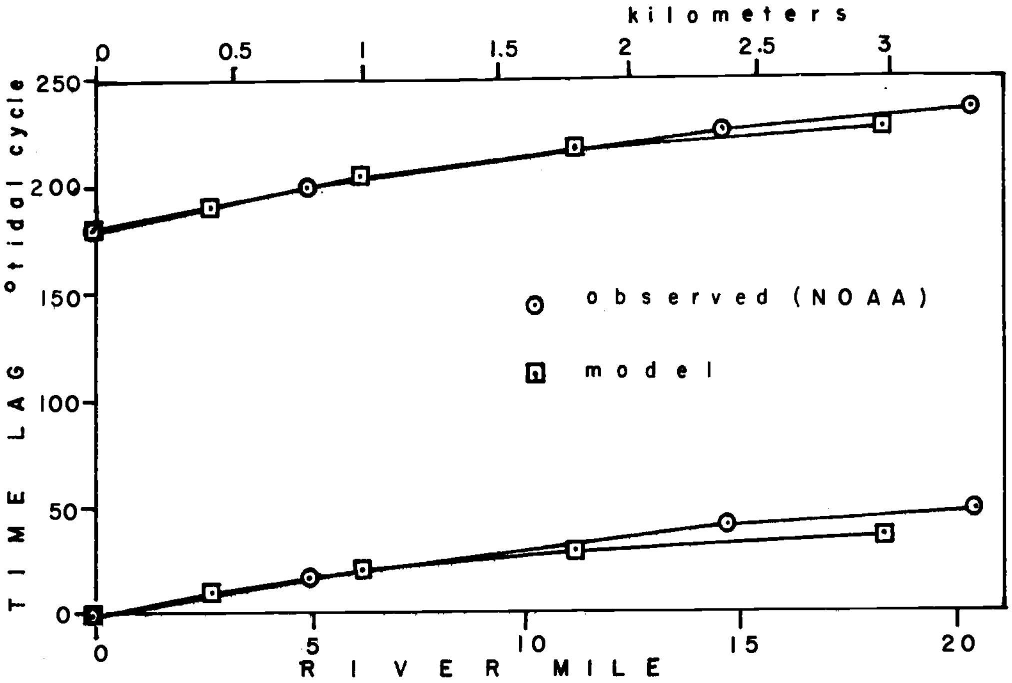

Figure 48. Measured vs. predicted high and low water time lag along river miles, Sept. 29½, 1974.

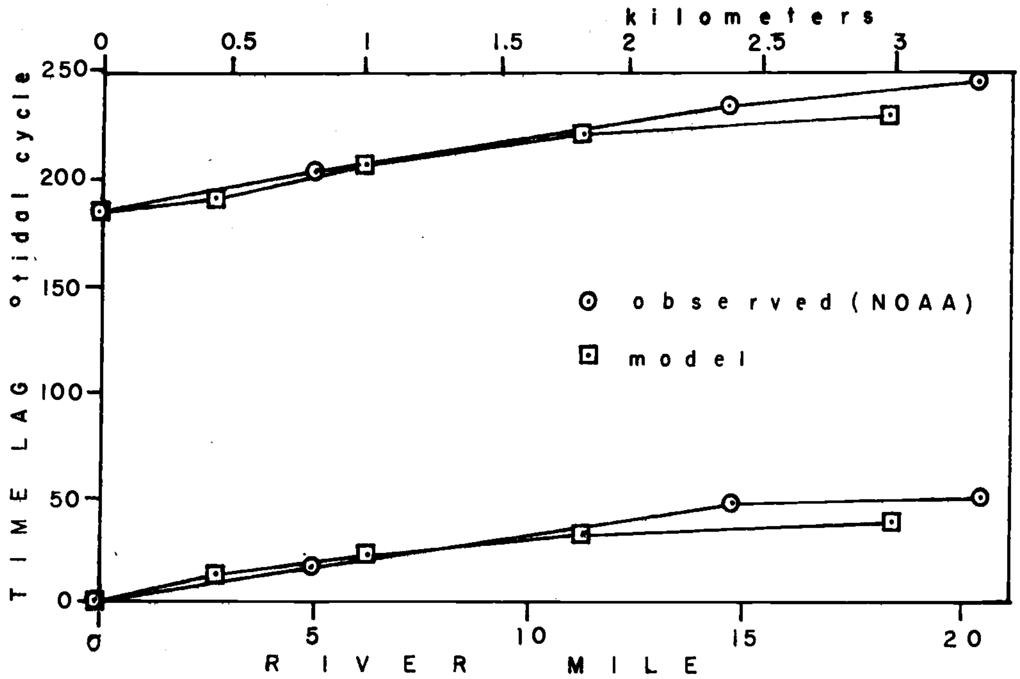

Figure 49. Measured vs. predicted high and low water time lag along river miles, Sept. 30, 1974.

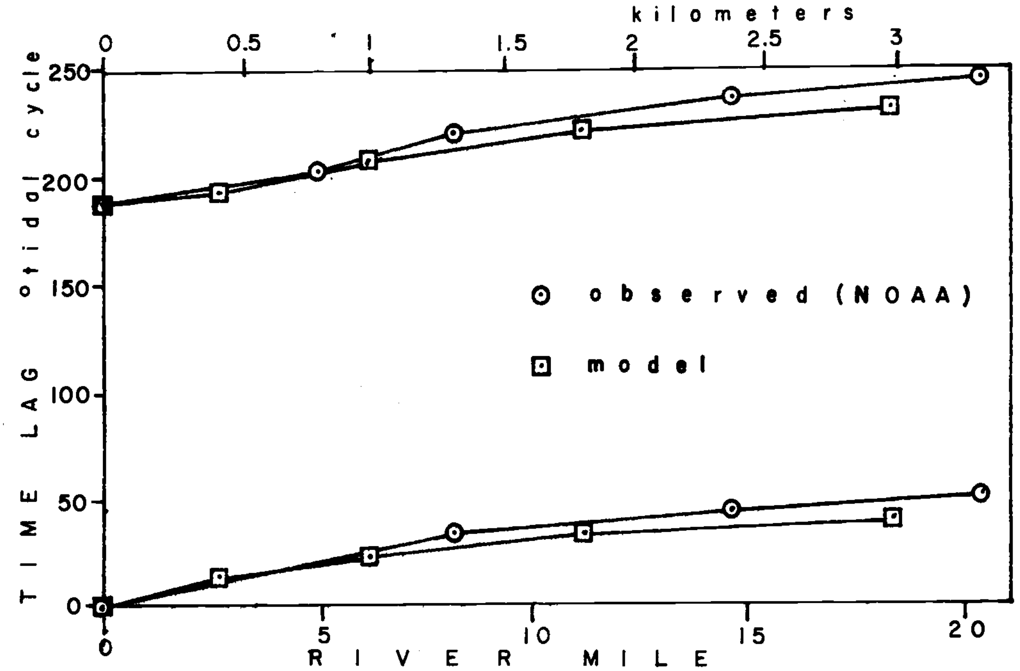

Figure 50. Measured vs. predicted high and low water time lag along river miles, Oct. 1, 1974.

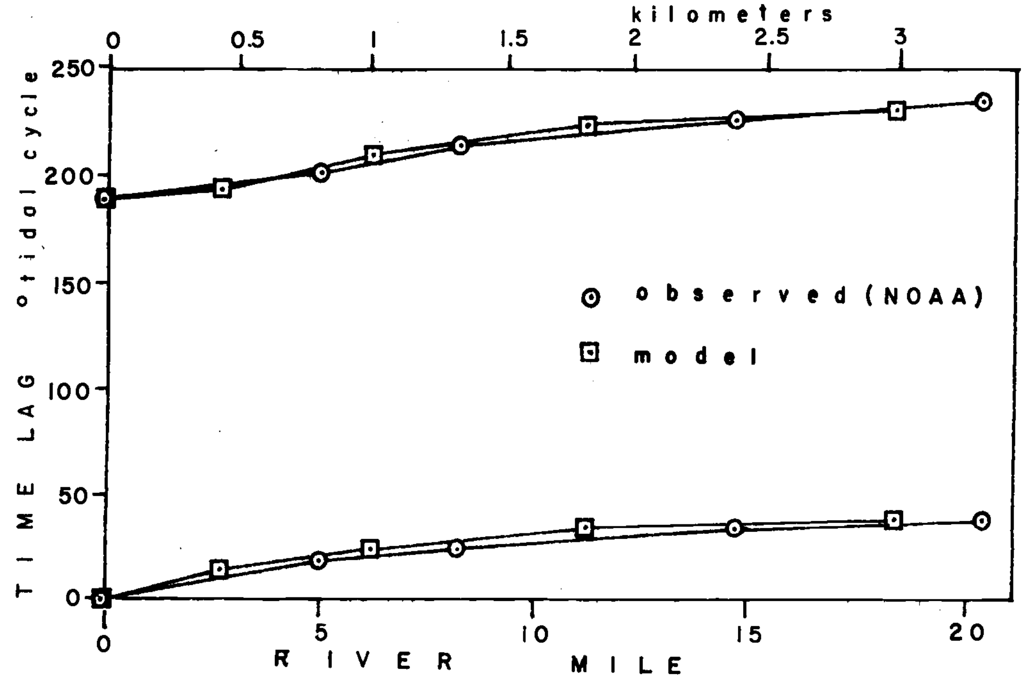

Figure 51. Measured vs. predicted high and low water time lag along river miles, Oct. 9, 1974.

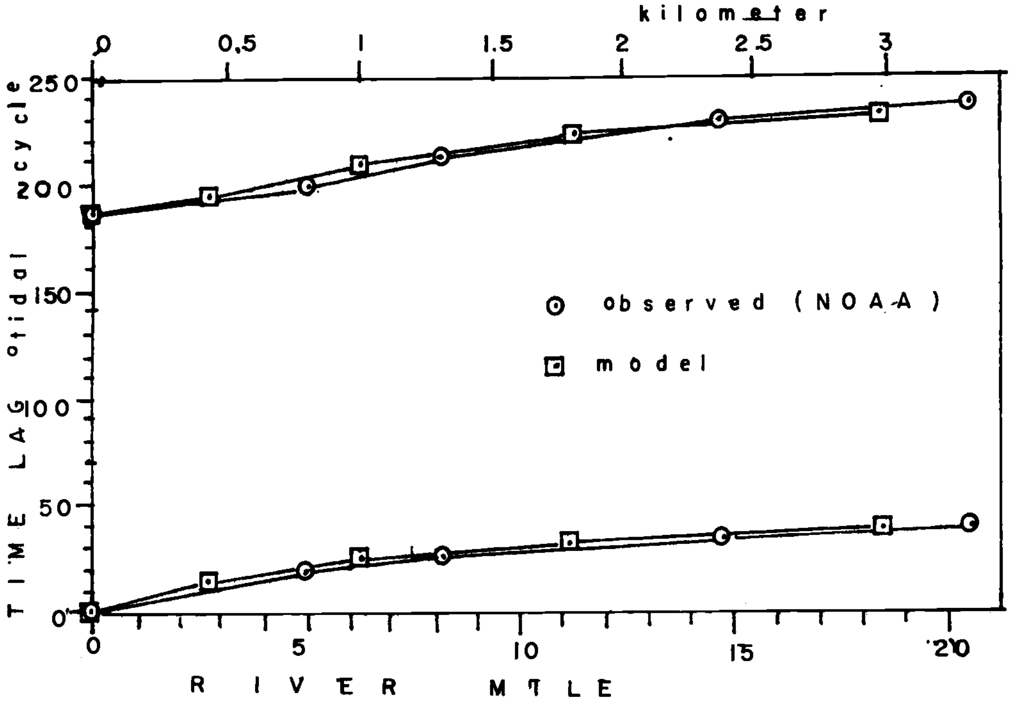

Figure 52. Measured vs. predicted high and low water time lag along river miles, Oct. 10, 1974.

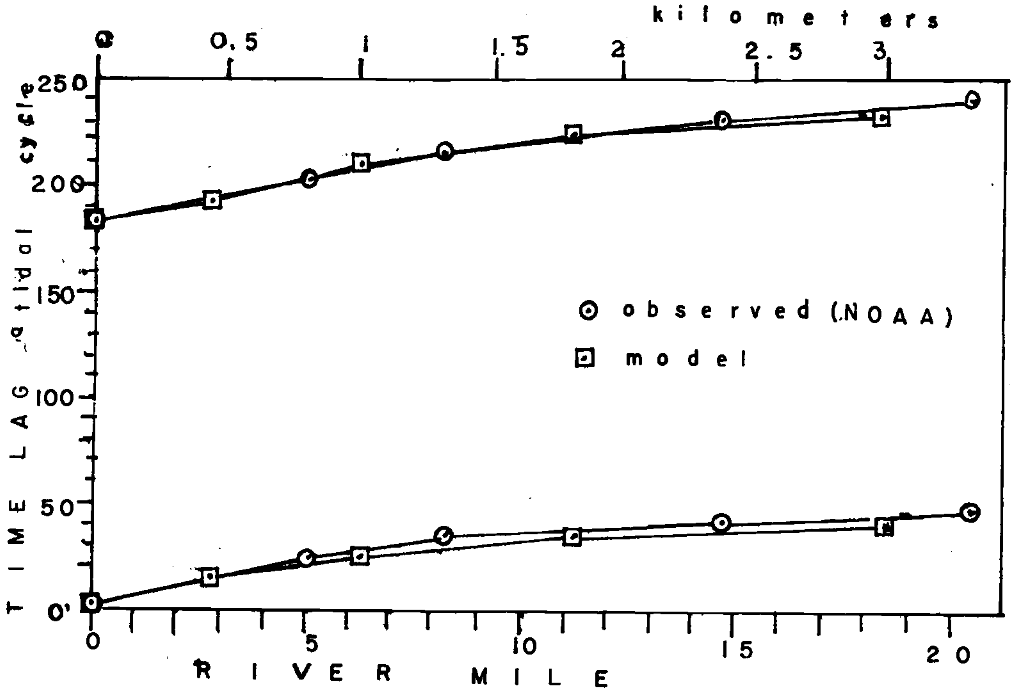

Figure 53. Measured vs. predicted high and low water time lag along river miles, Oct. 11, 1974.

