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July 1995

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Waterways Experiment Station

Monitoring of the Yaquina Bay Entrance North Jetty at Newport, Oregon; Summary and Results

by *Steven A. Hughes, Terri L. Prickett,*
Michael W. Tubman, William D. Corson

Prepared for Headquarters, U.S. Army Corps of Engineers

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Final report

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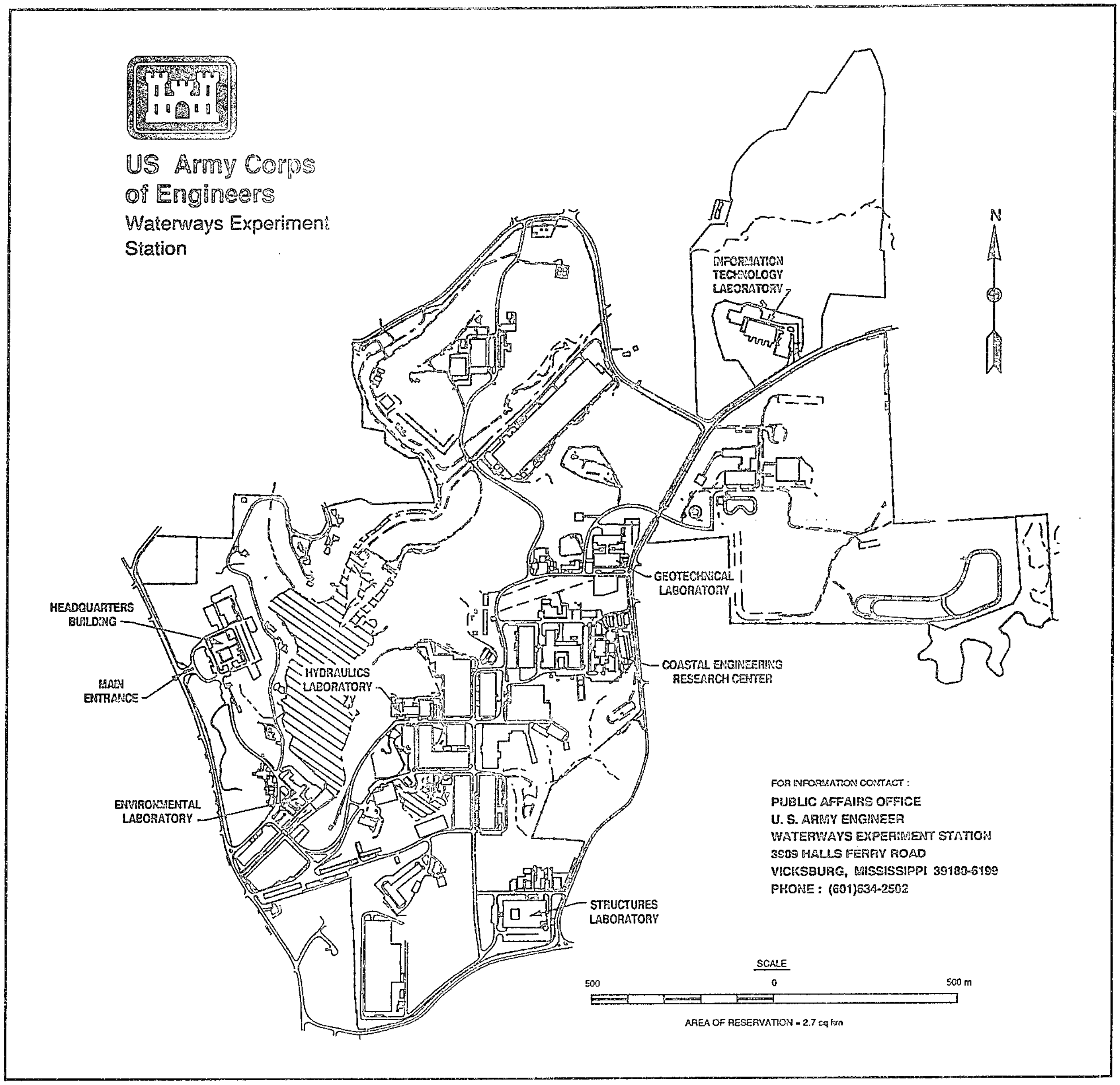

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Preface

This report was authorized by the Operations and Maintenance Division, Headquarters, U.S. Army Corps of Engineers (HQUSACE). It is a product of the U.S. Army Engineer Waterways Experiment Station (WES) Coastal Engineering Research Center (CERC) Monitoring Completed Coastal Projects (MCCP) Program under the "Monitoring of North Jetty at Yaquina Bay, Oregon," Work Unit 22117. Messrs. John H. Lockhart, Jr., John G. Housley, and Barry W. Holliday were HQUSACE Technical Monitors. The objectives of the monitoring efforts were to determine what mechanisms were responsible for recurring damage to the north jetty, to obtain data for use in possible future studies in support of a permanent repair to the north jetty, and to improve the Corps' design and construction capability for similar harsh environments.

Monitoring of the Yaquina Bay north jetty was conducted during the period October 1988 through September 1994 by CERC under the general direction of Dr. James R. Houston and Mr. Charles C. Calhoun, Jr., Director and Assistant Director, CERC, respectively; and under the direct supervision of Messrs. C. E. Chatham, Chief, Wave Dynamics Division (WDD), Thomas W. Richardson, Chief, Engineering Development Division, and William L. Preslan, Chief, Prototype Measurement and Analysis Branch (PMAB). Work Unit oversight was provided by Ms. Carolyn M. Holmes, MCCP Program Manager.

Between October 1988 and June 1990, the Yaquina Bay north jetty monitoring work unit was directed by Mr. William L. Preslan, PMAB; and from July 1990 to project completion, the overall monitoring effort was directed by Dr. Steven A. Hughes, WDD, who also authored portions of the final report. The report was coauthored by Ms. Terri L. Prickett, PMAB, (Geophysical Survey chapter); Michael W. Tubman, PMAB, (Side-Scan Sonar chapter); and William D. Corson, PMAB, (Wave Climatology chapter). Technical review of the report was provided by Mr. William L. Preslan, PMAB, and Mr. Kenneth R. Soderlind, U.S. Army Engineer District, Portland (NPP).

Large projects, such as the monitoring of Yaquina Bay north jetty, require dedicated efforts from many highly skilled professionals in order to assure that the work is performed correctly and that accurate results are obtained. The following CERC engineers and scientists were instrumental in the success of this project: Mr. Jonathan W. Lott, PMAB, who developed scopes of work for the photogrammetry, Acoustic Doppler current profiler, (ADCP), and (SEABAT) efforts, helped with the first workshop, supervised several data acquisition exercises in the field, and served as CERC point of contact on several of the efforts; Mr. Michael W. Tubman, PMAB, who interpreted the side-scan sonar data; Mr. William E. Grogg, PMAB, who directed the installation of the directional wave gauges; Mrs. Margaret Sabol, PMAB, who prepared all the plots, tables, and figures of the measured wave data; Mr. Jeffrey A. Melby, who helped prepare the minutes from the first workshop and organized the wave hindcasting; and Messrs. Michael J. Briggs, Robert D. Carver, Leland Hennington, and Raymond Reed, WDD, who planned and conducted the physical model laboratory experiments.

During the course of the study, Ms. Laura Hicks and Mr. Kenneth R. Soderlind, NPP, provided liaison between NPP and WES. Mr. Robert C. Peak, Chief, and Messrs. James D. Francis and Gregg M. Bertrand, NPP Cartography and Remote Sensing Branch, managed the contract for aerial photography and performed the photogrammetry analysis of the north jetty photographs.

This report was reviewed by Mr. William L. Preslan, PMAB, Mr. Kenneth R. Soderlind, NPP, and Ms. Heidi Moritz, NPP.

Dr. Robert W. Whalin was Director of WES at the time of publication of this report. COL Bruce K. Howard, EN, was Commander.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.028317	cubic meters
cubic inches	16.38706	cubic centimeters
cubic yards	0.7645549	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
knots	0.514444	meters per second
long tons	1.0160	tonnes
miles (U.S. nautical)	1.852	kilometers
miles (U.S. statute)	1.6093	kilometers
miles per hour (mph)	0.4470	meters per second
pounds (mass)	0.4535924	kilograms
square miles	2.590	square kilometers

1 Introduction

Many coastal navigation entrance channels are protected by one or two shore-connected jetties extending seaward from the shore and typically aligned parallel to the navigation channel. These coastal structures serve multiple purposes: the jetties direct and confine the tidal and/or river flow to help reduce channel shoaling, they reduce the amount of longshore-moving sand that enters the channel, and they protect the channel from severe wave action. Without these protective jetty systems, navigating coastal entrances would be hazardous, and in some instances, vessels would be lost.

Most jetties on the open coast are of rubble-mound construction with an inner core of smaller rock rubble protected by two or more outer layers of very large stones or concrete armor units. Generally, the size of the armor stone needed to prevent movement and subsequent unraveling of the rubble-mound structure increases with the severity of the expected wave climate. Consequently, development of the Nation's jettied entrances in high wave energy environments historically progressed with the capability to quarry, move, and place larger and larger armor stone.

Problem at the Yaquina Bay North Jetty

Original development of the jetty system protecting the entrance to Yaquina Bay at Newport, Oregon, was authorized by Congress in 1880, and the project was initiated in 1885 with construction of a jetty structure situated on the south side of the navigation channel. Shortly thereafter, construction began on a parallel jetty on the north side of the channel. Over the next 80 years, both jetties underwent a series of improvements and extensions until finally reaching their present authorized lengths in 1966 (north jetty) and 1972 (south jetty) as shown on Figure 1. (See Chapter 2 for a thorough historical overview of the jetty system.) In this configuration the seawardmost tip of the north jetty intersected a shore-parallel basaltic reef located approximately 1,370 m (4,500 ft) from the shoreline.

Almost immediately after completion of the 1966 north jetty extension, the seaward tip of the north jetty began to unravel under the fury of winter

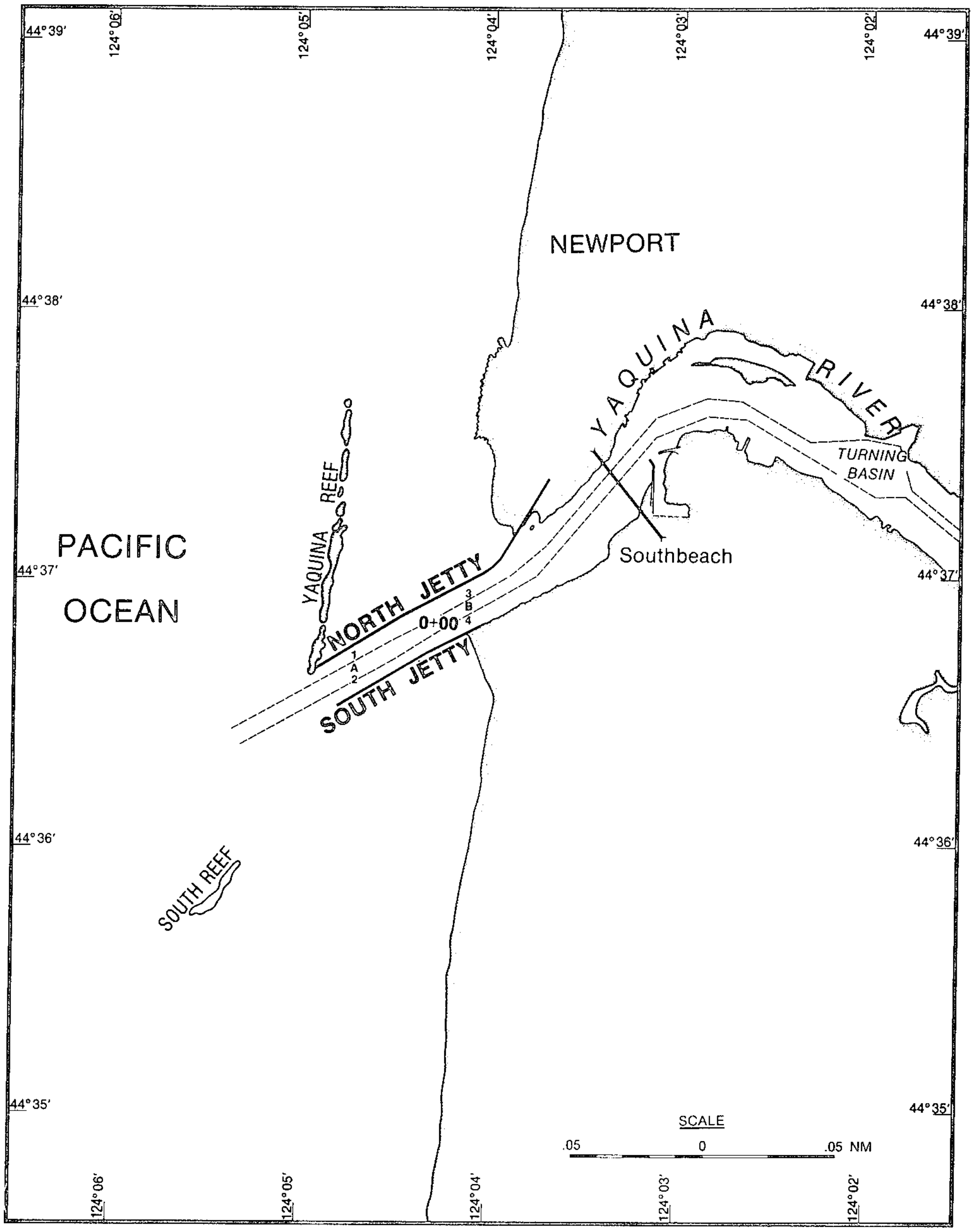

Figure 1. Yaquina Bay navigation channel jetty system[1]

storms. By 1970 about 95 m (310 ft) had been lost from the tip of the north jetty as waves "beat the structure down below water level." The partially damaged structure then appeared to reach a somewhat more stable configuration with minimal losses of jetty length occurring over the next several years.

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[1] A table of factors for converting non-SI units of measurement to SI units is presented on page xiii.

The north jetty was rebuilt to its authorized length in 1978, and it suffered the same fate over the next several winter storm seasons. By 1988 the structure had lost approximately 137 m (450 ft) from the seawardmost tip of the jetty. Meanwhile, the south jetty at Yaquina Bay, which was lengthened in 1972, did not suffer any damage despite being of similar construction, situated at similar depth, and presumably exposed to similar wave conditions.

The most recent rehabilitation of the Yaquina Bay north jetty was completed in 1988 with rebuilding of the jetty to its authorized length using larger armor stone. This rehabilitation fared better than its predecessors; however, armor stone began to disappear from an area on the north side of the north jetty, approximately 40 m (130 ft) landward from the tip forming a "notch" in the above-water portion of the jetty. Over the next several years, winter storm waves removed additional armor stone from the notch and began to erode the seawardmost tip of the jetty. The evolution of the above-water portion of the jetty tip and notch area that occurred between 1989 and 1993 is shown in Figure 2.

Monitoring Program at Yaquina Bay North Jetty

The U.S. Army Corps of Engineers recognized the benefits to be gained through monitoring the performance of coastal structures, and in 1981 the Corps initiated the national Monitoring of Completed Coastal Projects (MCCP) Program funded through its Operations and Maintenance Division. The purpose of the MCCP program is to determine how well projects are accomplishing their designed purpose and how well they stand up to the harsh physical environment.

The Portland District (NPP) of the Corps of Engineers nominated the Yaquina Bay north jetty as an MCCP monitoring site shortly after completion of the 1988 rehabilitation, and in 1988 the U.S. Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) began a 6-year monitoring effort at the Yaquina Bay north jetty.

Purpose of the monitoring project

Originally, damage that occurred after the north jetty was extended out to the offshore reef in 1966 was thought to have been caused by increased water currents resulting from the proximity of the jetty tip to the reef. It was hypothesized that these currents produced scour at the toe of the structure, thus causing the armor layer to slough off into the scour hole. Under this scenario it was concluded that the remains of the degraded tip of the structure would serve as a stable foundation for the repair performed in 1978. This premise was supported by experience at other jetty structures which had undergone similar rehabilitation. However, the rehabilitated north jetty at Yaquina Bay proved to be unstable, which led to a widening of the possible damage hypotheses to include foundation failure, wave focusing by local

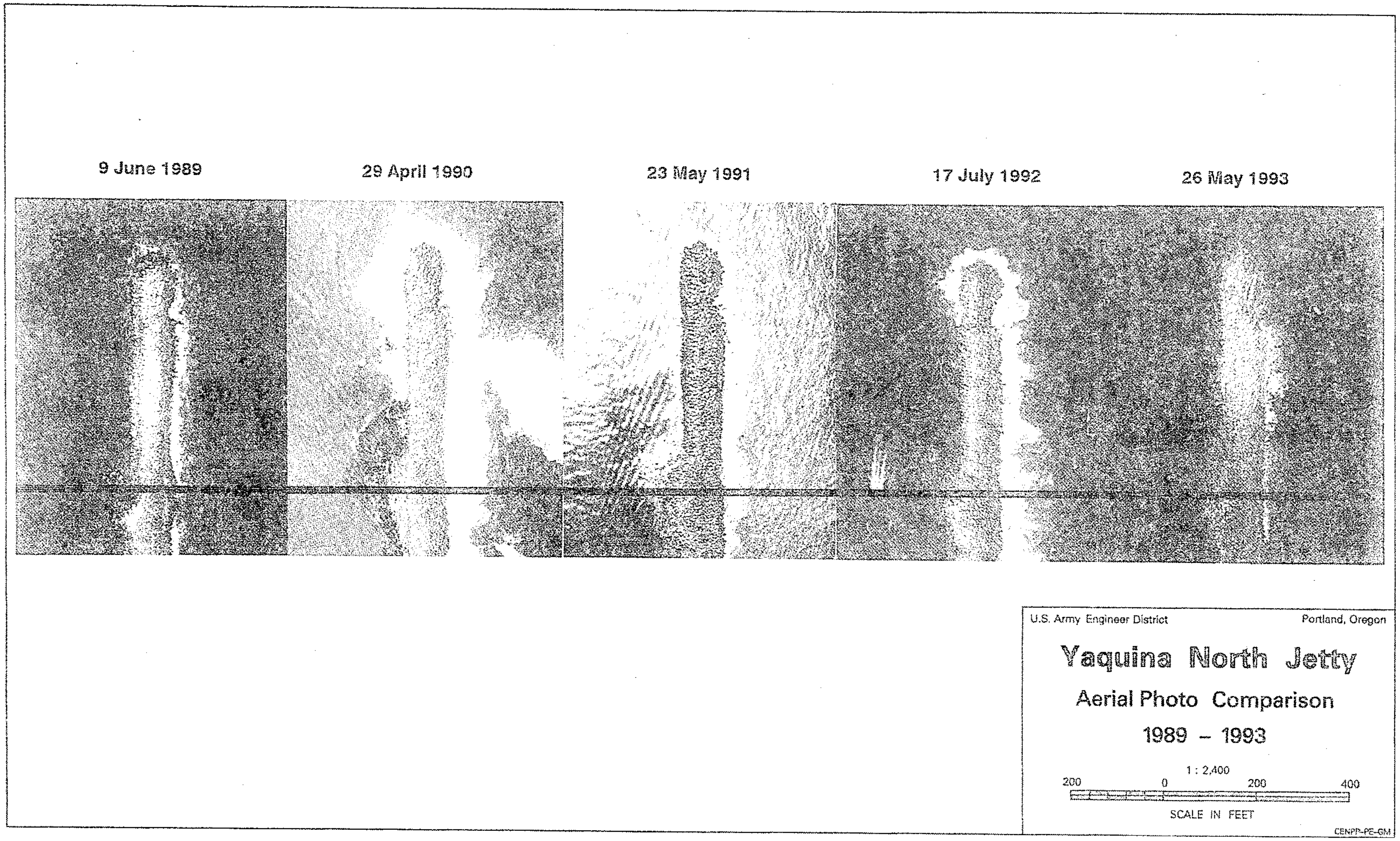

Figure 2. Yaquina Bay north jetty aerial photographs, 1989-1993

bathymetry, waves larger than the anticipated design waves, and wave/current interactions.

The main purpose of the Yaquina MCCP project was *to determine the likely cause for chronic damage experienced at the Yaquina Bay north jetty*. The MCCP project also offered the potential for increasing understanding of failure mechanisms associated with rubble-mound structures and for improving methods of monitoring coastal structure performance in hostile environments.

Monitoring study objectives

There were three stated objectives of the Yaquina Bay north jetty MCCP study, as follows:

a. Determine what mechanisms were responsible for damage that occurred at the Yaquina Bay north jetty.

b. Use the study information to improve Corps of Engineers' design and construction capability for similar harsh environments.

c. Obtain information for use in the design of a permanent repair of the north jetty at Yaquina Bay.

The third objective (item c) was added after it was discovered that a "notch" had started to form on the north side of the jetty near the tip, indicating that a future repair might be required.

Elements of the monitoring study

The MCCP monitoring program, conducted as a joint effort of CERC and NPP, began in October 1988 and extended 6 years until September 1994. Monitoring activities included the following principal elements:

a. Compilation of a thorough historical review of the Yaquina Bay entrance system.

b. Periodic fixed-wing and helicopter aerial photography and photogrammetric analyses.

c. Visual and side-scan sonar inspection of the north jetty.

d. Current velocity profiling and multibeam sonar scanning of the underwater portion of the north jetty and its intersection with the Yaquina Reef.

e. Collection of offshore and nearshore wave measurements.

f. Comprehensive bathymetric survey.

g. Geophysical investigation of the bottom and subbottom geologic composition.

h. Physical modeling efforts to evaluate various damage hypotheses.

i. Establishment of a digital database at the Portland District office.

j. Periodic workshops where Corps personnel and outside experts evaluated interim monitoring results and suggested viable damage hypotheses.

Report Contents and Organization

Chapter 2 presents a historical summary of the jetty system at Yaquina Bay. Covered topics include a summary of available historic data pertaining to the project and the chronological progression of jetty construction and repair activities.

Chapter 3 overviews the MCCP project elements and lists the important aspects of each element. This chapter is intended to give the reader a sufficient understanding of the monitoring program as a whole before delving into the details and results presented in subsequent chapters.

Chapter 4 presents summary results and statistics from offshore and nearshore wave measurements collected during the monitoring program. Directional and nondirectional results were obtained offshore in deep water and nearshore at different times during the project. Chronological and summary details of the wave measurements are presented in Appendices A-F.

Chapter 5 discusses results of a comprehensive geophysical and bathymetric survey that was centered about the Yaquina Bay north jetty. Results include charts indicating the depth to bedrock, contours of unconsolidated sediments, and detailed bottom bathymetric contours.

Chapter 6 gives an analysis of side-scan sonar images and echosounder traces obtained during the geophysical survey. This analysis established the extent of the north jetty toe and its position relative to Yaquina Reef.

Chapter 7 presents the results from a thorough photogrammetric analysis of aerial photographs of the north jetty obtained over a 5-year period. Analysis products included a stereo model of the north jetty, jetty elevation contours, yearly changes in jetty contours, selected jetty cross sections, and individual armor stone movement.

Chapter 8 describes two small-scale physical models that were conducted to test several jetty damage hypotheses. A fixed-bed model of the north jetty investigated the possibility that damage was due to armor instability caused by severe wave action. A movable-bed model investigated instability effects due to toe scour and the interaction of waves and seaward-flowing currents.

Chapter 9 summarizes two technical workshops conducted early in the monitoring program. These workshops drew together coastal experts to review the monitoring program and results, to suggest viable damage hypotheses, and to recommend monitoring strategies.

Chapter 10 contains results of current profiling measurements obtained in the vicinity of the north jetty and underwater profiles of the north jetty and Yaquina Reef as determined using a multibeam sonar.

Chapter 11 summarizes the monitoring study and results, and presents conclusions drawn from the monitoring.

2 Yaquina Bay Project History

Much of the material contained in this chapter was extracted or synthesized from a draft historical summary report prepared by the Portland District of the Corps of Engineers as part of the MCCP monitoring study (U.S. Army Engineer District, Portland 1989). Other references are cited in the text. Metric quantities were converted from quantities given in English units in the original source documents.

Location and Site Description

Yaquina Bay is a tidal estuary located on the Oregon coast approximately 177 km (110 miles) south of the mouth of the Columbia River as shown on Figure 3. Yaquina Bay is fed by the Yaquina River, which delivers fresh water inflow to the bay as it drains a predominantly forested watershed of approximately 630 km^2 (250 sq miles).

The present Corps of Engineers navigation project at Yaquina Bay consists of a maintained navigation channel protected by two parallel rubble-mound breakwaters separated by a distance of about 305 m (1,000 ft) as illustrated on Figure 4. The 122-m-wide, 12-m-deep (400-ft-wide, 40-ft-deep) entrance channel extends from deep water to a point about 580 m (1,900 ft) landward of the jetty system seaward terminus, at which point the channel uniformly decreases to 9-m depth and 91-m width (30-ft depth and 300-ft width). Additional Federal interests include channel maintenance and project elements in Yaquina Bay.

The two jetties, entrance channel, and other project features were constructed to provide safe navigation and access for vessels serving the Yaquina River ports of Newport in Yaquina Bay and Toledo, Oregon, located about 23 km (14 miles) upriver. Primary products presently handled by the ports include lumber, pulp, paperboard, logs, petroleum, and fresh seafood.

Portland District reported that, on average, two deep-draft ships navigate the Yaquina Bay entrance each month, and the average tonnage of waterborne commerce moving through the entrance was approximately 211,540 tonnes

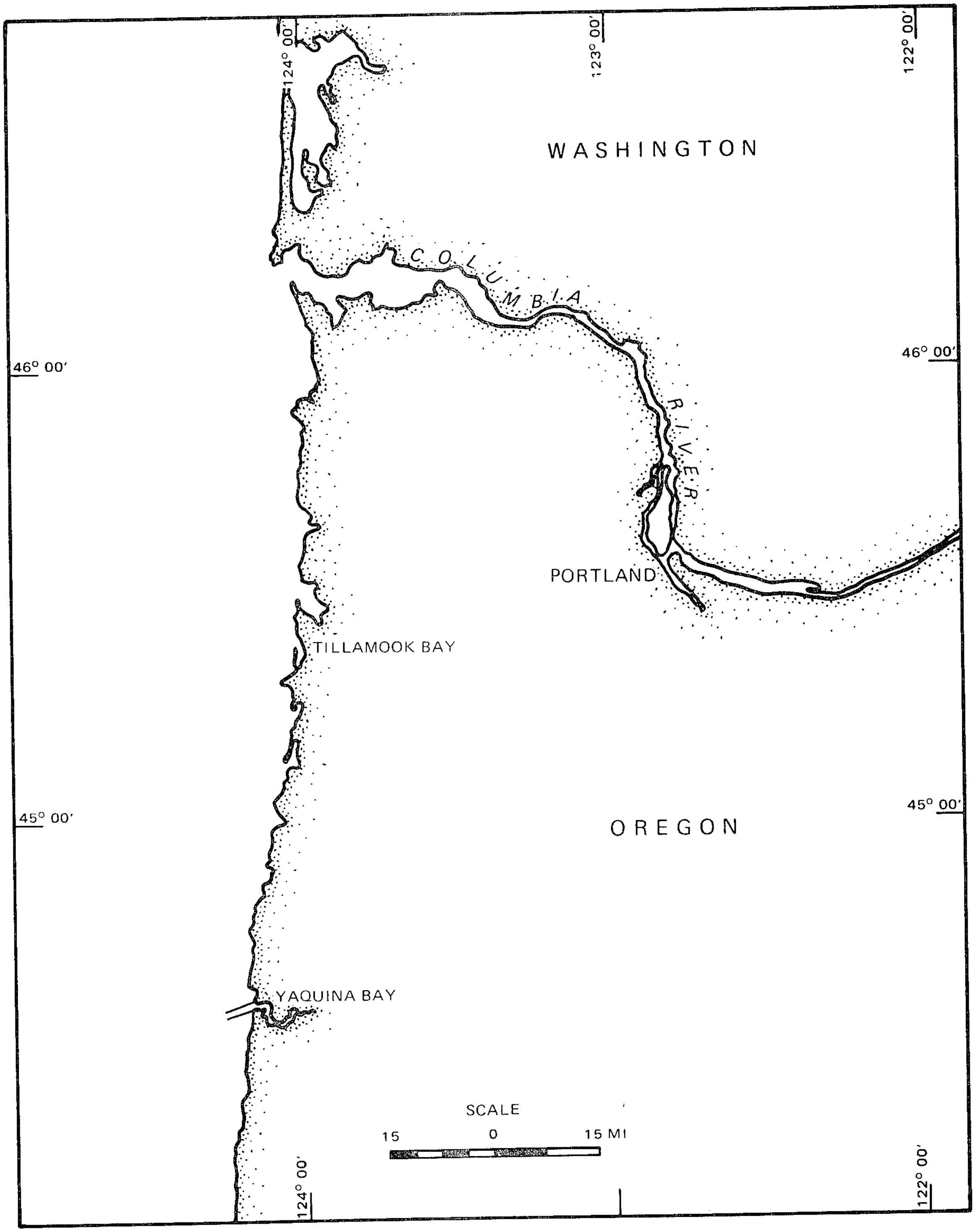

Figure 3. Yaquina Bay area map

(208,195 long tons) per year for the years 1978 to 1982 (U.S. Army Engineer District, Portland 1987). It was also reported that approximately

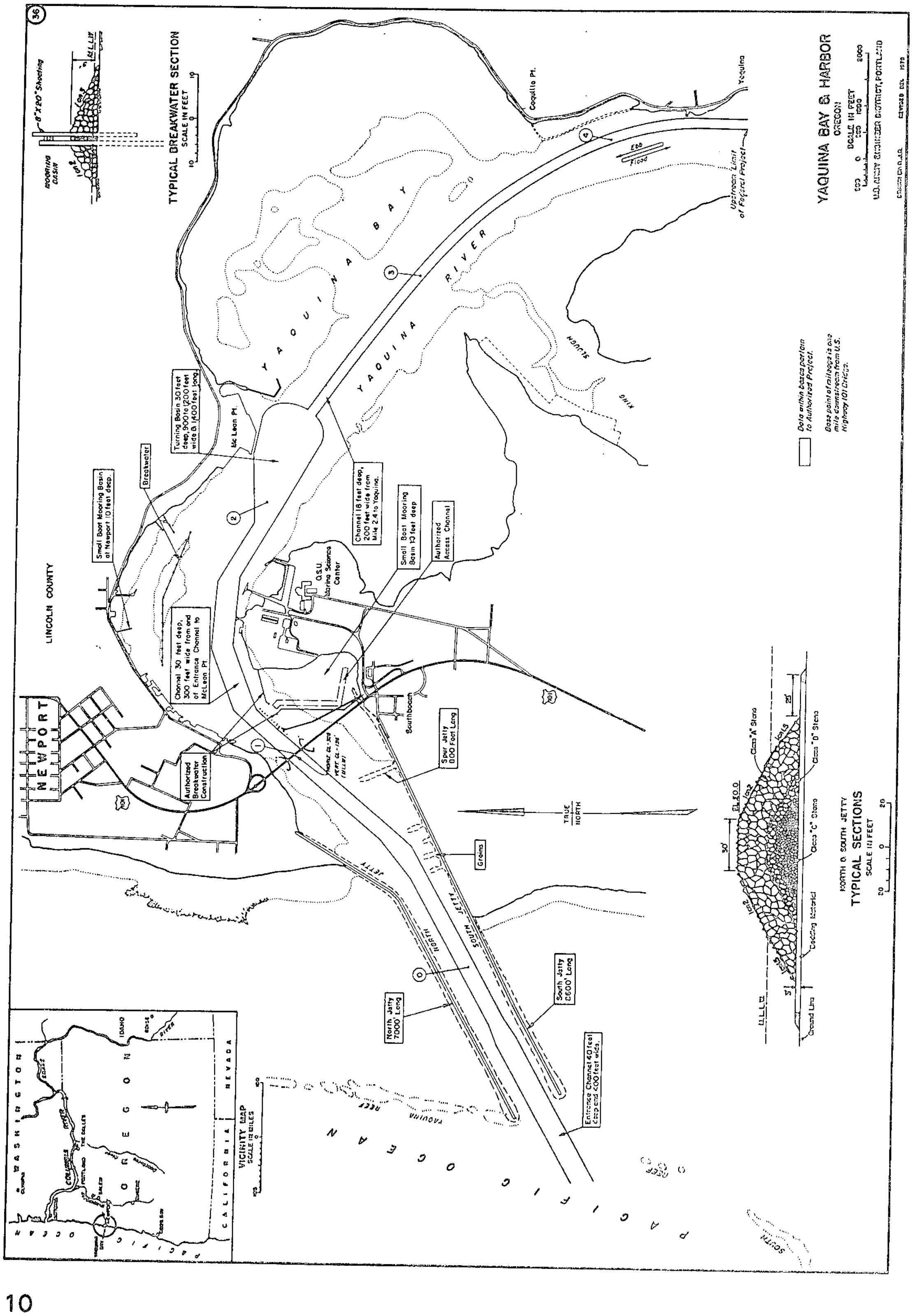

Figure 4. Yaquina Bay navigation project

350 commercial fishing vessels and 450 recreational boats are moored in Yaquina Bay during peak season.

Commercial fishing vessels transit the Yaquina Bay entrance all seasons of the year, although rough sea conditions during the winter months limit traffic at times. The total number of vessel arrivals and departures has been increasing in recent years for the ocean commercial fishing fleet, as well as for charter and recreational vessels. For 1992, the Port of Newport estimated arrivals and departures of more than 17,000 for the ocean commercial fishing fleet, 5,000 for the charter fleet, and about 30,000 for recreational vessels.

Early Project History (1879 - 1920)

Vessels navigating the entrance to Yaquina Bay have always had to contend with wave conditions influenced by the presence of a narrow basaltic offshore reef. The Yaquina Reef lies approximately 1,070 m (3,500 ft) seaward of river mile 0.0 (see Figure 1) and extends from a point about 760 m (2,500 ft) south of the present-day channel, northward for about 27 km (17 miles) (Grace and Dubose 1988).

As adopted in 1879, the original navigation improvement project at the entrance to Yaquina Bay was to build a brush and stone jetty about 1,200 m (4,000 ft) long on the south side of the navigation channel. This jetty would allow closure of the rock-obstructed south channel and force the ebb current against the reef of Yaquina Head to provide a scoured central channel depth of at least 3.7 m (12 ft) mean lower low water (mllw). A companion north jetty was planned for the future.

Construction began on the south jetty in June 1881. Fierce wave conditions and high currents required an abandonment of the original plan to construct the jetty from barges, and instead, the south jetty was built from the shore using a tramway to transport the jetty stone. By July 1887 a total jetty length of 767 m (2,517 ft) was constructed, but not completed to full height and strength. In addition, breaching at the shoreward end of the south jetty required shoreward lengthening by an additional 183 m (600 ft).

In 1889 construction began on a 700-m (2,300-ft) mid-tide north jetty extending seaward from Yaquina Bay to a point opposite the end of the south jetty. The purpose of the north jetty was to direct currents along the central navigation channel to provide a self-scouring channel of sufficient depth. In a report to the Chief of Engineers in 1893, the district engineer reported that a total of 113,970 tonnes (125,632 tons) of stone had been placed on the north jetty thus far, at a cost of $0.74 per tonne ($0.67 per ton) in place. Also, one worker was reported killed on October 31, 1892, when he was run over while switching a train.

By 1895 most of the south jetty had been raised to full height, with a total length of 1,097 m (3,600 ft). The north jetty had also been constructed to its authorized 700-m (2,300-ft) length, and a permanent channel with depths between 3.7 and 4.6 m (12 and 15 ft) existed through the outer bar. This channel remained in good condition, and work on the Yaquina Bay entrance navigation structures was suspended.

Between 1901 and 1902, several sandstone rocks in the navigation channel that posed a hazard were removed. Five tonnes (5.5 tons) of explosives were used to "surface blast" the rocks down to a depth of -3.7 m (-12 ft) mllw. It was estimated that 76 m^3 (100 yd^3) of rock were removed from the channel. In 1903 it was noted that the north and south jetties remained stable, but were "somewhat beaten down by the sea near their outer ends." The tramway used for construction had been all but destroyed by winter wave action. In a report to the Chief of Engineers in 1907 it was stated that "...the entrance to Yaquina Bay is considered not worthy of further improvement at the present time."

Between 1903 and 1920 no Federal expenditures occurred other than the cost of maintaining and decommissioning the Government plant used in the jetty construction. However, the ports of Newport and Toledo completed improvements in Yaquina Bay and deposited 36,235 tonnes (39,942 tons) of stone on the south jetty. The cost of this work was later credited to local interests, who at that time were required to bear half the costs for planned improvements to the existing project.

Project History (1920 - 1933)

In 1921 the Corps of Engineers assumed responsibility for a 670-m (2,200-ft) extension to the Yaquina Bay south jetty that was begun by local interests in 1918. The local interests had constructed the necessary approach and tramway for the south jetty extension and placed an estimated 201,850 tonnes (222,501 tons) of stone on the jetty extension. During 1921 the Corps finished the extension to the south jetty by adding another 27,063 tonnes (29,832 tons) of stone to the rubble-mound structure bringing the total south jetty length to about 1,770 m (5,800 ft).

Extension of the north jetty was also begun in 1921, and the work was completed by July 1924 after a total expenditure of $532,215. A report to the Chief of Engineers stated that 98,147 tonnes (108,189 tons) of stone had been placed during 1924, but it wasn't clear if this was the total for the north jetty extension or just the total for the year. This extension brought the north jetty length to 1,130 m (3,700 ft).

Between 1925 and 1933 most of the navigation improvements at Yaquina Bay consisted of surface blasting of reef rock in the navigation channel and maintaining and deepening the channel by dredging. A total of 144 tonnes (159 tons) of various types of explosives were used between 1925 and 1927 to lower the controlling navigation depth over the reef to -6 m (-20 ft) mllw at the highest point. Reports to the Chief of Engineers indicated that between 1927 and 1933 a total of 606,550 m^3 (793,339 yd^3) had been dredged from the ocean bar and navigation channel at a cost of $216,038, or an average of $0.36/$m^3$ ($0.27/$yd^3$). This activity produced increased navigation depths of -5.8 m (-19 ft) mllw over the ocean bar and -6 m (-20 ft) mllw in a 30-m-wide (100-ft-wide) portion of the navigation channel. The project was considered complete in 1930.

By 1929 the severe wave climate had damaged both jetty structures to the point that the north jetty tip had subsided below the tide level for a distance of about 183 m (600 ft) while the south jetty experienced similar damage over 335 m (1,100 ft) of its seawardmost portion. This reduced the above-tide jetty lengths to 1,430 m (4,700 ft) for the south jetty and 945 m (3,100 ft) for the north jetty. The ocean bar crest was located about 730 m (2,400 ft) seaward of the tip of the north jetty.

Project History (1933 - 1955)

A contract for rehabilitation of the Yaquina Bay jetties was awarded in January 1933, and the work was completed in May 1934, bringing the two jetties back to full height for their authorized lengths of 1,770 m (5,800 ft) for the south jetty and 1,130 m (3,700 ft) for the north jetty. It was estimated that 42,640 tonnes (47,000 tons) of class "A" stone and 20,865 tonnes (23,000 tons) of class "B" and "C" stone were used on the north jetty and 56,245 tonnes (62,000 tons) of class "A" stone and 43,545 tonnes (48,000 tons) of class "B" and "C" stone were used on the south jetty. Class "A" stone averaged 8 tonnes (9 tons) with a minimum weight of 5.5 tonnes (6 tons), and class "B" stone averaged 2.3 to 2.7 tonnes (2.5 to 3 tons) with a minimum weight of 0.9 tonnes (1 ton) (Ward 1988).

By 1939 the north jetty was undergoing a 305-m (1,000-ft) extension under a continuing contract. This work was completed in 1940 after placement of 239,296 tonnes (263,779 tons) of stone at a total cost of $681,227. About 13 percent of the stone was used to repair portions of the existing structure. Class "A" stone used in the construction varied between 5.5 and 23 tonnes (6 and 25 tons) with an average weight of 9 tonnes (10 tons). Class "B" stone averaged 2.3 to 2.7 tonnes (2.5 to 3 tons) (Ward 1988). Maintenance dredging between 1940 and 1942 removed 286,120 m^3 (374,231 yd^3) from the navigation channel at a total cost of $56,815, or $0.20/$m^3$ ($0.15/$yd^3$) of material.

Work on the navigation project at Yaquina Bay was suspended during the Second World War, and it was not until 1949 that the navigation channel was deepened to -6 m (-20 ft) mllw for a 91-m (300-ft) width from the seaward ends of the jetty upstream into the bay. During the same year other navigation works within Yaquina Bay were also initiated. Tramways were still being maintained on both jetties, and 83,100 tonnes (91,604 tons) of stone were placed on the south jetty and 77,547 tonnes (85,481 tons) were placed on the north jetty to repair and strengthen the existing structures.

Between 1950 and 1952, reef pinnacles were removed from between the jetties to provide a 6-m (20-ft) navigation depth. Maintenance dredging between 1949 and 1955 removed a total of 899,595 m^3 (1,176,625 yd^3) at a cost of \$448,785 (\$0.50/m^3 (\$0.38/yd^3) on the average).

Project History (1955 - 1970)

By 1955 the north jetty had suffered sufficient damage to warrant rehabilitation, which was completed in October 1956. In a report to the Chief of Engineers it was stated that 58 percent of the project was completed in 1955 with placement of 112,490 tonnes (124,000 tons). The total stone tonnage was estimated to be 199,580 tonnes (220,000 tons) with the class "A" stone averaging 9 tonnes (10 tons) and the class "B" averaging 2.7 tonnes (3 tons). A haul road was built on the jetty crest, and the stones were placed by dumping from a hauling vehicle. The seaward terminus of the north jetty was constructed using select class "A" stone weighing up to 18 tonnes (20 tons) (Ward 1988). The rehabilitation restored the north jetty to its authorized length of 1,430 m (4,700 ft). Blasting of reef outcroppings and removal of 9,220 m^3 (12,060 yd^3) of rock, boulders, mud, and sand was accomplished in 1956.

Maintenance dredging at the Yaquina Bay navigation project amounted to 521,840 m^3 (682,542 yd^3) during 1956-57 for a total cost of \$240,745, or \$0.46/m^3 (\$0.35/yd^3) on average. Between 1959 and 1963, a total of 556,460 m^3 (727,822 yd^3) was dredged; however, the total cost of \$374,525 was given for all maintenance expenses, not just dredging. Nevertheless, it would be safe to assume the vast majority of costs were related to channel dredging.

A contract for repair and extension of the Yaquina Bay north jetty to a new authorized project length of 2,130 m (7,000 ft) was awarded in 1963, and the 700-m (2,300-ft) extension was completed in September 1966. The seaward tip of the north jetty now intersected the offshore reef with a portion of the structure toe resting on top of the reef. Ward (1988) gave the jetty crest elevation as +6 m (+20 ft) mllw, crest width as 9 m (30 ft), and side slopes of 1:2 above mllw and 1:1.5 below mllw. The north jetty extension required 73,395 tonnes (80,904 tons) of select class "A" stone (minimum weight 18.6 tonnes (20.5 tons)), 248,790 tonnes (274,243 tons) of class "A" stone (minimum weight 12.3 tonnes (13.5 tons) with average of 15.4 tonnes (17 tons)), 174,735 tonnes (192,612 tons) of class "B" stone (minimum weight 5 tonnes (5.5 tons) with an average of 8 tonnes (9 tons)), 105,500 tonnes (116,296 tons) of class "C" stone, and 113,400 tonnes (125,024 tons) of bedding material weighing on average 226 kg (500 lb) per stone. A haul road was built for transporting the stones onto the jetty, and the armor layer stones were individually placed by a large crane. Design wave height for the jetty extension was specified as 6.6 m (21.8 ft). Total cost for the repair and extension was $5,519,491.

Maintenance dredging of the entrance bar and navigation channel between 1964 and 1970 amounted to a total of 1,822,640 m^3 (2,383,926 yd^3). In addition, over 1,530,000 m^3 (2,000,000 yd^3) were dredged under contract between 1966 and 1968 to deepen the entrance bar channel to the authorized depth of -12 m (-40 ft) mllw and the river channel to -9 m (-30 ft) mllw.

Project History (1970 - 1977)

A contract for extension of the Yaquina Bay south jetty to a total authorized length of 2,620 m (8,600 ft) was initiated in November 1970, and work on this 850-m (2,800-ft) extension was completed in 1972. Construction details were similar to the 1966 extension of the north jetty with a crest elevation of +6 m (+20 ft) mllw, crest width of 9 m (30 ft), and side slopes of 1:2 above mllw and 1:1.5 below mllw. The south jetty extension required an estimated 60,300 tonnes (66,500 tons) of select class "A" stone (minimum weight 20 tonnes (22 tons)), 162,600 tonnes (179,300 tons) of class "A" stone (minimum weight 11 tonnes (12 tons) with average of 15 tonnes (17 tons)), 167,000 tonnes (184,000 tons) of class "B" stone (minimum weight 5.5 tonnes (6 tons) with an average of 8 tonnes (9 tons)), 63,200 tonnes (69,700 tons) of class "C" stone, and 72,100 tonnes (79,500 tons) of bedding material (Ward 1988). Stones in the armor layer were individually placed by mobile crane. The design breaking wave height varied along the structure extension from 5.6 m to 8.2 m at the tip (18.5 ft to 27 ft). No further repair or maintenance of the south jetty structure has been required through the date of this monitoring report.

The extension to the north jetty, completed in 1966, started to experience damage at the seaward terminus so that by March 1970 the outer 95 m (310 ft) of the structure was submerged. Based on aerial photographs, the jetty tip continued to unravel, extending the submerged region to 120 m (394 ft) by 1973, 128 m (419 ft) by 1975, and 130 m (424 ft) by 1977.

Dredging activities sharply increased in the years between 1971 and 1977 due to the increased authorized navigation depth and deterioration of the outer 120 m (400 ft) of the north jetty. During this 7-year period, a total of 3,946,000 m^3 (5,161,132 yd^3) of sediment were removed from the navigation channel for an average of 563,700 m^3 (737,300 yd^3) per year. Presumably, the increased cross-sectional area of the discharge channel reduced tidal flow velocities which allowed greater amounts of sediment to be deposited in the channel, while at the same time the damaged north jetty became less effective in blocking the longshore moving sand.

North Jetty Rehabilitation (1976 - 1978)

Rehabilitation of the outer 140 m (460 ft) of the Yaquina Bay north jetty was authorized in 1976 and work was completed in September 1978 at an estimated cost of $4,400,000. Figure 5 shows the jetty cross section as designed for this rehabilitation. The class "A" core stone averaged 12.2 tonnes (13.5 tons) with minimum size of 9.2 tonnes (10.1 tons), and the select class "A" stone averaged 18 tonnes (19.8 tons) (minimum 13.5 tonnes (14.9 tons)), which was reduced from the armor stone size used on the 1966 jetty extension. The design wave height for this rehabilitation of the north jetty was 6.2 m (20.2 ft). In addition, a 4.6-m-wide (15-ft-wide) berm at -3 m (-10 ft) mllw was added to the channel side of the jetty, as shown on Figure 5.

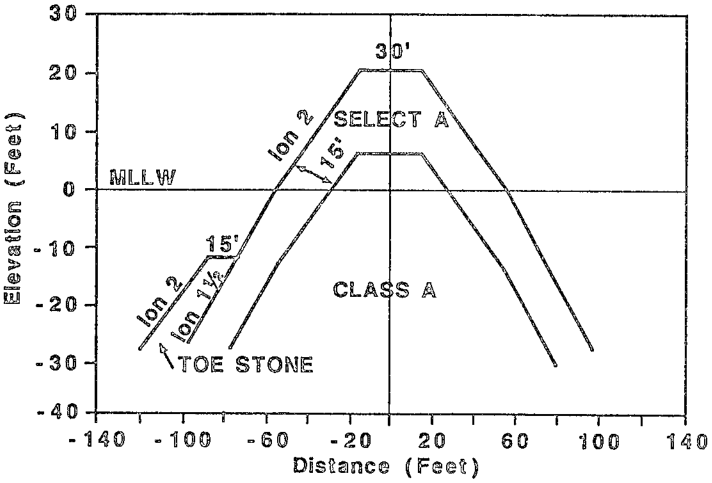

Figure 5. Yaquina Bay north jetty cross section, 1978 rehabilitation

During this work a 610-m-long (2,000-ft-long) portion of the jetty trunk (between stations 46+00 and 66+00) was sand tightened to decrease the structure's porosity and reduce sand movement through the jetty into the channel. This was accomplished by drilling to the interior of the jetty and splitting the stones with explosives (U.S. Army Engineer District, Portland 1987).

Almost immediately after completion of the north jetty rehabilitation, damage started to occur on the seaward tip of the structure. Aerial photographs indicated that 12 m (39 ft) of the tip was submerged by April 1979, with subsequent total submerged lengths of 68 m (224 ft) by October 1981, 115 m (379 ft) by September 1983, 124 m (406 ft) by August 1985, and 137 m (450 ft) by September 1987. This sequence of deterioration is shown by the aerial photographs in Figure 6 (the solid horizontal line on the figure is a common line of reference).

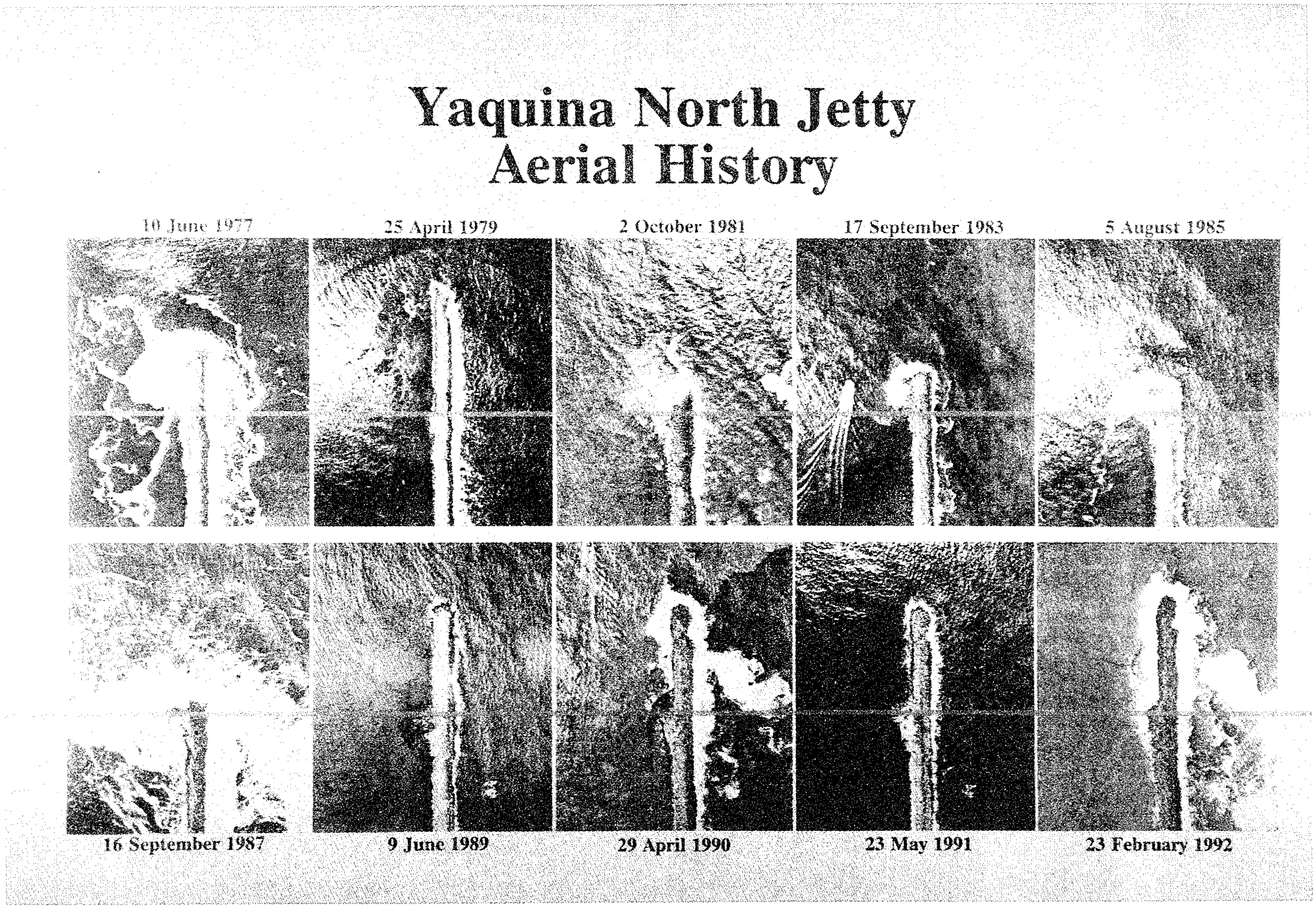

Figure 6. Yaquina Bay north jetty history from aerial photographs, 1977-1992

Degradation of the north jetty exposed a portion of the navigation channel to increased wave activity, and at times waves would be tripped by the submerged structure, creating difficult wave and current conditions for small craft in the navigation channel. During the winter and spring months, shoals formed on the south side of the channel, forcing boat traffic further northward in the channel (Grace and Dubose 1988). Maintenance dredging for the 10-year period 1978-1987 was estimated to total 2,609,735 m^3 (3,413,404 yd^3) for an average of 260,974 m^3 (341,340 yd^3) per year.

North Jetty Rehabilitation (1986 - 1988)

Adverse conditions in the Yaquina Bay entrance channel caused by the deteriorated condition of the seawardmost 137 m (450 ft) of the north jetty prompted Portland District to pursue studies aimed at providing a long-term solution to the recurring damage experienced at the north jetty. It was believed that jetty damage was caused by a combination of tidal and wave-induced coastal currents contributing to scour at the tip of the jetty with subsequent slumping of the armor layer into the scour holes.

A numerical model study performed by CERC estimated the currents near the tip of the north jetty for five rehabilitation scenarios (Cialone 1986). The study focussed on structural modifications to reduce the combined tidal and wave-induced currents, which were estimated in excess of 2.4 m/s (8 ft/s) near the north jetty tip. The model results led Portland District to conclude that rehabilitation of the north jetty to its 2,130-m (7,000-ft) authorized length would help improve the flow distribution across the entrance channel and reduce shoaling near the seaward ends of the structure. This would result in a reduction in required dredging, safer navigation conditions, and fewer delays for deep-draft vessels. It was recommended that the structure toe be protected by placing old jetty stone in existing scour holes (U.S. Army Engineer District, Portland 1987).

Figure 7 shows the nominal design cross section for rehabilitation of the seawardmost 30 m (100 ft) of the north jetty. The key differences of this design from the 1978 repair were elimination of the class "A" stone core and an increase in the size of the select class "A" armor stone. Thus, the entire end cross section of the jetty was constructed of select class "A" stone having an average weight of 29.5 tonnes (32.5 tons) with a minimum weight specified as 26.9 tonnes (29.7 tons). In addition, a 6-m-wide (20-ft-wide) bench was now included on both sides of the jetty. Behind the select class "A" stone repair section, the next 30-m (100-ft) repair length was armored using class "A" stone with an average weight of 23.4 tonnes (25.8 tons) (minimum 18.7 tonnes (20.6 tons)). The landwardmost portion of the rehabilitation was performed using class "B" stone having an average weight of 16.3 tonnes (18.0 tons) (minimum 12.2 tonnes (13.5 tons)). Details of the 1988 rehabilitation plan are shown on Figure 8. (Note that jetty stations given on Figure 8 do not correspond to jetty stations as labeled for this monitoring study.)

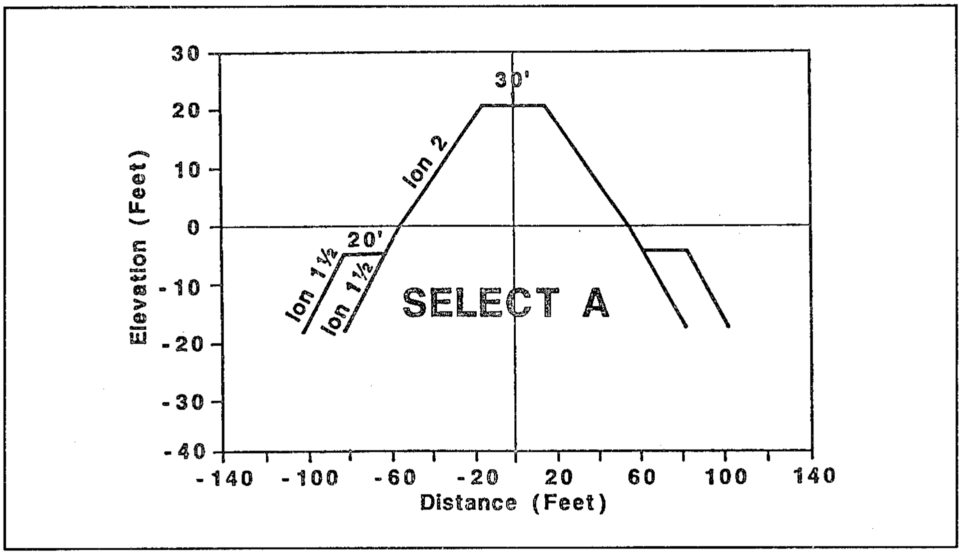

Figure 7. Yaquina Bay north jetty cross section, 1988 rehabilitation

Table 1
Yaquina Bay North Jetty Armor Stone Weight in Tonnes (Tons)

Year	Select A		Class A		Class B		Design Wave Height
	Min	Avg	Min	Avg	Min	Avg	
1966	18.6 (20.5)		12.3 (13.5)	15.4 (17.0)	5.0 (5.5)	8.0 (9.0)	6.6 m (21.8 ft)
1978	13.5 (14.9)	18.0 (19.8)	9.2 (10.1)	12.2 (13.5)	5.5 (6.0)	7.3 (8.0)	6.2 m (20.2 ft)
1988	26.9 (29.7)	29.5 (32.5)	18.7 (20.6)	23.4 (25.8)	12.2 (13.5)	16.3 (18.0)	8.5 m (28.0 ft)

The increase in armor stone sizes over the 1966 extension and 1978 rehabilitation (summarized in Table 1) stems from an increase in design wave height from about 6.6 m and 6.2 m (22 ft to 20 ft), respectively, to 8.5 m (28 ft). This wave height increase was based on deep-water wave statistics that became available in WIS Report 16 (Corson et al. 1987). These statistics were propagated into shallow water using numerical wave transformation techniques to account for refraction and shoaling. Probability of occurrence for the design wave conditions was 5 percent in any given year.

A three-dimensional small-scale physical model of the proposed north jetty rehabilitation was constructed and tested by CERC at WES in 1986 (Grace and Dubose 1988). The purpose of the small-scale model was to evaluate the armor stone stability for the proposed rehabilitation design. The 1-to-45 scale model featured molded bathymetry as obtained from nautical charts and other bathymetric surveys. Depth at the wave board represented the 18-m (58-ft)

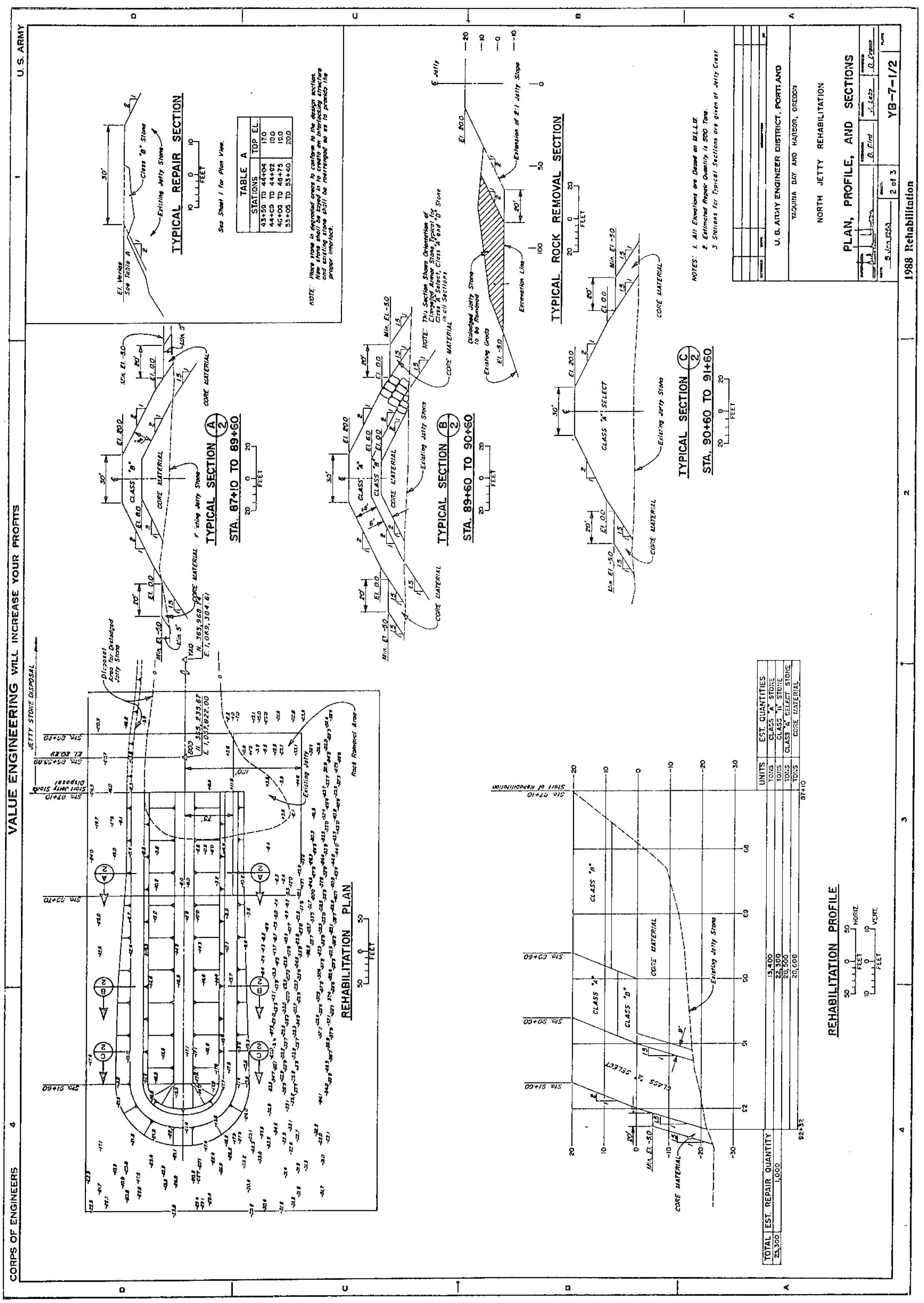

Figure 8. Yaquina Bay north jetty 1988 rehabilitation details

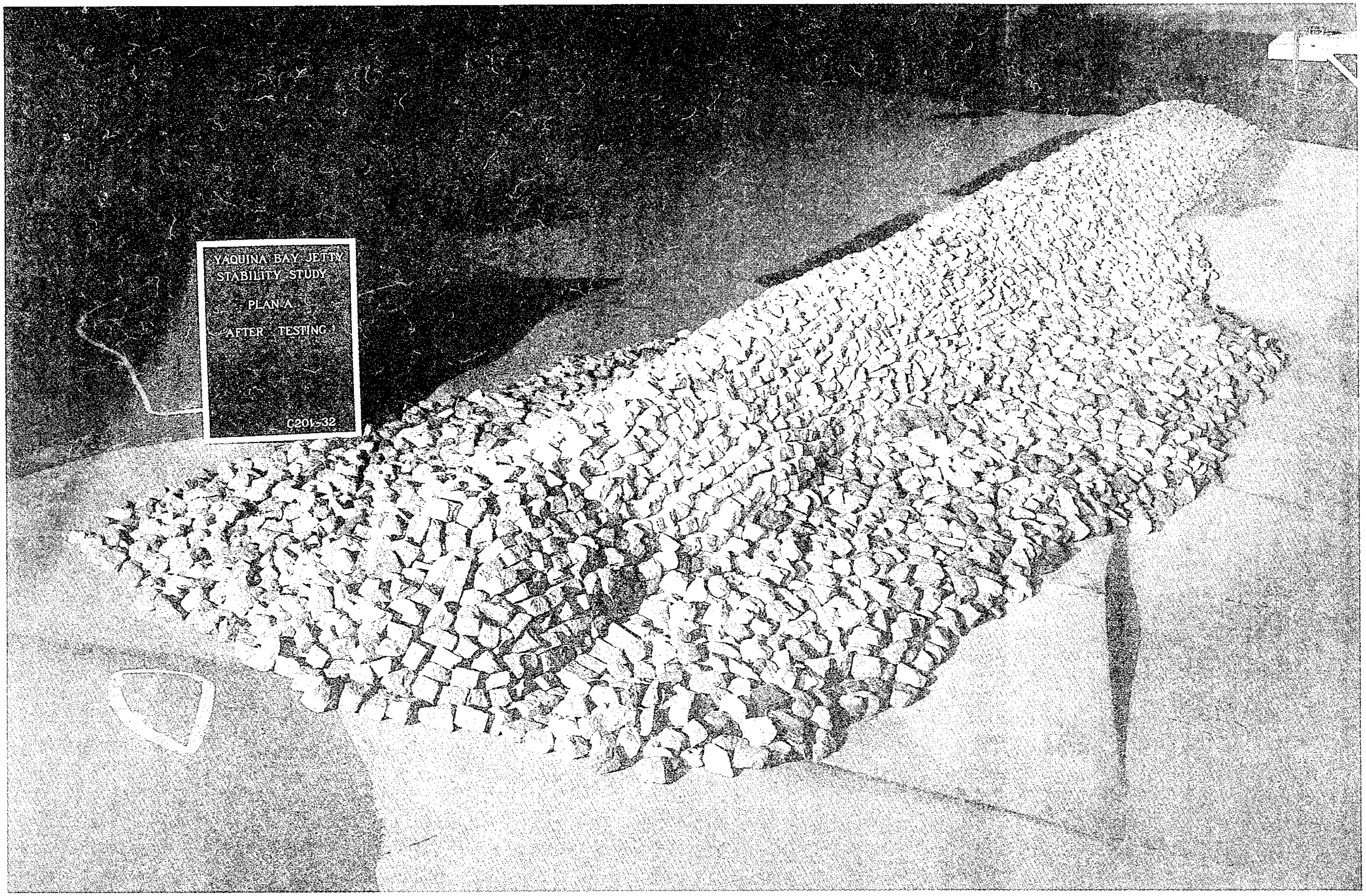

Figure 9. Photograph of 1986 physical model of Yaquina Bay north jetty

contour in the prototype, and no wave guides were used. Figure 9 is a photograph showing the model of the north jetty.

Model testing at two different water levels reproduced unidirectional irregular wave trains having significant wave height, peak period, and mean wave direction associated with the six most severe storms that were hindcast for that region of the north Pacific. Three different wave directions were tested. Maximum tested prototype significant wave height was 7.3 m (24 ft) at the wave board, which produced a 5.8-m (19-ft) significant wave height just seaward of the north jetty. This wave height corresponded to the shallow-water breaking wave limit. In addition, regular wave trains corresponding to the design wave height were also tested to examine differences between regular and irregular wave armor stability.

Physical model tests indicated that the north jetty design would be stable for the design wave conditions, provided the select class "A" stones were placed on the structure with the long axis of the stone oriented perpendicular to the face of the side slope. This type of construction was referred to as "special placement." It is important to note that tidal currents and longshore currents known to exist in the prototype were not reproduced as part of this model study.

A contract was awarded in March 1988 for repair of the seawardmost 137 m (450 ft) of the north jetty, and work was completed on the repair in September 1988. An estimated 67,300 m^3 (88,000 yd^3) of stone weighing a total of 178,000 tonnes (196,000 tons) were placed on the north jetty during the repair, and total cost of the rehabilitation was estimated to be $6,200,000.

Project History Summary

Since initial authorization of the Federal navigation project at Yaquina Bay, Oregon, over 100 years ago, the two jetties protecting the entrance channel have undergone a series of extensions and repairs, as summarized on Table 2. The south jetty has been extended three times to its present authorized length of 2,620 m (8,600 ft), and the north jetty also underwent three extensions to reach its present authorized length of 2,130 m (7,000 ft).

Prior to the final extension in 1972, the south jetty had been rehabilitated twice; but since 1972 no additional repair has been required. Conversely, the north jetty required three rehabilitations before its final extension in 1966, and since reaching full length the structure has required two additional rehabilitations for a total cost of $10,600,000. In both instances, severe wave conditions hammered the seawardmost 137 m (450 ft) of the structure down below water level, posing a hazard to navigation and creating increased dredging requirements.

The troublesome history of the Yaquina Bay north jetty, coupled with some of the harshest wave conditions on the west coast of the United States, prompted the establishment of a comprehensive monitoring program upon completion of the 1988 north jetty rehabilitation. An overview of this monitoring program is given in the following chapter.

Table 2
Yaquina Bay Jetties - Extension and Repair Summary

Year	South Jetty	North Jetty
1887	Completed to 767 m (2,517 ft)	-----
1895	Extended to 1,097 m (3,600 ft)	Completed to 700 m (2,300 ft)
1921	Repair/extended to 1,770 m (5,800 ft)	-----
1924	-----	Repair/extended to 1,130 m (3,700 ft)
1929	335 m (1,100 ft) eroded from tip	183 m (600 ft) eroded from tip
1934	Seaward 335 m (1,100 ft) repaired	Seaward 183 m (600 ft) repaired
1940	-----	Extended to 1,430 m (4,700 ft)
1956	-----	Structure rehabilitated
1966	-----	Extended to 2,130 m (7,000 ft)
1972	Extended to 2,620 m (8,600 ft)	-----
1978	-----	Seaward 140 m (460 ft) repaired
1988	-----	Seaward 137 m (450 ft) repaired
1989	-----	Monitoring began

3 Monitoring Overview

This chapter provides a brief overview of the monitoring program conducted at the Yaquina Bay north jetty as part of the MCCP Program. Short descriptions of the various elements of the monitoring program are given, along with the chronological history of the effort over the 6-year monitoring period. Detailed descriptions, results, analysis, and conclusions for each of the monitoring activities are contained in subsequent chapters.

Monitoring Plan Development

As stated in Chapter 1, the three objectives of the Yaquina Bay MCCP study were the following:

a. Determine what mechanisms were responsible for damage that occurred at the Yaquina Bay north jetty.

b. Use the study information to improve Corps of Engineers' design and construction capability for similar harsh environments.

c. Obtain information for use in the design of a permanent repair of the north jetty at Yaquina Bay.

Although these monitoring objectives may appear to be reasonably straightforward, formulating a suitable monitoring plan was complicated by not knowing a priori what had caused previous damage to the Yaquina Bay north jetty. Therefore, the monitoring program had to be designed with sufficient flexibility to allow the monitoring effort to evolve as results became available and understanding was gained about the possible damage mechanisms. This is in contrast to more usual monitoring efforts that are designed to monitor project performance. Understandably, the monitoring components actually conducted at Yaquina Bay varied somewhat from those originally envisioned at the start of the monitoring. In fact, the third objective listed above (item *c*) was added after monitoring results indicated that the newly rehabilitated structure was experiencing damage.

The harsh sea conditions also factored into development of the monitoring plan. For in situ instrumentation, issues of instrument survivability and field crew safety were paramount when selecting monitoring plan components. Likewise, planning for monitoring activities at the north jetty had to account for delays brought about by high seas and fog, even during the summer months of August and September when conditions are more likely to be accommodating.

Despite the uncertainties, the monitoring program provided valuable information that helped to explain the reason for chronic damage at the Yaquina Bay north jetty and assisted the Portland District in planning future maintenance of the Yaquina Bay navigation project. Undoubtedly, the involvement of engineers from the Portland District was a large factor contributing to the success of the monitoring program.

Major Monitoring Components

Yaquina Bay project history

One of the first accomplishments of the monitoring program was compilation of a historical overview of the Corps of Engineers' activities related to the navigation project at Yaquina Bay. This report was prepared by the Portland District, U.S. Army Corps of Engineers, and the historical aspects presented in that report are summarized in Chapter 2.

Beginning with the project's inception in 1879, the report detailed the Corps' involvement, as extracted from annual reports filed by the District Engineers. In the historical summary, emphasis was placed on documenting the original project construction, subsequent jetty extensions and rehabilitations, and improvements to and maintenance of the entrance navigation channel. Also included in the report was information related to the area's geology and physiography, characteristics of past oceanographic and meteorological measurements, and an analysis of the nearshore processes.

Awareness of the north jetty's past, combined with a description of the area's geological and environmental character, was a necessary first step toward establishing a coherent monitoring plan.

Wave climatology

Fundamental to practically all coastal project monitoring plans is the need to collect and analyze wave data. Off the Oregon coast the wave climate can be very harsh and unforgiving. Because waves provide the primary force loading on the north jetty at Yaquina Bay, it is almost assured that waves will factor heavily in any damage hypothesis. Consequently, wave data were needed to characterize the wave conditions near the north jetty. This became even more imperative when it was realized that structure damage was occurring during the monitoring period.

Wave data collected over the 6-year duration of the monitoring project included measurements of offshore nondirectional wave climatology (5 years of records), offshore directional wave information (2 years of records), nearshore nondirectional wave information (1 year of records), and nearshore directional wave information at two sites (1 year of records). Details of the wave measurements are presented in Chapter 4.

The collected wave data provide more than just wave statistics to characterize the site. These wave data will be essential for any future physical or numerical modeling efforts that might be conducted relative to the Yaquina Bay navigation project. In addition, the data can be used to relate wave conditions to known periods of jetty damage during the monitoring period. The relative severity of these damaging conditions could then be examined in the context of long-term probability statistics generated by wave hindcasts.

Geophysical survey

A precision geophysical survey was conducted in the area of the Yaquina Bay north jetty during the period August 5-23, 1991. The intent of the survey was to collect bathymetry, subsurface geophysical profiles, and side-scan sonar images. The primary objectives of this work were to obtain accurate bathymetry for possible future modeling efforts, to answer crucial questions about potential instrument sites and anchoring conditions, and to determine the subbottom sediment/rock structure in order to assess whether geological conditions might have contributed to jetty damage.

Geophysical survey products were detailed bathymetric charts, maps of seafloor features, charts showing depth to bedrock and sediment thickness, and geological profiles. The accuracy of horizontal vessel positioning was determined to ± 1 m (3 ft), and the bathymetric vertical accuracy (after heave compensation) was estimated to be ± 0.3 m (1 ft). Two tide gauges provided vertical reference elevations as a function of time. Surveying was conducted with vessel speeds between 1.5 and 3.0 m/s (3-6 knots), and in wave heights of about 1.0-1.2 m (3-4 ft). Details and results of the geophysical survey are presented in Chapter 5.

Side-scan sonar

As mentioned, side-scan sonar images were collected as part of the 1991 geophysical survey centered about the north jetty. These images were analyzed in conjunction with echo sounder profiles obtained on track lines spanning the regions covered by the side-scan sonar images. The objective of this analysis was to determine, to the extent possible, details about the underwater configuration of the jetty toe and its relationship to the Yaquina Reef and surrounding sandy bottom. This information was needed to better assess several of the jetty damage hypotheses and to construct a reasonable physical model of the north jetty resting on the reef. Details of the side-scan sonar analysis are given in Chapter 6 along with the resulting planview map showing the outline and location of the reef and the toe of the north jetty.

Photogrammetric analysis

A key component of the monitoring program was the acquisition of yearly controlled aerial photography and analysis of the stereo pair photographs. Beginning in 1989, aerial photographs showing both the north and south jetties at Yaquina Bay were obtained using a fixed-wing aircraft. In addition, low-level controlled aerial photographs were acquired in 1992 and 1993 using a helicopter.

The Portland District, Corps of Engineers, used the stereo photographs to establish a computer stereo-model of the above-water portion of the north jetty. Products from the stereo-model included contour maps of the jetty, cross sections through the jetty at regularly spaced intervals, and contours showing changes from one year to the next. The stereo-models were used to estimate volumetric changes due to armor stone loss in the vicinity of the "notch" region near the tip of the north jetty. (Similar products were obtained from the helicopter photographs.) The stereo photographs were also analyzed to determine and plot individual armor stone movement above water and to document above-water loss of jetty armor stones between successive years.

The products from the photogrammetric analyses provided a history of jetty response to storm conditions over the 6-year monitoring period. After initial settlement of the north jetty armor layer, the structure slowly began to lose armor stones near the jetty tip. Monitoring of this gradual deterioration provided insight into possible damage hypotheses, and it allowed the Portland District to plan for possible future maintenance requirements. Details and results from the photogrammetric analyses are given in Chapter 7.

North jetty physical models

Two physical model studies were conducted at the Waterways Experiment Station as part of the Yaquina Bay north jetty monitoring program. Both models are described in detail in Chapter 8. The first model was constructed and tested in 1990. This 1-to-45-scale model was a fixed-bed model representing the north jetty after the 1978 rehabilitation. The purpose of the physical model tests was to evaluate the hypothesis that damage experienced by the north jetty over the winter storm season of 1979-1980 was caused by armor instability due only to waves.

Severe storms that occurred during that time period were hindcast, and appropriate storm wave parameters were reproduced in the physical model. The model failed to reproduce any damage, even when more severe wave conditions were introduced. This led to the conclusion that damage at the Yaquina Bay north jetty was the result of more than just severe wave attack.

The second physical model was a semiquantitative model featuring a movable-bed portion. This 1-to-36-scale model was termed semiquantitative because exact features of the jetty and surrounding bathymetry were not reproduced in the model. Additionally, incident waves came only from one direction. However, the model jetty was constructed to be a reasonable facsimile of the prototype in terms of the above-water profile, armor stone size, and approximate toe location relative to the reef. This model was constructed and operated in 1993.

The purpose of the movable-bed physical model was originally to test the hypothesis that scour holes forming in the lee of Yaquina Reef caused the armor layer to slump into the hole, thus resulting in slope instability further up the armor layer. During the model tests, scour holes formed, but no armor layer damage was observed due to the mild slope of the underwater portion of the structure. However, the addition of seaward-flowing currents produced surprising results.

Seaward currents in the model modified the approaching waves and caused them to break more severely on the model jetty, resulting in extensive damage and ultimately eroding the tip of the structure to below the still-water level. This unanticipated outcome suggested that damage to the jetty was caused by waves interacting with a seaward-flowing current. Subsequent tests which varied the water level and current magnitude supported this hypothesis.

Technical workshops

Over the 6-year monitoring period, two technical workshops were held as part of the Yaquina Bay north jetty MCCP effort. These workshops were attended by several invited coastal engineering experts, representatives from the Corps of Engineers Portland District and North Pacific Division, staff of the Coastal Engineering Research Center and WES's Geotechnical Laboratory, and contractors actively working on the monitoring project. The workshop attendees worked together to review the facts surrounding the damage problem at the Yaquina Bay north jetty, to suggest plausible hypotheses for the damage, and to recommend suitable monitoring strategies and study efforts. This helped to focus the monitoring program and optimize benefits. An overview of both technical workshops is given in Chapter 9.

The first technical workshop was held in June 1989, near the beginning of the monitoring project, and its purpose was to suggest plausible damage hypotheses and suitable monitoring strategies. The second workshop was held about in the middle of the monitoring period in August 1991. The purposes of the second workshop were to review monitoring results to that date and to revise the list of possible damage hypotheses. During the second workshop, the focus was on damage that had occurred since rehabilitation of the north jetty and on the monitoring activities that could be accomplished.

Underwater jetty and current profiling

The purpose of the last field effort of the monitoring program was to obtain information about the underwater configuration of the jetty structure and to acquire representative current measurements in the vicinity of the north jetty. Field operations were conducted over a 5-day period in June 1994, during almost ideal conditions. Details and results of this effort are presented in Chapter 10.

The vertical profile of the underwater portion of the north jetty and portions of the Yaquina reef were sensed using a new instrument called SEABAT. The SEABAT is a multibeam sonar that obtains a seabed profile over a 90-deg arc in the vertical plane while being moved along a track line. (The sensor is affixed to the survey vessel.) Output from the instrument is corrected for sensor depth and motion and then combined with positional data to construct a topographic mesh of the profiled underwater feature. Two SEABAT track lines along the north side of the Yaquina Bay north jetty provided sufficient data to detail the jetty's underwater configuration. This information will prove to be invaluable for any future physical modeling efforts of the north jetty structure, and it provided Portland District a more accurate means of estimating stone requirements for potential jetty rehabilitation.

Currents were acquired on numerous track lines during differing conditions using an acoustic Doppler current profiler (ADCP). As the vessel was tracked using standard positioning techniques, the ADCP acquired current magnitude and direction profiles between the surface and bottom. These were the first comprehensive current measurements obtained in the vicinity of the north jetty, and results indicated that strong seaward-flowing currents existed adjacent to the north side of the north jetty. This was an important finding because it lent credence to the wave/current damage hypothesis. Also, information about the currents will help in calibrating any future physical models of the north jetty.

Chronological Summary of Monitoring Activities

The following sections briefly summarize the major monitoring activities accomplished during each fiscal year (October 1 to September 30) of the 6-year-long Yaquina Bay north jetty MCCP monitoring project.

First-year activities (October 1988 - September 1989)

Funding for FY89 was $136,000, and during the fiscal year the following major tasks were performed:

a. Portland District completed historical report on Yaquina Bay navigation project (May 1989).

b. First set of fixed-wing aerial photographs acquired (9 June 1989).

c. First technical workshop held in Vicksburg, MS (12 June 1989).

d. First technical workshop proceedings prepared and distributed.

Second-year activities (October 1989 - September 1990)

Funding for FY90 was $230,000, and during the fiscal year the following major tasks were performed:

a. Storms were identified that had occurred during 1979-1980 damage period.

b. Major 1979-1980 storms hindcast by the Wave Information Study (WIS) (March 1990).

c. Second set of fixed-wing aerial photographs acquired (29 April 1990).

d. Completed testing in fixed-bed jetty armor stability model (June 1990).

Third-year activities (October 1990 - September 1991)

Funding for FY91 was $563,000, and during the fiscal year the following major tasks were performed:

a. Third set of fixed-wing aerial photographs acquired (23 May 1991).

b. Second technical workshop held in Newport, OR (20 August 1991).

c. Detailed bathymetric/geophysical survey completed (August 1991).

d. Portland District completed photogrammetric analyses of first 3 years of photographic stereo pairs.

Fourth-year activities (October 1991 - September 1992)

Funding for FY92 was $430,000, and during the fiscal year the following major tasks were performed:

a. Offshore directional wave buoy installed (November 1991).

b. Two nearshore WaveRider buoys installed (January 1992).

c. Second technical workshop proceedings prepared and distributed.

d. Fourth set of fixed-wing aerial photographs acquired (23 February 1992).

e. First set of helicopter aerial photographs acquired (9 April 1992).

f. Portland District completed photogrammetric analyses of fourth-year photographic stereo pairs.

g. Portland District began establishing geographic information system (GIS) computer database for Yaquina Bay navigation project.

h. Components procured for two nearshore directional wave gauges.

i. Detailed analysis completed of side-scan sonar and echo sounder data to determine relative positions of jetty toe and Yaquina Reef.

Fifth-year activities (October 1992 - September 1993)

Funding for FY93 was $348,000, and during the fiscal year the following major tasks were performed:

a. Nearshore WaveRider buoys maintained.

b. Offshore directional wave buoy maintained.

c. Fifth set of fixed-wing aerial photographs acquired (26 May 1993).

d. Second set of helicopter aerial photographs acquired (26 May 1993).

e. Portland District completed photogrammetric analyses of fifth-year photographic stereo pairs.

f. Two nearshore directional wave gauges installed (August 1993).

g. Portland District continued efforts on GIS database.

h. Movable-bed north jetty scour physical model begun at WES (March 1993).

Sixth-year activities (October 1993 - September 1994)

Funding for FY94 was $130,000, and during the fiscal year the following major tasks were performed:

a. Movable-bed north jetty scour physical model tests completed (February 1993).

b. Underwater jetty profiling of the north jetty and current profiling in the vicinity of the north jetty (June 1994).

c. Two nearshore directional wave gauges retrieved (August 1994).

d. Monitoring report (this report) completed and reviewed.

A small amount of funding ($20,000) was provided in FY95 to prepare and publish the final version of this report.

4 Wave Climatology

Wave Measurements at Yaquina Bay

Fundamental to practically all coastal project monitoring plans is the need to collect and analyze wave data. Off the Oregon coast the wave climate can be very harsh and unforgiving, and it is reasonable to expect that waves impacting on the north jetty were largely responsible for armor layer damage experienced on the jetty. Consequently, wave data were needed to characterize the wave conditions near the north jetty and to evaluate the various damage hypotheses that had been proposed.

The importance of collecting wave data became more apparent when it was realized that jetty armor layer damage was occurring during the monitoring period. By relating observed damage to recorded wave conditions, the relative severity of the damage-inducing storms can be examined in the context of the long-term probability statistics available from wave hindcasts. This will be useful for evaluating any future maintenance options for the Yaquina Bay north jetty. In addition, these wave data will be essential for any future physical or numerical modeling efforts that might be conducted for the Yaquina Bay navigation project.

Prior to initiation of this monitoring project, there were scant wave data available for use in coastal design in the vicinity of Yaquina Bay. Oregon State University analyzed 10 years (1971 - 1981) of seismometer strip chart recordings and converted the results to estimates of the nearshore wave climatology (Creech 1981). The time series consisted of 10-min records collected at 6-hr intervals at the Marine Science Center located in Yaquina Bay.

Calibration factors for converting seismometer vertical acceleration signals to wave heights and periods were established by visual observations of a buoy moored at a depth of approximately 12 m (40 ft), supplemented by sparse observations from pressure gauges. Thompson, Howell, and Smith (1985) reviewed the methodology and compared seismometer results to measured wave data. They concluded that the seismometer method was reasonably accurate for wave heights, but wave period estimates were not as good. Wave statistics determined from the 10-year seismometer record were given in the draft historical report prepared by NPP (U.S. Army Engineer District, Portland 1989).

The Wave Information Study (WIS) also provided wave information in the form of wave hindcasts for the 20-year period between 1956 and 1975 (Corson et al. 1987). Available wave estimates from Phase II hindcasts represent deepwater waves many miles offshore of Yaquina Bay, but computer programs are available for transforming these estimates to nearshore water depths of 10 m (30 ft).

Wave data collected over the 6-year duration (1988 - 1994) of the Yaquina Bay north jetty monitoring project included measurements of offshore nondirectional wave climatology (5 years of records), offshore directional wave information (2 years of records), nearshore nondirectional wave information (1 year of records), and nearshore directional wave information at two sites (1 year of records). Details of the wave measurements and summary results are presented in the following sections.

Deepwater Wave Measurements

Wave data were measured at two locations in relatively deep water well offshore of Yaquina Bay. The wave buoys were owned and operated by the National Data Buoy Center (NDBC) with partial funding provided by the Yaquina Bay north jetty monitoring work unit. Liaison between CERC and NDBC was maintained by David McGehee of CERC.

Nondirectional NDBC buoy

The nondirectional NDBC buoy, identified as No. 46040, was deployed northwest of Yaquina Bay at latitude 44.80 °N and longitude 124.30 °W as indicated on Figure 10. This location was approximately 25 km (15 miles) offshore in a nominal depth of 110 m (360 ft). The nondirectional wave buoy operates by measuring vertical accelerations of the buoy heave and then integrating the signal twice to obtain time series of sea surface elevations. In addition, an anemometer mounted on the buoy recorded wind speed and wind direction.

The wave buoy recorded wave and wind data hourly over the 5-year deployment period from May 1987 through June 1992. Time-series wave records were spectrally analyzed to get values of zeroth-moment wave height (H_{mo}) and spectral peak period (T_p). Representative values of wind speed and wind direction were obtained by averaging over each recorded time series. (Note that H_{mo} is four times the square root of wave energy contained in the record and T_p is the inverse of the spectral frequency containing the most wave energy.)

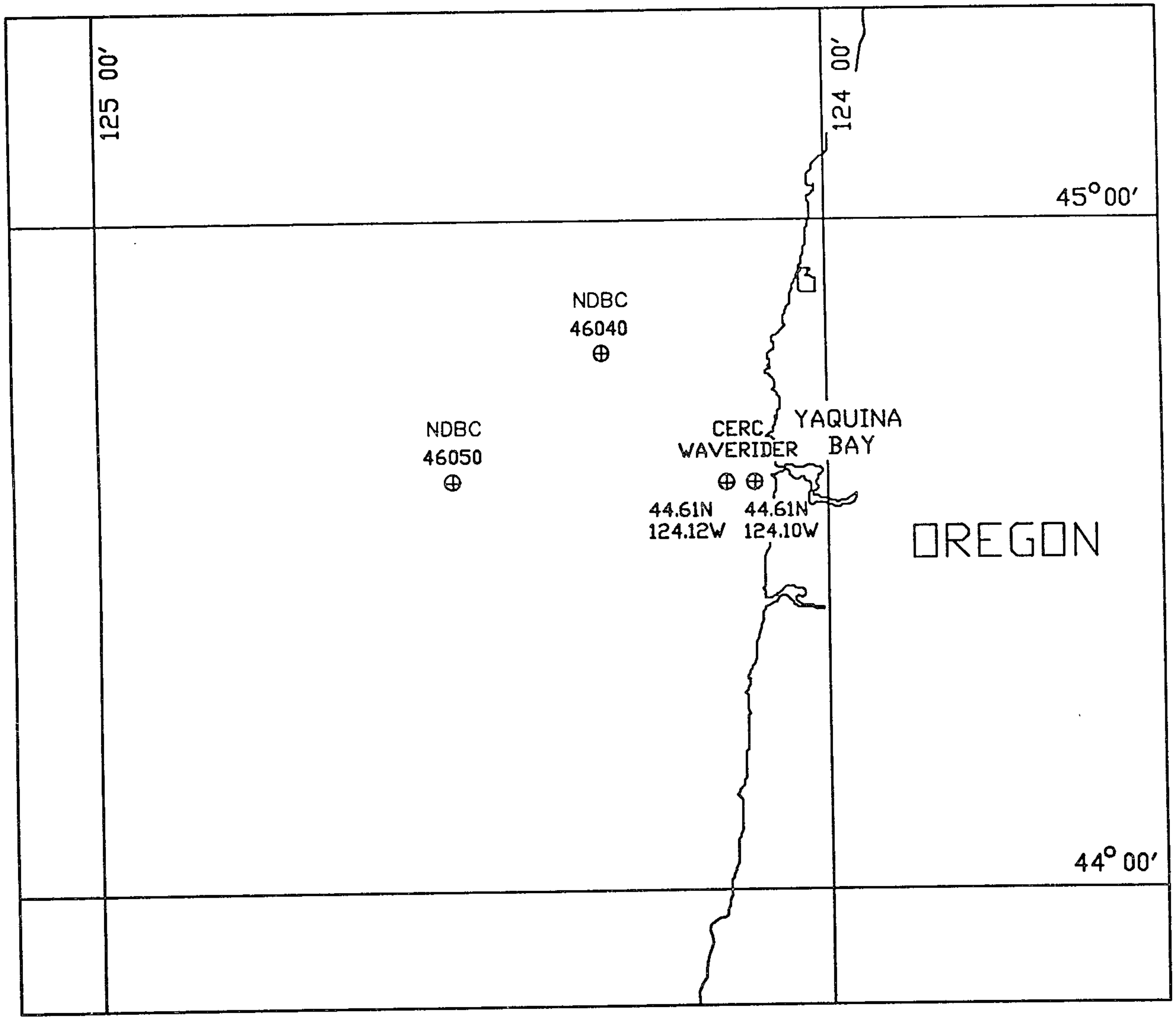

Figure 10. Wave buoy locations for Yaquina Bay north jetty monitoring study

Appendix A contains a series of plots showing values of wave height, wave period, wind speed, and wind direction for each month in the 5-year measurement period for buoy NDBC 46040. Despite the fact that data gaps (some up to 2 months in length) are present in the data, a fairly complete picture of the deepwater wave climatology off Yaquina Bay was obtained.

Table 3 summarizes the number of records collected from the offshore nondirectional wave buoy for each month during the 5-year data collection period, and Table 4 gives monthly distributions of mean and largest values of H_{mo}. As seen in Table 4, the largest offshore zeroth-moment wave height of the 36,864 wave records occurred in January 1988, with a height of 11.7 m (38.4 ft) and a peak period of 14.3 sec. The monthly mean H_{mo} ranged from 1.4 to 3.9 m (4.6 to 12.8 ft).

Table 3
NDBC Buoy No. 46040 Wave Records per Month

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1987	0	0	0	0	92	719	744	742	679	741	719	741
1988	744	695	742	109	120	710	737	729	712	731	323	0
1989	599	658	728	712	719	713	734	738	713	728	710	730
1990	727	657	734	476	680	712	729	738	706	734	577	0
1991	0	0	131	703	731	714	736	730	715	731	715	735
1992	737	565	47	718	722	43	0	0	0	0	0	0

The joint probability of zeroth-moment wave height and peak wave period as measured at the NDBC offshore nondirectional wave gauge is given in Table 5. The numerical values listed in this table correspond to the percent occurrence multiplied by a factor of 1,000. From Table 5 it is observed that almost 80 percent of the wave records had a zeroth-moment wave height less than 2.9 m (9.5 ft). Waves with heights of over 10 m (33 ft) occurred in only 0.016 percent of the records, and most of these highest waves had periods greater than 13.4 sec.

Directional NDBC buoy

The directional NDBC buoy, identified as No. 46050, was deployed due west of Yaquina Bay at latitude 44.61 °N and longitude 124.51 °W as indicated on Figure 10. This location was approximately 45 km (28 miles) offshore in a nominal depth of 128 m (420 ft). The directional wave buoy operates by measuring time series of the heave, pitch, and roll accelerations of the buoy and then processing the information to estimate the directional wave spectrum. The directional wave buoy also recorded wind speed, wind direction, and barometric pressure.

Table 4
NDBC Buoy No. 46040 Summary Wave Statistics

MEAN Hm0 (METRES) BY MONTH AND YEAR
NDBC BUOY 46040 (44.80N 124.30W)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1987	.	.	.	.	3.0	2.0	1.6	1.7	1.9	1.8	3.0	3.9	2.3
1988	3.2	2.6	3.0	3.5	2.5	1.8	1.4	1.5	1.9	1.9	3.7	.	2.3
1989	3.2	2.0	2.6	1.9	1.8	2.0	1.4	1.4	1.6	2.1	2.4	2.4	2.0
1990	3.9	3.6	2.5	1.8	2.1	1.8	1.6	1.4	1.5	2.7	2.8	.	2.3
1991	.	.	2.2	2.5	2.2	1.7	1.4	1.8	1.9	2.0	3.1	3.3	2.2
1992	3.6	2.9	2.0	2.2	1.8	1.9	.	.	.	.	.	.	2.6
MEAN	3.5	2.8	2.7	2.2	2.0	1.9	1.5	1.6	1.7	2.1	2.9	3.2	

LARGEST Hm0 (METRES) BY MONTH AND YEAR
NDBC BUOY 46040 (44.80N 124.30W)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1987	.	.	.	.	5.1	4.5	3.4	3.5	6.5	3.3	7.7	9.7
1988	11.7	6.2	6.9	6.2	3.6	6.3	2.9	3.4	4.2	3.7	8.3	.
1989	5.9	5.9	7.5	5.8	3.3	4.0	3.2	2.4	3.2	5.6	6.1	5.9
1990	10.3	8.7	5.9	3.3	4.5	3.6	3.3	2.4	3.5	6.4	5.9	.
1991	.	.	3.6	7.6	5.0	3.7	2.6	4.8	4.1	4.0	9.1	6.3
1992	7.8	6.7	2.6	4.4	3.0	2.8	.	.	.	.	.	.

STATISTICS FOR NDBC BUOY 46040 (44.80N 124.30W)

THE MEAN SIGNIFICANT WAVE HEIGHT (METRES) =	2.2
THE MEAN PEAK WAVE PERIOD (SECONDS) =	10.7
THE STANDARD DEVIATION OF Hm0 (METRES) =	1.2
THE STANDARD DEVIATION OF TP (SECONDS) =	3.0
THE LARGEST Hm0 (METRES) =	11.7
THE TP (SECONDS) ASSOC. WITH THE LARGEST Hm0 =	14.3
THE DATE OF LARGEST Hm0 OCCURRENCE IS	88011107

Hourly wave, wind, and pressure data were collected over the 2-year deployment period from November 1991 through November 1993. Buoy 46050 developed parity errors in data and went adrift in early December

Table 5
NDBC Buoy No. 46040 Percent Occurrence of H_{mo} and T_p

```
          BUOY STATION   46040   44.80 N 124.30 W   FOR ALL DIRECTIONS
                         PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)                       PEAK PERIOD(SECONDS)                          TOTAL

                  <6.9  6.9-  8.1-  8.8-  9.6- 10.6- 11.8- 13.4- 15.4-  18.2-
                        8.0   8.7   9.5  10.5  11.7  13.3  15.3  18.1  LONGER

 0.0-0.9          789   851   504   423   320   406   349   618   341    32      4633
 1.0-1.9         7077  6621  4950  5905  5821  5514  4058  2837  1364   401     44548
 2.0-2.9         1044  1912  2072  3455  4291  5978  6163  3651  1158   453     30177
 3.0-3.9           78   377   520   632  1093  2121  3553  2652   865   295     12186
 4.0-4.9            2    89   130   189   273   591  1348  1844   523    84      5073
 5.0-5.9            .    18    48    94   122   162   390   919   320    13      2086
 6.0-6.9            .     .    13    18    84   113   103   244   184    16       775
 7.0-7.9            .     .     .     5    32    46    67    70    75    18       313
 8.0-8.9            .     .     .     .     8    32    18     8    29    13       108
 9.0-9.9            .     .     .     .     .     8    16     2     5     8        39
10.0+               .     .     .     .     .     2     2     5     5     2        16
TOTAL            8990  9868  8237 10721 12044 14973 16067 12850  4869  1335

MEAN Hm0(M)=  2.2   LARGEST Hm0(M)= 11.7   MEAN TP(SEC)= 10.7   TOTAL CASES=  36864.
```

1993. After being recovered the buoy was redeployed in March 1994. The buoy failed September 19, 1994, and directional data between March and September 1994 are not valid.

For each directional spectrum estimated from the wave buoy records, the representative values of H_{mo}, T_p, and peak wave direction (D_p) were determined, along with average values of wind speed, wind direction, and barometric pressure. (Note that peak wave direction D_p is the direction from which wave energy of the peak frequency is approaching expressed in degrees clockwise from true north, i.e., waves approaching from due west would have a mean wave direction of 270 deg.)

Appendix B contains a series of plots showing values of wave height, wave period, wave direction, barometric pressure, wind speed, wind direction for each month in the 2-year measurement period for NDBC buoy 46050. Table 6 summarizes the number of records collected from the offshore directional wave buoy for each month. Overall, data recovery appeared to be very good despite the absence of data for July 1992.

Table 6
NDBC Buoy No. 46050 Wave Records per Month

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	0	0	0	0	0	0	0	0	0	0	304	707
1992	698	623	728	697	724	681	0	728	674	684	647	657
1993	672	597	663	647	676	573	662	614	581	668	594	0

Table 7 gives monthly distributions of mean and largest values of H_{mo}. As seen in Table 7, the largest offshore zeroth-moment wave height of the 15,499 wave records occurred on November 17, 1991, with a height of 9.1 m (29.9 ft) and a peak period of 12.5 sec. The monthly mean H_{mo} ranged from 1.4 to 3.9 m (4.6 to 12.8 ft).

Table 7
NDBC Buoy No. 46050 Summary Wave Statistics

MEAN Hm0 (METRES) BY MONTH AND YEAR
NDBC BUOY 46050 (44.61N 124.51W)

MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	MEAN
1991	.	.	.	.	.	.	.	.	.	.	3.9	3.4	3.5
1992	3.6	2.8	2.2	2.3	1.8	1.6	1.8	1.5	1.7	2.3	2.7	3.4	2.3
1993	2.4	2.4	2.6	3.1	2.0	1.6	1.6	1.7	1.4	1.7	2.5	.	2.1
MEAN	3.0	2.6	2.4	2.7	1.9	1.6	1.6	1.6	1.6	2.0	2.9	3.4	

LARGEST Hm0 (METRES) BY MONTH AND YEAR
NDBC BUOY 46050 (44.61N 124.51W)

MONTH

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	.	.	.	.	.	.	.	.	.	.	9.1	6.6
1992	7.5	6.1	4.0	4.4	3.1	3.1	1.8	2.7	4.2	5.6	7.0	8.0
1993	6.8	4.7	6.4	5.9	5.2	3.2	3.3	3.7	3.0	4.7	6.4	.

STATISTICS FOR NDBC BUOY 46050 (44.61N 124.51W)

THE MEAN SIGNIFICANT WAVE HEIGHT (METRES) =	2.3
THE MEAN PEAK WAVE PERIOD (SECONDS) =	11.3
THE MOST FREQUENT 22.5 (CENTER) DIRECTION BAND (DEGREES) =	292.5
THE STANDARD DEVIATION OF Hm0 (METRES) =	1.1
THE STANDARD DEVIATION OF TP (SECONDS) =	3.1
THE LARGEST Hm0 (METRES) =	9.1
THE TP (SECONDS) ASSOC. WITH THE LARGEST Hm0=	12.5
THE PEAK DIRECTION (DEGREES) ASSOC. WITH THE LARGEST Hm0=	202.0
THE DATE OF LARGEST Hm0 OCCURRENCE IS	91111704

The joint probability of zeroth-moment wave height and peak wave period for all wave directions as measured at the NDBC offshore directional wave gauge is given in Table 8. The numerical values listed in this table correspond to the percent occurrence multiplied by a factor of 1,000. From Table 8 it is observed that almost 78 percent of the wave records had a zeroth-moment wave height less than 2.9 m (9.5 ft). Waves with heights of over 10 m (33 ft) did not occur during this measurement period. About 58 percent of the peak wave periods were between 9.6 and 15.3 sec, whereas only about 2 percent of the wave records had peak periods greater than 18.2 sec.

Similar joint probability tables are shown in Appendix C for each of the 16 mean direction bands. The directional percent occurrence tables are representative of directional bands centered on 22.5-deg increments. Values in the directional probability tables represent the percentage of recorded data during which waves occurred from the specified direction range for the indicated H_{mo} and T_p ranges.

The information contained in the tables of Appendix C is summarized by the mean H_{mo} wave height rose shown in Figure 11. Each of the 22.5-deg direction bands is represented by a sector with a radius corresponding to the mean wave height of all the waves approaching from that direction. As expected, waves from the west to northwest are the most frequent, and few waves originated from the east. Waves from the south-southwest only occurred between 2 and 10 percent of the time; but note that when these waves did occur, the mean wave height was nearly 2.6 m (8.5 ft).

Table 8
NDBC Buoy No. 46050 Percent Occurrence of H_{mo} and T_p

BUOY STATION 46050 44.61 N 124.51 W FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	890	709	735	470	548	412	154	393	548	96	4955
1.0-1.9	4490	5374	4238	4787	4580	4348	3897	3458	1890	387	37449
2.0-2.9	1064	2000	2374	3355	4097	5961	8071	5664	2064	677	35327
3.0-3.9	58	348	419	593	1258	2277	3903	3142	1296	483	13777
4.0-4.9	.	58	77	212	303	612	1225	2148	812	103	5550
5.0-5.9	.	.	25	51	90	154	230	838	600	25	2073
6.0-6.9	.	.	.	.	58	70	103	283	148	.	662
7.0-7.9	.	.	.	.	12	32	51	51	6	.	152
8.0-8.9	.	.	.	.	.	.	6	6	.	.	12
9.0-9.9	.	.	.	.	.	.	6	.	.	.	6
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	6502	8489	7868	9468	10946	13866	17706	15983	7364	1771	

MEAN Hm0(M)= 2.3 LARGEST Hm0(M)= 9.1 MEAN TP(SEC)= 11.3 TOTAL CASES= 15499.

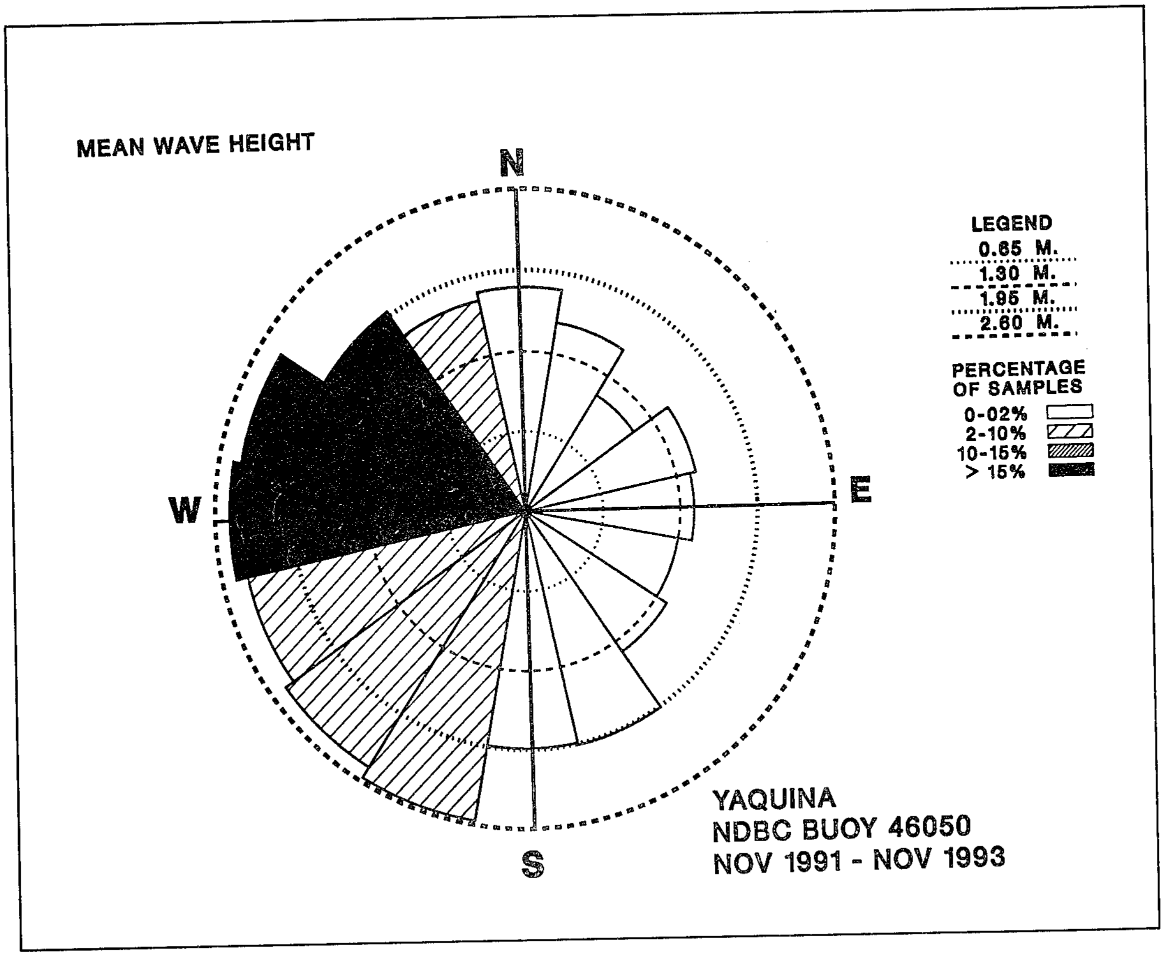

Figure 11. Directional wave rose for offshore NDBC buoy 46050

Shallow-Water Wave Measurements

Instruments for obtaining shallow wave measurements have to contend with a variety of problems that can negate successful data acquisition. Wave buoys are more apt to suffer damage from vessel traffic in shallow water, whether it is damage due to direct contact or due to severing of the mooring line. Also, breaking or near-breaking waves may cause the buoy to "surf" down the wave, giving spurious results. The main problem for bottom-mounted wave sensors in shallow water comes from interference with trawling nets.

During the latter years of the Yaquina Bay north jetty monitoring program, nearshore wave data were obtained first using two nondirectional WaveRider buoys, and later using two bottom-mounted directional wave gauges.

Nondirectional WaveRider buoy measurements

Nearshore WaveRider buoys were deployed either singly or in pairs over a 17-month period beginning in February 1992. Initially, two WaveRider buoys were placed at the positions indicated on Figure 10. For reference purposes in this report the seawardmost site (located at latitude 44.61 °N, longitude 124.12 °W) is referred to as WR-12, and the landwardmost site (located at latitude 44.61 °N, longitude 124.10 °W) is referred to as WR-10. Nominal water depth at WR-12 was 37 m (120 ft), whereas depth for WR-10 was 18 m (60 ft). These locations were approximately 3.5 km (2.1 miles) and 1.6 km (1 mile) west of the Yaquina Bay north jetty tip, respectively. The non-directional wave buoy operates by measuring vertical accelerations of the buoy heave and then integrating the signal twice to obtain time series of sea surface elevations. Results were telemetered to a collector computer at the shore station.

Table 9 summarizes the number of records collected from WaveRiders WR-12 (top) and WR-10 (bottom) for each month during the data collection period. Both buoys recorded data into the second month of deployment before WR-10 broke from its moorings and drifted with the coastal currents. After recovering the delinquent WaveRider, a decision was made to maintain only one WaveRider on station with the second being held in reserve for immediate deployment in case of loss of the first buoy. The buoy at WR-12 continued to record data until early January 1993 for a total of 12 months before it decided to take leave of its moorings and go off on an adventure. Weather conditions prohibited placement of the backup buoy at WR-12 until late January 1993. Data for January and February 1993 were not considered valid due to data transmission errors. Data transmission errors were corrected, and the buoy at WR-12 then collected data for 4 more months until its removal in June 1993.

Table 9
Wave Records per Month at WR-12 and WR-10

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Records by Month for CERC WaveRider WR-12												
1992	0	669	1,043	1,409	1,460	1,356	1,213	1,460	981	1,455	1,397	1,434
1993	357	0	1,309	1,251	1,381	1,410	0	0	0	0	0	0
Total Records by Month for CERC WaveRider WR-10												
1992	0	636	265	0	0	0	0	0	0	0	0	0

The WaveRider buoys recorded wave data at 30-min intervals over the 17-month deployment period from February 1992 through June 1993, except for the months of February and March 1992, which were recorded at 60-min intervals. Time series wave records were spectrally analyzed to get values of zeroth-moment wave height (H_{mo}) and spectral peak period (T_p).

Tables 10 and 11 give monthly distributions of mean and largest values of H_{mo} for WaveRider buoys at sites WR-12 (19,585 records) and WR-10 (901 records), respectively. The largest nearshore zeroth-moment wave height recorded at WR-12 occurred on December 9, 1992, with a height of 6.9 m (22.6 ft) and a peak period of 15.3 sec. The monthly mean H_{mo} ranged from 1.4 to 3.0 m (4.6 to 9.7 ft). Site WR-10 registered a maximum zeroth-moment wave height of 3.9 m (12.8 ft) on February 3, 1992. Data from buoy WR-10 are insufficient to give a yearly range of mean wave heights.

Appendix D contains a series of plots showing values of wave height and peak period for each month in the 17-month measurement period. Sixteen months of data from the seawardmost site WR-12 are given first, followed by plots showing the 2 months of data collected at WR-10.

Tables of percent occurrence of zeroth-moment wave height and peak wave period as measured at sites WR-12 and WR-10 are given in Tables 12 and 13, respectively. The numerical values listed in these tables correspond to the percent occurrence multiplied by a factor of 1,000. From Table 12 it is seen that almost 90 percent of the wave records at WR-12 had a zeroth-moment wave height less than 2.9 m (9.5 ft). Waves with heights of over 6.9 m (22.6 ft) occurred in only 0.09 percent of the records, and most of these highest waves had periods greater than 12.5 sec. The lack of wave data at WR-10 limits the statistical summaries for this site. The statistics are not representative of all types of waves that might occur at WR-10.

Directional wave gauge (DWG) measurements

Two nearshore directional wave gauges (DWG) were deployed in the vicinity of the Yaquina Bay north jetty on August 31 - September 1, 1993, at the locations shown on Figure 12. The south DWG (OR02) was located in a nominal water depth of 18 m (60 ft) at latitude 44.61 °N and longitude 124.09 °W. The north DWG (OR01) was in a similar water depth of 17 m (55 ft), and it was located at position 44.65 °N, 124.09 °W. Both DWGs were retrieved in August 1994, after successfully collecting nearshore directional wave data for just over 9 months. The south DWG was located about 850 m (2,800 ft) off the tip of the north jetty. Both DWGs were about the same distance seaward of Yaquina Reef.

The DWG is a bottom-mounted, trawler-resistant tripod equipped with three or more pressure transducers placed in a known array configuration. (The two DWGs deployed at Yaquina used four pressure sensors to provide redundancy in the measurements and to allow eventual estimation of directional wave reflection.) Synoptic time series of pressure are collected by each pressure sensor, and an onboard processor calculates cross-spectra between all two-sensor combinations. Analysis results are stored on the DWG

Table 10
Summary Wave Statistics at WR-12

```
                    MEAN HmO(METRES) BY MONTH AND YEAR
                    CERC WAVERIDER    (44.61N 124.12W)

                                  MONTH

        JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC
YEAR                                                                                         MEAN
1992     .     2.3    1.8    1.9    1.4    1.4    1.5    1.4    1.6    2.1    2.5    3.0     1.9
1993    2.1     .     2.3    2.8    1.8    1.5     .      .      .      .      .      .      2.1

MEAN    2.1    2.3    2.0    2.3    1.6    1.4    1.5    1.4    1.6    2.1    2.5    3.0


                   LARGEST HmO(METRES) BY MONTH AND YEAR
                    CERC WAVERIDER    (44.61N 124.12W)

                                  MONTH

        JAN    FEB    MAR    APR    MAY    JUN    JUL    AUG    SEP    OCT    NOV    DEC
YEAR
1992     .     4.5    2.9    3.6    2.5    2.6    2.3    3.0    3.9    5.5    5.9    6.9
1993    4.3     .     5.4    5.7    4.7    3.0     .      .      .      .      .      .


              STATISTICS FOR CERC WAVERIDER BUOY  (44.61  124.12W)

THE MEAN SIGNIFICANT WAVE HEIGHT(METRES)=                         1.9

THE MEAN PEAK WAVE PERIOD (SECONDS)=                             10.5

THE STANDARD DEVIATION OF HmO(METRES)=                            0.9

THE STANDARD DEVIATION OF TP(SECONDS)=                            3.0

THE LARGEST HmO(METRES)=                                          6.9

THE TP(SECONDS)ASSOC. WITH THE LARGEST HmO=                      15.3

THE DATE OF LARGEST HmO OCCURRENCE IS                        92120912
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for later processing after gauge retrieval. As presently configured, the three-sensor DWG can internally record data for periods up to 13 months at a collection rate of one record per hour, and the four-sensor array can collect 9 months of data at the same rate. A full description of the DWG is given by Howell (1992).

Data collected and processed by the two DWGs deployed at Yaquina Bay resulted in directional spectrum estimates every hour based on a 30-min-long time series of pressure variations due to the fluctuating sea surface elevation. This was the first time that high quality directional wave measurements were made at a nearshore site in the harsh conditions that typify the Pacific northwest. Table 14 summarizes the number of records collected from the south DWG (top) and the north DWG (bottom) for each month during the data

Table 11
Summary Wave Statistics at WR-10

```
                    MEAN Hm0(METRES) BY MONTH AND YEAR
                    CERC WAVERIDER    (44.61N 124.10W)

                                   MONTH

         JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     OCT     NOV     DEC

YEAR                                                                                                   MEAN
1992      .      2.0     1.9      .       .       .       .       .       .       .       .       .    2.0

MEAN      .      2.0     1.9      .       .       .       .       .       .       .       .       .


                   LARGEST Hm0(METRES) BY MONTH AND YEAR
                    CERC WAVERIDER    (44.61N 124.10W)

                                   MONTH

         JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     OCT     NOV     DEC

YEAR
1992      .      3.9     2.7      .       .       .       .       .       .       .       .       .


              STATISTICS FOR CERC WAVERIDER BUOY  (44.61  124.10W)

 THE MEAN SIGNIFICANT WAVE HEIGHT(METRES)=                           2.0

 THE MEAN PEAK WAVE PERIOD (SECONDS)=                               12.7

 THE STANDARD DEVIATION OF Hm0(METRES)=                              0.4

 THE STANDARD DEVIATION OF TP(SECONDS)=                              3.2

 THE LARGEST Hm0(METRES)=                                            3.9

 THE TP(SECONDS)ASSOC. WITH THE LARGEST Hm0=                        11.7

 THE DATE OF LARGEST Hm0 OCCURRENCE IS                          92020308
```

collection period. Data recovery over the 9-month period was nearly perfect, and data quality was excellent.

For each directional spectrum estimated from the directional wave gauges, the representative values of H_{mo}, T_p, and mean wave direction (D_p) were determined (note that mean wave direction D_p is the direction from which wave energy is approaching expressed in degrees clockwise from true north, i.e., waves approaching from due west would have a mean wave direction of 270 deg).

Appendix E contains a series of plots showing values of wave height, wave period, and wave direction for each month in the 9-month measurement period for both DWG instruments. Plots for the south DWG are presented first, followed by plots for the north DWG.

Table 12
Percent Occurrence of H_{mo} and T_p at WR-12

CERC WAVERIDER 44.61 N 124.12 W FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <7.2	7.2-8.3	8.4-9.0	9.1-9.9	10.0-11.0	11.1-12.4	12.5-14.2	14.3-16.5	16.6-19.9	20.0-LONGER	TOTAL
0.0-0.9	1404	2282	1245	1041	1000	474	566	1215	321	10	9558
1.0-1.9	7531	10548	8470	7658	5657	5187	4018	1970	1210	35	52284
2.0-2.9	592	2246	2251	3002	4370	6070	4993	2261	980	102	26867
3.0-3.9	45	275	291	617	1021	1695	2323	1383	719	5	8374
4.0-4.9	.	20	15	40	142	183	622	857	214	.	2093
5.0-5.9	.	.	5	20	15	51	239	301	76	.	707
6.0-6.9	.	.	.	5	5	5	40	30	.	.	85
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	9572	15371	12277	12383	12210	13665	12801	8017	3520	152	

MEAN Hm0(M)= 1.9 LARGEST Hm0(M)= 6.9 MEAN TP(SEC)= 10.5 TOTAL CASES= 19585.

Table 13
Percent Occurrence of H_{mo} and T_p at WR-10

CERC WAVERIDER 44.61 N 124.10 W FOR ALL DIRECTIONS
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	PEAK PERIOD(SECONDS) <7.2	7.2-8.3	8.4-9.0	9.1-9.9	10.0-11.0	11.1-12.4	12.5-14.2	14.3-16.5	16.6-19.9	20.0-LONGER	TOTAL
0.0-0.9	.	.	.	.	.	.	.	.	.	110	110
1.0-1.9	1775	1442	1775	4772	7436	12874	10432	7658	4439	110	52713
2.0-2.9	.	887	1109	1886	4661	10987	11764	9211	3662	110	44277
3.0-3.9	.	.	.	110	221	776	1109	554	110	.	2880
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	1775	2329	2884	6768	12318	24637	23305	17423	8211	330	

MEAN Hm0(M)= 2.0 LARGEST Hm0(M)= 3.9 MEAN TP(SEC)= 12.7 TOTAL CASES= 901.

Tables 15 and 16 give monthly distributions of mean and largest values of H_{mo} for the south DWG (6,413 records) and the north DWG (6,477 records), respectively. The largest nearshore zeroth-moment wave height recorded by both DWGs occurred on December 9, 1993. On that date the south DWG registered a height of 8.0 m (26.3 ft) and a peak period of 12.8 sec, and the north DWG gave a height of 7.7 m (25.3 ft) and a peak period of 14.2 sec. Monthly mean H_{mo} for the two DWGs ranged from 1.1 to 2.6 m (3.6 to

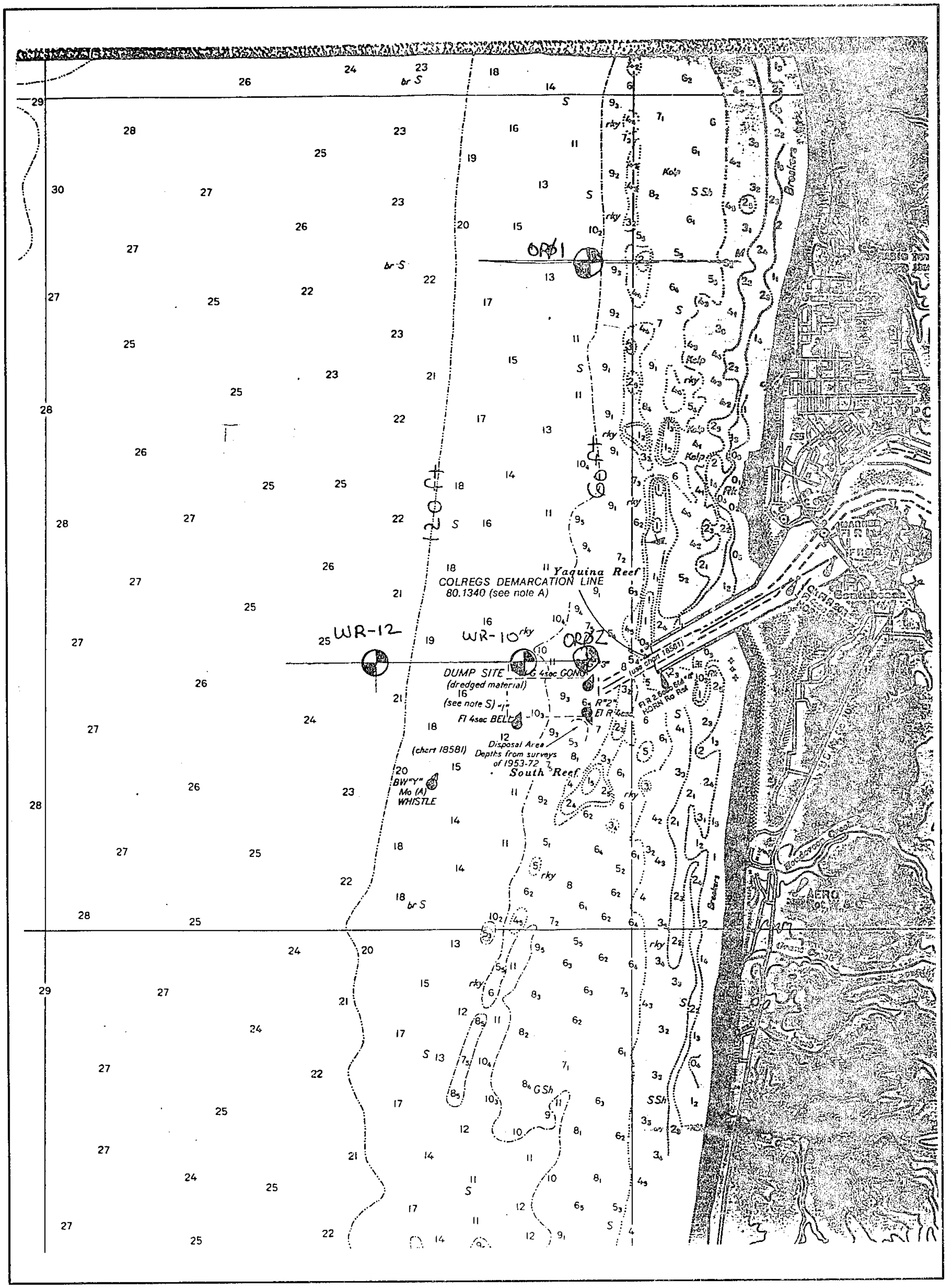


Figure 12. Nearshore wave measurement locations for Yaquina Bay north jetty monitoring study

Table 14
Wave Records per Month at OR02 and OR01

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Total Records by Month for South DWG (OR02)												
1993	0	0	0	0	0	0	0	0	710	744	720	744
1994	744	672	746	718	744	216	0	0	0	0	0	0
Total Records by Month for North DWG (OR01)												
1993	0	0	0	0	0	0	0	0	703	744	720	744
1994	744	672	744	720	744	216	0	0	0	0	0	0

8.5 ft), and the monthly mean for the north DWG usually was slightly higher than values determined for the south DWG. The time span covered by the DWG records was insufficient to give a yearly range of mean wave heights.

The joint probability of zeroth-moment wave height and peak wave period for all wave directions as measured by the south DWG and the north DWG are given in Tables 17 and 18, respectively. The numerical values listed in these tables correspond to the percent occurrence multiplied by a factor of 1,000. From Table 17 it is seen that almost 85 percent of the wave records had a zeroth-moment wave height less than 2.9 m (9.5 ft). Waves with heights of over 5.0 m (16.4 ft) occurred in only 1.2 percent of the records, and these highest waves had peak periods ranging from 8.0 to greater than 18.3 sec. The north DWG had a similar joint probability as indicated by Table 18. About 83 percent of the records had a H_{mo} less than 2.9 m (9.5 ft), and waves with heights of over 5.0 m (16.4 ft) occurred in 2.24 percent of the records over a fairly wide range in peak period.

Although the data for OR01 and OR02 cover slightly less than 1 year, the severe winter and fall seasons are included. The statistical summaries are somewhat biased toward winter and fall wave statistics due to the lack of complete coverage of the summer months.

Similar joint probability tables are shown in Appendix F for each of the 16 mean direction bands. The directional percent occurrence tables are representative of directional bands centered on 22.5-deg increments. Values in the directional probability tables represent the percentage of recorded data during which the mean direction of the waves occurred from the specified direction range for the indicated H_{mo} and T_p ranges. In Appendix F, directional probability tables for the south DWG are given first, followed by similar tables for the north DWG.

The information contained in the tables of Appendix F is summarized by the mean H_{mo} wave height roses shown in Figures 13 and 14 for the south

Table 15
Summary Wave Statistics at OR02

```
                 MEAN Hm0(METRES) BY MONTH AND YEAR
          YAQUINA, SOUTH SITE         (44.61N 124.09W)


                                 MONTH

        JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC

YEAR                                                                 MEAN
1993     .    .    .    .    .    .    .    .   1.2  1.4  2.1  3.1    1.9
1994    2.3  2.3  2.4  2.1  1.8  1.6   .    .    .    .    .    .     2.2



               LARGEST Hm0(METRES) BY MONTH AND YEAR
          YAQUINA, SOUTH SITE         (44.61N 124.09W)


                                 MONTH

        JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC

YEAR
1993     .    .    .    .    .    .    .    .   2.4  3.8  5.1  8.0
1994    5.4  6.2  6.3  5.1  3.3  3.4   .    .    .    .    .    .


     STATISTICS FOR YAQUINA, SOUTH SITE         (44.61N 124.09W)

THE MEAN SIGNIFICANT WAVE HEIGHT(METRES)=                              2.1

THE MEAN PEAK WAVE PERIOD (SECONDS)=                                  11.9

THE MOST FREQUENT 22.5(CENTER) DIRECTION BAND (DEGREES)=             270.0

THE STANDARD DEVIATION OF Hm0(METRES)=                                 1.0

THE STANDARD DEVIATION OF TP(SECONDS)=                                 2.9

THE LARGEST Hm0(METRES)=                                               8.0

THE TP(SECONDS)ASSOC. WITH THE LARGEST Hm0=                           12.8

THE PEAK DIRECTION (DEGREES) ASSOC. WITH THE LARGEST Hm0=            251.0

THE DATE OF LARGEST Hm0 OCCURRENCE IS                             93120901
```

DWG and the north DWG, respectively. Each of the 22.5-deg direction bands is represented by a sector with a radius corresponding to the mean wave height of all the waves approaching from that direction. As expected, waves from the west are the most frequent, and waves from the south-southwest occurred less than 2 percent of the time.

Table 16
Summary Wave Statistics at OR01

```
                  MEAN Hm0(METRES) BY MONTH AND YEAR
              YAQUINA, NORTH SITE          (44.65N 124.09W)

                                  MONTH

         JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC

                                                                     MEAN
YEAR
1993      .    .    .    .    .    .    .    .   1.1  1.5  2.2  3.3   2.1
1994     2.4  2.5  2.6  2.2  1.9  1.6   .    .    .    .    .    .    2.3


                 LARGEST Hm0(METRES) BY MONTH AND YEAR
              YAQUINA, NORTH SITE          (44.65N 124.09W)

                                  MONTH

         JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC

YEAR
1993      .    .    .    .    .    .    .    .   2.4  4.4  5.8  7.7
1994     5.2  6.2  6.3  5.2  3.7  3.8   .    .    .    .    .    .


     STATISTICS FOR YAQUINA, NORTH SITE          (44.65N 124.09W)

