WAVE HEIGHT MEASUREMENTS AT THE RACCOON ISLAND BREAK WATERS DEMONSTRATION (TE-29) PROJECT: REPORT ON JULY 1998 FIELD DEPLOYMENT

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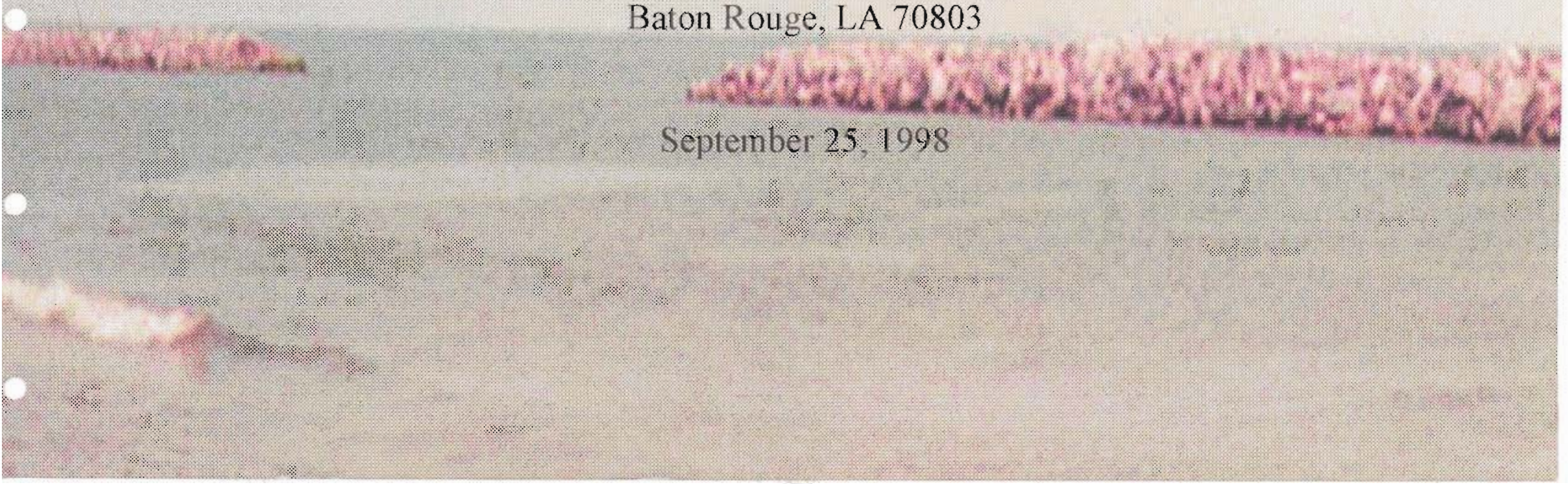

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INTRODUCTION

In May 1997, scientists in the Coastal Studies Institute at Louisiana State University, were contracted by the Louisiana Department of Natural Resources/Coastal Restoration Division, to monitor wave conditions at the Raccoon Island Breakwaters Demonstration Project (TE-29) funded under the Coastal Wetlands Planning, Protection and Restoration Act (see Figure 1 for location). This is the third of a series of reports in which the experimental design, field deployment, and information in the form of wave statistics and spectra are presented and interpreted along with bathymetric and topographic surveys of the site. Previous deployments are discussed in Stone et al. (1997, 1998). Comparisons with results obtained from the first and second deployments in October 1997 and March 1998, respectively, are also discussed.

The third wave measurement experiment at Raccoon Island was conducted on July 31st, 1998. Beach profile surveys occupying the same transects established in October 1997 and March 1998 were conducted along with the wave measurements. An additional beach survey was conducted in November 1997 due to rapid morphological adjustment to the breakwaters. Results from the November 1997 survey are also summarized in this report.

The objective of the study is to monitor and quantify the impact of the segmented breakwaters on the nearshore wave field and morphology. This report includes an explanation of the instrumentation and sampling scheme, a description of the sampling locations based on field observations, and a discussion of the breakwaters' influence on the wave field and nearshore morphology. An initial assessment of the breakwaters' performance during the first ten months after construction is provided based on three wave measurement experiments and four sets of beach surveys.

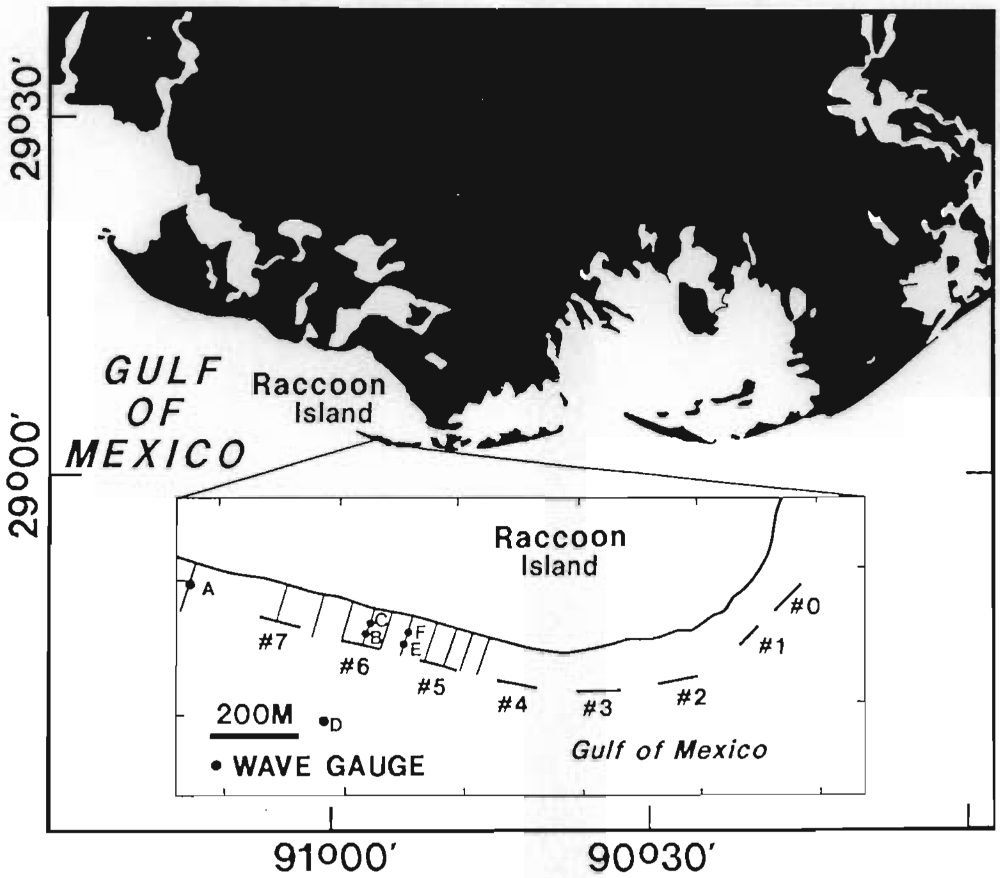

Figure 1. Study area, showing the locations of wave gages and survey lines.

INSTRUMENTATION AND SAMPLING SCHEMES

Wave height and period were measured with precise, Paroscientific digital quartz pressure transducers. One of the four pressure transducers malfunctioned at the beginning of the sampling during the July 1998 deployment. The pressure transducers, which record the instantaneous fluctuation of water level, are capable of 0.01% accuracy and 0.0001% resolution. For conditions at the Raccoon Island breakwaters site, the accuracy of the instrument is expected to be well within 5 mm (0.2 in). The pressure transducers were assembled by CSI personnel in a self-contained, solid-state recording package, suitable for underwater deployment. An example of the laboratory test of the pressure sensor array is shown in Plate 1. The instrument packages are capable of sampling at a high frequency of 4 Hz.

Plate 1. The pressure transducer array used in the Raccoon Island breakwater study. The pressure sensors and solid-state recorders are housed in a water-tight casing and are being tested in the Coastal Studies Institute's Wave Simulation Facility.

After a series of on-site experiments, an optimal sampling scheme was determined, which allowed maximum temporal coverage and efficient data processing. Two thousand and forty-eight (2048) readings (one burst of approximately 8.5 minutes) were recorded every 10 min at 4 Hz. The 4-Hz sampling allows reliable measurement of high-frequency wave components with periods as low as 1 second. The 8.5-minute burst, which is sufficient in duration to include 70 to 150 waves of 3- to 7-second periods, yields reliable data for statistical analysis of wave spectra and was deemed appropriate for the objectives of this study. The locations of the deployments are shown in Figure 1, and include those sites landward and seaward of the breakwaters, and the control site to the west. The latter provides information on the unprotected location.

The nearshore morphology was surveyed using the standard level and transit procedure utilizing a Topcon electronic total station. For the surveying range at the breakwater project, the accuracy of the instrument is expected to be within 10 mm (0.4 in.) in the horizontal and 5 mm (0.2 in.) in the vertical. Eleven survey lines spanning the three westernmost breakwaters were surveyed (Figure 1). A beach profile at the control site was surveyed to represent a no-structure scenario and allow some indication of potential changes to the profile due to the breakwater construction. Additional beach profiles covering the entire breakwater site were surveyed in November 1997. At the eastern portion of the project location, the exposure of vegetation at the shoreline and a muddy bottom between the shoreline and the breakwaters created some technical difficulties in conducting accurate surveys. Thus, morphological analyses concentrate on the western, sand-dominated portion. The profile locations of the project are shown in Figure 1. Temporary benchmarks were established using 1.5-m (5-ft) long PVC pipes. Beach posts and pipes protruding from the crown of the breakwaters were used as elevation controls. A temporary elevation, measured relative to an estimated zero water level during the October 1997 survey, was used but will be tied to the NGVD datum at a later date. The density of survey points along profile lines is a direct function of the topographic/bathymetric complexity. Significant breaks in slope associated with morphological/bathymetric features were recorded during each survey. The profile surveys start landward at the edge of the vegetation, and end seaward at the crown of the breakwater, or at the same relative locations for the survey lines in the gaps between breakwaters.

The bathymetric and topographic surveys were conducted to determine trends associated with sedimentation/erosion induced by the segmented breakwaters. The topographic survey and nearshore morphological analysis was not part of the contract with LADNR. However, this undertaking is viewed here as being critical to a more profound comprehension of the impacts of the breakwaters on coastal processes and sediment transport at the monitoring sites. The topographic surveys were conducted during each wave monitoring event on a quarterly basis. Nearshore morphological changes will be analyzed by comparing pre- and post-construction surveys (provided by LADNR), and each of the quarterly surveys. As discussed in the following sections, this additional undertaking of morphological monitoring has proven to be important and the results from which have significant implications for shoreline protection along Louisiana's coast.

WAVE MEASUREMENTS

The third wave measurement was conducted on July 31st, 1998 during a mild southerly wind condition. The incident wave conditions were observed to be quite different during the July 1998 measurements when compared to the October 1997 and March 1998 measurements. During the October 1997 and March 1998 measurements, choppy sea states, driven largely by local winds, were encountered. During the July 1998 measurements, long period swell waves dominated. Wave heights were observed to be generally lower than 0.3 m (1 ft) approaching perpendicular to the shoreline.

One of the four wave gages malfunctioned at the start of the measurement. The control wave gage A (Figure 1) stopped recording unexpectedly at the beginning of the deployment. The malfunction happened during the installation, and thus, the control gage failed to collect wave data. Wave gage B was deployed approximately 50 m (150 ft) landward of the center of breakwater #6 (Figure 1). Wave gages A and B were deployed at the same distance of approximately 40 m (120 ft) seaward of the shoreline. The average water depth at the inside location (B) was approximately 0.20 m (0.7 ft), considerably shallower than the 0.5 m at the control site. Wave gage C (Figure 1) which was used in the March 1998 measurement was judged unnecessary during the July 1998 measurement, mainly because of the extremely shallow water landward of the breakwaters. The shallow water landward of the breakwaters resulted from the significant amount of sand accumulation, discussed in the following sections, and a low tidal phase. Proper deployment of the present wave gages requires a minimum water depth of 0.2 m (0.7 ft). Wave gage D, measuring offshore wave conditions, was deployed approximately 200 m (600 ft) seaward of the center of breakwater #6. The average water depth at the offshore location was approximately 1.6 m (5.2 ft). The wave gage at site B was moved to the gap (site E) between breakwaters #6 and #5 (Figure 1). Deployment at site F, landward of the gap between the breakwaters, was not possible due to shallow water conditions. The water depth at site E was similar to that at site B.

The control wave gage A (malfunctioned during the July 1998 measurements) and the offshore gage (D) remained at the same location throughout the entire experiment.

Measurements at site B landward of the center of the breakwaters were conducted in the early afternoon. Measurements at site E landward of the breakwater gap were conducted in late afternoon. Comparisons between wave conditions in the protected (landward of the center of the breakwater), unprotected (malfunctioned during the July 1998 measurements), and offshore sites are based on simultaneous measurements. While comparisons between wave conditions in the protected sites and the gaps are influenced by the slight time difference, this influence is assessed by the continuous measurement at the control and offshore sites. During the July 1998 measurement, this difference had no influence on wave comparisons as discussed in the following sections.

DATA ANALYSES

One of the major objectives of this monitoring project is to quantify the influence of the breakwaters on incident wave conditions. This was accomplished by comparing wave conditions measured behind the breakwaters with the conditions at the control site, the latter being devoid of the influence of the breakwaters. Comparisons between wave conditions landward of the breakwater and those in the gap also provide direct information on the breakwaters' influences on waves in the immediate vicinity of the tips of the structures. This information is critical in establishing or refining the optimal segment length and spacing width ratio.

The raw data record of water level fluctuations is a composite of waves of different frequency (Appendix 1). In order to examine the energy contributions of each frequency and to obtain a statistical representation of the wave characteristics, a spectral analysis is necessary. The spectral analysis of the raw data was based on the "Field Wave Gaging

Program, Wave Data Analysis Standard," recommended by the Coastal Engineering Research Center (see Earle et al., 1995 for a detailed review).

Significant wave height was calculated based on CERC's recommended procedure

$$H_{mo} = 4.0\sqrt{m_o} \qquad \textbf{Eq. 1}$$

where the zero moment, m_o, is computed as

$$m_o = \sum_{n=1}^{N_b} C_{zz}(f_n)df_n \qquad \textbf{Eq. 2}$$

where $C_{zz}(f_n)$ is the power spectrum density of the *nth* frequency f_n, and df_n is the bandwidth. The peak period T_p is given by

$$T_p = \frac{1}{f_p} \qquad \textbf{Eq. 3}$$

where f_p, the peak frequency, is the frequency for which spectral wave energy density is a maximum. The power spectrum densities were calculated using the Welch method of the fast Fourier transformation (Welch, 1967).

Beach profile analyses, including shoreline-position comparisons and volume change calculations, were conducted using the software BMAP (Beach Morphology Analysis Package). BMAP was developed and verified in the Coastal Engineering Research Center for various beach profile analyses.

RESULTS

The high-frequency recordings allow a close examination of wave properties including significant wave height, peak wave period, and wave-energy distribution with respect to frequencies. Compared to conditions during the October 1997 and March 1998 experiments, significant morphological changes have occurred during the July 1998 measurements. The morphological changes are discussed quantitatively in the following sections. A brief summary is provided here for the convenience of discussing wave conditions. A large sand body emerged both landward and seaward of the breakwaters, spanning breakwaters #6, #5, #4, and partly #3 (Plate 2). The emerged sand body has filled the gaps between the above mentioned breakwater segments. The water body landward of the breakwaters became much shallower than at the beginning of the project. The water depth decreased beyond the minimum depth requirement (0.2 m) for the deployment of the instrumentation. The morphological conditions have changed significantly during the last four months between March 1998 and July 1998 surveys. These morphological changes have significantly altered the function of the structures. Results from the July 1998 wave measurements are not directly comparable with the results from previous measurements due to the dramatic morphological changes. More specifically, the breakwaters have been connected which thereby prevented the structures from direct contact with Gulf waves. Despite the significant differences, a similar format to those used in the previous reports is used in the present report for the convenience of time-series comparison.

Wave Diffraction and Breaking

Wave diffraction around the tips of the breakwaters and wave breaking were almost completely absent during the July 1998 measurements due to the emerged sand body in the vicinity of the breakwaters. This contrasted significantly with the field conditions encountered during the October 1997 and March 1998 measurements. Incident wave propagation from the Gulf was negligible along the Raccoon Island shoreline during the

July 1998 measurements. Little to no wave activity was observed landward of breakwaters #6, #5, #4, and #3.

Plate 2. The breakwaters #6, #5, #4, and #3 were surrounded by an emerged sand body and the structures were not directly exposed to wave action. Photograph looking east, July 31, 1998.

Hydrodynamic conditions landward of the breakwaters and at the Raccoon Island shoreline have changed substantially due to the emergence of the sand body in the gaps between breakwaters. Waves during fairweather conditions were entirely dissipated by the emerged sand body adjacent to the breakwaters. Wave breaking was not observed at the shoreline landward of the breakwaters (Plate 3).

Plate 3. Photograph showing negligible wave action landward of breakwaters #6 and #5 and at the adjacent Raccoon Island shoreline. Note the shallow water and emergence of part of the wave gage. Photograph looking northeast, July 31, 1998.