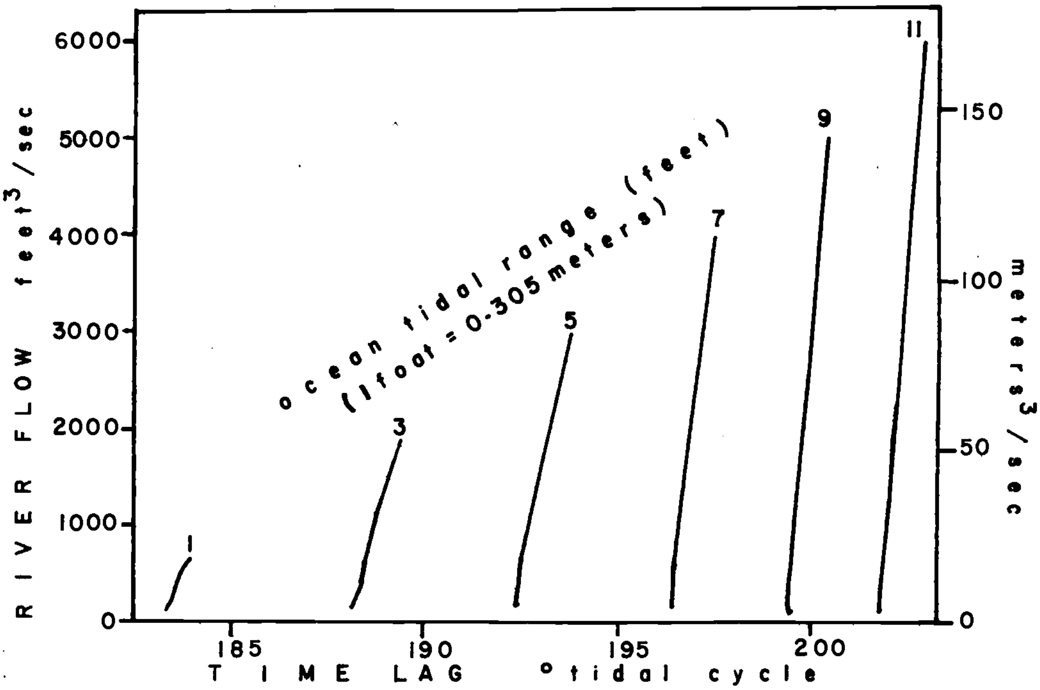

Figure 54. Low water time lag, river mile 2.75.

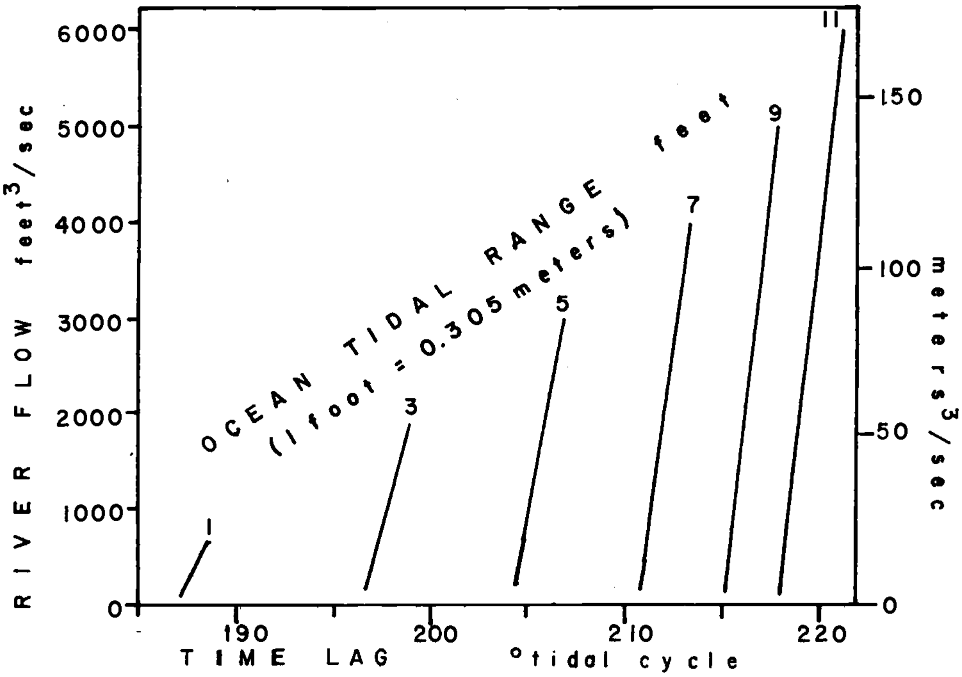

Figure 55. Low water time lag, river mile 6.25.

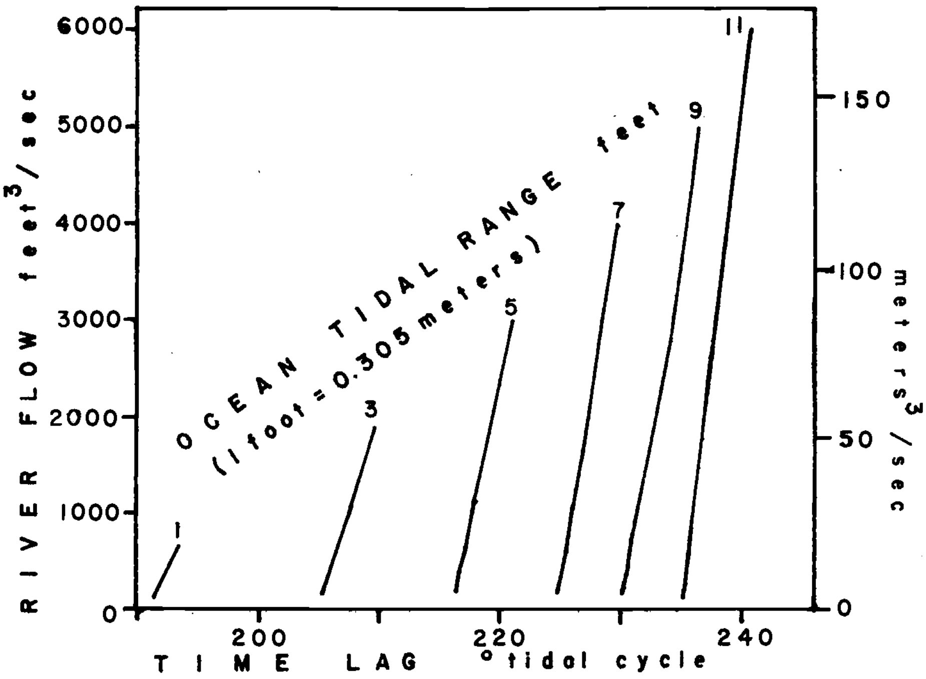

Figure 56. Low water time lag, river mile 11.20.

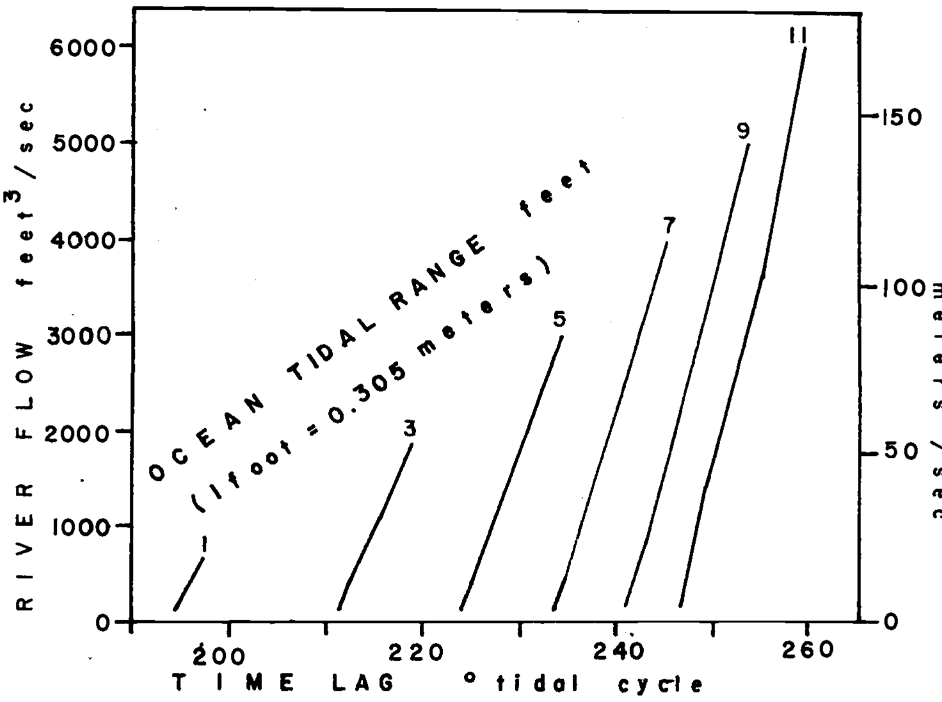

Figure 57. Low water time lag, river mile 18.45.

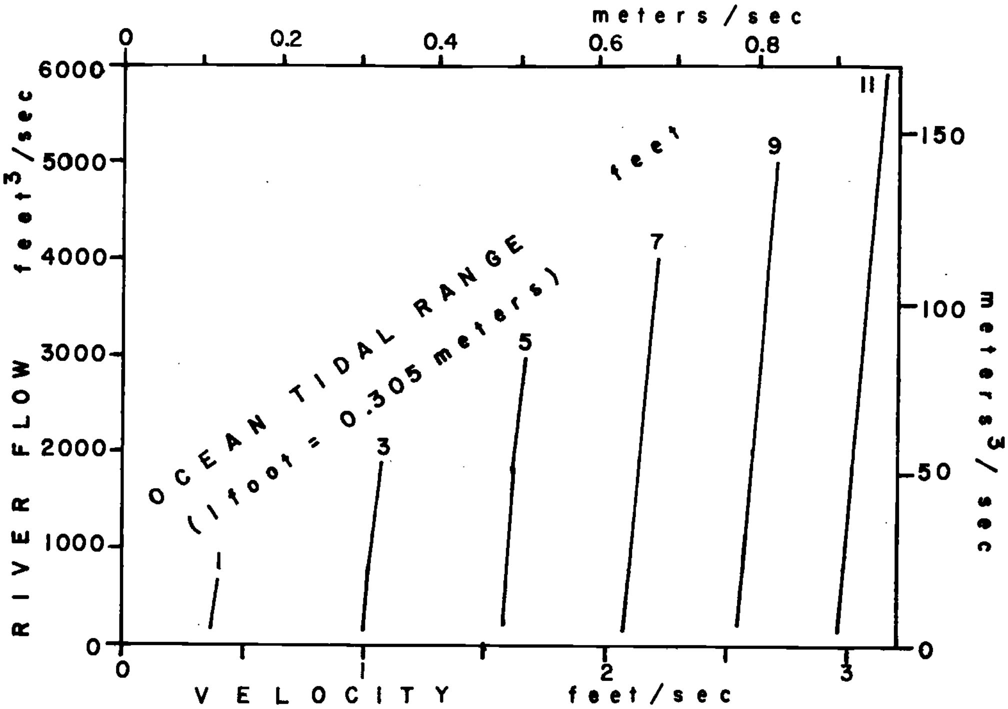

Figure 58. Maximum ebb velocity, river mile 4.5.