THE MEAN SIGNIFICANT WAVE HEIGHT(METRES)=                             2.2

THE MEAN PEAK WAVE PERIOD (SECONDS)=                                 12.0

THE MOST FREQUENT 22.5(CENTER) DIRECTION BAND (DEGREES)=            270.0

THE STANDARD DEVIATION OF Hm0(METRES)=                                1.0

THE STANDARD DEVIATION OF TP(SECONDS)=                                2.9

THE LARGEST Hm0(METRES)=                                              7.7

THE TP(SECONDS)ASSOC. WITH THE LARGEST Hm0=                          14.2

THE PEAK DIRECTION (DEGREES) ASSOC. WITH THE LARGEST Hm0=           252.0

THE DATE OF LARGEST Hm0 OCCURRENCE IS                            93120903
```

Wave Data Archiving

Wave data collected and analyzed as part of the monitoring program at the Yaquina Bay north jetty and summarized in this report have been archived on

Table 17
Percent Occurrence of H_{mo} and T_p at OR02

YAQUINA, SOUTH SITE 44.61N 124.09W FOR ALL DIRECTIONS

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	PEAK PERIOD(SECONDS) SHORTER-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3-LONGER	TOTAL
0.0-0.4	.	.	15	.	15	15	15	15	62	.	137
0.5-0.9	.	311	935	1263	514	389	296	1294	2105	592	7699
1.0-1.4	.	421	2619	7048	2635	2089	2728	1995	2042	873	22450
1.5-1.9	.	124	1075	5161	3087	4724	4475	3913	2494	1060	26113
2.0-2.4	.	77	421	4147	3009	3867	3181	1995	873	717	18287
2.5-2.9	.	31	467	1824	1496	2042	1512	1777	608	249	10006
3.0-3.4	.	15	187	764	888	1512	1434	1637	701	77	7215
3.5-3.9	.	.	31	389	218	545	748	1013	343	31	3318
4.0-4.4	.	.	15	249	202	187	545	608	280	124	2210
4.5-4.9	.	.	.	62	93	93	218	421	296	109	1292
5.0+	.	.	.	124	124	62	296	374	218	31	1229
TOTAL	0	979	5765	21031	12281	15525	15448	15042	10022	3863	

MEAN Hm0(M)= 2.1 LARGEST Hm0(M)= 8.0 MEAN TP(SEC)= 11.9 TOTAL CASES= 6413.

Table 18
Percent Occurrence of H_{mo} and T_p at OR01

YAQUINA, NORTH SITE 44.65N 124.09W FOR ALL DIRECTIONS

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD

HEIGHT(METRES)	PEAK PERIOD(SECONDS) SHORTER-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3-LONGER	TOTAL
0.0-0.4	.	.	15	30	15	.	.	.	30	.	90
0.5-0.9	.	617	1111	1698	633	524	293	833	1760	463	7932
1.0-1.4	.	432	2871	6036	2393	2393	1806	1667	1188	602	19388
1.5-1.9	.	77	864	4168	3350	3983	3597	3921	2053	1049	23062
2.0-2.4	.	46	478	3396	2902	4322	3041	3412	1574	988	20159
2.5-2.9	.	.	339	1852	1821	2393	1914	1976	880	401	11576
3.0-3.4	.	15	108	555	802	1482	1821	1543	710	185	7221
3.5-3.9	.	15	30	355	416	494	771	1296	756	123	4256
4.0-4.4	.	.	.	138	154	123	478	1049	324	77	2343
4.5-4.9	.	.	.	.	46	169	216	741	308	169	1649
5.0+	.	.	.	46	108	169	463	648	663	185	2282
TOTAL	0	1202	5816	18274	12640	16052	14400	17086	10246	4242	

MEAN Hm0(M)= 2.2 LARGEST Hm0(M)= 7.7 MEAN TP(SEC)= 12.0 TOTAL CASES= 6477.

a computer system operated by the Prototype Measurement and Analysis Branch, CERC, WES.

The form of the archived wave data depends on which instrument collected the data and how the time series was processed before the data were saved originally. For the non-directional measurement systems (NDBC 46040, WR-12, and WR-10), non-directional energy spectra are stored for each record. For the directional measurement systems (NDBC 46050, OR01, and

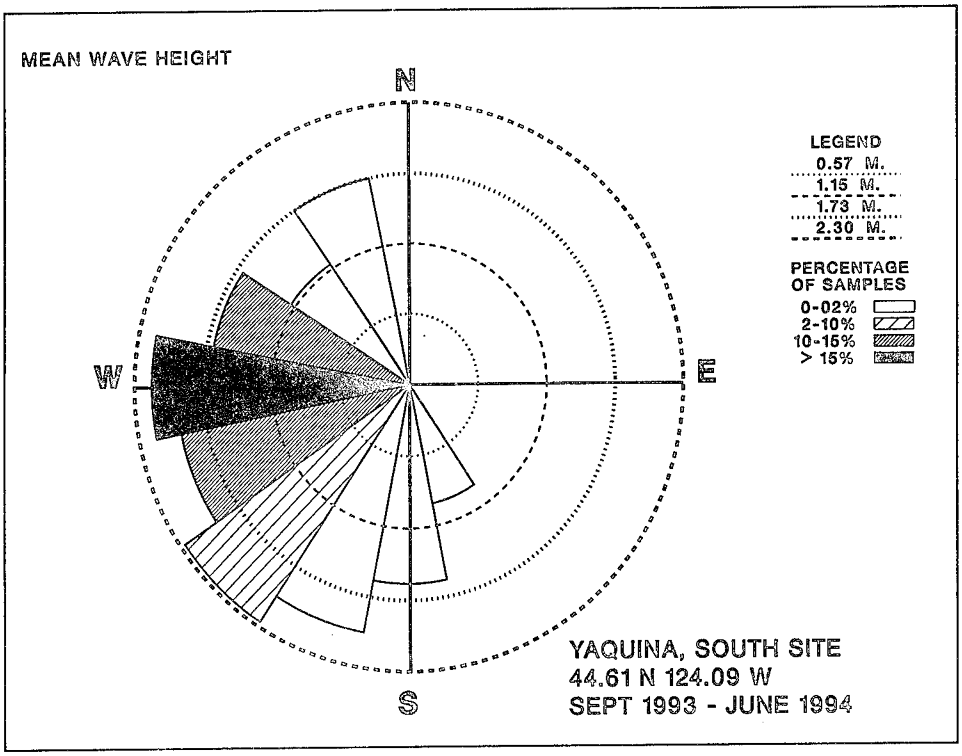


Figure 13. Directional wave rose for nearshore south DWG

OR02), energy and direction of each frequency band are stored for each record. H_{mo}, T_p, and D_p (where available) can be derived from the energy specta.

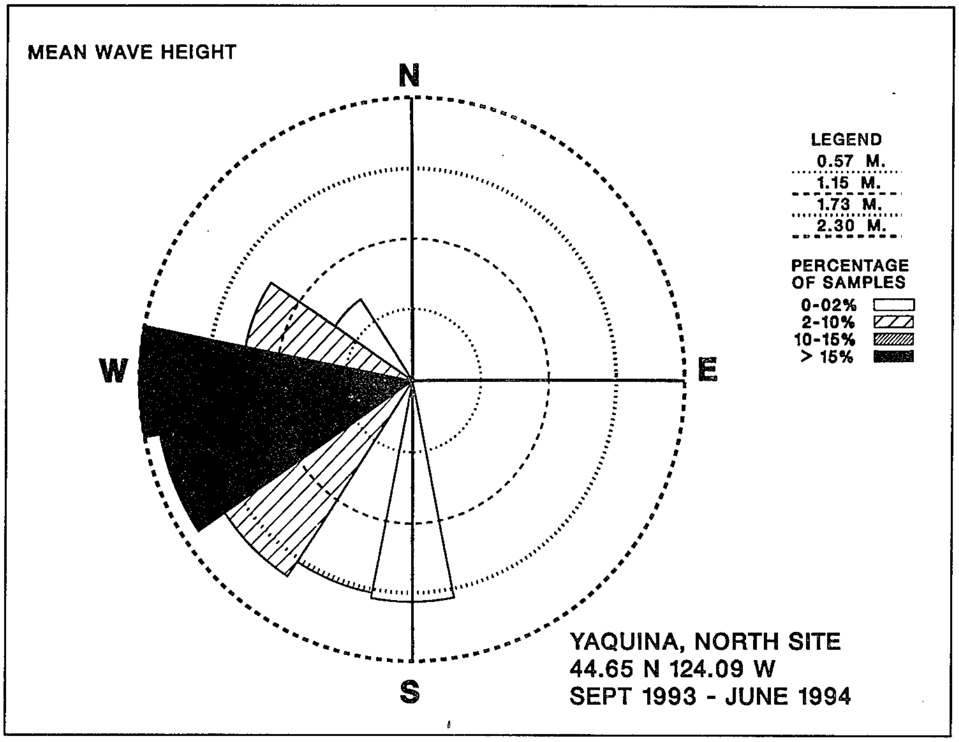


Figure 14. Directional wave rose for nearshore north DWG

5 Geophysical Survey

Introduction

A comprehensive bathymetric and geophysical survey was conducted in marine waters off Yaquina Bay at Newport, OR, during the period 5-23 August 1991. The main objective of this survey was to collect data to aid in assessing if geophysical conditions alone or in combination with other factors contributed to damage experienced at the Yaquina Bay north jetty. Other objectives were to provide accurate bathymetric data for possible physical modeling of the region around the north jetty and to determine bottom conditions for assessing the potential for anchoring in situ instruments for collecting wave and current measurements.

Overall project management was provided by Evans-Hamilton, Inc. (EHI). In addition, EHI acquired offshore tide measurements and provided tide data comparisons. David Evans and Associates provided the survey vessel and navigation, conducted bathymetric data collection and processing, and prepared maps of both bathymetric and geophysical data. Williamson and Associates conducted all geophysical data collection, processing, and interpretation.

Geophysical survey data were placed in a database established by NPP. This database also included photogrammetrically produced data, aerial photo analyses, and stone movement determinations prepared by the Corps of Engineers and contractors at the Yaquina Bay monitoring project area (see Chapter 7 for a description of the photogrammetry efforts). The purpose of this database was to provide much of the Yaquina Bay project information georeferenced to the same coordinate system for use in this and future studies.

This chapter discusses the equipment and procedures used in conducting the geophysical and bathymetric surveys, gives a description of the data collection, presents the survey results, and briefly describes the Portland District database. More details about the geophysical survey are given in a report prepared by Evans-Hamilton (1991).

Equipment and Control Procedures

The geophysical and bathymetric surveys were conducted onboard a 9.2-m (30-ft) aluminum V-hull survey vessel. The survey vessel was equipped with a Racal Survey Micro-Fix microwave navigation positioning system that utilized four shore stations for accurate positioning. Wind-induced waves restricted operating times for the survey from daybreak, when winds were negligible, to about 1300 hr, and when gradually increasing winds produced seas greater than 2 m (6 ft). No major storms affected the area during the study period.

Geophysical and bathymetric equipment

Standard bathymetric and geophysical data collection systems were integrated and automated to investigate the marine geology offshore of the Yaquina Bay area. The systems consisted of the following:

a. Precision echo sounder to determine bathymetry (topography of the seafloor).

b. Side-scan sonar to determine surficial characteristics of seafloor and jetties.

c. High-resolution subbottom profiling to determine layering of near-bottom sediments.

d. Seismic reflection profiling to determine deeper sediment layering and total sediment thickness above bedrock.

Figure 15 illustrates the configuration of geophysical instrumentation onboard the survey vessel.

Bathymetric data were collected with an Innerspace 448 thermal printing fathometer that included a 3-deg, 200-kHz transducer deployed approximately amidships off the port side of the vessel. A heave compensator was used with the fathometer to produce heave-compensated soundings by removal of water depth variations produced by wave and swell-induced motion of the survey vessel. Acoustic velocity profiles were measured with a velocity probe, and the data were used to calibrate the sound velocity used by the fathometer. A personal computer with Coastal Oceanographics software was used for real-time processing of the navigation and bathymetric data sets.

An EG&G side-scan sonar provided information on the surficial characteristics of the seafloor to either side of the survey vessel as it progressed along the trackline. For this survey the sonogram (acoustic picture of the seafloor) usually represented a total coverage, or range, of 75 m (246 ft) on either side of the survey trackline. The resultant sonogram depicted the amount of acoustic (sound) energy that was back-scattered (reflected) from varying seafloor

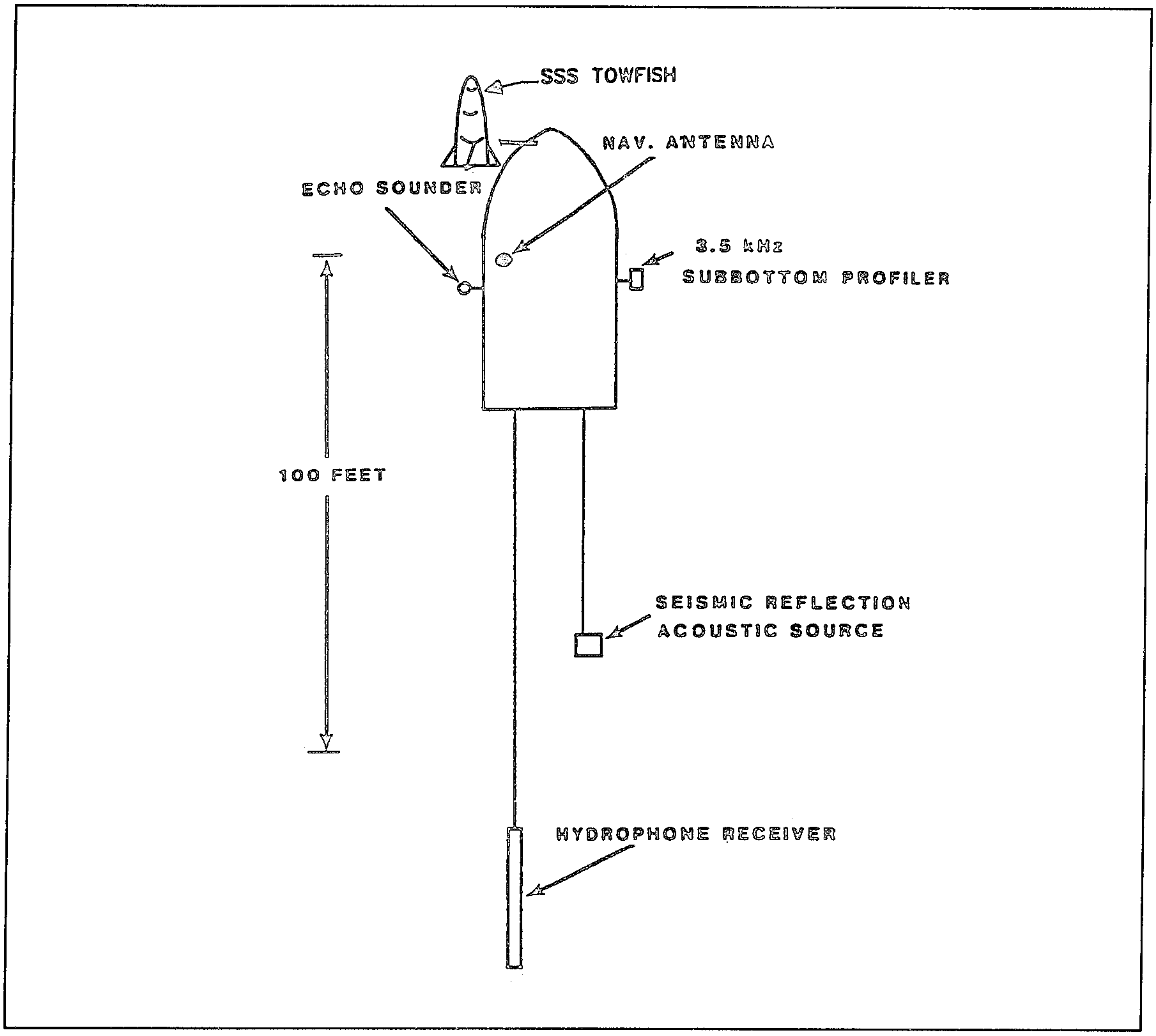


Figure 15. Configuration and deployment of geophysical instrumentation on survey vessel

sediments (different grain size), seafloor relief, and density of reflecting surfaces (i.e., rock outcrops).

A Datasonics high-resolution 3.5-kHz sub-bottom profiler deployed off the port side of the vessel approximately amidships was used to penetrate through the seafloor to identify layering in unconsolidated, fine-grained sediments. The depth of subsurface penetration is a function of the sediment density. During this survey, maximum subsurface penetration was 6 m (20 ft).

Subsurface penetration greater than that provided by the sub-bottom profiler was achieved using a 500-kHz low-resolution seismic reflection system (SRS). This system included a seismic reflection acoustic source and hydrophone receiver, and it was deployed off the stern of the survey vessel. Increased penetration by the SRS allowed broader coverage in establishing depth to bedrock, which ranged in some areas from approximately 15 to 45 m (50 to 150 ft).

Additionally, grab samples of seafloor sediments were taken to verify unconsolidated sediment types observed on side-scan sonar and sub-bottom profiler records. Sediment samples were taken at selected sites based on preliminary geophysical interpretations made during the project. Bedrock or outcrop samples could not be obtained with the grab sampler.

Tide gauges

Two electronic tide gauges were deployed in the project area during most of the geophysical survey to collect water level measurements for correction of survey results to a vertical reference datum and for comparison of inshore and offshore tides. A Stevens 420 Level Logger tide gauge was mounted on a stilling well at the front range marker of the Yaquina Bay Channel (Easting: 1073455.38, Northing: 367445.55). This gauge, which will be referred to as the inshore tide gauge, was linked to an Innerspace 453 Data Link that recorded and transmitted tide height via telemetry to the survey vessel. In addition, a temporary staff gauge was also deployed at the inshore tide gauge site for visual comparison to the inshore tide gauge data. The second electronic gauge was a self-contained, internally recording Seabird Wave and Tide recorder deployed on a fixed mooring offshore and northwest of the Yaquina Bay north jetty (Easting: 1066224, Northing: 367903). Both gauges were time-synchronized with sampling intervals of 1 min.

Most bathymetric survey data were processed while the survey was in progress. When corrections to mean sea level were needed, water level measurements from the inshore tide gauge at the front range marker were used. Data from the offshore tide gauge were not available until after the survey was completed. Hence, offshore water level data were intended only for use in postprocessing if it was judged that the survey results required additional corrections to the vertical reference datum.

Navigation positioning control

A control network consisting of newly placed and existing control stations was used to establish the horizontal control necessary for range-range positioning of the survey vessel and to set the vertical control for the inshore tide gauging site. Navigation control surveys for this study were conducted with four Trimble Navigation 4000 ST Global Positioning System (GPS) single frequency receivers deployed at four control stations surveyed by GPS. Additionally, supplemental differential surveying of the control network points was conducted with a surveying level and rod.

Hydrographic survey calibrations

In order to maintain accurate horizontal positioning control during surveying, predetermined vessel tracks and positioning control point data files were loaded into the computer. This provided real-time navigational information to the coxswain to help maintain the proper trackline. A baseline of known coordinates was established and crossed by the vessel at the beginning and end of each day. As the baseline was crossed, 1-sec range updates were recorded. The two daily baseline ranges were averaged and the result was compared to the known overall distance of the baseline to determine positioning accuracy. Deviation from the known distance was typically less than 1 m (3 ft).

The fathometer was calibrated daily by conducting tests inside Yaquina Bay. Static draft settings were checked and verified with acoustic velocity readings taken with the velocity probe. Other daily calibrations were conducted offshore of Yaquina Bay at one of two sites (depending on where surveying was being conducted). These tests included acquiring acoustic velocity profiles at 3-m (10-ft) intervals. From the velocity profiles a new speed of sound was computed from the arithmetic mean of the observations, and this value was input into the sounder prior to any data logging. In addition, the two sites were used as areas of repeatability where initial depths were logged by the fathometer. Throughout each day of the project, the survey vessel would return to these sites and log heave-corrected depth along with time and tide measurements. These reference measurements were used to determine mean elevation along with the standard and maximum deviations.

Each day while heading offshore and when returning to port, observations of water level and time were made at the temporary staff gauge located at the front range marker of the Yaquina Bay Channel (the inshore tide gauge site). These visual observations were compared to inshore gauge data. Over the course of the survey the hydrographer maintained a log consisting of range line numbers, gauge information, vessel speed, obstacles that inhibited coverage, and any other information that would be of value for data reduction and interpretation following the survey.

Data Collection

The general survey area in the vicinity of the Yaquina Bay north jetty was divided into individual areas which had different surveying requirements with regard to coverage and data acquisition (Figure 16). A description of these distinct regions and the type of data acquisition within each region is given below:

a. *General area.* This largest rectangular area, including the U-Shaped and Special Areas, extended 1.8 km (1 n.m.) north, west, and south of the tip of the Yaquina Bay north jetty. The eastward extent of the

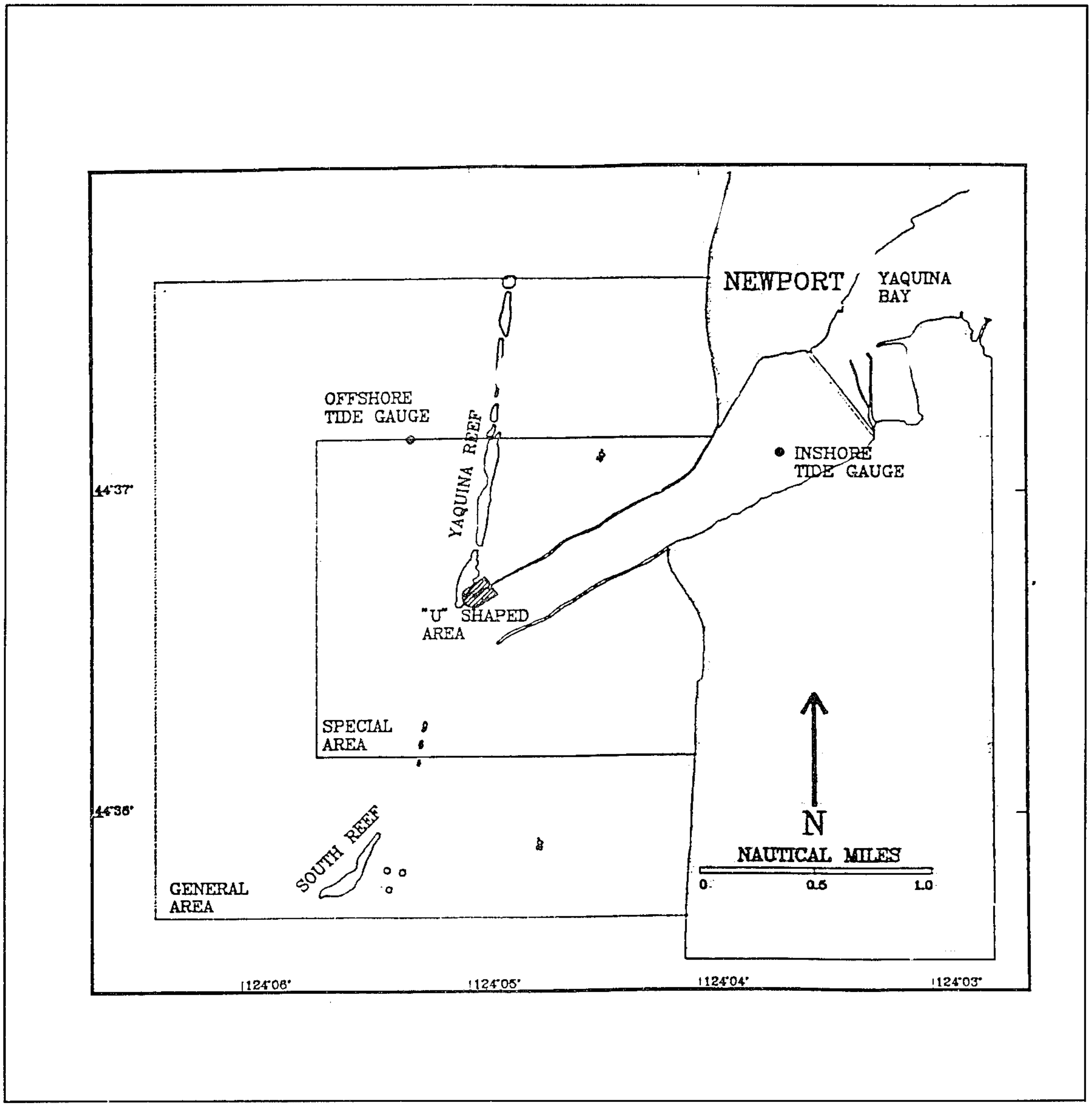


Figure 16. Yaquina Bay geophysical study areas

general area was the inshore region considered safely navigable by the pilot of the survey vessel. Portions of the General Area that were outside of the Special Area were surveyed with only bathymetric instruments. Bathymetric transects were oriented east-west at 23-m (75-ft) intervals.

b. *Special area.* The Special Area was a rectangular area extending 0.9 km (1/2 n.m.) north, west, and south of the tip of the north jetty (including the U-shaped area). The eastward boundary of this area was the inshore region considered safely navigable by the pilot of the survey vessel. Bathymetry and subbottom profiles were obtained on east-west lines at 12-m (40-ft) intervals. Seismic reflection data were obtained at 24-m (80-ft) line intervals, and side-scan sonar data were obtained at 73-m (240-ft) line intervals. The 73-m (240-ft) line interval provided 100 percent overlap in side-scan sonar coverage based on the 150-m (500-ft) range of the side-scan sonar sonogram.

c. *U-shaped area.* The U-Shaped area extended approximately 60 m (200 ft) north, west, and south of the tip of the Yaquina Bay north jetty. In this area, the geophysical systems were operated along a series of transects that paralleled the north jetty (north and south of the jetty). North-south transects were also run west of the jetty tip at 9-m (30-ft) intervals. Additional transects which acquired only bathymetric data were run at 3- to 6-m (10- to 20-ft) intervals perpendicular to the jetty.

d. *Reefs and shoreline.* Geophysical survey transects were run from north to south in the immediate vicinity of Yaquina Reef and South Reef (see Figure 16). These transects ran along the centerline of both reefs and parallel to the shoreline north of the north jetty at intervals ranging from 15 to 45 m (50 to 150 ft).

Geophysical Results

Data from the geophysical survey were reduced and processed, resulting in maps containing the following features from which interpretations were made:

a. Depth-to-bedrock contours.

b. Unconsolidated sediment thickness contours.

c. Bathymetry contours.

d. Surficial characteristics.

In addition, ten vessel transects from areas surveyed north, south, and west of the jetty were selected because of high geophysical data quality, coverage, and geologic features. Utilizing data from all geophysical measurement systems, geologic profiles of the ten selected transects were produced and overlain with bathymetry profiles to construct cross sections of the survey area for further interpretation.

Regional geology

The following description of regional and local geology was extracted from the draft historical report prepared by the Portland District (U.S. Army Engineer District, Portland 1989).

The geologic setting in the vicinity of Yaquina Bay is a stratified, westward dipping rock sequence, mainly consisting of marine sedimentary rocks, although several volcanic beds are observed. The Yaquina and South Reefs, for example, are composed of a 17-m-thick (55-ft-thick) layer of basalt.

Bedrock in the Yaquina Bay region is reported to be well-stratified rocks of the Miocene and younger ages. The general dip angle is shallow and relatively westward, between 10 and 20 deg. Strike of the rock sequences is usually within a few degrees of north. The age of these rock sequences becomes younger in the offshore direction.

Overlying the bedrock, the Nye Formation extends from the eastern edge of Yaquina Bay to approximately 730 m (2,400 ft) seaward of the Highway 101 bridge. The western contact for this formation is not located in the survey area defined for this study. The Nye Formation is predominantly composed of massively bedded mudstones interspersed with siltstone and sandstone lenses. These deposits support the coastal bluffs and their coastal terrace deposits below the town of Newport. This formation is also present inside the Yaquina Bay channel and underlies both jetties at their nearshore ends.

The Astoria Formation unconformably overlies the Nye Formation to the west and is composed of carbonaceous sandstones, siltstones, claystones, and mudstones, all of shallow, marine origin. Most of the jetty channel cuts through the Astoria Formation. This formation includes some thick- to thin-bedded harder rock layers, which form a wave-cut bench along the nearby shoreline. Few of the sedimentary layers produce prominent subsurface seismic reflections and outcrops along the seafloor.

Unconformably overlying the Astoria rocks at the outer section of the jetties is an unnamed rock unit that includes a 17-m-thick (55-ft-thick) basalt formation comprising the Yaquina and South Reefs. Other rocks observed in the offshore zone include layers consisting of basalt debris, fine-grained tuff beds, and fine-grained sandstones. The basalt is overlain by a sandstone unit.

Local geology

The Yaquina Reef and South Reef are formed from a basalt flow of approximately 17-m (55-ft) thickness (U.S. Army Engineer District, Portland 1989). The geology offshore of the reefs consists mainly of an unnamed unit that is thought to be composed of water-laid, fragmental basalt debris, a fine-grained tuff, and fine-grained sandstone. The unnamed unit lies unconformably over the Astoria Formation. The contact between the unnamed unit and the Astoria Formation lies within the outer reaches of the jetty channel, although the exact location of the contact is unknown.

The Astoria Formation is composed of olive-gray, fine- to medium-grained micaceous, arkosic sandstones and dark-gray carbonaceous siltstones, mudstones, and claystones, all of shallow marine origin. This formation underlies Yaquina Reef and is exposed towards the shore. The general geology east of South Reef is similar to that of the region east of Yaquina Reef. Much of the geology known within the study area has been identified by drilling and dredging conducted prior to the monitoring survey described in this chapter.

Depth to bedrock

A reduced map of the depth-to-bedrock contours (relative to mean sea level) for the General Area is shown in Figure 17 (reduction to report size has obscured much of the detail). The bedrock gradually slopes (approximately 5 deg westward) in an undulating pattern from approximately 9-m (30-ft) depths at Yaquina Reef and South Reef to bedrock depths averaging approximately 26 m (85 ft) in the offshore portion of the study area. A 17-m-deep (55-ft-deep) depression in the bedrock (saddle) is located between the south end of Yaquina Reef and the north end of South Reef. This depression was caused by an offsetting structural fault and by previous blasting and dredging to enlarge and deepen the entrance channel to Yaquina Bay (see Chapter 2).

A shallow bedrock channel is located adjacent to the eastern edge of Yaquina Reef and follows the directional trend of the reef (slightly northeast to southwest). The southern end of the channel is interrupted by the presence of the north jetty. Figure 18 is a seismic profile showing an apparent bedrock channel configuration. Subsequent 1993 investigations of the apparent buried bedrock channel of unconsolidated sediments shown on Figure 18 indicate this channel does not exist and the area consists entirely of bedrock with only a thin veneer of overlying silts and sands.

A steep-sided bedrock channel directed approximately north-south borders the eastern (shoreward) edge of South Reef (see Figure 17). The observed maximum depth to bedrock in this channel is approximately 50 m (165 ft). About midway along the reef, the channel bends to the southeast in a direction opposite to that of the reef and becomes slightly shallower, with depth to bedrock averaging 44 m (145 ft). The eastern boundary of this channel slopes upward to form a fairly flat-lying platform with depth-to-bedrock averaging about 9 m (30 ft). A small saddle trending north to south is observed in the flat-lying bedrock with an average depth of 13 m (44 ft).

Unconsolidated sediment thickness

Figure 19 is a reduction of a contour map of unconsolidated sediment thicknesses as determined from the geophysical survey. No unconsolidated sediments overlay the western edges of Yaquina Reef, the tip of the north jetty, and South Reef. Unconsolidated sediments gradually increase in thickness westward of the reefs to approximately 5 to 6 m (15 to 20 ft), thinning slightly towards the south, where the thickness is approximately 1.5 m (5 ft),

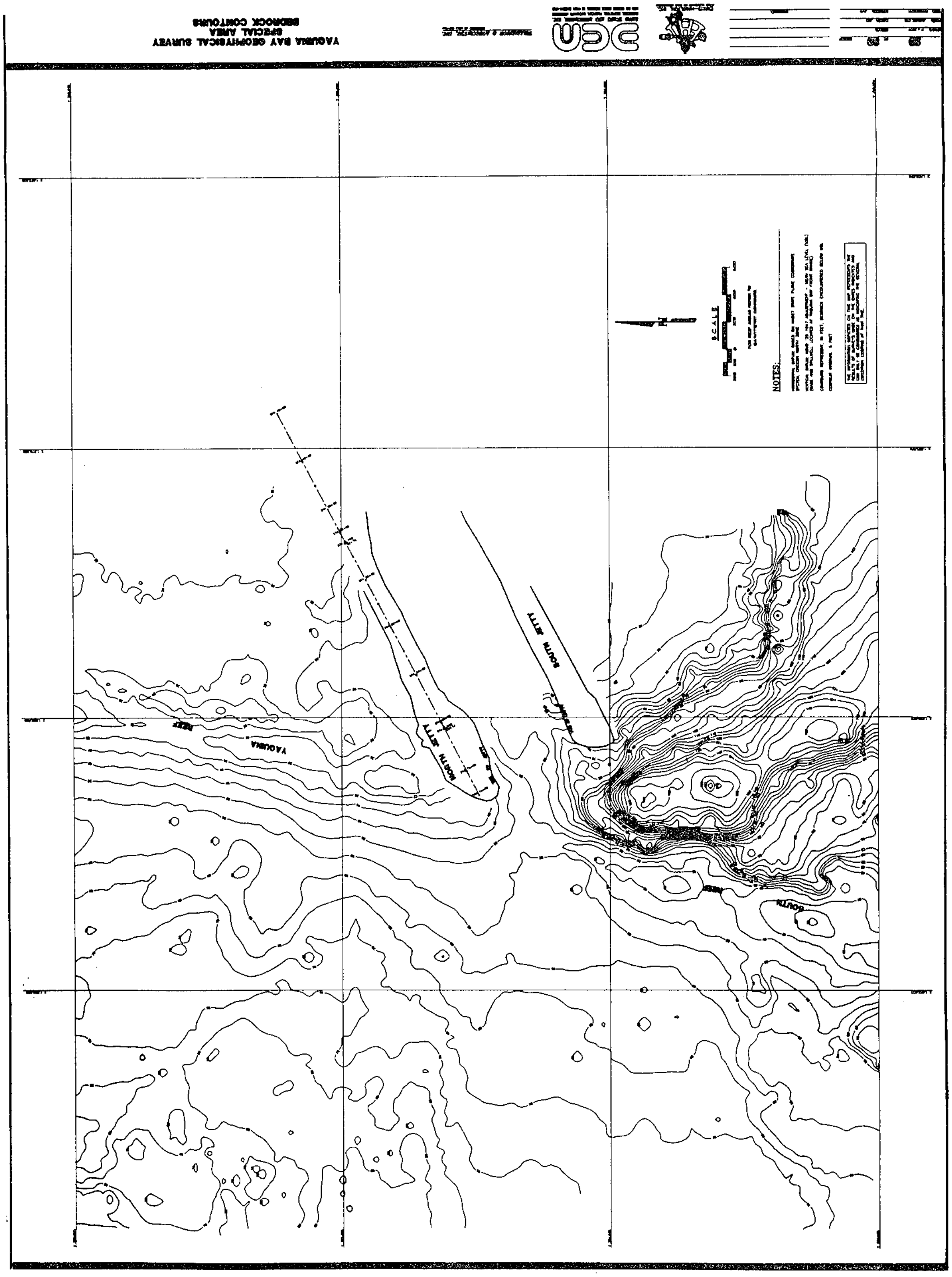


Figure 17. Yaquina Bay area depth-to-bedrock contours (relative to mean sea level)

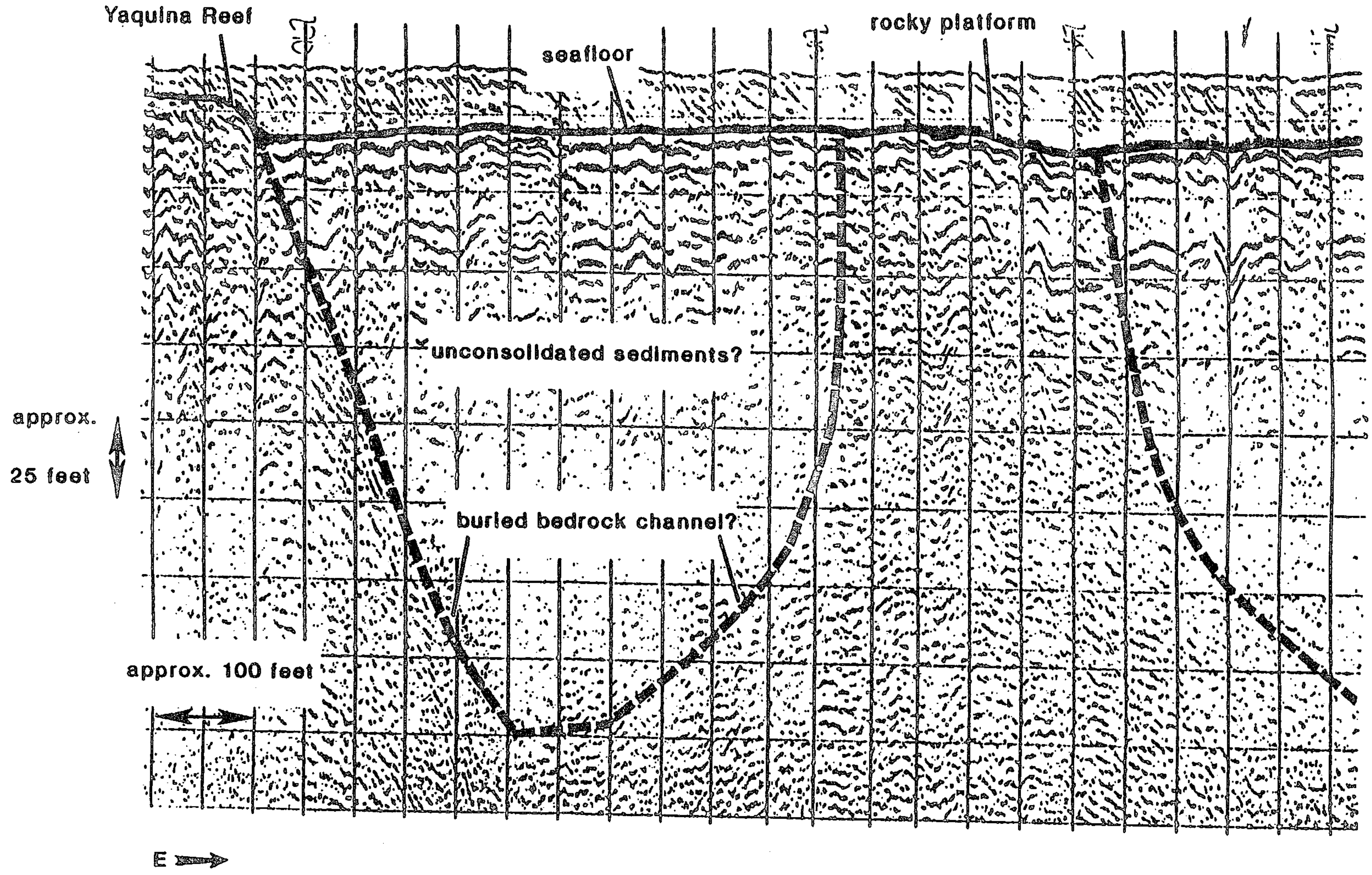


Figure 18. Seismic reflection profile showing buried bedrock channel

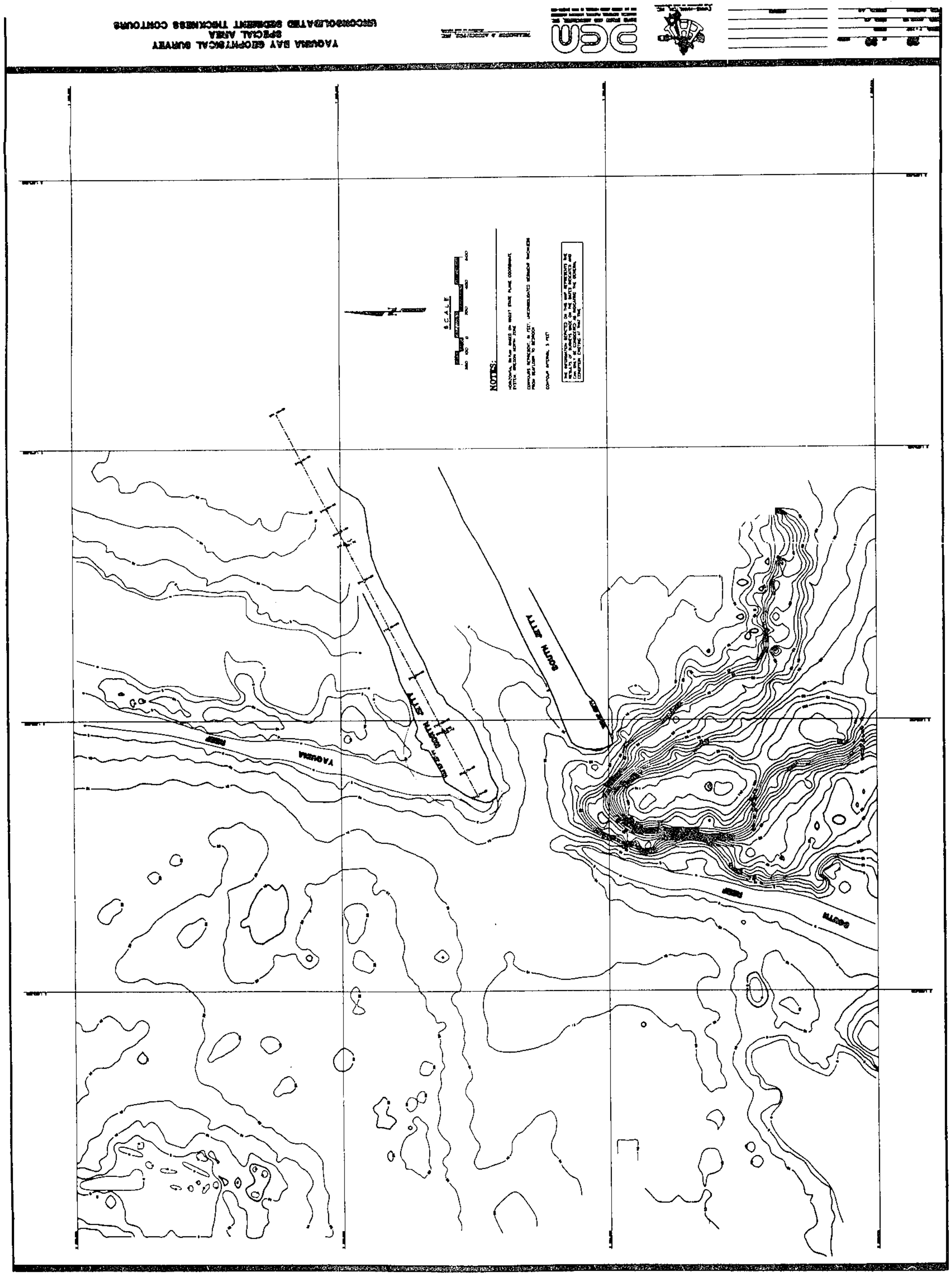


Figure 19. Yaquina Bay contours of unconsolidated sediment thickness

and to the west of South Reef. Maximum sediment thickness is approximately 7.6 m (25 ft). In the northwest and southwest portion of the study area, discontinuous rock outcrops were observed with no sediment cover.

Sediment thickness averages between 1.5 and 3.0 m (5 and 10 ft) in the eroded bedrock channel that runs along the eastern edge of Yaquina Reef. The rock platform adjacent to the channel and landward of the reef has no sediment cover, and sediment thickness gradually increases from nil at the rock platform to 6 m (20 ft) toward the shore.

Unconsolidated sediments up to 36 m (120 ft) thick fill the bedrock channel adjacent to South Reef. Because of the bedrock channel configuration (steep slopes on both sides) unconsolidated sediments are confined to the channel and are not found along the edge of South Reef. East of the South Reef channel and south of the south jetty on the flat-lying bedrock, unconsolidated sediment thickness averages about 3 m (10 ft). Also, unconsolidated sediment thickness in the channel jetty averages about 3 m (10 ft).

Bathymetry

Detailed bathymetry of the survey area collected as part of this monitoring effort is shown in Figure 20. Bathymetry contours in the region west of Yaquina Reef, the jetties, and South Reef follow the gentle sloping trend of the bedrock, a westward-facing slope of approximately 5 deg. The bathymetry covered on Figure 20 ranges from about 23-m (75-ft) depths in the west, rising to depths between 6 and 9 m (20 and 30 ft) at the Yaquina and South Reefs.

An elongated channel runs along the eastern edge of the Yaquina Reef in an approximately northeast to southwest trend, reaching depths greater than 10 m (32 ft). A shallow rock platform with an average depth of 8.5 m (28 ft) just east of the channel runs approximately north to south and has been identified as bedrock.

A smaller, elongated channel runs along the eastern edge of the South Reef and reaches depths greater than 16 m (52 ft) at the north tip of the reef. This channel is more discontinuous than the channel at Yaquina Reef because of a small high point located midway in the channel. A small saddle is located adjacent to the channel with average depths of approximately 13.5 m (44 ft). In areas east of the northern rock platform and the southern saddle, the bathymetry returns to the westward-facing 5-deg slope. In the southern area, depth varies from 13.5 m (44 ft) to less than 4.3 m (14 ft) towards the shore.

The channel between the jetties has an average depth of 13 m (42 ft). Also, two deeper areas were observed in the vicinity of the jetties. One area approximately 18 m (60 ft) in depth is located southwest of and near the tip of the north jetty. The second deeper area is located at the tip of the south jetty, and it is approximately 18 to 21 m deep (60 to 70 ft deep).

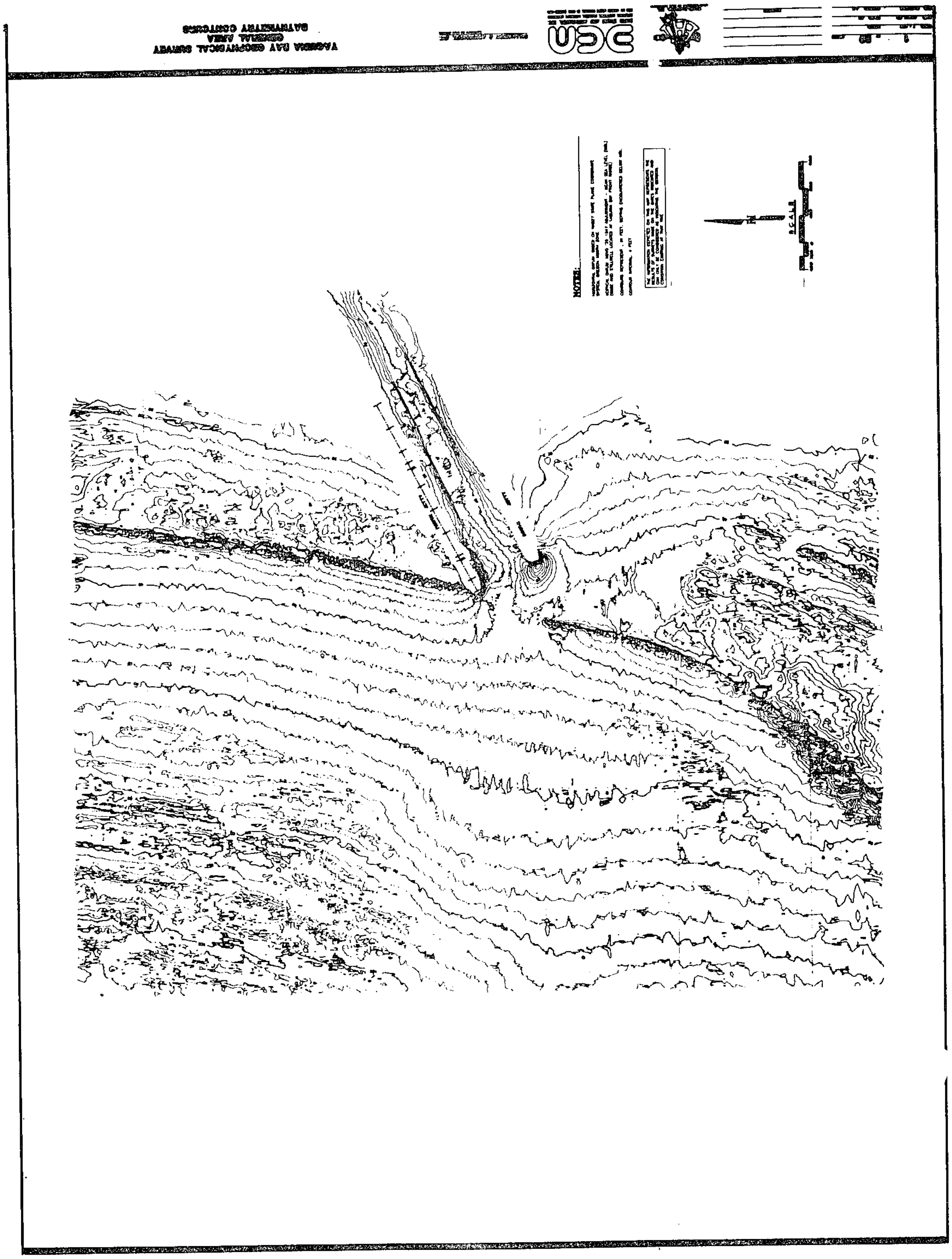


Figure 20. Yaquina Bay "General Area" detailed bathymetry

Surficial characteristics

Seafloor surficial materials offshore of the reefs consist primarily of fine- to medium-grained sands and silts. However, an elongated zone of coarse-grained sands that is approximately parallel to Yaquina Reef is present offshore. Southwest of that zone and due west of the entrance channel to Yaquina Bay, a second, larger patch of coarser-grained sediments and rock was observed. Both areas were identified by higher reflectivity on the side-scan sonar images. Samples collected from the second area west of the channel mainly consisted of medium-grained sands and sand dollars. One sample from that area contained small amounts of fine-grained sands.

The most northwest and southwest portions of the study area exhibited zones of discontinuous or isolated rock outcrops. Westward dipping stratification was observed in seismic reflection profiles traversing those outcrops. Samples collected from a discontinuous outcrop in the southwestern General Study Area consisted of medium-grained sands and fragmented siltstones, sandstones, and shells.

The Yaquina and South Reefs were clearly identified on side-scan sonar images by a hummocky reflectivity pattern as shown on Figure 21. Also shown on the figure is the shallow bedrock platform located east of Yaquina Reef which is an area of high reflectivity. Surficial material in areas adjacent to the rock platform is most likely composed of fine- to medium-grained sand and silt.

A side-scan image of the intersection between the north jetty and the Yaquina Reef is shown in Figure 22. This image depicts a displaced jetty stone located approximately 15 m (50 ft) to the north of the Yaquina Bay north jetty, and it shows the approximate location of the toe adjacent to the notch in the north jetty. Surficial materials east of South Reef and south of the south jetty consist of fine- to medium-grained sand and silt. Several rock outcrops are located in this area. Two sediment samples collected in this area consisted of fine- to medium-grained, well-compacted sand. Sand waves were observed in the area between the jetties. These sand waves were presumably created by currents flowing toward the offshore, within the jetty channel. Additional side-scan sonar details and interpretation are given in Chapter 6.

Water Level Measurements and Comparison

Water levels were calculated from the offshore tide gauge using a value of 1,026 kg/m^3 for ocean water density and correcting for atmospheric pressure variations. It was assumed that the mean water levels computed at both the offshore and inshore tide gauge would represent a common elevation datum. Those mean values were subtracted from each tide time series and the resulting water level variations are compared graphically on Figure 23.

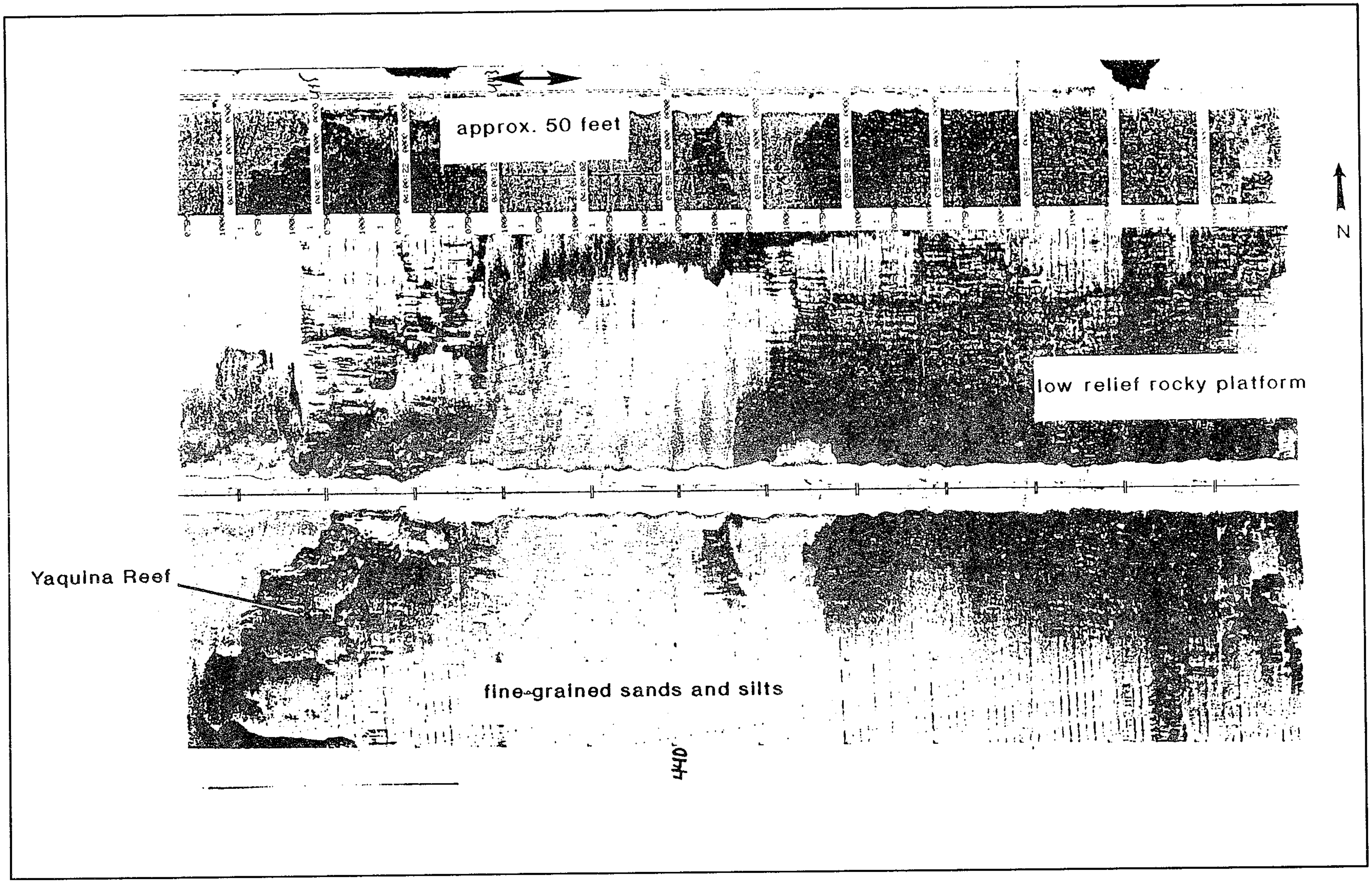


Figure 21. Side-scan sonar image showing Yaquina Reef

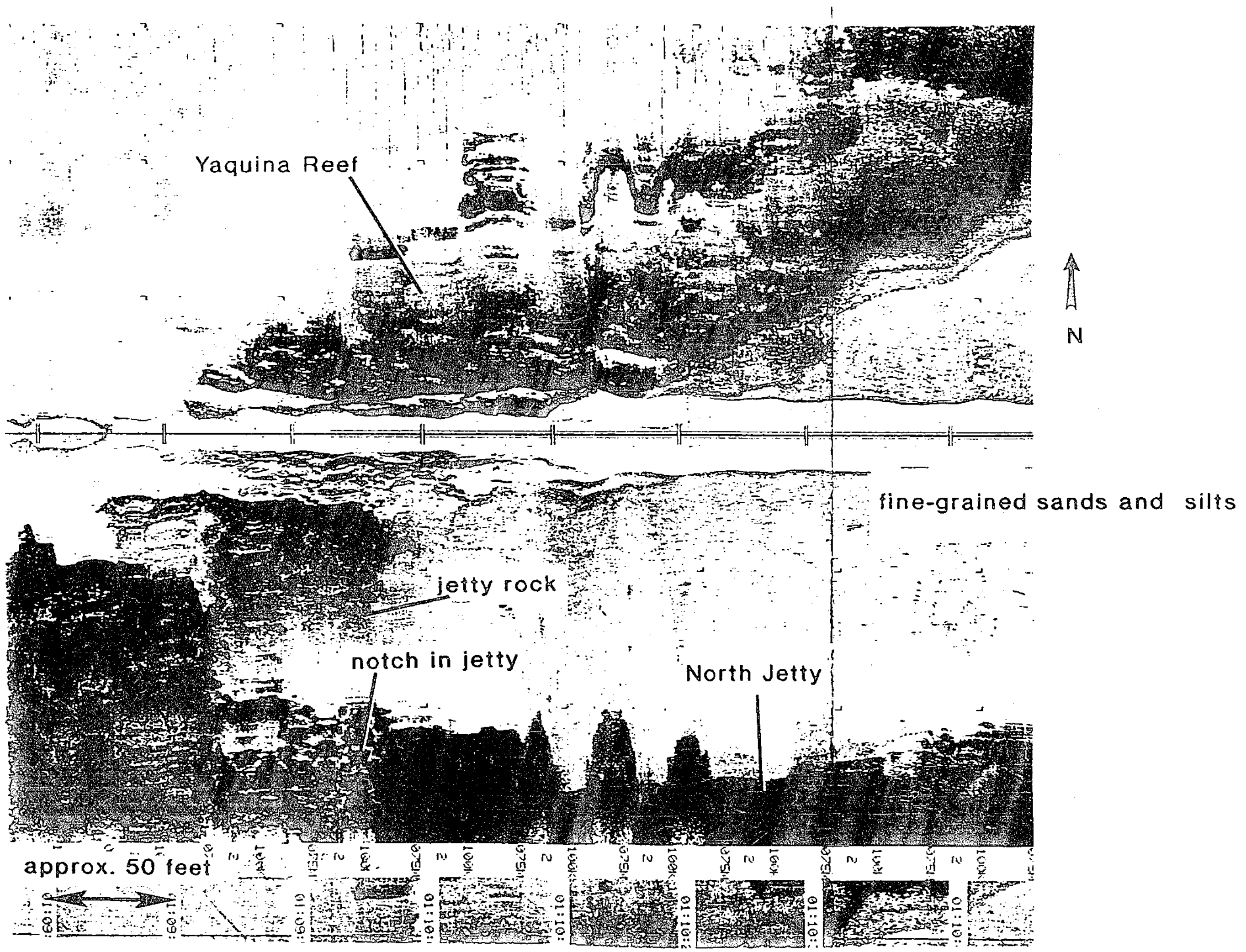


Figure 22. Side-scan sonar image showing Yaquina Reef and north side of the north jetty

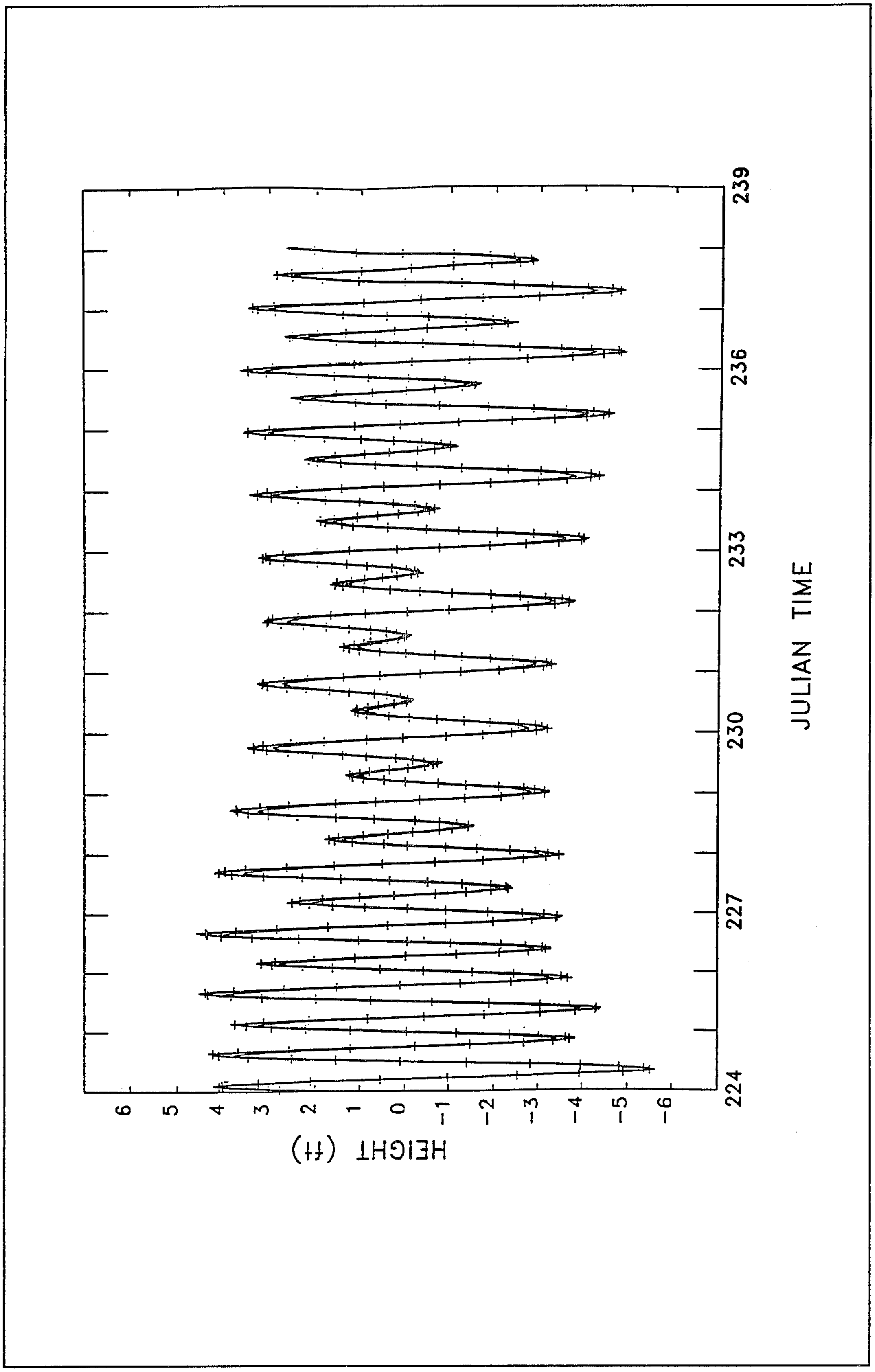


Figure 23. Time series of tide levels during study period at offshore (solid) and inshore (+) gauges

The comparison between both data sets over the entire time of the survey showed that the difference in height between the two stations was more pronounced on the higher/lower ends of the tidal cycle. The inshore station (+ marks) exhibited higher high tides and lower low tides than the offshore station (solid lines). Water level differences varied between ± 0.3 m (± 1 ft). Water level variation on the inshore station was observed to lag the offshore station by as much as 20 min.

Without more in-depth analysis of the data using classical tidal constituent analysis, the true nature of the water level variation between the two stations cannot be determined. However, it was felt the observed differences are caused more by flow restrictions as opposed to a resonance of the bay to the tidal period. In a separate task, a portion of the bathymetric data was recalculated using the offshore water level data. The resulting changes in bathymetric contours were insignificant. It was concluded that the 1991 survey results were reliable when adjusted for tide level using the inshore tide gauge.

Description of the Portland District Database

Data collected from the 1991 geophysical survey were placed in the Yaquina north jetty database established by NPP. In addition to the geophysical information, the database included photogrammetrically produced data, stone movement determinations, and aerial photo analyses prepared or collected by the Corps of Engineers and contractors at the Yaquina Bay project area (see Chapter 7). Database information dates from 1989.

The database was set up on an Intergraph Microstation utilizing different modules. All data within the database are geo-referenced to the same coordinate system. Uses of the database include production of digital terrain models and analyses of aerial photos for jetty-stone movements. Table 19 provides a list of all the elements within the database resulting from the Yaquina Bay north jetty MCCP monitoring project.

Table 19
Yaquina North Jetty Database

Filename (xxxx.dgn)	Description
Corps of Engineers Fixed Wing Photogrammetry	
yaq89, yaq90, yaq92	1989, 1990, and 1992 contours by modeler
yaq8990, yaq9091, yaq9192, yaq8992	1989-1992 contour differencing
yaq89phot, yaq90phot, yaq91phot, yaq92phot	1989-1992 fixed wing photogrammetric contours
sound9089, sound9190	Delineates area of volume computations, shows soundings
xsection	1989-1992 photogrammetric cross sections, 10-ft intervals
xsec7230	X-section at 72+30 of jetty, north and south from geophysical and photogrammetry data
Corps of Engineers Stone Movement Determinations	
yaquina	1989-1993 stone movements, jetty extents, and general areas of change
1991 Geophysical Information	
dea-1, dea-2, dea-3, dea-4, dea-5	General Area Bathymetric Contours
dea-6, dea-7, dea-8, dea-9, dea-10	Special Area Bathymetric Contours
dea-11	U-Shaped Area Bathymetric Contours
dea-12, dea-13, dea-14, dea-15, dea-16	General Area Spot Elevations
dea-17, dea-18, dea-19, dea-20, dea-21	Special Area Spot Elevations
dea-22	U-Shaped Area Spot Elevations
dea-23, dea-24, dea-25, dea-26, dea-27	Special Area Bedrock Contours
dea-28	U-Shaped Area Bedrock Contours
dea-29, dea-30, dea-31, dea-32, dea-33, dea-34	Special Area Unconsolidated Sediment Thickness Contours
dea-35	Special Area Surficial Features Map
dea-36	U-Shaped Area Surficial Features Map
dea-37, dea38, dea-39	Special Area (South/North/Jetty) Geologic Profiles

(Continued)

Table 19 (Concluded)

Filename (xxxx.dgn[1])	Description
Helicopter Photogrammetry (1992 Files)	
top04921 and top04922	Topography, April 1992
rbdavis.control	ASCII file of survey control for R.B. Davis
corps.control	ASCII file of survey control for Corps of Engineers
pnt0492.xyz	Photogrammetrically produced xyz points for DTM
yaqctl	Sheet with control points
xsec0492	Cross-section plots, 10-ft intervals
1993 Files	
all93ref	Plate showing both dates of contours and differencing
del93ref	Plate showing differencing elevation net
delcon	Differencing elevation 1-ft contours
deldtm	Differencing elevation net
grid93	1993 net
net0492	April 1992 net
pnt93	1993 net
topo93a	1993 1-ft contours, innermost part of jetty
topo93b	1993 1-ft contours, middle part of jetty
topo93c	1993 1-ft contours, tip of jetty
xsec93	Cross sections
yaqctl93	Yaquina control
pnt93.asc	ASCII file of datum points
xsec93.asc	ASCII file of cross-section points
yaqctl93.lst	List of control points
yaqctl93.cdf	List of control points in alternate format

[1] Unless otherwise noted.

6 Side-Scan Sonar

Introduction

A geophysical investigation was conducted during the period August 5-23, 1991, in the marine waters around the Yaquina Bay north jetty as part of the MCCP monitoring of the north jetty. Chapter 5 provides details of this investigation. During the geophysical survey extensive data were obtained around the north jetty seaward end using a precision echo sounder and a side-scan sonar. These data were acquired and analyzed to provide information about the underwater configuration of the north jetty toe and the surrounding seafloor.

Analysis and interpretation of these data helped in evaluating various north jetty damage hypotheses. One of the key elements of the interpretation was determining with confidence the point of intersection of the jetty toe and Yaquina Reef. Previous documents show the tip of the north jetty resting on the Yaquina Reef as shown on Figure 4; however, it was necessary to verify this reef/jetty intersection and to map the structure toe for possible future modeling efforts. This chapter presents the results of the side-scan sonar analysis and interpretation.

Survey Instrumentation

The echo sounder used for the survey was an Interspace Model 448 operating at a nominal 200 kHz. The transducer had a 3-deg beam width and was mounted amidships in a sea chest. A TSS 320B processor/display unit linked with a TSS 325 pent-axial heave-roll-pitch sensor was hardwired to the echosounder to produce heave-compensated soundings on the analog echo sounding records.

The side-scan sonar was an EG&G Model 260 operating at a nominal 100 kHz. The range setting of the side-scan sonar used during the survey was either 50 m or 75 m (164 ft or 246 ft) covering a swath of the seafloor of either 100 m or 150 m (328 ft or 492 ft). The EG&G Model 260 has an image-correcting capability that corrects the sonar image for slant range. This correction removes the section of the record that represents returns from the water column beneath the sonar tow body, making the image dimensionally correct in the direction perpendicular to the tow body. During the survey it was not always possible for the side-scan sonar to track bottom, which is a necessary requirement for the instrument to correct the image for slant range. Both corrected and uncorrected records were present in the data set.

Survey Data Set

In the immediate area surrounding the tip of the north jetty, 78 track lines of echo sounder data were run, with an average line spacing of roughly 6 m (20 ft). Of the 78 track lines of echo sounder data, 17 lines covering the three sides of the north jetty tip are presented here to describe the in-depth analysis applied to the data.

Side-scan sonar data were also obtained on 27 of the 78 echo sounder lines. Waves encountered during the survey had a significant effect on the quality of the side-scan sonar data. Many of the side-scan sonar images exhibited geometric distortions caused by wave-induced translational and rotational instabilities of the side-scan sonar tow body. These geometric distortions made interpretation of the side-scan sonar images difficult. The four most useful side-scan sonar records were selected for detailed analysis, along with the 17 selected bathymetric echo sounder traces. Run lines for the selected bathymetric and side-scan sonar data are shown on Figure 24. Three of the side-scan sonar lines were run without echo sounder data, whereas echo sounder and side-scan sonar data were collected synoptically on one line.

Method of Analysis

Side-scan sonar records obtained in the vicinity of the tip of the Yaquina Bay north jetty show areas on the seafloor that produced strong acoustic return signals recorded by the side-scan sonar tow body. An example of this strong acoustic return is shown in Figure 25. The track of the tow fish is the heavy center line of the three closely spaced lines running from left to right in the middle of the record. The tick marks along the track of the tow fish correspond to the timed event marks shown on the upper portion of the Figure 25 image. The position of the towbody corresponding to the tick marks was determined from the navigation data and noted in the field records.

Using well-established side-scan sonar image interpretation techniques, the light areas shown on the Figure 25 image were identified as unconsolidated sediments and the dark areas were identified as "rock." The key question in terms of the underwater configuration of the north jetty tip was differentiation between reef rock and jetty armor stone. Because of geometric distortions in the side-scan sonar records, this question could not be answered using only side-scan sonar images. Instead, the analysis had to be performed taking into account complimentary echo sounder data.

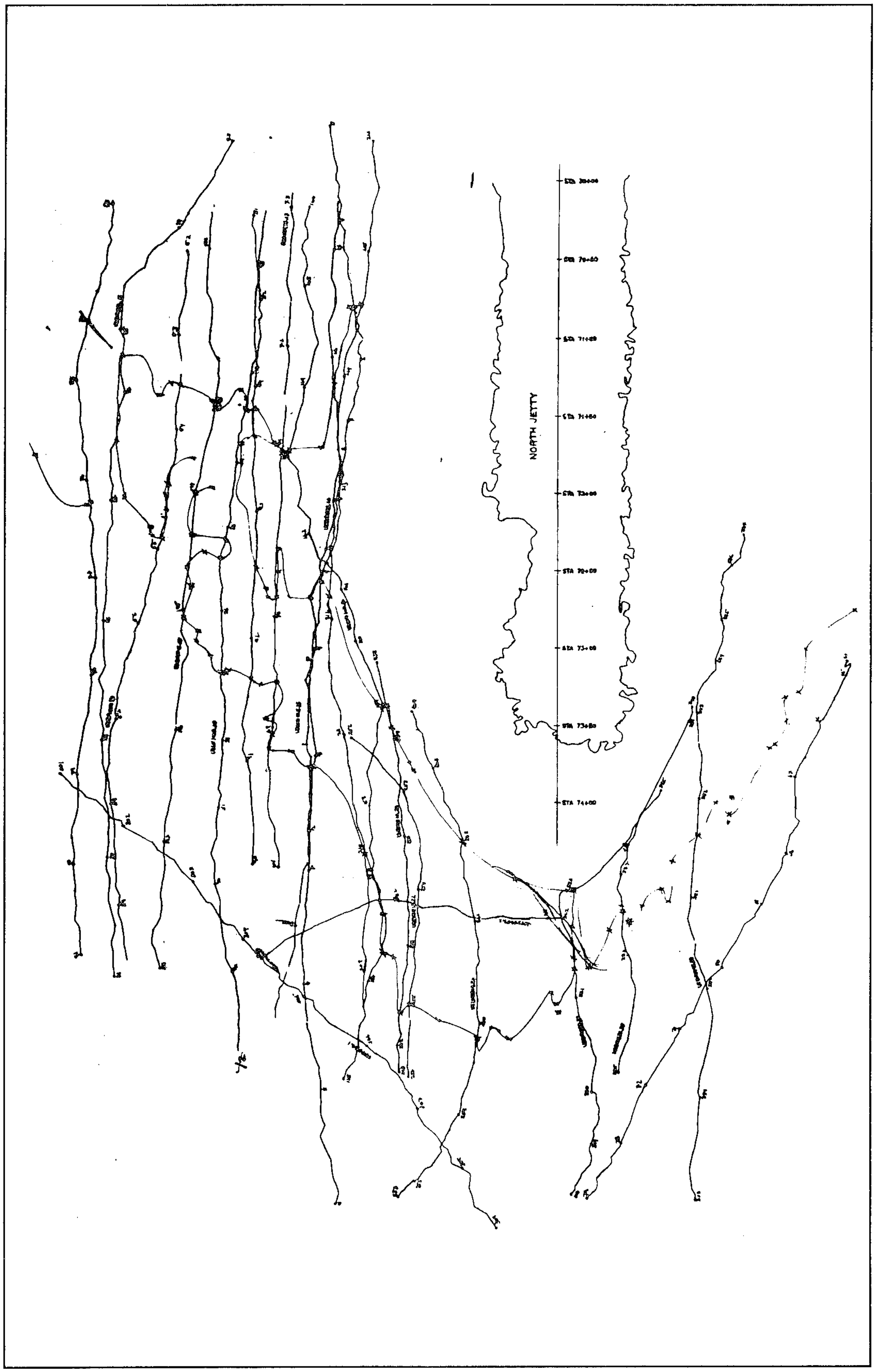


Figure 24. Selected echo sounder and side-scan sonar tracklines around the north jetty

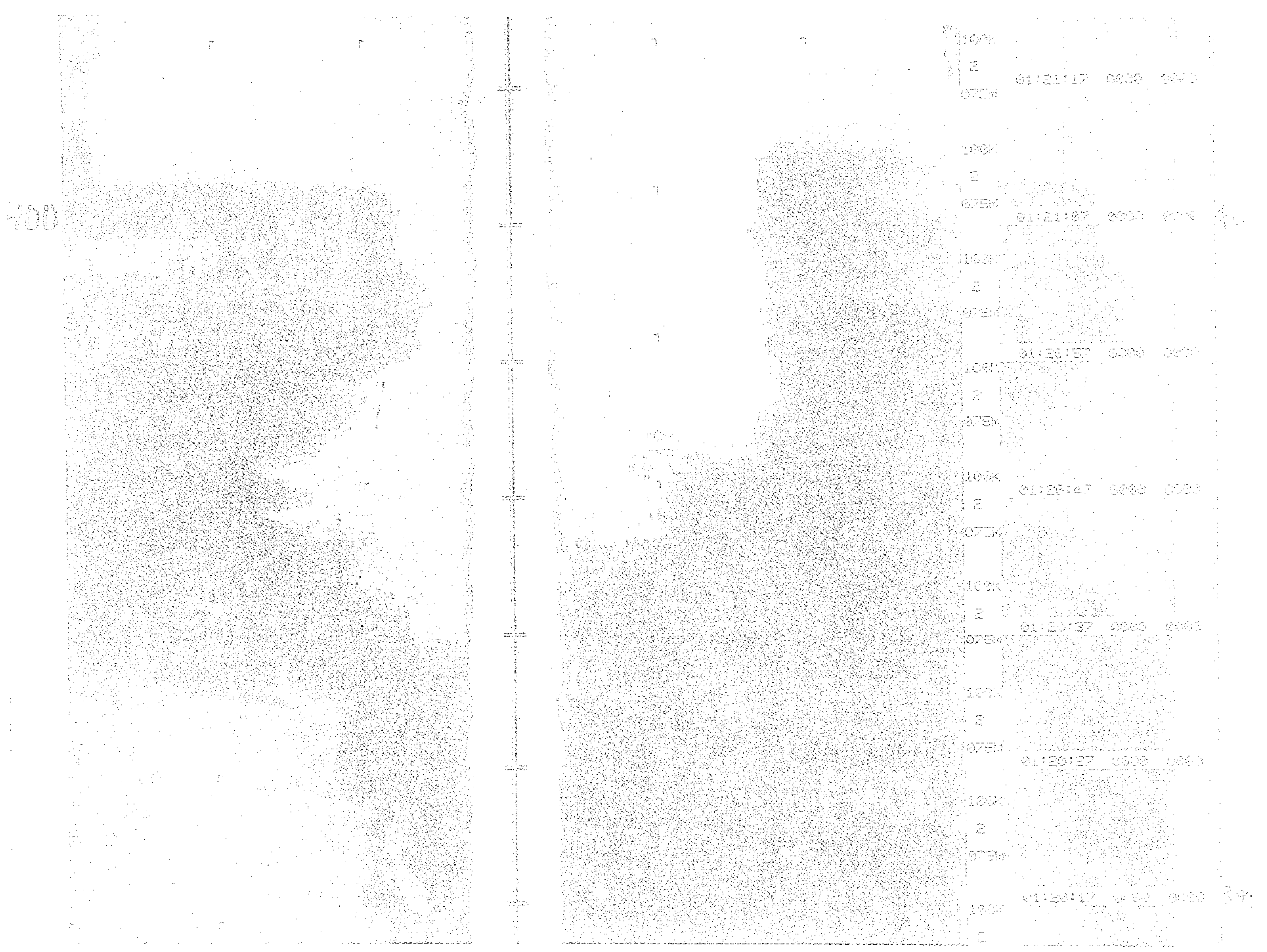


Figure 25. Example of side-scan sonar data showing strong reflections from rock (dark portion)

Examples of echo sounder data collected on track lines near the tip of the Yaquina Bay north jetty are shown in Figure 26. The numbered tick marks on the figure are event marks corresponding to positions that were noted in the navigation record. The vertical length scale shown on Figure 26 was based on the echo sounder's range setting, and the along-track (horizontal) length scale was estimated from the navigation data.

The top bathymetric trace shown on Figure 26 was acquired on a track line that was aligned somewhat perpendicular to the reef approximately 275 m (900 ft) north of the center axis of the north jetty. The left side of the trace is offshore of the reef, and the right side is landward of the reef as indicated by a navigation chart for the area. The top trace on Figure 26 shows a comparatively smooth hummocky profile with a steep face on the landward (right) side and a 1.5-m to 2.0-m (5-ft to 7-ft) dip or hole in the seafloor next to the face. The corresponding side-scan records (not shown) indicated a transition from unconsolidated sediment to rock (i.e., from light to dark images) moving from left to right along this track line between event marks 99 and 100. Moving further onshore (to the right) there was another transition from rock back to unconsolidated sediments at approximately event mark 102. The groove seen to the right of event mark 101 was also evident in other profiles, and it is a feature that runs along the Yaquina Reef.

The bottom bathymetric trace shown on Figure 26 was also acquired on a line perpendicular to the reef, but this run was approximately 55 m (180 ft) north of the north jetty center line (i.e., much closer to the north jetty than the top trace). As in the top trace, seaward is to the left of the trace, and landward is toward the right. This echo sounder trace shows a "rougher" profile that also exhibited a steep face on the right (shoreward) side and a 1.5-m to 2.0-m (5-ft to 7-ft) dip or hole in the seafloor next to the steep face. Moving left to right, the side-scan sonar record indicated the transition from unconsolidated sediment to rock along this track line was located approximately around event mark 69, and the transition from rock back to unconsolidated sediment was at event mark 71.

Between event marks 70 and 71 on the lower trace of Figure 26, there was a section of rock with pronounced "roughness elements." The general size of these roughness elements (2-3 m (7-10 ft)) is consistent with the diameter of armor stones used to construct the tip of the north jetty. The corresponding spatial positions of the roughness elements near event mark 71 was located on the side-scan sonar image shown in Figure 27. As labeled on the figure, there were three closely spaced rounded objects at this location that were interpreted to be jetty stones. The remainder of the rock section shown on the bottom trace of Figure 26 between event marks 69 and 70 is about as smooth as that in the top trace.

Aided by the side-scan sonar record shown in Figure 27, the bottom echosounder trace of Figure 26 was interpreted to be a section of the Yaquina Reef with jetty armor stones resting on the reef, whereas the top trace of Figure 26 shows a section of the Yaquina Reef without jetty stones. The noticeable dip

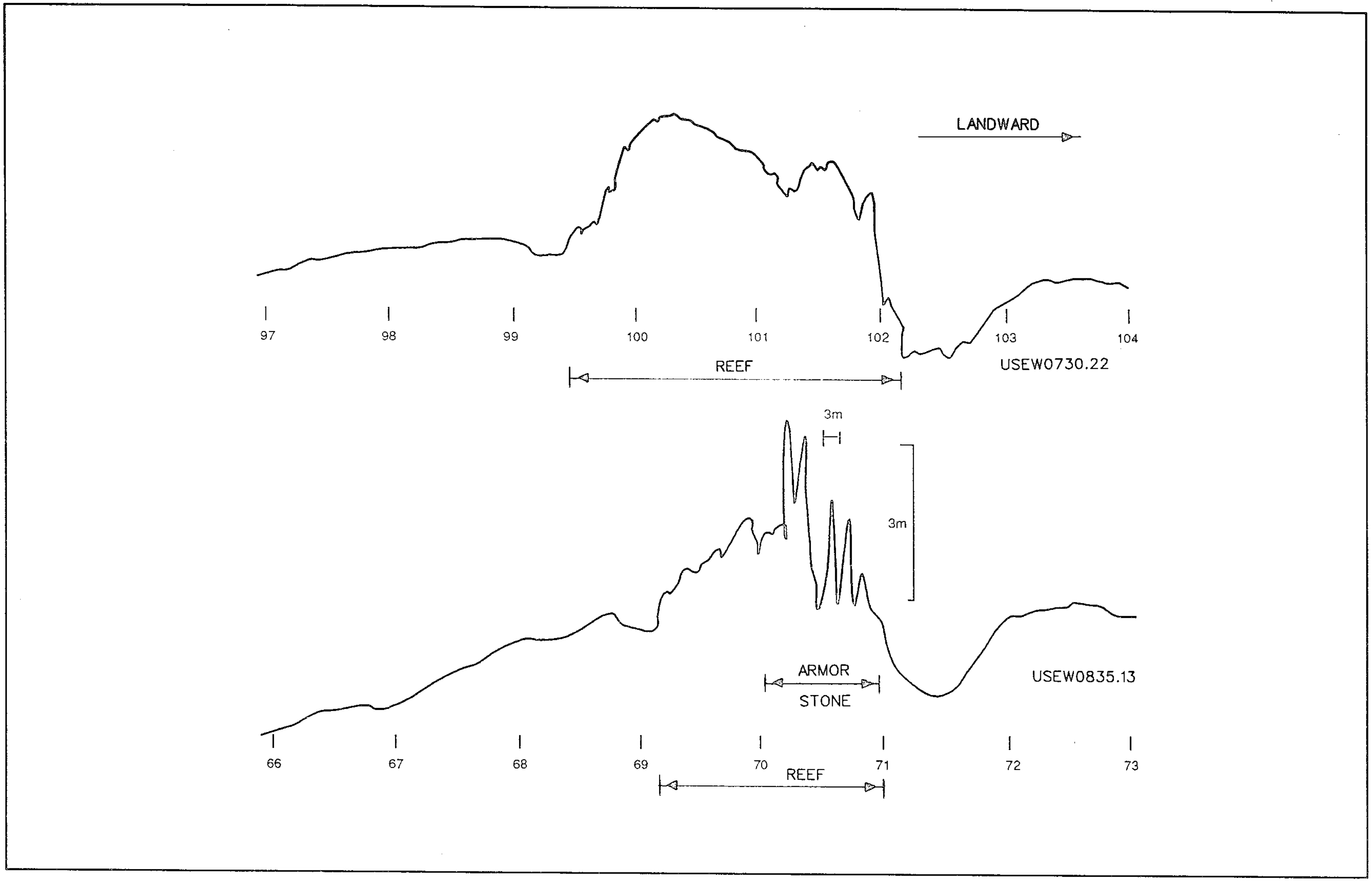


Figure 26. Examples of echo sounder traces transecting the Yaquina Reef

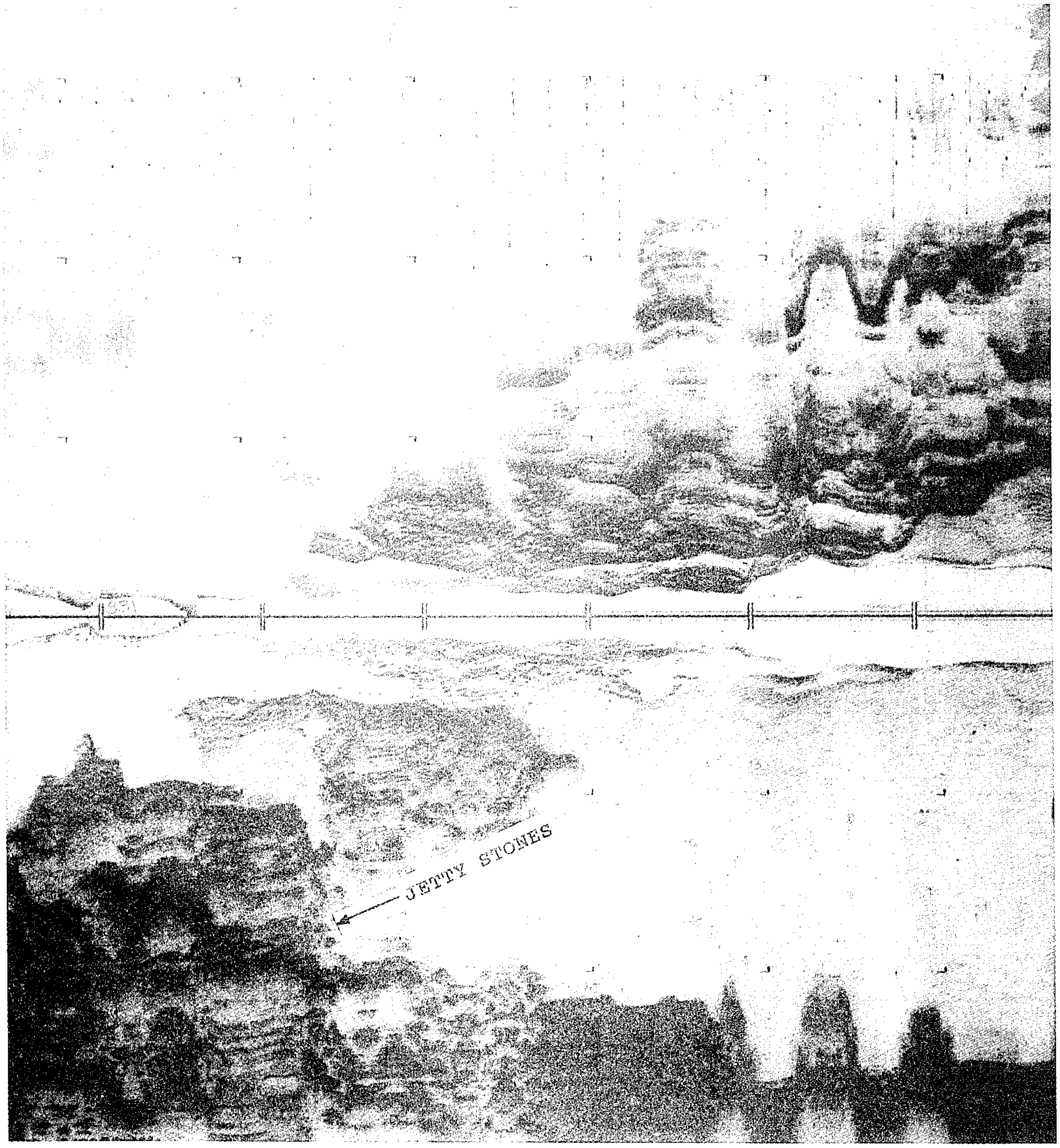


Figure 27. Side-scan sonar image from north side of the Yaquina Bay north jetty

evident in both echo sounder traces landward (right) of the steep eastern face of the reef was interpreted to be a scour trench in unconsolidated sediments.

The above example illustrates the method used in this study to analyze and interpret the collected echo sounder and side-scan sonar data. Similar analysis and interpretation formed the basis for determining the underwater toe configuration of the Yaquina Bay north jetty.

Data Analysis

For analysis, the 17 bathymetric traces and accompanying side-scan sonar lines were partitioned into four groups, denoted as "north side of jetty," "northwest side of jetty," "west side of jetty," and "southwest side of jetty." These four areas were defined by the boxes drawn on Figure 28. Each box has one side that is not a straight line. This crooked side is the actual track line for the side-scan sonar image analyzed in conjunction with the echo sounder track lines within that box.

The bathymetric traces corresponding to each box were dimensionally adjusted in the horizontal along the track line to coincide with the horizontal scale of the side-scan sonar images. (Note that the horizontal and vertical scales on the echo sounder profiles are not the same.) Track lines for the 17 bathymetric records were plotted and overlain on the side-scan sonar images. This technique facilitated using the side-scan sonar image to identify particular features evident on each of the 17 bathymetric traces presented in this section. Accumulation of information from many of the 17 track lines in the vicinity of the north jetty tip provided an understanding of the orientation of the jetty toe relative to the Yaquina Reef and regions of unconsolidated sediments.

North side of jetty

Figure 29 shows the side-scan sonar image recorded along track line USEW1012.25. North is to the top of the figure, and landward is toward the right of the figure. Overlain on the image are six bathymetric track lines that were rescaled to correspond to the side-scan sonar image horizontal scale.

On the jetty side (bottom side) of the side-scan sonar tow fish track shown in Figure 29 (near side-scan sonar event marker 8), rounded strong reflectors can be seen in the side-scan sonar image that have length dimensions on the order of 2.5-3.0 m (8-10 ft). These rounded objects were interpreted to be individual jetty stones. Further seaward on the track line between event marks 9 and 13, there are no rounded images characteristic of jetty stones, which indicated an absence of jetty stones in this location.

Bottom profiles for the echo sounder trace lines overlain on Figure 29 are displayed in Figure 30. Generally, the profiles are arranged in order beginning with the most northerly profile and moving closer to the side-scan sonar track. The bathymetric traces are relatively smooth and hummocky with the exception of a roughness element near event mark 74 on track line USEW1038.1 (top profile on page 89), and some roughness elements around event mark 93 on track line USEW0840.11 (middle profile on page 90).

The side-scan sonar image of Figure 29 depicted fingers of rock to the north (top side) of track line USEW1038.1. These rock fingers have been

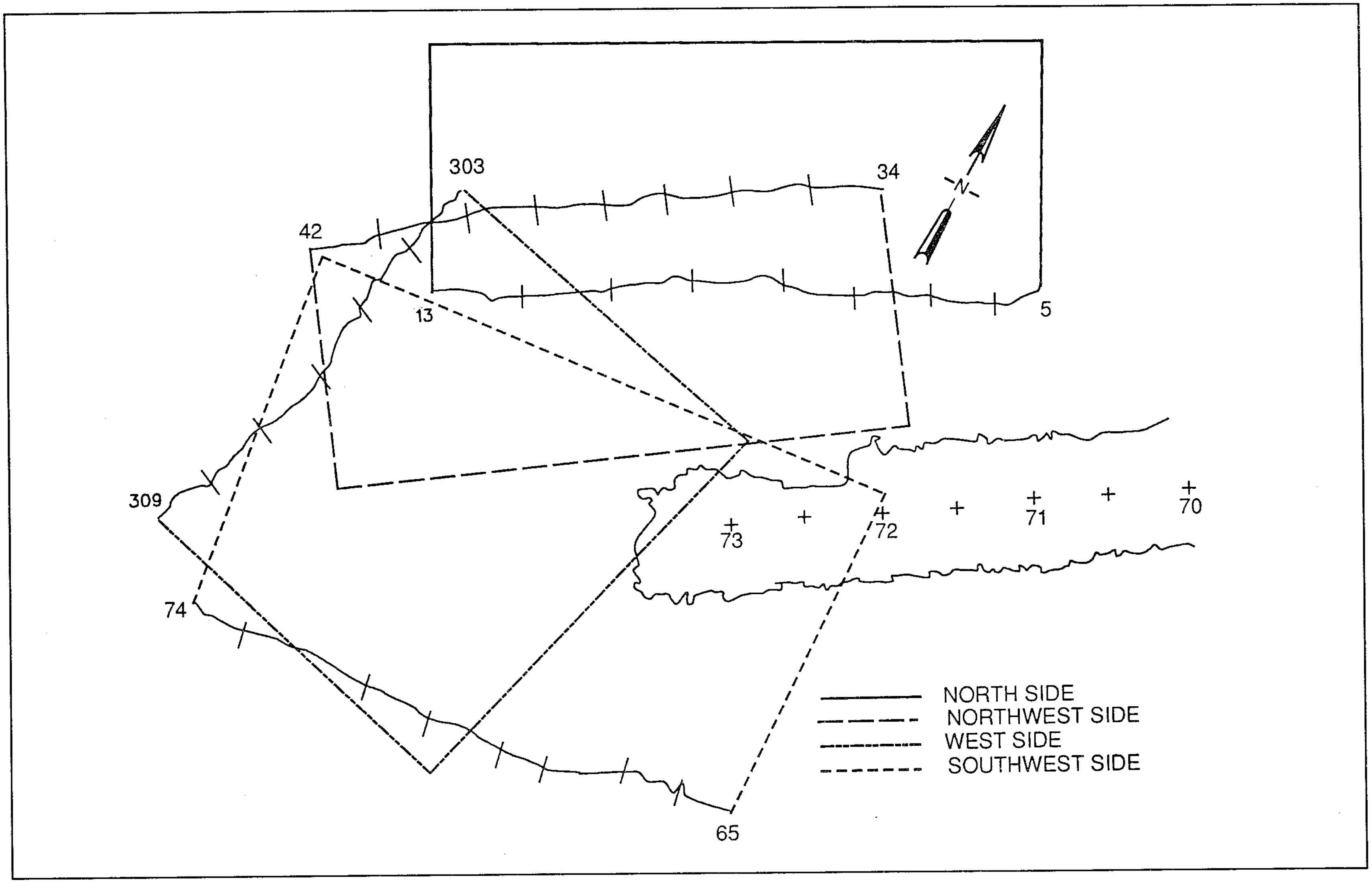


Figure 28. Yaquina Bay north jetty side-scan sonar analysis areas

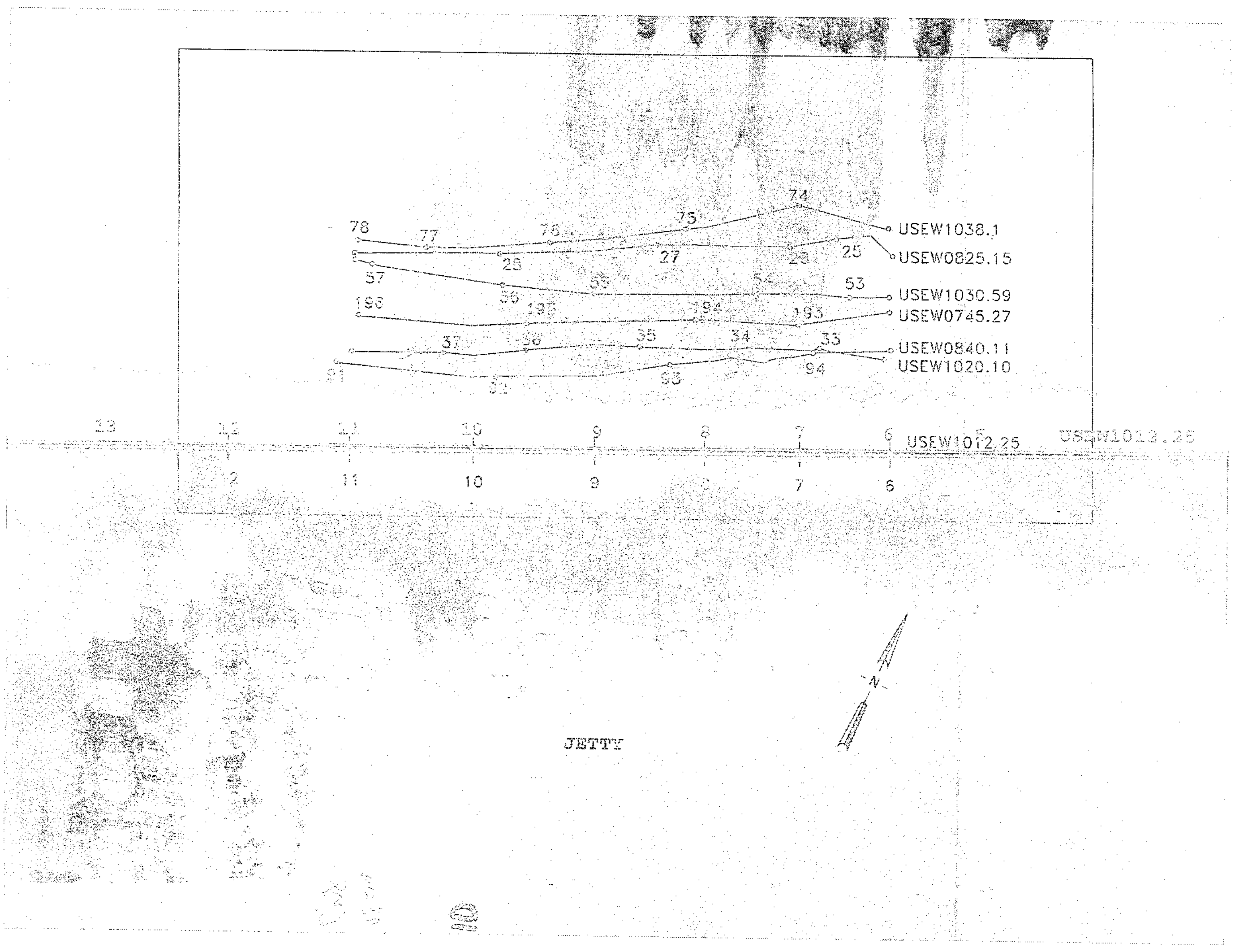


Figure 29. Side-scan sonar record along trackline USEW1012.25 for "north side of jetty" region

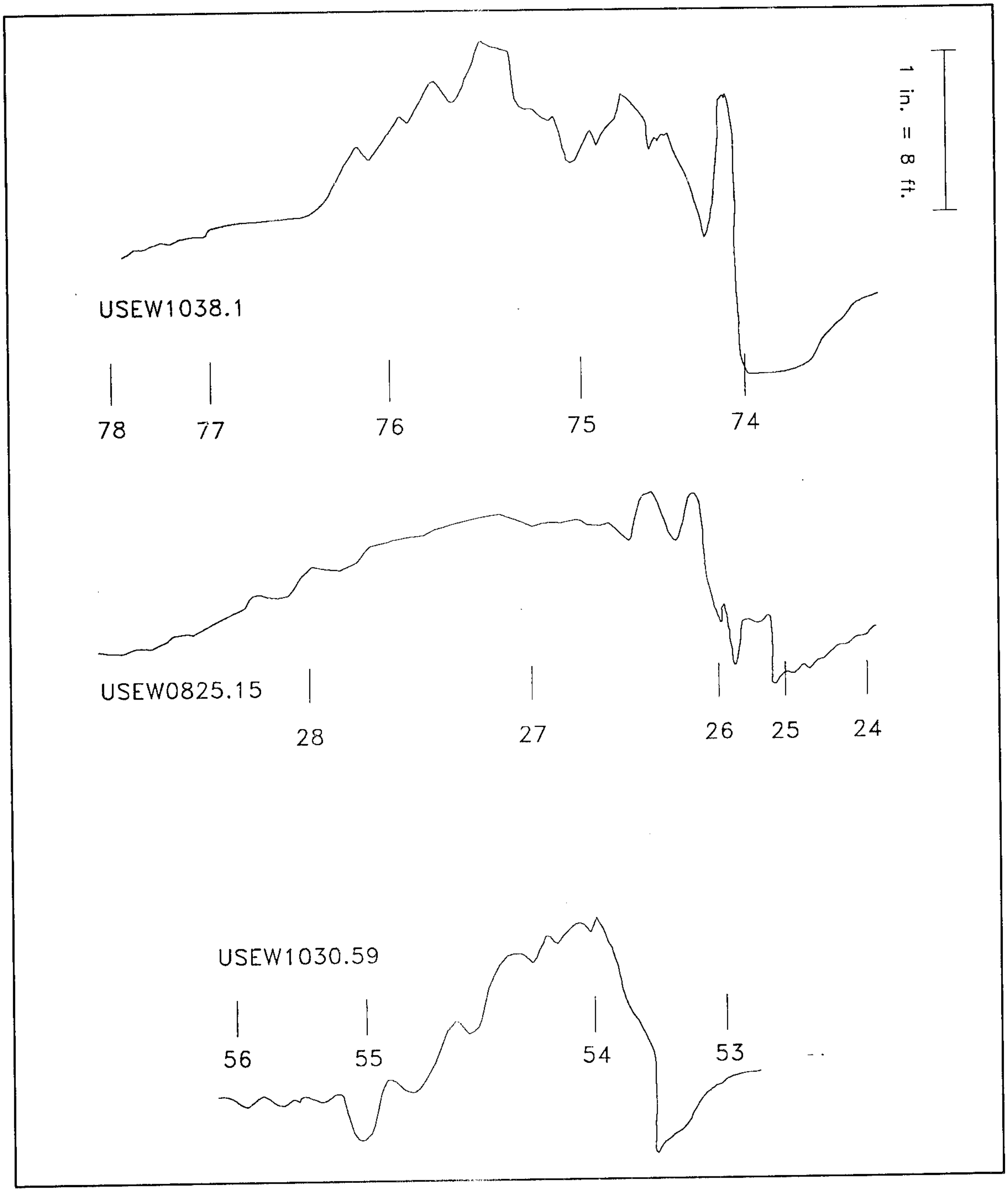


Figure 30. Echo sounder profiles for "north side of jetty" region (Continued)

accentuated by geometric distortion. This same area of the seafloor is shown with a more correct appearance in the upper right-hand portion of the side-scan sonar image of Figure 27. The tick mark on the far right side of the side-scan sonar track line shown in Figure 27 is at approximately the same east-west position as event mark 7 on the image given in Figure 29.