Significant Wave Heights

During the two previous wave measurements conducted on October 1997 and March 1998, a considerable wave-height reduction of more than 70%, was measured during both normally (October, 1997) and obliquely (March, 1998) incident wave conditions when compared to the unprotected site. A greater percentage of wave-height reduction landward of the center of the breakwaters was measured during normally incident waves. This is directly attributable to the influence of the breakwaters. In the gap between the breakwaters, wave heights were virtually unchanged when compared to the unprotected site during normally incident wave conditions. A substantial wave-height reduction of 50% was measured, however, during obliquely incident waves.

Substantially modified morphological conditions were encountered during the July 1998 measurements, and waves from the Gulf were completely dissipated by the emerged sand body surrounding the breakwaters. There were no differences between wave conditions landward of the center of the breakwaters and landward of the gap between the breakwaters (Plate 3). Due to the extremely shallow water landward of the breakwaters, technical difficulties were encountered during the installation of the instruments. Water depths were significantly different at the inside and gap sites when compared with the depth at the control site. Thus, comparisons of wave conditions among the protected and unprotected sites can only be conducted based on visual observations. The following discussion on wave conditions in the vicinity of the breakwaters is based on both measurements and field observations.

It is noteworthy that in contrast to conditions encountered during the October 1997 and March 1998 measurements, waves landward of the breakwaters during the July 1998 measurements were locally wind generated as opposed to having propagated across the shelf. Due to low wind speeds encountered during the July 1998 measurements, practically no waves were observed landward of the breakwaters (Plate 3), landward of the center and the gaps.

Significant wave heights measured at the offshore site ranged from 0.19 m (0.62 ft) to 0.26 m (0.85 ft) with an average of 0.21 m (0.69 ft) (Figure 2). Wave conditions remained reasonably constant throughout the day (Figure 3). Similar wave heights were observed visually at the control site. Landward of the breakwaters, the average water depth was less than 25 cm (0.82 ft) throughout the period of measurements in July 1998, and the water body was almost entirely isolated from the Gulf (Plate 4). The wave measurement landward of the breakwaters is believed to be less accurate than those from the offshore measurements and from the previous measurements due to 1) technical difficulties in gage installation caused by the very shallow water, 2) extremely low magnitude of the signal and low signal-to-noise ratio, and 3) very high frequency wind ripples. Visual observations indicated a ripple height of less than 3 cm landward of the breakwaters. Results from the October 1997 and March 1998 measurements are also included in Figure 2 for comparison. It is worth emphasizing that the difference between landward of the center of the breakwater and landward of the gap did not exist during the July 1998 measurements, and wave heights were reduced by nearly 100% landward of the breakwaters. No sediment transport was observed landward of the breakwaters and at the Raccoon Island shoreline.

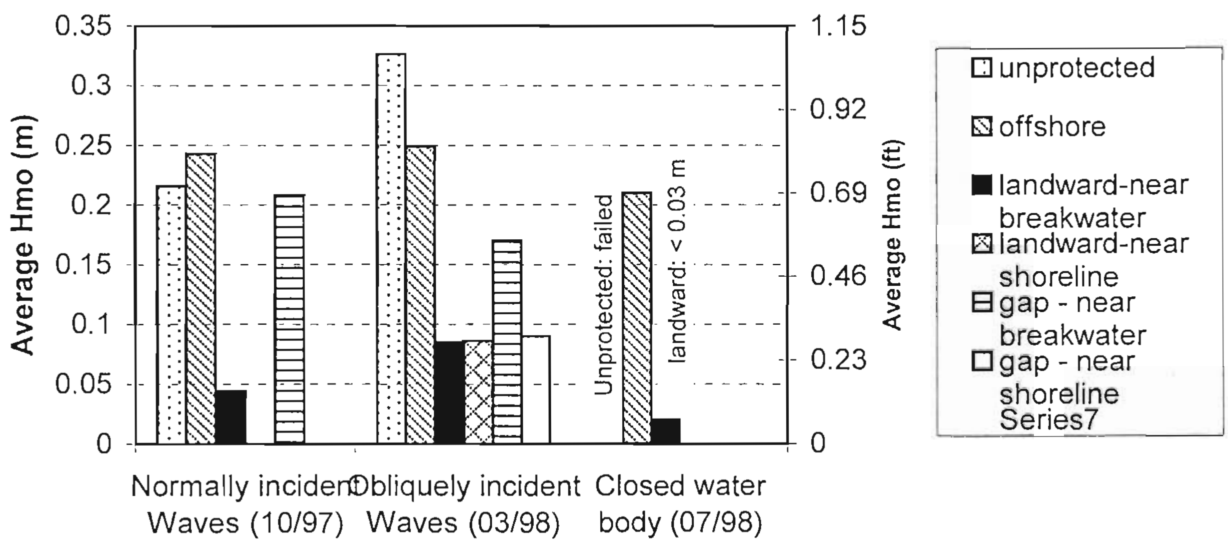

Figure 2. Comparison of significant wave heights at different locations for October 1997, March 1998, and July 1998 deployments.

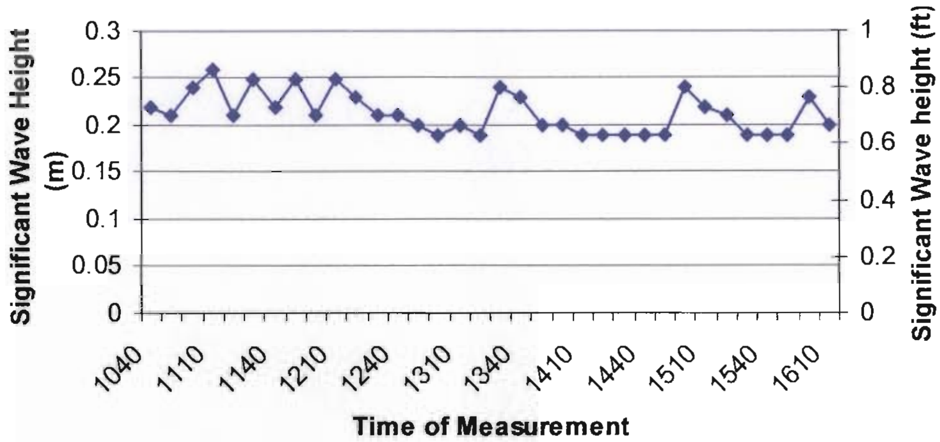

Figure 3. Time series of significant wave heights measured at the offshore site.

Plate 4. Photograph showing emerged sand body extending from breakwater #6 through #3 resulting in an enclosed shallow water body landward of the breakwaters. Photograph looking east, July 31, 1998.

Peak Wave Period and Wave Spectra

Peak wave period, also referred to as dominant wave period or period of maximum wave energy, is defined as the wave period corresponding to the center frequency of the frequency band with the maximum non-directional spectral density. It is generally accepted that permeable rubble-mound breakwaters, such as those at the study site, function somewhat similar to a low-pass filter in that they reduce higher frequency waves more effectively than their lower frequency counterparts (SPM, 1984). This low-pass effect was apparent during the normally incident wave conditions encountered in October 1997 (Figure 4). The average peak wave period measured landward of the center of the breakwaters was considerably longer than those at other sites, especially that at the unprotected site. Differences in peak wave period were minimal during the oblique incident wave conditions (Figures 4 and 5) encountered during the March 1998 measurements.

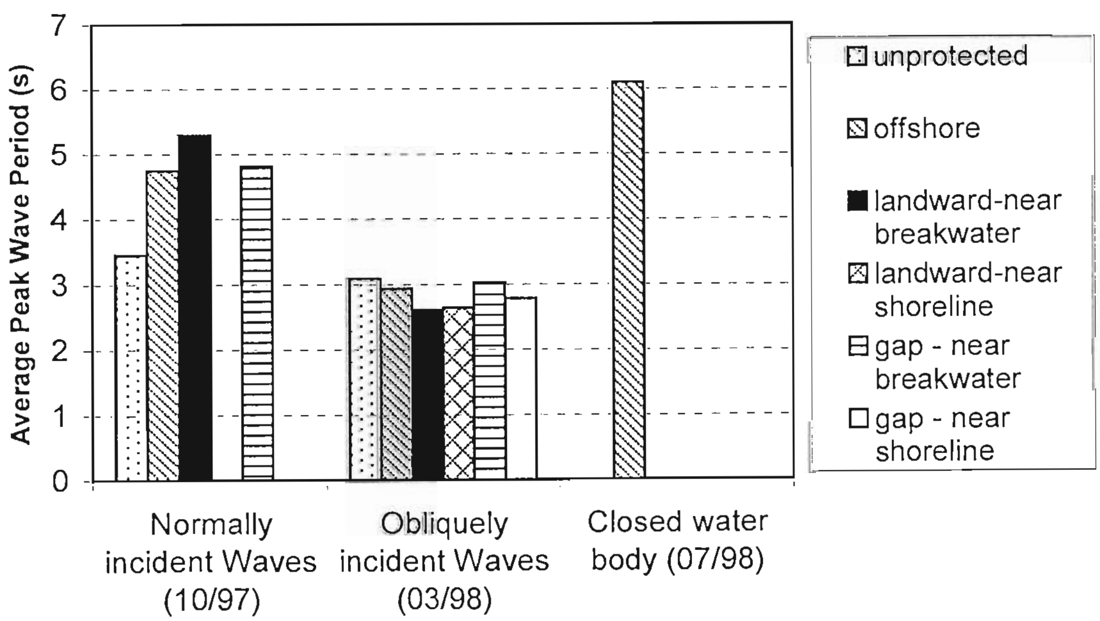

Figure 4. Comparison of peak wave periods at different locations.

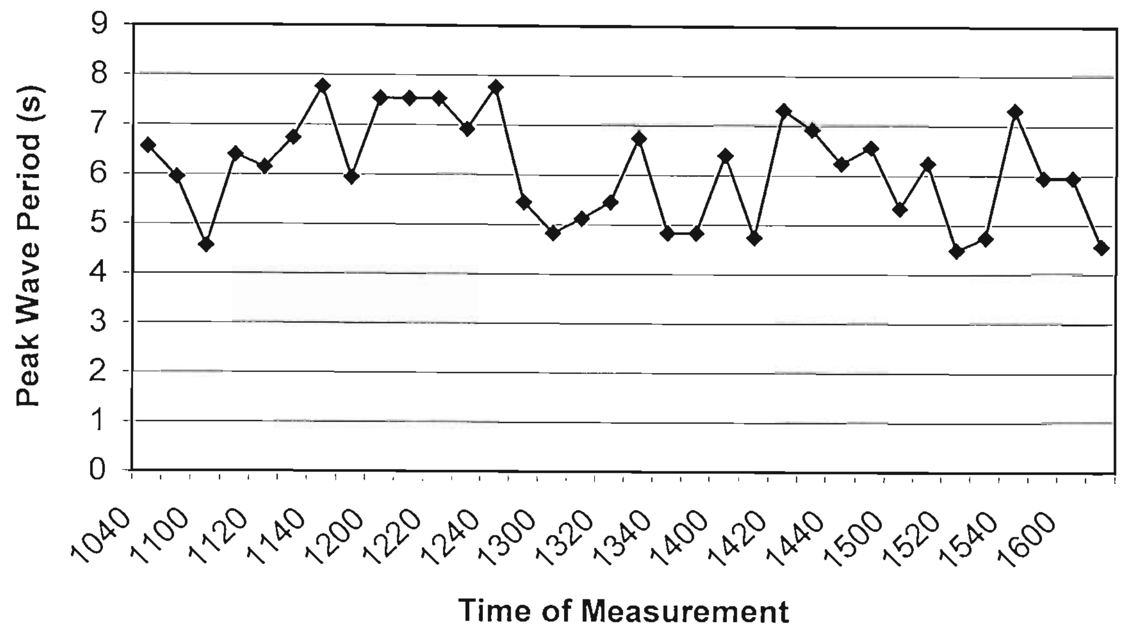

Figure 5. Measured peak wave period during July 1998. Note the relatively long period averaging 6 s indicating swell-dominated conditions.

During the July 1998 measurement, the offshore wave periods were much longer than those encountered during the previous two measurements, indicating swell-dominated conditions as opposed to wind-sea dominated conditions. Peak wave period cannot be determined reliably from the landward gage due to the shallow water and low signal strength as discussed earlier. Visual observations indicated that the ripples landward of the breakwaters were locally generated.

The results from the wave spectral analysis are summarized in Appendix 2. The wave spectra illustrate the distribution of wave energy with respect to each frequency component. The peaks in the wave spectra indicate that the waves of the specific frequencies carry more energy than other frequencies. Several distinct features were observed from the March 1998 measurements:

1. The magnitudes of the power spectral density obtained at the landward locations are very low and their distribution patterns do not reflect the characteristics of water waves. The irregular distribution patterns are believed to be caused by the low signal strength and low signal-to-noise ratio.
2. Almost all the wave energy was distributed between 0.1 to 1.0 Hz, or 1.0 to 10 seconds. Contributions from wave components with periods longer than 10 s or shorter than 1.0 s were not significant during the period of measurement.
3. Compared to the October 1997 and March 1998 measurements, more wave energy was distributed in lower frequency components, indicating a swell-dominated situation instead of the locally wind-generated wave conditions encountered during the previous measurements.

Shoreline Morphology and Nearshore Bathymetry

As discussed in the previous reports (Stone et al., 1997, 1998), the presence of the segmented breakwaters has induced a significant change in nearshore morphology. As an immediate and mostly expected response, development of beach cusps or salients was observed along Raccoon Island shortly after the construction of the breakwaters. A zero water depth estimated during the first beach profile survey in October, 1997 was used here as a temporary indicator of shoreline position. All the elevations will be tied to NGVD at a later date. Both field observation and quantitative data obtained from beach-profile surveys indicate that the shoreline adjustment in the form of salient development seemed to have reached a quasi-equilibrium condition (Figure 6) landward of most of the segments after November 1997. No significant further adjustment in the vicinity of the shoreline was observed or measured between October 1997 and March 1998 (Stone et al., 1998). Slight shoreline retreat was measured in March 1998, as compared to October 1997. More retreat was measured between the gap of the breakwaters (2 to 3 m) than that landward of the center of the breakwaters (approximately 1m) from the March 1998 beach profile survey, although the overall change in the vicinity of the shoreline was small (Stone et al., 1998).

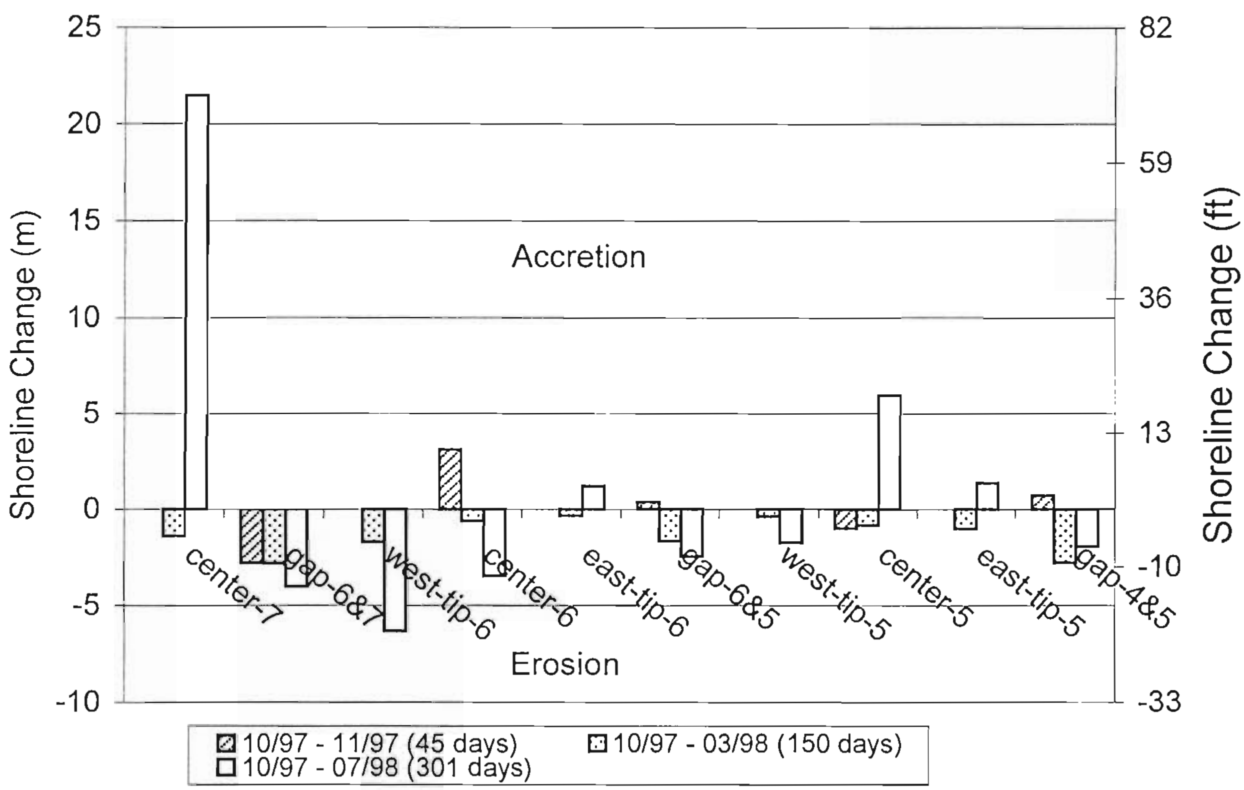

Figure 6. Shoreline change during October 1997 to November 1997, October 1997 to March 1998, and October 1997 to July 1998, respectively. Note the overall small magnitude of change, when compared to the amount of sand that had been accumulating across the entire profile (Figure 7). Transects across the tips of the breakwaters were not surveyed in November 1997.

