NOAA Technical Memorandum NOS OES 003

SAN FRANCISCO BAY CURRENT PREDICTION QUALITY ASSURANCE MINIPROJECT

Rockville, Maryland
June 1992

noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service

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Oceanography --- what a joy!
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Office of Ocean and Earth Sciences

NOTICE

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ABSTRACT The Coastal and Estuarine Oceanography Branch of NOAA's National Ocean Service deployed four acoustic Doppler current profilers in San Francisco Bay from April 28 to May 29, 1992, in the field phase of a Quality Assurance *miniproject.* A QA miniproject is a relatively inexpensive method used to evaluate the quality of published NOAA tidal current predictions by comparing them with new data from a small number of high technology instruments using an objective statistical evaluation of the differences between observed and predicted currents. The miniproject was conducted in response to concerns expressed by the Harbor Safety Committee of the San Francisco Bay region that NOAA Tidal Current Table predictions do not accurately represent actual conditions in the Bay at several locations. These data were analyzed and compared with 1992 NOAA Tidal Current Table predictions at the deployment sites. Historical data from the 1979-1980 NOAA-USGS (U.S. Geological Survey) survey were re-analyzed and compared with present predictions that were hindcast to the times of data collection. This report summarizes the 1992 data collected and compares both the 1992 data and the 1979-80 survey data with NOAA Tidal Current Table predictions. Recommendations based on this analysis for improved current information for the Bay include development of new reference stations at Golden Gate Bridge and Carquinez Strait, new analysis of the 1979-80 survey data, reoccupation of selected stations, development of a numerical hydrodynamic model, development of a model-based current circulation atlas and digital prediction products, and deployment of a physical oceanographic real-time system (PORTS).

INTRODUCTION

The quality assurance (QA) *miniproject*, an inexpensive deployment of a few instruments to obtain the high quality data necessary to obtain an objective statistical analysis of existing predictions described in this technical report, was conducted to assess the uncertainties in predictions for San Francisco Bay contained in the NOAA Tidal Current Tables 1992 - Pacific Coast of North America and Asia[1].

Highlights of events that led to the initiation and conduct of this QA miniproject are as follows:

In July, 1991, as part of an ongoing quality assurance review, the National Ocean Service (NOS) evaluated the Tidal Current Charts - San Francisco Bay[2], prepared from data collected prior to 1969, against the Tidal Current Tables 1991 - Pacific Coast of North America and Asia[3] based mainly on data collected in 1979 and 1980. Current speed differences exceeding 0.5 knot were found for six of eight locations.

In October, 1991, NOS issued a Notice to Mariners that it was withdrawing the Tidal Current Charts - San Francisco Bay from distribution effective October 21, 1991. Based on earlier expressions of concern from mariners using San Francisco Bay, NOS also issued a Notice to Mariners to exercise caution and discretion in the use of tidal current predictions at San Francisco Bay Entrance and Carquinez Strait.

Subsequently, the Chief, Coastal and Estuarine Oceanography Branch (CEOB), met with the San Francisco Bar Pilots and the Coast Guard Marine Safety Office and briefed the Tides and Currents Subcommittee of the Marine Exchange of the San Francisco Bay Region. Discussions included the circumstances and actions that led to the issuance of the Notices to Mariners. The CEOB Chief discussed the more recent science and technology in use by NOS to provide improved predictions, model-simulated circulation and water level atlases, and physical oceanographic real-time systems (PORTS), using the Tampa Bay Oceanography Project as an example.

During November, the Commander, Eleventh Coast Guard District, requested NOS to develop a tidal circulation and water level atlas and a PORTS for San Francisco Bay.

In January, 1992 the Chief, CEOB, briefed the Harbor Safety Committee of the San Francisco Bay Region about the problems with existing tide and current predictions and the solutions for improved information, particularly as they related both to oil spill prevention and response. The Committee requested NOS to conduct the QA miniproject as soon as possible.

In March 1992, CEOB oceanographers conducted a reconnaissance of San Francisco Bay in preparation for the QA miniproject and enlisted the assistance of Alameda Naval Air Station (divers), Coast Guard Aids-to-Navigation (buoy tender), Coast Guard Marine Safety Office and San Francisco Bar Pilots (requirements), and the NOAA/National Weather Service (wind data during miniproject).

MEASUREMENTS DURING THE QA MINIPROJECT

Four internally recording acoustic Doppler current profilers (ADCPs), manufactured by RD Instruments, San Diego, CA[4], were deployed in San Francisco Bay from April 28 to May 29, 1992. These instruments use the Doppler shift of backscattered water mass echoes to remotely measure the speed and direction of the currents through the water column. The echoes are segmented into depth cells (bins) over ranges that vary with the frequency of the ADCP. ADCP units of two frequencies were deployed during the QA miniproject: three 1200-kHz units (range up to 30 meters, 1-meter bin size) at Yerba Buena Island (S10), Red Rock (S7), and Roe Island (S9), and one 600-kHz unit (range up to 60 meters, 2-meter bin size) at Carquinez Strait (S5, refer to Figure 1). An ADCP was also deployed at Golden Gate Bridge, but no data were recovered. The ADCP can measure currents in the velocity range of 0 to 10 meters per second and has a long term theoretical accuracy of 0.5 centimeter per second according to manufacturer's specifications. The ADCPs used to collect the QA miniproject data described in this report were calibrated at the U. S. Naval Ship Research and Development Center in Carderock, Maryland. The errors were well below 10 percent with a measurement uncertainty of less than 5 cm/s. These units were deployed on the bottom, mounted in special platforms that were designed for instrument protection and leveling (Figure 2). The instruments were recovered by activating acoustic releases on command from the support vessel. Because the bottom-mounted ADCP platforms present a low profile, they can be placed in the center of navigation channels — an impossible task for buoy-moored current meters.

In addition to the ADCP measurements, water level data at the Presideo and at Port Chicago were obtained from NOAA's Ocean and Lake Levels Division, and wind velocity data at Angel Island and Davis Point were obtained from NOAA's National Weather Service (Figure 1). These data were used to provide background information in the interpretation of the current measurements.

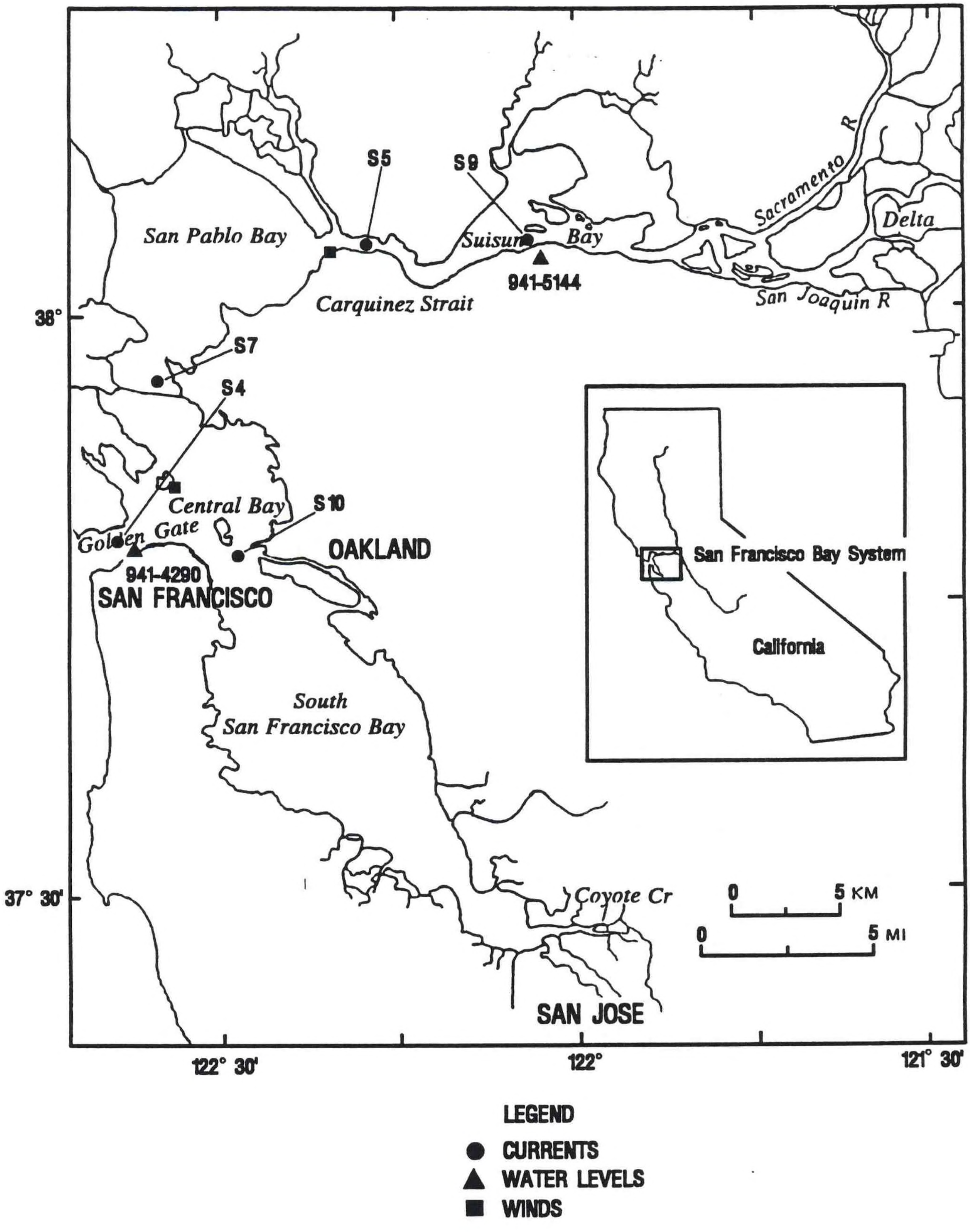

Figure 1. Station locations for San Francisco Bay miniproject

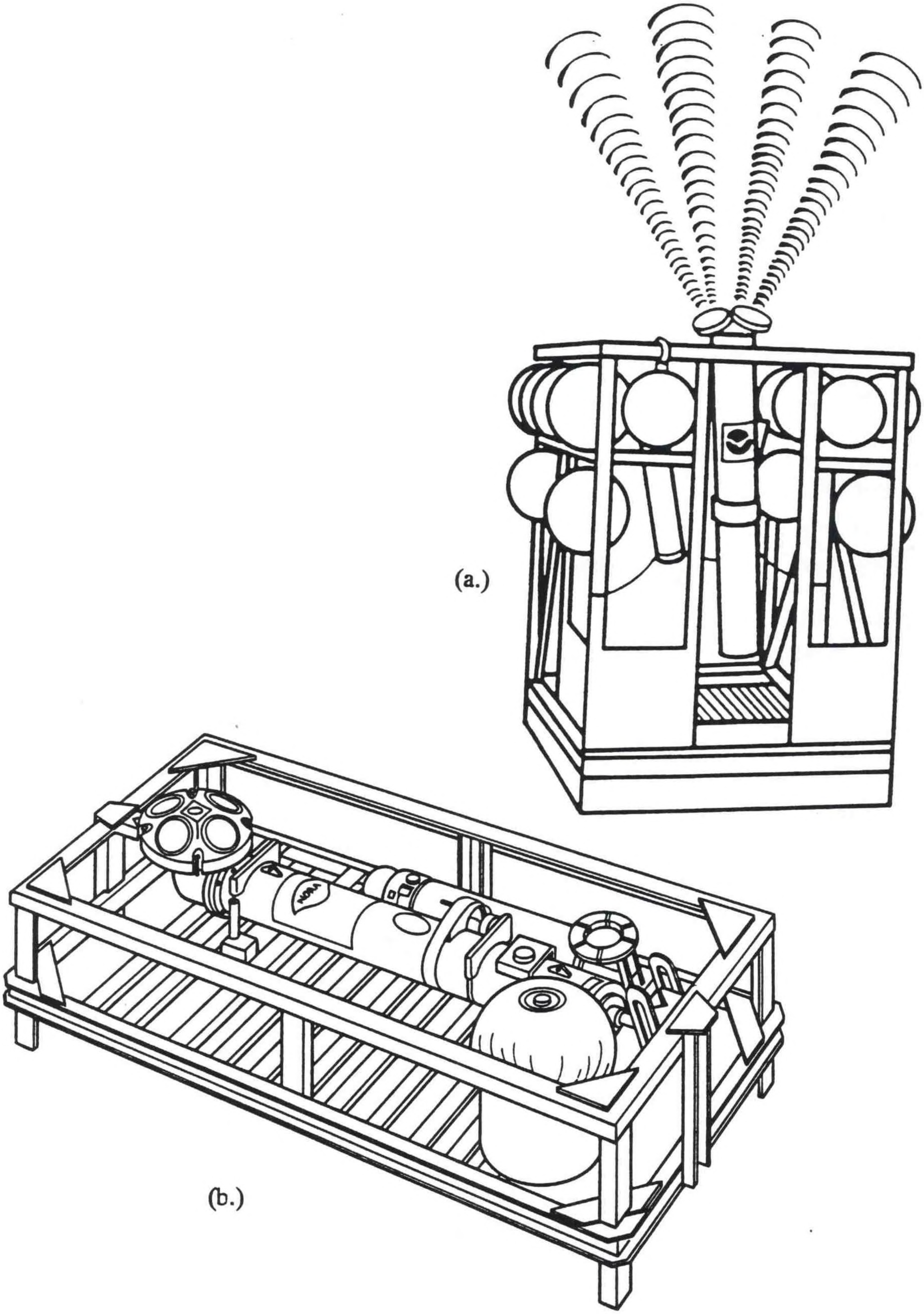

Figure 2. Bottom-mounted ADCP systems deployed in San Francisco Bay. (a.) Self-leveling platform for deep deployments. (b.) Shallow water diver-leveled platform.

The locations, water depths, and time periods of valid data acquisition for the ADCPs are shown in Table 1. The deployment and retrieval times are shown in greater detail in Figure 3. All data used in this report passed standard quality control procedures (Rotondi et al., 1990[5]). The depths chosen for the analysis of the QA miniproject ADCP profile data correspond to the depths for which predictions are given in the NOAA Tables (Table 2).