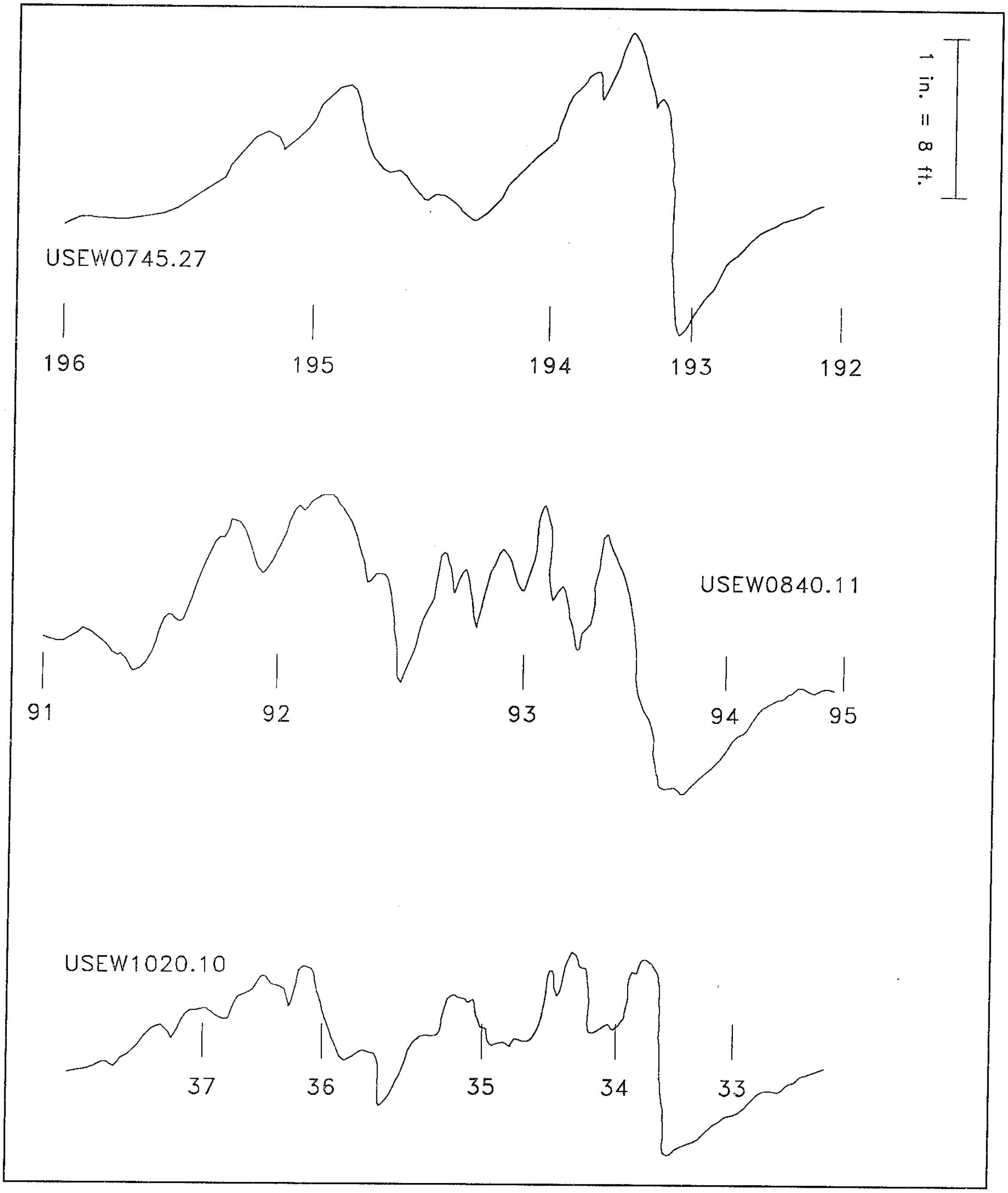


Figure 30. (Concluded)

Despite the geometric distortion problem, it is clear there are no rounded objects indicative of jetty armor stones on the side-scan sonar image near event mark 74 on track line USEW1038.1 (Figure 29). Therefore, it is concluded that the roughness element visible on the corresponding profile on Figure 30 is a result of the track line crossing the reef rock finger indicated on the side-scan sonar image at event mark 74.

A similar conclusion is drawn regarding the roughness elements shown on Figure 30 profile USEW0840.11 in the vicinity of event mark 93. As seen on Figure 29, this echo sounder track line overlays reef rock fingers, but there is no indication of armor stones in the image near event mark 93. The round image approximately halfway between event marks 93 and 94 along track line USEW0840.11 was most likely caused by the presence of a hole in the reef rather than an armor stone. Interpretation of the remaining four bathymetric profiles shown in Figure 30 resulted in the conclusion that all six echo sounder track lines crossed the Yaquina Reef to the north of any armor jetty stones.

Northwest side of jetty

Figure 31 shows the side-scan sonar image recorded along track line USEW1012.10. As before, north is to the top of the figure, and landward is toward the right in the figure. Overlain on the image are four bathymetric track lines that were rescaled to correspond to the side-scan sonar image horizontal scale. Bottom profiles for the echo sounder trace lines overlain on Figure 31 are displayed in Figure 32. The profiles are arranged in order beginning with the profile closest to the side-scan sonar track line and moving closer to the Yaquina Bay north jetty.

Along track line USEW0822.16 (top profile on page 93) the bathymetric profile is smooth between event marks 7 and 8, indicative of unconsolidated sediment seafloor. This is confirmed by the side-scan sonar image, which shows a transition from sand to rock at approximately event mark 8 along this echo sounder track line. The relatively smooth profile on this track line between event mark 8 and halfway between event marks 9 and 10 exhibits the return signal signature of reef rock. Beginning halfway between event marks 9 and 10 and extending landward (right in figure), profile USEW0822.16 has a series of evenly spaced roughness elements that have the correct horizontal dimensions to be jetty armor stones; however, the vertical dimension appears to be too small to be individual armor stones resting on the bottom.

The side-scan sonar image of Figure 31 shows rounded objects in the vicinity of event marks 9 and 10 of echo sounder track line USEW0822.16, leading to the conclusion that the roughness elements observed in the corresponding bathymetric profile are the result of overlapping (i.e., stacked) jetty stones. In contrast, a pronounced roughness element displaying horizontal and vertical dimensions characteristic of an individual jetty armor stone is observed on this same bathymetric profile between event marks 10 and 11. In conclusion it appears that track line USEW0822.16 crossed the Yaquina Reef, beginning at event mark 8, until halfway between event marks 9 and 10, where it then crossed over the toe of the north jetty .

Along track line USEW0903.17 the side-scan sonar image of Figure 31 shows the transition from sand to rock to be approximately at event mark 210.

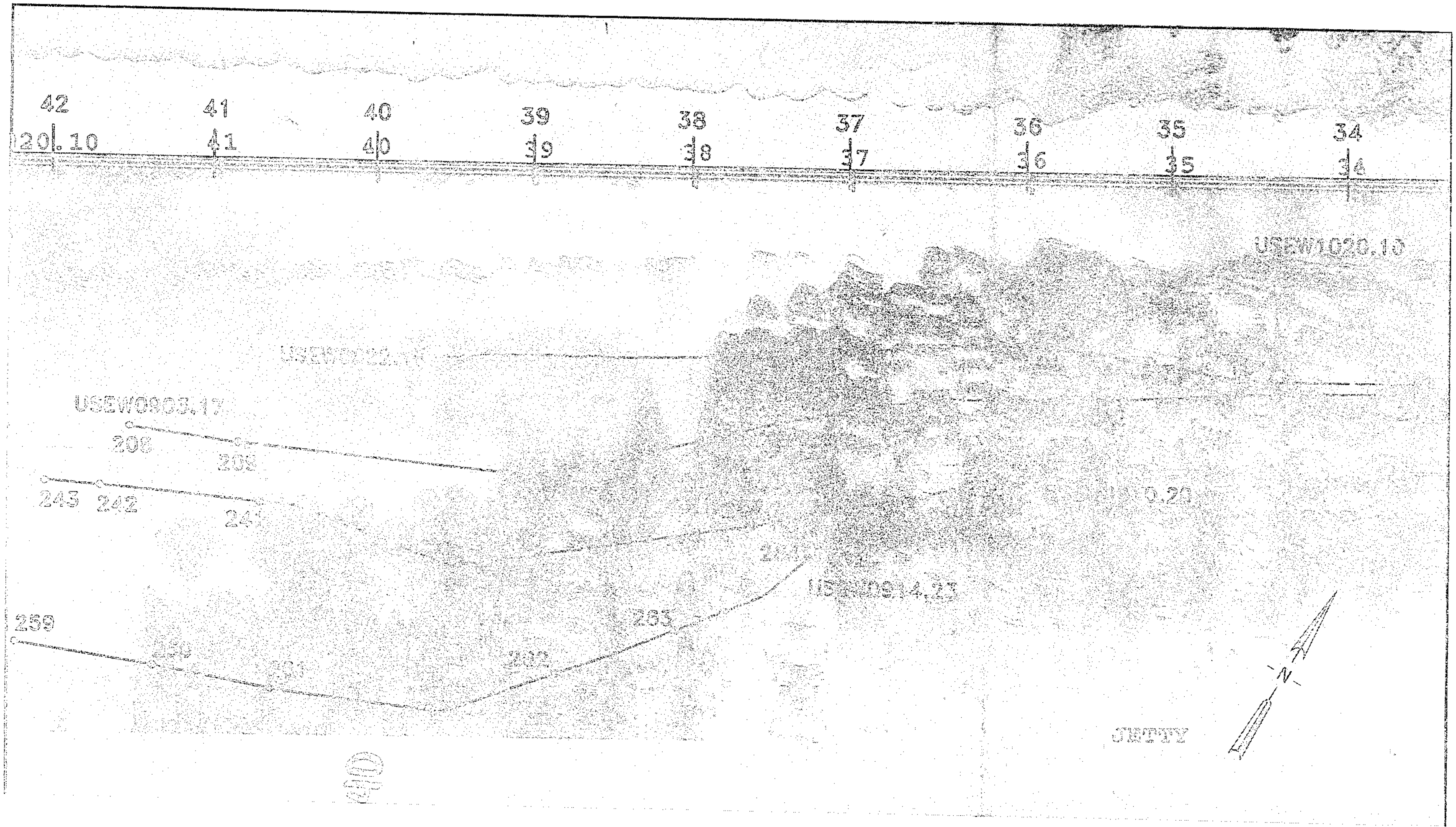


Figure 31. Side-scan sonar record along trackline USEW1020.10 for "northwest side of jetty" region

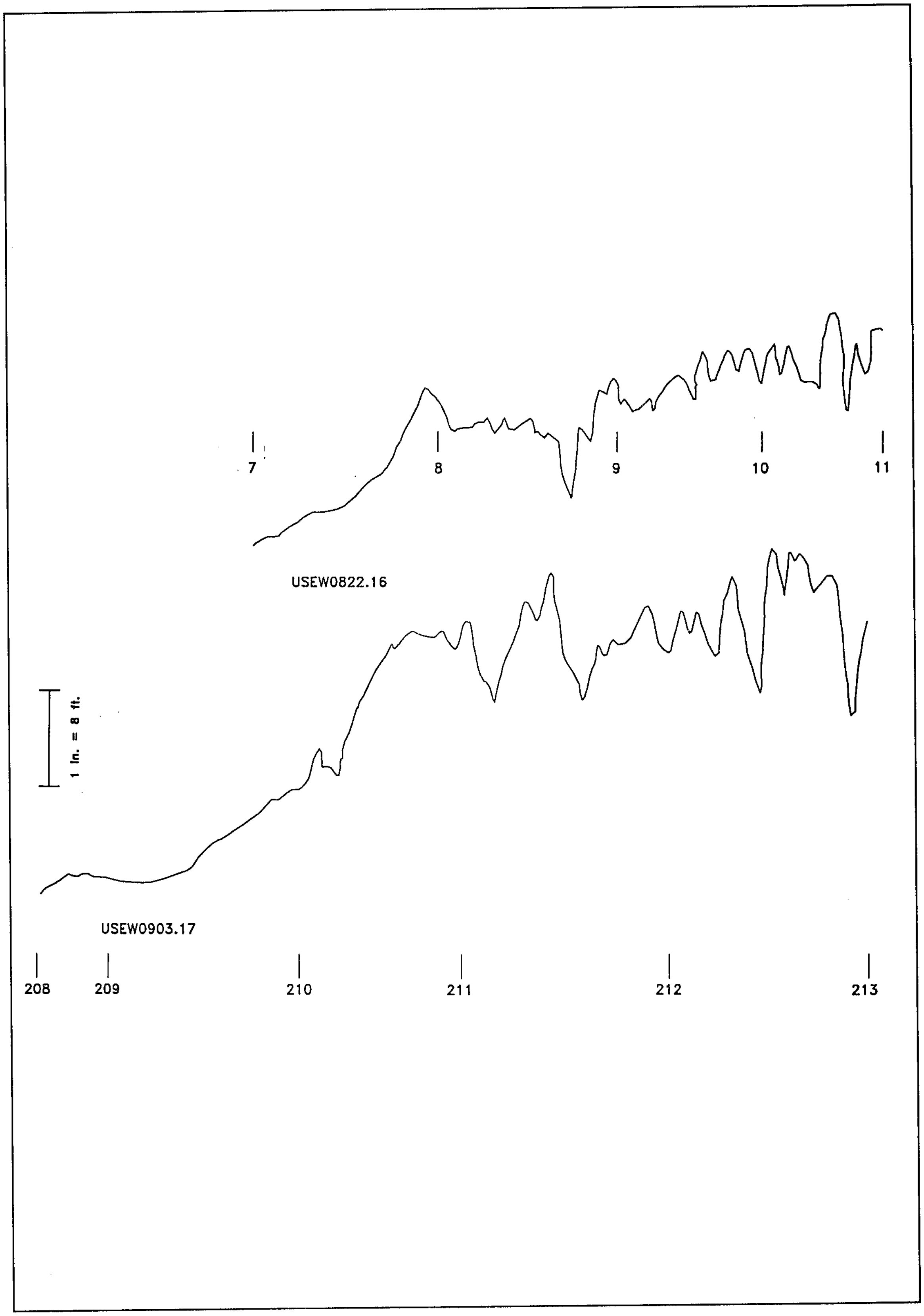


Figure 32. Echo sounder profiles for "northwest side of jetty" region (Continued)

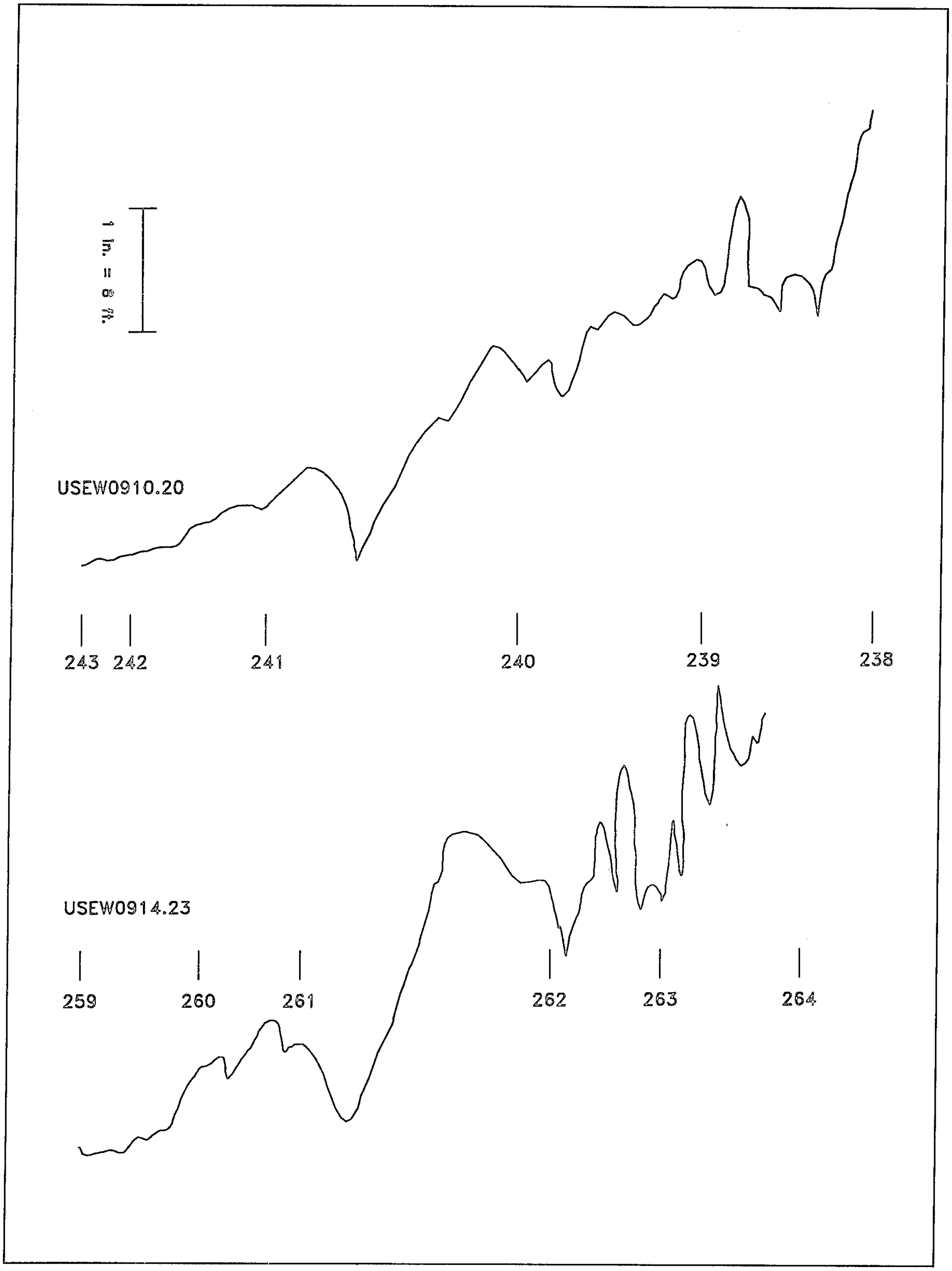


Figure 32. (Concluded)

On the corresponding bathymetric profile (bottom profile on page 93) there is a peaked bottom feature shown between event marks 211 and 212. Interpretation of the side-scan sonar record in this location concluded that this peaked feature is a wide rock finger. Around event mark 212 there are evenly spaced roughness elements similar to those seen around event mark 10 on track line USE0822.16. These roughness elements are also interpreted to be overlapping jetty stones. In conclusion, the interpretation for track line USEW0903.17 was that the track line crossed the Yaquina Reef beginning at event mark 210, and continued until event mark 212, where it then crossed over the toe of the north jetty.

Roughness elements also appeared on bathymetric profile USEW0910.20 near event mark 239 and on profile USEW0914.23 starting near event mark 262 and continuing toward event mark 264 (see Figure 32). These roughness elements were interpreted to be individual jetty stones resting on the seafloor. The corresponding side-scan sonar image of Figure 31 shows the transition from unconsolidated sediment to rock to be at event mark 241 along track line USEW0910.20 and at event mark 260 along track line USEW0914.23.

The interpretation for these two echo sounder track lines was that track line USEW09010.20 began crossing over the reef at event mark 241, and continued until mark 239 where it crossed over the jetty. Similarly, trackline USEW0914.23 started crossing the reef at event mark 260 until event mark 262, where it started crossing the jetty. Finally it is noted that all four bathymetric profiles clearly show the smooth hummocky appearance interpreted to be reef rock on their western end (left side of profiles in Figure 32).

West side of jetty

Figure 33 shows the side-scan sonar image recorded along track line YRFP0959.1 for the west side of the jetty. The upper portion of the figure is landward of the track line, and the bottom portion is seaward. Side-scan sonar track line event mark 303 denotes the northern limit of the track. Overlain on the image are four bathymetric track lines that were rescaled to correspond to the side-scan sonar image horizontal scale. Bottom profiles for the echo sounder trace lines overlain on Figure 33 are displayed on Figure 34.

Demarcation between unconsolidated sediments and reef rock is clearly discernable on the side-scan sonar image of Figure 33. This transition is just seaward of event mark 412 along trackline JETY0659.2, halfway between event marks 155 and 156 along trackline USEW0740.25, at event mark 255 along track line USEW0913.22, and halfway between event marks 259 and 260 along track line USEW0914.23.

The bathymetric profile for track line JETY0659.2 shown on Figure 34 is relatively smooth, and the large roughness elements are generally wider in the horizontal and shorter in the vertical than those of individual jetty stones. The

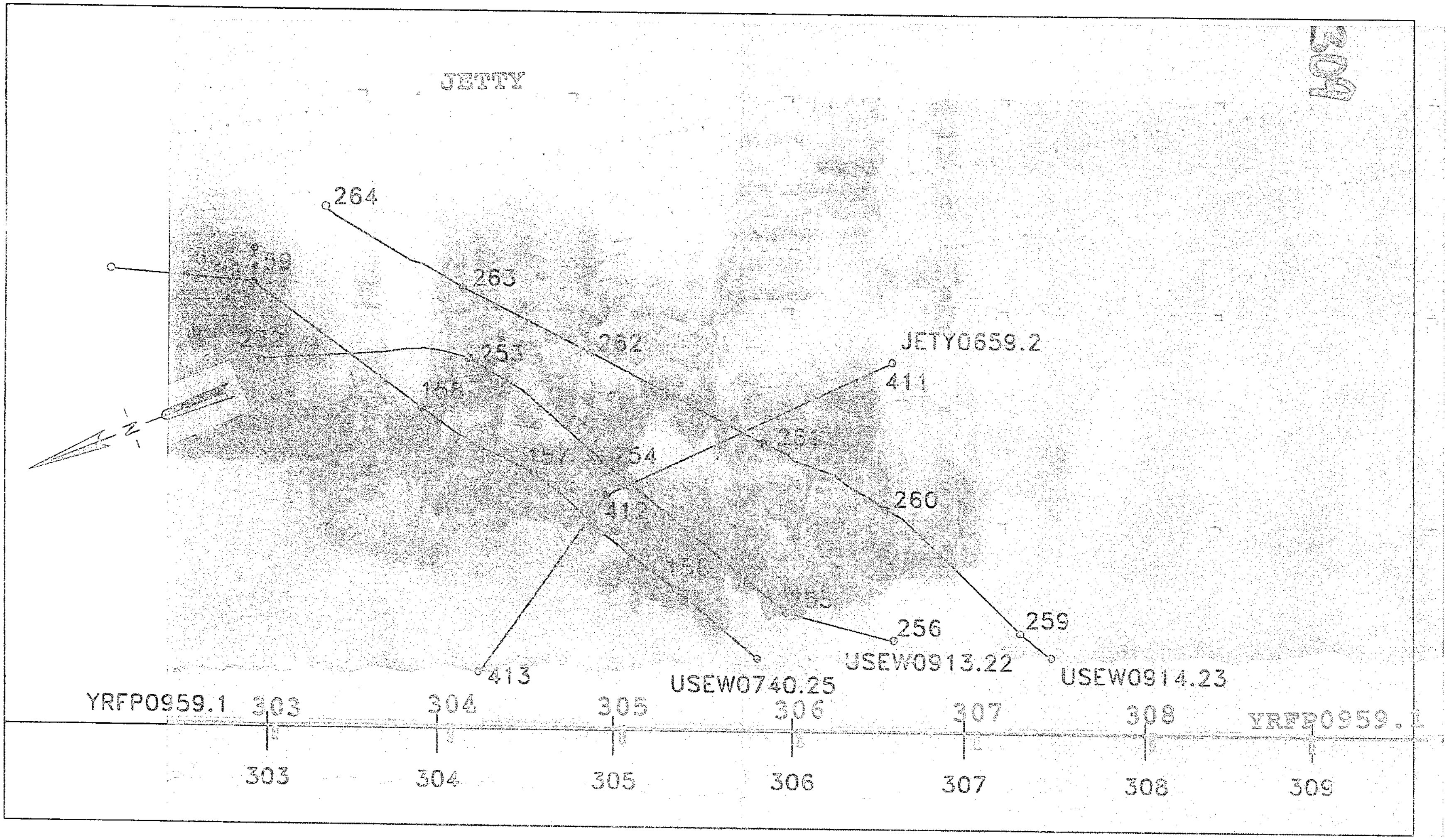


Figure 33. Side-scan sonar record along trackline YRFP0959.1 for "west side of jetty" region

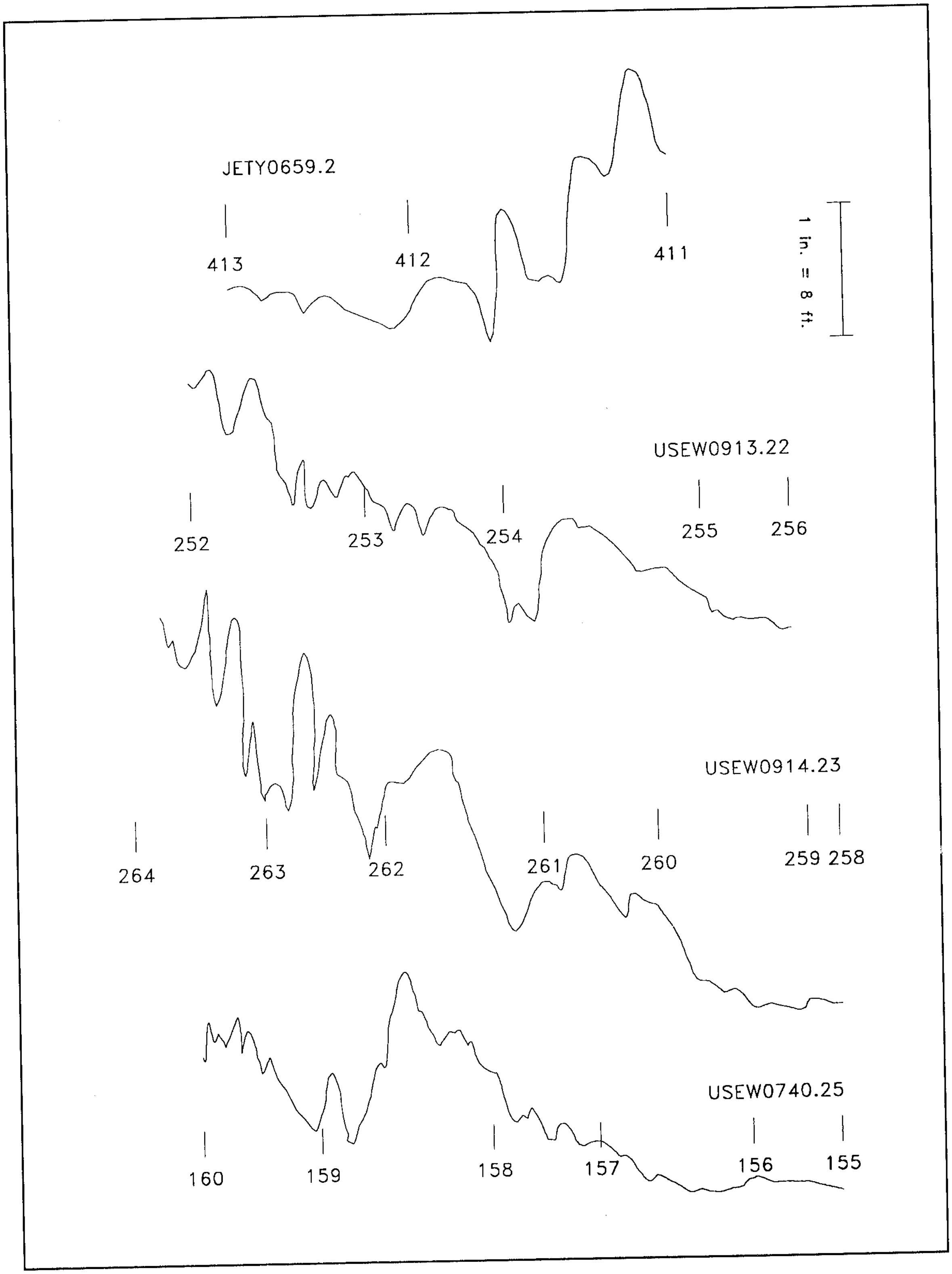


Figure 34. Echo sounder profiles for "west side of jetty" region

corresponding side-scan sonar image of Figure 33 showed no rounded objects along this track line. However, there were light areas that may be areas of sand. The interpretation from the echo sounder and side-scan sonar data is that trackline JETY0659.2 passed entirely over reef rock which contained isolated sand pockets overlaying the Yaquina Reef.

The bathymetric profile for trackline USEW0740.25 shown on Figure 34 is also relatively smooth until halfway between event marks 159 and 160. Unfortunately, the corresponding side-scan sonar image is no help in this region because the return signal is very dark, and it is hard to discern any rounded features. It was tentatively concluded that trackline USEW0740.25 crossed over the seaward edge of the Yaquina Reef between event marks 155 and 156, and passed over the reef until between event marks 159 and 160 where small, regularly spaced roughness elements were recorded that may be overlapping jetty armor stones.

The side-scan sonar image of Figure 33 was too dark to permit a clear interpretation along echo sounder track line USEW0913.22 in the region of event mark 252. Therefore, the bathymetric profile around event mark 252 cannot be interpreted with certainty. The small regular roughness elements present on this profile in Figure 34 around event mark 253 exhibit the shape of overlapping jetty armor stones, and this interpretation is confirmed by the rounded images returned from the side-scan sonar around this event mark. The bathymetric profile also has the smooth hummocky appearance of reef rock between the offshore boundary of the reef at event mark 255, shoreward until event mark 254. The conclusion for echo sounder trackline USEW0913.22 was that the track line crossed from unconsolidated sediments to reef rock near event mark 255 and passed over the Yaquina Reef until event mark 254, where the trackline crossed over the north jetty toe.

The bathymetric profile for trackline USEW0914.23 on Figure 34 shows a region of roughness elements between event marks 262 and 264 that have correct dimensions to be individual jetty armor stones. Rounded objects that appear to be jetty armor stones are clearly seen in this region in the Figure 33 side-scan sonar image. From event mark 262 seaward to halfway between event marks 260 and 259 the rock formation has the smooth hummocky appearance of the Yaquina Reef. Therefore, echo sounder trackline USEW0914.23 passed over the seaward edge of the reef between event marks 259 and 260, crossed over the reef until event mark 262, then crossed over the toe of the north jetty.

Southwest side of jetty

Figure 35 shows the side-scan sonar image recorded along trackline SPCS0629.5 for the southwest side of the jetty. The portion of the figure above the track line is directed toward the north jetty in a north direction. The left side of the figure is seaward of the jetty. Overlain on the image are three bathymetric track lines that were rescaled to correspond to the side-scan

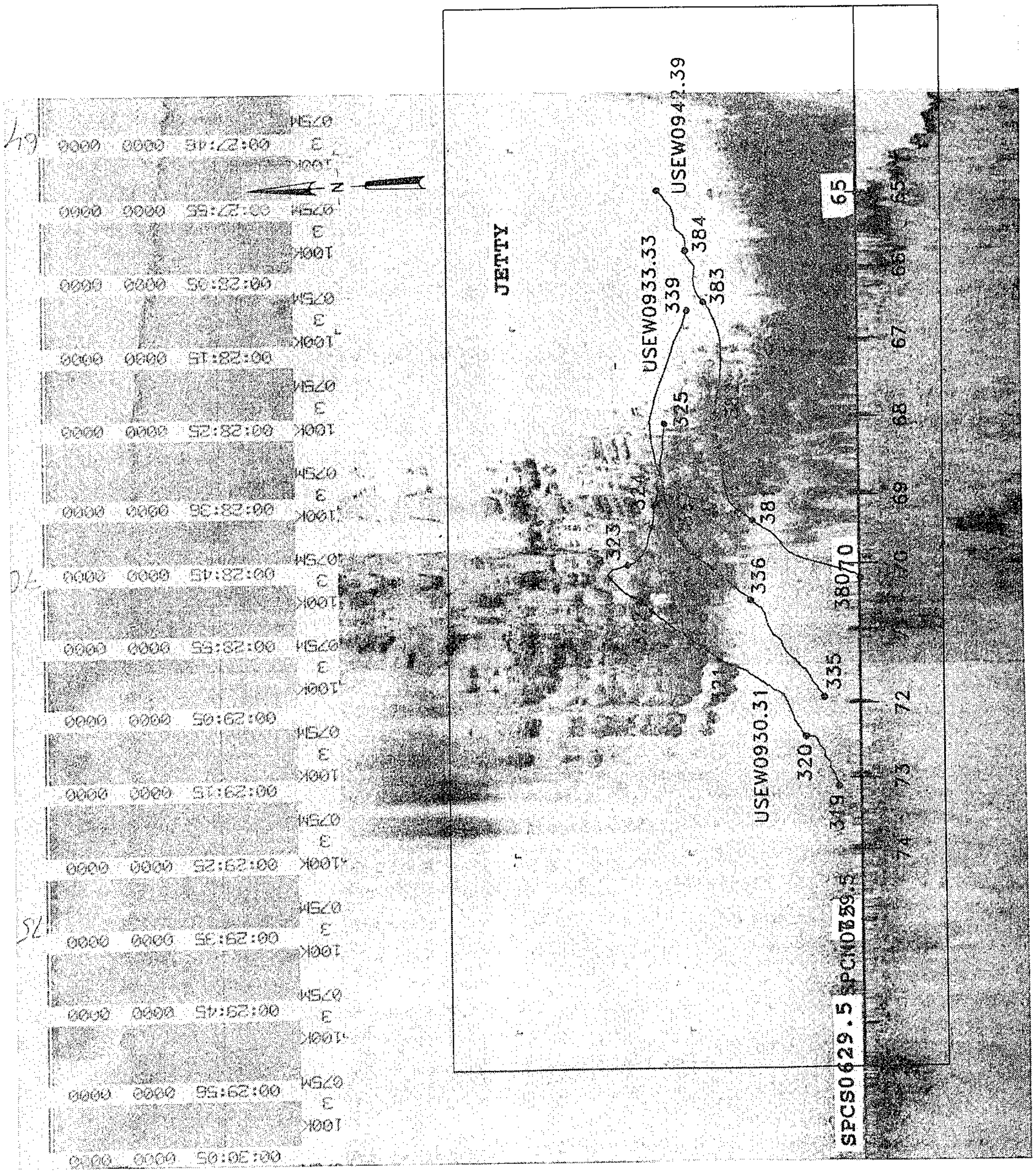


Figure 35. Side-scan sonar record along trackline SPCS0629.2 for "southwest side of jetty" region

sonar image horizontal scale. Bottom profiles for the echo sounder trace lines overlain on Figure 35 are displayed in Figure 36.

The side-scan sonar image of Figure 35 indicated that the transition from offshore unconsolidated sediments to rock occurred along echo sounder trackline USEW0930.31 near event mark 321, along track line USEW0933.33 between event marks 336 and 337, and along trackline USEW0942.39 between event marks 381 and 382. All three bathymetric profiles on Figure 36 showed a large scour trench just seaward of the rock area (southwest of the north jetty tip).

The identified rock portions of all three bathymetric profiles contained small regularly spaced roughness elements characteristic of overlapping jetty armor stones. Rounded objects were also seen in the Figure 35 side-scan sonar image over all portions that were indicative of rock. None of the bathymetric profiles had portions containing the smooth hummocky appearance of reef rock, with the possible exception of around event mark 322 along trackline USEW0930.31. However, the interpretation of these data in conjunction with other data led to the conclusion that there is no exposed reef in this immediate area. The presence of the deep scour trench immediately seaward of the jetty supports the contention that the toe of the north jetty in this region is resting on sand rather than resting on a portion of the reef that was covered with sand.

Position of North Jetty Relative to Yaquina Reef

The four side-scan sonar images presented in Figures 29, 31, 33, and 35 were used to delineate the border between rock and unconsolidated sand around the Yaquina Bay north jetty head. This demarcation line was drawn on Figure 37 to show its position relative to the above-water portion of the north jetty.

The transition from reef rock to jetty armor stones was also marked on the chart in Figure 37 using all 78 available bathymetric profiles collected in the four areas surrounding the jetty head. These reef-to-stone transition locations were determined using the four side-scan sonar images in conjunction with the echo sounder profiles that showed roughness elements. Analysis was performed similar to that described above.

Side-Scan Sonar Conclusions

Along track line USEW0910.20 just to the landward side (right side) of event mark 241 (see Figure 31) the side-scan sonar data indicated a region that is definitely rock. However, the smooth region in the bathymetric profile for this area (see Figure 32 between event marks 241 and 239) is not at all representative of jetty armor stones. Consequently, there is little doubt that a

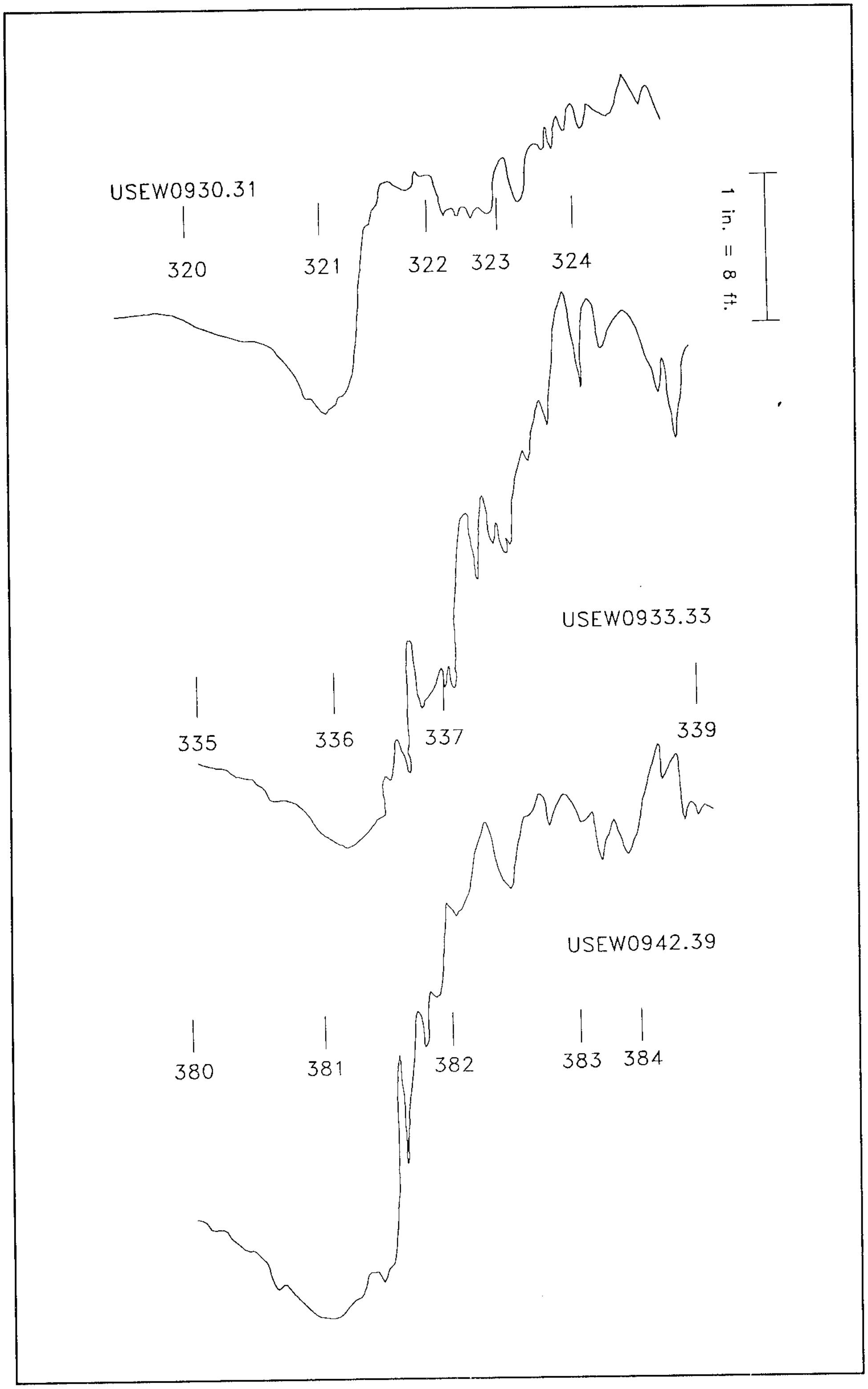


Figure 36. Echo sounder profiles for "southwest side of jetty" region

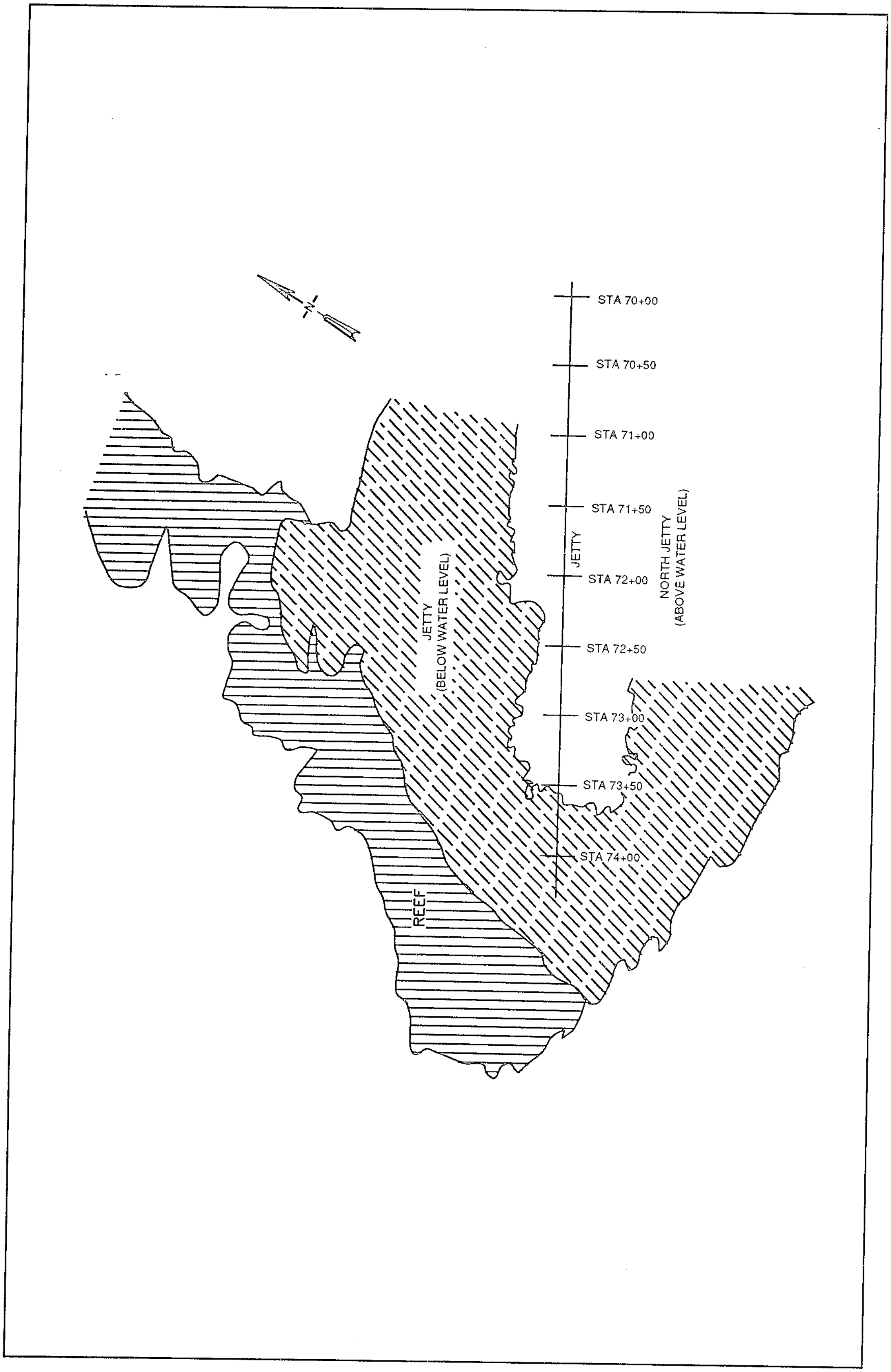


Figure 37. Position of Yaquina Bay north jetty relative to Yaquina Reef

portion of the Yaquina Reef sticks out seaward of the northwest tip of the Yaquina Bay north jetty. However, interpreting roughness elements on the bathymetric profiles as jetty armor stones involved a certain degree of subjectivity. Therefore, the line marking the toe of the north jetty on Figure 37 is not absolutely definitive.

Analysis and interpretation of side-scan sonar and echo sounder data have determined the location and extent of reef not covered by jetty armor stones, as shown on Figure 37. This interpretation agreed well with the rendition of the reef shown in Figure 4. Based on the foregoing analysis, it was concluded that the Yaquina Reef extends seaward of the north jetty toe for a maximum distance of approximately 30 m (100 ft) on the west side and a minimum distance of about 15 m (50 ft) on the northwest side.

Figure 37 also shows a "bulb" of jetty armor stone located on the north side of the jetty and overlaying the landward side of the Yaquina Reef. This pile of armor stones has approximate dimensions of 30 m (100 ft) in the east-west direction with a width of about 15 m (50 ft). Further to the west (seaward) of this pile of armor stones, but still along the north side of the jetty, a stretch of bare reef extends 15 m (50 ft) northward of the jetty.

The results presented in this chapter support the accuracy of the chart shown in Figure 4, which clearly located the tip of the Yaquina Bay north jetty overlaying the Yaquina Reef. Furthermore, the location of the jetty toe relative to the above-water edge of the jetty structure indicated the jetty has a below-water structure slope that is substantially milder than originally thought (1:4 in some places). In retrospect this was not surprising because a milder below-water slope helps to account for armor stones lost from the jetty during prior damage sequences. In other words, as damage occurred, armor stones above the mllw level were carried down-slope and deposited near the toe. This eventually resulted in a wide foundation on which the last jetty rehabilitation was built. Unfortunately, there were insufficient data for a volumetric calculation of excess stone in the jetty foundation.

7 Photogrammetric Analyses

Photogrammetry as a Monitoring Tool

Rubble-mound structures, such as those protecting the entrance channel to Yaquina Bay, consist of a mound of core material protected by one or more layers of progressively larger stone. The final *armor layer* is usually constructed of randomly placed stone or, in some cases, artificial armor units such as dolos. After construction, the mound undergoes nesting as the armor units settle into a stable position under the action of the waves. Damage occurs to rubble-mound structures when individual armor units are displaced by intense wave action, exposing the smaller underlying material which can then be eroded. Depending on the severity and duration of wave action, the structure may stabilize in a damaged (but still functional) condition, or it may continue to unravel until the structure no longer serves its intended purpose.

One aspect of monitoring the performance of rubble-mound structures requires that sufficient information be obtained so that movement of individual armor units can be determined. In theory, this could be done using conventional ground surveying techniques where repeated surveys locate the position of permanent markers on individual armor units. However, in practice, the ground surveying method is difficult and expensive; and in the case of a structure like the Yaquina Bay north jetty where waves regularly sweep across the crest near the tip, this method is unsafe and foolhardy.

The expense and danger of ground surveying methods have led to the development of photogrammetry techniques, which allow precise determination of armor unit movement from properly acquired aerial photography. Naturally, photogrammetric analysis can only be applied to that portion of the structure visible above the waterline; hence, aerial overflights are scheduled to coincide with low tide level to maximize the benefits.

The first step in photogrammetric monitoring of a rubble-mound structure is establishing permanent benchmarks on or near the structure that can be easily recognized in the aerial photographs. The horizontal and vertical positions of these benchmarks are established using conventional ground surveying techniques, and they are used in the photogrammetry analysis to correct for aircraft tilt, roll, and yaw; to determine the camera position and orientation relative to ground features; and to compensate for the earth's curvature. Next, high-quality, low-level stereo photographs of the structure are obtained using standard stereo-mapping equipment and techniques. The photographic stereo pairs are used along with the ground survey information to establish a stereo model, which is a three-dimensional representation of the study area that is free of geometric distortion. Stereo models are usually constructed using a computer. Annual flights of the same structure using the same control reference points facilitate comparisons between stereo models to extract information such as stone movement and yearly structure profile change above water level.

There are several requirements for successful monitoring using aerial photogrammetry, as follows:

a. Good quality equipment and experienced personnel should be employed. If possible, the same equipment and personnel should be retained throughout the entire monitoring program.

b. The pilot should be experienced in low-level, low-speed flight in order to obtain blur-free, high-resolution photographic images.

c. Best results come during calm weather with clear visibility and low water levels to maximize coverage of the structure. The sun should be nearly overhead to minimize shadows.

d. Photographic forward overlap should be at least 60 percent and no greater than 80 percent.

e. There should be at least five or six evenly distributed control points in each photographic stereo pair in order to level and scale properly the stereo model.

Additional information on photogrammetry related to rubble-mound structures can be found in two Coastal Engineering Technical Notes: "Monitoring Rubble-Mound Coastal Structures with Photogrammetry" (U.S. Army Engineer Waterways Experiment Station 1984) and "Surveys of Coastal Structures" (U.S. Army Engineer Waterways Experiment Station 1991). Corps of Engineers monitoring of the Crescent City Breakwater using aerial photogrammetry was described by Kendall (1988).

Fixed-Wing Photogrammetry at Yaquina Bay

Photogrammetric analysis from controlled aerial photographs of the north Yaquina jetty was performed on stereo pair photographs acquired between 1989 and 1993. NPP conducted the fixed-wing photogrammetry effort with funds provided as part of this MCCP monitoring. The controlled aerial photography was obtained by NPP under a contract to a private firm, and photogrammetric analysis was accomplished by the Portland District's Geotechnical Engineering Branch; GIS, Survey, and Mapping Section.

The purpose of the photogrammetric analysis was to determine distance and direction of individual stone movements at the seaward end of the Yaquina Bay north jetty. The photogrammetric analysis covered the seawardmost 183 m (600 ft) of the north jetty. In addition to stone movement, computerized stereo models were constructed and used to produce a digital terrain model (DTM) from which topographic contour maps, maps denoting significant changes between overflight dates, and above-water cross-section comparisons at selected range stations were derived.

Methodology

Stereo pairs of photographs were analyzed using two different techniques to provide quantitative comparisons of changes that occurred between annual overflights. First, a state plane grid with 30.5-m (100-ft) grid ticks was produced for the study area using a computer-assisted mapping system, and known ground survey control points were located on the grid. Additional control points were generated to help in matching the images to the grid. Surveyed and generated control points are shown in Figure 38.

The photogrammetrist then used a Wild A-10 stereoplotter connected to an Intergraph Interpro workstation to compile irregularly spaced three-dimensional data in the form of contours, spot elevations, and cross sections. This is the critical phase of the interpretation where operator skill and experience are paramount. These data were interpolated onto a uniform square grid having 0.6-m (2-ft) spacing. Similar analyses produced computer files of uniformly spaced elevations for each of the different dates of aerial photography. Contour maps of the seawardmost 183 m (600 ft) of the north jetty were then produced from each of the uniformly spaced grid files; and when two grid files were combined, it was possible to produce *difference contours* showing changes to the above-water portion of the structure between flights. Finally, above-water cross sections were produced for the seawardmost portion of the structure for each of the overflight episodes, and the cross sections were plotted to illustrate changes that occurred over time as the jetty withstood severe wave attack.

For each monitoring episode, the seawardmost 183 m (600 ft) of the north jetty was adequately covered by three overlain photograph stereo pairs from the mapping camera. Each photograph was enlarged by a factor of 8-1/3 from the 1:3000-scale negative. This gave a scale on the enlargements of approximately 1:360 or 10 cm = 36 m (1 in. = 30 ft), which was the largest possible photo size that still retained adequate photo resolution.

For the second analysis procedure, Mylar overlays of each overflight episode were prepared from the stereo models to indicate jetty stone corners or centers. These overlays were scaled for use in a stereo zoom transfer scope.

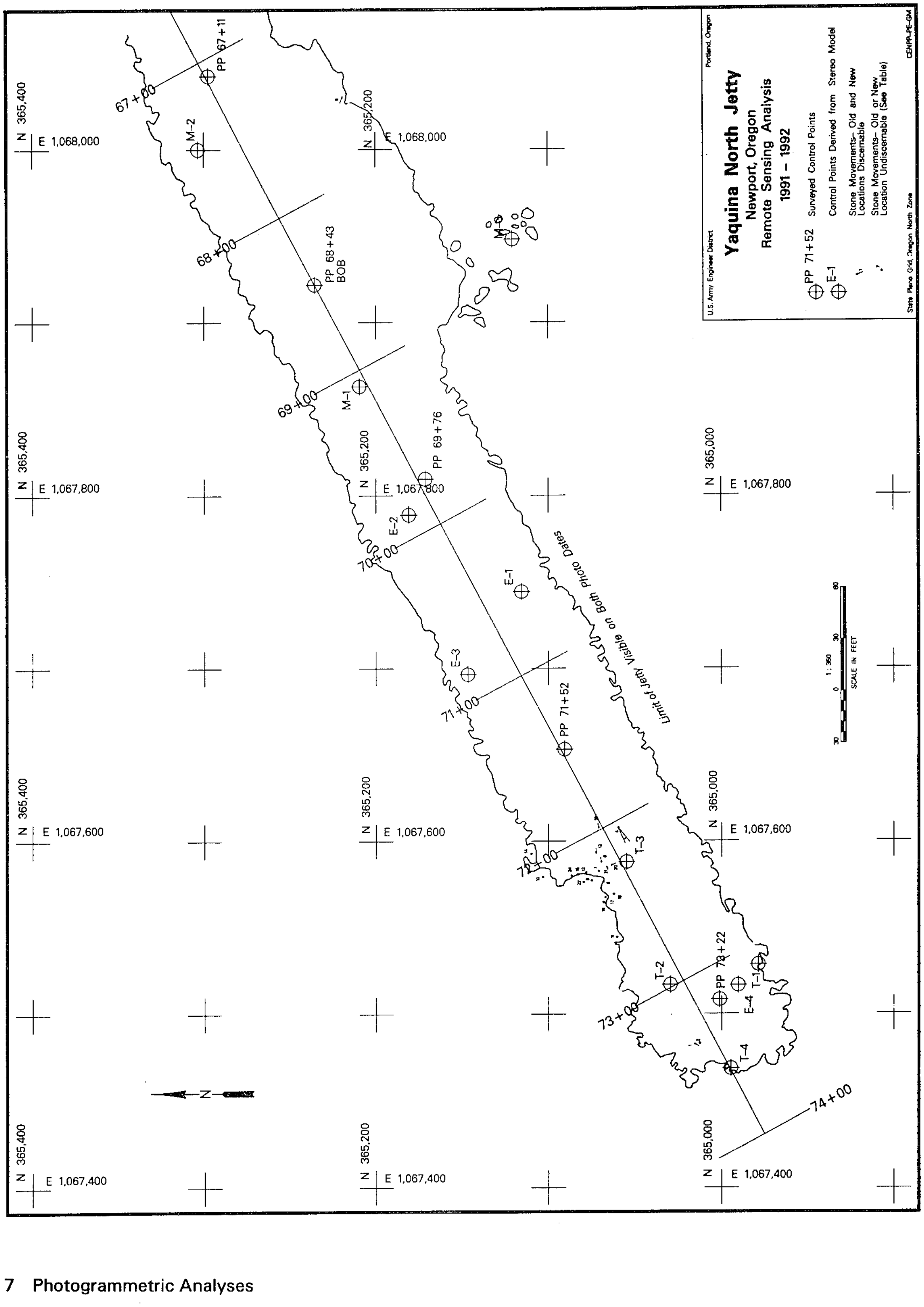


Figure 38. Fixed-wing photogrammetry control points on north jetty

Next, stereo pairs of photographs were set up in the stereo zoom transfer scope for detection of horizontal stone movement. When stone movement was detected, the movement was indicated on the Mylar overlay by numbered arrows, and a table was produced to record information such as direction and distance of movement for each stone. Stones that disappeared between overflights or stones that appeared from unknown locations were also noted on the tables.

Analyses

Photogrammetric analyses were completed for all five annual fixed-wing photographic overflights that occurred during the Yaquina Bay north jetty monitoring program. Dates of the fixed-wing flights are given in Table 20.

Table 20
Dates of Fixed-Wing Photogrammetry Flights

9 June 1989
29 April 1990
23 May 1991
23 February 1992
26 May 1993

Figure 39 shows a sequence of five photographs of the seawardmost portion of the north jetty taken on the dates shown in Table 20 (except for the 1992 photograph, which came from a different overflight in 1992 funded by NPP). These photographs document the gradual formation and enlargement of a "notch" on the northern side of the north jetty (right side in the photographs). The right side is the side away from the navigation channel. Monitoring activities at Yaquina Bay and specific products from the photogrammetry analyses have concentrated on behavior of the jetty armor stone in the vicinity of this notch. Complete photodocumentation obtained from the five overflights is contained in Appendix G.

Analysis of the photogrammetry was not without problems, and the Portland District reported the following difficulties that interfered with the analyses of elevation difference and jetty armor stone movement:

a. Even though flights are scheduled for low water levels, there was still a significant difference in water level between dates of photographs. For example, many of the armor stones visible at the water's edge in the 1990 photographs were under water in the 1989 photographs. Similarly, stones under water in the 1991 photos are visible in the 1990 photographs.

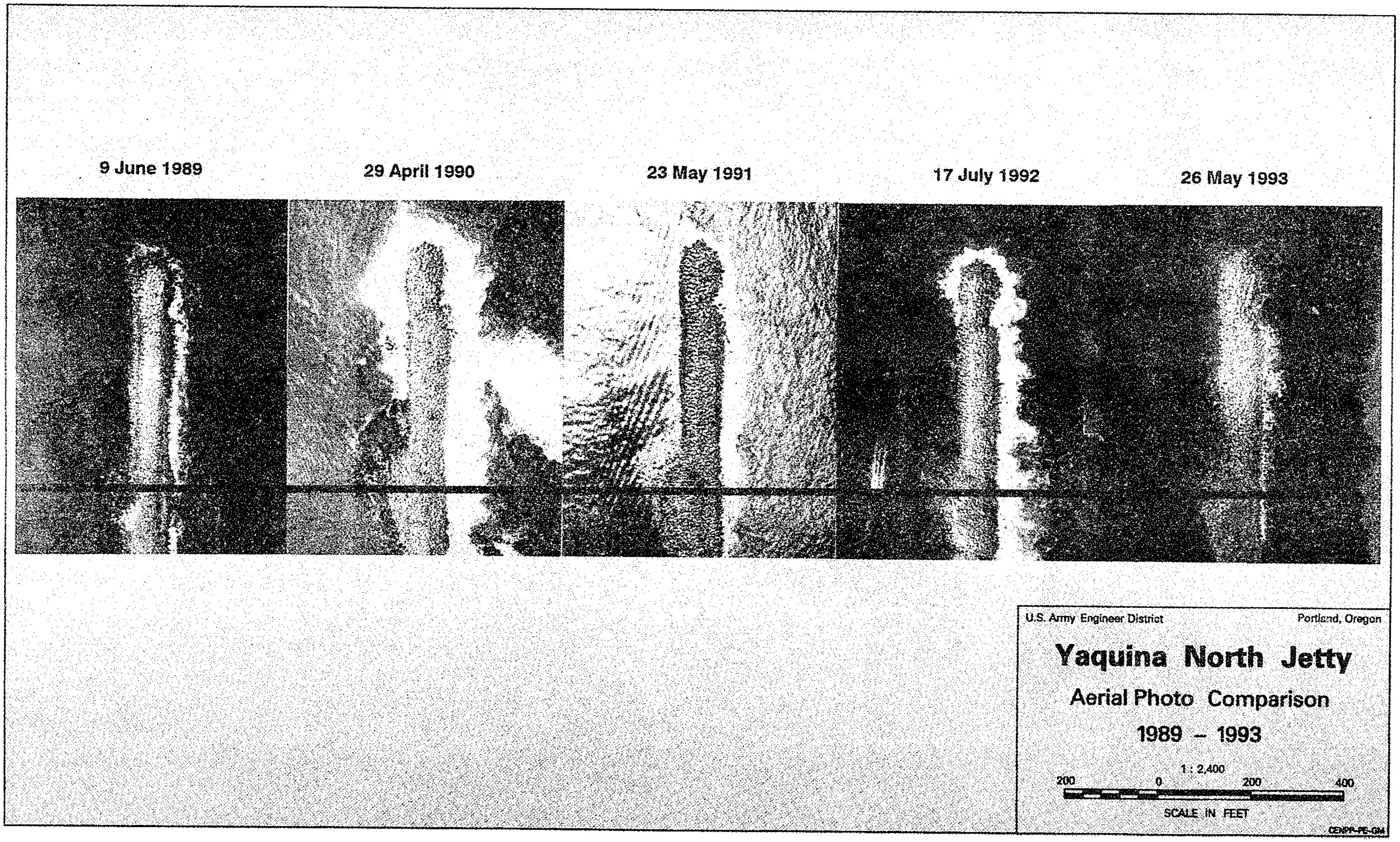


Figure 39. Aerial photographic sequence, Yaquina Bay north jetty

b. Large breakers on portions of the jetty captured during the 1990 and 1992 photographs (lower tide level) obscured stones that would otherwise be visible.

c. Spectral reflectance characteristics are different between sets of photographs. The presence or absence of moisture on the armor stones caused great variation in appearance, sometimes making identification of individual stones difficult for the stone movement analyses.

d. The position of the sun overhead was different for each flight, giving different shadows and complicating direct comparisons for determining stone movement. The 1990 photographs had longer shadows than the 1989 set. Shadows were different between 1990 and 1991 because the sun direction was from the south on the 1990 photographs and from the southwest on the 1991 photographs. The 1992 photographs were taken with low sun angle (winter) compared to the high angle of the 1991 photographs. These factors can give the illusion of stone movement where none had occurred.

e. The 1992 photograph set was dark and grainy relative to previous years and to the 1993 photographs. This most likely was a result of winter sunlight being less bright. These lower resolution photos made individual stone identification more difficult because of the lack of contrast. Many of the stones visible in the 1993 photographs were very dark, grainy, and indistinguishable in the 1992 photographs.

Stone movement was reported only when it was certain that the same area was visible on both sets of photographs acquired on different dates. No determination of movement was made if stones were obscured in either photograph. If a stone was missing, it was marked without a directional arrow on the Mylar overlay.

Profile results

Analysis of each photogrammetry overflight produced a contour map of the jetty showing elevation contours at 30-cm (1-ft) vertical intervals for that region of the structure visible above the tide level. Figures 40 and 41 show the above-water north jetty elevation contours determined from the February 1992 and the May 1993 overflights. Particularly noticeable is the steep face of the "notch" area clearly visible near the jetty tip. The stereo model data can also be used to create three-dimensional "mesh" drawings of the jetty as shown in Figure 42 for the 1993 helicopter photogrammetric analysis.

As mentioned, gridded elevations from different dates can be combined to produce difference contours. Figure 43 shows the difference contours found between stereo models for the 1992 and 1993 overflights. This figure is included only to give an impression of the product. The original products

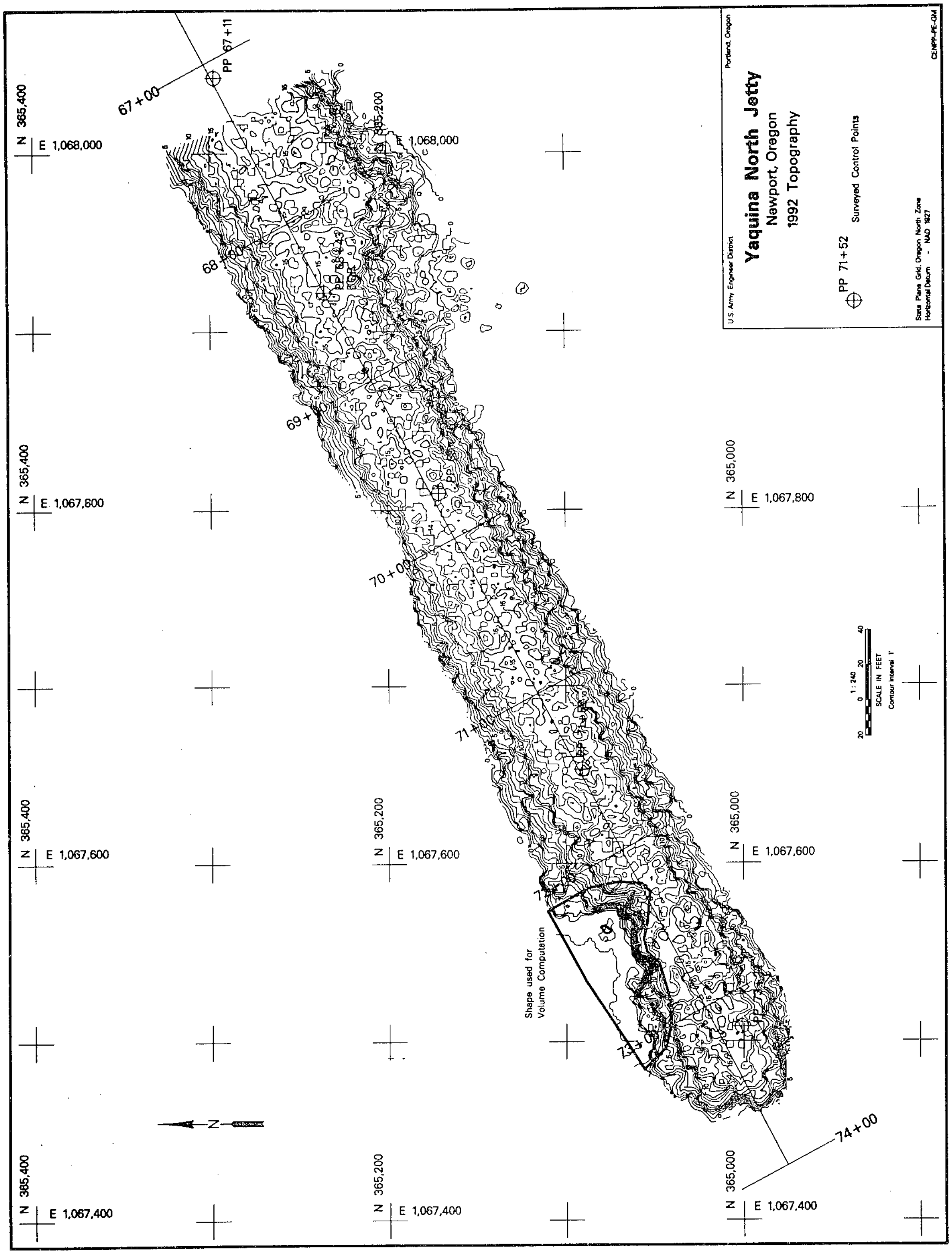


Figure 40. Yaquina Bay north jetty 1992 topography

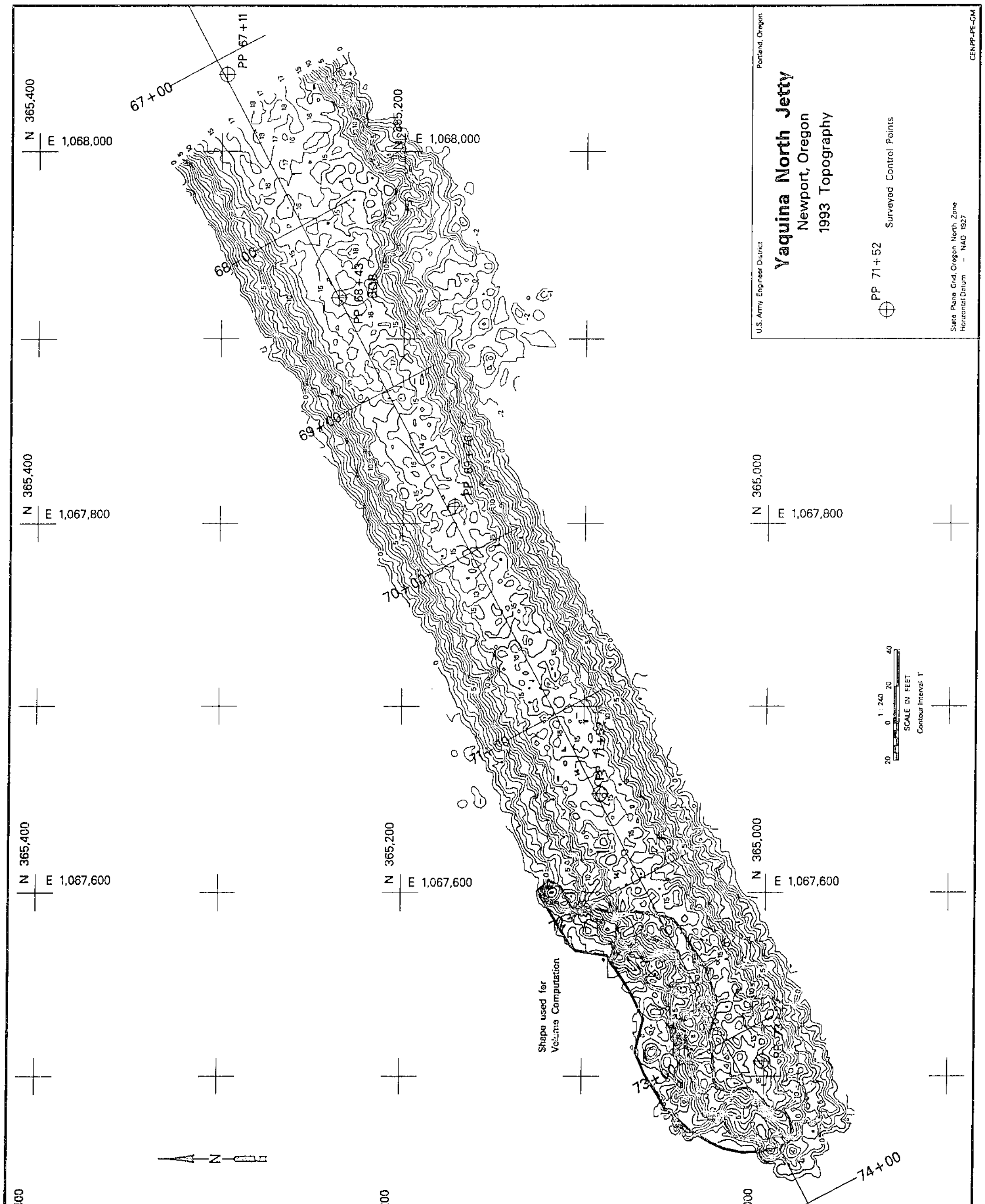


Figure 41. Yaquina Bay north jetty 1993 topography

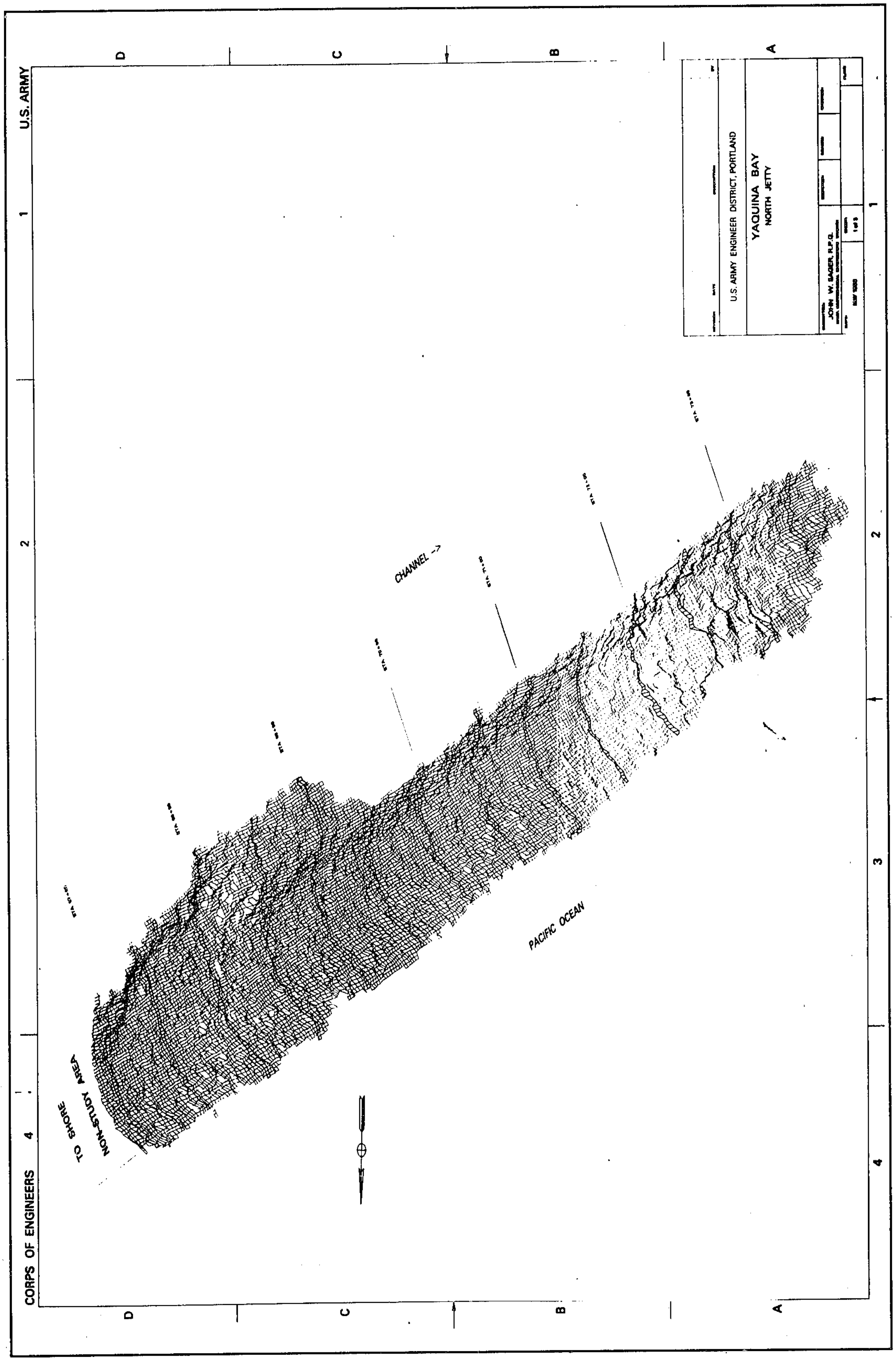


Figure 42. Yaquina Bay north jetty 1993 three-dimensional relief map

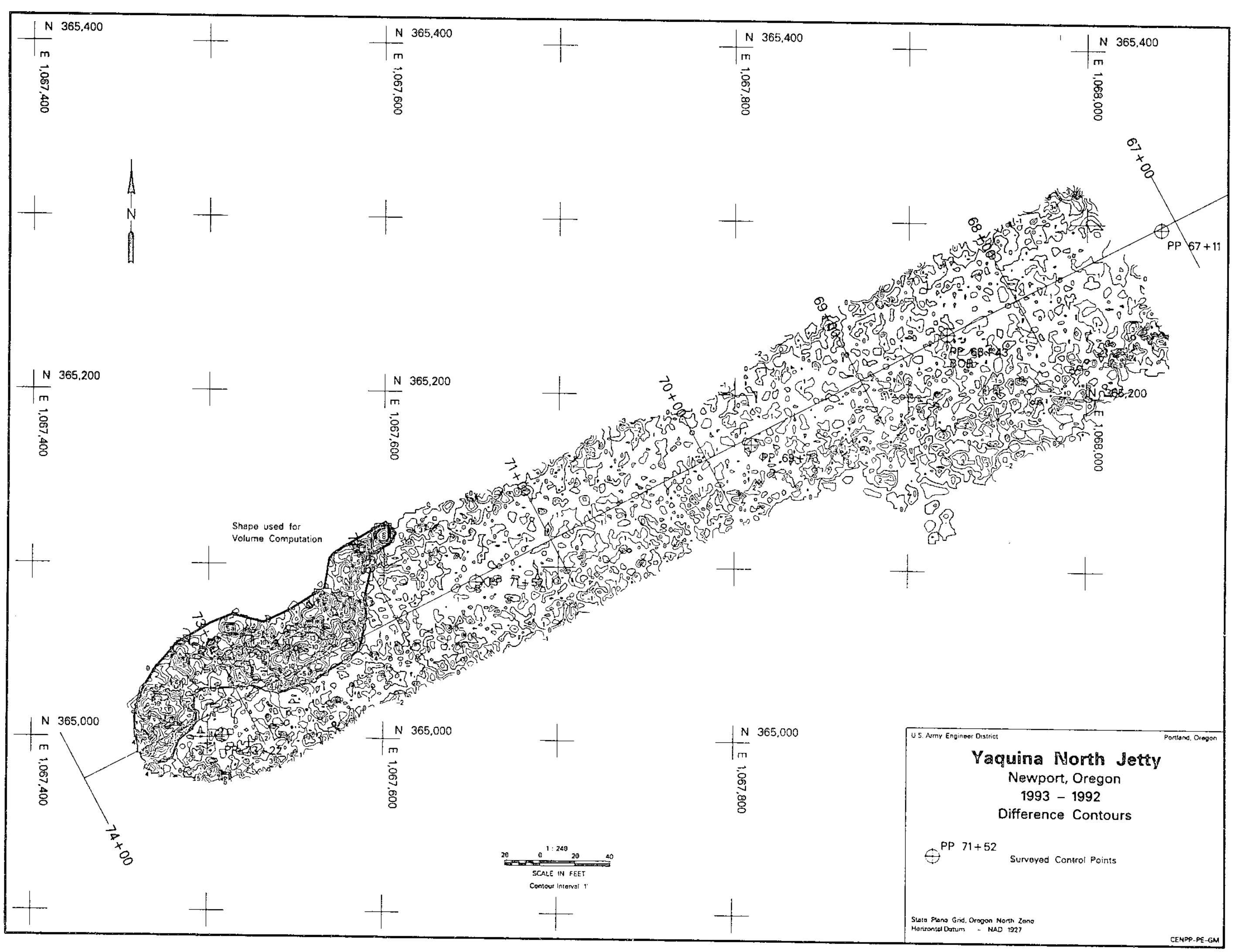


Figure 43. Difference between 1992 and 1993 north jetty contours

have different colored contours to denote positive and negative differences, and they are far more informative than what is shown in black and white on Figure 43.

Perhaps the most vivid demonstration of the utility of aerial photogrammetric analysis comes from examination of cross-section comparisons between different dates. Throughout the course of the study, year-to-year comparisons were made, and these comparisons provided the best means of assessing the changes that had occurred to the structure over time. Profile comparisons were derived from the stereo model database at 3-m (10-ft) horizontal spacings beginning at station 71+50 and continuing seaward to the tip of the jetty. Figure 44 shows the location of each cross section taken perpendicular to the jetty's center-line reference. The lines are shown superimposed on the 1992 contour drawing for visual reference.

Profile comparisons from six cross sections are shown in Figures 45 - 47. Each figure shows profile comparisons for two ranges between the years 1989 and 1993. Profile ranges were selected to span the "notch" region and to show changes near the jetty tip. The full set of 24 comparative profiles for the years 1989 - 1993 is given in Appendix H. Profiles were originally drawn at the scale of 1:120 or 10 cm = 12 m (1 in. = 10 ft). However, the plots were reduced by about 50 percent for placement in the figures, so the approximate scale on Figures 45 - 47 is 1:240 or 10 cm = 24 m (1 in. = 20 ft).

The following conclusions were drawn, based on inspection of the profile comparisons shown on Figures 45 - 47 and in Appendix H:

a. Repeatability of the photogrammetric methodology is confirmed by examining the various profile comparisons on the channel side of the north jetty (left side in figures) where little change has occurred to the structure.

b. The structure appears to have undergone some initial vertical settlement on the order of 1-2 m (3-6 ft) out near the tip as "nesting" occurred during the first 2 years after construction. This settlement was expected, and questions about inaccuracies in the analyses near the jetty tip were answered by subsequent results in the years 1990 - 1992, which show a relatively stable profile (see range 73+50, Figure 47). Winter storms between 1992 and 1993 substantially eroded the jetty tip. This was the first damage noted on the extreme tip during the monitoring period.

c. The most profile change occurred in the vicinity of the "notch" (Figure 45, range 72+40). Significant damage occurred between the years 1989 - 1991. This was followed by a year when the only armor stone losses in the notch area occurred on the landward side of the notch. However, between the 1992 and 1993 overflights, massive profile losses occurred in the notch area to the extent that stones were lost over much of the structure's crest (see range 72+70, Figure 46).

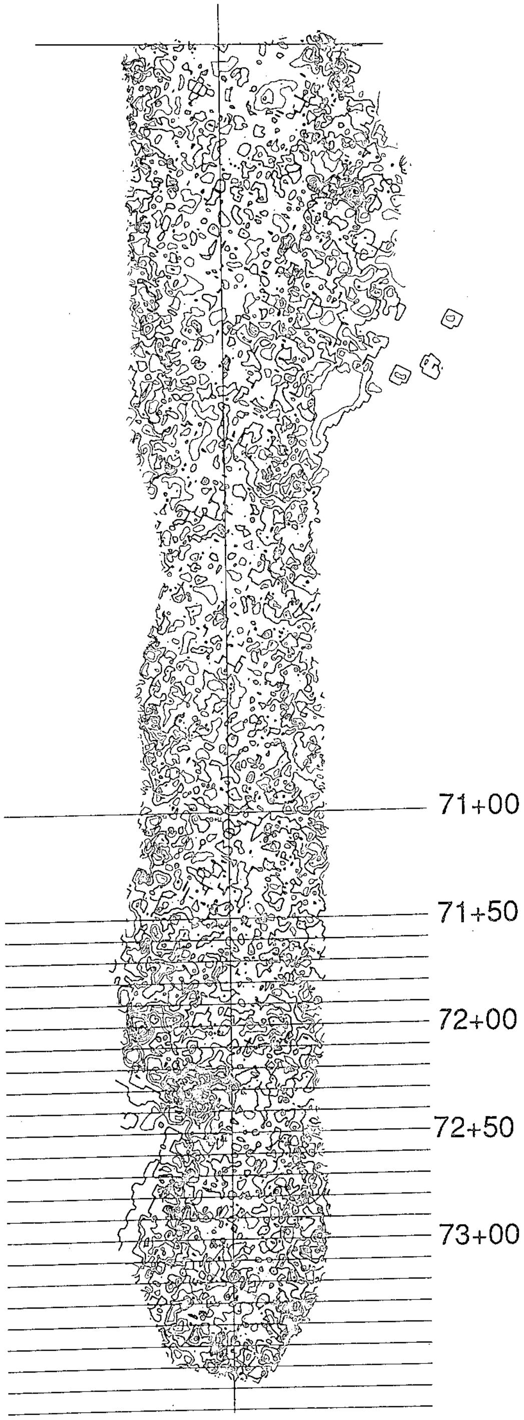


Figure 44. Photogrammetry cross-section range lines

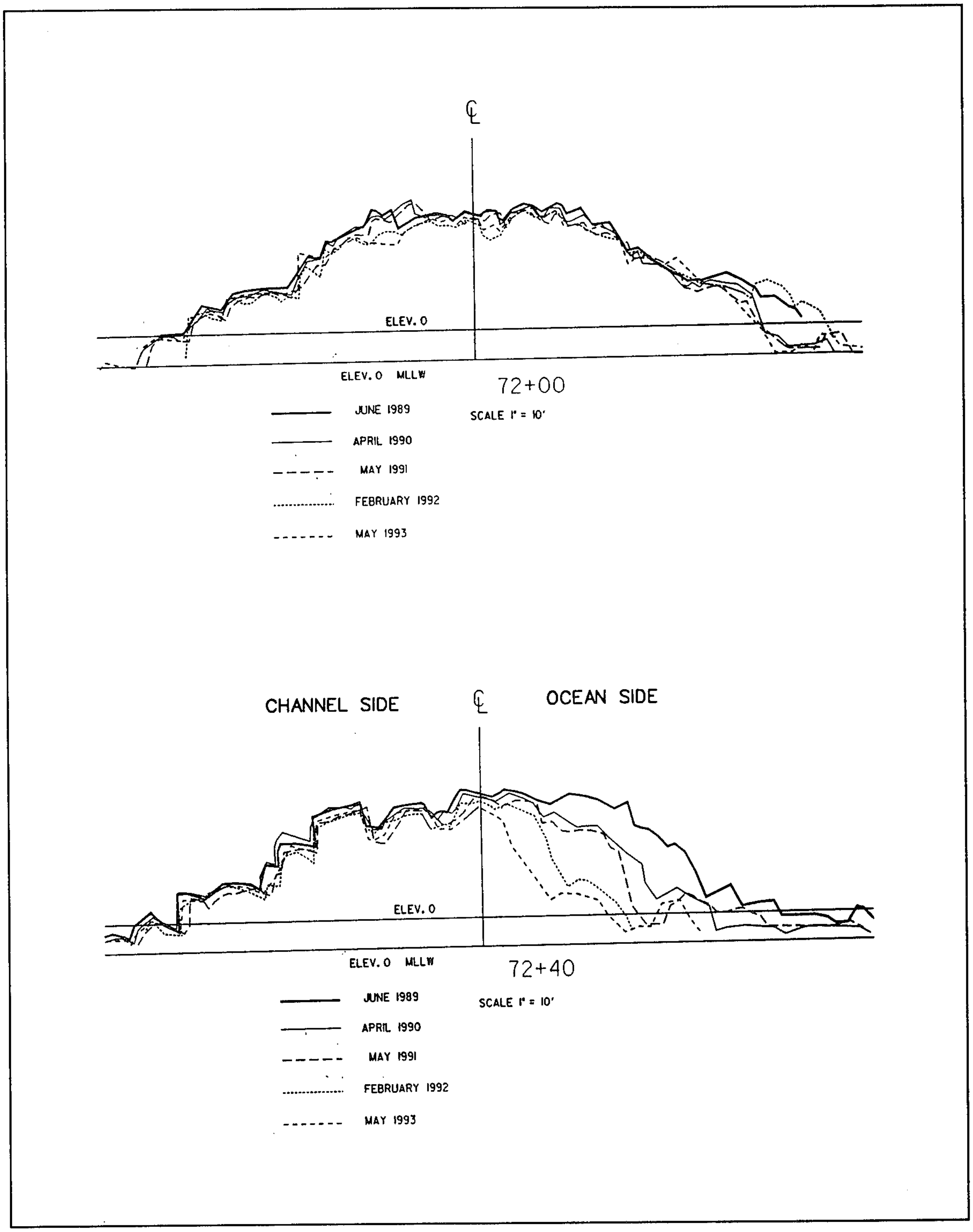


Figure 45. Stereo model jetty profile comparisons, ranges 72+00 and 72+40

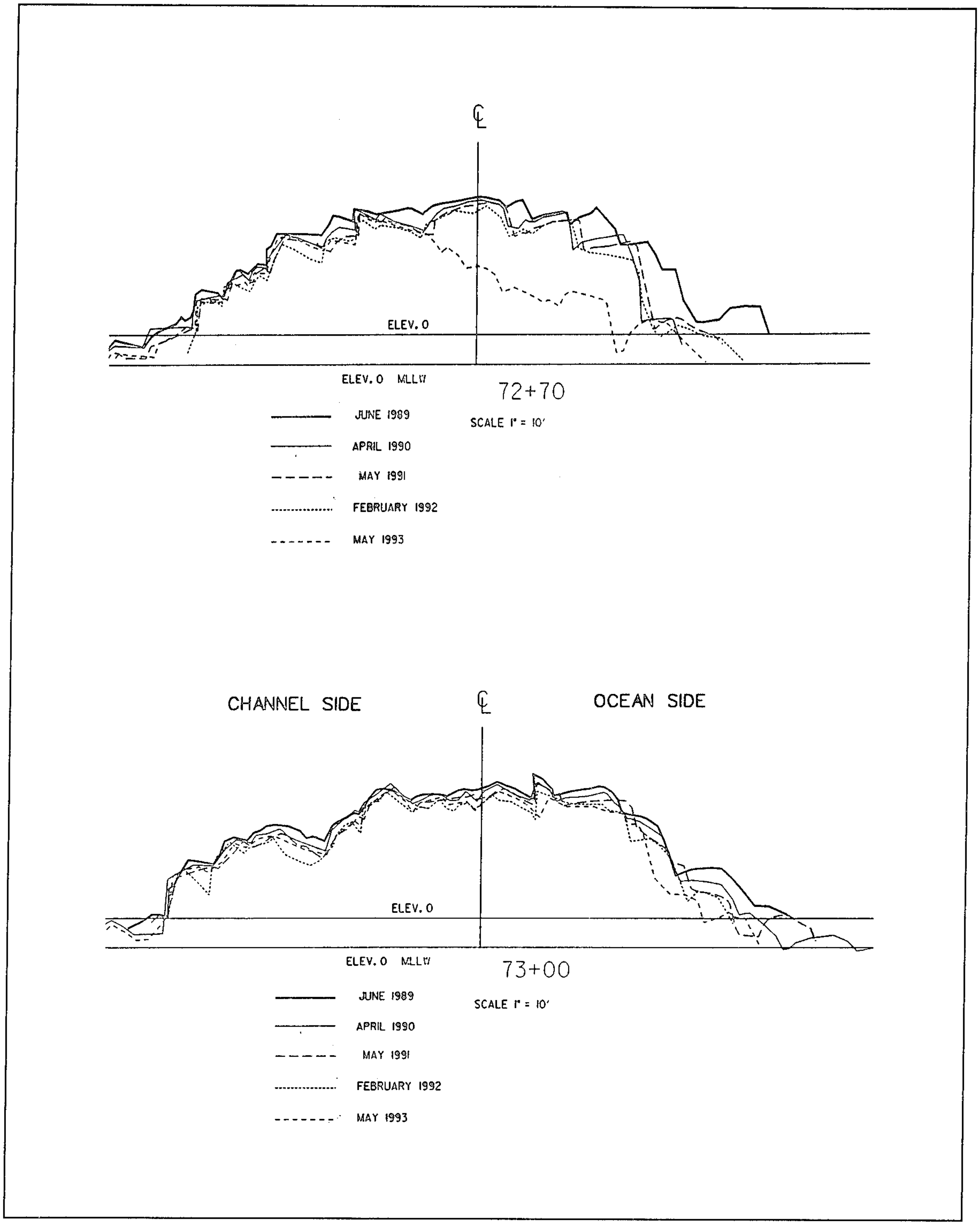


Figure 46. Stereo-model jetty profile comparisons, ranges 72+70 and 73+00

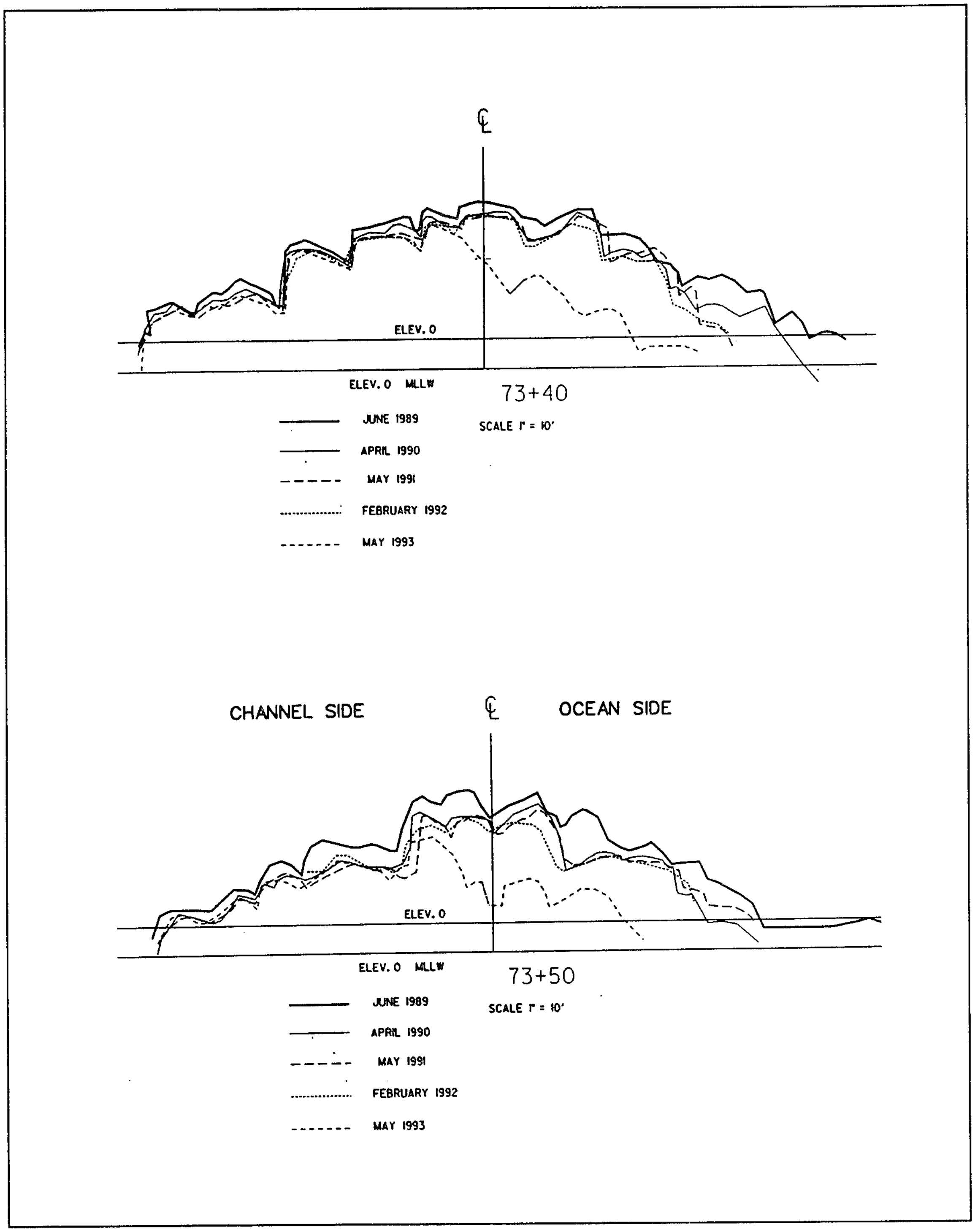


Figure 47. Stereo-model jetty profile comparisons, ranges 73+40 and 73+50

d. These results would have been very difficult to obtain by conventional surveying methods, and the accuracy appears to be within acceptable limits.

Stone movement results

Movement and loss of individual armor stones between overflight dates was documented on Mylar overlays. Each stone that had been lost between consecutive sets of photographs was represented as a numbered dot. Stones that had moved, but were still identifiable, were shown as a vector pointing in the direction of movement with the vector length representing the distance moved. This same information was tabulated by stone number along with additional remarks about the individual stones, such as rotation or other comments.

Between the 1989 and 1990 photographs there was a significant amount of stone movement detected in the vicinity of the "notch" as the structure made its initial adjustment to the environmental conditions. The comparison between 1990 and 1991 showed little movement of stone in the notch area, with only four armor stones disappearing and three stones moving distances ranging between 1 and 3 m (3 and 10 ft).

Stone movement determinations made for the 1991 - 1992 time span showed significant stone movement around the landward end of the notch region. Figure 48 shows the waterline on the jetty and the numbered stones that moved or disappeared between 1991 and 1992. Figure 49 provides the corresponding description for each numbered stone. Movement of 6 of the 23 stones averaged about 0.8 m (2.5 ft), and 11 stones disappeared from the notch region during this time span.

The winter season between 1992 and 1993 resulted in the loss of approximately 17 identifiable armor stones as determined from aerial photography. Ten of the larger select class "A" stones were lost from the previously stable region at the very tip of the north jetty as shown on the stone movement drawing (Figure 50). More stones were undoubtedly lost from underneath the removed top stones, but the actual number cannot be determined because they cannot be identified on the earlier photographs. Curiously, eight stones on the 1993 photographs were identified that were not present in the 1992 photographs. It is presumed that these armor stones, located high on the crest near the jetty center line, were swept up the structure slope from the notch area or from somewhere below the waterline. Also, some stone movement was noted on the channel side of the north jetty around Station 68+50 (see Figure 50).

Figure 51 summarizes the stone movements that occurred between 1992 and 1993. Although most stone movements were less than 2 m (7 ft), there was one stone near the notch that moved about 3.4 m (11 ft) downslope and one stone at the tip that was displaced a total of 6.4 m (21 ft).

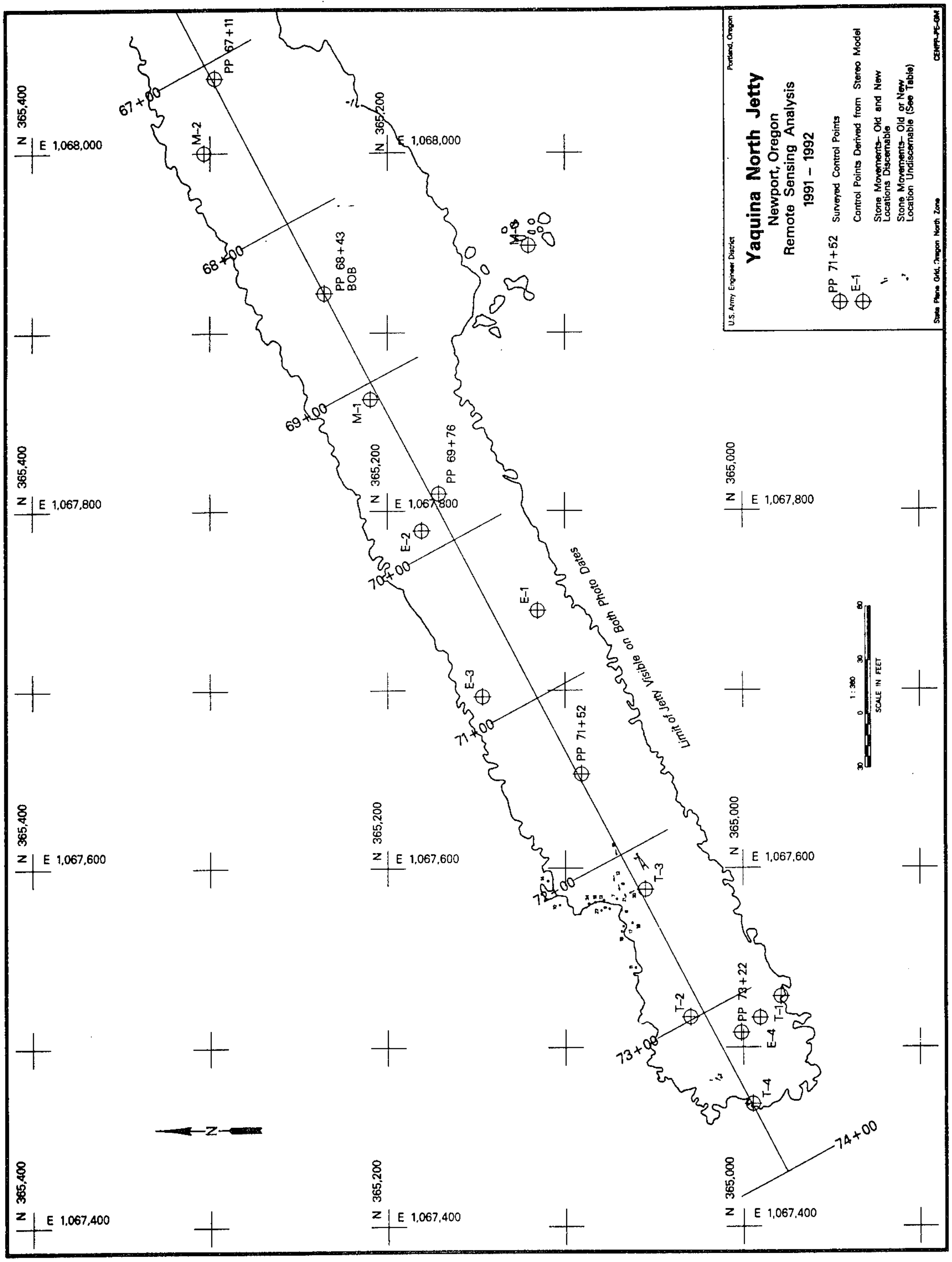


Figure 48. Individual armor stone movements between 1991 and 1992

CENPP-PE-GM

11-May-92

YAQUINA NORTH JETTY

Stone Movement Determinations

1991 - 1992

Stone #	Length of Movement (In Feet)	Direction of Movement	Comments
1	2.6	N60.0E	Stone moved and rotated under stone #2.
2			Stable Rock.
3	No entry, stable.		
4			Rotated 15 degrees cc about centroid.
5			Rotated and moved.
6			Stone no longer visible.
7			Stone no longer visible.
8	2.5	S81.7W	Moved.
9			Stone no longer visible.
10			Stone not on 1991 photo, possibly from above.
11			Stone not on 1991 photo, possibly from above.
12			Stone no longer visible.
13	2.9	S87.3W	Moved.
14			Stone not on 1991 photo, origin unknown.
15			Stone no longer visible.
16			Stone no longer visible.
17			Stone no longer visible.
18			Stone no longer visible.
19	2.6	S80.0W	Moved.
20	2.4	N25.7W	Moved.
21	1.3	N67.7E	Moved, partially beneath stone #8.
22			Stone no longer visible.
23			Stone no longer visible.
24			Stone no longer visible.

Figure 49. Stone movement determinations, 1991 - 1992

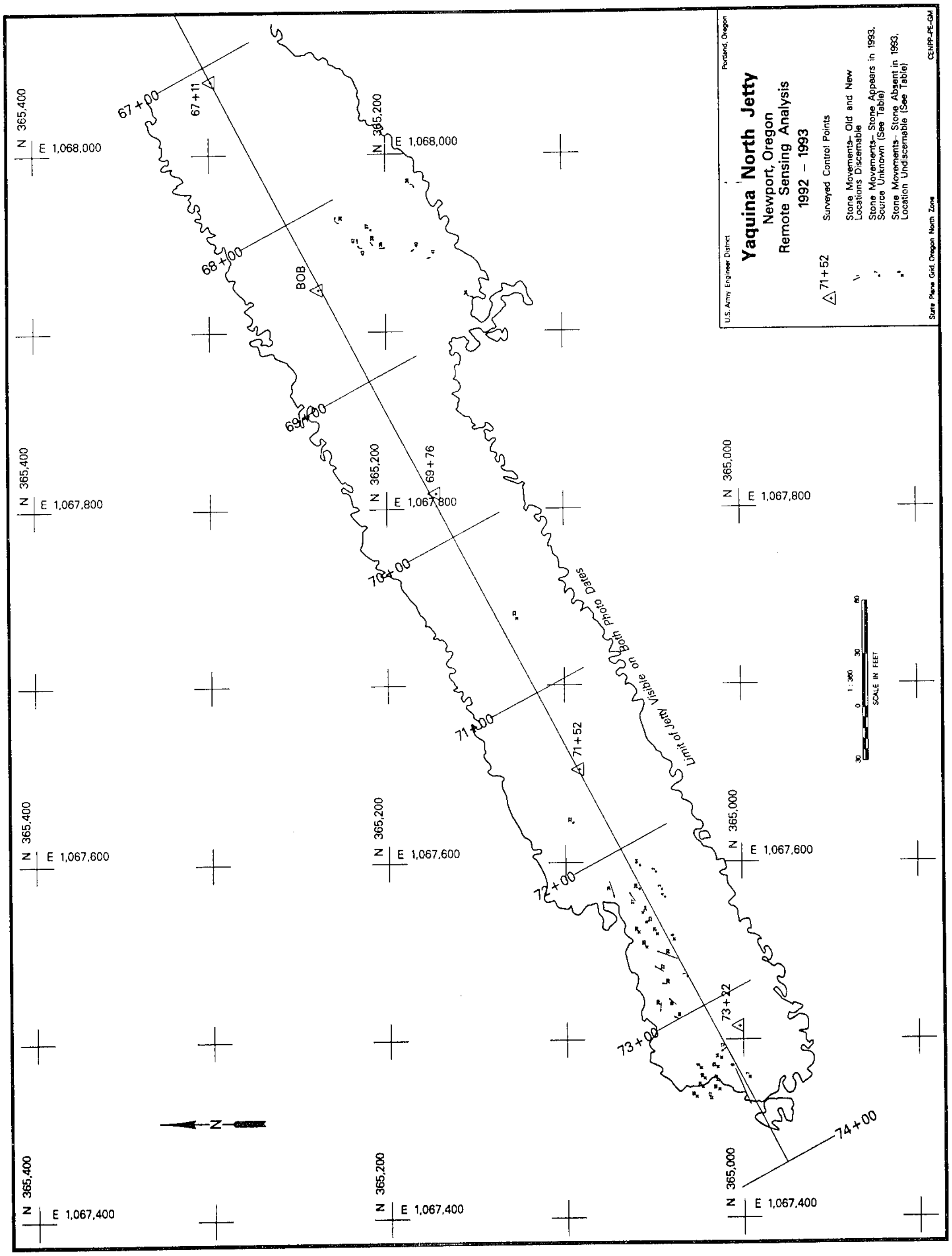
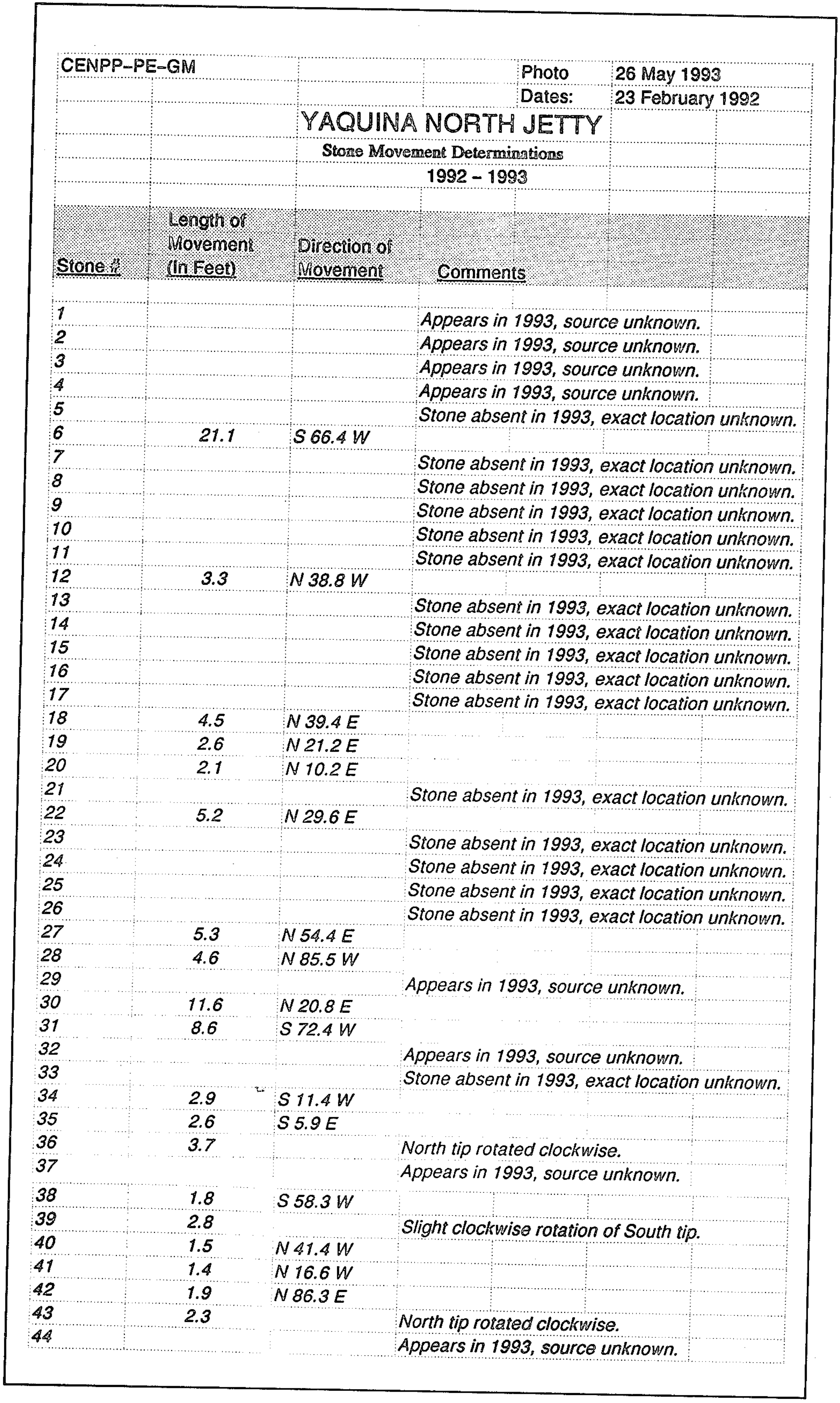


Figure 50. Individual armor stone movement between 1992 and 1993



CENPP-PE-GM

Photo Dates: 26 May 1993
23 February 1992

YAQUINA NORTH JETTY

Stone Movement Determinations

1992 - 1993

Stone #	Length of Movement (In Feet)	Direction of Movement	Comments
1			Appears in 1993, source unknown.
2			Appears in 1993, source unknown.
3			Appears in 1993, source unknown.
4			Appears in 1993, source unknown.
5			Stone absent in 1993, exact location unknown.
6	21.1	S 66.4 W	
7			Stone absent in 1993, exact location unknown.
8			Stone absent in 1993, exact location unknown.
9			Stone absent in 1993, exact location unknown.
10			Stone absent in 1993, exact location unknown.
11			Stone absent in 1993, exact location unknown.
12	3.3	N 38.8 W	
13			Stone absent in 1993, exact location unknown.
14			Stone absent in 1993, exact location unknown.
15			Stone absent in 1993, exact location unknown.
16			Stone absent in 1993, exact location unknown.
17			Stone absent in 1993, exact location unknown.
18	4.5	N 39.4 E	
19	2.6	N 21.2 E	
20	2.1	N 10.2 E	
21			Stone absent in 1993, exact location unknown.
22	5.2	N 29.6 E	
23			Stone absent in 1993, exact location unknown.
24			Stone absent in 1993, exact location unknown.
25			Stone absent in 1993, exact location unknown.
26			Stone absent in 1993, exact location unknown.
27	5.3	N 54.4 E	
28	4.6	N 85.5 W	
29			Appears in 1993, source unknown.
30	11.6	N 20.8 E	
31	8.6	S 72.4 W	
32			Appears in 1993, source unknown.
33			Stone absent in 1993, exact location unknown.
34	2.9	S 11.4 W	
35	2.6	S 5.9 E	
36	3.7		North tip rotated clockwise.
37			Appears in 1993, source unknown.
38	1.8	S 58.3 W	
39	2.8		Slight clockwise rotation of South tip.
40	1.5	N 41.4 W	
41	1.4	N 16.6 W	
42	1.9	N 86.3 E	
43	2.3		North tip rotated clockwise.
44			Appears in 1993, source unknown.

Figure 51. Stone movement determinations, 1992 - 1993

Volumetric stone loss estimate

Finally, NPP used the uniformly gridded jetty elevation data to make volumetric calculations of net volume loss on the seawardmost 183 m (600 ft) of the north jetty between overflight dates. Volumetric calculations were confined to the notch and jetty tip area outlined in Figure 41. The margin of error of the volumetric calculations will increase when there has not been much change between annual overflights. Chronological progression of cumulative volume loss is shown in Figure 52, which shows year-to-year calculations. Summation of the 1989 - 1990, 1990 - 1991, 1991 - 1992, and 1992 - 1993 volume changes gave a total volumetric stone loss of about 1,394 m^3 (1,823 yd^3), whereas direct calculation comparing the stereo model data from 1989 and 1993 gave a net total loss of 1,369 m^3 (1,791 yd^3). Some portion of this volume loss can be attributed to settlement of the jetty, but what percentage is unknown. The primary cause for difference between the two total volume estimates is slight differences between stereo models in the boundary of the region selected for volumetric calculation.

Assuming the ratio of void volume to total volume for the special construction at the Yaquina Bay north jetty is about 0.35, then the total volumetric loss of stone would be 65 percent of the total volume loss, or about 900 m^3 (1,175 yd^3). If an average stone is assumed to have a weight of about 27 tonnes (30 tons), then its volume on average would be approximately 10 m^3 (13.5 yd^3); and the total volume loss would translate into a rough estimate of about 90 armor stones lost in the notch and tip area above the low tide level. The actual number of lost stones will also depend on settlement and variation in stone size.

Figure 53 gives a visual impression of the stone loss that occurred between 1992 and 1993. Subtraction of the 1992 stereo-model orthographic projection "mesh" from the 1993 mesh produced a mesh showing just the changes in elevation between the two overflights, which translates into stone loss. Difference contours were also produced from the stereo-models.

Helicopter Photogrammetry at Yaquina

In 1992 and 1993 aerial photogrammetry efforts at the Yaquina Bay north jetty were expanded to include analysis of controlled aerial photographs acquired from a helicopter flying at low altitude. The Portland District contracted this effort with the Richard B. Davis Company, Inc., of Smith River, CA.

Besides acquiring and analyzing controlled aerial photography, the contract also included necessary ground surveying to establish additional "targets" for the lower-level flights. The purpose of the helicopter effort was to compare results from the fixed-wing and helicopter photogrammetry and to assess the advantages and disadvantages of each. Appendix I contains the contractor's report for the first helicopter flight and analyses.

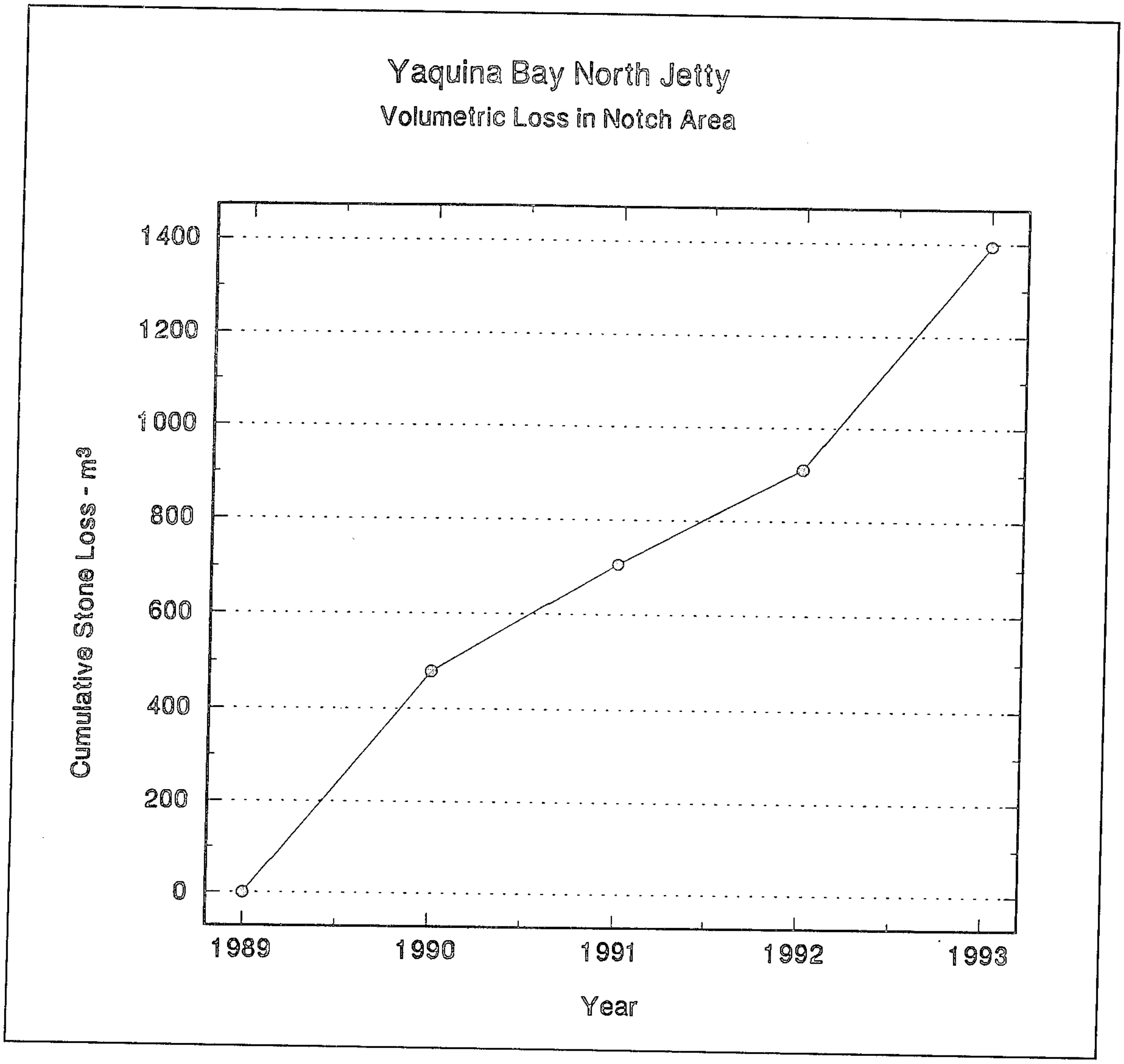


Figure 52. Volumetric change in the "notch" area between 1989 and 1993

Methodology

Much of the methodology for obtaining and analyzing aerial photography using photogrammetric methods is the same for low-altitude helicopters as it is for fixed-wing aircraft. Davis and Kendall (1992) reported on the unique aspects of helicopter photogrammetry. A special camera was mounted in the helicopter, and stereo photographs were acquired with a 60-percent forward overlap. Coverage was over the seawardmost 183 m (600 ft) of the north jetty.

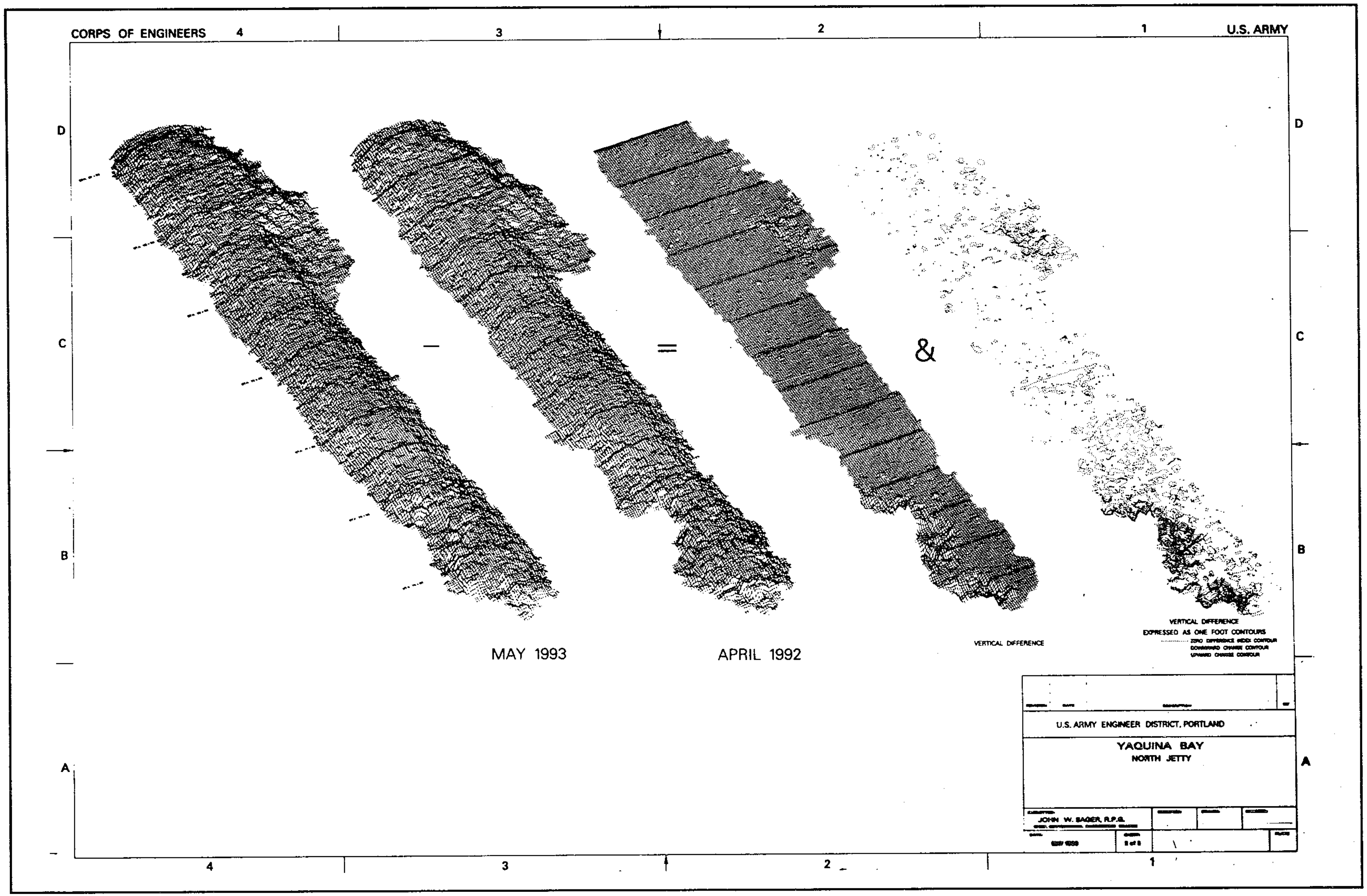


Figure 53. Yaquina Bay north jetty stone loss between 1992 and 1993

Two helicopter flight plans were followed. The first was scheduled for an altitude of 37 m (120 ft) on a flight line parallel to the center line of the north jetty. This altitude would produce photographs with a scale of about 1:240 or 10 cm = 2.4 m (1 in. = 20 ft). The second plan was to fly three side-by-side flight lines at 61 m (200 ft) altitude on paths perpendicular to the north jetty center line. A third overflight was planned from an altitude of 183 m (600 ft) to obtain a single stereo pair of photographs of the entire study area.

Because of the low altitude, the helicopter photographs will have higher resolution than fixed-wing photographs, but none of the photographs would contain a sufficient number of existing ground-surveyed points to establish a reliable stereo model. It was therefore necessary to place additional targets on the jetty and survey them back to established reference points used in the fixed-wing flights. The additional targets consisted of markers placed on aluminum plates affixed to jetty stones. The continual sea spray kept much of the jetty too wet to paint targets directly on the armor stones. Some of the targets placed for the helicopter survey were swept away overnight and had to be replaced before the flight.

Aerial photography was planned for 22 March 1992, but high seas prevented completion of target installation on the jetty. Photographs were obtained on 9 April 1992 under less than ideal conditions. An approaching storm generated waves above 2 m (6 ft) in height, and a low overcast prevented photography above 120 m (400 ft). Southeast winds affected the pilot's ability to maintain exact flight lines. Nevertheless, the flight was successful and usable photography was obtained. Several passes of the jetty were made to assure the best possible images for analysis.

Stereo models were developed using the best stereo pairs for each section of the jetty tip. Elevation data were related to the ground targets, and in turn expressed relative to the State Plane coordinate system. The computer then generated a 0.6-m by 0.6-m (2-ft by 2-ft) grid, and elevations were measured and recorded. Grid points which overlaid voids and unreadable locations were rejected. The final grid file contained approximately 15,000 elevations. This file was used to generate contour plots, cross sections, and 3-D projections of the above-water portion of the seaward 183 m (600 ft) of the jetty.

Results

The contractor report in Appendix I contains an analysis of errors involved in the ground survey and photogrammetric analysis. Generally the errors were small. For example, overlaps between stereo pairs were analyzed, and the average difference in elevation was 2.4 cm (0.08 ft).

Figure 54 shows a composite photograph of the seaward tip of the north jetty acquired during the 1992 helicopter overflight. Figure 55 shows the contours developed from the photogrammetry, similar to the fixed-wing

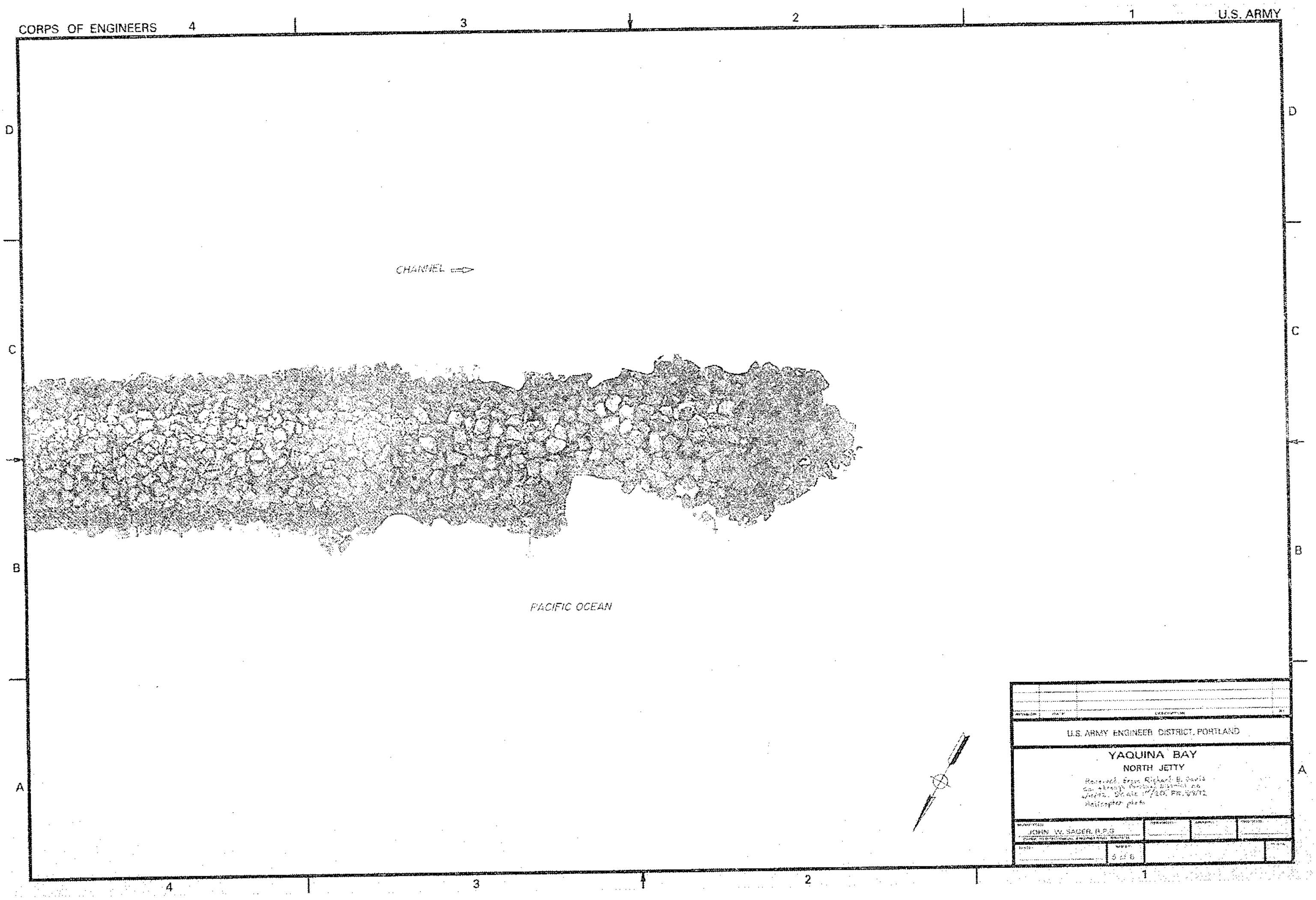


Figure 54. Helicopter photograph of Yaquina Bay north jetty tip, 1992

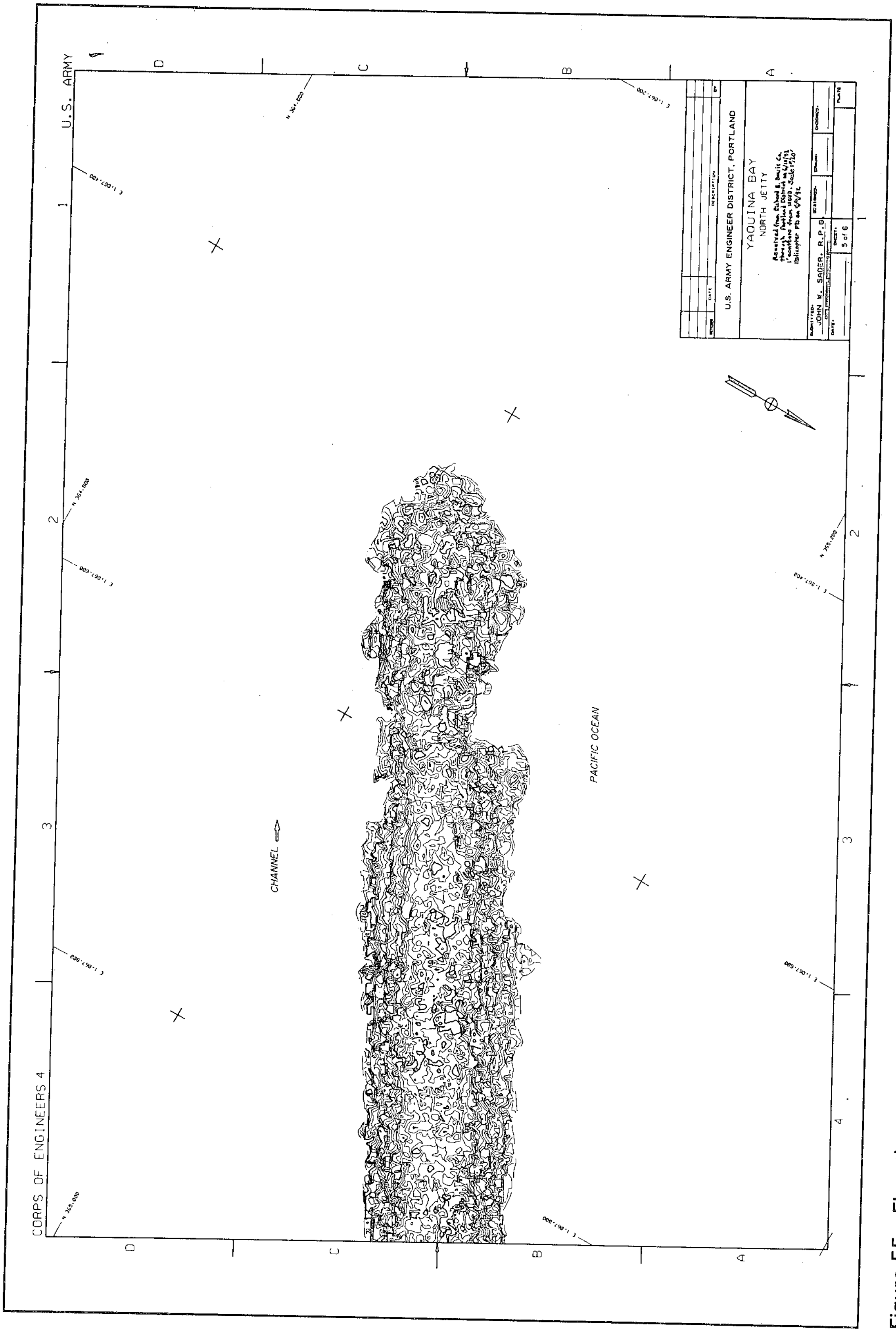


Figure 55. Elevation contours from the 1992 helicopter overflight

photogrammetry shown in Figure 40. A "mesh" orthographic projection of the jetty also was plotted from the stereo model, as shown in Figure 56.

Above-water cross sections of the north jetty were plotted from the 1992 and 1993 helicopter stereo models for the same stations as the fixed-wing flights. The full set of cross sections is given in Appendix J. The Portland District reported that section 71+52 on the helicopter cross sections corresponds to 71+50 on the fixed-wing flights. A similar offset in the profile range specification is consistent throughout the helicopter photogrammetry cross sections. This offset arose when stations were re-established on the jetty in slightly different positions.

Figure 57 compares three of the 1992 helicopter cross sections (solid line) to the respective fixed-wing cross section (dashed line) that were obtained about 6 weeks earlier. For this limited comparison, reasonable agreement is observed overall, but isolated differences in elevation up to about 3 m (10 ft) are noted. This may be due to misalignment of the coordinate systems used in the two stereo models or interpretation of the stereo photographs. Whichever the case, it is not possible to state absolutely which profiles are correct without further ground-truth from land-based surveys.

Photogrammetry Conclusions

The photogrammetry efforts at Yaquina delivered precise and useful information about the evolution of the above-water structure at the seawardmost tip of the north jetty as it weathered successive storm seasons. Unfortunately, similar information on what has happened to the structure beneath the water surface is not available.

The primary difference between the two systems employed as part of the monitoring study was the camera platform. Each platform has advantages and disadvantages, some of which are cited in Table 21.

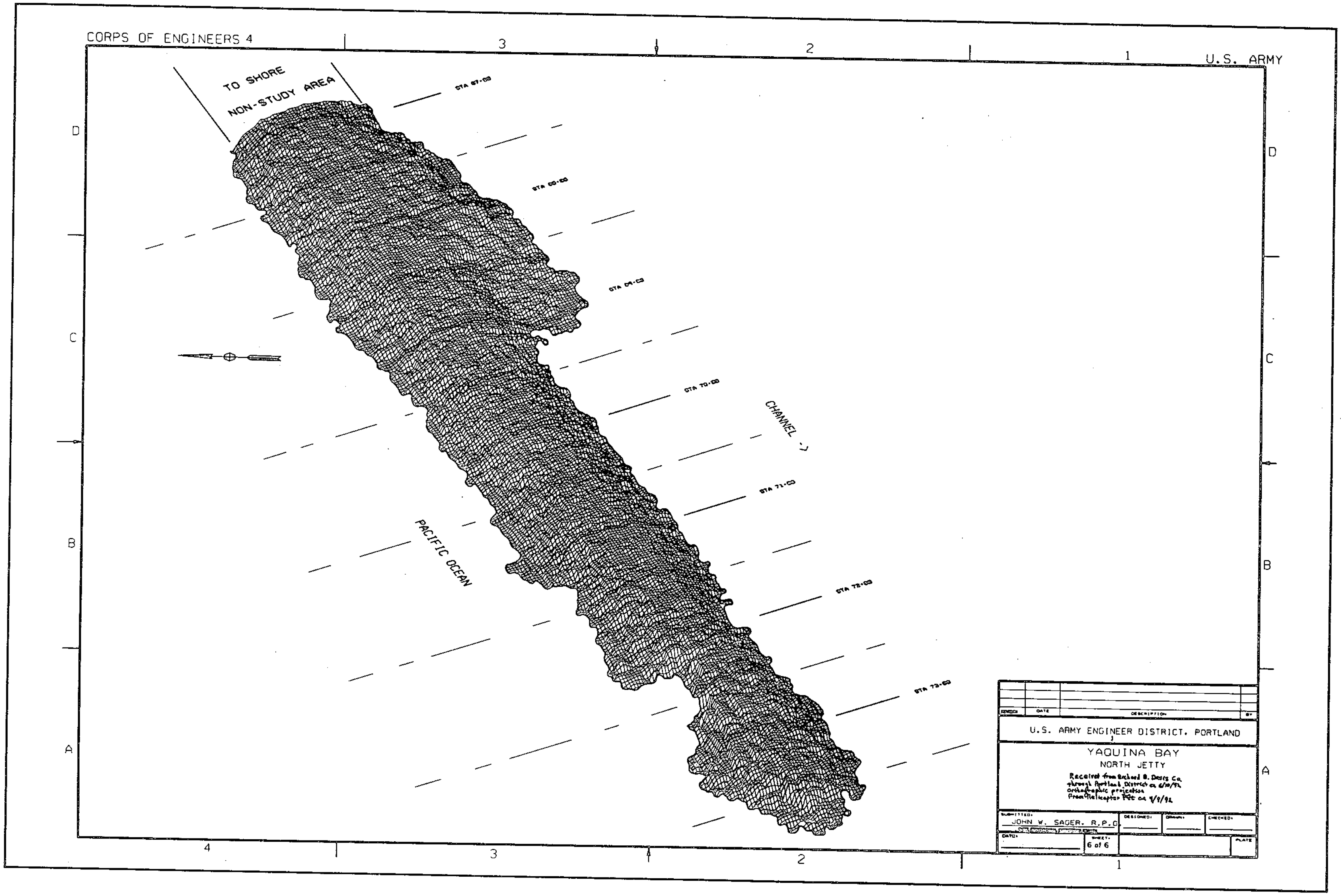


Figure 56. Orthogonal projection from the 1992 helicopter overflight