A considerably different shoreline change pattern was measured from the July 1998 survey (Figure 6). The most dramatic change at the shoreline is the approximate 22 m

(72 ft) gain landward of the center of breakwater #7. Sand accumulation at breakwater #7 is apparently related to the impoundment of longshore sediment transport. In addition, the closure of the gaps between adjacent breakwaters may be increasing the trapping efficiency at the westernmost structure by further reducing the amount of wave energy arriving at the downdrift shoreline (during westerly wind and/or incident waves propagating from the west). The shoreline landward of the gap between breakwaters #7 and #6, and landward of breakwater #6 experienced 3 m (10 ft) to 6 m (20 ft) of shoreline retreat during the 301 days between October 1997 to July 1998. Except for a near 6 m (20 ft) shoreline gain measured landward of the center of breakwater #5, shoreline changes at all the other locations were small. Similar to the findings from the March 1998 survey, the overall changes in the vicinity of the shoreline were of much lower magnitude when compared to the changes across the entire profile and in the vicinity of the breakwaters.

Substantial sand accumulation (Figure 7) was measured directly landward of the breakwaters with a large body of sand having aggraded to a height of approximately 0.3 m above an estimated zero water level during the March 1998 survey (Stone et al., 1998). Considerable sand accumulation (Figure 7) was also measured in the gap between the breakwater segments when the October 1997 and the March 1998 surveys were compared (Stone et al, 1998).

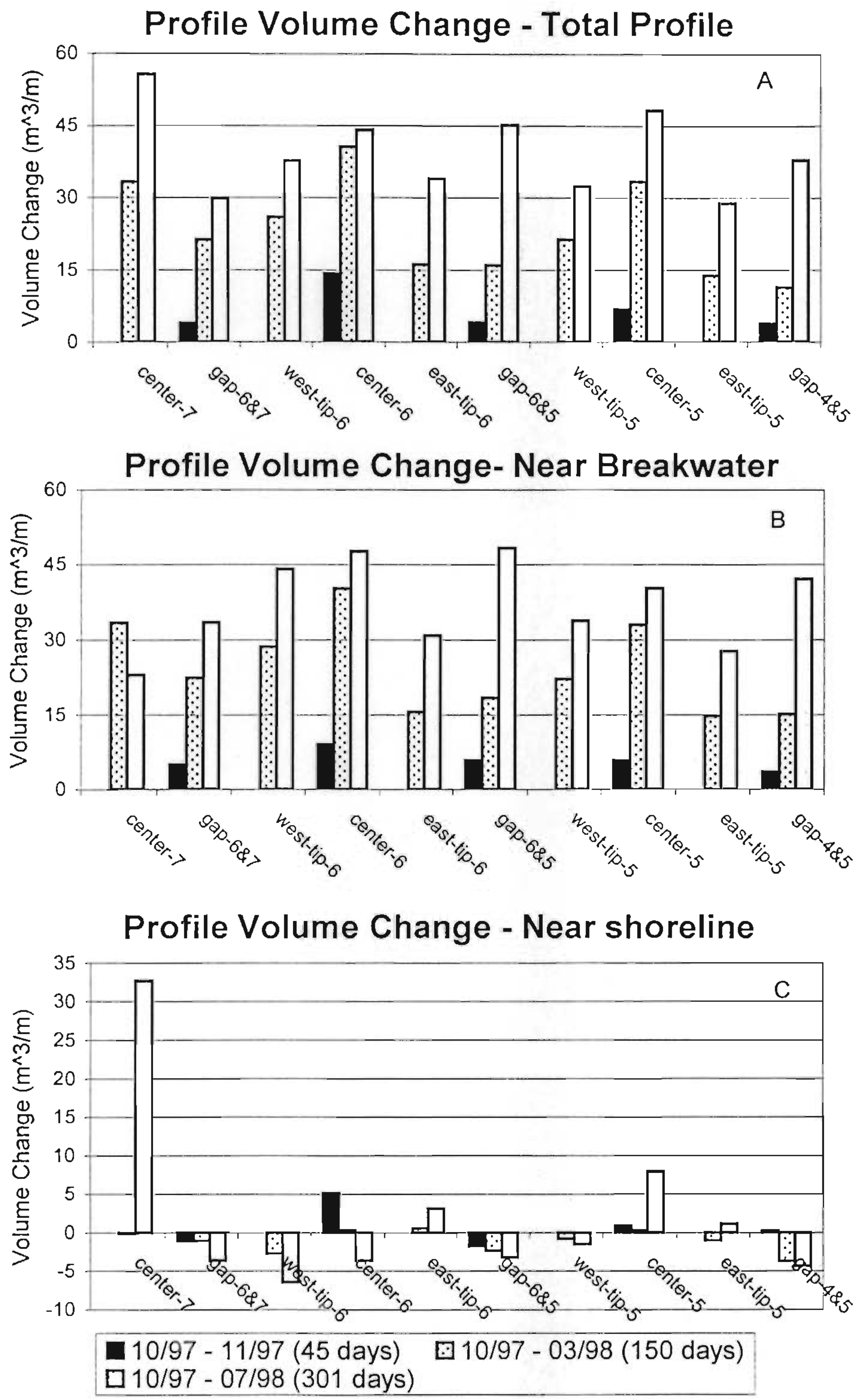

Figure 7. Beach-profile volume changes from the vegetation line to the breakwaters (A). Changes landward adjacent to the breakwaters, from bottom of trough to the end of the profiles (B). Changes in the vicinity of the shoreline, from the vegetation line to the trough bottom (C). Positive indicates volume gain and negative volume loss.

Results from the July 1998 survey show that the trend of sand accumulation in the vicinity of the breakwaters has continued between March 1998 and July 1998 (Figure 7). The continued sand accumulation in the vicinity of the breakwaters, which is apparently related to the presence of the breakwaters, has significantly changed the impact of the breakwaters on the nearshore wave field. Beach profiles at the control site, devoid of the influence of the breakwaters, did not show the pattern of sand accumulation measured in the region influenced by the breakwaters (Figure 8). The gaps between breakwaters, #6 and #5, #5 and #4, and #4 and #3 have been experiencing net deposition, forming a long, emerged sand bar approximately 50 m from the present Raccoon Island shoreline (Plate 4). A large amount of sand has also accumulated seaward of the breakwaters, forming an up to a 20 m (60 ft) wide sandy beach seaward of the breakwaters during the low-tide condition (Plate 5). Breakwaters #6, #5, #4, and #3 were surrounded by the emerged sand body and were not directly exposed to the Gulf waves during the July 1998 survey. Our present survey, as a compliment to the wave measurements, did not extend seaward of the breakwaters.

Sand accumulations on the beach profiles between the vegetation line and the breakwaters were measured during the 10-month period between the beginning of October, 1997 to the end of July, 1998. Deposition varied from 30 m^3/m typically landward of the tips of the breakwaters to nearly 60 m^3/m landward of the center of breakwater #7 (Figure 7). Patterns of sand accumulation appear to follow the trend evident from the March 1998 survey (Stone et al, 1998). Except at the westernmost breakwater (#7), most of the sand accumulation occurred in the immediate leeward vicinity of the breakwaters (Figure 7). The magnitude of deposition or erosion in the vicinity of the shoreline is much smaller than that in the vicinity of the breakwater, except at breakwater #7.

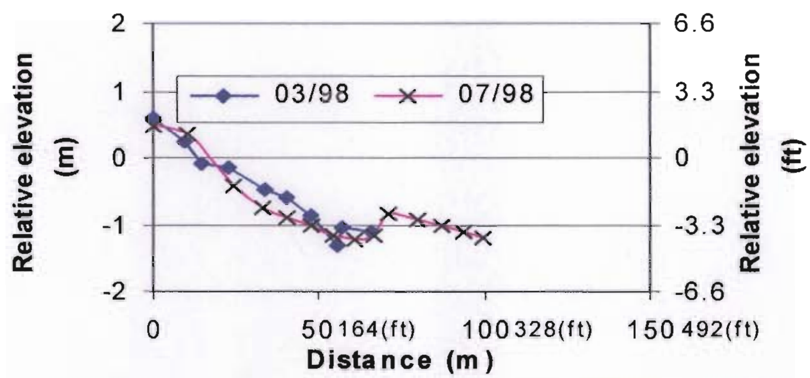

Figure 8. Beach profiles at the control site for March and July 1998 surveys.

Plate 5. Sand accumulation seaward of the breakwaters, July 31, 1998. Photograph was taken looking east.

Between March 1998 and July 1998, most sand accumulation occurred in the gaps between the breakwater segments, resulting in an expansive emerged sand body. A large amount of sand accumulation was measured in the vicinity of the shoreline landward of the center of breakwater #7, resulting in salient growth (Plate 6). Slight shoreline retreat and volume loss were measured immediately east of the salient, i.e., landward of breakwater #6. Approximately 29 and 26 m^3/m sand accumulation were measured between the gaps of breakwaters #6 and #5 and breakwater #5 and #4, respectively. It is worthy of note that this amount of accumulation was measured between the center of the breakwater relative to the vegetation line. Since a significant amount of sand has accumulated seaward of the breakwaters, the actual amount of sand accumulation in the nearshore system is significantly greater (Plates 2 and 4).

Plate 6. Development of a salient landward of the westernmost breakwater (#7), July 31, 1998.

Results from the March 1998 survey indicated that the maximum accumulation occurred landward of the center of the breakwaters and decreased toward the gaps. Results from the July 1998 survey, on the other hand, indicate that the sand accumulation has shifted to the gaps between the breakwater segments (Figures 7 and 9). An elevation change of up to 1 m (3 ft) was measured in the gap between the breakwaters, especially between #6 and #5 and between #5 and #4 (Figure 9). It is likely that as the significant sand accumulation occurred in the gaps, the sand supply to the landward flank of the breakwaters was significantly reduced, resulting in a commensurate reduction in the rate of sand accumulation landward of the center of the structures. Wave energy landward of the breakwaters was insufficient to transport significant amounts of sediment after the gaps were closed.

Sand accumulation was concentrated directly in the immediate leeward vicinity of the breakwaters and the gaps (Appendix 3). This sand accumulation pattern has not been documented by previous studies on similar types of detached, segmented breakwaters (e.g., Toyohira, 1974; Walker et al., 1980). The implications at this juncture are that sand accumulating in the vicinity of the Raccoon Island breakwaters cannot be attributed to longshore transport only. At this stage of the study, it is reasonable to hypothesize that the presence of the breakwaters has significantly influenced the cross-shore sediment transport patterns in addition to being a longshore sediment trap as typically expected. The emergence of a sand body seaward of several of the breakwaters provides direct evidence of onshore sediment transport and shoaling (Plate 7). The development of the salient at the westernmost breakwater (#7) during March 1998 to July 1998 appears to be directly related to the impoundment of longshore sediment transport along the shoreline.

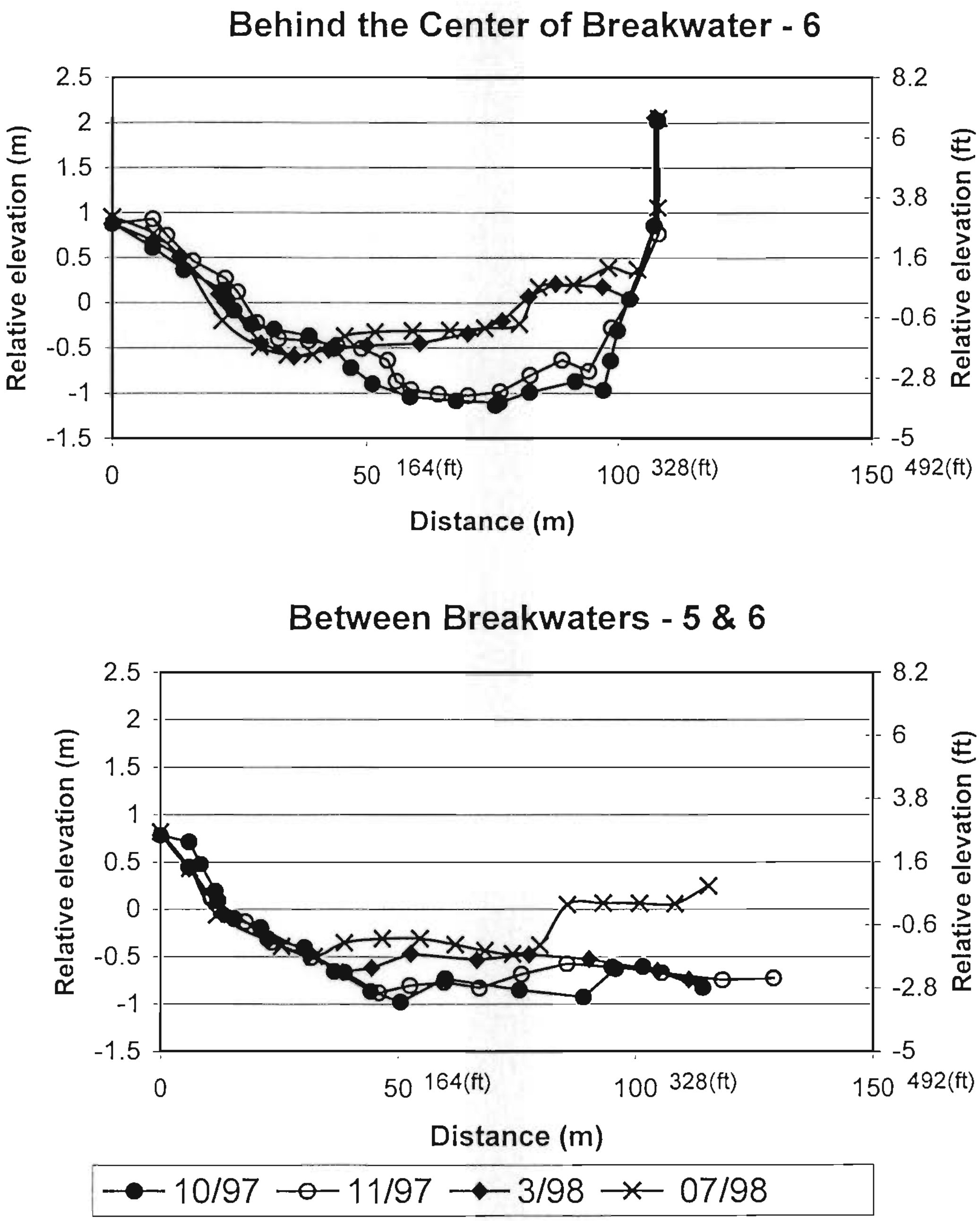

Figure 9. Examples of beach profiles across the center of the breakwaters and across the gap between segments.

Plate 7. Shoaling of an offshore sand body south of the recently deposited beach seaward of breakwater #3, July 31, 1998. Photograph taken looking to the east.

SUMMARY

The results from the October 1997, March 1998, and July 1998 deployments allow for the following summary.

The results from the first two wave measurement deployments before the gaps between breakwaters #6, #5, #4, and #3 were closed by rapid sand accumulation, indicate that the detached, segmented breakwaters functioned differently in terms of wave-height reduction during normally and obliquely incident wave approaches. During normally incident waves, wave height was 90% lower landward of the center of the breakwater than that at the unprotected site, while wave propagation through the gaps between the segments was largely unaffected. Wave diffraction around the tips of the breakwaters during the shore-perpendicular wave approaches created zones where longshore transport converged near the shoreline behind the center of the breakwaters (caused by convergent wave trains) in addition to zones of divergence behind the gaps. This wave-breaking pattern was observed to induce the development of a salient. During the oblique incident waves encountered in the March 1998 measurements, a reduction of wave height of approximately 70% was measured, when compared to the unprotected site, landward of the center of the breakwaters. This indicates a 20% reduction when compared to conditions during normally incident waves (90% wave-height reduction). Wave heights landward of the gaps between the segments were 50% lower than at the unprotected site under obliquely incident waves, while wave conditions in the gap were almost the same under normally incident waves.

The July 1998 measurements, ten months after breakwater construction, indicate that changes in the nearshore morphology have significantly altered the functioning of the breakwaters. The gaps between breakwaters #6, #5, #4, and #3 have been in filled by sand in addition to a spit growing landward from the western tip of breakwater #6. The latter has resulted in a nearly closed, shallow water body landward of these breakwaters. Results from the wave measurements in July 1998 are not directly comparable to the results from the two previous measurements due to the significant morphological changes in the vicinity of the breakwaters. The presence of the emerged sand body adjacent to the breakwaters has resulted in filtering out waves from the Gulf. Because of the presence of the emerged sand body, wave height landward of the breakwaters were reduced by nearly 100%. Results from wave measurements in July 1998 should not be compared directly with the results from March 1998 and October 1997 measurements due to the significant change in nearshore morphology.

A rapid shoreline response in the form of rhythmic salient development, was observed shortly after the construction of the breakwaters. The initial shoreline adjustment reached quasi-equilibrium approximately three months after breakwater construction. No significant further planform shoreline adjustment was measured between months three and six. Between months six and ten, shoreline position remained fairly stable except at the westernmost breakwater (#7). An apparent salient has developed resulting in a shoreline gain of more than 20 m (60 ft) landward of the center of breakwater #7. The development of the salient at breakwater #7 may be due to the impoundment of longshore sediment transport by the detached breakwaters, as generally expected for this type of structure and previously observed at many other locations. Seasonal wind and wave patterns may have contributed to the eastward trend of longshore sediment transport and the development of the salient during the summer.