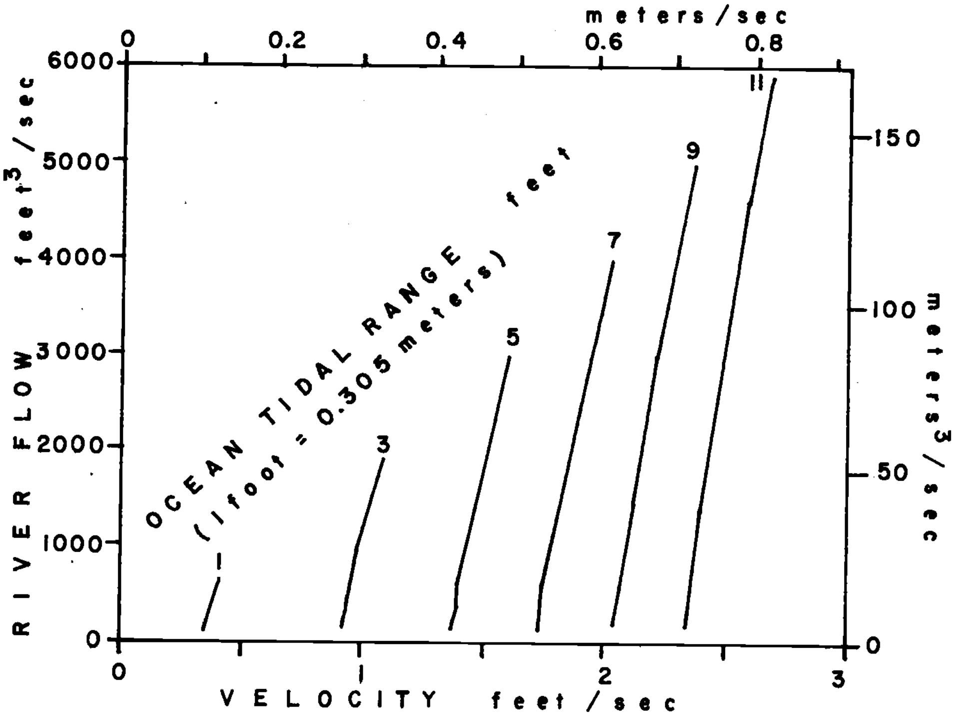

Figure 59. Maximum ebb velocity, river mile 8.0.

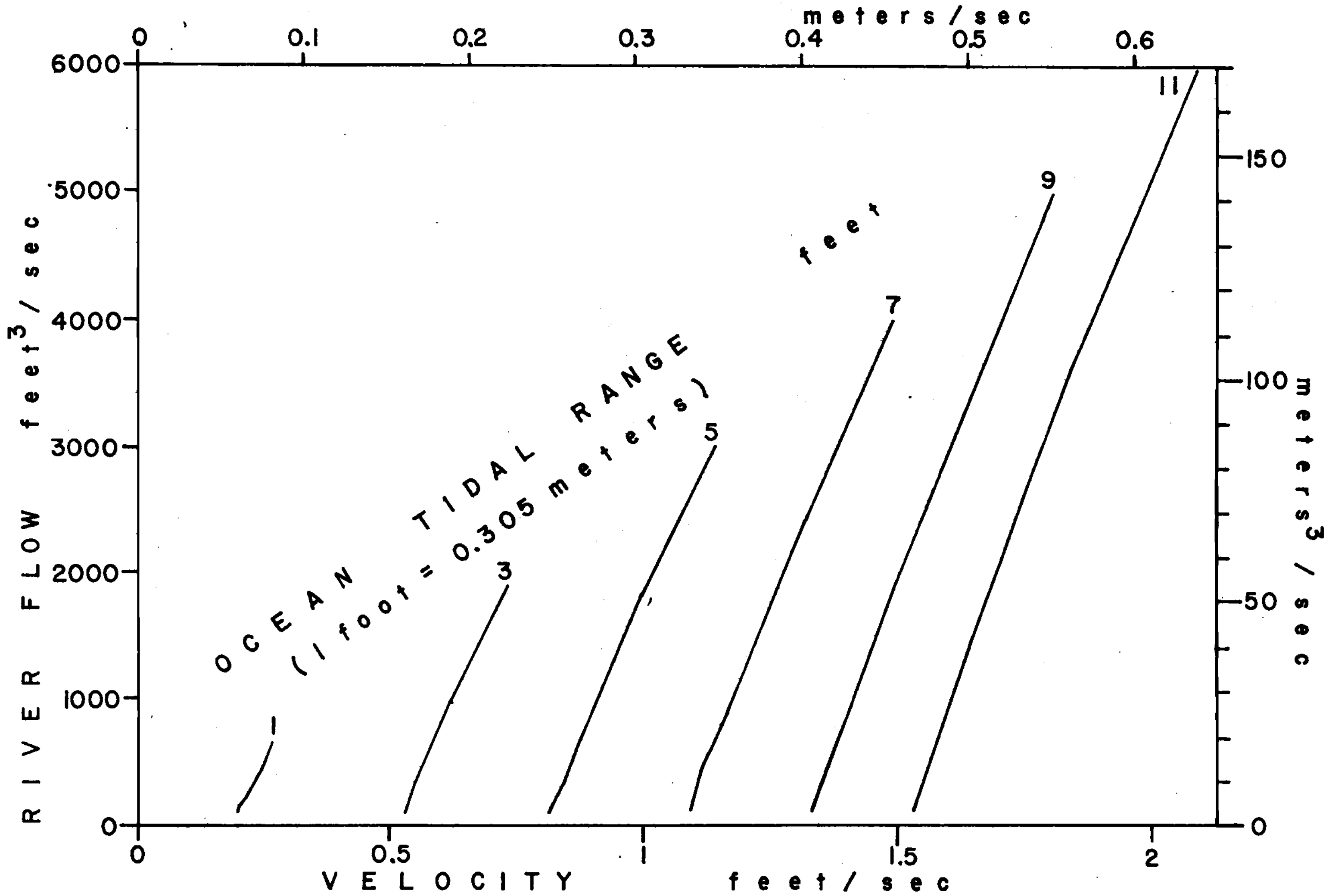

Figure 60. Maximum ebb velocity, river mile 14.4.

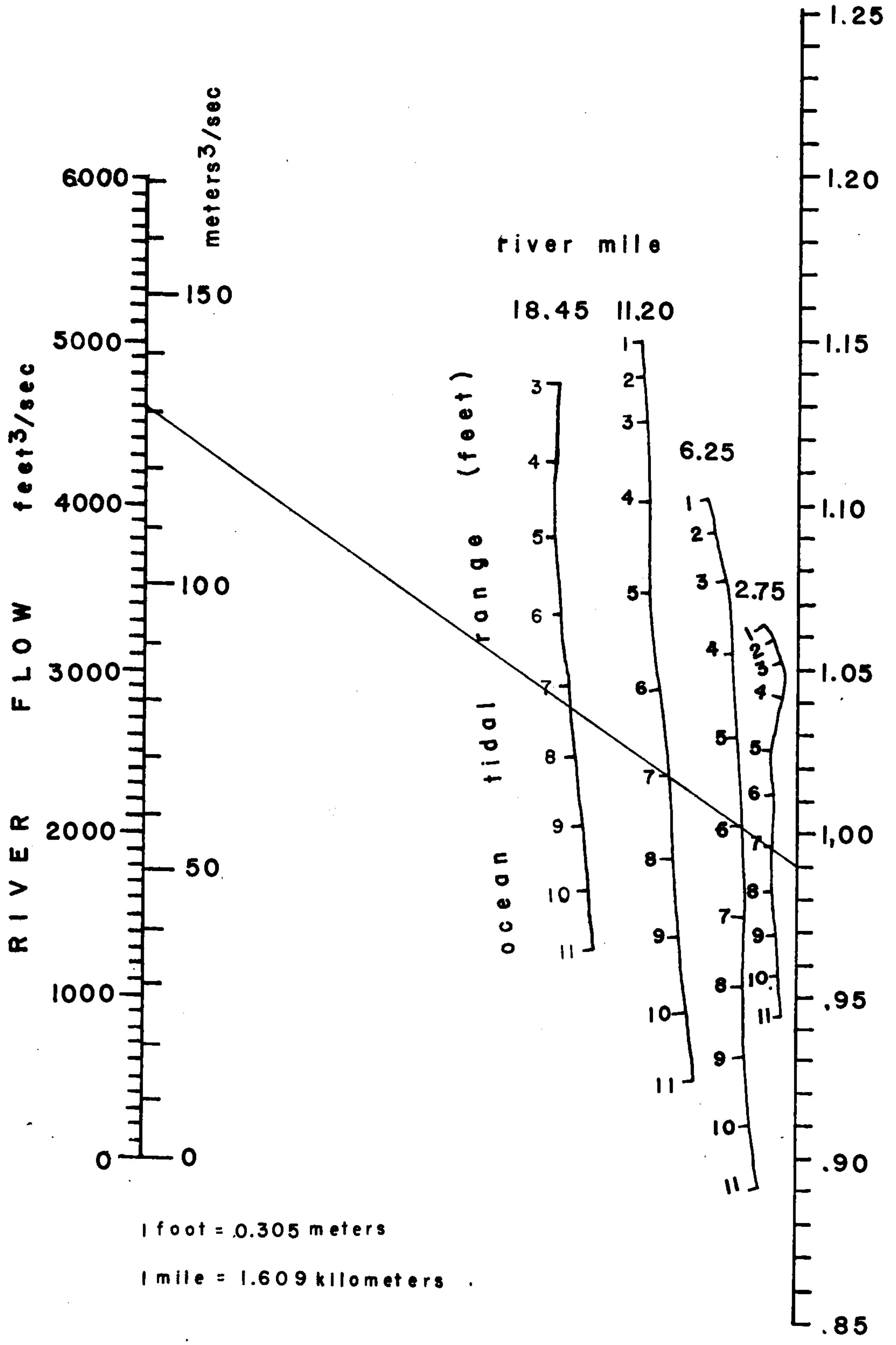

Figure 61. Amplification factors nomogram.

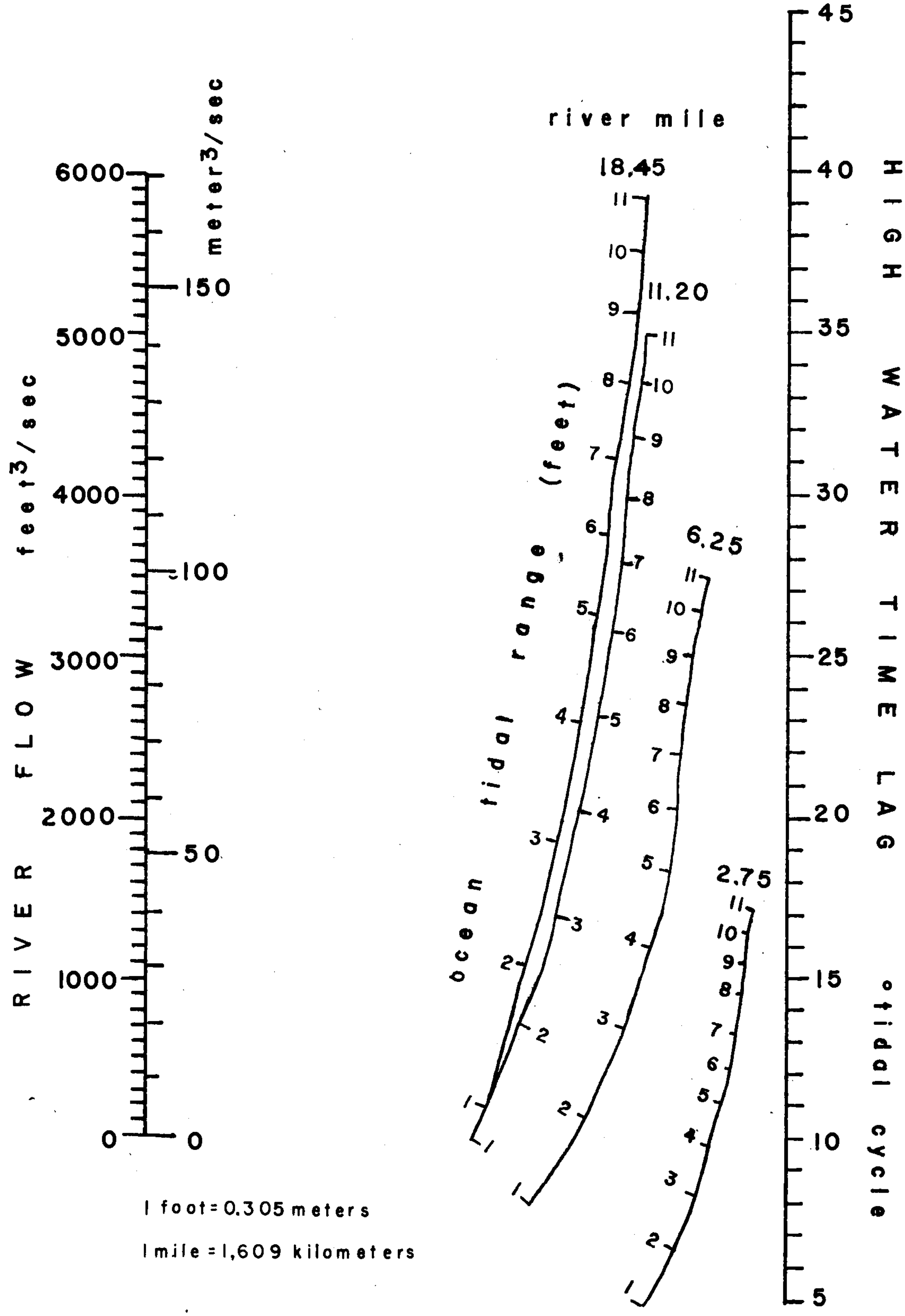

Figure 62. High water time lag nomogram.