TABLE 1

SAN FRANCISCO BAY STATION LOCATIONS

Station	Measurement	Station Name	Location	Depth	Instrument Frequency	S/N	Deployment Period
S05	Currents	Carquinez Strait	38° 03.48' N 122° 25.50' W	24m (78 ft)	600 kHz	263	4/22/92-5/30/92
S06	Currents	Golden Gate Bridge	37° 49.10' N 122° 28.27' W	96m (317 ft)	300 kHz	256	4/22/92-5/29/92
S07	Currents	Red Rock	37° 56.02' N 122° 25.50' W	18m	1200 kHz (60 ft)	160	4/28/92-5/28/92
S09	Currents	Roe Island	38° 03.57' N 122° 01.83' W	14m (45 ft)	1200 kHz	260	4/27/92-5/28/92
S10	Currents	Oakland Bar Channel	37° 47.98' N 122° 21.25' W	14m (45 ft)	1200 kHz	177	4/28/92-5/29/92
941-4290	Water Levels	Presideo					
941-5144	Water Levels	Port Chicago					
	Wind Velocity	Angel Island					
	Wind Velocity	Davis Point					

TABLE 2

LOCATIONS AND DEPTHS OF PUBLISHED PREDICTION STATIONS

QA Station Number	NOAA Table Number	Prediction Station Name	Location	Depth
S05	625	Carquinez Strait	38° 03.68'N 122° 13.1'W	20 ft (6m) below MLLW
S07	541	Red Rock, 0.6 nmi NNE	37° 56.40'N 122° 25.60'W	17 ft (5m) below MLLW
S07	541	Red Rock, 0.6 nmi NNE	37° 56.40'N 122° 25.60'W	23 ft (7m) below MLLW
S07	541	Red Rock, 0.6 nmi NNE	37° 56.40'N 122° 25.60'W	38 ft (12m) below MLLW
S09	677	Roe Island, southof	38° 04'N 122° 02'W	9 ft (3m) below MLLW
S10	281	Yerba Buena Island, 03. nmi SE	37° 48.25'N 122° 21.43'W	23 ft (7m) below MLLW
S10	285	Yerba Buena Island, 03. nmi S	37° 48.1'N 122° 21.7'W	8 ft (2m) below MLLW

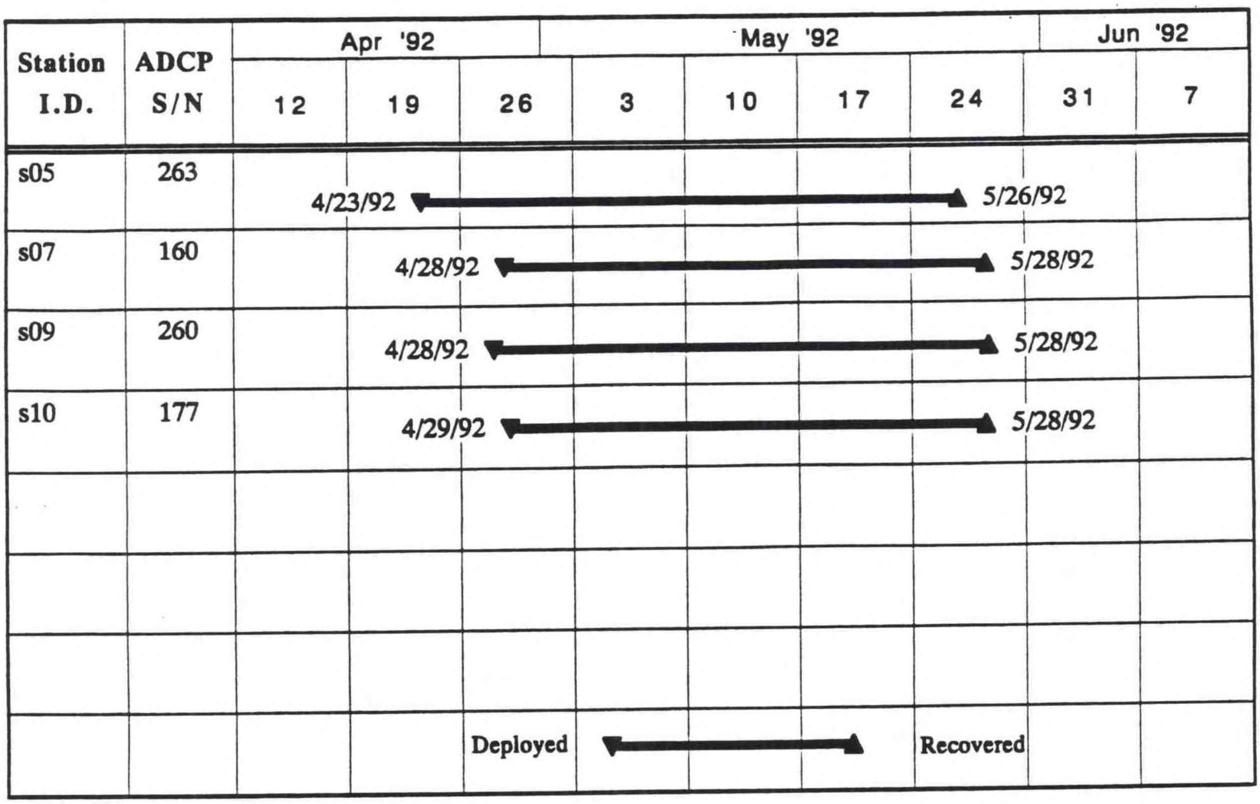

Figure 3. Deployment-retrieval schedule.

ANALYSIS

The current data were analyzed to produce time series plots, summary statistics, times and velocities of maximum flood current (MFC) and maximum ebb current (MEC), and times of slack before flood (SBF) and slack before ebb (SBE). These times and velocities are collectively referred to as the *NOS tidal current parameters*. The differences between new observations and NOAA Tidal Current predictions given in the published NOAA Tables were tested against uncertainty guidelines for adequacy established for the QA miniproject (Figure 4). There are no absolute standards for accuracy of predictions; these working guidelines were developed for evaluating numerical hydrodynamic models in consultation with marine pilots . Adapted for QA miniproject use, they represent a goal which NOS is striving to achieve.

The same analysis methods were used to compare measurements from the 1979-80 circulation survey (Welch et al., 1985[6], Cheng and Gartner, 1984[7]) with "predictions" obtained from the same harmonic constituents, amplitude ratios, and phase (time) differences used for the 1992 Current Tables.

RESULTS

Statistical analysis of differences between the published NOAA tidal current table parameters and those computed from the QA miniproject measurements, based on more than 30 days of data, shows that the presently published predictions are marginal at Carquinez Strait, adequate at Roe Island and Red Rock, not meeting uncertainty guidelines at Yerba Buena Island,—particularly NOAA Table 2 station No. 285, which has been withdrawn from the Tables based on this analysis.

The results of the statistical analysis of the differences between the NOAA Tidal Current Table parameters and those computed from the 1992 QA miniproject ADCP measurements are presented graphically as histograms and in tables. The statistical tables give maximum and minimum observed differences, means, standard deviations, and 90% limits (5% of the data equal to or greater than the upper limit and 5% equal to or less than the lower limit). Time series plots of QA miniproject-measured current velocity and that predicted by the NOAA Tidal Current Tables are given in 10 day increments.

In order to fully meet QA miniproject requirements, 90% of the differences between observed data and current table predictions must fall within QA uncertainty guidelines; i.e, the 90% limits must be within guidelines. Since the guidelines are somewhat arbitrary, a station may still be regarded as acceptable if the 90% limits do not fall far outside the guidelines, especially if the distributions are narrow and nearly symmetrical. Differences in the means should fall within guidelines. If the distribution of differences extends well beyond the QA guidelines, the station is considered unacceptable and any published table predictions for this location are therefore inadequate. For further details, see Wilmot and Williams, 1987[8].

In the following paragraphs, results are given for each station - first for the comparison with 1992 QA field data, and then for the comparison with 1979-80 circulation survey data.

Carquinez Strait

Carquinez Strait is a reference station for all locations in the San Francisco Bay region to the north and east. It is based on analysis of 200 days of Aanderaa current meter data taken during the

UNCERTAINTY GUIDELINES

NOAA Prediction for:	90% of Differences Between New Data and Predictions Within:		
	Minutes	cm	cm/sec
Mean High Tide	15		
Mean High Tide		15	
Mean Low Tide	15		
Mean Low Tide		15	
Slack Before Flood	15		
Slack Before Ebb	15		
Maximum Flood Current	30		
Maximum Flood Current			32
Maximum Ebb Current	30		
Maximum Ebb Current			32

Figure 4. Uncertainty guideline for tidal currents and water levels used for evaluation of QA miniproject data.

1979-1980 circulation survey. This dataset was assembled from records of individual deployments typically of 15 - 30 days duration. Frequent deployments and retrievals were necessary for instrument maintenance and data extraction (Welch et al, 1985[6])

QA Field Data

Maximum flood current speeds are within QA uncertainty guidelines; ebb current speeds are almost within guidelines, with predicted currents tending to be larger than observed currents (Table 3, Figure 5). Observed maximum flood and ebb currents occur sooner than predicted (Figure 6). The mean differences of measured slack times are within NOS working guidelines. Although the 90% limits extend beyond guidelines, they are close compared to most QA miniproject stations. The 0.3 nautical mile separation between the sites of the 1979-80 measurements and the 1992 QA miniproject measurements is a factor contributing toward the differences. The QA miniproject station was located closer to the Bridge on the north side of the Strait, whereas the 1979-80 survey station was located farther east of the Bridge and on the south side of the channel. It was necessary to change the deployment site because the rough nature of the bottom at the site of the 1980 current meter moorings was unsuitable for ADCP deployment. The effect on the slack times is very small. There is a difference of 11 degrees in mean flood direction at the two sites, as might be expected from the rapidly changing shoreline at the west end of the Strait.

The direction for the flood current given in NOAA Table 2 is 103 degrees; the direction for the ebb current is 283 degrees. The direction of the flood current from the QA data is 92 degrees; the direction for the ebb current is 272 degrees, determined by principal component analysis. These directions approximately coincide with the main axis of the channel at the measurement sites. From the QA measurements, it appears that large vertical shears can occur, especially during the time of tidal current transition.

TABLE 3

DIFFERENCE STATISTICS FOR CARQUINEZ STRAIT
1992 OBSERVED - 1980 PREDICTED
Beginning Date: 4/22/92 Ending Date: 5/29/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-114.0	-92.0	32.5	-33.5	13.0	19.0	70
MFC Speed (cm/s)	-17.2	-13.3	10.9	13.5	30.3	33.0	70
SBE Time (minutes)	-35.0	-27.0	14.4	6.2	32.0	39.0	70
MEC Time (minutes)	-100.0	-95.0	36.3	-21.2	23.0	50.0	70
MEC Speed (cm/s)	-31.3	-23.7	21.2	8.4	42.1	64.9	70
SBF Time (minutes)	-58.0	-46.0	14.4	-14.4	2.0	11.0	70

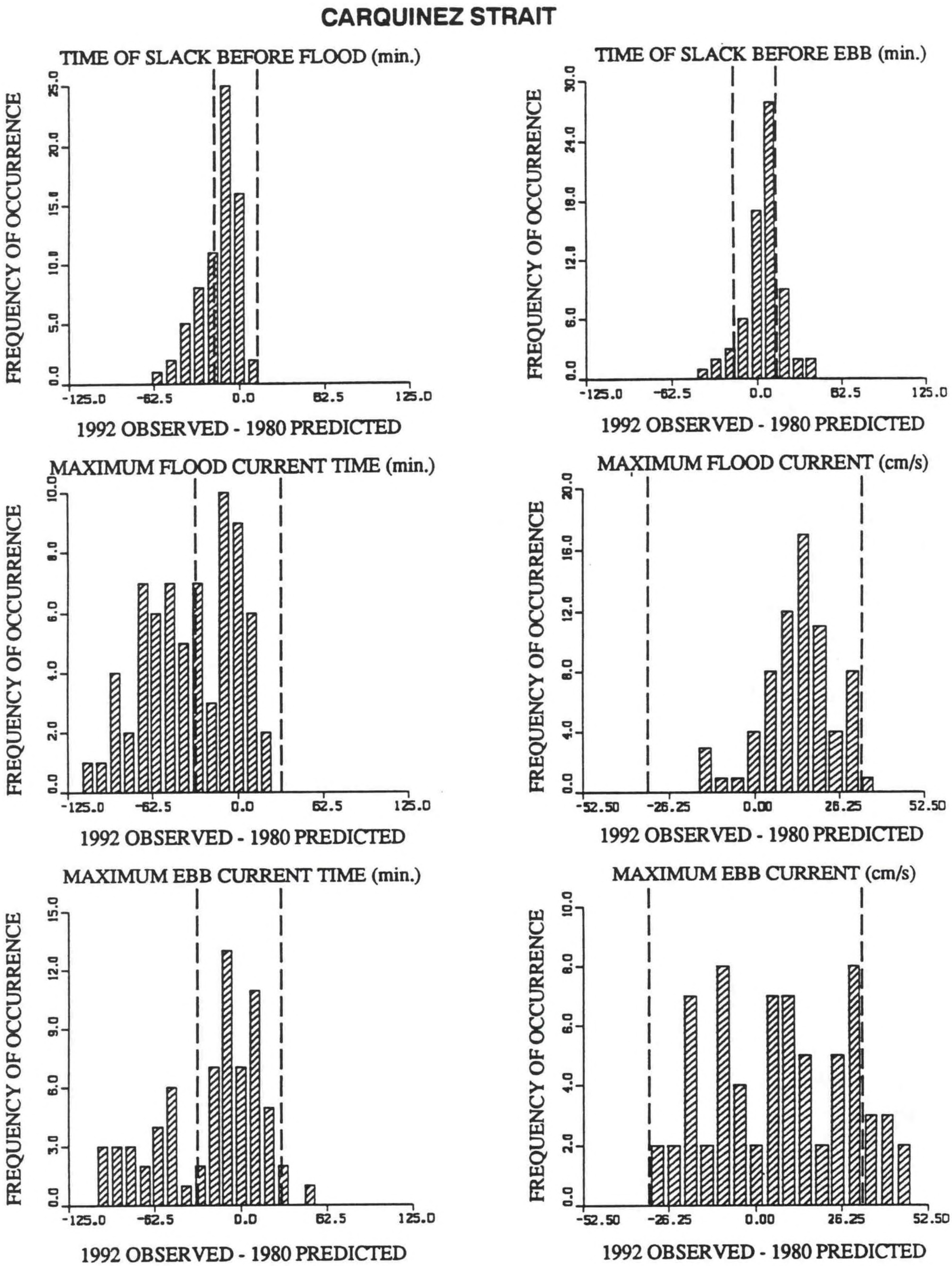

Figure 5. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Carquinez Strait, station S5.