A substantial amount of sand accumulation, ranging from 15 to 50 m^3/m, was measured in the immediate vicinity of the breakwater segments, as well as in the gaps between the breakwaters. A sand body has emerged both landward and seaward of the breakwaters. This large amount of sand accumulation, ranging from 30 to 60 m^3/m between the breakwater and the vegetation line on Raccoon Island, cannot be readily explained with our present understanding of the coastal processes and sediment transport in this area. Field observations during the March 1998 and July 1998 measurements indicate that the presence of the breakwater structures has apparently influenced the previous cross-shore equilibrium.

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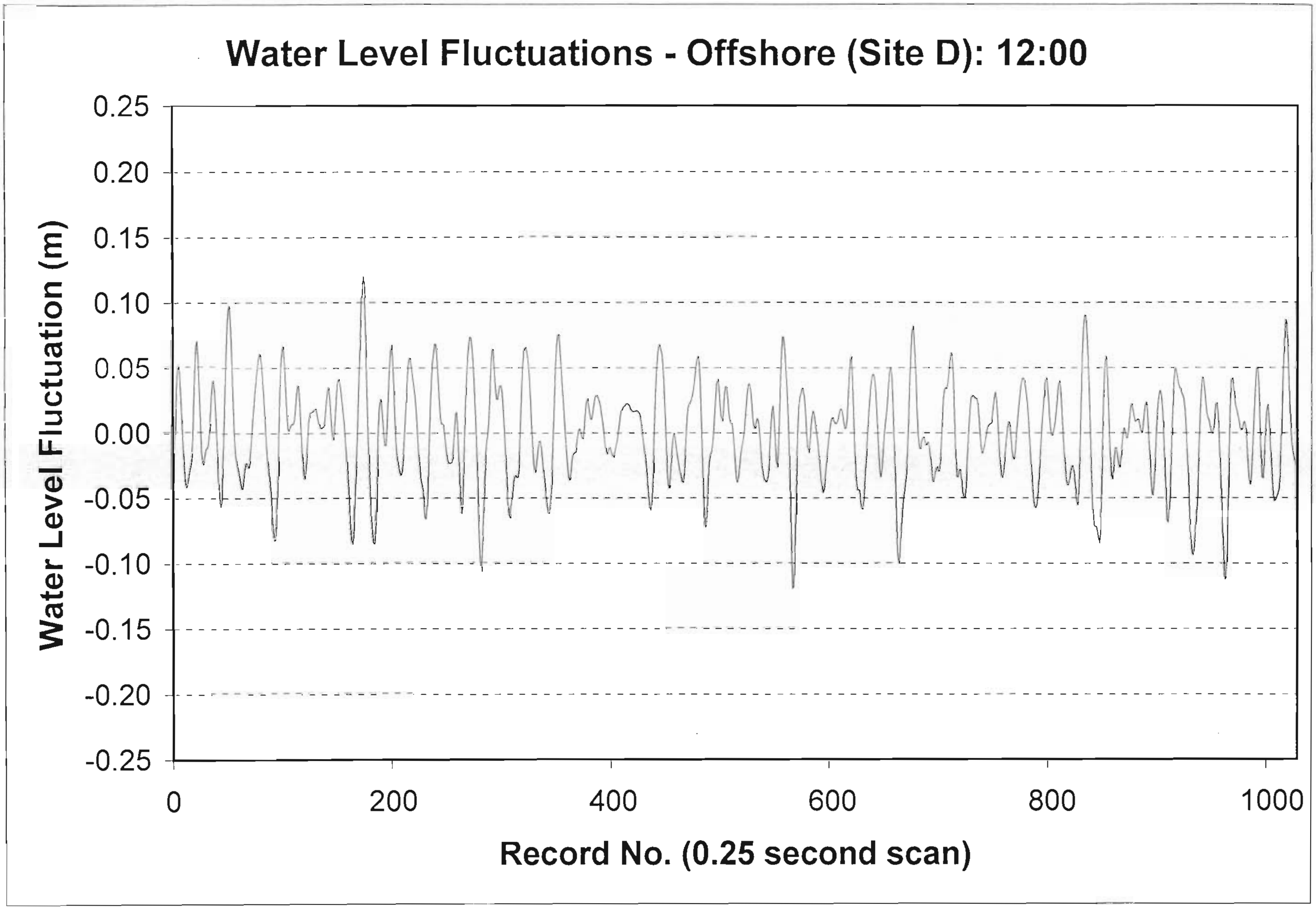
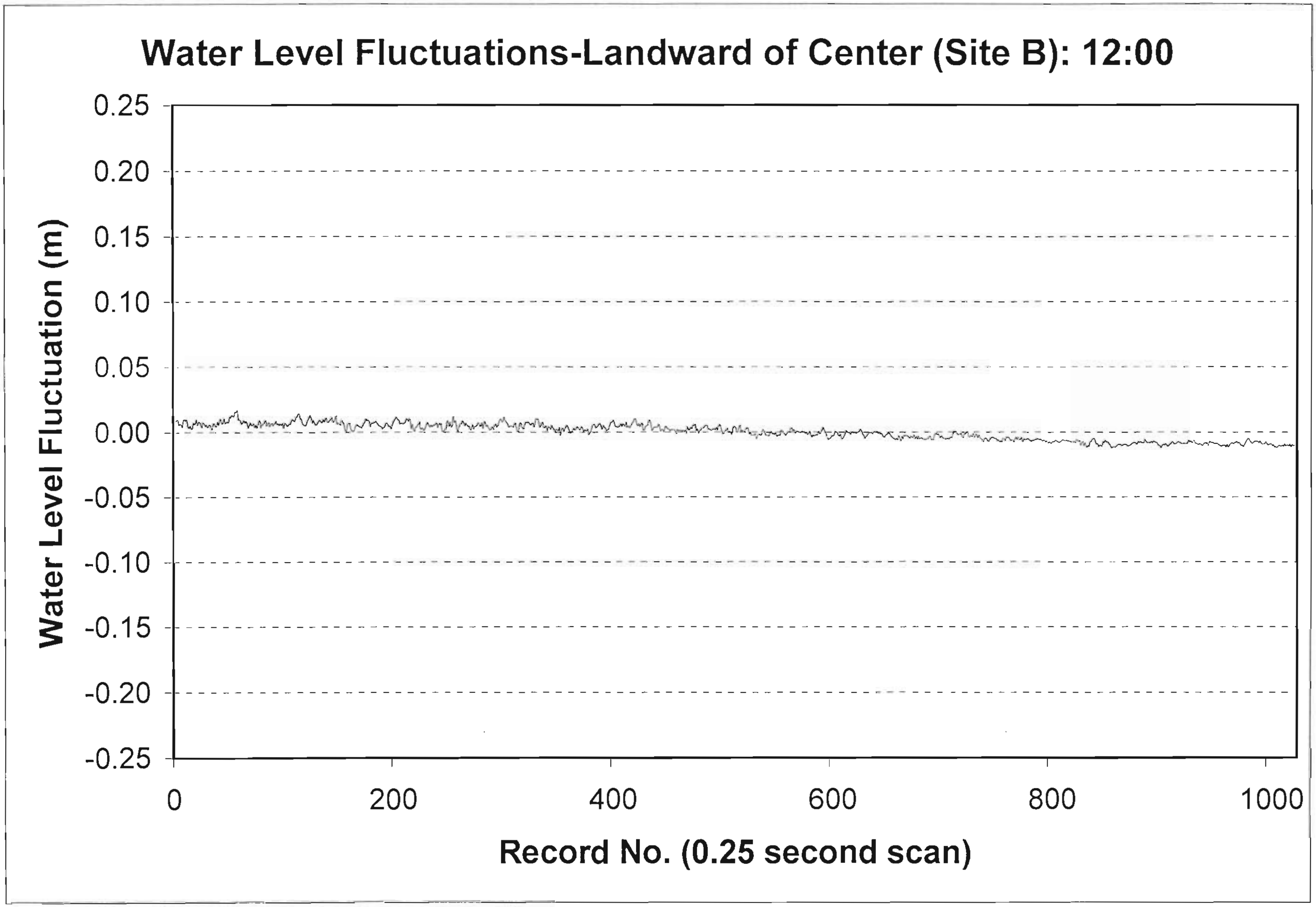
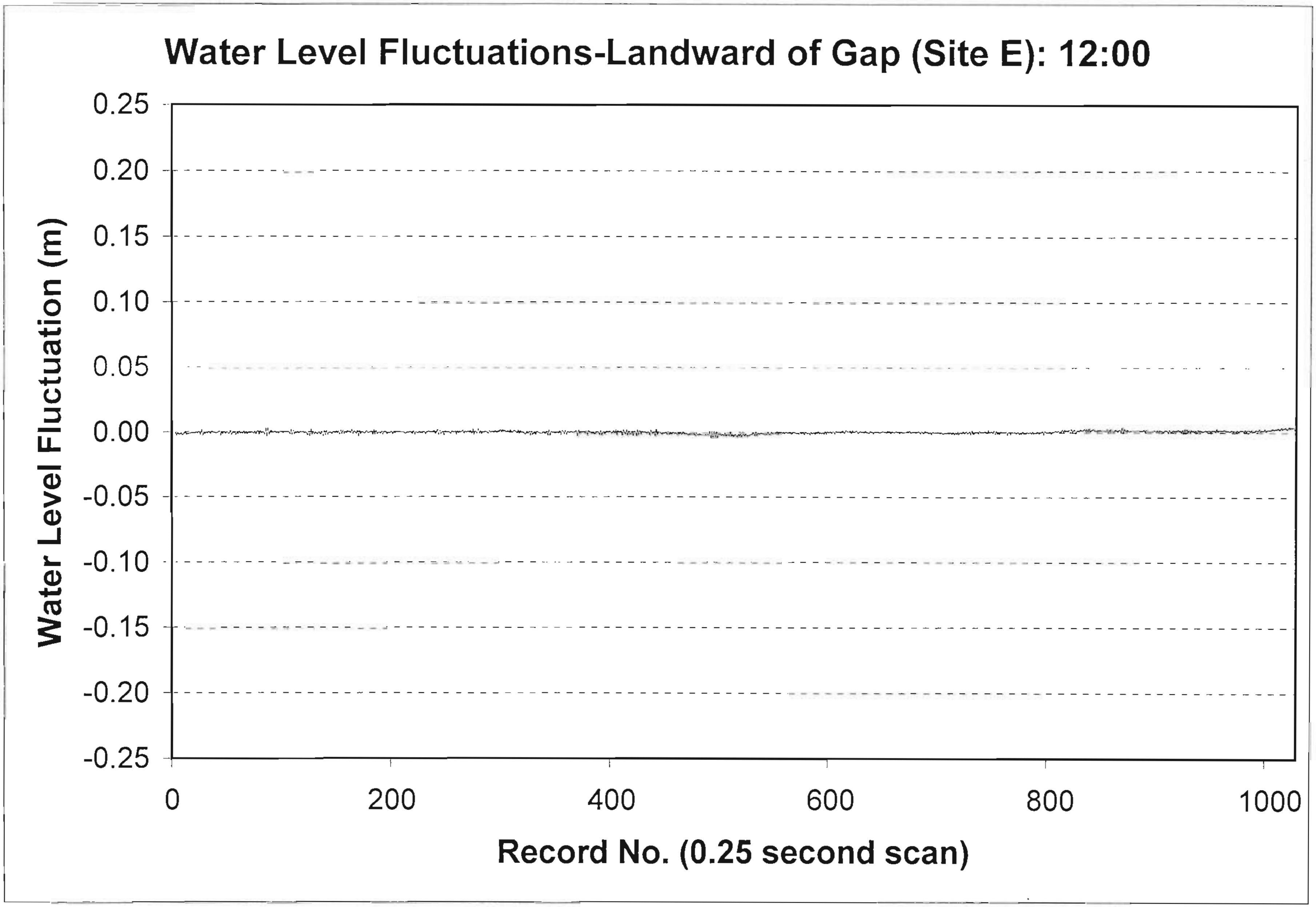
APPENDIX 1

Examples of raw water-level data at the study sites showing the complexity and presence of various waves at different frequencies.



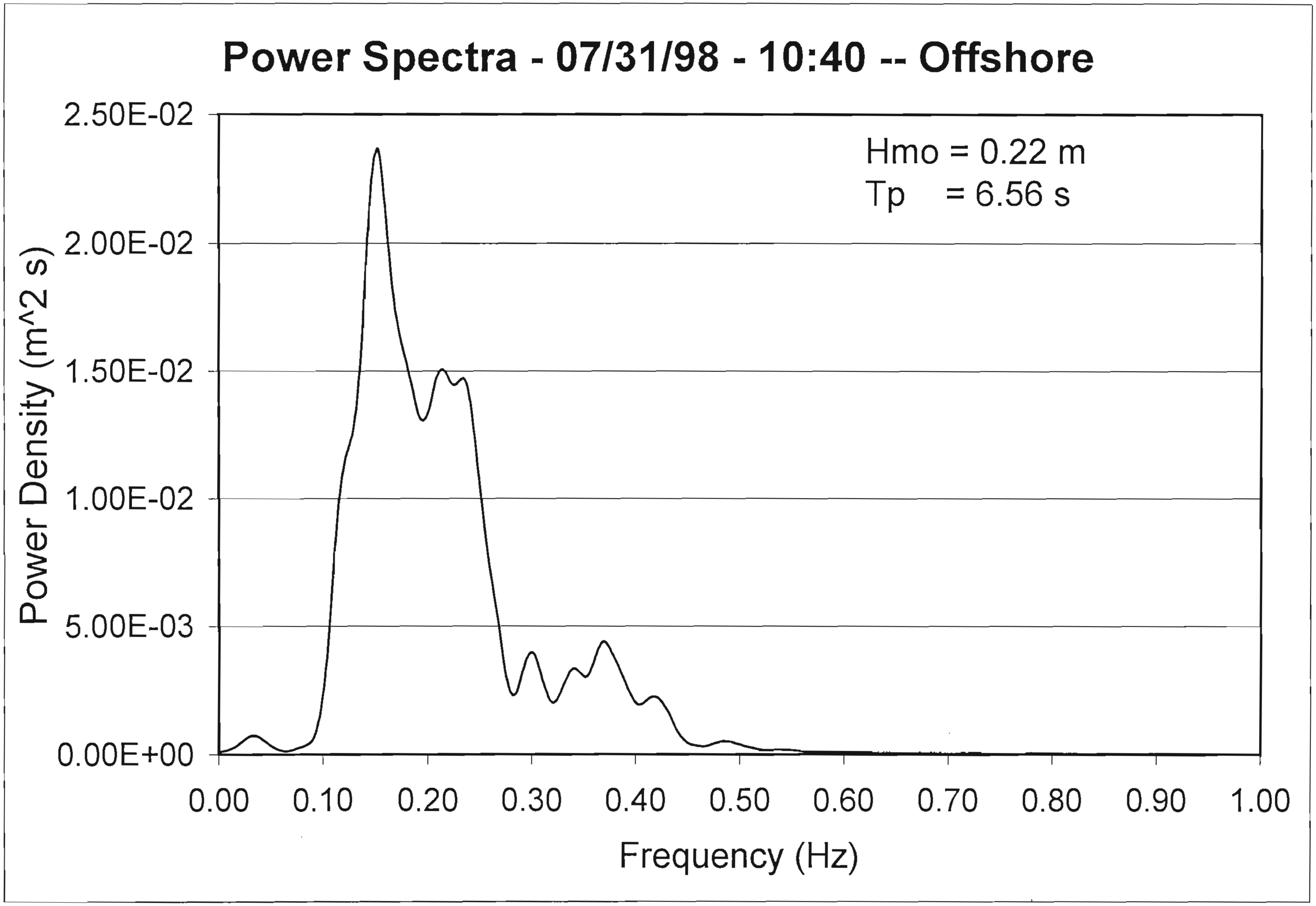
Water Level Fluctuations - Offshore (Site D): 12:00
Water Level Fluctuation (m)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
0
200
400
600
800
1000
Record No. (0.25 second scan)