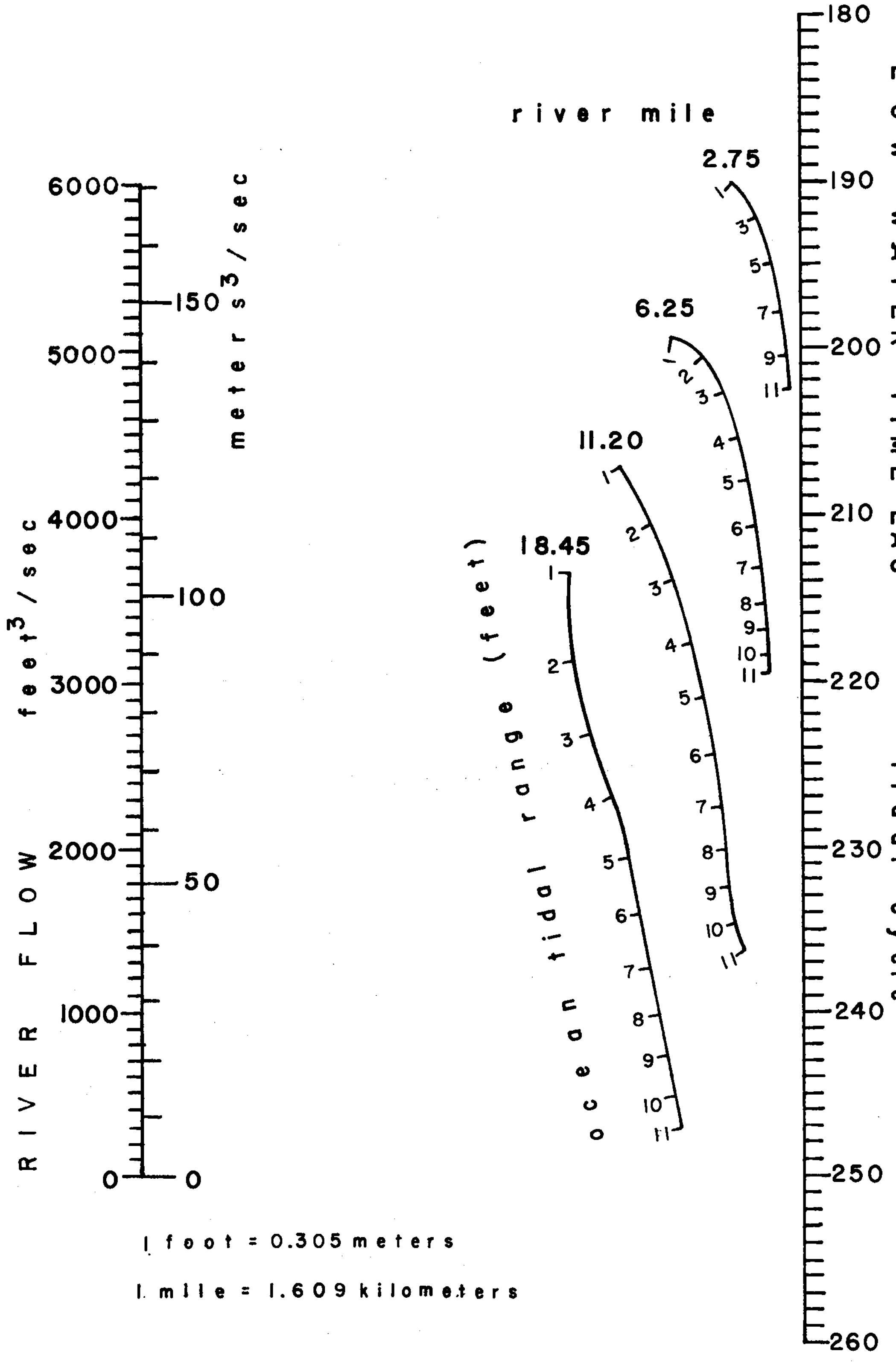

Figure 63. Low water time lag nomogram.

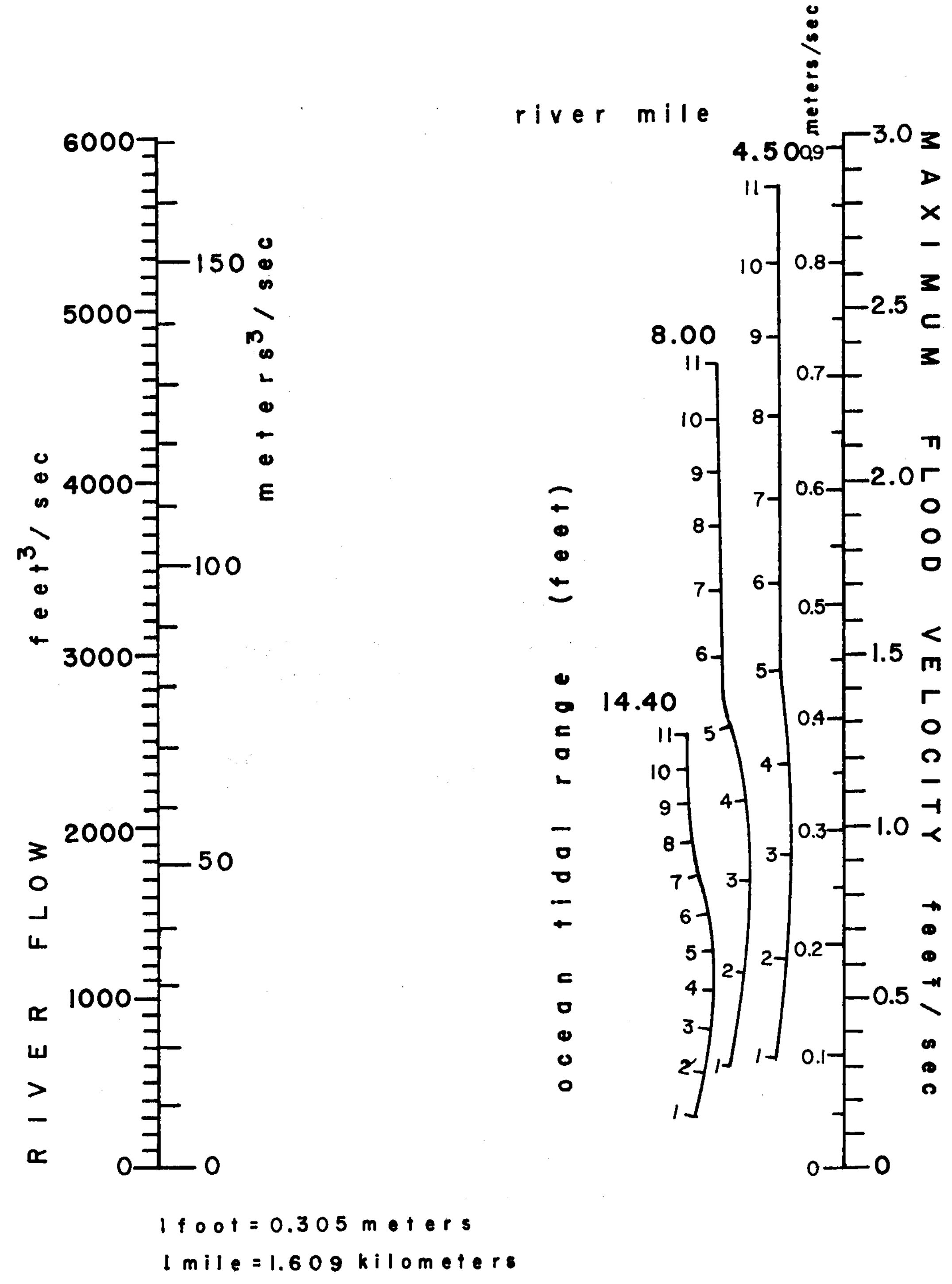

Figure 64. Maximum flood velocity nomogram.

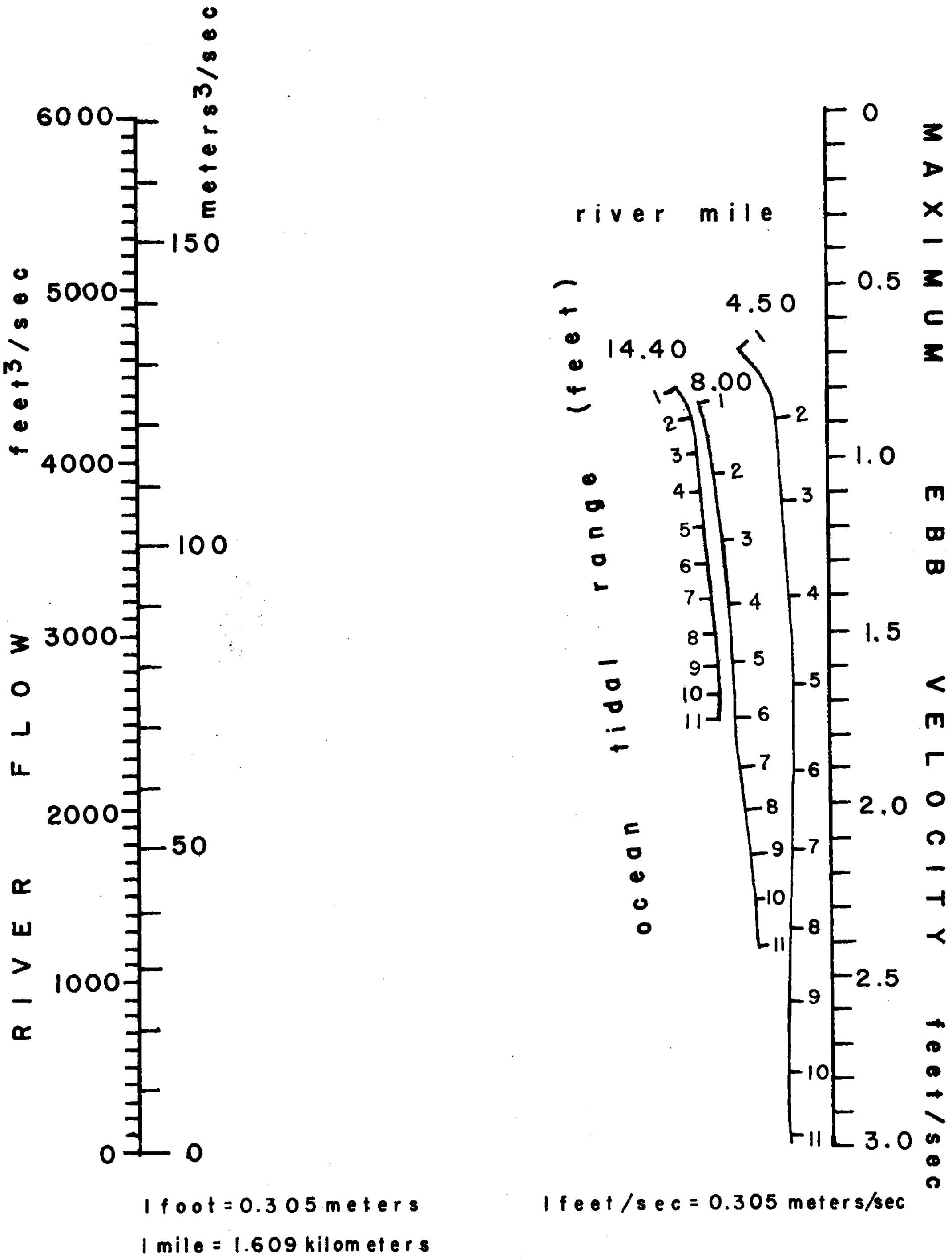

Figure 65. Maximum ebb velocity nomogram.

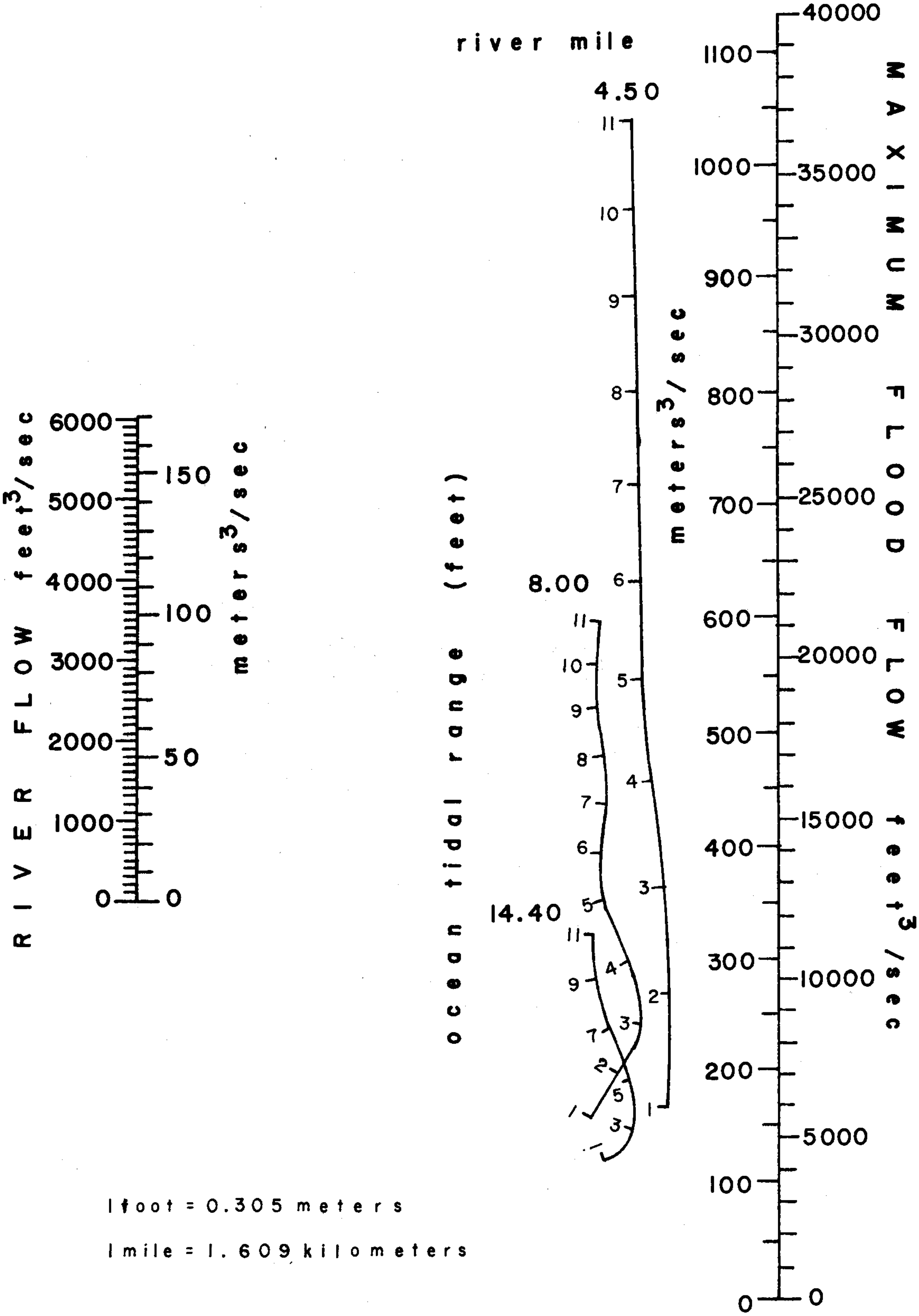

Figure 66. Maximum flood flow nomogram.