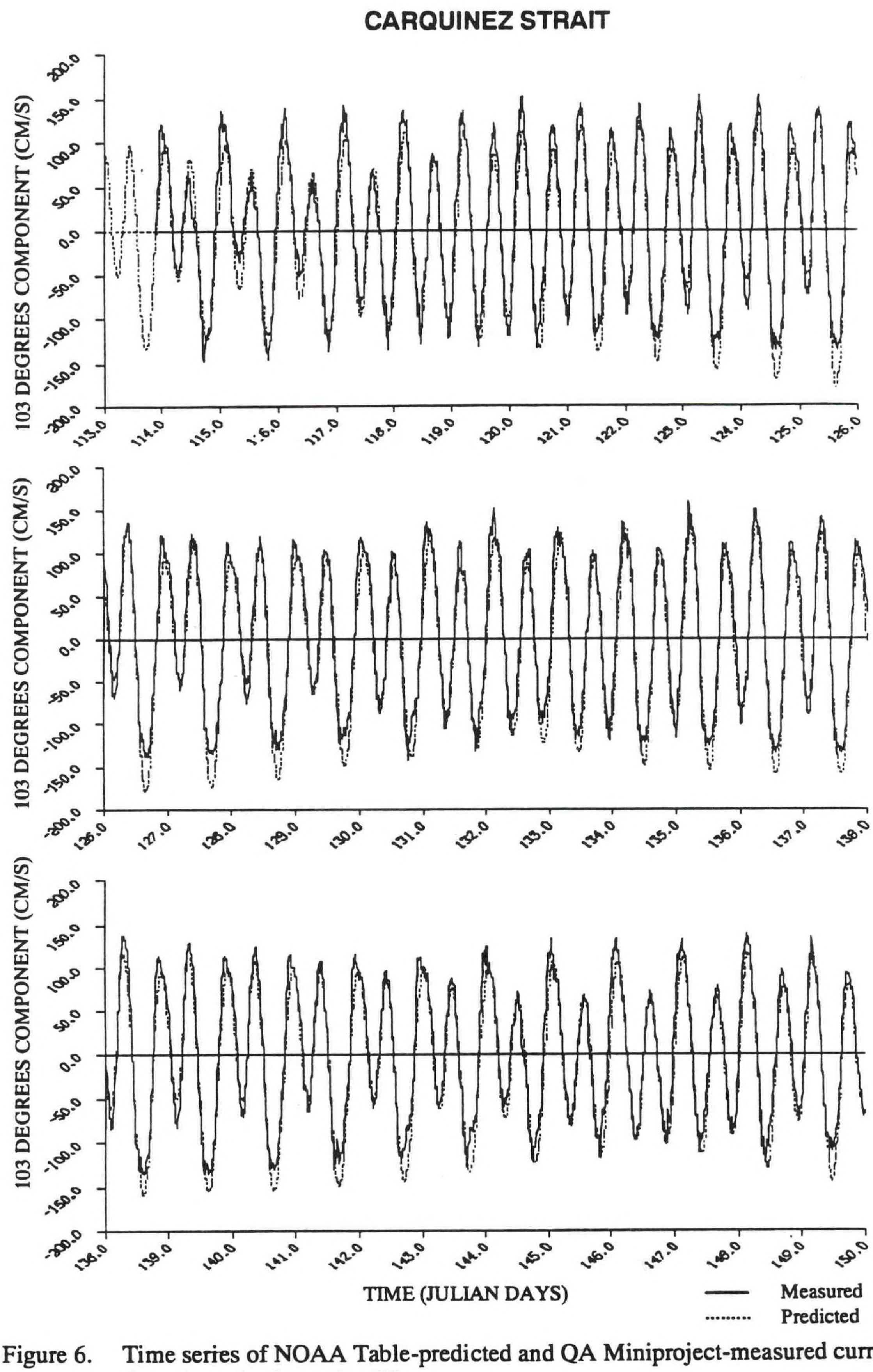

Figure 6. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Carquinez Strait, station S5.

1979-80 Survey Data

Difference statistics for Carquinez Strait, station C24, based on 200 days of historical data taken in 1980, are given in Table 4; histograms of difference statistics are shown in Figure 7. The mean difference for maximum flood current times is within QA uncertainty guidelines, but the range is on the order of 2 hours. The mean differences in the slack times are seen to be about 30 minutes; the ranges in the differences are about 1 hour. From the ranges in the maximum flood current time and the slack times, we infer that there is a non-tidal influence on the circulation, largely atmospheric, which cannot be predicted by tidal current tables. Time-dependent vertical shears can also add variability in slack times. These considerations suggest that a physical oceanographic real-time system (PORTS) may be required to provide adequate current information for piloting.

TABLE 4

DIFFERENCE STATISTICS FOR CARQUINEZ STRAIT
1980 OBSERVED - 1980 PREDICTED
Beginning Date: 4/4/80 Ending Date: 10/19/80

NOS Parameter (Units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-105.0	-54.0	41.0	13.4	83.0	117.0	395
MFC Speed (cm/s)	-52.9	-34.3	20.0	-2.0	32.9	60.0	395
SBE Time (minutes)	-35.0	-9.0	24.7	29.8	71.0	96.0	383
SBE Speed (cm/s)	-2.2	-1.1	.7	.0	1.1	1.7	383
MEC Time (minutes)	-117.0	-86.0	49.6	-1.3	76.0	107.0	411
MEC Speed (cm/s)	-65.0	-43.0	21.8	-6.4	28.0	47.2	411
SBF Time (minutes)	-26.0	-13.0	23.9	25.8	66.0	91.0	382
SBF Speed (cm/s)	-2.2	-1.3	.8	.0	1.4	2.5	382

Roe Island

NOAA Table 2 stations in San Francisco Bay were occupied for much shorter periods of time than the reference stations (on the order of 2 weeks). NOAA Table 2 correction factors at Roe Island (south of, station 677 in the published tables), referred to Carquinez Strait, are not based on data from the 1979-80 survey, but rather on data from 1930.

QA Field Data

The maximum flood current time is the only tidal current parameter to clearly fail QA working guidelines (Table 5, Figure 8). The predicted maxima tend to occur later than the observed times (Figure 9). Maximum flood and ebb current speeds are well within uncertainty guidelines. The slack time differences are close to being within guidelines. Maximum ebb current time almost passes the QA guidelines. It is unlikely that new measurements would improve these predictions.

CARQUINEZ STRAIT

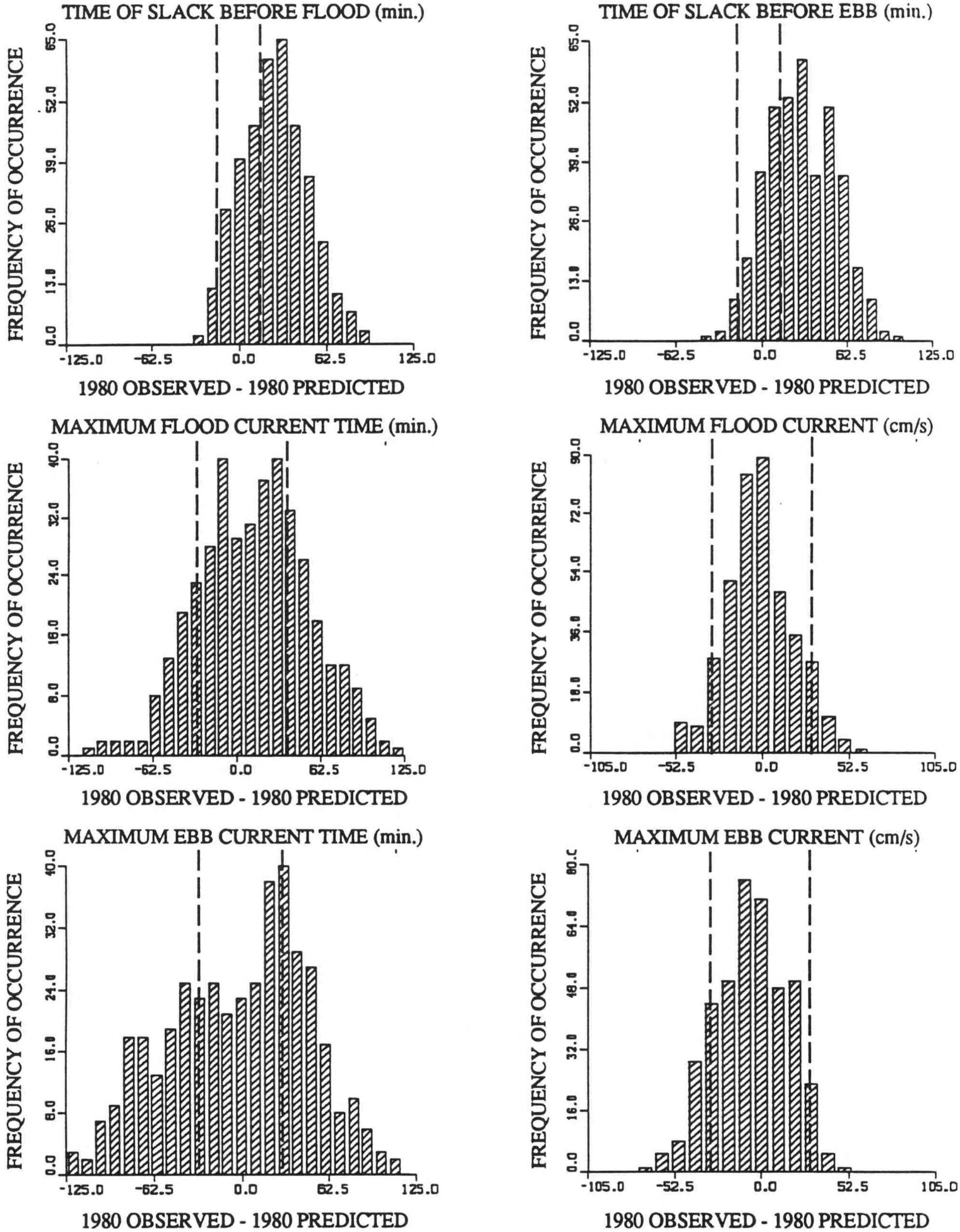

Figure 7. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Carquinez Strait, station C24.

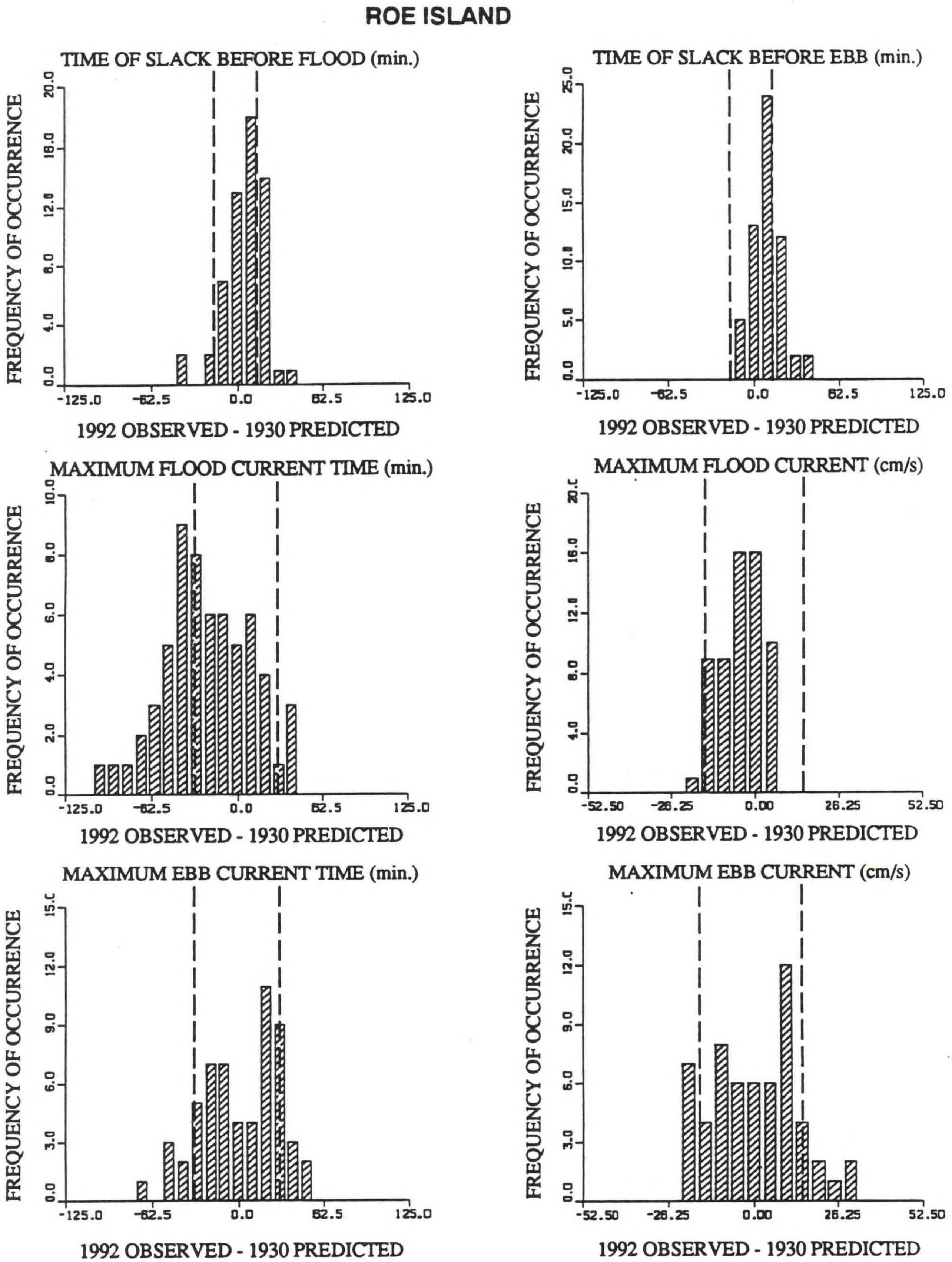

Figure 8. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Roe Island, station S9.

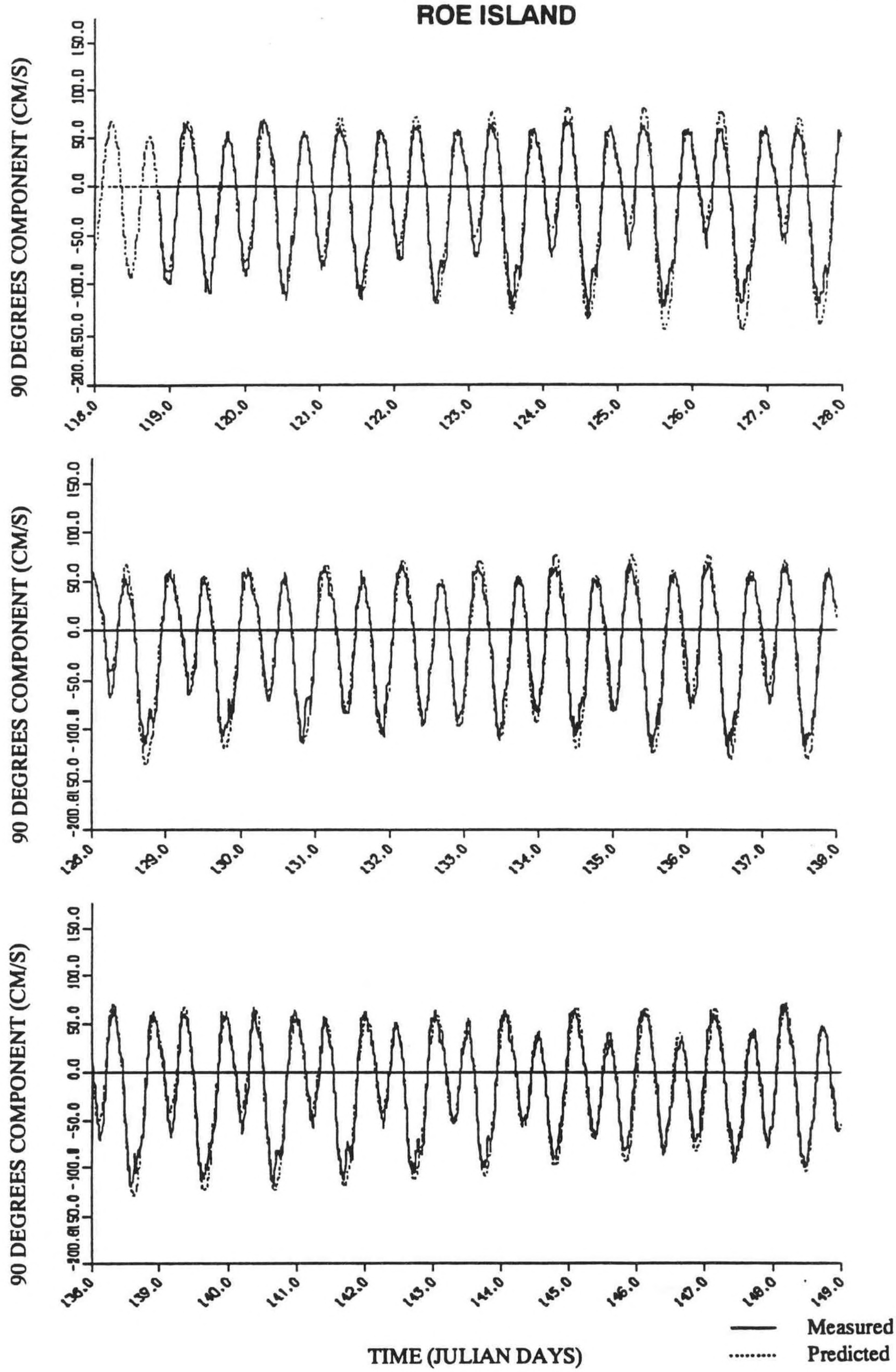

Figure 9. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Roe Island, station S9.