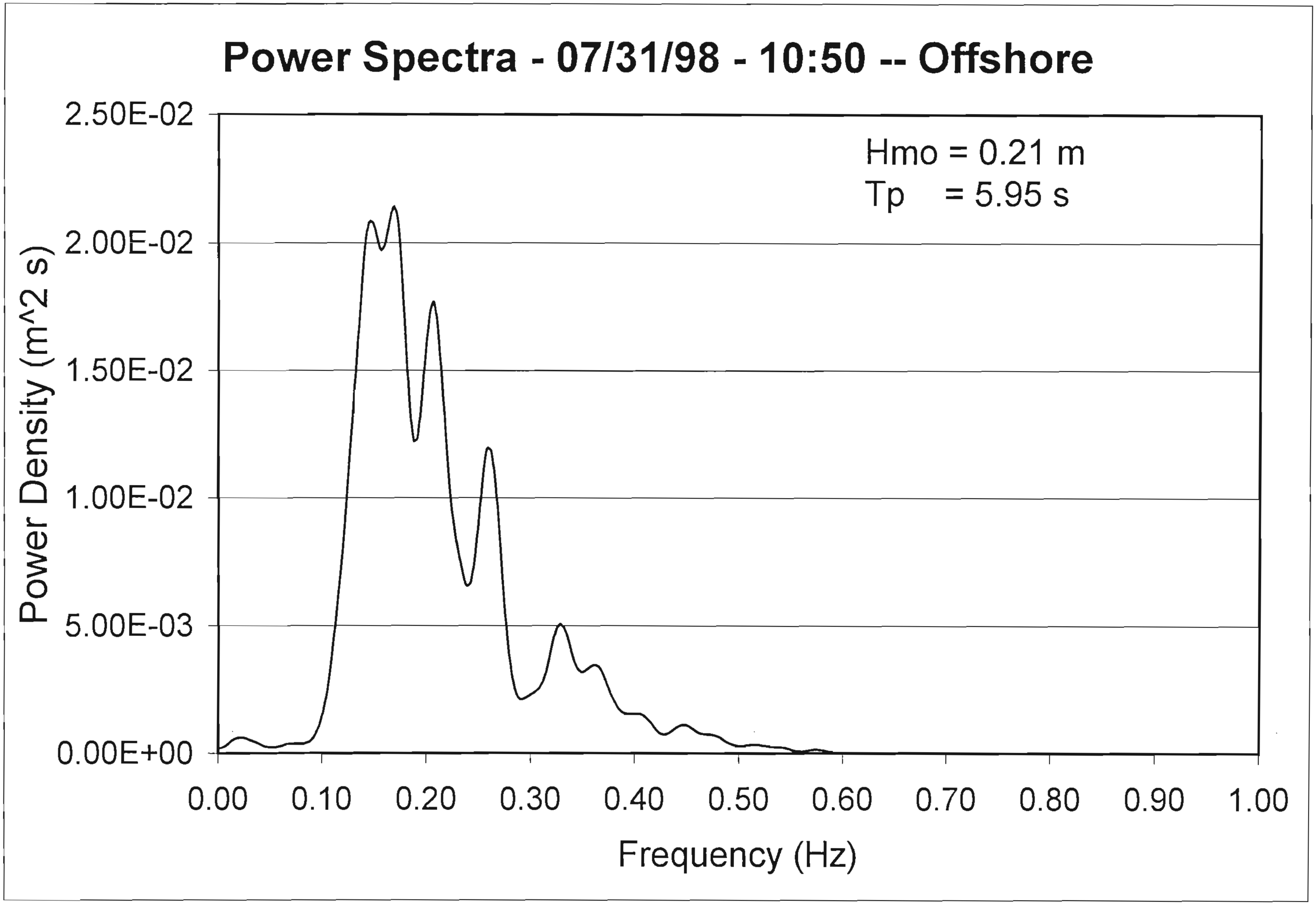

Water Level Fluctuations-Landward of Center (Site B): 12:00
Water Level Fluctuation (m)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
0
200
400
600
800
1000
Record No. (0.25 second scan)


Water Level Fluctuations-Landward of Gap (Site E): 12:00
Water Level Fluctuation (m)
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
0
200
400
600
800
1000
Record No. (0.25 second scan)

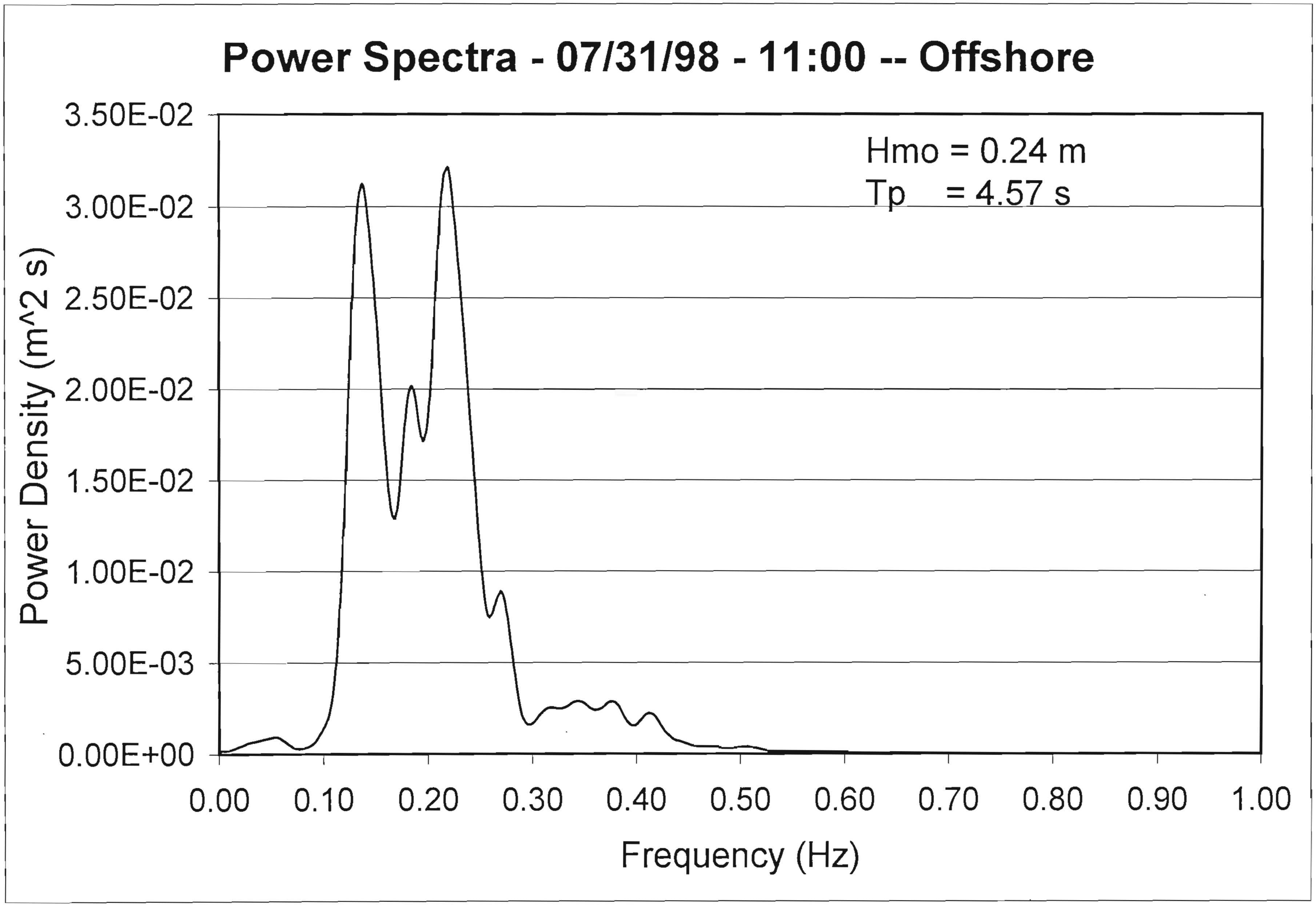
APPENDIX 2

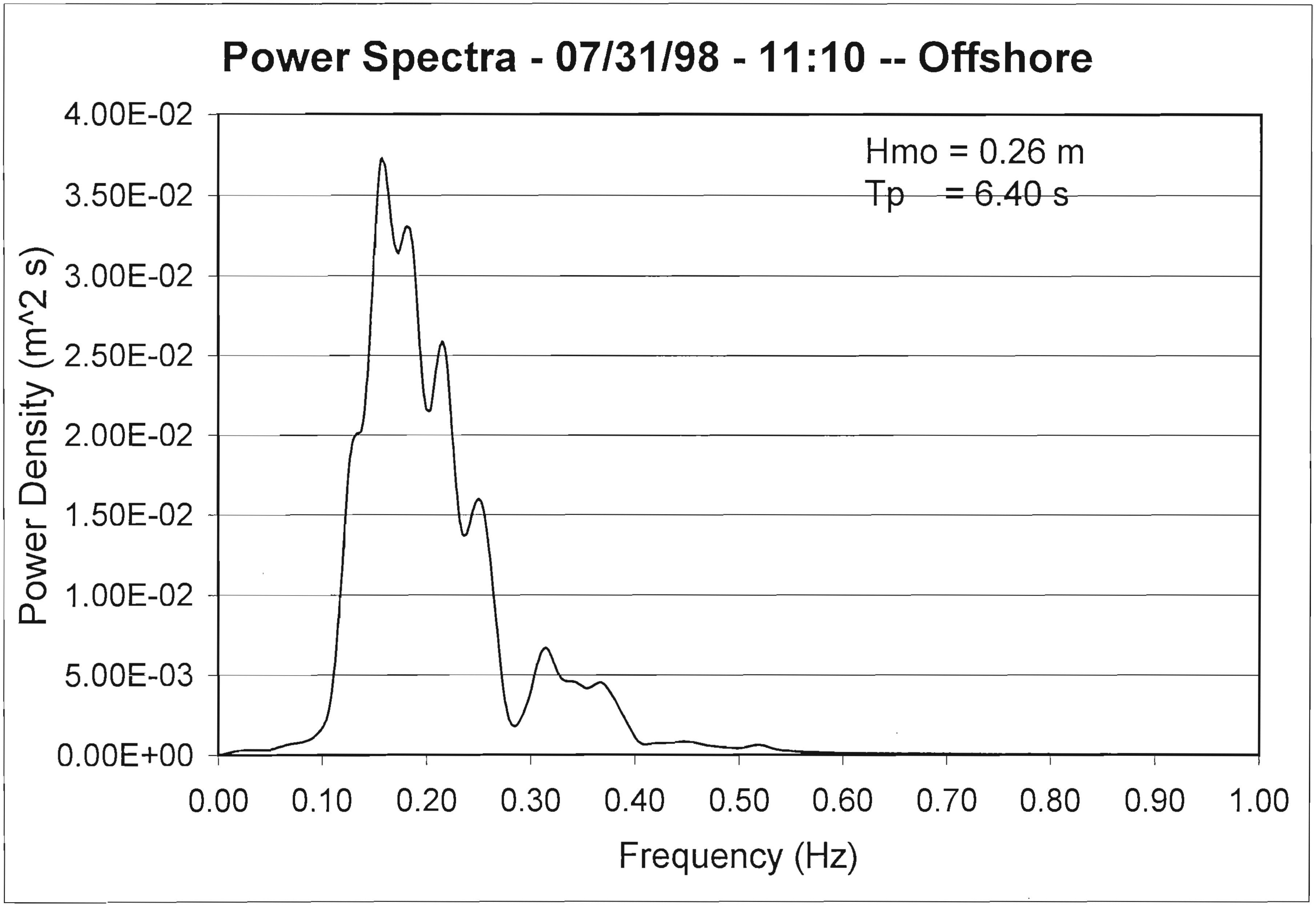
Wave spectra measured during July 1998 deployment. Spectral distributions obtained from the inside measurements were not reliable due to the very shallow water and low signal strength and low signal-to-noise ratio

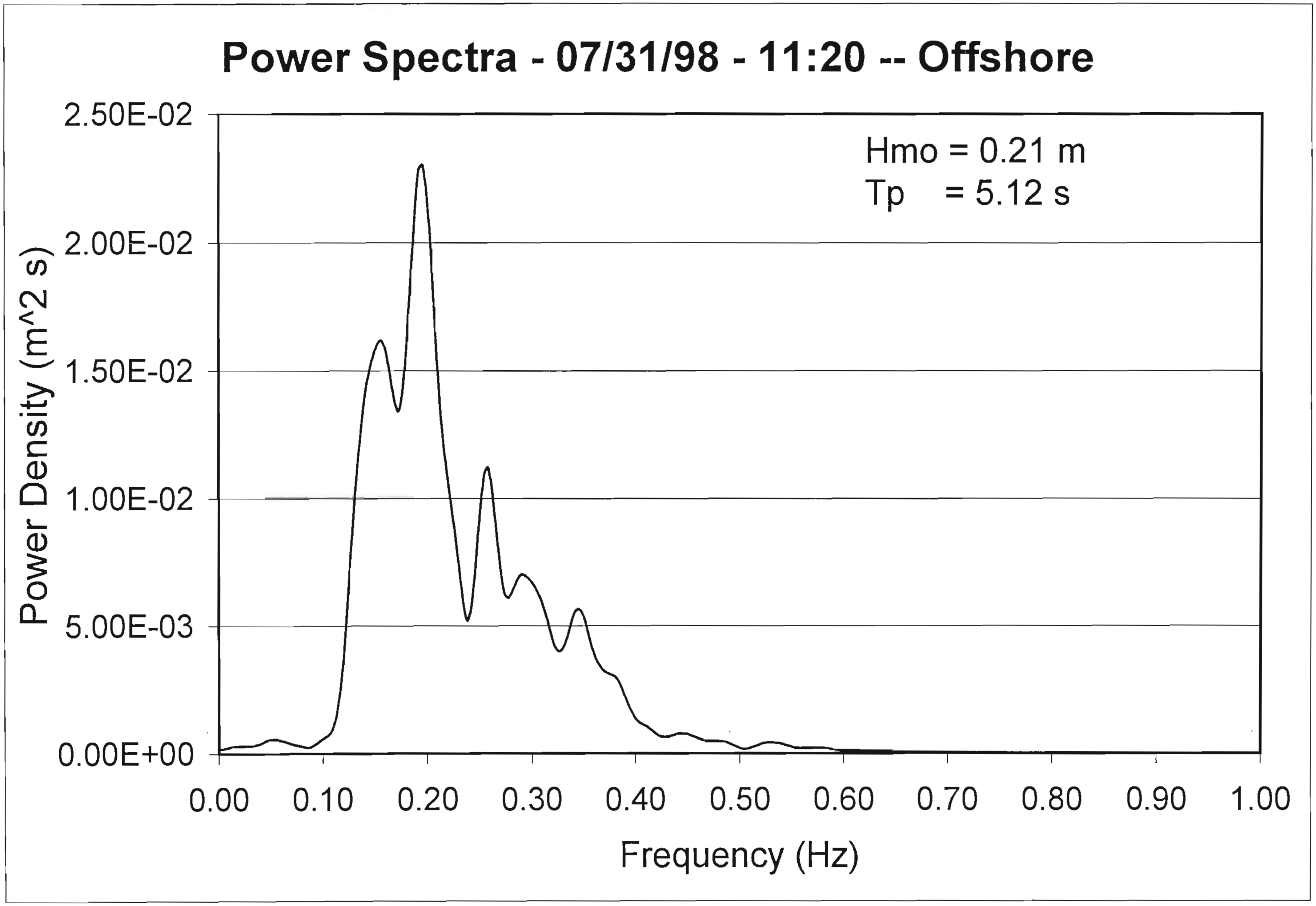

Power Spectra - 07/31/98 - 10:40 -- Offshore
Hmo = 0.22 m
Tp = 6.56 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