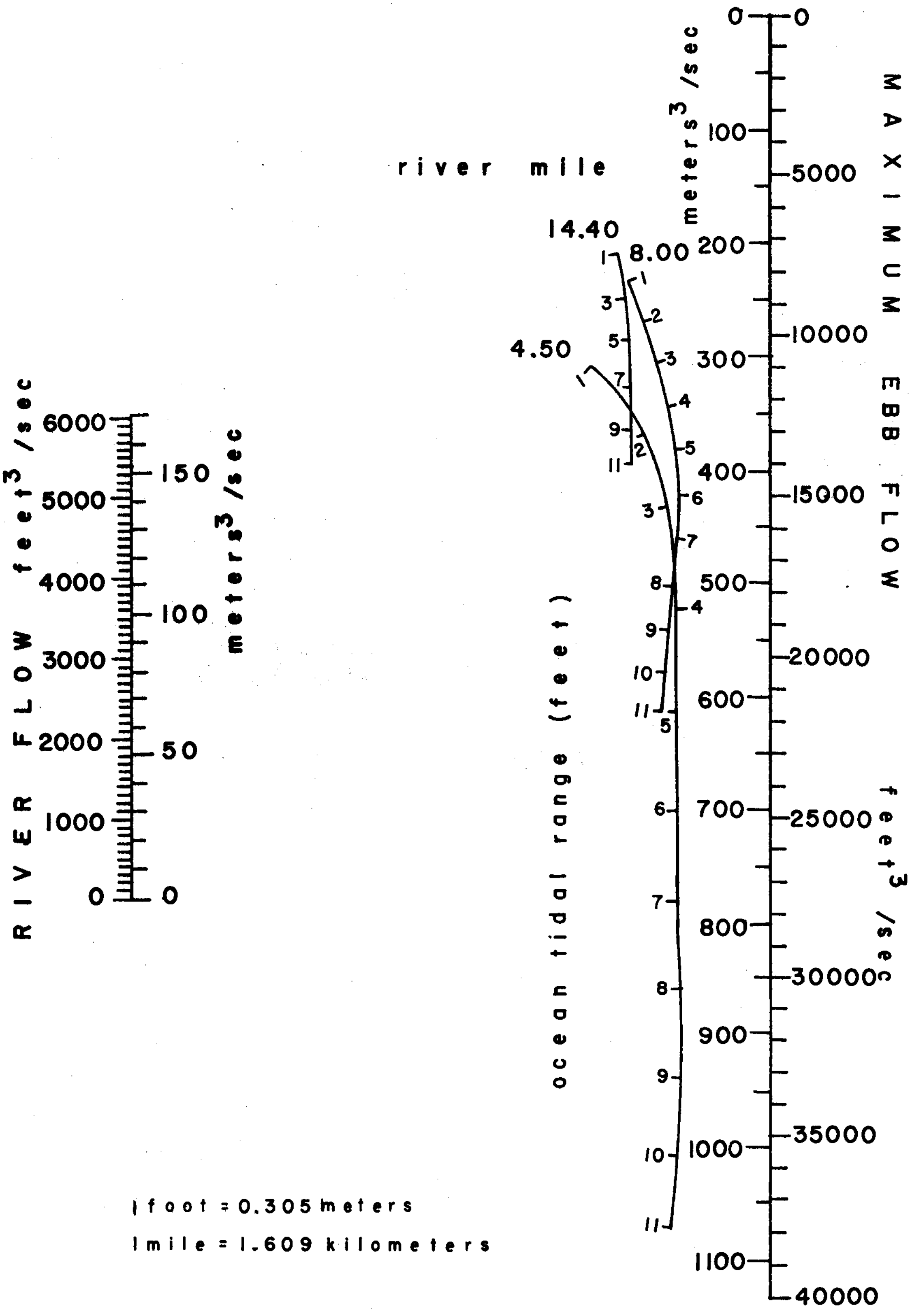

Figure 67. Maximum ebb flow nomogram.

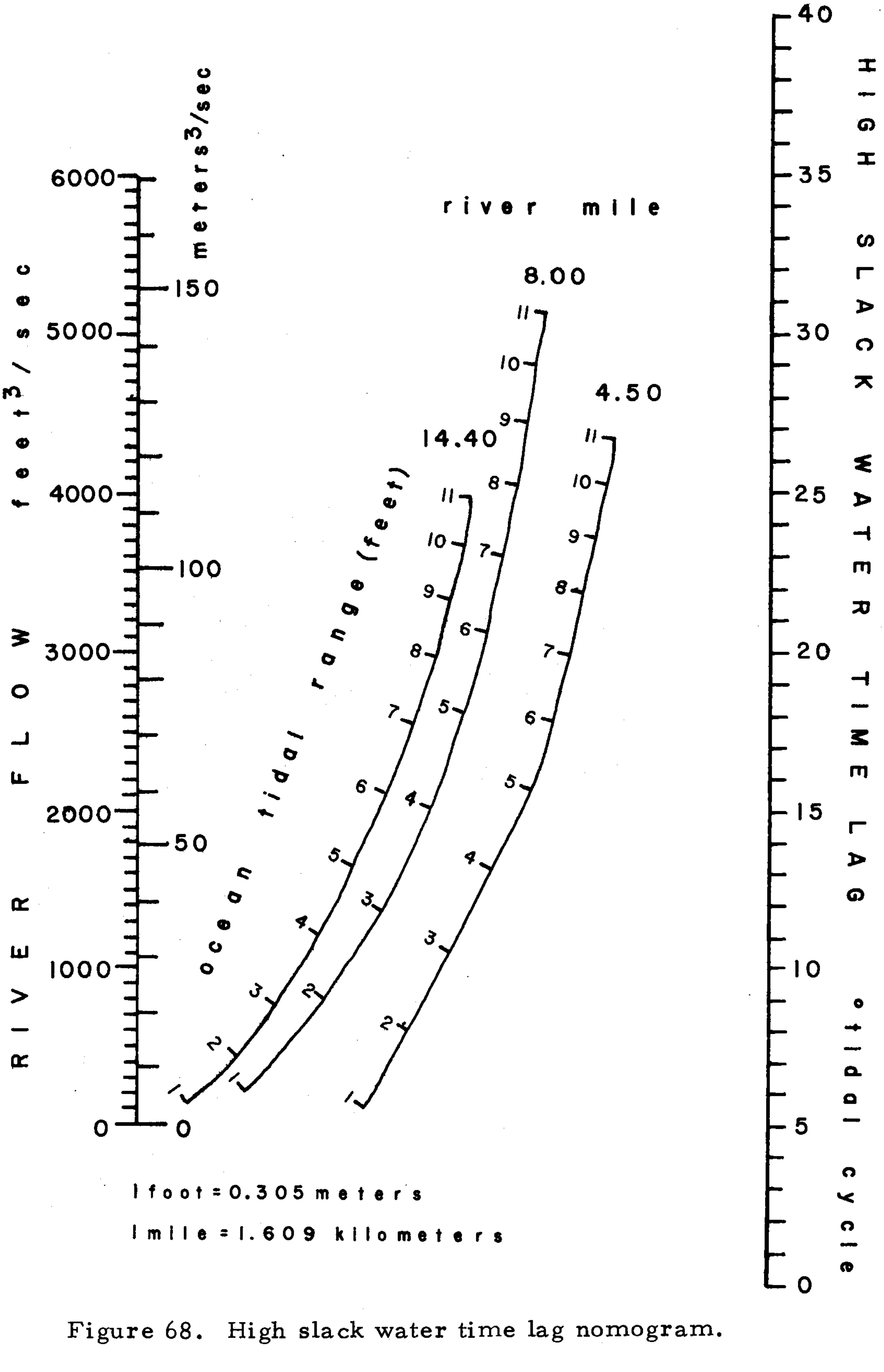

Figure 68. High slack water time lag nomogram.

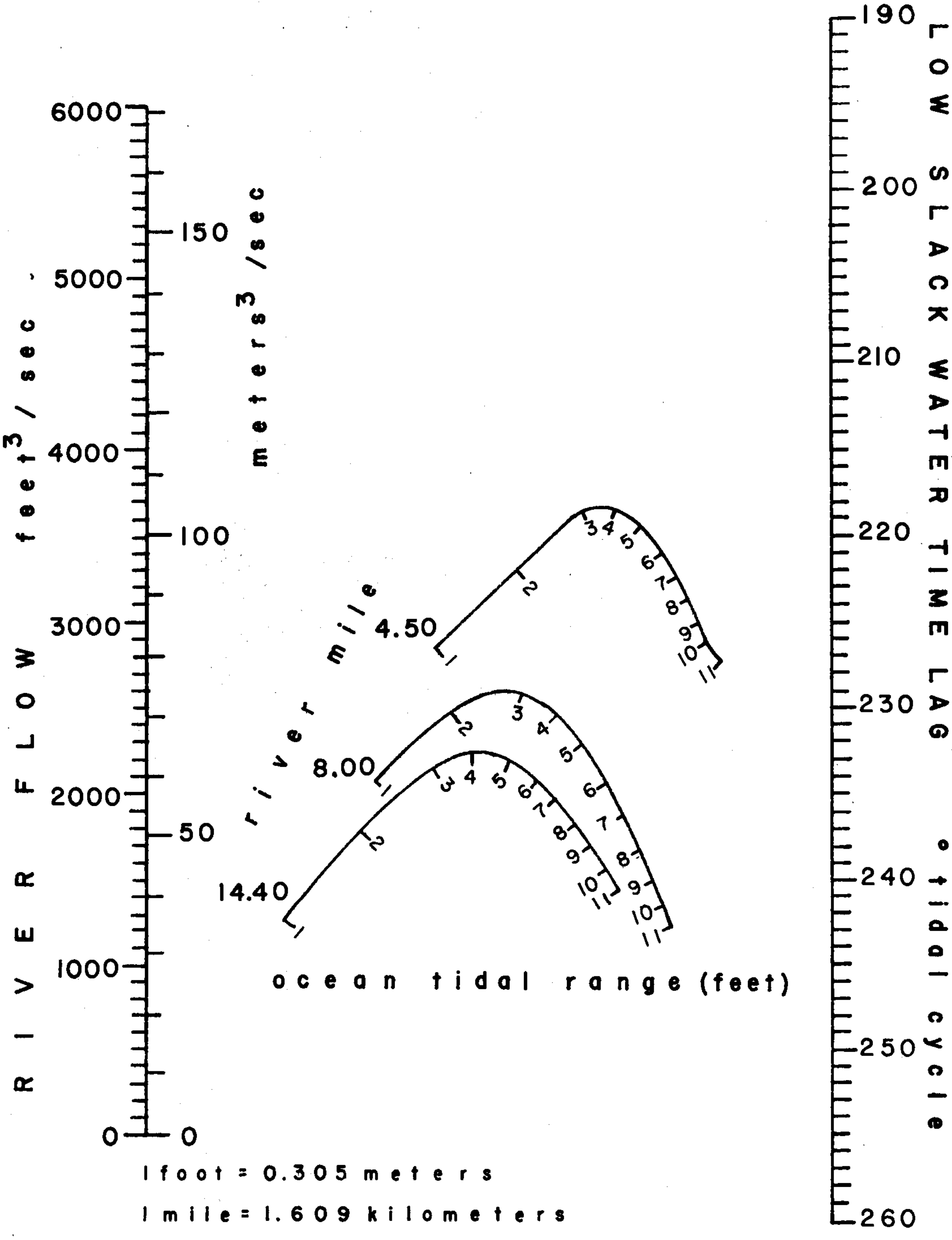

Figure 69. Low slack water time lag nomogram.