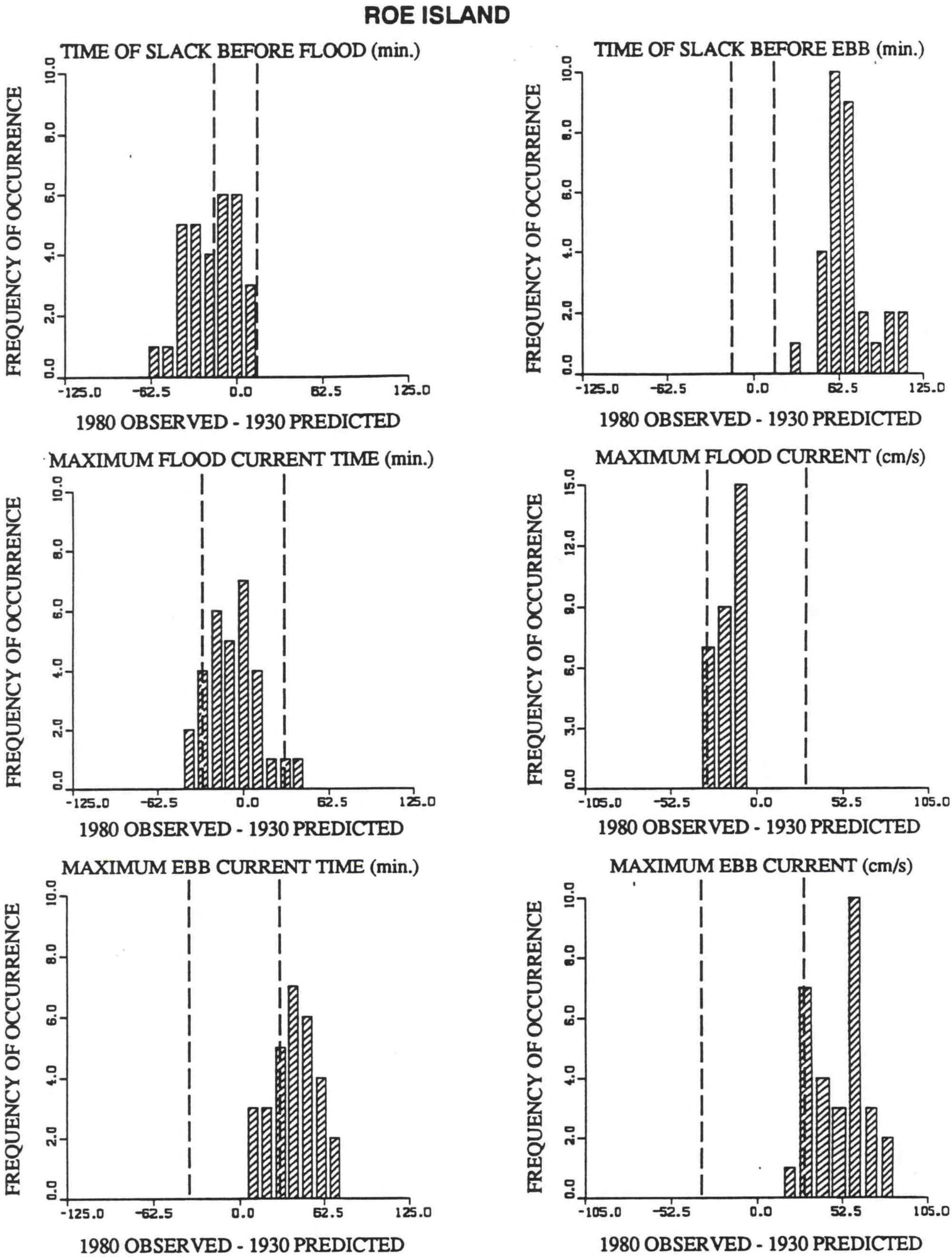

Figure 10. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Roe Island, station C237.

TABLE 5

DIFFERENCE STATISTICS FOR ROE ISLAND
1992 OBSERVED - 1930 PREDICTED
Beginning Date: 4/27/92 Ending Date: 5/28/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-103.0	-75.0	31.4	-20.9	30.0	43.0	61
MFC Speed (cm/s)	-20.1	-15.0	6.4	-4.5	3.8	6.9	61
SBE Time (minutes)	-13.0	-12.0	10.7	10.5	34.0	40.0	58
MEC Time (minutes)	-66.0	-51.0	28.0	2.6	42.0	51.0	58
MEC Speed (cm/s)	-22.1	-21.7	13.1	.5	24.8	28.1	58
SBF Time (minutes)	-37.0	-35.0	14.1	6.9	25.0	37.0	58

1979-80 Survey Data

The 1979 station was located to the west of the NOAA Table station Roe Island, just south of the western tip of the island. Difference statistics between the 1979 survey data and the NOAA Tidal Current Table predictions show very poor agreement between measured and predicted current parameters, with large mean offsets (Table 6, Figure 10). This result is in sharp contrast to the comparison between the 1992 QA miniproject-measured currents and NOAA Table predictions, which showed good agreement (Figure 8). Review of the documentation for the 1979 survey suggests that the quality of the data for this station was in question.

TABLE 6

DIFFERENCE STATISTICS FOR ROE ISLAND
1980 OBSERVED - 1930 PREDICTED
Beginning Date: 11/2/80 Ending Date: 11/17/80

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-44.0	-44.0	19.3	-7.7	32.0	43.0	31
MFC Speed (cm/s)	-29.7	-29.7	7.4	-17.3	-7.4	-7.1	31
SBE Time (minutes)	33.0	33.0	17.8	69.6	110.0	114.0	31
MEC Time (minutes)	9.0	9.0	16.8	40.1	69.0	73.0	30
MEC Speed (cm/s)	23.9	23.9	16.7	50.2	77.7	81.5	30
SBF Time (minutes)	-57.0	-57.0	17.6	-17.9	9.0	13.0	31

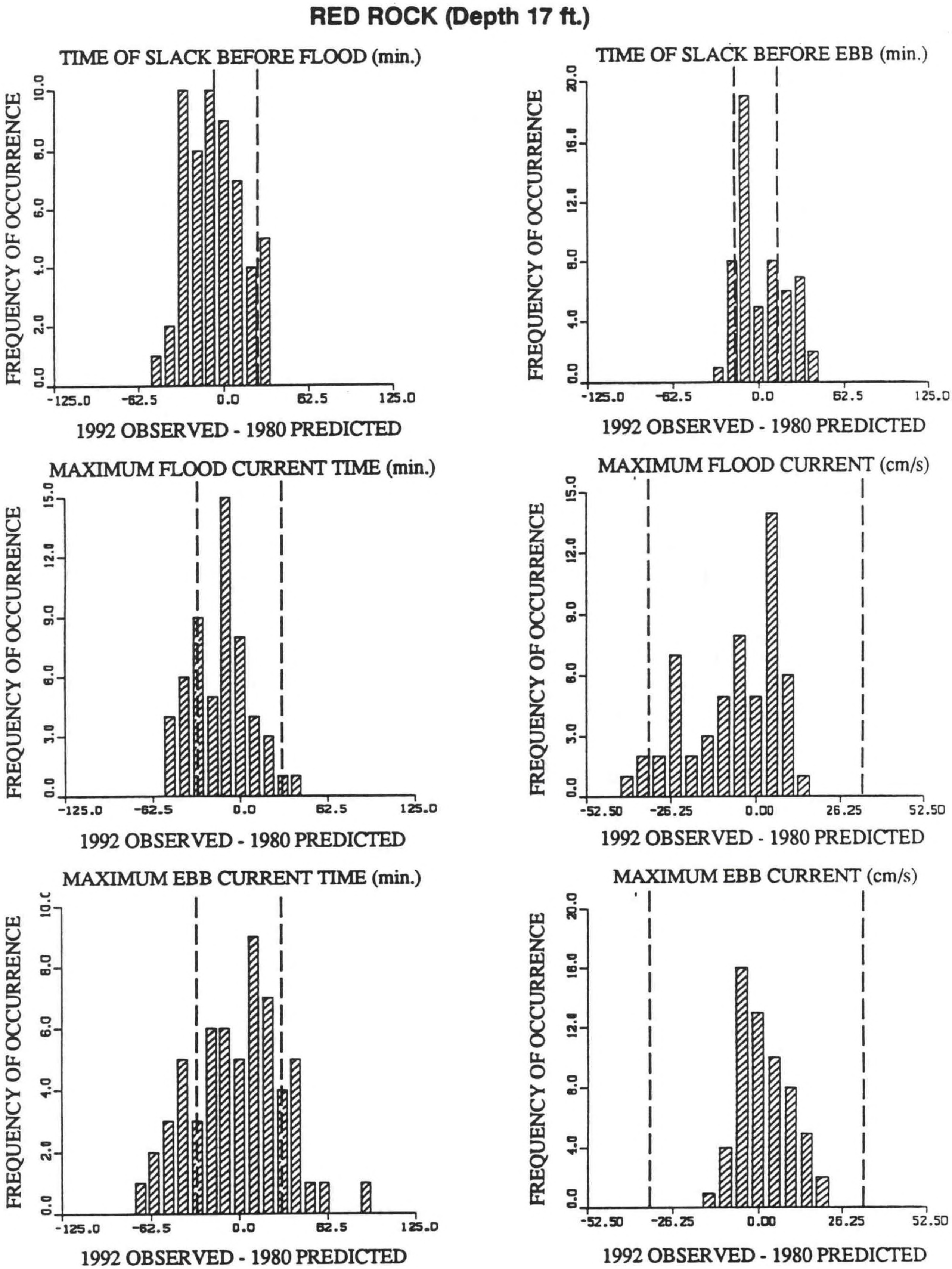

Figure 11. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Red Rock, station S7.

Red Rock

Red Rock (0.60 nmi, NNE of, in NOAA Table 2) is referred to San Francisco Bay Entrance, with predictions for three depths (17 ft, 23 ft, 38 ft) based on data from the 1979-80 circulation survey. QA statistics and plots are given below for each of the three depths.

QA Field Data

The mean differences for all current parameters at 17 ft (5.2 m) are within guidelines (Table 7). Only in the case of maximum flood current times is a large percentage of differences outside guidelines (Figure 11). Predicted current maxima tend to occur somewhat later than measured, especially at times when the diurnal inequality is large (Figure 12). Maximum flood and ebb current speeds are within guidelines. Maximum ebb current time is close to being within guidelines.

As with the 17-ft depth, maximum flood current times at 23 ft (7.0 m) are not within QA guidelines, with predicted currents occurring later than observed (Table 8, Figure 13). The slacks again are outside QA limits, but the distributions are narrow and it is unlikely that they would be improved significantly by new predictions. Maximum current speeds are within QA limits. The lower 90% limit for maximum flood current time is outside guidelines, indicating predicted currents occurring sooner than observed currents (Figure 14).

At 38 ft (11.6 m), the means of all parameters are within guidelines (Table 9). Maximum flood current times extend well beyond QA guidelines (Figure 15). There is a pronounced negative offset in the distribution of differences resulting from predicted maxima occurring later than measured maxima (Figures 15, 16). Differences in slack before ebb are outside guidelines; measured slacks tend to occur sooner than the predicted slacks. Slack before flood differences are beyond guidelines with predicted ebbs occurring earlier than observed ebbs.

For the station in general, the predicted slack time differences are acceptable, except for slack before ebb at 38 ft. Measured maximum currents tend to occur sooner than the predicted maxima.

TABLE 7

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 17 FT.
1992 OBSERVED - 1980 PREDICTED
Beginning Date: 4/29/92 Ending Date: 5/29/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-51.0	-51.0	20.2	-13.6	20.0	36.0	56
MFC Speed (cm/s)	-37.9	-34.4	14.3	-6.6	11.5	15.7	56
SBE Time (minutes)	-30.0	-24.0	18.0	2.3	34.0	36.0	56
MEC Time (minutes)	-66.0	-64.0	32.5	-.4	53.0	93.0	59
MEC Speed (cm/s)	-15.4	-10.2	7.9	2.1	16.1	19.6	59
SBF Time (minutes)	-45.0	-39.0	20.1	-6.6	30.0	33.0	56

TABLE 8

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 23 FT.
1992 OBSERVED - 1980 PREDICTED
Beginning Date: 4/29/92 Ending Date: 5/29/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-95.0	-85.0	26.3	-31.9	6.0	49.0	58
MFC Speed (cm/s)	-17.4	-17.2	11.5	3.7	19.6	23.7	58
SBE Time (minutes)	-30.0	-19.0	20.2	8.4	41.0	50.0	56
MEC Time (minutes)	-81.0	-68.0	35.2	2.6	60.0	79.0	58
MEC Speed (cm/s)	-9.4	-6.2	9.2	7.8	23.3	25.8	58
SBF Time (minutes)	-42.0	-39.0	19.0	-3.0	32.0	34.0	56

TABLE 9

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 38 FT.
1992 OBSERVED - 1980 PREDICTED
Beginning Date: 4/29/92 Ending Date: 5/29/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-104.0	-87.0	28.9	-30.6	9.0	28.0	59
MFC Speed (cm/s)	-23.4	-22.2	12.0	-1.1	14.8	16.3	59
SBE Time (minutes)	-43.0	-36.0	21.9	-4.3	36.0	36.0	56
MEC Time (minutes)	-89.0	-67.0	38.4	1.7	59.0	96.0	62
MEC Speed (cm/s)	-17.4	-12.6	6.4	-2.2	9.8	12.2	62
SBF Time (minutes)	-30.0	-30.0	19.8	3.9	39.0	40.0	56