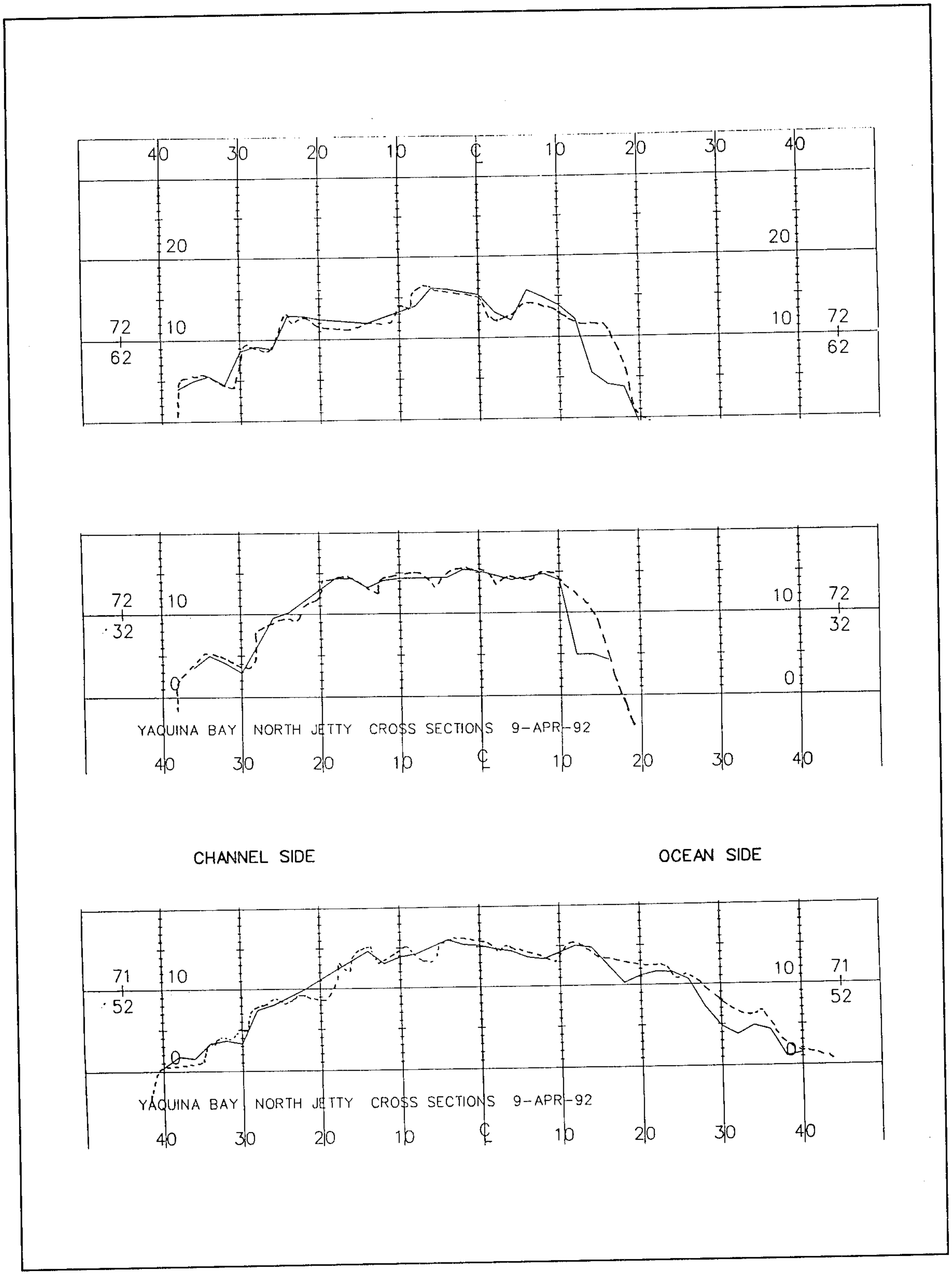


Figure 57. Comparison between 1992 helicopter (solid line) and fixed-wing (dashed line) cross sections

Table 21
Advantages and Disadvantages of Camera Platform

Fixed-Wing Aircraft Advantages
Less expensive than helicopter flights.
More commonly available (which provides more contract competition).
Requires less ground truth in the form of surveyed and recognizable targets.
Disadvantages
Higher flight elevation gives lower photographic resolution which may lead to inaccuracies in the analyses and makes the photogrammetrist's job more difficult.
Flight times are limited to days with high ceilings.
Photogrammetric analyses may be more time-consuming because of the decreased resolution offered by higher altitude photographs.
Helicopter Advantages
Lower flight altitude gives higher photo resolution, which provides easier analysis (if need for project).
Lower altitude lessens geometric "weakness" and results in more accuracy in the stereo-models.
Flights can occur during low ceiling levels that would rule out fixed-wing flights.
Disadvantages
More expensive and less vendors competing for work.
The lower altitude requires that additional ground targets be placed and surveyed on the structure.
Target maintenance and replacement may be a significant cost to ongoing monitoring efforts and may be dangerous for personnel out on the jetty.
More images are needed to cover an area, which increases analysis costs.

8 North Jetty Physical Models

Stability Study of the 1978 Jetty Rehabilitation

A major focus of the first Yaquina north jetty workshop, held in Vicksburg, MS, on June 12-13, 1989, was to establish viable damage hypotheses related to past deterioration of the Yaquina Bay north jetty. One of the recommendations stemming from the workshop was that CERC conduct a physical model study with the purpose of attempting to recreate actual jetty damage that occurred at Yaquina after the 1978 rehabilitation. This "forensic" study would test the hypothesis that past damage occurred because of armor stone instability as waves broke directly on the structure. Also, this hypothesis was the easiest to examine. Details of this physical model armor stability study are given by Carver and Briggs (1994), which served as the source for the following description of the physical model and model results.

Physical model description

The 1-to-45 scale (model-to-prototype) physical model of the 1978 rehabilitated north jetty was constructed in the same 29-m-long by 37-m-wide (96-ft-long by 121-ft-wide) wave basin that was previously used in 1987 to test the stability of the 1988 rehabilitation (Grace and Dubose 1988). This basin still contained the Yaquina north jetty model bathymetry that had been molded using data from nautical charts and surveys, and this bathymetry was retained without modification for the stability study of the 1978 jetty configuration.

The wave board in the basin was located at a depth corresponding to -17.7 m (-58 ft) mllw in the prototype, and the molded bathymetry extending from the wave board to the jetty was intended to provide the same wave transformation in the model that occurs in the prototype. The model plan view is shown in Figure 58. Passive wave absorbers consisting of "horsehair" rubberized mats placed on metal support frames were used to minimize wave reflections by the basin boundaries.

The geometrically undistorted physical model reproduced approximately 440 m (1,440 ft) of the seawardmost portion of the north jetty, 274 m (900 ft)

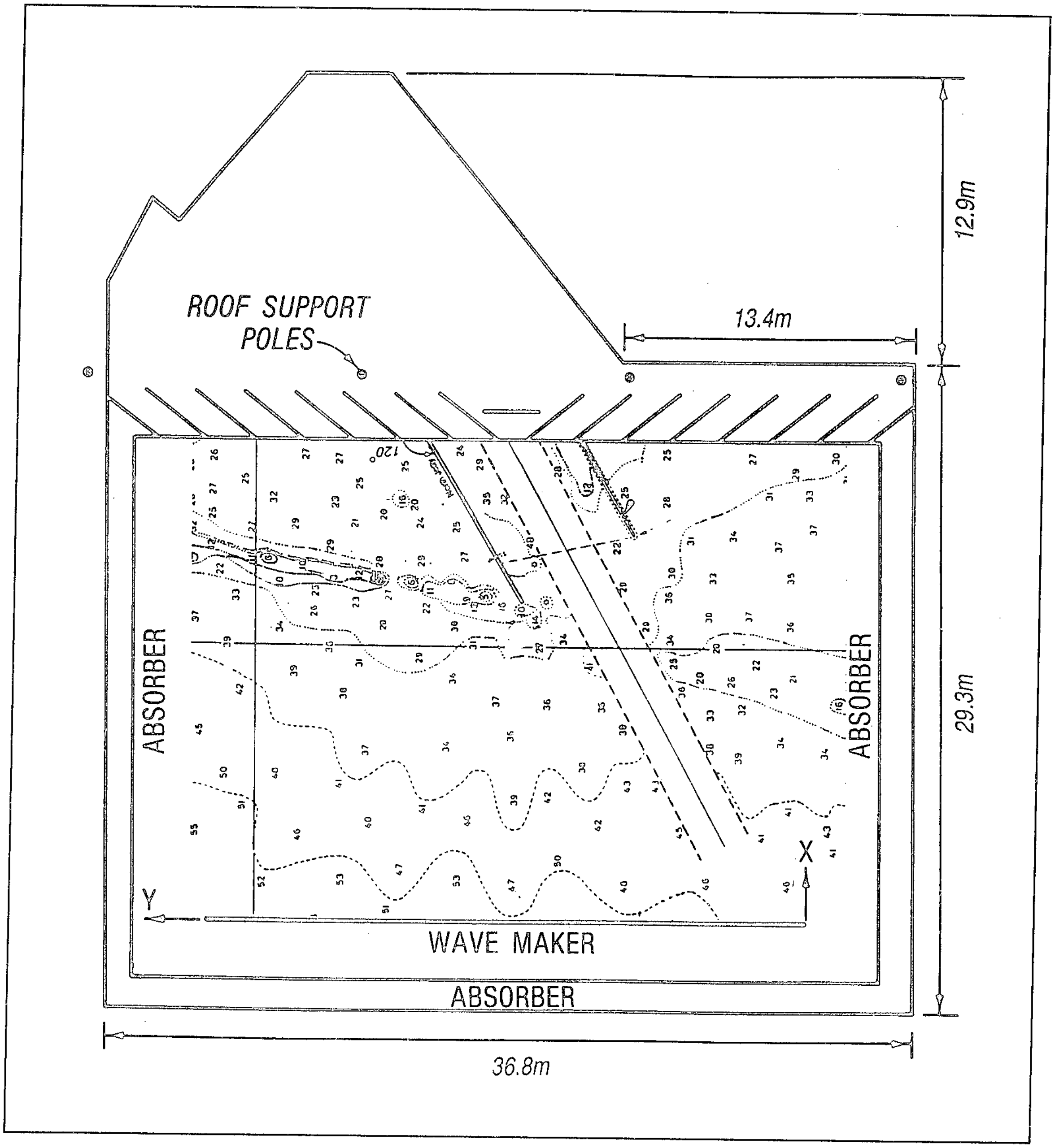


Figure 58. Physical model layout for stability study of 1978 north jetty rehabilitation

of the south jetty tip, and a region about 520 m (1,700 ft) north of the north jetty. The orientation of the north jetty was selected to allow a 50-deg range of incident wave direction without substantial loss of wave energy due to diffraction effects.

The north jetty in the model was constructed according to the cross sections as given in Figures 59 and 60. (Note that jetty station numbering differs from the scheme used in the MCCP study.) No information was available on the condition of the bedding layer and remnants of the 1966 construction in

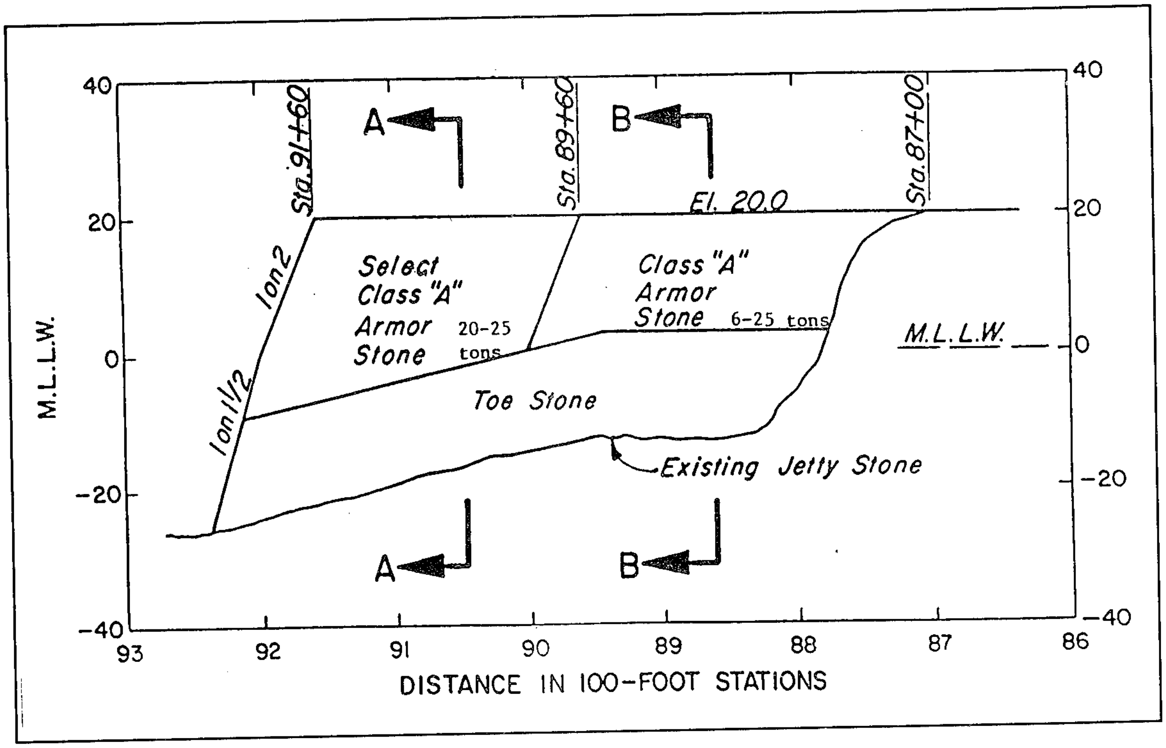


Figure 59. Yaquina Bay north jetty 1978 rehabilitation jetty profile

the portion of the jetty that had been damaged before the 1978 rehabilitation. Therefore, bedding and core materials were placed in a manner similar to a new construction, but with a wider base. The two layers of select class "A" stone used as the primary armor were specially shaped parallelpiped stones with a maximum length between two and three times the shortest dimension. Scaling for the 1:45 scale model resulted in average select "A" class 18-tonne (20-ton) armor stones in the prototype being represented by model armor stones with a mass of about 0.2 kg (0.44 lb). These model armor stones were handmade to Portland District specifications. Above mllw, stones were placed with their long axis perpendicular to the jetty slope. Below the waterline, stone placement was random. Special placement of the slab-like armor stones results in increased stability compared to randomly placed stone. Figure 61 shows a photograph of the completed north jetty model structure.

Selection and generation of waves

Aerial photography of the Yaquina Bay north jetty indicated that between 61 and 76 m (200 and 250 ft) of the north jetty tip was beaten down below the waterline during the 1979-1980 storm season. Such a dramatic change over one storm season implied that most of the damage was a direct result of waves from several severe winter storms striking the jetty, rather than a slow unraveling of the structure over time. Because physical modeling is better suited to simulating relatively short-duration events, it was decided to attempt

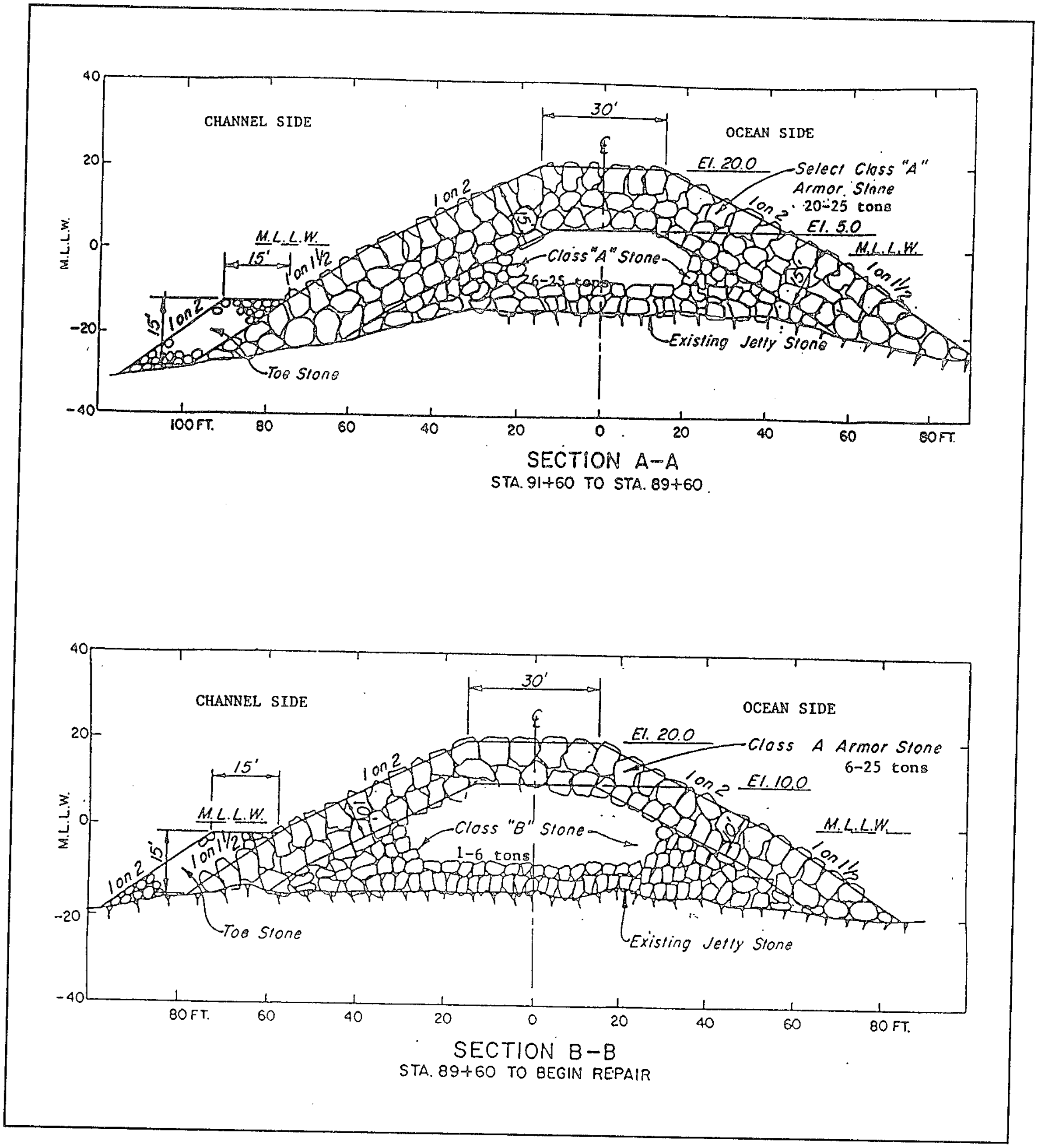


Figure 60. Yaquina Bay north jetty 1978 rehabilitation jetty cross section

recreation of the 1979-1980 winter season storm damage using only the severe storms from that period.

An analysis of meteorological and National Oceanic and Atmospheric Administration buoy data identified three major storm periods occurring at Yaquina Bay during the winter of 1979-1980. These storm periods were: October 17-23, 1979; November 17-23, 1979; and December 19-27, 1979. Directional wave spectra from these storm episodes were hindcast over a 111-km (60-n.m.) grid of the entire Pacific Ocean using the WIS deepwater

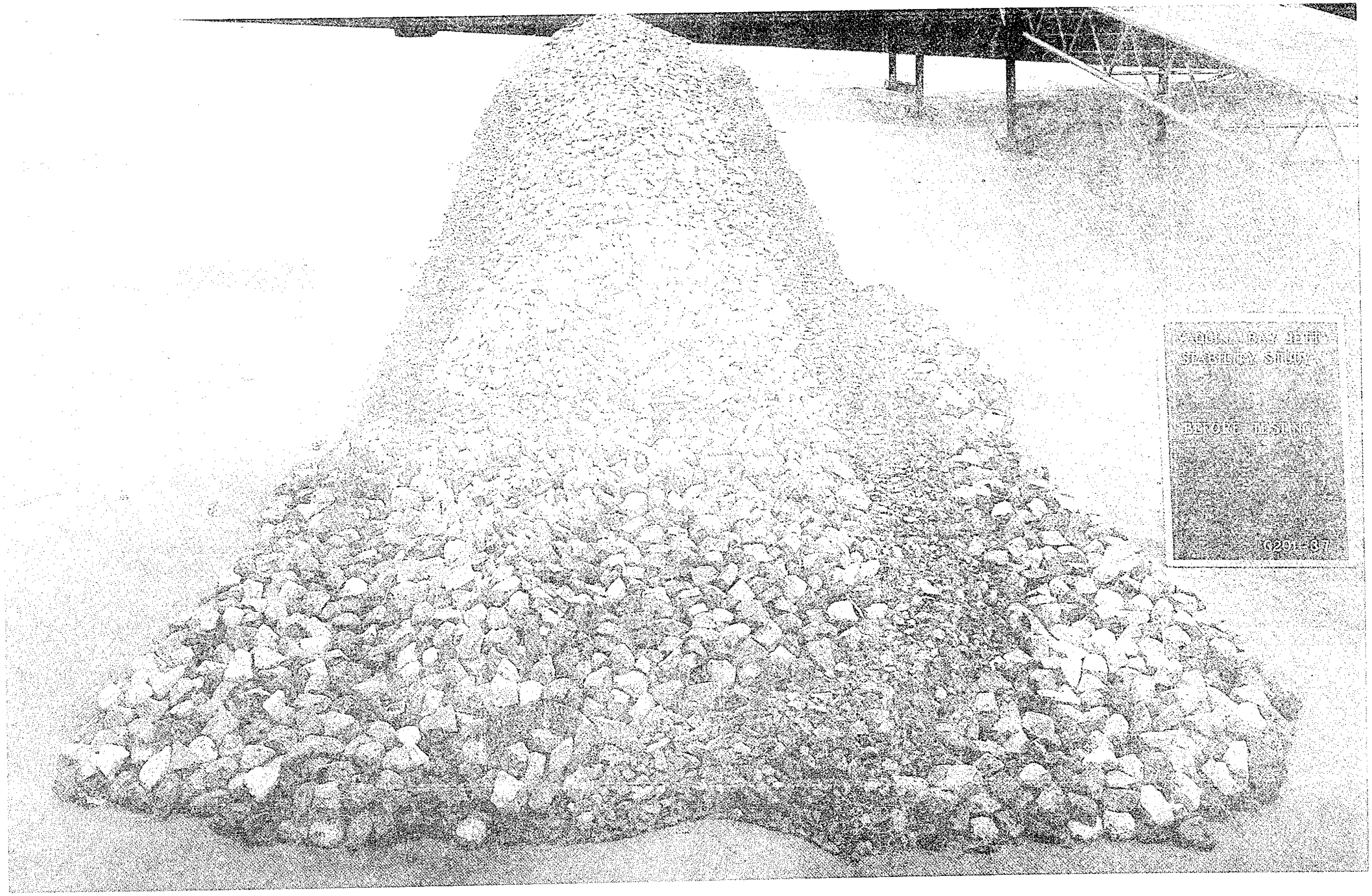


Figure 61. Photograph of model north jetty from stability study of 1978 rehabilitation

numerical hindcast model DWAVE (Corson et al. 1987). Input to the DWAVE model consisted of vector wind fields generated from atmospheric pressure maps, and model results were output at locations corresponding to the seaward input boundary grid points of a second wave propagation numerical model.

Deepwater hindcast wind and wave parameters are compared to those measured at NOAA buoy 46002 in Carver and Briggs (1994). Reasonable agreement between model estimates and buoy data was noted for significant wave heights and peak spectral wave periods of the November and December storm sequences; however, the numerical model underpredicted wave heights and peak period for the October storm sequence.

The numerical model SHALWV (Hughes and Jensen 1986) was used to transform deepwater spectral wave conditions into shallow water on a 9.3-km (5-n.m.) grid. This simulation took into account wave refraction and shoaling effects as the waves were propagated into a water depth of -16.8 m (-55 ft) mllw. Each storm period was represented as a time sequence of directional spectra given at 12-hr intervals. Additional details about this numerical wave hindcast for Yaquina Bay are given in Carver and Briggs (1994).

Originally, a total of 46 individual wave conditions were shoaled to the depth of the wave generator using the numerical transformation model. However, because of duplication, low energy events, and storm tracks not directly impacting the Yaquina Bay jetties, the original number of storm sequence segments was reduced to 13 segments representing the most severe conditions. Prototype values for peak spectral wave period (T_p), significant wave height (H_{mo}), and approaching wave direction (0 deg is shore-normal approach, and positive is approaching from north of shore-normal) for the 13 conditions are given in Table 22.

Because of time and funding constraints, each 12-hr storm segment was simulated in the physical model for a model time equivalent to 6 hr in the prototype. Each 6-hr segment was divided into two 3-hr segments, with one segment being run at high tide and the other run at low tide level, as determined from the Yaquina Bay tide gauge. Thus, the model jetty was subjected to a total of 26 different combined wave and water level conditions during simulation of the 1979-1980 winter storms.

Control signals for the 61 individual wave paddles of the directional spectral wave machine were generated using a high-speed computer. Each set of signals approximated one of the numerically hindcast directional wave spectra, and an iteration technique was employed to refine wave conditions in the model basin so that the model directional spectra closely matched the target conditions. Carver and Briggs (1994) provided complete details of the directional wave basin calibration phase.

Table 22
Prototype 1979 Storm Parameters Tested in Physical Model

Date 1979	T_p (sec)	H_{mo} (m)	Direction (deg)
Oct 22 12pm	10.0	4.4	35
Oct 23 12am	12.5	4.5	18
Oct 23 12pm	11.1	3.8	6
Nov 20 12pm	14.3	2.1	5
Nov 21 12am	14.3	1.6	11
Nov 21 12pm	16.7	2.5	6
Nov 22 12am	16.7	3.1	6
Nov 22 12pm	16.7	3.2	5
Nov 23 12am	14.3	3.1	11
Nov 23 12pm	14.3	3.3	23
Dec 24 12pm	14.3	5.2	22
Dec 25 12am	16.7	5.0	15
Dec 25 12pm	12.5	3.7	16

Physical model tests and results

The irregular multidirectional waves representing the major hindcast storm sequences shown on Table 22 were run in the physical model. Each storm was run as a time sequence of varying wave parameters and water level. The October storm sequence produced only minor rocking of a few armor stones followed by a general loosening of 8 to 10 armor stones. However, the structure was intact and in good condition at the end of the October storm test sequence.

The November storm sequence was generally milder than October's conditions, and the structure survived with only minor armor stone rocking occurring during the entire sequence. Similarly, the December storm sequence had little impact on the structure. One armor stone was displaced and several stones rocked over the course of the test, but overall the model structure only showed some general loosing of stone above the still-water level.

At the end of all three storm sequence simulations in the physical model, it was discovered that processing errors in the numerical wave hindcast had resulted in significant wave height and peak period parameters for the October storm that were too low. However, this error was not considered to be significant in view of the inherent stability exhibited by the model jetty structure throughout the entire 26-step test series.

Because physical model tests which were intended to replicate the actual wave conditions that existed at Yaquina failed to produce any damage to the model structure, it was decided to test the model structure using more extreme wave conditions. The December storm wave conditions were repeated with the wave heights increased by 20 to 40 percent over the hindcast wave heights. The purpose of these tests was to eliminate the possibility that the hindcast had underpredicted wave heights. It also was thought that increased wave heights would smother any model effects that might have occurred due to inaccurate bathymetry in the model. These increased wave height tests also failed to induce any damage to the model structure beyond the displacement of a few armor stones.

The next step in the model testing was to run several of the extreme wave conditions used in 1986 to test the present design (Grace and Dubose 1988). These wave conditions represented the maximum wave heights of the six most severe storms that had been hindcast over a 20-year period between 1956 and 1975. Both unidirectional and multidirectional spectra were generated and run in the physical model. These wave conditions had prototype values of significant wave height ranging between 4.7 m and 7.0 m (15.4 ft and 23.0 ft) with peak periods between 12.5 and 16.7 sec. Each of these extreme wave conditions was run for a short duration at the maximum water level; and even though a few more of the armor stones were displaced, the north jetty structure remained stable with very little damage compared to what occurred in the prototype.

Thinking that the model structure had been built too tightly, “hot spots” were initiated in the jetty armor layer by dislodging and selectively removing stones from the jetty. Selected storm sequences for December were run for short durations, and the structure once again demonstrated remarkable stability with only minor damage to the armor layer.

Finally, the jetty was reconstructed in the physical model with very loose armor stone placement to see if part of the model response was linked to construction of an overly tight model jetty. Testing of this loose structure under the original hindcast wave conditions did not result in damage; however, minor damage was observed when more severe wave conditions were run. The following table summarizes the physical modeling efforts.

Table 23
Physical Model Test Results from Stability Study of 1978 North Jetty Rehabilitation

Test	Result
Tested as hindcast	No damage
Tested with hindcast storms at 140%	No damage
Tested using 1986 test conditions	No damage
Initiated hot spots in jetty head	No damage
Structure rebuilt loosely	Minor damage

Stability physical model conclusions

Throughout the entire physical model series of stability tests the recorded damage in the model did not even begin to resemble the extensive damage that actually occurred at Yaquina during the winter of 1979 - 1980. After a review of the physical modeling technology, it was concluded that past armor layer instability at the Yaquina Bay north jetty was not a result of wave attack alone, but instead a combination of waves and other environmental conditions such as strong currents or toe scour.

This conclusion was quite disturbing because the design of the 1988 north jetty rehabilitation was also shown to be stable under severe wave attack in a physical model. However, if other factors not reproduced in the physical model are contributing to structure damage, then there is a definite possibility that the latest repair is not as stable as indicated by the 1988 physical model test results.

Movable-Bed Tests, 1988 North Jetty Rehabilitation

The second technical workshop, held at Newport, OR, in August 1991, suggested possible physical mechanisms that might be causing the recurring damage to the tip of the Yaquina Bay north jetty. Scour of the seabed at the toe of the structure just landward of the Yaquina Reef was thought to be a significant factor leading to structure damage. Formation of a sizable scour hole in this location could result in portions of the armor layer sliding into the scour hole, which in turn would cause armor loss further up the structure slope. This scour hypothesis was examined using physical model tests conducted at WES during the period September to December, 1993.

Physical model description

Examination of the "scour hole hypothesis" required the use of a movable-bed physical model that recreated the seawardmost portion of the Yaquina Bay north jetty. There are several difficulties involved in conducting movable-bed models, but the main difficulty is maintaining proper similitude between the model and prototype sediments. Given the median grain size of the prototype sediment comprising the seabed in the vicinity of the north jetty tip, strict sediment similitude between prototype and model was not possible except at a model scale that would be too large for any of the model facilities available at CERC. This scale restriction, coupled with available funds, prompted the construction of a "quasi-quantitative" physical model. Figure 62 is a plan view of the model facility, known as the L-Shaped Flume, with the Yaquina north jetty model located in the testing area.

The quasi-quantitative movable-bed model was constructed at a 1-to-36 length scale to represent an approximation of the actual situation at the Yaquina Bay north jetty during the monitoring period. The approximations are as follows:

a. Bathymetry in the vicinity of the north jetty was not reproduced in the physical model due to cost constraints. Instead, waves shoaled on an existing plane 1:30 slope before striking the jetty structure.

b. The movable-bed portion of the model consisted of a sand pit located in the concrete floor of the model facility. The model jetty was constructed over a sand bed (median grain size diameter 0.13 mm) with the tip of the jetty resting on the concrete bottom, which simulated the hard reef bottom (see Figure 62). The straight edge of concrete next to the sand bed was used to represent the landward edge of the Yaquina Reef. (In the prototype this demarcation line is not straight.)

c. The model jetty was oriented so the jetty center line formed an angle of about 54 deg with the edge of the concrete. This angle was a reasonable approximation of the orientation of the reef intersection with the north jetty. Also note that the physical model was constructed as a mirror image of the prototype so that reflected waves would be directed toward the absorbing beach. This did not impact the results in any way.

d. Testing was limited to regular unidirectional waves propagating from a single direction. Therefore, model waves represented waves in the prototype approaching from a direction perpendicular to the Yaquina Reef.

e. The tip of the north jetty was constructed using properly scaled stone sizes to represent the 1988 rehabilitated north jetty. The above-water jetty profile cross section was known from the photogrammetry information, but below water only the location of the structure toe was known. Therefore, the below-water portion of the structure was approximated as a plane 1:4 slope as shown on Figure 63. (This relatively mild slope from the waterline to the bottom is assumed to be composed of relic stone left from previous damage episodes.) Only a short portion of the structure was constructed, and it rested on a horizontal bottom.

Despite the simplification invoked in the movable-bed physical model, it was still felt that the model would reproduce scour in the lee of the reef, although the scour hole dimensions would probably not be in similitude. By correctly scaling the model armor stone weights, any subsequent failure of the armor slope into the scour hole should occur in the model in a manner similar to the prototype. It is also important to remember that the main purpose of the model was to investigate whether scour hole development was a likely cause of structure damage. This hypothesis could be tested in the

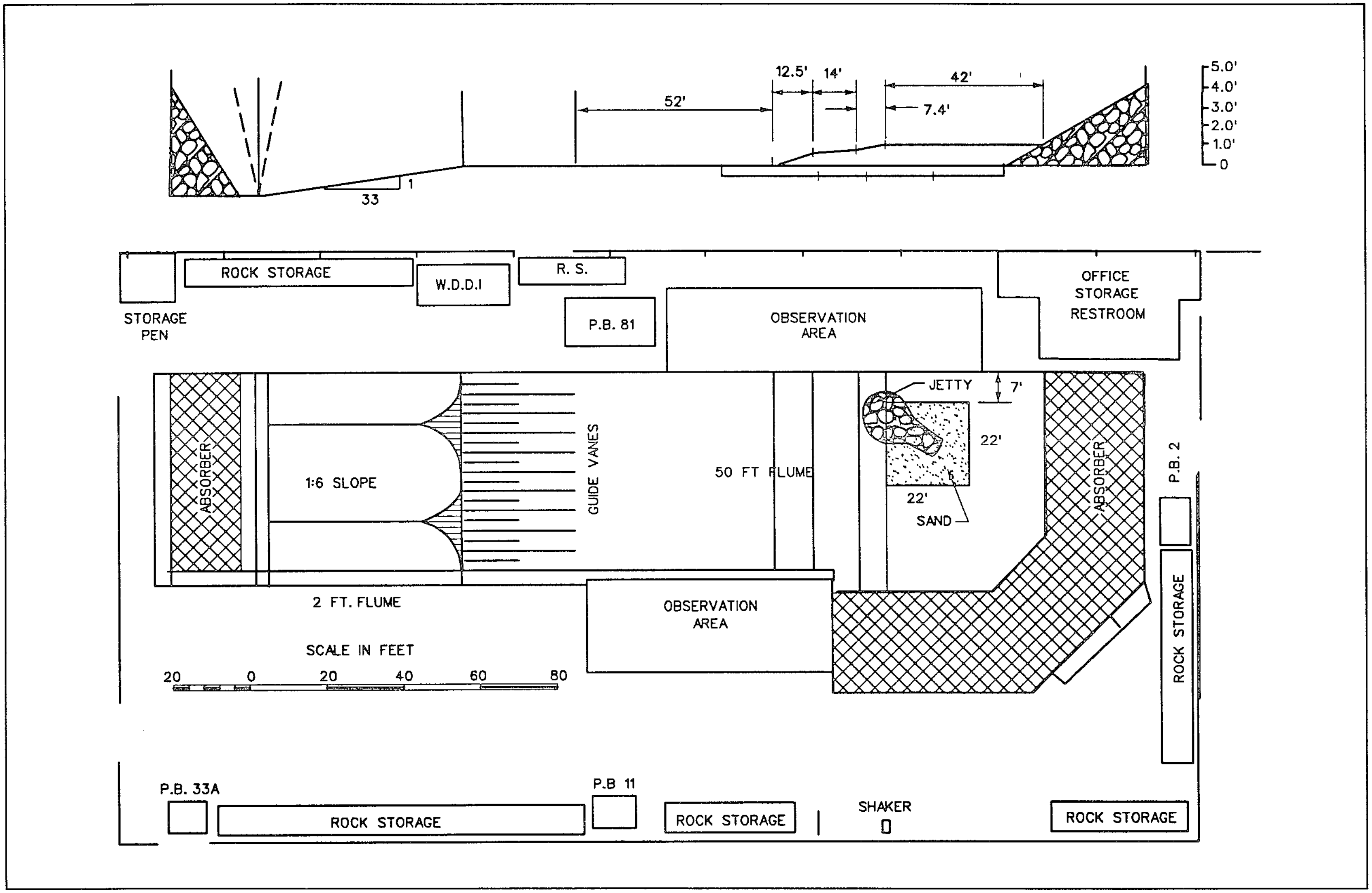


Figure 62. L-Shaped Flume plan view with movable-bed Yaquina Bay north jetty model

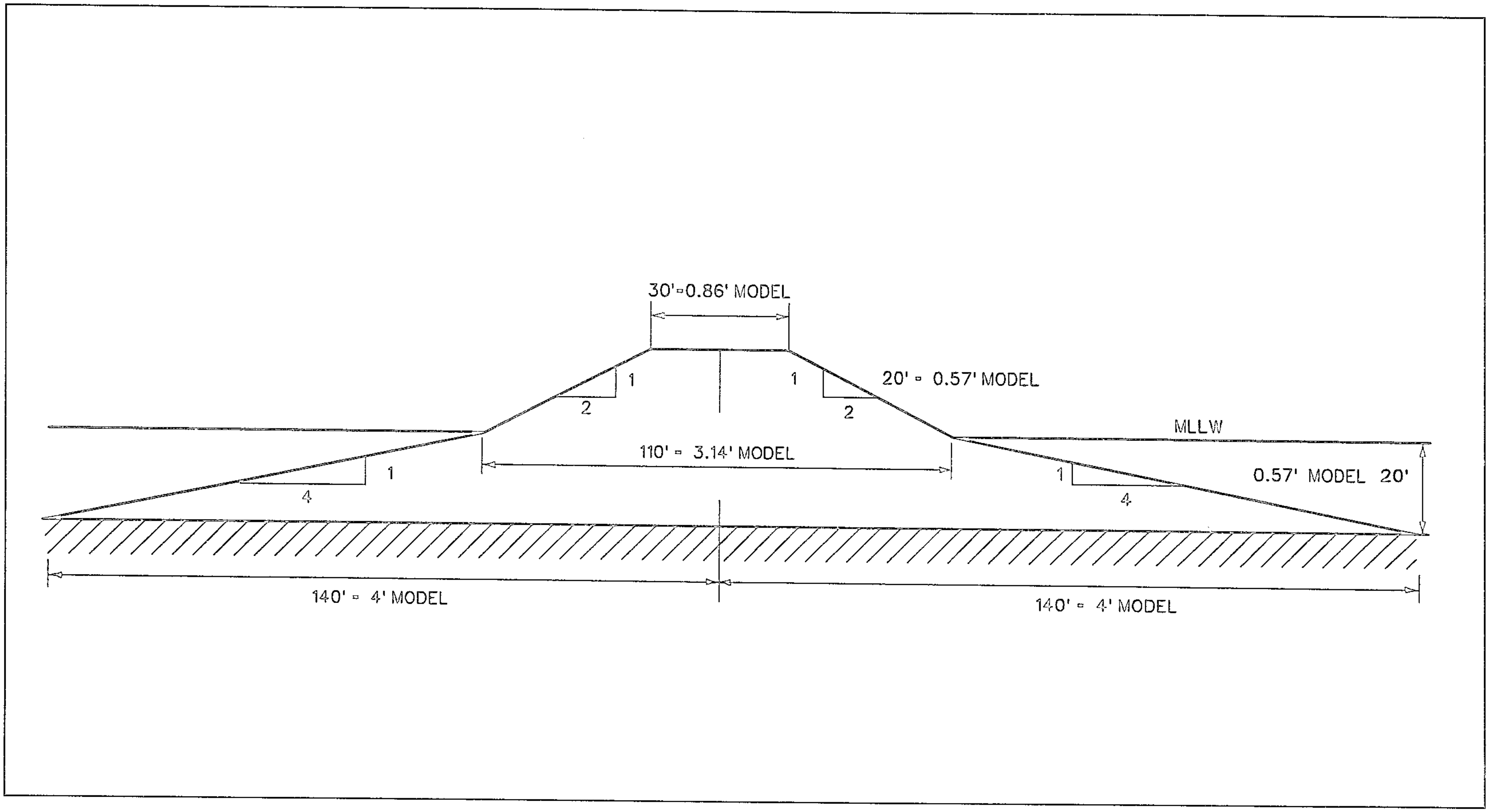


Figure 63. Physical model jetty cross section

quasi-quantitative model even though the extent of damage would likely not be correct.

Test of the scour hole hypothesis

The water depth in the model was 25 cm (10 in.), which corresponded to a prototype depth of 9.14 m (30 ft). This depth represented a water level about 3 m (10 ft) above mllw. Regular waves having a 3-sec period were generated in the L-Shaped Flume, and the wave board stroke was adjusted to provide a wave that broke directly on the head of the structure. This wave would be most damaging to the armor layer, and it would contribute significantly to the development of a scour hole. The model wave corresponded to a prototype wave with a period of 18 sec and a breaking wave height of about 7 m (23 ft).

Waves were run in 1-hr bursts over several days so that a scour hole would develop landward of the transition between concrete and sand. Ultimately, a scour hole formed under wave action alone; but the hole was not very deep, and its presence had little effect on the stability of the armor layer. In retrospect this result should have been expected because of the mild structure slope below the water level. Figure 64 shows photographs of the movable-bed model before testing (top photograph) and after testing (bottom photograph). The condition of the armor layer is unchanged with only a few armor stones at the toe being displaced.

Stability tests with waves and currents

Although the quasi-quantitative movable-bed physical model was originally constructed with the intent of testing the scour-hole hypothesis, it also offered the opportunity to test another damage hypothesis. At the August 1991 workshop it was postulated that armor stone instability might be caused by incident waves propagating on an adverse current flowing seaward along the north trunk of the north jetty. This current could be caused by wave-induced longshore currents being directed seaward by the north jetty, or they might arise as a result of water level differences landward of the Yaquina Reef due to wind stresses. These currents could also contribute to increased scour about the toe of the jetty.

Seaward-flowing currents in the physical model were generated using a large pumping system with its outlet manifold positioned to direct a current along the side of the model jetty representing the north side of the prototype jetty (recall the model was a mirror image of the prototype). Selection of an appropriate current speed was difficult because prototype current measurements had not been a part of the monitoring program up to this time due to uncertainties involving instrument survivability and the safe installation of in situ gauges. It was assumed that current velocities in the prototype could be as large as 2 m/s (6.6 ft/s), and this flow velocity was recreated in the model by generating model flows of about 0.3 m/s (1.0 ft/s).

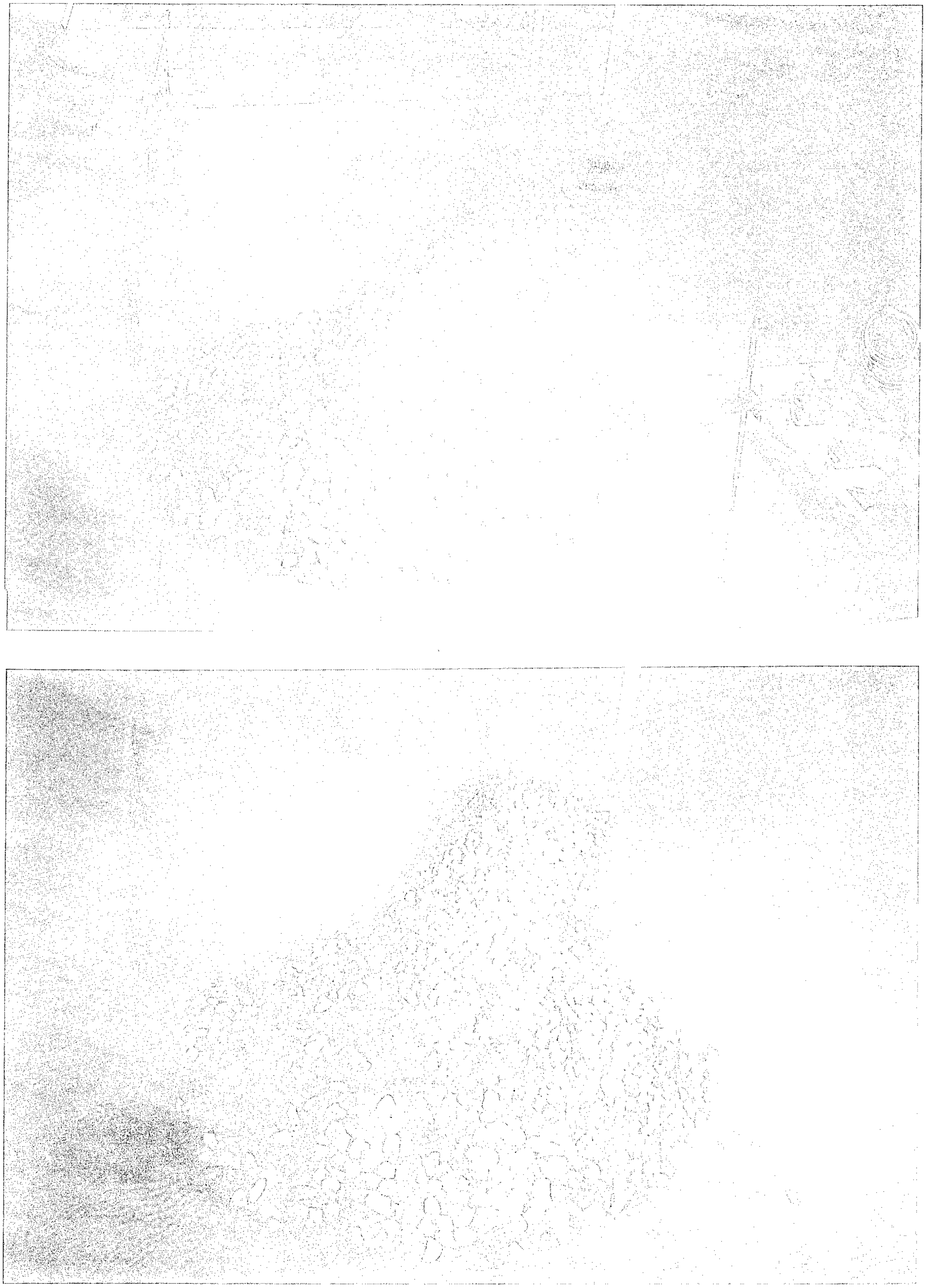


Figure 64. Movable-bed scour hole model before testing (top) and after testing (bottom)

The first wave/current stability test was conducted using the same water level (+3 m mllw prototype) and regular wave condition (prototype 18-s breaking wave) used in the scour test. Almost immediately, damage to the armor layer at the tip of the model jetty began to occur. Surprisingly, after several 1-hr wave action sequences the jetty head had suffered severe damage, and the test was ended after about 1 full day of testing because most of the jetty head had been "beaten down" below the still-water level.

The remarkable difference between the results of this test and the results of the previous test where no damage occurred can be directly attributed to the effect of the seaward-flowing current on the waves. The current affects the waves in two ways: (a) the adverse current alters wave steepness and causes waves to break with more force, and (b) the oblique wave/current interaction alters the wave approach angle, which might redirect the force of the wave more directly onto the "notch" area of the north jetty.

This initial model result prompted additional "exploratory" physical model tests to determine the importance of both water level and current speed on armor layer instability. Although armor stone weight had been properly scaled from the prototype and the hydrodynamics were reasonably scaled, the other aforementioned model approximations limited interpretation of the model results relative to the prototype in terms of absolute damage. Nevertheless, it was still felt that the model was a reasonable indicator of the Yaquina Bay north jetty armor layer stability when subjected to waves and seaward-flowing currents.

Stability test results

Five additional physical model tests were conducted to examine armor stability under different conditions. These tests (Nos. 2-6) are summarized in Table 24 along with the initial test (No. 1).

Table 24
Parameters of Wave/Current Armor Stability Physical Model

Test	Water Level (m)	Wave Period (s)	Wave Height	Current Speed (m/s)	Result
1	+3	18	H_b	2	Demolished head
2	+3	18	H_b	0	Minor stone movement
3	+3	18	H_b	1	Extensive head damage
4	+0	18	H_b	2	Significant stone movement
5	+3	18	H_b	0	Minor stone movement
6	+3	18	H_b	2	Extensive head damage

Note: Water level is elevation above mllw datum. H_b denotes breaking wave height.

After reconstruction of the demolished model jetty, Test 2 was conducted using the same wave conditions as Test 1, but without currents, to assure that the structure was indeed stable when subjected to only breaking wave attack. Test 3 examined jetty stability when the magnitude of the seaward-flowing current was reduced to a prototype value of 1.0 m/s (3.3 ft/s). This was intended to give an indication of the minimum damage-inducing current. Damage was reduced somewhat from the case with higher flow speeds, but still the structure was heavily damaged after a short duration of wave action. In fact, the testing was curtailed while damage was still occurring so that less effort would be needed to reconstruct the model jetty.

Test 4 used the same wave and current conditions as the initial model Test 1, but the water level was reduced to mllw. This resulted in less damage because the breaking waves were not as big (note that the wave board amplitude was adjusted to provide the worst case breaking wave at each water depth). Finally, Tests 5 and 6 were repeats of Tests 2 and 1, respectively. Both repeat tests produced results that were similar to the original tests.

Figure 65 shows the reconstructed Yaquina Bay north jetty head prior to testing. The armor stones in different shaded regions of the structure had been painted so that damage would be easier to spot. Figure 66 shows the condition of the jetty head at the end of Test 6. Although it is difficult to see in the photograph, the armor underlayer had been exposed in an area that

Figure 65. Wave/current stability model prior to Test 6

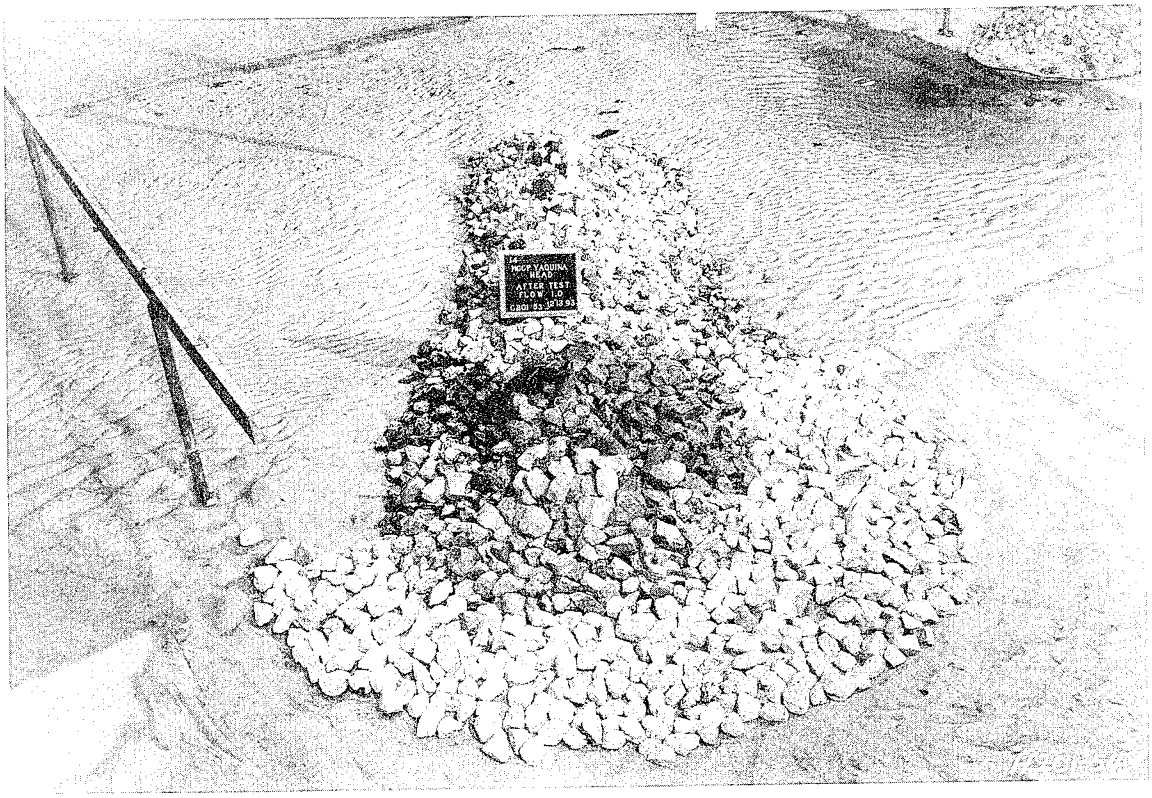


Figure 66. Wave/current stability model showing damage after Test 6

corresponds to the "notch" in the prototype (to the right side of the structure center line), and extensive damage had occurred on the lee side of the structure. Also sand had accreted and completely covered the toe of the jetty on the lee side (channel side) of the structure during this test.

Movable-bed physical model conclusions

A 1-to-36-scale movable-bed physical model was constructed to resemble the physical situation at the Yaquina Bay north jetty, but without the necessary details to be a faithful reproduction of the prototype. Thus, the physical model can be considered a "quasi-quantitative" model because the effects of bathymetric details on the local hydrodynamics were not included in the model simulations.

Tests with only waves indicated that scour hole formation at the toe of the Yaquina jetty did not contribute to armor instability. Part of the reason lies with the mild structure slope below mllw, which is less prone to slope failure after scour hole development. This observation was confirmed during subsequent wave/current stability tests when even larger scour holes formed but no local armor layer failure was observed.

Results from the physical model tests which investigated armor stability in the presence of obliquely incident waves and seaward-flowing currents strongly suggested that instabilities previously experienced at the Yaquina Bay north jetty stemmed from an interaction of the waves, seaward-flowing current, and hard-bottom reef located at the tip of the structure. The presence of the reef plays a critical role because the reef's elevation triggers waves to break directly on the structure. If the reef were not present, the north jetty probably would not have experienced as much armor layer instability.

Although the extent of damage reproduced in the physical model cannot be strictly related to prototype because of the aforementioned model shortcomings, the physical mechanisms producing the damage are thought to be legitimate representations of what occurs in the prototype. Previous armor stability tests of the north jetty at Yaquina Bay were conducted with only wave action, and these models experienced no damage. It is quite likely that the introduction of seaward-directed currents in these previous studies would have produced some armor layer instability.

In some respects the south jetty at Yaquina Bay serves as a "control case" because it is presumably subjected to a similar wave climate, it is located in the same water depth, it has the same armor stone protection as the 1966 north jetty rehabilitation, and ebb currents of similar magnitude interact with the approaching waves just as the seaward-flowing current does at the north jetty. The key difference between the two jetties is that the south jetty does not terminate on a hard-bottom reef of relatively shallow depth like the north jetty. Therefore, the waves striking the south jetty are not forced into a breaking mode. Instead, the seafloor in front of the south jetty has been scoured and a permanent scour hole has developed.

9 Technical Workshops

Over the 6-year monitoring period, two technical workshops were held as part of the Yaquina Bay north jetty MCCP effort. These workshops were attended by several invited coastal engineering experts, representatives from NPP and the Corps of Engineers North Pacific Division, staff of CERC, GL, and contractors actively working on the monitoring project. The first technical workshop was held near the beginning of the monitoring project, and the second workshop was conducted in about the middle of the monitoring period.

The attendees of the technical workshops worked together to review the facts surrounding the damage problem at the Yaquina Bay north jetty, to suggest plausible hypotheses for the damage, and to recommend suitable monitoring strategies and study efforts. This helped to focus the monitoring program and optimize benefits.

First Technical Workshop (June 12-13, 1989)

Workshop overview

The first technical workshop was held in a conference room at the Coastal Engineering Research Center, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS, on June 12-13, 1989. The workshop was summarized in a Memorandum for Record (MFR) prepared by Mr. Jeffrey Melby, WES, and that MFR served as the main source for the following summary of the workshop.

The purpose of the first technical workshop was to assemble a group of experts to develop and examine possible hypotheses for the frequent damage that has occurred at the Yaquina Bay north jetty. Workshop attendees were asked to specify additional data and propose tests that could be used to evaluate systematically the merits and relative importance of each hypothesis. Associated with these workshop goals was a discussion of the risks involved with trying to obtain field data under such adverse conditions. Names and affiliations of the 25 workshop attendees are given in Table 25.

Table 25
First Technical Workshop Attendees

Name	Affiliation
Dr. Robert G. Dean	University of Florida
Dr. Bernard L. Le Mehaute	University of Miami
Dr. William G. McDougal	Oregon State University
Prof. Robert L. Wiegel	University of California, Berkeley
Mr. Harold Herndon (retired)	Portland Dist., Corps of Engineers
Ms. Laura Hicks	Portland Dist., Corps of Engineers
Mr. John Oliver	North Pacific Div., Corps of Engineers
Mr. John P. Ahrens	Waterways Experiment Station, CERC
Mr. Michael J. Briggs	Waterways Experiment Station, CERC
Mr. H. Lee Butler	Waterways Experiment Station, CERC
Mr. C. E. Chatham	Waterways Experiment Station, CERC
Ms. Mary A. Cialone	Waterways Experiment Station, CERC
Mr. D. D. Davidson	Waterways Experiment Station, CERC
Mr. Paul Gilbert	Waterways Experiment Station, GL
Dr. James R. Houston	Waterways Experiment Station, CERC
Mr. Gary L. Howell	Waterways Experiment Station, CERC
Dr. Steven A. Hughes	Waterways Experiment Station, CERC
Dr. Richard H. Ledbetter	Waterways Experiment Station, GL
Mr. Jonathan W. Lott	Waterways Experiment Station, CERC
Mr. Dennis G. Markle	Waterways Experiment Station, CERC
Mr. Jeffrey A. Melby	Waterways Experiment Station, CERC
Mr. William L. Preslan	Waterways Experiment Station, CERC
Mr. Thomas W. Richardson	Waterways Experiment Station, CERC
Mr. David P. Simpson	Waterways Experiment Station, CERC
Dr. Thomas E. White	Waterways Experiment Station, CERC

Workshop summary

The morning of the first day of the technical workshop was spent providing attendees with background information needed to evaluate the various damage hypotheses. Prepared talks were given on the history of the north jetty at Yaquina Bay, the MCCP Program, recent jetty rehabilitations, numerical and physical model studies that had been performed in support of the rehabilitations, and possible damage hypotheses. These presentations effectively summarized the state of knowledge with respect to the north jetty at the time of the workshop, and they provided a sound basis for debating various jetty damage hypotheses and proposing new ones.

During the discussion period following the presentations, questions highlighted the need for data to address the preliminary failure hypotheses. Unavailable data included the following:

a. Cross sections of sediment and rock underlying and surrounding the jetty.

b. Times of principal damage (for relating to storm events).

c. Locations of principal damage.

d. Wave and current field characteristics corresponding to principal damage periods.

e. Water level setup shoreward of the Yaquina Reef.

The attendees also indicated the need for more sophisticated physical modeling capabilities pertaining to wave/current interaction and evolution of movable beds. Other discussion centered on questions concerning particular details about the Yaquina Bay north jetty, its foundation, and its performance history.

The afternoon of the first day focused on developing and discussing damage hypotheses. The most favored damage hypotheses included (in no particular order):

a. Armor instability due to concentration of wave energy caused by local bathymetry, hard-bottom reef, wave/current interaction, multidirectional waves, and/or very steep breaking waves.

b. Armor instability due to high pressure gradient within the jetty.

c. Long waves carrying armor stones up and over the structure crest.

d. Armor instability due to steep structure slopes or undersized armor stones.

e. Spreading of the jetty foundation due to scour at the structure toe (scour could be caused by wave-induced currents and/or currents resulting from water level setup shoreward of the reef).

f. Spreading of the jetty foundation due to cyclic excess pore pressure leading to excessive settlement.

g. Spreading of the jetty foundation from piping of sand due to pressure gradients within the jetty.

h. Any combination of the above factors.

It was also noted during the discussion that armor stone fracturing was not evident, no linkage could be made between specific storm events and jetty damage, scour holes formed during storm events might be quickly healed by ample littoral transport, and aerial photography suggested that armor stones were being sheared off the jetty rather than the jetty spreading laterally from the base.

Activity on the second day of the technical workshop focused on evaluation of the various damage hypotheses, discussion of monitoring elements that could be included in the study, and final recommendations from the workshop attendees. One of the most interesting outcomes of the second morning's discussion was the recognition that a "notch" had started to form on the north side of the outer tip of the north jetty, as indicated by recent aerial photography. The prospect that the 1988 north jetty rehabilitation was beginning to experience damage caused great concern and lent a sense of urgency to the formulation of the monitoring plan.

For the remainder of the morning, workshop attendees were divided into two groups focusing on which modeling efforts and field efforts were necessary to test the damage hypotheses. The groups were asked to take a tiered approach in which the decision to proceed on a particular monitoring task would be based on the outcome of a previous task.

The modeling group determined that useful field data needed for physical modeling efforts included photographic records of the above-water portion of the structure, structure settlement and movement information, tides in deep water and behind the Yaquina Reef, currents in the vicinity of the jetty tip, detailed bathymetry, offshore wave records, and results from dye studies. It was noted that numerical models could provide some of the hydrodynamic information, but it would be essential to verify the models with field data.

Workshop attendees recommended that an attempt be made to recreate previous armor layer damage on the north jetty by simulating hindcast storm conditions in a physical model. This effort would hinge on identifying the dates of known damage occurrence. If previous damage cannot be recreated in the physical model, and if limited office and laboratory geotechnical studies lend support to the possibility of foundation failure, then geotechnical field investigations should be considered. The north jetty underlayer composition would need to be determined with a few borings. There would also be a need to determine shear wave velocities in the underlayer and pore pressure time histories throughout the jetty.

The field group recognized that field tests of the damage hypotheses would be expensive. Thus, it would be imperative to orient the tests to optimize information for the least expenditure. Useful inexpensive tests that could be performed included dye studies to verify current direction and jetty permeability, side-scan sonar to determine the extent of the stone apron and location of the jetty toe, and photogrammetry to determine armor stone movement. Additionally, photographic documentation of the structure performance under wave action would be useful for verifying physical model wave conditions.

More expensive field data collection efforts suggested by the field group included directional wave measurements, current measurements, and tide measurements. Besides providing factual information for assessing hypotheses, these measurements would be used to establish boundary conditions for numerical and physical models and for validating the models. Other recommendations included sub-bottom profiling to determine the underlying geology, pore pressure measurements within the structure underlayer, and internal jetty pressure measurements to establish the magnitude of pressure gradients within the jetty core.

First workshop conclusions and recommendations

The first technical workshop was judged to be highly successful, largely due to the enthusiasm and knowledge of coastal engineering possessed by the workshop attendees. The attendees concluded that the primary cause for damage to the Yaquina Bay north jetty was armor instability resulting from the combination of storm waves interacting with the local bathymetry, reef, and local currents. Scour around the jetty tip was also suggested as a possible damage mechanism. The coastal engineering experts stated that physical and numerical models of situations similar to the Yaquina navigation entrance should include the nonlinear wave/tide/current interaction, and movable-bed physical modeling capabilities needed to be developed and applied to model the Yaquina Bay north jetty accurately.

General agreement was reached regarding the overall plan for future study of the Yaquina Bay north jetty. NPP personnel were to conduct an initial site visit to determine if the "notch" on the north side of the jetty tip was continuing to unravel. A comprehensive office study would then be performed to determine when past damage occurred, and it was suggested that additional anecdotal information could be collected by interviews with locals, review of local newspapers, and review of Corps documents and aerial photographs. A performance comparison should be made between Yaquina jetties and other Oregon jetties that have not experienced extensive damage.

Workshop attendees recommended that field data collection be planned to optimize information needed for physical and numerical modeling efforts. They envisioned that numerical models would be used to establish the forcing boundary conditions for any physical model efforts. A caveat was that the numerical model must be capable of correctly modeling nonlinear wave/current interaction along with radiation-induced currents, tidal currents, and currents resulting from water ponding landward of the Yaquina Reef. The physical model should incorporate directional wave/tide/current interactions along with accurately reproduced detailed bathymetry. Finally, it was recommended that past storms thought to have caused significant damage to the north jetty should be accurately recreated in a physical model in an attempt to reproduce past damage episodes.

Second Technical Workshop (August 20-21, 1991)

Workshop overview

The second technical workshop on the Yaquina Bay north jetty was held on August 20-21, 1991, at the Shilo Inn in Newport, OR. The workshop was organized by CERC, WES. The workshop is summarized in an MFR prepared by Dr. Steven Hughes using transcripts prepared by Ms. Karen Wood. That MFR served as the main source for the following summary of the workshop.

Technical workshop attendees (listed on Table 26) included personnel from CERC, NPP, and the North Pacific Division of the Corps of Engineers, along with several internationally recognized experts in coastal engineering. Of the 22 workshop participants, 11 had attended the first technical workshop held in 1989, as noted on Table 26.

The purpose of the second technical workshop was to obtain additional understanding of the damage mechanism(s) occurring at the Yaquina north jetty. Specific objectives of the second workshop were the following:

a. Critically review information about the jetty obtained since the last technical workshop.

b. Develop more precise hypotheses on cause(s) of the present structure deterioration.

c. Develop and prioritize data needs for determining the cause of the problem and designing permanent repair of the structure.

d. Develop a "road map" for future efforts on the Yaquina Bay north jetty MCCP monitoring.

Workshop summary

The first morning of the second technical workshop consisted of prepared talks that reviewed the purpose of the monitoring, presented the purpose and objectives of the workshop, summarized the history of the Yaquina Bay jetty system, and presented the results of a physical model study intended to

Table 26
Second Technical Workshop Attendees

Name	Affiliation
Dr. Hans F. Burcharth	University of Aalborg, Denmark
Dr. Robert G. Dean [1]	University of Florida
Dr. Bernard L. Le Mehaute [1]	University of Miami
Dr. Charles K. Sollitt	Oregon State University
Prof. Robert L. Wiegel [1]	University of California, Berkeley
Mr. James Francis	Portland Dist., Corps of Engineers
Mr. Richard Gamble	Portland Dist., Corps of Engineers
Mr. Philip Grubaugh	Portland Dist., Corps of Engineers
Mr. Harold Herndon [1] (retired)	Portland Dist., Corps of Engineers
Ms. Laura Hicks [1]	Portland Dist., Corps of Engineers
Mr. John Oliver [1]	North Pacific Div., Corps of Engineers
Mr. D. D. Davidson [1]	Waterways Experiment Station, CERC
Ms. Carolyn Holmes	Waterways Experiment Station, CERC
Mr. Gary L. Howell [1]	Waterways Experiment Station, CERC
Dr. Steven A. Hughes [1]	Waterways Experiment Station, CERC
Mr. Jonathan W. Lott [1]	Waterways Experiment Station, CERC
Mr. William L. Preslan [1]	Waterways Experiment Station, CERC
Dr. Charles L. Vincent	Waterways Experiment Station, CERC
Mr. Donald L. Ward	Waterways Experiment Station, CERC
Mr. Jon Dasler	David Evans and Associates
Mr. Terry Sullivan	Evans-Hamilton, Inc.
Mr. Richard Sylwester	Evans-Hamilton, Inc.

[1] Also attended the first technical workshop.

reproduce damage experienced on the north jetty in 1979-1980. (See Chapter 8 for details on the physical model study.)

During the historical overview it was noted that the main difference between the present north jetty and previous constructions of the jetty was increased armor stone size. Also, the location of stone lost from the north jetty head remains unknown. In 1979, one year after the 1978 north jetty rehabilitation, a notch appeared on the north side near the head. The location was somewhat similar to the noticeable notch that had begun to form on the north jetty after the 1988 rehabilitation; however, it was thought that the notch location was not quite the same. (The most recent notch appeared to be located at the transition point between Select and Class A armor stone.)

After the presentation on the unsuccessful physical model attempt to recreate previous storm damage on the Yaquina Bay north jetty, it was suggested that either the physical model study was incorrectly performed or that some other mechanisms were acting in conjunction with the waves to cause damage to the structure. The physical modeling uncertainties were reviewed and discussed by the workshop participants. It was noted that tidal and longshore currents were not generated in the physical model. A suggestion was made that high-speed filming of the model with playback at slower speeds would provide a "real time" view of the wave action.