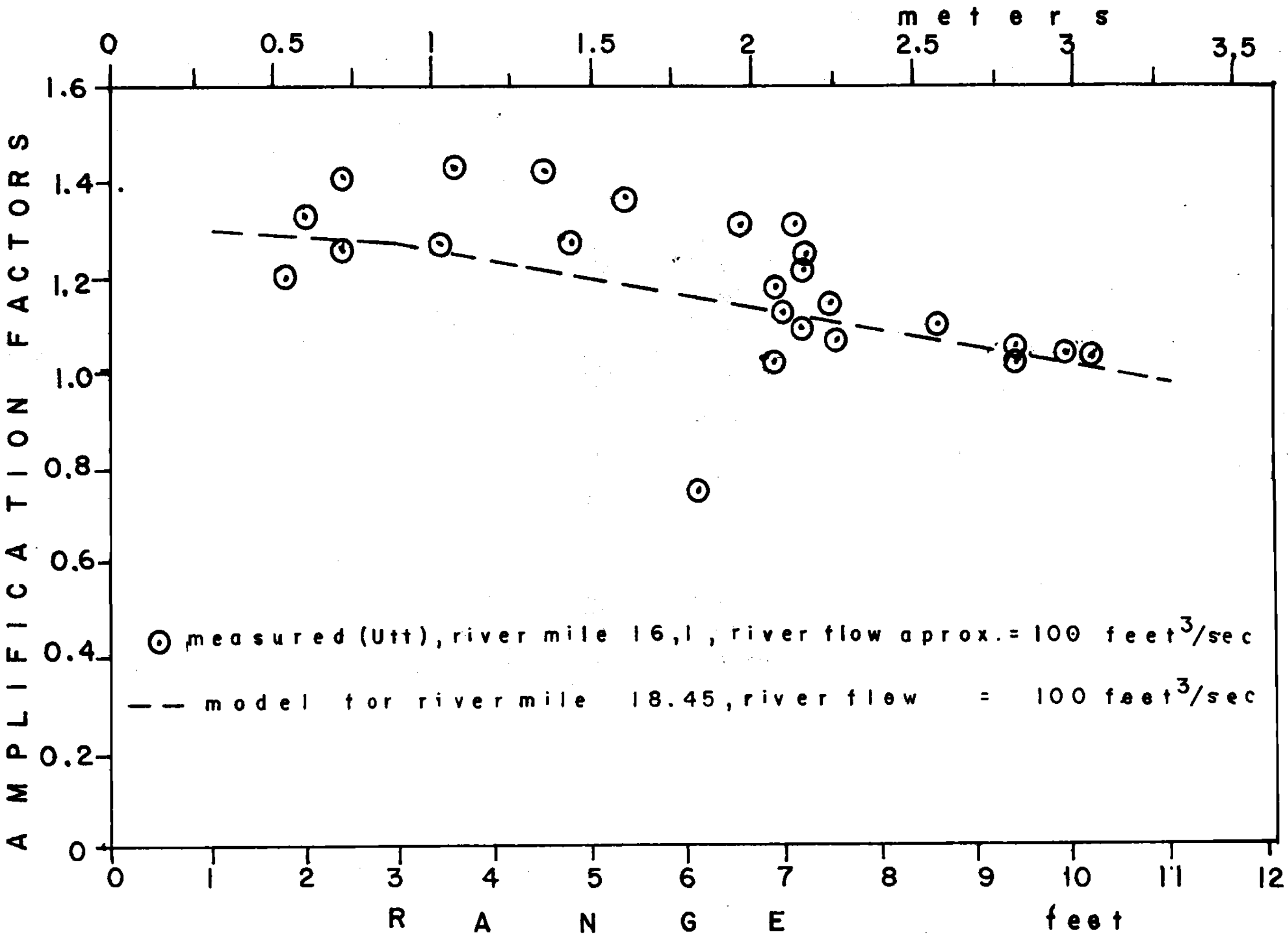

Figure 70. Measured and predicted amplification factors vs. tidal range for a constant river flow of about 100 cubic feet/sec.

BIBLIOGRAPHY

1. Bourke, R. H., Glenne, B., and Adams, B. W. 1971. The nearshore physical oceanographic environment of the Pacific Northwest coast. Oregon State University Reference 71-45, Dept. of Oceanography, OSU, Corvallis, Oregon.

2. Burt, W. V. and McAlister, B. 1958. Hydrography of Oregon estuaries, June 1955 to September 1958, Office of Naval Research Reference 58-6, School of Science, Oregon State College, Corvallis, Oregon.

3. Burt, W. V. and McAlister, B. 1959. Recent studies in the hydrology of Oregon estuaries, Research Briefs, vol. 7, #1, Fisheries Commission of Oregon, July 1959, pp. 14-27.

4. Chow, V. T. 1959. Open Channel Hydraulics, McGraw Hill.

5. Dronkers, J. J. 1964. Tidal computations in rivers and coastal waters. North Holland Publishing Co.

6. Dronkers, J. J. 1969. Tidal computations for rivers, coastal areas and seas, Proceedings of the American Society of Civil Engineers, Journal of the Hydraulics Division, Vol. 95, #HY 1, Proceeding Paper 6341, January 1969, pp. 29-77.

7. Evangelisti, G. 1955. On tidal waves in a canal with variable cross-section. Proceedings Sixth General Meeting International Association for Hydraulic Research, The Hague, Netherlands, paper A-10.

8. Giger, R. D. 1972. Some estuarine factors influencing ascent of Anadromous Cut-throat Trout in Oregon, Proceedings of the Second Annual Technical Conference on Estuaries of the Pacific Northwest, Oregon State University, Corvallis, Oregon.

9. Goodwin, C. R., Emmett, E. W. and Glenne, B. 1970. Tidal study of three Oregon estuaries, Corvallis, Oregon State University, Bulletin 45, 33 pp.

10. Goodwin, C. R. 1974. Estuarine tidal hydraulics one-dimensional model and predictive algorithm, Ph.D. Thesis, Oregon State University.

11. Hansen, W. 1956. Theorie zur errechnung des wasserstandes und der stromungen in randmeeren nebst anwendungen, Tellus, Vol. 8.

12. Harleman, D. R. F. and Lee, C. H. 1969. The computation of tides and currents in estuaries and canals, Technical Bulletin #16, Hydrodynamics Laboratory, Massachusetts Institute of Technology, Cambridge, Massachusetts.

13. Ippen, A. T. and Harleman, D. R. F. 1961. Analytical studies of salinity intrusion in estuaries and canals, phase 1: one-dimensional analysis, Technical Bulletin #5, Committee on Tidal Hydraulics, U.S. Army Corps of Engineers.

14. Ippen, A. T. (editor) 1966. Estuary and coastline hydrodynamics, McGraw Hill Book Co., New York.

15. Johnson, J. W. 1972. Tidal inlets on the California, Oregon and Washington coasts, Hydraulic Engineering Laboratory HEL 24-12, University of California, Berkeley, California.

16. Johnson, J. W. 1973. Characteristics and behavior of Pacific coast tidal inlets, Proceedings of the American Society of Civil Engineers, Journal of the Waterways, Harbors and Coastal Engineering Division #WW 3, proc. paper 9927, August 1973.

17. Lai, Ch. 1965. Flow of homogeneous density in tidal reaches, solution by implicit method, U.S. Geological Survey, open file Report.

18. Liggett, J. J. and Woolhiser, D. A. 1967. Difference solution of the shallow water equation, Proceedings of the American Society of Civil Engineers, Journal of the Engineering Mechanics Division, #EM 2, proc. paper 5189, April 1967.

19. Lipka, J. 1918. Graphical and Mechanical Computation, John Wiley and Sons.

20. Marriage, L. D. 1958. The bay clams of Oregon, Fisheries Commission of Oregon, Educational Bulletin #2, Portland, Oregon.

21. Mavis, F. T. 1939. The construction of nomographic charts, International Textbook Co.

22. NOAA, 1975. High and low water tide observations for Siuslaw estuary during summer and fall, 1974; in personal communication to Larry Slotta, Director of Ocean Engineering Programs, OSU, March 1975.

23. O'Brien, M. P. 1931. Estuary tidal prisms related to entrance area, Civil Engineering, Vol. 1, #8.

24. Oregon Division of State Lands. 1972. Inventory of filled lands in Siuslaw estuary, Salem, Oregon.

25. Oregon Estuaries, State of Oregon. 1973. Division of State Lands, Salem, Oregon.

26. Oregon State University, Dept. of Oceanography. 1971. Comprehensive inventory of scientific information relating to the physical and biological characteristics of the estuaries of Oregon, preliminary proposal, Corvallis, Oregon.

27. Oregon State Water Resource Board. 1967. Stream mile summary mid coast basin, Salem, Oregon.

28. Otter, J. R. H. and Day, A. S. 1960. Tidal flow computations, The Engineer, Vol. 209, #5427, Jan. 1960.

29. Pearcy, K. L. et al., 1973. Descriptions and information sources for Oregon estuaries, WRRI 19, Water Resources Research Institute, Oregon State University, Corvallis, Oregon.

30. Pritchard, D. W. 1967. What is an estuary: physical viewpoint; in "Estuaries", G. H. Lauff, editor, AAAS publication #83.

31. U.S. Army Coastal Engineering Research Center. 1973. Shore Protection Manual. Department of the Army Corp of Engineers.

32. U.S. Army Engineer District, Portland, Oregon. 1973. Channel extension Siuslaw river and bar, Lane County, Oregon.

33. U.S. Dept. of the Interior, Geological Survey. 1970. Water Resources data for Oregon, Part I: surface water records, Portland, Oregon.

34. U.S. National Ocean Survey, NOAA, 1973 and 1974. Tide tables, high and low water predictions, west coast of North and South America, Dept. of Commerce, Washington, D.C.

35. Utt, M. E. 1974. Seasonal variations in tidal dynamics, water quality and sediments in the Siuslaw estuary, M.Sc. Thesis, Oregon State University.

APPENDIX

APPENDIX

Definitions

The definitions of the tidal terms appearing in this list were obtained from the following sources: Pearcy, K. L. et al. (29) and U.S. Army Coastal Engineering Research Center (31).

Amplification factor - The ratio of the tidal range at a point to the tidal range at mouth.

Conveyance channel - Portion of the total estuary channel where all the longitudinal water flow is assumed to be confined.

Displacement of the water surface - Instantaneous water surface elevation with respect to a given datum level (MSL or MLLW).

Diurnal range - The range between the lowest and the highest tides occurring during one tidal day.

Ebb tide - The period of the tide between a high water and the succeeding low water; a falling tide.

Extreme tidal range - The range between the highest and the lowest tides of the year.

Flood tide - The period of the tide between a low water and the succeeding high water; a rising tide.

Head of high tide - The farthest point up a stream that tidal fluctuations are felt.

Hydraulic radius - Ratio between the cross sectional area and the wetted perimeter of the cross section of the channel.

Higher high water (HHW) - The higher of the two high waters of any tidal day.

High water (HW) - Same as high tide; the maximum height reached by each rising tide.

Lower low water (LLW) - The lower of the two low waters of any tidal day.

Low water (LW) - Same as low tide; the minimum height reached by each falling tide.

Mean high water (MHW) - The average height of the high waters (HW) over a period of 19 years.

Mean higher high water (MHHW) - The average height of the higher high waters (HHW) over a 19 year period.

Mean low water (MLW) - The average height of the low waters (LW) over a 19 year period.

Mean lower low water (MLLW) - The average height of the lower low waters (LLW) over a 19 year period.

Mean sea level (MSL) - The average height of the surface of the sea for all stages of the tide over a 19 year period.

Mean tide level (MTL) - A tidal datum midway between mean high water (MHW) and mean low water (MLW).

Mean tide range - The average range of consecutive high and low tides over a 19 year period.

Mixed tides - Tides in which the presence of a diurnal wave is conspicuous by a large inequality in either the high or low water heights or in both, with two high waters and two low waters occurring each tidal day.

Ocean offset - Height with respect to mean sea level (MSL) of the midway level between high water (HW) and low water (LW).

Partly mixed system - Estuarine system where the salinity change from top to bottom has a value between 4 ppt to 19 ppt at the nearest station where mean salinity is 17 ppt.

Progressive wave - A wave that moves relative to a fixed coordinate system in a fluid.

Slack tide (or slack water) - The state of a tidal current when its velocity is near zero, especially the moment when a reversing current changes direction and its velocity is zero.

Standing wave - A type of wave in which the surface of the water oscillates vertically between fixed points, called nodes, without progression. The points of maximum vertical rise and fall are called antinodes. At the nodes the underlying water particles exhibit no vertical motion, but maximum horizontal motion; and, at the antinodes, the underlying water particles have no horizontal motion but maximum vertical.

Stratified system - Estuarine system where the salinity change from top to bottom has a value of 20 ppt or over, at the nearest station where mean salinity is 17 ppt.

Tidal amplitude - One half of the difference in height between consecutive high and low (or higher high and lower low) waters.

Tidal prism - The total amount of water that flows into a harbor or estuary and out again with the movement of the tide, excluding any freshwater flow.

Tidal range - The difference in height between consecutive high and low (or higher high and lower low) waters.

Well mixed system - Estuarine system where the salinity change from top to bottom has a value of 3 ppt or less, at the nearest station where mean salinity is 17 ppt.

Table A.1. Model Output for February 5, 1973.

ANGLE STATION NUMBER--- February 5, 1973.