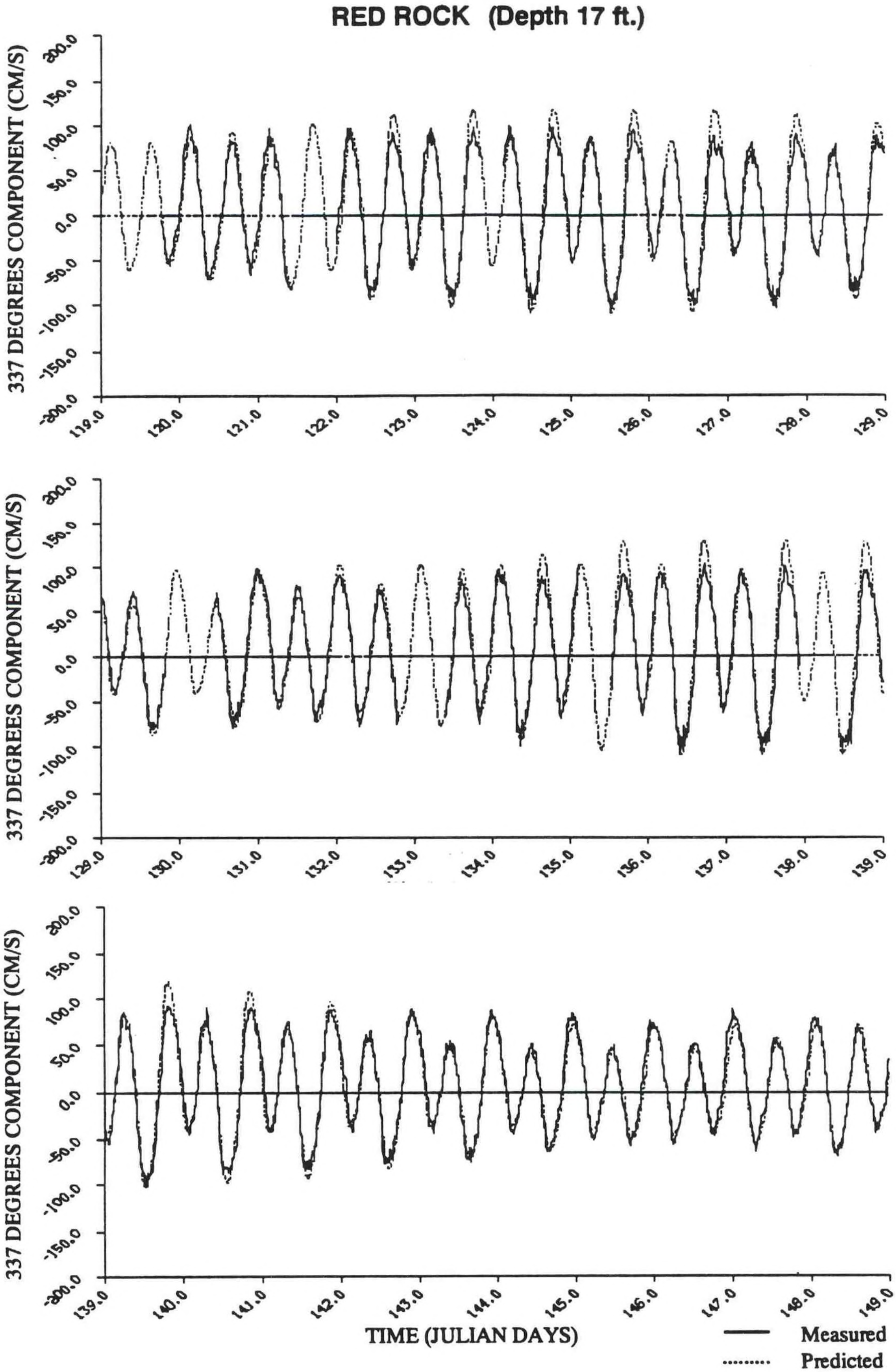

Figure 12. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Red Rock, station S7.

RED ROCK (Depth 23 ft.)

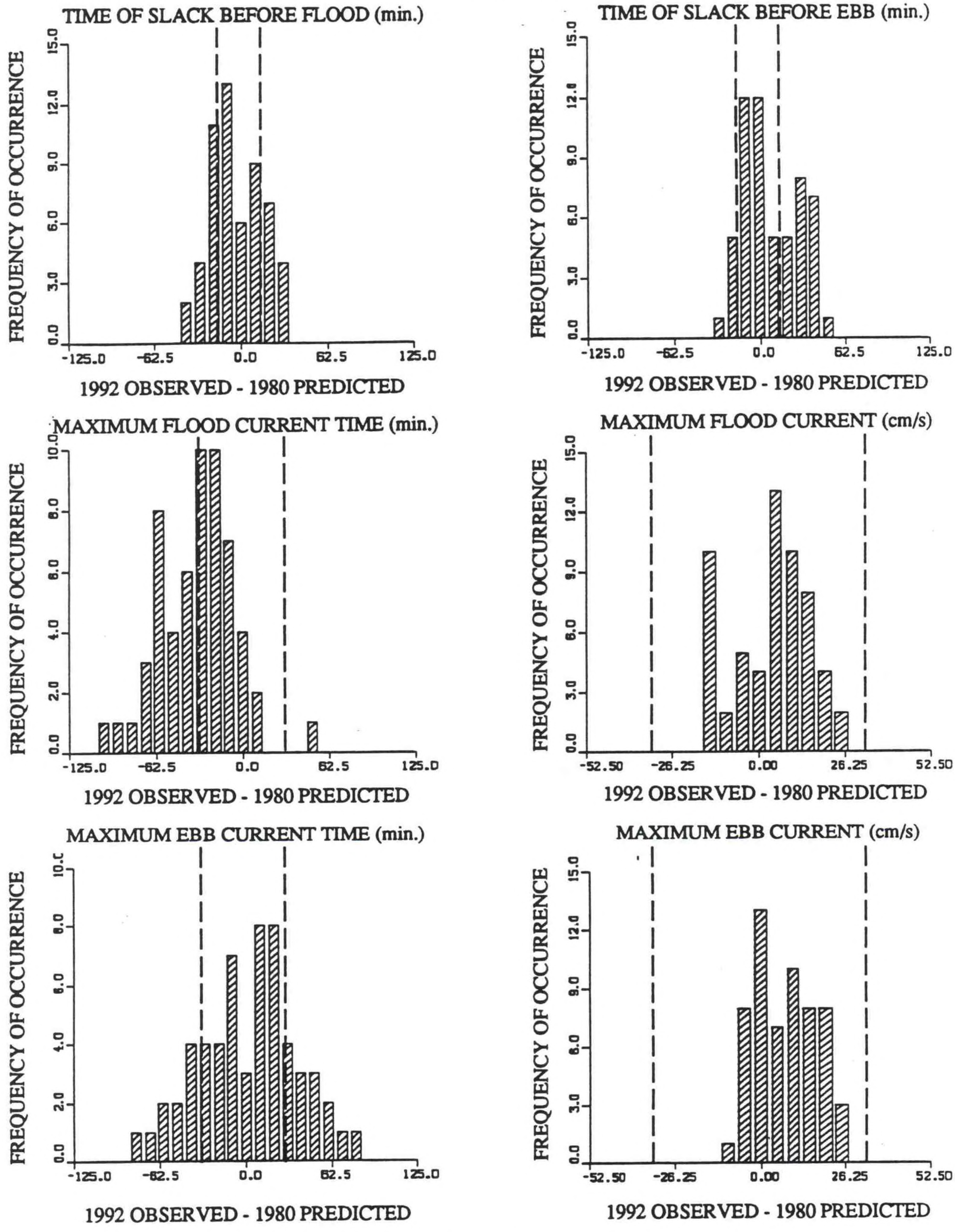

Figure 13. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Red Rock, station S7.

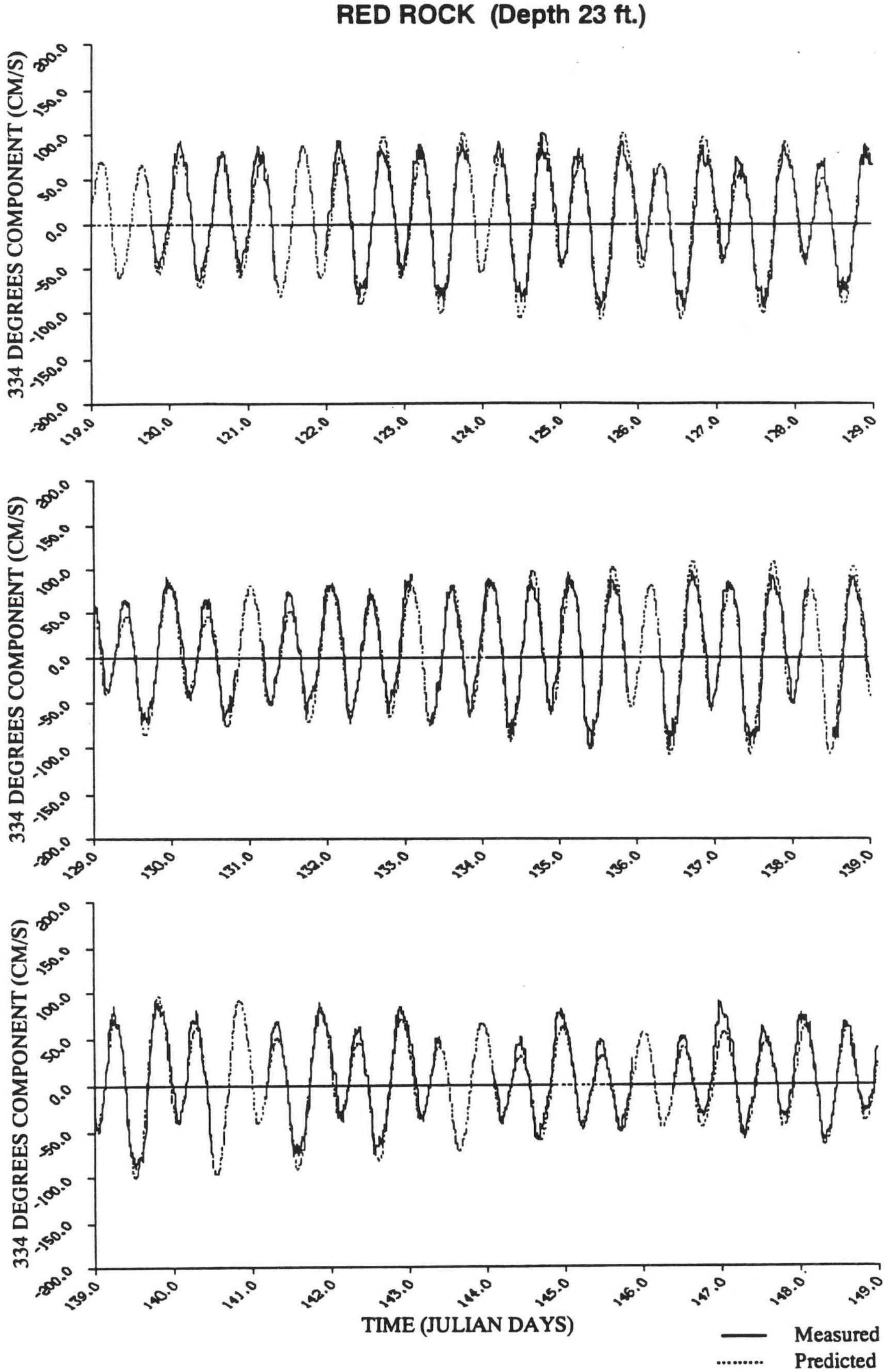

Figure 14. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Red Rock, station S7.

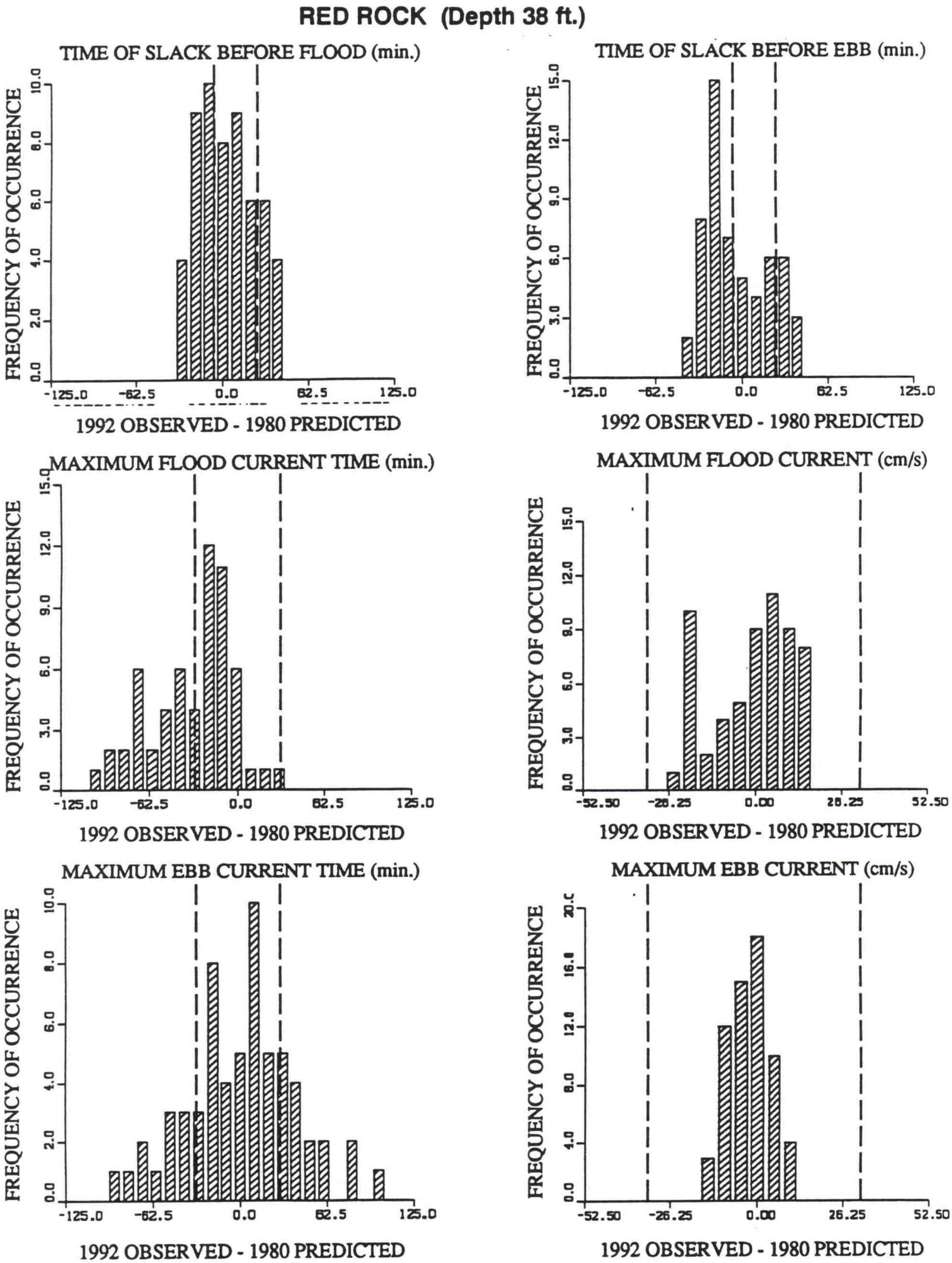

Figure 15. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Red Rock, station S7.