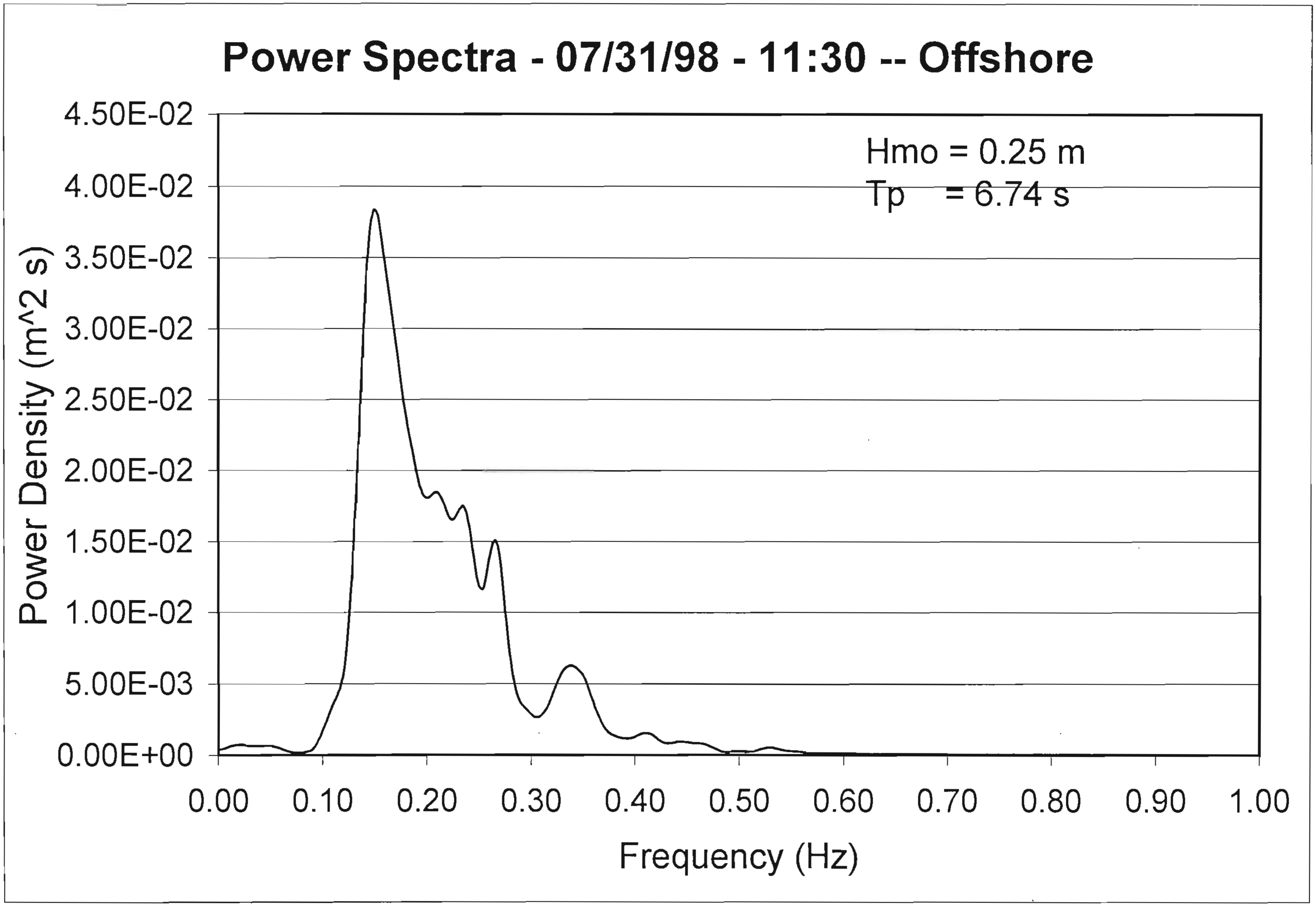


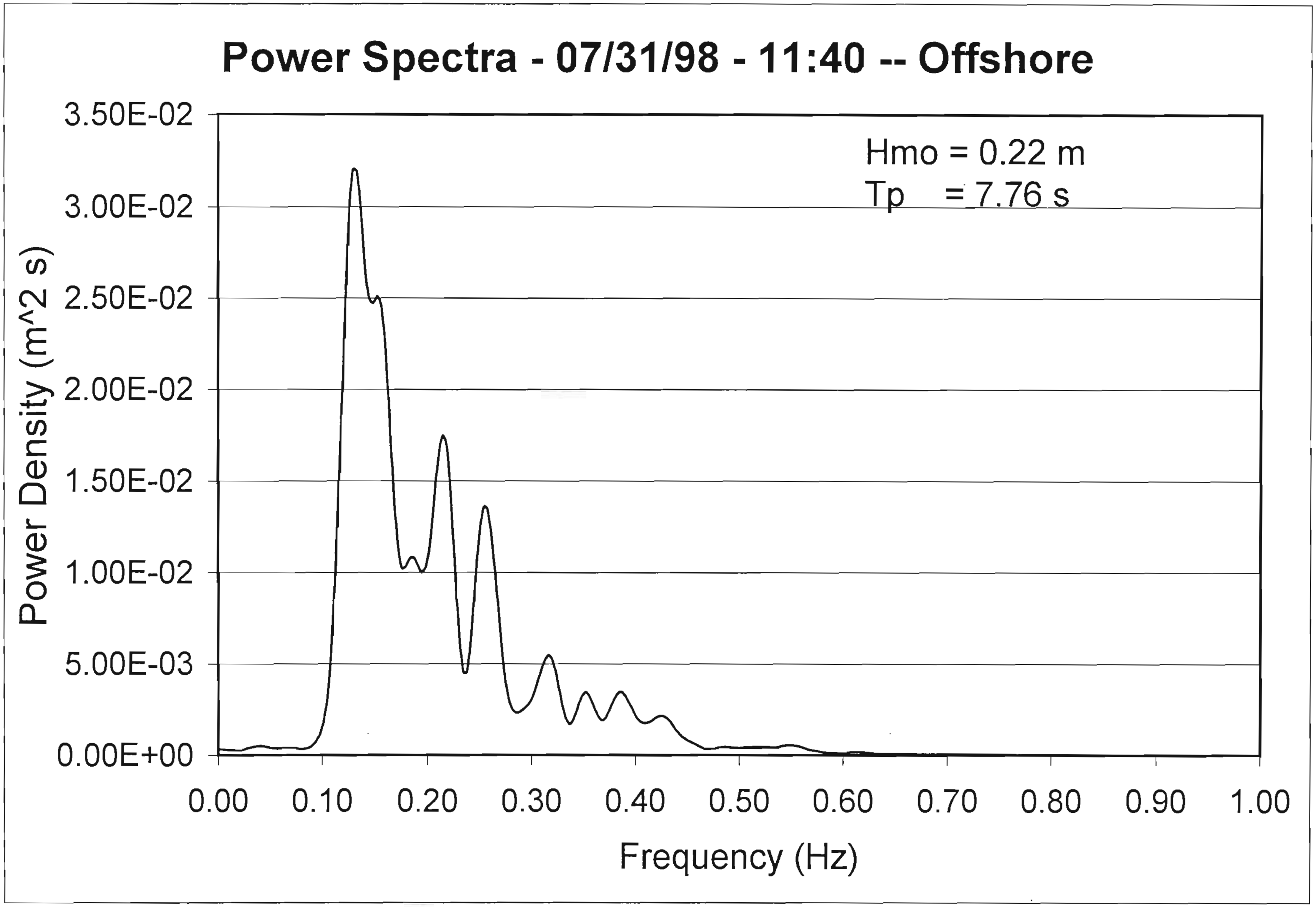
Power Spectra - 07/31/98 - 10:50 -- Offshore
Hmo = 0.21 m
Tp = 5.95 s
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

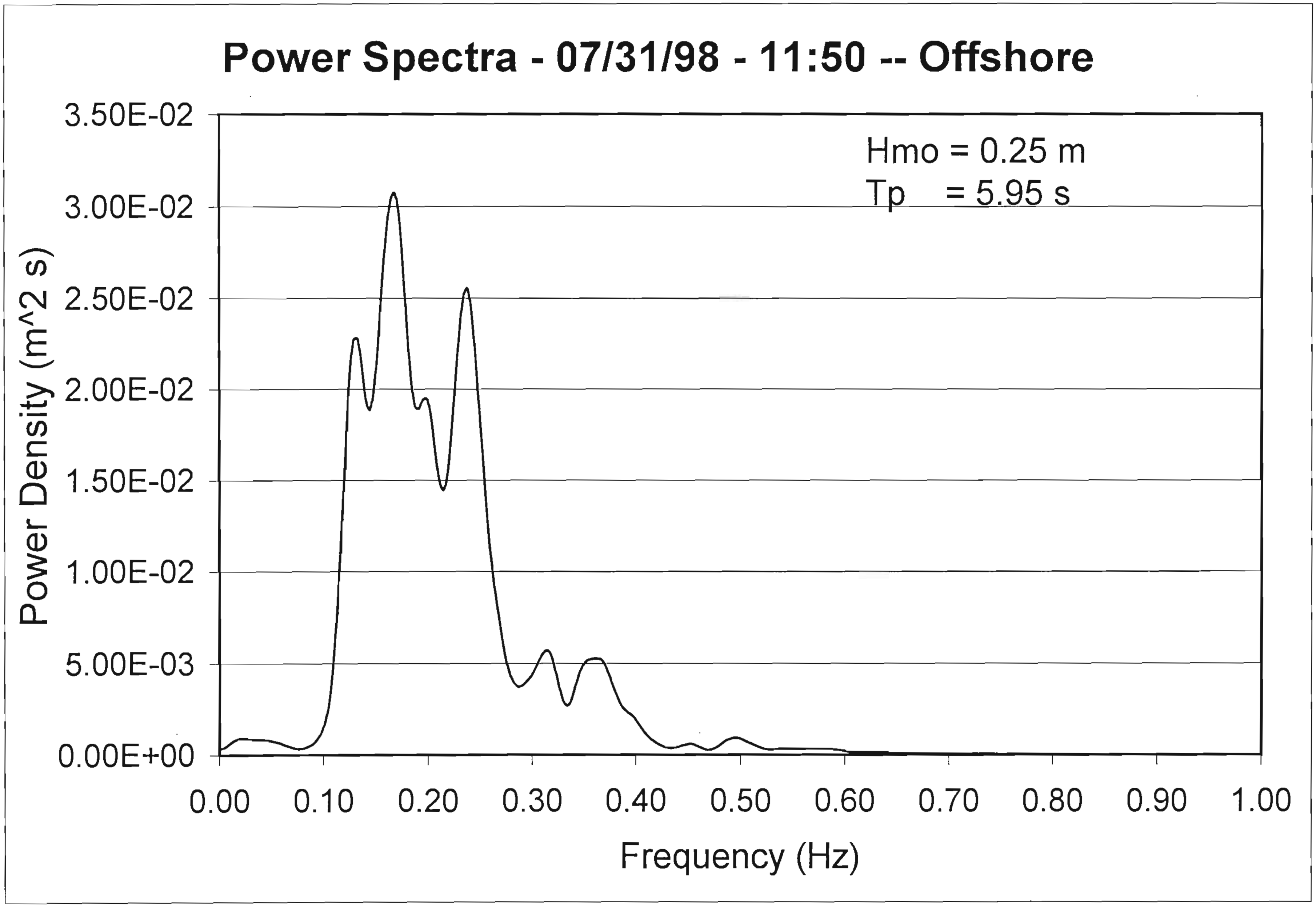

Power Spectra - 07/31/98 - 11:00 -- Offshore
Hmo = 0.24 m
Tp = 4.57 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

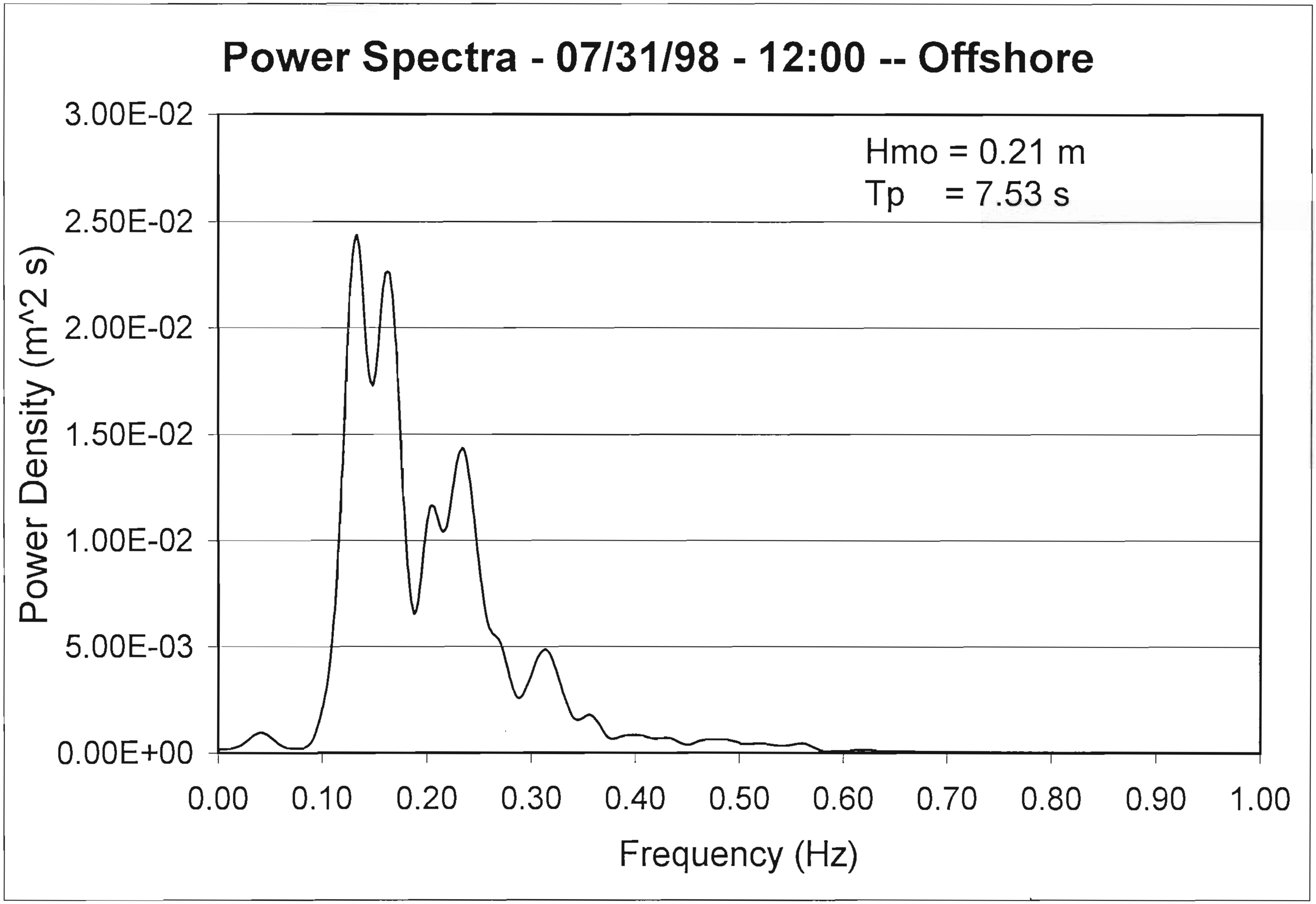

Power Spectra - 07/31/98 - 11:10 -- Offshore
Hmo = 0.26 m
Tp = 6.40 s
Power Density (m^2 s)
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

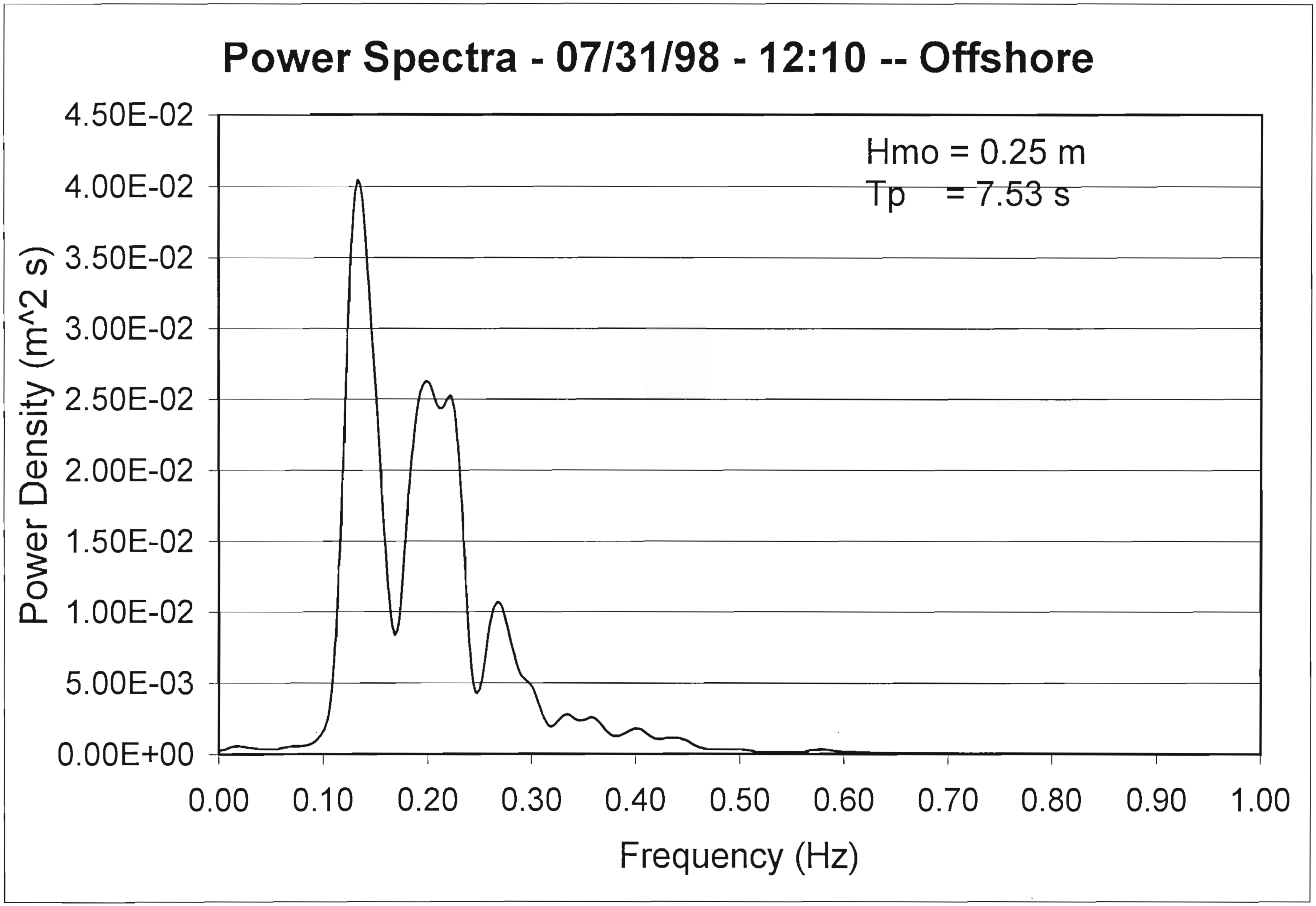

Power Spectra - 07/31/98 - 11:20 -- Offshore
Hmo = 0.21 m
Tp = 5.12 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