ANGLE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0 H:	3.0200		3.0963		3.1455		3.2227		3.3065	
-5 Q:		1.377E 04		1.124E 04		6.595E 03		1.907E 03		-1.893E 03
-5 V:		7.984E-01		7.113E-01		7.423E-01		2.497E-01		
30 H:	2.7011		2.9529		3.1800		3.4958		3.7194	
25 Q:		-7.694E 03		-4.711E 03		-2.397E 03		-1.757E 03		-1.862E 03
25 V:		-4.494E-01		-2.982E-01		-2.654E-01		-2.234E-01		
60 H:	1.8300		2.1391		2.4247		2.7664		3.0181	
55 Q:		-2.360E 04		-1.736E 04		-1.046E 04		-5.542E 03		-1.892E 03
55 V:		-1.438E 00		-1.111E 00		-1.195E 00		-7.273E-01		
90 H:	.6400		1.0364		1.3916		1.7152		1.9117	
85 Q:		-2.721E 04		-1.965E 04		-1.163E 04		-5.952E 03		-1.887E 03
85 V:		-1.759E 00		-1.356E 00		-1.400E 00		-8.318E-01		
120 H:	-0.5500		-0.1424		.2575		.6165		.8549	
115 Q:		-2.505E 04		-1.892E 04		-1.129E 04		-5.683E 03		-1.885E 03
115 V:		-1.799E 00		-1.427E 00		-1.444E 00		-8.501E-01		
150 H:	-1.4211		-1.1261		-0.7672		-0.4238		-0.1649	
145 Q:		-2.165E 04		-1.648E 04		-1.051E 04		-5.479E 03		-1.869E 03
145 V:		-1.585E 00		-1.355E 00		-1.427E 00		-8.771E-01		
180 H:	-1.7400		-1.6731		-1.5007		-1.2888		-1.0705	
175 Q:		-1.435E 04		-1.226E 04		-8.734E 03		-4.898E 03		-1.894E 03
175 V:		-1.088E 00		-1.075E 00		-1.247E 00		-8.358E-01		
210 H:	-1.4211		-1.5863		-1.7059		-1.7817		-1.7198	
205 Q:		-3.162E 03		-5.041E 03		-5.246E 03		-3.726E 03		-1.679E 03
205 V:		-2.384E-01		-4.489E-01		-7.696E-01		-6.665E-01		
240 H:	-0.5500		-0.8056		-1.0863		-1.4423		-1.7432	
235 Q:		1.332E 04		7.658E 03		2.818E 03		-6.923E 02		-1.871E 03
235 V:		9.564E-01		6.463E-01		4.054E-01		-1.237E-01		
270 H:	.6400		.2850		-0.0970		-0.4537		-0.6046	
265 Q:		2.259E 04		1.543E 04		8.475E 03		3.017E 03		-1.893E 03
265 V:		1.523E 00		1.195E 00		1.152E 00		5.046E-01		
300 H:	1.8300		1.4899		1.1402		.8481		.7798	
295 Q:		2.685E 04		1.907E 04		1.007E 04		3.067E 03		-1.861E 03
295 V:		1.693E 00		1.346E 00		1.278E 00		4.684E-01		
330 H:	2.7011		2.5267		2.3465		2.1808		2.1394	
325 Q:		2.453E 04		1.831E 04		9.795E 03		3.092E 03		-1.888E 03
325 V:		1.465E 00		1.187E 00		1.160E 00		4.338E-01		
360 H:	3.0200		3.0963		3.1455		3.2228		3.3060	
355 Q:		1.378E 04		1.125E 04		6.597E 03		1.907E 03		-1.886E 03
355 V:		7.990E-01		7.118E-01		7.426E-01		2.496E-01		
HMAX:T			3.138, 10.0		3.287, 16.4		3.539, 22.2		3.732, 25.7	
HMIN:T			-1.723,191.4		-1.723,203.6		-1.805,216.0		-1.862,226.6	
QMAX:T			26978,300.7		19378,305.6		10169,305.8		3175,277.5	
QMIN:T			-27280, 90.8		-19675, 89.3		-11630, 82.0		-6036, 74.8	
VMAX:T			1.69,293.1		1.35,294.3		1.28,292.2		.51,272.9	
VMIN:T			-1.81,104.8		-1.43,116.0		-1.45,125.8		-0.88,144.6	
Q0:T,T			16.1,211.0		17.3,217.5		18.7,226.4		13.1,238.9	
HR:			1.021		1.053		1.123		1.175	

Table A.2. Model Output for August 2, 1973.

ANGLE STATION NUMBER---AUGUST 2, 1973

ANGLE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0 H:	2.8200		2.7149		2.5433		2.2612		2.1025	
-5 Q:		2.547E 04		2.166E 04		1.407E 04		6.401E 03		-8.196E 01
-5 V:		1.506E 00		1.382E 00		1.657E 00		9.006E-01		
30 H:	2.3739		2.6640		2.8955		3.1800		3.3690	
25 Q:		3.426E 03		6.069E 03		6.278E 03		3.325E 03		-8.137E 01
25 V:		2.031E-01		3.841E-01		7.100E-01		4.346E-01		
60 H:	1.1550		1.6128		2.0685		2.6182		3.0130	
55 Q:		-2.610E 04		-1.779E 04		-9.557E 03		-4.000E 03		-8.217E 01
55 V:		-1.635E 00		-1.173E 00		-1.105E 00		-5.269E-01		
90 H:	-0.5100		.1752		.7747		1.2497		1.4432	
85 Q:		-3.296E 04		-2.329E 04		-1.354E 04		-6.019E 03		-8.148E 01
85 V:		-2.235E 00		-1.694E 00		-1.673E 00		-8.612E-01		
120 H:	-2.1750		-1.4139		-0.7040		-0.2197		-0.0192	
115 Q:		-3.111E 04		-2.186E 04		-1.246E 04		-5.116E 03		-8.255E 01
115 V:		-2.320E 00		-1.801E 00		-1.671E 00		-8.059E-01		
150 H:	-3.3939		-2.7836		-2.0656		-1.5823		-1.3463	
145 Q:		-2.512E 04		-1.831E 04		-1.110E 04		-4.676E 03		-8.241E 01
145 V:		-2.054E 00		-1.725E 00		-1.619E 00		-8.105E-01		
180 H:	-3.8400		-3.6139		-3.1023		-2.7403		-2.5534	
175 Q:		-1.714E 04		-1.395E 04		-9.349E 03		-4.158E 03		-8.258E 01
175 V:		-1.452E 00		-1.458E 00		-1.436E 00		-7.465E-01		
210 H:	-3.3939		-3.5619		-3.6048		-3.5897		-3.5541	
205 Q:		-5.625E 03		-7.609E 03		-6.510E 03		-3.227E 03		-8.222E 01
205 V:		-4.767E-01		-7.951E-01		-1.000E-00		-5.793E-01		
240 H:	-2.1750		-2.5537		-3.0215		-3.5455		-3.9204	
235 Q:		1.408E 04		7.178E 03		2.695E 03		9.729E 01		-8.162E 01
235 V:		1.133E 00		7.322E-01		4.140E-01		1.747E-02		
270 H:	-0.5100		-1.1132		-1.8587		-2.5442		-2.9277	
265 Q:		2.634E 04		1.736E 04		9.936E 03		4.456E 03		-8.245E 01
265 V:		1.927E 00		1.555E 00		1.526E 00		8.000E-01		
300 H:	1.1550		.5008		-0.2787		-1.0532		-1.4703	
295 Q:		3.378E 04		2.378E 04		1.336E 04		5.294E 03		-8.204E 01
295 V:		2.249E 00		1.854E 00		1.870E 00		9.363E-01		
330 H:	2.3739		1.9027		1.3408		.6734		.2704	
325 Q:		3.456E 04		2.628E 04		1.533E 04		6.523E 03		-8.258E 01
325 V:		2.132E 00		1.818E 00		1.951E 00		1.024E 00		
360 H:	2.8200		2.7149		2.5434		2.2612		2.1025	
355 Q:		2.547E 04		2.166E 04		1.407E 04		6.401E 03		-8.138E 01
355 V:		1.506E 00		1.382E 00		1.657E 00		9.006E-01		

HMAX;T	2.814, 13.7	2.917, 24.3	3.202, 34.8	3.488, 39.9
HMIN;T	-3.708, 193.4	-3.605, 210.9	-3.746, 224.8	-3.950, 233.9
QMAX;T	35263, 313.1	26296, 322.7	15446, 331.9	6738, 338.9
QMIN;T	-33075, 90.7	-23332, 88.7	-13543, 84.2	-6141, 78.8
VMAX;T	2.26, 302.5	1.88, 307.0	1.96, 319.1	1.02, 326.8
VMIN;T	-2.34, 106.5	-1.80, 116.1	-1.69, 97.0	-0.86, 84.4
QO;T, T	28.0, 215.1	31.8, 221.8	37.0, 228.7	39.6, 234.4
HR:	.979	.979	1.043	1.117

Table A.3. Model Output for August 3, 1973.

STATION NUMBER-- AUGUST 3, 1973

ANGLE	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0 H:	2.5200		2.4812		2.3937		2.2485		2.1762	
-5 Q:		2.090E 04		1.776E 04		1.156E 04		5.239E 03		-7.961E 01
-5 V:		1.251E 00		1.147E 00		1.364E 00		7.334E-01		
30 H:	2.1409		2.4127		2.6314		2.9274		3.1261	
25 Q:		7.026E 02		3.121E 03		3.954E 03		2.193E 03		-7.885E 01
25 V:		4.220E-02		1.982E-01		4.523E-01		2.900E-01		
60 H:	1.1050		1.4856		1.8628		2.3154		2.6330	
55 Q:		-2.365E 04		-1.650E 04		-9.146E 03		-3.953E 03		-7.957E 01
55 V:		-1.492E 00		-1.102E 00		-1.072E 00		-5.314E-01		
90 H:	0.3100		.2217		.6980		1.0777		1.2306	
85 Q:		-2.921E 04		-2.074E 04		-1.202E 04		-5.293E 03		-7.863E 01
85 V:		-1.976E 00		-1.513E 00		-1.498E 00		-7.680E-01		
120 H:	-1.7250		-1.1626		-0.6225		-0.2358		-0.0704	
115 Q:		-2.765E 04		-1.955E 04		-1.114E 04		-4.585E 03		-7.880E 01
115 V:		-2.030E 00		-1.591E 00		-1.494E 00		-7.251E-01		
150 H:	-2.7608		-2.3394		-1.8287		-1.4557		-1.2684	
145 Q:		-2.240E 04		-1.648E 04		-1.000E 04		-4.237E 03		-7.889E 01
145 V:		-1.775E 00		-1.503E 00		-1.444E 00		-7.299E-01		
180 H:	-3.1400		-3.0149		-2.7219		-2.4784		-2.3492	
175 Q:		-1.468E 04		-1.218E 04		-8.187E 03		-3.685E 03		-7.860E 01
175 V:		-1.221E 00		-1.215E 00		-1.258E 00		-6.616E-01		
210 H:	-2.7609		-2.9432		-3.0620		-3.1486		-3.1818	
205 Q:		-3.442E 03		-5.374E 03		-4.909E 03		-2.554E 03		-7.866E 01
205 V:		-2.848E-01		-5.513E-01		-7.541E-01		-4.584E-01		
240 H:	-1.7250		-2.0593		-2.4716		-2.9427		-3.2976	
235 Q:		1.439E 04		8.287E 03		3.931E 03		1.031E 03		-7.902E 01
235 V:		1.119E 00		7.967E-01		6.038E-01		1.850E-01		
270 H:	-0.3100		-0.8037		-1.3991		-1.9651		-2.2796	
265 Q:		2.453E 04		1.661E 04		9.657E 03		4.215E 03		-7.916E 01
265 V:		1.761E 00		1.430E 00		1.433E 00		7.567E-01		
300 H:	1.1050		.5921		-0.0052		-0.5953		-0.9216	
295 Q:		3.024E 04		2.156E 04		1.222E 04		4.974E 03		-7.872E 01
295 V:		2.003E 00		1.651E 00		1.670E 00		8.462E-01		
330 H:	2.1408		1.7954		1.3871		.9117		.6392	
325 Q:		2.986E 04		2.280E 04		1.342E 04		5.739E 03		-7.877E 01
325 V:		1.853E 00		1.576E 00		1.690E 00		8.810E-01		
360 H:	2.5200		2.4812		2.3937		2.2485		2.1761	
355 Q:		2.090E 04		1.776E 04		1.156E 04		5.239E 03		-7.898E 01
355 V:		1.251E 00		1.147E 00		1.364E 00		7.334E-01		

HMAX;T	2.555, 12.8	2.670, 22.1	2.929, 31.4	3.169, 36.4
HMIN;T	-3.087, 192.6	-3.066, 207.5	-3.219, 219.9	-3.405, 228.5
QMAX;T	30965, 308.8	22959, 317.6	13417, 325.4	5785, 332.0
QMIN;T	-29312, 90.7	-20770, 88.5	-12030, 83.1	-5412, 77.7
VMAX;T	2.01, 299.0	1.66, 302.7	1.71, 313.0	.88, 319.1
VMIN;T	-2.05, 104.7	-1.59, 113.1	-1.51, 96.2	-0.77, 82.9
QO;T, T	25.7, 211.2	28.9, 217.7	33.4, 223.8	36.1, 228.9
HR:	.997	1.013	1.086	1.161

Table A.4. Model Output for November 16, 1973.

ANGLE STATION NUMBER--- November 16, 1973.