The discussion that followed focused on the physical model and possible explanations about why it was not successful in reproducing past damage. Possible factors related to model performance included wave diffraction; the effect of suspended material; armor stone shape, size, and density; armor placement; toe stability; and fixed-bed modeling.

Next on the workshop agenda were presentations summarizing monitoring efforts initiated since the first technical workshop. Photogrammetric analyses of aerial stereo photography were presented and discussed by the group. The spatial stability of the photogrammetry control points was discussed, and differences found in jetty profiles obtained from the first and second year stereo model contour maps were thought to be due to settlement of the rubble-mound structure. It was noted that past surveys have indicated this settling process takes several years. Ground control has been surveyed all the way to the ends of the jetties, but it was not resurveyed for each aerial flyover. There are eight reliable control points on the south jetty and four on the north jetty. The last ground survey of control points was in 1989. It was recommended at the workshop that the control points be resurveyed.

Workshop participants were also briefed about a helicopter bathymetric survey that was performed by Portland District shortly after the notch was identified. The purpose of the survey was to determine whether or not a scour hole may have caused the notch. No scour hole was found during the survey, but the possibility was raised that a hole could have existed during a storm and had since filled in with sand.

The comprehensive geophysical and bathymetric survey centered on the Yaquina Bay north jetty had been nearly completed at the time of the second technical workshop, and results to date were presented and discussed. This effort, which began in early August 1991, was aimed at collecting bathymetry, subsurface geophysical profiles, and side-scan sonar images. The primary purpose of the work was to obtain accurate bathymetry for possible future modeling efforts, to answer crucial questions about potential in situ instrument sites, and to determine the subbottom sediment/rock structure. Geophysical survey products included detailed bathymetric charts, maps of seafloor features, charts showing depth to bedrock and sediment thickness, and geological profiles.

Instrumentation used to obtain the various measurements and their accuracy were summarized. Horizontal vessel positioning was determined to be accurate to within ±1 m (3 ft), and bathymetric vertical accuracy (after heave compensation) was said to be ±0.3 m (1 ft). The contractors responsible for conducting the geophysical/bathymetric survey explained many of the survey details. Surveying was conducted with vessel speeds between 1.5 and 3.0 m/s (3 and 6 knots), and in wave heights of about 1.0 to 1.2 m (3 to 4 ft). The contractors gave a comprehensive overview of the preliminary survey results and explained their interpretation of the high-frequency sonar returns. Keen interest was shown in the vicinity of the "notch" where there appeared to be signs of displaced armor units. The roundness of the side-scan images indicated they were indeed armor stones and not rock outcroppings.

The geophysical charts showed that the bottom in the notch area had a sand veneer about 5 m (17 ft) thick over what was thought to be bedrock. However, it was not possible to confirm this. Also interesting was the fact that bedrock was exposed further shoreward of the reef on the north side of the jetty. The work crew still had some more surveying to complete, and they hoped to be able to get a little closer to the jetty in the notch area before they finished the work to better define the subbottom in that region.

After lunch the fine weather permitted a helicopter flyover of the Yaquina Bay jetty system for all workshop attendees who wished to take the ride. The helicopter ferried passengers in groups of three. After the helicopter flights, several of the workshop attendees took a boat tour of the north jetty on an Oregon State University research vessel stationed at Yaquina Bay. Other workshop attendees walked on the jetty for a first-hand look.

The remainder of the first day was spent discussing a variety of topics related to the jetty, the monitoring program, and possible causes of the problem. These topics are itemized below:

a. The Yaquina Bay north jetty rehabilitations in 1978 and 1988 were built on top of whatever remained of the jetty below the surface.

b. Observers on the lunchtime vessel inspection of the jetty reported that armor stones on the south jetty appeared to be more regular, somewhat larger, and more tightly placed than on the north jetty. The stones on the south jetty had been placed in 1972, and were thought to be the same size as the north jetty. However, the stones could have been shaped better to allow the special placement technique. The armor at the structure heads is the same for both jetties. Nevertheless, it was commented that placement was more precise on the south jetty, despite the fact that the same crane operator built both jetties.

c. Workshop hikers on the jetty (Mr. Davidson and Mr. Howell) relayed their observations from walking out to the region of the notch near the tip of the jetty. Both agreed that a row of stone just above the notch on the crest of the structure was in jeopardy. If a key stone were to be lost, the whole row would tumble down. This would possibly cause additional unraveling of the structure. Overtopping was not thought to be the cause of the notch formation because there appeared to be stone lost from the notch area below the waterline, and overtopping would not cause this loss.

d. Continued rehabilitation of the seawardmost 90-120 m (300-400 ft) of the north jetty was justified on dredging costs. (This topic was discussed in detail during the second morning of the workshop.)

e. If the problem is determined to be caused by scour occurring in the vicinity of the notch, then recreating the failure with a physical model will be very difficult.

f. Dr. Burcharth estimated that the water velocity necessary to move a block that weighed about 24 tonnes (26 tons) would be about 6 m/s (20 ft/s) if the block rested on a horizontal rock bed. It was debated whether this was an excessively high velocity, and the conclusion was that the magnitude is not at all unreasonable in this kind of breaking wave climate. Dr. Burcharth felt that toe stability problems might occur if the toe stone were placed directly on the exposed reef. The observed south jetty stability may be a result of the toe being placed over sand.

g. It was noted that physical model construction for the "forensic" tests was done without knowledge of what actually underlaid the structure, and this could impact the model results. A description was given on the toe placement used in the model.

h. Dr. Dean described the formation of scour holes downdrift of nonerodible surfaces (i.e., Yaquina Reef) during a storm. Once the scour holes start, they are self-perpetuating. He felt that the physical model might be used to provide some qualitative insight into this mechanism. After a storm, currents and the ready supply of sediment could easily fill in the scour hole.

i. Potential movable-bed physical model tests were discussed, along with the attendant scaling problems, and other considerations.

The opening talk on the second morning of the technical workshop was given by Mr. John Oliver of the North Pacific Division, Corps of Engineers. He stated that most jetties are constructed on the basis of economics. In the case of the Yaquina Bay jetties, the economic justification is savings associated with decreased maintenance dredging of the navigation channel. If the tip of the Yaquina Bay north jetty continues to be damaged on a regular basis, the

Corps of Engineers will need to reassess the economics, and possibly cap the damaged jetty at a shorter length. He felt that the hydraulics around the end of the structure and the integrity of the foundation had more to do with damage than any other aspect. Similar scour problems exist at other jetties on the west coast, so this project has potential return benefits at other sites. In the past, repair costs had been lower, but these costs have dramatically increased over the past several decades.

Significant discussion centered on what would happen if the north jetty structure was allowed to fail and the Corps decided not to rebuild. Issues included whether or not relic stone would have to be removed and whether the south jetty would suffer increased exposure. There was concern about increased flow of littoral sand around the shortened jetty resulting in increased dredging requirements.

Several other presentations were made during the second morning focusing on future monitoring plans related to aerial photogrammetry, wave measurements, and geophysical monitoring. Workshop attendees contributed significantly by asking questions about various aspects of the monitoring and recommending additional tasks. Several of the discussion topics are listed below:

a. It was pointed out that photogrammetry does nothing toward telling what is happening to the structure below the surface, and videotaping wave patterns was suggested as a means of gathering information about scour holes that could influence wave refraction patterns. Video of storm wave action would play an important role in calibrating a future physical model.

b. There was some discussion about specific storms composed of multiple wave trains, and how this might affect jetty stability.

c. No additional bathymetric or side-scan sonar work was planned as part of the MCCP project. Original plans to ground-truth the subbottom profiling with cores were abandoned because it was felt to be too dangerous for the work crews. Limited bottom samples may be available. Based on beach sediment, the grain size of the sediment in the vicinity of the jetty head was assumed to be about 1.2 mm mean diameter and very uniform.

Oregon State University (OSU) proposed a study plan to obtain directional wave and current measurements in the vicinity of the north jetty head. The measurement program was proposed to start in the winter of 1991-92 and the plan was developed around acoustic current meters. The proposed sampling schedule called for twice-a-day recording of a 512-sec time series at a 1-Hz rate. The internal recording instruments were capable of storing 41 days of data at this collection rate.

Current meters would be attached to 2.3-tonne (5,000-lb) concrete slabs having dimensions of approximately 2.4 m x 2.4 m x 0.3 m (8 ft x 8 ft x 1 ft). This slab should resist overturning in water velocities of 12 m/s (40 ft/s) and sliding at 9 m/s (30 ft/sec). Four current meter installations are proposed with data package retrieval scheduled for three times between December and May. This required a total of 24 dives and 6 favorable weather windows.

Discussion following OSU's presentation included questions about the need for the instrument to be vertical, the effect of placing the instrument slab on uneven rock outcropping, and the impacts bubble entrainment and strong vertical fluid accelerations might have on the measurements. Dr. Sollitt noted that any current meter will suffer degraded performance if sediment and/or air bubbles are present in the sample control volume. (Note: This proposal for deploying current meters was not funded because of uncertainties associated with instrument survival and risks involved in that many diving missions.)

A short presentation was made on measurement strategies for the hostile environment at Yaquina Bay. It was stated by Mr. Howell that design of any program to obtain field measurements at Yaquina Bay must consider: installation capability; sensor and instrument survival; data and/or instrument recovery; and data analysis feasibility. It is also important to remember why the measurements were being made and for what purpose they are intended. If the measurements are to be used in a physical model as validation, comparison, or calibration data, scaling of measurements, laboratory instrumentation, measurement feasibility, and prototype boundary condition data must be considered. The presentation was followed by discussion about potential instrument deployment strategies.

The second technical workshop ended with enumeration and prioritization of damage hypotheses, discussion of MCCP study needs, and a series of recommendations, which are given in the following section.

Second workshop conclusions and recommendations

Based on information presented at the workshop and actual onsite observation of the Yaquina Bay north jetty, the assembled technical workshop participants suggested and ranked possible damage hypotheses. Monitoring data obtained since the first workshop were factored into the prioritized list of damage hypotheses shown below.

a. **Toe instability:** Toe instability could be caused either by the toe armor units being placed directly on exposed bedrock or by scour which produces a loss of bearing capacity and results in a slumping of the armor layer into the scour hole.

b. **Wave damage, construction, and/or underdesign:** The largest waves are being tripped by the Yaquina Reef and impacting directly on the jetty head. This presents a possibility of damage if the design waves were underestimated or the construction of the jetty head wasn't as tight as planned.

c. **Liquefaction**: Liquefaction was considered a possible hypothesis, but this depends on what definition is applied. There is no blanket under the rubble-mound. Individual stones resting on sand could experience localized liquefaction. The absence of a filter also allows foundation material to be eroded out through the voids in the mound.

There was still no indication as to whether the structure fails rapidly over a single storm event or gradually as a result of cumulative storm impacts. The question of rock quality was raised, but it was not thought to be a problem based on visual observations. There could be a problem with stone shape being less than optimal for the special placement technique.

The workshop attendees also suggested measurement and monitoring needs at the Yaquina Bay north jetty as part of the MCCP project. Numerous suggestions were made, and from those suggestions, the following prioritized list of needs was developed:

a. Documentation of characteristics of the "notch" and the sand pocket adjacent to the notch where scour potentially occurs.

b. Diver observations (sand samples) and reef surface characteristics (smoothness or roughness).

c. Measurement of nearshore waves/currents a short distance offshore of the end of the north jetty.

d. Helicopter photographs/videos and observation walks on both jetties.

e. Development and deployment of a scour gauge.

f. Measurement of currents in the immediate neighborhood of the "notch."

Frequent visual observation was stressed so that if further damage occurs, it will be known when the problem occurred and how much damage was sustained. Photographic and video documentation are important to the monitoring record. Requesting the Coast Guard to assist by making daily observations was also recommended.

A description was given of the Coastal Structure Acoustic Raster Scanner (CSARS) instrument that could be set on the bottom to scan images of the underwater notch area in the structure. Boat-launched CSARS would require a very good weather window, but it may be one of the few suitable ways to get subsurface information about the structure. Profiling the structure in the notch area using either helicopter or a crane boom sounding ball were also discussed. (Later development of the SEABAT multibeam sonar overcame some of these difficulties. See Chapter 10 of this report).

There was much discussion in relation to scour at the notch and what could be done to repair the present damage. Cost was recognized as a fundamental aspect of any decision on repairing the structure at this time.

Placement of an instrument pile (during any jetty repair) was offered as a potential means of supporting various instrument packages so they would have a better chance of survival. This strategy would depend on how deep the pile could be placed (into bedrock) and how strong the currents are around the pile.

It was recommended that the damage presently confined to the "notch" area be repaired on an emergency basis if this was feasible. This repair would help prevent further deterioration for a number of years so that the Corps of Engineers would be better equipped to design a permanent rehabilitation. A temporary repair was preferred over letting the structure progressively deteriorate. An additional recommendation was that all photogrammetric ground survey points should be resurveyed as soon as possible.

The workshop participants generated a list of potential research topics. These topics were related to the problems at Yaquina Bay north jetty, but they also have wider applicability in terms of providing benefits to other Corps of Engineers' structures. No priorities were suggested for these research topics, which are listed below in random order:

a. Improvement of underwater inspection techniques.

b. Influence of bottom topography on armor stability.

c. Toe stability on rock and on sand base, and development of adequate physical modeling techniques.

d. Development of the capability to simulate scour phenomena in a movable-bed physical model.

e. Armor placement techniques.

f. Improved field assessment of structure condition.

g. Investigation and improvement of existing design methodology.

The second technical workshop provided practical suggestions for monitoring the Yaquina Bay north jetty for the remainder of the monitoring period. To the extent possible, most of the suggestions were implemented in one form or another, as detailed in the other chapters of this report.

10 Currents and Jetty Profiles

Introduction

Results from the movable-bed physical model strongly suggested that seaward-flowing currents along the north trunk of the Yaquina Bay north jetty contribute to armor layer instability during harsh wave conditions. (The physical model study is detailed in Chapter 8.) During the technical workshop held in 1991 the issue of in situ current meters was discussed, and it was the workshop consensus that in situ current meters would probably not survive. Therefore, no attempt was made to deploy any in situ current meters near the north jetty. However, when it became apparent late in the monitoring study that currents appeared to be an important part of the problem, plans were formulated for a field measurement program to at least characterize some of the flow patterns in the vicinity of the north jetty.

During a geophysical survey conducted by Portland District in 1993, an ADCP was briefly operated from the survey vessel. Results indicated that the ADCP could provide accurate current magnitudes and directions along the vessel trackline. Current data collected by a ship-borne ADCP are potentially more valuable than in situ current measurements because currents can be characterized over a large spatial area. This provides a better representation of the current patterns than can be derived from several in situ current meters. One drawback to using the ADCP is that the currents measured are only for the conditions at that time, whereas an in situ current meter will show the variations as sea and wind conditions change. Nevertheless, time and cost factors, combined with high probability of success, prompted a 1-week monitoring effort using an ADCP to obtain quasi-synoptic maps of current velocity in the area of the Yaquina Bay north jetty and along the Yaquina Reef just north of the jetty.

The flow velocity measurements were conducted under contract during the last week of June 1994. David Evans and Associates, Inc., (Portland, OR) performed the field work and data processing as a subcontractor to Evans-Hamilton, Inc. (Houston, TX). Onsite project supervision was provided by Mr. Jonathan Lott of WES. In addition to ADCP measurements, bathymetric data were collected using a SEABAT 9001 multibeam sonar. This sonar is capable of mapping the underwater portions of structures such as rubble-mound jetties, and the focus of the SEABAT portion of the survey was to acquire bathymetry and underwater structure profile data near the tip of the north jetty. Objectives of the ADCP study and the SEABAT study were met during the field deployment.

Survey Vessel Instrumentation and Positioning

The ADCP/SEABAT study was conducted using a 9-m (30-ft) aluminum V-hull survey vessel powered by a 7,500-cm^3 (460-in^3) inboard engine with a jet pump propulsion system. In addition to the ADCP and SEABAT instrumentation, the survey vessel carried a Trimble SSE 4000 differential global positioning system (DGPS), a TSS 325 pent-axial heave-roll-pitch sensor and TSS 320B processor/display unit, an Odom Digibar electronic sound velocity sensor, and a KVH 314a self-compensating fluxgate compass. Output from the positioning system and motion sensor was processed on an onboard PC 486/66 portable computer to provide real-time output for navigation and event notation.

Tide levels during the study were monitored using a Stevens 420 electronic gauge mounted in a stilling well at the Yaquina Bay entrance channel front range marker. Tide elevations were related to a vertical control monument established for the 1991 geophysical survey.

Real-time vessel positioning during the survey was achieved using DGPS with a single local reference receiver. This required re-establishment of one of the control monuments (No. 5 HOUSE) used in the 1991 survey. (Note that the 1991 geophysical survey required four horizontal control positions to establish vessel positioning without DGPS.) Survey results were referenced to the same horizontal and vertical datum established for the 1991 geophysical survey (Evans-Hamilton 1991).

Acoustic Doppler Current Profiler Survey

ADCP description and operation

Velocities in the vicinity of the Yaquina Bay north jetty were measured using a 600-kHz RDI broadband ADCP. The ADCP utilizes the Doppler principle to analyze frequency shifts in the returned acoustic signal and relate them to flow velocity. This particular instrument is a current profiler, and it provides horizontal and vertical current magnitude and direction in discrete 1-m (3-ft) depth bins throughout the water column while the survey vessel is under way. ADCP current direction is integrated with accurate vessel heading information obtained from the compass. When combined with position data from the DGPS system, current vectors can be expressed relative to the study reference coordinates.

Vertical profiles of horizontal velocity were sampled at a rate of one profile per second while the vessel navigated along the track line. This sampling rate provided sufficient frequency to enable filtering of orbital wave velocities for waves having periods greater than 2 s; however, it did introduce greater errors in the measurements. Fortunately, these errors were reduced during postprocessing when results from several velocity profiles were averaged to filter out the short-wave periodic signal.

Determining absolute horizontal current velocities required decoupling horizontal vessel motions from the ADCP signal. As mentioned, ADCP current directions are corrected for vessel heading using the ship's compass. Over-the-bottom vessel speed was determined by a separate ADCP "bottom-tracking ping" that echoes off the bottom. The Doppler shift in the return signal was processed for vessel speed relative to the fixed bottom. Combining the vessel speed with the heading produced a vessel velocity vector that was then subtracted from the ADCP velocity vector. Relatively rapid dynamic motion by the survey vessel required that the vessel velocity vector be updated at the same rate the ADCP data were being acquired, i.e., every second.

ADCP data processing

Raw ADCP horizontal velocities at each vertical bin were averaged over each set of ten consecutive profiles using post-processing software. This resulted in an average vertical profile representing 10 sec along the track line. With vessel speeds between 1.5 and 3.6 m/s (3 and 7 knots), the averaged profile represented currents over a spatial length of between 12 and 30 m (40 and 100 ft). This averaging provided current velocity values free of oscillatory wave velocities for all but the occasional longer period wave. Longer averaging periods would have given profiles with less contamination by long-period oscillatory waves, but the spatial distance of the average would have been excessive. Averaging over 10 s appeared to provide an optimum value for a "spot" measurement of the velocity profile.

Prior to beginning each ADCP surveying episode (multiple track lines), the ADCP and its data acquisition system were time-synchronized with the navigation computer so that ensemble velocity profile averages could be related to the appropriate mean vessel position (in-state plane coordinates). Matching of velocity with location was performed post-survey.

Once matched with position, a top, bottom, and depth-averaged mean velocity were calculated for each time-averaged velocity profile. The top velocity (highest in the water column) was taken as the first good bin in each profile. Typically, this was the value obtained from the first 1-m (3-ft) bin in the profile, centered at a depth of approximately 2 m (7 ft) below the tide level (wave motions not included). The bottom velocity value was taken to be the last good bin in each time-averaged profile. Due to side lobe interference, this was between 15 and 20 percent of the profiling range (depth in shallow water) off the bottom. The depth-averaged velocity was calculated as the average of all good bins in each time-averaged profile.

Finally, graphical representations of the velocity data were prepared. Although sufficient velocity data existed to include the entire vertical velocity profile at each location, displaying these data graphically would so overcrowd the plot that it would be difficult to interpret the measurements. Consequently, the vector current plots presented in the next section show only values of depth-averaged currents at each location along the tracklines. Each depth-averaged current magnitude and direction was represented as a vector arrow drawn to scale on a map of the study area. For each vector, the tail of the arrow was located at the position assigned to the profile average, and the length of the arrow was drawn proportional to the current magnitude. Length and velocity scales on the current vector plots are given in English units.

ADCP survey results

The goal of the ADPC survey was to obtain quasi-synoptic maps of the current velocity field in the area surrounding the north jetty. In addition, track lines were run extending north along the Yaquina Reef and seaward of the reef to characterize the current field outside the influence of the jetty system and reef. Predetermined track lines were established to aid in the data collection, but actual track lines were strongly influenced by daily local wave conditions and safety considerations. Because wind and sea state are subject to rapid changes, measurement efforts were concentrated on obtaining data for short periods of time during as many different forcing conditions as occurred during the study period. The primary strategy was to obtain velocity data during different portions of the tidal cycle. However, field operations were largely dependent on favorable wind and wave conditions, and this formed the basis for most of the survey and instrument deployment decisions.

First ADCP deployment (June 27, 1994). Four ADCP measurement episodes were conducted over the 3-day period of 27-29 June 1994. Sea state was worst for the first deployment on June 27. Winds with an average speed of 10 m/s (20 knots) blew out of the northwest creating rough conditions for the survey vessel and crew. The ADCP survey on June 27 was conducted over a 1-hr period beginning at 1533 PDT in the afternoon with the flood tide nearly at its peak elevation. Figure 67 is a velocity vector plot produced from the ADCP data collected during this survey episode. The survey period relative to the tidal cycle is shown in the lower corner of the figure.

The first trackline was begun offshore and run landward parallel to the outside of the north jetty as close as safely possible. The vessel then turned seaward near the breaker line and headed offshore beyond Yaquina Reef in a northwesterly direction. Next, two tracklines were run parallel to the reef, one offshore and one inshore of the reef. Worsening sea conditions forced the vessel to return to safe harbor after completing four tracklines.

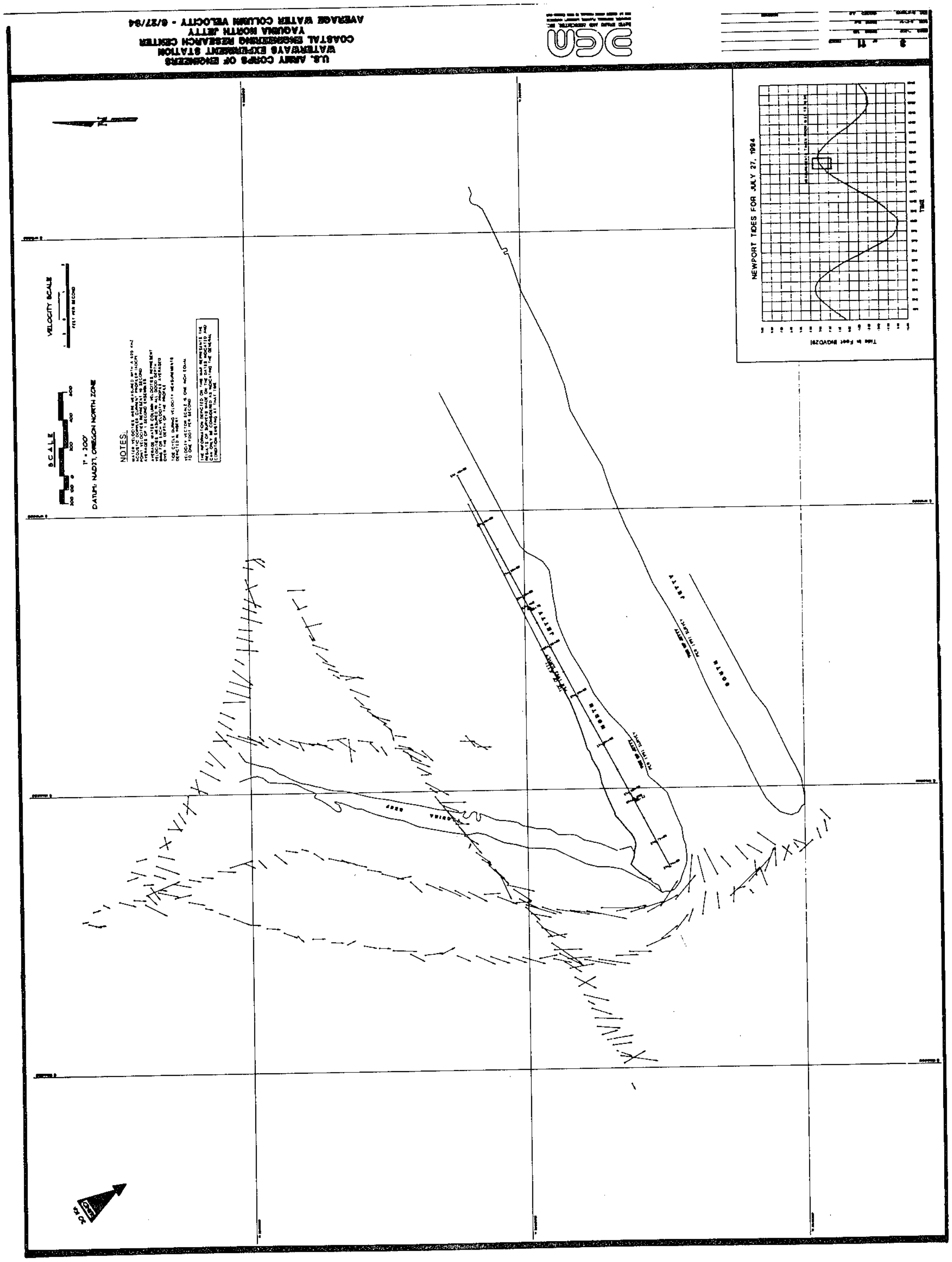


Figure 67. Depth-averaged current velocity vectors at Yaquina Bay north jetty (27 June 1994)

The currents shown on Figure 67 indicated a fairly uniform southerly longshore current of about 20-30 cm/s (0.7-1.0 ft/s). Closer to the north jetty, flow was directed seaward parallel to the jetty, but magnitudes on this trackline were not very large. From the data it cannot be determined if higher seaward velocities were present closer to the north jetty. Current magnitude increased close to the jetty tip due to flood currents in the entrance channel. Despite moderately rough conditions, flow velocities measured on June 27 did not appear to be out of the ordinary.

The strategy for the remaining surveys was to repeat the course of the tracklines run during the first survey and to extend the survey area further offshore and closer to the north jetty when conditions permitted. Comparisons between different surveys along the same trackline provided a small indication of temporal variation that could occur under different forcing conditions.

Second ADCP deployment (June 28, 1994). The second ADCP deployment began at 0825 PDT on the morning of June 28, 1994, and data collection lasted for almost 2 hr. Variable winds between 2.5 and 5 m/s (5 and 10 knots) from due north made for mild wave conditions over much of the survey area. Tides during this survey episode were falling with low tide occurring just at the end of survey. The ADCP depth-averaged velocity vectors are drawn on Figure 68, which also shows (in the lower corner) the survey time relative to tide stage.

Waves consistently breaking over Yaquina Reef at low tide prevented the survey vessel from running tracklines landward of the reef parallel to the north jetty or parallel to the reef. Consequently, the vector plot of Figure 68 provides information primarily on current patterns seaward of the reef and entrance system. Close to the reef, the longshore current field exhibited fairly constant current magnitudes less than 30 cm/s (1 ft/s), but current direction varied substantially about the mean southerly direction. Farther offshore, the southerly longshore currents appeared more uniform both in magnitude and direction. Ebb currents were present across the Yaquina Bay entrance, but at this stage of the tide, little tidal influence was evident along the seawardmost trackline.

Third ADCP deployment (June 29, 1994). Conditions of June 29 were ideal for complete ADCP coverage of the area near the north jetty and along both sides of Yaquina Reef. Two surveys were conducted on this day which provided velocity data at different tide stages under reasonably steady wave and wind conditions. The morning survey, which began at 0840 PDT and lasted 2 hr, was conducted during ebb flow conditions with low tide arriving at the end of the survey. Wind was steady at 7 m/s (13 knots) out of the north-northwest, and wave action was calm enough to allow the survey vessel to cruise very close to the north jetty and across the submerged toe of the jetty tip.

Depth-averaged velocity vectors for the morning ADCP deployment are drawn on Figure 69. Survey time relative to the tidal cycle is illustrated on

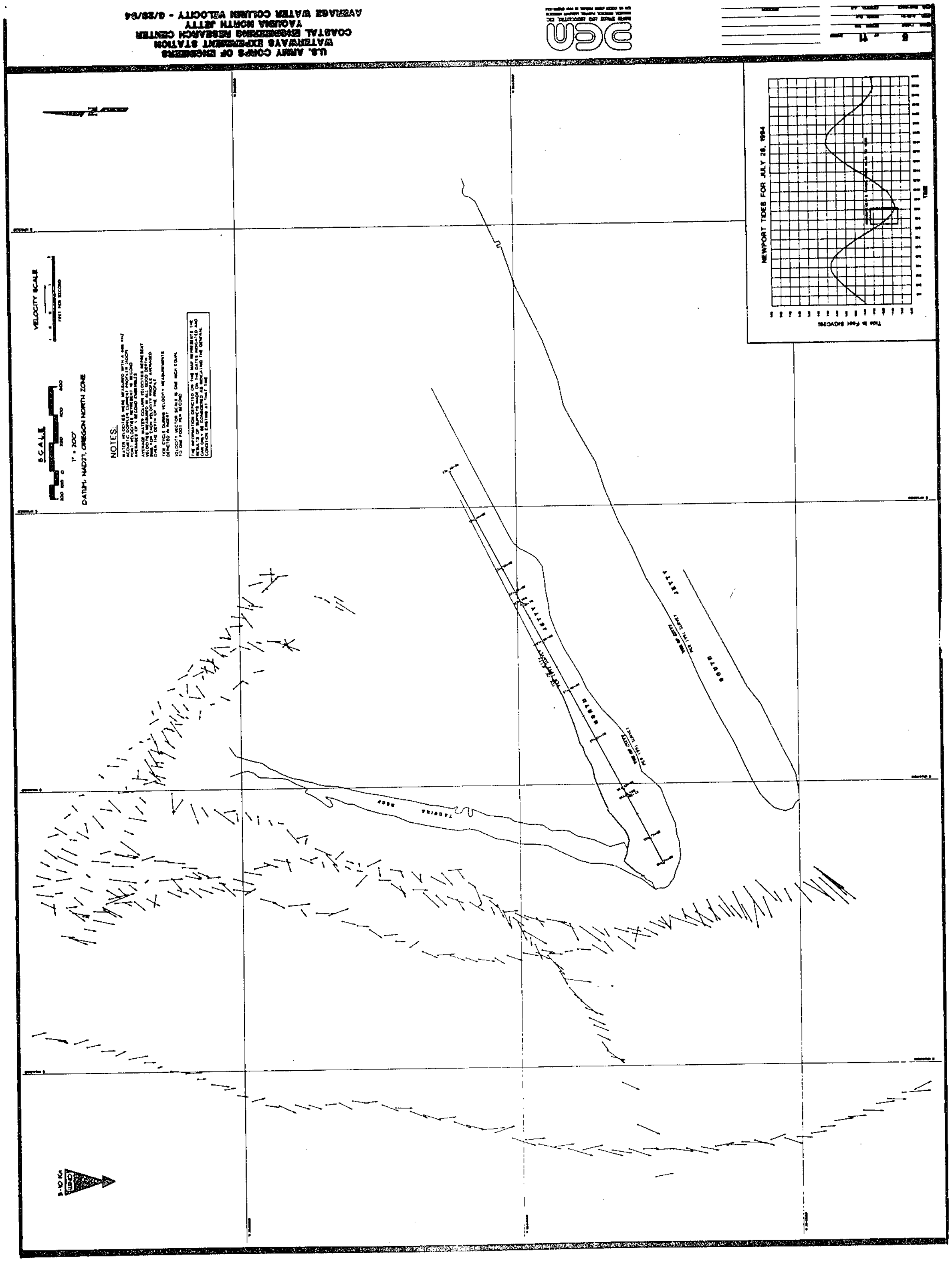


Figure 68. Depth-averaged current velocity vectors at Yaquina Bay north jetty (28 June 1994)

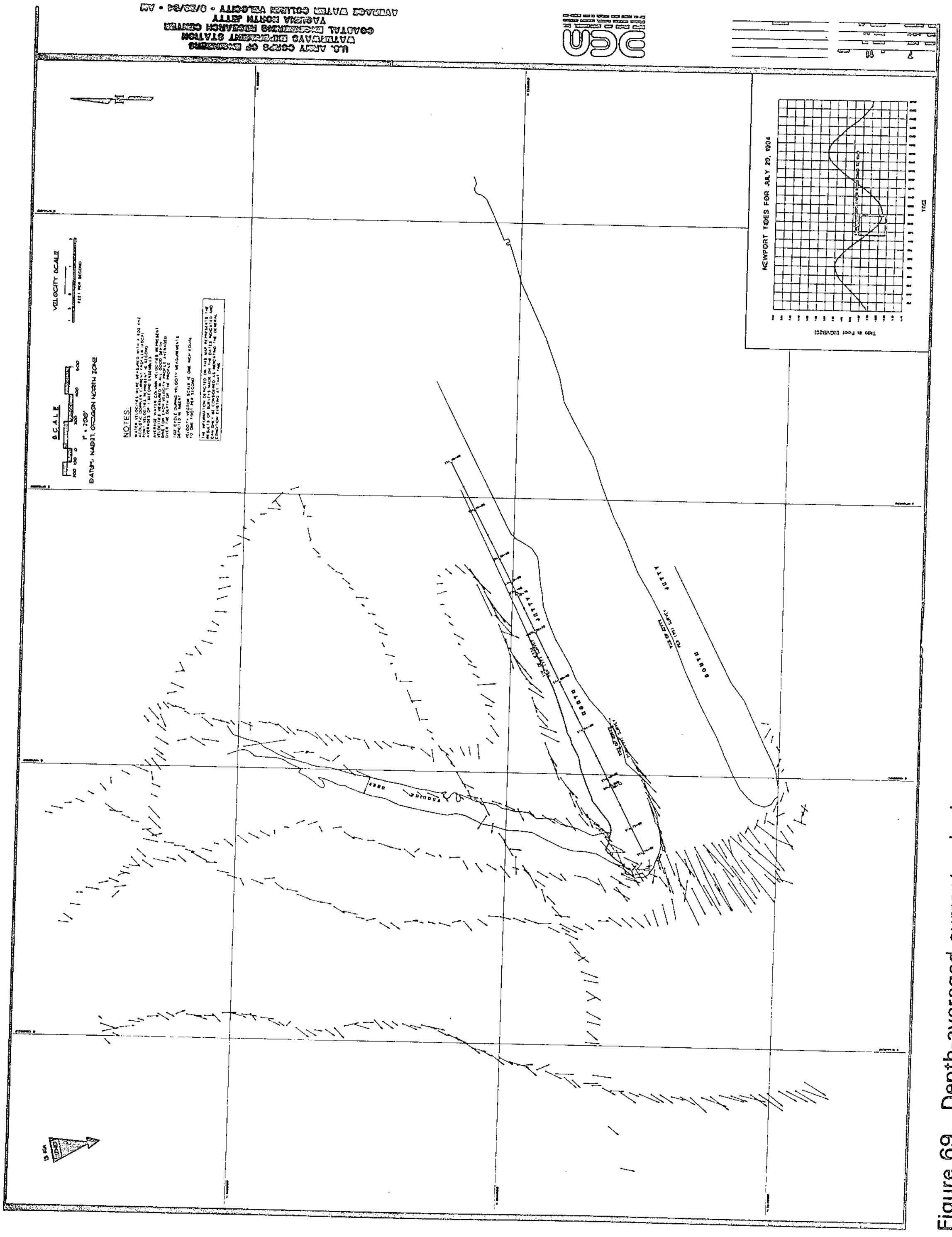


Figure 69. Depth-averaged current velocity vectors at Yaquina Bay north jetty (morning of 29 June 1994)

the lower corner of the figure. Longshore current velocities were relatively weak with average magnitudes around 10-20 cm/s (0.3-0.7 ft/s) during the survey period. However, even with this weak forcing, the role played by the north jetty in accelerating the longshore flow and redirecting it seaward is evident. Largest flow velocities on Figure 69 correspond to the ebb tidal flow at the navigation entrance.

Fourth ADCP deployment (June 29, 1994). The fourth and final ADCP deployment began at 1512 PDT and lasted about 2 hr. Wind and wave conditions remained the same as experienced during the previous survey episode that morning, but the time-averaged water level over the survey was about 1.5 m (5 ft) higher. Current velocity vectors and the tide stage over the survey duration are shown on Figure 70.

Offshore, the longshore current remained weak in the southerly direction with some noticeable variation in magnitude and direction. The influence of the jetty in redirecting the longshore currents seaward is clearly evident on all three tracklines run parallel to the north jetty. The strongest currents were measured near the jetty tip where powerful tidal currents accelerated the longshore and seaward-directed currents into the entrance channel. Current magnitudes in excess of 60 cm/s (2 ft/s) were present close to the jetty tip, with a maximum current near 80 cm/s (2.6 ft/s) measured in the entrance channel.

ADCP survey summary

Results from the four ADCP measurement episodes provided “snapshots” of the current field in the vicinity of the Yaquina Bay north jetty. These snapshots represent moderate to very calm wind and wave conditions which could be considered untypical for most of the year off the Oregon coast. Nevertheless, the current patterns indicated that the north jetty redirects the southward-flowing longshore current seaward, as suspected. This observation lends further credence to the hypothesis that seaward-flowing currents interact with incoming waves which then break over the Yaquina Reef directly on the tip of the north jetty. Without direct measurements it is impossible to estimate maximum seaward-flowing velocity magnitudes that might exist during extreme conditions. However, data gathered during the ADCP field survey should prove very useful for calibrating any future physical or numerical modeling efforts to simulate storm-induced flow fields in the vicinity of the Yaquina Bay north jetty.

SEABAT Multibeam Sonar Jetty Profile Survey

SEABAT description and operation

The underwater portion of the Yaquina Bay north jetty near the tip was surveyed using a SEABAT 9001 multibeam bathymetric sonar system. The

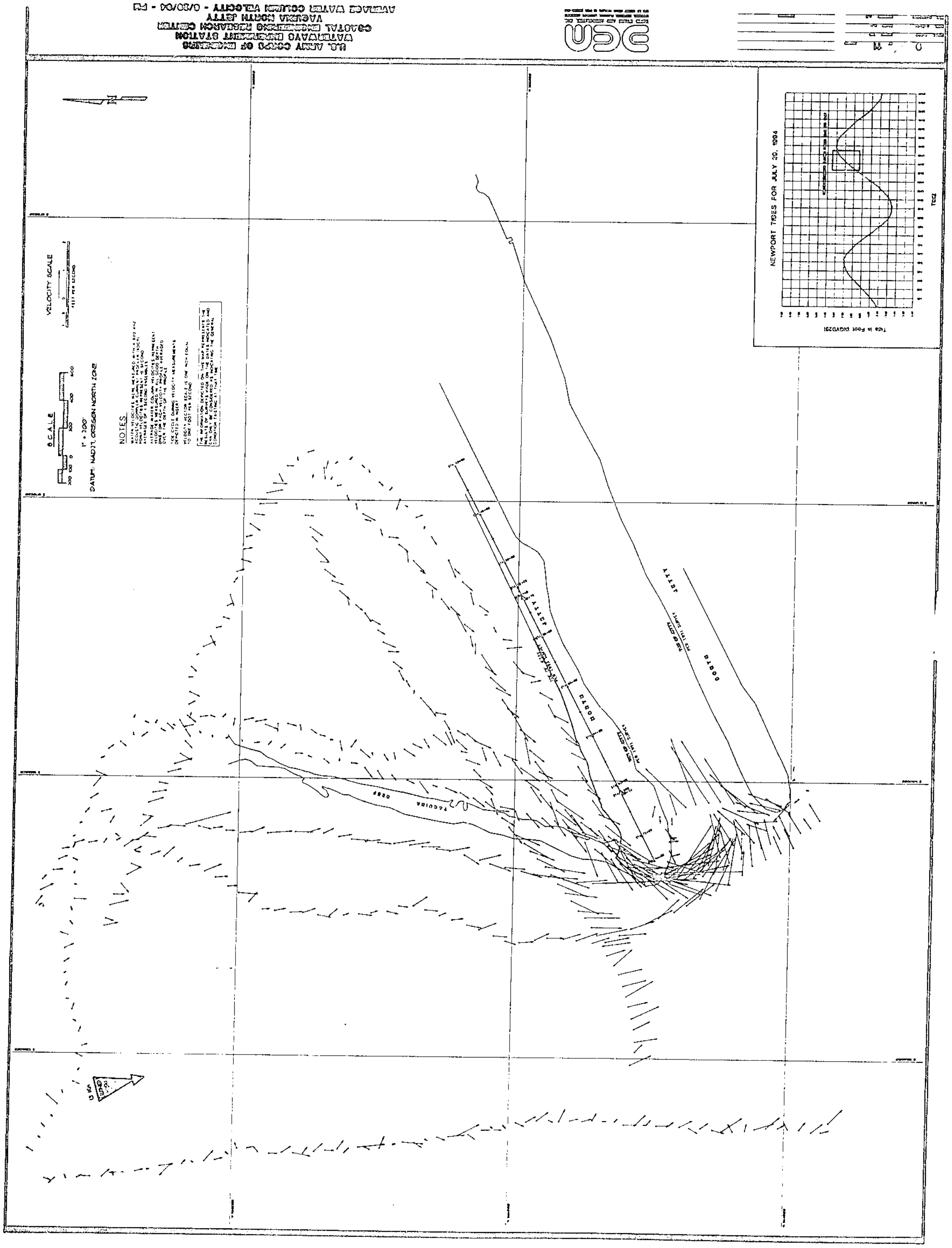


Figure 70. Depth-averaged current velocity vectors at Yaquina Bay north jetty (afternoon of 29 June 1994)

system was also used to map the bathymetry of the Yaquina Reef and its intersection with the north jetty. Prior to the SEABAT survey the underwater configuration of the north jetty near the tip was generally unknown, other than a good estimate of the jetty toe location. Therefore, successful completion of the SEABAT survey of the north jetty was important because it provided information crucial for any future north jetty repair and maintenance efforts and/or future physical models of the jetty.

The SEABAT 9001 multibeam sonar calculates distances along 60 radial lines evenly spaced within a 90-deg sounding swath centered at the transducer head. Distances to reflecting objects (i.e., seafloor or submerged structures) are determined from the speed of sound in water and travel time along each radial of the reflected pulse. Distance measurements from all 60 radials in the swath are completed in just a fraction of a second, and for this survey, complete swath data were logged at a 3-Hz rate. Naturally, spatial density of soundings decreases as distance along the radial increases.

Usually, the SEABAT is deployed in a downward-looking orientation with the center beam directly beneath the transducer and bottom coverage 45 deg to each side of the vertical. For the survey of the underwater portion of the north jetty, the SEABAT was oriented with the center beam 40 deg to the port side of the vertical, and the swath plane was perpendicular to the vessel center line (i.e., parallel to the ship's beam). The transducer head was mounted off the starboard side of the vessel and positioned at a depth of 0.7 m (2.3 ft) below the survey vessel's waterline, which allowed all beams in the swath to pass beneath the vessel's keel. This mounting position and orientation were chosen so the survey of the north side of the north jetty could be conducted while heading offshore into the incident waves (safest direction). Swath coverage was approximately between 5 deg to starboard of the vertical and 5 deg from the water surface to port. The 5-deg orientation below the water surface helped to reduce the amount of error induced by sea surface sonic reflections due to either wave fluctuations or vessel roll, and it also helped to decrease errors caused by aeration in the upper water column near the jetty. SEABAT mounting and swath coverage are illustrated in Figure 71.

Critical to the success of the SEABAT survey was the capability to couple SEABAT output to accurate vessel location, attitude, and heading information. Range data from the DGPS system were logged by computer at a 1-Hz rate; headings from the compass were also stored at a 1-Hz rate; and heave, pitch, and roll data from the TSS motion sensor were logged at rates between 7 and 10 Hz. Corrections for the time lags between each device's records and the time of SEABAT measurements were applied in post-survey data processing.

Prior to logging SEABAT soundings, the speed of sound profile over the water column was measured at 3-m (10-ft) intervals near the study area using the Digibar sound velocity probe, and the arithmetic mean of the observations was input to the SEABAT processor for calculating the radial distances of the sounding slant ranges. Tide data were measured at the tide gauging site,

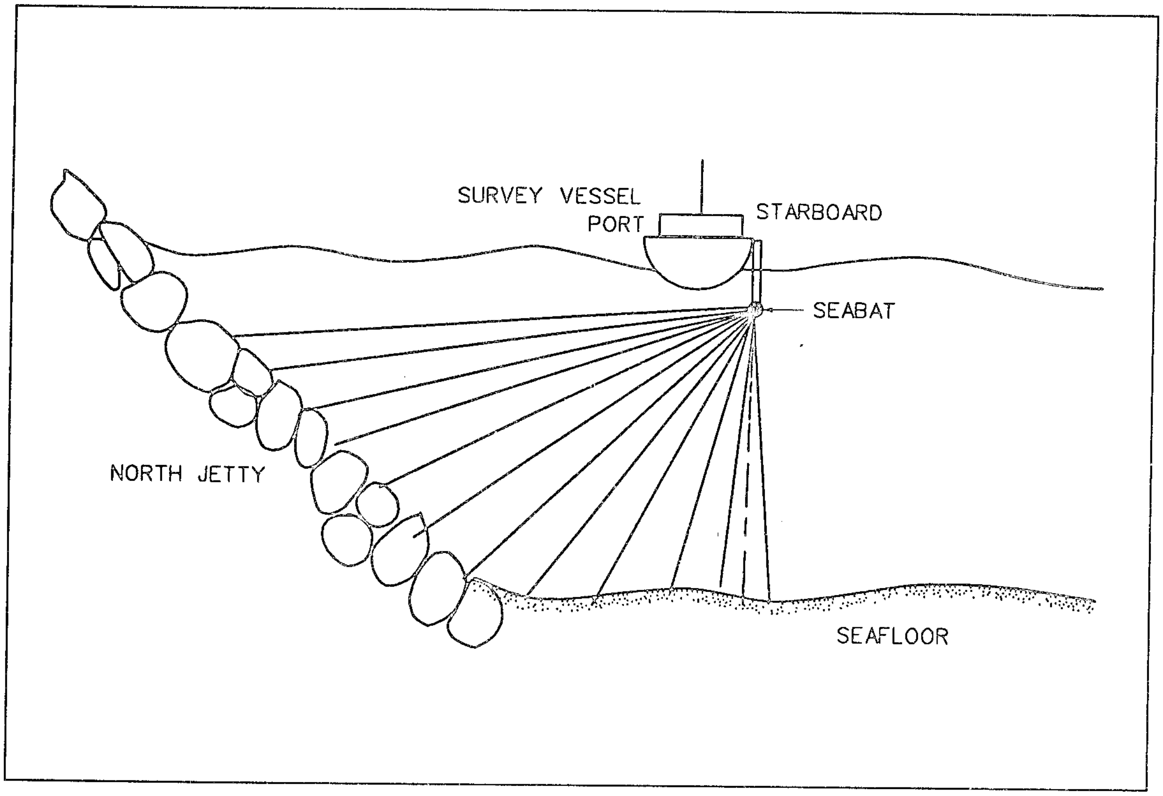


Figure 71. SEABAT mounting and swath coverage

telemetered to the survey vessel, and logged at 1-min intervals. Checks of the transmitted tide data were made before and after the survey by visual comparison to a temporary staff gauge mounted at the tide gauging site.

SEABAT data processing

Real-time onboard displays of the uncorrected SEABAT profile images were videotaped for possible future reference and for post-survey data quality checks. Post-processing of the SEABAT observations required that the data be corrected for time-varying vessel position, heading, and three degrees of motion (heave, pitch, and roll). Data from the DGPS, compass, and motion sensor were interpolated in time to correspond to times of SEABAT swath data acquisition. The interpolated values were then coupled with the SEABAT ranges and radial angles to produce three spatial coordinates (expressed relative to the study site's Cartesian coordinate system) for the location of the reflective surface that produced each sounding in the swath at each time interval.

Each post-processed sounding was tagged with a Julian date and time and saved on the computer along with the vessel's interpolated roll angle for that time. Anomalies that show up in plots of the processed data can be traced back to specific swaths, and data accuracy can be examined in conjunction with data from the other sensors as linked through the time stamp. Also, the real-time video image of any suspect SEABAT profile can be isolated via the video's time stamp.

The SEABAT processor performs several internal quality checks before assigning a quality index between 0 and 3 to each sounding. Provided the sounding passed a "brightness test" (strong return relative to the background) and was within acceptable range variation of the immediate neighboring ranges (co-linearity test), the data point was assigned a quality index of 3. One point was deducted for failing each test. Rejecting data with quality indexes less than 3 eliminated the vast majority of bad soundings. All the data presented on the plots in the next section had quality indexes of 3.

SEABAT survey results

Weather conditions on June 30, 1994, were favorable for surveying the underwater portion of the Yaquina Bay north jetty near the tip. Two SEABAT tracklines were run on the north side of the north jetty parallel to the jetty center line and continued around the jetty tip to the channel side. The tracklines began at about jetty station 64+00 and extended seaward to the tip. In addition, two tracklines were run parallel to Yaquina Reef, more or less along the reef center line.

Corrected elevation and position data from all the SEABAT tracklines were used in a digital terrain model to create a three-dimensional "mesh" of the seafloor, Yaquina Reef, and underwater portion of the north jetty covered by the survey. Figure 72 presents a view of this mesh from a perspective landward of Yaquina Reef and to the northeast of the north jetty tip. The north jetty is shown extending seaward from the left of the figure and intersecting with the reef. The smooth line to the top of the jetty mesh portion represents the uppermost limit of SEABAT data.

Note in particular on Figure 72 that the north jetty underwater slope becomes very mild toward the location where the jetty intersects with Yaquina Reef. This mild slope is assumed to consist of relic armor stone left from the last two rehabilitations. Also notice the very steep face on the landward side of Yaquina Reef. This reef formation could have significance in helping to direct longshore flowing currents seaward along the jetty.

The SEABAT elevation data were referenced to the same coordinate system used to display the photogrammetric elevation results for the above-water portion of the jetty. This allowed construction of cross-section profiles from the 0.3-x 0.3-m (1-ft x 1-ft) mesh grid that corresponded to selected jetty stations. Underwater profile cross sections for north jetty stations 72+00 through 73+00 are shown on Figure 73. The profiles are drawn at a scale that is only slightly distorted. The black dot drawn on each profile represents the approximate position of the north jetty profile at the mllw datum. The gap

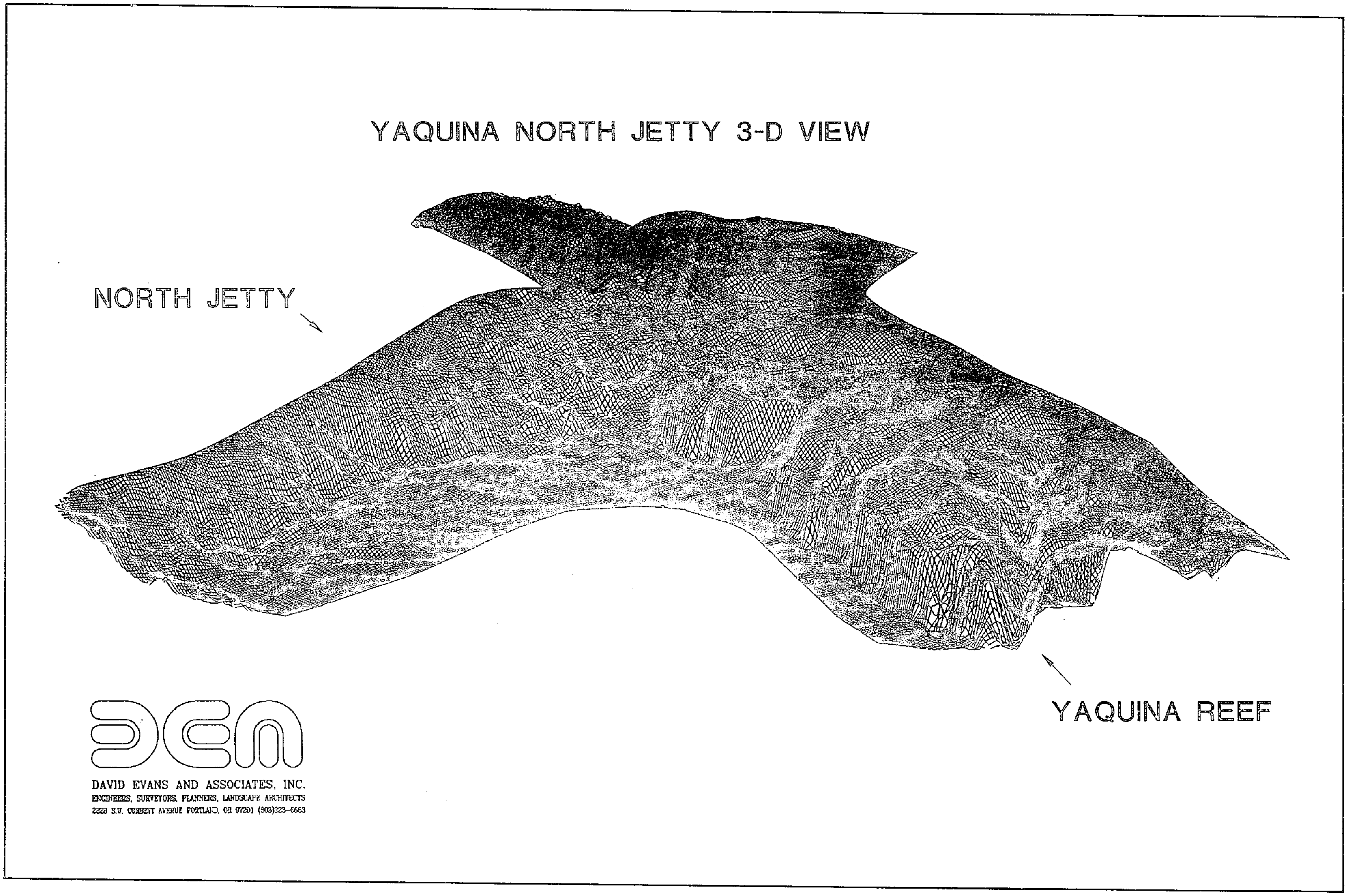


Figure 72. Orthographic "mesh" of Yaquina Bay north jetty and Yaquina Reef below-water bathymetry

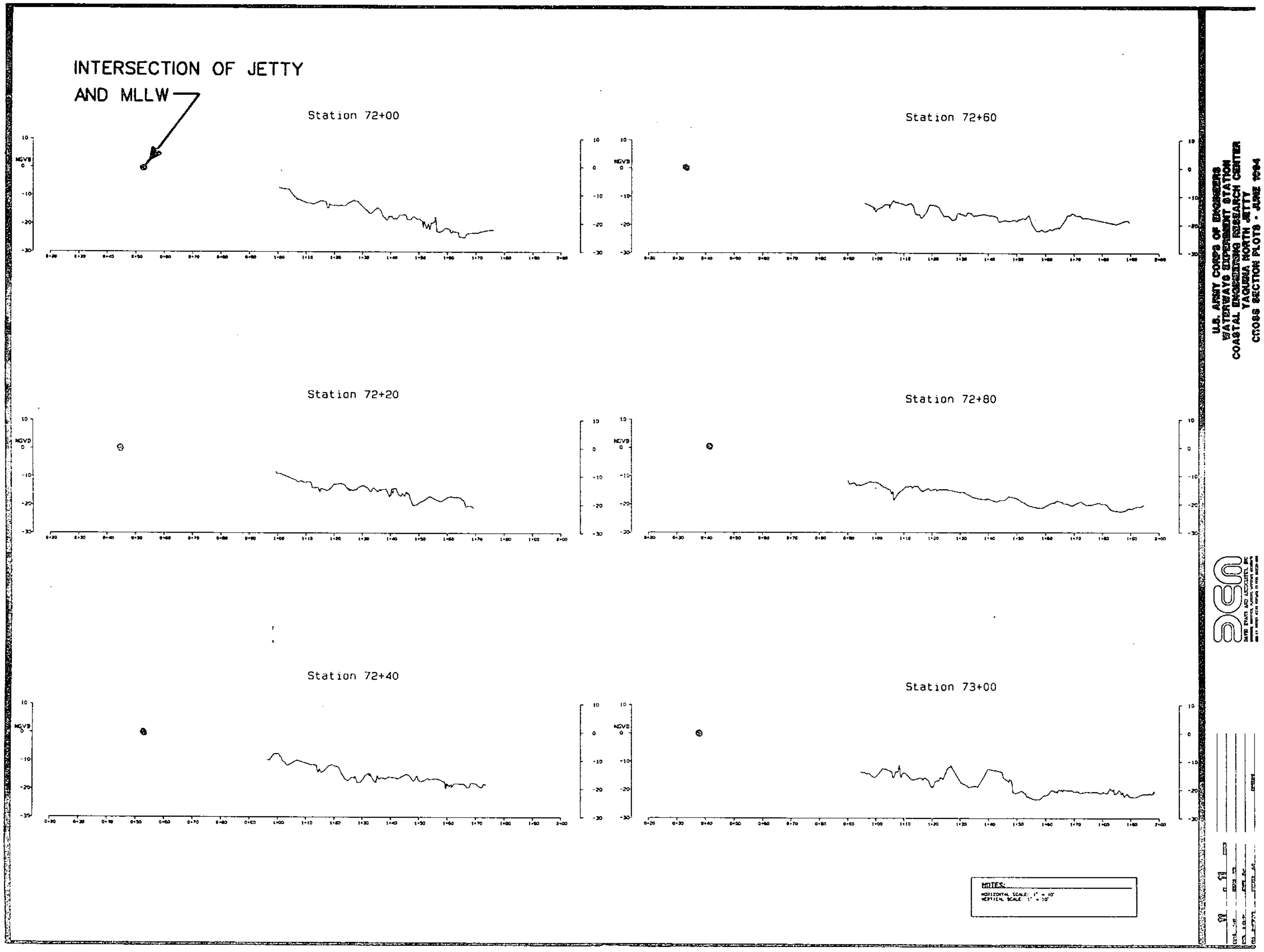


Figure 73. Underwater SEABAT profiles of the north side of the Yaquina Bay north jetty

between the dot and the profile is the region of the jetty that could not be surveyed by either photogrammetric methods or by SEABAT.

The profile for station 72+00 has a slope of about 1:4, and seaward of this station, the slopes become milder. For example, Station 72+20 has an approximate slope of 1:6 and Station 72+80 (seaward side of the notch region) has an estimated slope of 1:10.

SEABAT survey summary

Deployment of the SEABAT multibeam bathymetric sonar provided the first detailed picture of the underwater configuration of the Yaquina Bay north jetty and its positioning relative to Yaquina Reef. Data of this type are extremely valuable in helping to understand the historical evolution of existing coastal structures and planning for future rehabilitations. The SEABAT deployment at Yaquina Bay demonstrated the utility of the SEABAT sonar for gathering important monitoring information at sites where more conventional structure surveying techniques are not likely to be successful due to harsh environmental conditions.

11 Summary and Conclusions

Monitoring Summary

The rubble-mound north jetty protecting the entrance to Yaquina Bay has experienced appreciable damage throughout its long service history. For over 100 years the jetty was repaired and extended, and since the last seaward extension in 1966 the tip of the jetty has rested on the offshore Yaquina Reef. Since 1966 the north jetty has been rehabilitated twice after severe winter storm waves eroded the seawardmost 140 m (460 ft) of the jetty head. The most recent rehabilitation was completed in 1988, and later that same year a 6-year jetty monitoring effort was initiated under the Corps of Engineers' Monitoring Completed Coastal Projects Program.

The principal purpose of the monitoring was to determine the likely cause for chronic damage to the Yaquina Bay north jetty. The monitoring also offered the potential for increasing understanding of failure mechanisms associated with rubble-mound structures and for improving methods of monitoring coastal structure performance in similar hostile wave and current environments.

Devising a monitoring plan for the north jetty was complicated by not knowing a priori what physical mechanisms had caused previous damage to the jetty armor layer. Thus, a flexible monitoring plan had to be developed to allow plan modifications as results became available. Early in the monitoring program two technical workshops were conducted to help focus the monitoring project on tasks likely to produce an understanding of the damage mechanisms. These workshops were attended by Corps and non-Corps coastal engineering experts who contributed greatly to the monitoring project's success. Equally important to the success of the monitoring was the close coordination with the Portland District throughout the duration of the project.

The following monitoring activities constitute the key elements that comprised the MCCP monitoring of the Yaquina Bay north jetty:

a. Compilation of a thorough historical review of the Yaquina Bay entrance system.