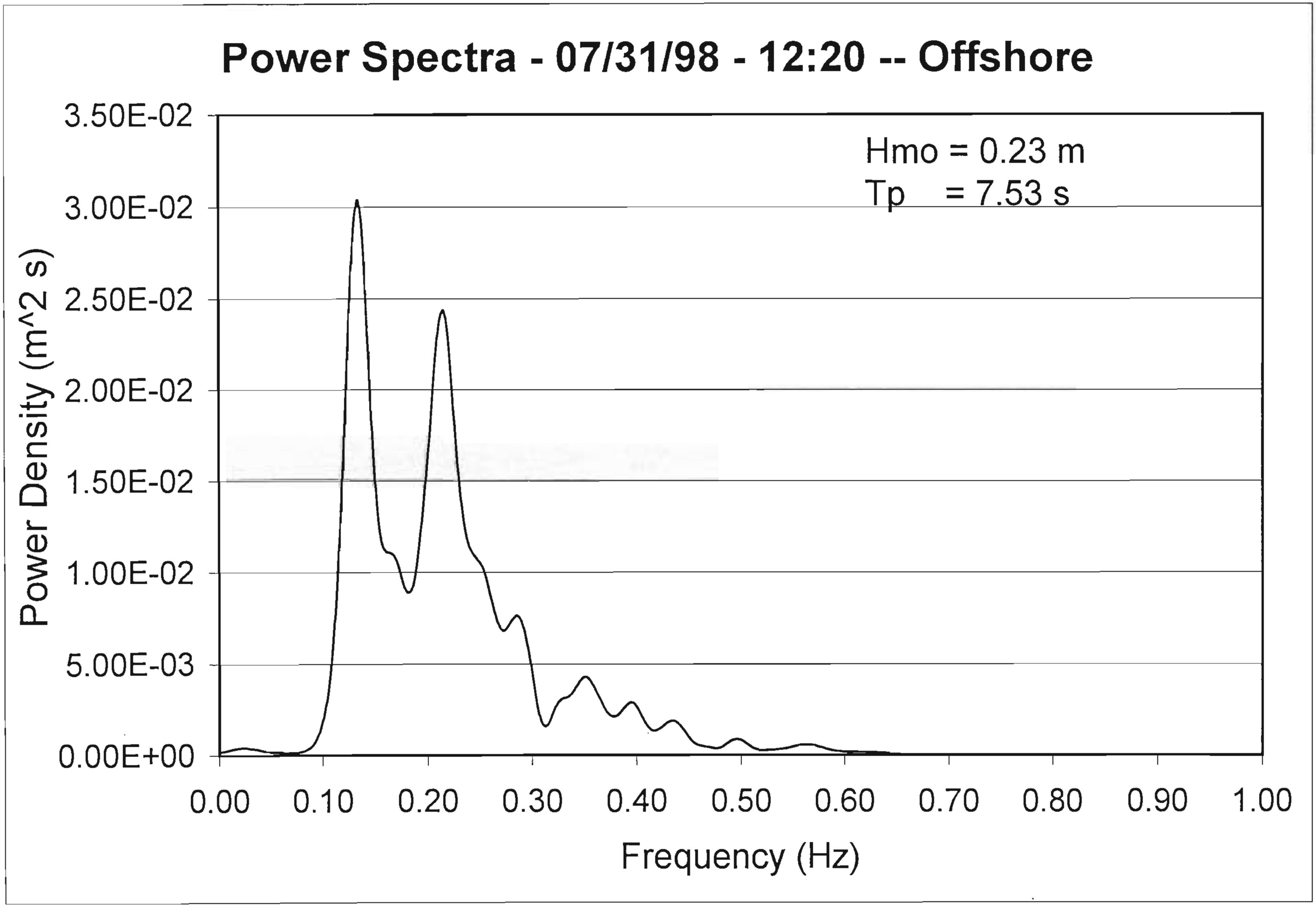

Power Spectra - 07/31/98 - 11:30 -- Offshore
Hmo = 0.25 m
Tp = 6.74 s
Power Density (m^2 s)
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

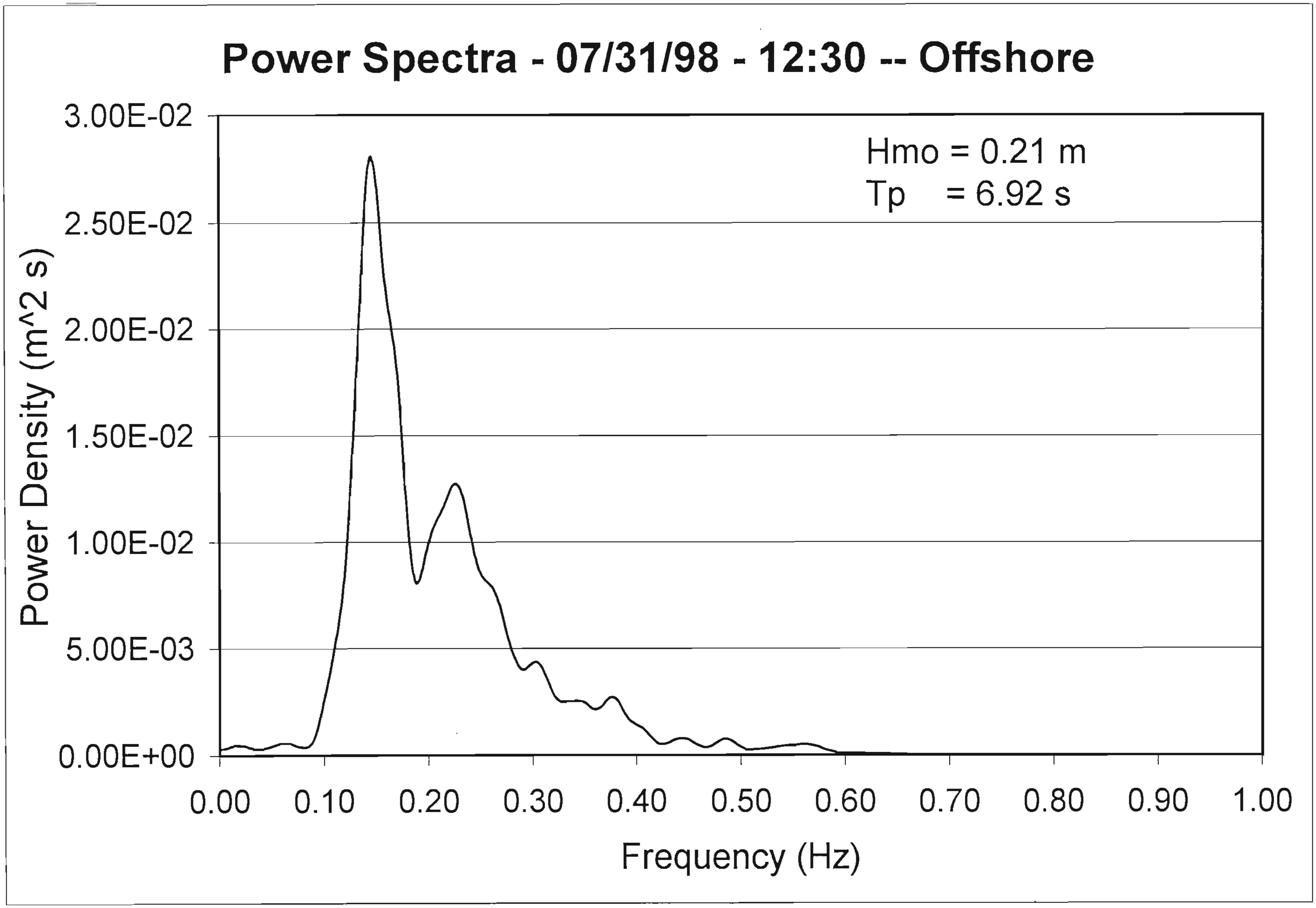

Power Spectra - 07/31/98 - 11:40 -- Offshore
Hmo = 0.22 m
Tp = 7.76 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 07/31/98 - 11:50 -- Offshore
Hmo = 0.25 m
Tp = 5.95 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

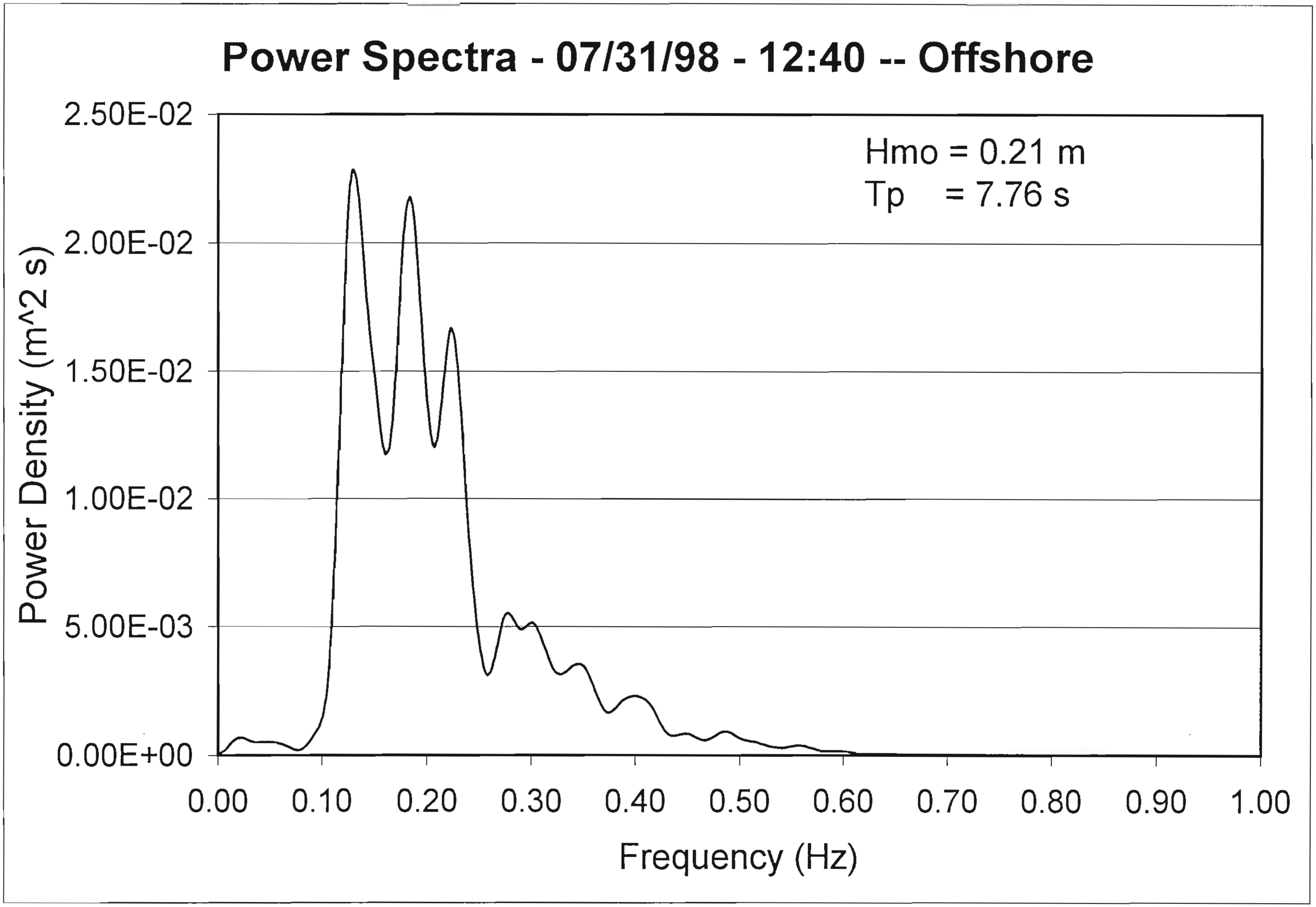

Power Spectra - 07/31/98 - 12:00 -- Offshore
Hmo = 0.21 m
Tp = 7.53 s
Power Density (m^2 s)
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

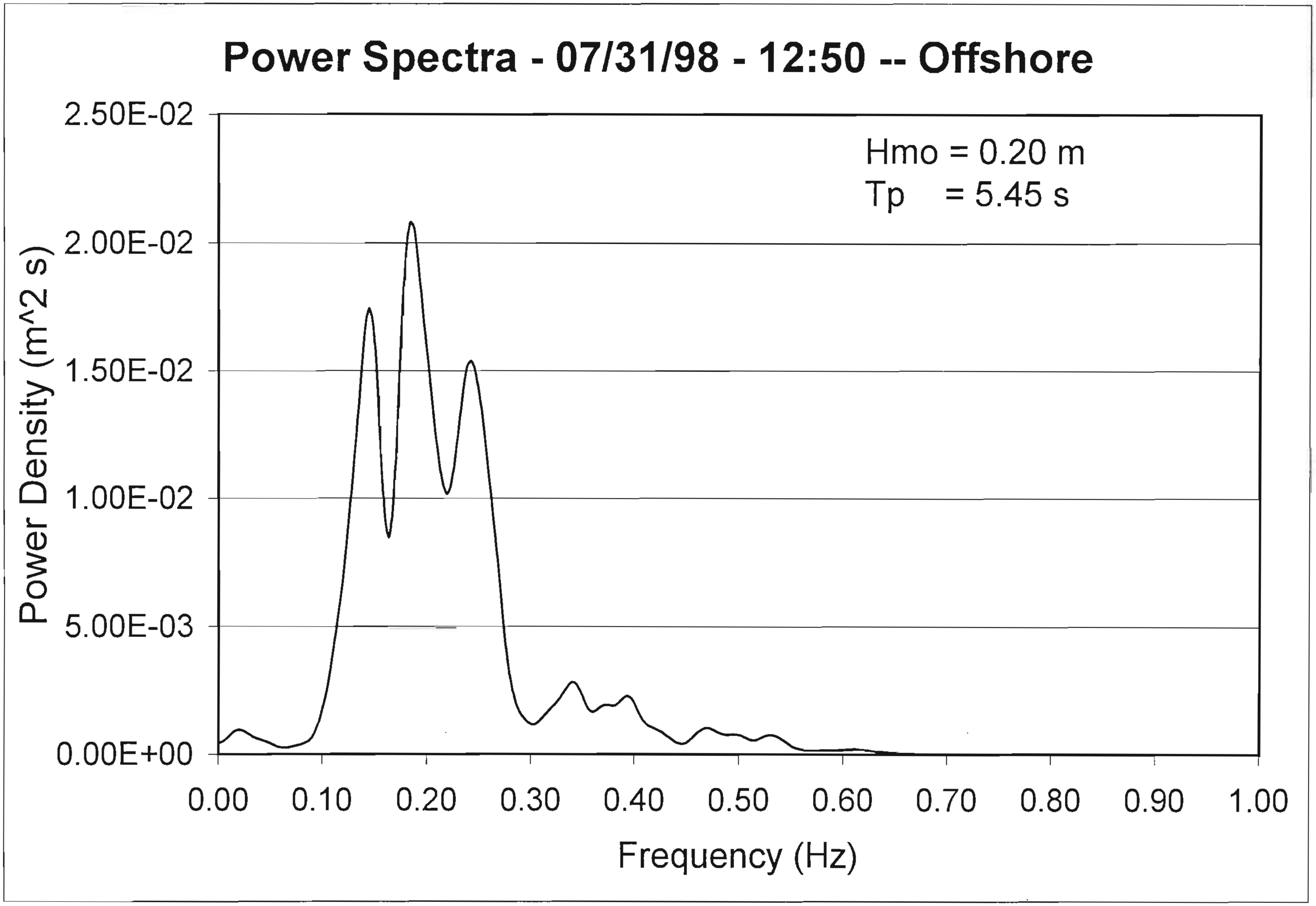

Power Spectra - 07/31/98 - 12:10 -- Offshore
Hmo = 0.25 m
Tp = 7.53 s
4.50E-02
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 07/31/98 - 12:20 -- Offshore
Hmo = 0.23 m
Tp = 7.53 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

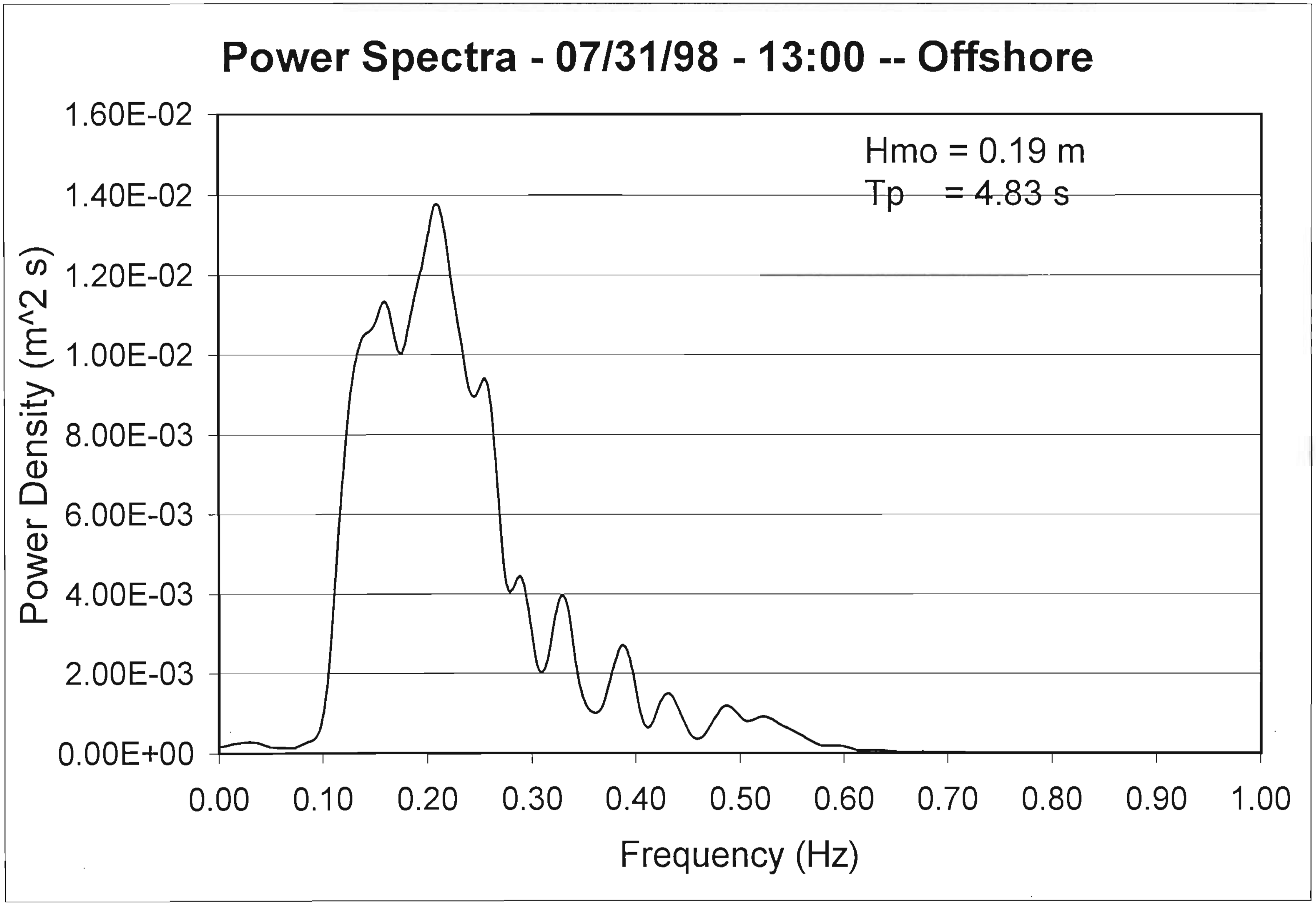


Power Spectra - 07/31/98 - 12:30 -- Offshore
Hmo = 0.21 m
Tp = 6.92 s
Power Density (m^2 s)
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