ANGLE		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0	H:	2.4600		2.6264		2.8824		3.6415		5.5913	
-5	Q:		-1.602E 04		-1.720E 04		-1.948E 04		-2.168E 04		-2.364E 04
-5	V:		-9.513E-01		-1.089E 00		-2.175E 00		-2.700E 00		
30	H:	2.2322		2.5272		2.9286		3.8702		5.9933	
25	Q:		-2.376E 04		-2.219E 04		-2.162E 04		-2.235E 04		-2.375E 04
25	V:		-1.418E 00		-1.405E 00		-2.392E 00		-2.783E 00		
60	H:	1.6100		2.0729		2.6457		3.8192		6.1236	
55	Q:		-3.075E 04		-2.700E 04		-2.413E 04		-2.338E 04		-2.349E 04
55	V:		-1.880E 00		-1.729E 00		-2.687E 00		-2.911E 00		
90	H:	.7600		1.3838		2.1499		3.5472		6.0058	
85	Q:		-3.498E 04		-3.017E 04		-2.599E 04		-2.425E 04		-2.343E 04
85	V:		-2.219E 00		-2.012E 00		-2.946E 00		-3.020E 00		
120	H:	-0.0900		.6320		1.5610		3.1566		5.7308	
115	Q:		-3.612E 04		-3.142E 04		-2.704E 04		-2.485E 04		-2.364E 04
115	V:		-2.388E 00		-2.201E 00		-3.141E 00		-3.094E 00		
150	H:	-0.7122		-0.0034		1.0095		2.7393		5.3526	
145	Q:		-3.452E 04		-3.102E 04		-2.735E 04		-2.515E 04		-2.359E 04
145	V:		-2.365E 00		-2.277E 00		-3.258E 00		-3.132E 00		
180	H:	-0.9400		-0.3674		.5956		2.3370		4.9975	
175	Q:		-3.083E 04		-2.930E 04		-2.687E 04		-2.480E 04		-2.381E 04
175	V:		-2.157E 00		-2.223E 00		-3.271E 00		-3.134E 00		
210	H:	-0.7122		-0.3592		.4028		2.0352		4.7392	
205	Q:		-2.548E 04		-2.636E 04		-2.569E 04		-2.440E 04		-2.364E 04
205	V:		-1.782E 00		-2.021E 00		-3.173E 00		-3.135E 00		
240	H:	-0.0900		.0536		.5312		1.9334		4.5769	
235	Q:		-1.906E 04		-2.239E 04		-2.409E 04		-2.397E 04		-2.338E 04
235	V:		-1.302E 00		-1.688E 00		-2.980E 00		-3.105E 00		
270	H:	.7600		.7861		1.0200		2.1033		4.5854	
265	Q:		-1.274E 04		-1.785E 04		-2.206E 04		-2.348E 04		-2.358E 04
265	V:		-8.351E-01		-1.289E 00		-2.688E 00		-3.030E 00		
300	H:	1.6100		1.6282		1.7584		2.5582		4.7550	
295	Q:		-8.816E 03		-1.424E 04		-1.994E 04		-2.279E 04		-2.358E 04
295	V:		-5.519E-01		-9.703E-01		-2.359E 00		-2.895E 00		
330	H:	2.2322		2.3098		2.4662		3.1592		5.1012	
325	Q:		-9.985E 03		-1.390E 04		-1.881E 04		-2.201E 04		-2.369E 04
325	V:		-6.030E-01		-8.987E-01		-2.153E 00		-2.741E 00		
360	H:	2.4600		2.6261		2.8818		3.6399		5.5780	
355	Q:		-1.603E 04		-1.721E 04		-1.948E 04		-2.166E 04		-2.344E 04
355	V:		-9.521E-01		-1.089E 00		-2.176E 00		-2.698E 00		

HMAX:T	2.639, 7.5	2.954, 18.8	3.884, 39.4	4.577,246.0
HMIN:T	-0.414,194.5	.400,214.1	1.932,237.4	4.575,255.9
QMAX:T	-8553,304.0	-13535,312.6	-18796,329.0	-21648,349.9
QMIN:T	-36143,111.4	-31458,121.8	-27355,142.6	-25153,148.8
VMAX:T	-0.53,305.7	-0.89,317.3	-2.13,337.0	-2.70,349.9
VMIN:T	-2.40,126.4	-2.28,148.2	-3.28,163.2	-3.75, 0
Q0:T,T	0, 0	0, 0	0, 0	0, 0
HR:	.898	.751	.574	.001

Table A.5. Model Output for November 19, 1973.

ANGLE STATION NUMBER--- November 19, 1973.

ANGLE		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0	H:	2.3600		2.4754		2.5716		2.7161		2.8242	
-5	Q:		1.116E 04		8.483E 03		3.566E 03		-1.012E 03		-4.683E 03
-5	V:		6.679E-01		5.433E-01		4.126E-01		-1.364E-01		
30	H:	2.0251		2.2909		2.5498		2.8995		3.2196	
25	Q:		-1.225E 04		-8.571E 03		-5.625E 03		-4.566E 03		-4.723E 03
25	V:		-7.406E-01		-5.464E-01		-6.423E-01		-5.993E-01		
60	H:	1.1100		1.4602		1.7997		2.2258		2.6326	
55	Q:		-2.455E 04		-1.839E 04		-1.205E 04		-7.698E 03		-4.691E 03
55	V:		-1.551E 00		-1.234E 00		-1.420E 00		-1.040E 00		
90	H:	-0.1400		.3426		.8097		1.2865		1.7107	
85	Q:		-2.811E 04		-2.064E 04		-1.321E 04		-8.131E 03		-4.665E 03
85	V:		-1.888E 00		-1.496E 00		-1.637E 00		-1.161E 00		
120	H:	-1.3900		-0.8576		-0.2907		.2657		.7828	
115	Q:		-2.746E 04		-2.041E 04		-1.328E 04		-8.050E 03		-4.695E 03
115	V:		-1.980E 00		-1.621E 00		-1.743E 00		-1.222E 00		
150	H:	-2.3051		-1.8694		-1.2972		-0.7203		-0.1262	
145	Q:		-2.354E 04		-1.836E 04		-1.271E 04		-7.943E 03		-4.706E 03
145	V:		-1.808E 00		-1.600E 00		-1.769E 00		-1.284E 00		
180	H:	-2.6400		-2.4484		-2.0448		-1.5621		-0.9499	
175	Q:		-1.703E 04		-1.483E 04		-1.128E 04		-7.495E 03		-4.727E 03
175	V:		-1.360E 00		-1.387E 00		-1.654E 00		-1.287E 00		
210	H:	-2.3051		-2.3938		-2.3428		-2.1198		-1.5970	
205	Q:		-7.669E 03		-9.308E 03		-8.779E 03		-6.722E 03		-4.706E 03
205	V:		-6.102E-01		-8.900E-01		-1.328E 00		-1.207E 00		
240	H:	-1.3900		-1.6123		-1.8280		-2.0842		-1.9230	
235	Q:		7.125E 03		1.363E 03		-3.588E 03		-5.227E 03		-4.695E 03
235	V:		5.381E-01		1.240E-01		-5.375E-01		-9.384E-01		
270	H:	-0.1400		-0.4496		-0.7717		-1.0471		-1.3474	
265	Q:		1.876E 04		1.154E 04		4.904E 03		-1.081E 03		-4.731E 03
265	V:		1.319E 00		9.488E-01		6.936E-01		-1.891E-01		
300	H:	1.1100		.7848		.4510		.2033		.2406	
295	Q:		2.423E 04		1.649E 04		8.035E 03		1.227E 03		-4.695E 03
295	V:		1.588E 00		1.228E 00		1.058E 00		1.954E-01		
330	H:	2.0251		1.8629		1.7079		1.6473		1.6726	
325	Q:		2.270E 04		1.628E 04		7.482E 03		2.374E 02		-4.691E 03
325	V:		1.403E 00		1.108E 00		9.152E-01		3.435E-02		
360	H:	2.3600		2.4750		2.5707		2.7149		2.8287	
355	Q:		1.117E 04		8.501E 03		3.592E 03		-1.003E 03		-4.744E 03
355	V:		6.687E-01		5.444E-01		4.156E-01		-1.351E-01		

HMAX:T	2.522, 9.8	2.697, 14.3	2.966, 19.7	3.229, 26.1
HMIN:T	-2.512,192.8	-2.344,208.7	-2.208,224.8	-1.923,240.1
QMAX:T	24650,304.8	17200,309.5	8278,305.4	1328,289.9
QMIN:T	-28329, 95.0	-20793, 96.5	-13312,103.8	-9155, 78.8
VMAX:T	1.59,298.6	1.24,301.7	1.07,300.9	.22,289.4
VMIN:T	-1.98,110.6	-1.63,126.1	-1.77,136.8	-1.29,161.5
Q0:T,T	10.8,222.3	11.1,232.0	8.3,246.4	335.8,272.0
HR:	1.007	1.008	1.035	1.030

Table A.6. Model Output for July 24, 1974.

ANGLE STATION NUMBER--- July 24, 1974.

ANGLE		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
0	H:	2.0600		2.0274		1.9446		1.8131		1.7511	
-5	Q:		1.945E 04		1.652E 04		1.078E 04		4.816E 03		-2.109E 02
-5	V:		1.192E 00		1.102E 00		1.302E 00		6.918E-01		
30	H:	1.6983		1.9588		2.1711		2.4582		2.6535	
25	Q:		5.426E 02		2.825E 03		3.589E 03		1.932E 03		-2.135E 02
25	V:		3.338E-02		1.853E-01		4.205E-01		2.627E-01		
60	H:	.7100		1.0728		1.4401		1.8783		2.1896	
55	Q:		-2.225E 04		-1.552E 04		-8.718E 03		-3.833E 03		-2.131E 02
55	V:		-1.436E 00		-1.070E 00		-1.046E 00		-5.292E-01		
90	H:	-0.6400		-0.1354		.3309		.7037		.8643	
85	Q:		-2.755E 04		-1.956E 04		-1.148E 04		-5.137E 03		-2.118E 02
85	V:		-1.901E 00		-1.470E 00		-1.461E 00		-7.635E-01		
120	H:	-1.9900		-1.4568		-0.9266		-0.5470		-0.3754	
115	Q:		-2.615E 04		-1.851E 04		-1.071E 04		-4.494E 03		-2.134E 02
115	V:		-1.955E 00		-1.548E 00		-1.462E 00		-7.260E-01		
150	H:	-2.9783		-2.5789		-2.0759		-1.7105		-1.5168	
145	Q:		-2.125E 04		-1.567E 04		-9.631E 03		-4.161E 03		-2.136E 02
145	V:		-1.713E 00		-1.467E 00		-1.414E 00		-7.310E-01		
180	H:	-3.3400		-3.2200		-2.9235		-2.6863		-2.5530	
175	Q:		-1.401E 04		-1.167E 04		-7.994E 03		-3.681E 03		-2.109E 02
175	V:		-1.183E 00		-1.192E 00		-1.228E 00		-6.609E-01		
210	H:	-2.9783		-3.1476		-3.2534		-3.3303		-3.3556	
205	Q:		-3.549E 03		-5.368E 03		-4.868E 03		-2.600E 03		-2.142E 02
205	V:		-2.980E-01		-5.609E-01		-7.477E-01		-4.668E-01		
240	H:	-1.9900		-2.3067		-2.7006		-3.1452		-3.4794	
235	Q:		1.337E 04		7.584E 03		3.532E 03		7.857E 02		-2.135E 02
235	V:		1.057E 00		7.477E-01		5.425E-01		1.411E-01		
270	H:	-0.6400		-1.1055		-1.6785		-2.2130		-2.4960	
265	Q:		2.308E 04		1.560E 04		9.095E 03		3.960E 03		-2.134E 02
265	V:		1.688E 00		1.380E 00		1.373E 00		7.109E-01		
300	H:	.7100		.2277		-0.3458		-0.8994		-1.1947	
295	Q:		2.839E 04		2.022E 04		1.151E 04		4.574E 03		-2.128E 02
295	V:		1.919E 00		1.593E 00		1.602E 00		7.942E-01		
330	H:	1.6983		1.3759		.9851		.5411		.2896	
325	Q:		2.792E 04		2.129E 04		1.257E 04		5.302E 03		-2.132E 02
325	V:		1.772E 00		1.517E 00		1.616E 00		8.327E-01		
360	H:	2.0600		2.0274		1.9446		1.8132		1.7514	
355	Q:		1.945E 04		1.652E 04		1.078E 04		4.815E 03		-2.123E 02
355	V:		1.192E 00		1.102E 00		1.302E 00		6.916E-01		

HMAX:T	2.096, 12.6	2.207, 22.1	2.460, 31.4	2.693, 36.4
HMIN:T	-3.286,192.3	-3.256,207.9	-3.401,220.2	-3.575,228.8
QMAX:T	29021,308.2	21460,317.1	12568,324.8	5345,331.8
QMIN:T	-27654, 91.2	-19605, 89.2	-11483, 84.0	-5234, 78.2
VMAX:T	1.92,298.8	1.60,302.4	1.64,312.4	.84,320.3
VMIN:T	-1.97,104.9	-1.55,113.8	-1.47, 98.0	-0.76, 84.0
QO:T,T	25.6,211.9	28.8,218.4	33.1,224.7	35.4,230.1
HR:	.997	1.012	1.085	1.161