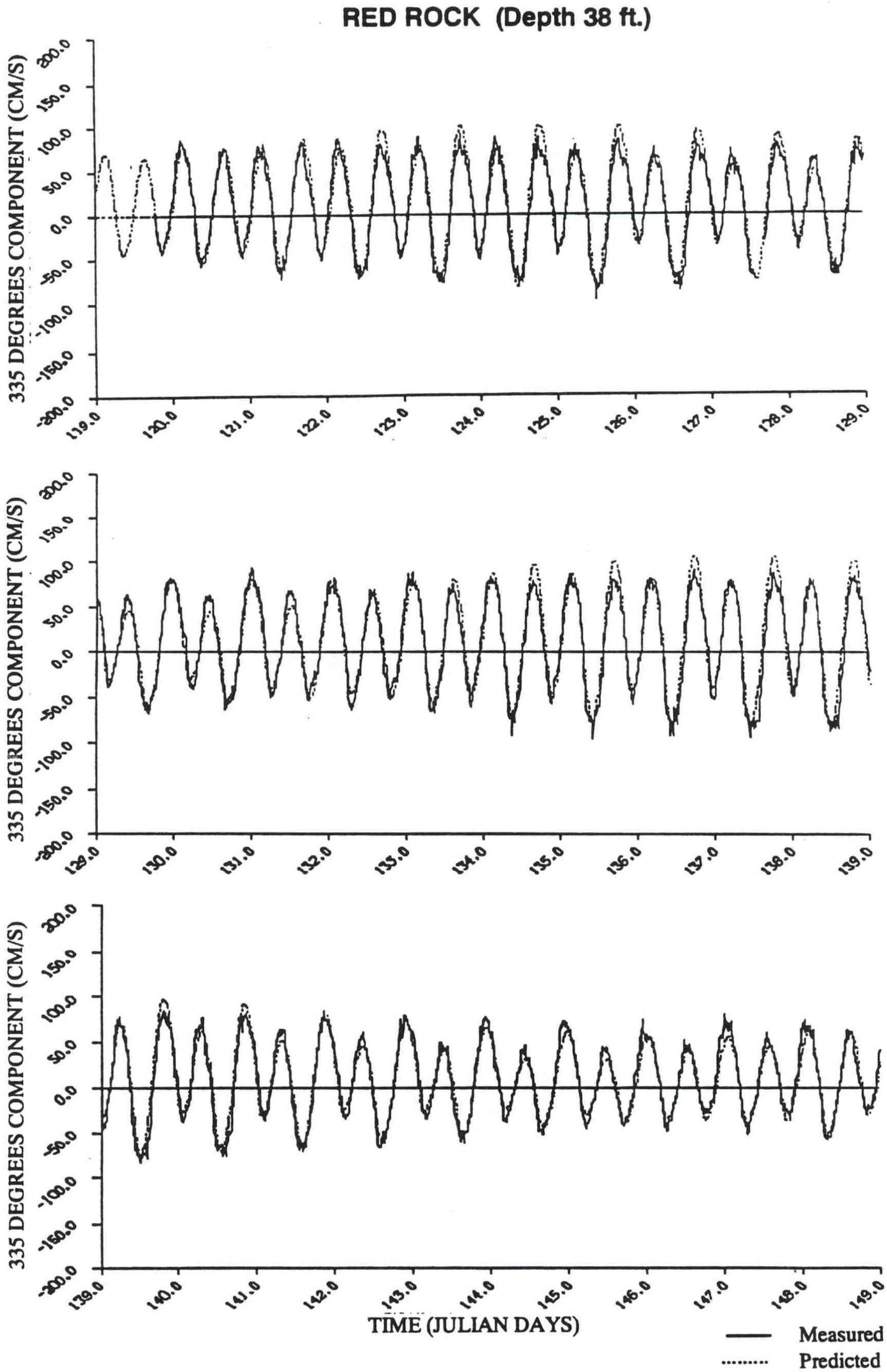

Figure 16. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Red Rock, station S7.

1979-80 Survey Data

Maximum speeds for both flood and ebb currents at 17 ft are within QA uncertainty guidelines (Table 10, Figure 17). Maximum flood current times are within limits, but maximum ebb current times are not, with measured maximum currents occurring later than predicted currents. The distribution of the slack before flood differences is skewed in a positive direction, indicating that measured slacks are occurring later than predicted slacks. Slack before ebb differences show a large mean offset resulting in a positively skewed distribution. This indicates measured slacks occurring later than predicted slacks. The spread in the slack times is about one hour.

The statistics of the differences at 23 ft (Table 11, Figure 18) and 38 ft (Table 12, Figure 19) show patterns similar to those at 17 ft, with maximum flood current times within QA guidelines, maximum flood and ebb current speeds within guidelines, but maximum ebb current times and slack times outside guidelines.

Predictions of slack water for this station would appear to be improved by adjusting the means of the distributions.

TABLE 10

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 17 FT.
1980 OBSERVED - 1980 PREDICTED
Beginning Date: 9/14/80 Ending Date: 9/30/80

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-38.0	-38.0	20.6	8.8	37.0	43.0	29
MFC Speed (cm/s)	-33.9	-33.9	13.0	-6.3	11.0	15.8	29
SBE Time (minutes)	2.0	2.0	17.8	28.4	52.0	79.0	29
MEC Time (minutes)	-45.0	-45.0	25.8	28.5	57.0	67.0	29
MEC Speed (cm/s)	-19.4	-19.4	8.0	-4.0	14.0	15.6	29
SBF Time (minutes)	-46.0	-46.0	26.7	16.0	65.0	72.0	30

TABLE 11

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 23 FT.
1980 OBSERVED - 1980 PREDICTED
Beginning Date: 9/20/80 Ending Date: 10/8/80

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-48.0	-48.0	24.4	11.8	54.0	62.0	33
MFC Speed (cm/s)	-32.3	-32.3	11.5	-1.6	18.7	19.7	33
SBE Time (minutes)	-17.0	-17.0	20.5	24.5	53.0	58.0	32
MEC Time (minutes)	-23.0	-23.0	24.0	23.8	61.0	61.0	33
MEC Speed (cm/s)	-5.6	-5.6	7.5	9.3	21.0	24.0	33
SBF Time (minutes)	-24.0	-24.0	23.6	15.5	46.0	62.0	33

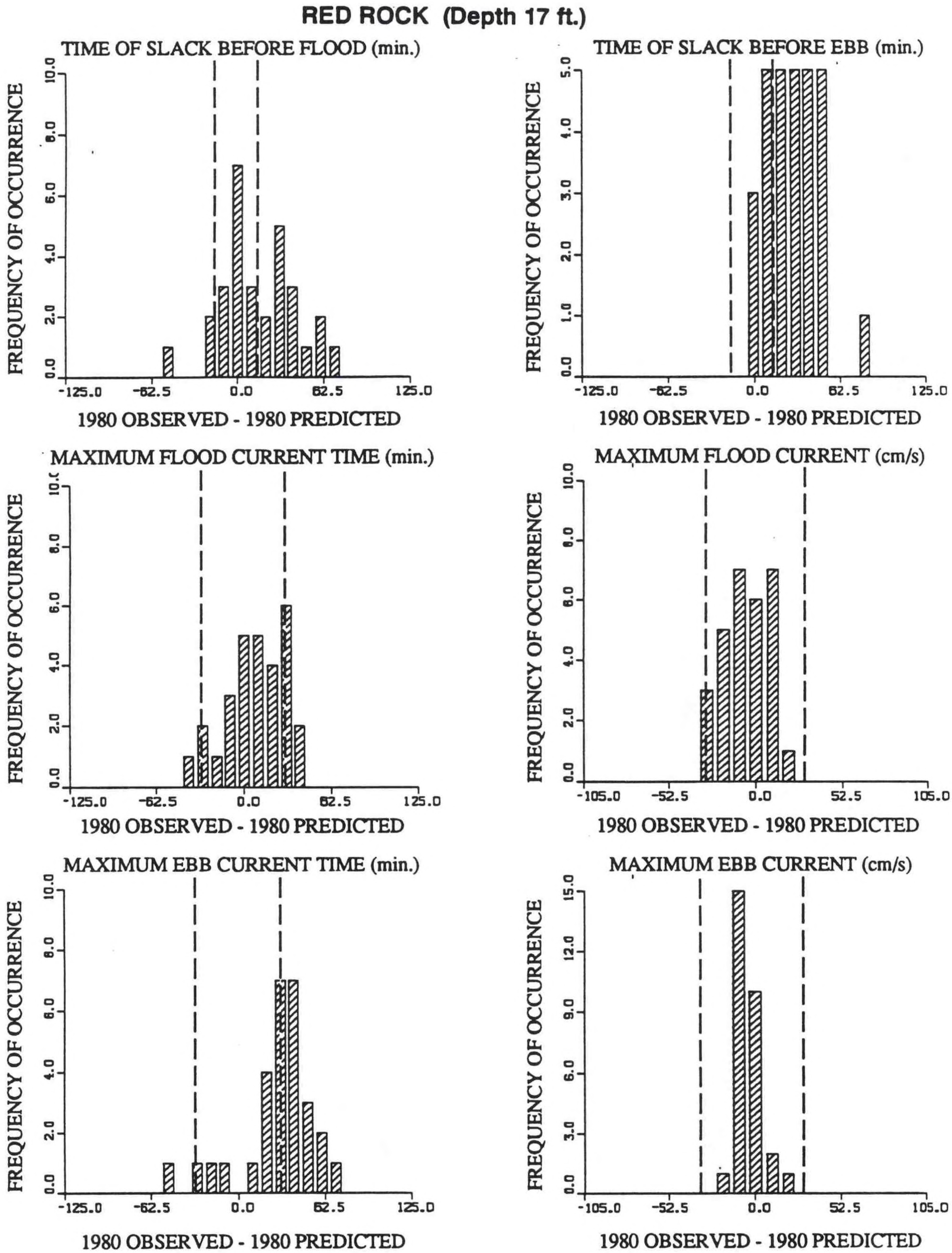

Figure 17. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Red Rock, station C216.

RED ROCK (Depth 23 ft.)

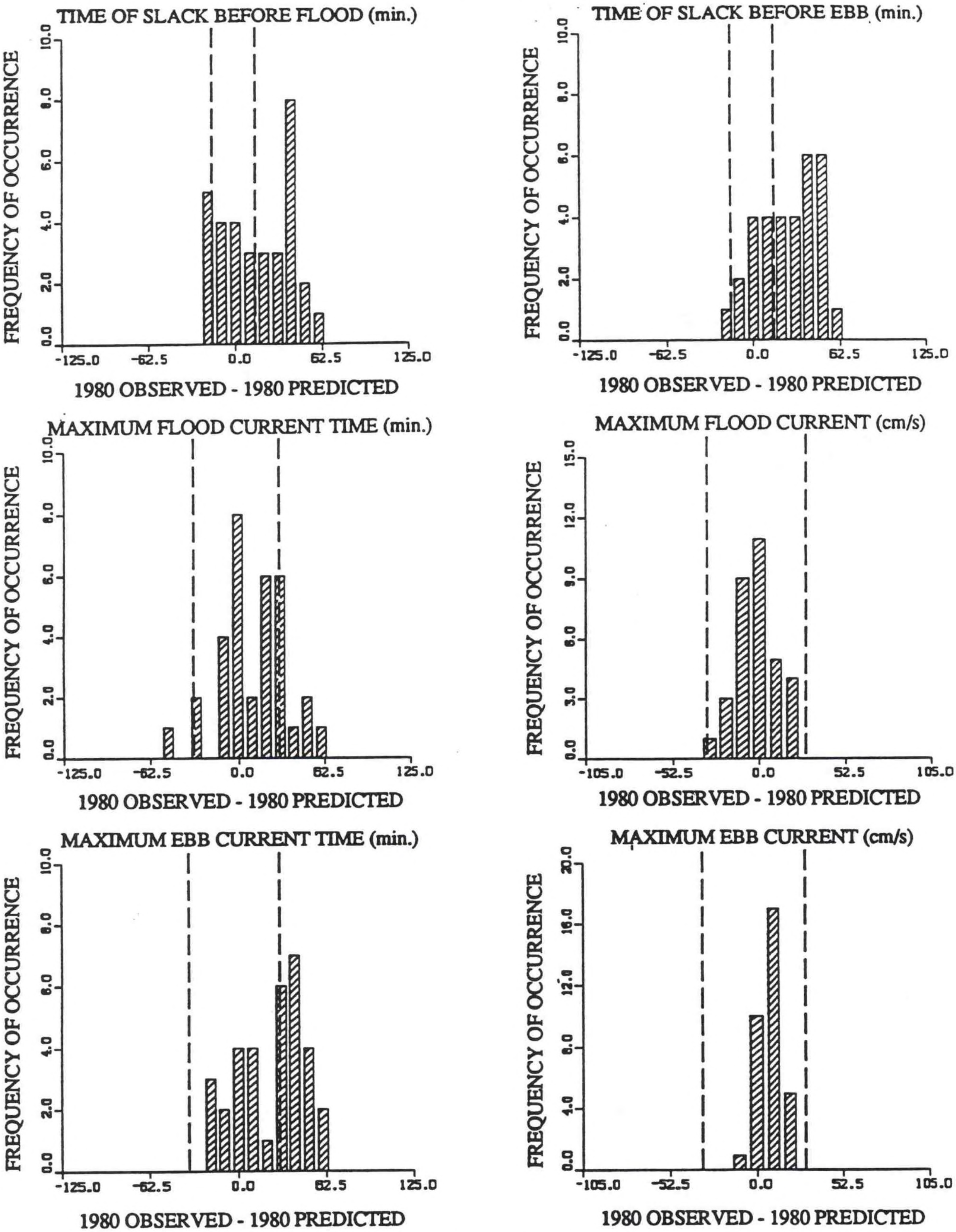

Figure 18. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Red Rock, station C216.

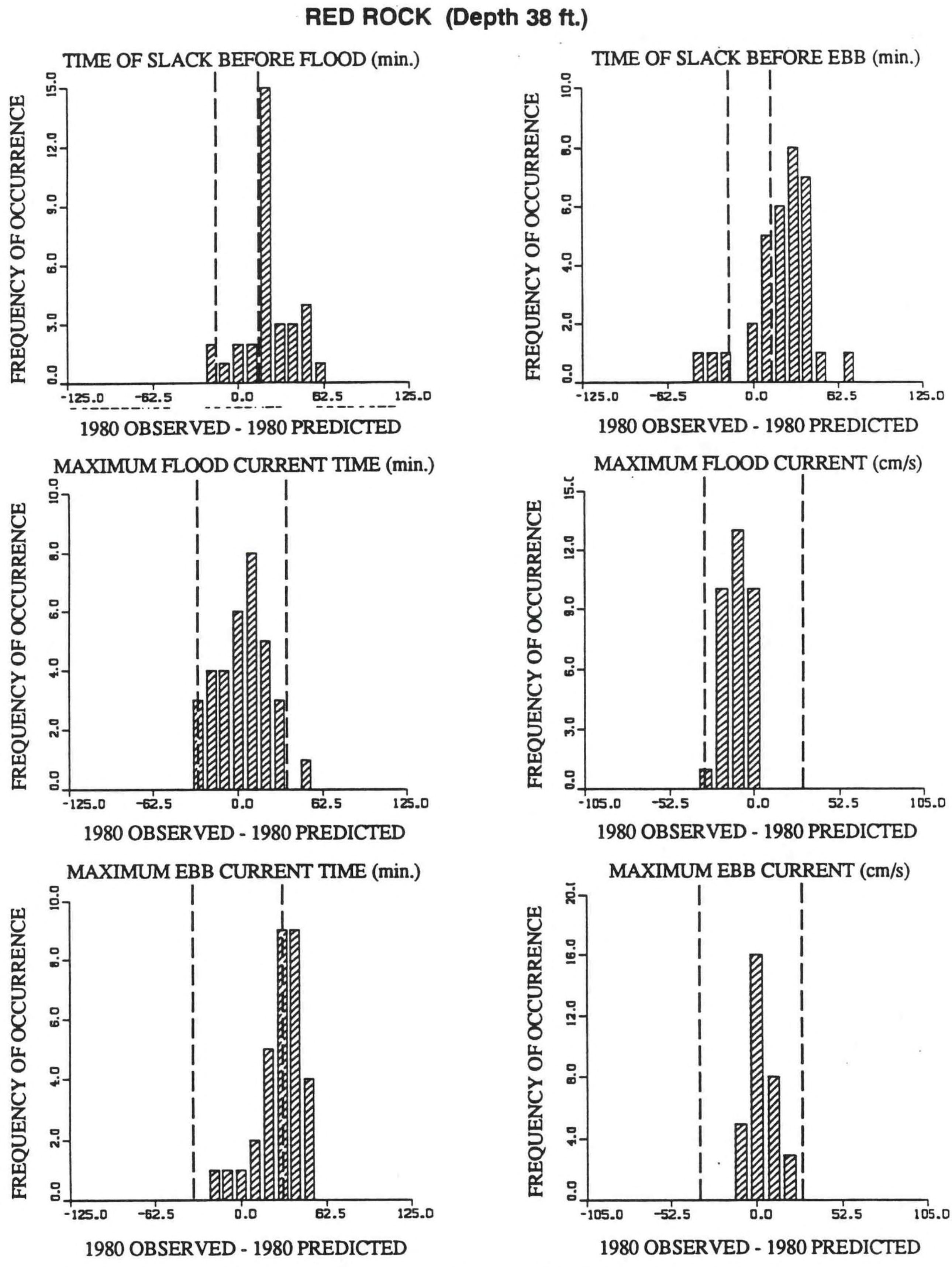

Figure 19. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Red Rock, station C216.