b. Periodic fixed-wing and helicopter aerial photography and photogrammetric analyses.

c. Visual and side-scan sonar inspection of the north jetty.

d. Current velocity profiling and multibeam sonar scanning of the underwater portion of the north jetty and its intersection with the Yaquina Reef.

e. Collection of offshore and nearshore wave measurements.

f. Comprehensive bathymetric survey.

g. Geophysical investigation of the bottom and subbottom geologic composition.

h. Physical modeling efforts to evaluate various damage hypotheses.

i. Establishment of a digital database at the NPP office.

j. Periodic workshops where Corps personnel and outside experts evaluated interim monitoring results and suggested viable damage hypotheses.

Each of these elements contributed understanding about either the physical environment around the Yaquina Bay entrance or the performance of the 1988 north jetty rehabilitation over the monitoring period.

Monitoring Results and Conclusions

Chapters 4-10 detailed each of the principal components of the monitoring study. Included were descriptions of instruments, deployment and analysis methodologies, results of the effort, and interpretation of the results relative to various damage hypotheses that had been suggested. The following paragraphs summarize the major results and conclusions from each of the monitoring efforts.

Wave climatology

Wave data collected over the 6-year duration of the monitoring project included measurements of offshore nondirectional wave climatology (5 years of records), offshore directional wave information (2 years of records), nearshore nondirectional wave information (1 year of records), and nearshore directional wave information at two sites (1 year of records).

Over the 9-month collection period of the nearshore directional wave gauges, the highest value of significant wave height (H_{mo}) was about 8 m (26.3 ft) in a depth of about 18 m (60 ft). The monthly mean H_{mo} ranged from 1.1 m (3.6 ft) during the calmer summer months to 2.6 m (8.5 ft) for the winter storm season. One of the more important aspects of the nearshore wave data collection was obtaining directional information along with the usual distribution of wave energy as a function of frequency.

The collected wave data not only provide wave statistics characterizing the site, they also will be essential for any future physical or numerical modeling efforts that might be conducted relative to the Yaquina Bay navigation project.

Geophysical survey

The precision geophysical survey conducted in the area of the Yaquina Bay north jetty provided detailed bathymetric charts, maps of seafloor features, charts showing depth to bedrock and sediment thickness, and geological profiles. In accomplishing these tasks, crucial questions were answered about the subbottom characteristics and how the existing geology might have contributed to jetty instability. A sandy bottom landward of Yaquina Reef in the vicinity of the "notch" has the potential to scour during storm events, but there is no deep "buried" sedimentary channel beneath the jetty. This finding prompted a movable-bed modeling study to test whether scour would lead to armor layer instability.

Decisions about potential in situ instrumentation siting and anchoring were made using results from the geological profiles, and future modeling efforts at the Yaquina Bay entrance will be able to utilize the accurate bathymetry collected during the geophysical survey.

Side-scan sonar

Side-scan sonar images collected as part of the geophysical survey centered about the north jetty. These images were analyzed in conjunction with echo sounder profiles obtained on tracklines spanning the regions covered by the side-scan sonar images. This analysis established with reasonable certainty the underwater configuration of the jetty toe and its relationship to the Yaquina Reef and surrounding sandy bottom.

Based on the analysis, it was concluded that the Yaquina Reef extends seaward of the north jetty toe for a maximum distance of approximately 30 m (100 ft) on the west side and a minimum distance of about 15 m (50 ft) on the northwest side. The tip of the Yaquina Bay north jetty was clearly located overlaying Yaquina Reef. Furthermore, the location of the jetty toe relative to the above-water edge of the jetty structure indicated the jetty has a below-water structure slope that is substantially milder than originally thought (milder than 1:4 near the jetty tip). In retrospect this was not surprising because a milder below-water slope helps to account for armor stones lost from the jetty during prior damage sequences. In other words, as damage occurred, armor stones above the mllw level were carried down-slope and deposited near the toe. This eventually resulted in a wide foundation on which the last jetty rehabilitation was built.

Photogrammetric analysis

A key component of the monitoring program was the acquisition of yearly fixed-wing controlled aerial photography beginning in 1989 and continuing until 1993. In addition to photography obtained using fixed-wing aircraft, low-level controlled aerial photographs were acquired in 1992 and 1993 using a helicopter.

Products from the photogrammetric analysis included contour maps of the jetty, cross sections through the jetty at regularly spaced intervals, and contours showing changes from one year to the next. The photogrammetry stereo models were used to estimate volumetric changes due to armor stone loss in the vicinity of the "notch" region near the tip of the north jetty. (Similar products were obtained from the helicopter photographs.) Stereo photographs were also analyzed to determine and plot individual armor stone movement above water and to document above-water loss of jetty armor stones between successive years.

Products from the photogrammetric analyses provided a history of jetty response to storm conditions over the 6-year monitoring period. After initial settlement of the north jetty armor layer, the structure slowly began to lose armor stones near the jetty tip at a somewhat steady rate. Portland District continued to acquire and analyze aerial photography after the completion of the MCCP monitoring to determine whether the cumulative armor stone loss would continue to increase. Monitoring of this gradual deterioration indicated that armor layer unraveling occurs during severe storm conditions and most likely is not associated with liquefaction of the jetty foundation.

North jetty physical models

Two physical model studies were conducted at WES as part of the Yaquina Bay north jetty monitoring program. The first model was a fixed-bed model representing the north jetty after the 1978 rehabilitation. The purpose of the physical model tests was to evaluate the hypothesis that damage experienced by the north jetty over the winter storm season of 1979-1980 was caused by armor instability due only to waves. The model failed to reproduce any damage, even when more severe wave conditions were introduced. It was concluded that damage at the Yaquina Bay north jetty was the result of more than just severe wave attack.

The second physical model was a "semi-quantitative" model featuring a movable-bed portion. The purpose of the movable-bed physical model was originally to test the hypothesis that scour holes forming in the lee of Yaquina Reef caused the armor layer to slump into the hole, thus resulting in slope instability further up the armor layer. Tests with only waves indicated that scour hole formation at the toe of the north jetty did not contribute to armor instability. Part of the reason lies with the mild structure slope below mllw, which is less prone to slope failure after scour hole development. This observation was confirmed during subsequent wave/current stability tests when larger scour holes formed but no local armor layer failure was observed.

However, seaward-flowing currents in the physical model modified the approaching waves and caused them to break more severely on the model jetty, resulting in extensive damage and ultimately eroding the tip of the structure to below the still-water level. These results strongly suggested that instabilities previously experienced at the Yaquina Bay north jetty stemmed from an interaction of obliquely approaching waves, seaward-flowing current, and hard-bottom reef located at the tip of the structure. The presence of the reef plays a critical role because the hard bottom triggers waves to break directly on the structure. If the reef were not present, there is ample reason to believe that the north jetty would not have experienced as much armor layer instability.

Although the extent of damage reproduced in the movable-bed physical model could not be strictly related to prototype damage because of the model shortcomings, the physical mechanisms producing the damage were thought to be legitimate representations of what occurs in the prototype. Previous armor stability tests of the north jetty at Yaquina Bay were conducted with only wave action, and these models experienced no damage.

Technical workshops

Over the 6-year monitoring period, two technical workshops were held as part of the Yaquina Bay north jetty MCCP effort. These workshops were attended by several invited coastal engineering experts, representatives from NPP and the North Pacific Division, CERC, and contractors actively working on the monitoring project. Workshop attendees worked together to review the facts surrounding the damage problem at the Yaquina Bay north jetty, to suggest plausible hypotheses for the damage, and to recommend suitable monitoring strategies and study efforts. This helped to focus the monitoring program and optimize benefits.

Underwater jetty and current profiling

The purpose of the last field effort of the monitoring program was to acquire representative current measurements in the vicinity of the north jetty and to obtain information about the north jetty underwater configuration.

Currents were acquired on numerous tracklines during different conditions using ADCP. These were the first comprehensive current measurements obtained in the vicinity of the north jetty, and results indicated that even in very mild wave conditions the north jetty redirects longshore-flowing currents to produce moderate seaward-flowing currents adjacent to the north side of the north jetty. This was an important finding because it lent credence to the wave/current damage hypothesis. Also, the current measurements will help in calibrating any future physical models of the north jetty.

The vertical profile of the underwater portion of the north jetty and portions of the Yaquina Reef were sensed using a multibeam acoustic ranging instrument that scans in an arc on a vertical plane while being moved along a trackline. Output from the instrument is corrected for sensor depth and motion and then combined with positional data to construct a topographic mesh of the scanned underwater feature.

The two SEABAT tracklines along the north side of the Yaquina Bay north jetty provided sufficient data to detail the jetty's underwater configuration. As suspected, the underwater structure slope near the tip of the jetty is very mild, with slopes varying between 1:4 and 1:10. These mild slopes are the direct result of armor stones being displaced from previous jetty rehabilitations and moved down the slope. On a positive note, these mild armored slopes beneath the still-water level have provided a more stable foundation for the tip of the present north jetty, and this may help explain why the jetty has survived longer than its predecessors. Only time will tell whether the jetty will continue to erode or perhaps reach a stable (but functional) configuration that would not require additional rehabilitation.

Finally, the SEABAT profile information will prove invaluable for any future physical modeling efforts of the north jetty structure, and the data have provided Portland District a means for more accurately estimating stone requirements for potential jetty rehabilitation.

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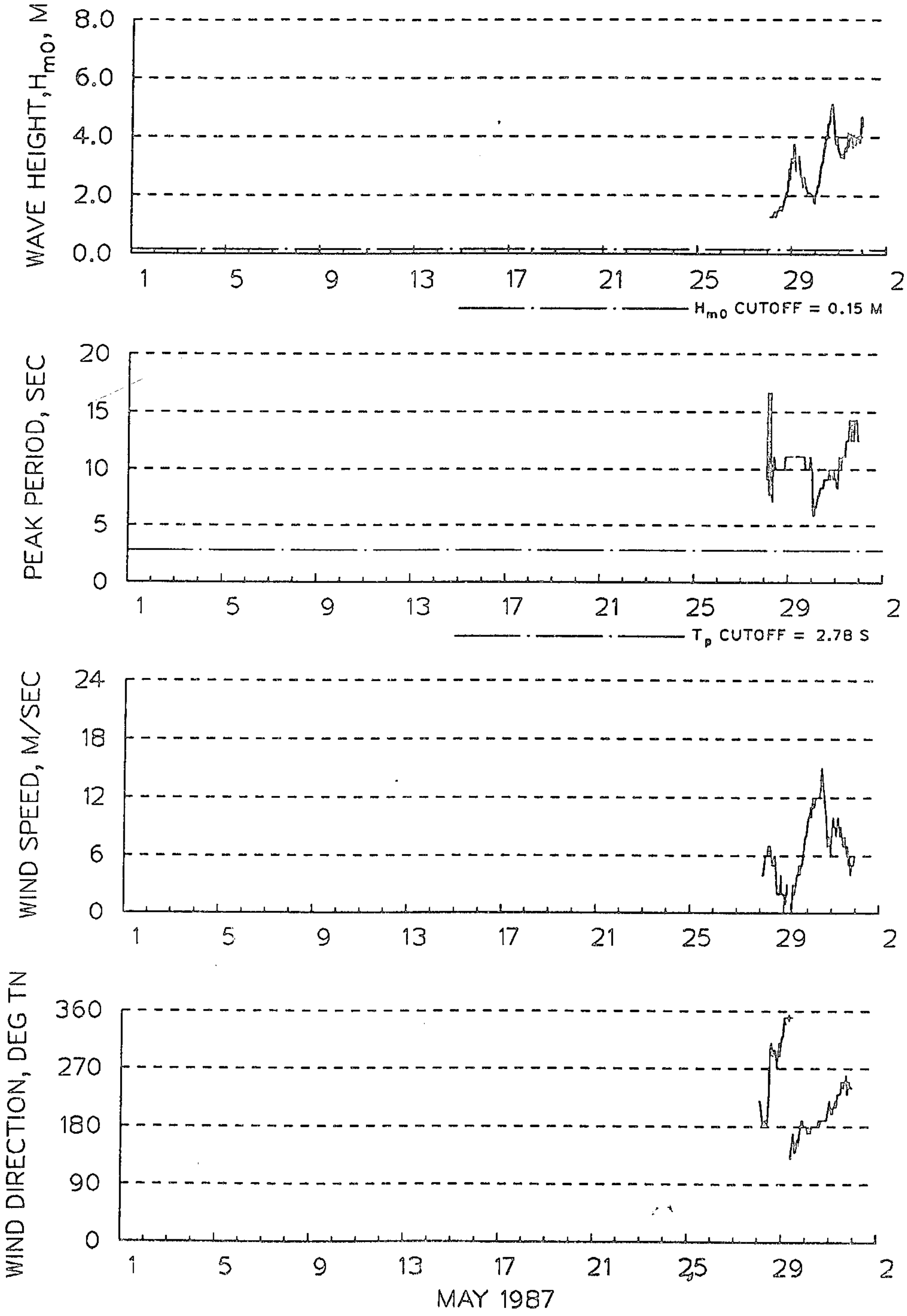
Appendix A
Monthly Time Series Plots for Deepwater NDBC 46040

YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W



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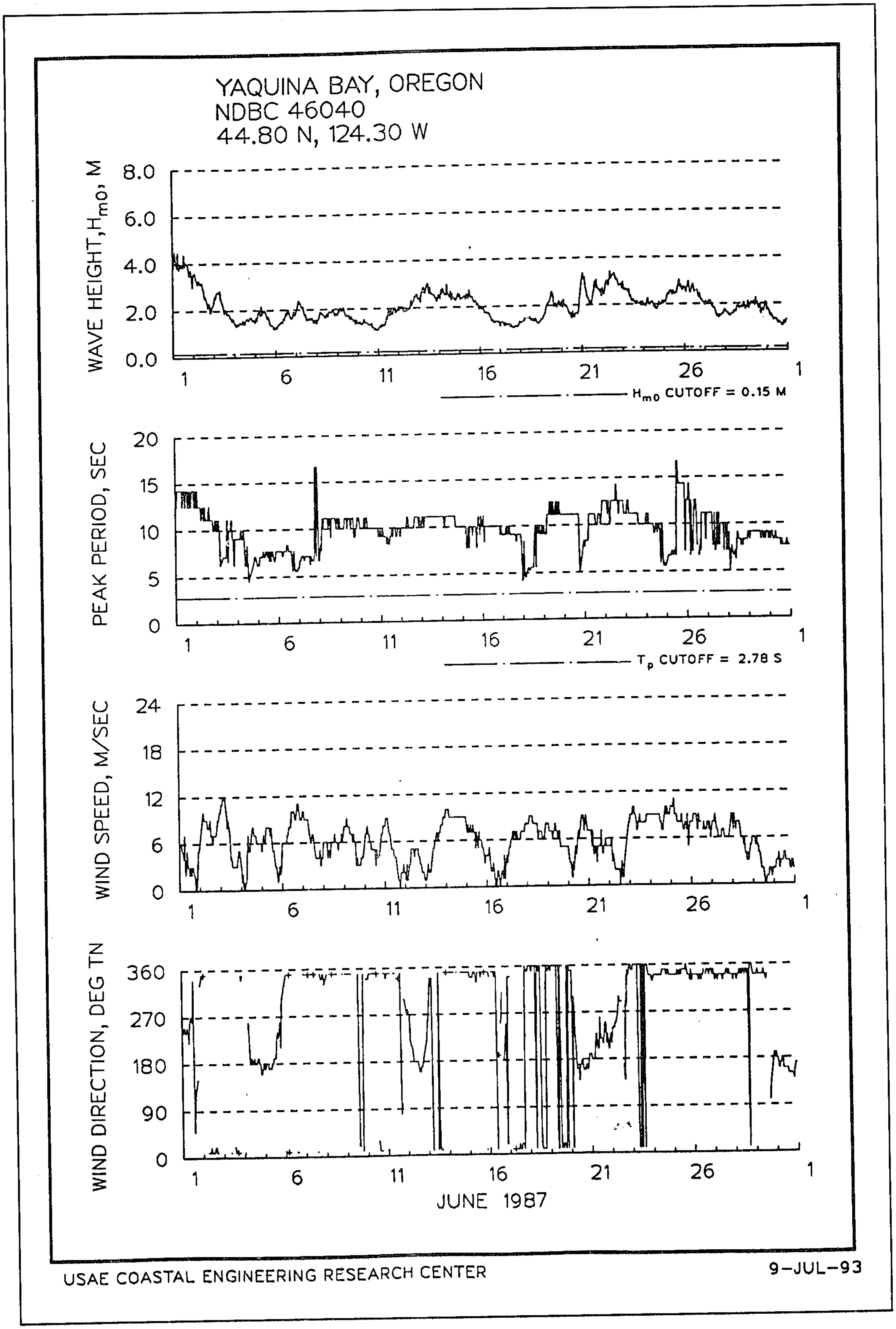
YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
WIND DIRECTION, DEG TN
360
270
180
90
0
JUNE 1987
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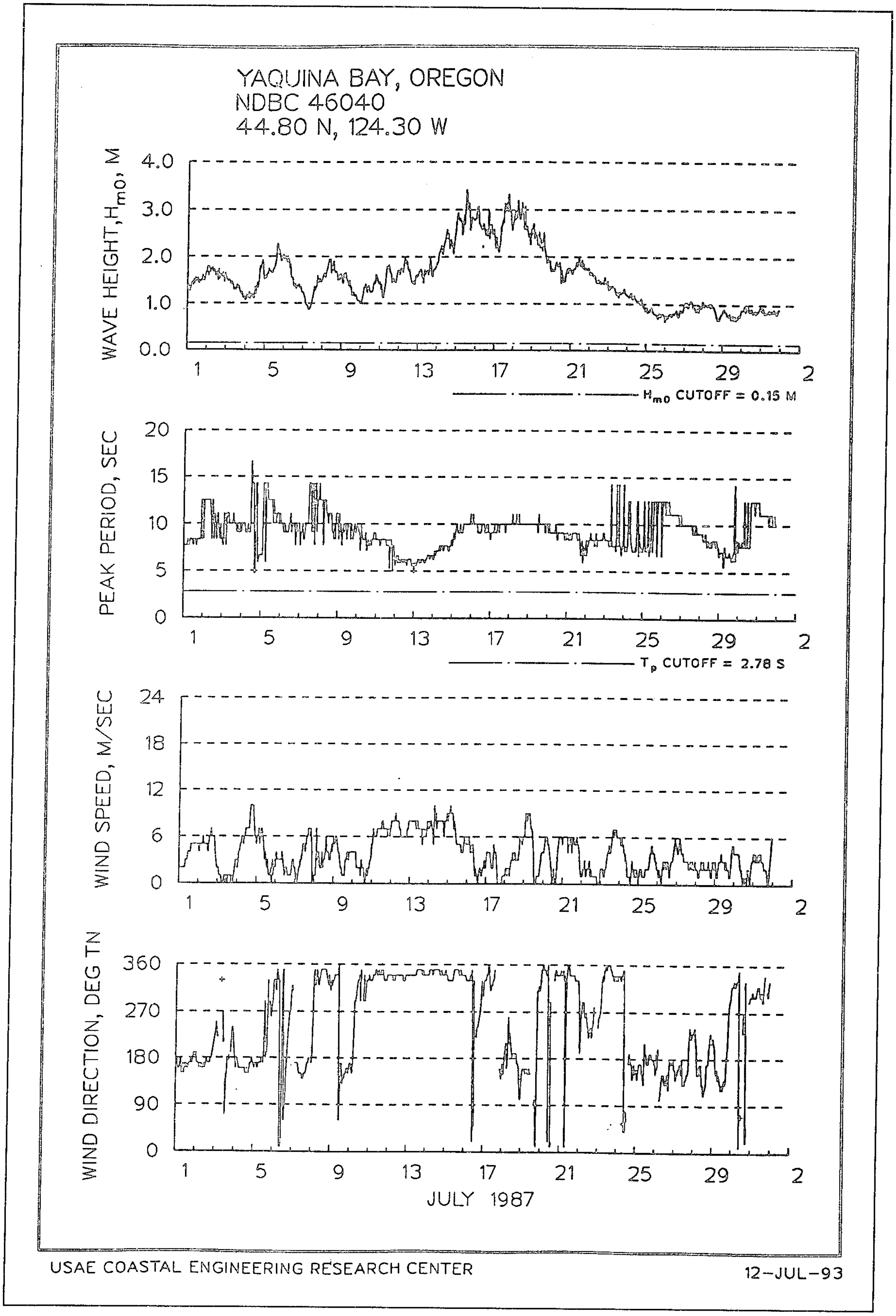
YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
WAVE HEIGHT, H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
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25
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JULY 1987
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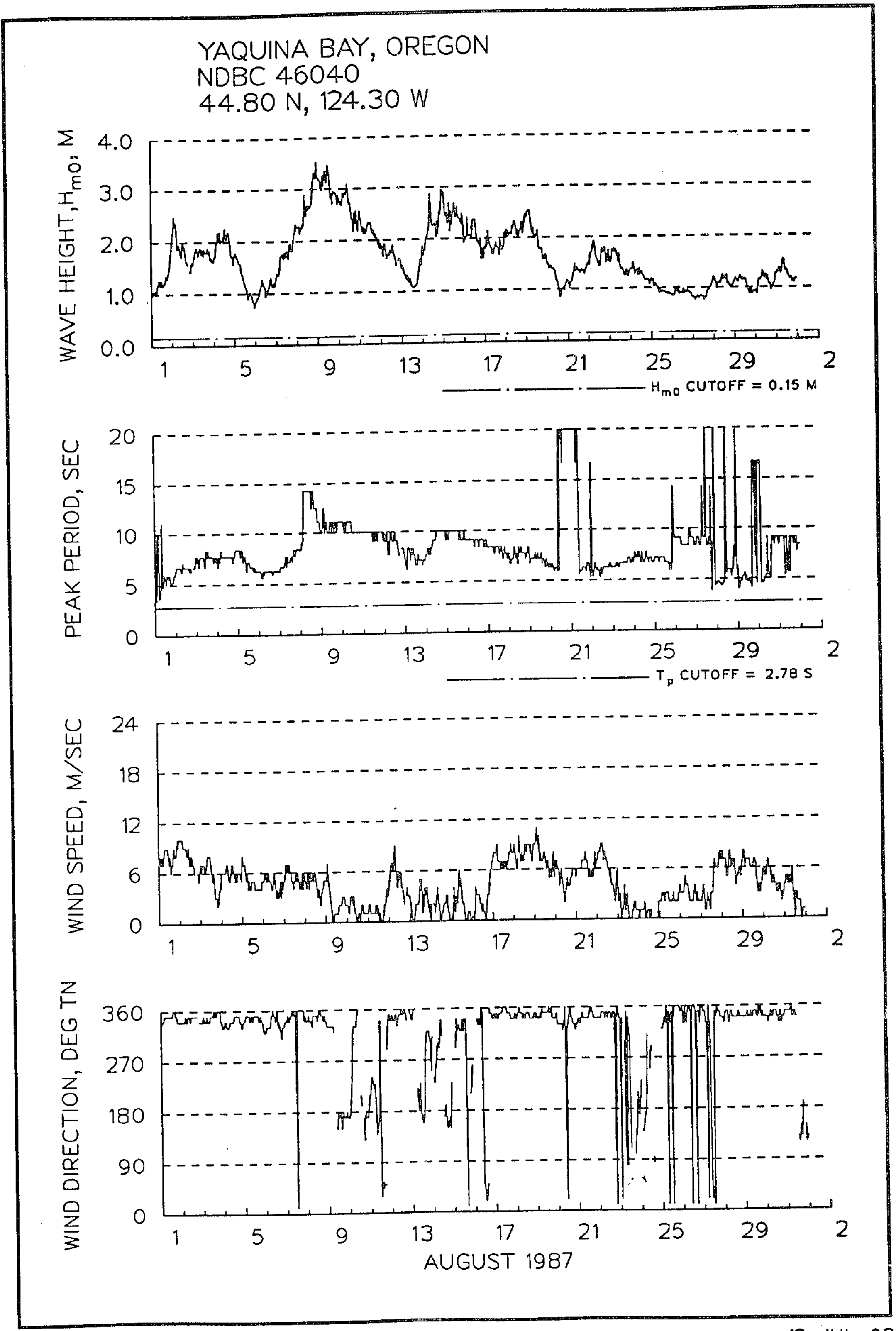

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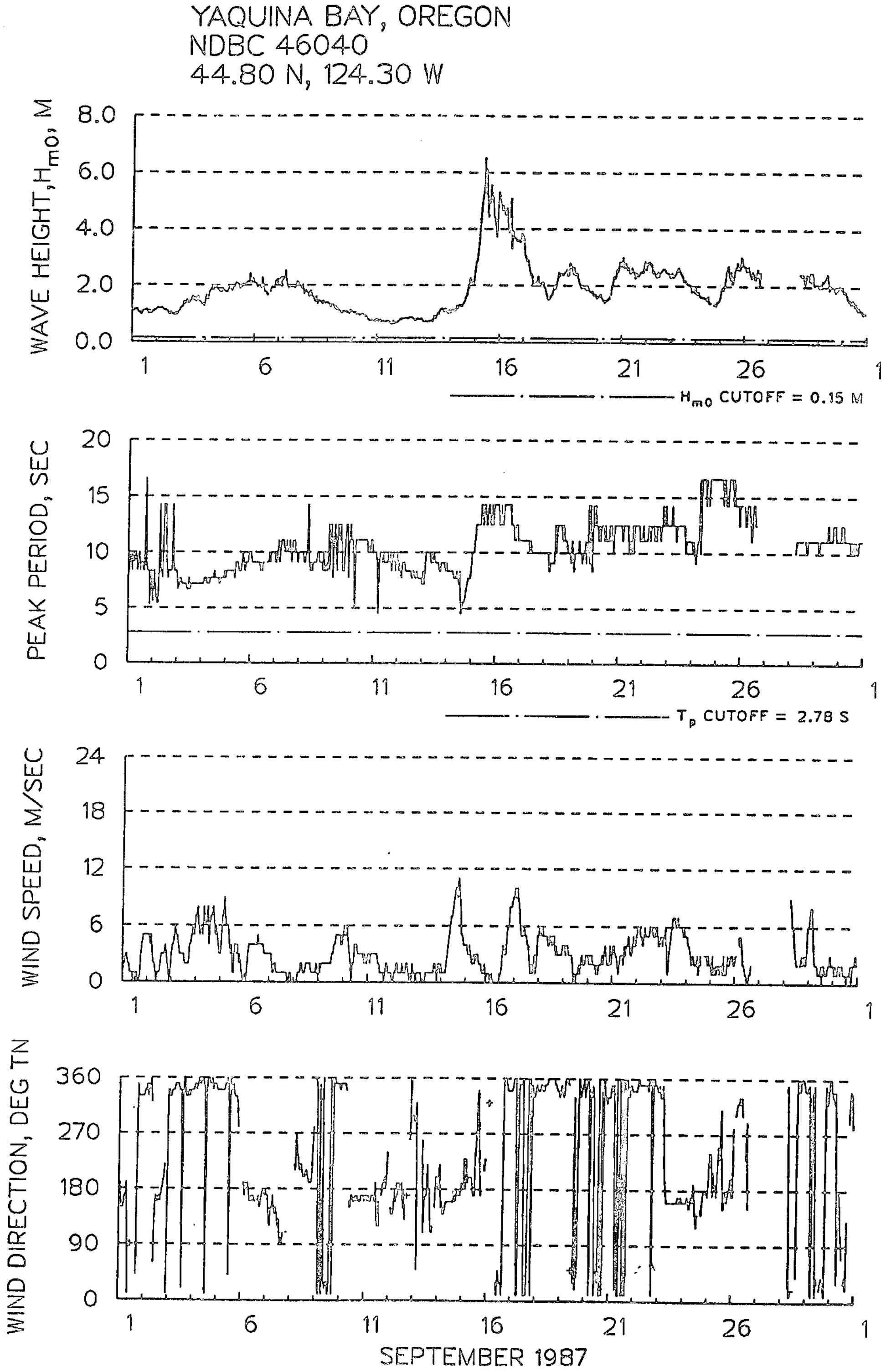

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NDBC 46040
44.80 N, 124.30 W

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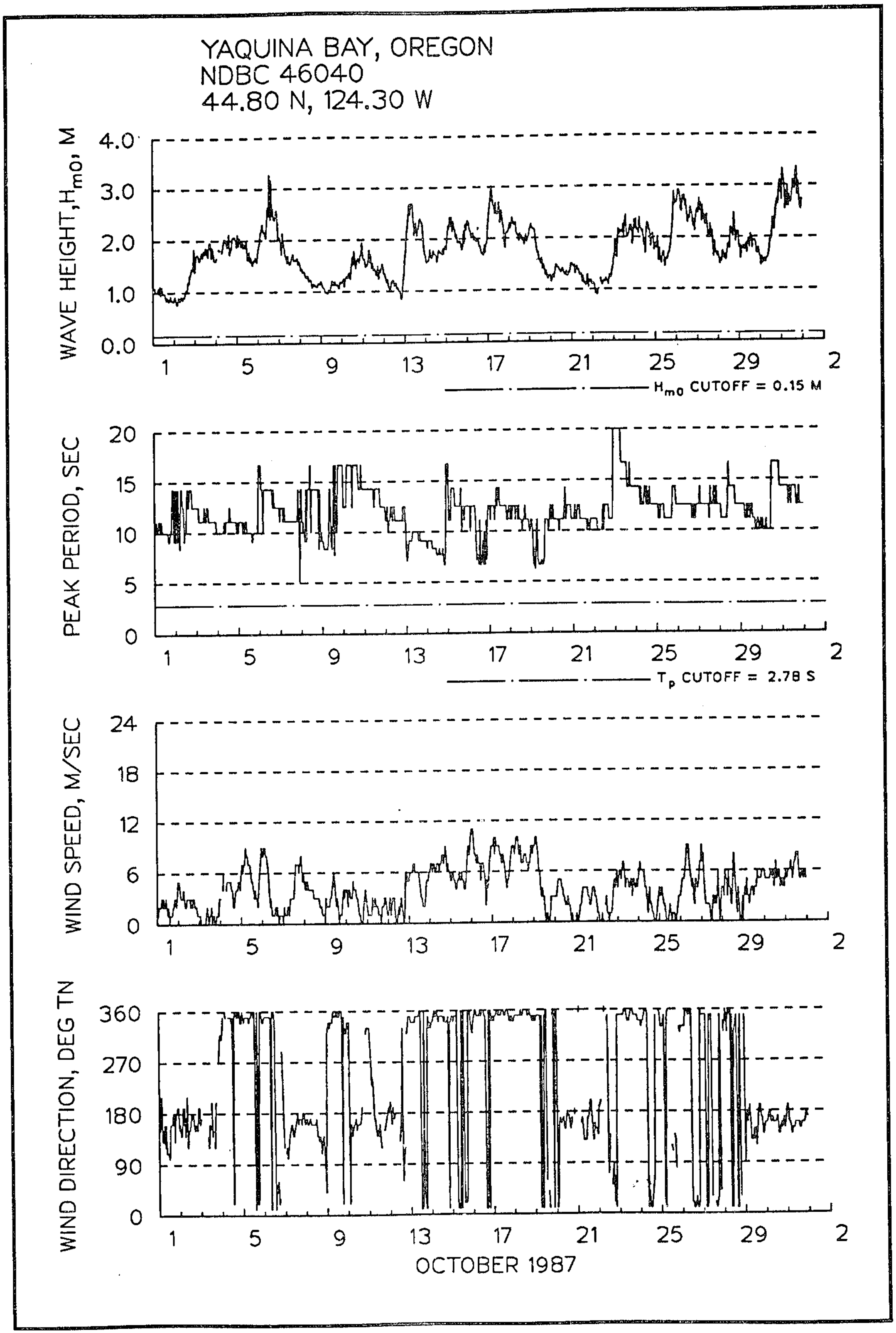
12-JUL-93



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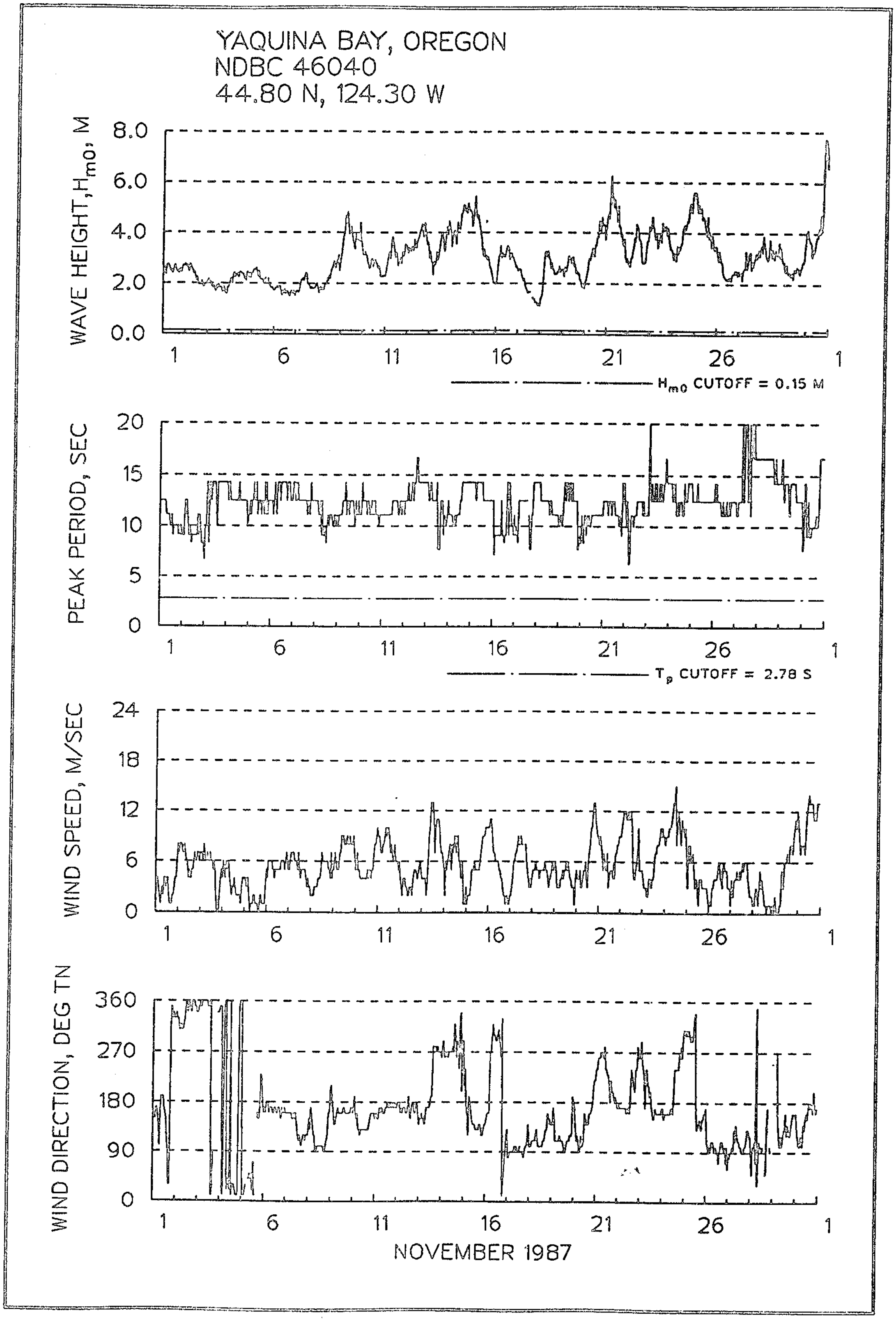

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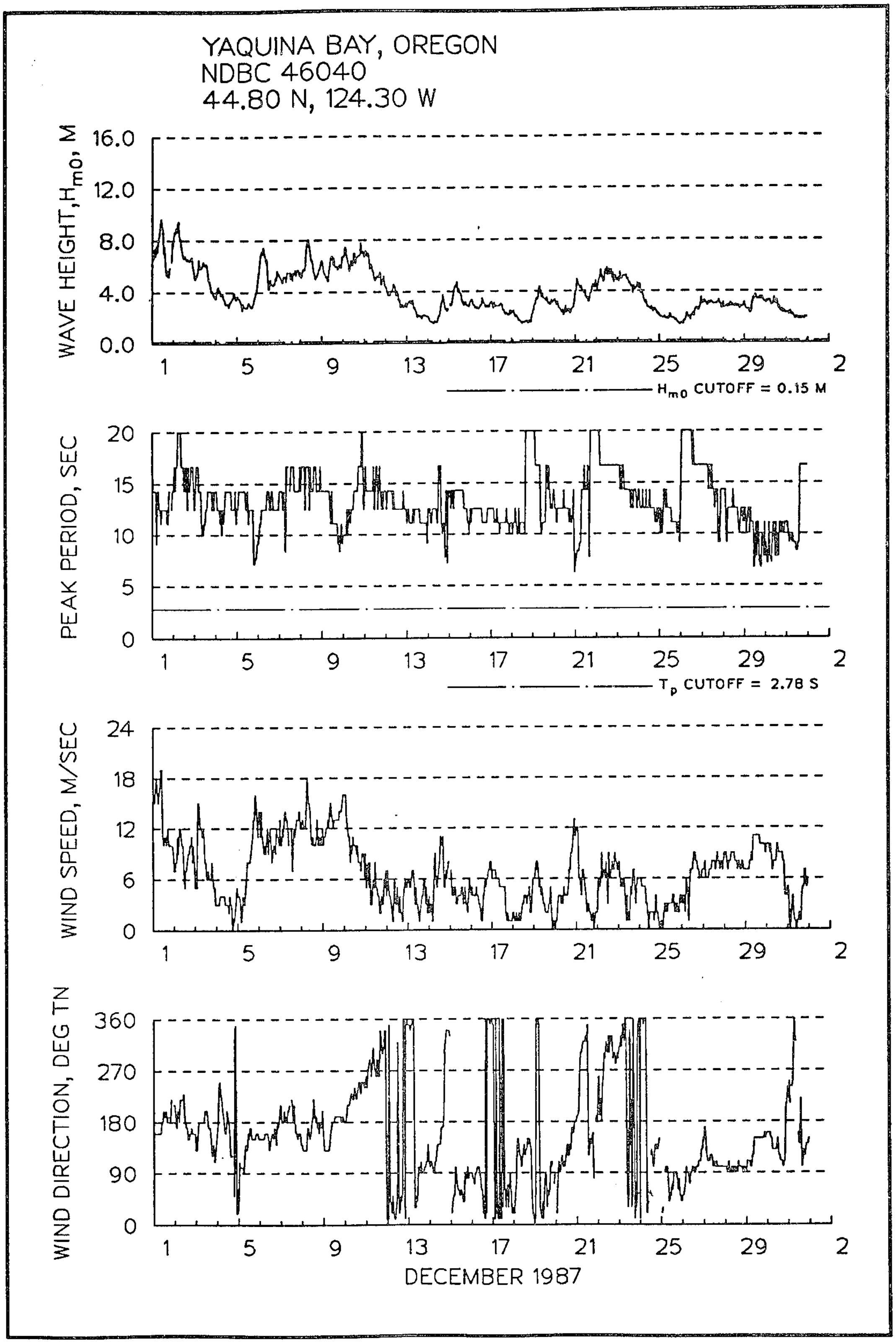

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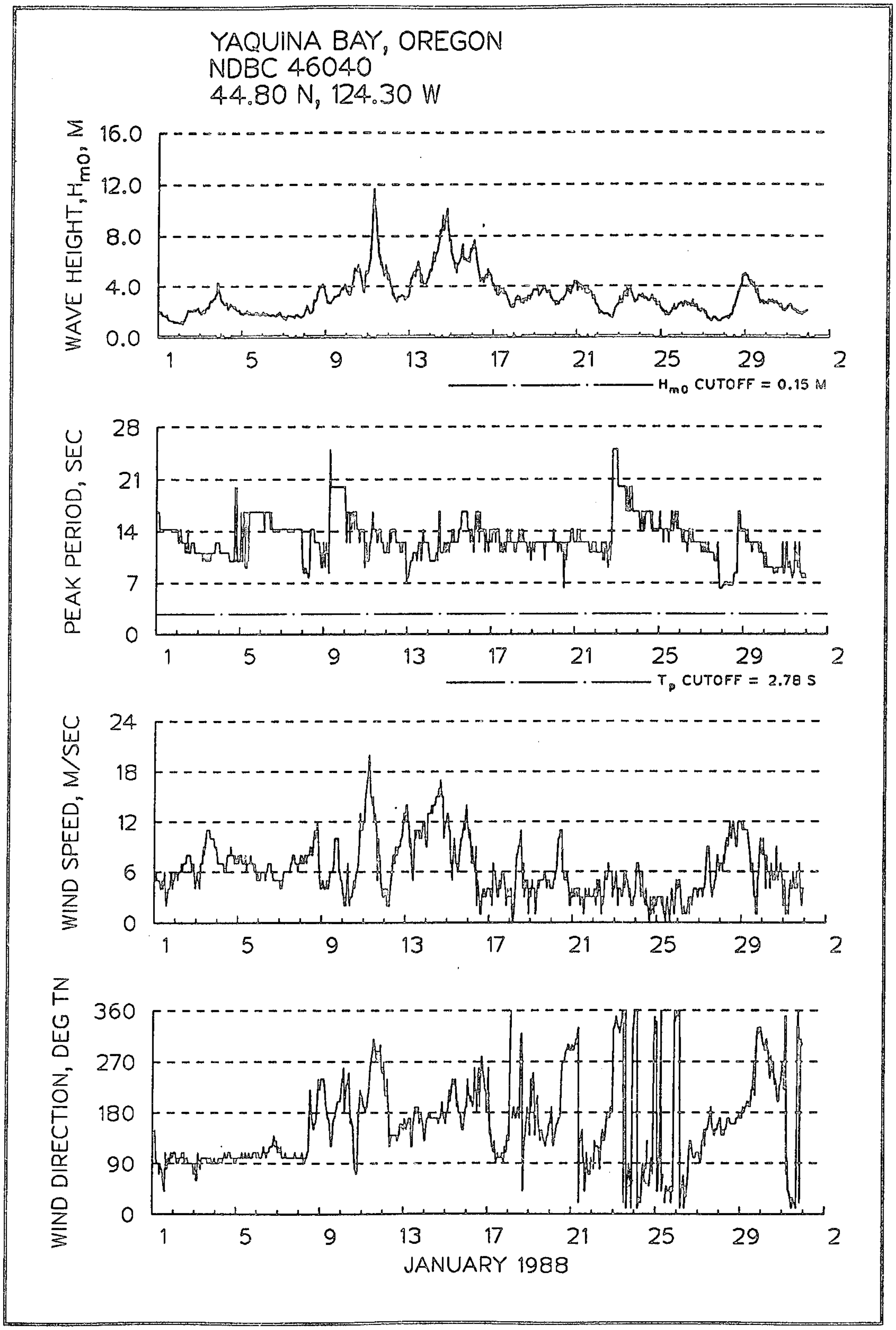
12–JUL–93



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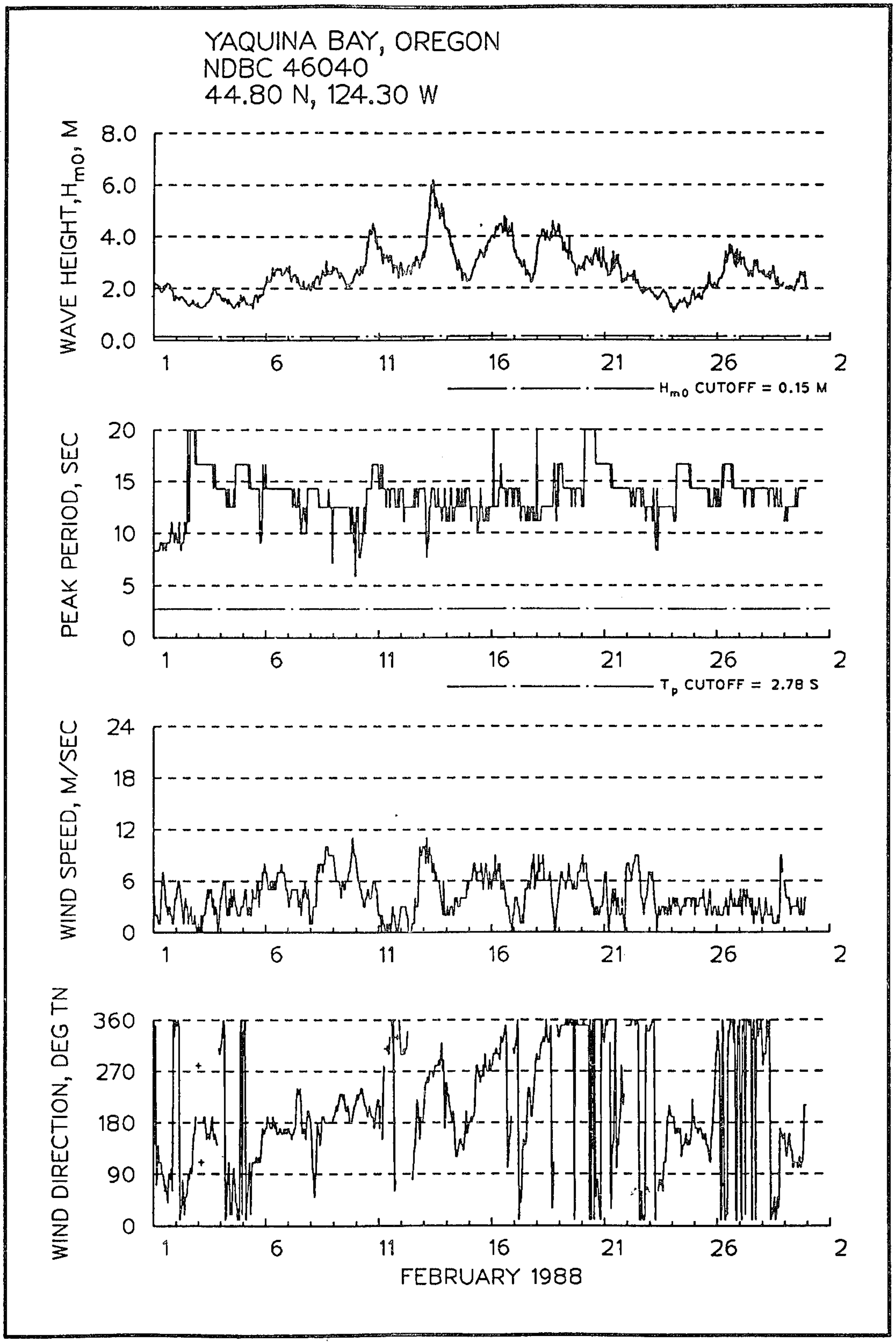

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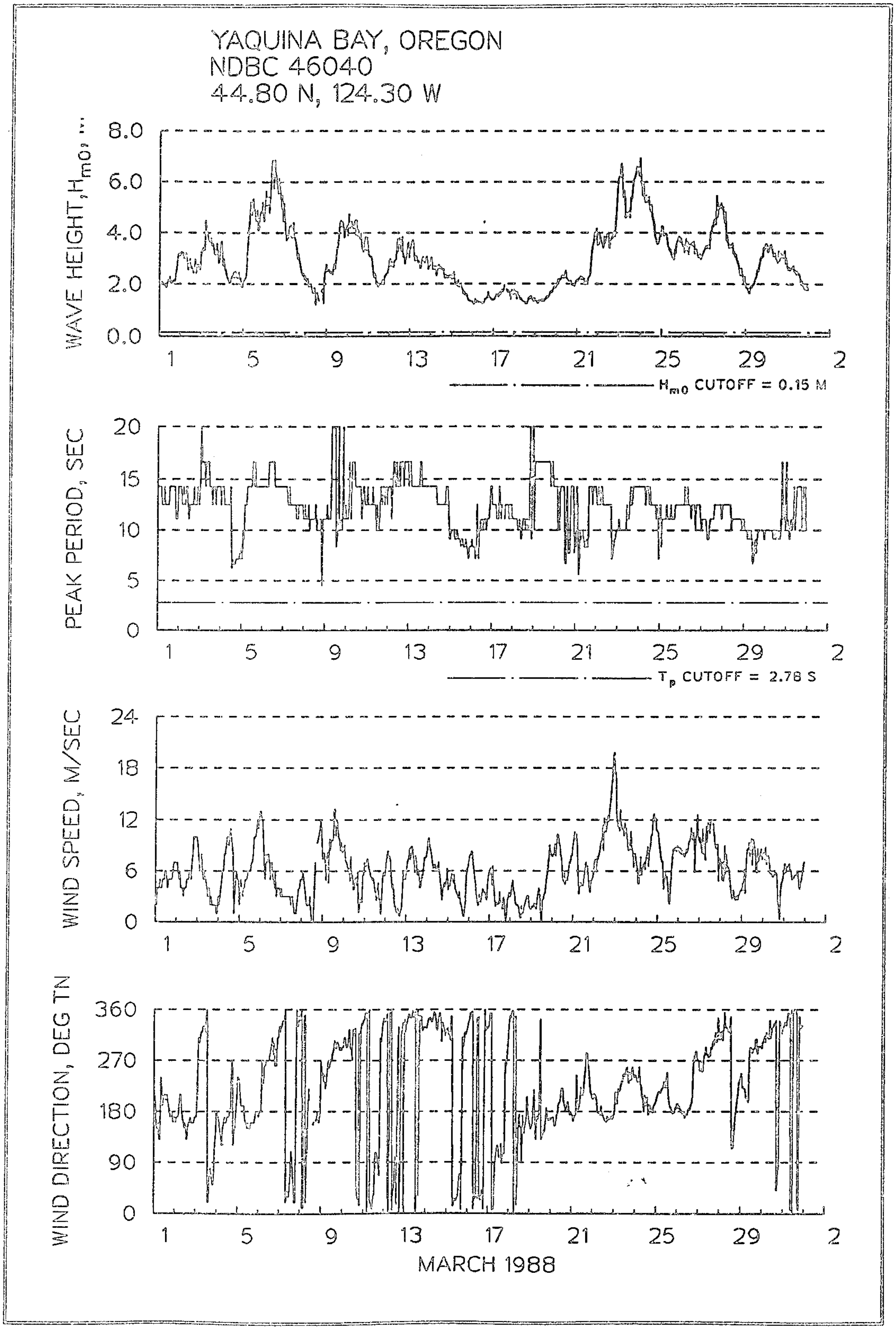

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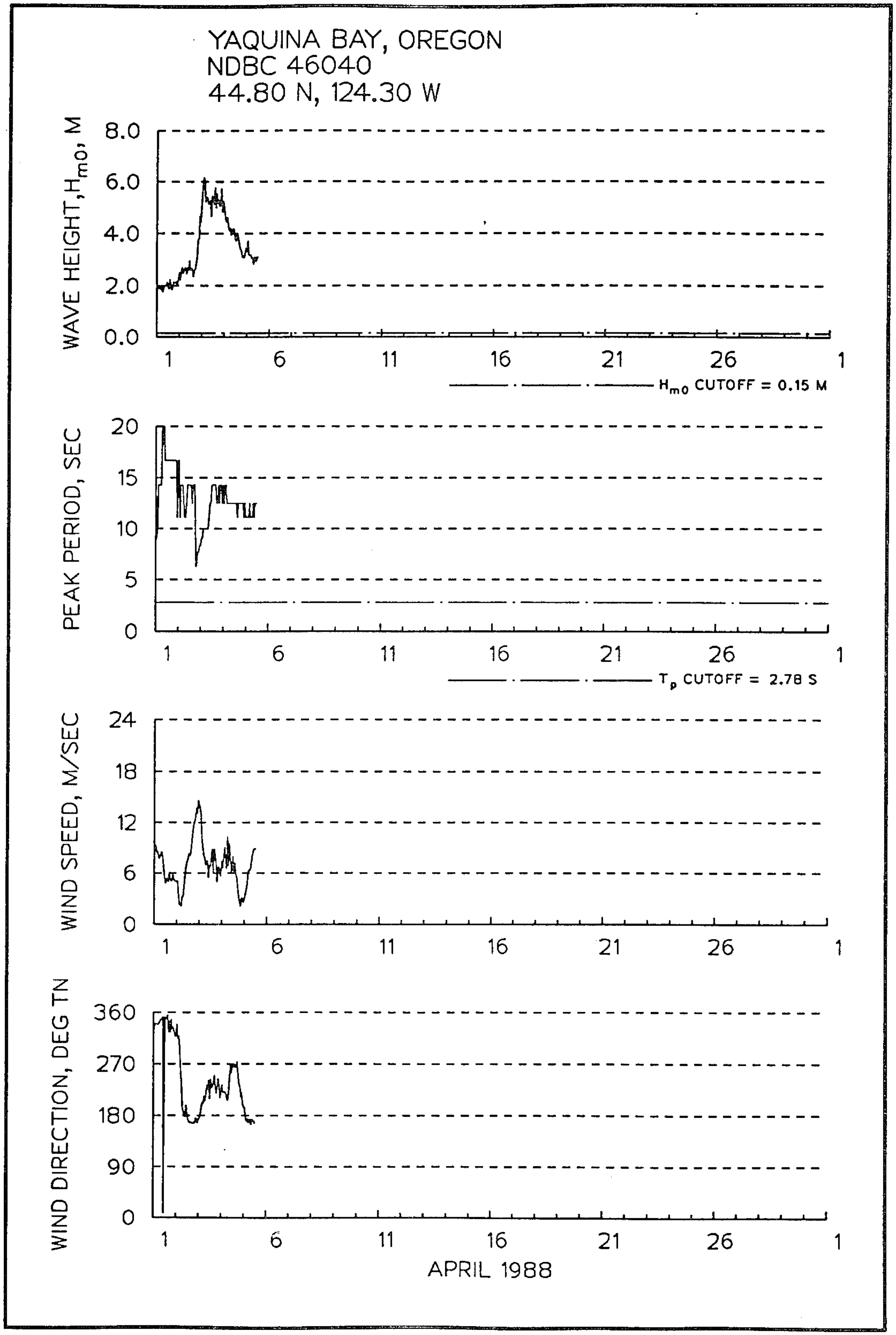
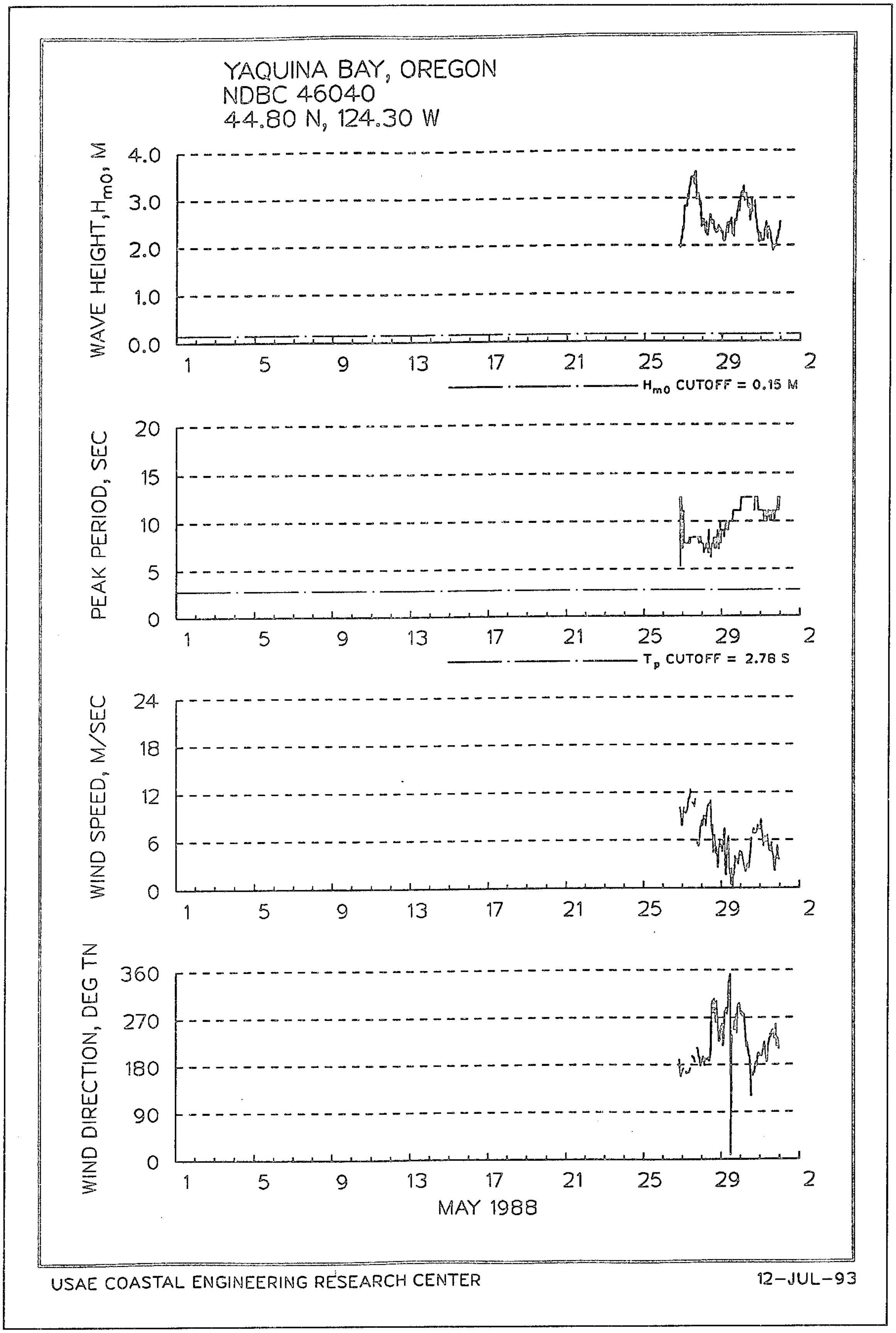
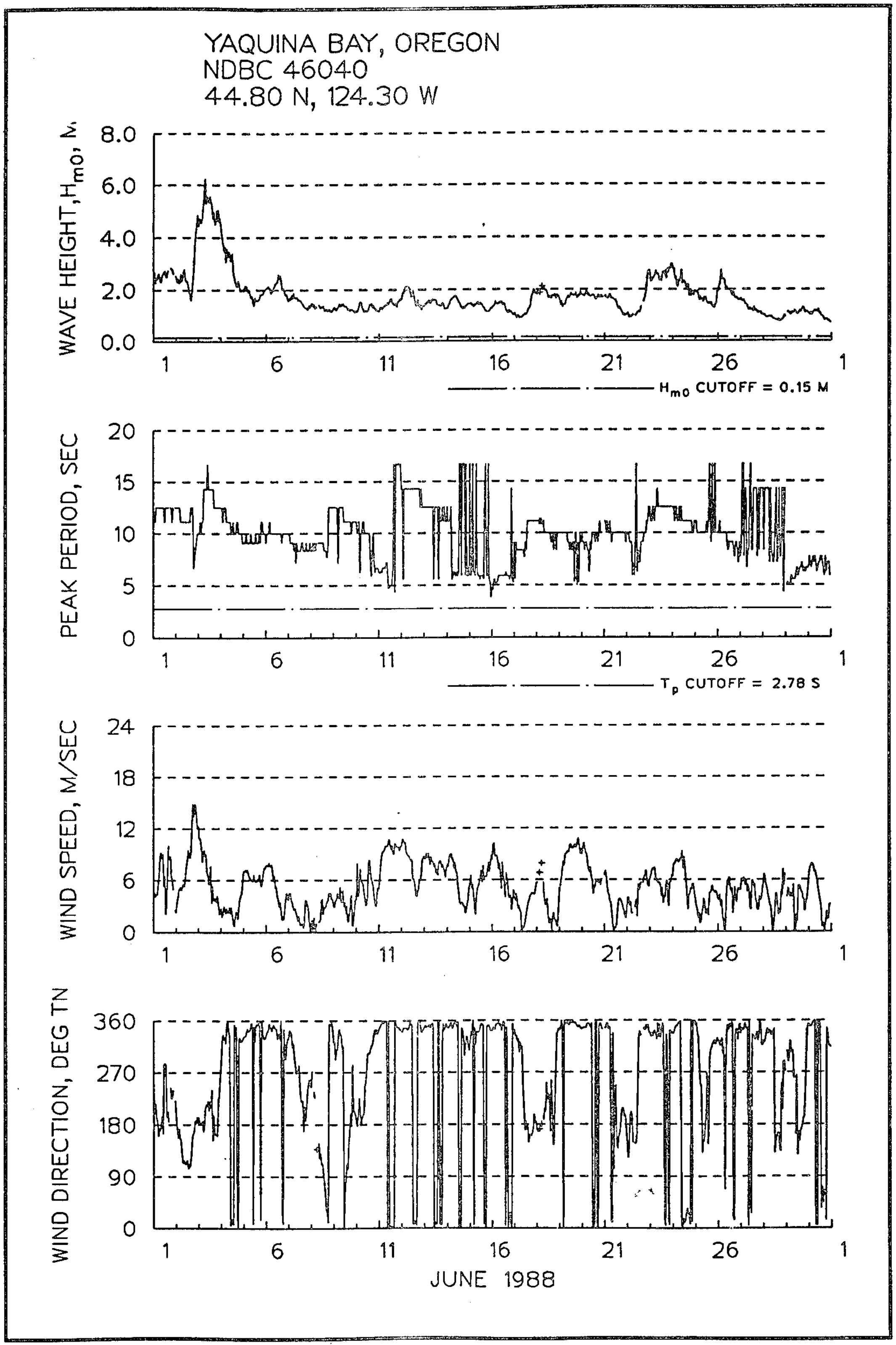


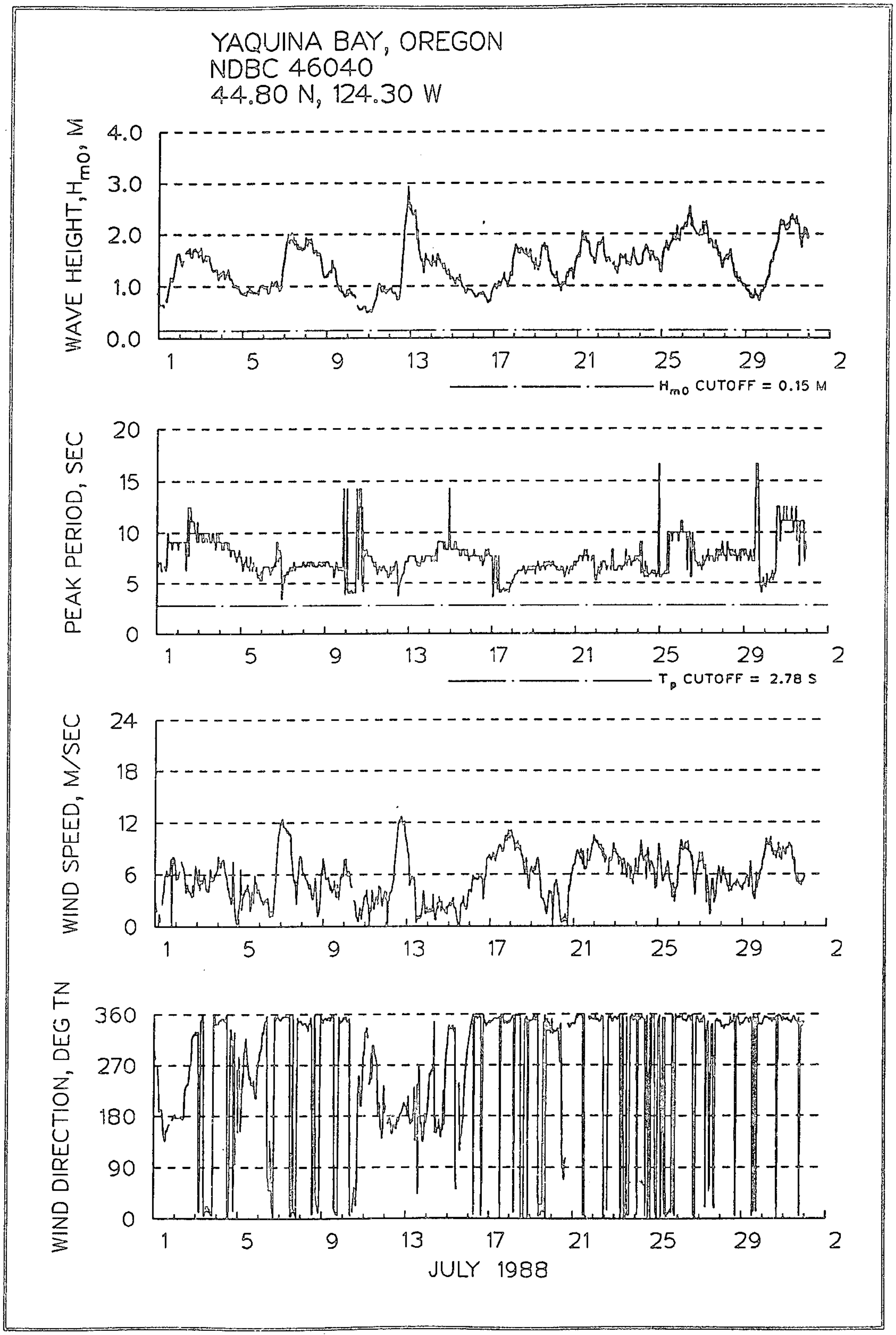
USAE COASTAL ENGINEERING RESEARCH CENTER 12-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
WAVE HEIGHT, H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
WIND DIRECTION, DEG TN
360
270
180
90
0
MAY 1988
USAE COASTAL ENGINEERING RESEARCH CENTER
12-JUL-93

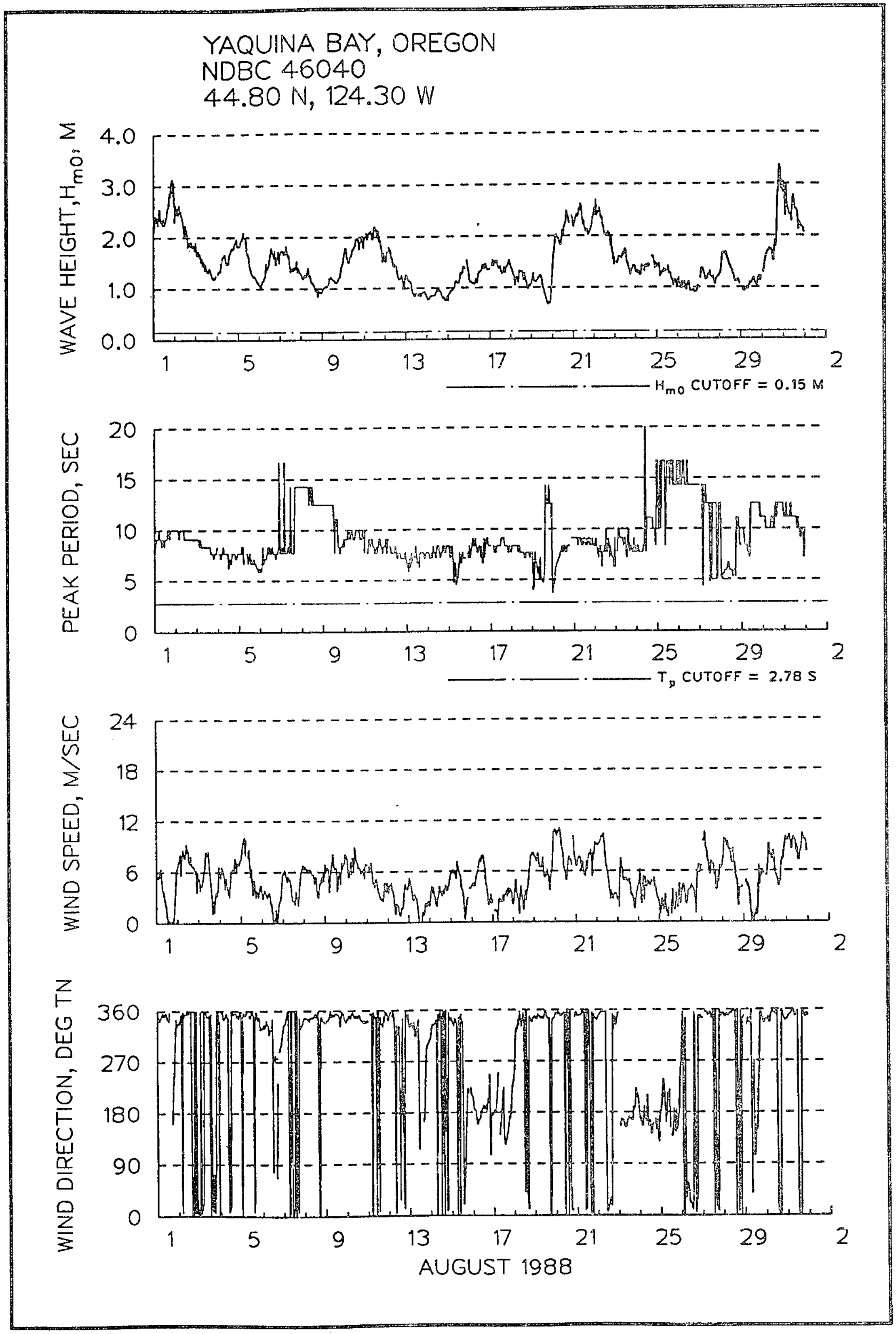


YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W

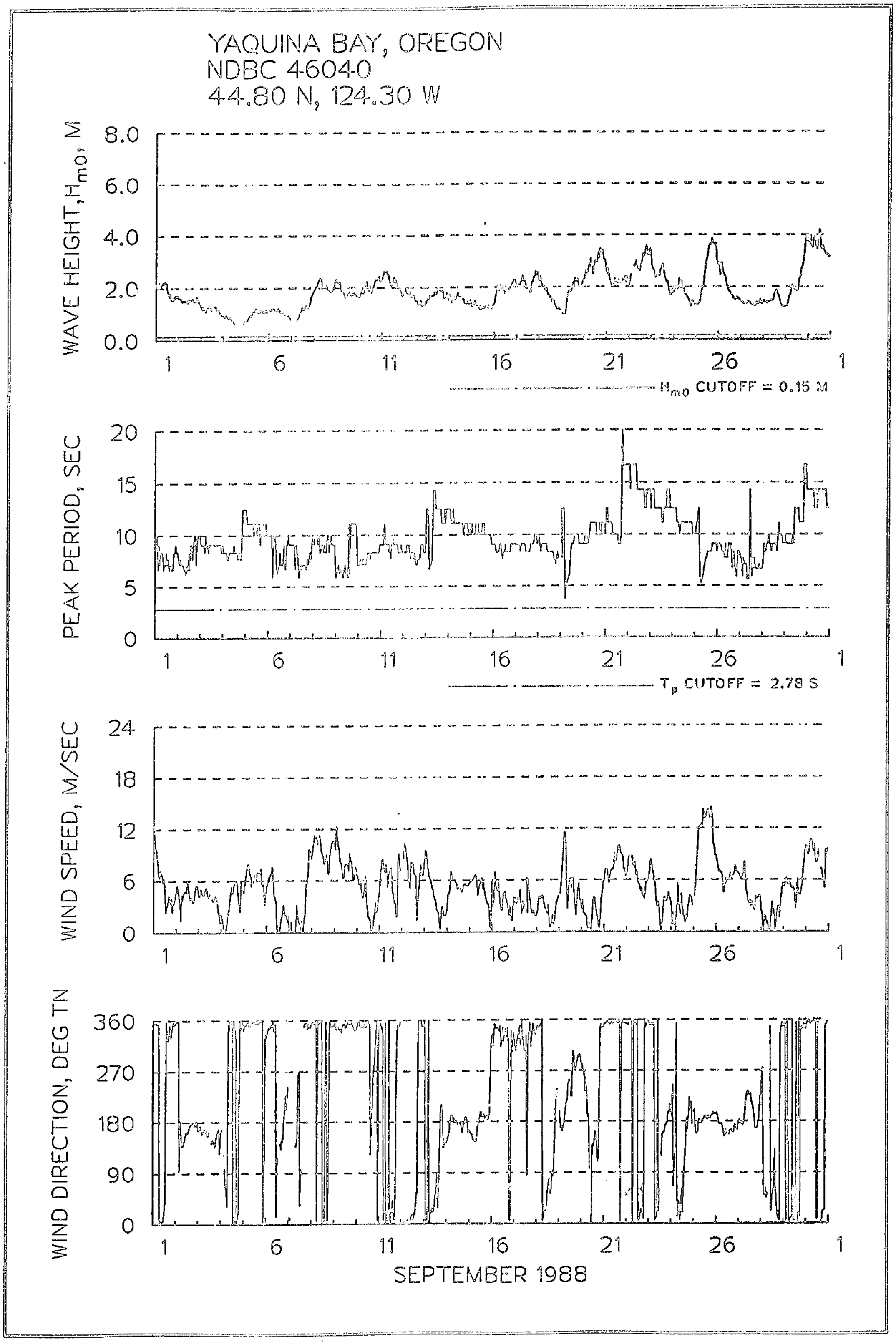
USAE COASTAL ENGINEERING RESEARCH CENTER 12–JUL–93



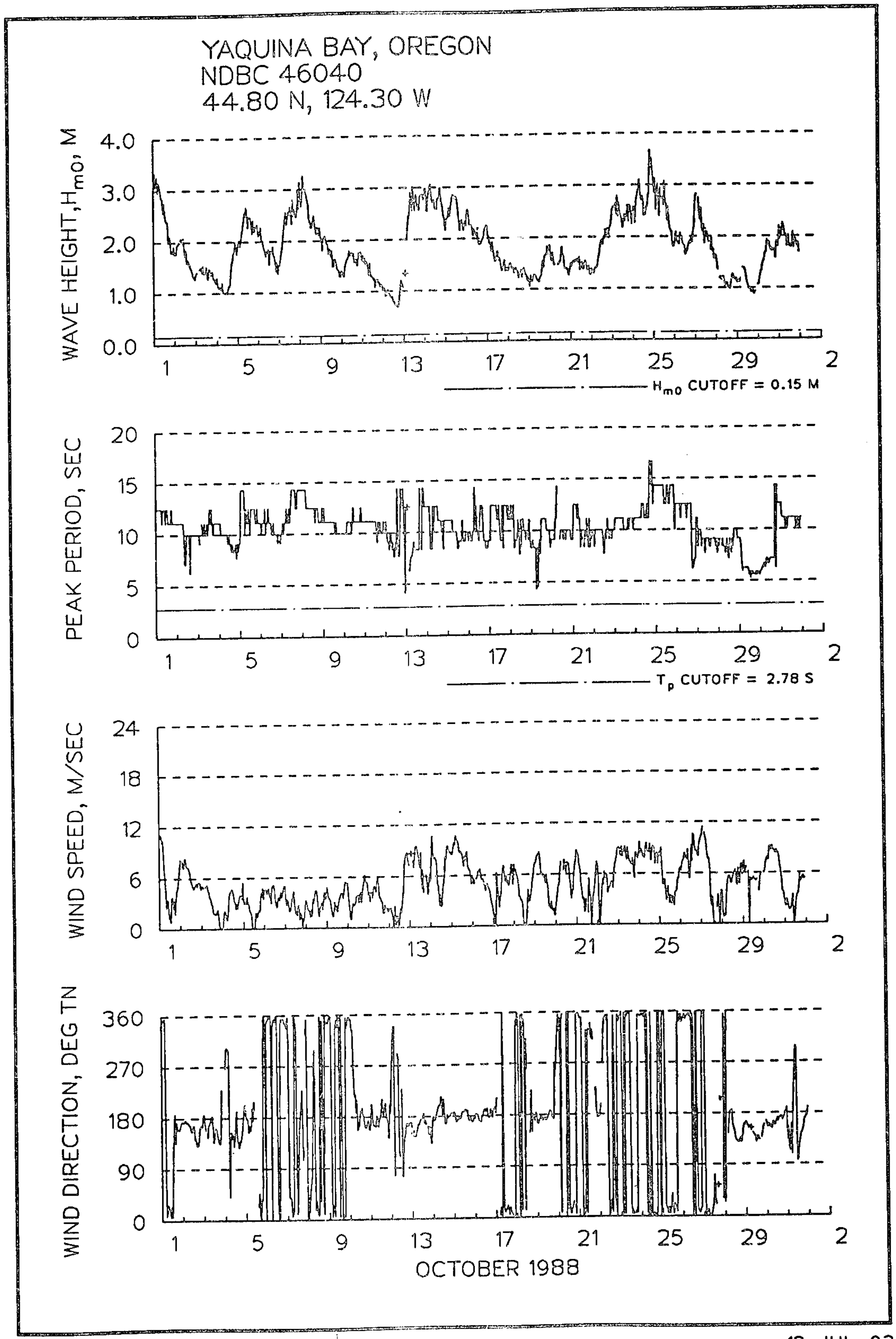
USAE COASTAL ENGINEERING RESEARCH CENTER 12–JUL–93



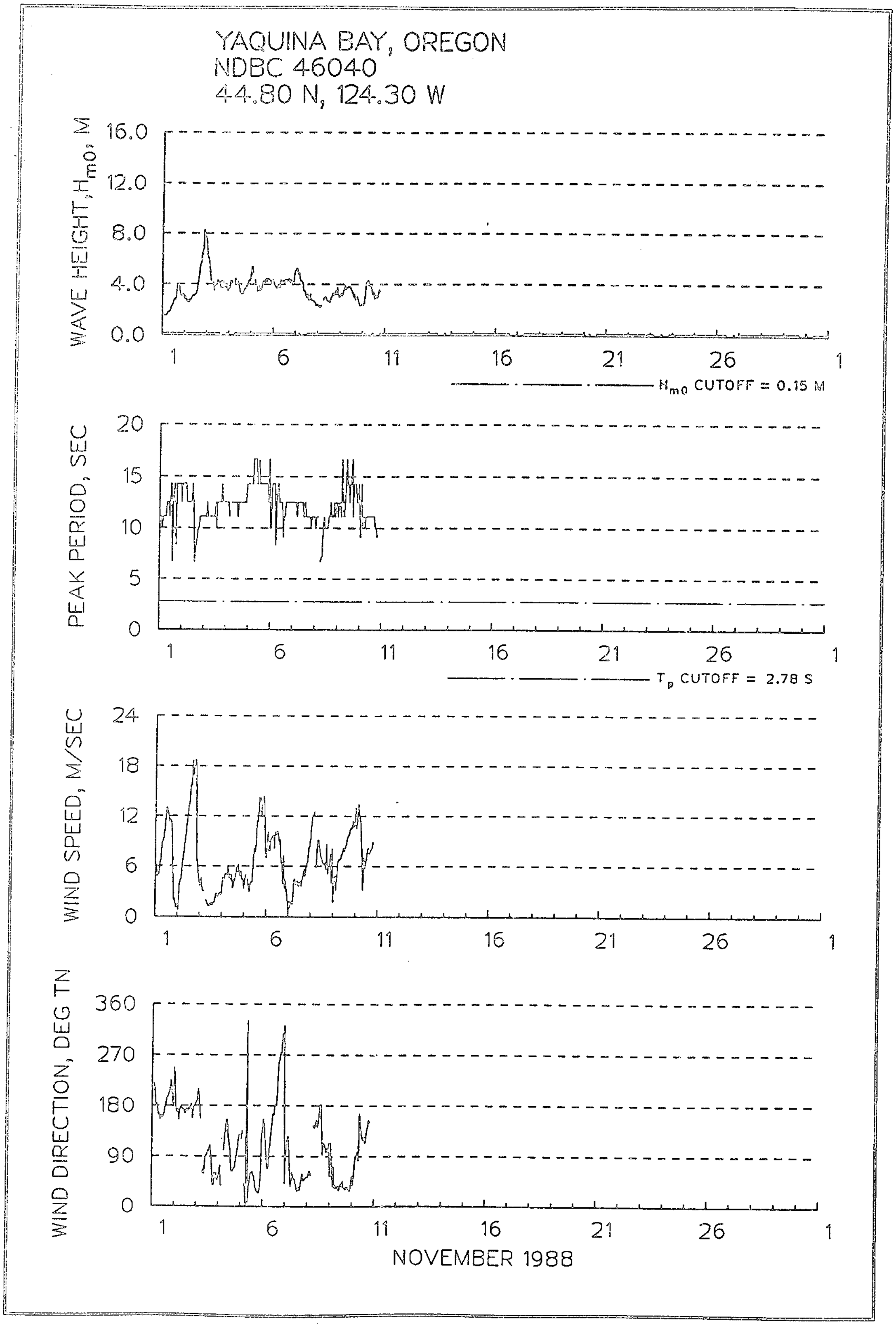
USAE COASTAL ENGINEERING RESEARCH CENTER 12–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER 12-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 12–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER

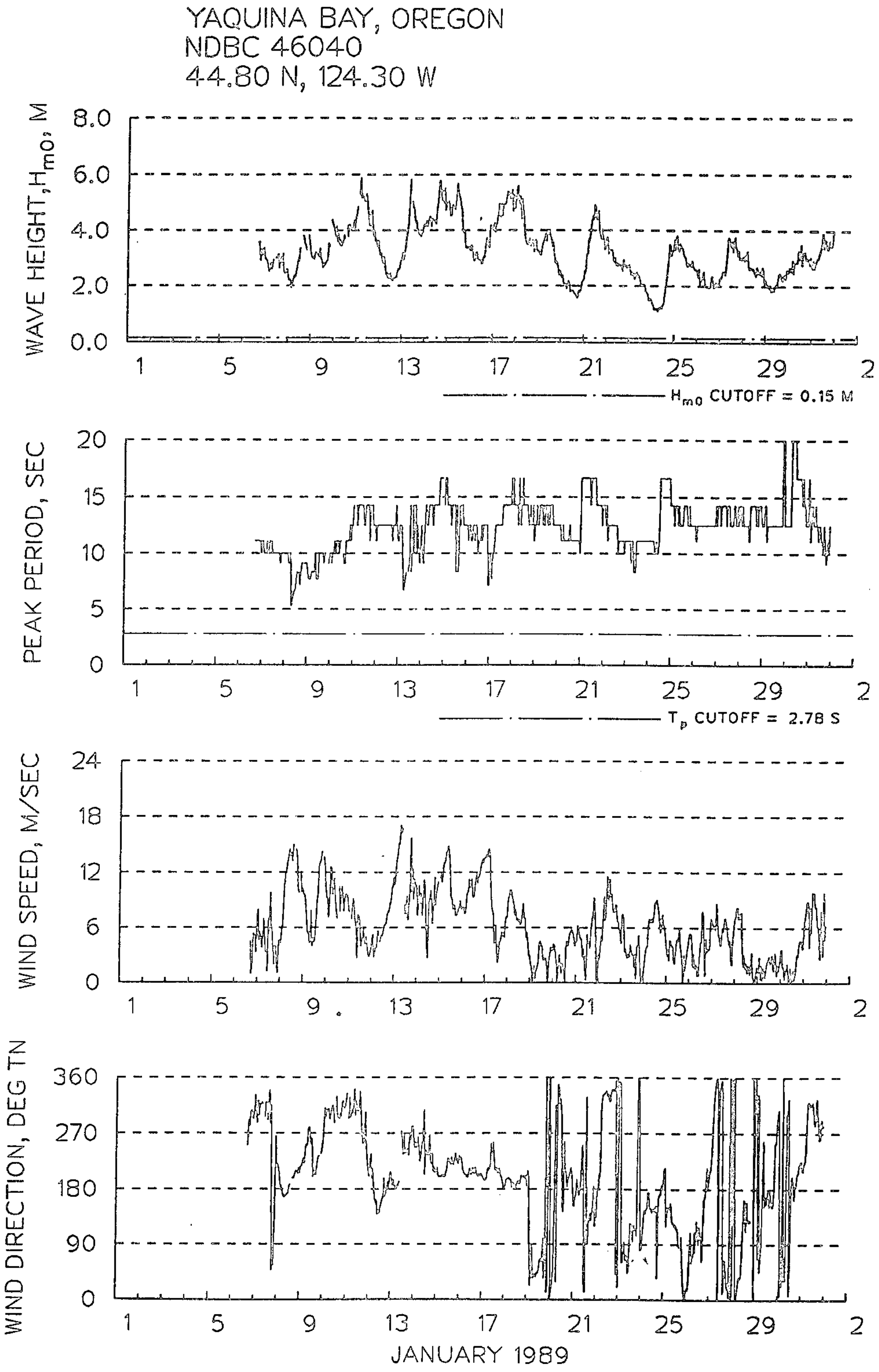
12-JUL-93

YAQUINA BAY,OREGON
NDBC 46040
44.78 N 124.30 W

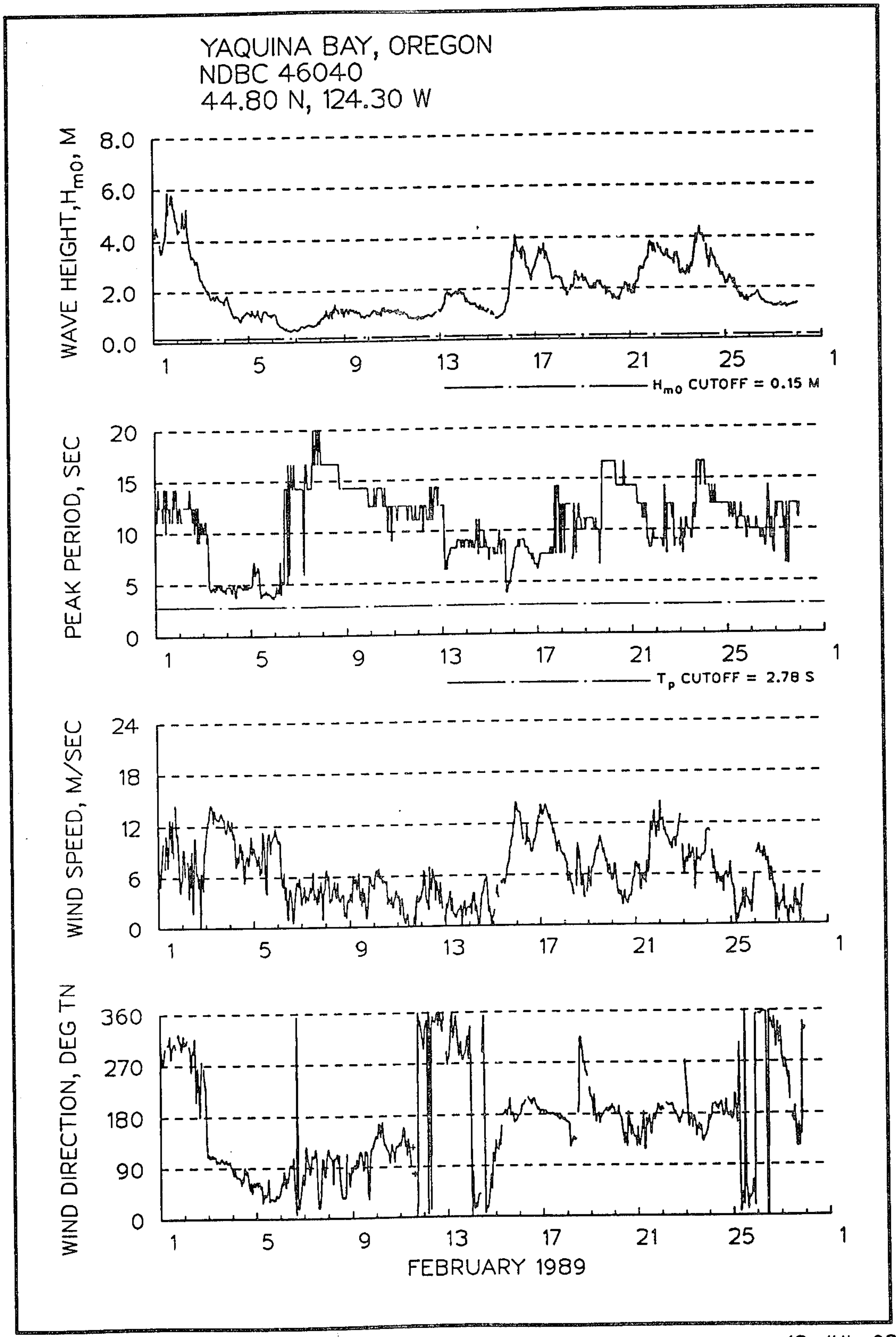
NO DATA AVAILABLE

DECEMBER 1988

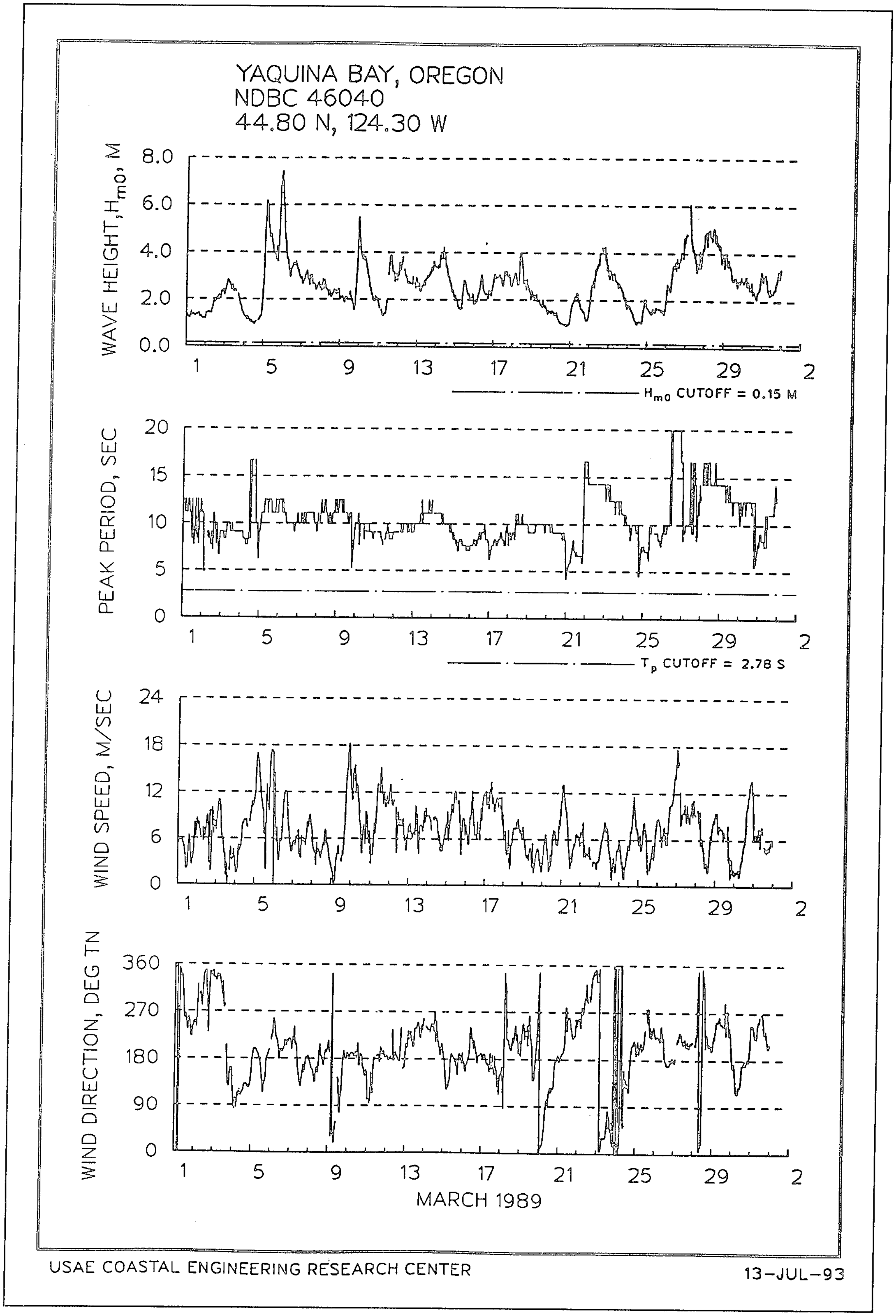
USAE COASTAL ENGINEERING RESEARCH CENTER 21-NOV-94



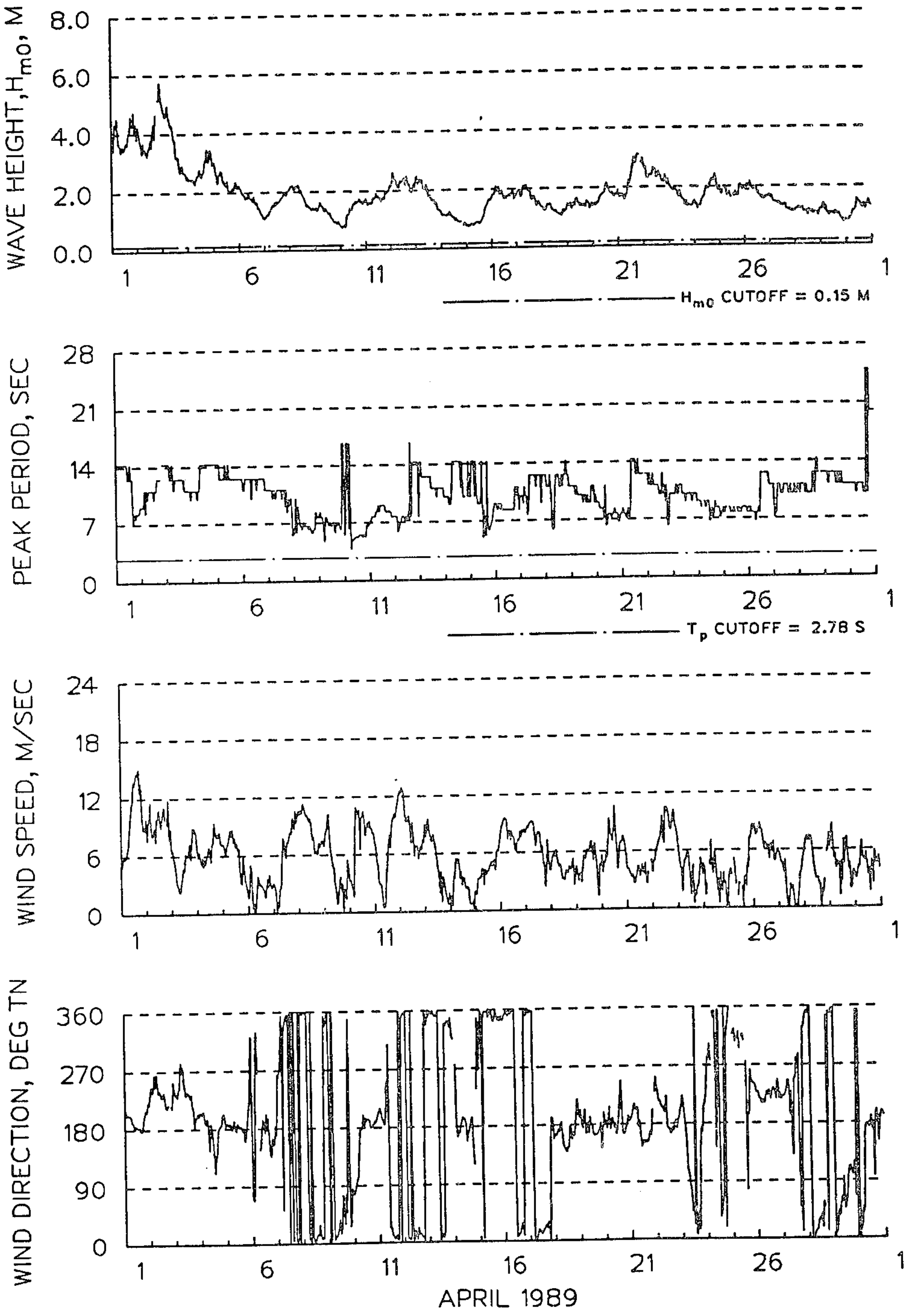
USAE COASTAL ENGINEERING RESEARCH CENTER 13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13–JUL–93

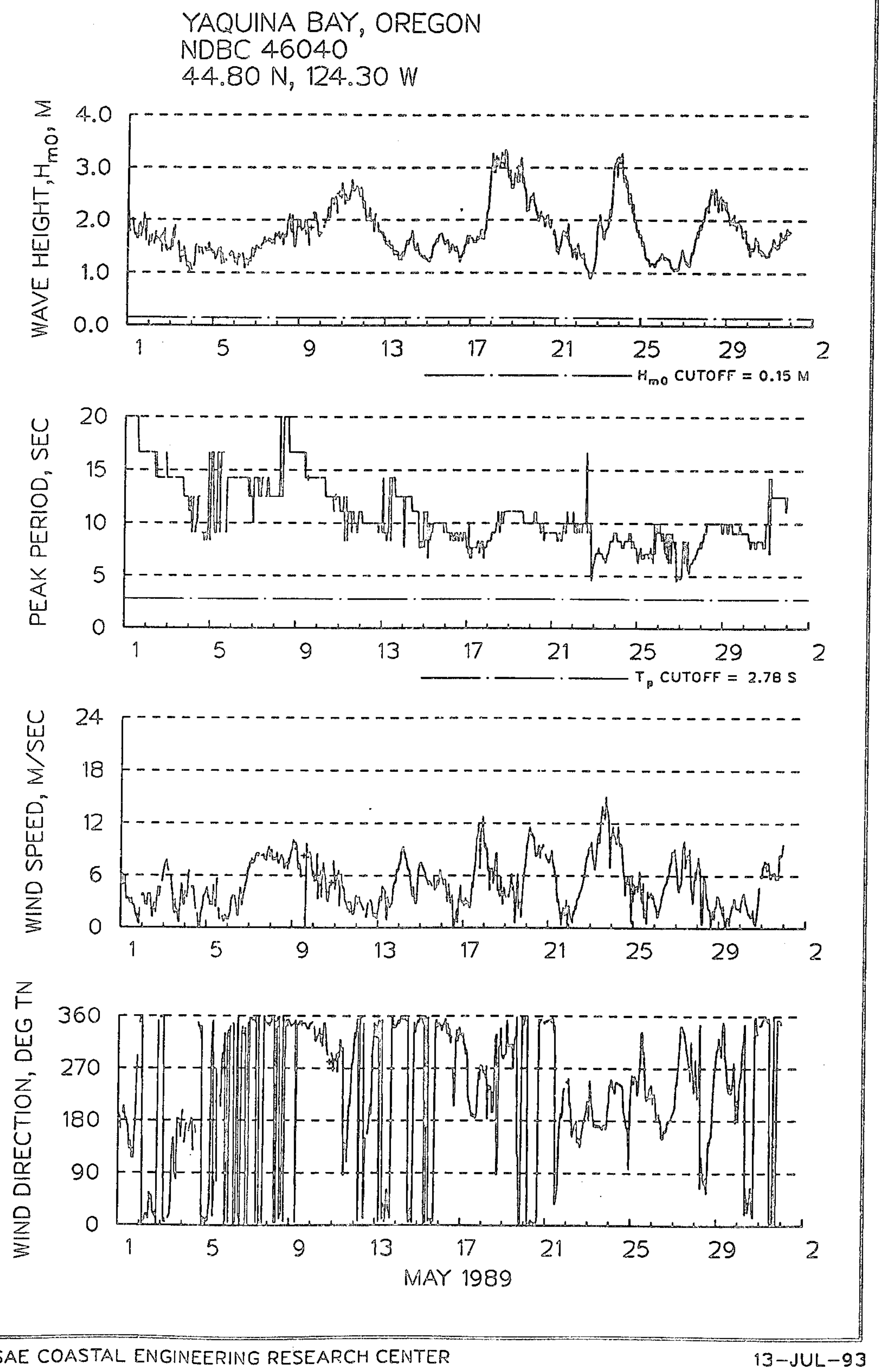

YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MARCH 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93

YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W



USAE COASTAL ENGINEERING RESEARCH CENTER

13–JUL–93


YAQUINA BAY, OREGON
NDBC 46040
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WAVE HEIGHT, H_{mo}, M
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2.0
1.0
0.0
1
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2
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
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WIND DIRECTION, DEG TN
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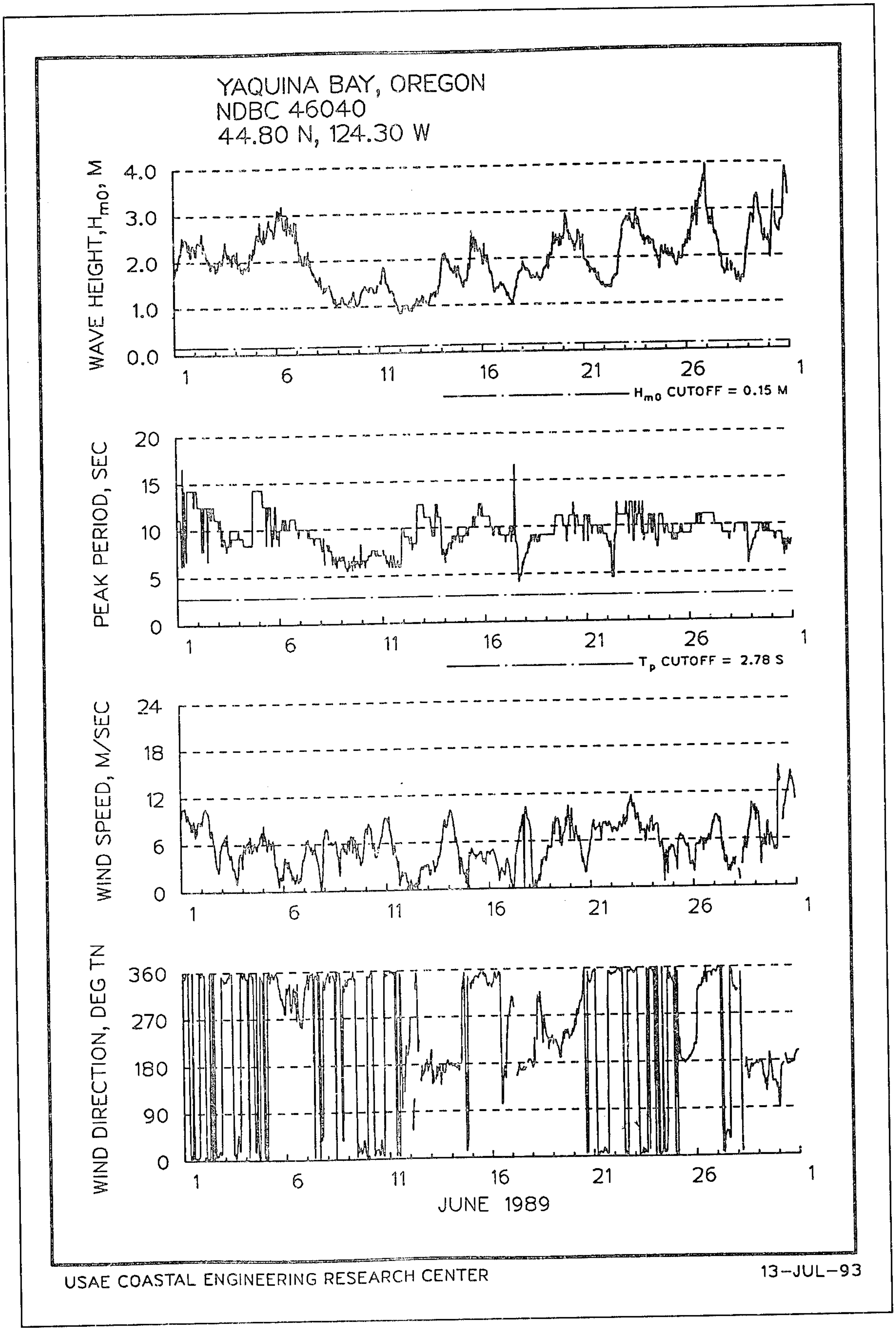
MAY 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93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1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
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6
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16
21
26
1
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
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6
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21
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WIND DIRECTION, DEG TN
360
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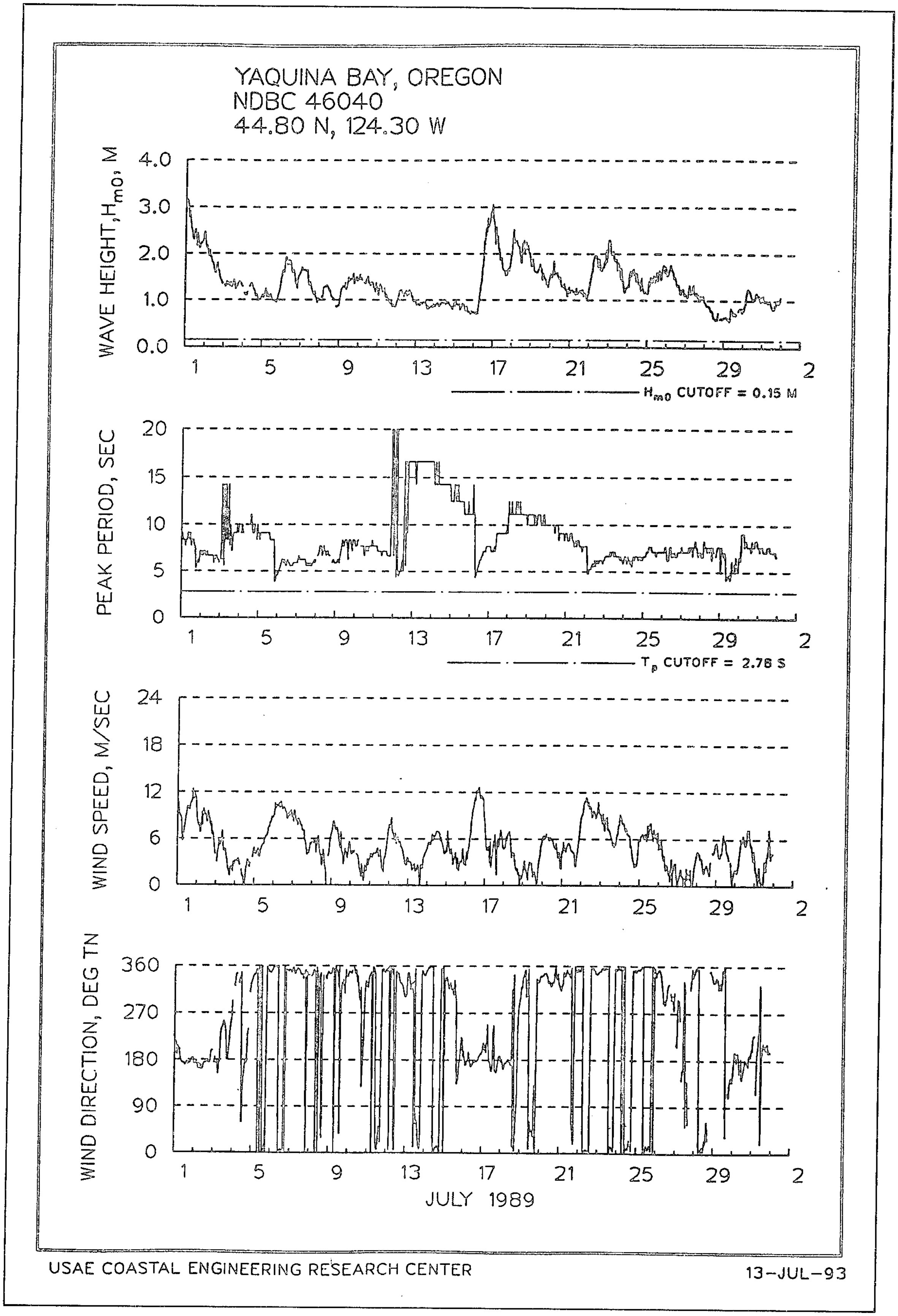
JUNE 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93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H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
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2
WIND DIRECTION, DEG TN
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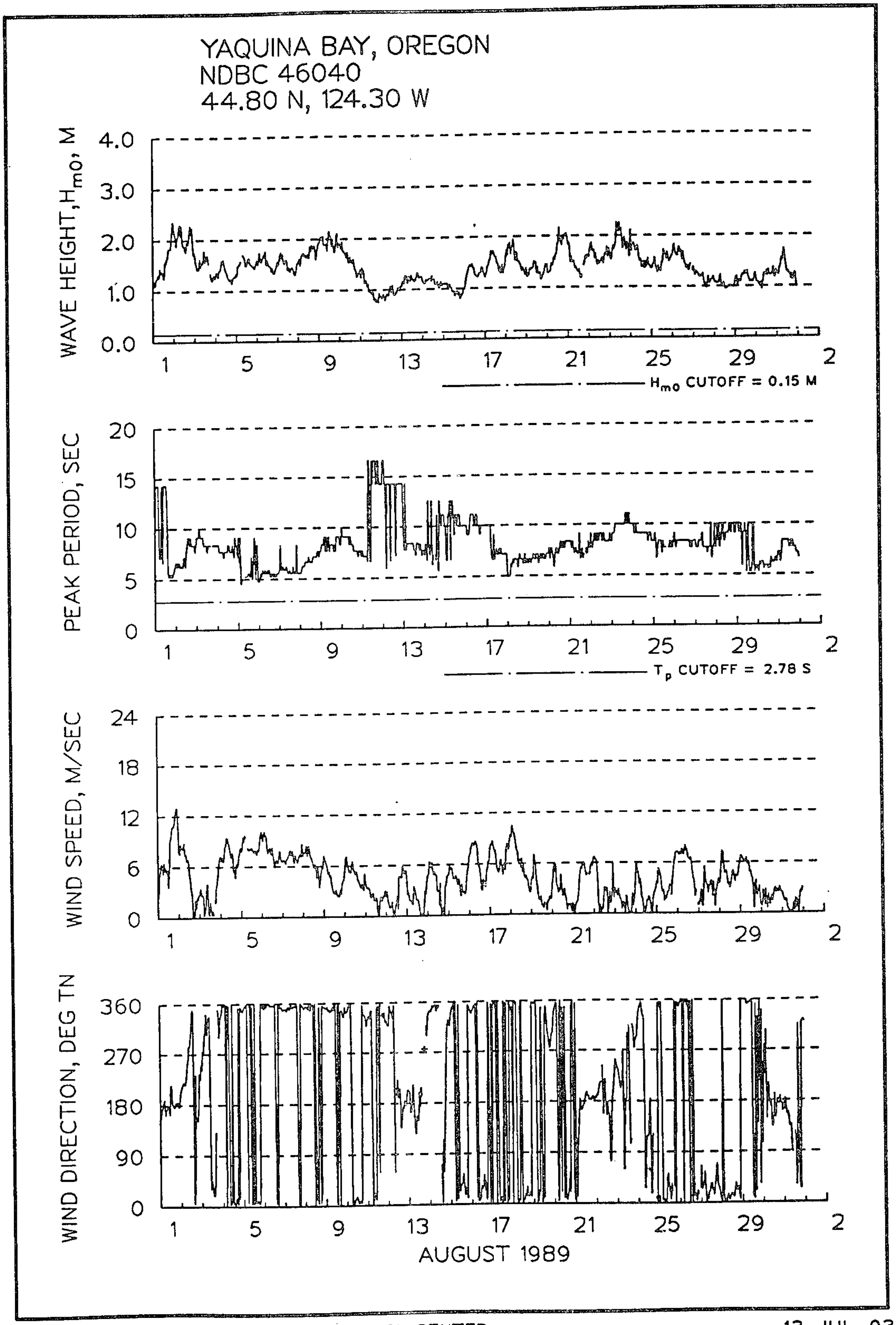
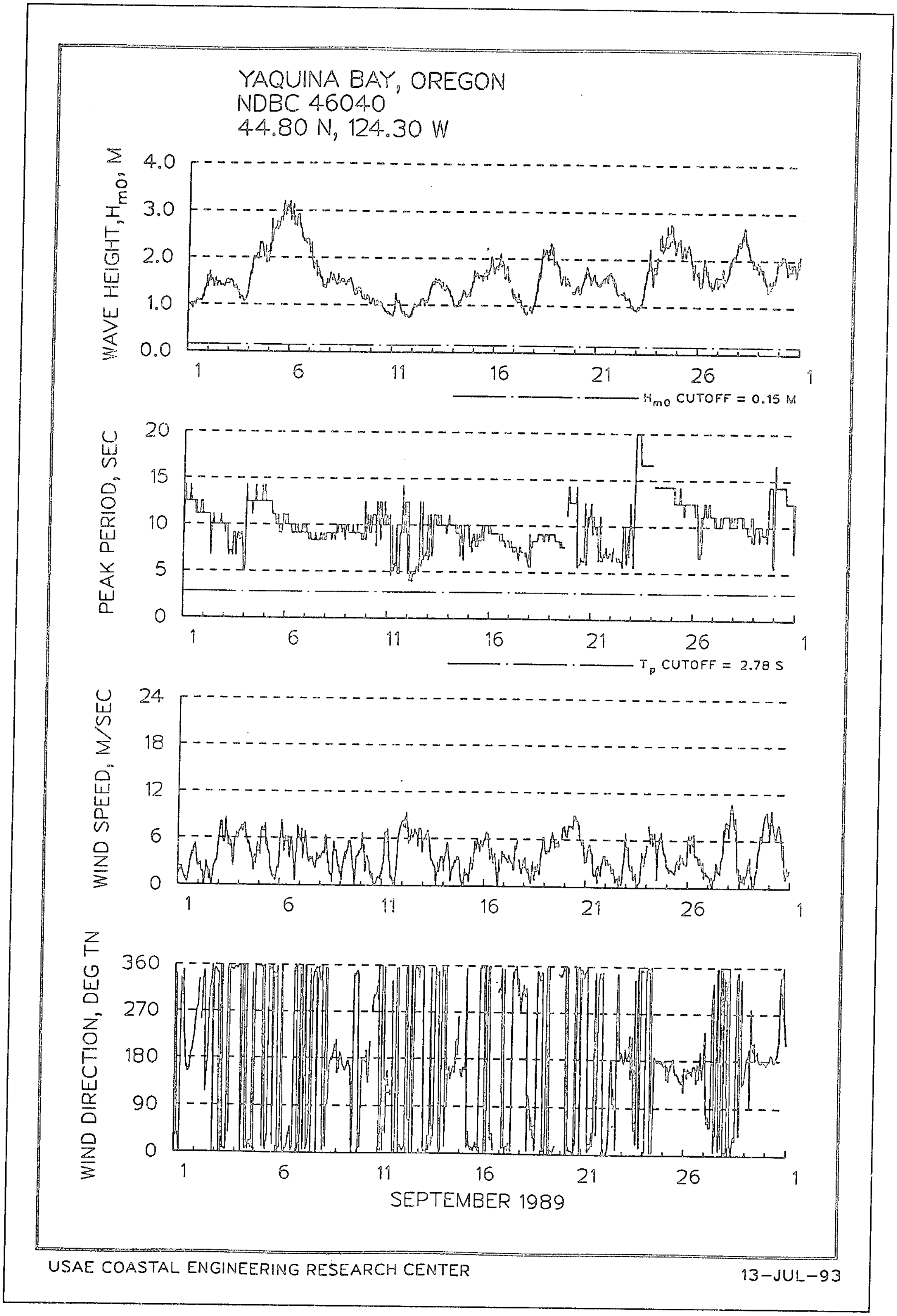
JULY 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13–JUL–93


YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
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H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
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1
WIND DIRECTION, DEG TN
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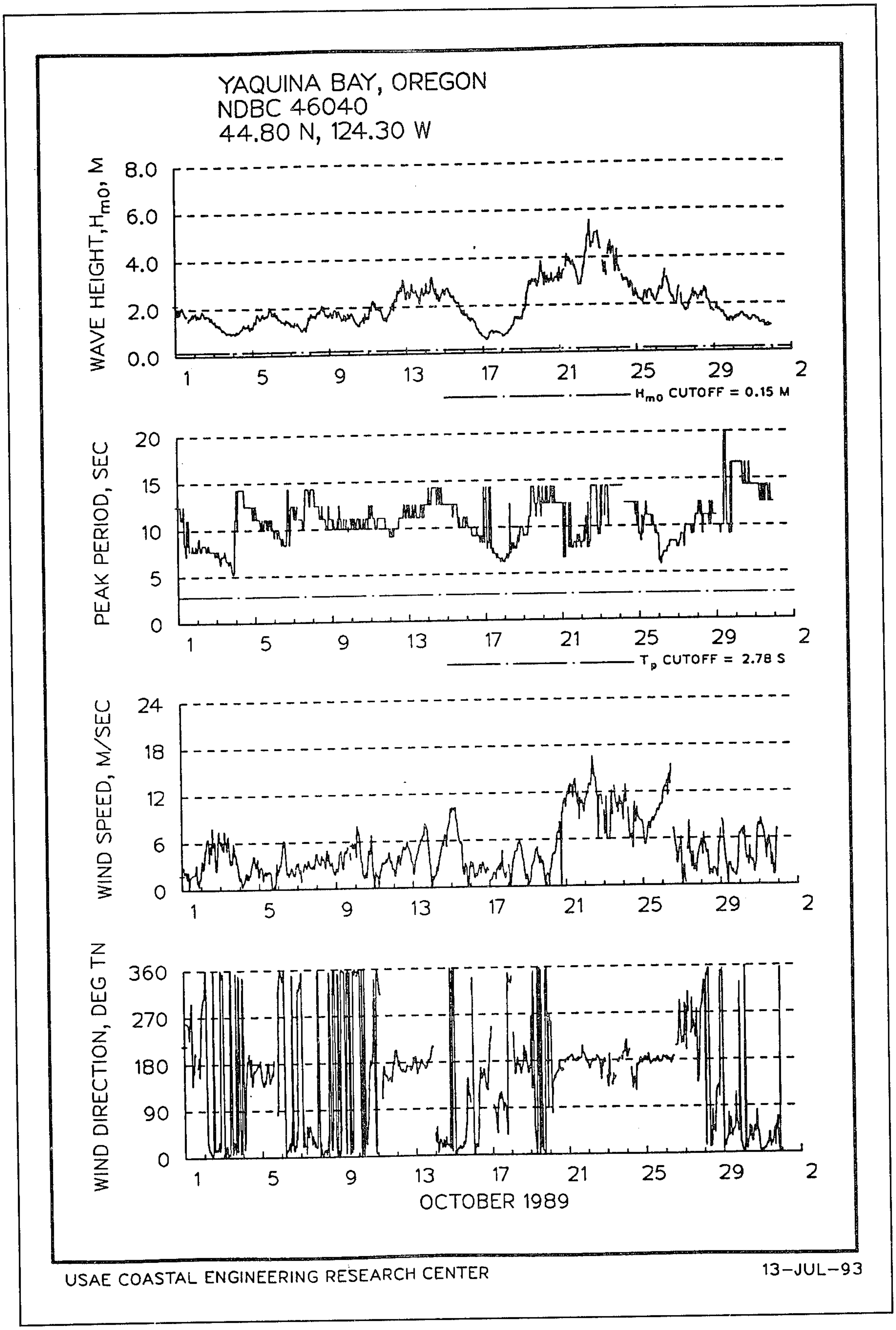
SEPTEMBER 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W
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H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
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WIND DIRECTION, DEG TN
360
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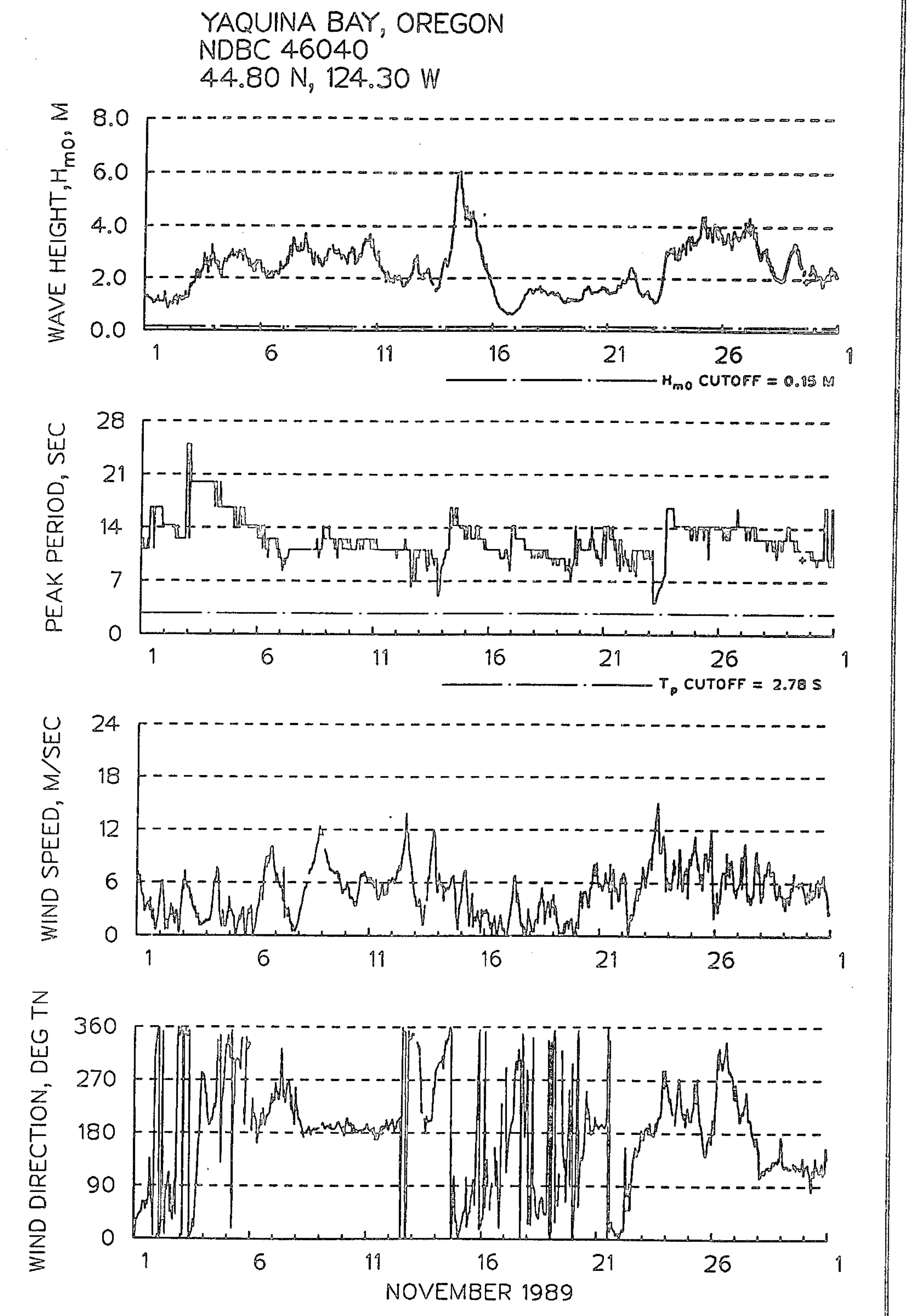
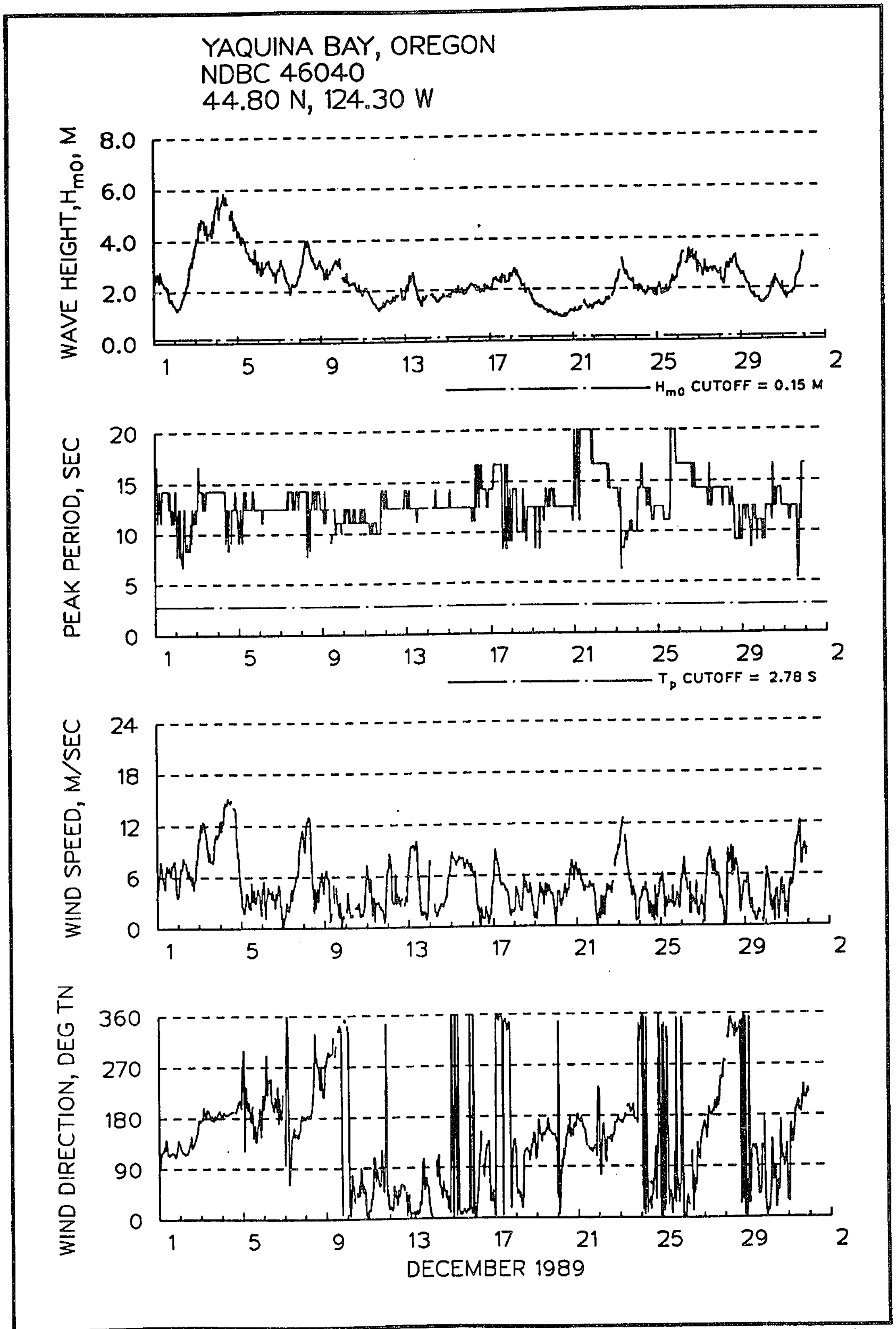
OCTOBER 1989
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93

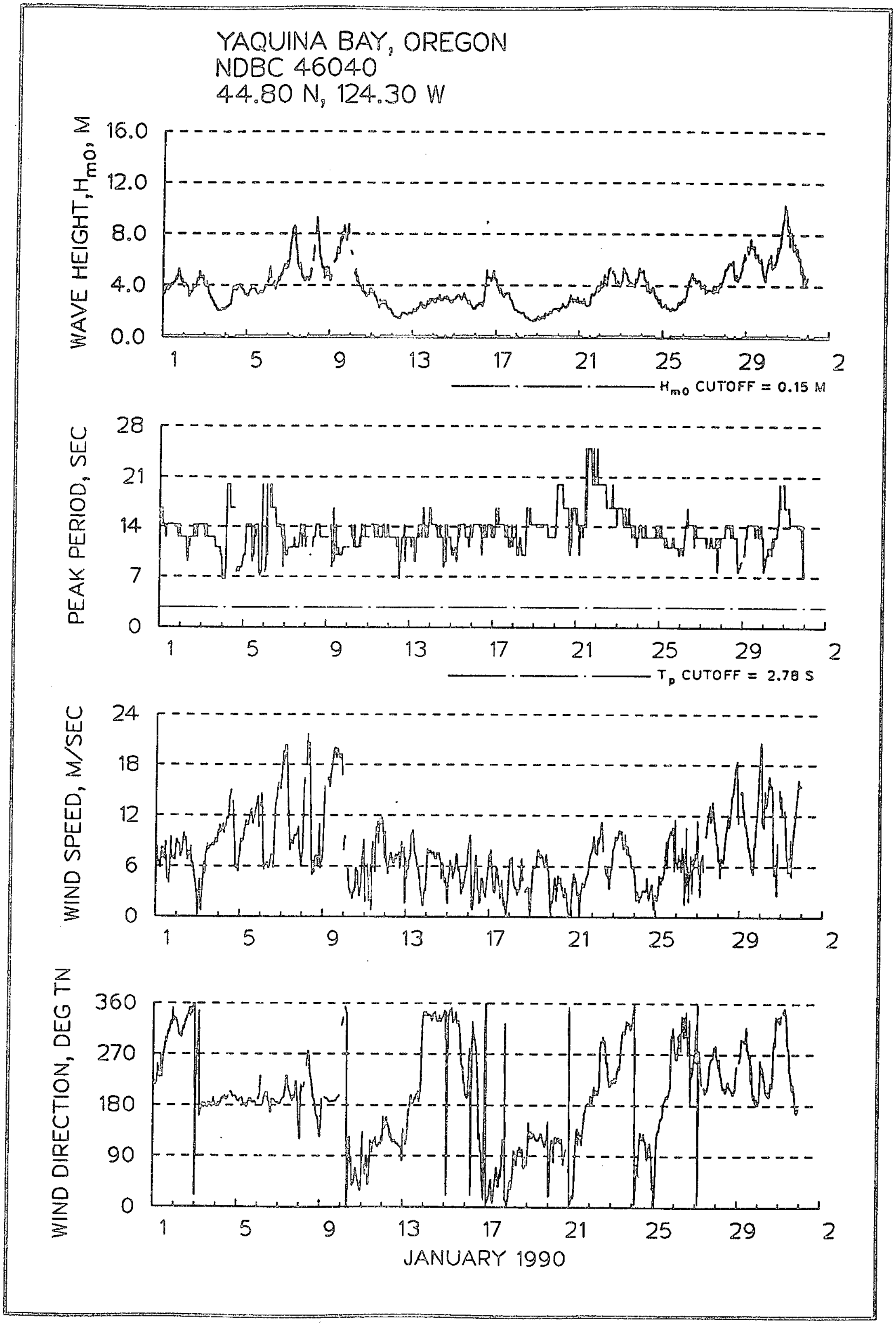

YAQUINA BAY, OREGON
NDBC 46040
44.80 N, 124.30 W

USAE COASTAL ENGINEERING RESEARCH CENTER

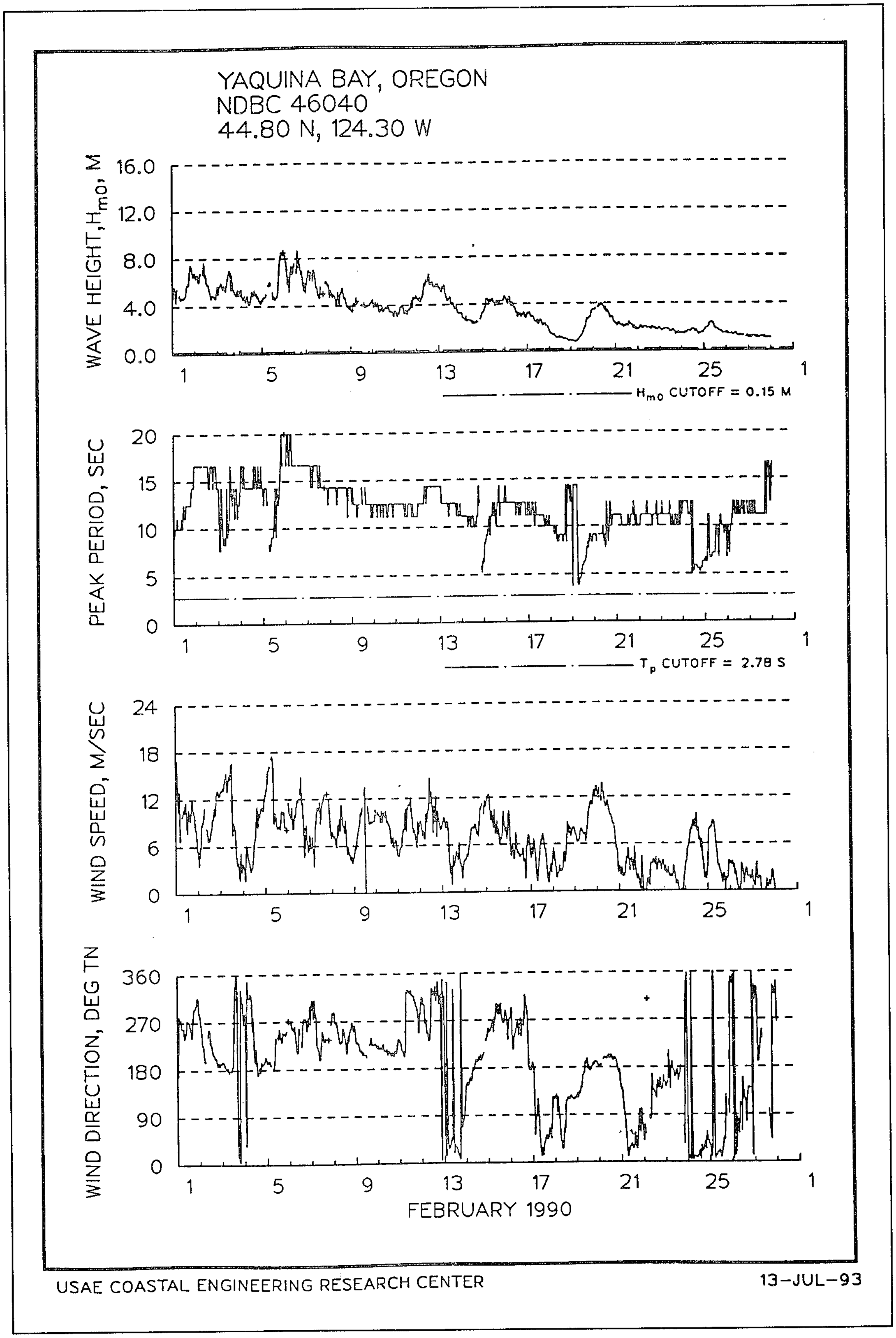
13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER 13–JUL–93


YAQUINA BAY, OREGON
NDBC 46040
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4.0
0.0
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1
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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5
0
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
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WIND DIRECTION, DEG TN
360
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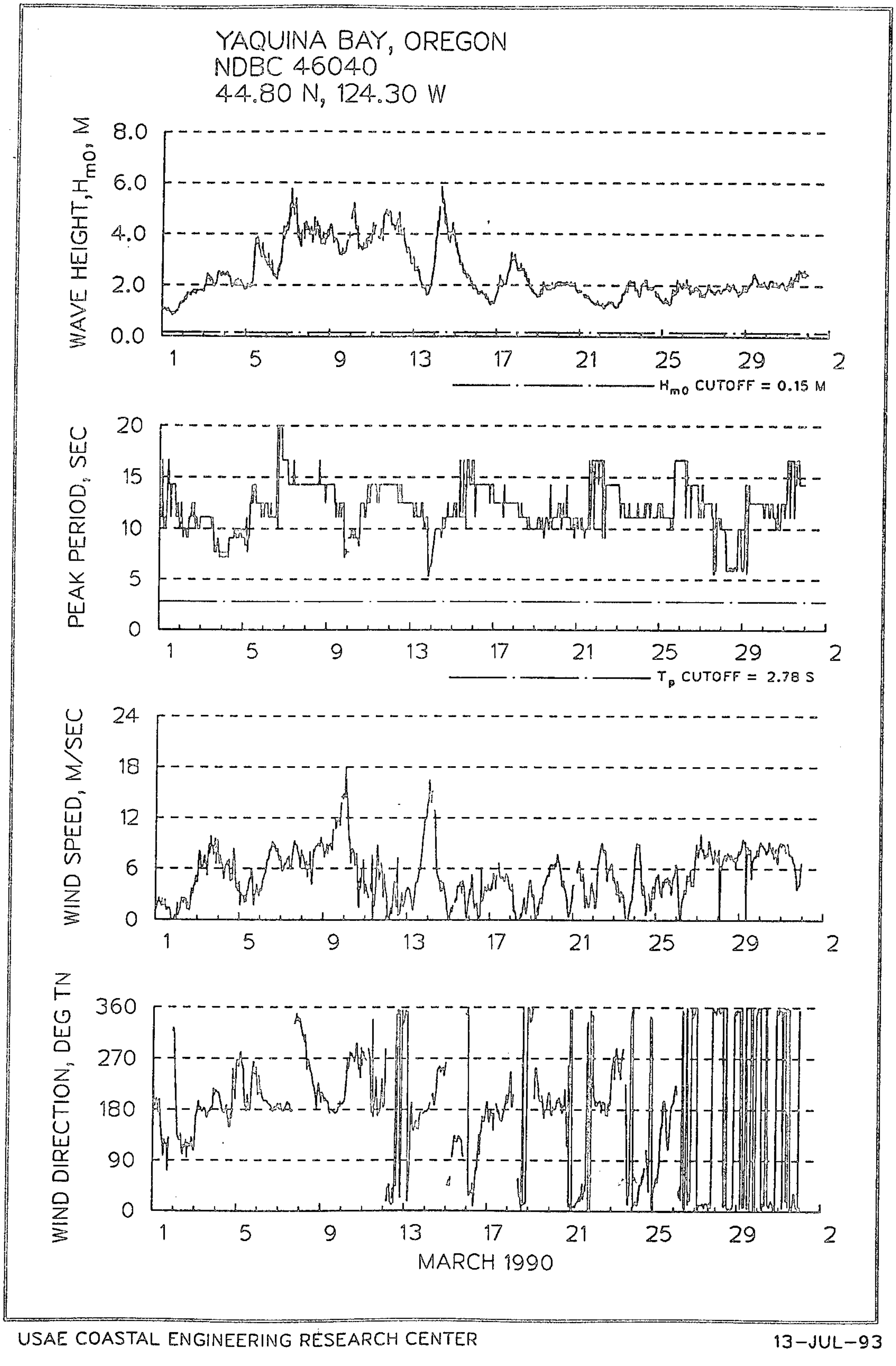
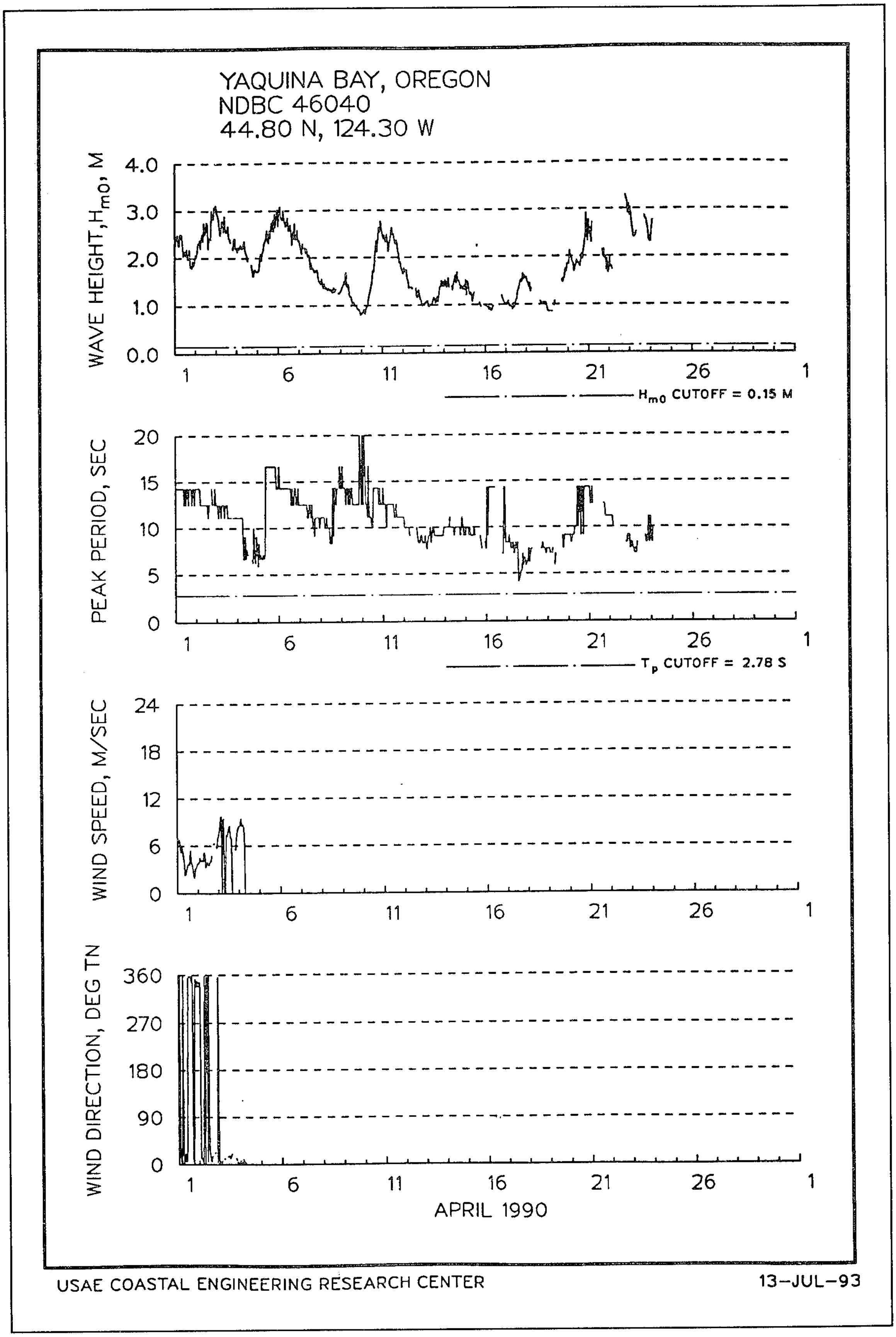
90
0
FEBRUARY 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
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PEAK PERIOD, SEC
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1
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
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1
WIND DIRECTION, DEG TN
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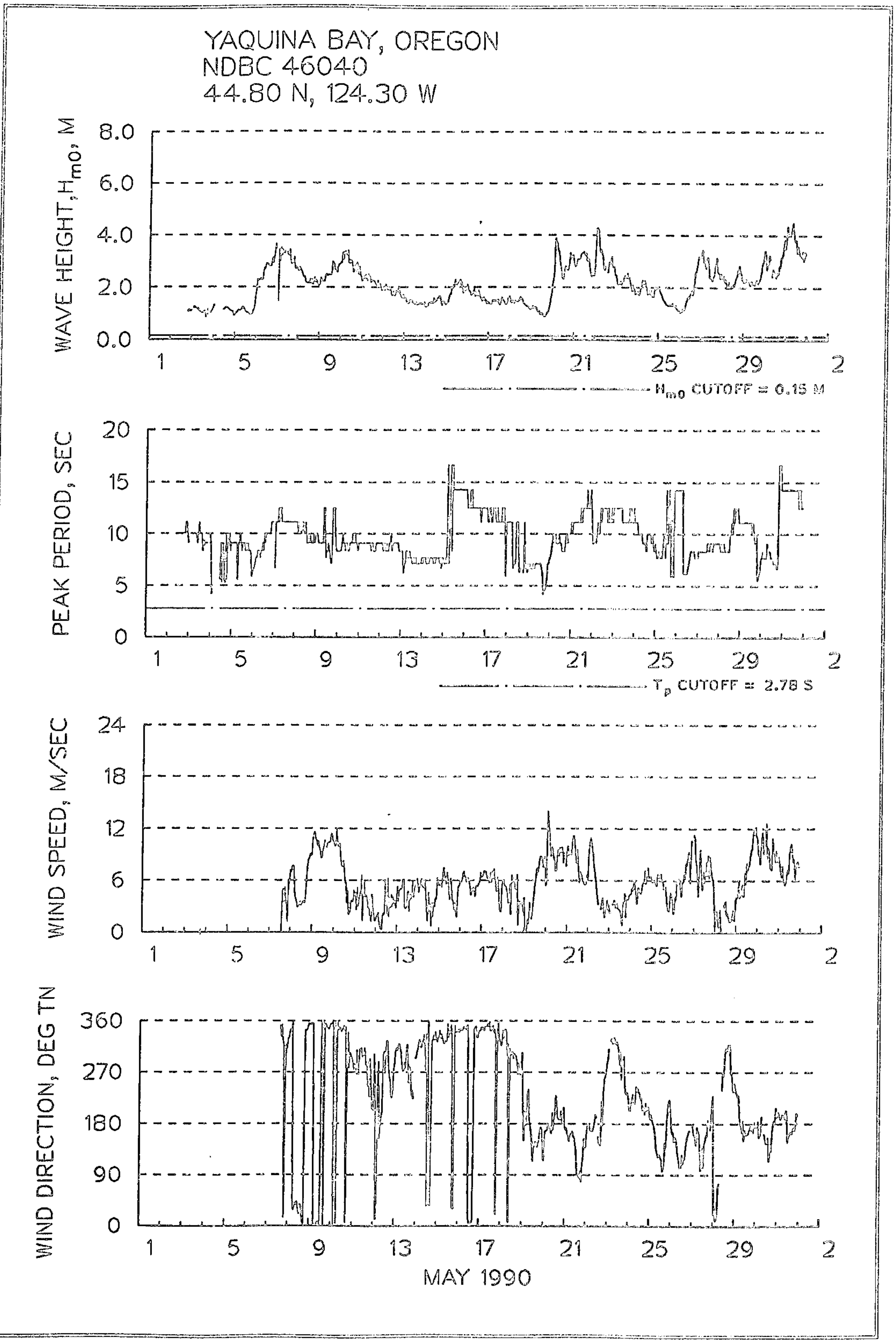
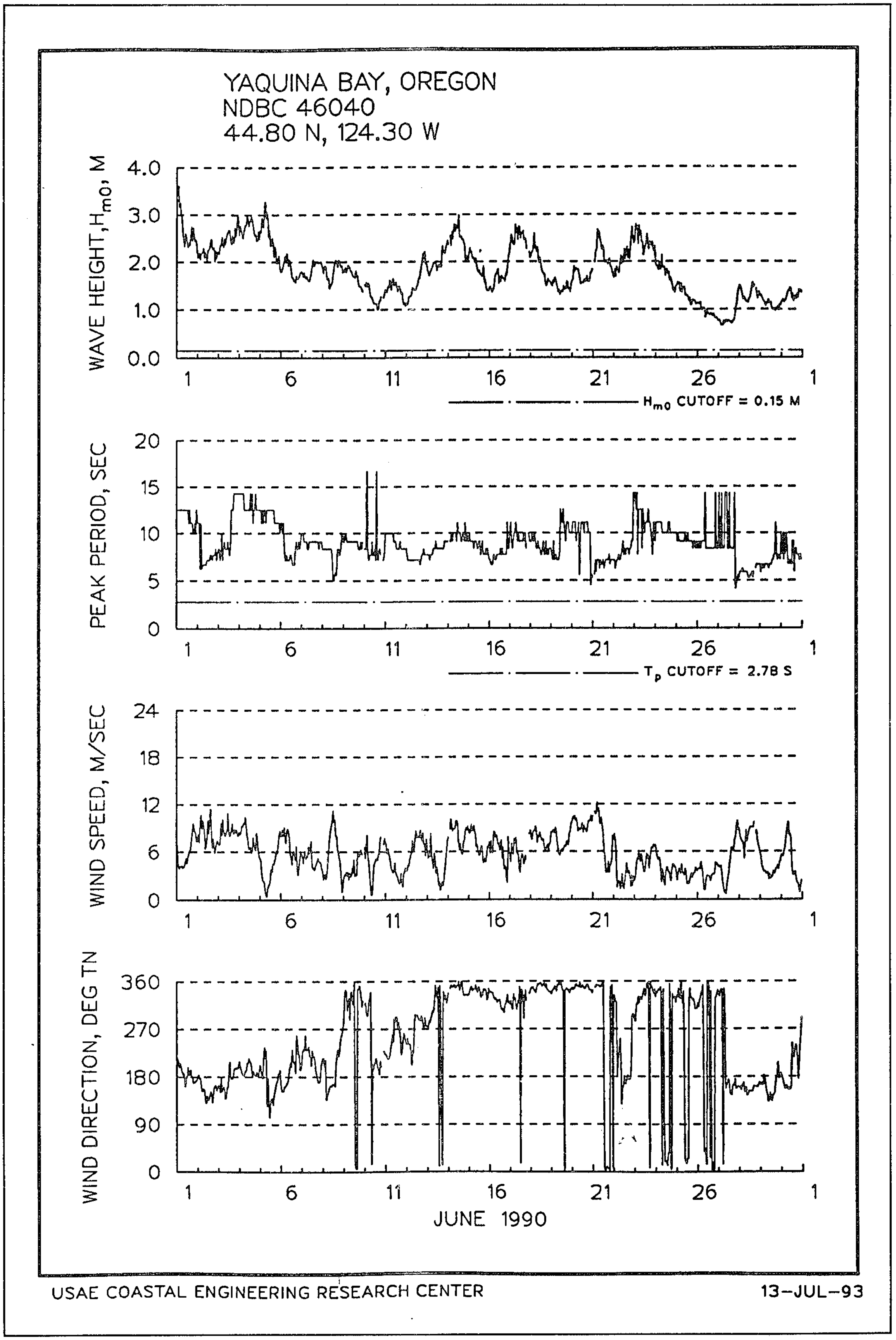
APRIL 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
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WAVE HEIGHT, H_{m0}, M
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1
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11
16
21
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1
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
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10
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6
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16
21
26
1
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
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16
21
26
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WIND DIRECTION, DEG TN
360
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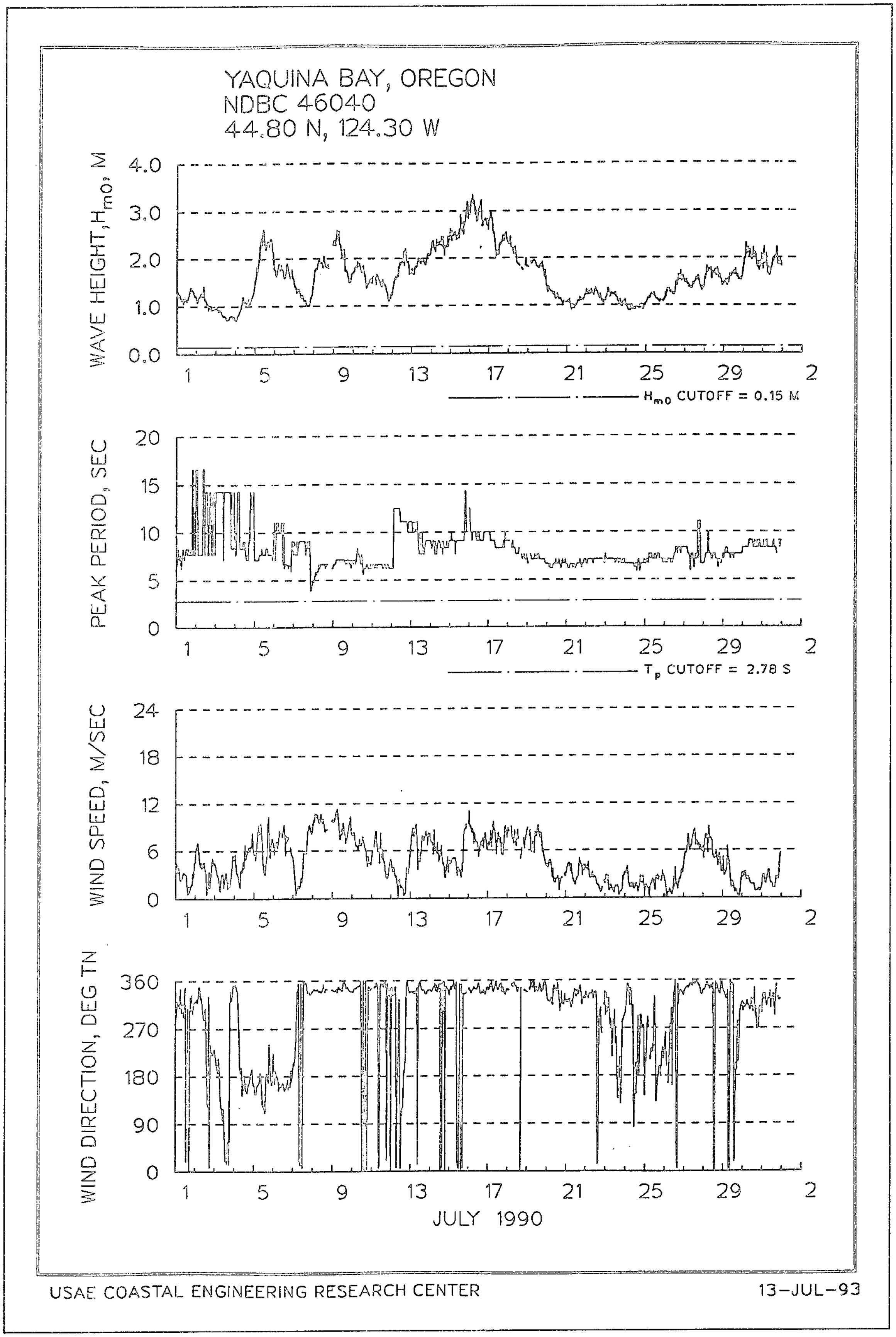
JUNE 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
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1.0
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9
13
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2
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
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2
WIND DIRECTION, DEG TN
360
270
180
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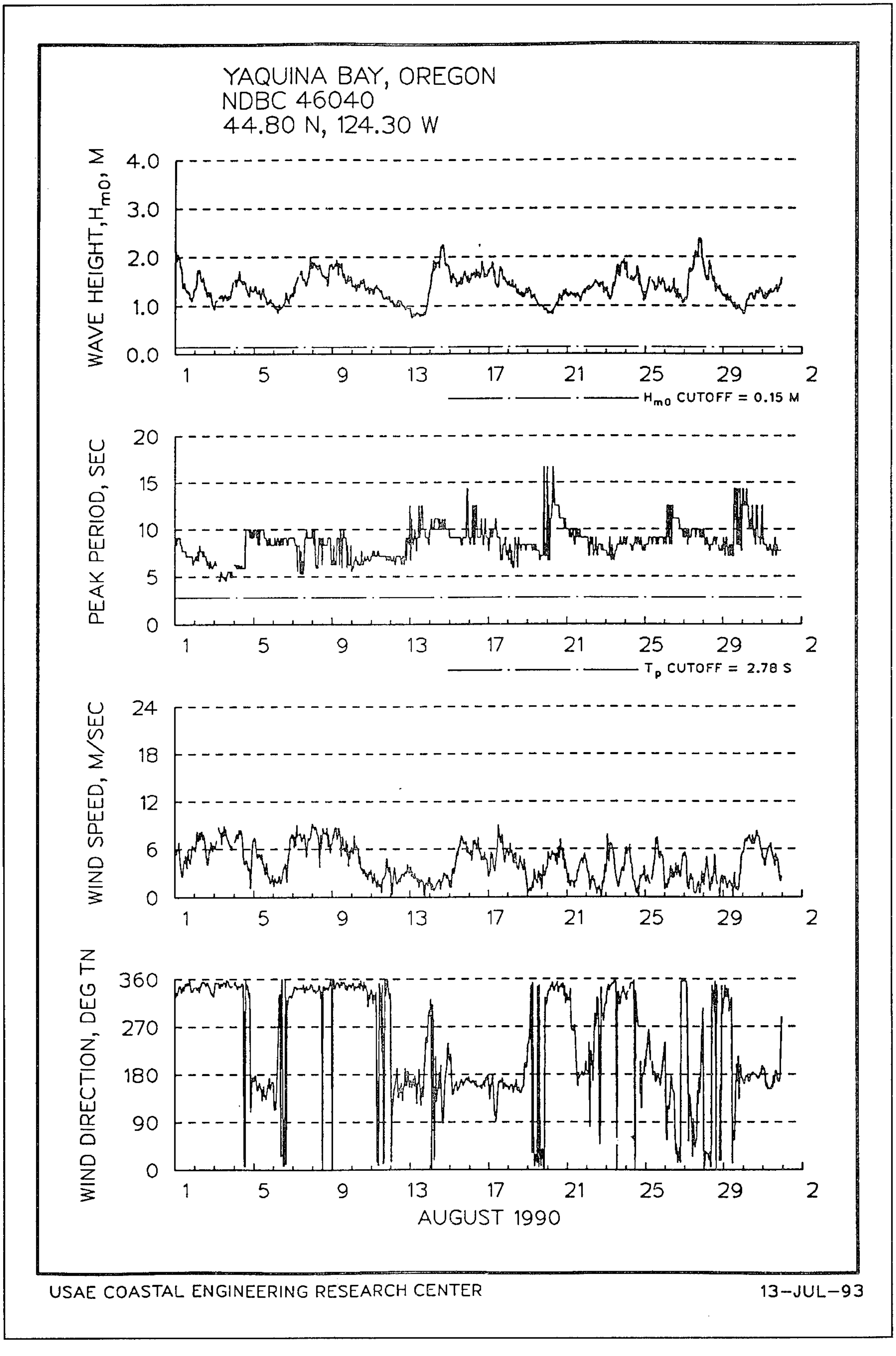
JULY 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
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2
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
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9
13
17
21
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2
WIND DIRECTION, DEG TN
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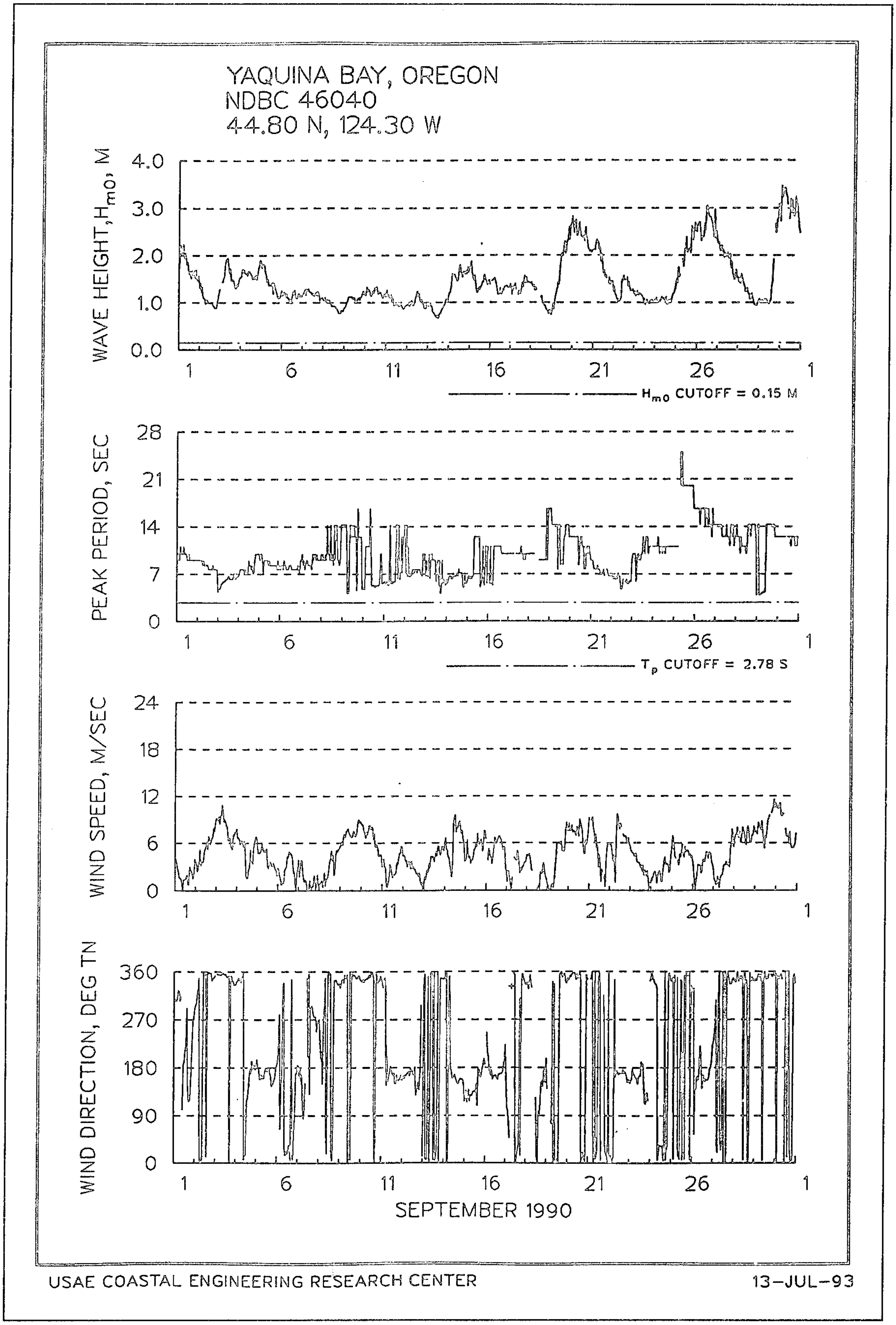
AUGUST 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
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1
6
11
16
21
26
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H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
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T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
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WIND DIRECTION, DEG TN
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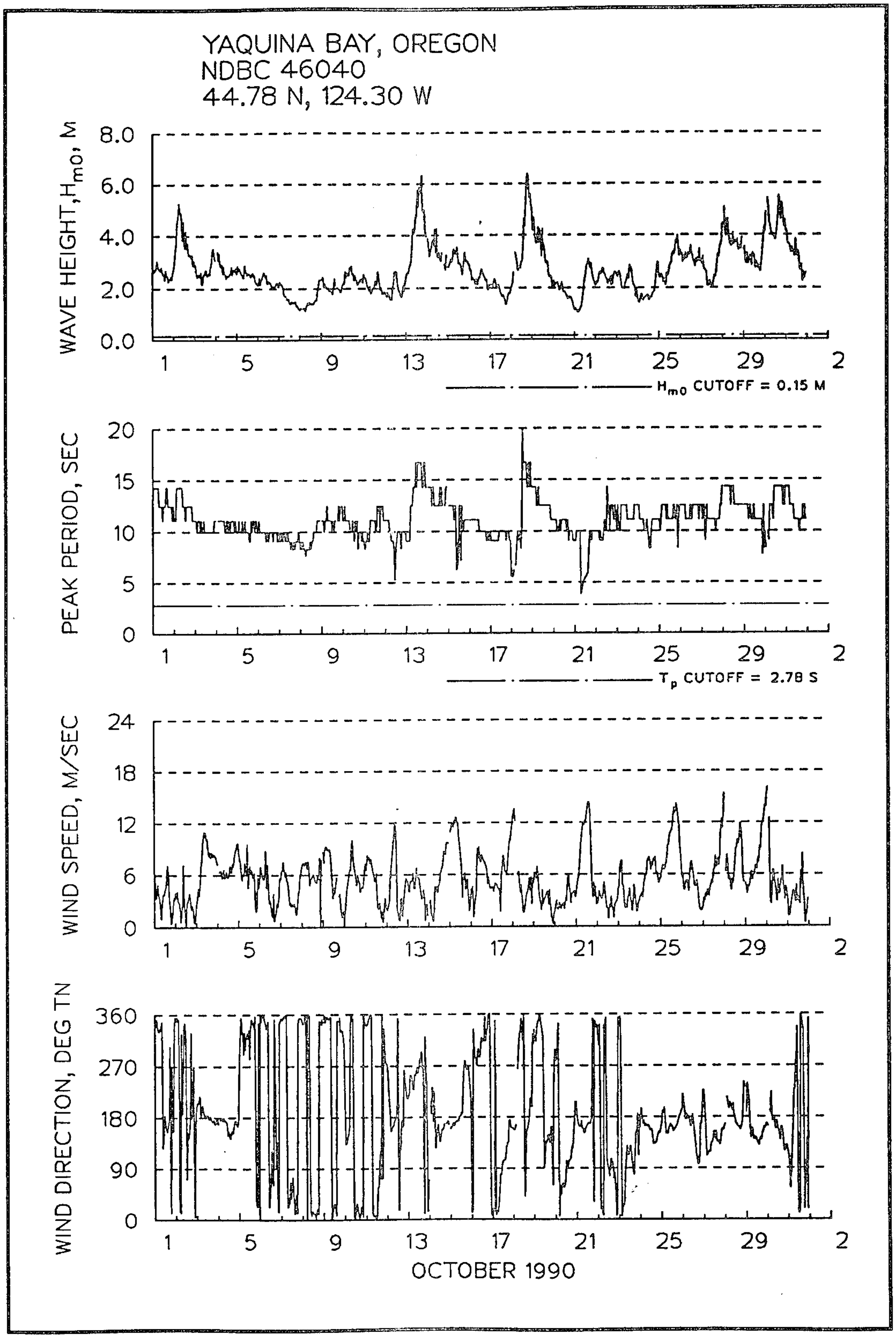
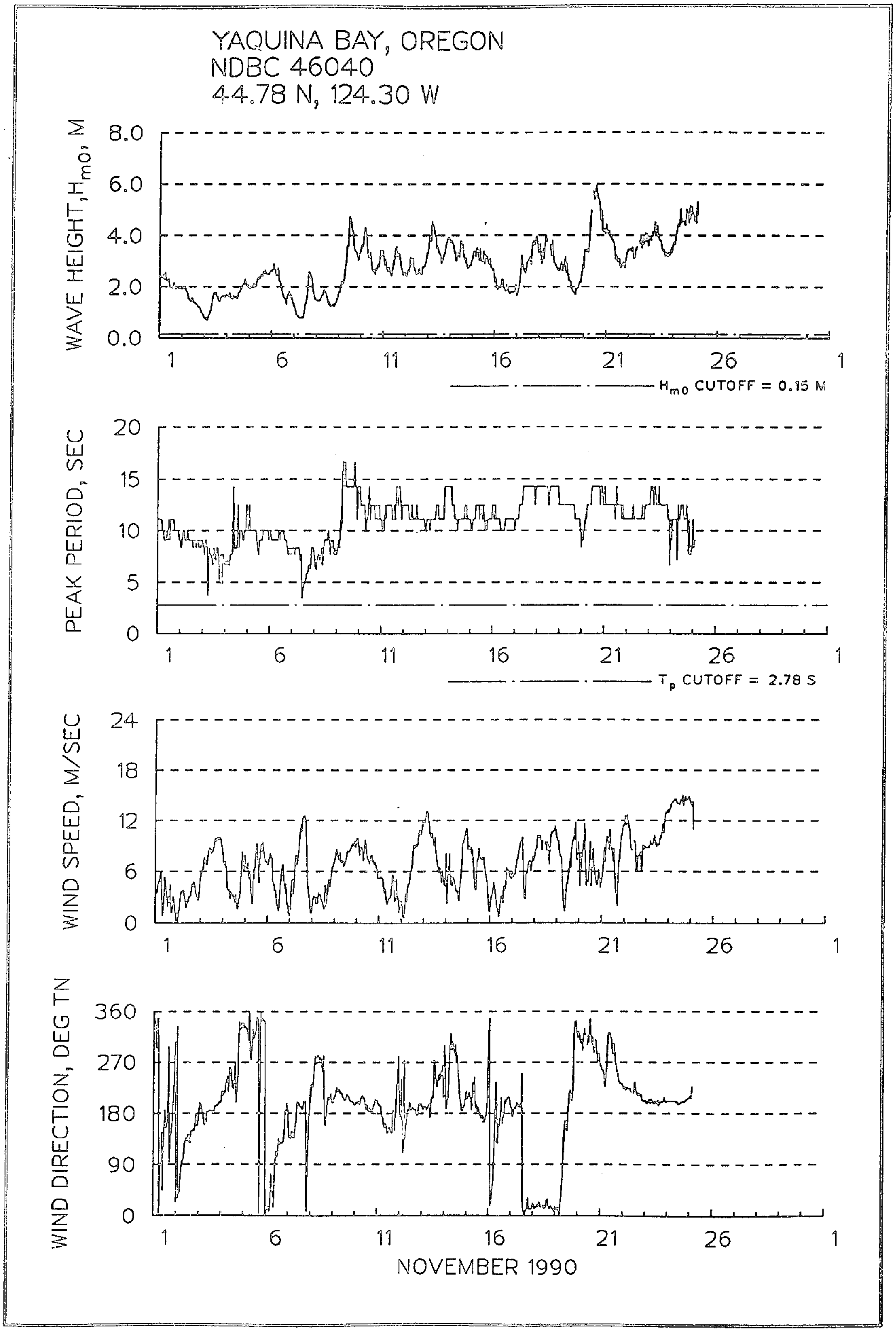
SEPTEMBER 1990
USAE COASTAL ENGINEERING RESEARCH CENTER
13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 13–JUL–93

YAQUINA BAY,OREGON
NDBC 46040
44.78 N 124.30 W

NO DATA AVAILABLE

DECEMBER 1990

USAE COASTAL ENGINEERING RESEARCH CENTER 21–NOV–94

YAQUINA BAY,OREGON
NDBC 46040
44.78 N 124.30 W

NO DATA AVAILABLE

JANUARY 1991

USAE COASTAL ENGINEERING RESEARCH CENTER

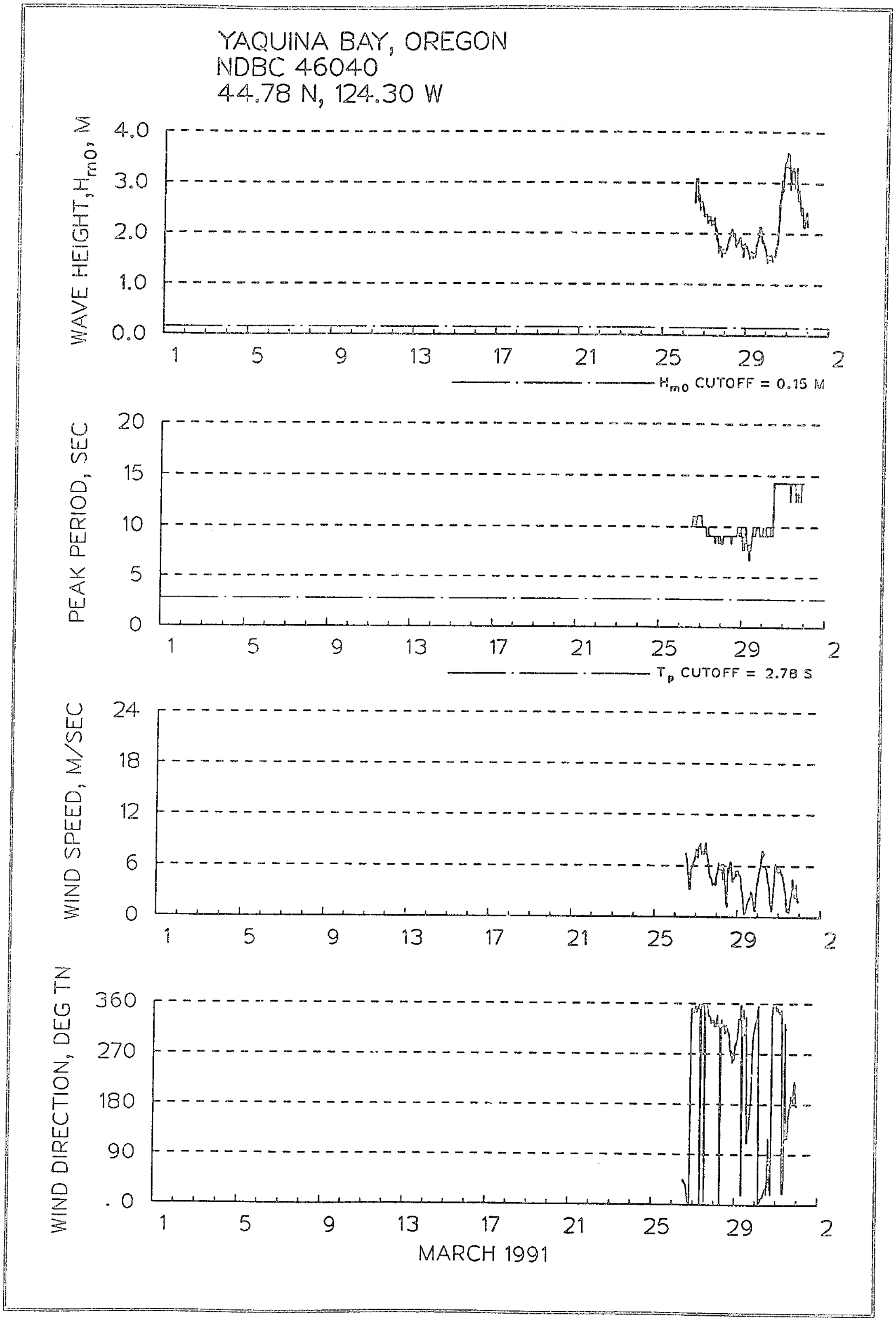
21-NOV-94

YAQUINA BAY,OREGON
NDBC 46040
44.78 N 124.30 W

NO DATA AVAILABLE

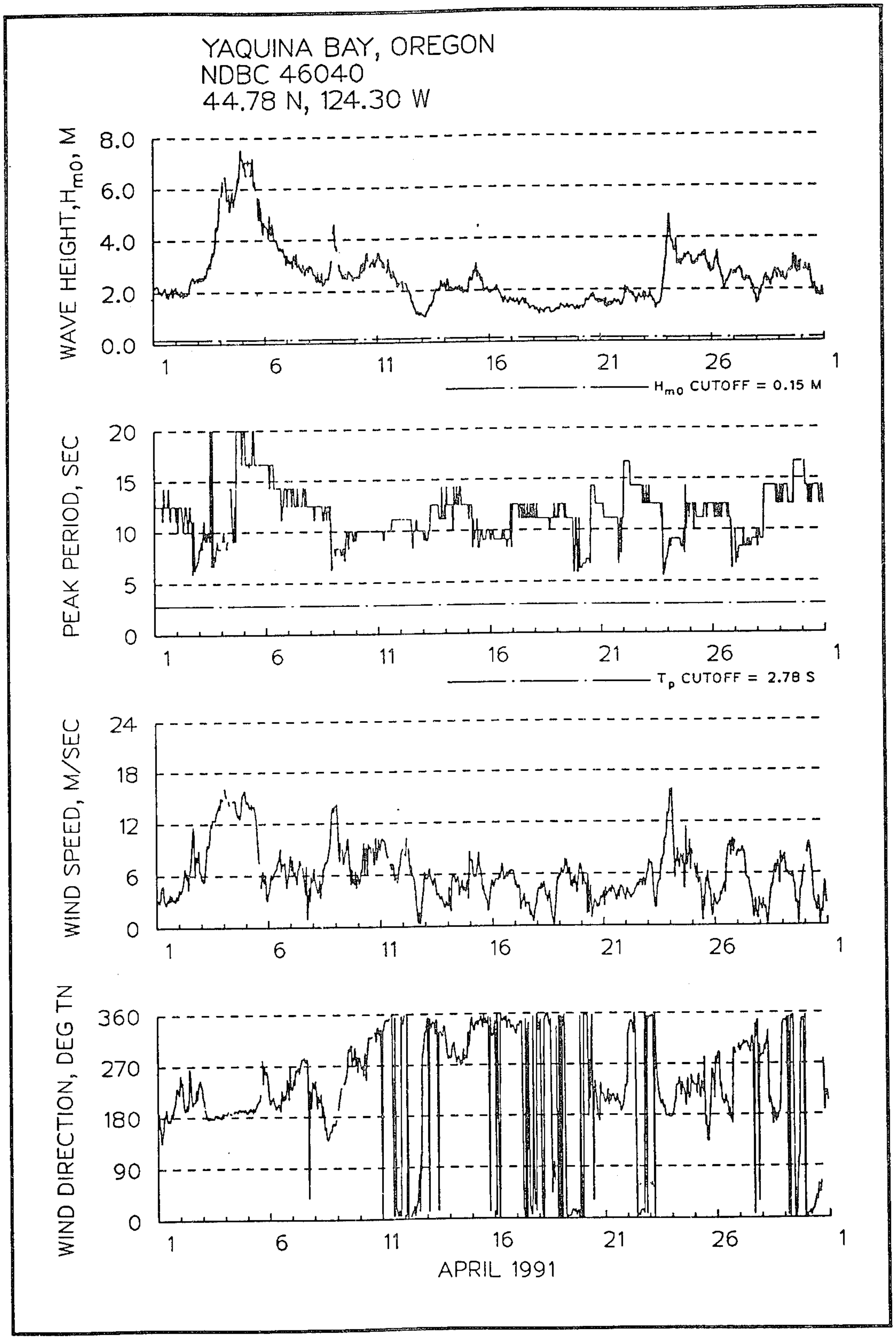
FEBRUARY 1991

USAE COASTAL ENGINEERING RESEARCH CENTER 21-NOV-94

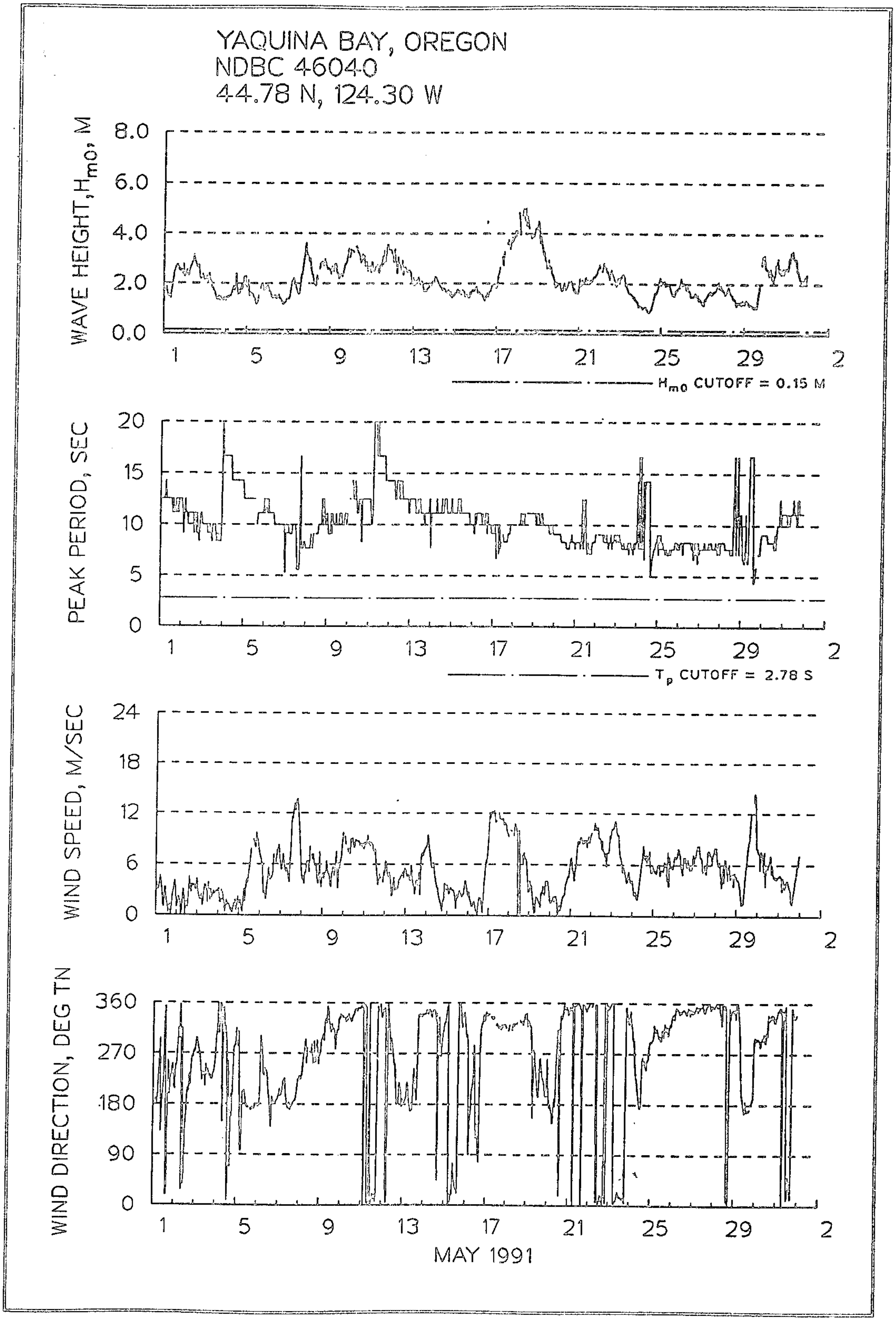


USAE COASTAL ENGINEERING RESEARCH CENTER

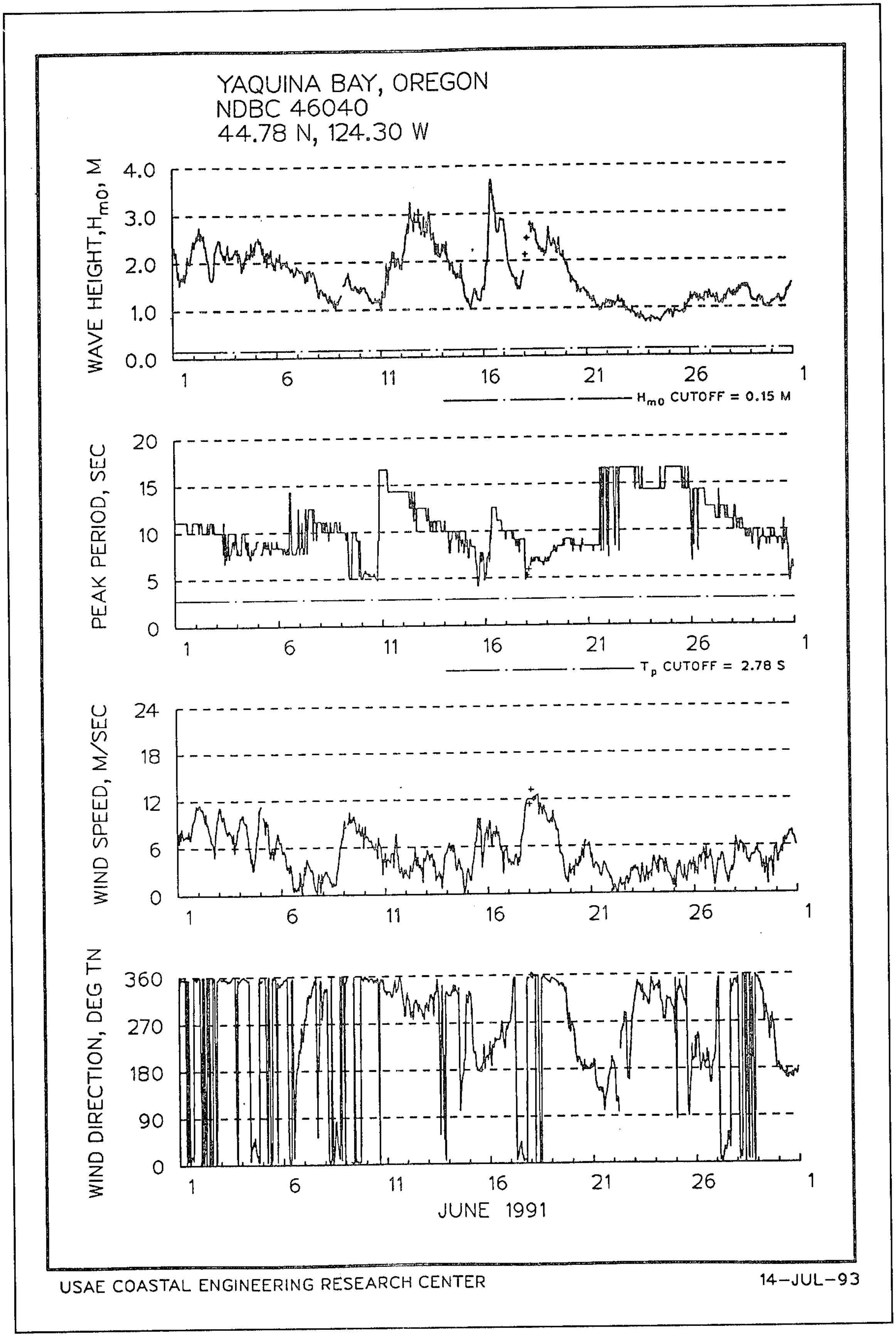
14-JUL-93

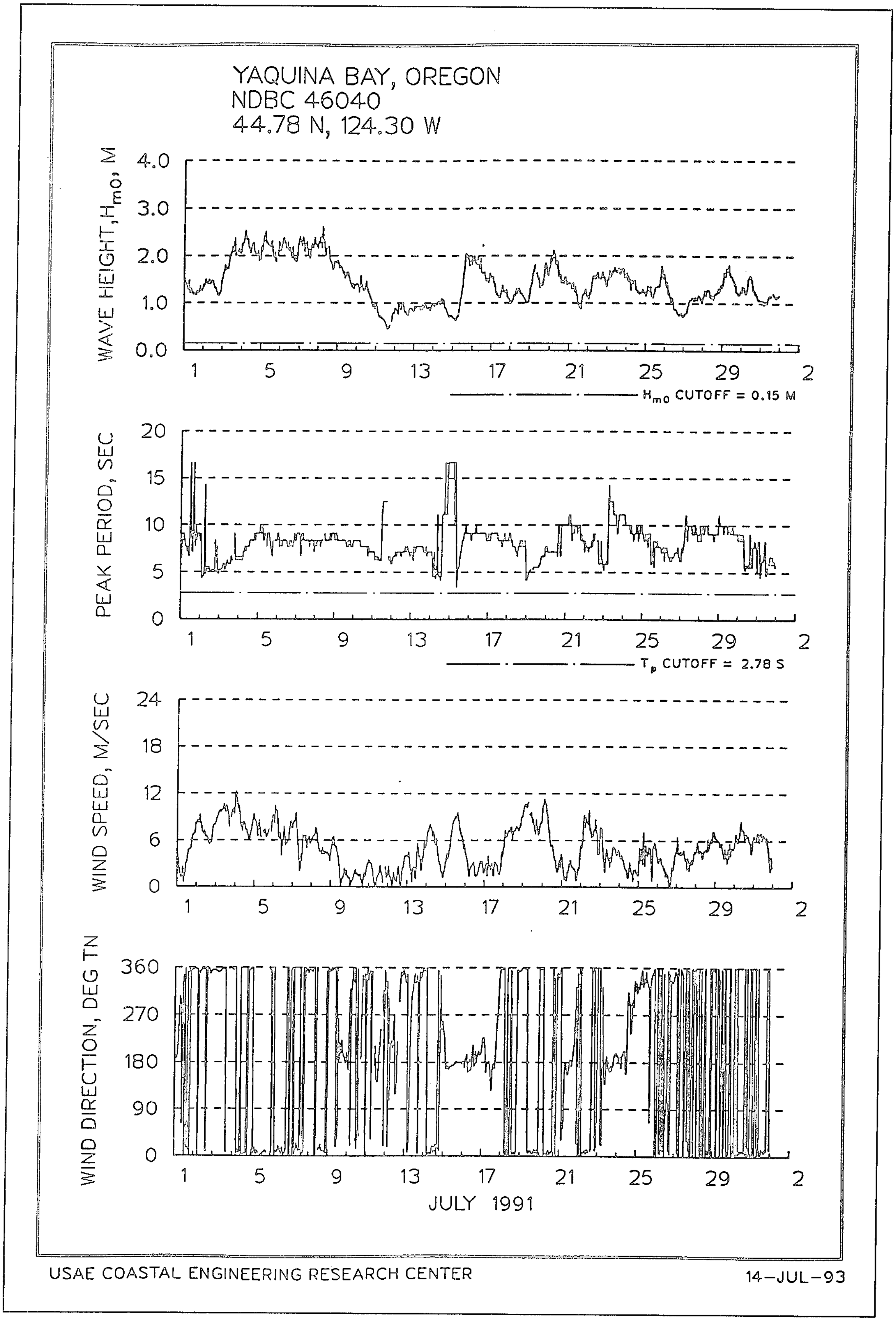


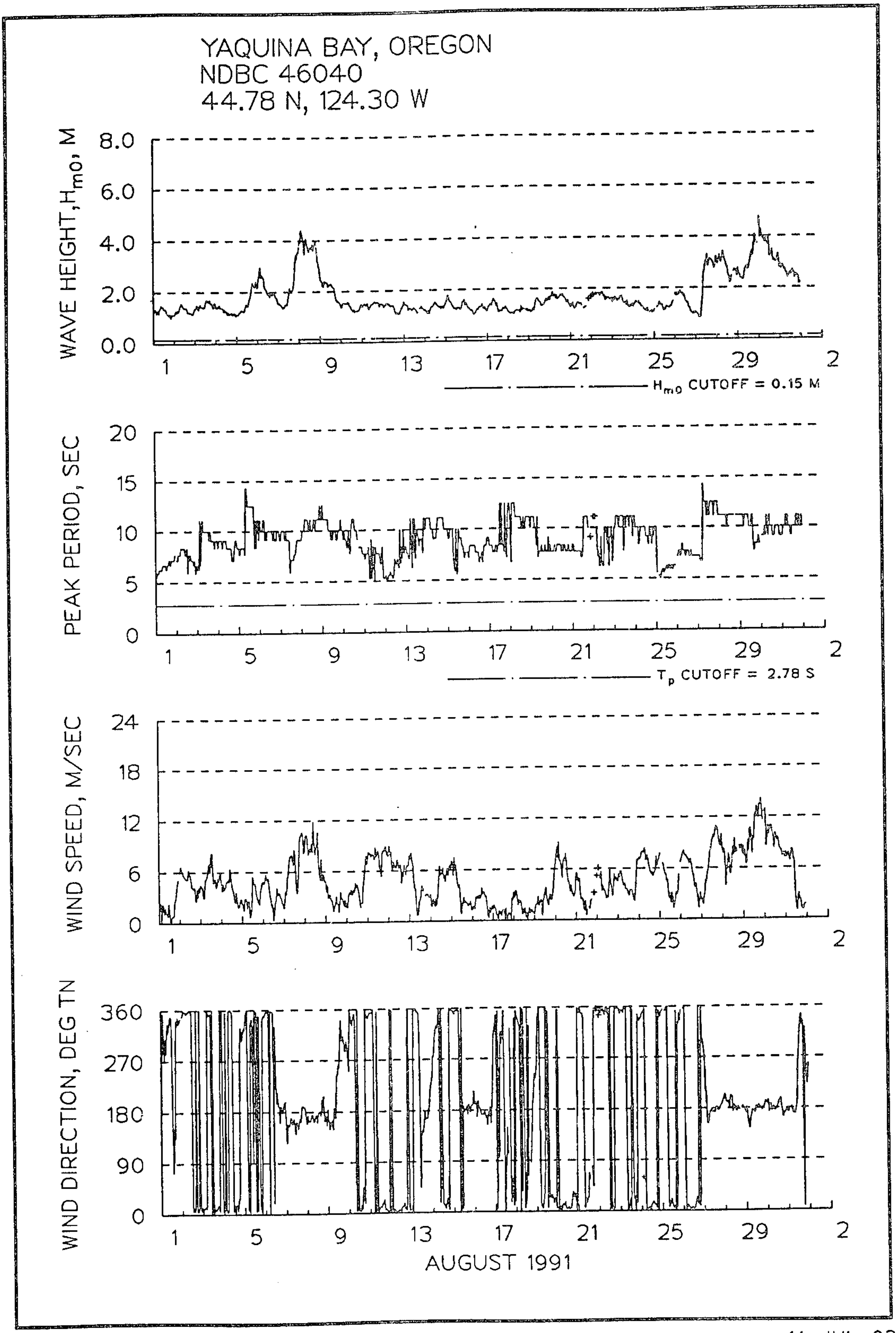
USAE COASTAL ENGINEERING RESEARCH CENTER 14-JUL-93



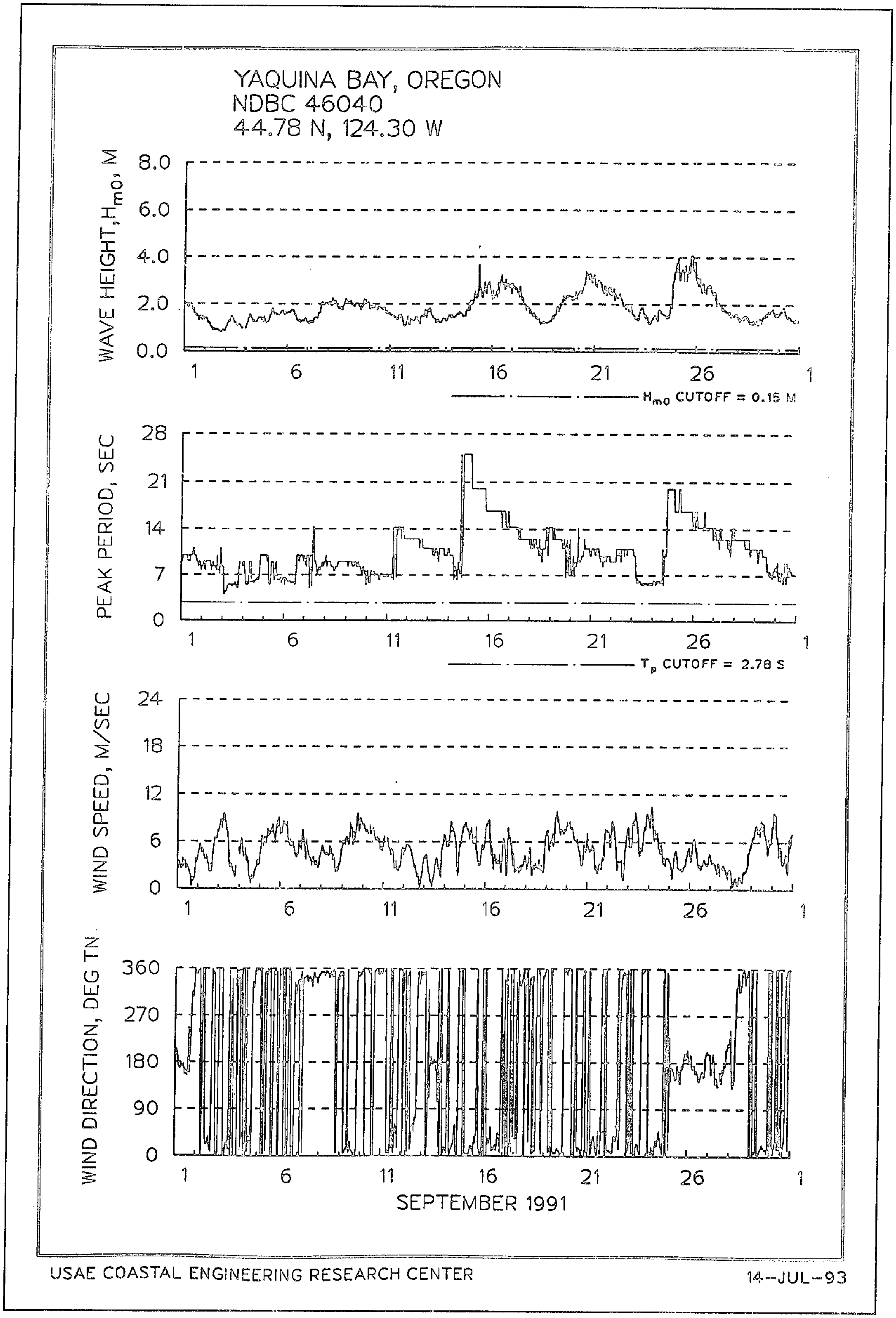
USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

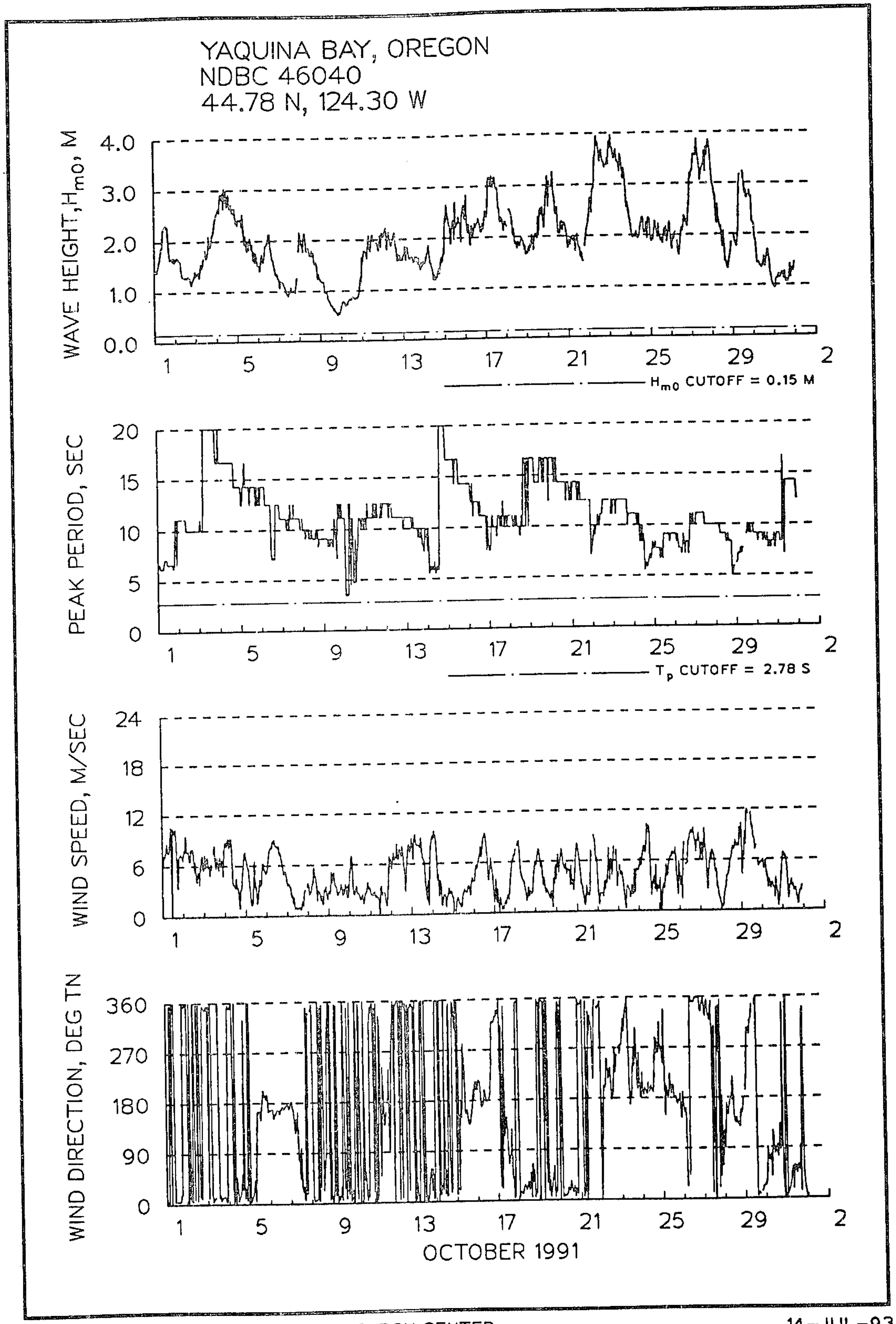

YAQUINA BAY, OREGON
NDBC 46040
44.78 N, 124.30 W
WAVE HEIGHT, H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
6
11
16
21
26
1
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
WIND DIRECTION, DEG TN
360
270
180
90
0
JUNE 1991
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93


YAQUINA BAY, OREGON
NDBC 46040
44.78 N, 124.30 W
WAVE HEIGHT, H_{mo}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
JULY 1991
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93

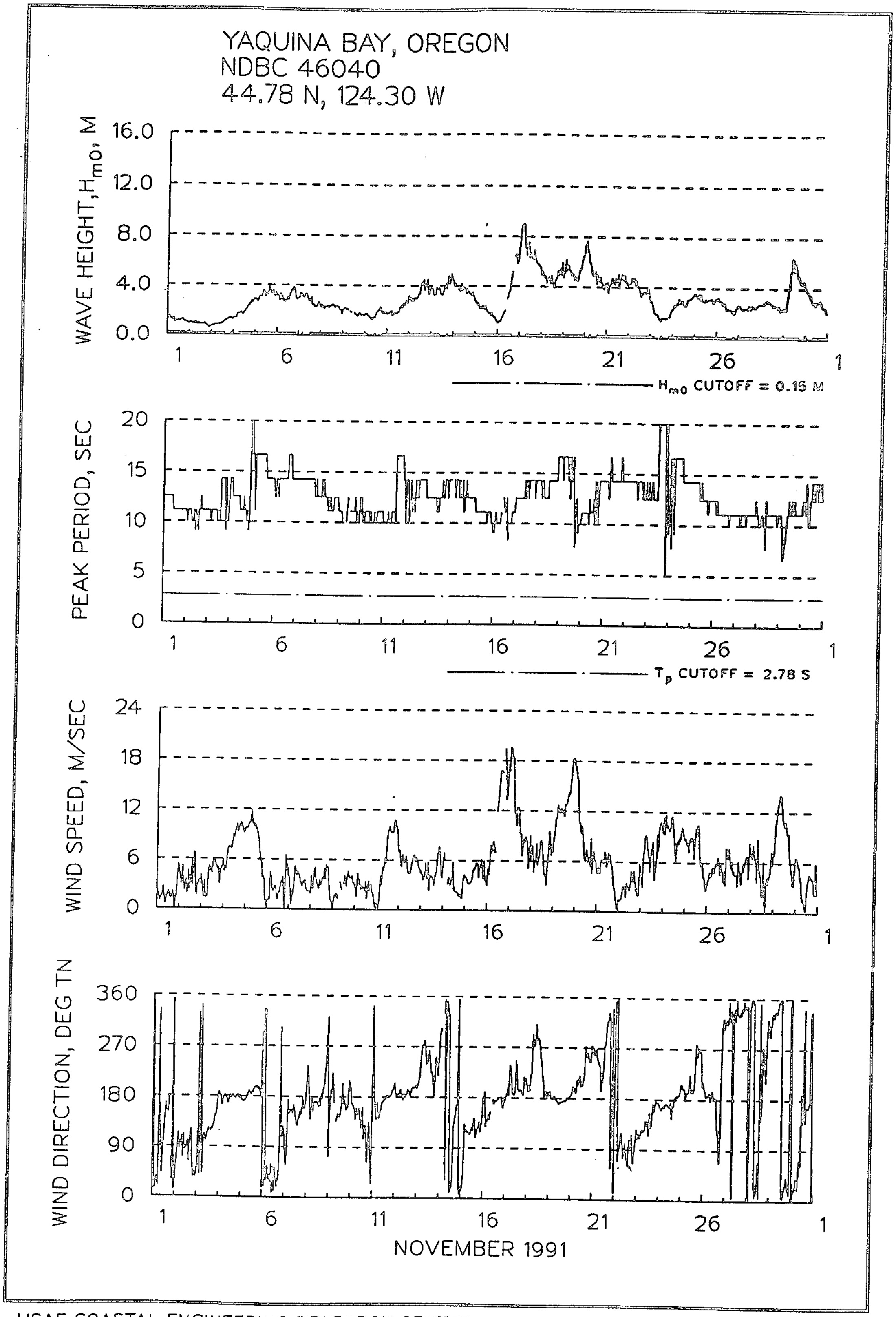


USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93


YAQUINA BAY, OREGON
NDBC 46040
44.78 N, 124.30 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.15 M
PEAK PERIOD, SEC
28
21
14
7
0
1
6
11
16
21
26
1
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
1
6
11
16
21
26
1
WIND DIRECTION, DEG TN
360
270
180
90
0
1
6
11
16
21
26
1
SEPTEMBER 1991
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93

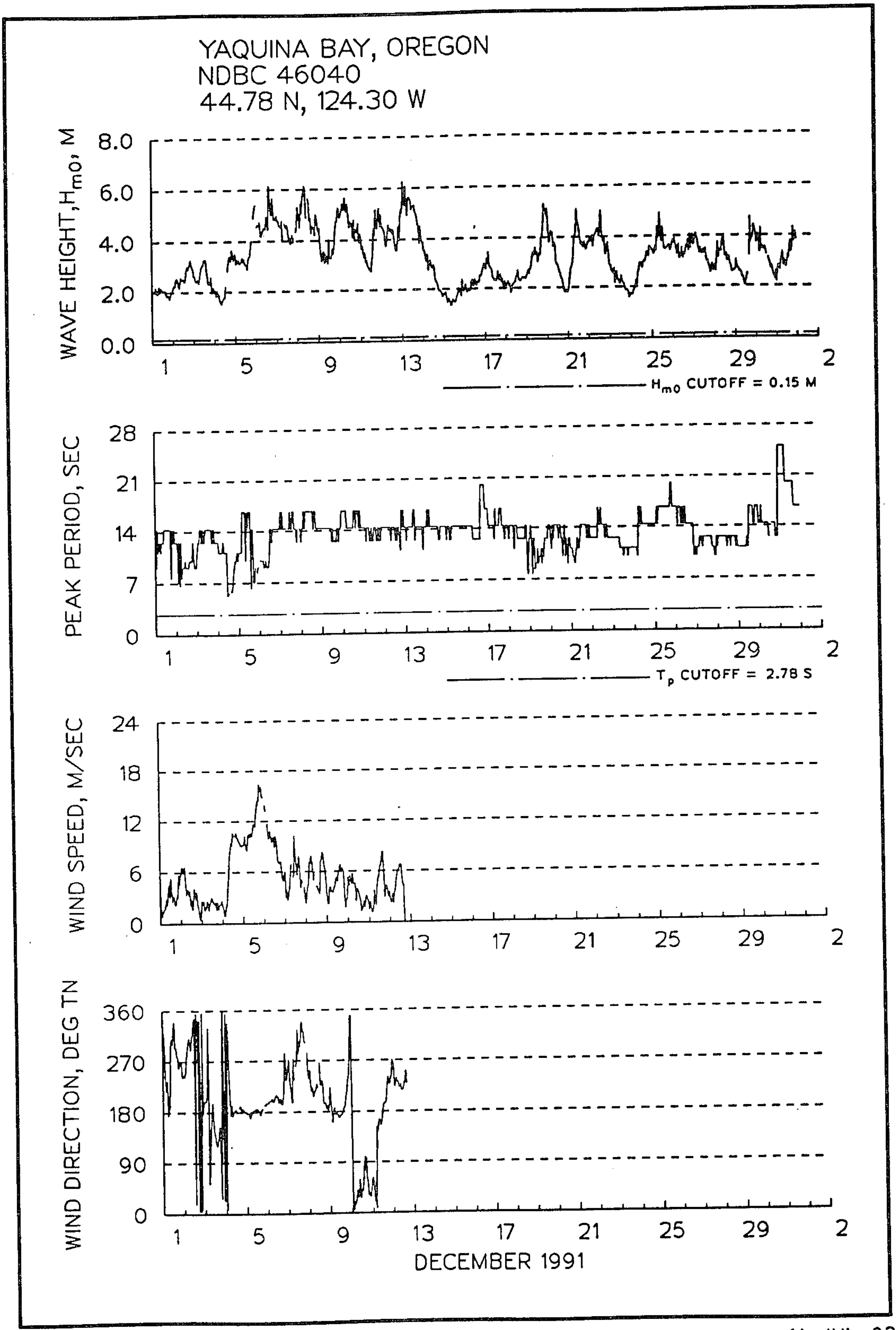


USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER

14–JUL–93



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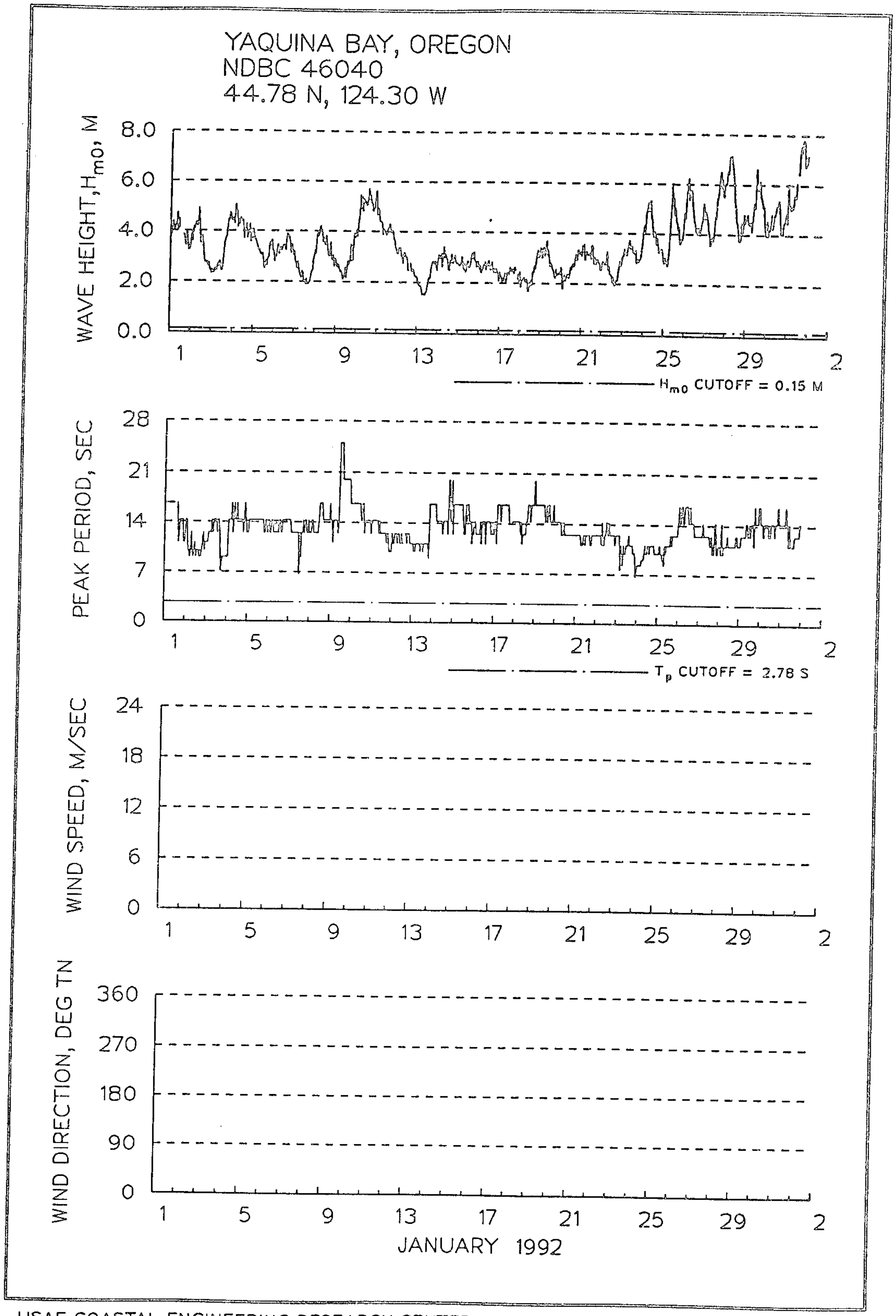
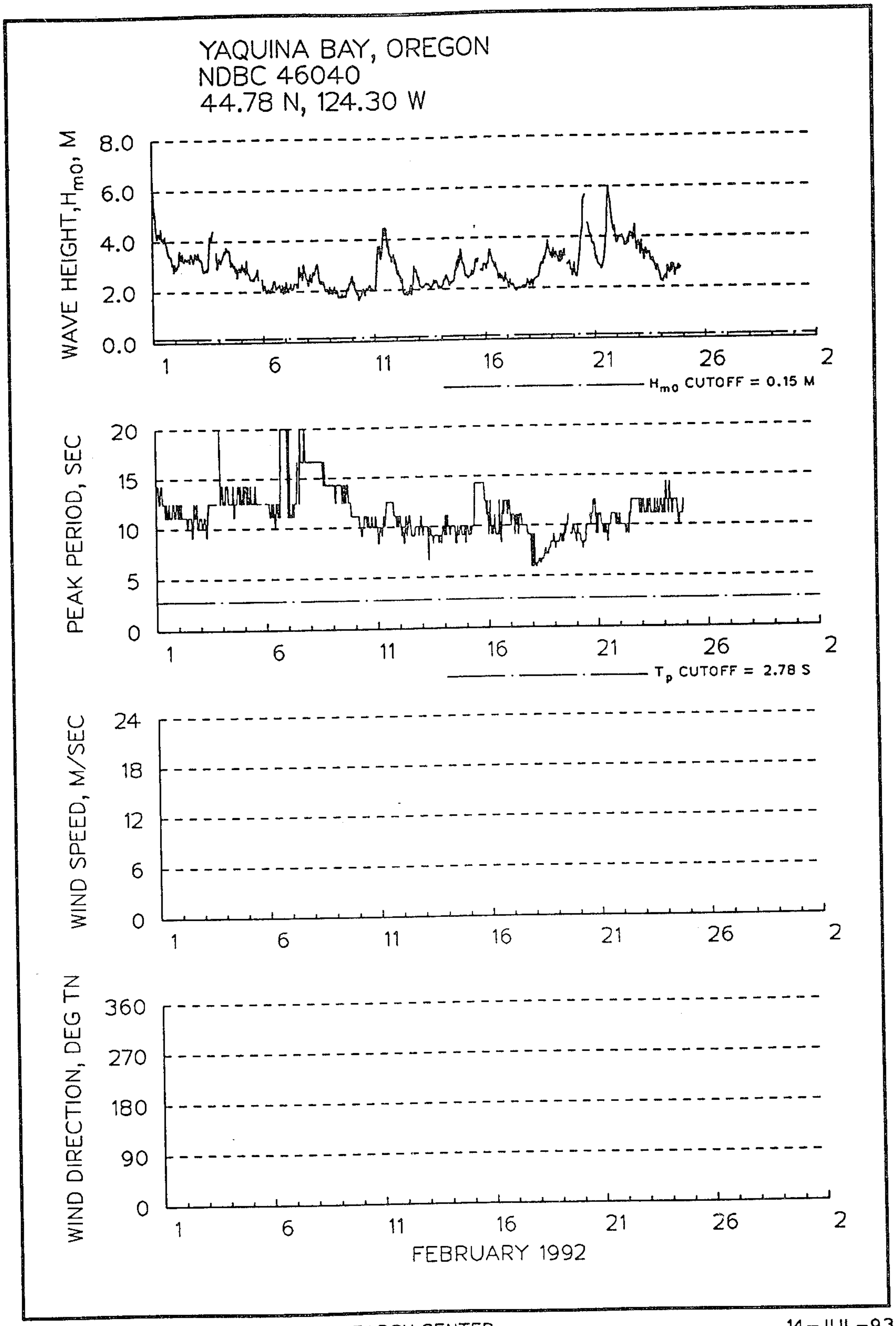
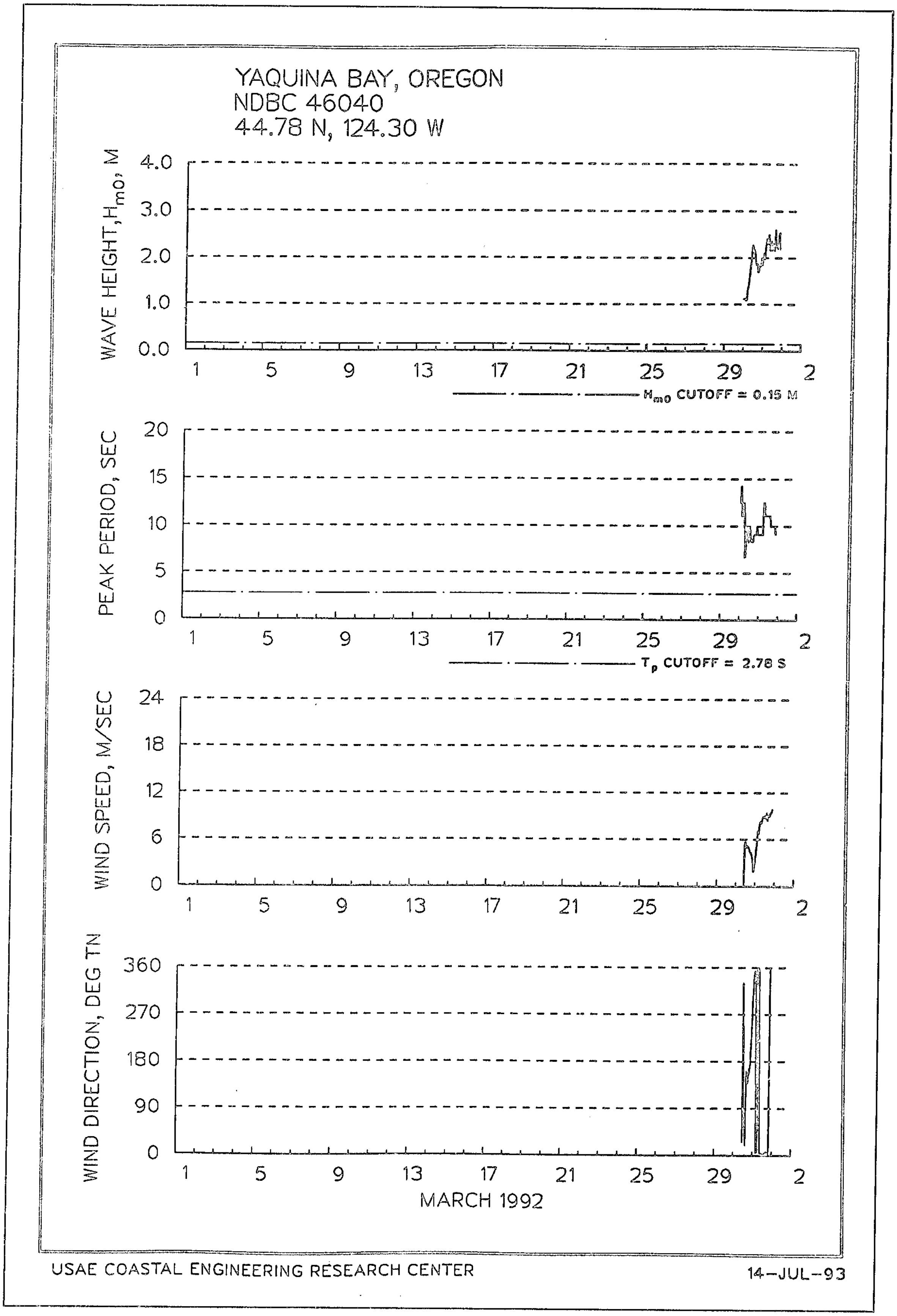


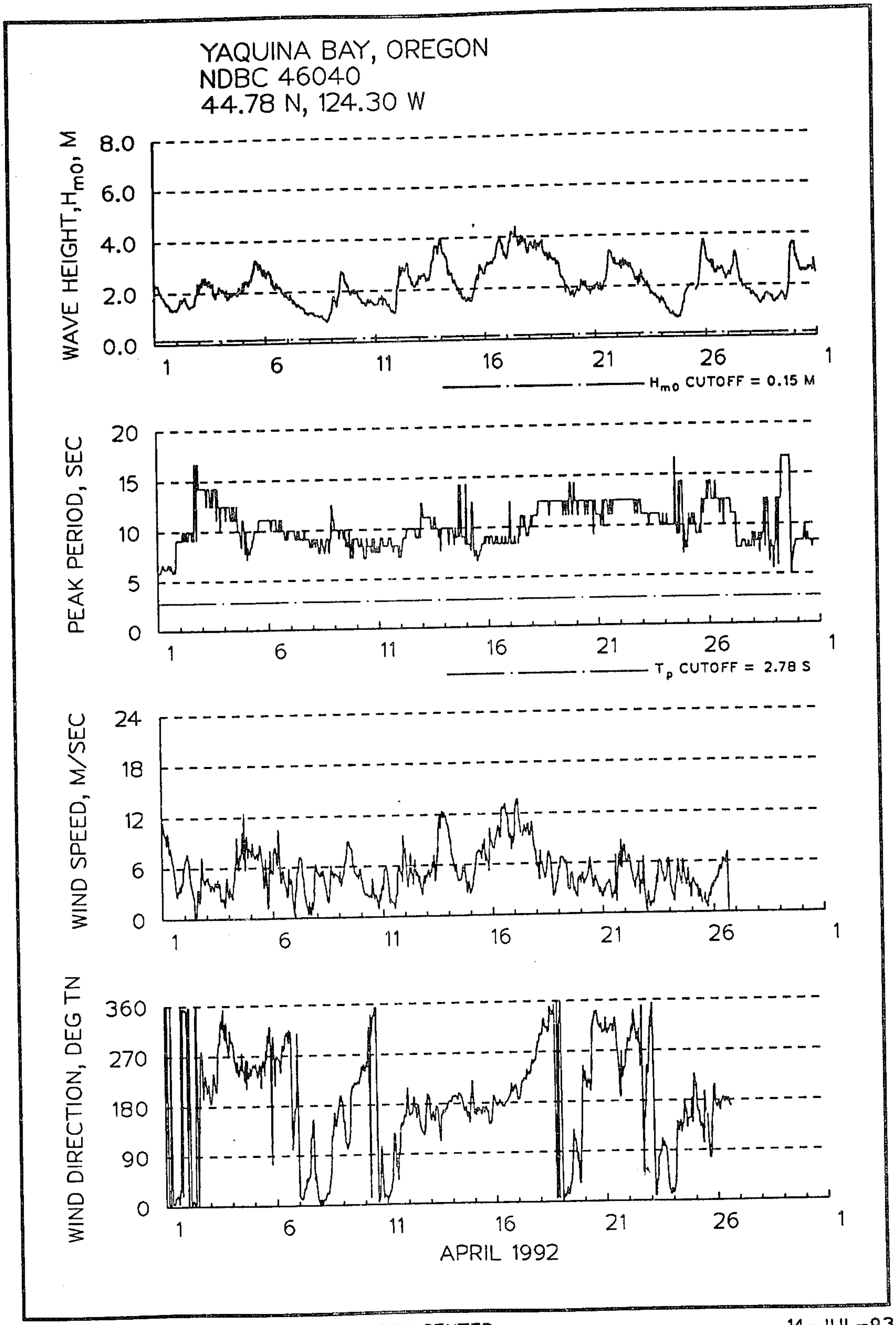
USAE COASTAL ENGINEERING RESEARCH CENTER

14–JUL–93

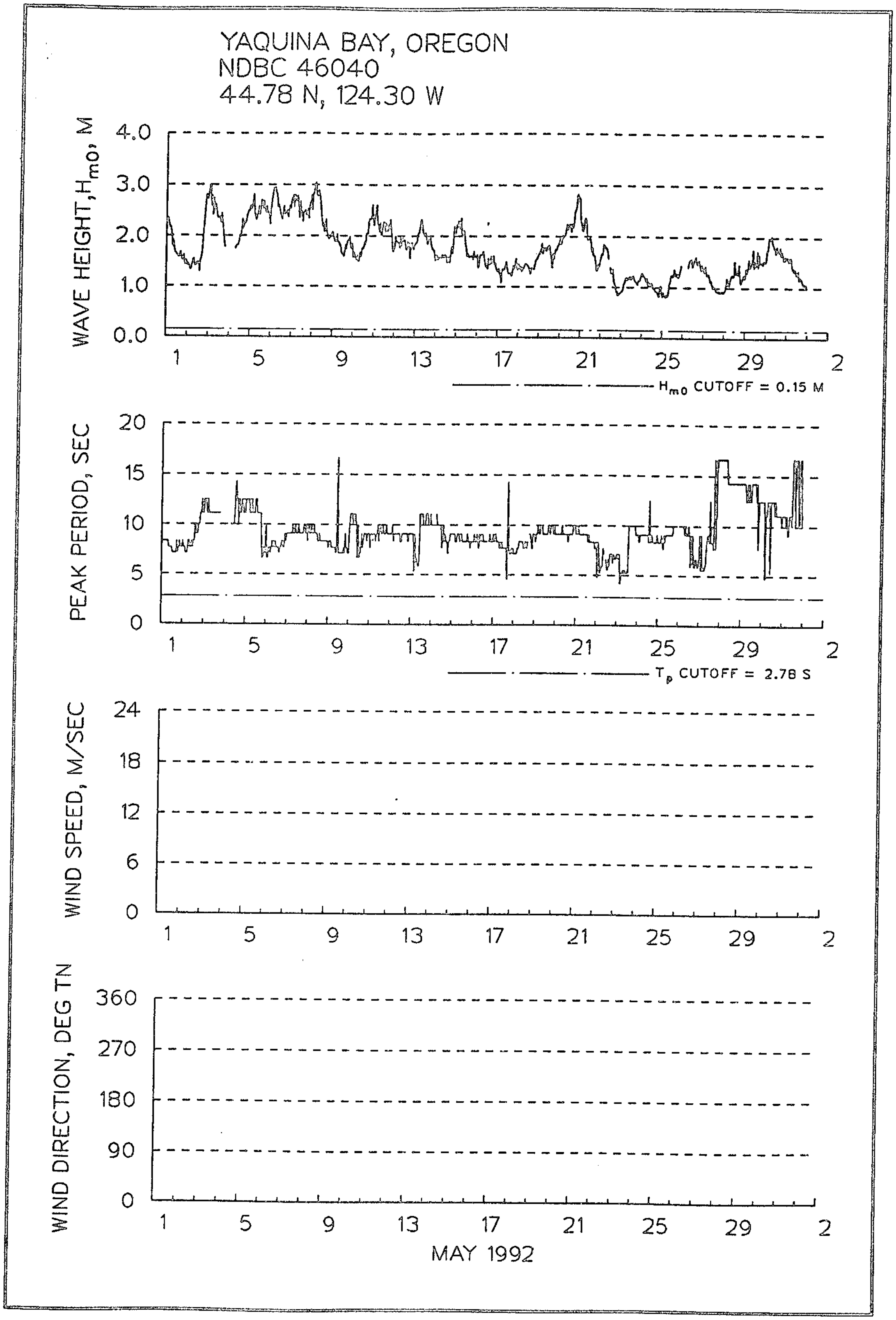


USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

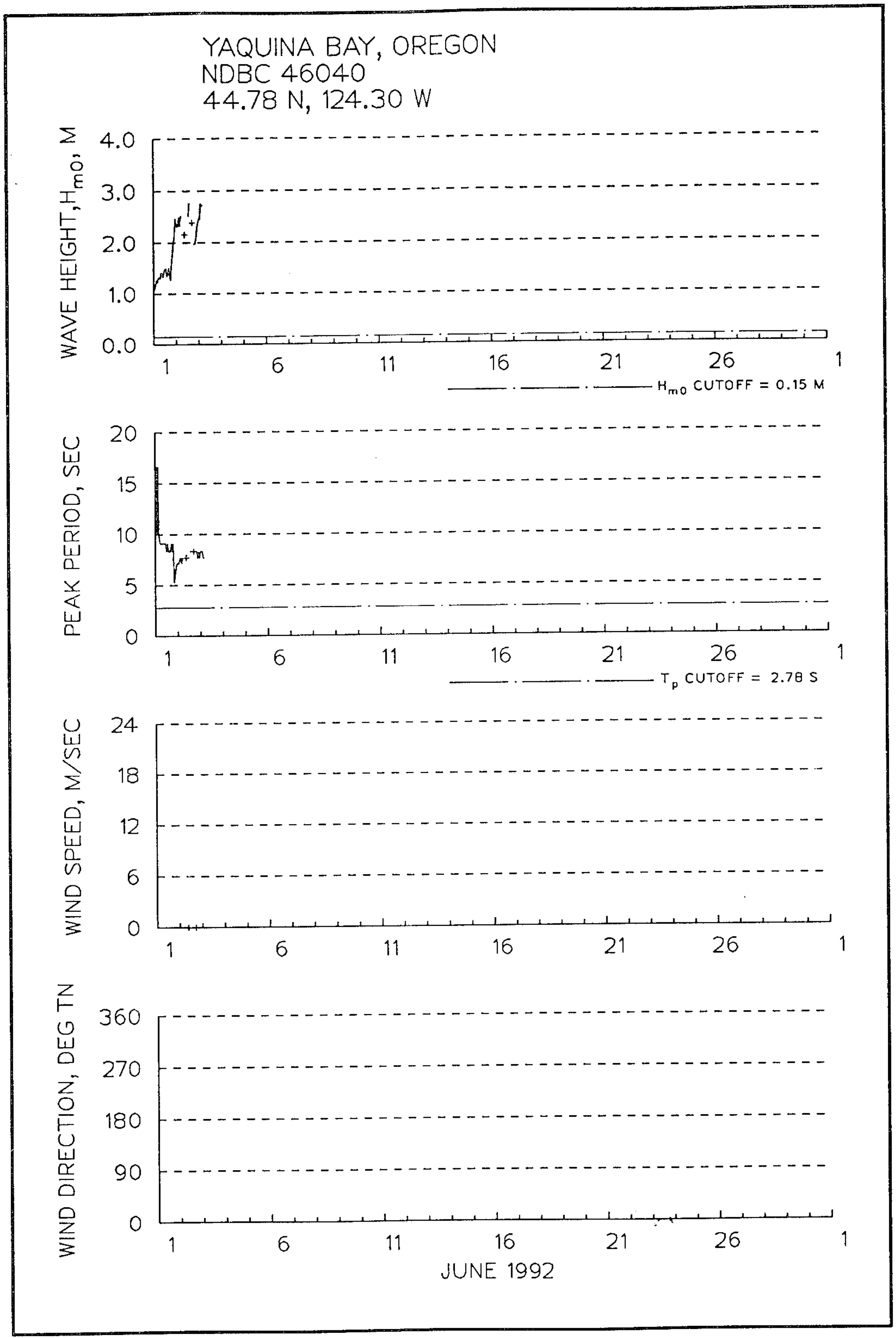

YAQUINA BAY, OREGON
NDBC 46040
44.78 N, 124.30 W
WAVE HEIGHT, H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
PEAK PERIOD, SEC
20
15
10
5
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MARCH 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
14–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER 14-JUL-93



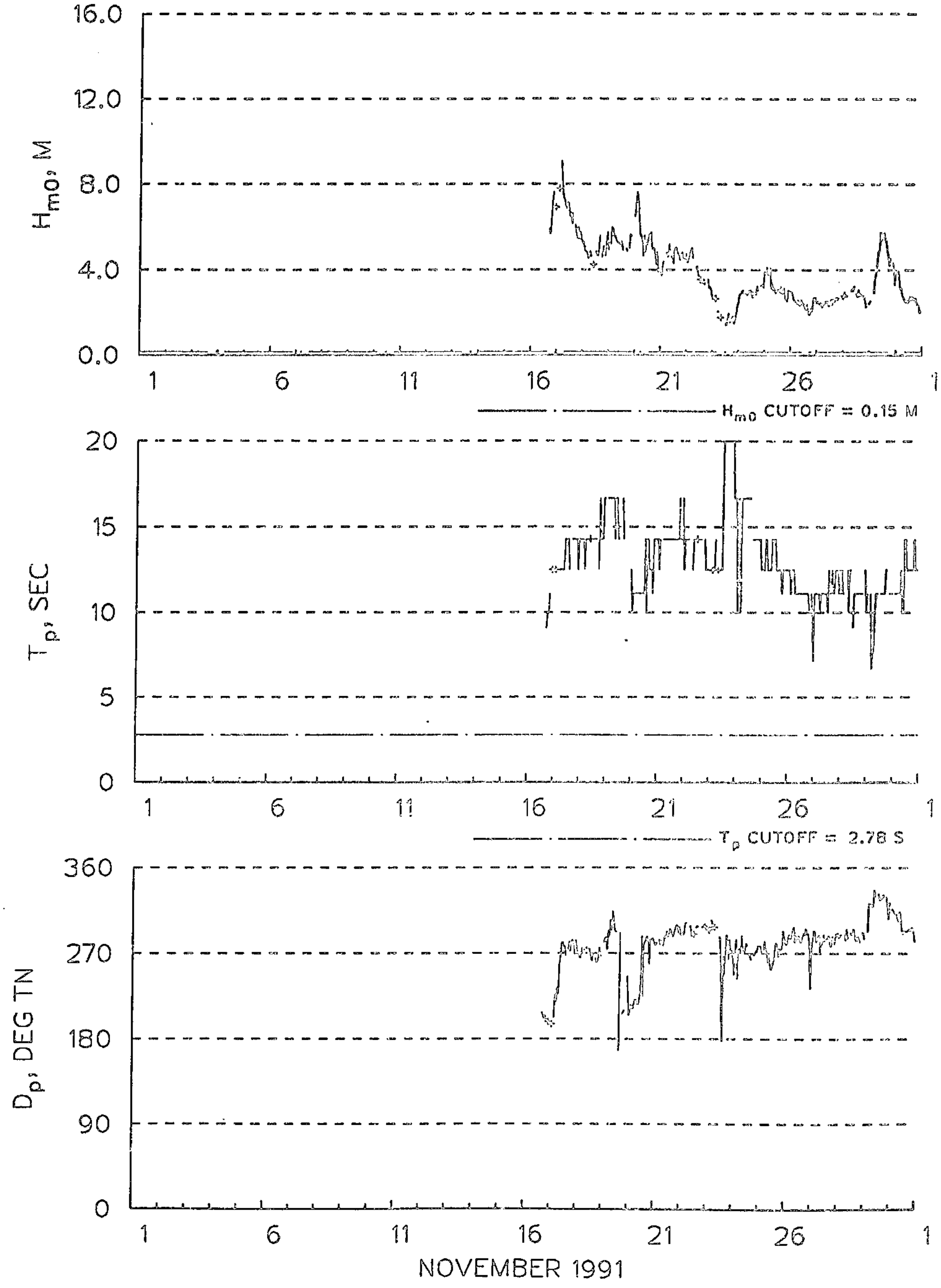
USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93



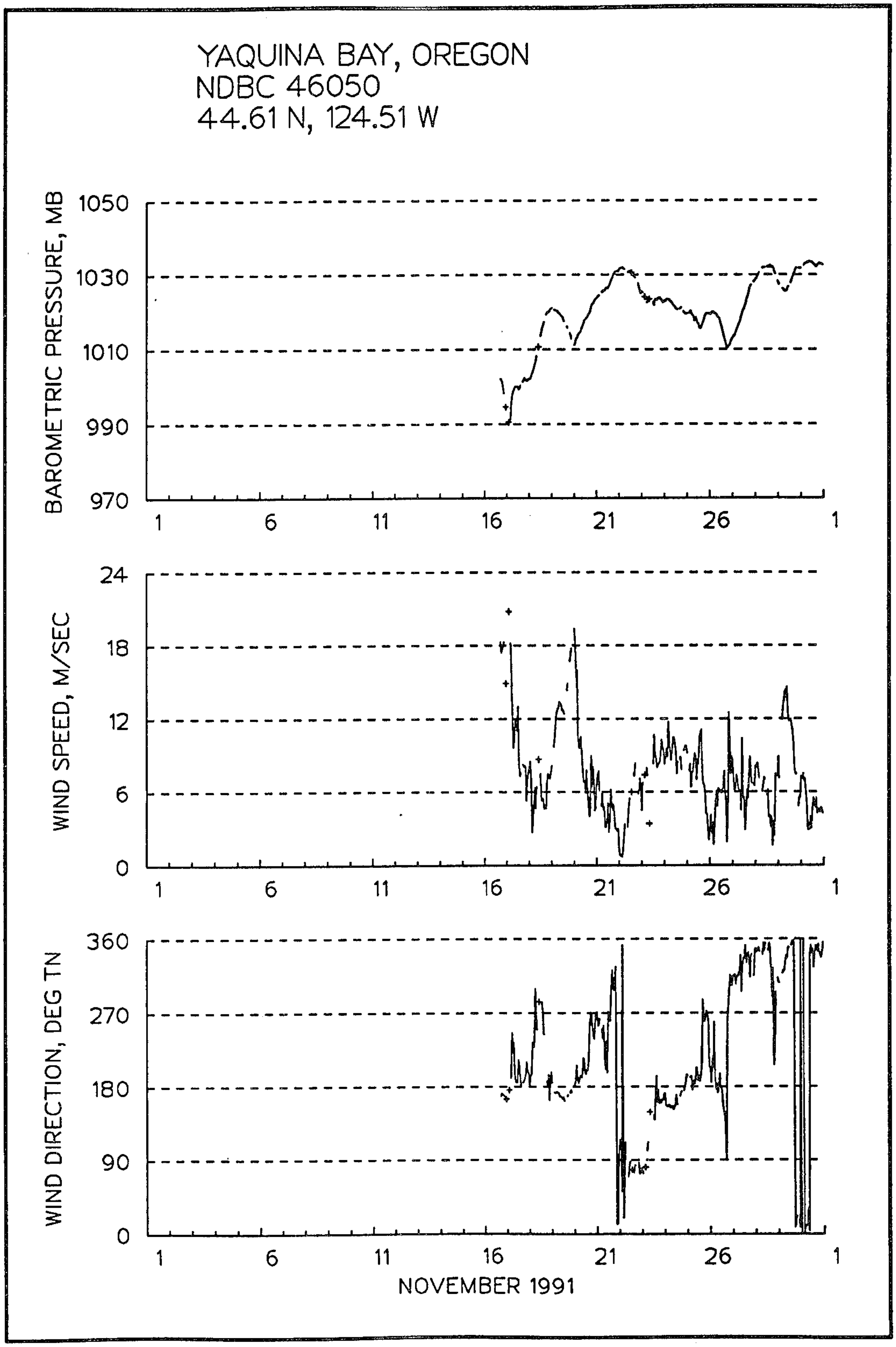
USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

Appendix B
Monthly Time Series Plots for Deepwater NDBC 46050

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



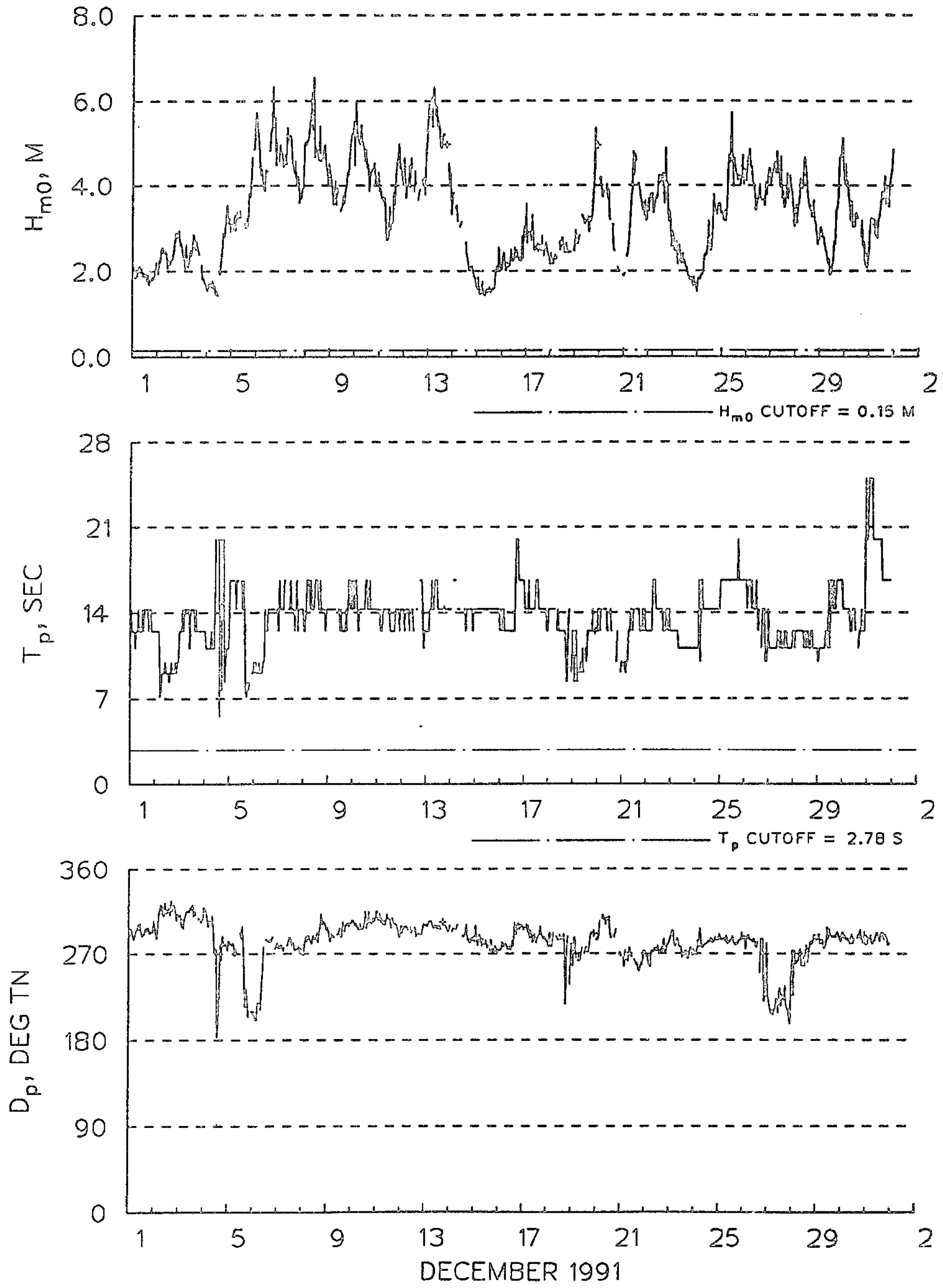
USAE COASTAL ENGINEERING RESEARCH CENTER 14-JUL-93



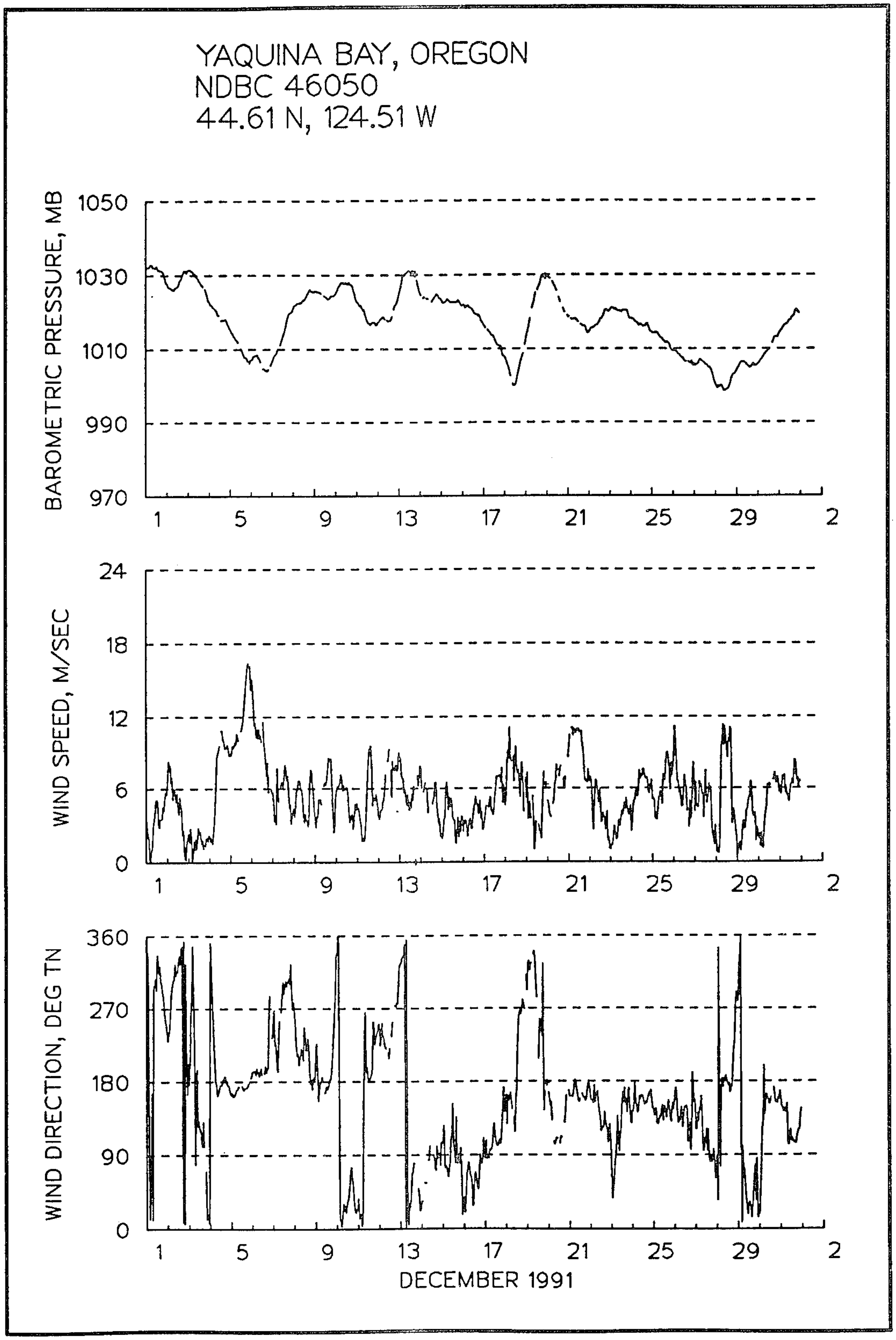
YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W

USAE COASTAL ENGINEERING RESEARCH CENTER 14-JUL-93

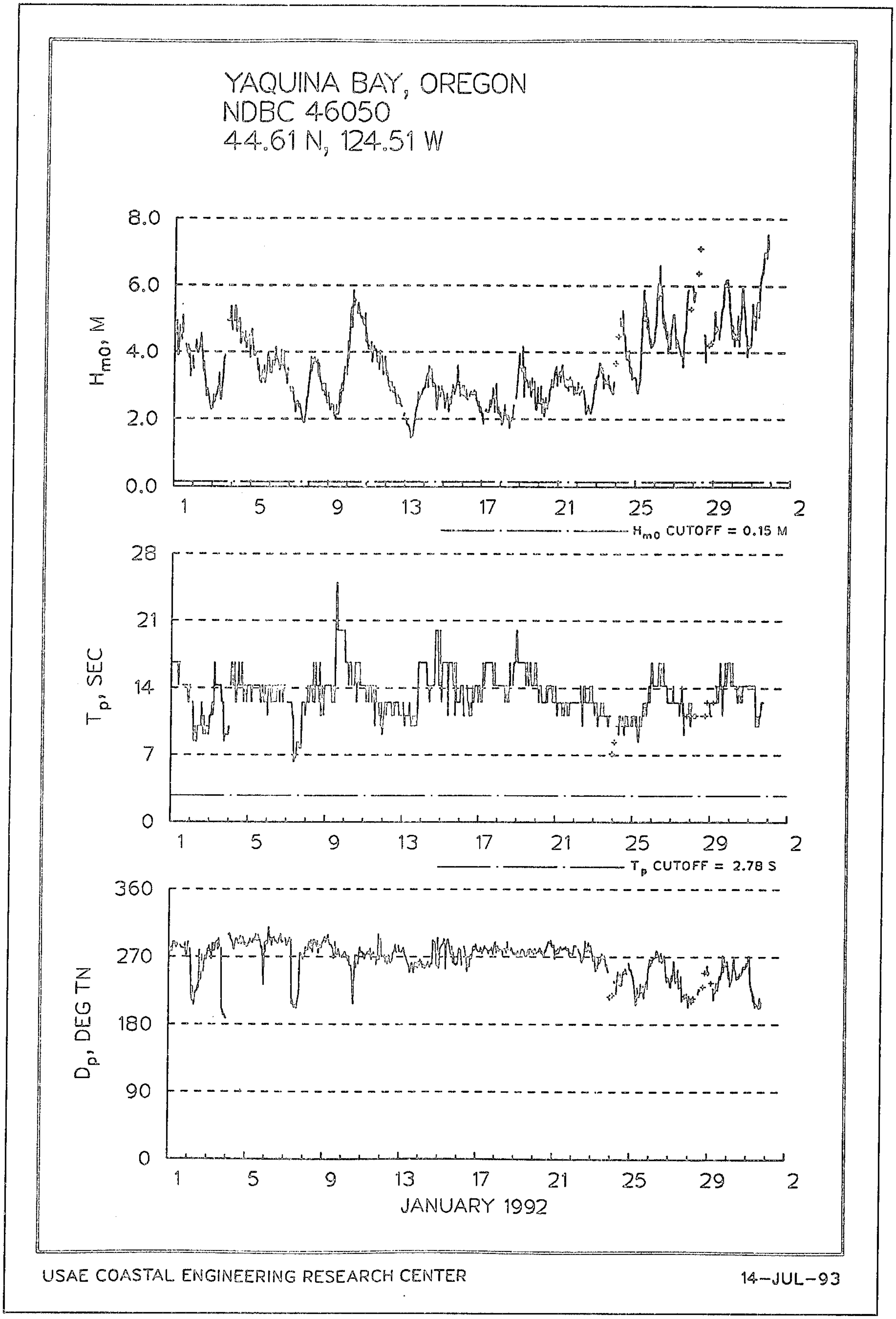
YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W

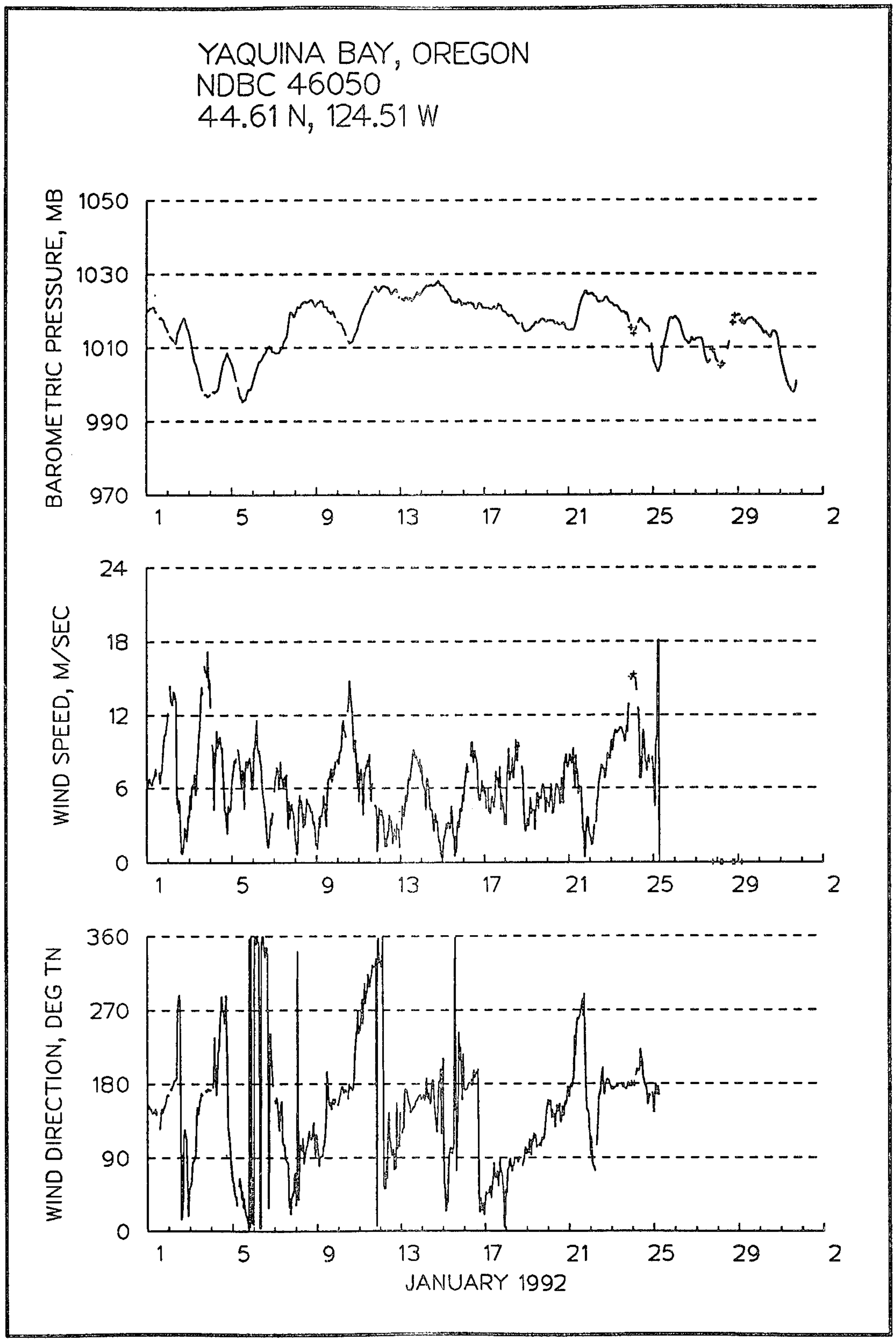


USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93



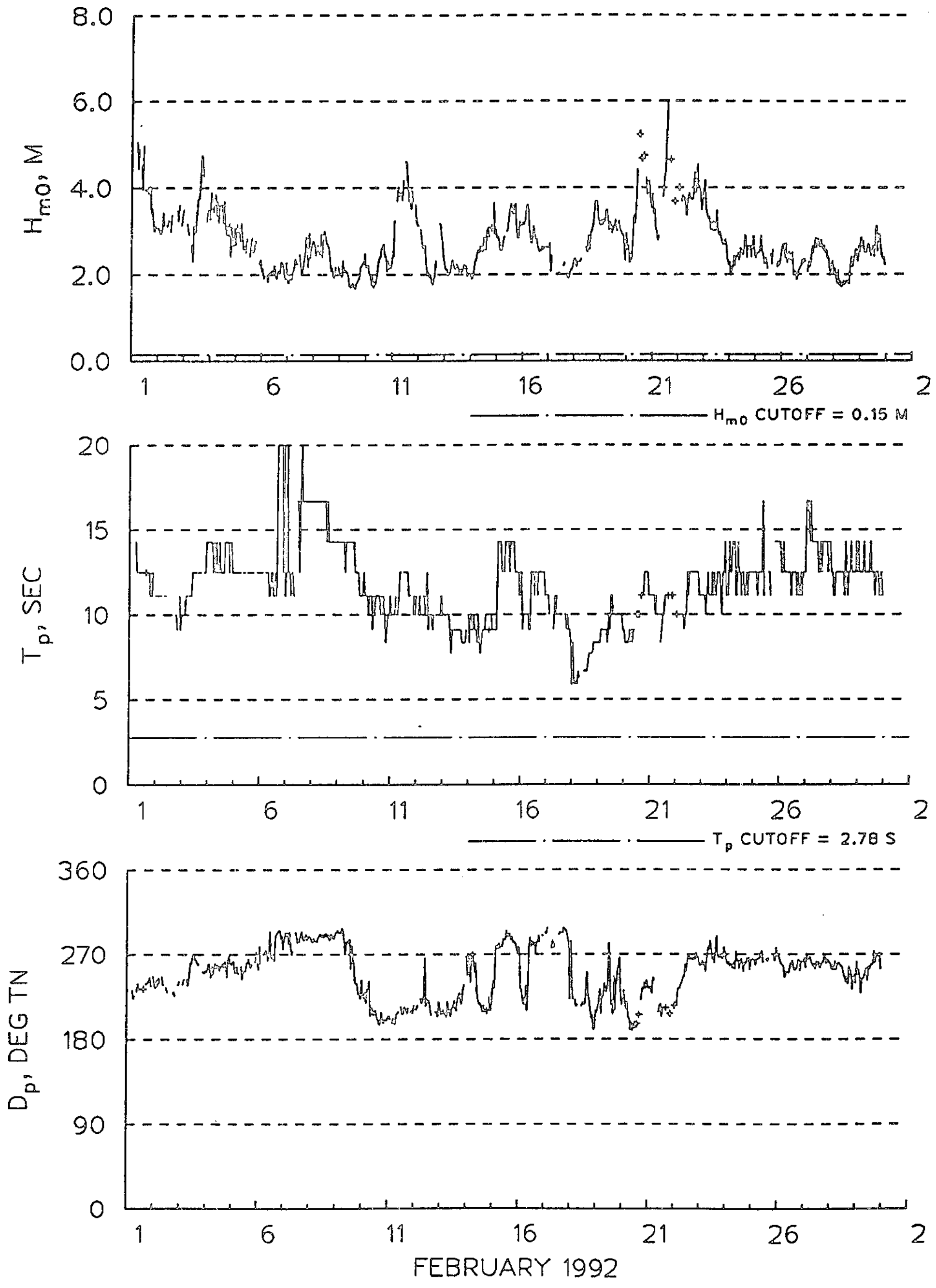
USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93


YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
T_p, SEC
28
21
14
7
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
D_p, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
JANUARY 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



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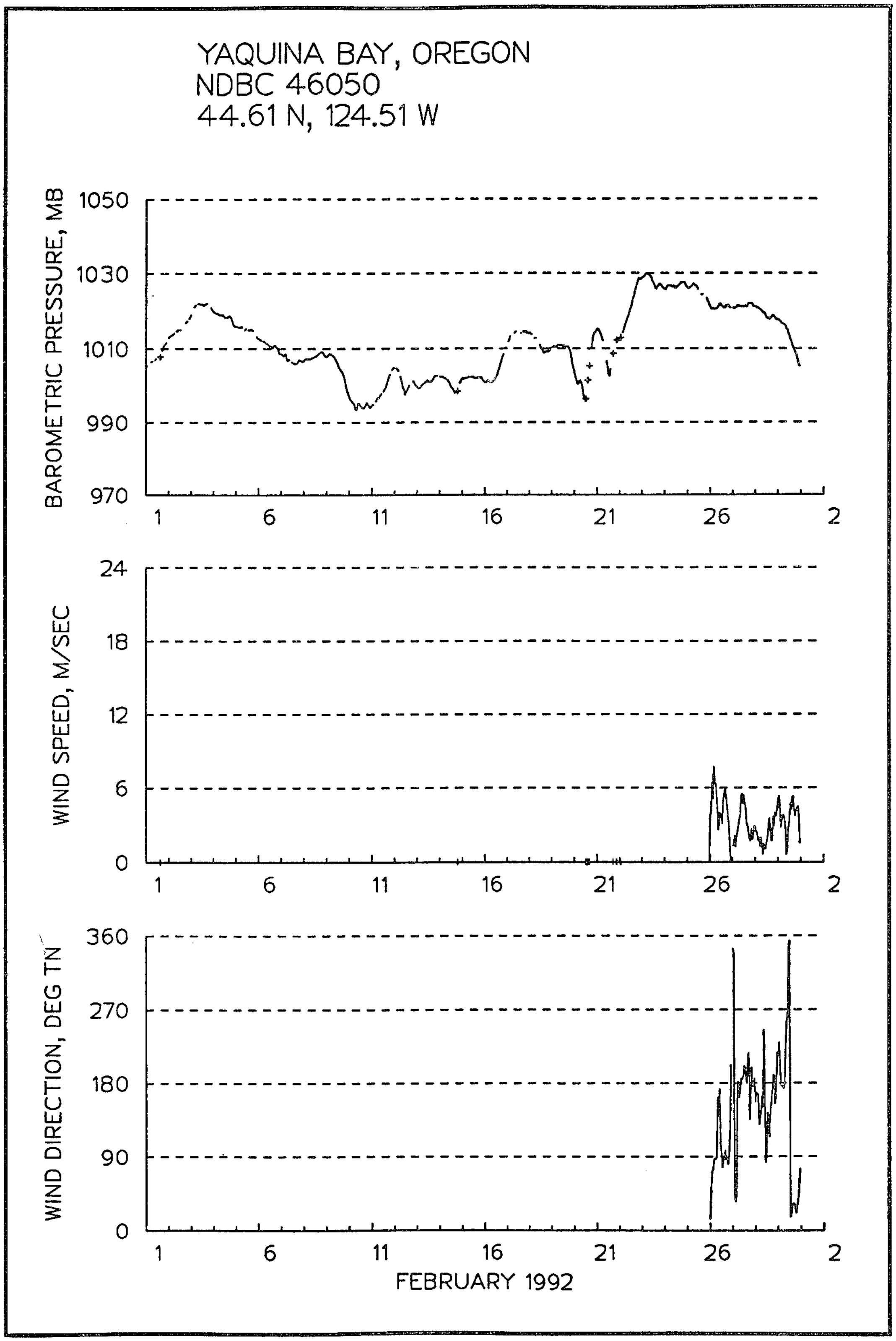
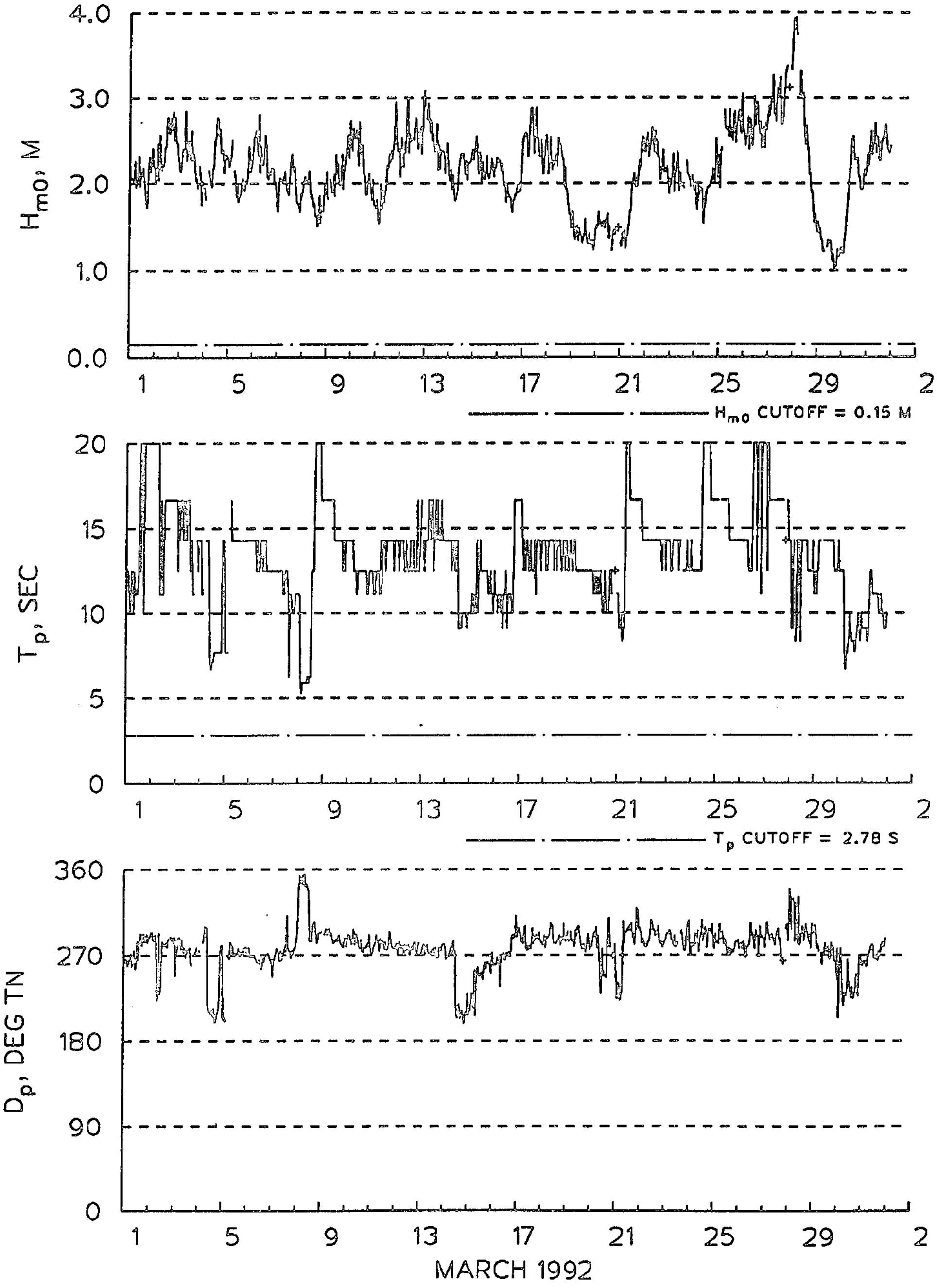
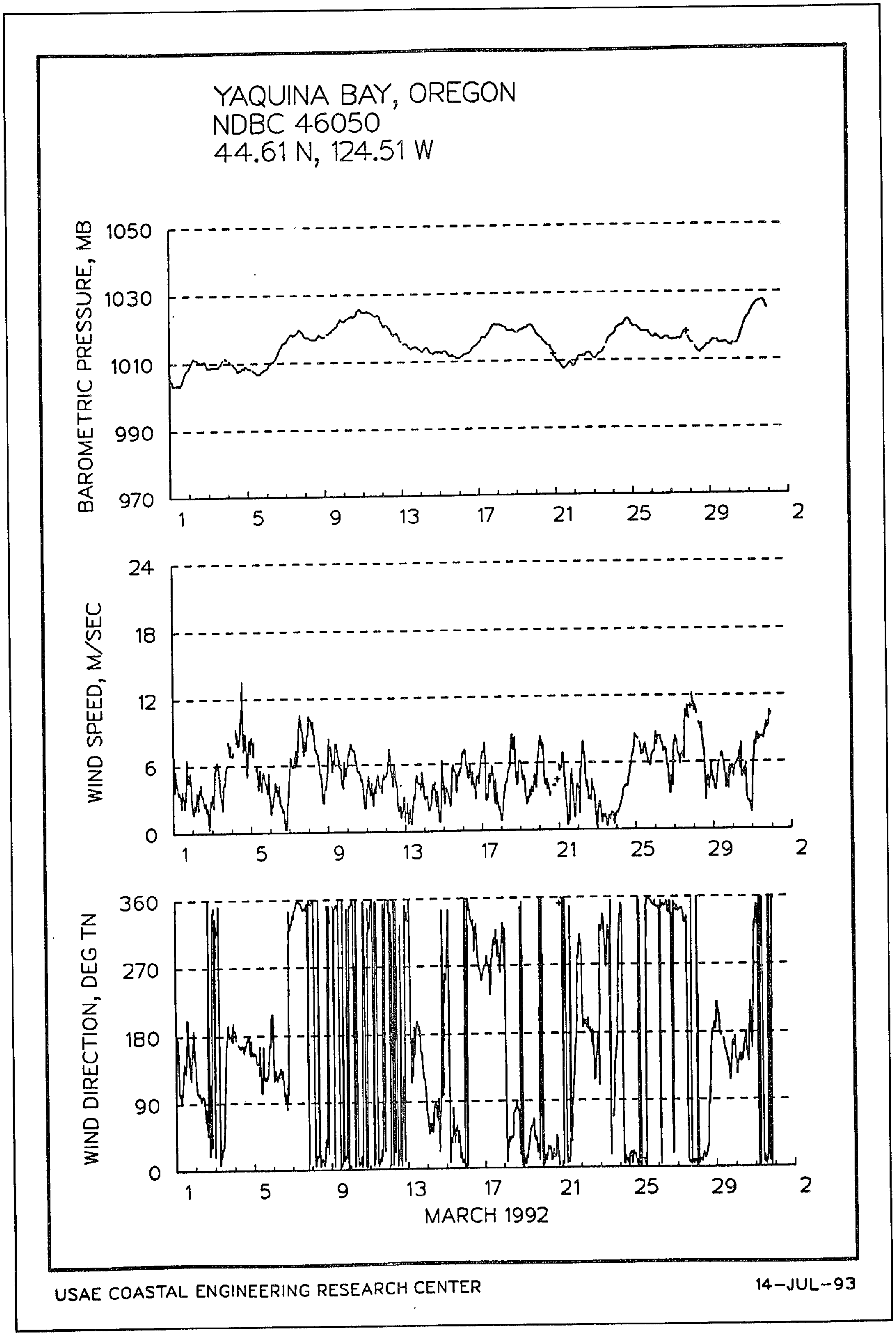


USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

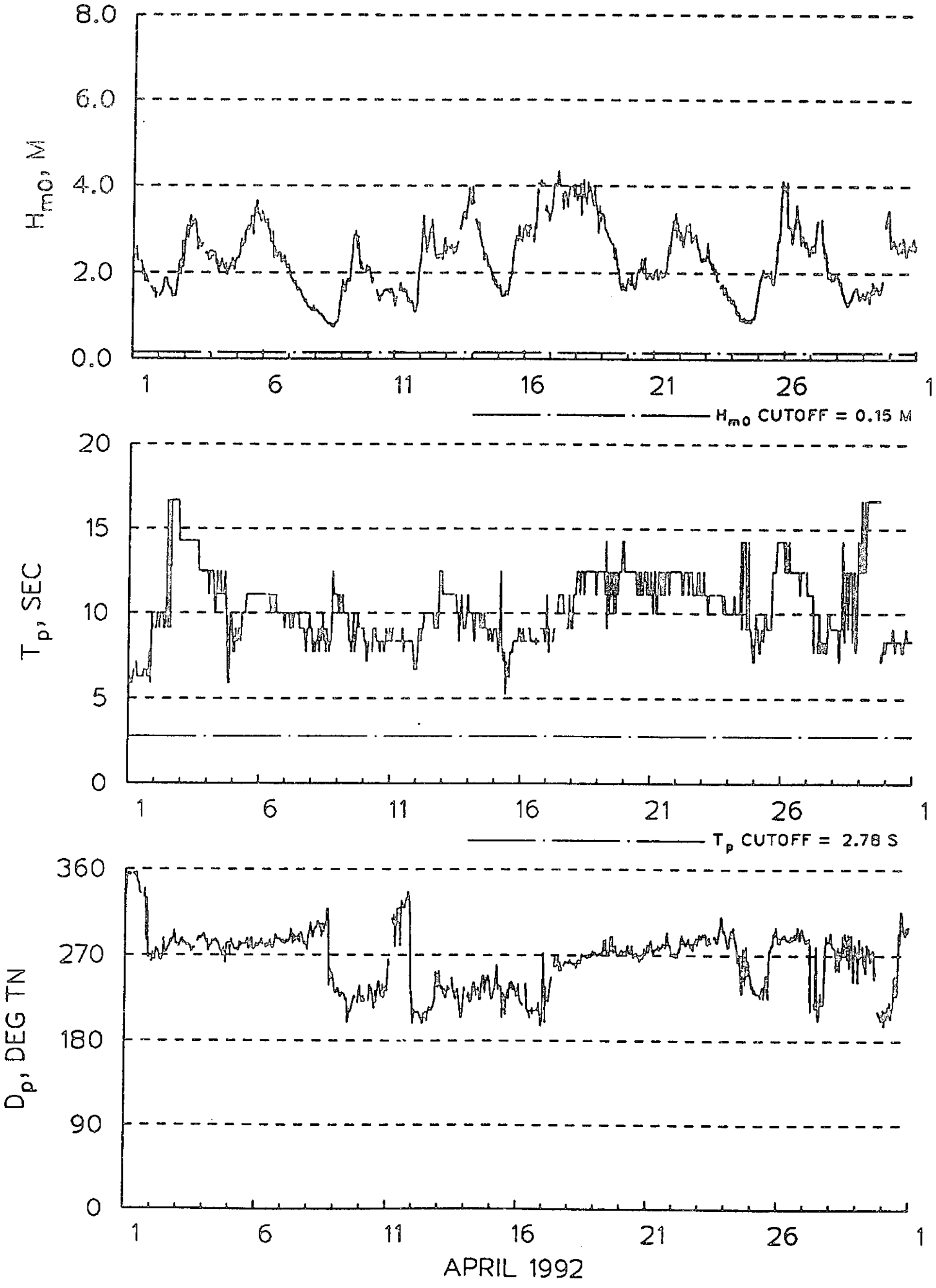
YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93


YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
5
9
13
17
21
25
29
2
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MARCH 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93

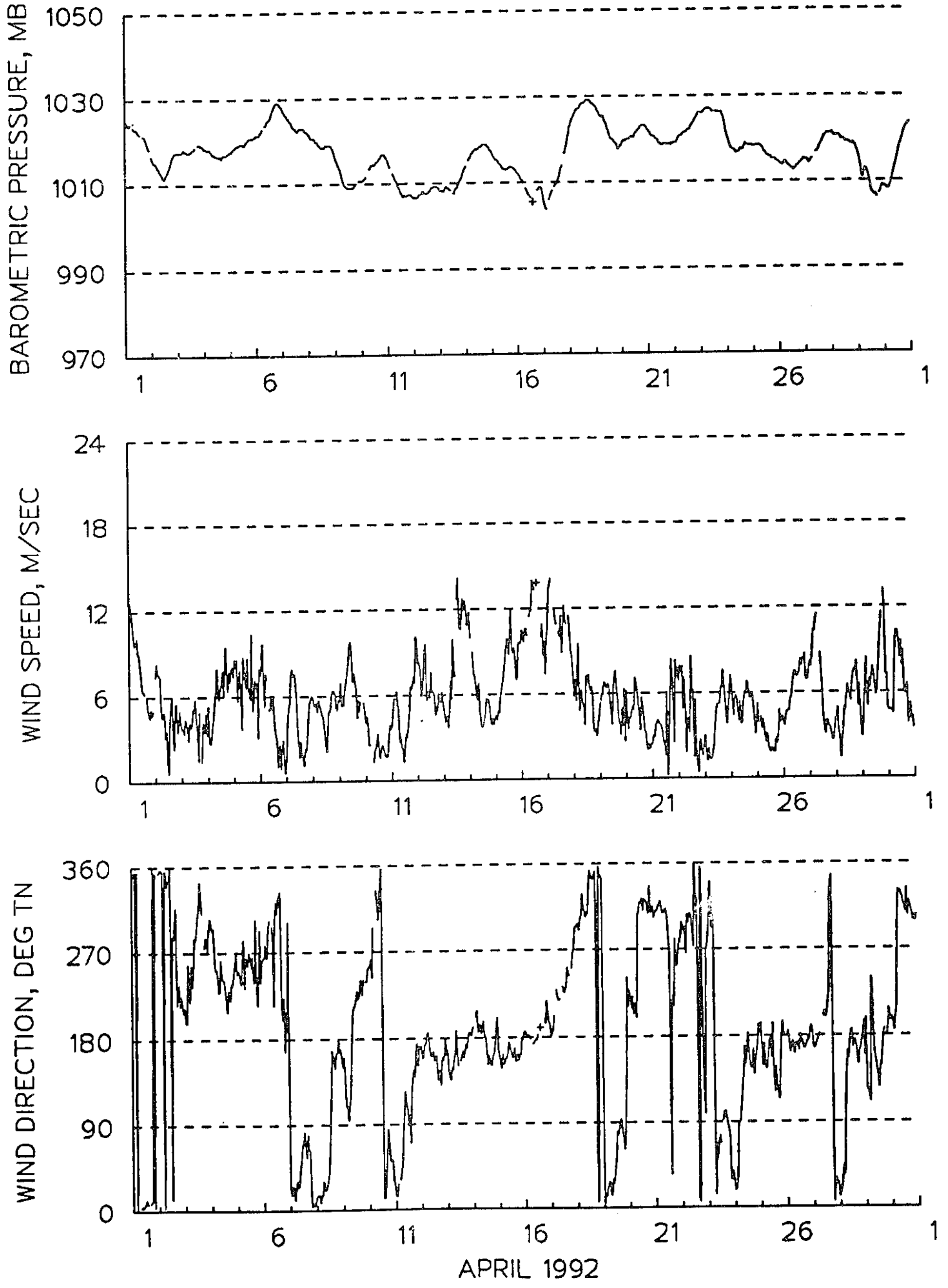
YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



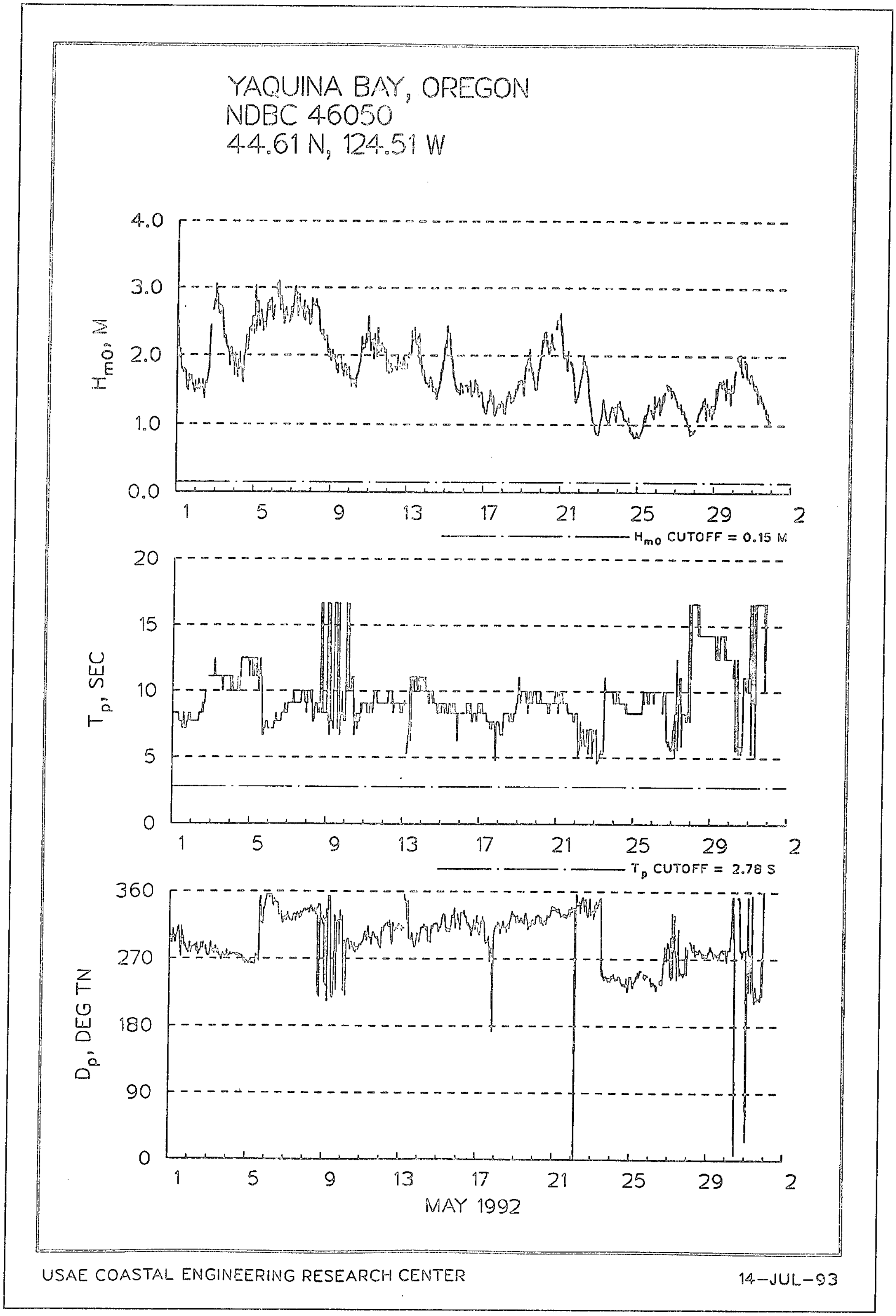
USAE COASTAL ENGINEERING RESEARCH CENTER

14-JUL-93

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



USAE COASTAL ENGINEERING RESEARCH CENTER 14-JUL-93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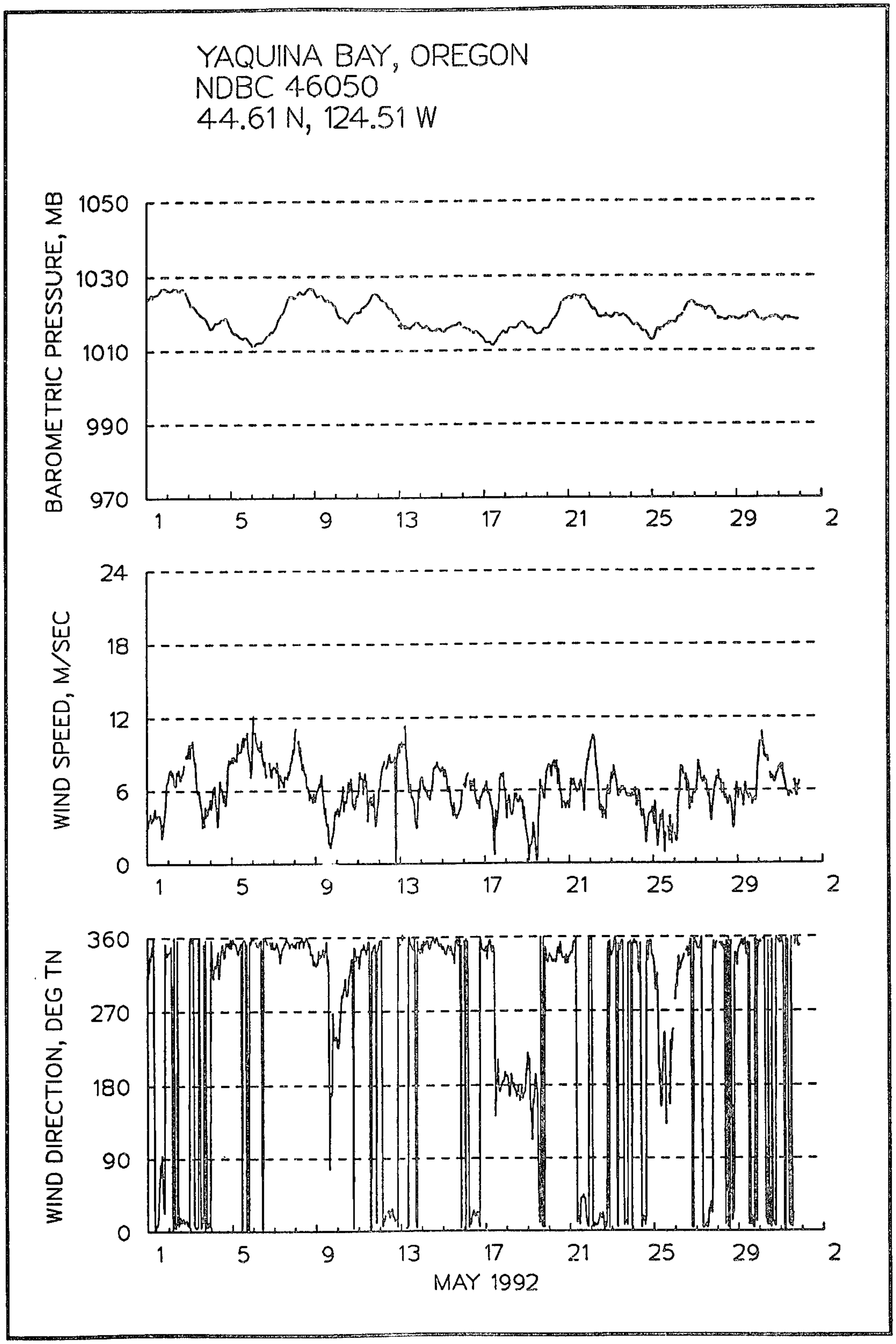
NDBC 46050
44.61 N, 124.51 W
H_{m0}, M
4.0
3.0
2.0
1.0
0.0
1
5
9
13
17
21
25
29
2
H_{mo} CUTOFF = 0.15 M
T_p, SEC
20
15
10
5
0
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
D_p, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MAY 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 14–JUL–93

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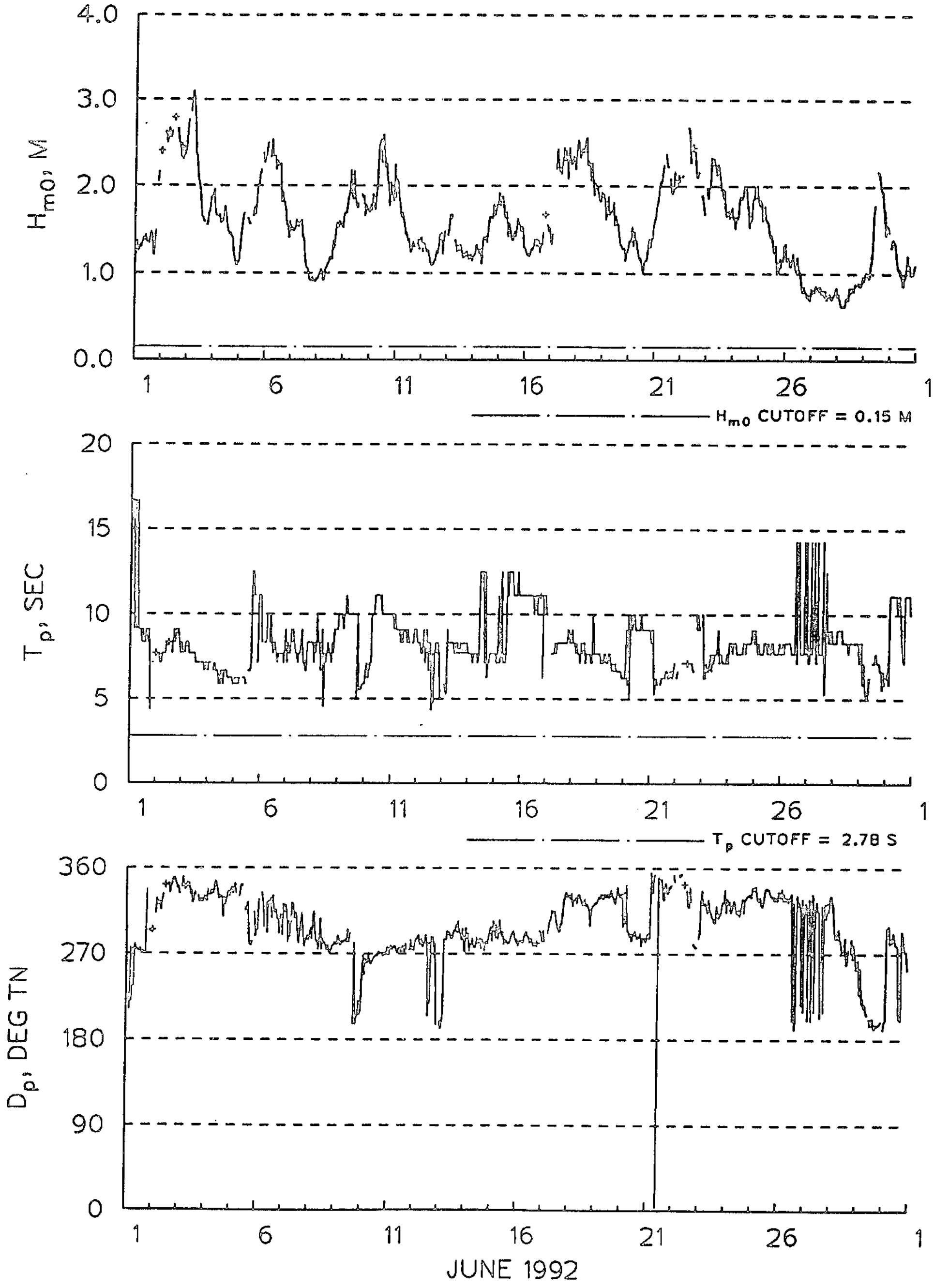
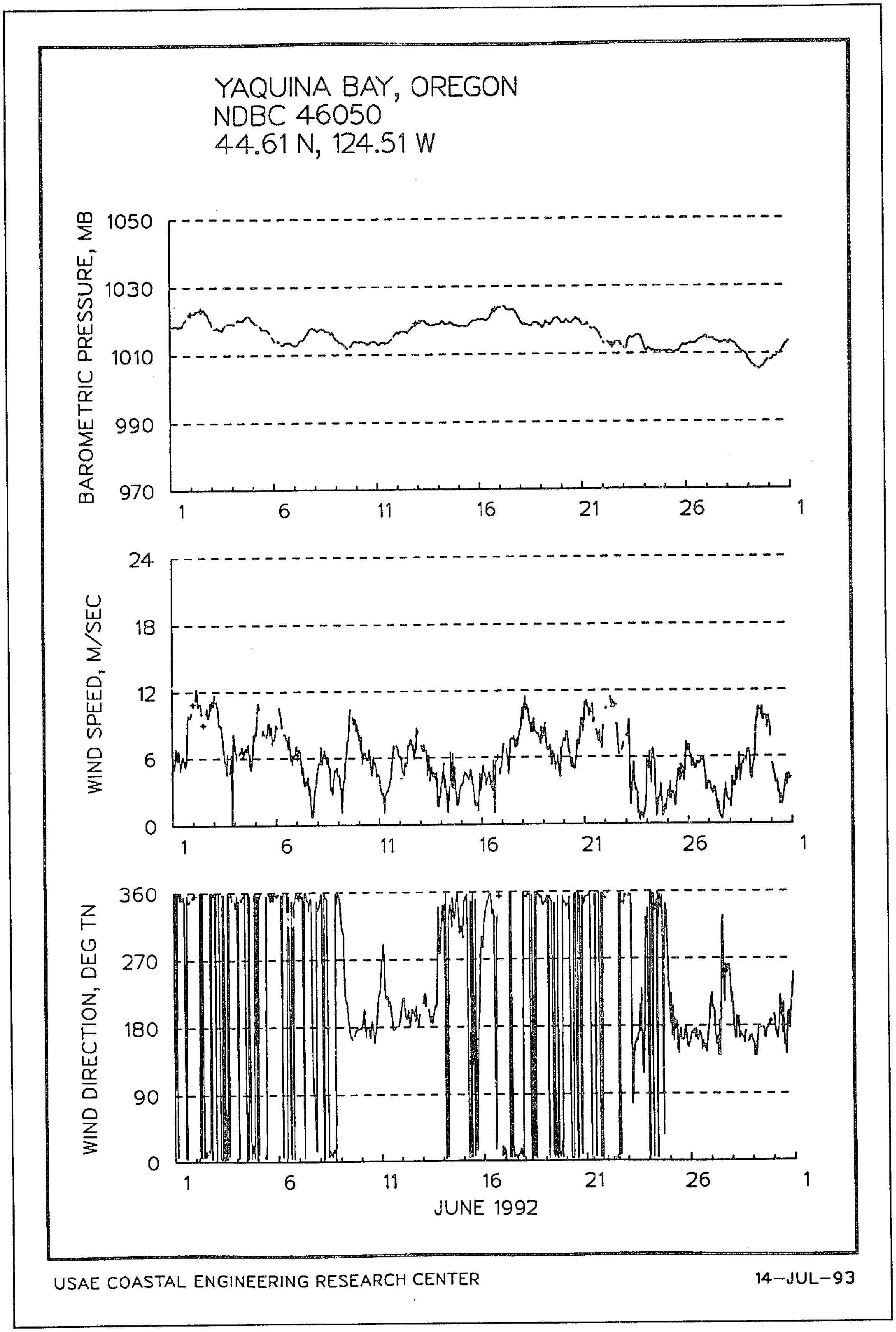


USAE COASTAL ENGINEERING RESEARCH CENTER

14–JUL–93


YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
6
11
16
21
26
1
WIND SPEED, M/SEC
24
18
12
6
0
1
6
11
16
21
26
1
WIND DIRECTION, DEG TN
360
270
180
90
0
1
6
11
16
21
26
1
JUNE 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
14-JUL-93

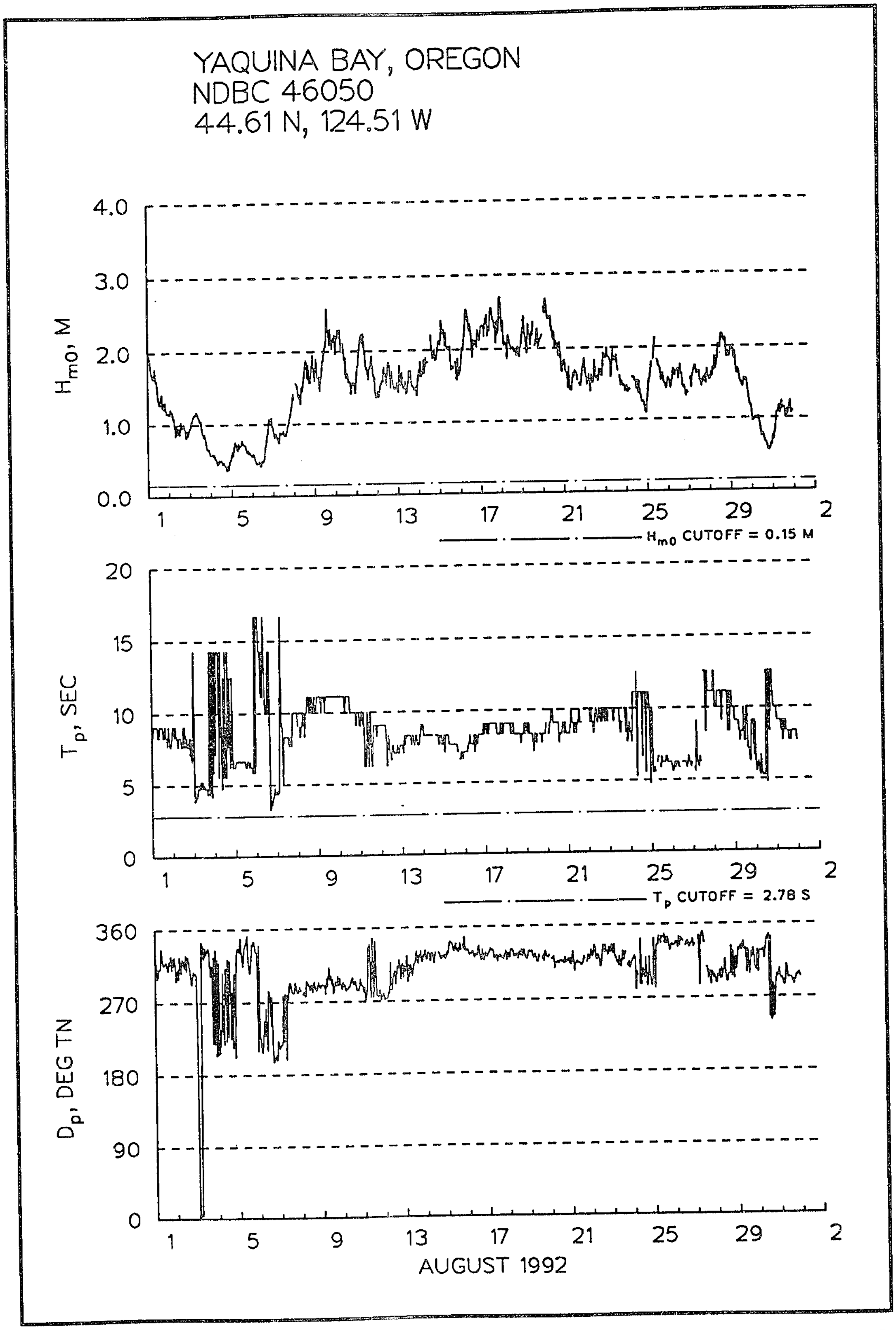
STONEWALL BANK
NDBC 46050
44.63 N 124.52 W

NO DATA AVAILABLE

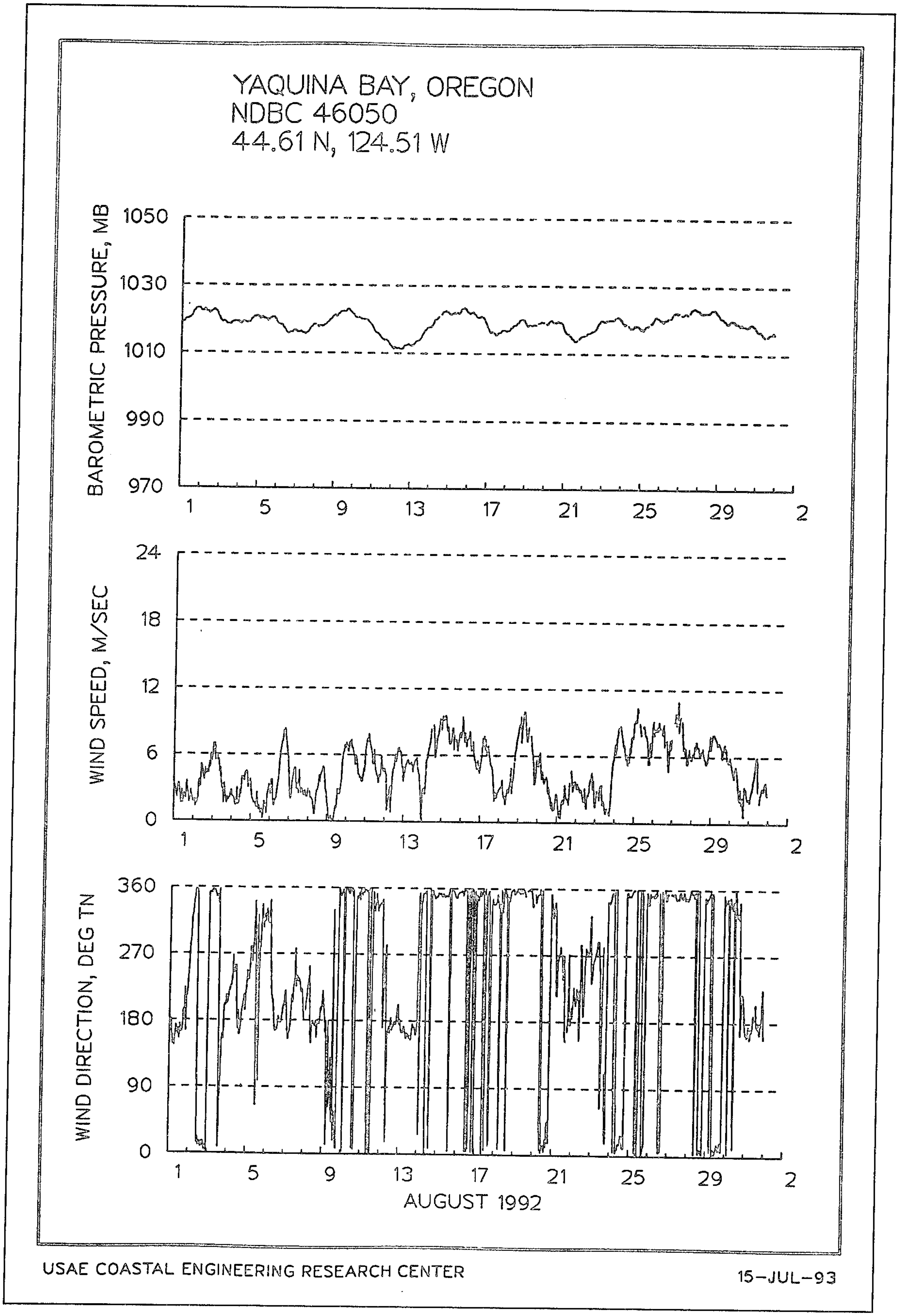
JULY 1992

USAE COASTAL ENGINEERING RESEARCH CENTER

28-NOV-94



USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93


YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
5
9
13
17
21
25
29
2
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
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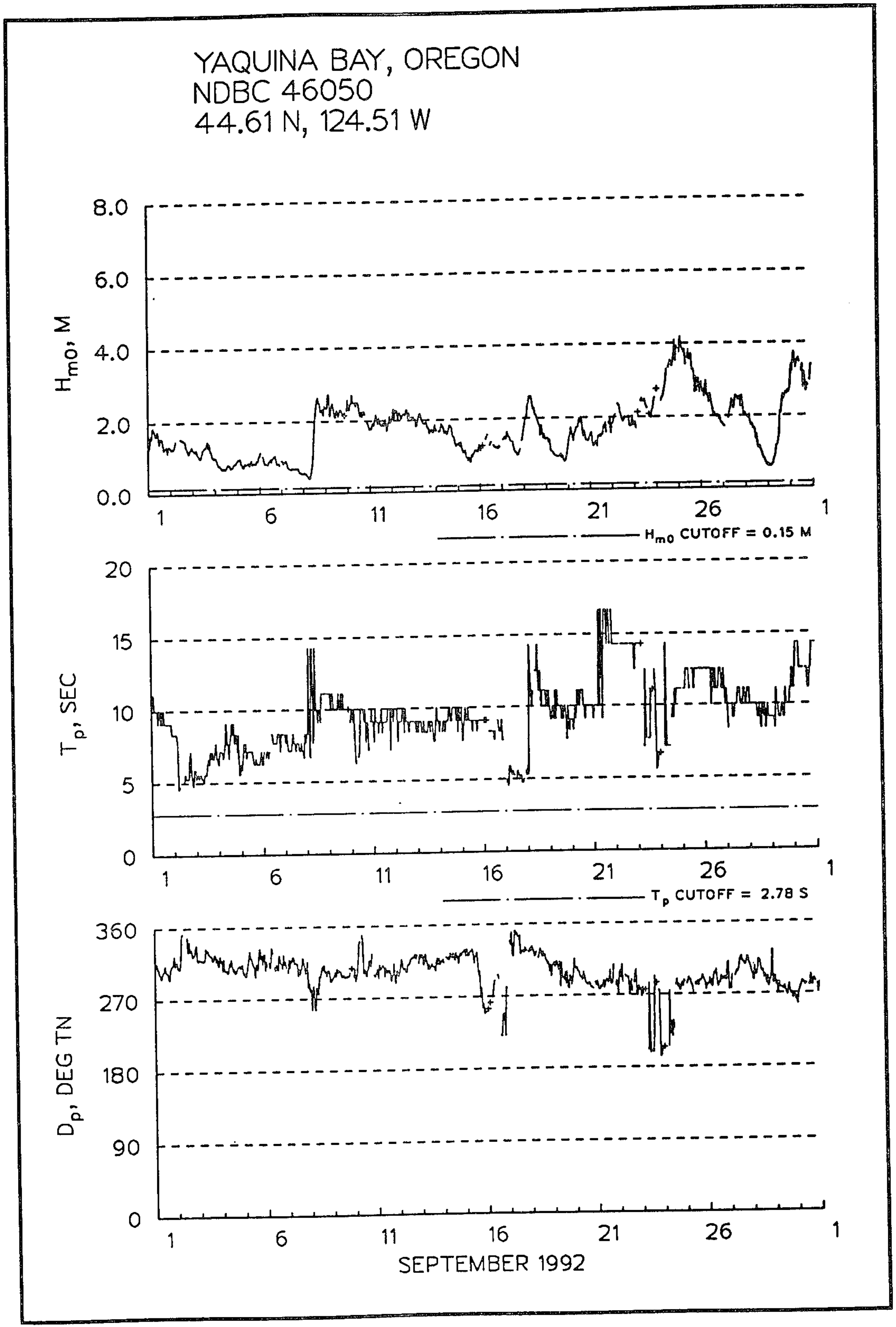
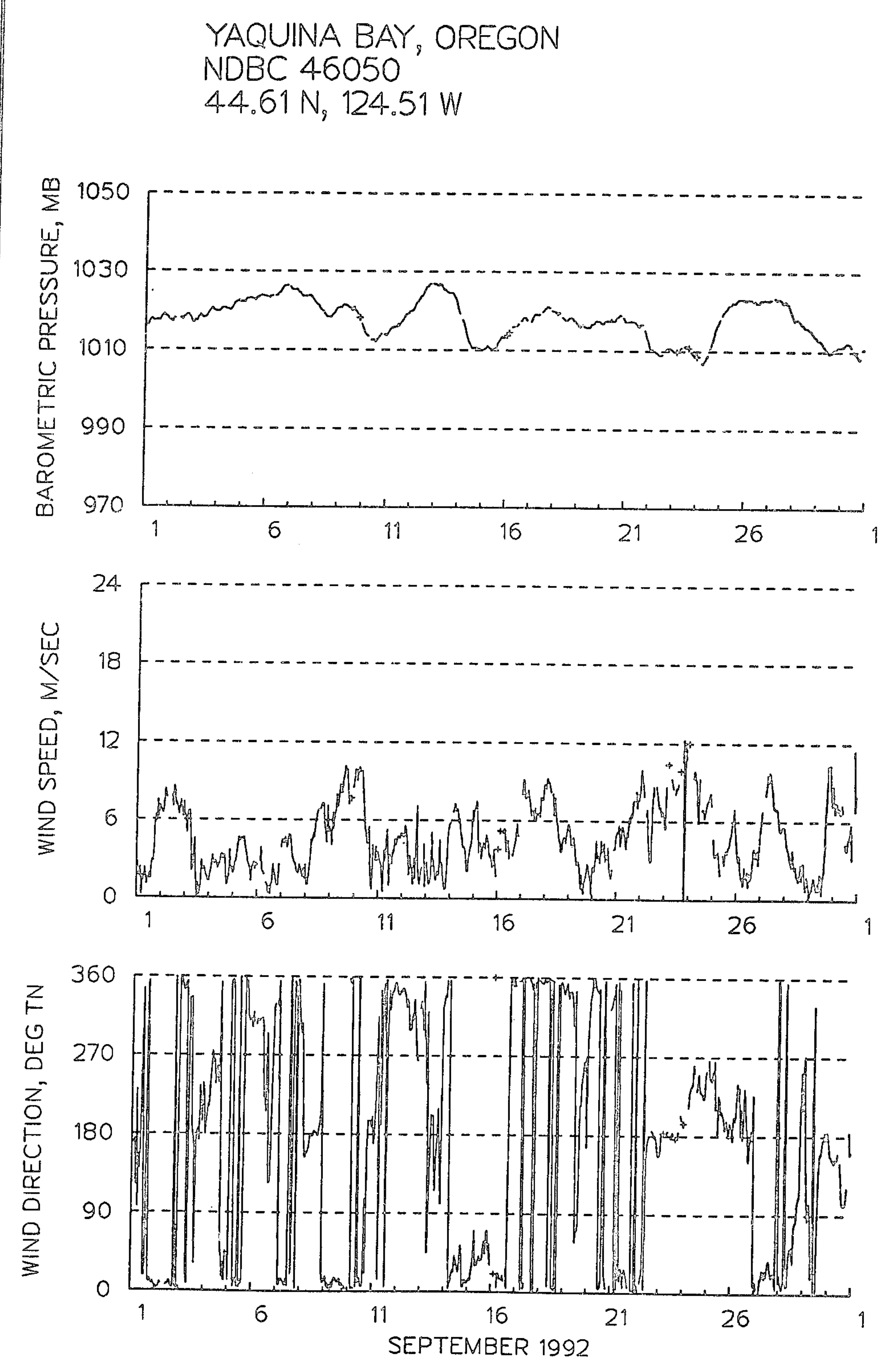
25
29
2
AUGUST 1992
USAE COASTAL ENGINEERING RESEARCH CENTER
15-JUL-93



USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93



USAE COASTAL ENGINEERING RESEARCH CENTER 15-JUL-93

YAQUINA BAY, OREGON
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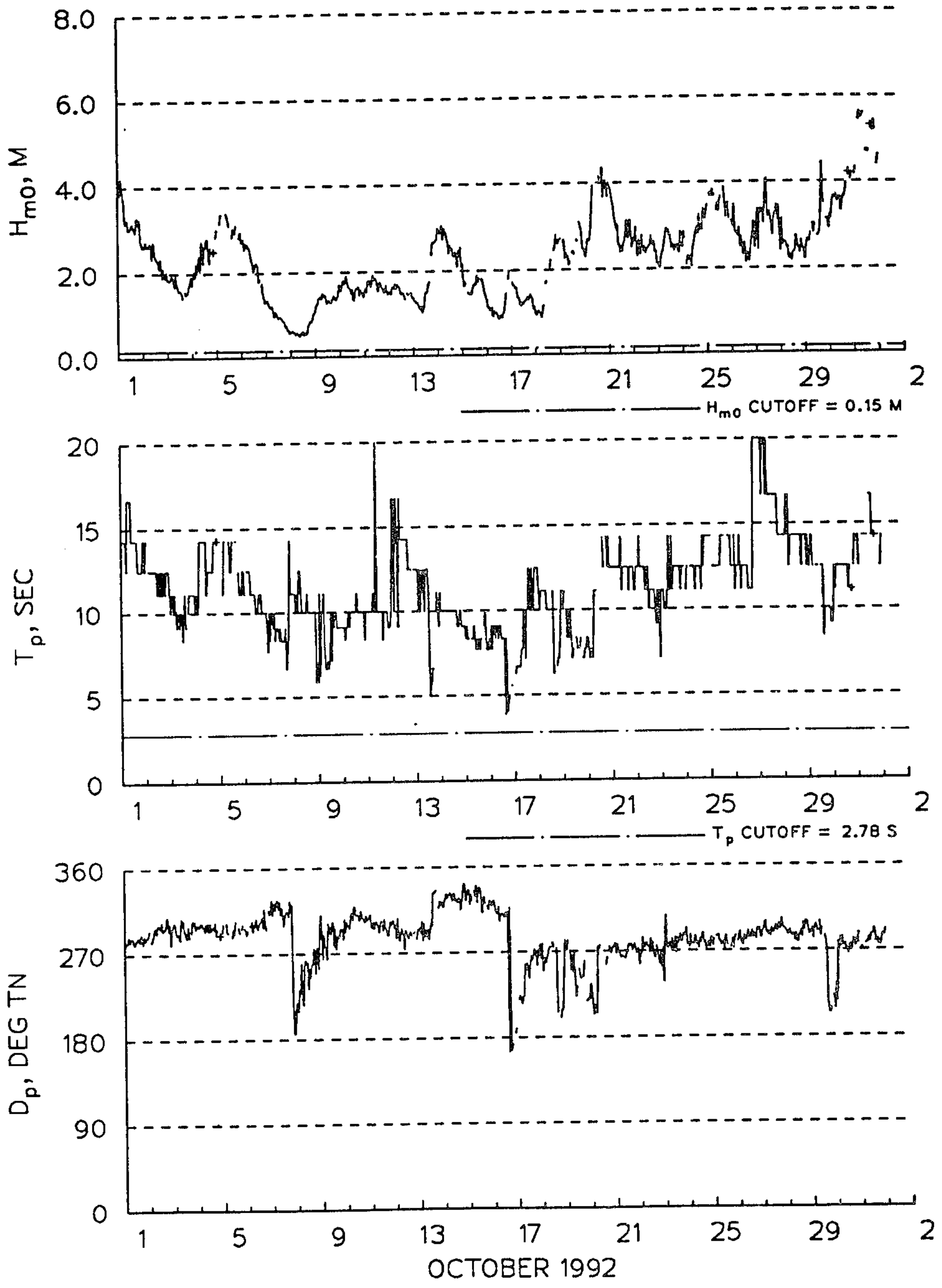

USAE COASTAL ENGINEERING RESEARCH CENTER 15-JUL-93

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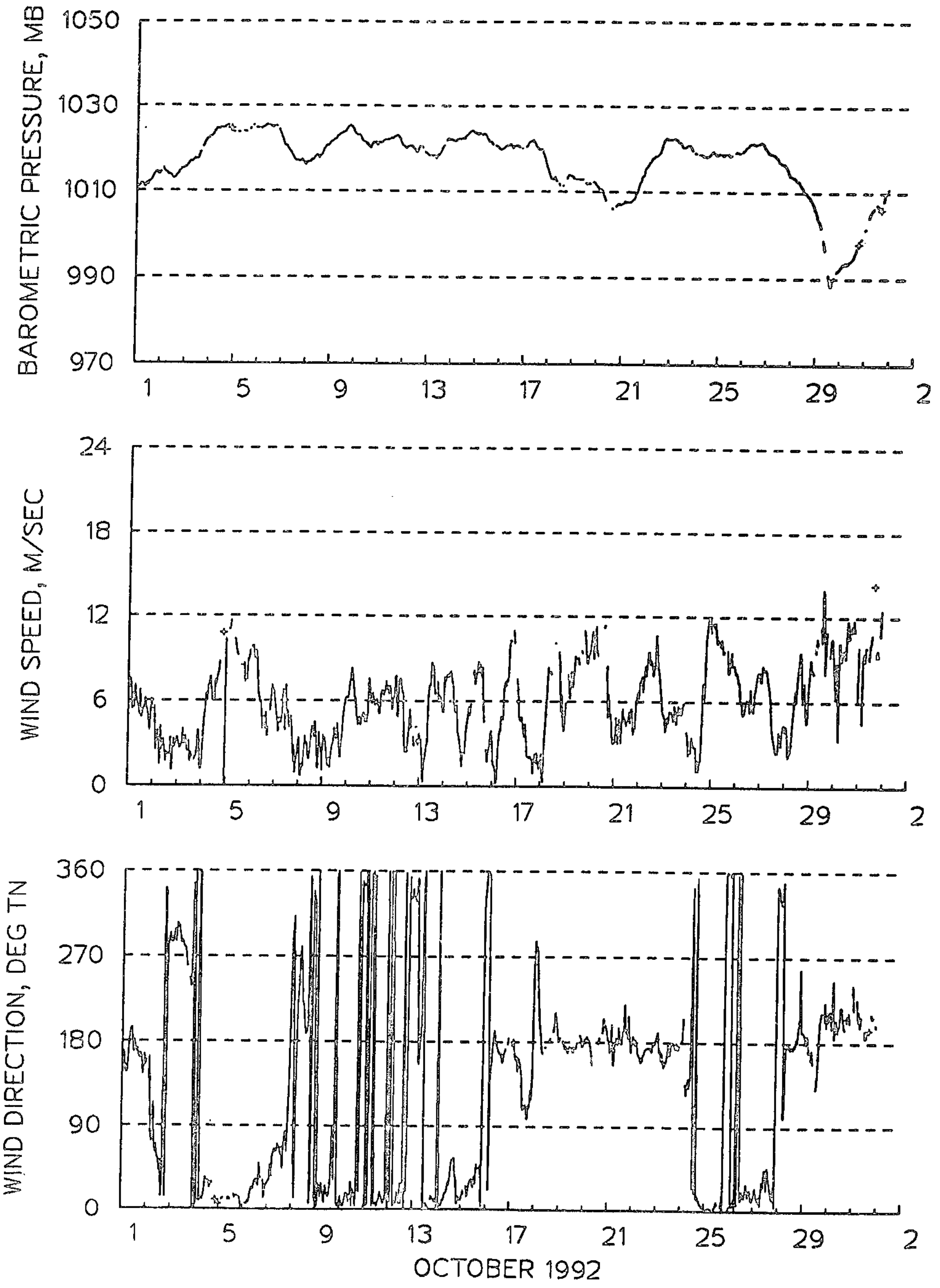

USAE COASTAL ENGINEERING RESEARCH CENTER

15-JUL-93

YAQUINA BAY, OREGON
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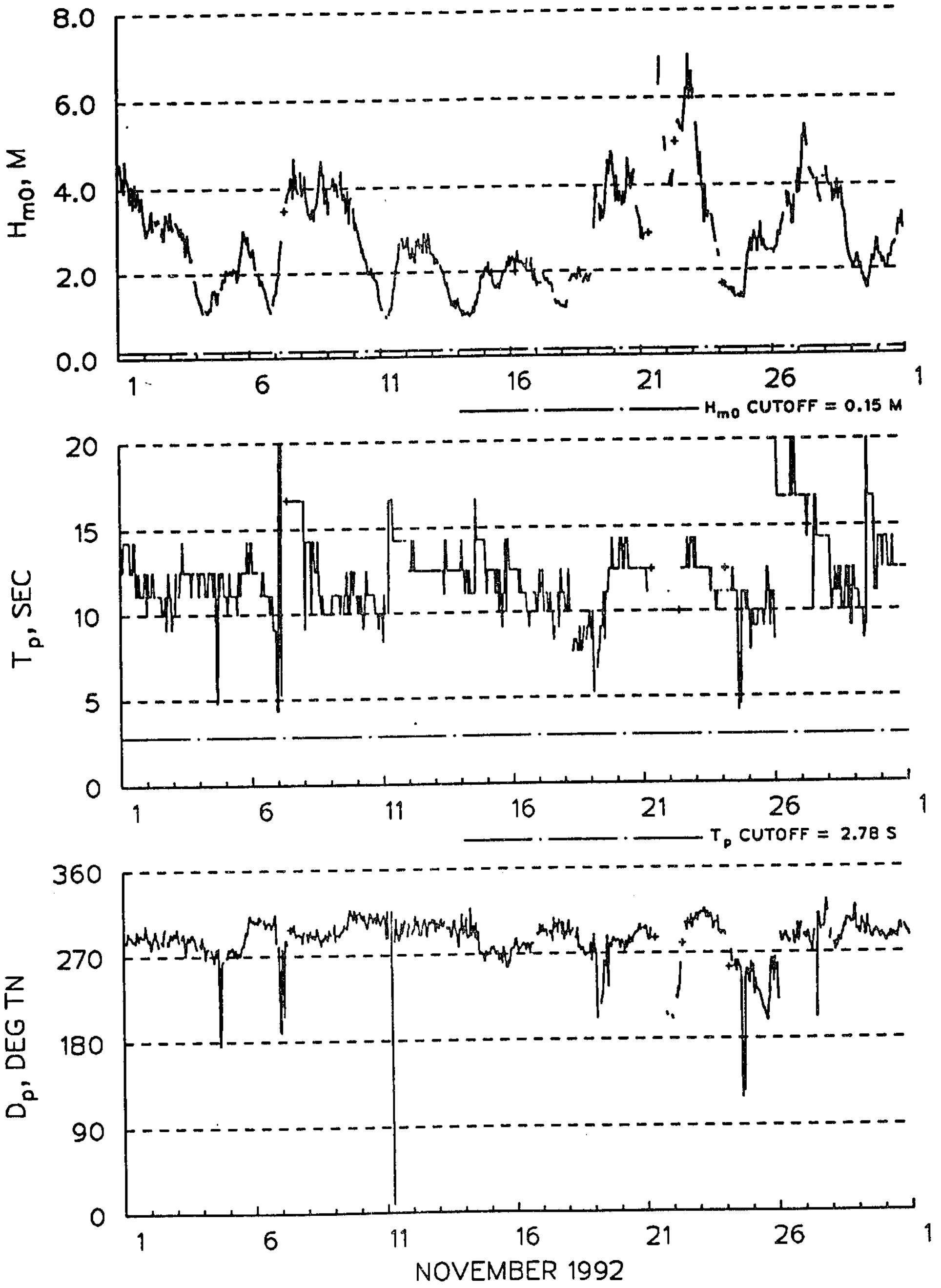

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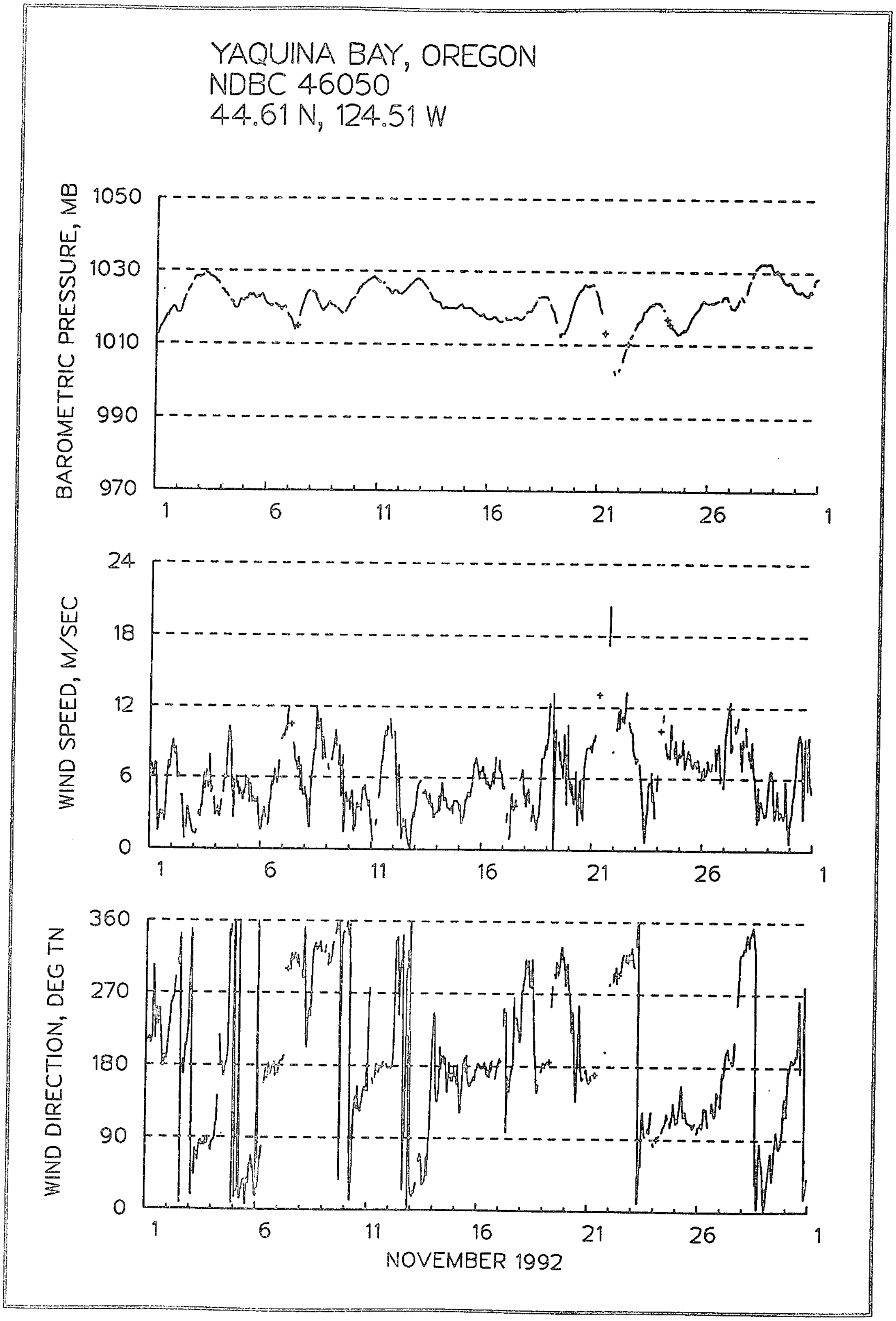
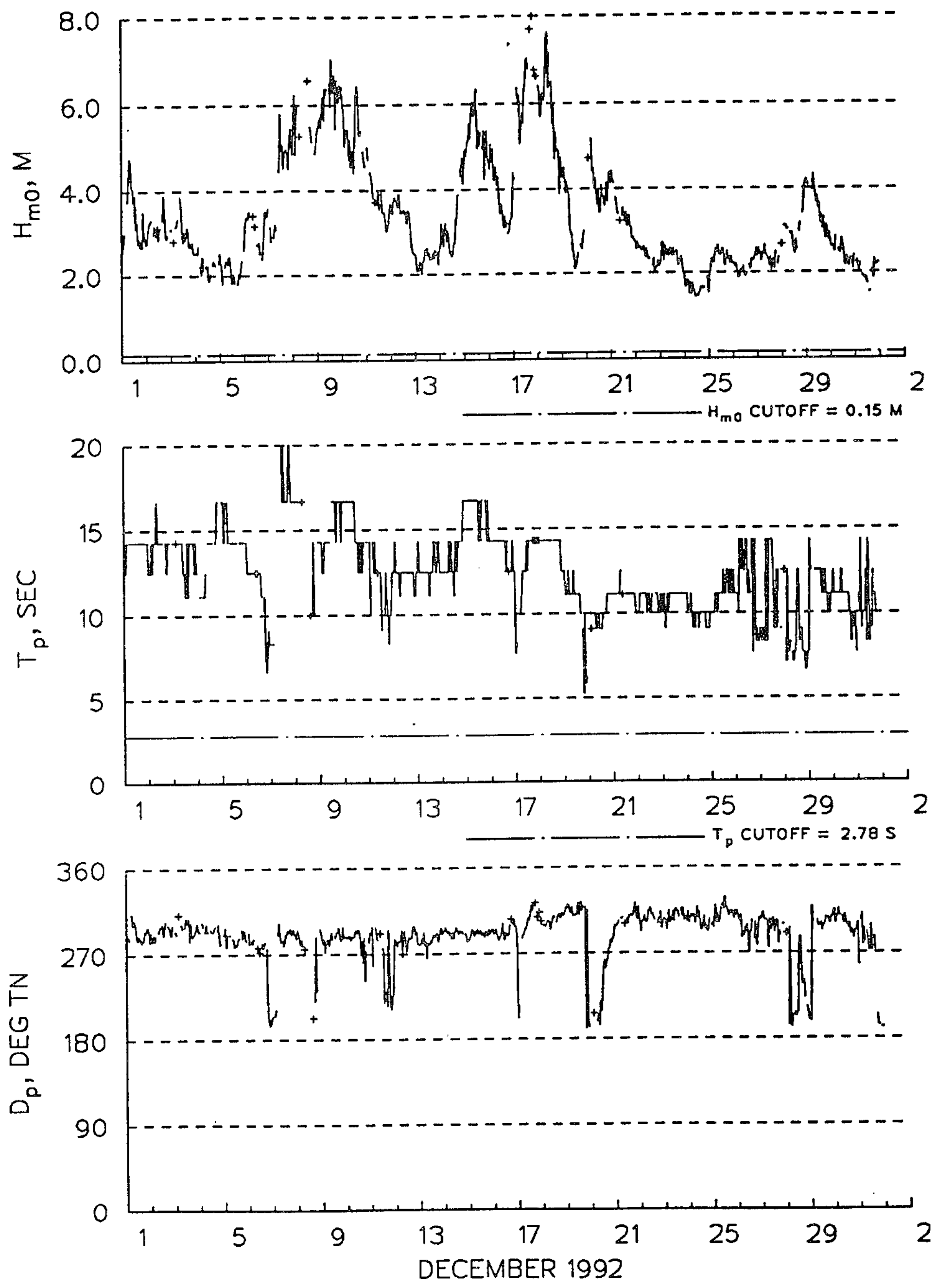


USAE COASTAL ENGINEERING RESEARCH CENTER

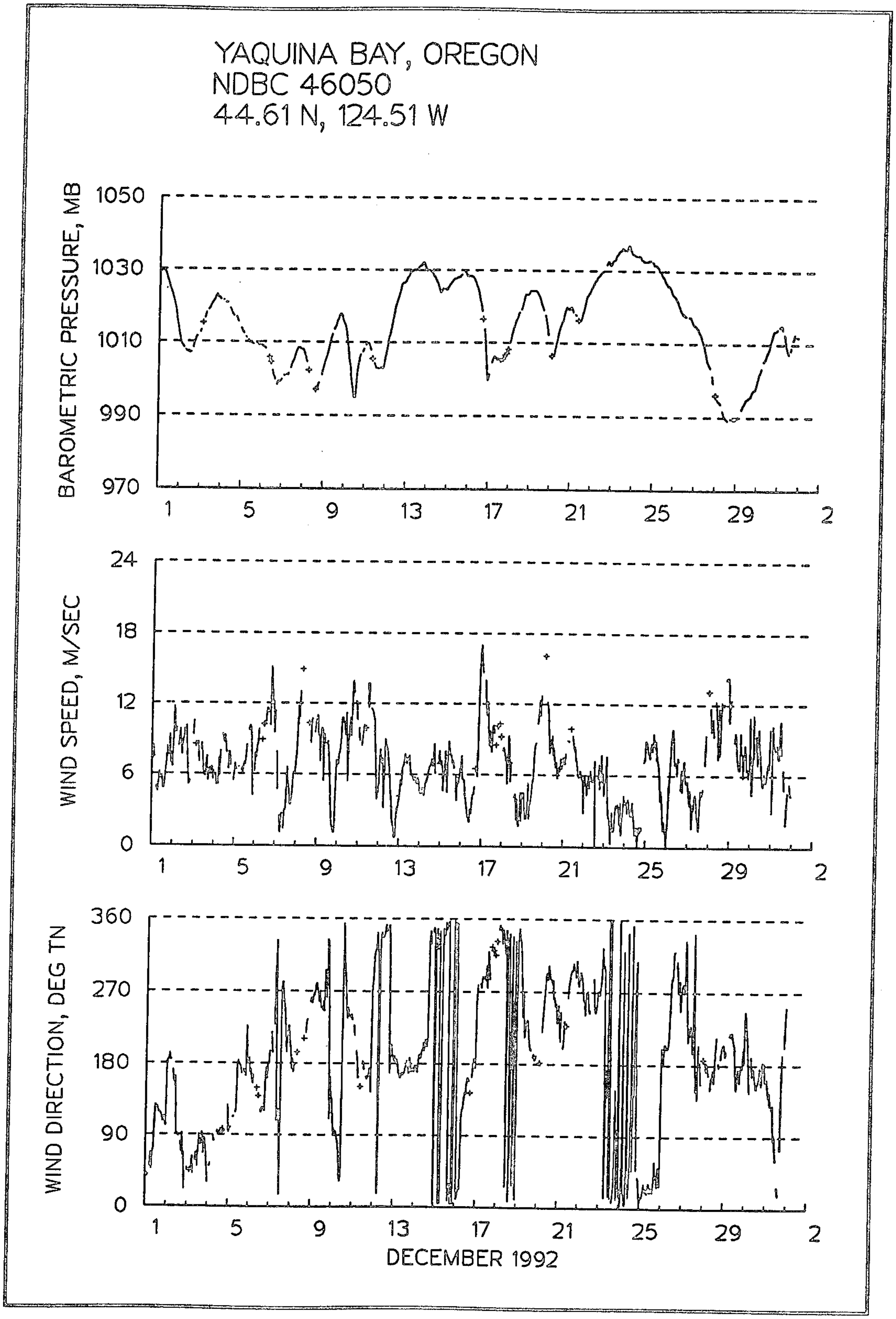
15-JUL-93

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



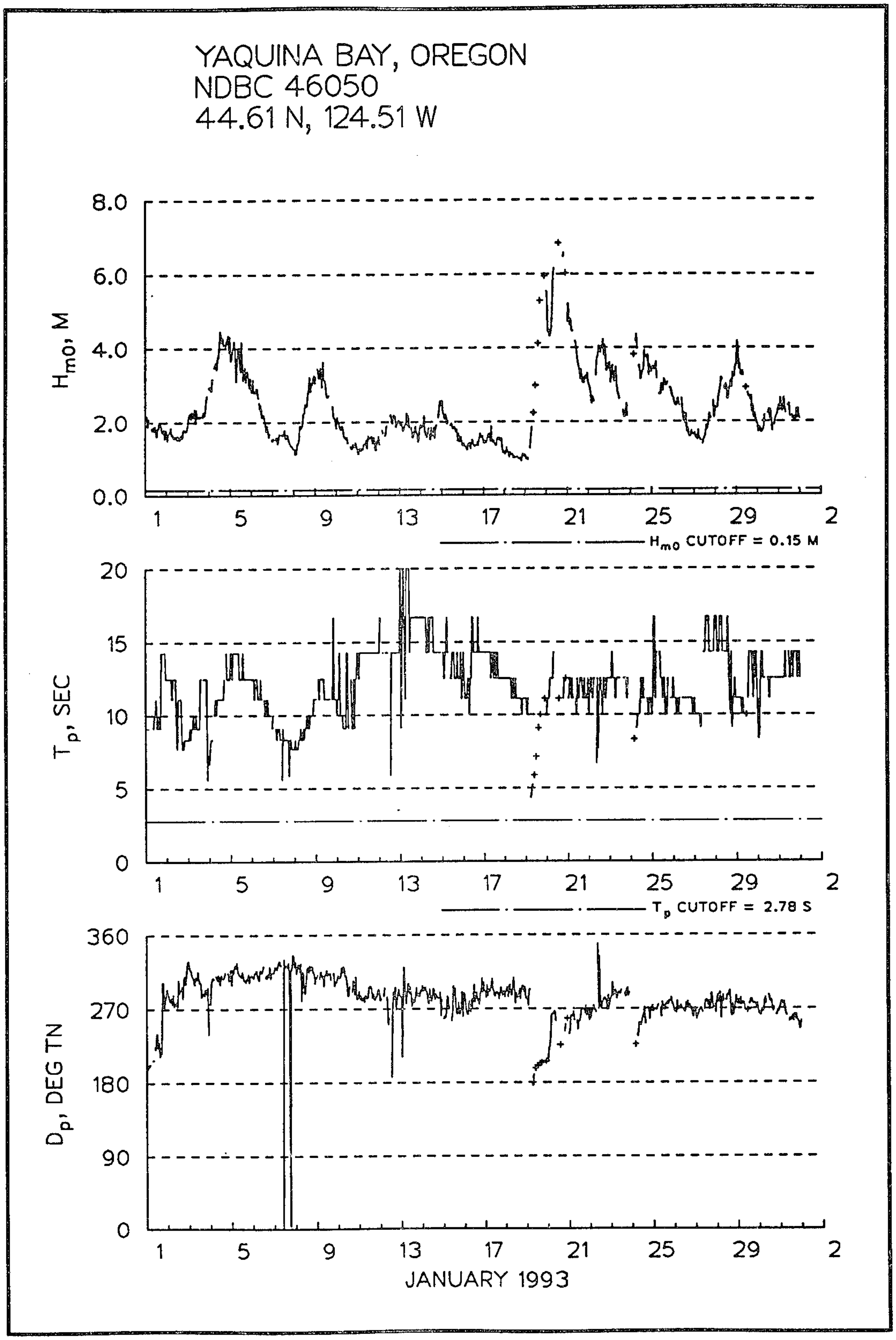
USAE COASTAL ENGINEERING RESEARCH CENTER

15–JUL–93

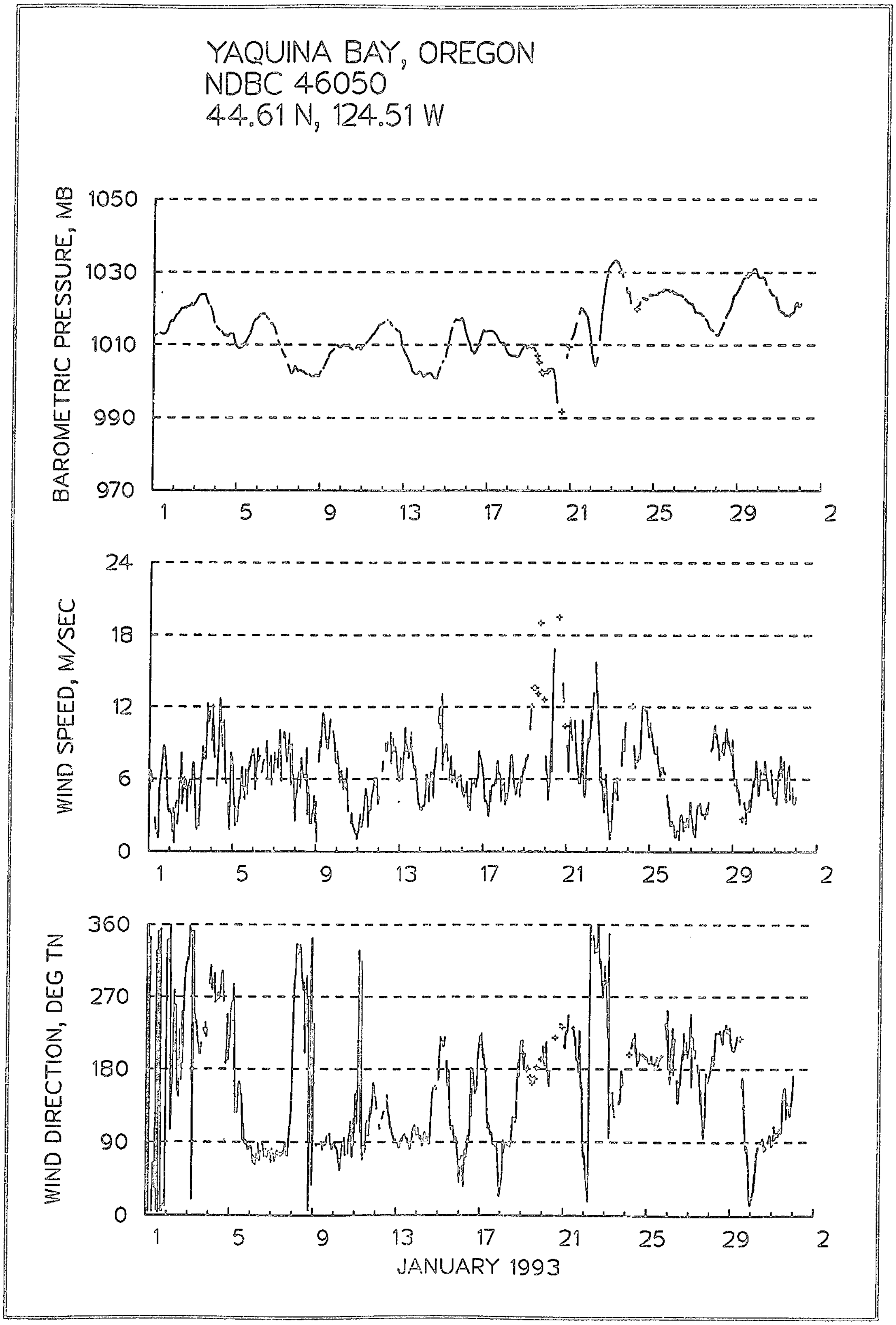


USAE COASTAL ENGINEERING RESEARCH CENTER

15-JUL-93

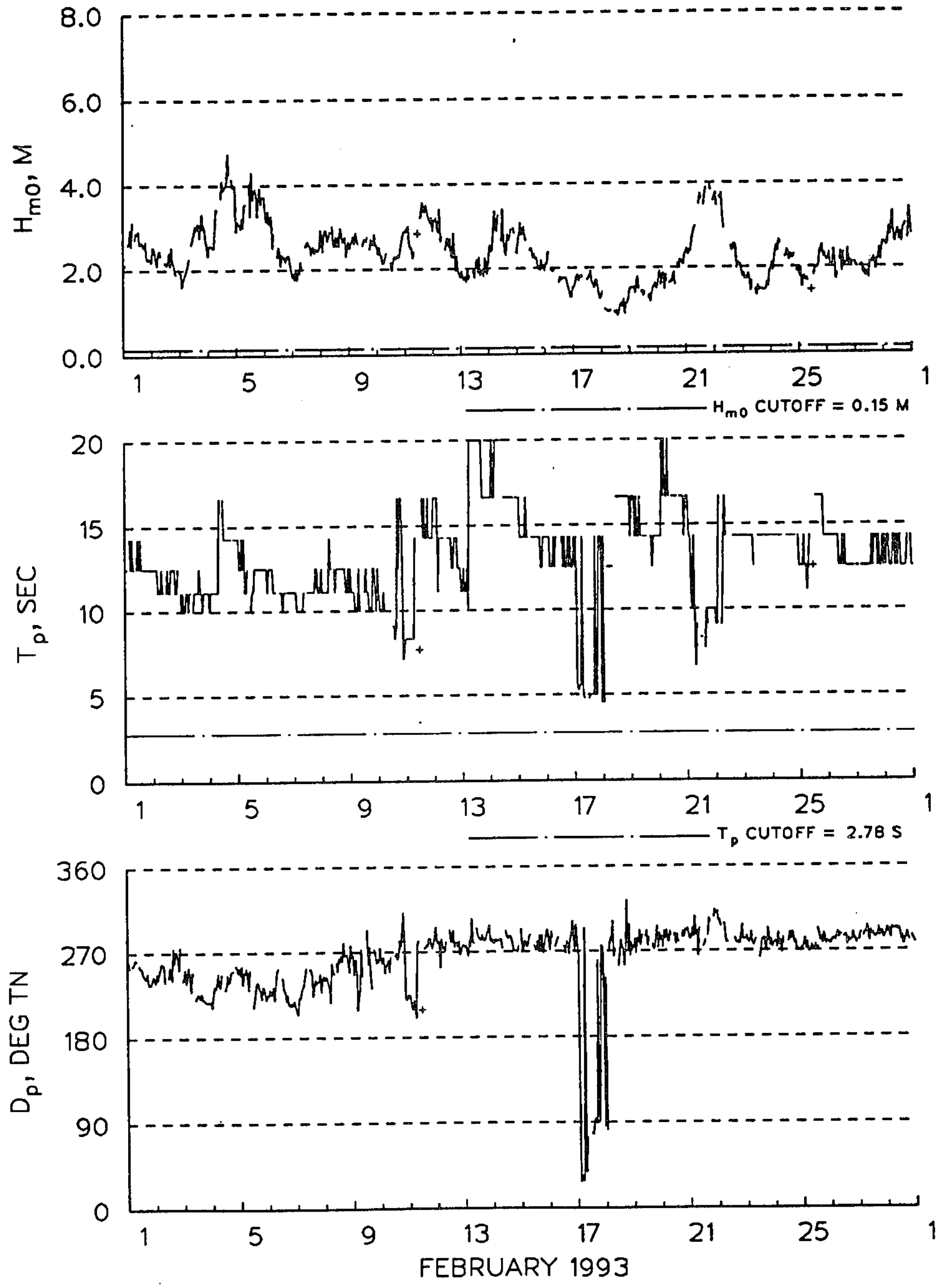


USAE COASTAL ENGINEERING RESEARCH CENTER 15-JUL-93

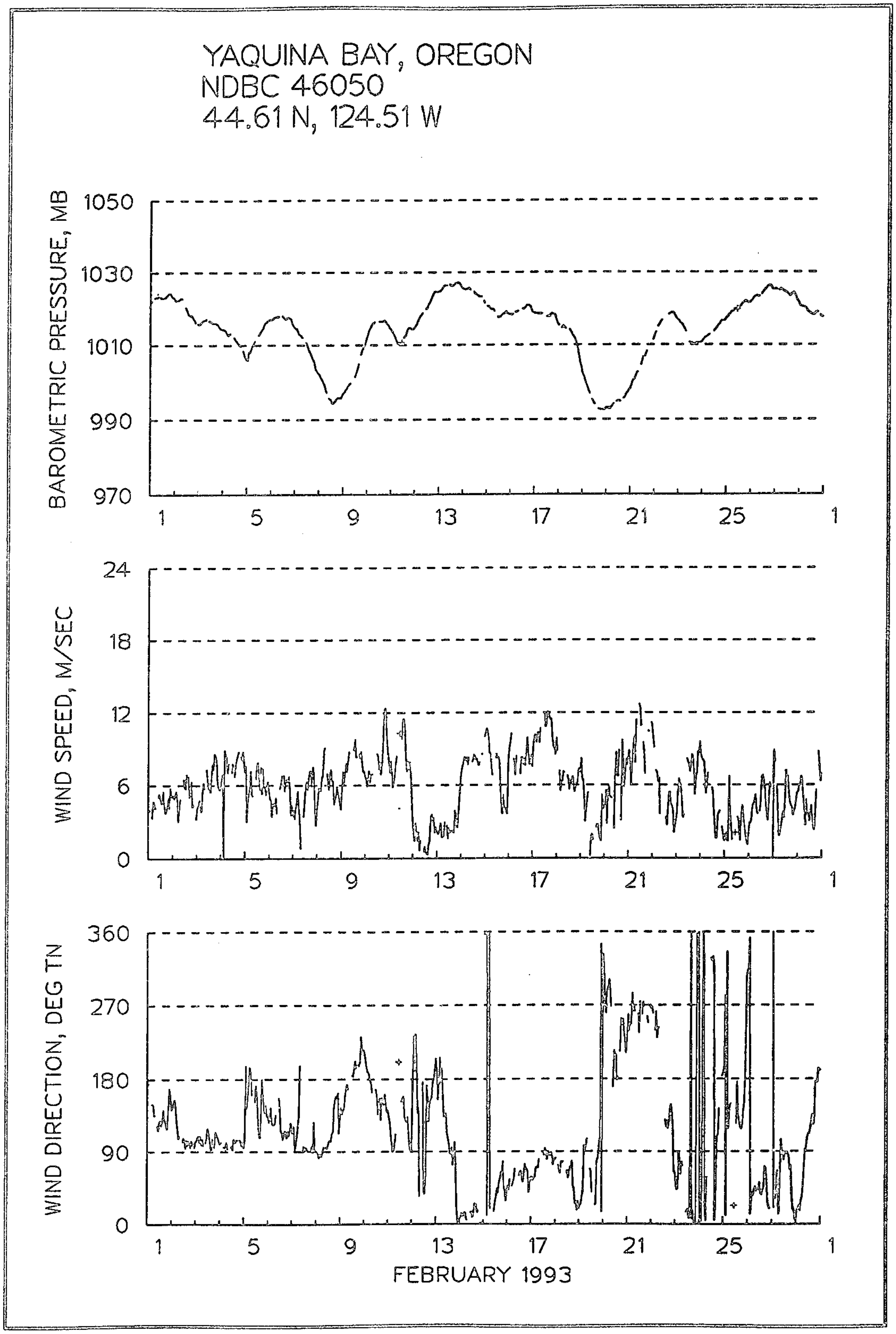


USAE COASTAL ENGINEERING RESEARCH CENTER 15-JUL-93

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W

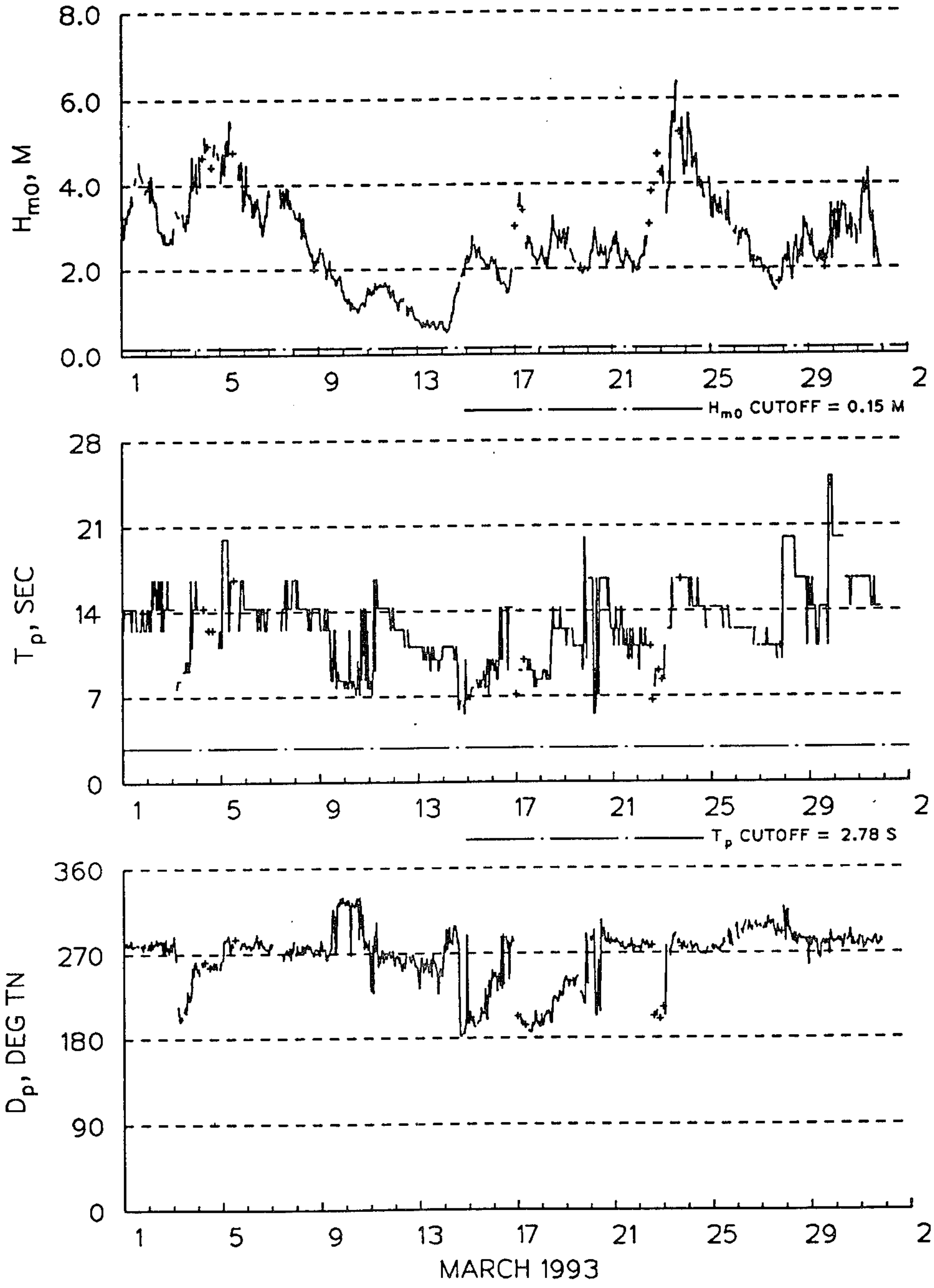


USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93



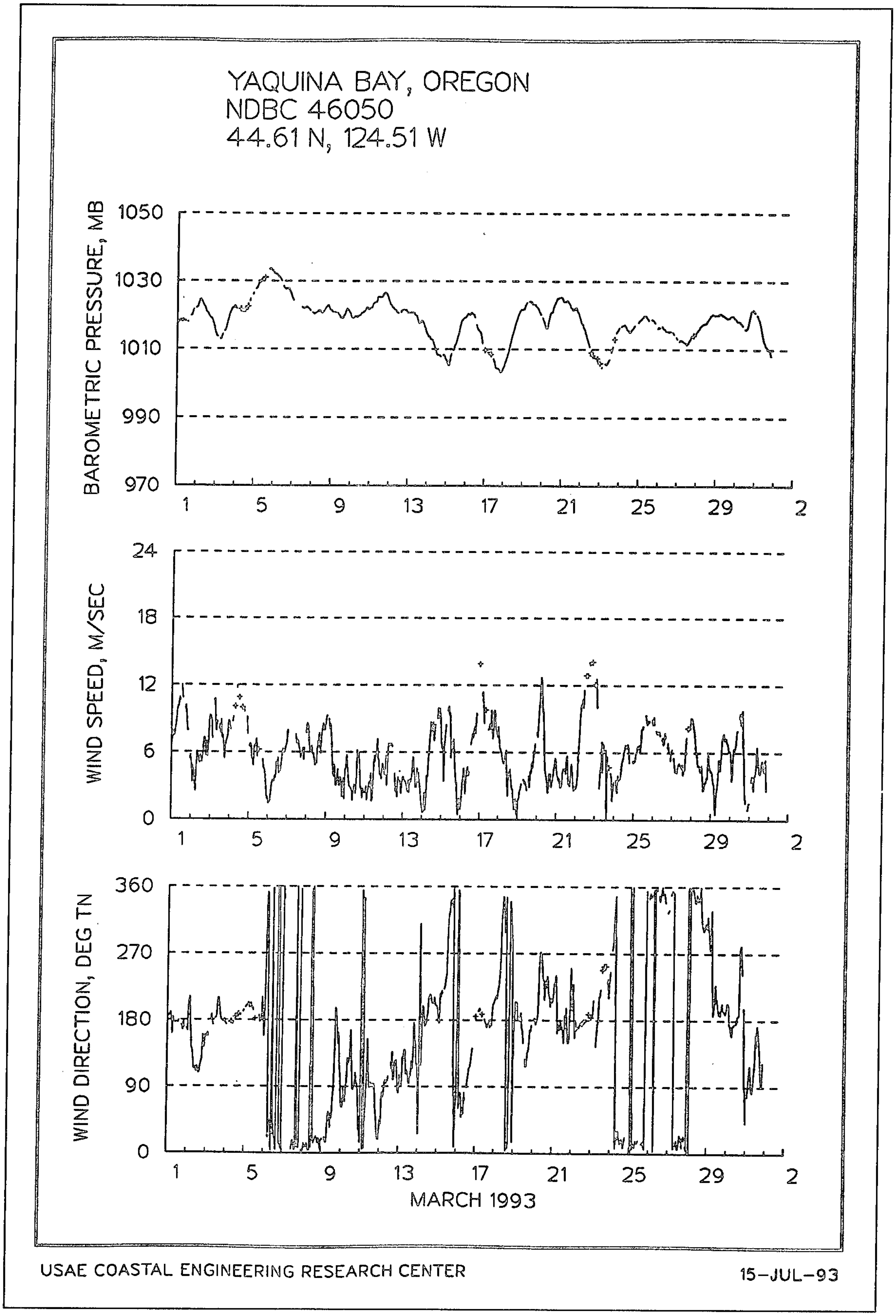
USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93

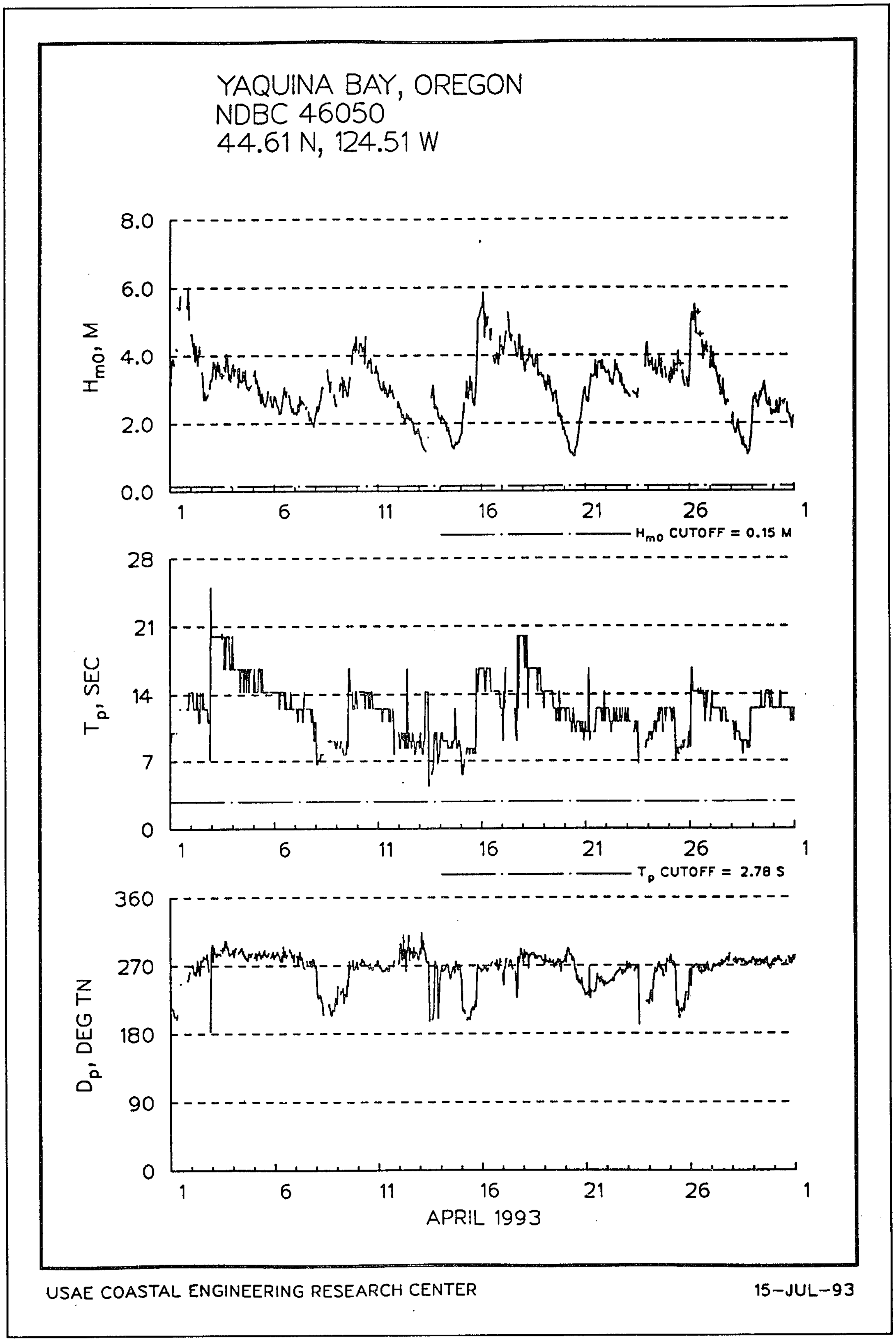
YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



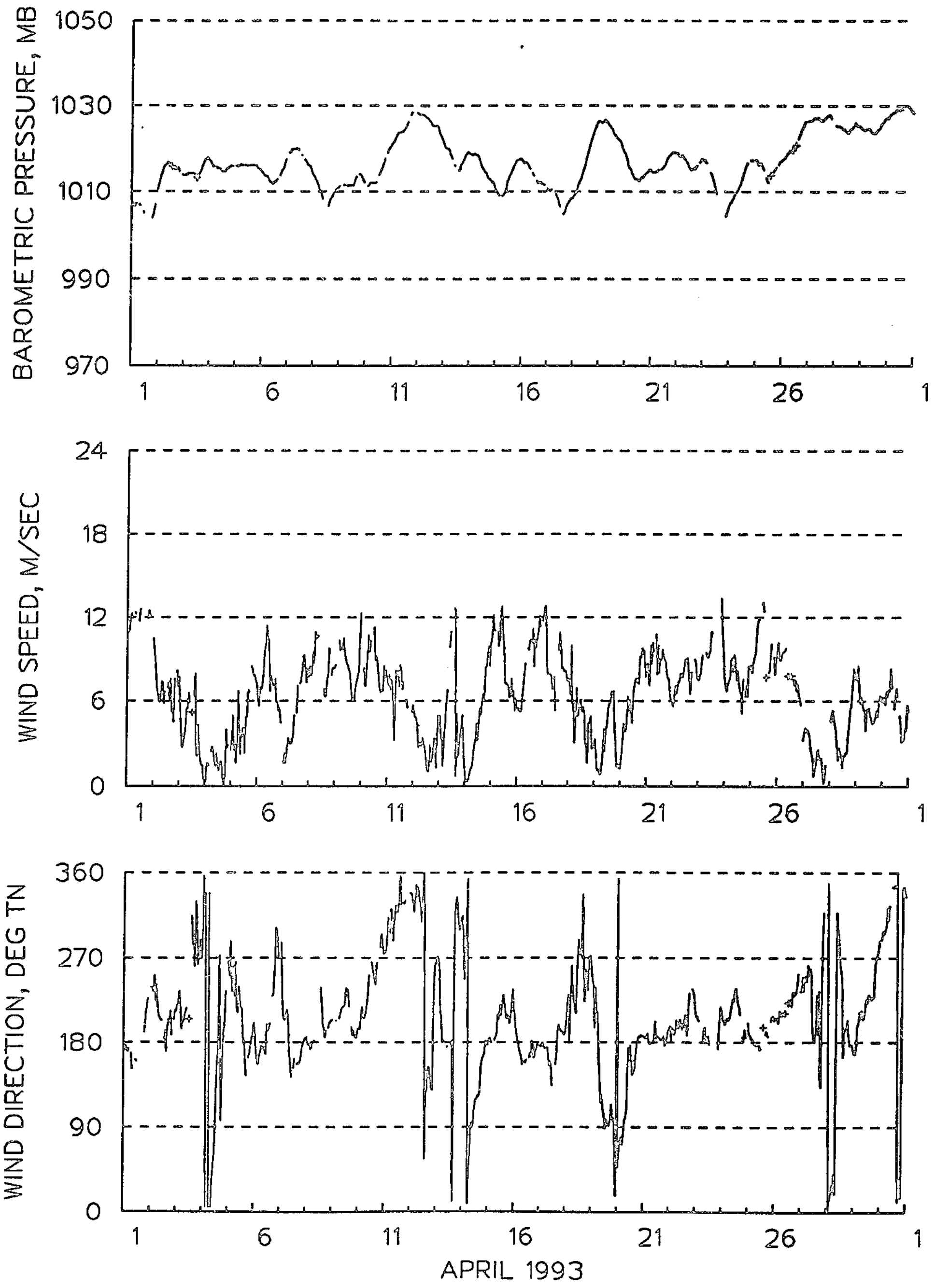
USAE COASTAL ENGINEERING RESEARCH CENTER

15-JUL-93

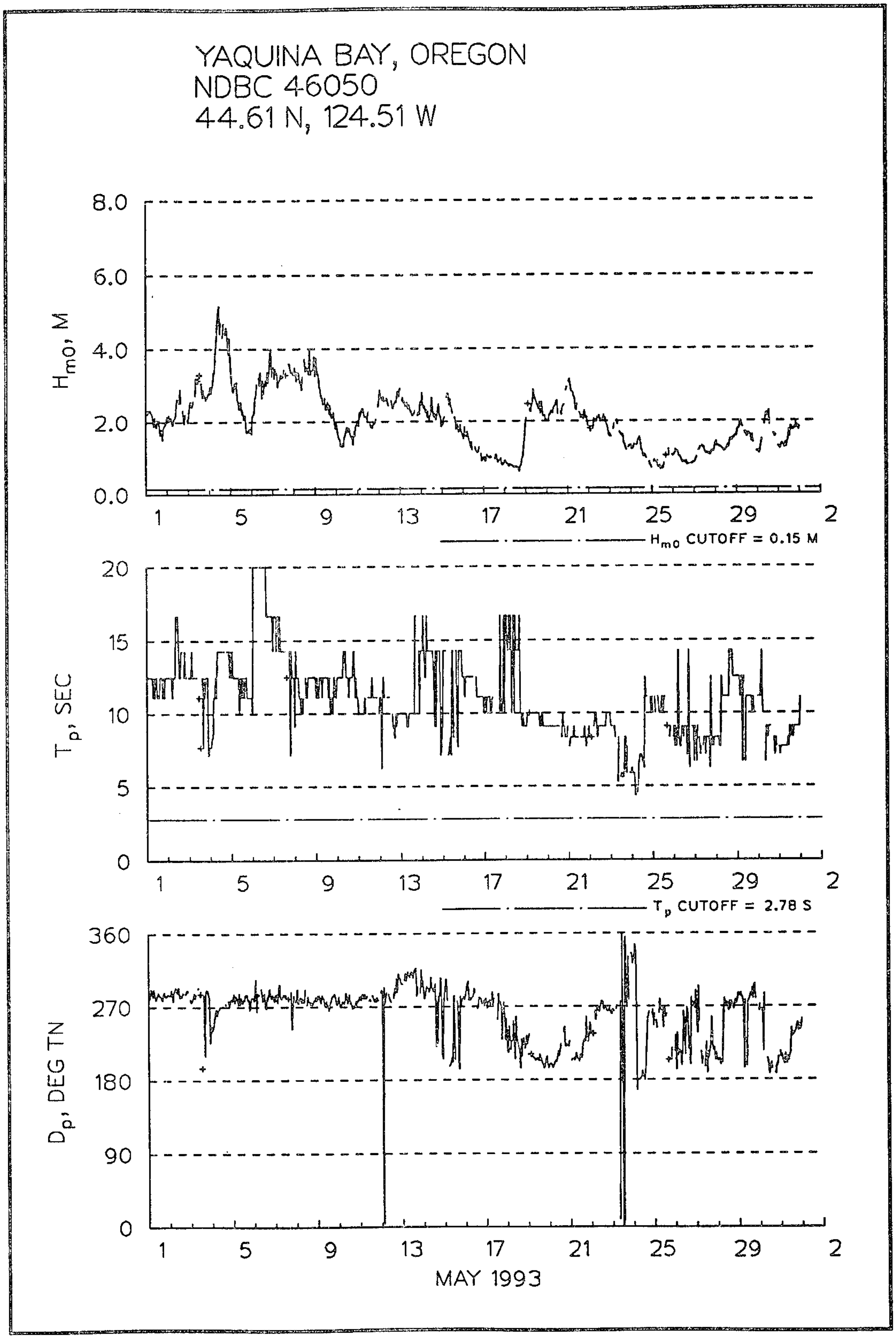

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
5
9
13
17
21
25
29
2
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MARCH 1993
USAE COASTAL ENGINEERING RESEARCH CENTER
15-JUL-93


YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W
H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
H_{mo} CUTOFF = 0.15 M
T_p, SEC
28
21
14
7
0
1
6
11
16
21
26
1
T_p CUTOFF = 2.78 S
D_p, DEG TN
360
270
180
90
0
1
6
11
16
21
26
1
APRIL 1993
USAE COASTAL ENGINEERING RESEARCH CENTER
15-JUL-93

YAQUINA BAY, OREGON
NDBC 46050
44.61 N, 124.51 W



USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93



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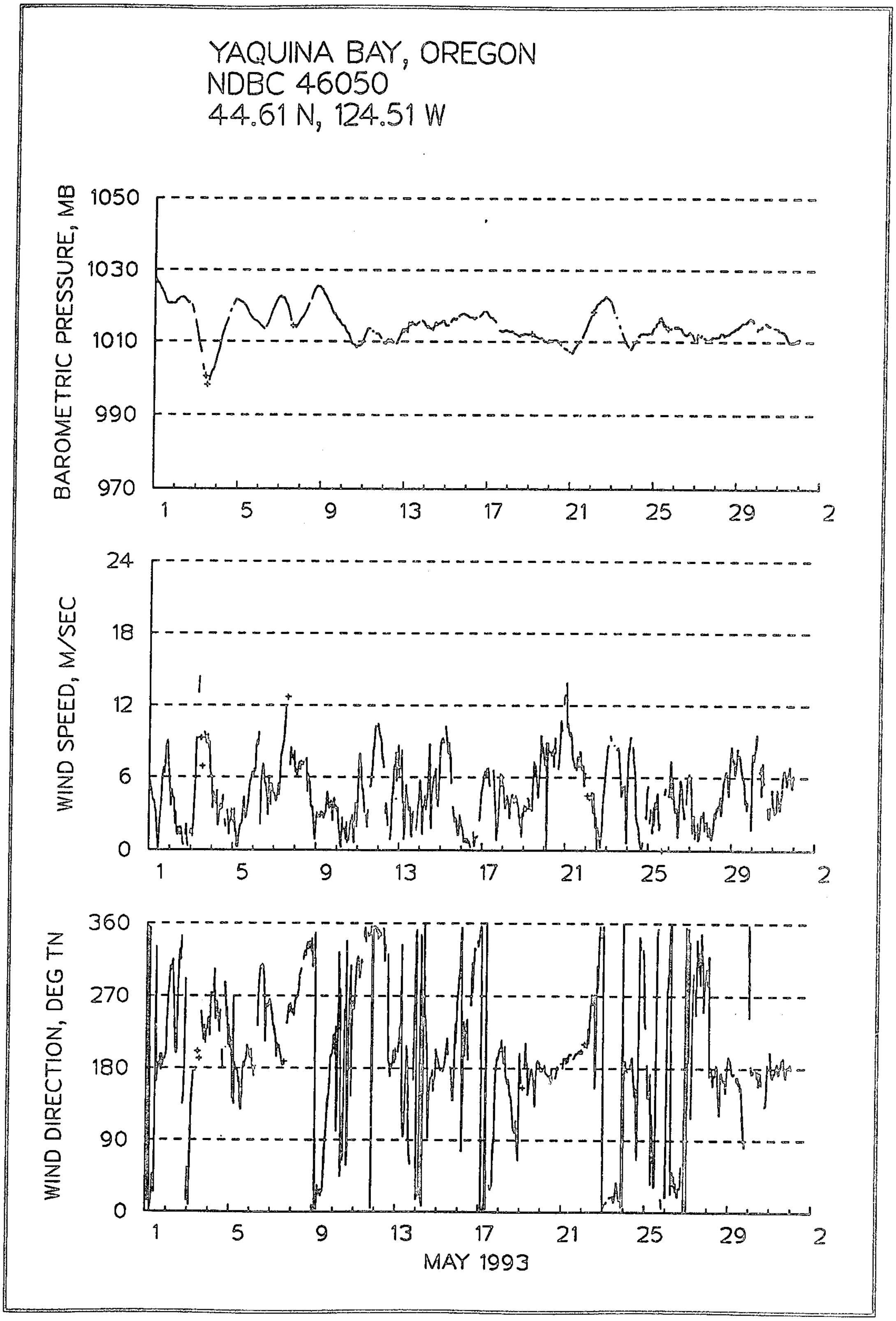
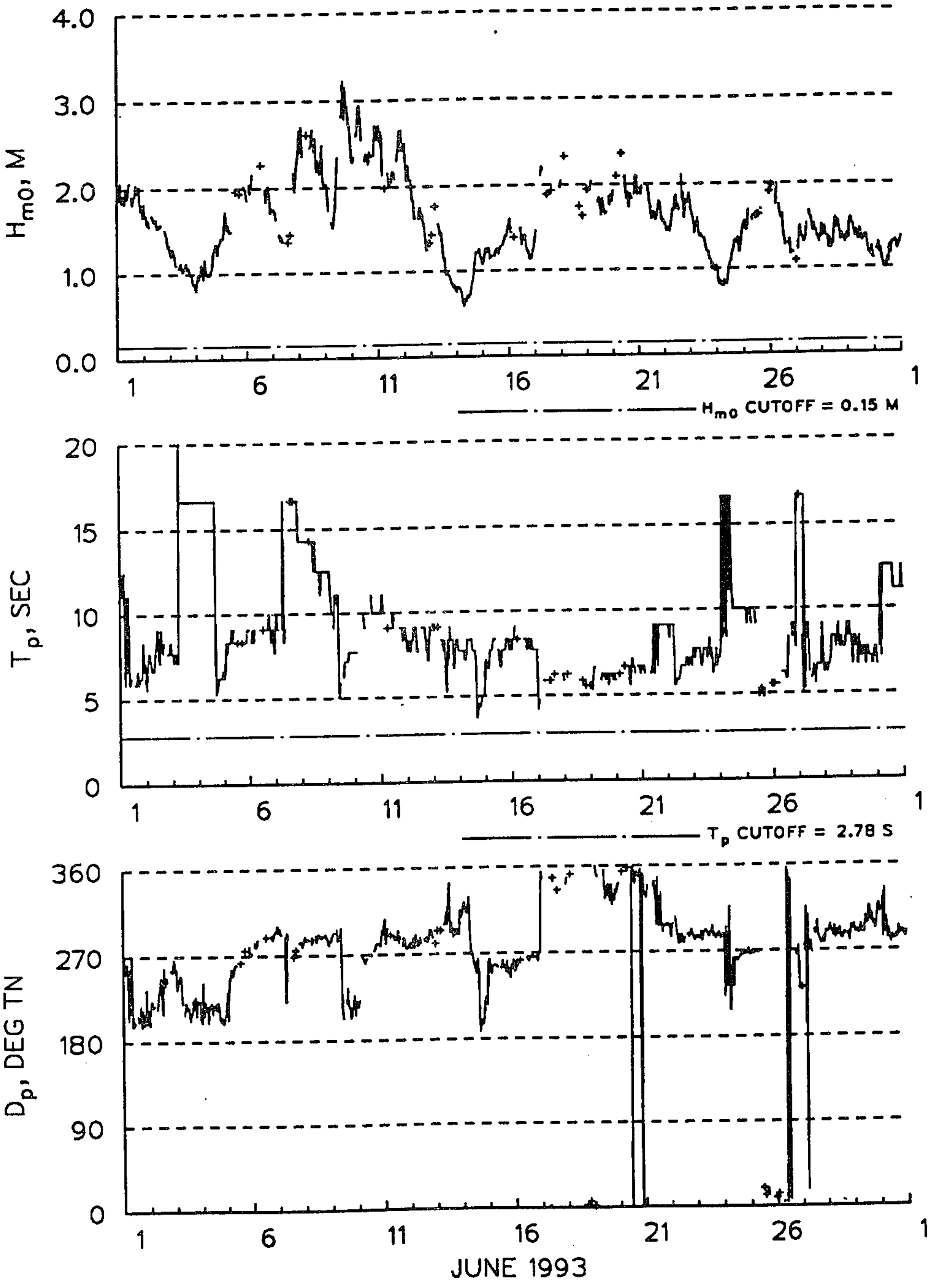


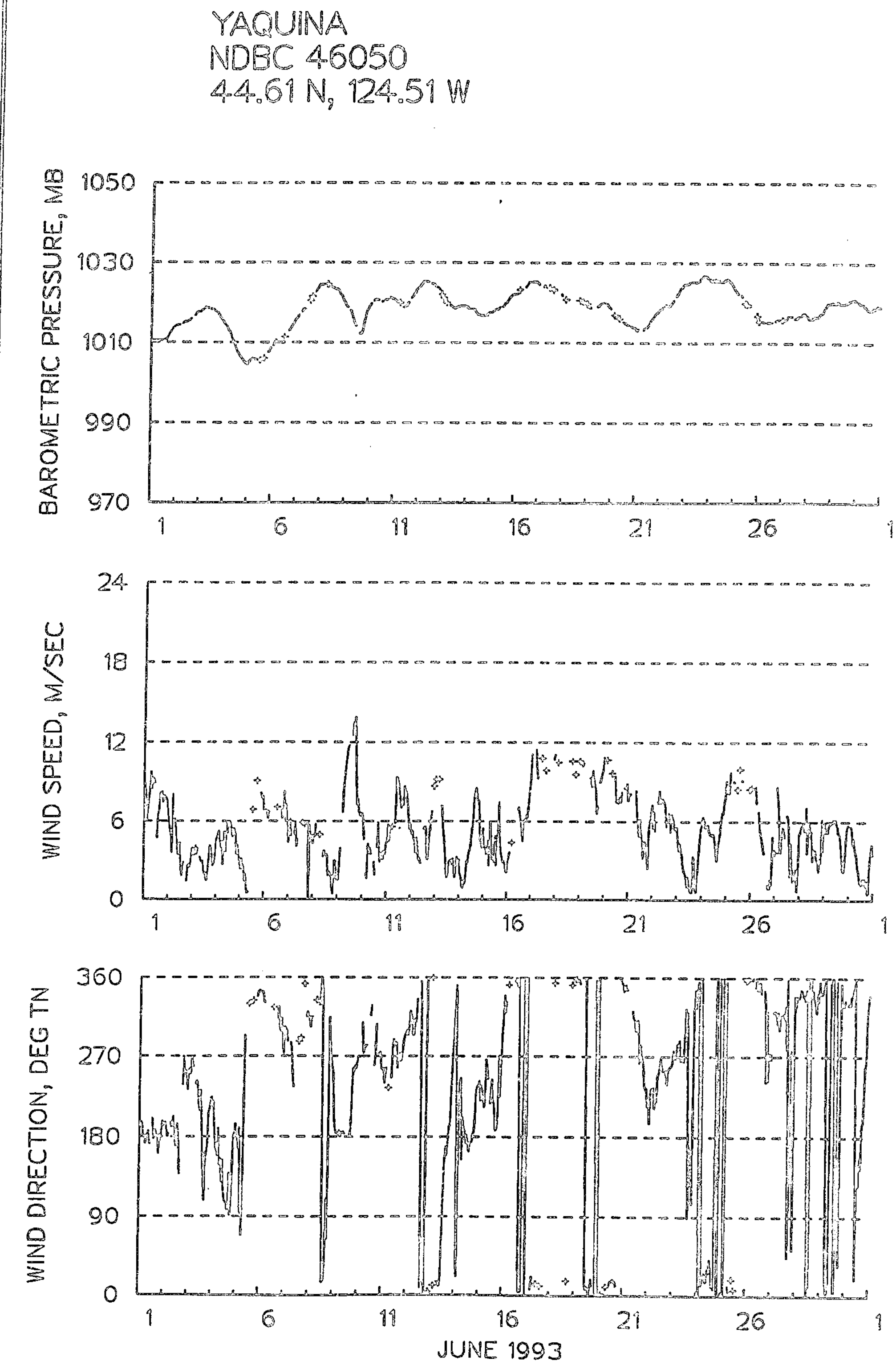
USAE COASTAL ENGINEERING RESEARCH CENTER 15–JUL–93

YAQUINA
NDBC 46050
44.61 N, 124.51 W

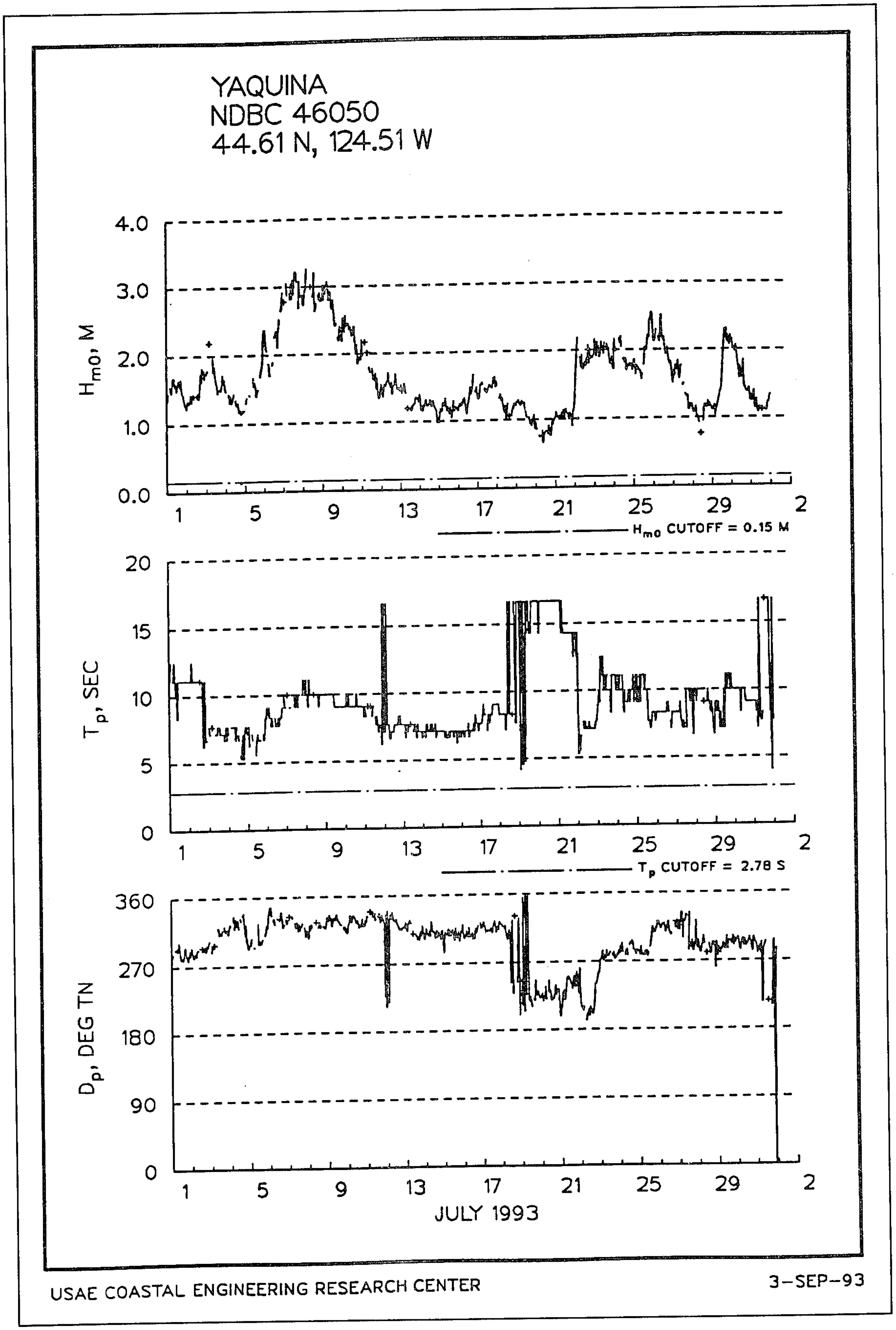


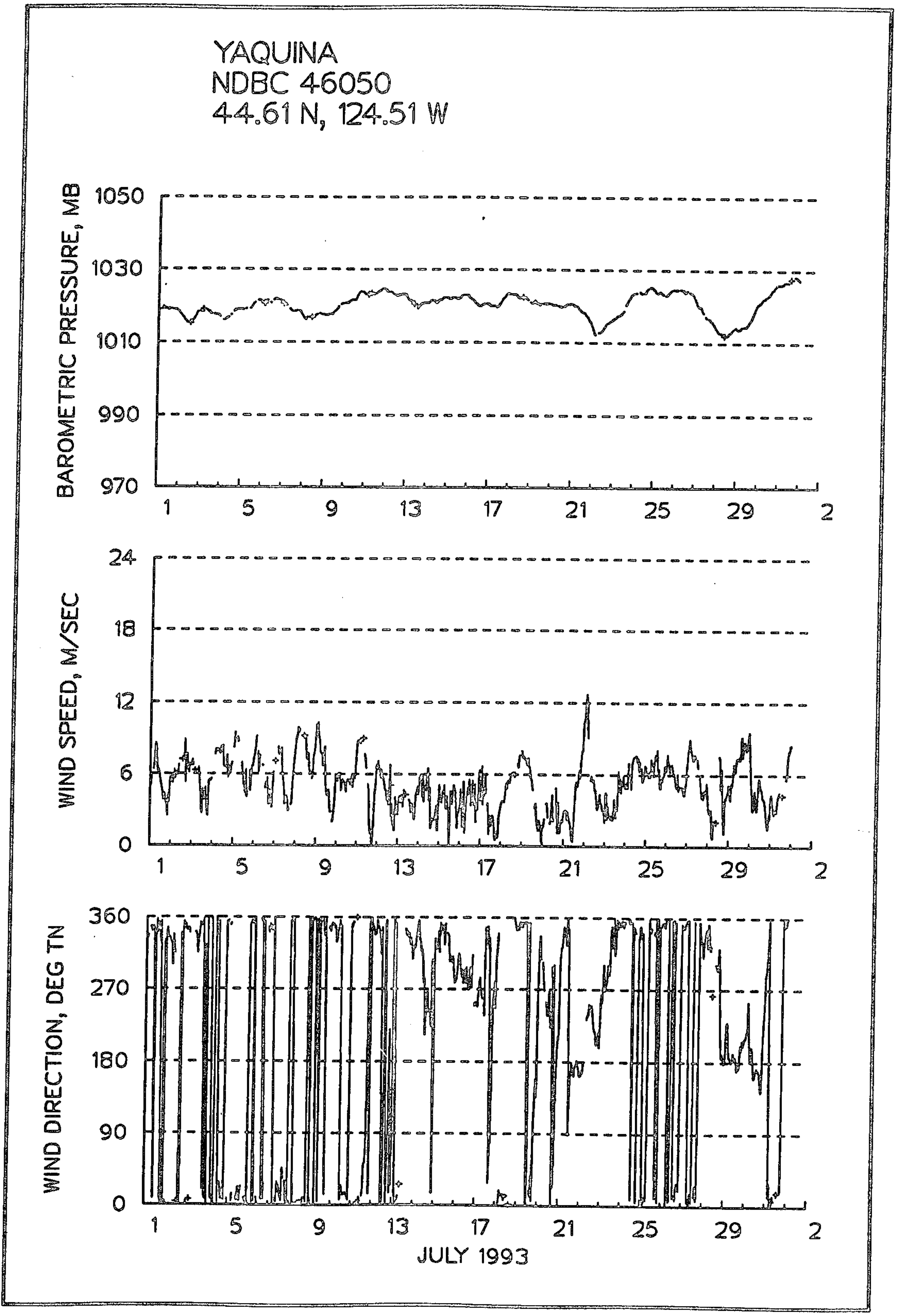
USAE COASTAL ENGINEERING RESEARCH CENTER

1–SEP–93

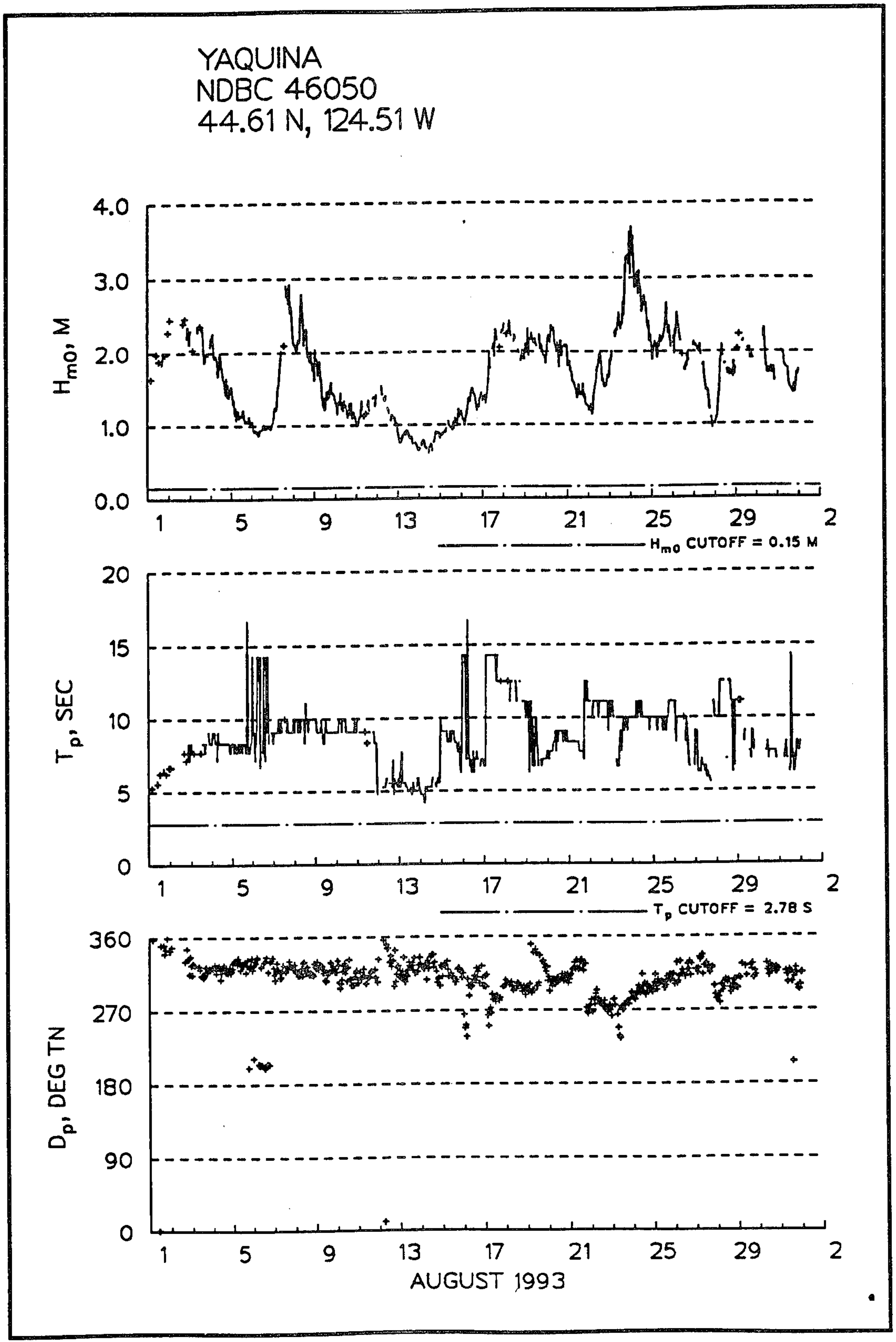


USAE COASTAL ENGINEERING RESEARCH CENTER 1-SEP-93

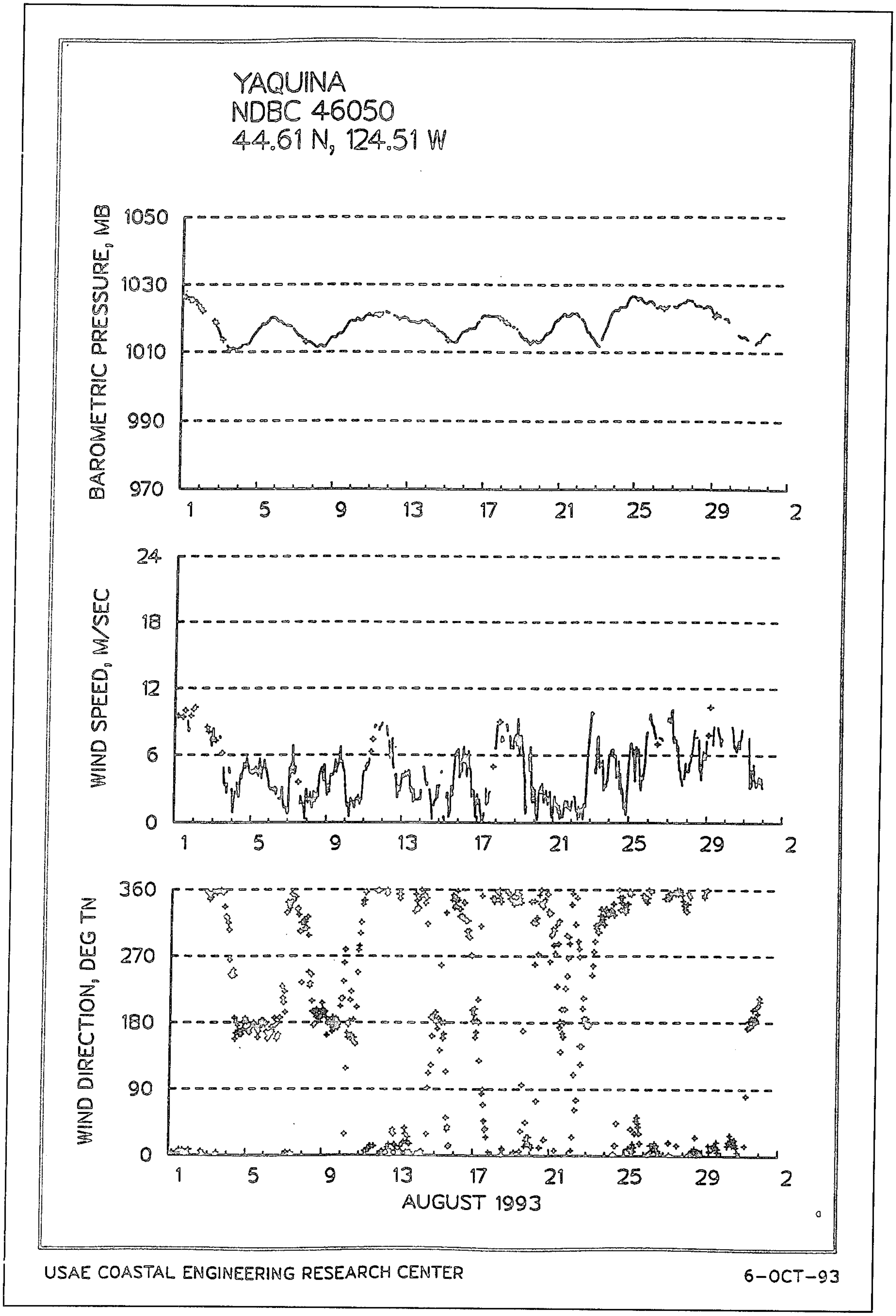

YAQUINA
NDBC 46050
44.61 N, 124.51 W
4.0
3.0
2.0
1.0
0.0
H_{m0}, M
1
5
9
13
17
21
25
29
2
H_{m0} CUTOFF = 0.15 M
20
15
10
5
0
T_p, SEC
1
5
9
13
17
21
25
29
2
T_p CUTOFF = 2.78 S
360
270
180
90
0
D_p, DEG TN
1
5
9
13
17
21
25
29
2
JULY 1993
USAE COASTAL ENGINEERING RESEARCH CENTER
3-SEP-93



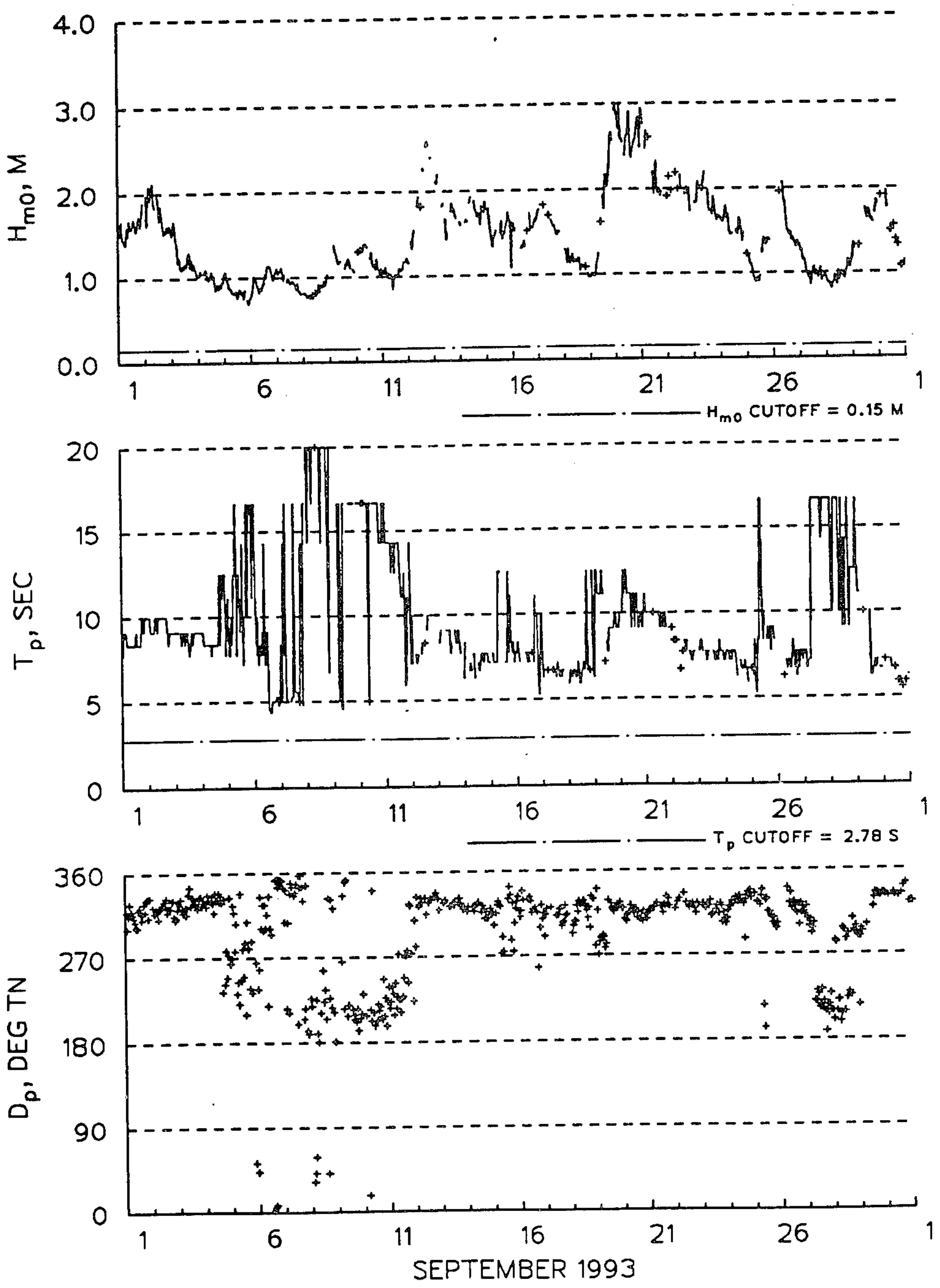
USAE COASTAL ENGINEERING RESEARCH CENTER 3–SEP–93



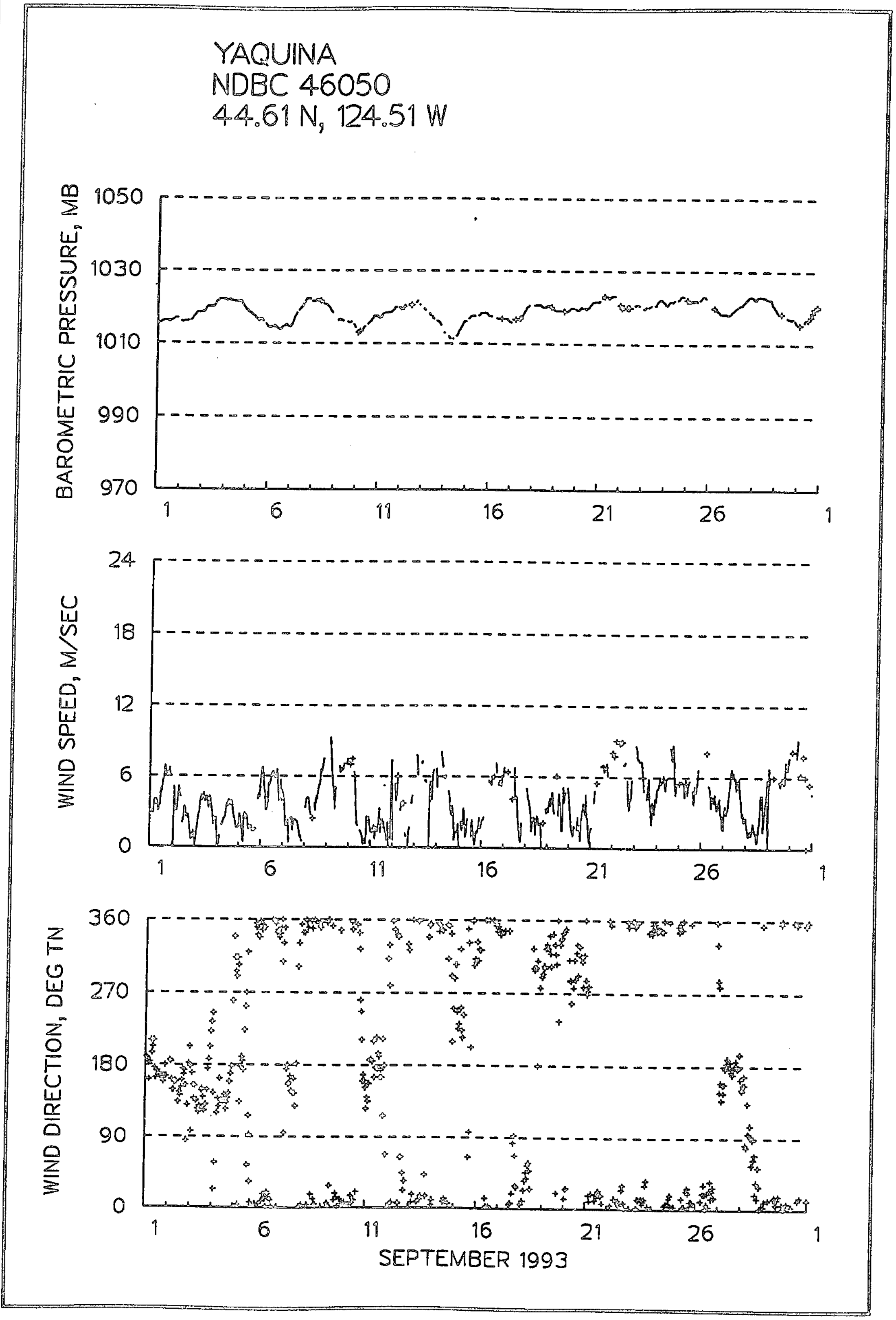
USAE COASTAL ENGINEERING RESEARCH CENTER 6–OCT–93


YAQUINA
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
5
9
13
17
21
25
29
2
WIND SPEED, M/SEC
24
18
12
6
0
1
5
9
13
17
21
25
29
2
WIND DIRECTION, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
AUGUST 1993
USAE COASTAL ENGINEERING RESEARCH CENTER
6-OCT-93

YAQUINA
NDBC 46050
44.61 N, 124.51 W

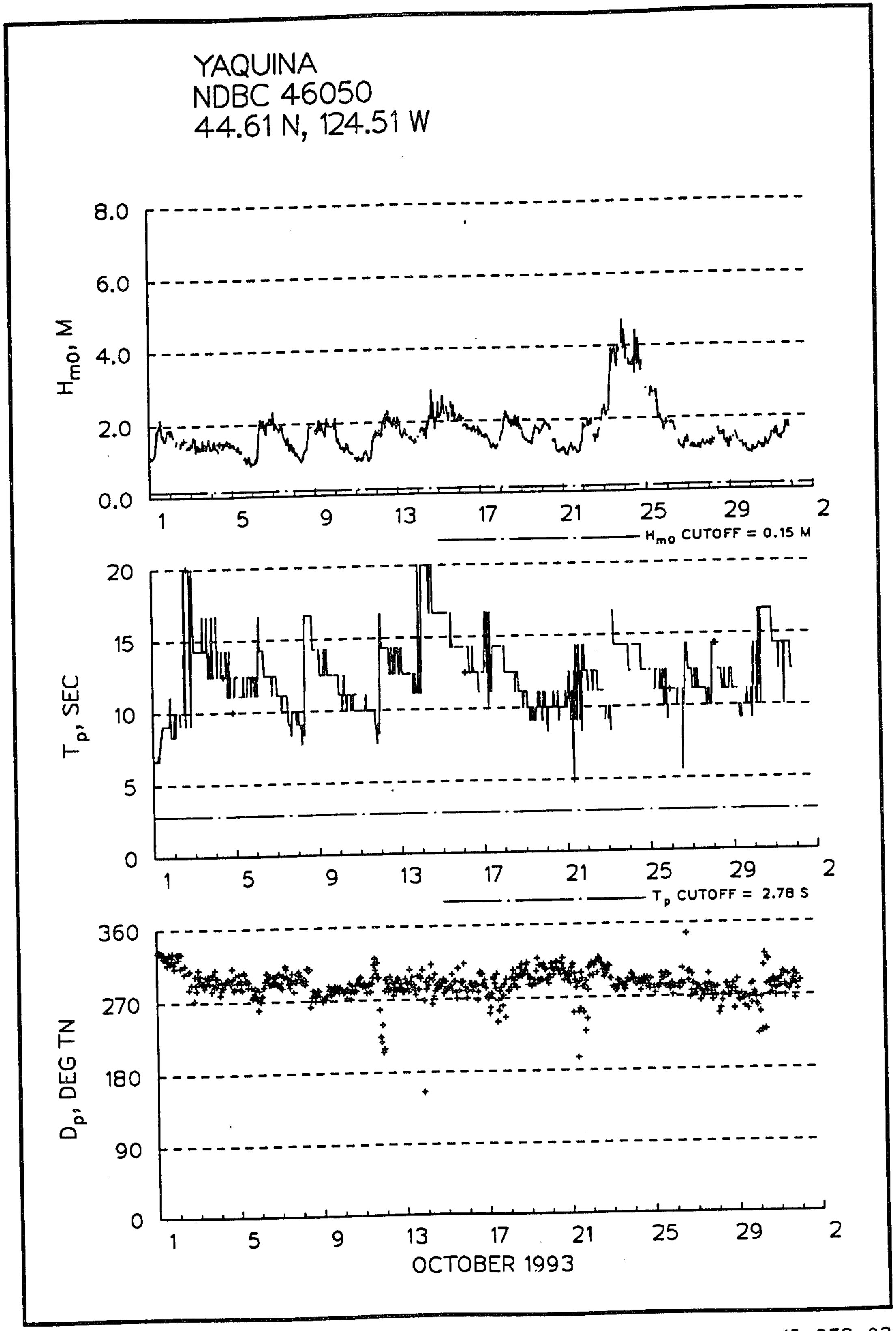


USAE COASTAL ENGINEERING RESEARCH CENTER 28-OCT-93



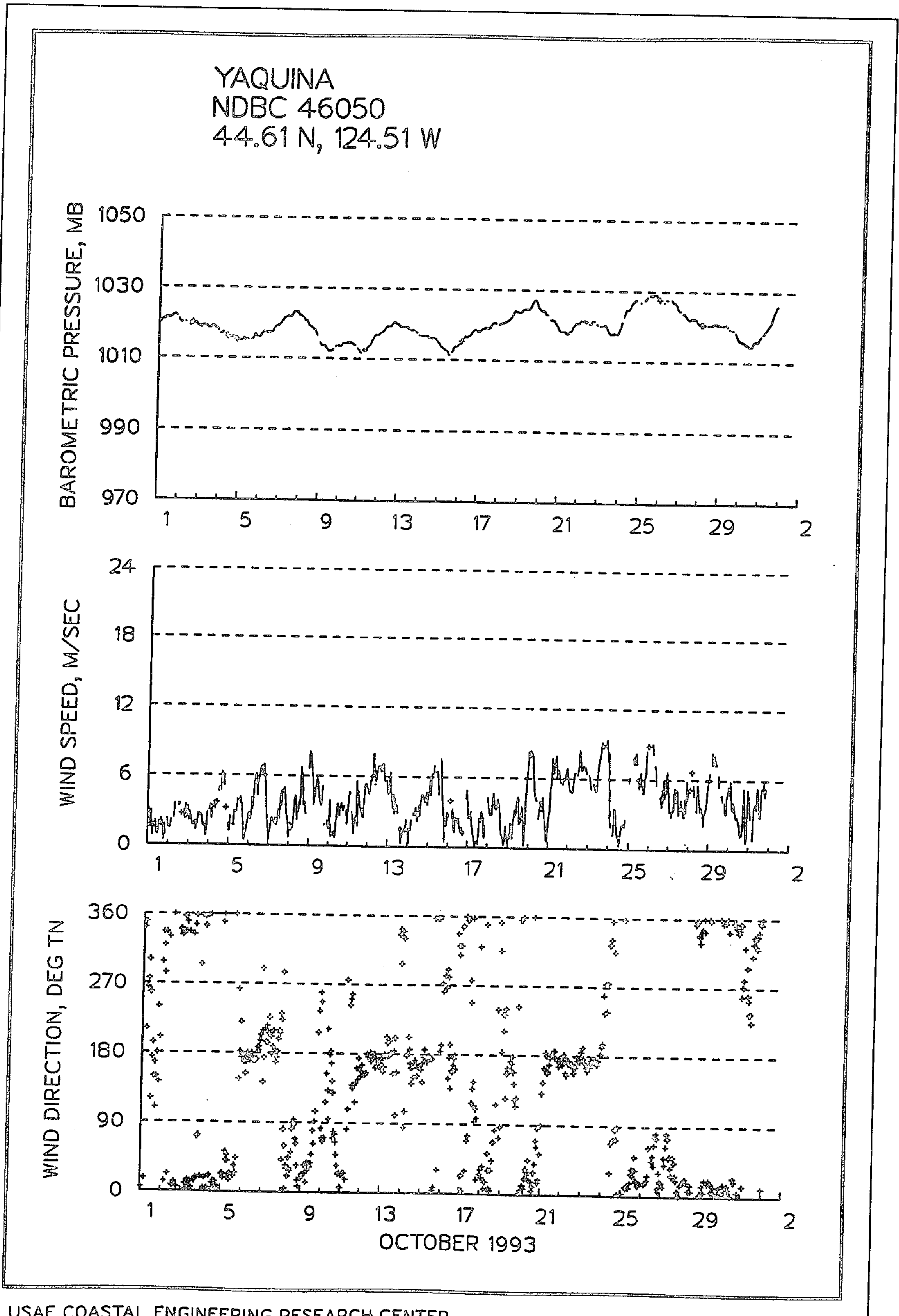
USAE COASTAL ENGINEERING RESEARCH CENTER

28-OCT-93



USAE COASTAL ENGINEERING RESEARCH CENTER

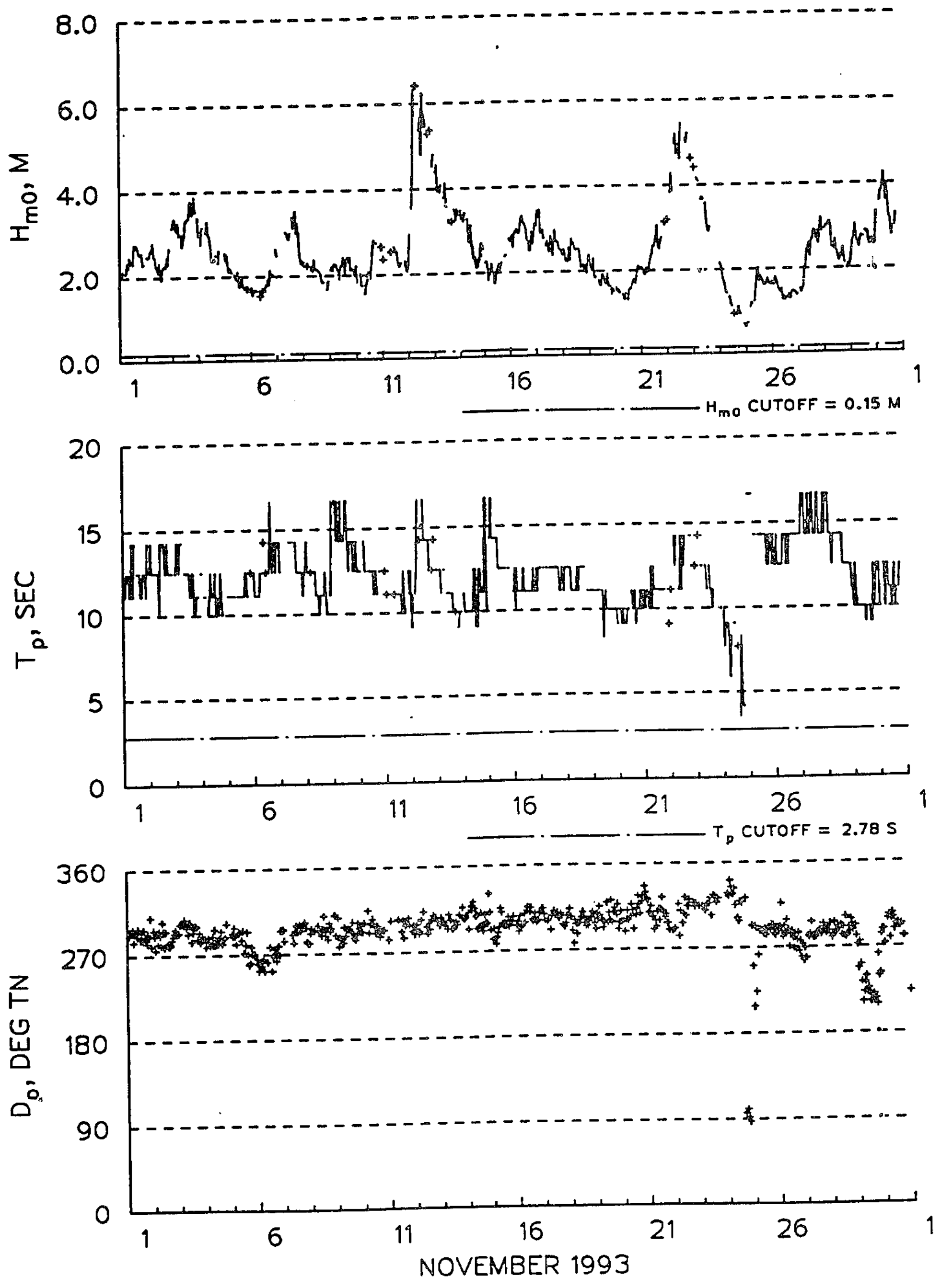
15-DEC-93



USAE COASTAL ENGINEERING RESEARCH CENTER

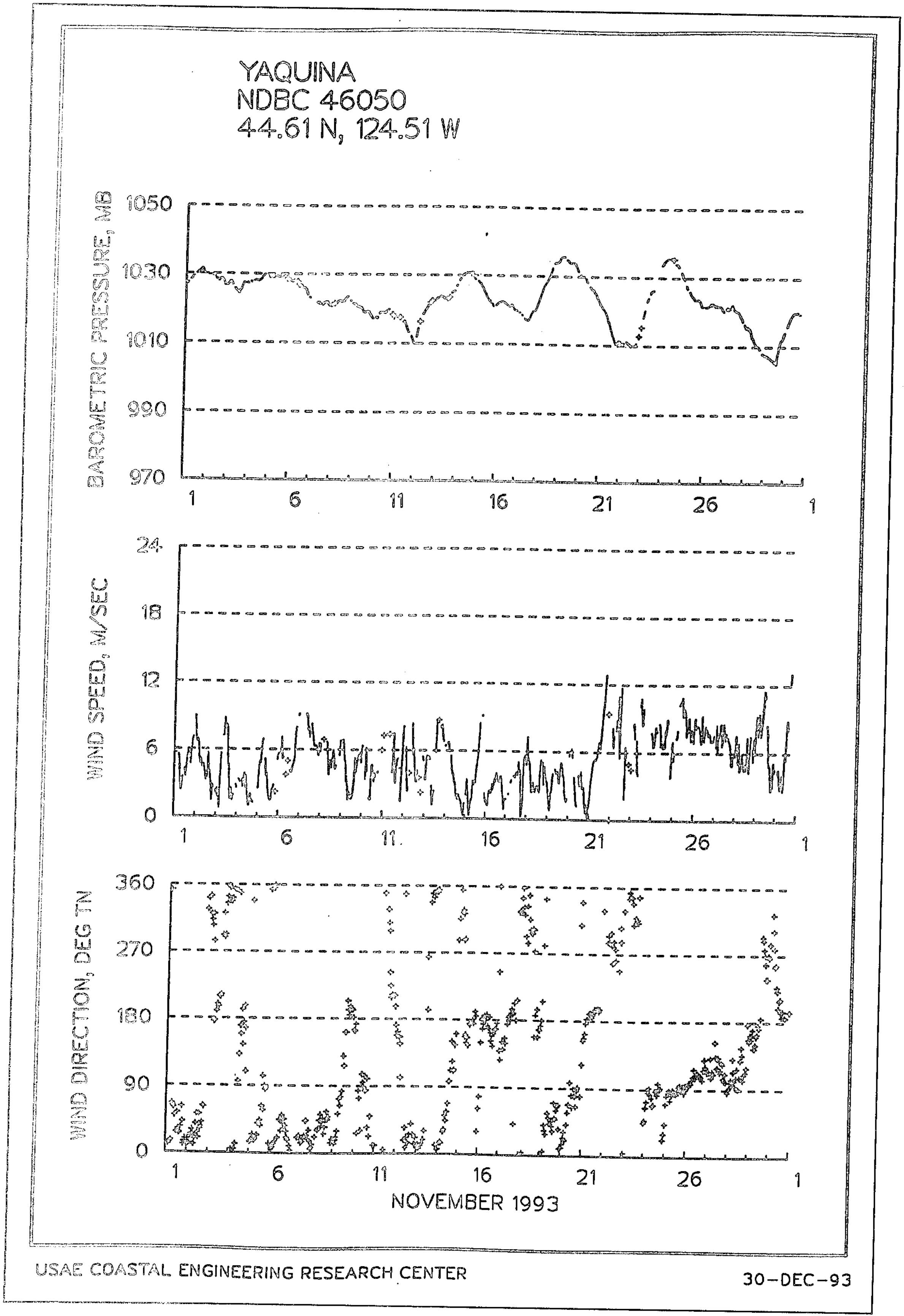
15-DEC-93

YAQUINA
NDBC 46050
44.61 N, 124.51 W



USAE COASTAL ENGINEERING RESEARCH CENTER

30-DEC-93


YAQUINA
NDBC 46050
44.61 N, 124.51 W
BAROMETRIC PRESSURE, MB
1050
1030
1010
990
970
1
6
11
16
21
26
1
WIND SPEED, M/SEC
24
18
12
6
0
1
6
11
16
21
26
1
WIND DIRECTION, DEG TN
360
270
180
90
0
1
6
11
16
21
26
1
NOVEMBER 1993
USAE COASTAL ENGINEERING RESEARCH CENTER
30-DEC-93

Appendix C
Percent Occurrence Tables for Deepwater NDBC 46050

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH (DEGREES) = 0.0
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	38	.	.	.	.	.	.	.	6	.	44
1.0-1.9	477	6	.	.	.	.	.	.	6	.	489
2.0-2.9	264	70	.	12	.	.	.	.	.	.	346
3.0-3.9	6	19	6	.	.	.	.	.	.	.	31
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	785	95	6	12	0	0	0	0	12	0	

MEAN Hm0 (M) = 1.8 LARGEST Hm0 (M) = 3.3 MEAN TP (SEC) = 6.0 NO. OF CASES= 142.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH (DEGREES) = 22.5
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	.	.	.	.	.	.	.	.	.	6	6
1.0-1.9	32	.	.	.	.	.	.	.	19	.	51
2.0-2.9	6	.	.	.	.	.	.	.	.	.	6
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	38	0	0	0	0	0	0	0	19	6	

MEAN Hm0 (M) = 1.5 LARGEST Hm0 (M) = 2.0 MEAN TP (SEC) = 10.2 NO. OF CASES= 10.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH (DEGREES) = 45.0
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	.	.	.	.	.	.	.	.	12	12	24
1.0-1.9	12	.	.	.	.	.	.	.	.	.	12
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	12	0	0	0	0	0	0	0	12	12	

MEAN Hm0 (M) = 1.1 LARGEST Hm0 (M) = 1.8 MEAN TP (SEC) = 14.0 NO. OF CASES= 6.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH (DEGREES) = 67.5
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9-8.0	8.1-8.7	8.8-9.5	9.6-10.5	10.6-11.7	11.8-13.3	13.4-15.3	15.4-18.1	18.2-LONGER	
0.0-0.9	.	.	.	.	.	.	.	.	.	6	6
1.0-1.9	12	.	.	.	.	.	.	.	.	.	12
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	12	0	0	0	0	0	0	0	0	6	

MEAN Hm0 (M) = 1.5 LARGEST Hm0 (M) = 1.8 MEAN TP (SEC) = 9.9 NO. OF CASES= 3.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) = 90.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	12	.	.	.	.	.	.	.	.	.	12
1.0-1.9	64	.	.	.	.	.	.	.	.	.	64
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	76	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 1.4 LARGEST Hm0(M) = 1.9 MEAN TP(SEC) = 4.6 NO. OF CASES= 12.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =112.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.9	6	.	.	.	.	.	.	.	.	.	6
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	6	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 1.3 LARGEST Hm0(M) = 1.3 MEAN TP(SEC) = 4.2 NO. OF CASES= 1.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =135.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.9	6	.	.	.	.	.	.	.	.	.	6
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	.	.	0
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	6	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 1.4 LARGEST Hm0(M) = 1.4 MEAN TP(SEC) = 4.6 NO. OF CASES= 1.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =157.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	6	.	.	.	.	.	.	.	.	.	6
1.0-1.9	12	.	.	.	.	.	.	.	.	6	18
2.0-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0-5.9	.	.	.	.	.	.	.	.	6	.	6
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	18	0	0	0	0	0	0	0	6	6	

MEAN Hm0(M) = 2.0 LARGEST Hm0(M) = 5.0 MEAN TP(SEC) = 9.8 NO. OF CASES= 5.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =180.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	.	.	.	.	.	12	.	6	12	12	42
1.0-1.9	141	32	6	.	.	.	.	.	.	6	185
2.0-2.9	19	6	6	12	19	.	.	.	.	12	74
3.0-3.9	12	6	12	.	.	.	.	.	.	.	30
4.0-4.9	.	.	.	12	6	.	.	.	.	.	18
5.0-5.9	.	.	.	6	.	.	.	.	.	.	6
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	172	44	24	30	25	12	0	6	12	30	

MEAN Hm0(M) = 1.9 LARGEST Hm0(M)= 5.4 MEAN TP(SEC)= 8.6 NO. OF CASES= 57.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =202.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	25	.	6	.	6	6	12	135	109	19	318
1.0-1.9	374	245	96	45	19	19	6	64	277	.	1145
2.0-2.9	206	393	296	354	361	70	.	.	6	.	1686
3.0-3.9	25	154	193	154	141	64	6	.	.	.	737
4.0-4.9	.	38	45	77	51	64	25	6	.	.	306
5.0-5.9	.	.	25	38	51	19	.	.	6	.	139
6.0-6.9	.	.	.	.	45	25	6	.	.	.	76
7.0-7.9	.	.	.	.	12	19	25	.	.	.	56
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	6	.	.	.	6
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	630	830	661	668	686	286	86	205	398	19	

MEAN Hm0(M) = 2.6 LARGEST Hm0(M)= 9.1 MEAN TP(SEC)= 9.5 NO. OF CASES= 697.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =225.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	25	12	45	6	25	25	38	161	290	19	646
1.0-1.9	148	174	180	154	167	32	19	167	477	6	1524
2.0-2.9	116	322	309	290	290	341	90	12	38	6	1814
3.0-3.9	6	109	122	193	309	174	154	.	6	.	1073
4.0-4.9	.	12	32	64	116	96	103	32	6	.	461
5.0-5.9	.	.	.	6	25	77	25	45	6	.	184
6.0-6.9	.	.	.	.	.	25	6	25	6	.	62
7.0-7.9	.	.	.	.	.	12	19	.	.	.	31
8.0-8.9	.	.	.	.	.	.	6	.	.	.	6
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	295	629	688	713	932	782	460	442	829	31	

MEAN Hm0(M) = 2.5 LARGEST Hm0(M) = 8.0 MEAN TP(SEC) = 10.9 NO. OF CASES= 904.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =247.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	6	38	90	38	103	109	58	64	64	6	576
1.0-1.9	38	251	245	367	309	245	154	212	83	12	1916
2.0-2.9	32	51	141	167	212	503	593	187	45	.	1931
3.0-3.9	.	32	19	45	148	309	296	135	12	.	996
4.0-4.9	.	.	.	38	38	83	96	161	25	.	441
5.0-5.9	.	.	.	.	6	12	77	77	6	.	178
6.0-6.9	.	.	.	.	.	12	25	19	.	.	56
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	76	372	495	655	816	1273	1299	855	235	18	

MEAN Hm0(M) = 2.4 LARGEST Hm0(M) = 6.6 MEAN TP(SEC) = 11.2 NO. OF CASES= 949.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =270.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	6	12	116	96	225	187	38	19	12	.	711
1.0-1.9	90	322	483	851	922	1580	1664	1387	406	83	7788
2.0-2.9	25	45	135	329	832	1903	3238	2238	496	103	9344
3.0-3.9	.	.	25	70	154	800	1754	1103	483	109	4498
4.0-4.9	.	.	.	12	25	122	470	851	232	32	1744
5.0-5.9	.	.	.	.	6	.	45	309	219	.	579
6.0-6.9	.	.	.	.	.	.	25	51	12	.	88
7.0-7.9	.	.	.	.	.	.	6	6	.	.	12
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	121	379	759	1358	2164	4592	7240	5964	1860	327	

MEAN Hm0(M) = 2.5 LARGEST Hm0(M) = 7.2 MEAN TP(SEC) = 12.5 NO. OF CASES= 3843.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =292.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	58	90	193	161	161	70	6	6	32	.	777
1.0-1.9	425	1122	741	1393	1800	2077	1883	1580	580	245	11846
2.0-2.9	6	122	245	458	1090	2148	3606	3013	1419	522	12629
3.0-3.9	.	12	6	64	225	574	1412	1703	780	367	5143
4.0-4.9	.	.	.	.	51	135	354	980	529	70	2119
5.0-5.9	.	.	.	.	.	6	103	309	335	25	778
6.0-6.9	.	.	.	.	12	6	12	129	109	.	268
7.0-7.9	.	.	.	.	.	.	.	6	6	.	12
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	489	1346	1185	2076	3339	5016	7376	7726	3790	1229	

MEAN Hm0(M) = 2.4 LARGEST Hm0(M) = 7.5 MEAN TP(SEC) = 12.6 NO. OF CASES= 5208.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =315.0
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	425	432	238	148	19	.	.	.	6	.	1268
1.0-1.9	993	2335	1793	1613	1225	387	167	45	38	25	8621
2.0-2.9	51	645	825	1206	1006	980	535	206	51	32	5537
3.0-3.9	6	6	12	45	225	354	277	200	12	6	1143
4.0-4.9	.	6	.	.	12	90	161	116	19	.	404
5.0-5.9	.	.	.	.	.	12	38	96	19	.	165
6.0-6.9	.	.	.	.	.	.	25	58	19	.	102
7.0-7.9	.	.	.	.	.	.	.	38	.	.	38
8.0-8.9	.	.	.	.	.	.	.	6	.	.	6
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	1475	3424	2868	3012	2487	1823	1203	765	164	63	

MEAN Hm0(M) = 2.0 LARGEST Hm0(M)= 8.0 MEAN TP(SEC)= 9.3 NO. OF CASES= 2683.

BUOY STATION 46050 44.61 N 124.51 W AZIMUTH(DEGREES) =337.5
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

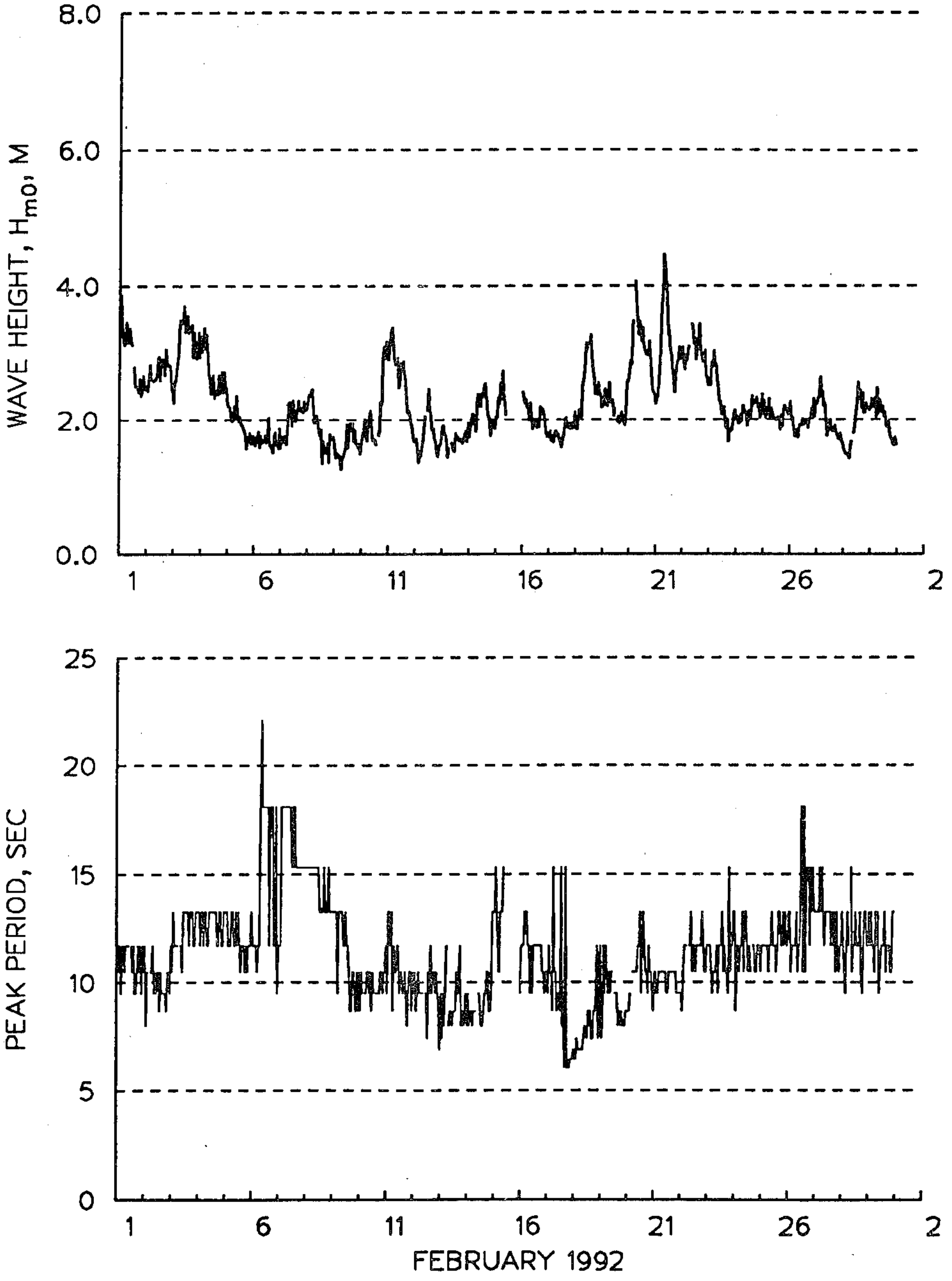
HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	<6.9	6.9- 8.0	8.1- 8.7	8.8- 9.5	9.6- 10.5	10.6- 11.7	11.8- 13.3	13.4- 15.3	15.4- 18.1	18.2- LONGER	
0.0-0.9	283	122	45	19	6	.	.	.	.	12	487
1.0-1.9	1651	883	690	361	135	6	.	.	.	.	3726
2.0-2.9	335	341	412	522	283	12	6	6	6	.	1923
3.0-3.9	.	6	19	19	51	.	.	.	.	.	95
4.0-4.9	.	.	.	6	.	19	12	.	.	.	37
5.0-5.9	.	.	.	.	.	25	.	.	.	.	25
6.0-6.9	.	.	.	.	.	.	.	.	.	.	0
7.0-7.9	.	.	.	.	.	.	.	.	.	.	0
8.0-8.9	.	.	.	.	.	.	.	.	.	.	0
9.0-9.9	.	.	.	.	.	.	.	.	.	.	0
10.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	2269	1352	1166	927	475	62	18	6	6	12	

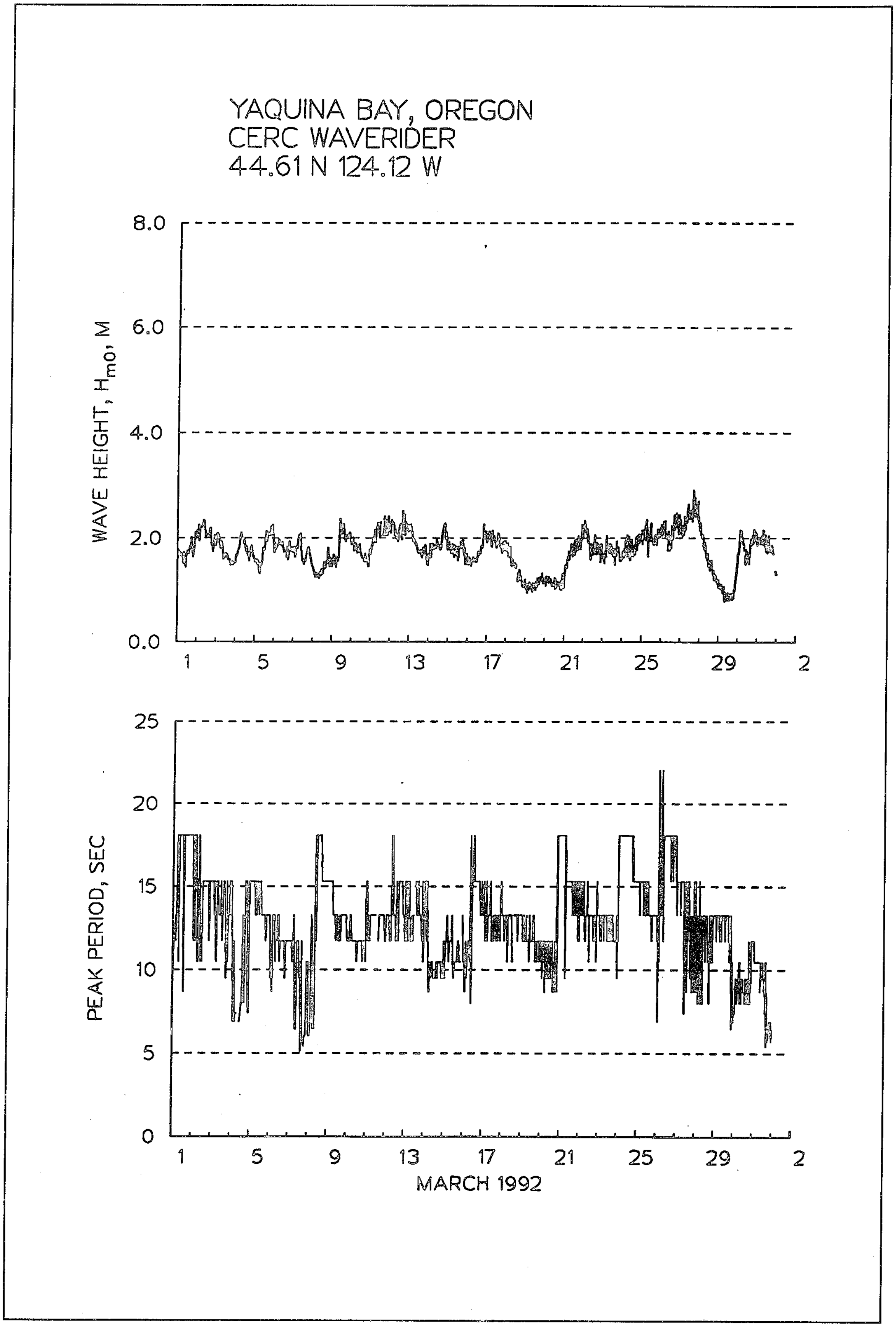
MEAN Hm0(M) = 1.7 LARGEST Hm0(M)= 5.8 MEAN TP(SEC)= 7.6 NO. OF CASES= 978.

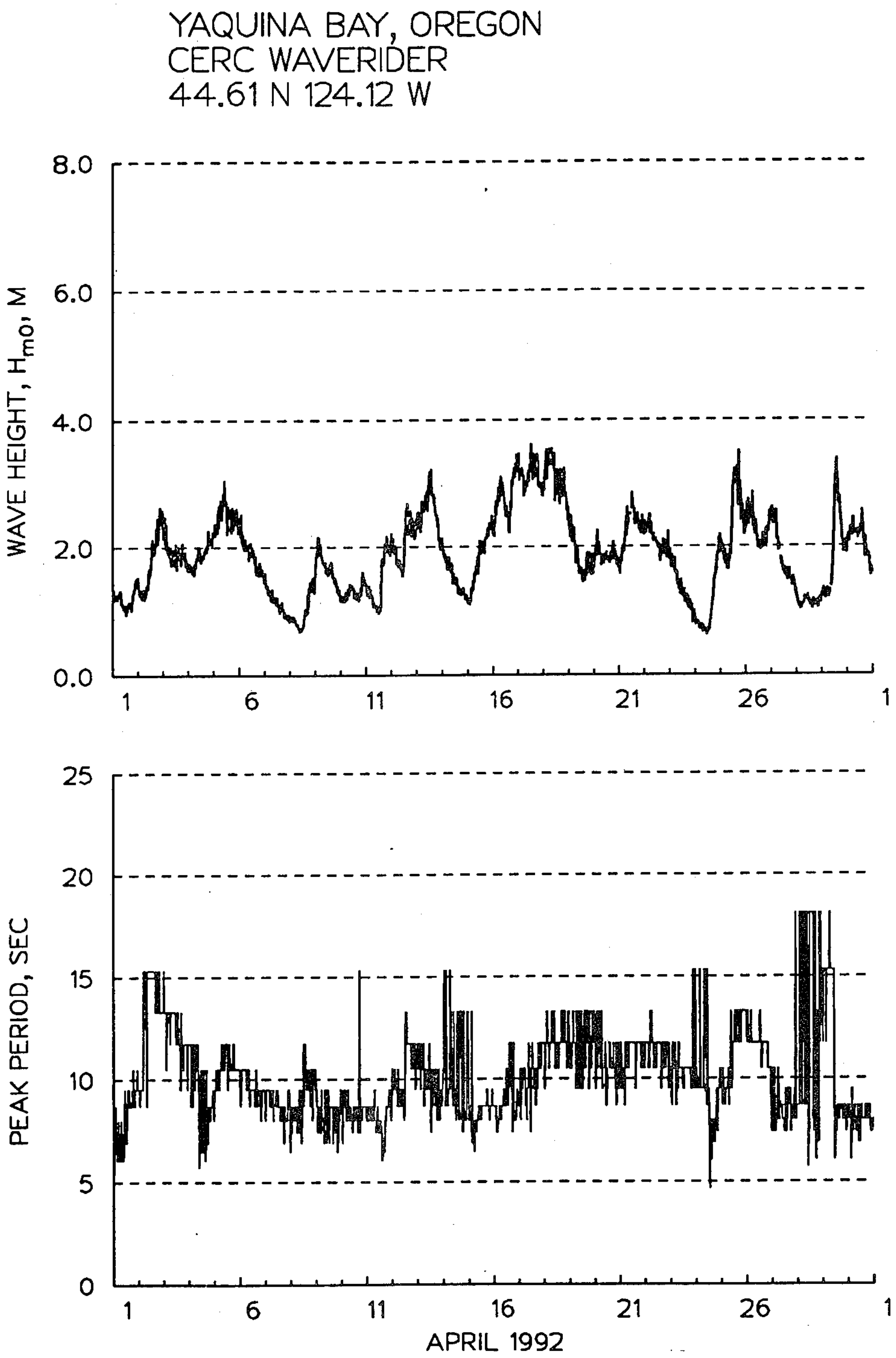
Appendix D
Monthly Time Series Plots for Nearshore WaveRiders

Plots for WaveRider WR-12

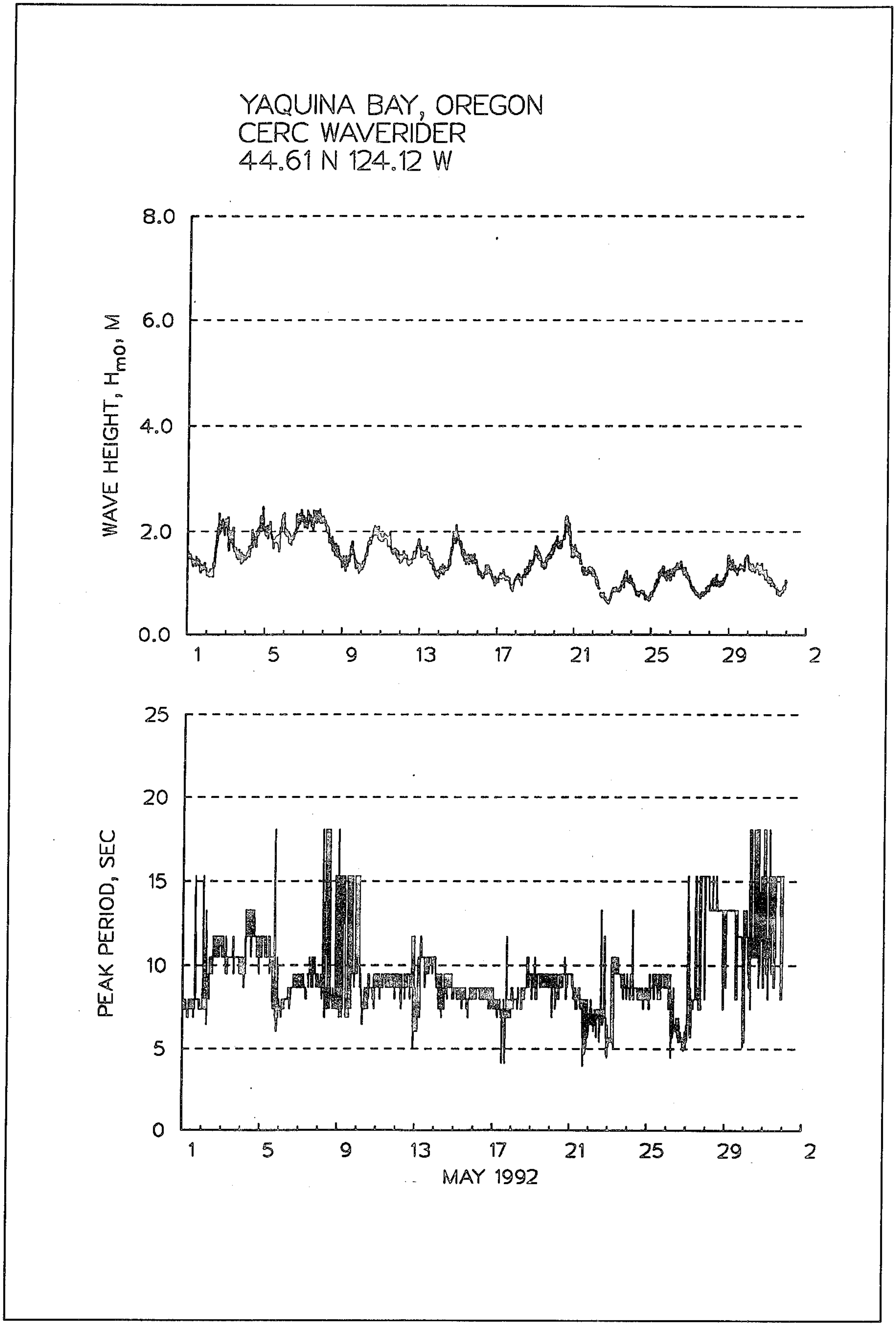
YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W

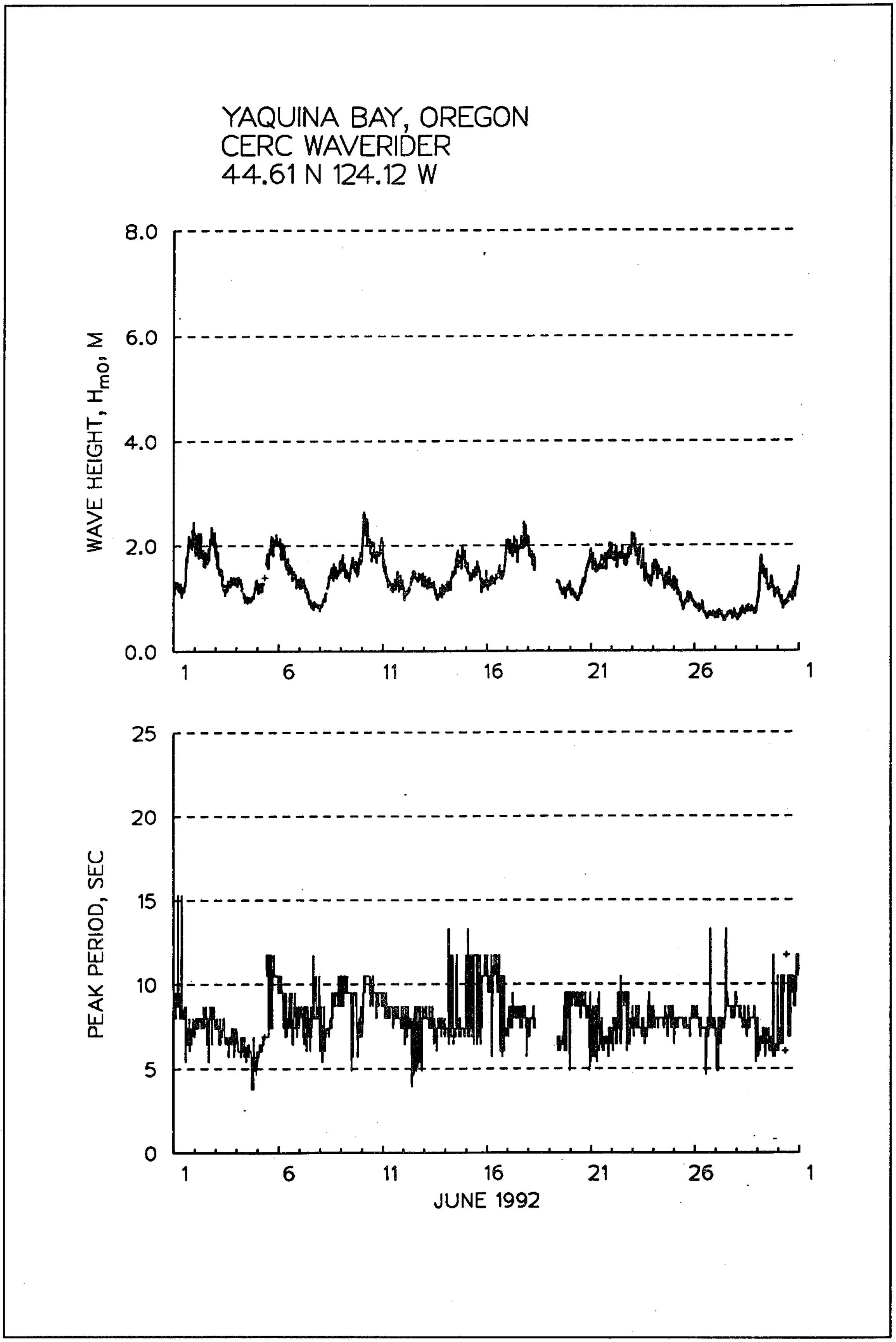


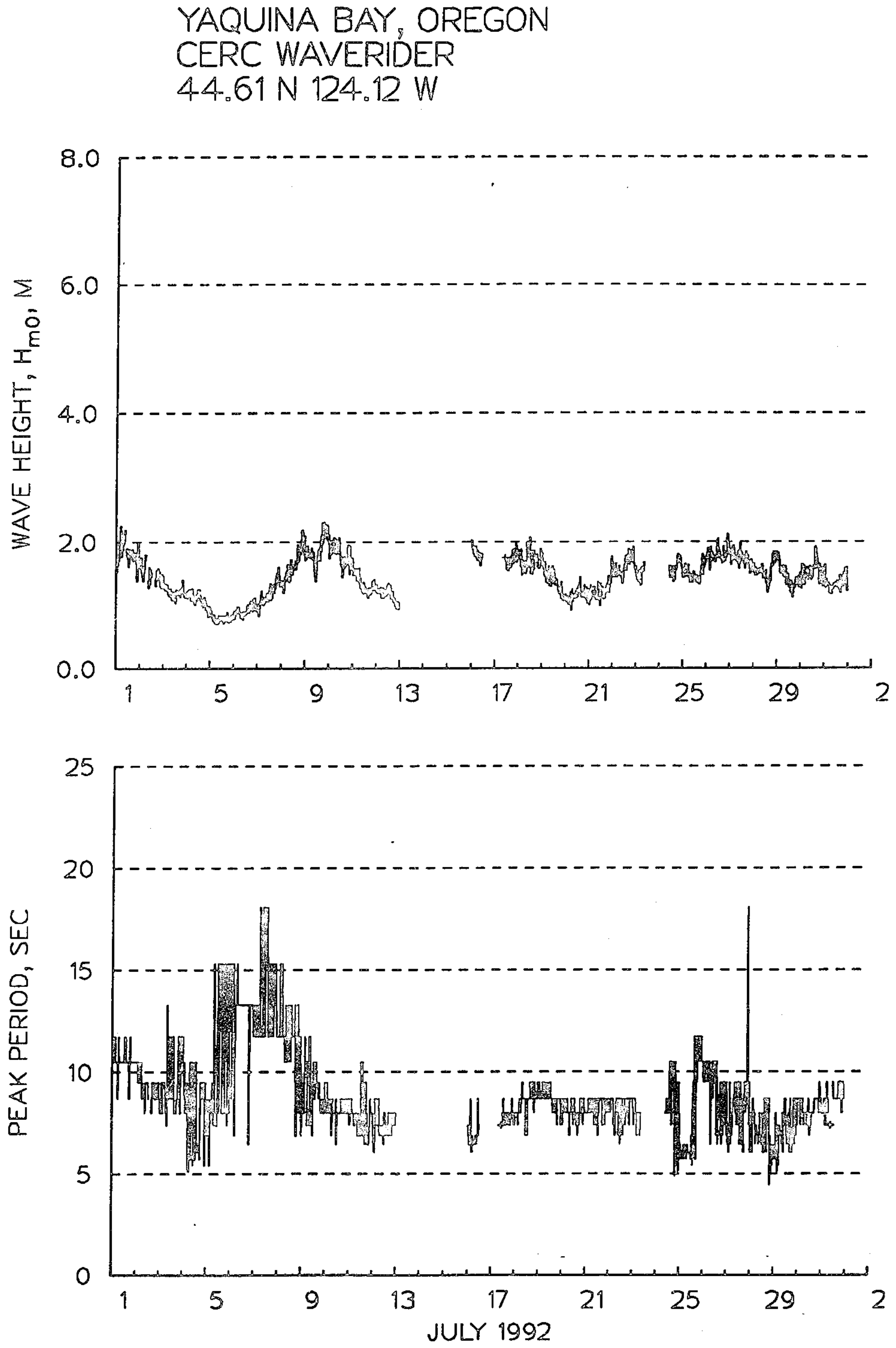

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
5
9
13
17
21
25
29
2
MARCH 1992

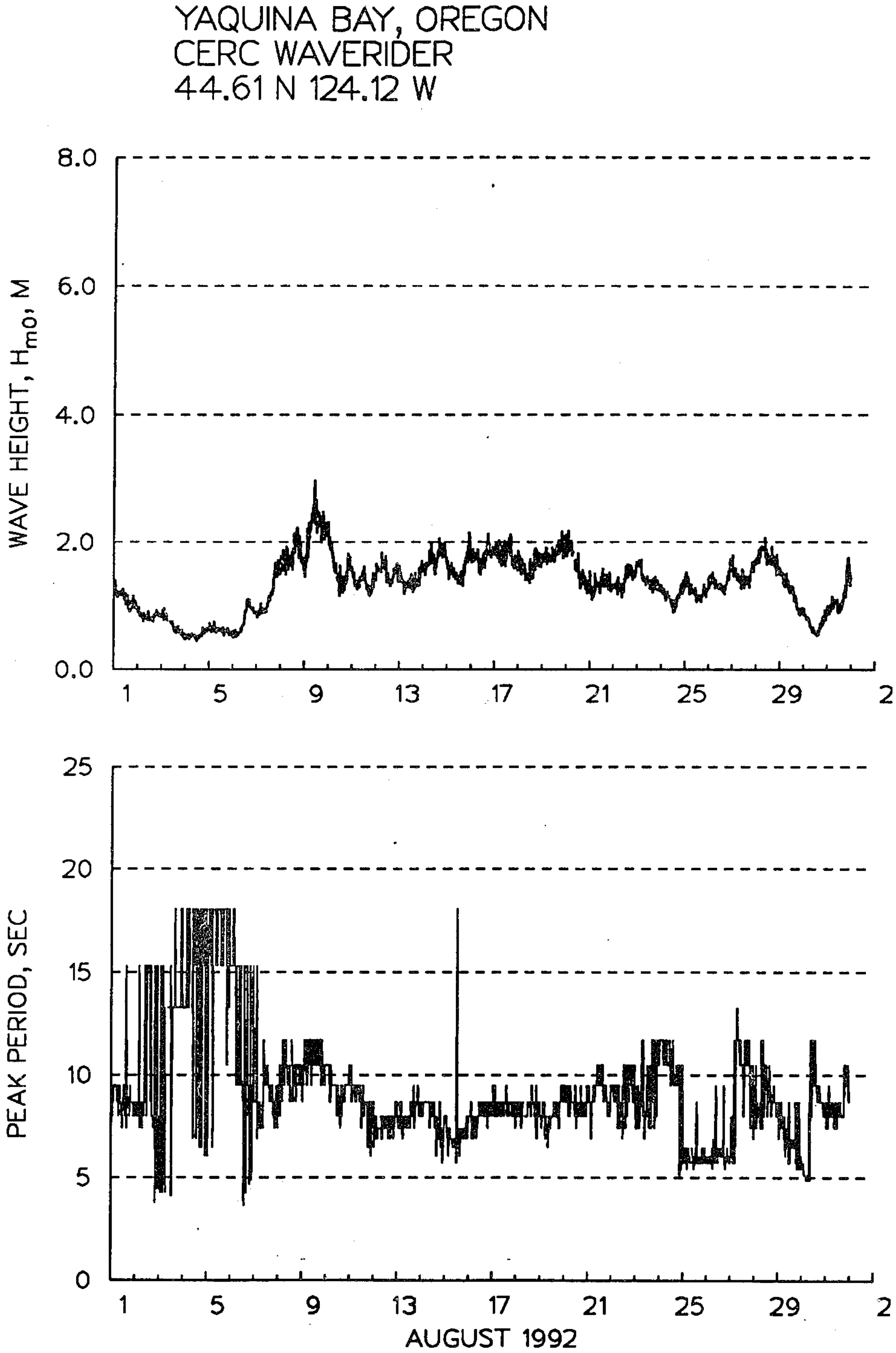


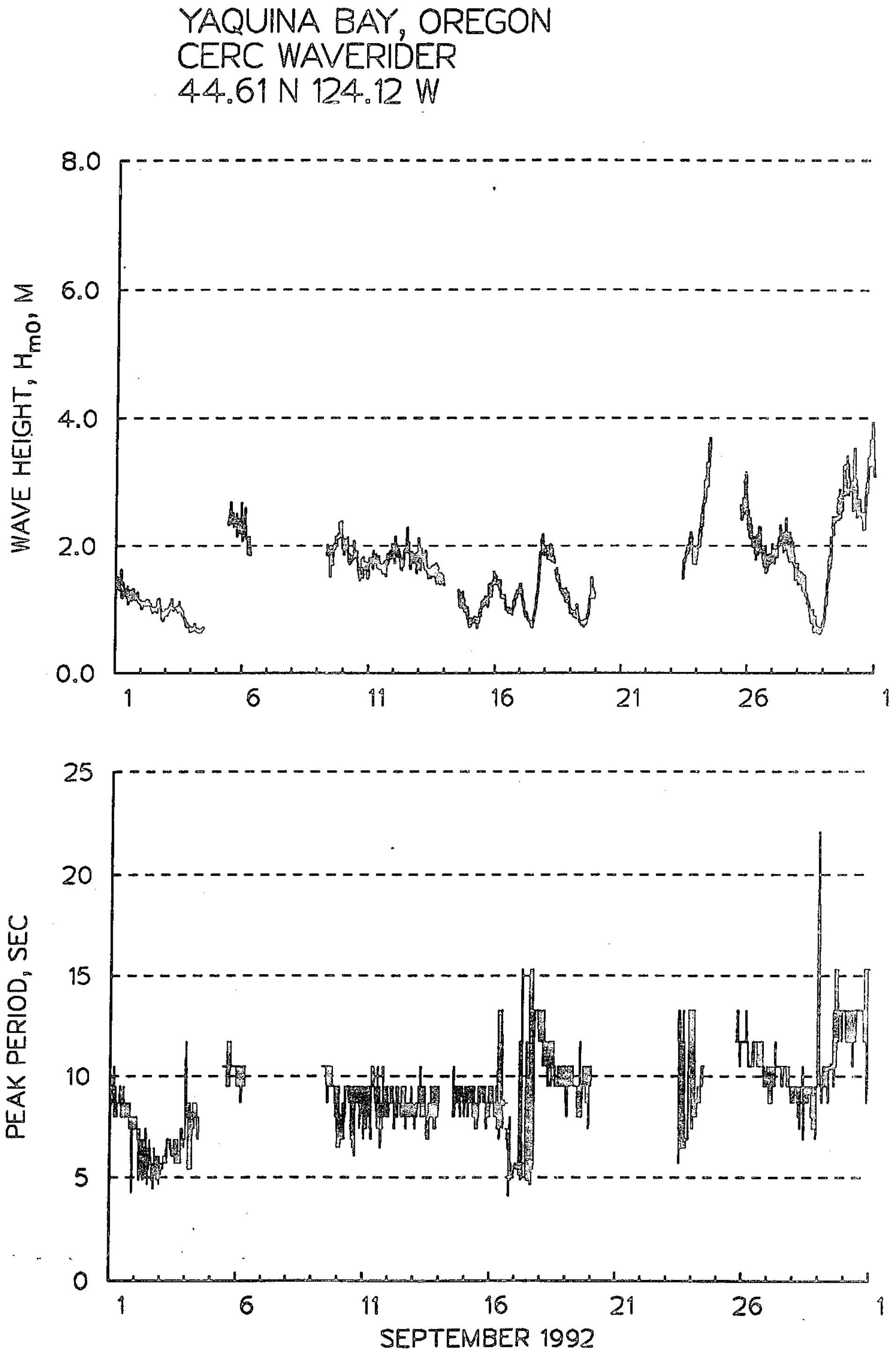
YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W


YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
5
9
13
17
21
25
29
2
MAY 1992

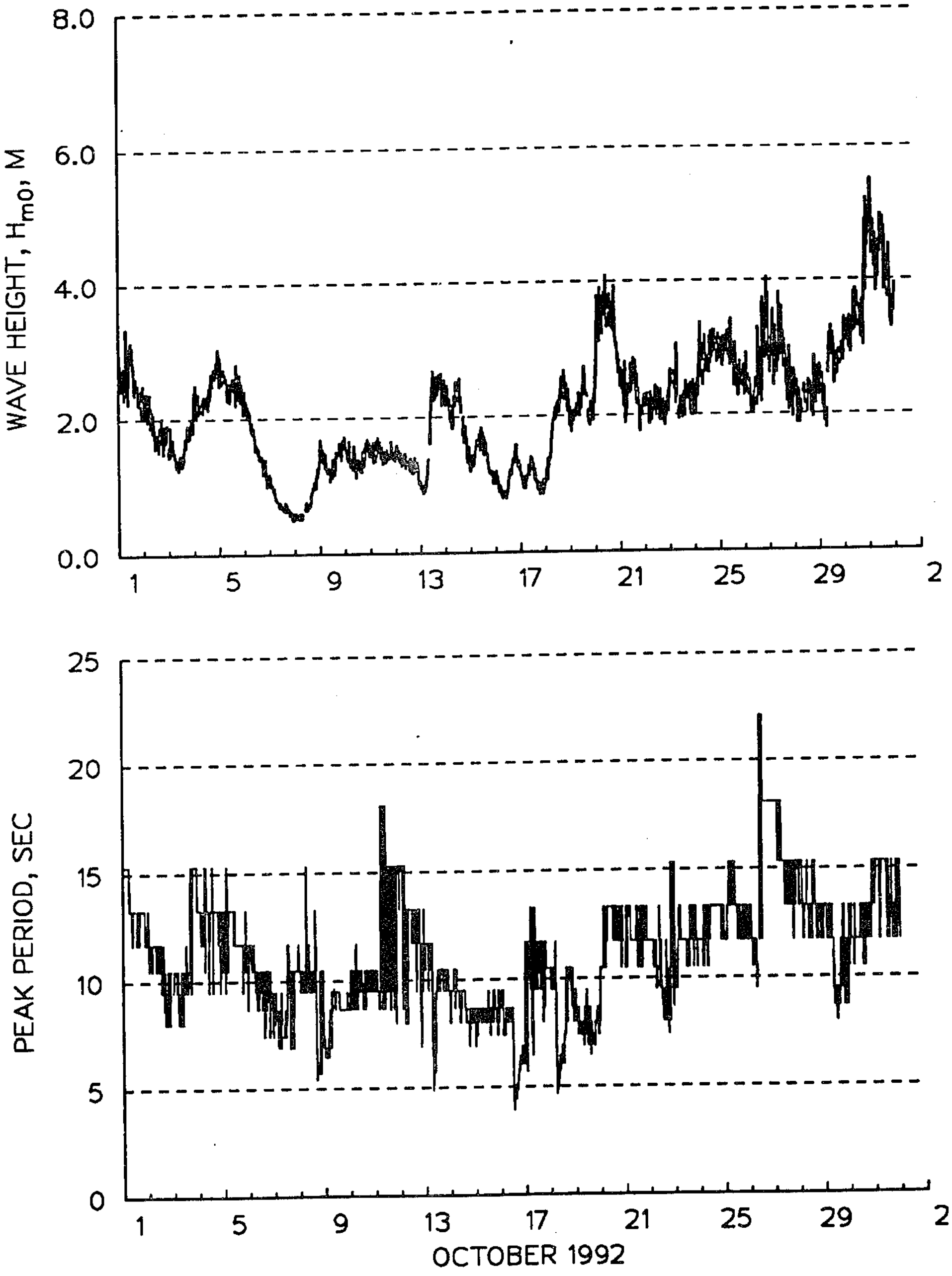

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
PEAK PERIOD, SEC
25
20
15
10
5
0
1
6
11
16
21
26
1
JUNE 1992


YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
5
9
13
17
21
25
29
2
JULY 1992

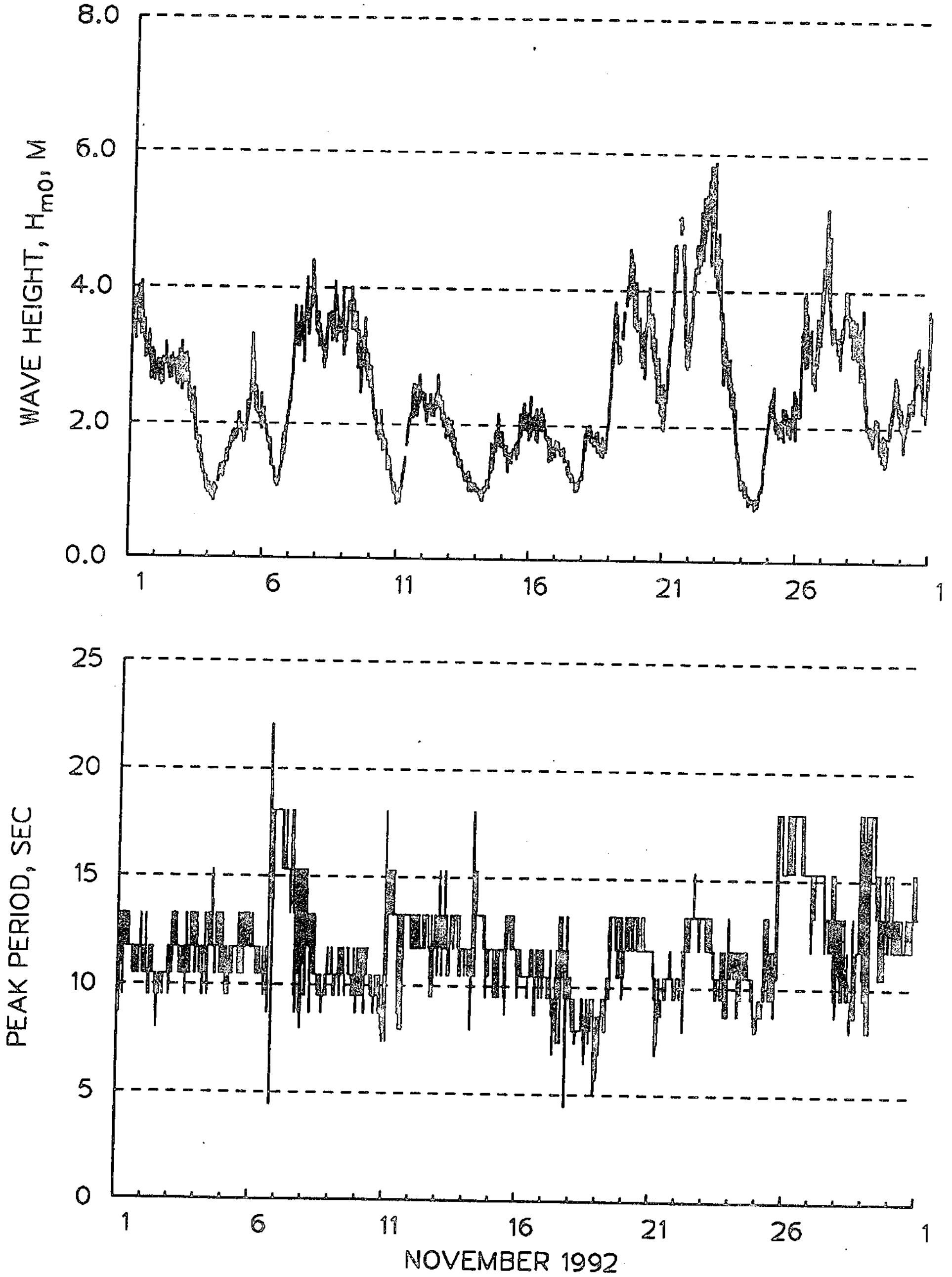

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
5
9
13
17
21
25
29
2
AUGUST 1992

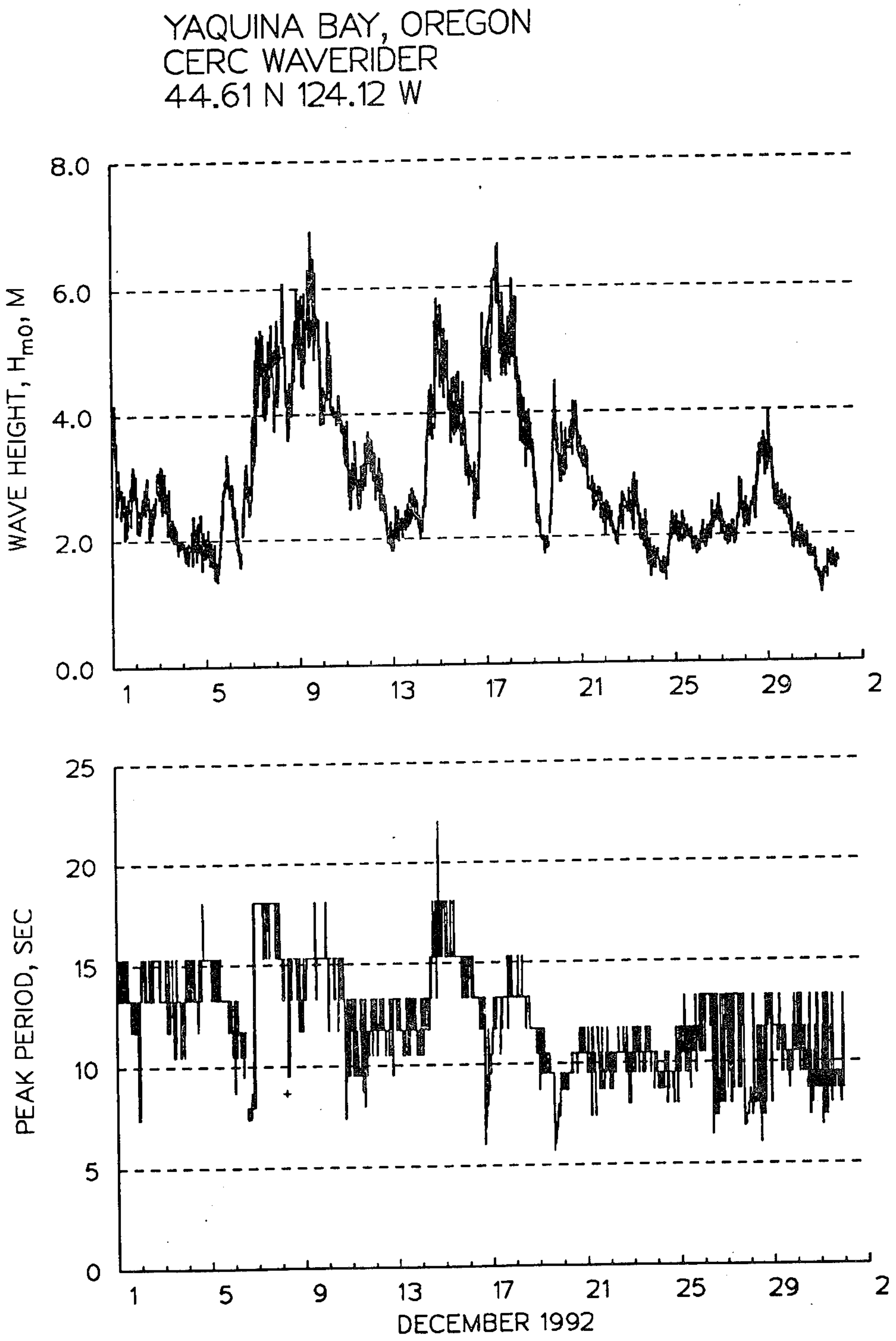

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
PEAK PERIOD, SEC
25
20
15
10
5
0
1
6
11
16
21
26
1
SEPTEMBER 1992

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W



YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W




YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
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10
5
0
1
5
9
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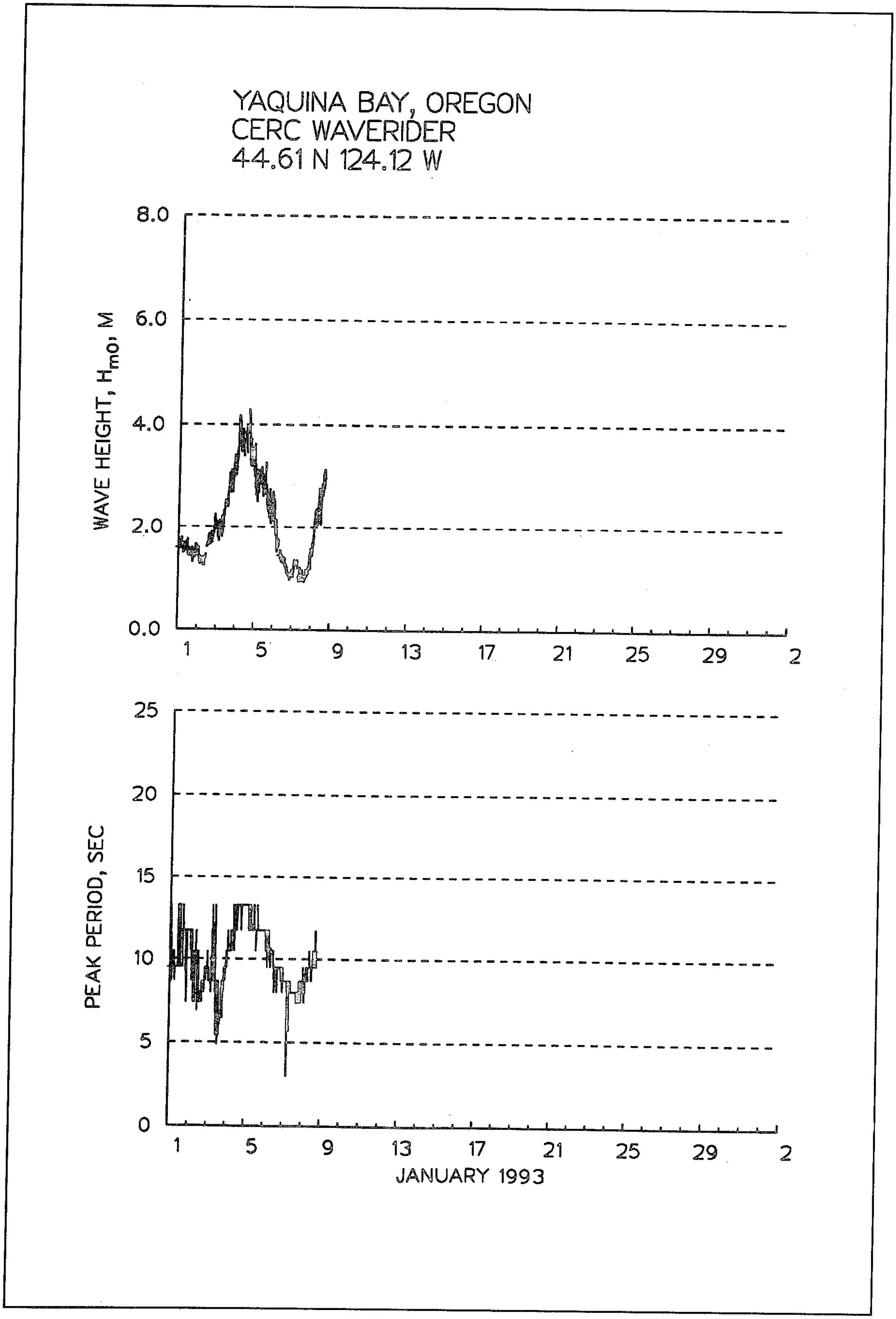
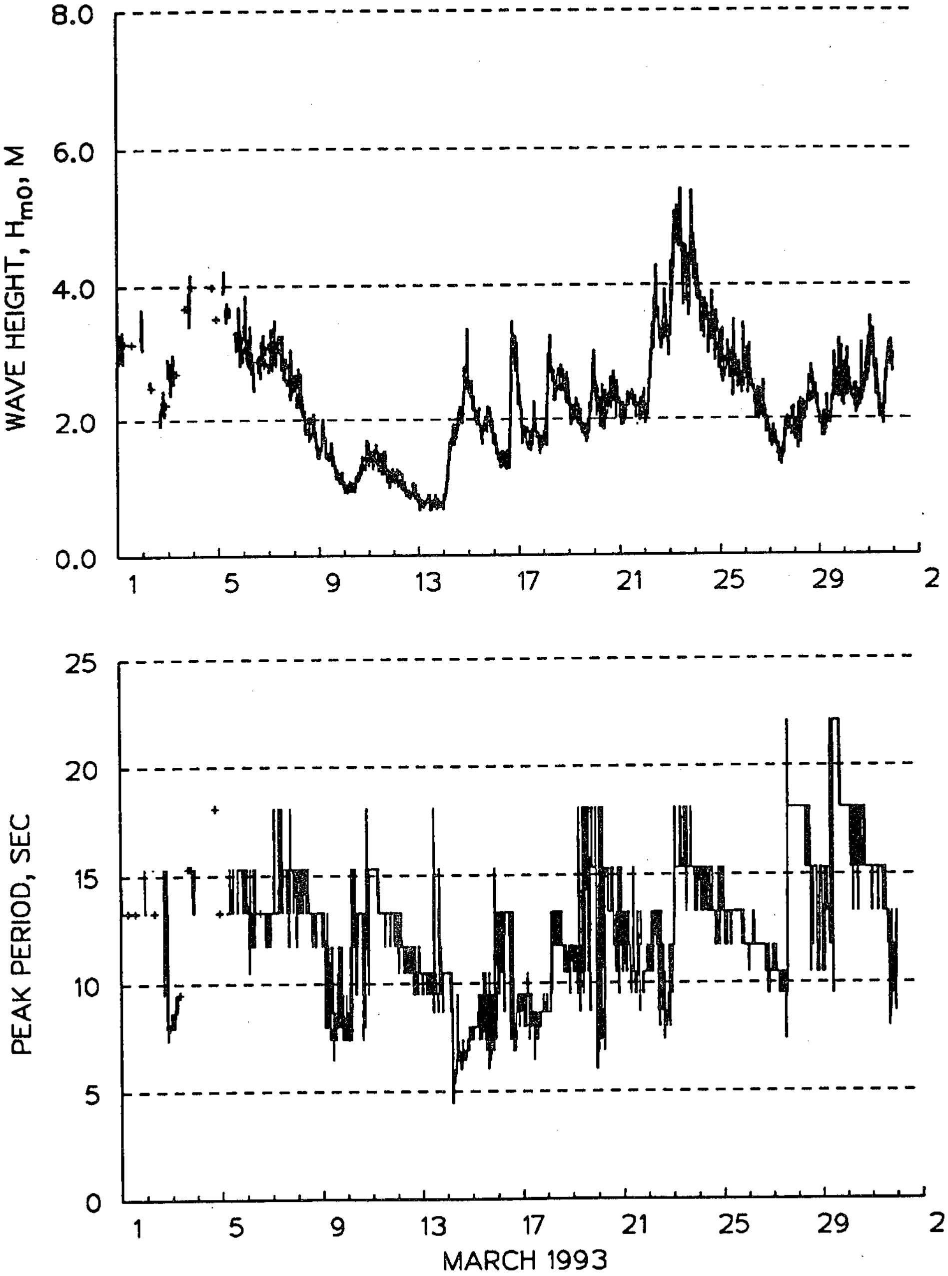
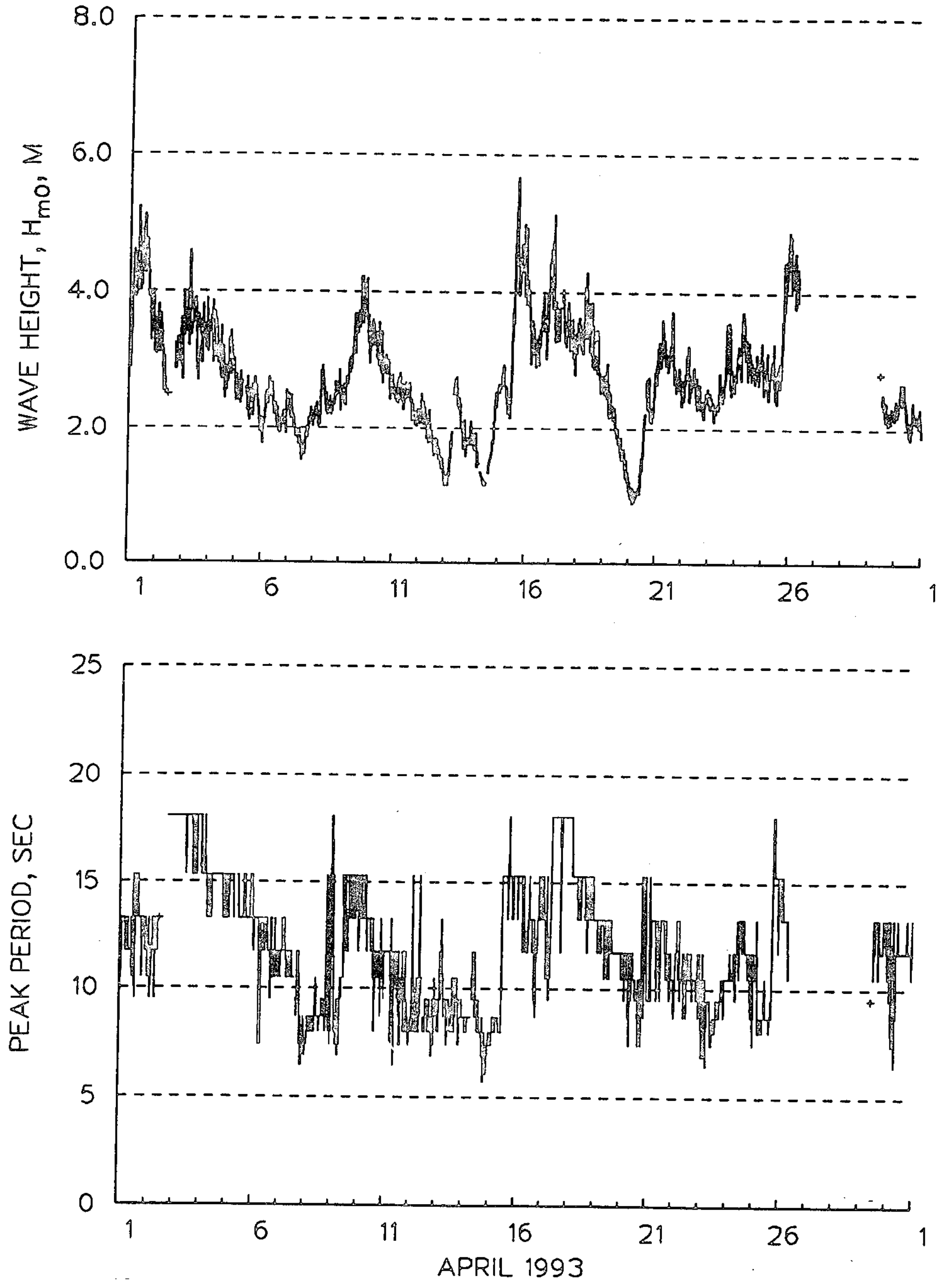
25
29
2
DECEMBER 1992

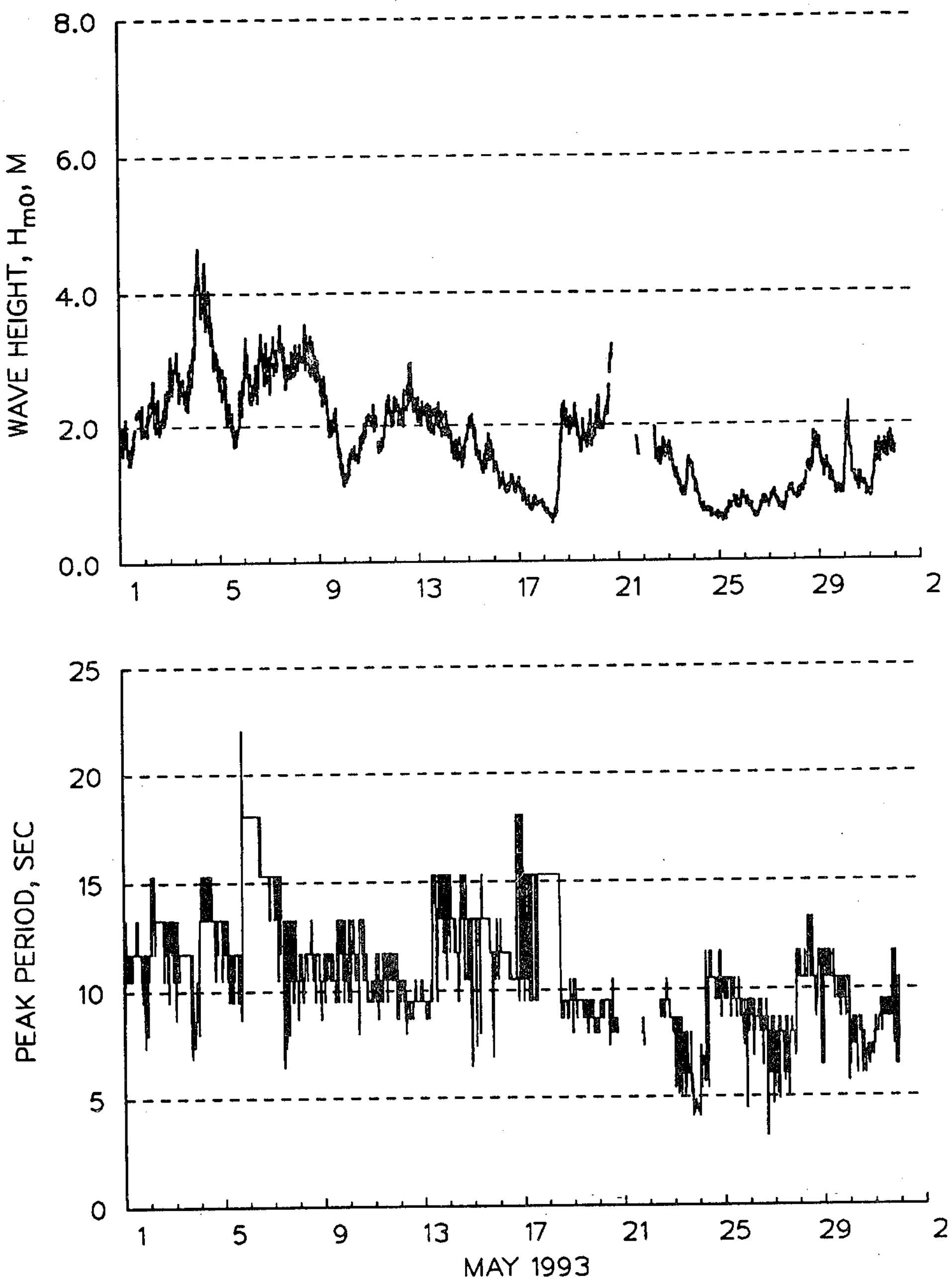

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
5
9
13
17
21
25
29
2
JANUARY 1993

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W

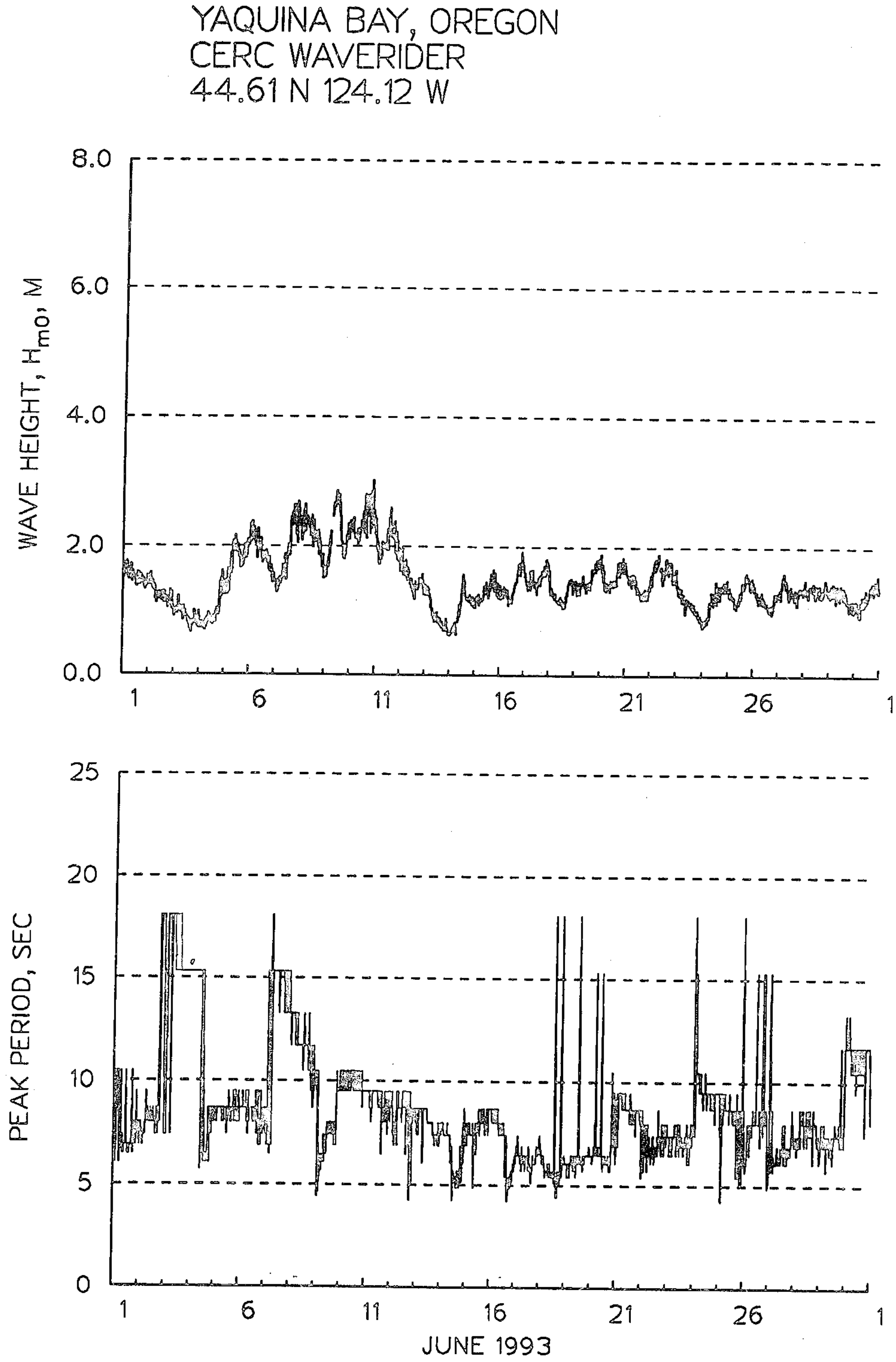


YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W

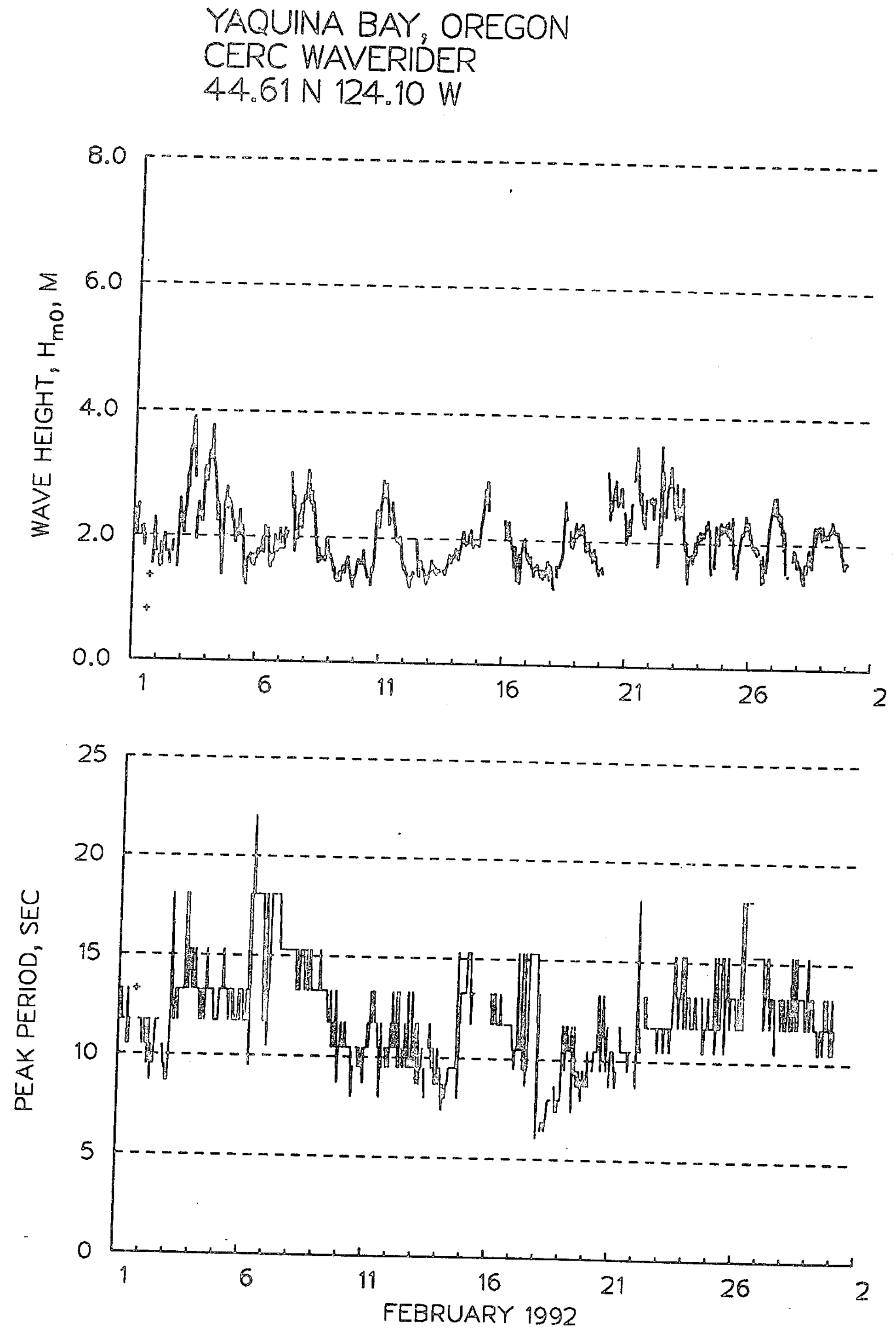


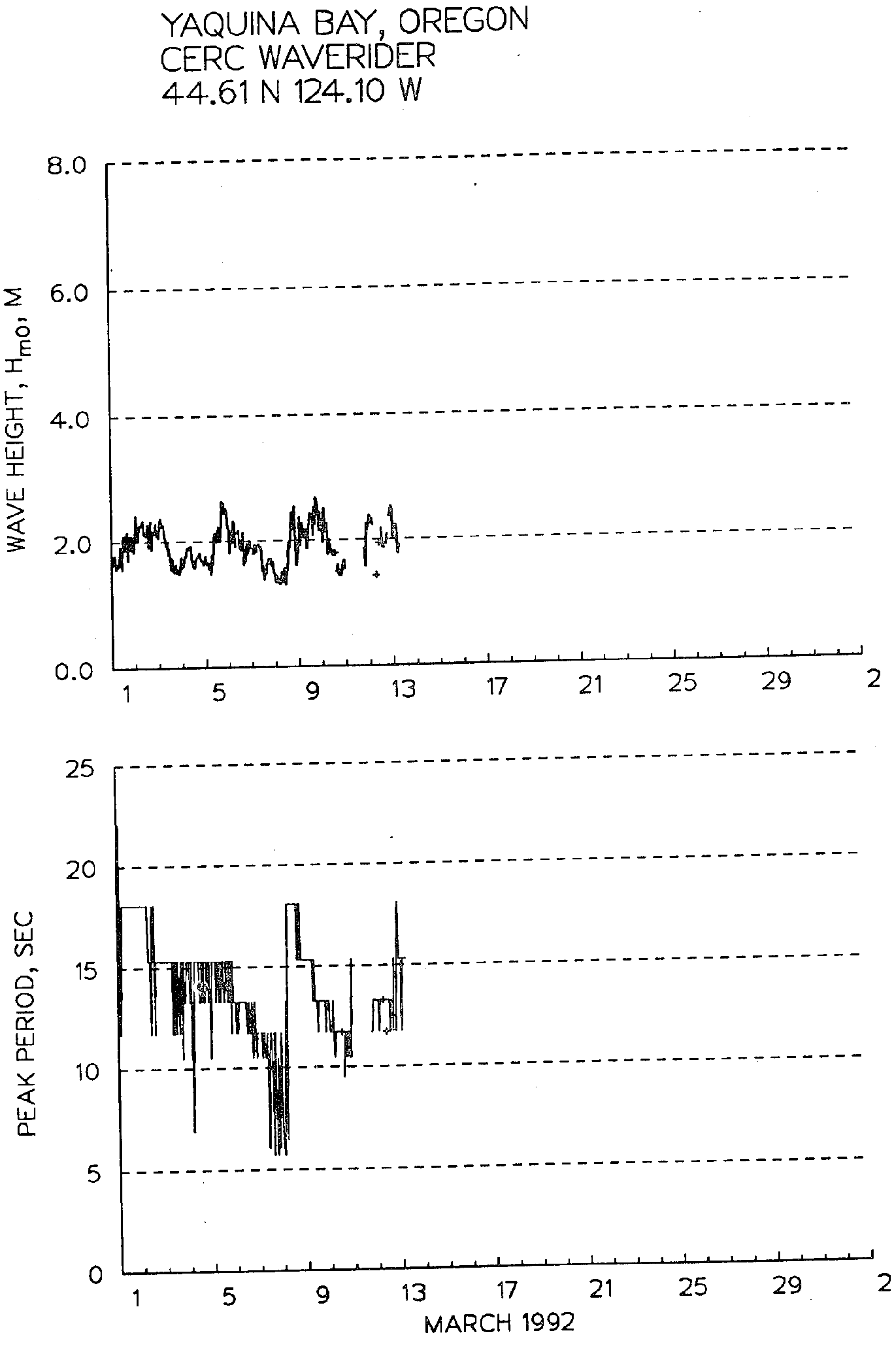


YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W

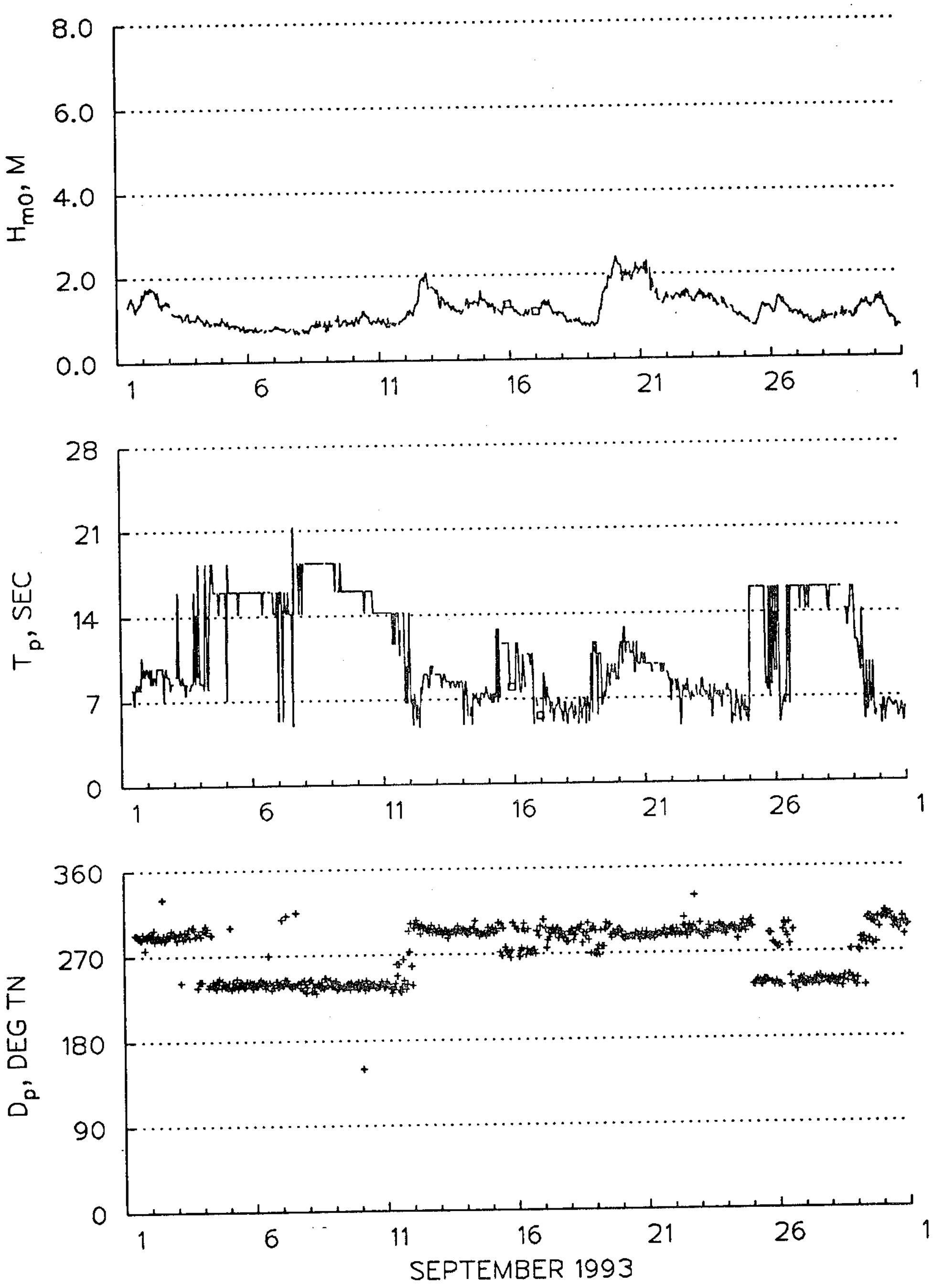

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.12 W
WAVE HEIGHT, H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
PEAK PERIOD, SEC
25
20
15
10
5
0
1
6
11
16
21
26
1
JUNE 1993

Plots for WaveRider WR-10


YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.10 W
WAVE HEIGHT, H_{mo}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
2
PEAK PERIOD, SEC
25
20
15
10
5
0
1
6
11
16
21
26
2
FEBRUARY 1992

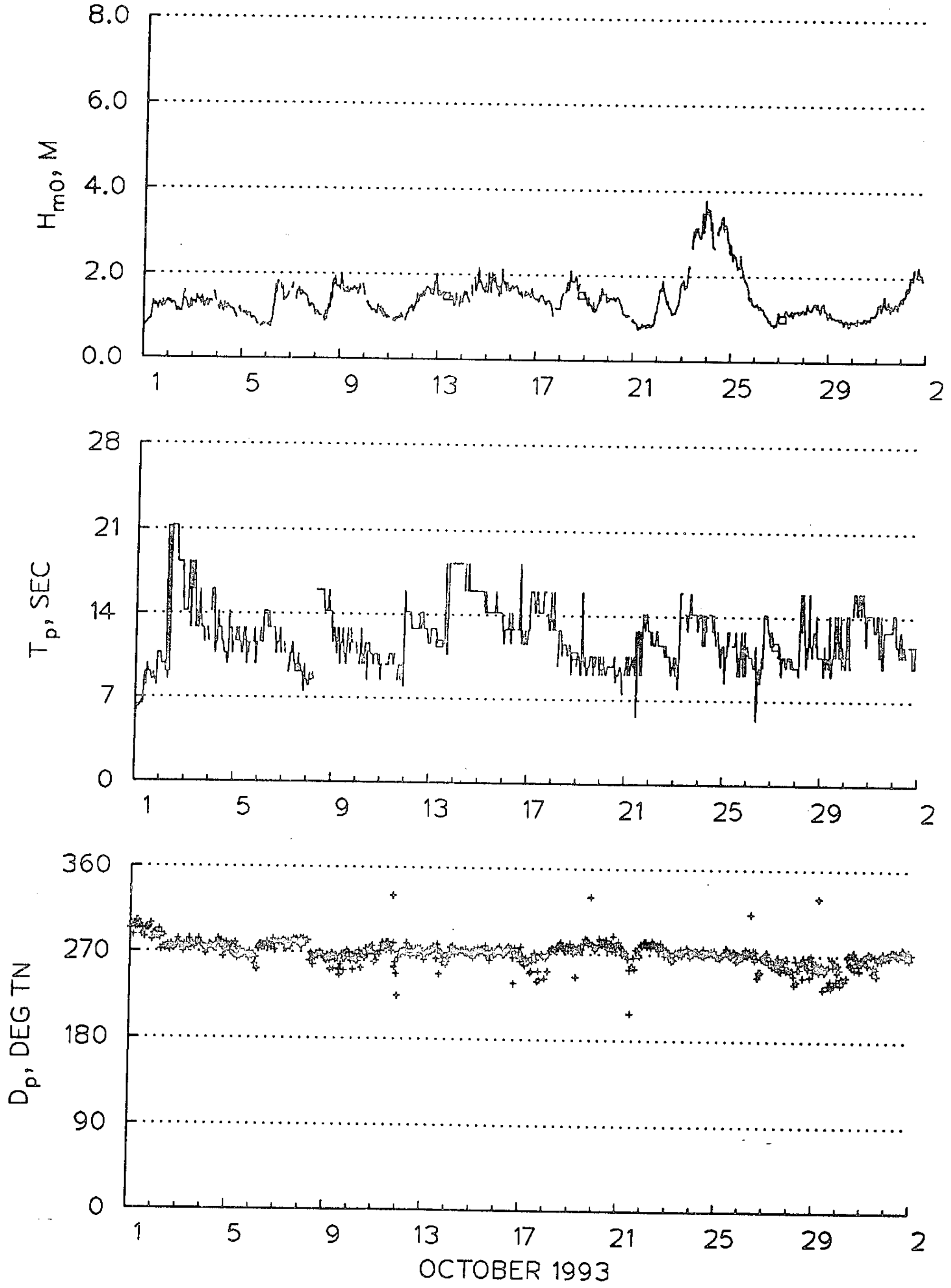

YAQUINA BAY, OREGON
CERC WAVERIDER
44.61 N 124.10 W

YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W



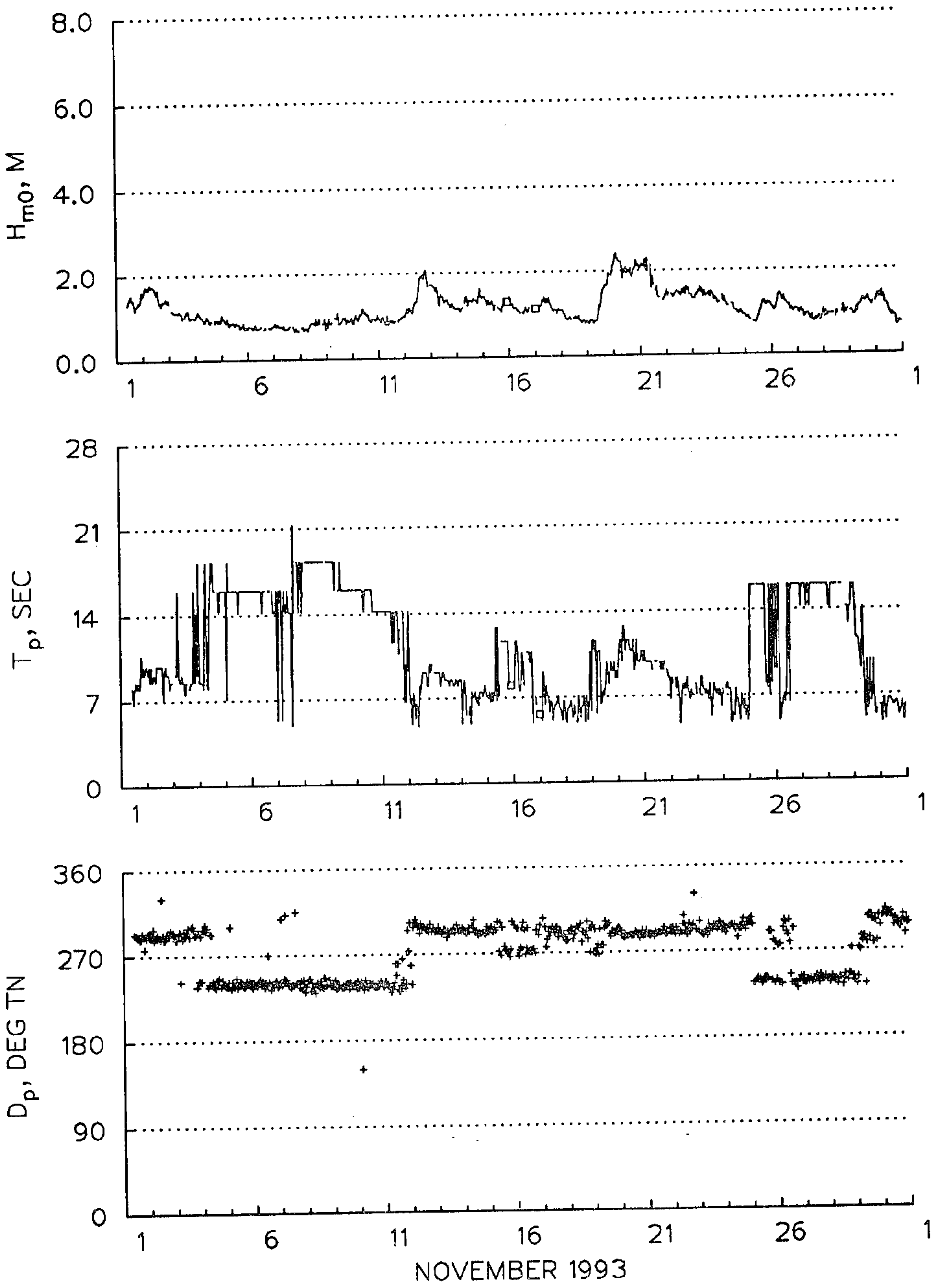
D_p and T_p not reported where H_{mo} less than .2 M

YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W

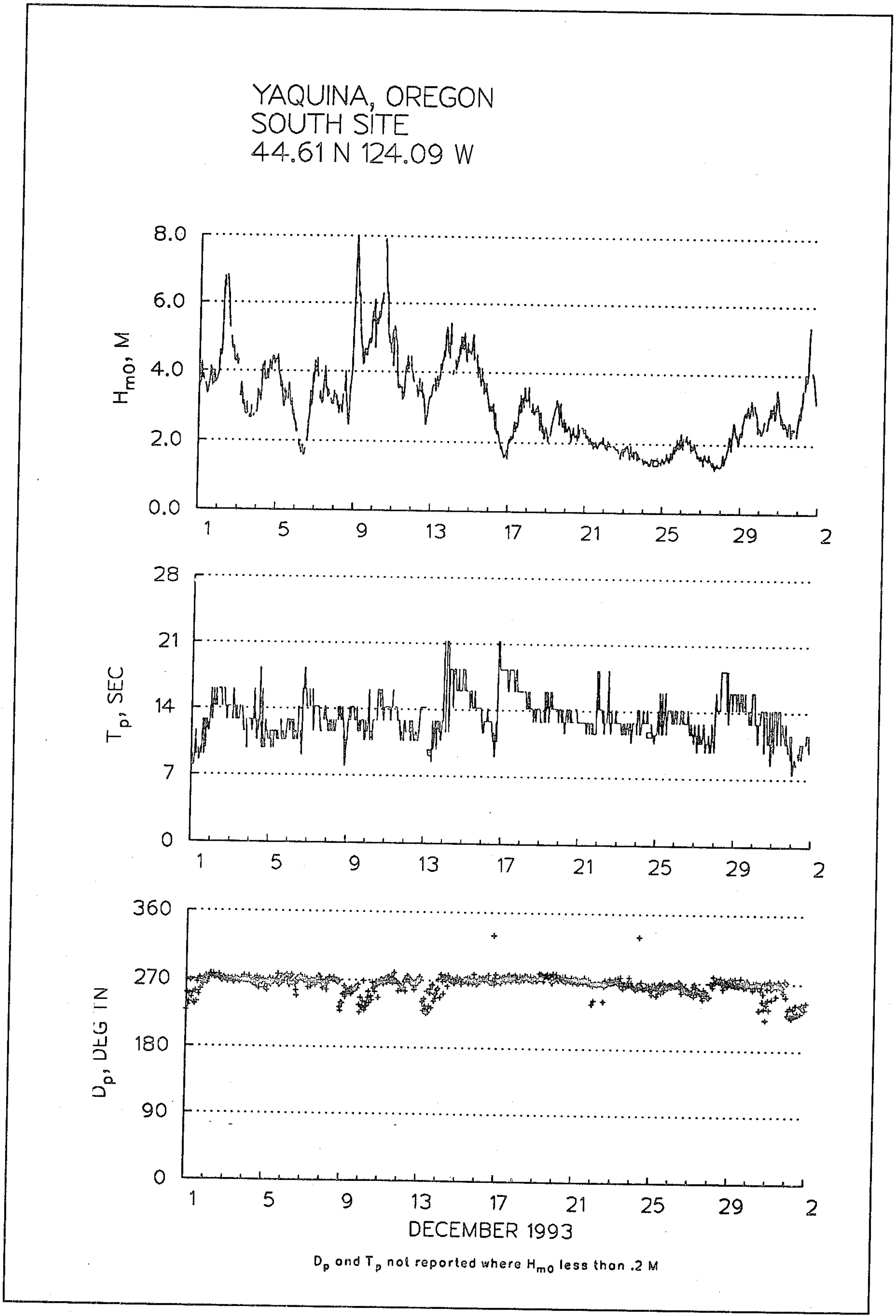


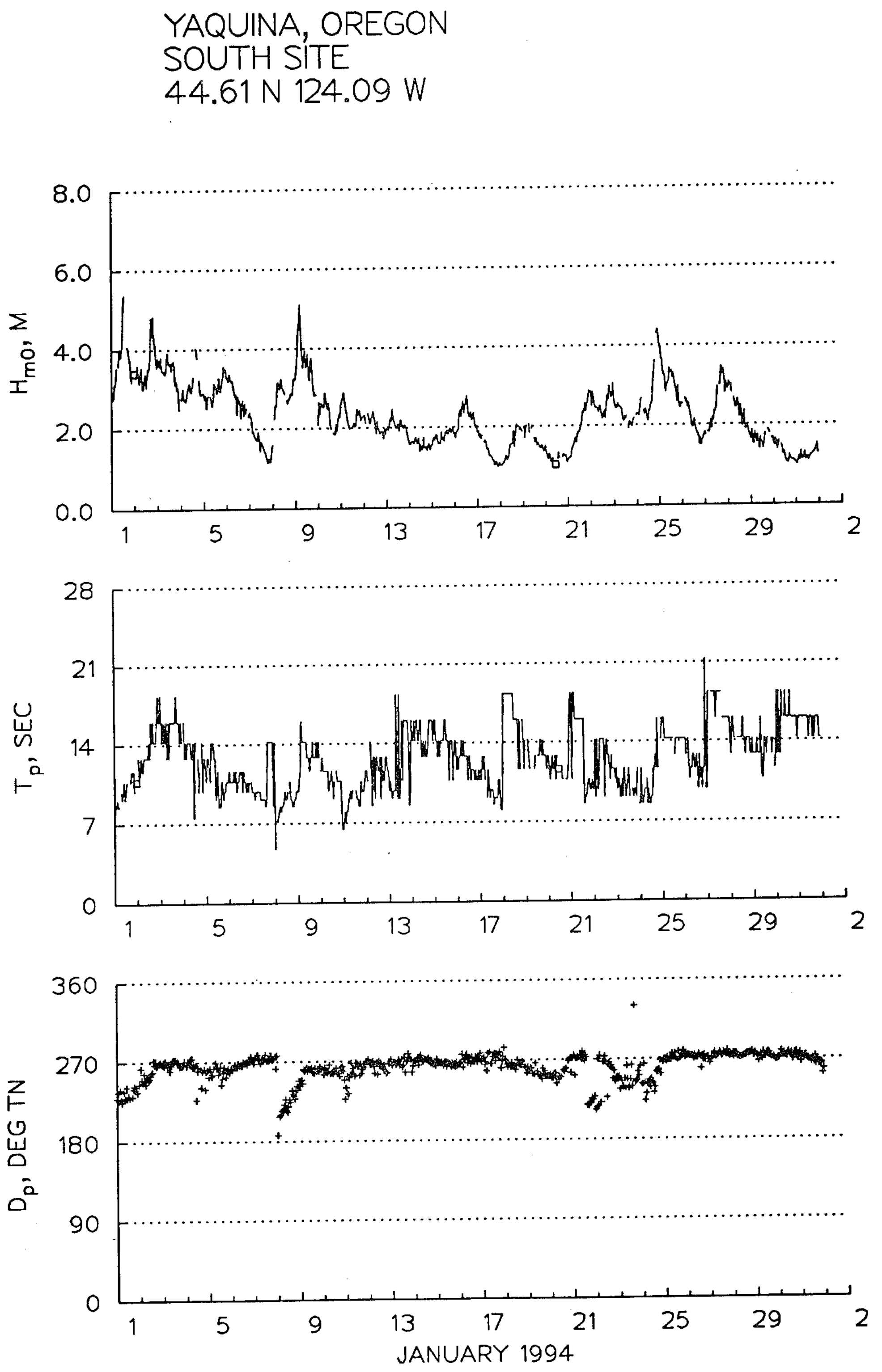
D_p and T_p not reported where H_{mo} less than .2 M

YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W

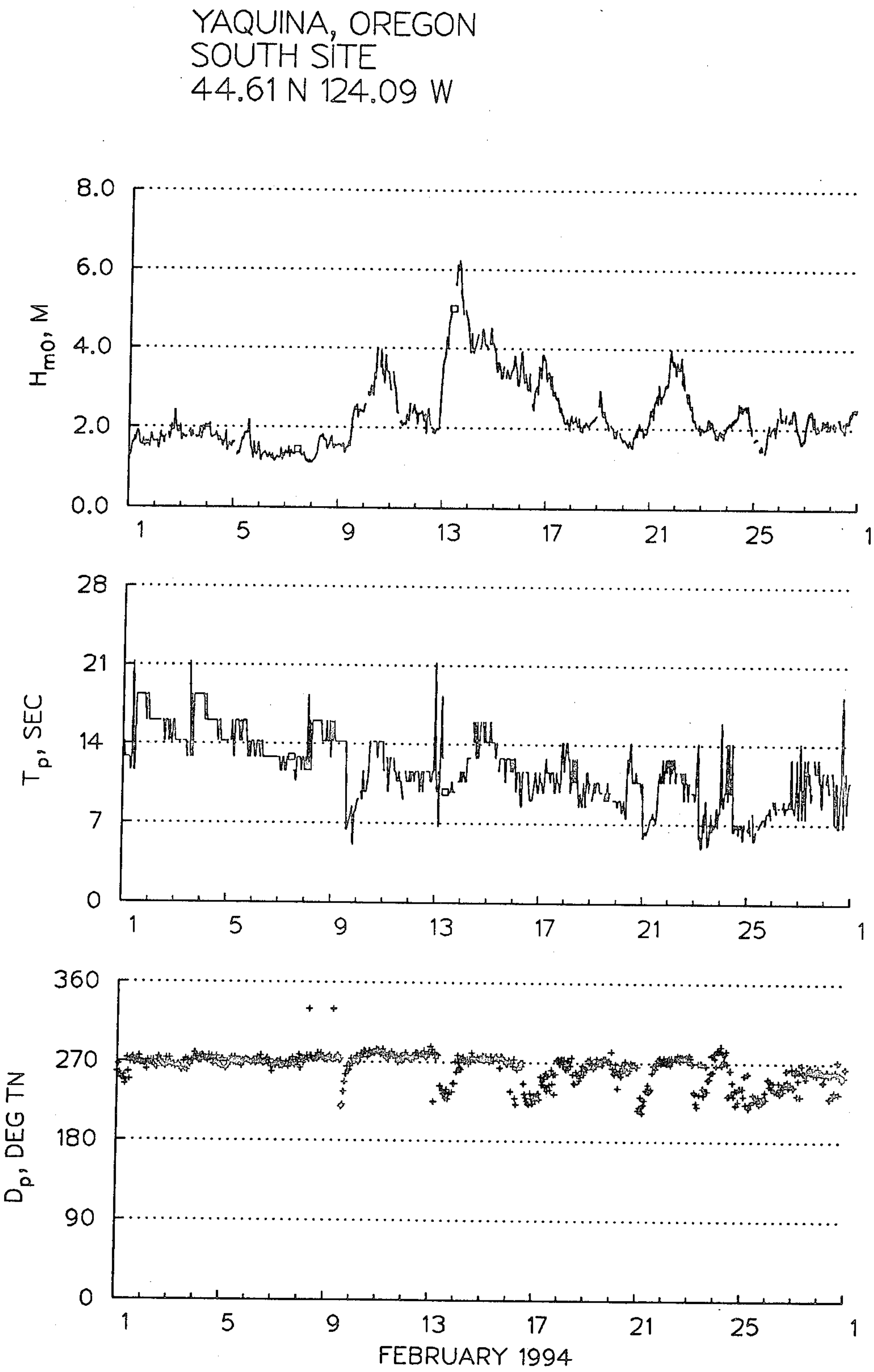


D_p and T_p not reported where H_{m0} less than .2 M


YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W
H$_{m0}$, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
T$_p$, SEC
28
21
14
7
0
1
5
9
13
17
21
25
29
2
D$_p$, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
DECEMBER 1993
D$_p$ and T$_p$ not reported where H$_{m0}$ less than .2 M

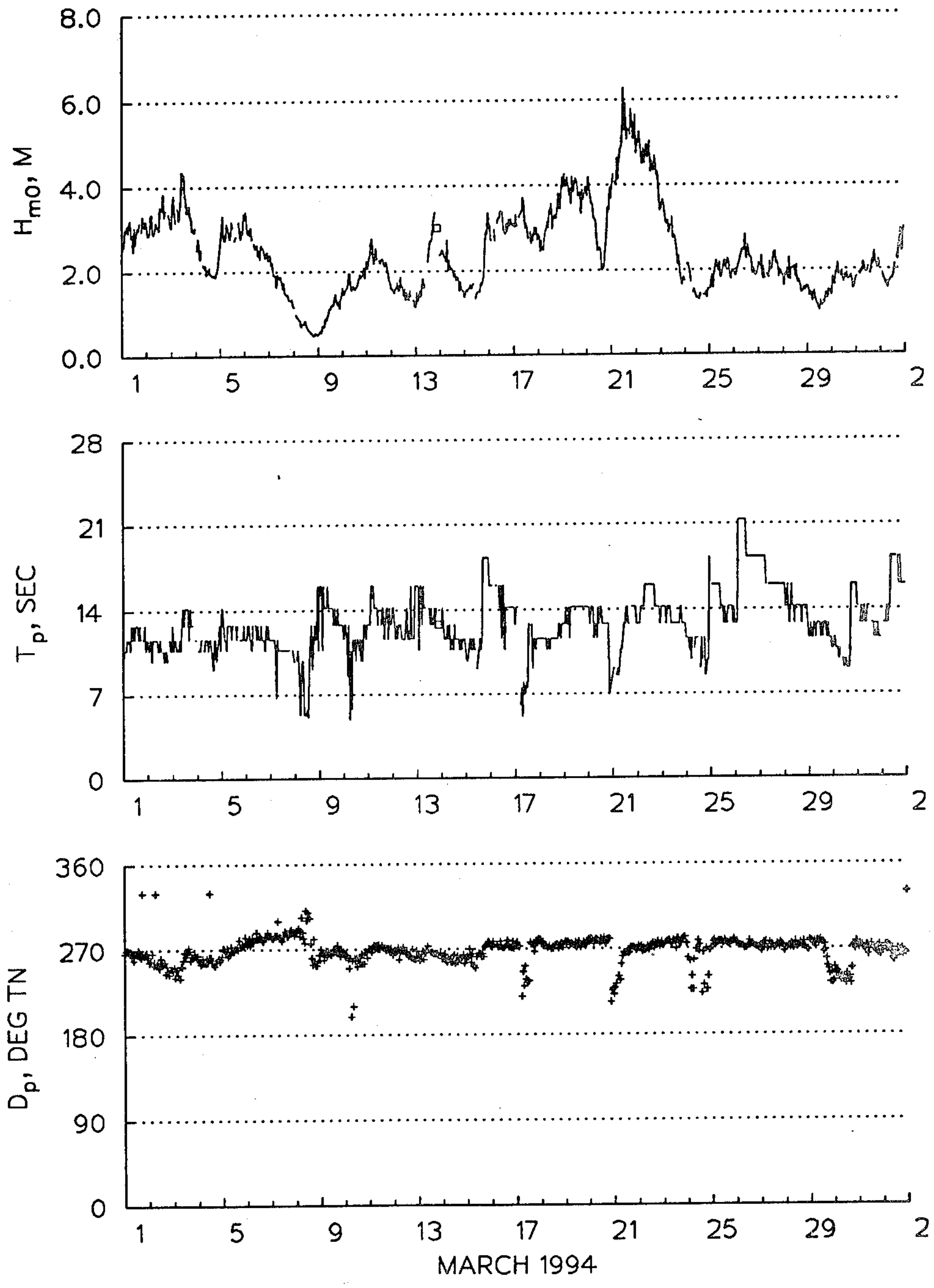


D_p and T_p not reported where H_{m0} less than .2 M

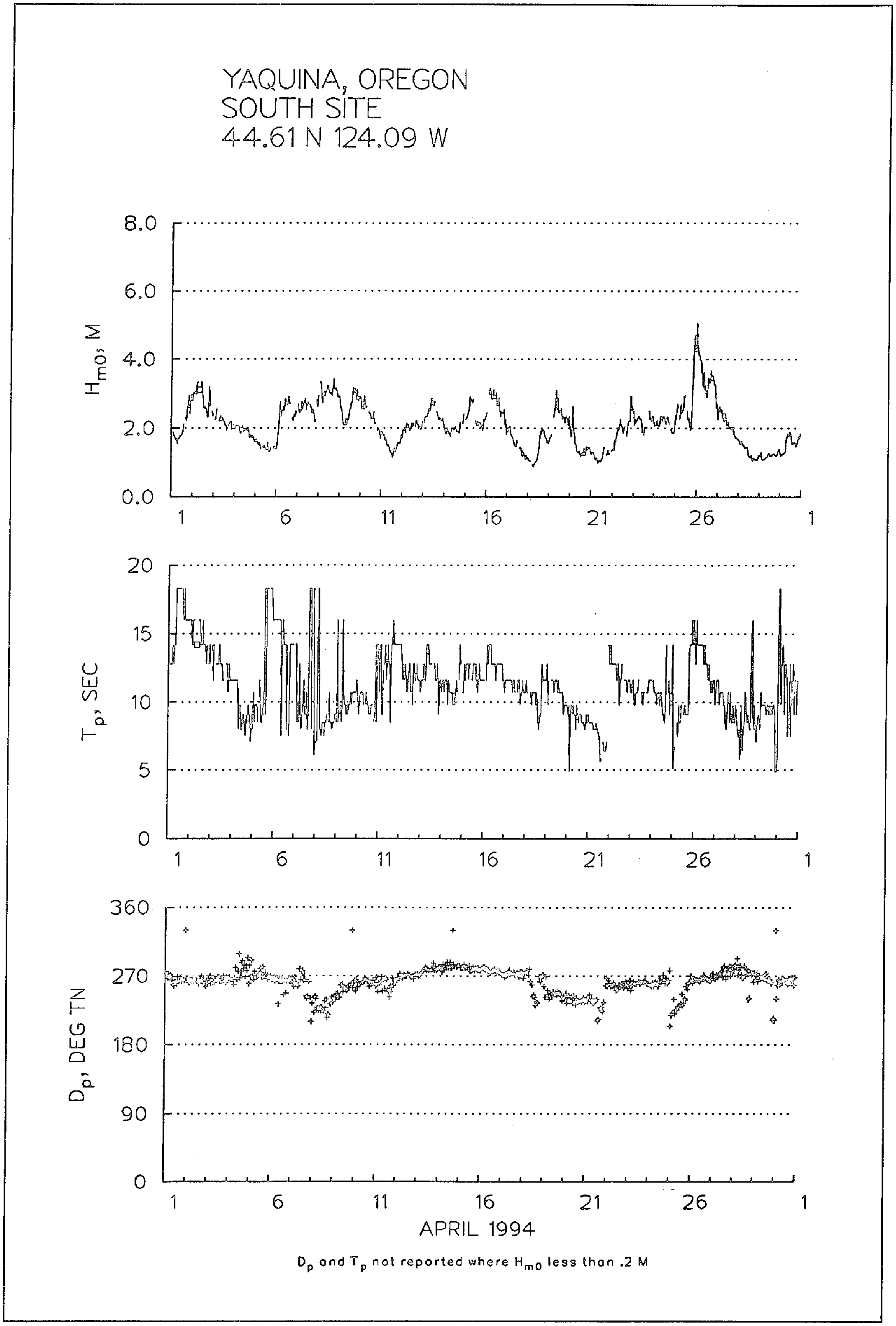


D_p and T_p not reported where H_{m0} less than .2 M

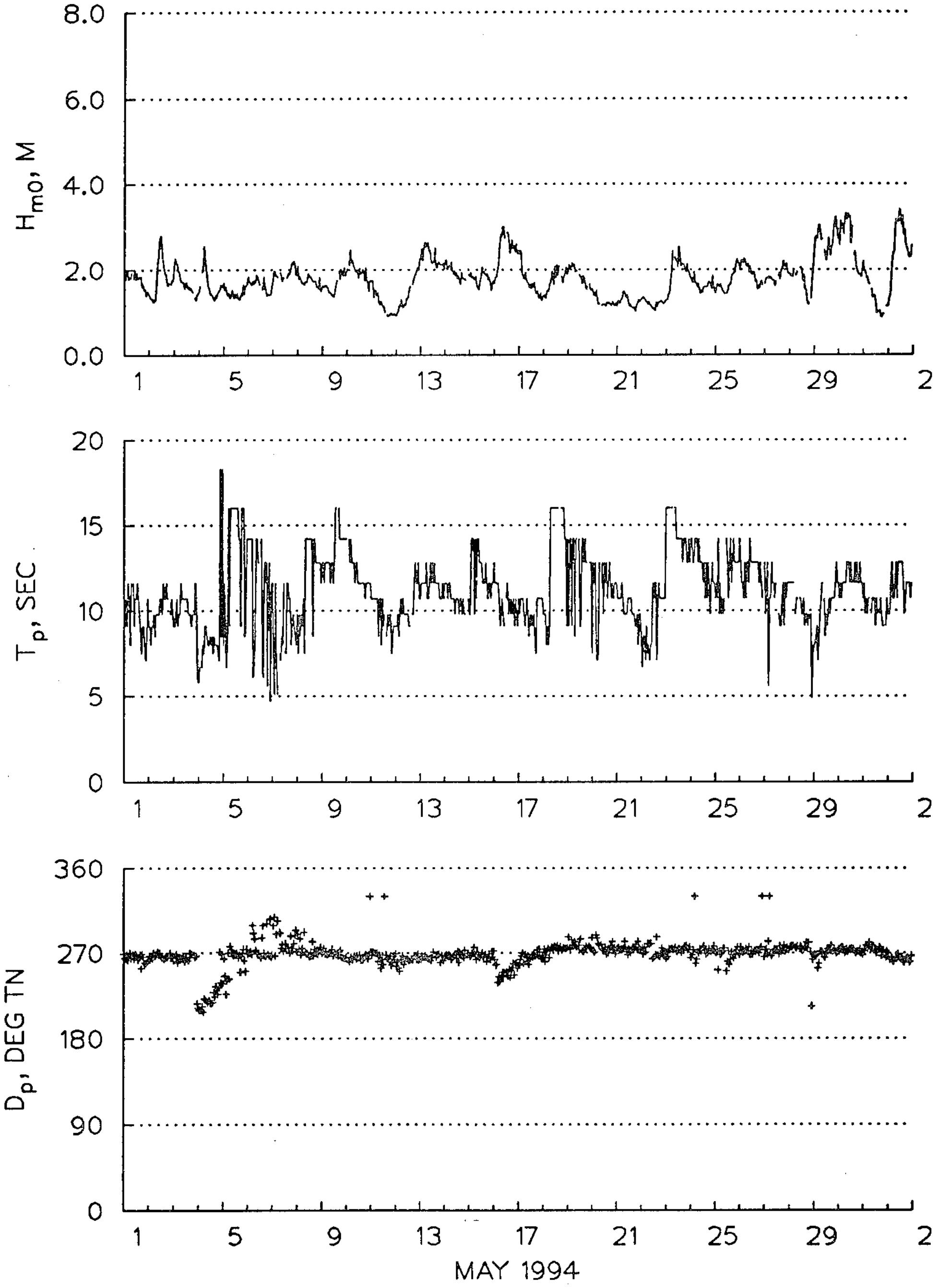
YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W



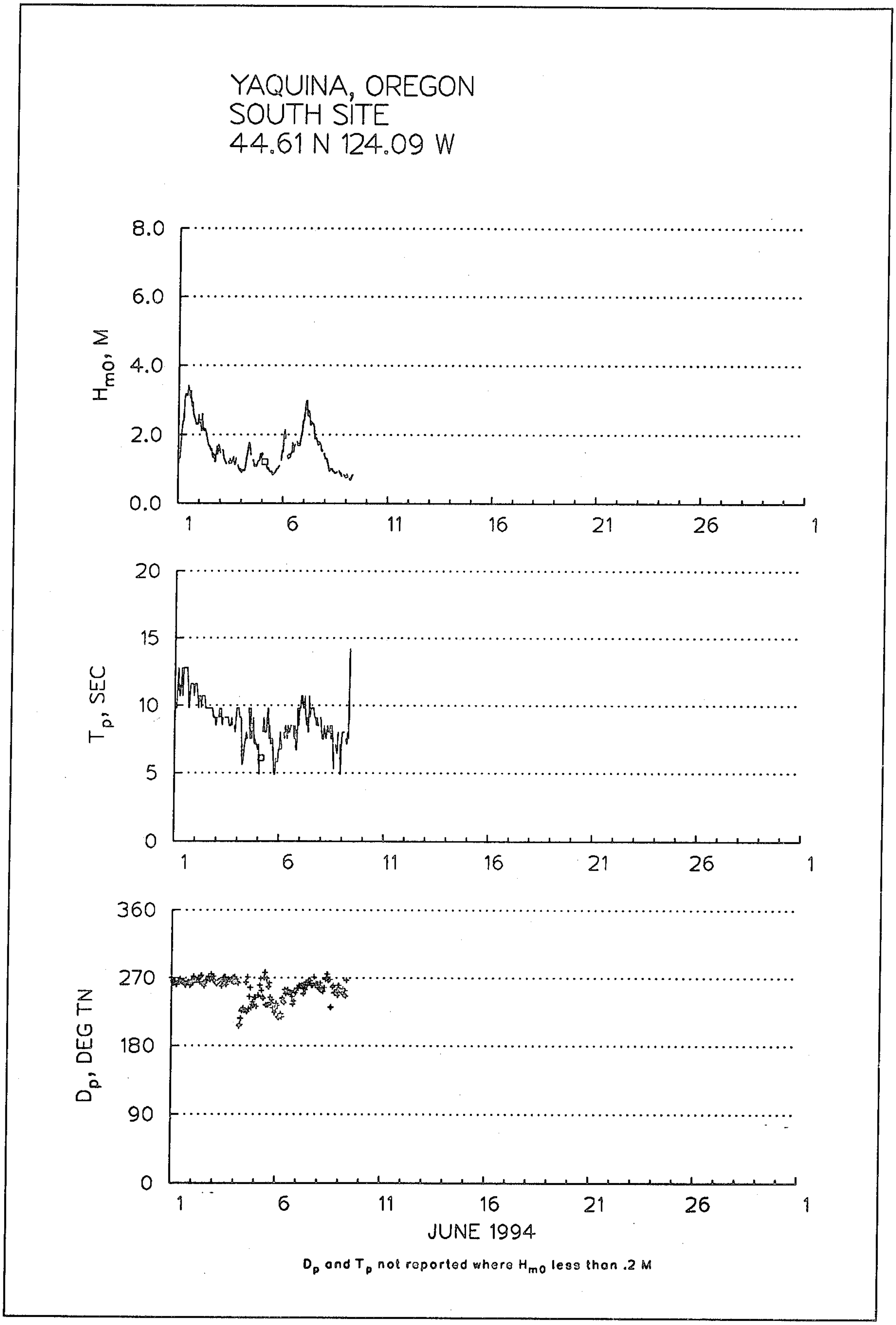
D_p and T_p not reported where H_{m0} less than .2 M


YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W
8.0
6.0
4.0
2.0
0.0
H_{m0}, M
1
6
11
16
21
26
1
20
15
10
5
0
T_p, SEC
360
270
180
90
0
D_p, DEG TN
APRIL 1994
D_p and T_p not reported where H_{m0} less than .2 M

YAQUINA, OREGON
SOUTH SITE
44.61 N 124.09 W

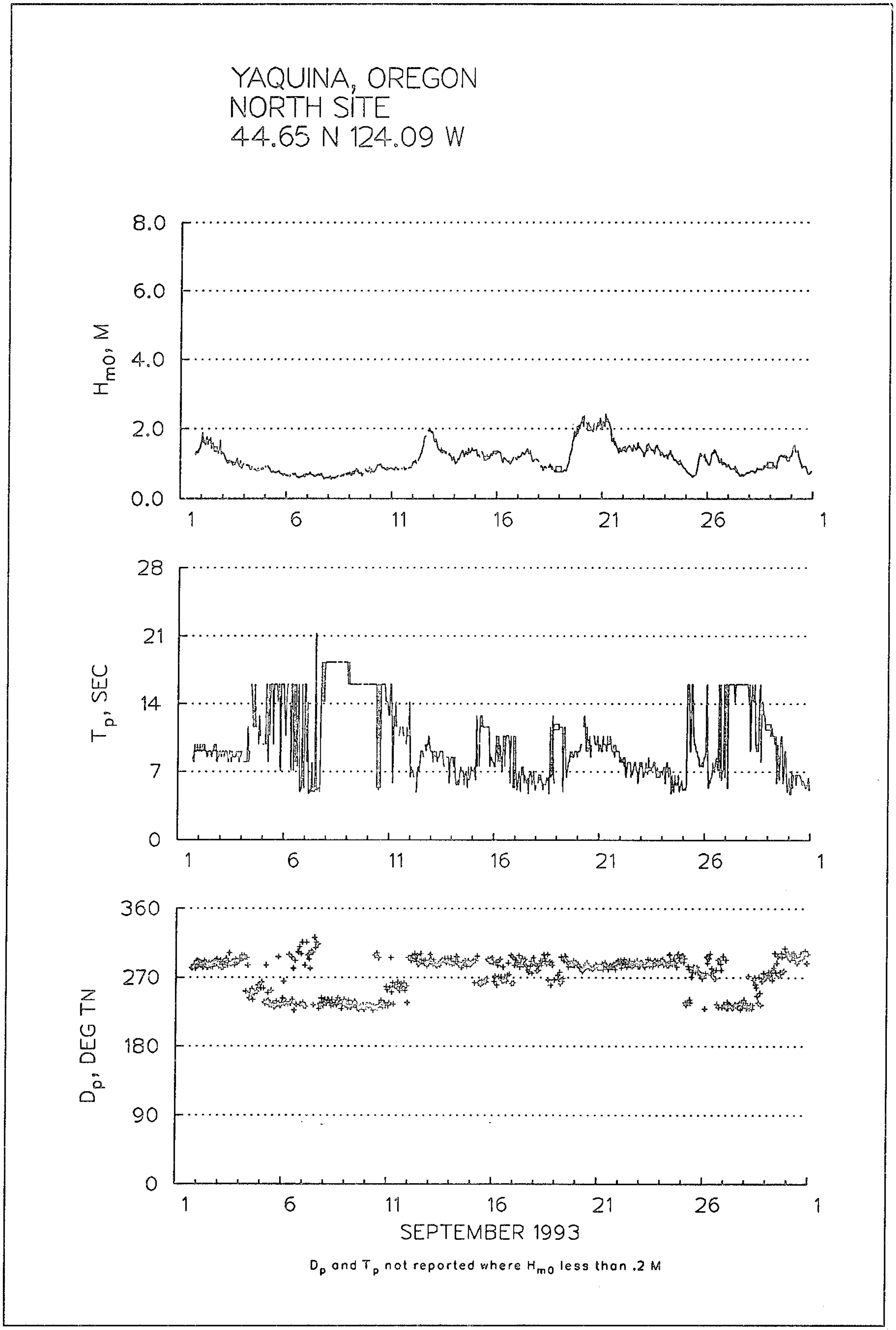


D_p and T_p not reported where H_{m0} less than .2 M

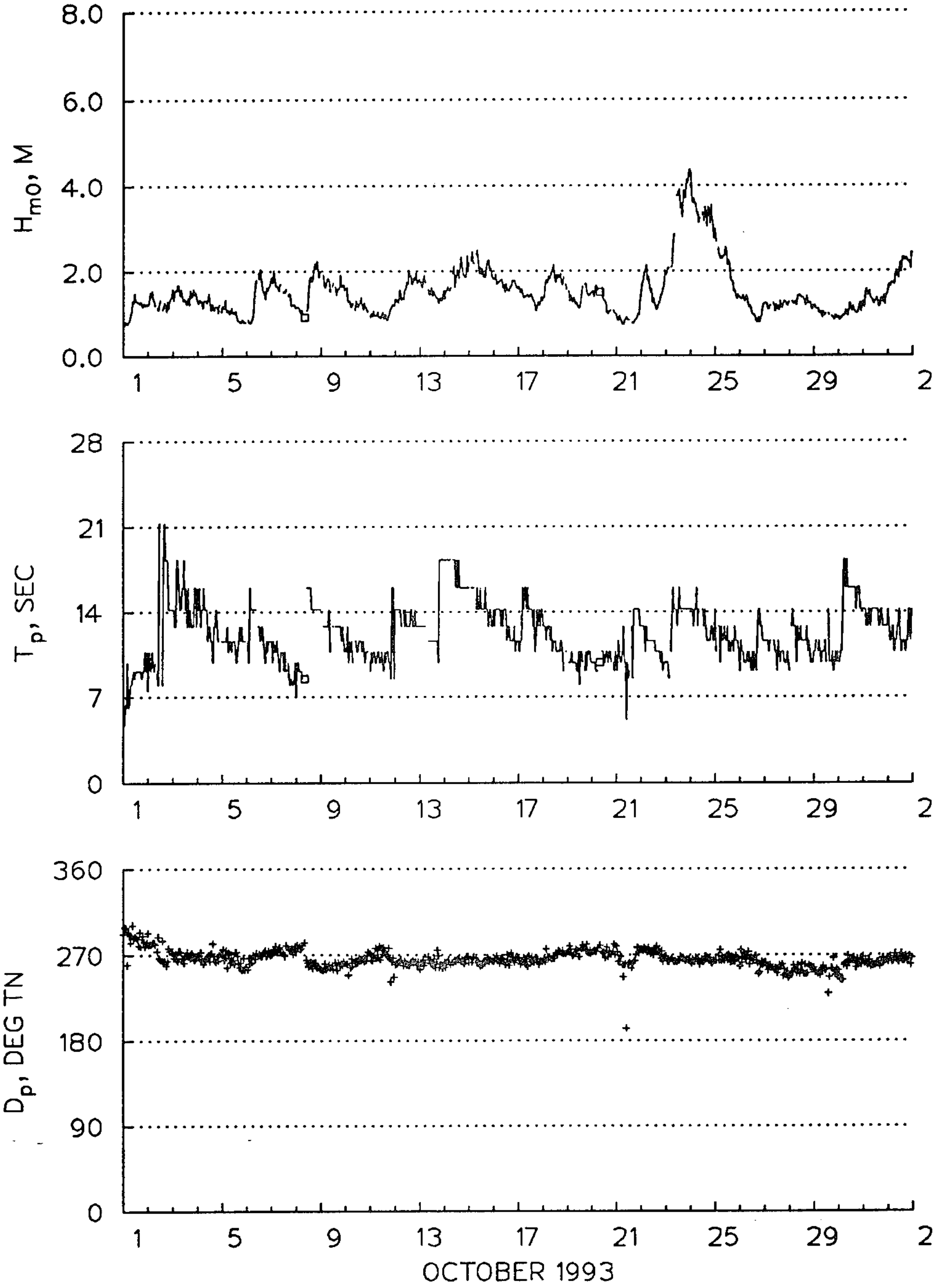


D_p and T_p not reported where H_{m0} less than .2 M

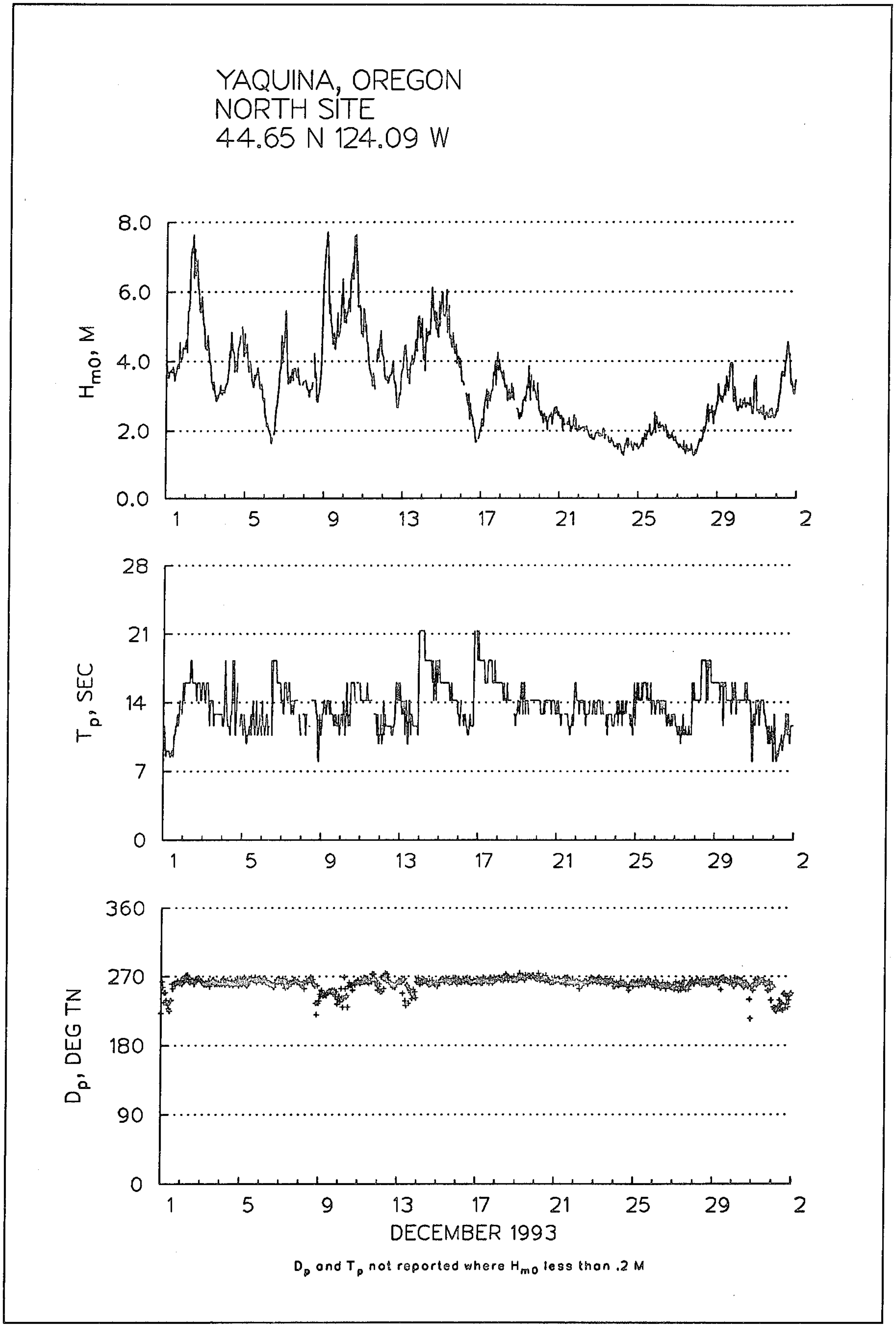
North DWG


YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W
H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
6
11
16
21
26
1
T_p, SEC
28
21
14
7
0
1
6
11
16
21
26
1
D_p, DEG TN
360
270
180
90
0
1
6
11
16
21
26
1
SEPTEMBER 1993
D_p and T_p not reported where H_{m0} less than .2 M

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W



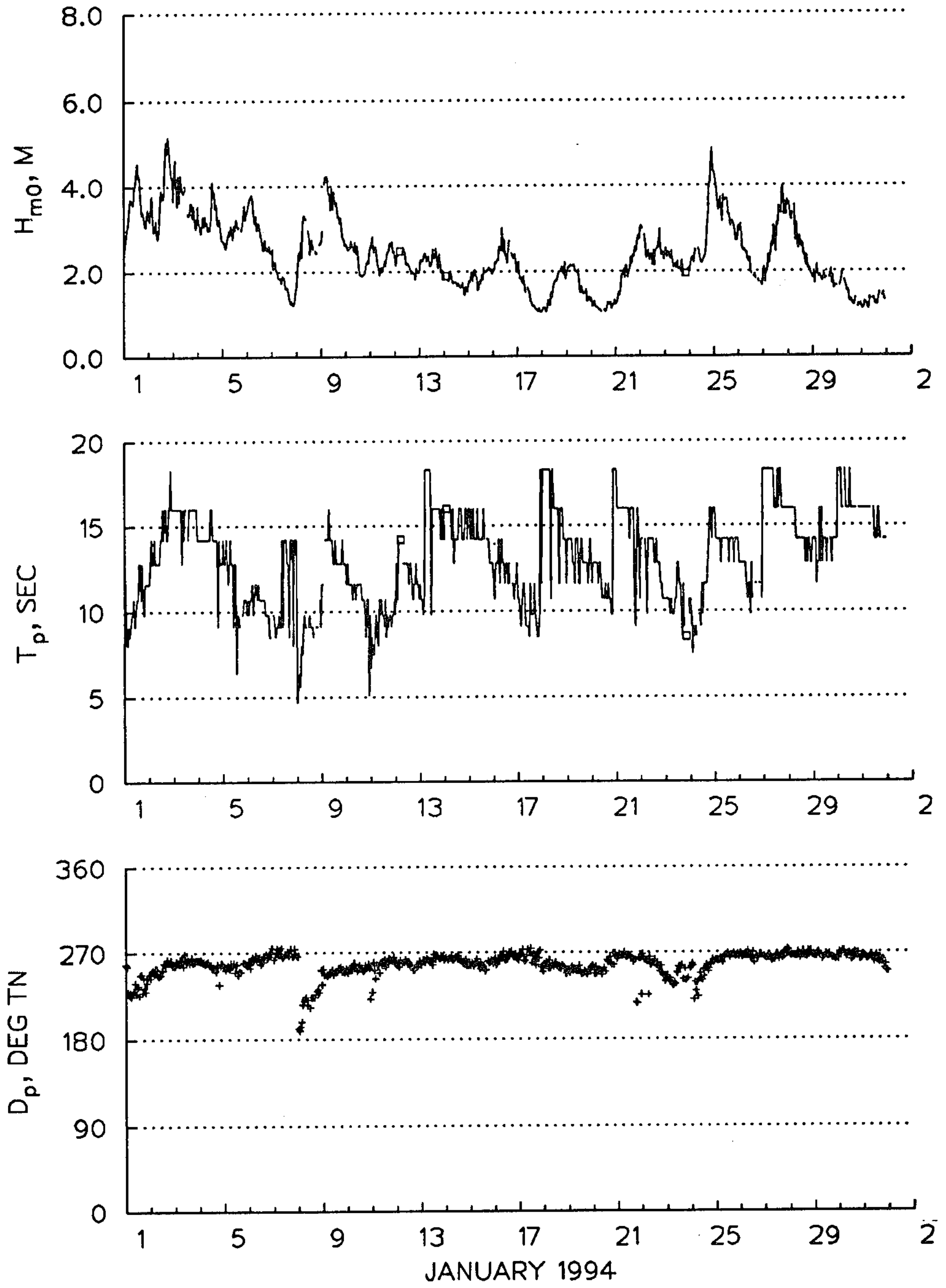
D_p and T_p not reported where H_{mo} less than .2 M



YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W

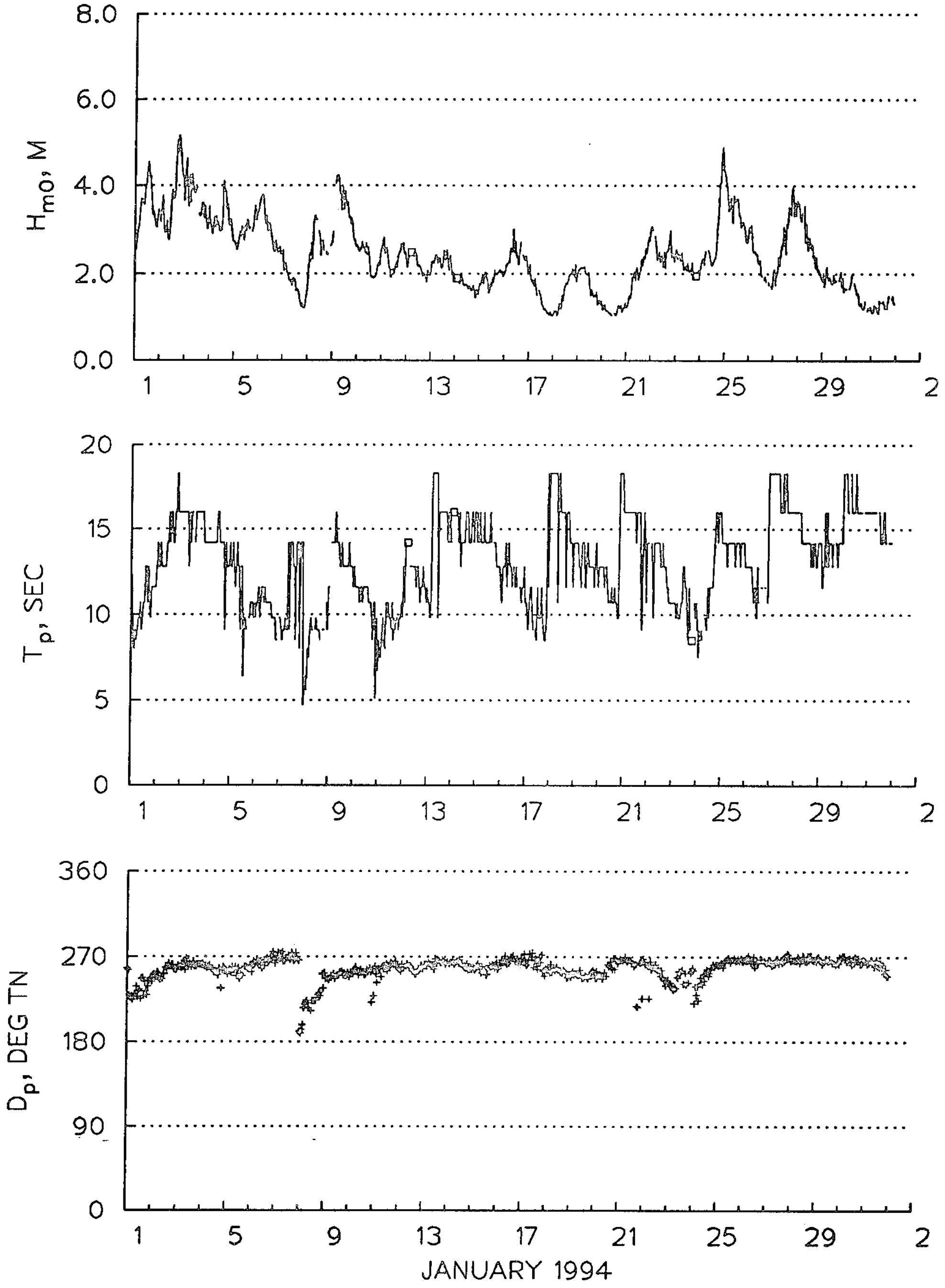
D_p and T_p not reported where H_{mo} less than .2 M

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W

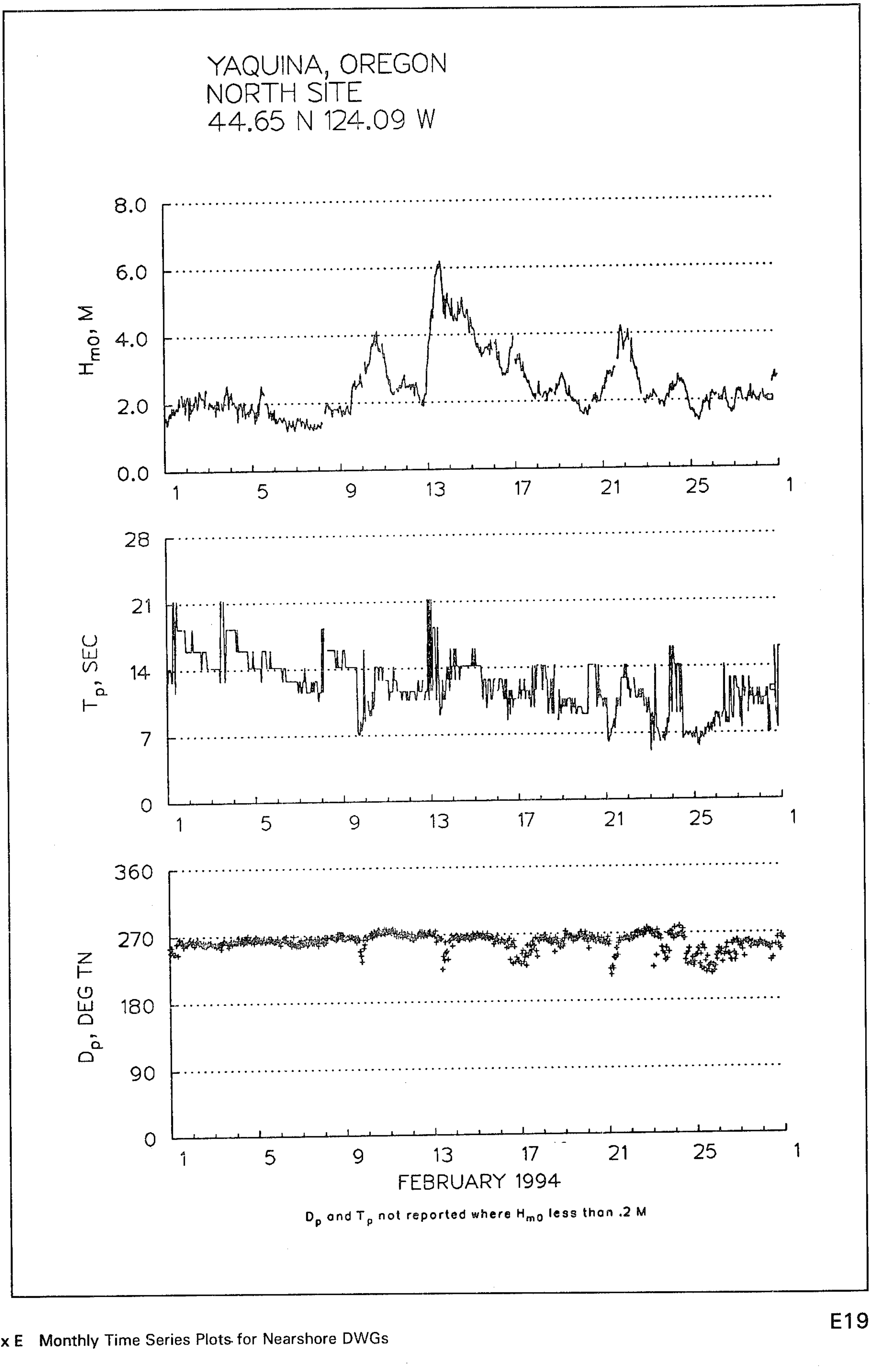


D_p and T_p not reported where H_{mo} less than .2 M

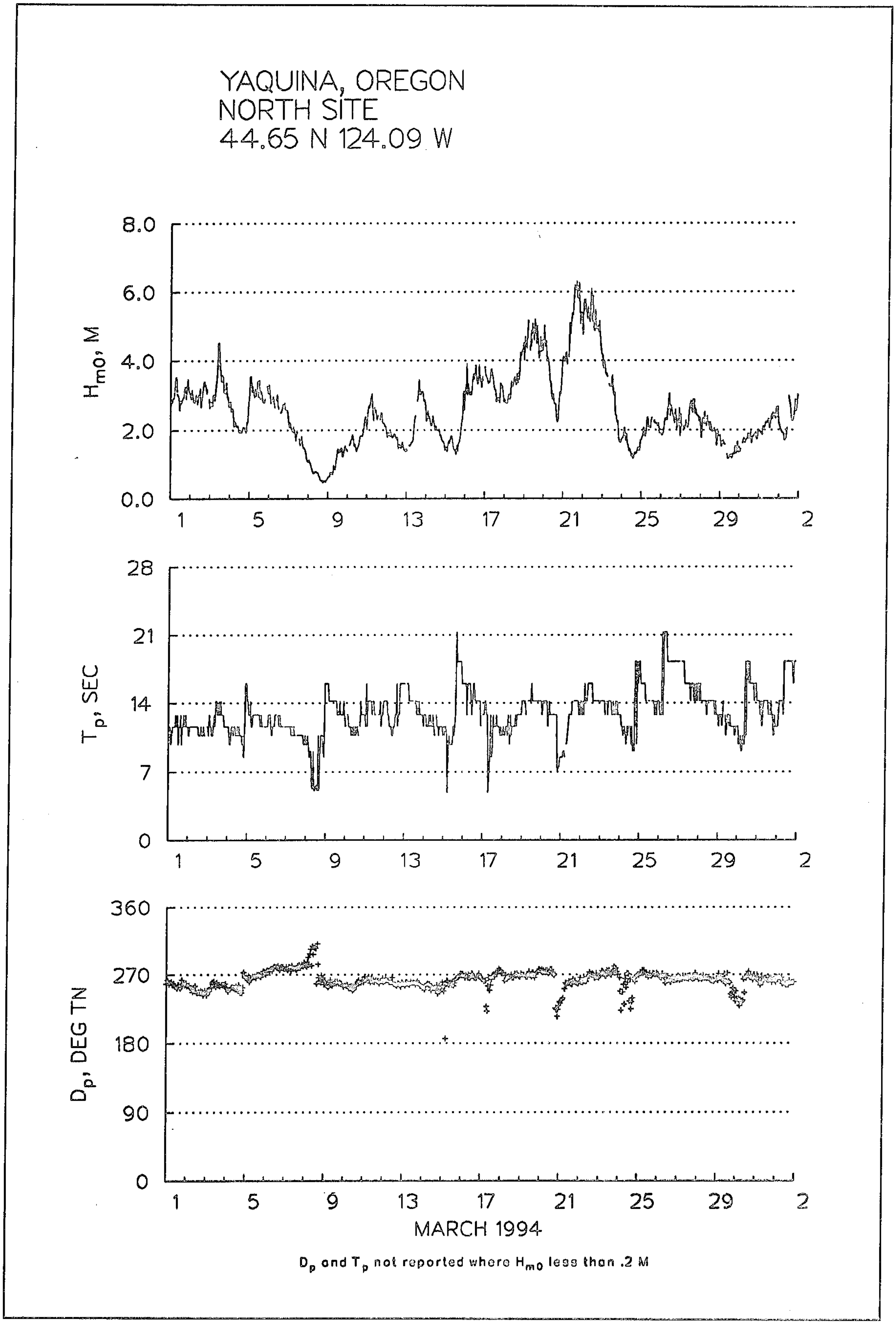
YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W



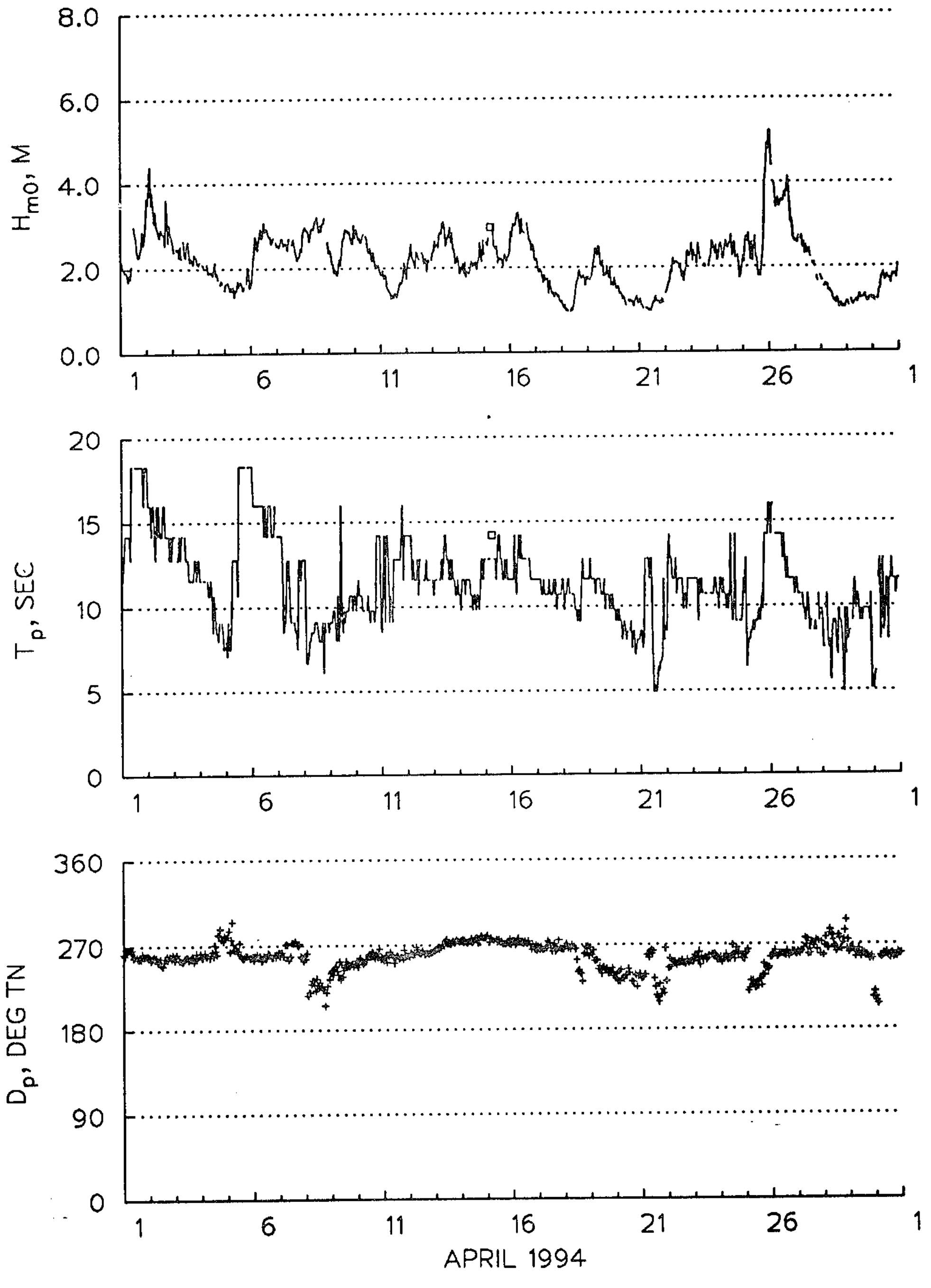
D_p and T_p not reported where H_{mo} less than .2 M


YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W

D_p and T_p not reported where H_{m0} less than .2 M

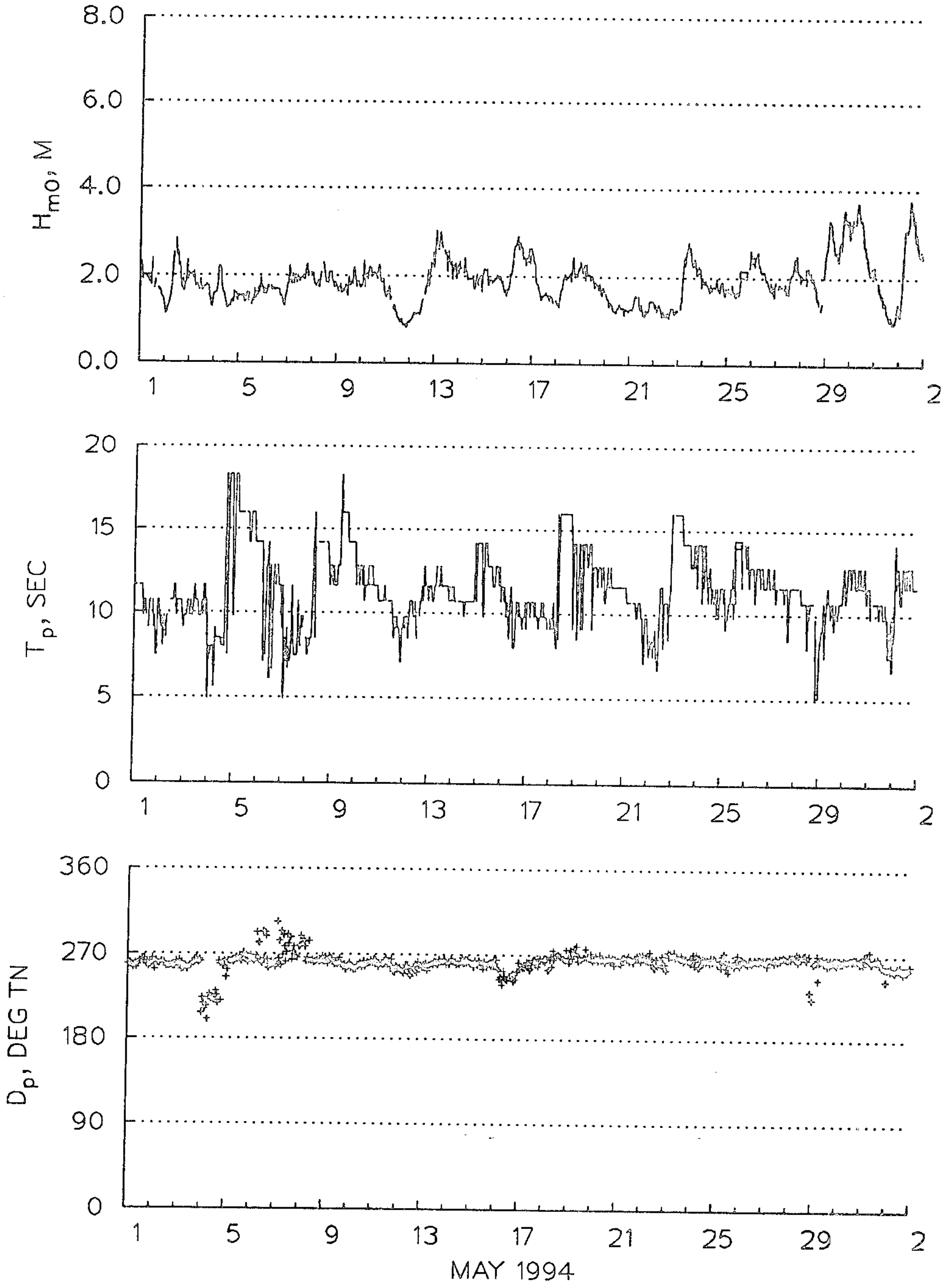

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W
H_{m0}, M
8.0
6.0
4.0
2.0
0.0
1
5
9
13
17
21
25
29
2
T_p, SEC
28
21
14
7
0
1
5
9
13
17
21
25
29
2
D_p, DEG TN
360
270
180
90
0
1
5
9
13
17
21
25
29
2
MARCH 1994
D_p and T_p not reported where H_{m0} less than .2 M

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W



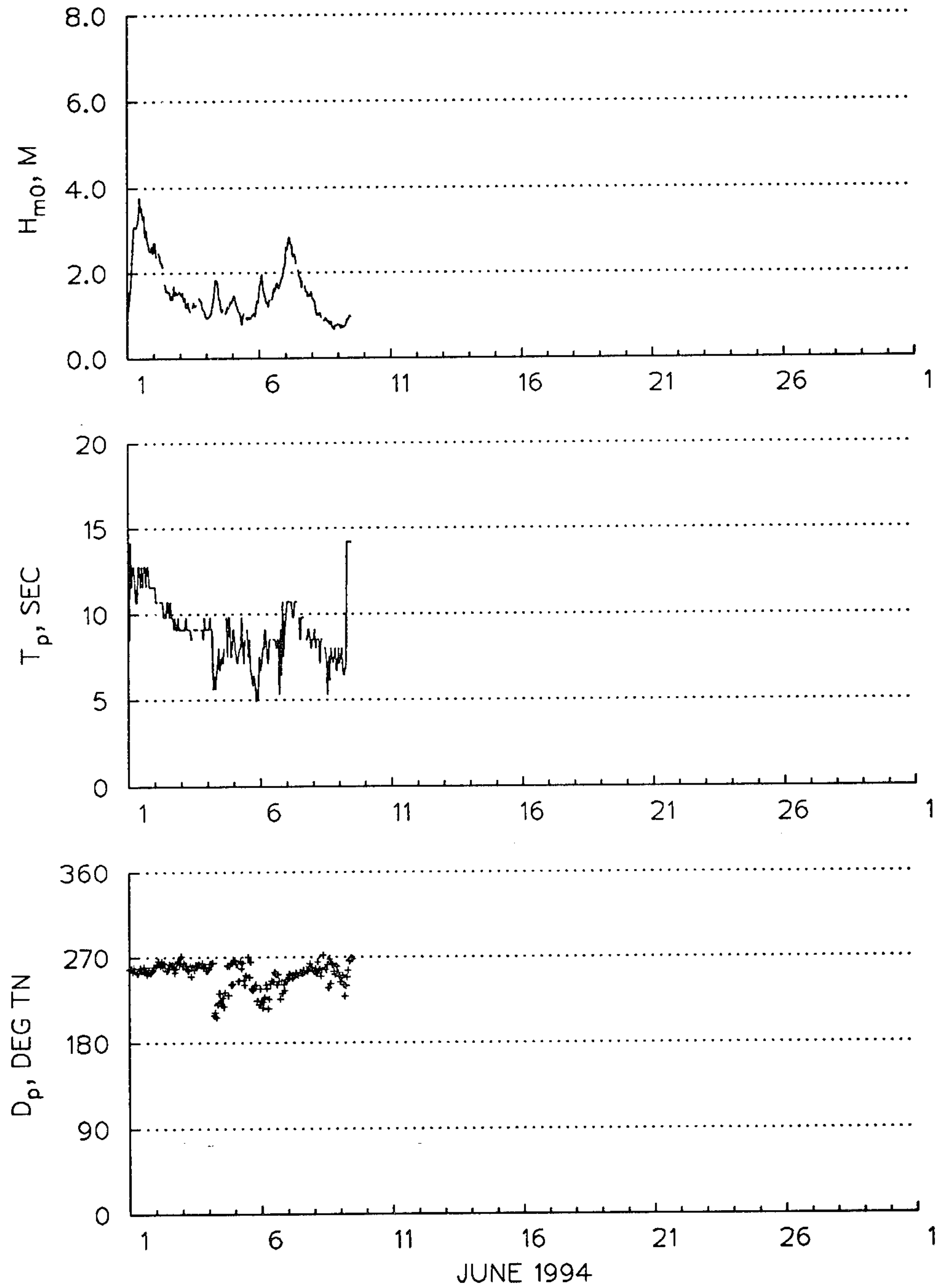
D_p and T_p not reported where H_{mo} less than .2 M

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W



D_p and T_p not reported where H_{m0} less than .2 M

YAQUINA, OREGON
NORTH SITE
44.65 N 124.09 W



D_p and T_p not reported where H_{m0} less than .2 M

Appendix F
Percent Occurrence Tables for Nearshore DWGs

South DWG

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) = 0.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) = 22.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