TABLE 12

DIFFERENCE STATISTICS FOR RED ROCK, DEPTH 38 FT.
1980 OBSERVED - 1980 PREDICTED
Beginning Date: 8/27/80 Ending Date: 9/15/80

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-32.0	-32.0	19.1	3.5	34.0	50.0	34
MFC Speed (cm/s)	-25.5	-25.5	8.0	-11.4	.7	.8	34
SBE Time (minutes)	-36.0	-36.0	22.5	22.1	48.0	73.0	33
MEC Time (minutes)	-18.0	-18.0	16.4	29.6	54.0	54.0	32
MEC Speed (cm/s)	-10.7	-10.7	7.4	3.0	15.9	16.3	32
SBF Time (minutes)	-20.0	-20.0	18.5	22.5	54.0	58.0	33

Yerba Buena Island

The QA miniproject ADCP at Yerba Buena Island was located at approximately the same distance from two NOAA Table 2 stations: No. 281, Yerba Buena Island, 0.61nmi southeast of, and No. 285, Yerba Buena Island, 0.6 mi south of. (See Table 2 of this report.) The predictions from No. 281, based on the 1979-80 survey data, are given for a depth of 5 ft (1.5m) above the bottom; the predictions for No. 285, based on 1952 survey data, are given for a depth of 8 ft (2.4m) below the chart datum.

QA Field Data: Prediction Station 281

Analysis of the data from QA station S10 indicates that the current is rotary in nature rather than reversing. Hence, the direction is nearly continuously turning. The predictions were based on the assumption that the current is reversing from a given flood to a given ebb direction.

Table 13 shows that all tidal current parameters fail to pass QA working guidelines except for maximum flood current speed. The slack times have large mean offsets which, if corrected for, would result in a better comparison (Figure 20). The distributions of differences of the other parameters indicate poor agreement between predictions and measurements as well as a wide spread in the differences, suggesting that wind effects are important and that a real-time system is required to provide adequate current information. The time series of differences is shown in Figure 21.

QA Field Data: Prediction Station 285

Table 14 shows that all tidal current parameters fail to pass QA uncertainty guidelines. Distributions of differences exhibit wide scatter, except for slack before ebb (Figure 22). Large differences between measured and predicted currents are seen in the time series (Figure 23). The wide spread of the distributions suggests, as did the comparison with station #281, that a real-time system is required.

YERBA BUENA ISLAND

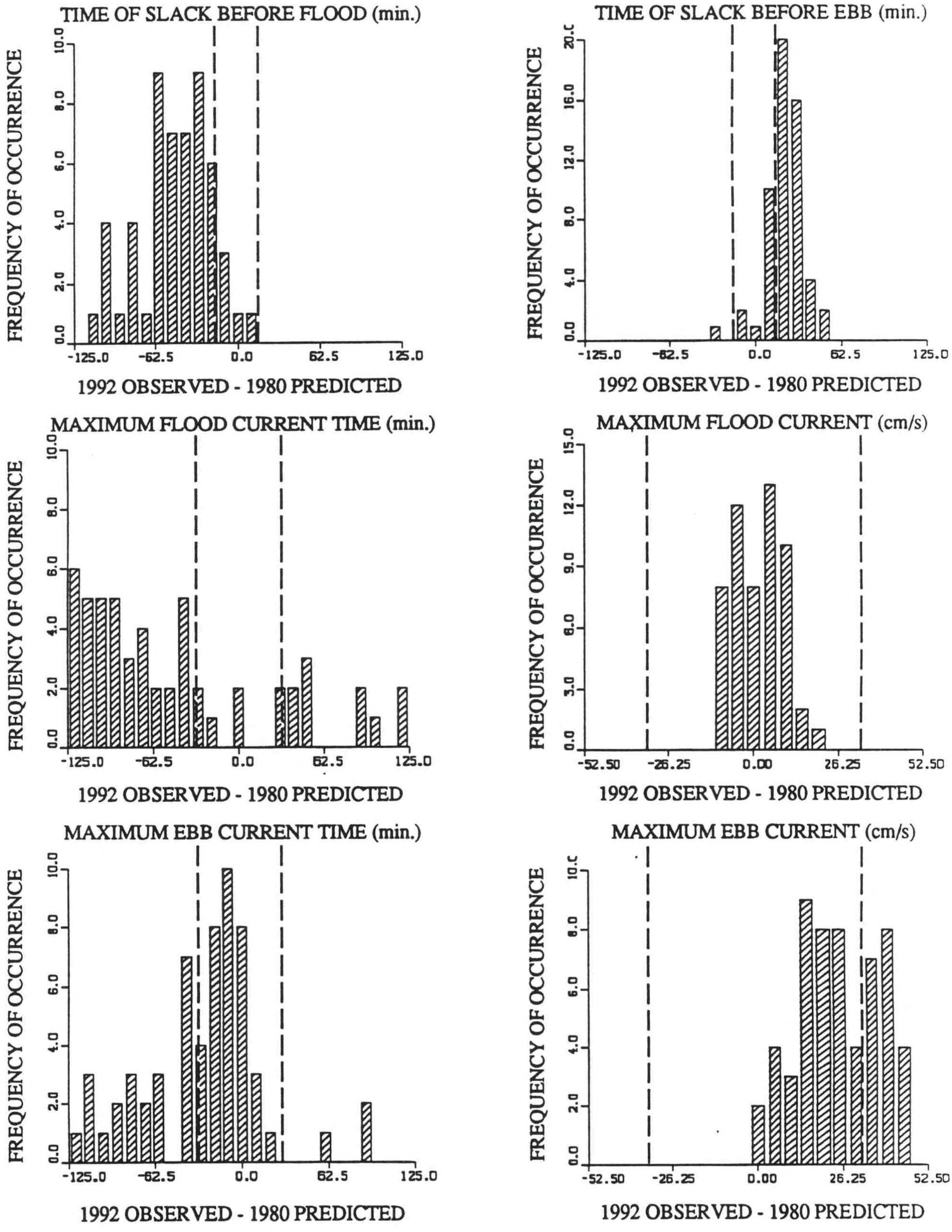

Figure 20. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Yerba Buena Island, station S10, using NOAA Table station #281 (1980).

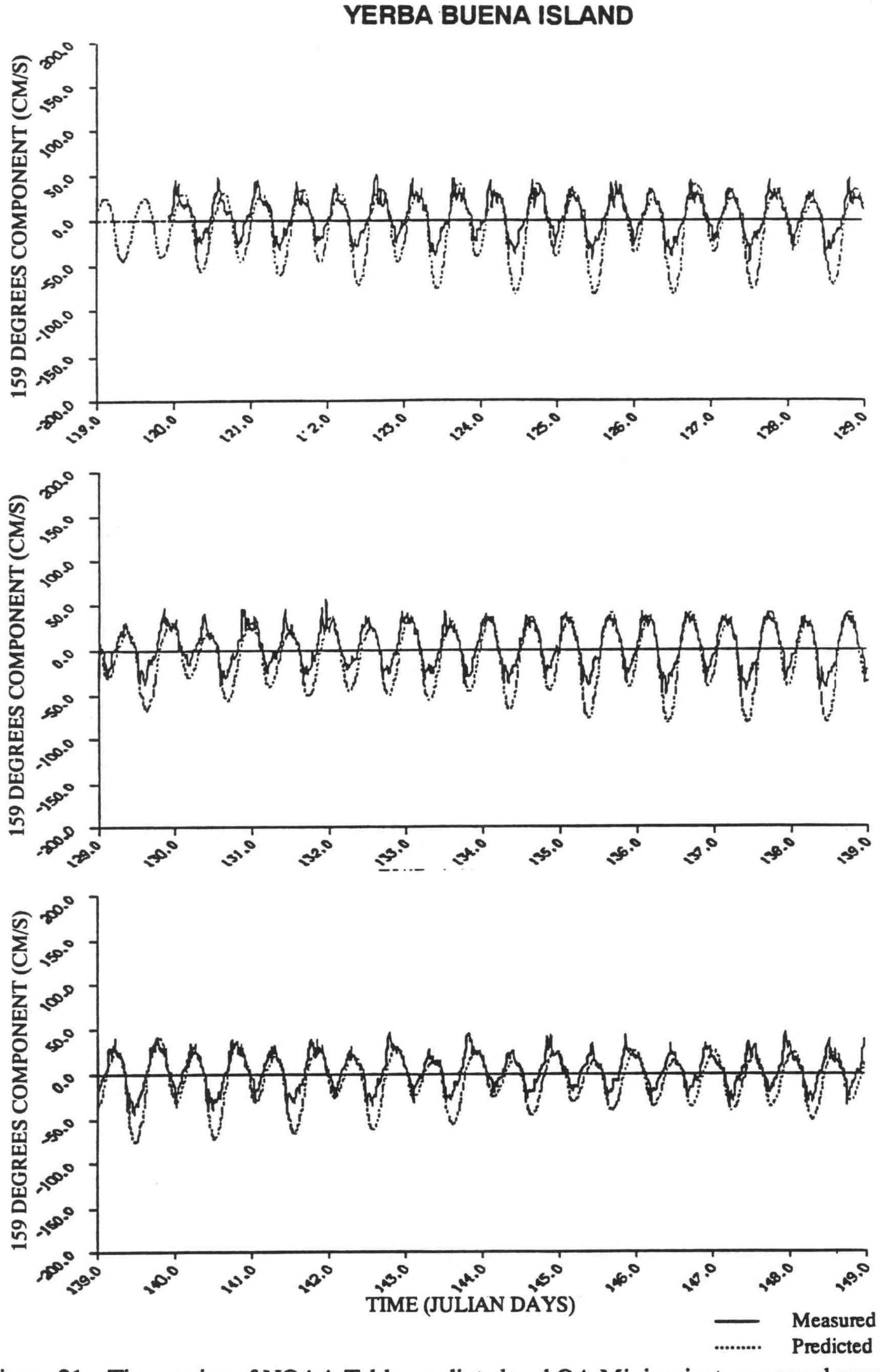

Figure 21. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Yerba Buena Island, station S10, using NOAA Table station #281.

YERBA BUENA ISLAND

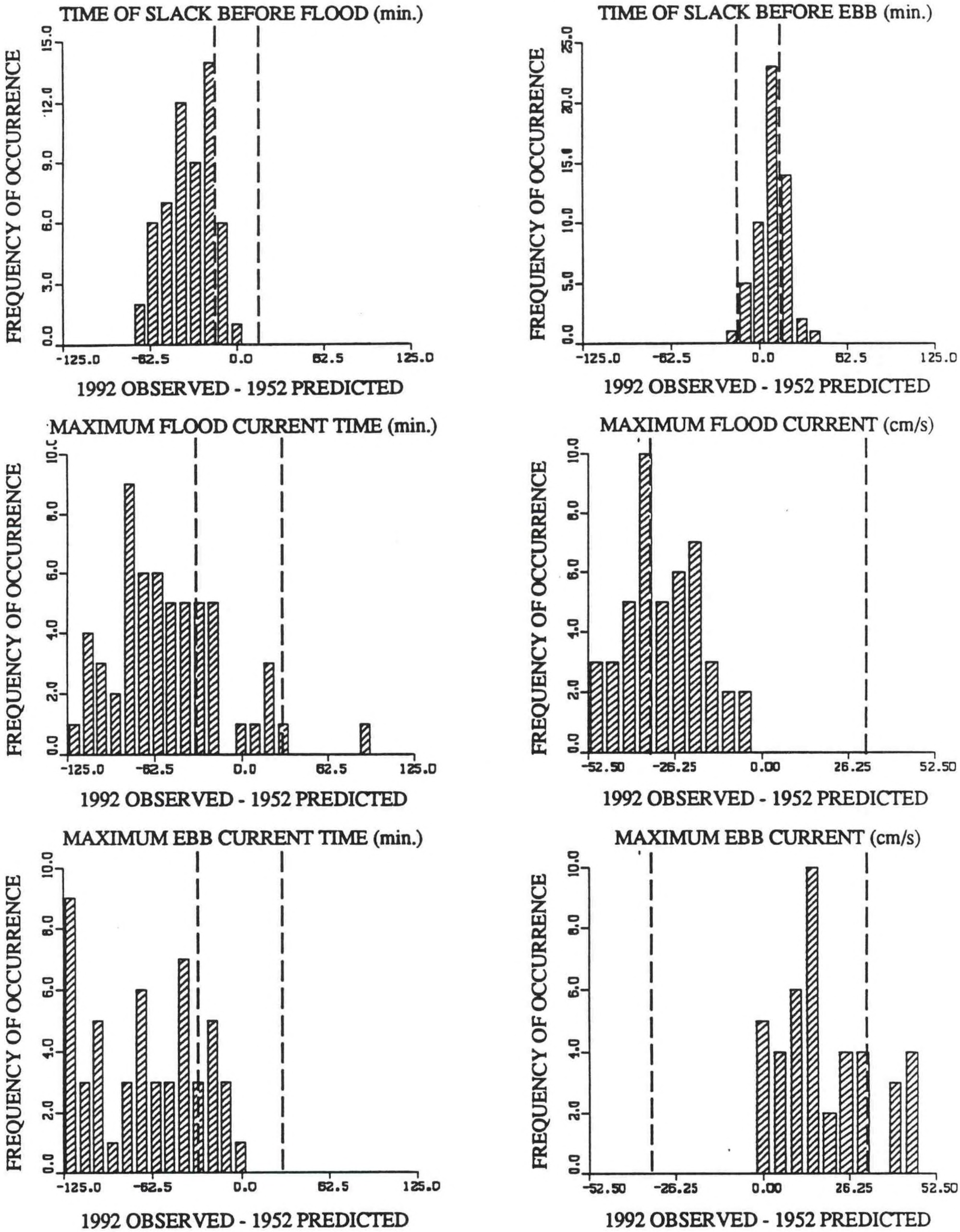

Figure 22. Histograms of differences between NOAA Table-predicted and 1992 QA Miniproject-measured tidal current parameters for Yerba Buena Island, station S10, using NOAA table station #285.