```
     YAQUINA, SOUTH SITE              44.61N 124.09W      AZIMUTH(DEGREES) = 45.0
                                 SEPTEMBER 1993 - JUNE 1994
                        PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


  HEIGHT(METRES)                           PEAK PERIOD(SECONDS)                       TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                     4.5   5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

  0.0-0.4              .     .      .      .      .      .      .      .      .      .       0
  0.5-0.9              .     .      .      .      .      .      .      .      .      .       0
  1.0-1.4              .     .      .      .      .      .      .      .      .      .       0
  1.5-1.9              .     .      .      .      .      .      .      .      .      .       0
  2.0-2.4              .     .      .      .      .      .      .      .      .      .       0
  2.5-2.9              .     .      .      .      .      .      .      .      .      .       0
  3.0-3.4              .     .      .      .      .      .      .      .      .      .       0
  3.5-3.9              .     .      .      .      .      .      .      .      .      .       0
  4.0-4.4              .     .      .      .      .      .      .      .      .      .       0
  4.5-4.9              .     .      .      .      .      .      .      .      .      .       0
  5.0+                 .     .      .      .      .      .      .      .      .      .       0
  TOTAL                0     0      0      0      0      0      0      0      0      0

  MEAN Hm0(M) =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=       0.
```

```
     YAQUINA, SOUTH SITE              44.61N 124.09W      AZIMUTH(DEGREES) = 67.5
                                 SEPTEMBER 1993 - JUNE 1994
                        PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


  HEIGHT(METRES)                           PEAK PERIOD(SECONDS)                       TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                     4.5   5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

  0.0-0.4              .     .      .      .      .      .      .      .      .      .       0
  0.5-0.9              .     .      .      .      .      .      .      .      .      .       0
  1.0-1.4              .     .      .      .      .      .      .      .      .      .       0
  1.5-1.9              .     .      .      .      .      .      .      .      .      .       0
  2.0-2.4              .     .      .      .      .      .      .      .      .      .       0
  2.5-2.9              .     .      .      .      .      .      .      .      .      .       0
  3.0-3.4              .     .      .      .      .      .      .      .      .      .       0
  3.5-3.9              .     .      .      .      .      .      .      .      .      .       0
  4.0-4.4              .     .      .      .      .      .      .      .      .      .       0
  4.5-4.9              .     .      .      .      .      .      .      .      .      .       0
  5.0+                 .     .      .      .      .      .      .      .      .      .       0
  TOTAL                0     0      0      0      0      0      0      0      0      0

  MEAN Hm0(M) =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=       0.
```

```
  YAQUINA, SOUTH SITE            44.61N 124.09W     AZIMUTH(DEGREES) = 90.0
                              SEPTEMBER 1993 - JUNE 1994
                   PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)                        PEAK PERIOD(SECONDS)                        TOTAL

                SHORTER-  4.6-  5.6-  8.0- 10.7- 11.6- 12.8- 14.2- 16.0- 18.3-
                    4.5   5.5   7.9  10.6  11.5  12.7  14.1  15.9  18.2  LONGER

0.0-0.4               .     .     .     .     .     .     .     .     .     .      0
0.5-0.9               .     .     .     .     .     .     .     .     .     .      0
1.0-1.4               .     .     .     .     .     .     .     .     .     .      0
1.5-1.9               .     .     .     .     .     .     .     .     .     .      0
2.0-2.4               .     .     .     .     .     .     .     .     .     .      0
2.5-2.9               .     .     .     .     .     .     .     .     .     .      0
3.0-3.4               .     .     .     .     .     .     .     .     .     .      0
3.5-3.9               .     .     .     .     .     .     .     .     .     .      0
4.0-4.4               .     .     .     .     .     .     .     .     .     .      0
4.5-4.9               .     .     .     .     .     .     .     .     .     .      0
5.0+                  .     .     .     .     .     .     .     .     .     .
TOTAL                 0     0     0     0     0     0     0     0     0     0

MEAN Hm0(M) =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=      0.
```

```
  YAQUINA, SOUTH SITE            44.61N 124.09W     AZIMUTH(DEGREES) =112.5
                              SEPTEMBER 1993 - JUNE 1994
                   PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)                        PEAK PERIOD(SECONDS)                        TOTAL

                SHORTER-  4.6-  5.6-  8.0- 10.7- 11.6- 12.8- 14.2- 16.0- 18.3-
                    4.5   5.5   7.9  10.6  11.5  12.7  14.1  15.9  18.2  LONGER

0.0-0.4               .     .     .     .     .     .     .     .     .     .      0
0.5-0.9               .     .     .     .     .     .     .     .     .     .      0
1.0-1.4               .     .     .     .     .     .     .     .     .     .      0
1.5-1.9               .     .     .     .     .     .     .     .     .     .      0
2.0-2.4               .     .     .     .     .     .     .     .     .     .      0
2.5-2.9               .     .     .     .     .     .     .     .     .     .      0
3.0-3.4               .     .     .     .     .     .     .     .     .     .      0
3.5-3.9               .     .     .     .     .     .     .     .     .     .      0
4.0-4.4               .     .     .     .     .     .     .     .     .     .      0
4.5-4.9               .     .     .     .     .     .     .     .     .     .      0
5.0+                  .     .     .     .     .     .     .     .     .     .
TOTAL                 0     0     0     0     0     0     0     0     0     0

MEAN Hm0(M) =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=      0.
```

```
 YAQUINA, SOUTH SITE               44.61N 124.09W     AZIMUTH(DEGREES) =135.0
                            SEPTEMBER 1993 - JUNE 1994
                  PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)                          PEAK PERIOD(SECONDS)                      TOTAL

                SHORTER-  4.6-  5.6-  8.0- 10.7- 11.6- 12.8- 14.2- 16.0- 18.3-
                     4.5   5.5   7.9  10.6  11.5  12.7  14.1  15.9  18.2 LONGER

 0.0-0.4               .     .     .     .     .     .     .     .     .     .       0
 0.5-0.9               .     .     .     .     .     .     .     .     .     .       0
 1.0-1.4               .     .     .     .     .     .     .     .     .     .       0
 1.5-1.9               .     .     .     .     .     .     .     .     .     .       0
 2.0-2.4               .     .     .     .     .     .     .     .     .     .       0
 2.5-2.9               .     .     .     .     .     .     .     .     .     .       0
 3.0-3.4               .     .     .     .     .     .     .     .     .     .       0
 3.5-3.9               .     .     .     .     .     .     .     .     .     .       0
 4.0-4.4               .     .     .     .     .     .     .     .     .     .       0
 4.5-4.9               .     .     .     .     .     .     .     .     .     .       0
 5.0+                  .     .     .     .     .     .     .     .     .     .       0
TOTAL                  0     0     0     0     0     0     0     0     0     0

MEAN Hm0(M) =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=       0.


 YAQUINA, SOUTH SITE               44.61N 124.09W     AZIMUTH(DEGREES) =157.5
                            SEPTEMBER 1993 - JUNE 1994
                  PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)                          PEAK PERIOD(SECONDS)                      TOTAL

                SHORTER-  4.6-  5.6-  8.0- 10.7- 11.6- 12.8- 14.2- 16.0- 18.3-
                     4.5   5.5   7.9  10.6  11.5  12.7  14.1  15.9  18.2 LONGER

 0.0-0.4               .     .     .     .     .     .     .     .     .     .       0
 0.5-0.9               .     .     .     .     .     .     .     .    15     .      15
 1.0-1.4               .     .     .     .     .     .     .     .     .     .       0
 1.5-1.9               .     .     .     .     .     .     .     .     .     .       0
 2.0-2.4               .     .     .     .     .     .     .     .     .     .       0
 2.5-2.9               .     .     .     .     .     .     .     .     .     .       0
 3.0-3.4               .     .     .     .     .     .     .     .     .     .       0
 3.5-3.9               .     .     .     .     .     .     .     .     .     .       0
 4.0-4.4               .     .     .     .     .     .     .     .     .     .       0
 4.5-4.9               .     .     .     .     .     .     .     .     .     .       0
 5.0+                  .     .     .     .     .     .     .     .     .     .       0
TOTAL                  0     0     0     0     0     0     0     0    15     0

MEAN Hm0(M) =  1.0  LARGEST Hm0(M)=   1.0  MEAN TP(SEC)= 16.0  NO. OF CASES=       1.
```

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =180.0

SEPTEMBER 1993 - JUNE 1994

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	15	.	.	.	.	.	.	.	.	15
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	15	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 1.6 LARGEST Hm0(M) = 1.6 MEAN TP(SEC) = 4.7 NO. OF CASES= 1.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =202.5

SEPTEMBER 1993 - JUNE 1994

PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	15	.	.	.	.	.	.	.	15
1.0-1.4	.	15	93	.	.	.	.	.	.	.	108
1.5-1.9	.	15	46	.	.	.	.	.	.	.	61
2.0-2.4	.	31	15	.	.	.	.	.	.	.	46
2.5-2.9	.	.	77	15	.	.	.	.	.	.	92
3.0-3.4	.	.	15	15	.	.	.	.	.	.	30
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	61	261	30	0	0	0	0	0	0	

MEAN Hm0(M) = 2.0 LARGEST Hm0(M) = 3.2 MEAN TP(SEC) = 6.3 NO. OF CASES= 23.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =225.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	15	31	.	.	.	.	202	343	155	746
1.0-1.4	.	31	327	358	15	31	.	46	202	.	1010
1.5-1.9	.	31	265	233	.	.	.	.	.	.	529
2.0-2.4	.	31	280	467	31	.	.	.	.	.	809
2.5-2.9	.	31	265	467	46	.	.	.	.	.	809
3.0-3.4	.	15	109	343	46	31	.	.	.	.	544
3.5-3.9	.	.	15	187	15	15	.	.	.	.	232
4.0-4.4	.	.	15	93	31	.	.	.	.	.	139
4.5-4.9	.	.	.	46	15	15	.	.	.	.	76
5.0+	.	.	.	93	46	46	.	.	.	.	185
TOTAL	0	154	1307	2287	245	138	0	248	545	155	

MEAN Hm0(M) = 2.3 LARGEST Hm0(M) = 6.2 MEAN TP(SEC) = 9.7 NO. OF CASES= 327.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =247.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	15	15	15	62	.	107
0.5-0.9	.	15	140	171	62	46	124	717	1496	436	3207
1.0-1.4	.	31	140	935	311	218	187	374	623	62	2881
1.5-1.9	.	15	202	764	311	483	389	140	15	62	2381
2.0-2.4	.	.	93	1294	592	296	109	31	31	46	2492
2.5-2.9	.	.	124	608	374	389	77	15	15	46	1648
3.0-3.4	.	.	62	280	280	171	93	15	.	15	916
3.5-3.9	.	.	15	171	62	155	31	15	.	.	449
4.0-4.4	.	.	.	93	31	31	77	.	.	.	232
4.5-4.9	.	.	.	15	46	31	31	15	.	.	138
5.0+	.	.	.	31	77	15	171	46	.	.	340
TOTAL	0	61	776	4362	2146	1850	1304	1383	2242	667	

MEAN Hm0(M) = 1.9 LARGEST Hm0(M) = 8.0 MEAN TP(SEC) = 11.8 NO. OF CASES= 951.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =270.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS) SHORTER-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3-LONGER	TOTAL
0.0-0.4	.	.	.	.	15	.	.	.	.	.	15
0.5-0.9	.	.	109	779	436	327	171	374	249	.	2445
1.0-1.4	.	.	171	3227	2027	1746	2479	1528	1216	810	13204
1.5-1.9	.	.	93	2775	2354	3898	4038	3757	2463	982	20360
2.0-2.4	.	15	31	1715	1902	3165	2869	1949	842	670	13158
2.5-2.9	.	.	.	670	966	1418	1341	1762	576	202	6935
3.0-3.4	.	.	.	93	561	1200	1278	1559	701	62	5454
3.5-3.9	.	.	.	15	140	343	639	935	343	31	2446
4.0-4.4	.	.	.	62	124	140	436	592	280	124	1758
4.5-4.9	.	.	.	.	31	46	155	358	296	109	995
5.0+	.	.	.	.	.	.	124	327	218	31	700
TOTAL	0	15	404	9336	8556	12283	13530	13141	7184	3021	

MEAN Hm0(M) = 2.2 LARGEST Hm0(M) = 6.8 MEAN TP(SEC)= 12.7 NO. OF CASES= 4329.

YAQUINA, SOUTH SITE 44.61N 124.09W AZIMUTH(DEGREES) =292.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS) SHORTER-4.5	4.6-5.5	5.6-7.9	8.0-10.6	10.7-11.5	11.6-12.7	12.8-14.1	14.2-15.9	16.0-18.2	18.3-LONGER	TOTAL
0.0-0.4	.	.	15	.	.	.	.	.	.	.	15
0.5-0.9	.	171	608	265	15	15	.	.	.	.	1074
1.0-1.4	.	218	1715	2526	280	77	31	15	.	.	4862
1.5-1.9	.	.	452	1341	343	327	46	.	.	.	2509
2.0-2.4	.	.	.	670	467	405	202	15	.	.	1759
2.5-2.9	.	.	.	62	93	218	93	.	.	.	466
3.0-3.4	.	.	.	31	.	93	62	62	.	.	248
3.5-3.9	.	.	.	15	.	31	77	62	.	.	185
4.0-4.4	.	.	.	.	15	15	31	15	.	.	76
4.5-4.9	.	.	.	.	.	.	31	46	.	.	77
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	389	2790	4910	1213	1181	573	215	0	0	

MEAN Hm0(M) = 1.7 LARGEST Hm0(M) = 4.9 MEAN TP(SEC) = 9.0 NO. OF CASES= 724.

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     YAQUINA, SOUTH SITE              44.61N 124.09W      AZIMUTH(DEGREES) =315.0
                               SEPTEMBER 1993 - JUNE 1994
                    PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


 HEIGHT(METRES)                         PEAK PERIOD(SECONDS)                       TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                   4.5    5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

 0.0-0.4            .      .      .      .      .      .      .      .      .      .       0
 0.5-0.9            .    109     31      .      .      .      .      .      .      .     140
 1.0-1.4            .    124    171      .      .      .      .      .      .      .     295
 1.5-1.9            .     46      .      .      .      .      .      .      .      .      46
 2.0-2.4            .      .      .      .      .      .      .      .      .      .       0
 2.5-2.9            .      .      .      .      .      .      .      .      .      .       0
 3.0-3.4            .      .      .      .      .      .      .      .      .      .       0
 3.5-3.9            .      .      .      .      .      .      .      .      .      .       0
 4.0-4.4            .      .      .      .      .      .      .      .      .      .       0
 4.5-4.9            .      .      .      .      .      .      .      .      .      .       0
 5.0+               .      .      .      .      .      .      .      .      .      .       0
 TOTAL              0    279    202      0      0      0      0      0      0      0

 MEAN Hm0(M)  =  1.2  LARGEST Hm0(M)=   2.0  MEAN TP(SEC)=  5.5  NO. OF CASES=     31.


     YAQUINA, SOUTH SITE              44.61N 124.09W      AZIMUTH(DEGREES) =337.5
                               SEPTEMBER 1993 - JUNE 1994
                    PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


 HEIGHT(METRES)                         PEAK PERIOD(SECONDS)                       TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                   4.5    5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

 0.0-0.4            .      .      .      .      .      .      .      .      .      .       0
 0.5-0.9            .      .      .     46      .      .      .      .      .      .      46
 1.0-1.4            .      .      .      .      .     15     31     31      .      .      77
 1.5-1.9            .      .     15     46     77     15      .     15     15     15     198
 2.0-2.4            .      .      .      .     15      .      .      .      .      .      15
 2.5-2.9            .      .      .      .     15     15      .      .     15      .      45
 3.0-3.4            .      .      .      .      .     15      .      .      .      .      15
 3.5-3.9            .      .      .      .      .      .      .      .      .      .       0
 4.0-4.4            .      .      .      .      .      .      .      .      .      .       0
 4.5-4.9            .      .      .      .      .      .      .      .      .      .       0
 5.0+               .      .      .      .      .      .      .      .      .      .       0
 TOTAL              0      0     15     92    107     60     31     46     30     15

 MEAN Hm0(M)  =  1.7  LARGEST Hm0(M)=   3.2  MEAN TP(SEC)= 11.8  NO. OF CASES=     26.
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North DWG

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   YAQUINA, NORTH SITE                    44.65N 124.09W      AZIMUTH(DEGREES) =  0.0
                              SEPTEMBER 1993 - JUNE 1994
                    PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

 HEIGHT(METRES)                              PEAK PERIOD(SECONDS)                            TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                    4.5    5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

 0.0-0.4             .      .      .      .      .      .      .      .      .      .         0
 0.5-0.9             .      .      .      .      .      .      .      .      .      .         0
 1.0-1.4             .      .      .      .      .      .      .      .      .      .         0
 1.5-1.9             .      .      .      .      .      .      .      .      .      .         0
 2.0-2.4             .      .      .      .      .      .      .      .      .      .         0
 2.5-2.9             .      .      .      .      .      .      .      .      .      .         0
 3.0-3.4             .      .      .      .      .      .      .      .      .      .         0
 3.5-3.9             .      .      .      .      .      .      .      .      .      .         0
 4.0-4.4             .      .      .      .      .      .      .      .      .      .         0
 4.5-4.9             .      .      .      .      .      .      .      .      .      .         0
 5.0+                .      .      .      .      .      .      .      .      .      .         0
 TOTAL               0      0      0      0      0      0      0      0      0      0

 MEAN Hm0(M)  =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=        0.
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   YAQUINA, NORTH SITE                    44.65N 124.09W      AZIMUTH(DEGREES) = 22.5
                              SEPTEMBER 1993 - JUNE 1994
                    PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

 HEIGHT(METRES)                              PEAK PERIOD(SECONDS)                            TOTAL

                SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                    4.5    5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

 0.0-0.4             .      .      .      .      .      .      .      .      .      .         0
 0.5-0.9             .      .      .      .      .      .      .      .      .      .         0
 1.0-1.4             .      .      .      .      .      .      .      .      .      .         0
 1.5-1.9             .      .      .      .      .      .      .      .      .      .         0
 2.0-2.4             .      .      .      .      .      .      .      .      .      .         0
 2.5-2.9             .      .      .      .      .      .      .      .      .      .         0
 3.0-3.4             .      .      .      .      .      .      .      .      .      .         0
 3.5-3.9             .      .      .      .      .      .      .      .      .      .         0
 4.0-4.4             .      .      .      .      .      .      .      .      .      .         0
 4.5-4.9             .      .      .      .      .      .      .      .      .      .         0
 5.0+                .      .      .      .      .      .      .      .      .      .         0
 TOTAL               0      0      0      0      0      0      0      0      0      0

 MEAN Hm0(M)  =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=        0.
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YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) = 45.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) = 67.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH (DEGREES) = 90.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS) SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	TOTAL
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0 (M) = 0.0 LARGEST Hm0 (M) = 0.0 MEAN TP (SEC) = 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH (DEGREES) =112.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE (X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT (METRES)	PEAK PERIOD (SECONDS) SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	TOTAL
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0 (M) = 0.0 LARGEST Hm0 (M) = 0.0 MEAN TP (SEC) = 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =135.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =157.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	.	.	.	.	.	.	.	.	.	0
2.0-2.4	.	.	.	.	.	.	.	.	.	.	0
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	0	0	0	0	0	0	0	0	0	

MEAN Hm0(M) = 0.0 LARGEST Hm0(M)= 0.0 MEAN TP(SEC)= 0.0 NO. OF CASES= 0.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =180.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	.	.	.	.	.	.	.	.	.	0
1.0-1.4	.	.	.	.	.	.	.	.	.	.	0
1.5-1.9	.	30	.	.	.	.	.	.	.	.	30
2.0-2.4	.	.	15	.	.	.	.	.	.	.	15
2.5-2.9	.	.	.	.	.	.	.	.	.	.	0
3.0-3.4	.	.	.	.	.	.	.	.	.	.	0
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	30	15	0	0	0	0	0	0	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 2.1 MEAN TP(SEC)= 5.1 NO. OF CASES= 3.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =202.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	15	.	.	.	.	.	.	.	.	15
1.0-1.4	.	61	61	.	.	.	.	.	.	.	122
1.5-1.9	.	15	15	15	.	.	.	.	.	.	45
2.0-2.4	.	.	46	.	.	.	.	.	.	.	46
2.5-2.9	.	.	.	15	.	.	.	.	.	.	15
3.0-3.4	.	15	15	.	.	.	.	.	.	.	30
3.5-3.9	.	.	.	.	.	.	.	.	.	.	0
4.0-4.4	.	.	.	.	.	.	.	.	.	.	0
4.5-4.9	.	.	.	.	.	.	.	.	.	.	0
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	106	137	30	0	0	0	0	0	0	

MEAN Hm0(M) = 1.8 LARGEST Hm0(M)= 3.0 MEAN TP(SEC)= 5.9 NO. OF CASES= 18.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =225.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	.	.	0
0.5-0.9	.	15	46	.	.	.	.	247	1142	231	1681
1.0-1.4	.	61	308	293	.	.	.	15	30	.	707
1.5-1.9	.	30	293	401	30	15	.	.	.	.	769
2.0-2.4	.	30	200	416	30	.	.	.	.	.	676
2.5-2.9	.	.	185	401	15	.	.	.	.	.	601
3.0-3.4	.	.	61	262	46	15	.	.	.	.	384
3.5-3.9	.	15	30	185	61	.	.	.	.	.	291
4.0-4.4	.	.	.	77	30	.	.	.	.	.	107
4.5-4.9	.	.	.	.	15	.	.	.	.	.	15
5.0+	.	.	.	30	46	15	.	.	.	.	91
TOTAL	0	151	1123	2065	273	45	0	262	1172	231	

MEAN Hm0(M) = 1.9 LARGEST Hm0(M)= 6.4 MEAN TP(SEC)= 10.7 NO. OF CASES= 346.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =247.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	.	.	.	.	.	30	.	30
0.5-0.9	.	15	216	370	169	231	154	247	540	200	2142
1.0-1.4	.	.	216	1235	571	602	648	324	92	169	3857
1.5-1.9	.	.	154	1018	802	1003	771	555	231	169	4703
2.0-2.4	.	.	123	1204	926	1173	494	432	92	30	4474
2.5-2.9	.	.	138	586	633	725	524	293	185	30	3114
3.0-3.4	.	.	30	92	231	463	385	231	61	30	1523
3.5-3.9	.	.	.	138	123	46	154	216	108	.	785
4.0-4.4	.	.	.	30	46	15	108	123	30	.	352
4.5-4.9	.	.	.	.	15	92	61	46	30	15	259
5.0+	.	.	.	15	46	138	231	138	46	15	629
TOTAL	0	15	877	4688	3562	4488	3530	2605	1445	658	

MEAN Hm0(M) = 2.2 LARGEST Hm0(M)= 7.7 MEAN TP(SEC)= 11.8 NO. OF CASES= 1419.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =270.0
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	.	15	15	.	.	.	.	.	30
0.5-0.9	.	.	123	818	463	293	138	339	77	30	2281
1.0-1.4	.	.	355	2779	1713	1790	1157	1327	1065	432	10618
1.5-1.9	.	.	138	1806	2346	2918	2825	3365	1821	880	16099
2.0-2.4	.	.	61	1312	1837	3134	2547	2979	1482	957	14309
2.5-2.9	.	.	.	802	1157	1667	1374	1682	694	370	7746
3.0-3.4	.	.	.	200	509	988	1374	1312	648	154	5185
3.5-3.9	.	.	.	30	231	447	602	1080	648	123	3161
4.0-4.4	.	.	.	30	77	108	324	833	293	77	1742
4.5-4.9	.	.	.	.	15	77	154	663	277	154	1340
5.0+	.	.	.	.	15	15	231	509	617	169	1556
TOTAL	0	0	677	7792	8378	11437	10726	14089	7622	3346	

MEAN Hm0(M) = 2.3 LARGEST Hm0(M) = 7.6 MEAN TP(SEC) = 12.8 NO. OF CASES= 4152.

YAQUINA, NORTH SITE 44.65N 124.09W AZIMUTH(DEGREES) =292.5
SEPTEMBER 1993 - JUNE 1994
PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION

HEIGHT(METRES)	PEAK PERIOD(SECONDS)										TOTAL
	SHORTER- 4.5	4.6- 5.5	5.6- 7.9	8.0- 10.6	10.7- 11.5	11.6- 12.7	12.8- 14.1	14.2- 15.9	16.0- 18.2	18.3- LONGER	
0.0-0.4	.	.	15	15	.	.	.	.	.	.	30
0.5-0.9	.	355	679	509	.	.	.	.	.	.	1543
1.0-1.4	.	308	1914	1729	108	.	.	.	.	.	4059
1.5-1.9	.	.	262	926	169	46	.	.	.	.	1403
2.0-2.4	.	.	30	463	108	15	.	.	.	.	616
2.5-2.9	.	.	15	46	15	.	15	.	.	.	91
3.0-3.4	.	.	.	.	15	15	61	.	.	.	91
3.5-3.9	.	.	.	.	.	.	15	.	.	.	15
4.0-4.4	.	.	.	.	.	.	46	92	.	.	138
4.5-4.9	.	.	.	.	.	.	.	30	.	.	30
5.0+	.	.	.	.	.	.	.	.	.	.	0
TOTAL	0	663	2915	3688	415	76	137	122	0	0	

MEAN Hm0(M) = 1.4 LARGEST Hm0(M) = 4.8 MEAN TP(SEC) = 8.0 NO. OF CASES= 520.

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   YAQUINA, NORTH SITE              44.65N 124.09W      AZIMUTH(DEGREES) =315.0
                               SEPTEMBER 1993 - JUNE 1994
                       PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


HEIGHT(METRES)                             PEAK PERIOD(SECONDS)                            TOTAL

                 SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                     4.5   5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

0.0-0.4                .     .      .      .      .      .      .      .      .      .         0
0.5-0.9                .   216     46      .      .      .      .      .      .      .       262
1.0-1.4                .     .     15      .      .      .      .      .      .      .        15
1.5-1.9                .     .      .      .      .      .      .      .      .      .         0
2.0-2.4                .    15      .      .      .      .      .      .      .      .        15
2.5-2.9                .     .      .      .      .      .      .      .      .      .         0
3.0-3.4                .     .      .      .      .      .      .      .      .      .         0
3.5-3.9                .     .      .      .      .      .      .      .      .      .         0
4.0-4.4                .     .      .      .      .      .      .      .      .      .         0
4.5-4.9                .     .      .      .      .      .      .      .      .      .         0
5.0+                   .     .      .      .      .      .      .      .      .      .         0
TOTAL                  0   231     61      0      0      0      0      0      0      0

MEAN Hm0(M)  =  0.8  LARGEST Hm0(M)=   2.2  MEAN TP(SEC)=  5.2  NO. OF CASES=      19.
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   YAQUINA, NORTH SITE              44.65N 124.09W      AZIMUTH(DEGREES) =337.5
                               SEPTEMBER 1993 - JUNE 1994
                       PERCENT OCCURRENCE(X1000) OF HEIGHT AND PERIOD BY DIRECTION


HEIGHT(METRES)                             PEAK PERIOD(SECONDS)                            TOTAL

                 SHORTER-  4.6-   5.6-   8.0-  10.7-  11.6-  12.8-  14.2-  16.0-  18.3-
                     4.5   5.5    7.9   10.6   11.5   12.7   14.1   15.9   18.2  LONGER

0.0-0.4                .     .      .      .      .      .      .      .      .      .         0
0.5-0.9                .     .      .      .      .      .      .      .      .      .         0
1.0-1.4                .     .      .      .      .      .      .      .      .      .         0
1.5-1.9                .     .      .      .      .      .      .      .      .      .         0
2.0-2.4                .     .      .      .      .      .      .      .      .      .         0
2.5-2.9                .     .      .      .      .      .      .      .      .      .         0
3.0-3.4                .     .      .      .      .      .      .      .      .      .         0
3.5-3.9                .     .      .      .      .      .      .      .      .      .         0
4.0-4.4                .     .      .      .      .      .      .      .      .      .         0
4.5-4.9                .     .      .      .      .      .      .      .      .      .         0
5.0+                   .     .      .      .      .      .      .      .      .      .         0
TOTAL                  0     0      0      0      0      0      0      0      0      0

MEAN Hm0(M)  =  0.0  LARGEST Hm0(M)=   0.0  MEAN TP(SEC)=  0.0  NO. OF CASES=       0.
```
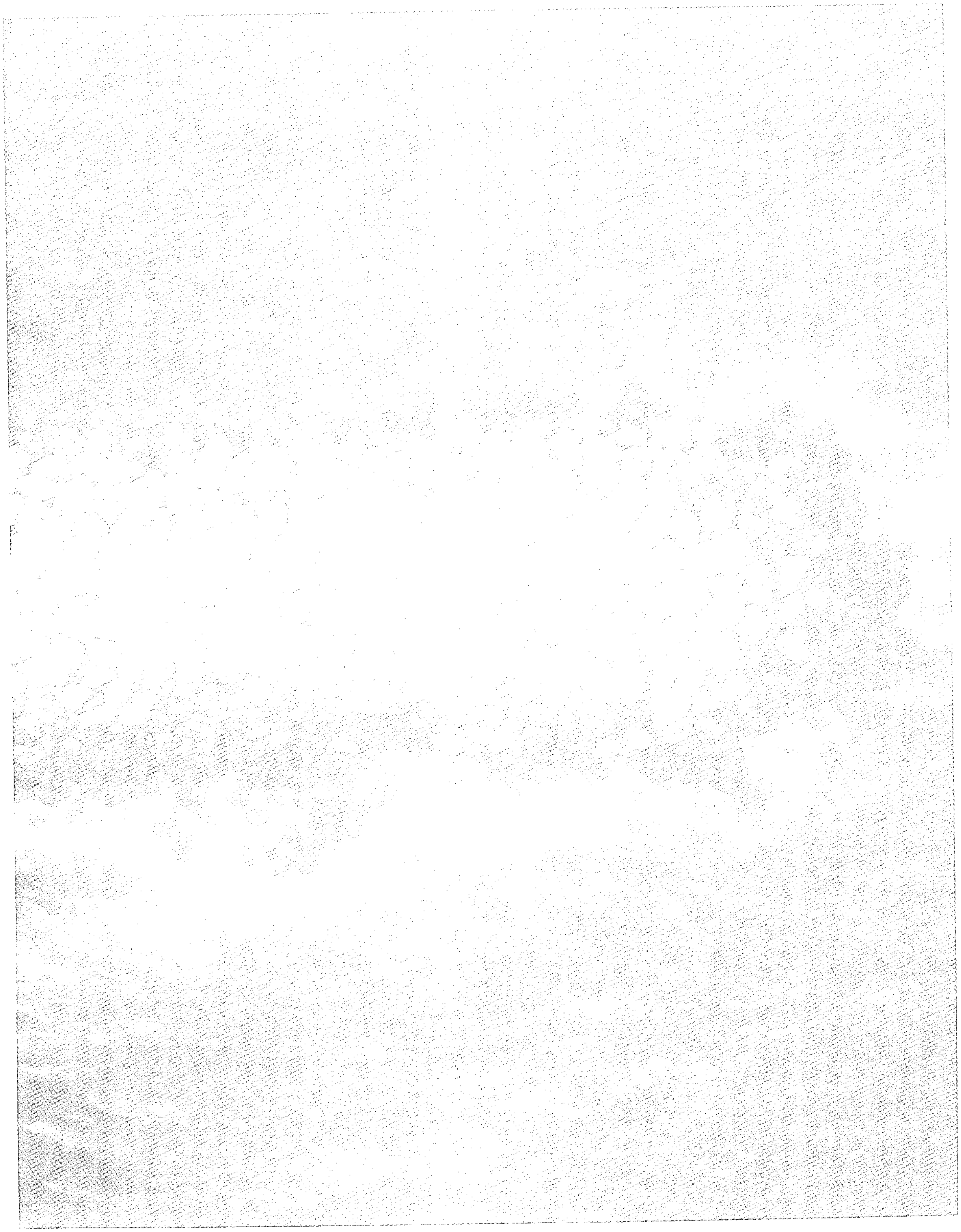

Appendix G
Aerial Photographs of Yaquina Bay North Jetty

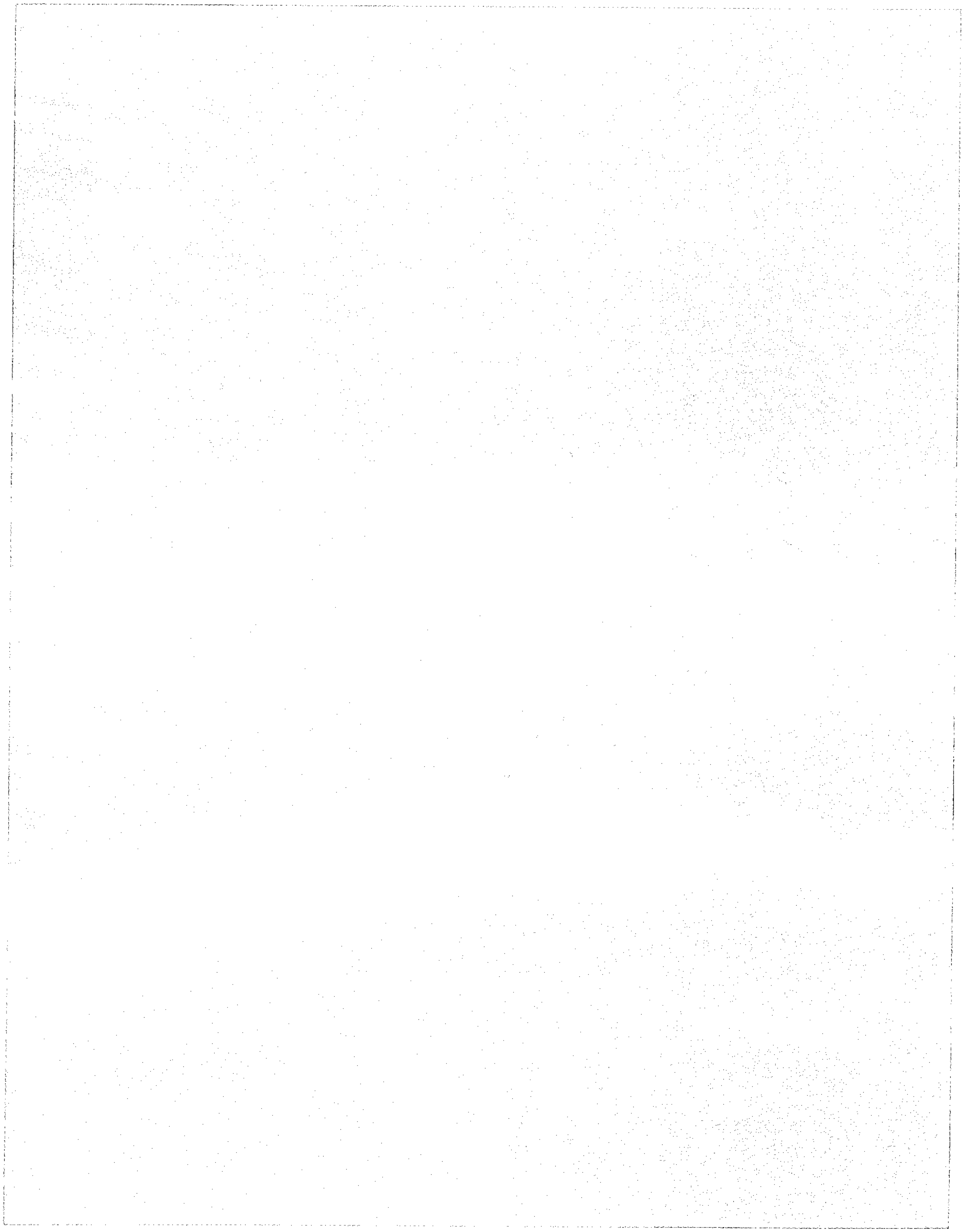
Enlarged Fixed-Wing Aerial Photographs
Yaquina Bay North Jetty

9 June 1989



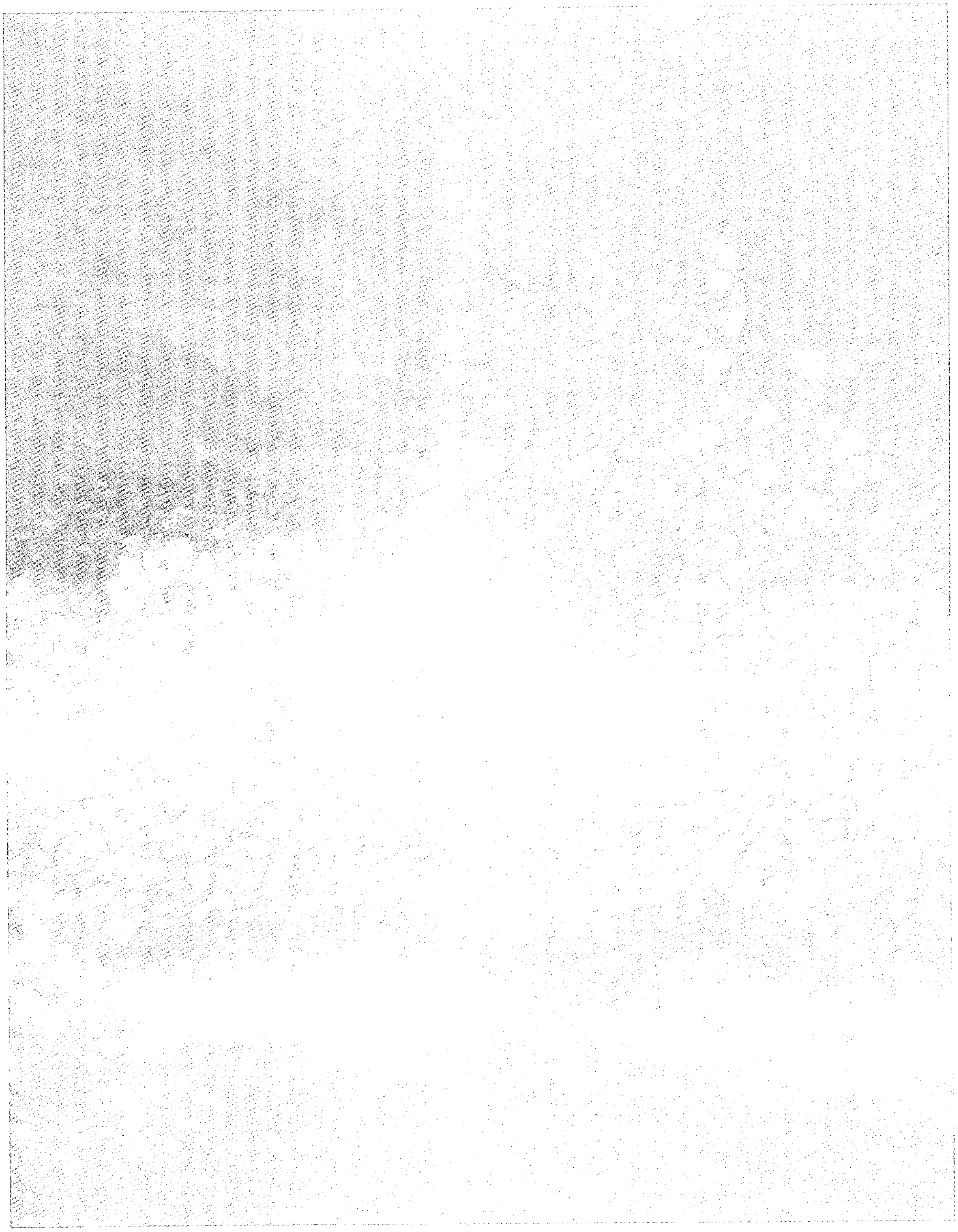
9 June 1989

1-89



9 June 1989

2-89

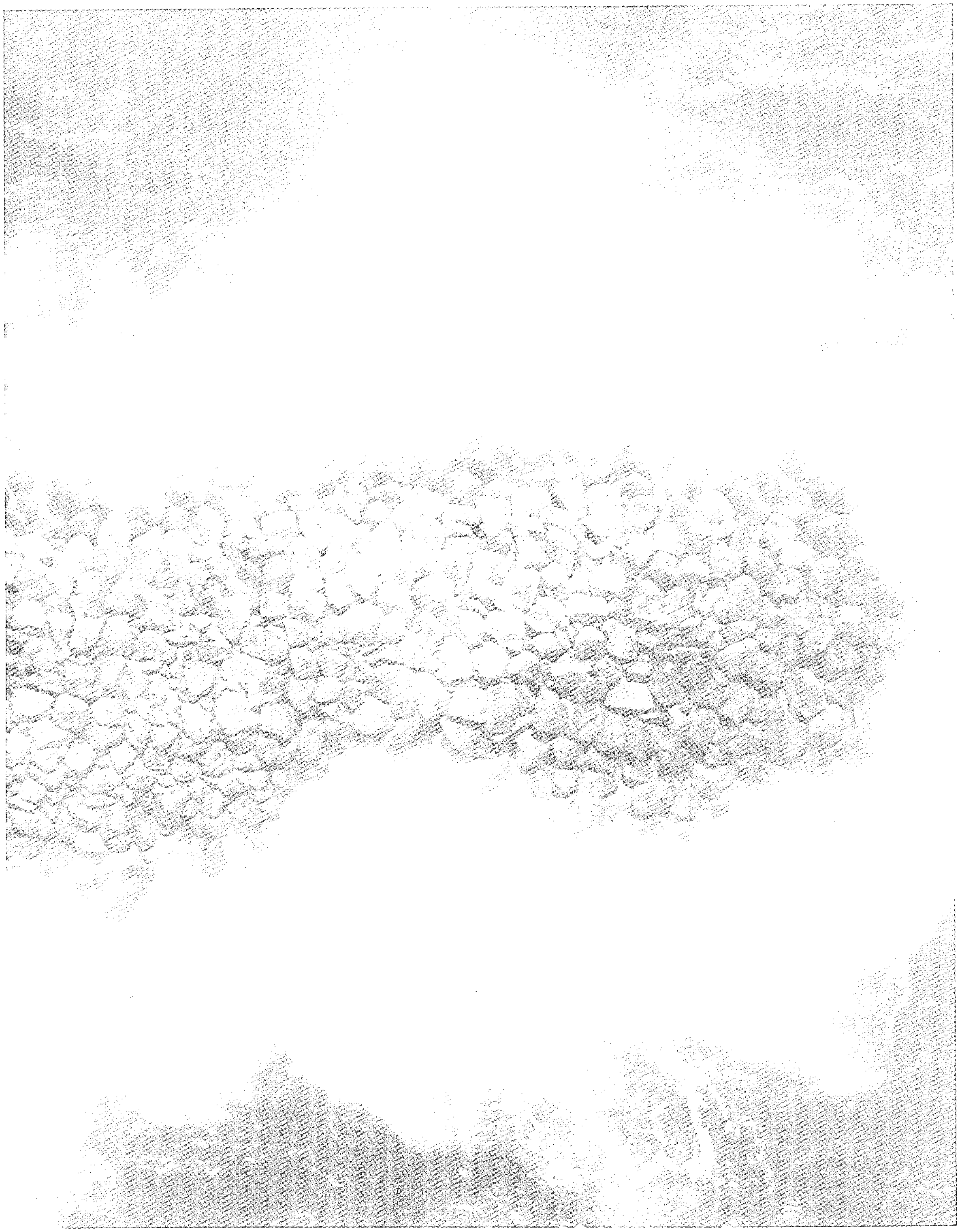


9 June 1989

3-89

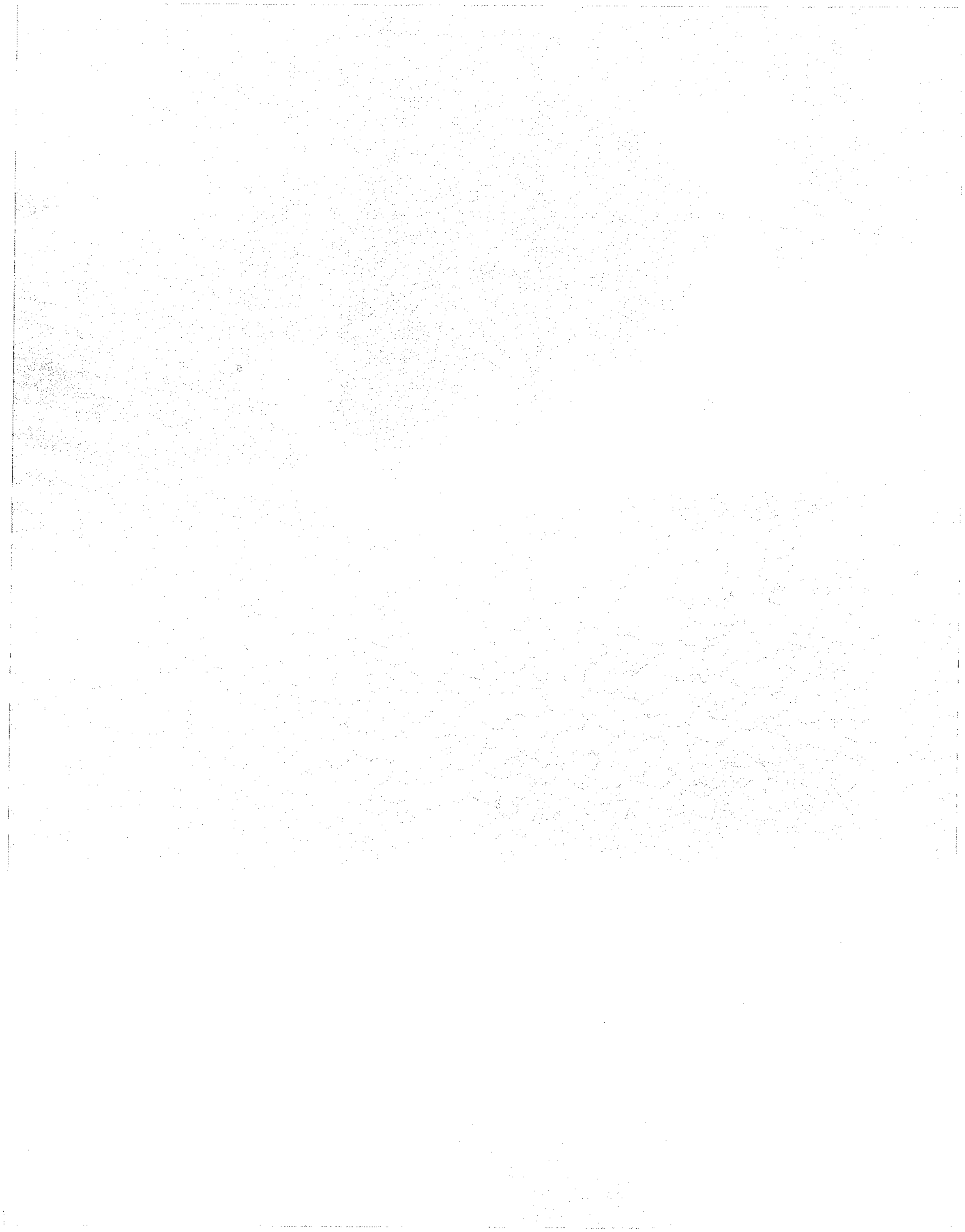
Enlarged Fixed-Wing Aerial Photographs
Yaquina Bay North Jetty

29 April 1990



29 April 1990

1-90



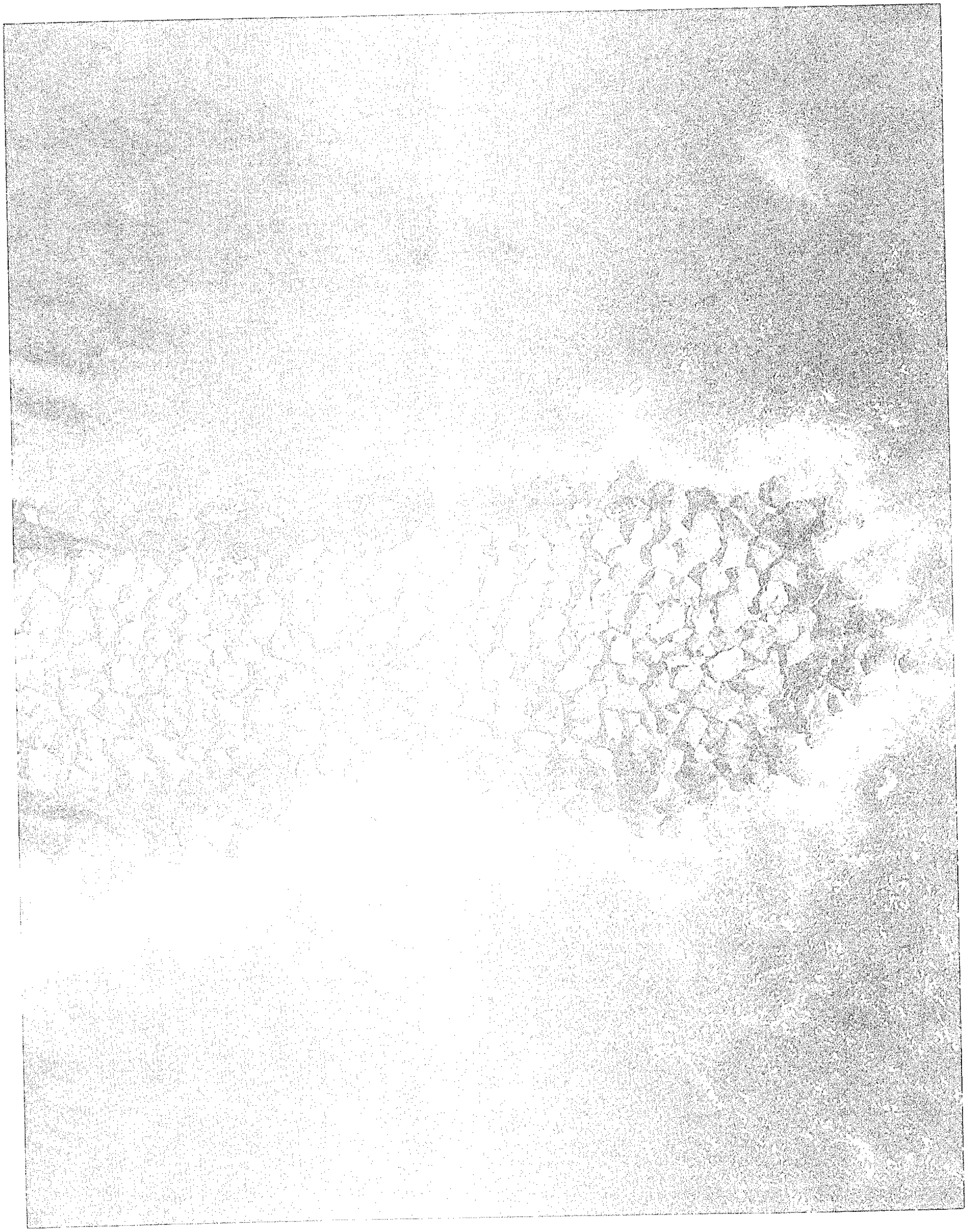
29 April 1990 2-90

29 April 1990

3-90

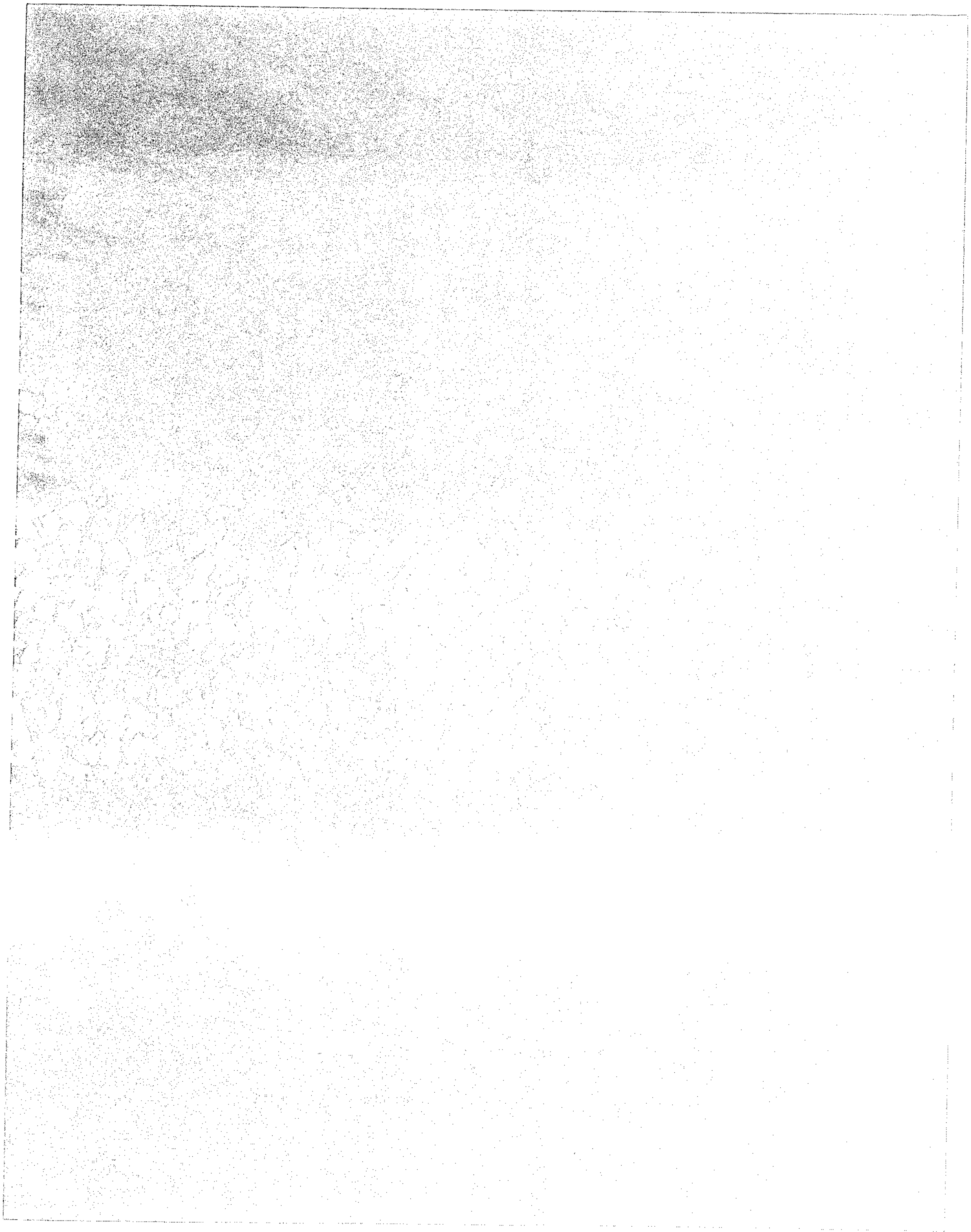
Enlarged Fixed-Wing Aerial Photographs
Yaquina Bay North Jetty

23 May 1991



23 May 1991

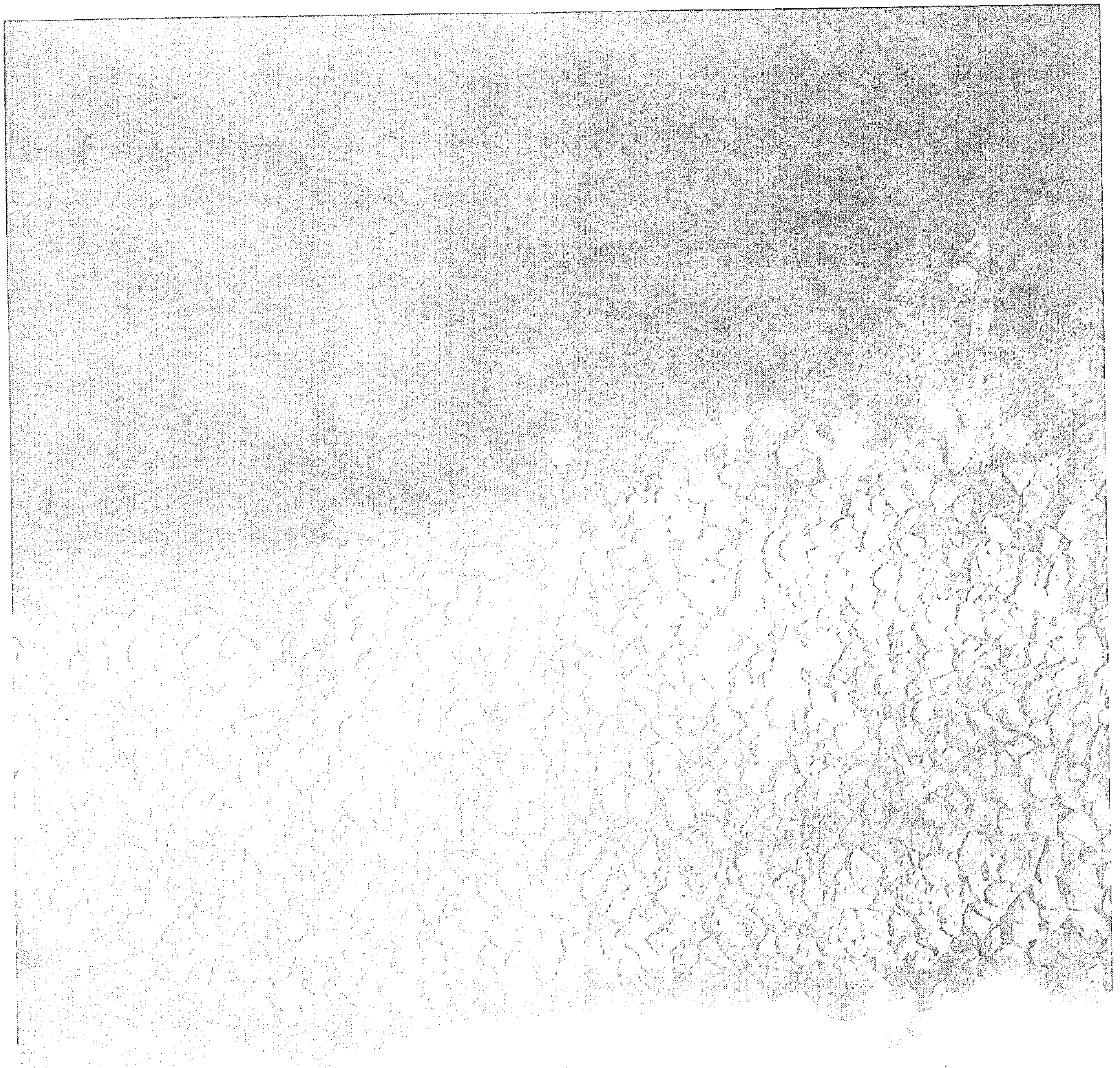
1-91



23 May 1991

2-91

G12

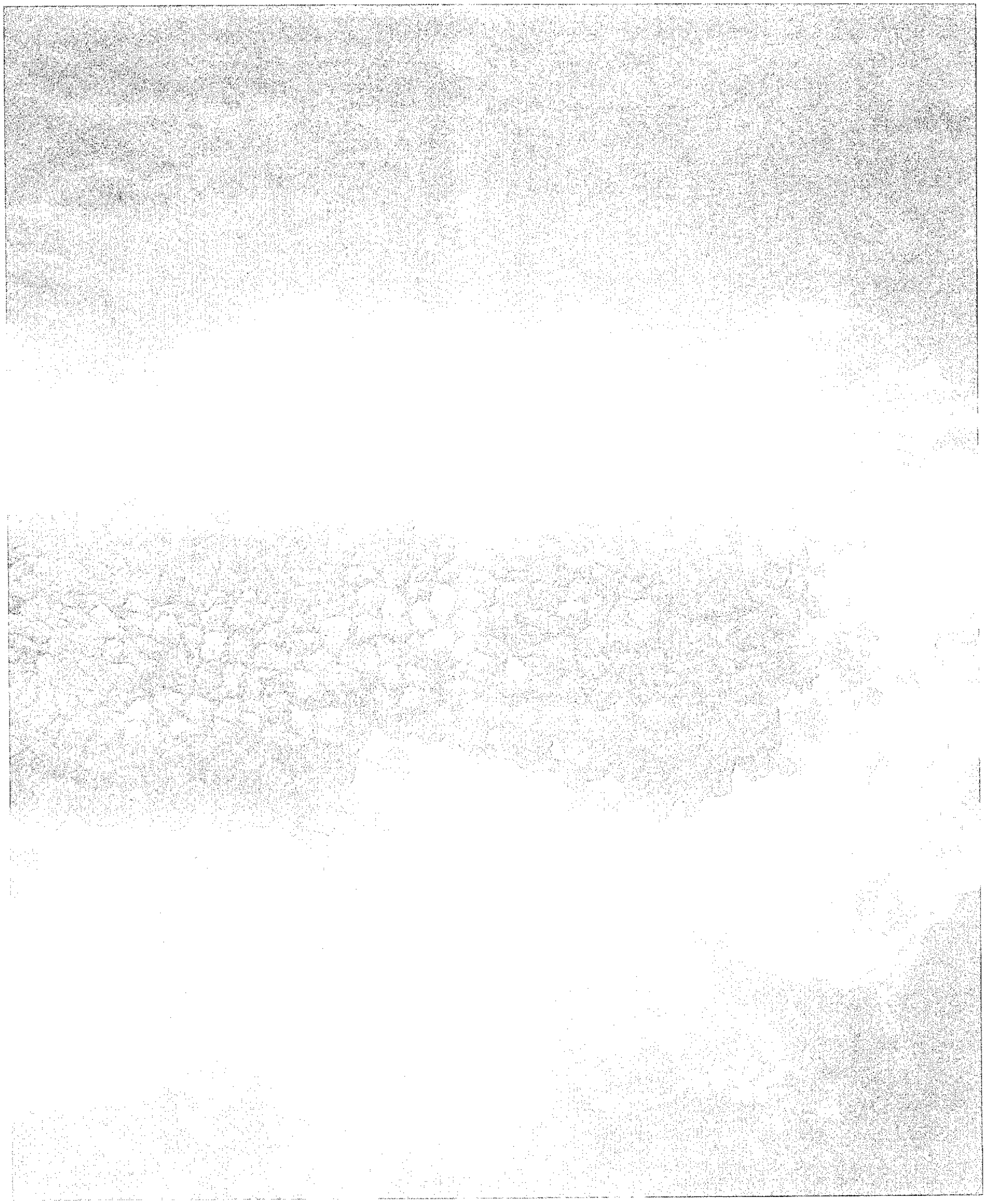


23 May 1991

3-91

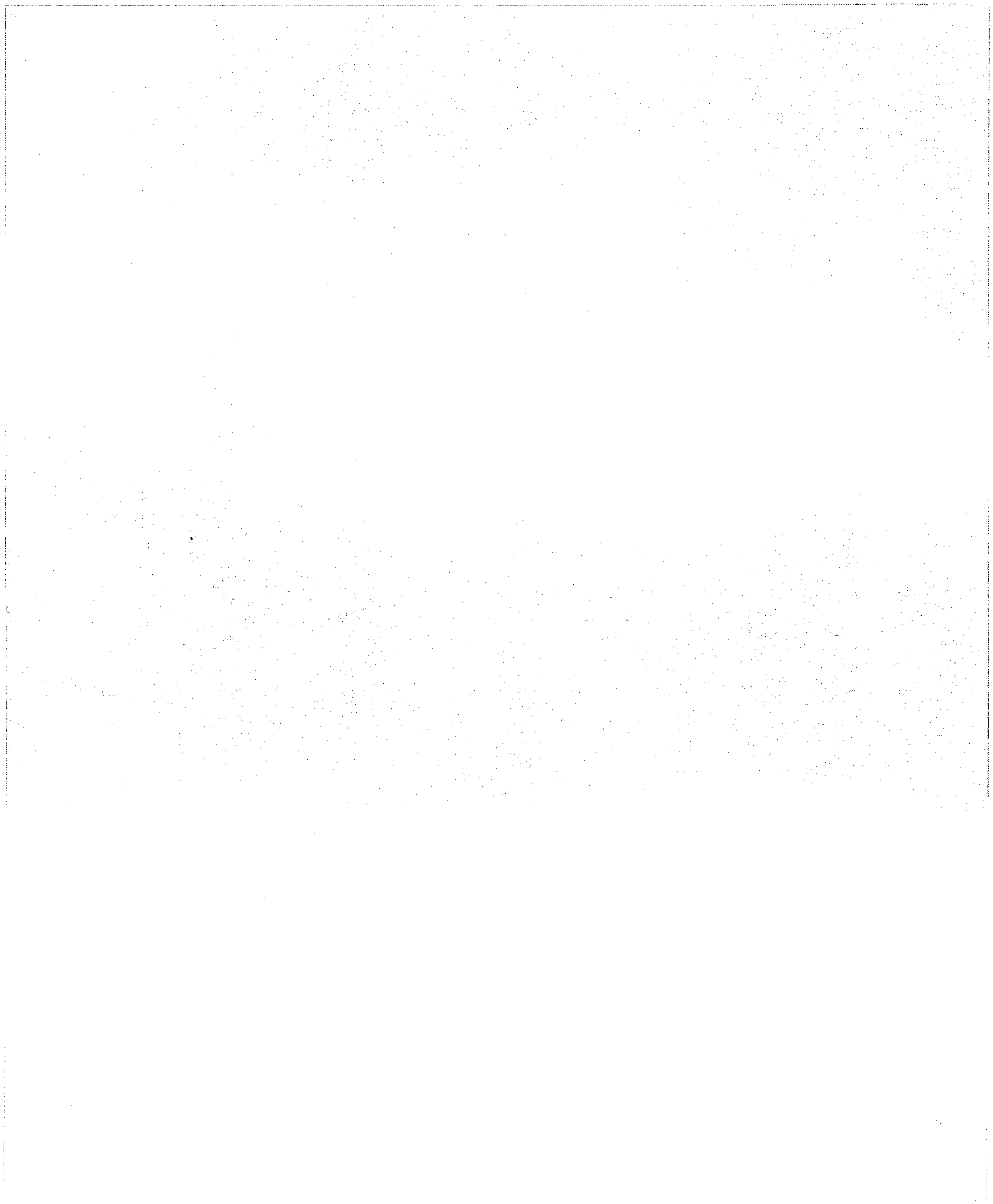
Enlarged Fixed-Wing Aerial Photographs
Yaquina Bay North Jetty