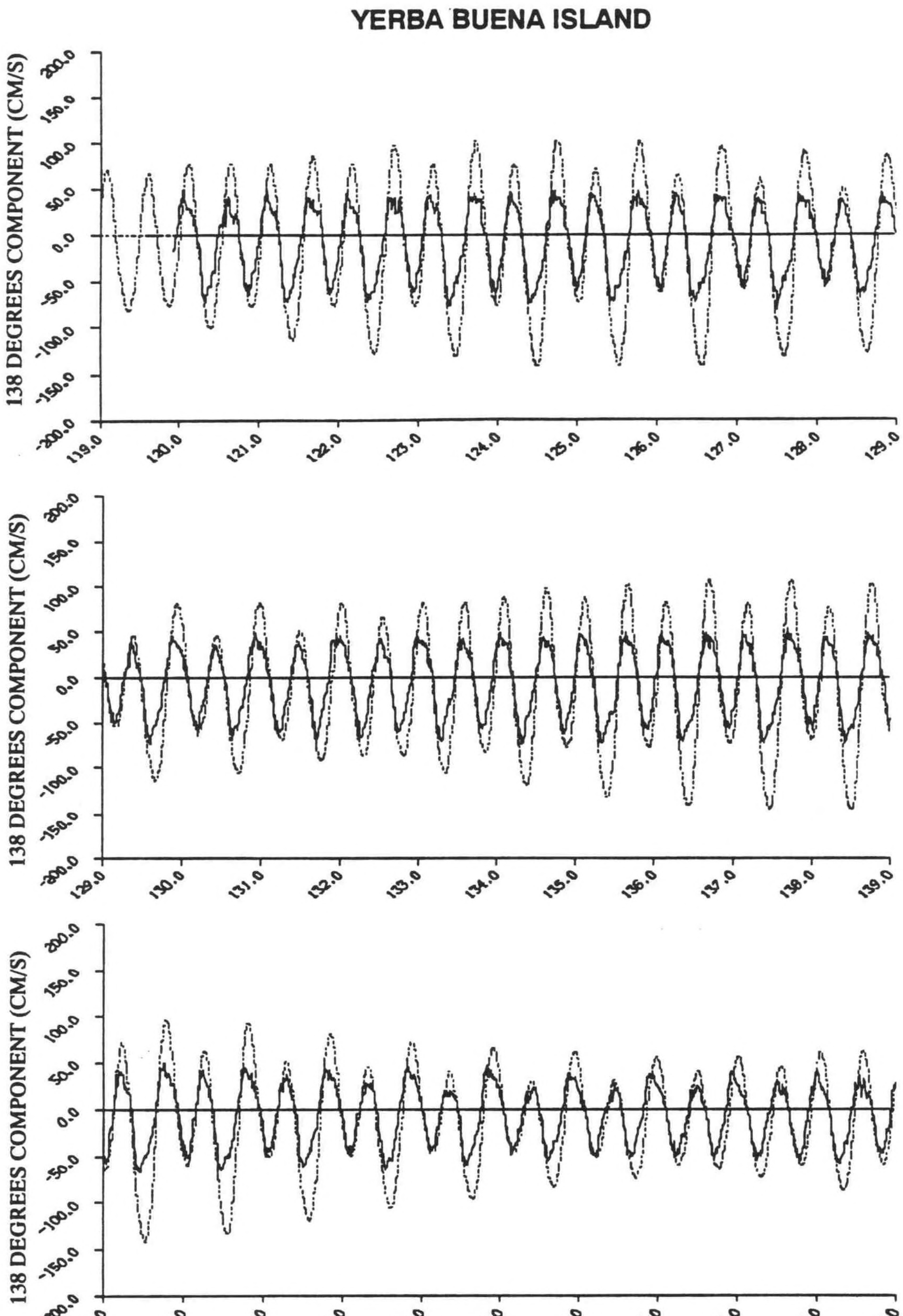

Figure 23. Time series of NOAA Table-predicted and QA Miniproject-measured currents for Yerba Buena Island, station S10, using NOAA Table station #285.

TABLE 13

DIFFERENCE STATISTICS FOR YERBA BUENA ISLAND ON STATION 281
1992 OBSERVED - 1980 PREDICTED
Beginning Date: 4/28/92 Ending Date: 5/28/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-120.0	-119.0	69.3	-45.1	104.0	120.0	54
MFC Speed (cm/s)	-12.3	-11.6	7.5	1.6	13.0	17.7	54
SBE Time (minutes)	-27.0	-5.0	12.7	21.5	38.0	50.0	56
MEC Time (minutes)	-118.0	-112.0	43.0	-27.2	65.0	94.0	59
MEC Speed (cm/s)	-1.1	2.3	13.9	25.6	46.9	62.2	59
SBF Time (minutes)	-108.0	-103.0	27.3	-47.0	-7.0	9.0	54

TABLE 14

DIFFERENCE STATISTICS FOR YERBA BUENA ISLAND ON STATION 285
1992 OBSERVED - 1952 PREDICTED
Beginning Date: 4/28/92 Ending Date: 5/28/92

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-118.0	-114.0	40.4	-52.0	23.0	89.0	58
MFC Speed (cm/s)	-62.6	-62.3	15.9	-35.7	-10.0	-6.5	58
SBE Time (minutes)	-16.0	-14.0	11.1	10.2	29.0	37.0	56
MEC Time (minutes)	-120.0	-120.0	37.3	-66.5	-11.0	4.0	52
MEC Speed (cm/s)	.1	.4	22.3	28.1	73.1	77.9	52
SBF Time (minutes)	-67.0	-66.0	16.8	-33.4	-10.0	2.0	57

1979-80 Survey Data

Difference statistics for the comparison of the 1980 data with NOAA Table predictions at station #281, Yerba Buena Island (0.3 nmi SE of), which were computed from these data show there is poor agreement between measured and predicted currents. This is also true for the 1992 QA-measured data (Table 15, Figure 24). This is largely the result of the fact that the current at this location is rotary, as shown by the 1992 data. The analysis on which the table predictions are based assumed the current was rectilinear, thus leading to large errors. This result, along with the large spread in the differences (slack before ebb of about one hour and maximum ebb current about two hours) adds support to our contention that this station must be re-occupied and that a PORTS be deployed in the general area of the central Bay.

YERBA BUENA ISLAND

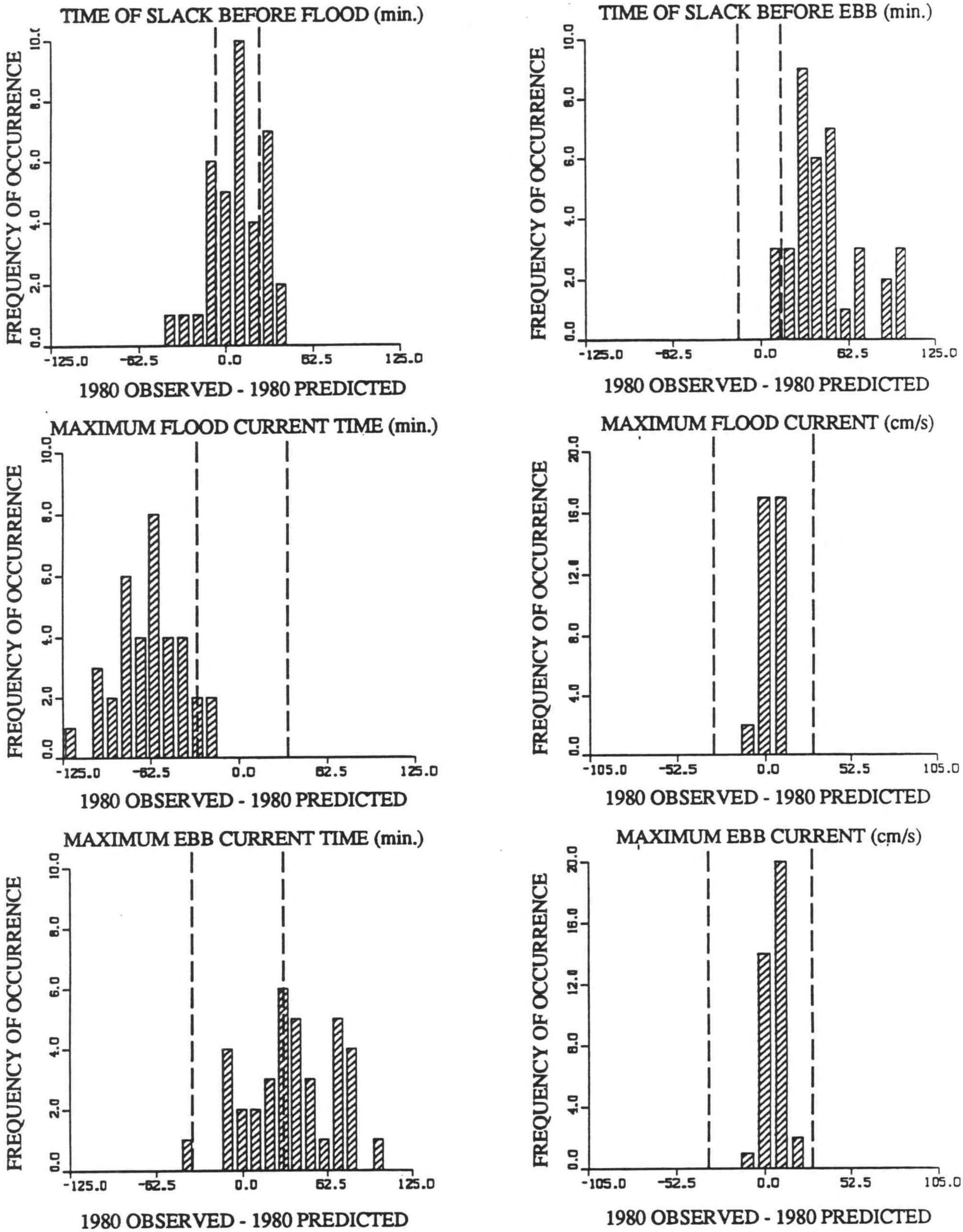

Figure 24. Histograms of differences between NOAA Table-predicted and 1980 survey-measured tidal current parameters for Yerba Buena Island, using NOAA Table station #281.

TABLE 15

DIFFERENCE STATISTICS FOR YERBA BUENA ISLAND ON STATION 281
1980 OBSERVED - 1980 PREDICTED
Beginning Date: 11/13/80 Ending Date: 12/3/80

NOS Parameter (units)	Minimum	Lower 90%	SD	Mean	Upper 90%	Maximum	No. pairs
MFC Time (minutes)	-119.0	-119.0	23.0	-64.1	-22.0	-20.0	36
MFC Speed (cm/s)	-7.3	-7.3	4.1	2.6	7.6	8.1	36
SBE Time (minutes)	7.0	7.0	24.5	46.6	100.0	101.0	37
MEC Time (minutes)	-38.0	-38.0	32.5	36.9	83.0	100.0	37
MEC Speed (cm/s)	-5.8	-5.8	5.7	7.5	5.9	17.9	37
SBF Time (minutes)	-37.0	-37.0	18.2	8.6	37.0	37.0	37

CONCLUSIONS

The conclusions based on the results of this study are as follows.

- Historical stations, such as Red Rock should be reanalyzed with state-of-the-art techniques to improve the quality of predictions.
- It is not evident that a complete new survey is necessary to provide significant improvement in tidal current predictions for San Francisco Bay. Differences in 1980-measured and predicted slack times indicate that the reference station at Carquinez Strait should be reoccupied. The wide spread in the differences suggests that a PORTS may be required in this location to provide improved information for piloting.
- The current at Yerba Buena Island is rotary, and is influenced significantly by non-tidal forces; most probably wind stress. The previous analysis of this data, which assumed a reversing tidal current is in error. This station requires complete revision, using new data. Based on the results of this analysis, NOAA Table station number 285 has been withdrawn.
- Since the QA miniproject sampled but a few of the total number of NOAA Table stations, it is reasonable to assume that other stations in the central Bay region may require new data and possibly PORTS.

RECOMMENDATIONS

The following actions are recommended to provide improved knowledge of currents:

- The reference stations for San Francisco Bay Entrance and Carquinez Strait should be re-established with ADCP deployments for at least 6 months.
- The 1979-80 survey data should be reanalyzed using new methods to upgrade predictions.
- Yerba Buena Island (NOAA Table station #281) should be reoccupied.
- A numerical hydrodynamic model should be applied making use of historical data determined to be valid, with the addition of data from the new reference and secondary stations to develop a new tide and tidal current forecast atlas.
- Real-time current and wind measuring systems (PORTS) should be deployed in the Central Bay region, probably in the vicinity of the Yerba Buena Island and at other locations to be determined by a more complete study. Carquinez Strait should be evaluated further as a possible site for a PORTS.
- The fixed current measurements should be supplemented by towed ADCP measurements to determine spatial scales of variability, to locate areas where new stations and PORTS are needed, and to provide optimum locations for the PORTS ADCP.
- NOS tidal current predictions should be revised based on model analysis incorporating data from the 1979-80 survey plus a limited number of re-occupied stations, including new reference stations at Golden Gate Bridge and Carquinez Strait. A new model-based tidal current atlas should be issued, along with digital predictions of current velocity in place of NOAA Table 2 station predictions.

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ACKNOWLEDGEMENTS

Many elements of the maritime community in San Francisco Bay were essential to this project. The U.S. Coast Guard Group San Francisco provided exemplary ship and logistical support. We are grateful to all men and officers who contributed to the project.

BMC C. Curtin and the Aids to Navigation team (ATON) based at Yerba Buena Island deserve special thanks. Coast Guard elements from Station Mare Island and from Air Station San Francisco also were contributors to our project. U.S. Coast Guard Personnel aboard Buoy Tender 55101 who provided ship support for all deployments and retrievals are particularly commended. The officers and crew of the USCG BLACKHAW who deployed two platforms also deserve recognition.

Diving services were provided by U.S. Navy divers based at the Shore Intermediate Maintenance Activity (SIMA) aboard NAS Alameda. The flexibility and professionalism of the SIMA divers were commendable. They were essential to our mission. BMCS G. Crow and ENC B. Edgley who coordinated our efforts are thanked.

The USCG Marine Safety Office at Coast Guard Island, in particular QMC C. Young, provided advice and encouragement. Capt C. Bowler of the San Francisco Bar Pilots Association provided assistance in many ways and was a driving force in initiating the miniproject.

The National Weather Service (NWS) in Redwood City, CA, provided meteorological data in support of this QA. Roger Williams, Deputy Meteorologist in Charge, met with the NOAA QA team and recommended stations and data formats for our use. He provided access to station data in near-real time during the course of the miniproject. A computer program to access NWS data by modem on a daily basis was written by Lawrence Adkins.

NOS personnel—Dan Torres and Jim Bascom performed the data processing and data quality control and produced the statistical tables and computer graphics. Dan provided many innovative suggestions for improving the analysis and the graphics. The NOS field party consisted of LTJG Fran Nowadly, Dan Torres, and Jim Bascom. Technical editing was performed by Patrick McHugh. Desktop publishing was performed by Brenda Via and Karen Earwaker, who also provided many helpful suggestions. Ulysses Harris coordinated shipping and arranged for equipment to arrive on schedule on very short notice.