23 February 1992

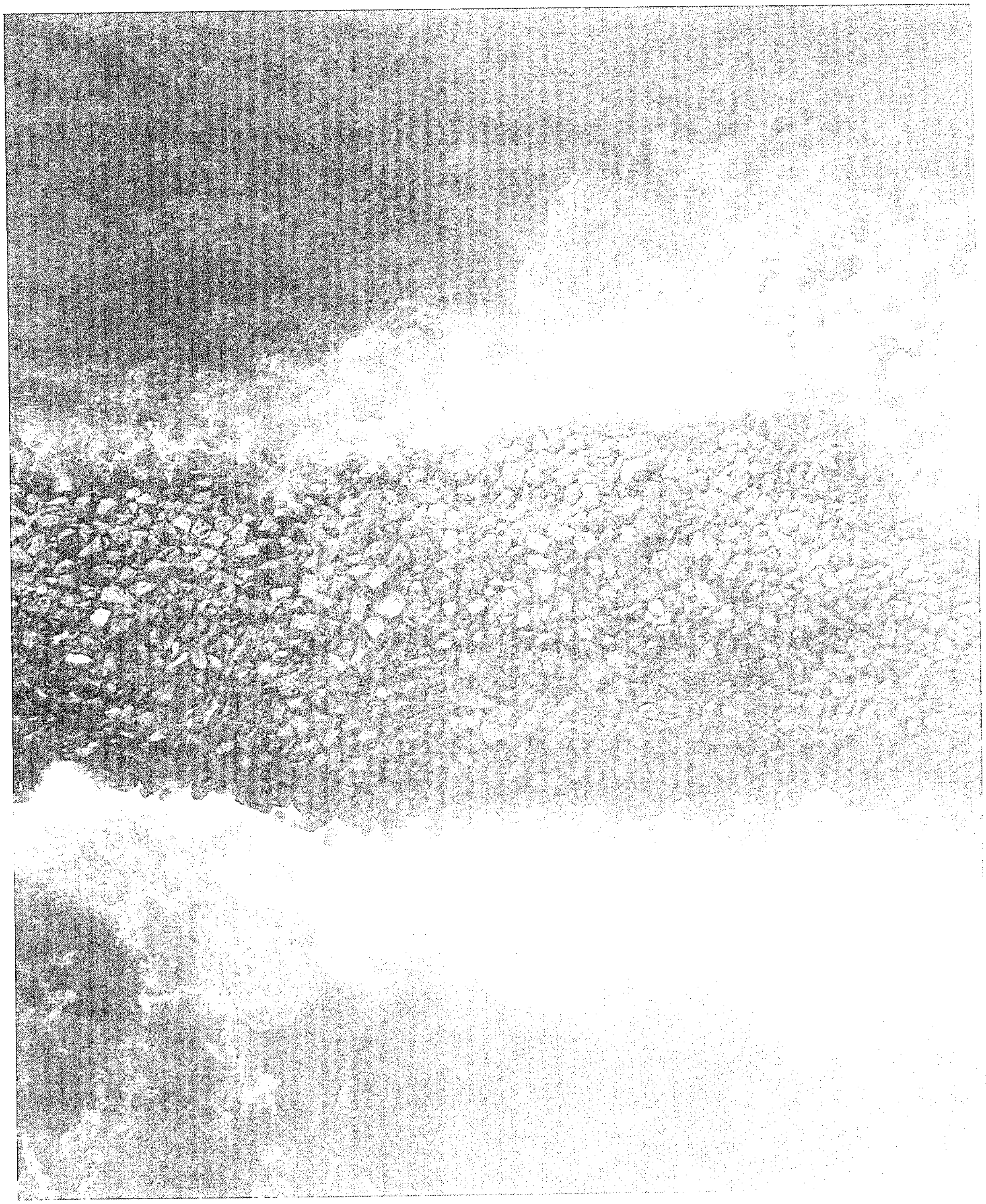


23 February 1992

1-92



23 February 1992 2-92

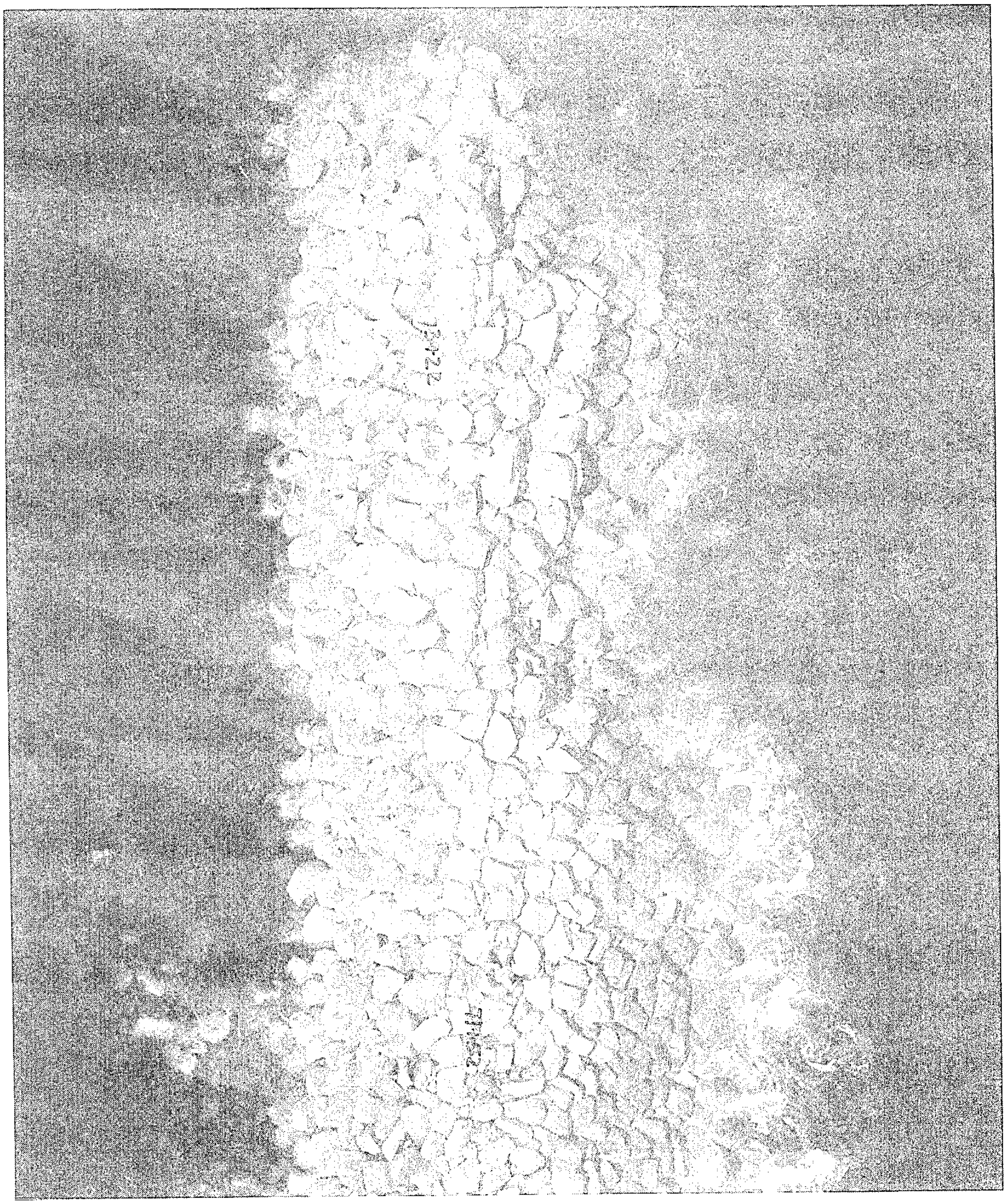


23 February 1992

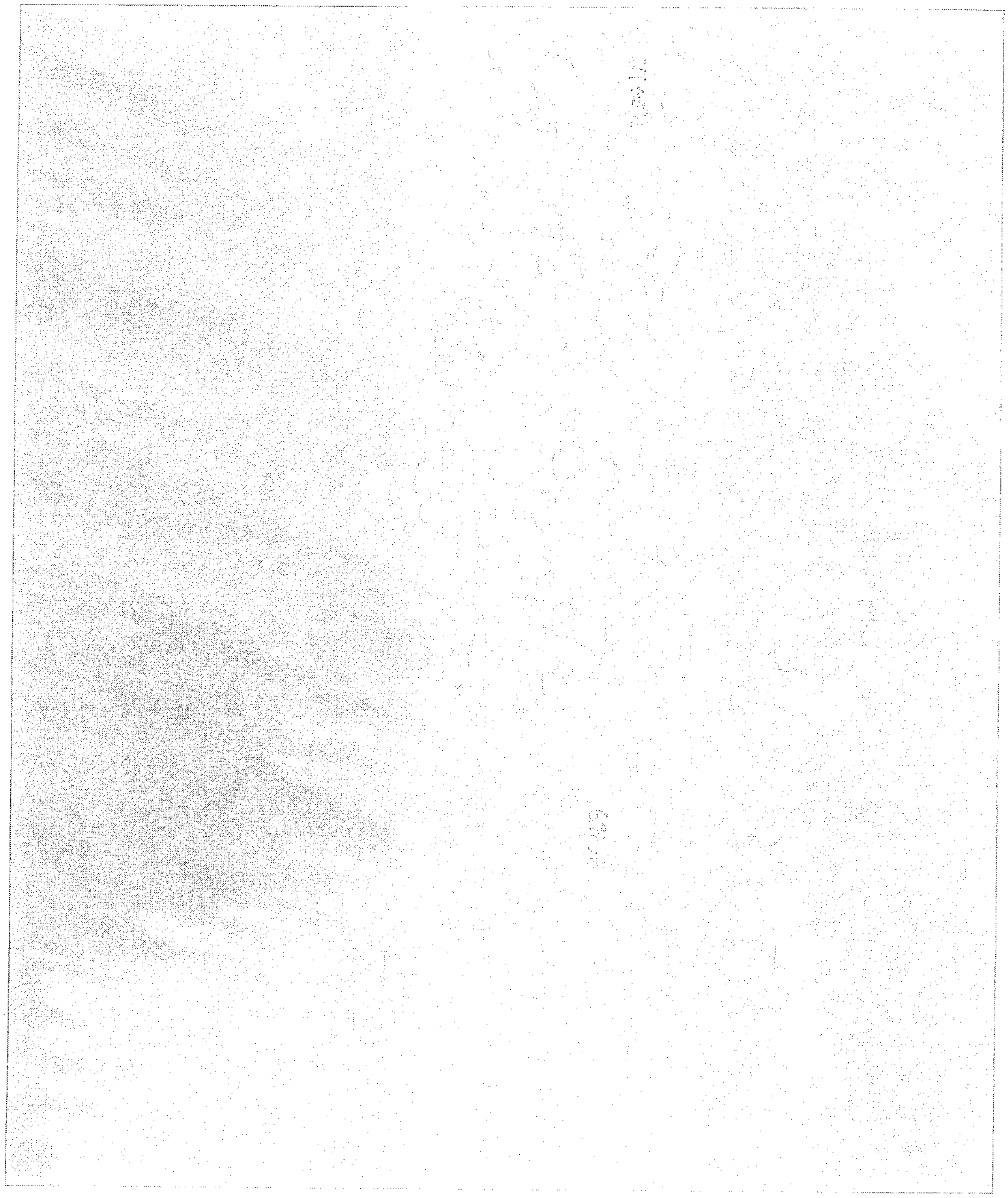
3-92

Enlarged Fixed-Wing Aerial Photographs
Yaquina Bay North Jetty

26 May 1993

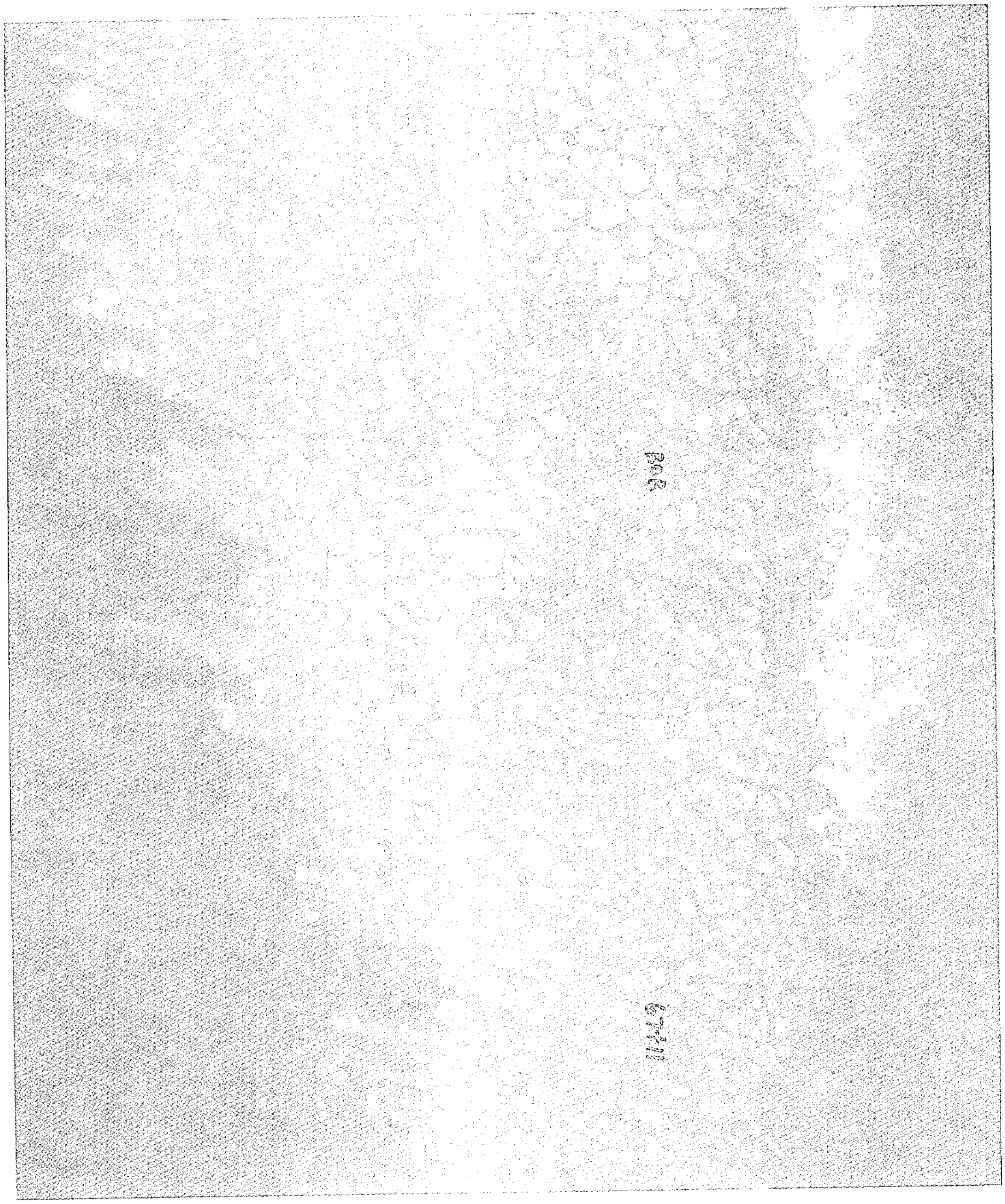


26 May 1993 1-93



26 May 1993

2-93

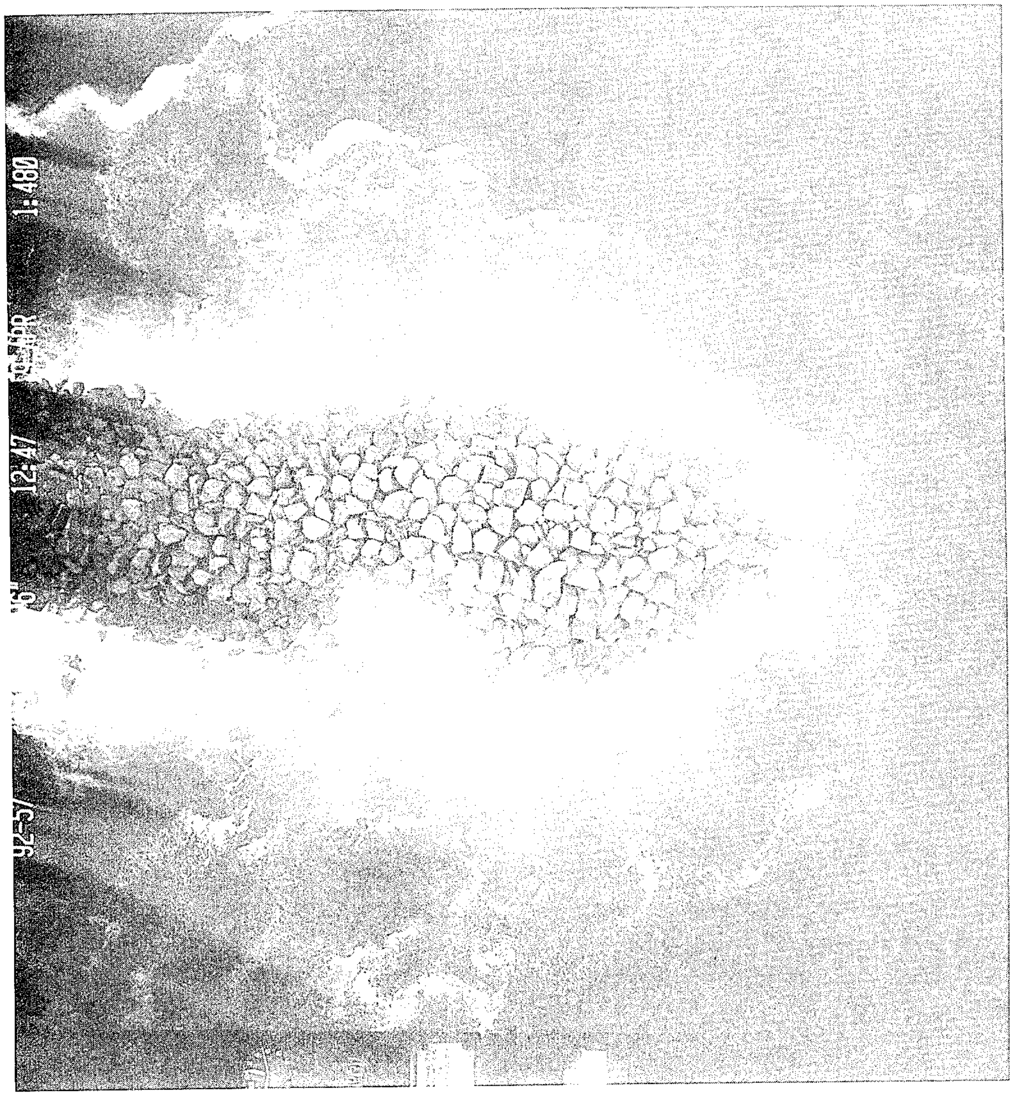


26 May 1993

3-93

Enlarged Helicopter Aerial Photographs
Yaquina Bay North Jetty

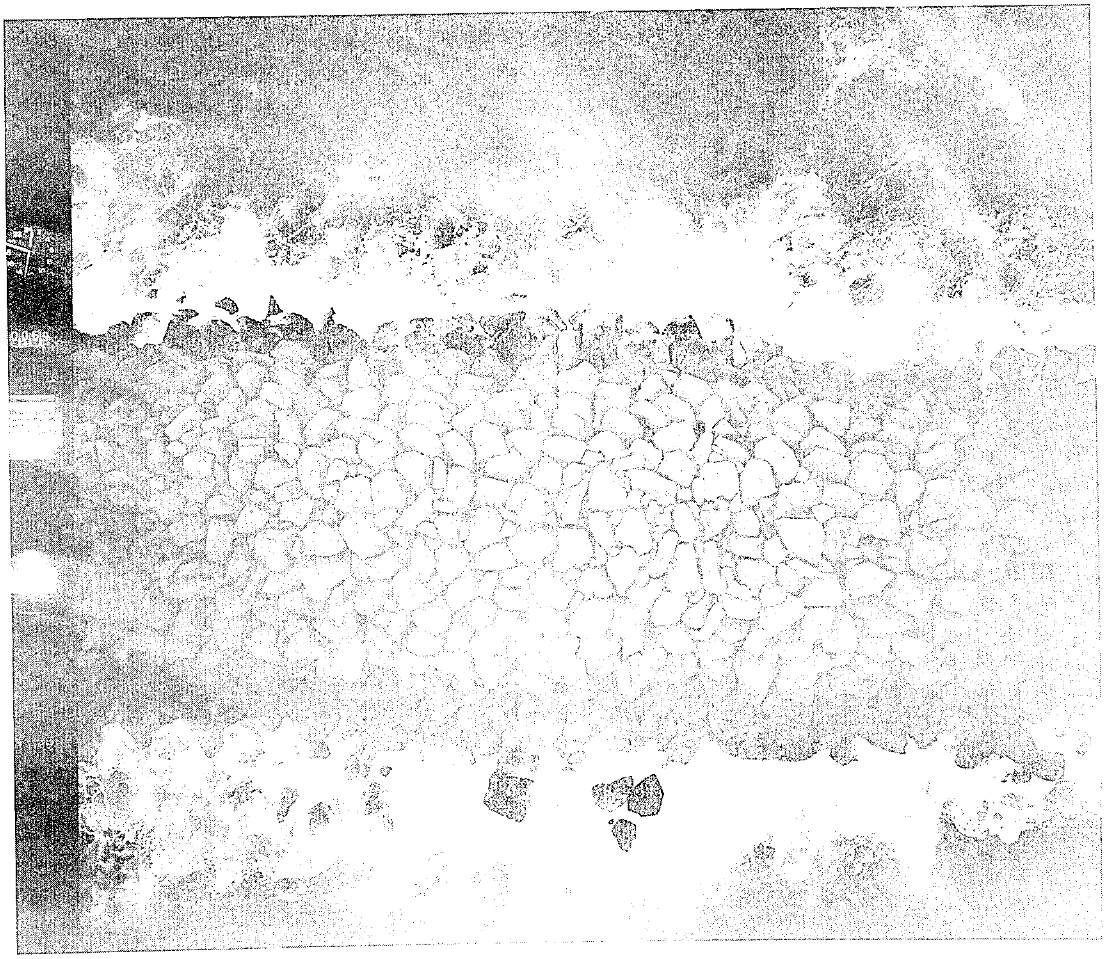
9 April 1992



9 April 1992

1-92

9 April 1992 2-92

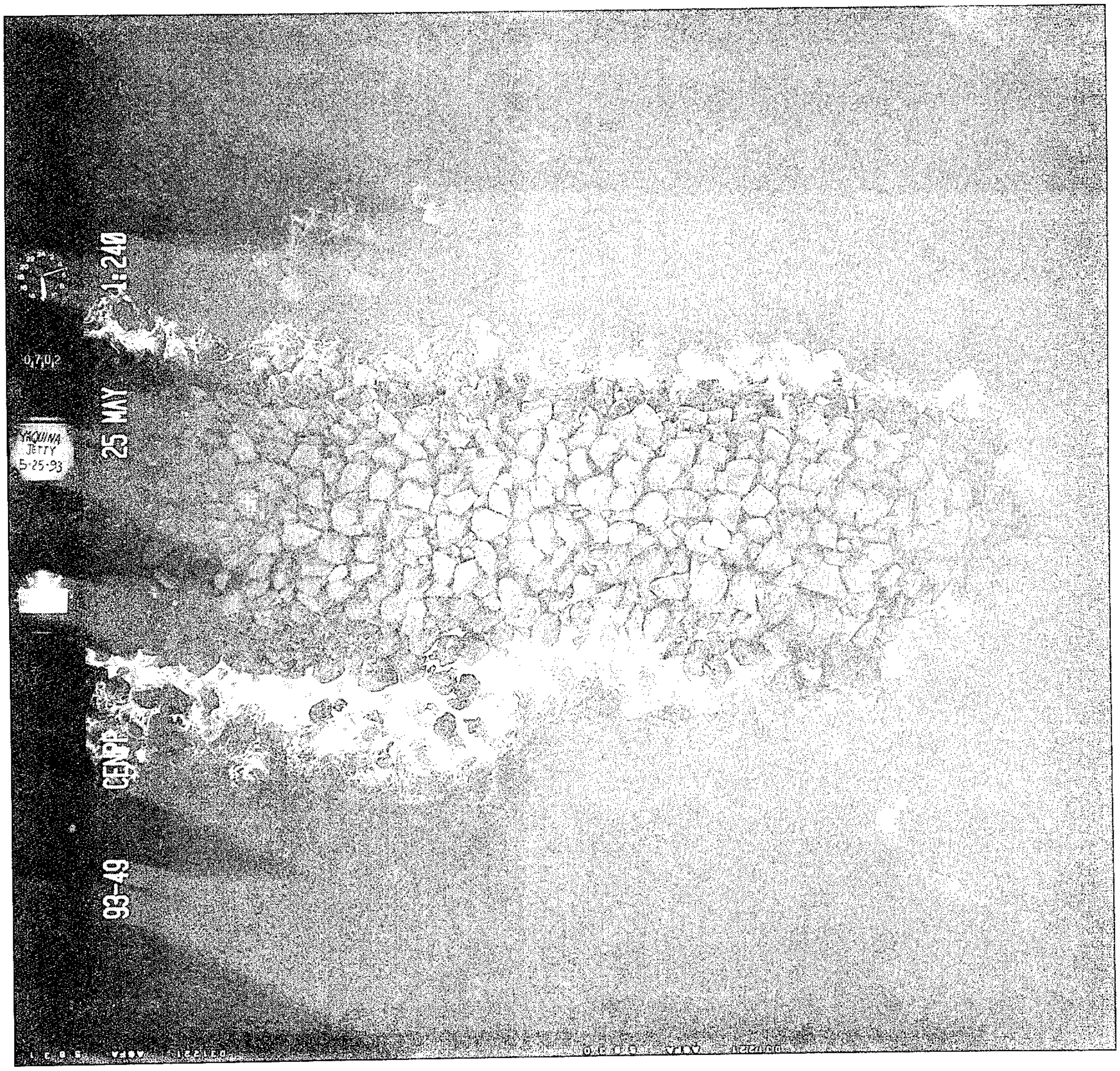


9 April 1992

3-92

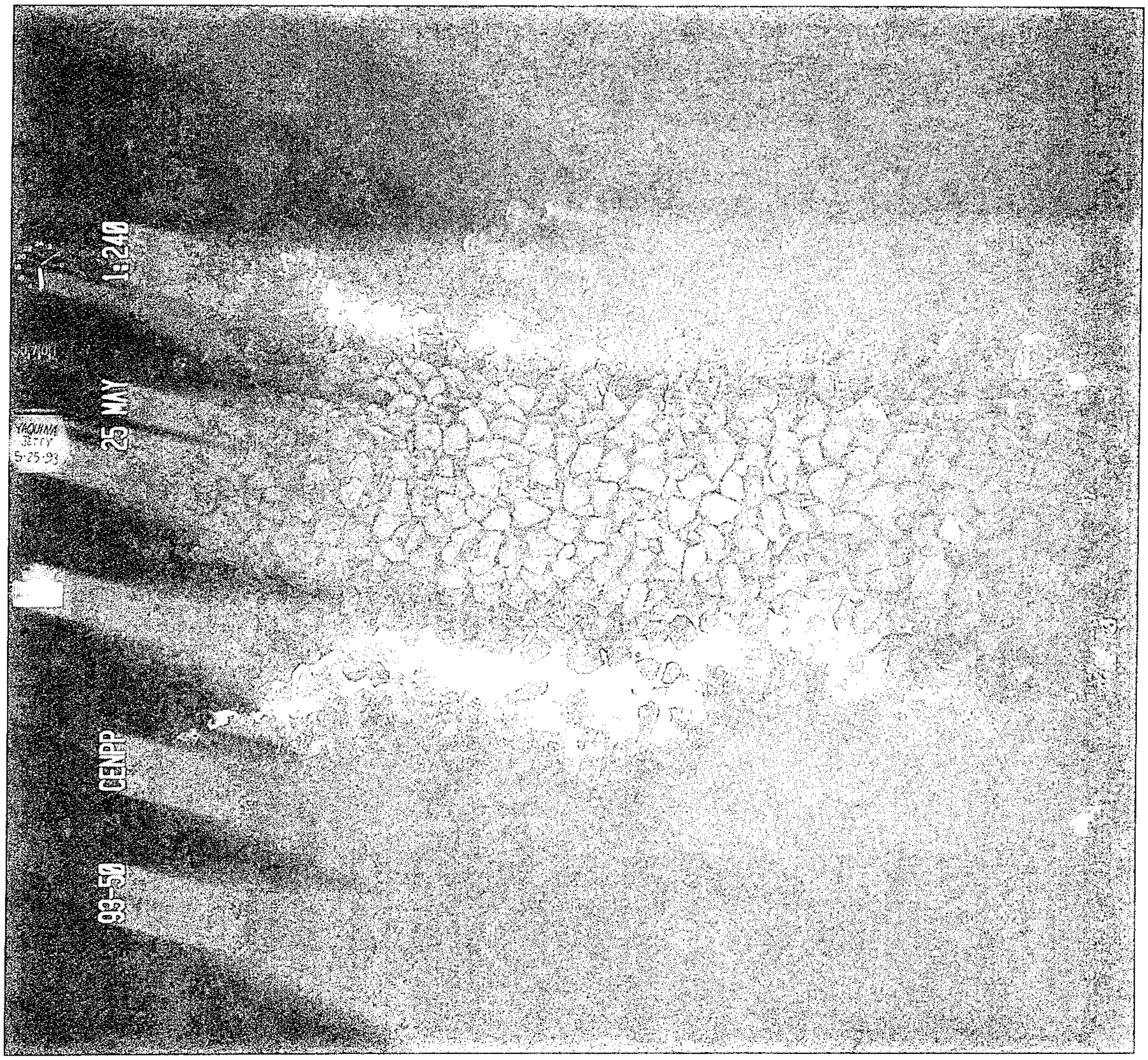
Enlarged Helicopter Aerial Photographs
Yaquina Bay North Jetty

25 May 1993



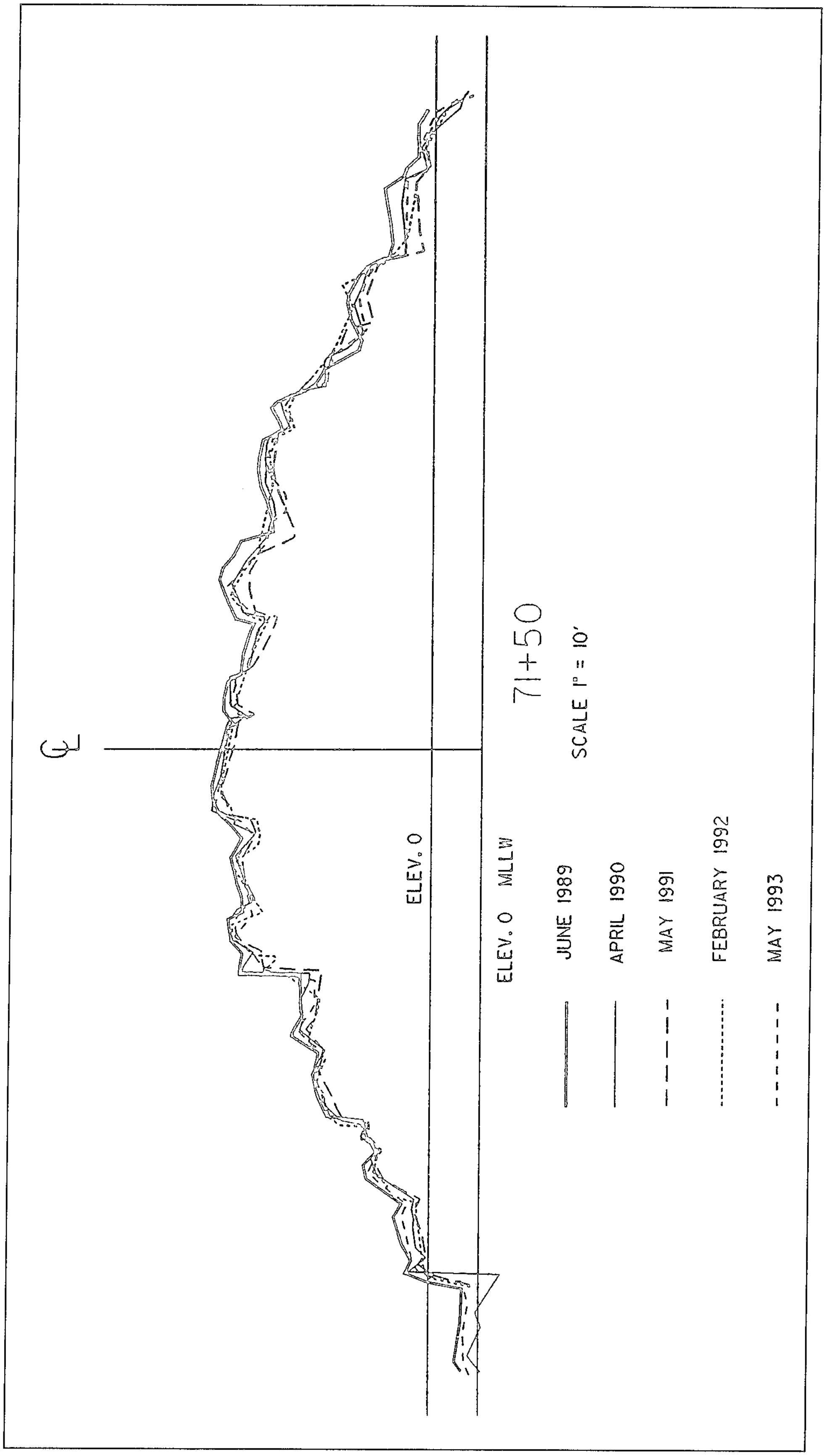
25 May 1993

1-93



25 May 1993 2-93

Appendix H
Yaquina Bay North Jetty Profile Comparisons from Photogrammetric Analysis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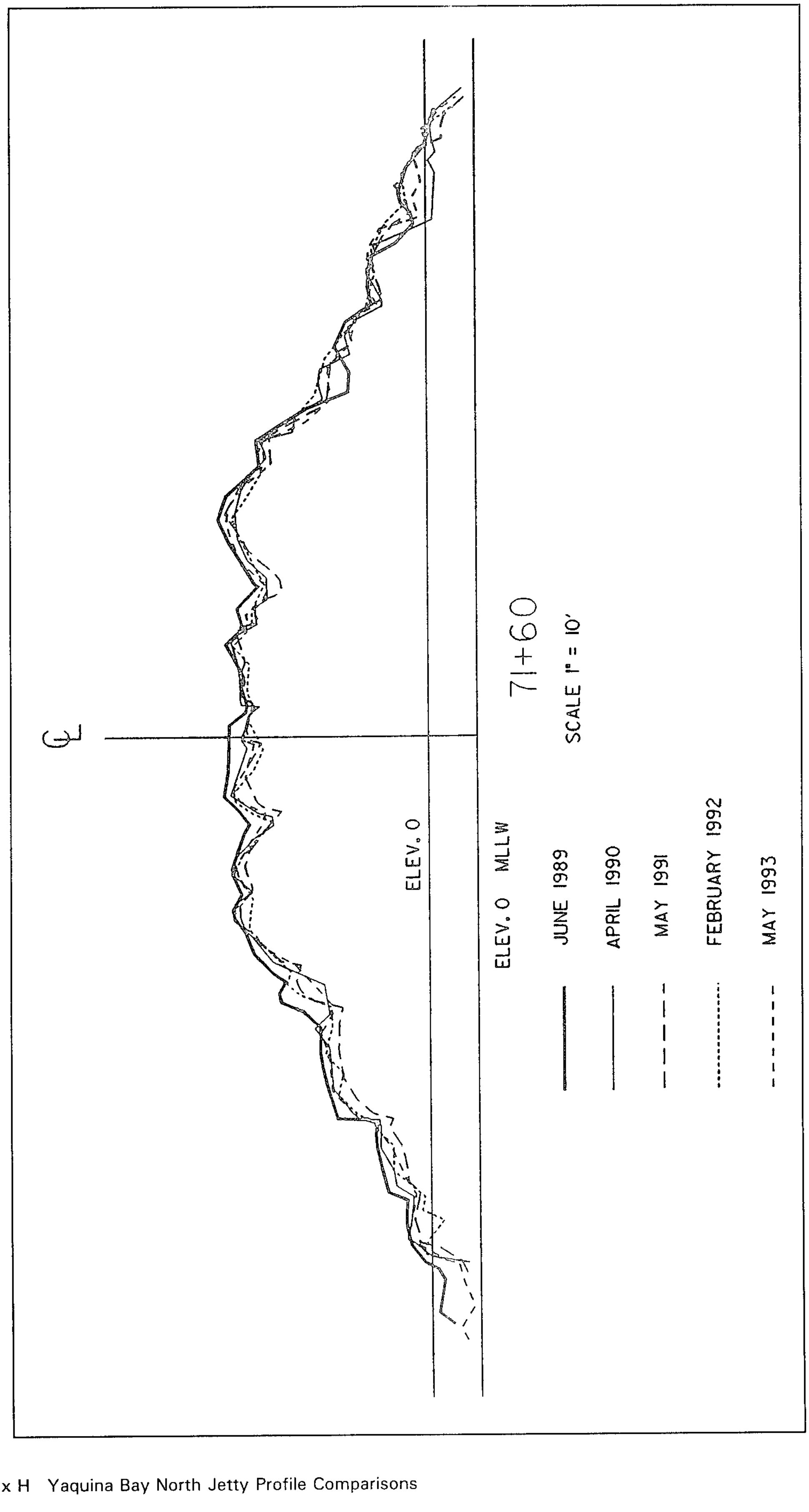
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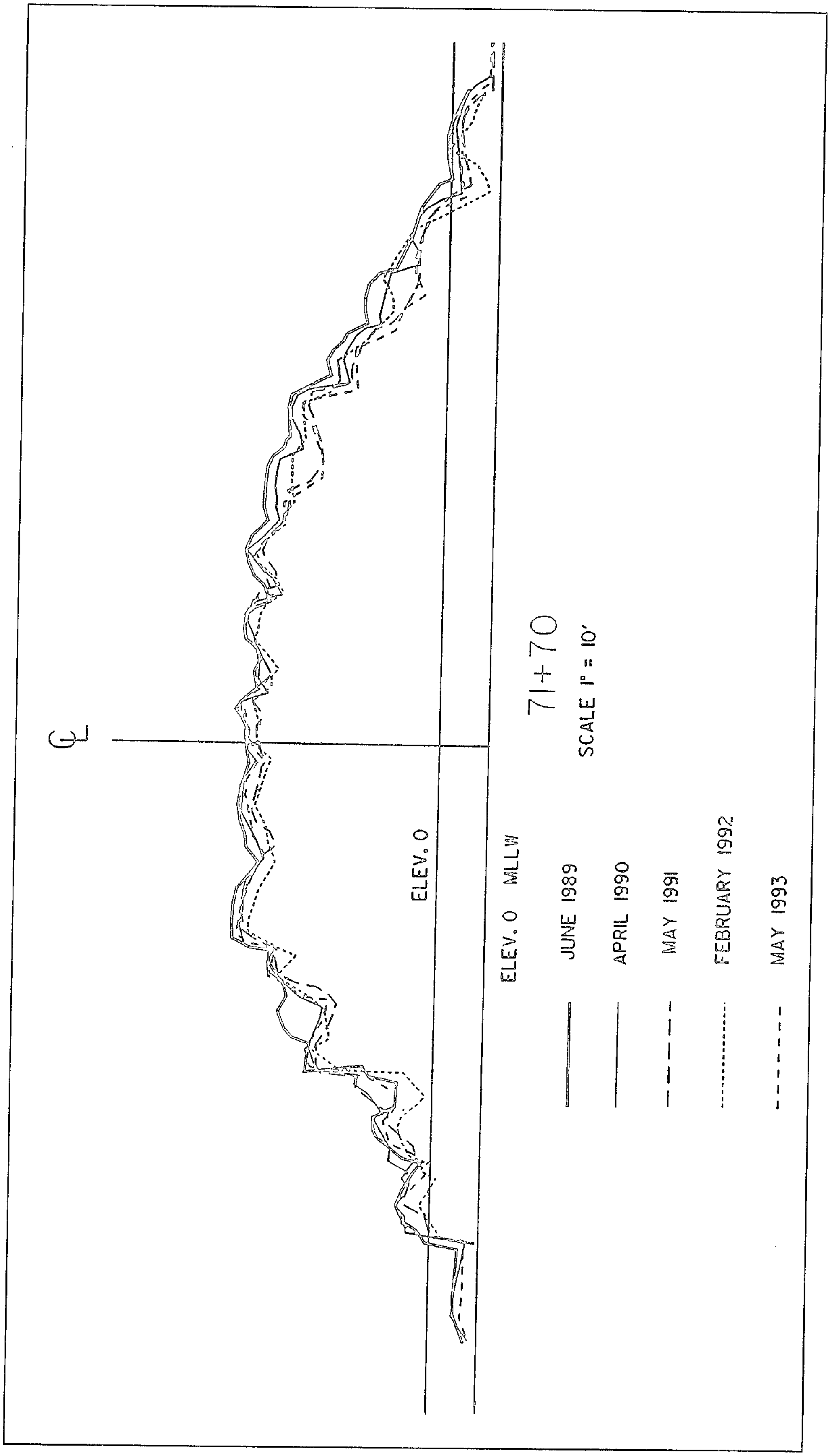
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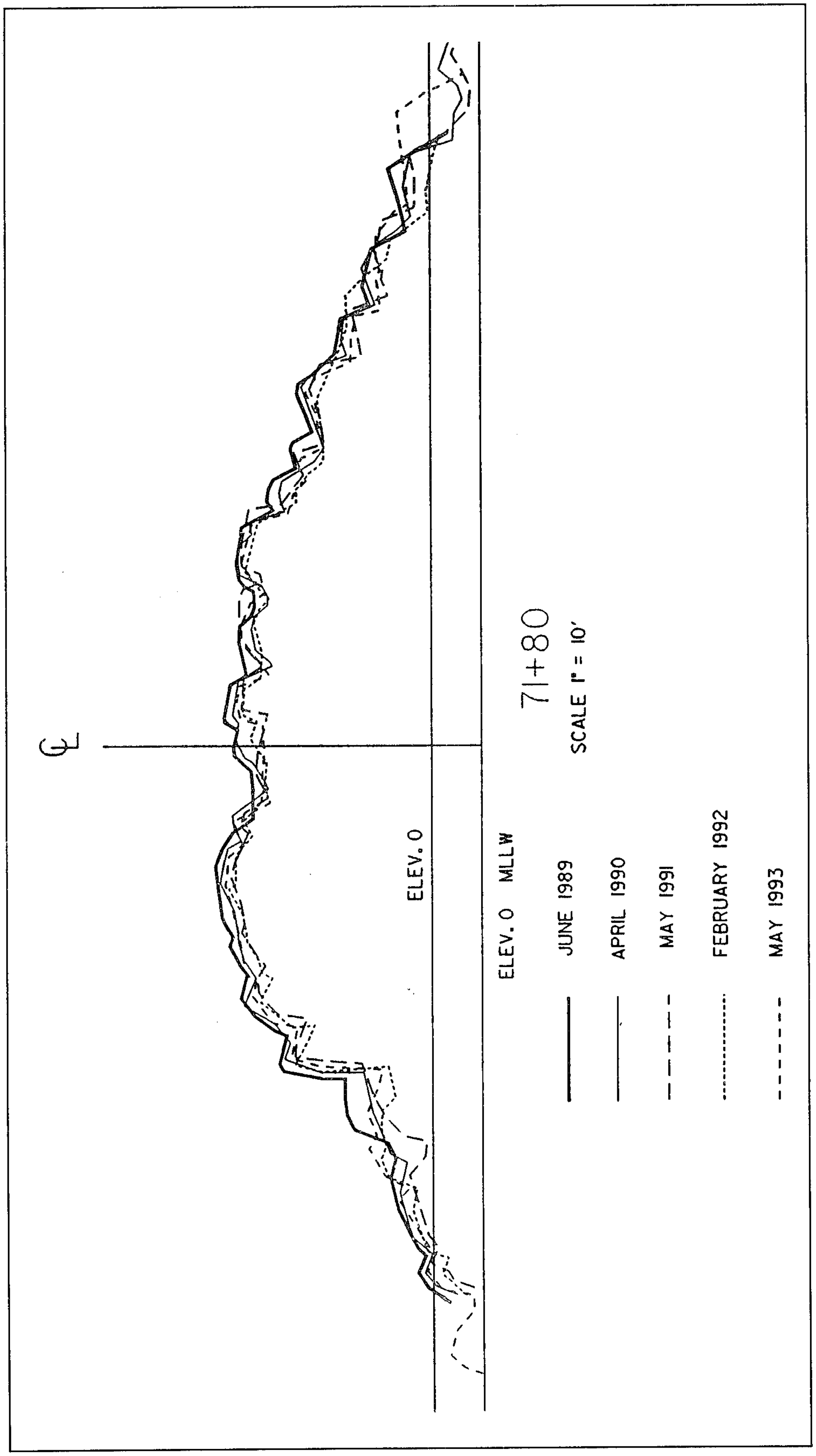
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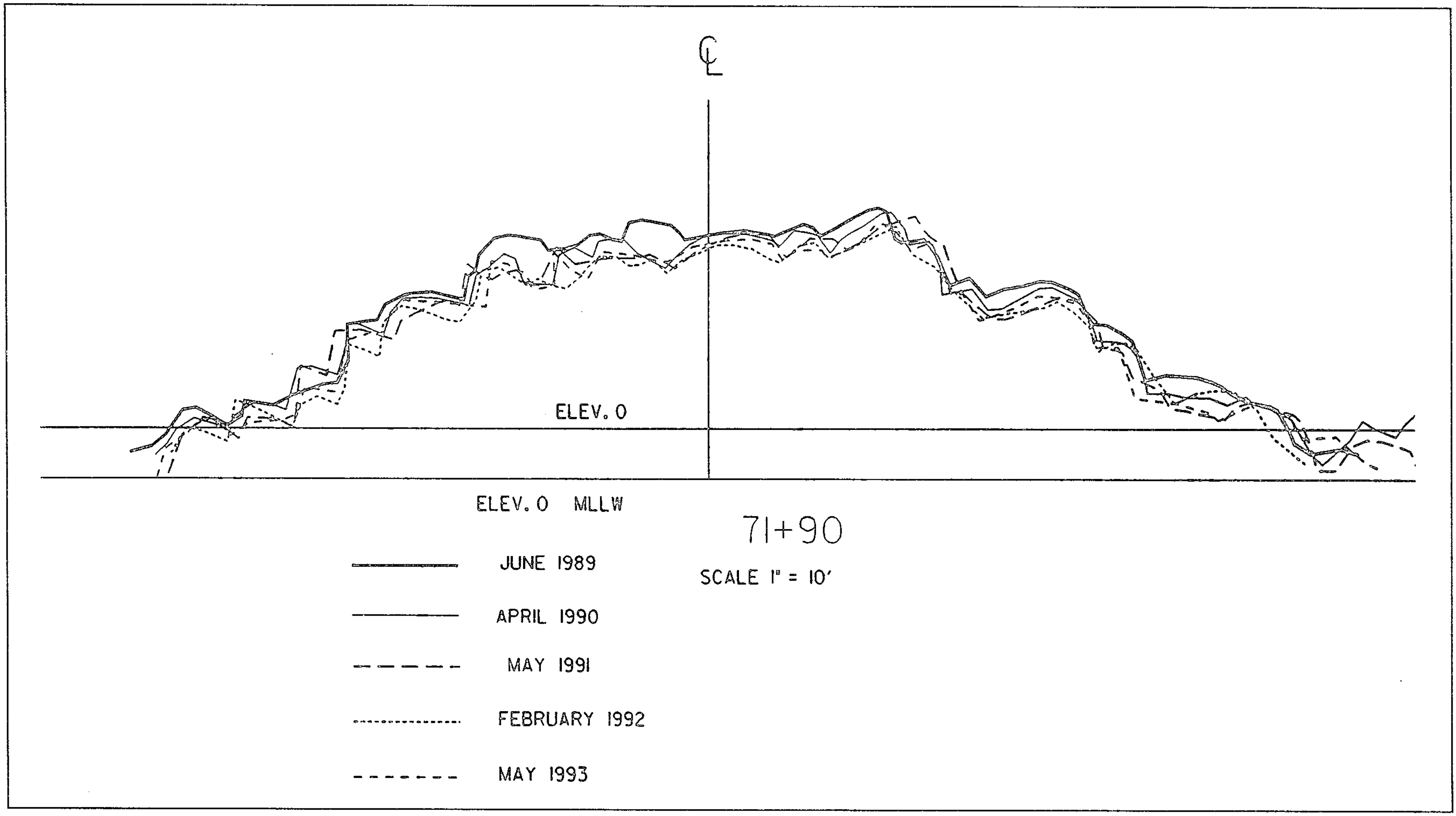
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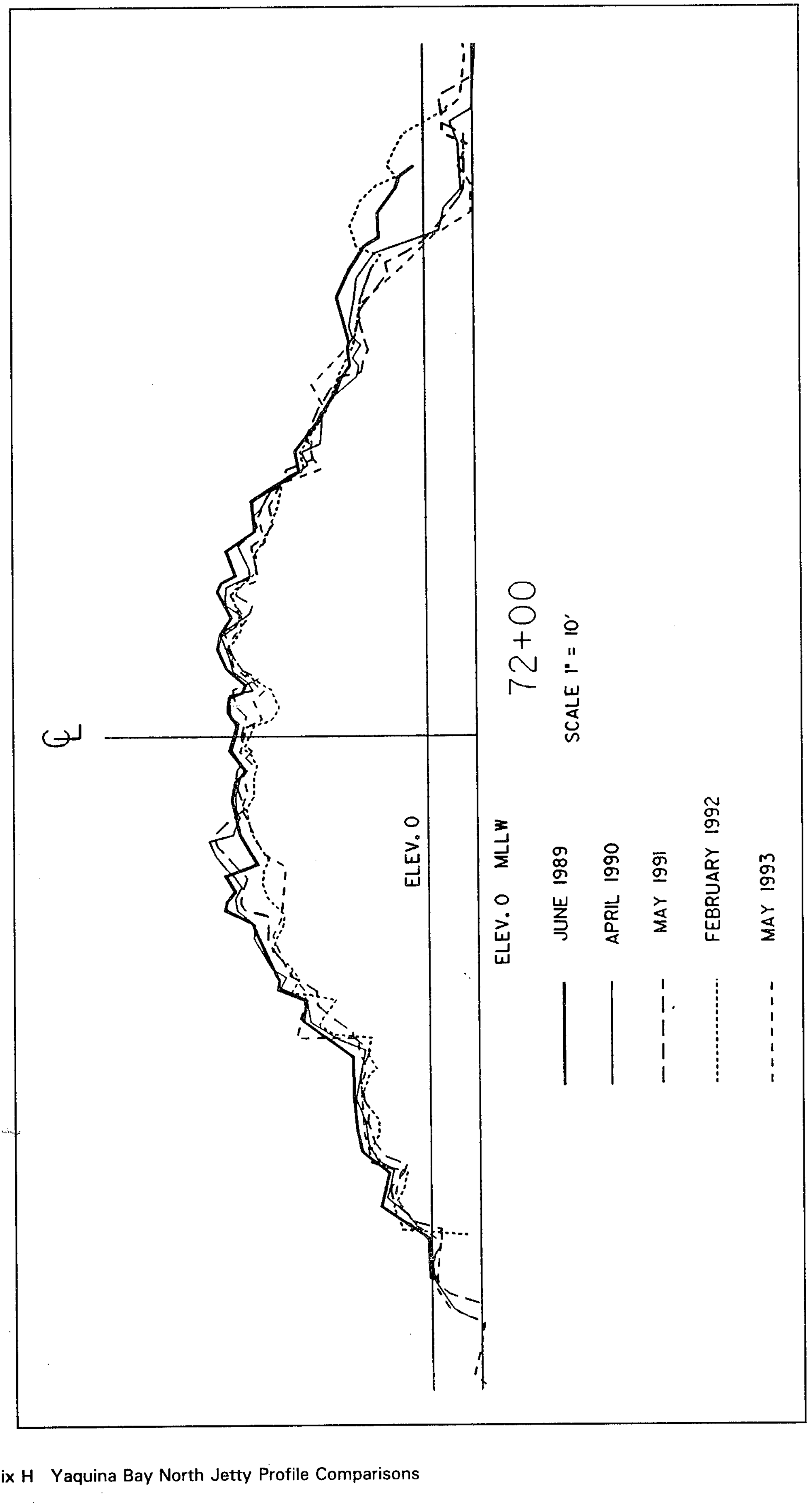
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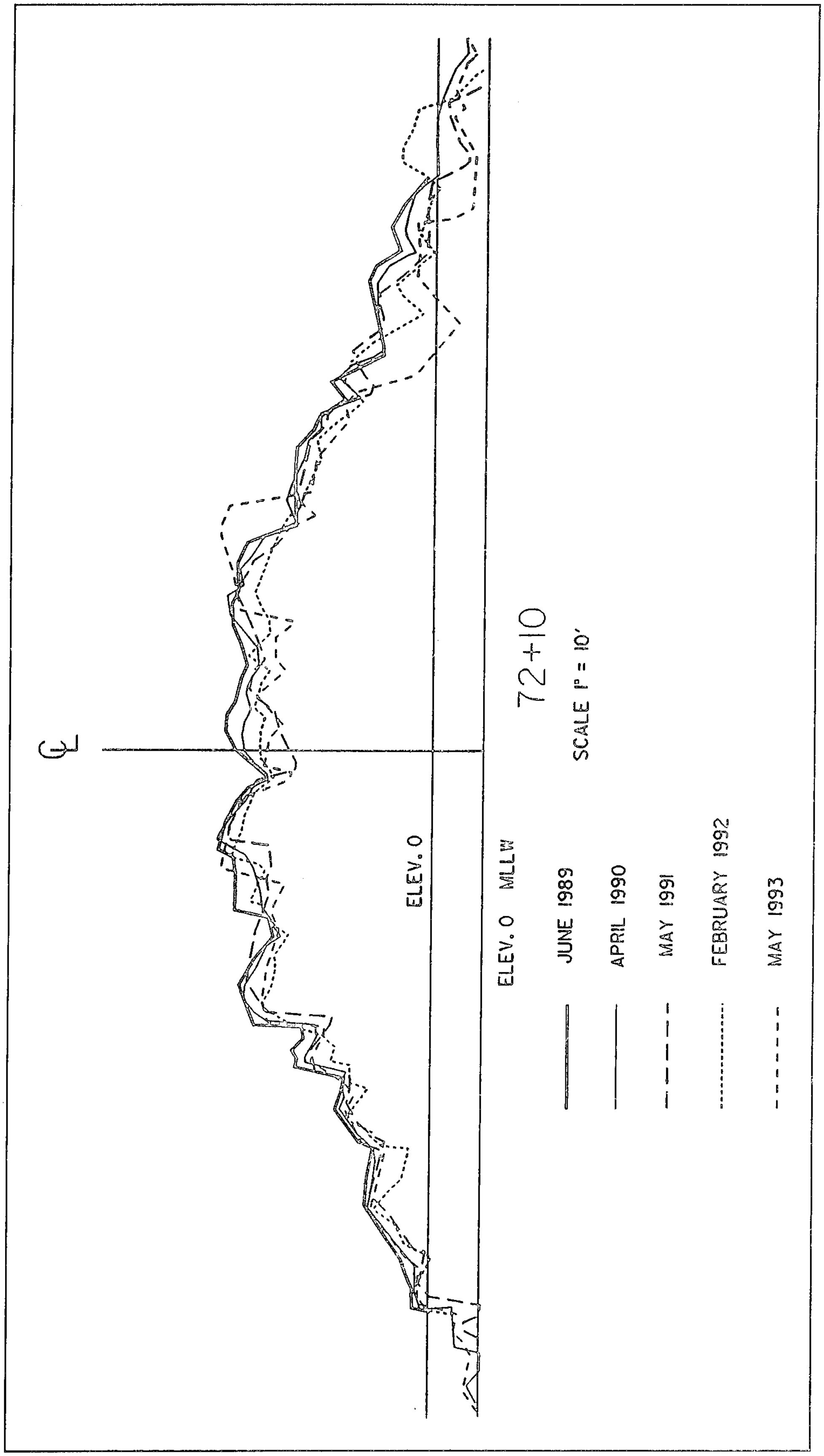
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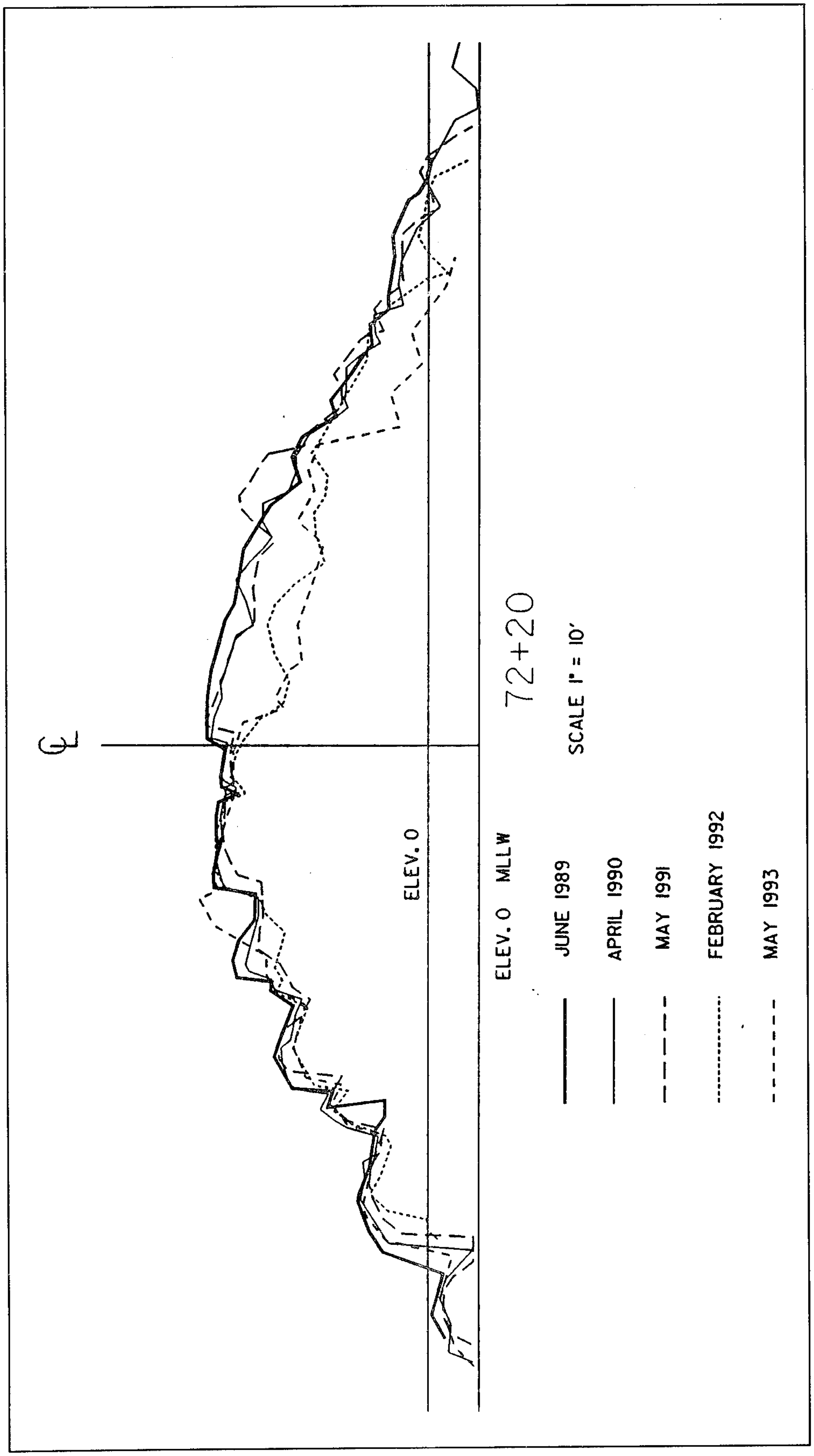
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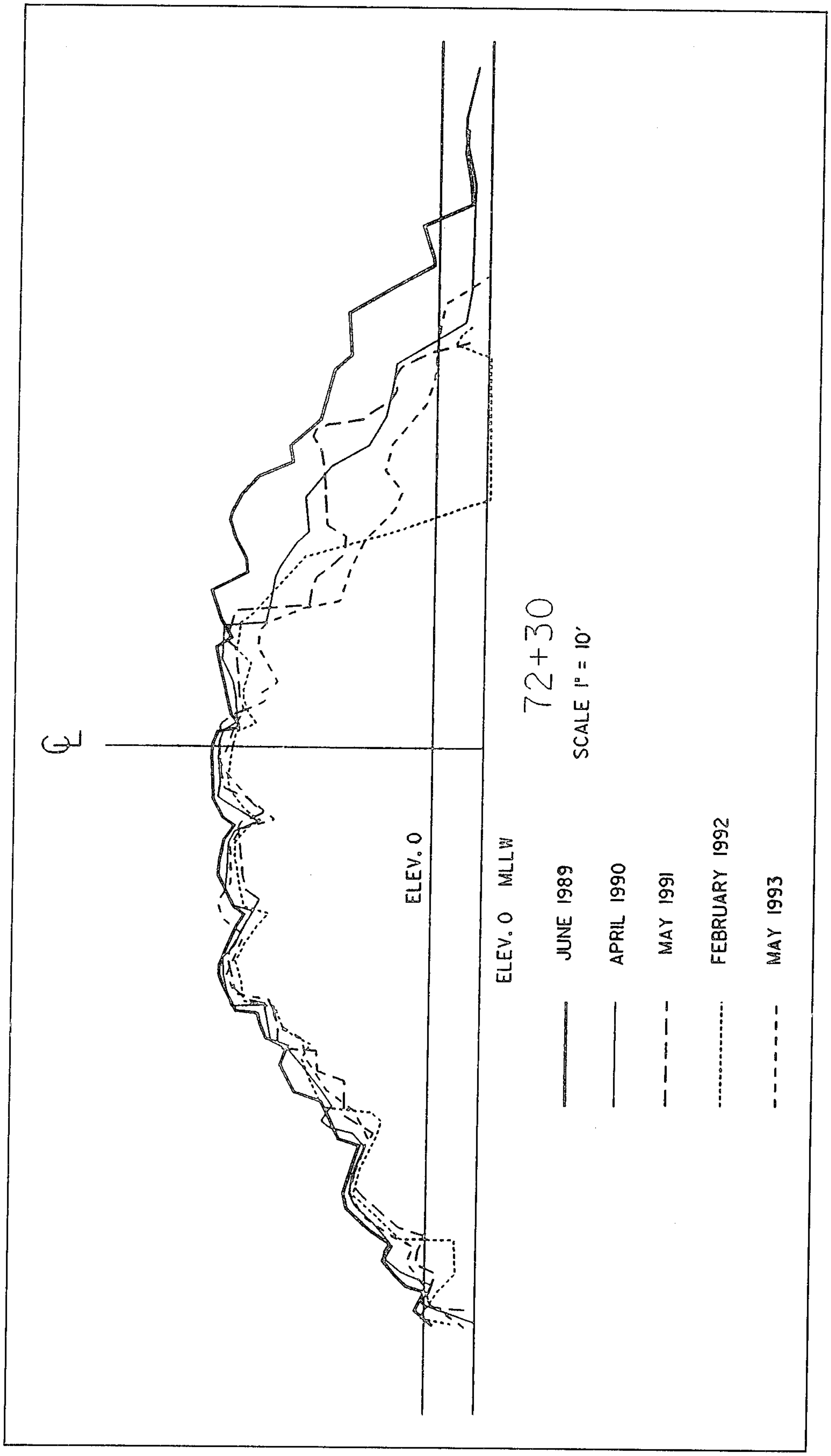

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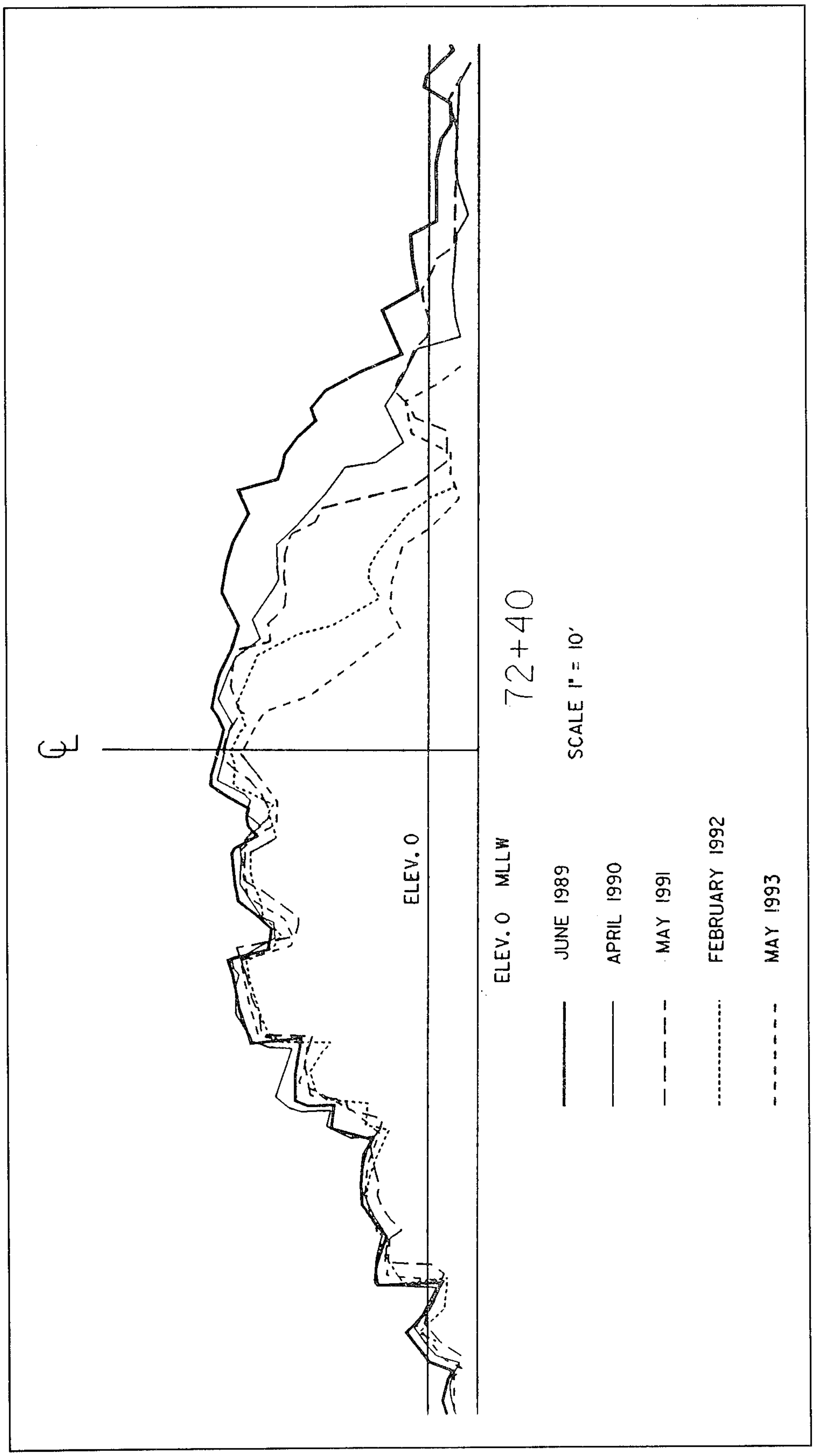
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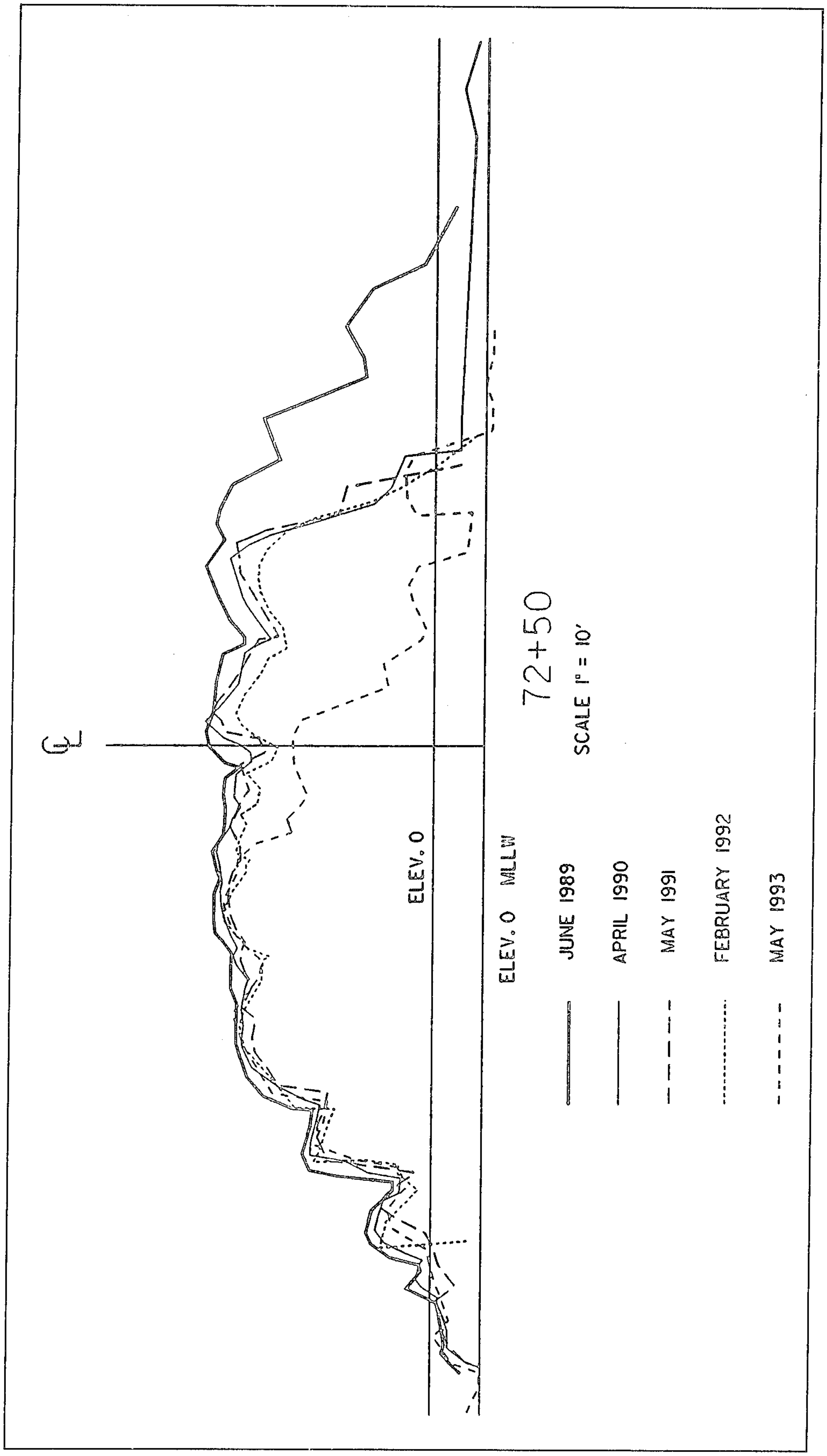
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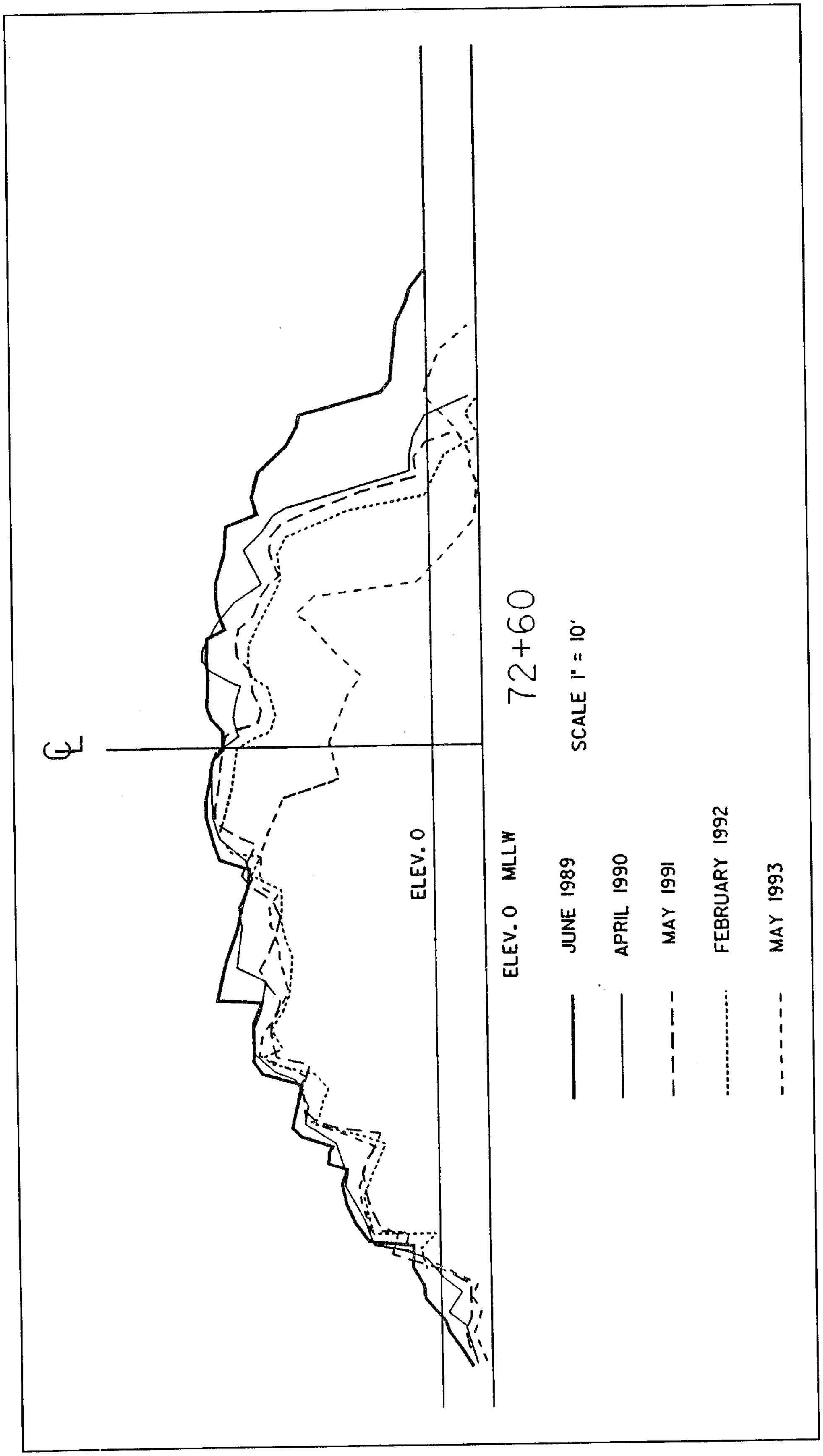
MAY 1993



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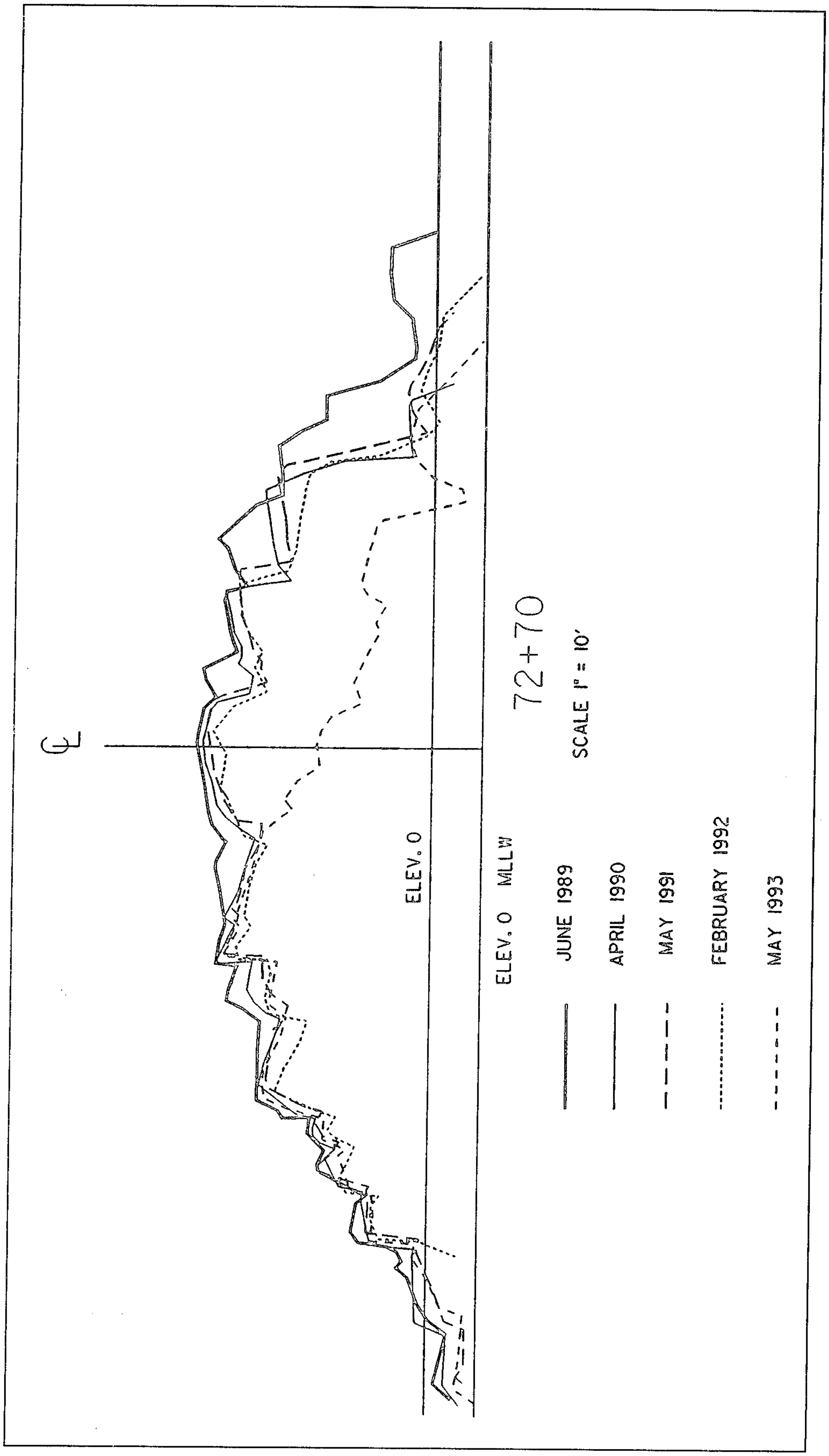
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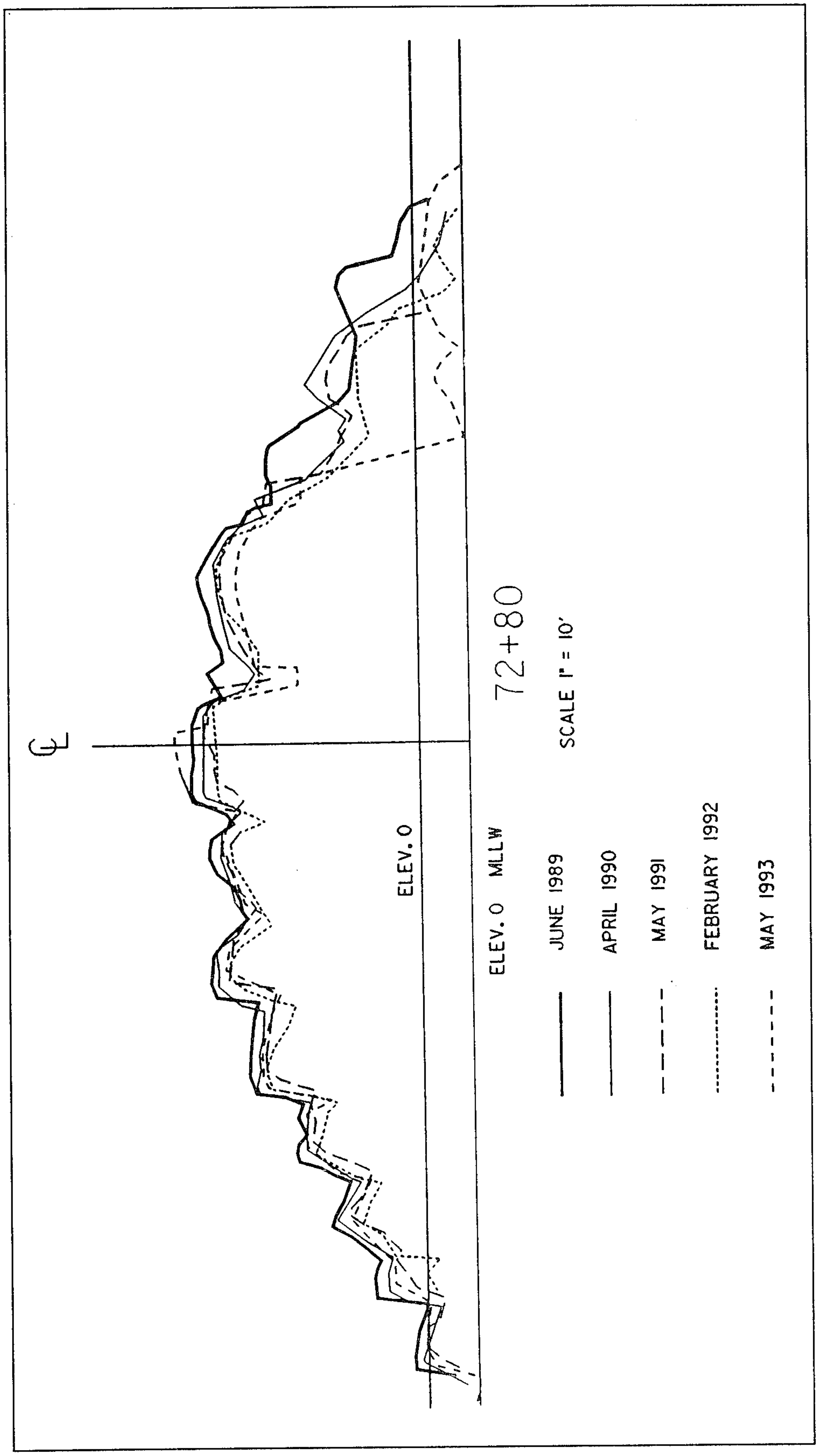
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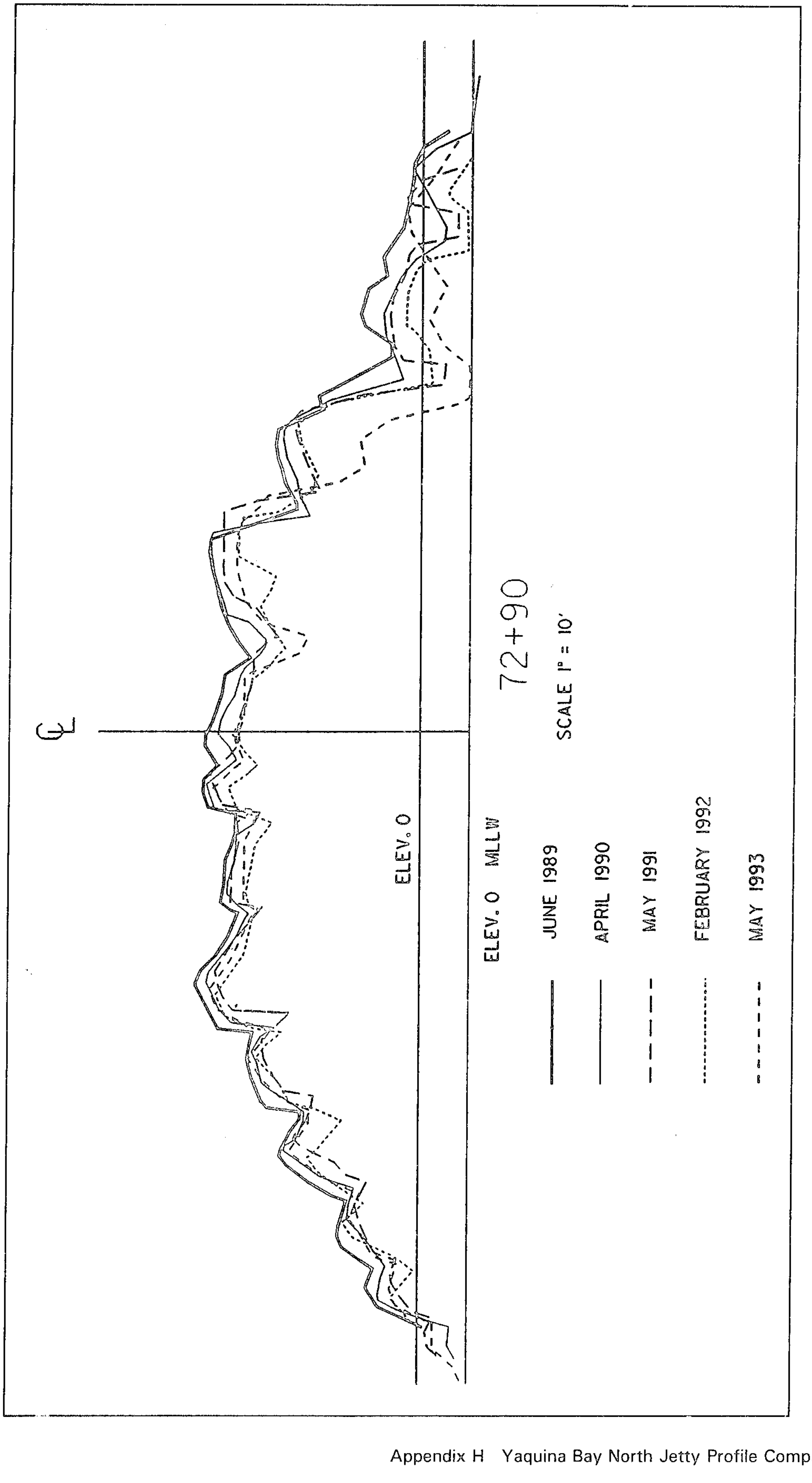

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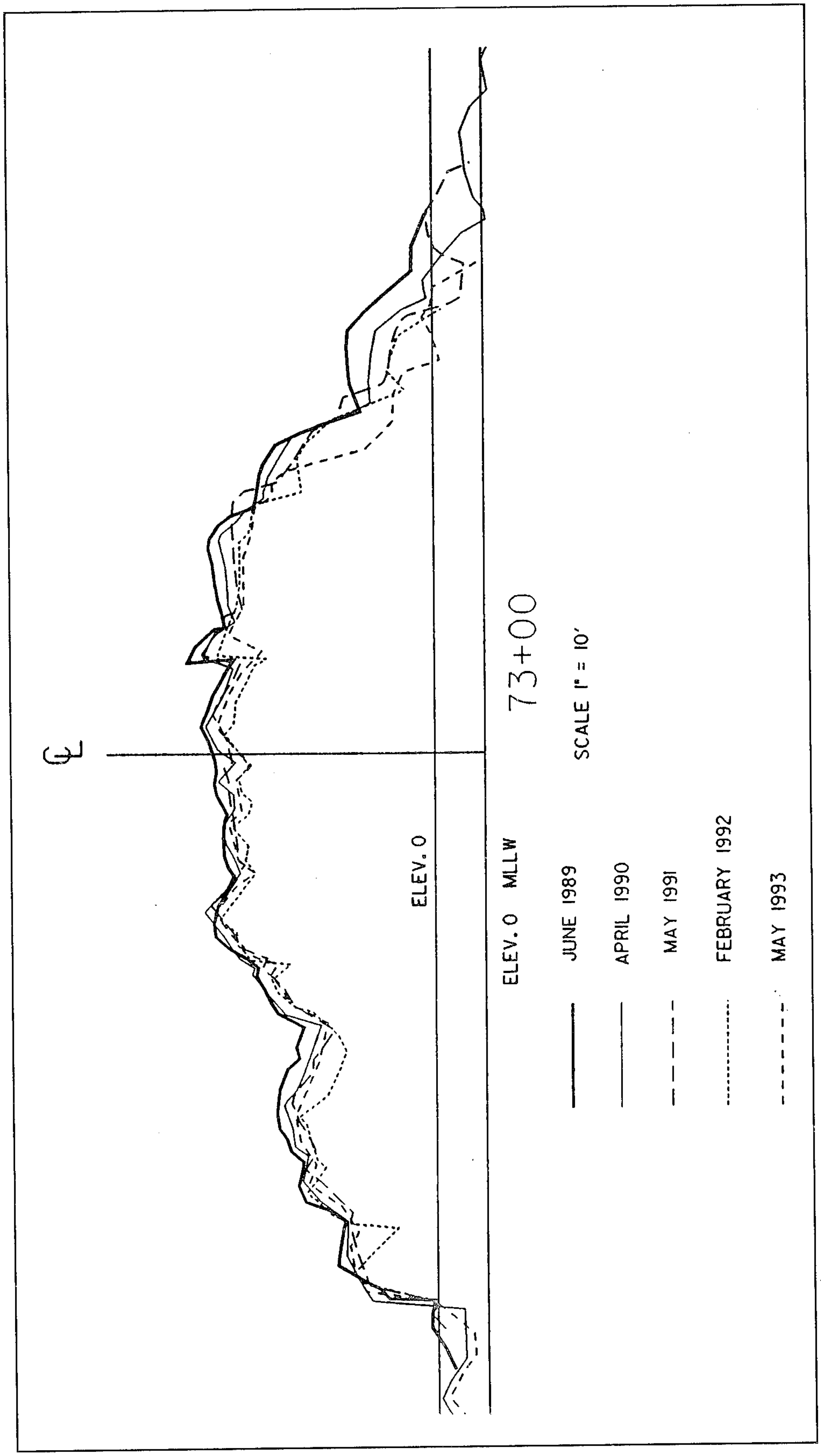
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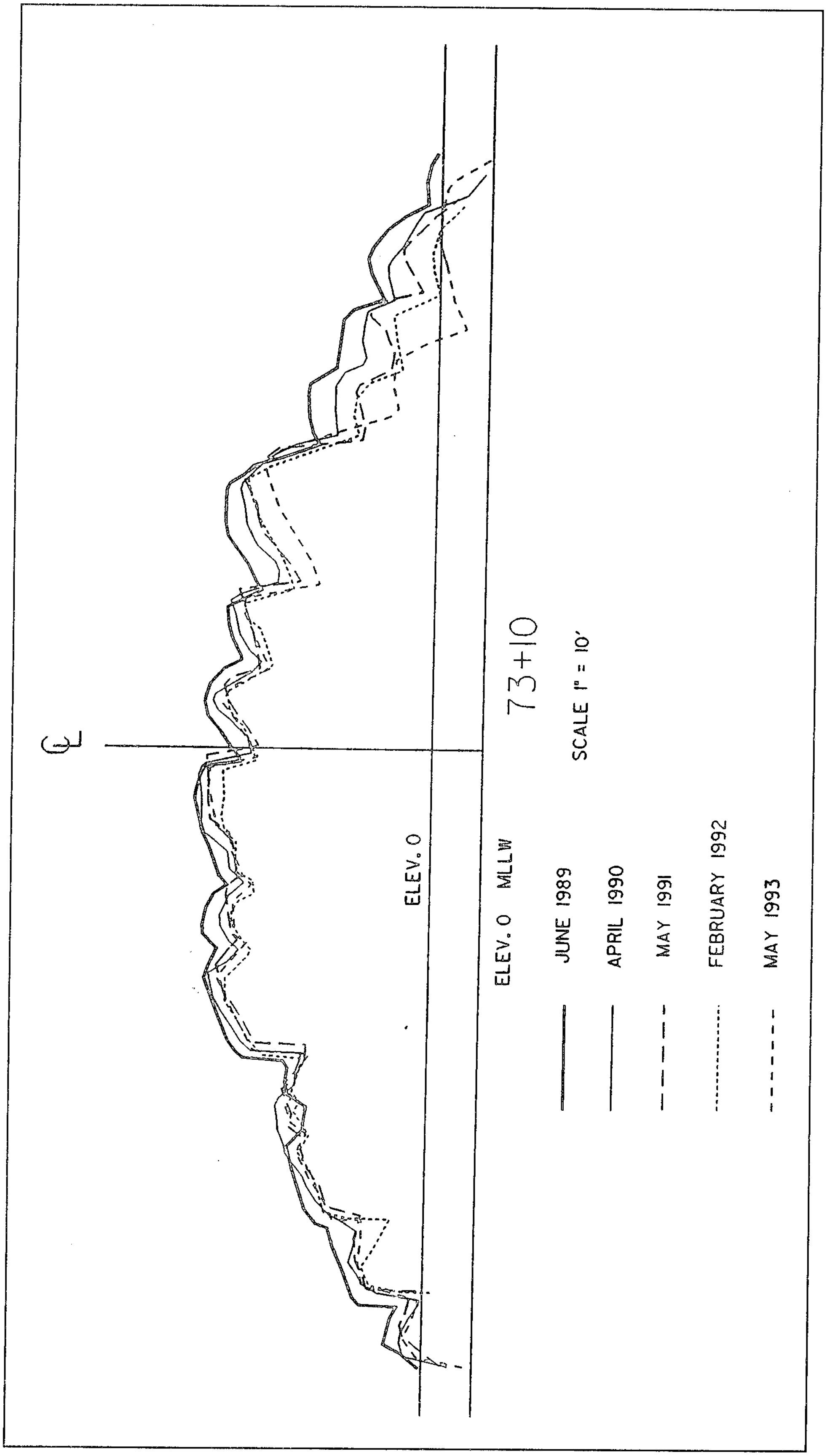
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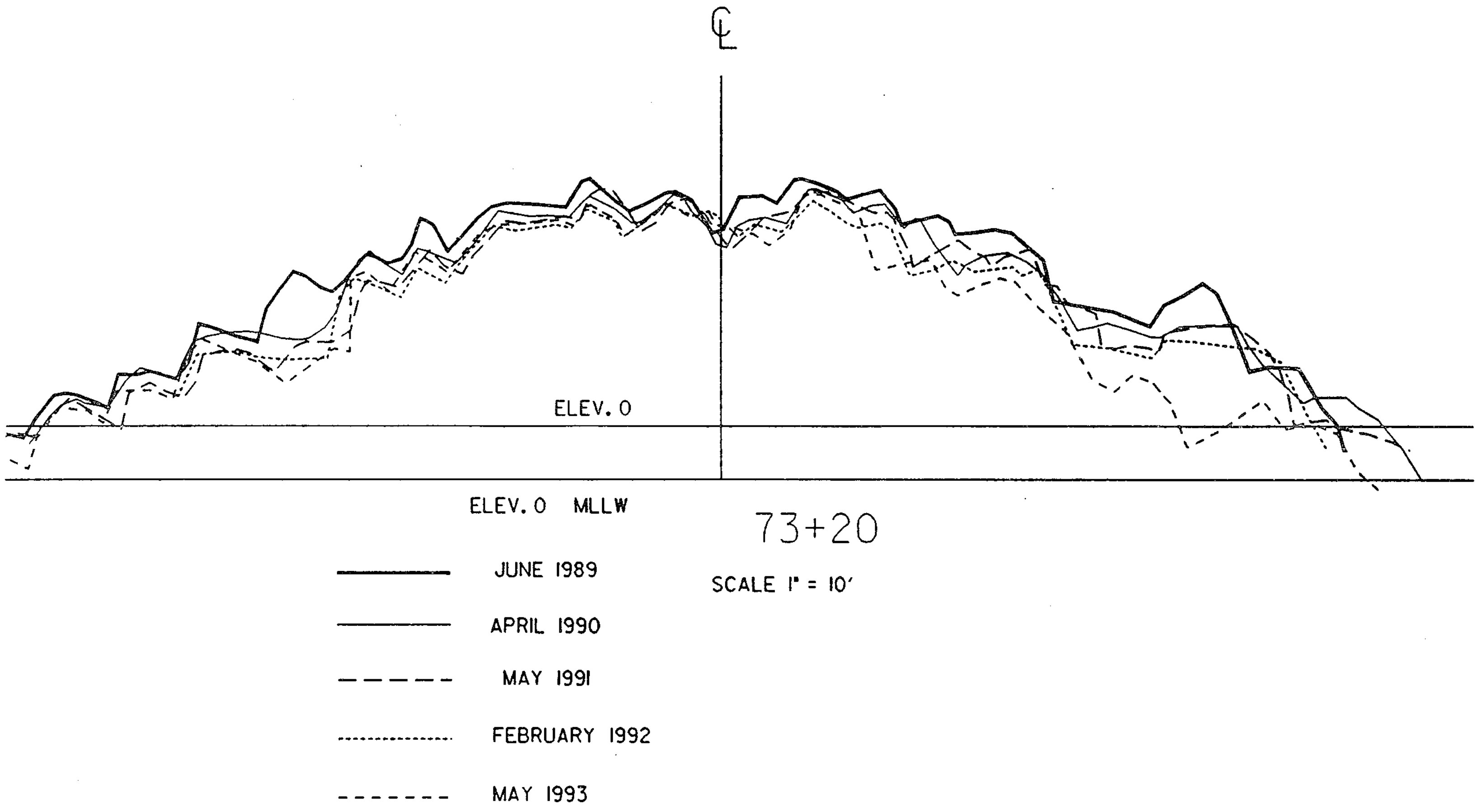
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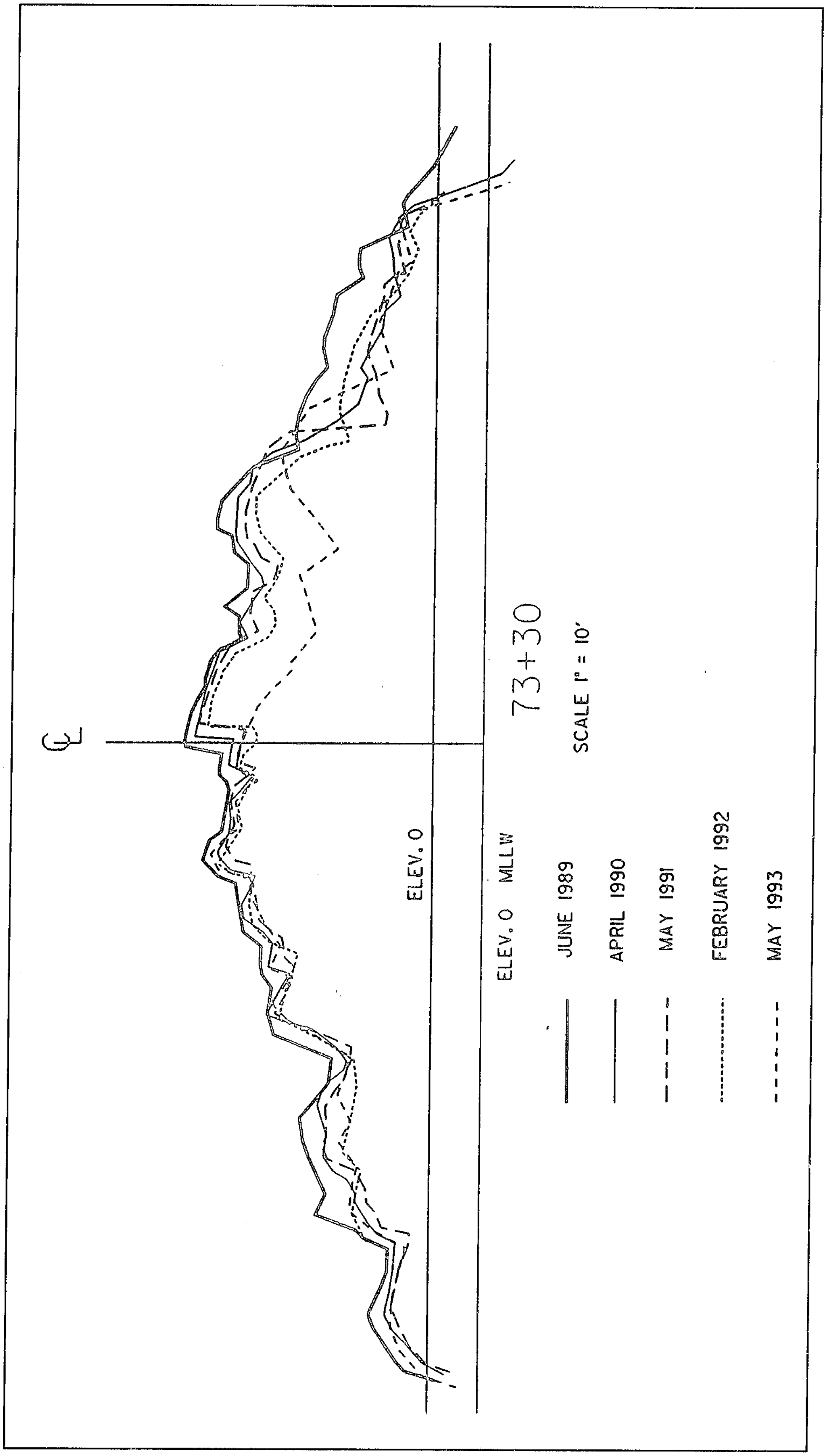

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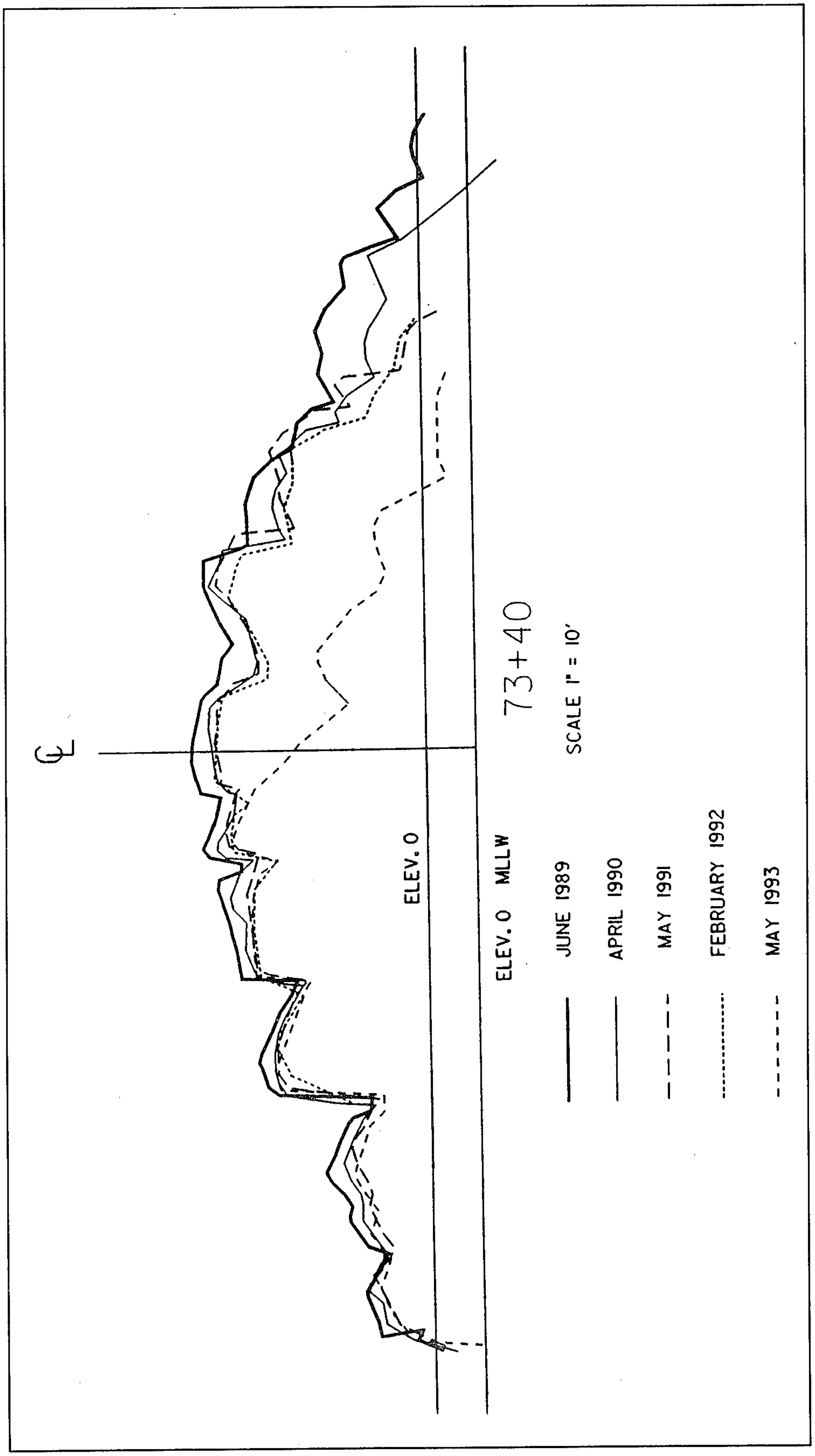

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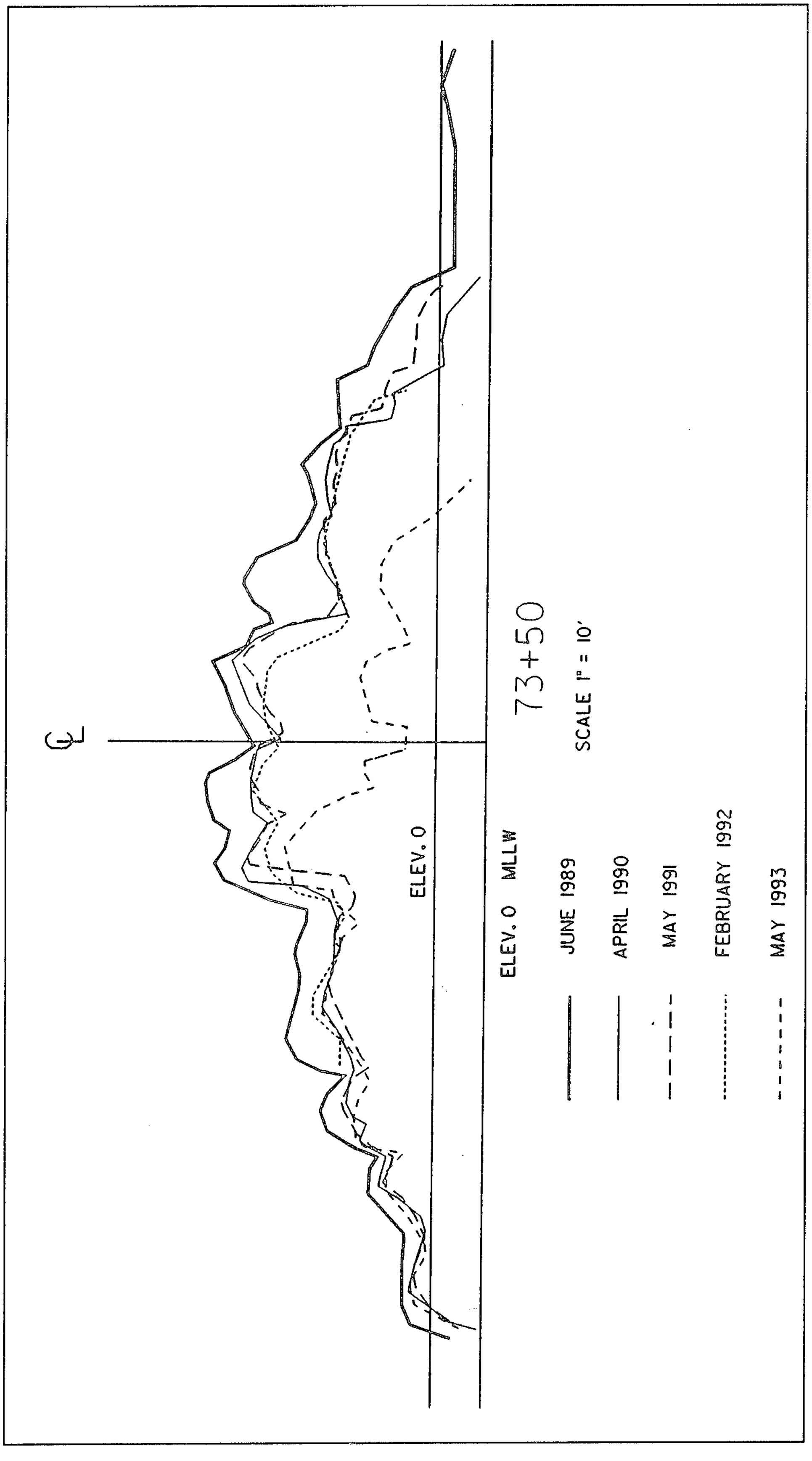
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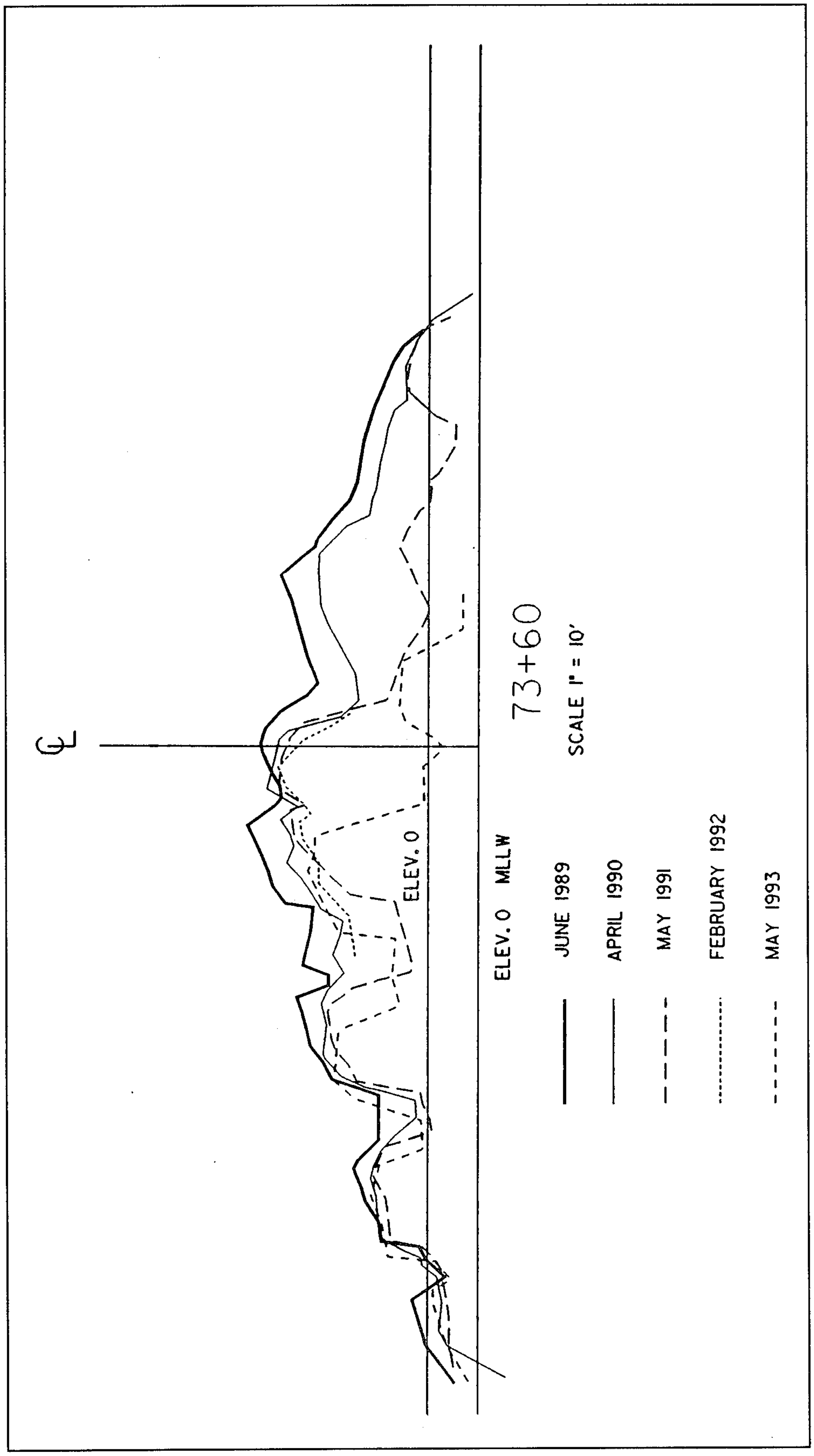
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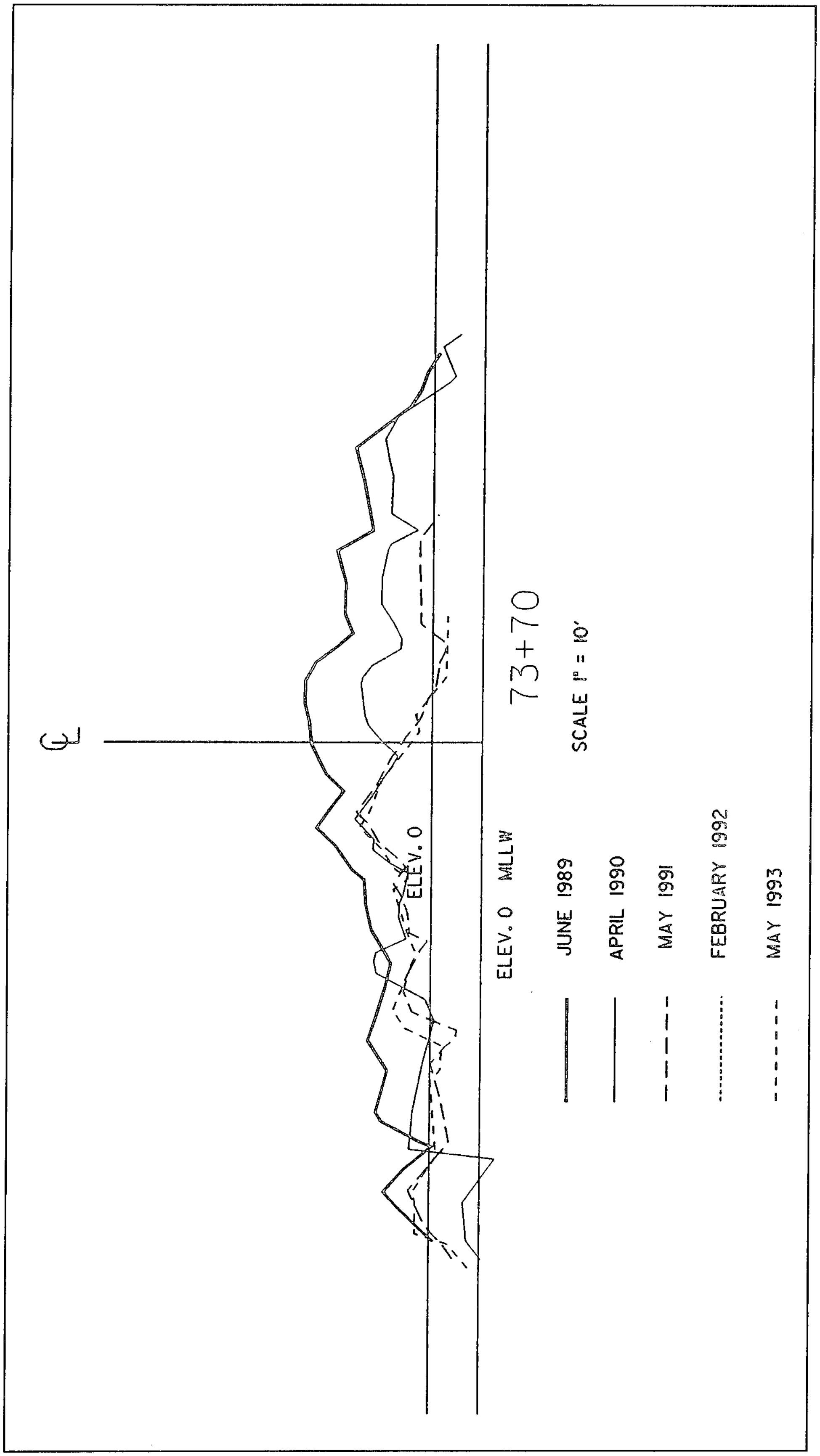
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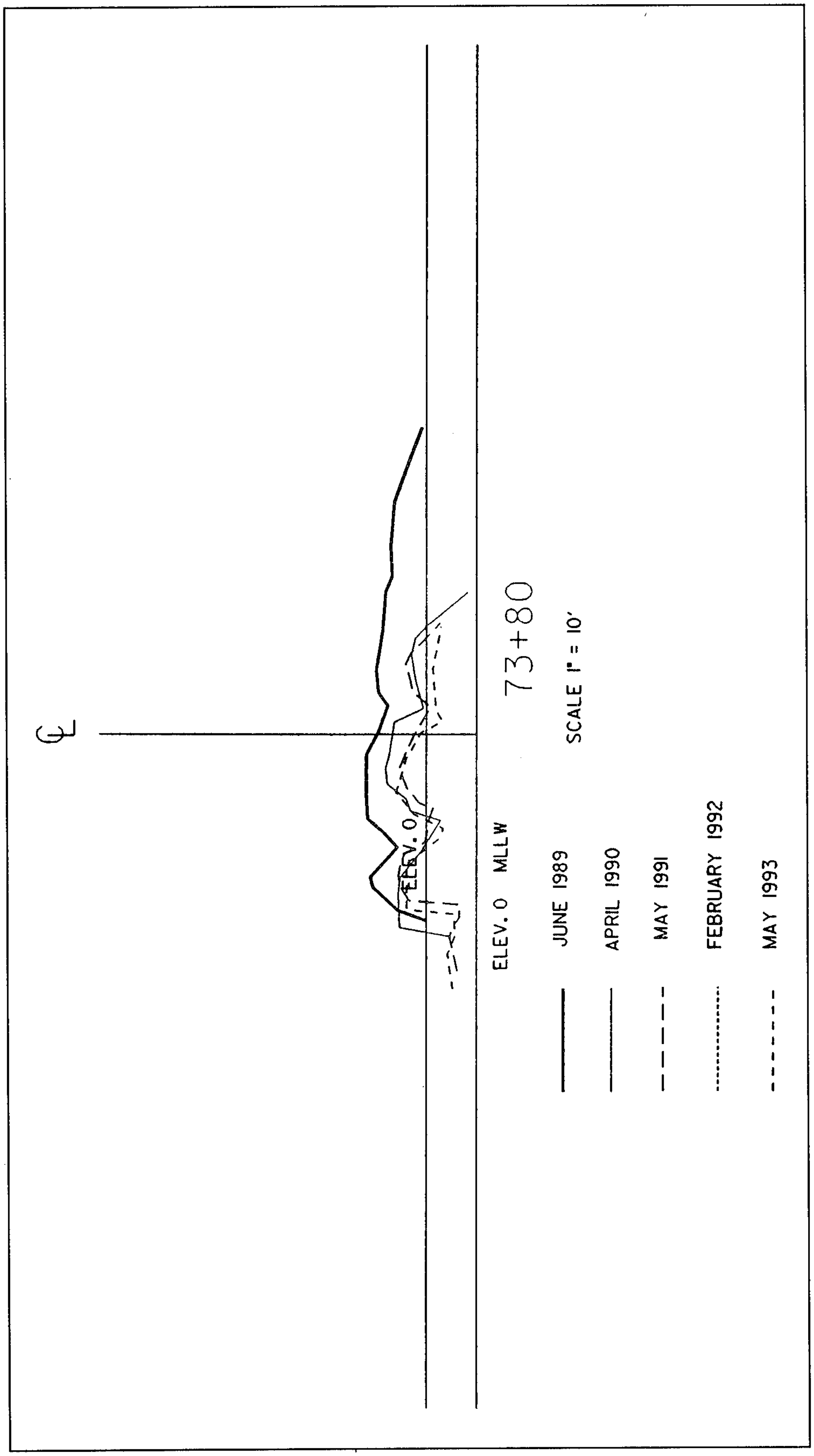

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MAY 1991
FEBRUARY 1992
MAY 1993

Appendix I
Contractor's Report on Helicopter Photogrammetry

REPORT ON THE LOW ALTITUDE PHOTOGRAMMETRIC STUDY OF THE WESTERLY 700 FEET OF THE NORTH JETTY AT NEWPORT (YAQUINA BAY) OREGON

May 27, 1992

Submitted to:

Mr. Robert Peak, Cartographer
U.S. Army Corps of Engineers
Portland District
P.O. Box 2946
Portland, OR 97208-2946

Submitted by:

Richard B. Davis Co., Inc.
140 Rowdy Creek Road
P.O. Box 950
Smith River, CA 95567-0950

REPORT ON THE LOW ALTITUDE PHOTOGRAMMETRIC STUDY OF THE WESTERLY 700 FEET OF THE NORTH JETTY AT NEWPORT (YAQUINA BAY) OREGON

May 27, 1992

PURPOSE OF THIS STUDY

The purpose of this helicopter aerial photogrammetric study was to develop an accurate digital elevation model (DEM) which would show elevations taken on a 2 foot by 2 foot spacing over that above-water portion of the North jetty lying westerly of Engineers station 67+00. The nodal points of the DEM are referenced to the Oregon Coordinate System, North Zone, for horizontal position so that each point can be remeasured on future flights and the resulting data analyzed to detect possible movement or "unraveling" of any portion of the structure within the study area.

EQUIPMENT USED

The following equipment was used to conduct this study:

Trimble 4000ST GPS receivers and Trimnet adjustment software;
Wild T-2000 and T-1600 electronic total stations with data collectors;
Robinson R-22 helicopter;
Fairchild T-12 calibrated mapping camera (6 inch focal length) with less than 10 microns radial distortion;
Qasco SD-4 analytical stereoplotter;
Personal 386 computers with Microstation software.

FLIGHT PLANNING

Two helicopter flight plans were followed for this project. Plan 1 was designed at a flight altitude of 120 feet above sea level and was parallel with the centerline of the North jetty. This plan was designed to produce 60% forward overlap and a photo scale of approximately 1:240 or 1"=20'. Plan 2 was designed to require three side-by-side flight lines flown at an altitude of 200 feet above sea level, and perpendicular to the centerline of the North jetty. The sidelap between these stereomodels was approximately 30%. A third and higher flight at an altitude of 600 feet above sea level to include all the study area in a single stereopair of photographs was also planned.

Aerial photography was ideally planned to be taken on a clear or high overcast day during a period of low tide (no greater than 0.0 ft. Mean

Lower Low Water), calm sea conditions, good illumination, and between the hours of 10:00 AM and 2:00 PM Pacific Standard Time.

Aerial photography was initially planned for Sunday, March 22, but was scrubbed as high seas prevented the completion of targeting of the control points. The field survey was completed on April 9, 1992, with the photographic flight made at low tide at noon on the same day. Less than ideal flight conditions existed, as an approaching storm caused seas above 6 feet, and a low overcast prevented reaching altitudes above 400 feet. Winds from the Southeast made controlling the helicopter on the exact flight lines quite difficult. The flight was successful, however, and usable photography was obtained.

GROUND SURVEY METHODS

The field control survey portion of this study was performed utilizing Trimble 4000ST Global Positioning System (GPS) receivers which measured a triangle between control stations "PARK", "DAVIS" AND "BOB". Station "PARK" is located in the small park near the Northwest end of the Highway 101 bridge over Yaquina Bay. Station "DAVIS" is in the lawn southeasterly of the South end of the same bridge. Station "BOB" is on the North jetty at Engineer's Station 68+43.80. The state plane coordinate position and elevation of "PARK" as furnished by the Portland District, Corps of Engineers, was held for control.

The line "PARK" - "BOB" was used for azimuth, and an additional station (No. 2) was established at the most westerly end of the North Jetty, and closed back to "PARK". At all points selected for small aerial targets for the helicopter photography, 3/8" diameter by 1/2" deep holes were drilled into the rock, and an attempt was made to paint the surface with the a target design. Because of the high seas caused by an approaching weather disturbance, as well as the proximity of the offshore reef, a nearly continuous spray of sea water kept the target locations nearest the water too wet to paint. Aluminum target plates were riveted to the drill hole and a mylar self-stick target design centered on the aluminum. The force of the seas completely removed several of these lower targets overnight, and they had to be replaced prior to the flight. I believe that maintenance of the helicopter targets will be required prior to each flight.

Total stations were then set up at "BOB" and "No. 2", and direct ties made simultaneously from these two stations to all photo control targets plus the twenty previously established Corps targets (10 each on the North and South jetties). All target points on the North jetty were used to control the aerial photography.

PHOTOGRAMMETRIC METHODS

Because of the wind, lighting and sea conditions on the date of flight, several passes were made to capture the best possible imagery of the jetty. The best resulting stereopairs were selected for data capture.

Stereomodels were formed in a Qasco SD-4 fully analytical stereoplotter with up to 10 control points per model utilized in the absolute orientation.

The stereoplotter was then programmed to drive to coordinate intersections on a 2 foot by 2 foot grid, and the Z or elevation value for each point was measured and recorded. Those points which fell in unreadable locations (e.g. in voids between rocks or in the water) were rejected. Approximately 15,000 points were read and recorded into computer files.

DIGITAL DATA ANALYSIS

The digital data was initially processes through a Triangulated-Irregular-Network (TIN). The results were then graphically analyzed by developing a contour map, cross-sections and a 3-D orthographic projection of the DEM (fishnet surface plot) in an oblique view. These graphical exhibits are included along with this report.

The data captured in this first field survey and photogrammetric flight are designed to be the bench mark against which the data gathered from future surveys and flights will be compared.

ERROR ANALYSIS

Field Surveys

The GPS field control survey between stations "BOB", "PARK" and "DAVIS" closed with an error ratio of 1:820,000. The secondary triangle between stations "BOB", "No. 2" and "PARK" closed with an error ratio of 1:36,400.

All target locations were measured simultaneously in X-Y-Z from total stations occupying control points "BOB" and "No. 2". The average and maximum differences between the two readings obtained at each target point were as follows:

Coordinate Differences (ft)	X	Y	Z
Average Difference	0.051	0.061	0.041

Maximum Difference	0.101	0.101	0.101

The mean position for each point was used.

Photogrammetric Survey

The average and maximum coordinate value residual errors from the absolute orientation of all the stereomodels set in this study were as follows:

Coordinate Differences (ft)	X	Y	Z
Average Difference	0.030	0.036	0.043
Maximum Difference	0.095	0.106	0.123

In the area of overlap between adjacent stereomodels, 211 DEM points were observed in both stereomodels and the Z or elevation values were later compared. The results were as follows:

Elevation Difference (ft)	Z
Average Difference	0.08
Maximum Difference	0.71
Median	0.05

Of the 211 points compared, only 6 showed differences in excess of 0.30 feet.

DIGITAL DATA FORMATS AND DATA BASE ORGANIZATION

Raw stereoplotter tri-ordinates are provided in ASCII format on 3-1/2" floppy diskettes. These points are also provided in MicroStation and AutoCad drawings on the same media.

The contour maps, control diagrams, 3-D fishnet and cross-section diagrams are also included in the MicroStation and AutoCad drawing files.

The ground control survey tri-ordinates are included in ASCII and Lotus 1-2-3 format on diskettes.

CONCLUSION

The results of this study show that a helicopter-borne mapping camera coupled with an accurate ground control survey and a fully analytical stereoplotter can produce accurate three-dimensional data which can help in the analysis of the movement or initial signs of deterioration of coastal structures.

A major benefit in the use of the helicopter is the ability to design flight altitudes low enough to eliminate the geometric weakness and associated problems of working with "water models" which have rendered photogrammetry quite useless on many coastal structures.

Acquisition of the 3-D data points on a precise grid which is tied to the State Plane Coordinate System allows these nodal points to be exactly revisited, remeasured and the data sets compared on future flights.

The accuracy of the digital data obtained from the low altitude stereomodels exceeds that which can normally be obtained from conventional fixed-wing photography. Additionally, helicopter aerial photography can be obtained under less than ideal conditions, especially during periods when fixed-wing aircraft photography would not be possible due to low ceilings.

Targeting of survey control points remains a problem, but it is felt that the benefits to be derived from the low altitude studies may well offset the costs associated with refreshing and recontrolling some of the targets prior to each flight.

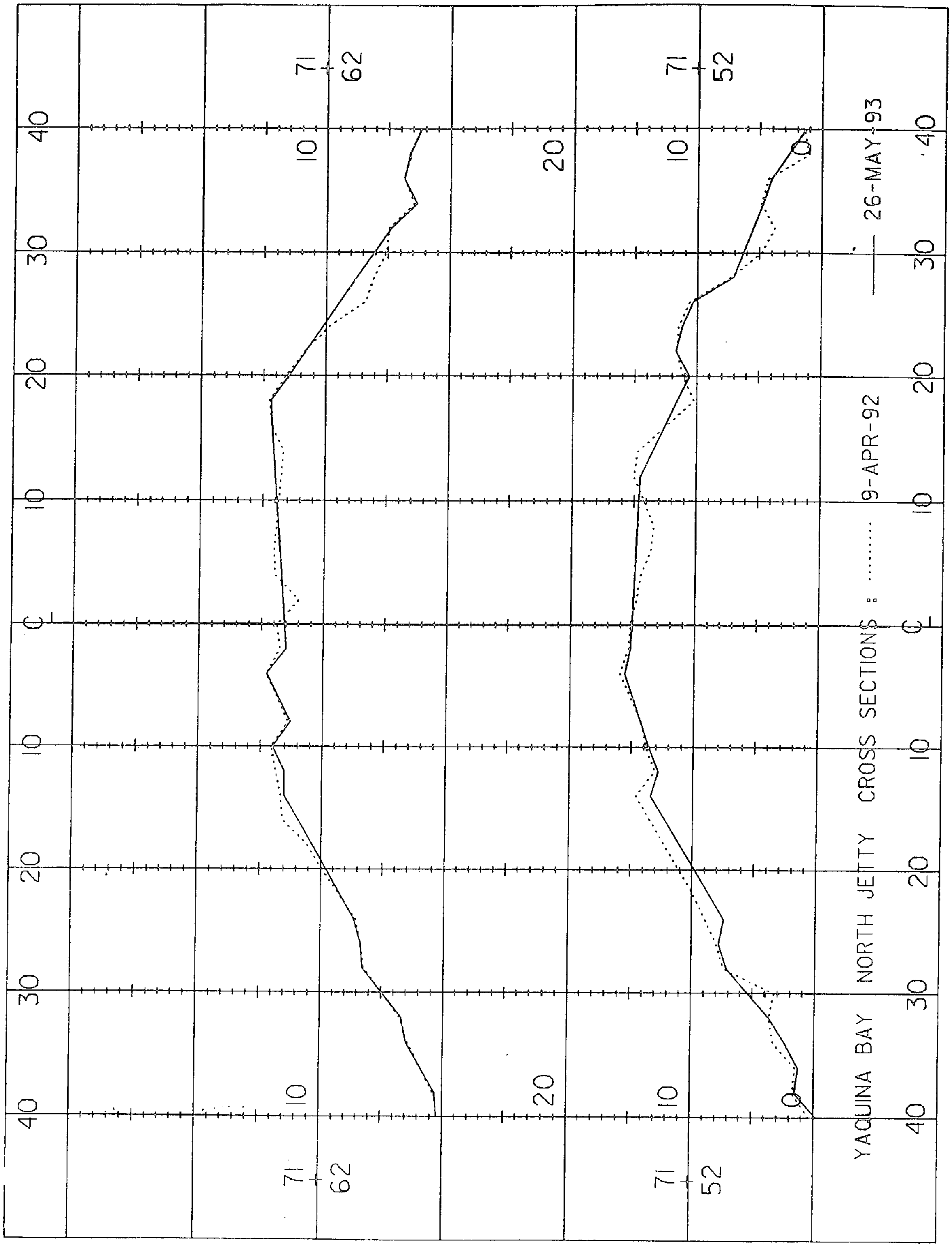
Please feel free to contact me with any additional questions.

Submitted on May 27, 1992

Richard B. Davis

Richard B. Davis
Professional Land Surveyor
Certified Photogrammetrist (ASP)

Appendix J
Yaquina Bay North Jetty Profiles from Helicopter Photogrammetry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20
10
C
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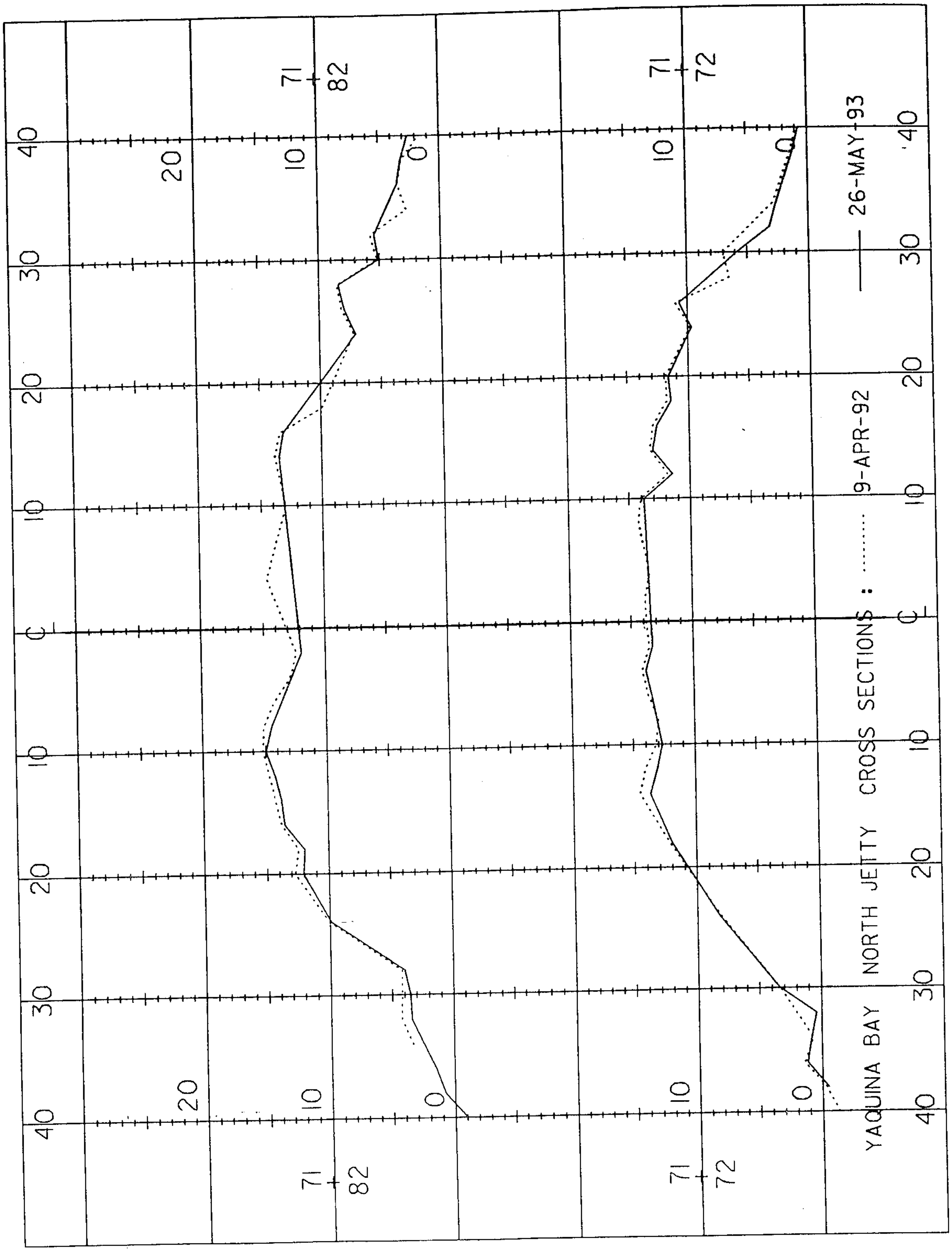
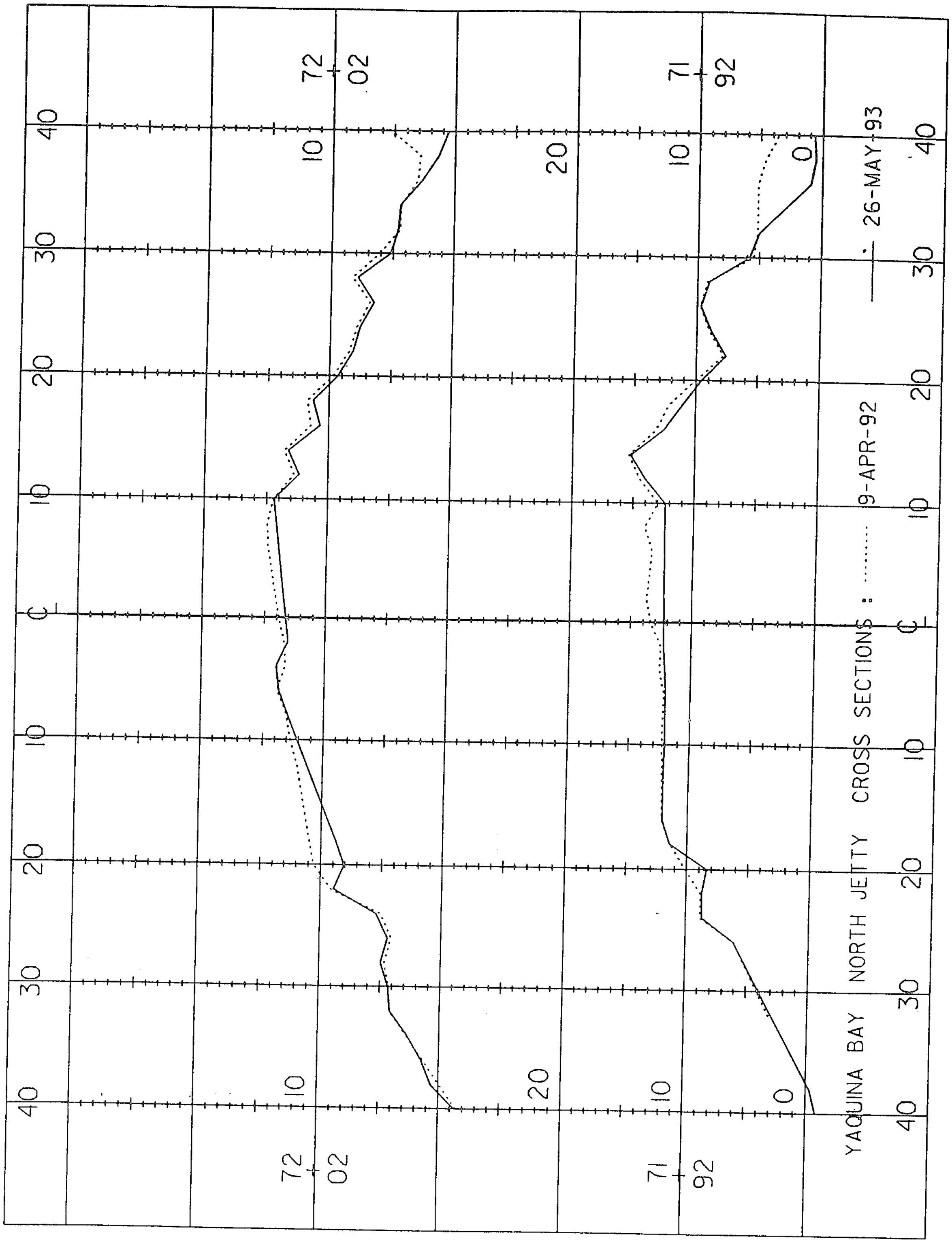
30
40
10
20
10
0



Appendix J Yaquina Bay North Jetty Profiles from Helicopter Photogrammetry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—— 26-MAY-93
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C
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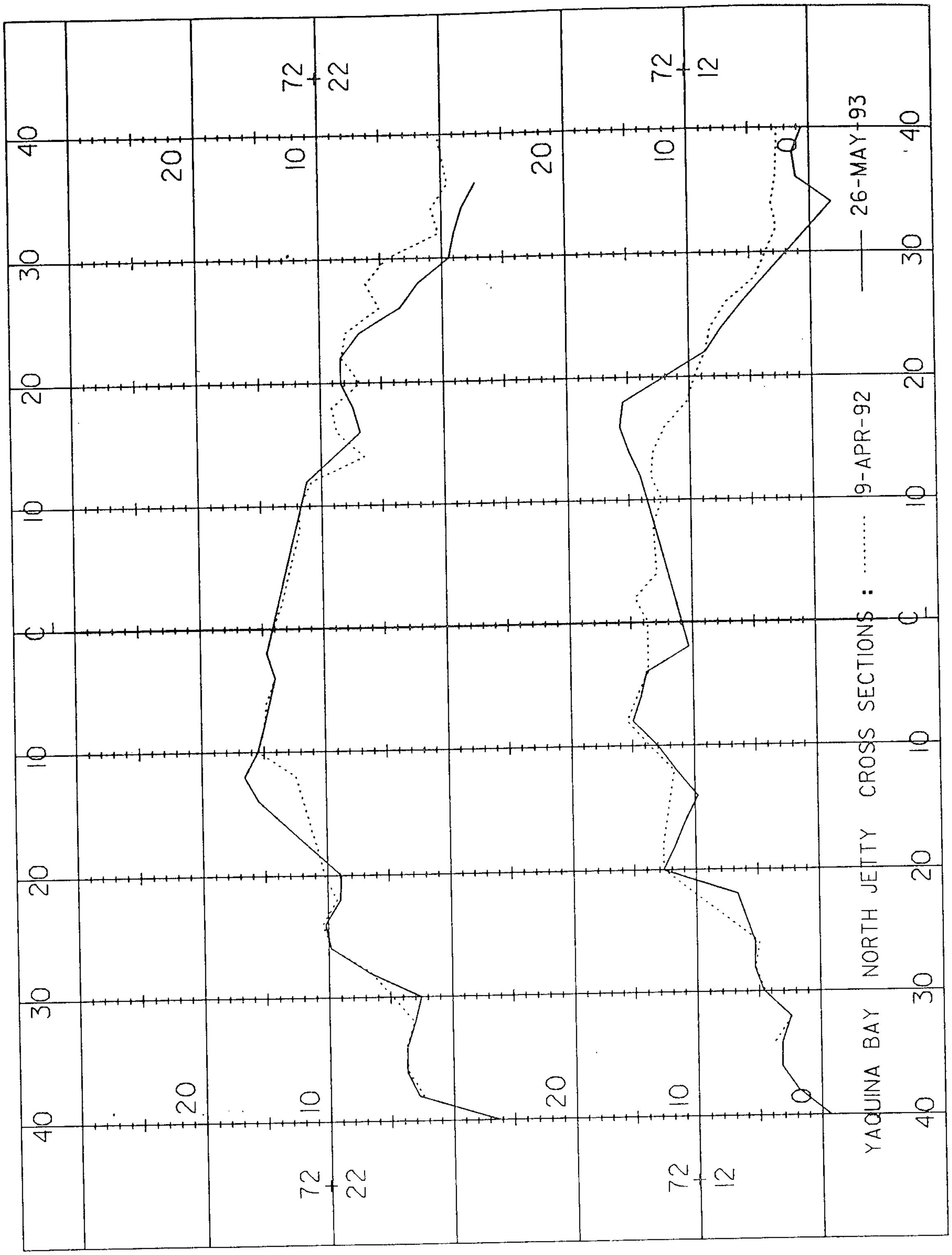
10
20
10
0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—— 26-MAY-93
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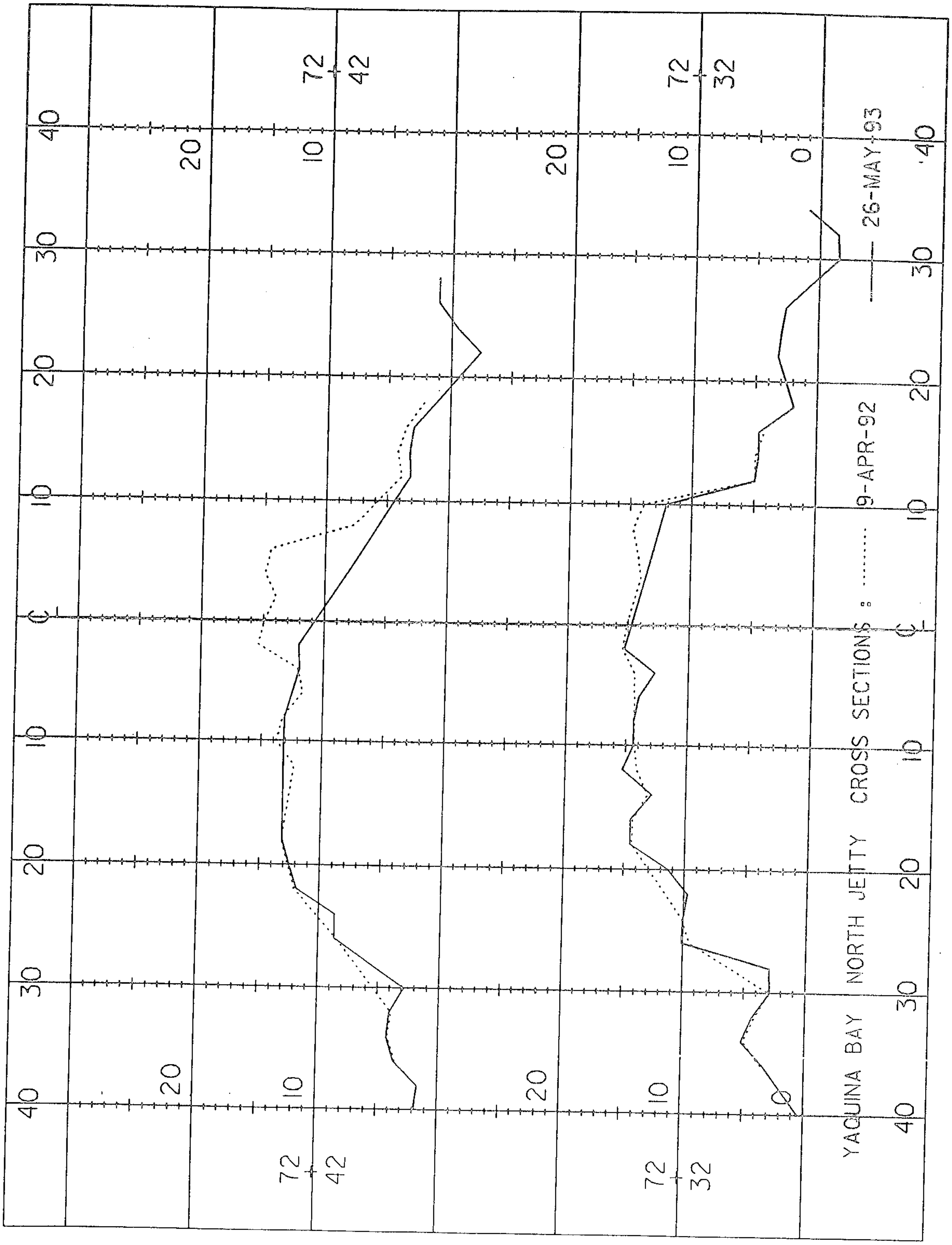
20
30
40
20
10
0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10
C
10
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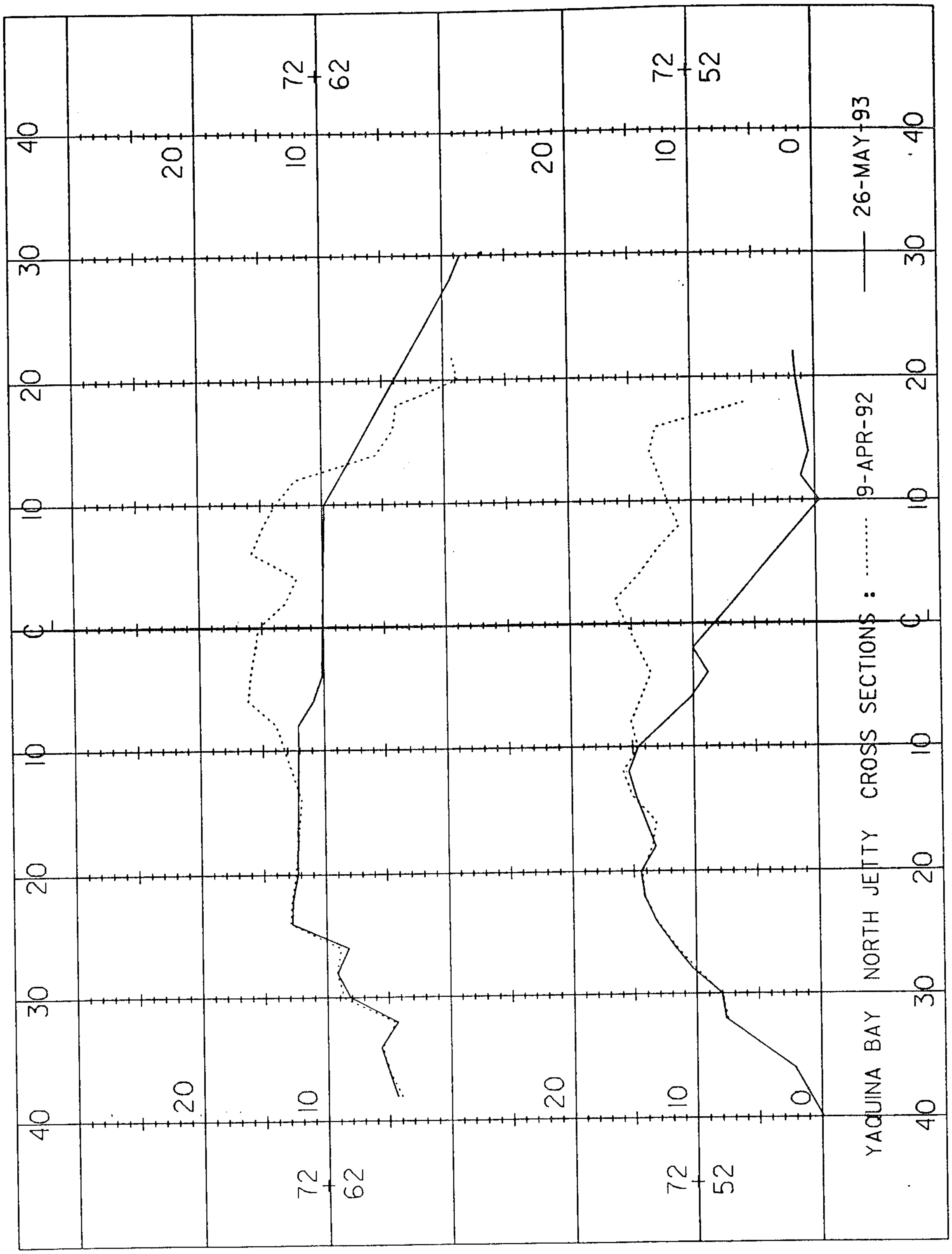
72+32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C
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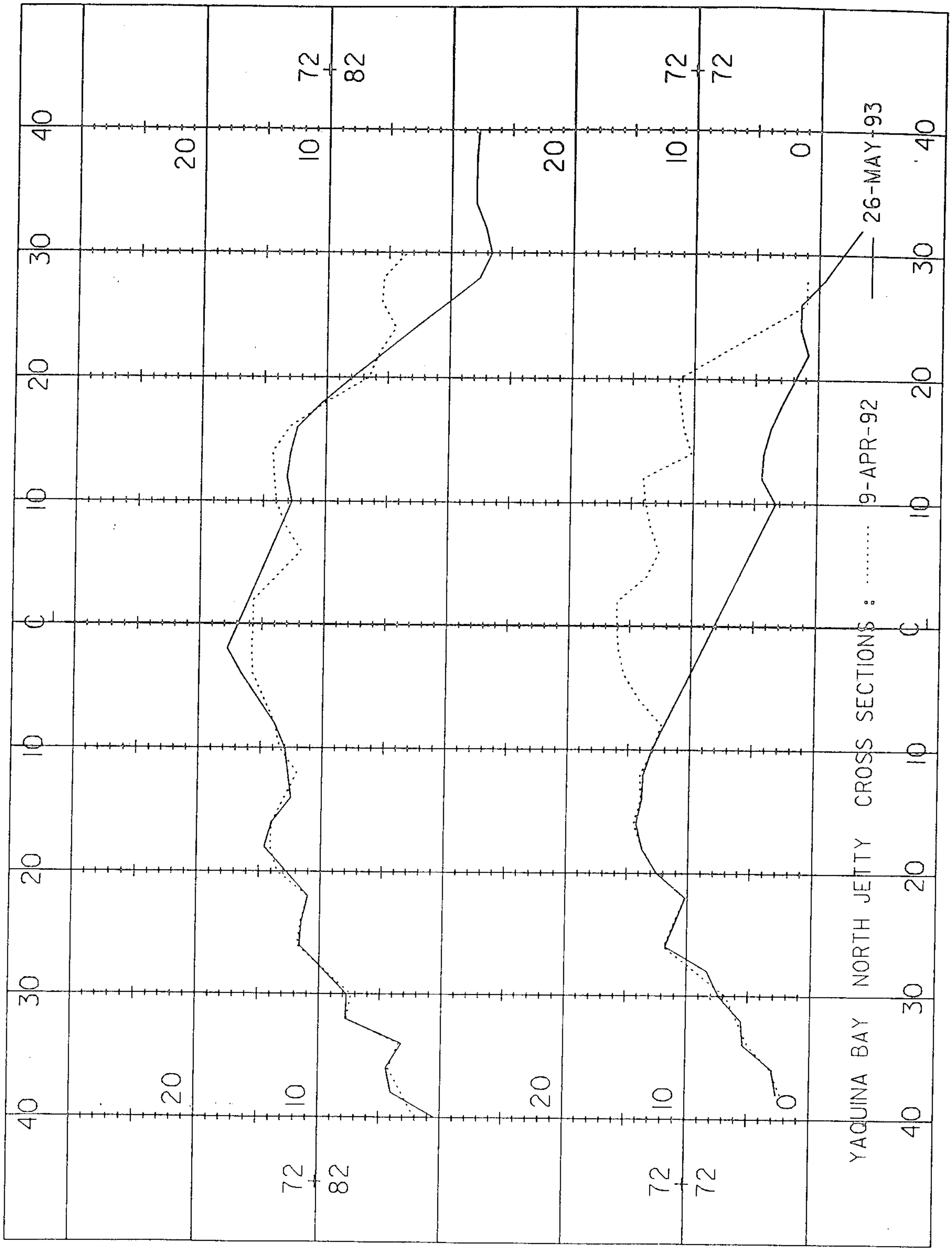
20
10
0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10
C
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30
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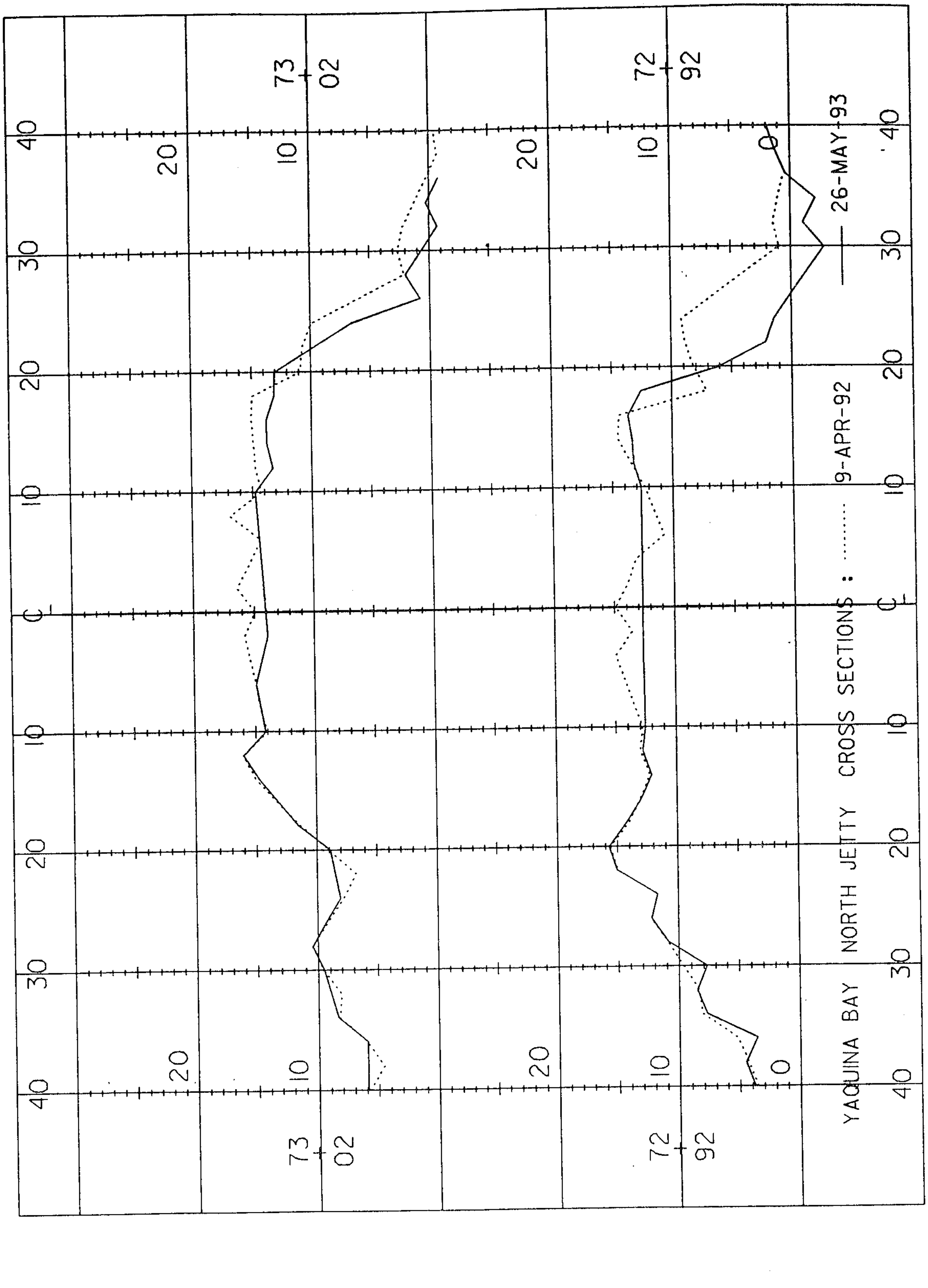
0
20
10
0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73+02
72+92
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30
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C
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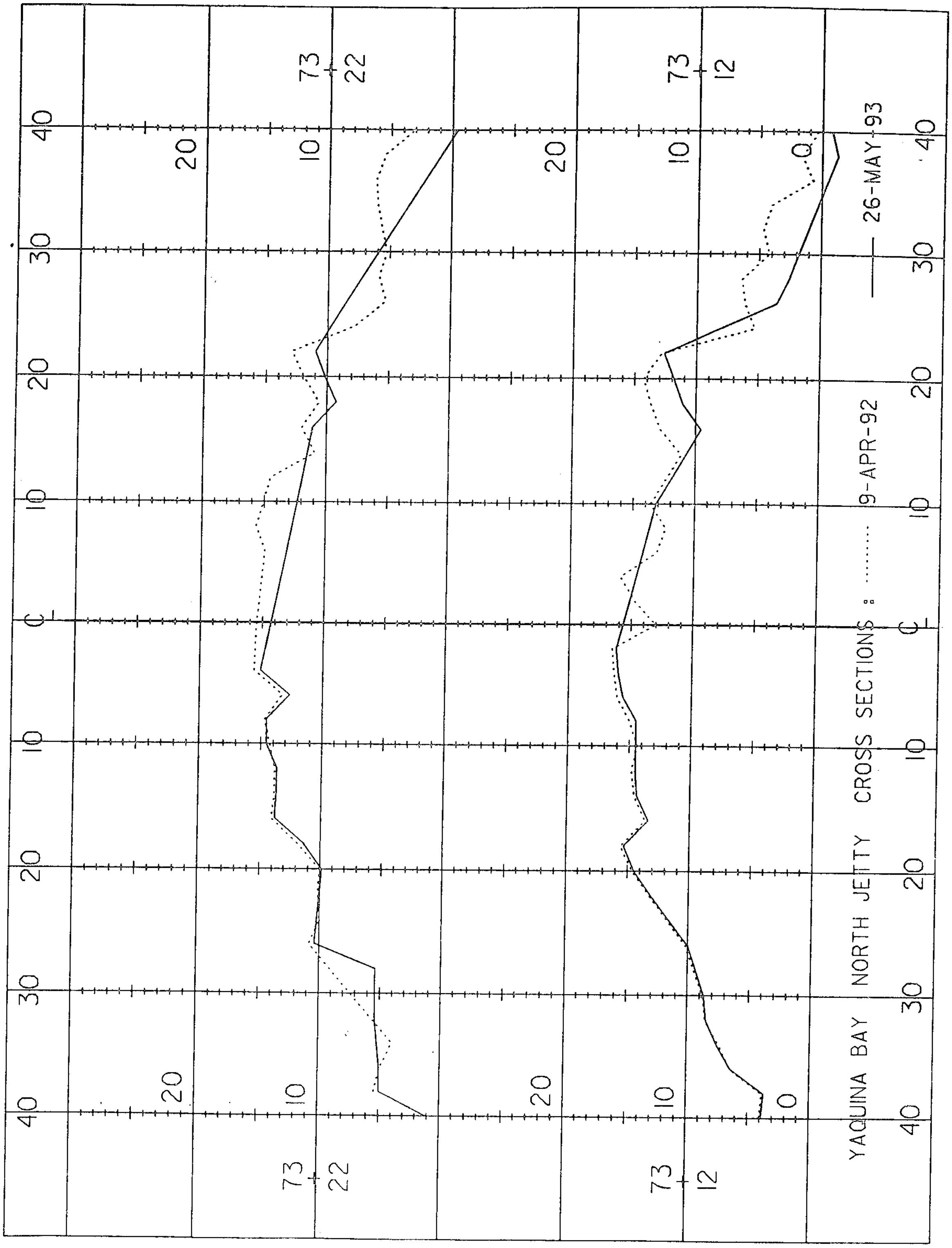
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73+12
40
30
20
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C
10
20
30
40
20
10
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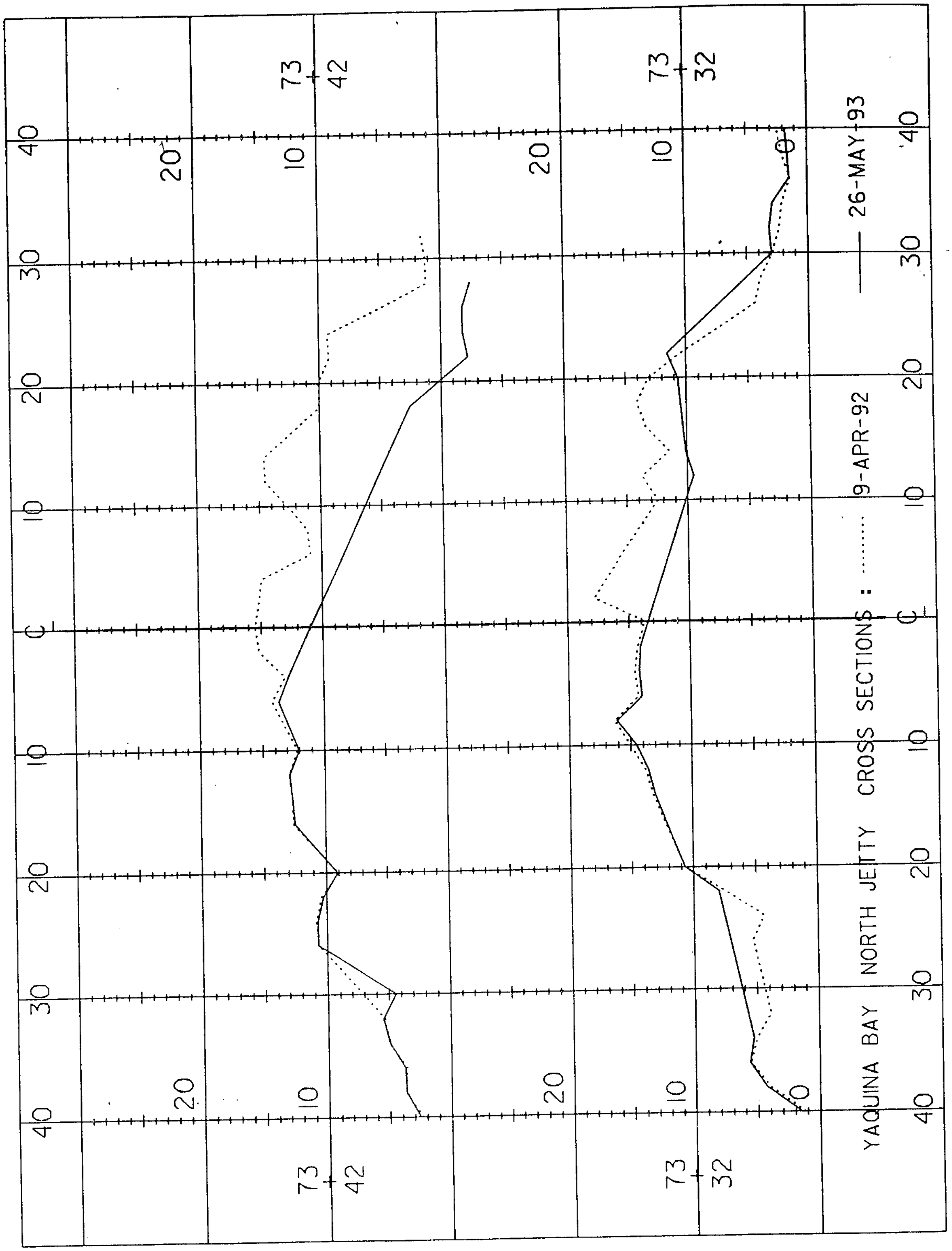
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30
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10
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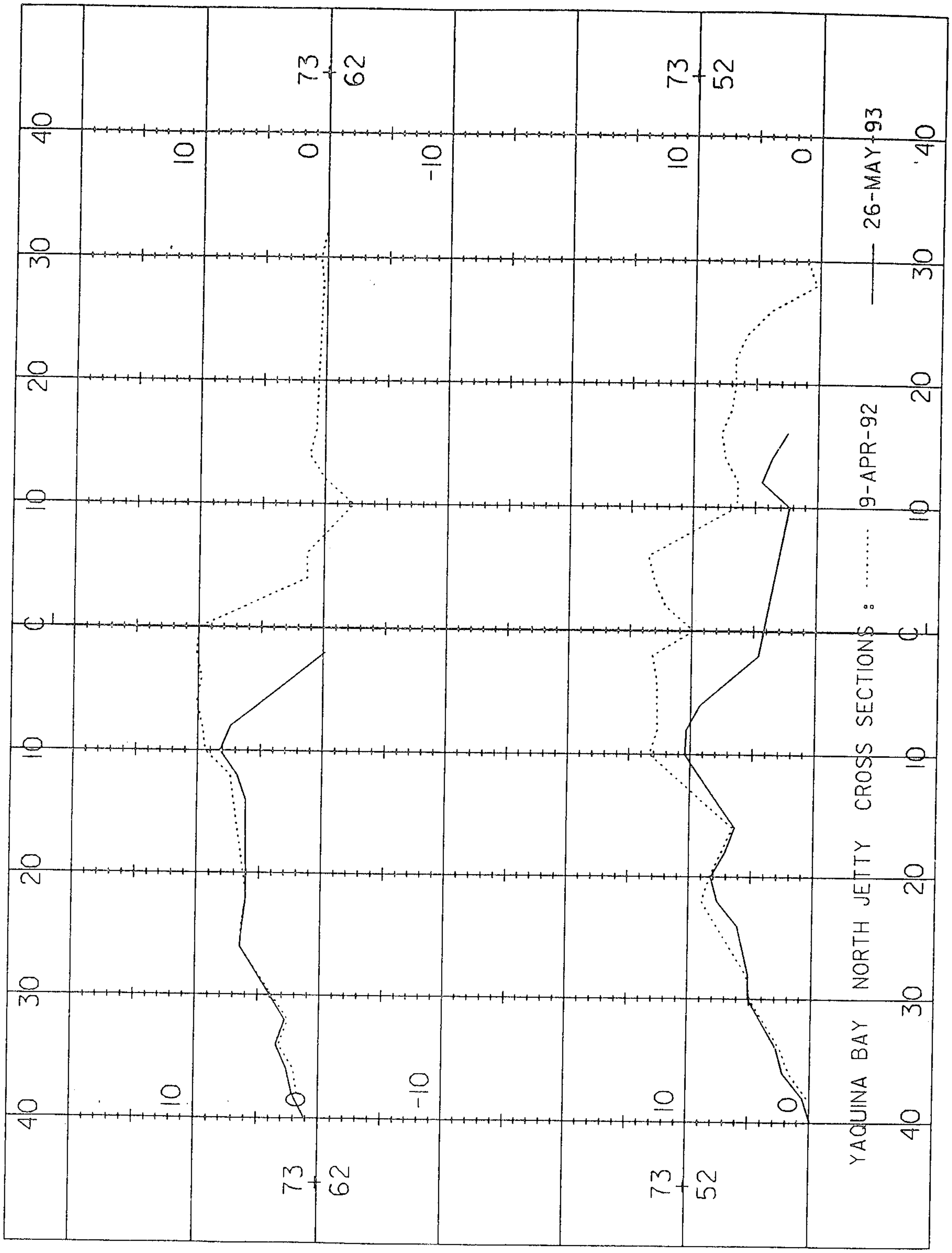
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20
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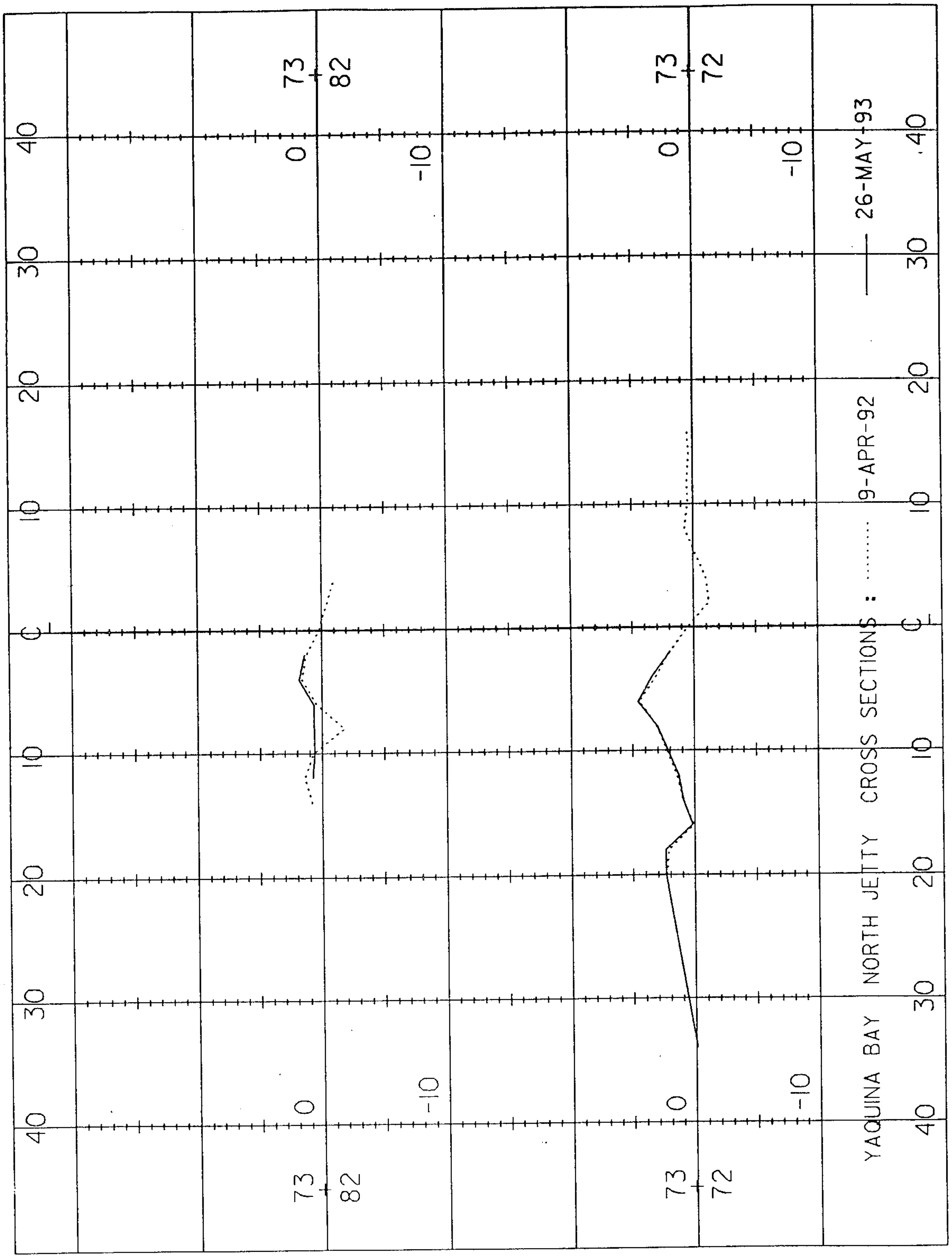
0
-10
10
0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—— 26-MAY-93
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20
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C
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20
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40
0
-10
0
-10
73+82
73+72

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The rubble-mound north jetty protecting the entrance to Yaquina Bay has experienced appreciable damage throughout its long service history. Since 1966 the north jetty has been rehabilitated twice after severe winter storm waves eroded the seawardmost 140 m (460 ft) of the jetty head. After the most recent rehabilitation in 1988 a 6-year jetty monitoring effort was initiated under the Corps of Engineers' *Monitoring of Completed Coastal Projects* Program.

Principal purposes of the monitoring were to determine the likely cause for chronic damage to the Yaquina Bay north jetty, to improve monitoring methods for similar hostile environments, and to gain understanding of failure mechanisms associated with rubble-mound structures.

Yaquina Bay north jetty monitoring considered of the following monitoring elements:

- Compilation of a thorough historical review of the Yaquina Bay entrance system.
- Periodic fixed-wing and helicopter aerial photography and photogrammetric analyses.

(Continued)

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- Visual and side-scan sonar inspection of the north jetty.
- Current velocity profiling and multibeam sonar scanning of the underwater portion of the north jetty and its intersection with the Yaqina Reef.
- Collection of offshore and nearshore wave measurements.
- Comprehensive bathymetric survey.
- Geophysical investigation of the bottom and subbottom geologic composition.
- Physical modeling efforts to evaluate various damage hypotheses.
- Establishment of a digital database at the Portland District office.
- Periodic workshops where Corps personnel and outside experts evaluated interim monitoring results and suggested viable damage hypotheses.

Results and conclusions from each of these monitoring activities are provided in this report, along with descriptions of the methodologies utilized.

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