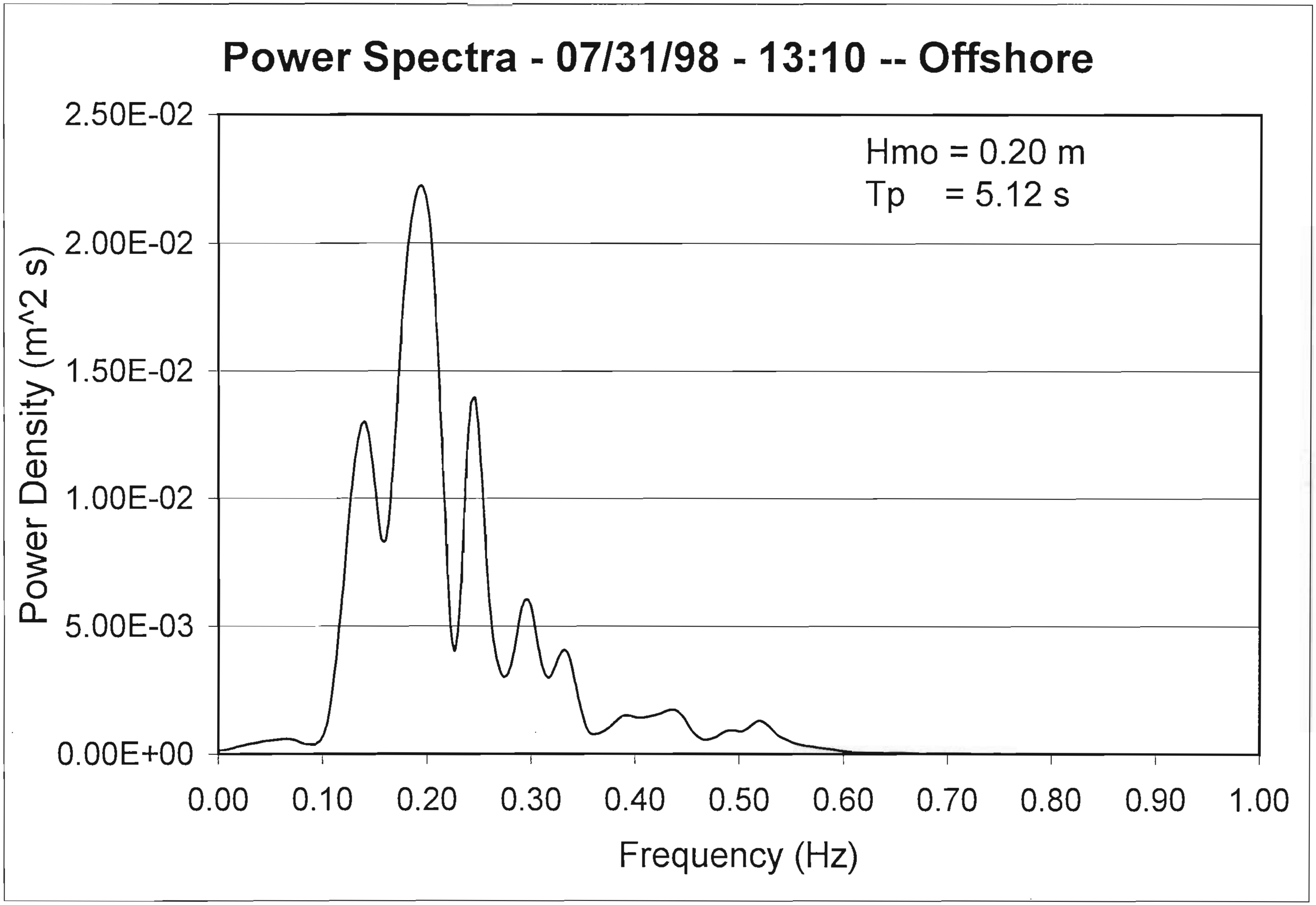

Power Spectra - 07/31/98 - 12:40 -- Offshore
Hmo = 0.21 m
Tp = 7.76 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

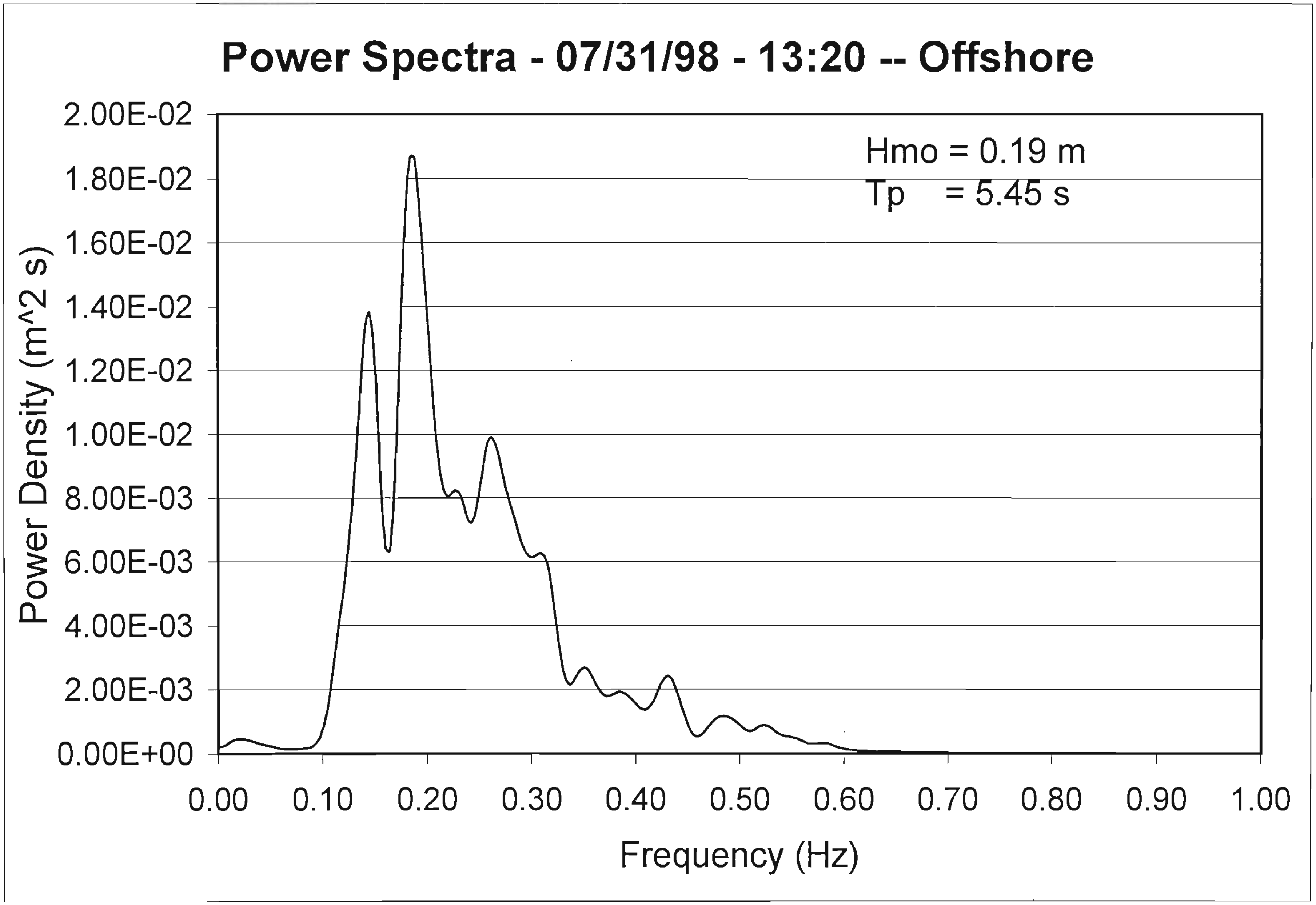


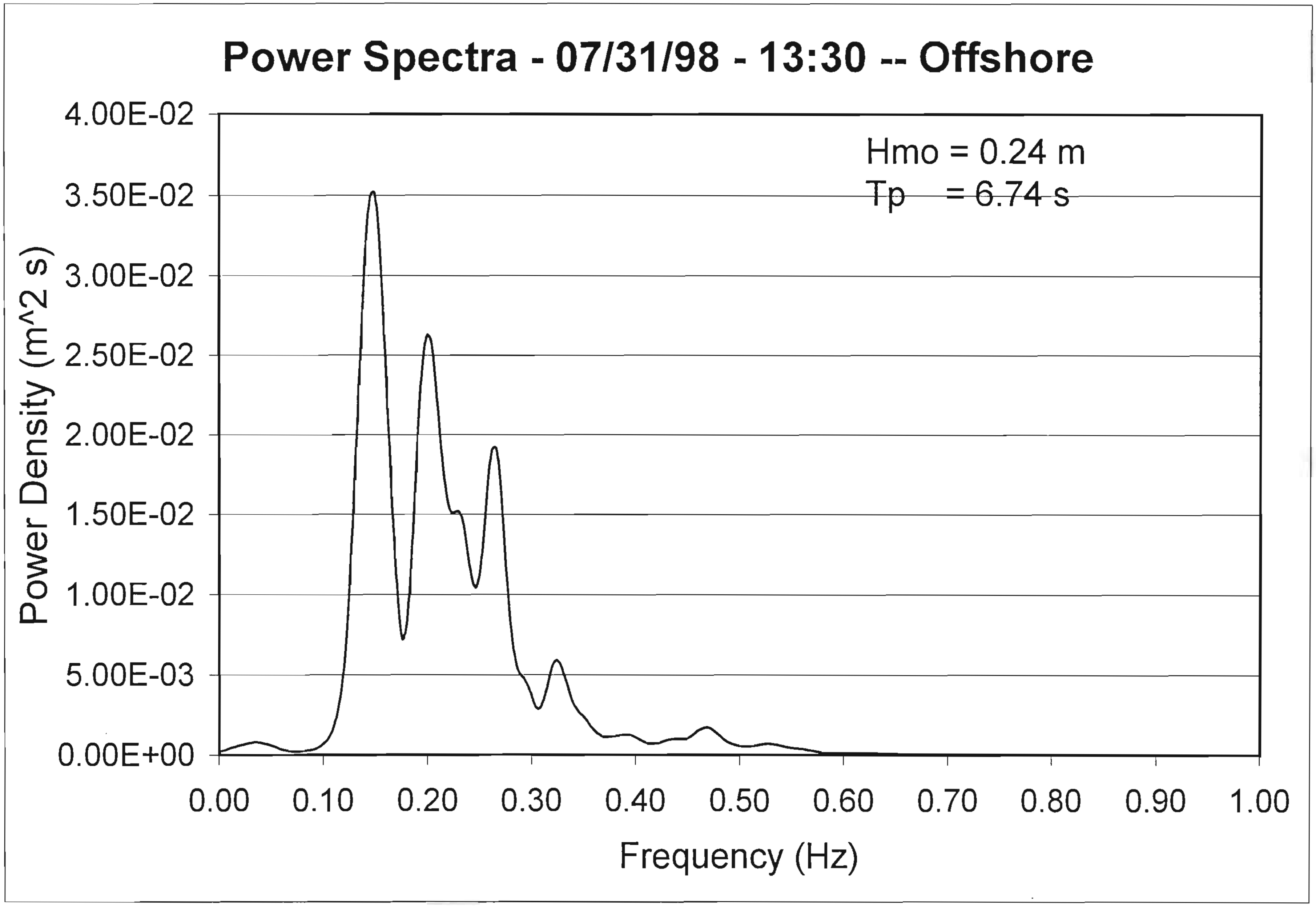
Power Spectra - 07/31/98 - 12:50 -- Offshore
Hmo = 0.20 m
Tp = 5.45 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

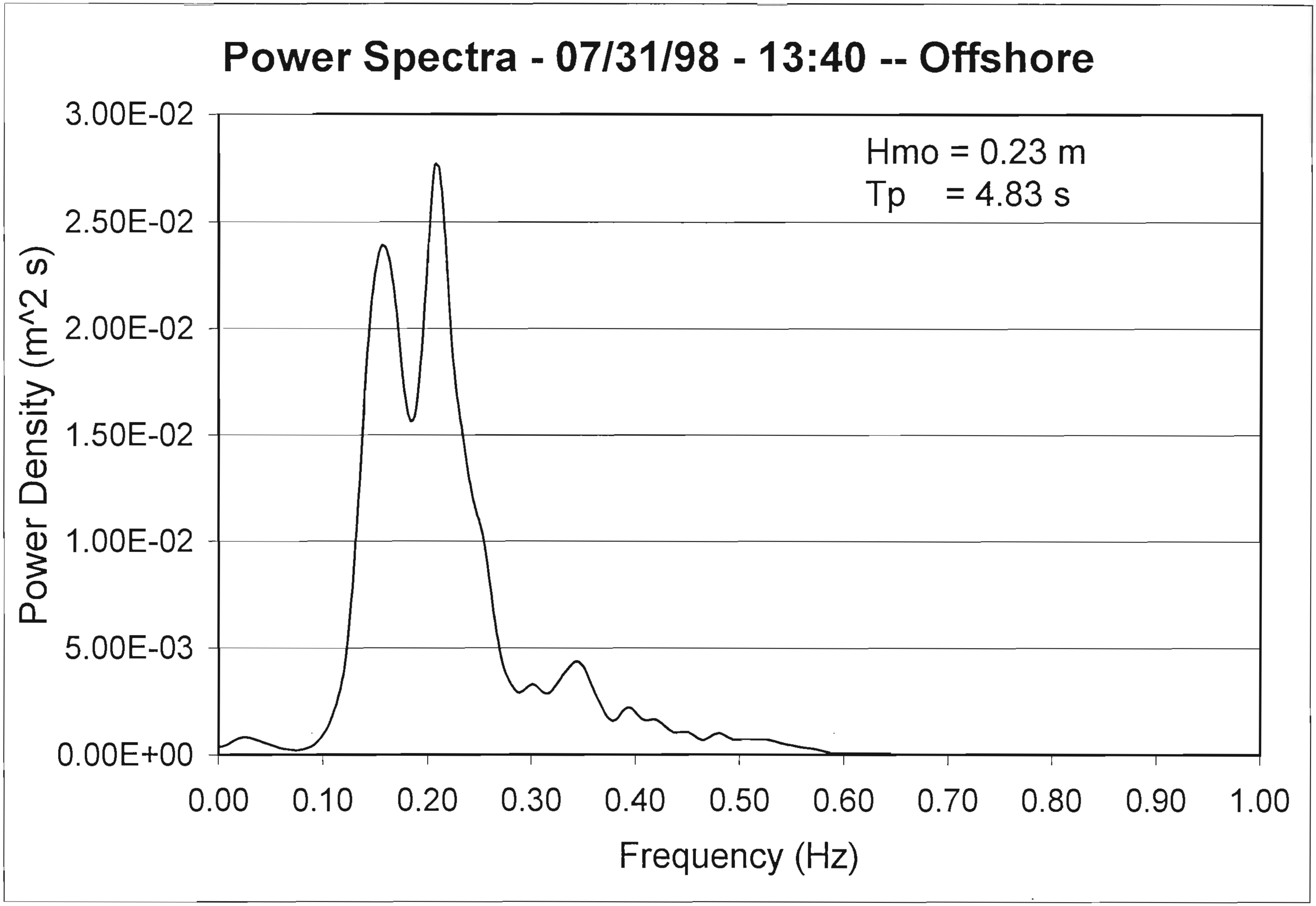


Power Spectra - 07/31/98 - 13:00 -- Offshore
Hmo = 0.19 m
Tp = 4.83 s
Power Density (m^2 s)
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

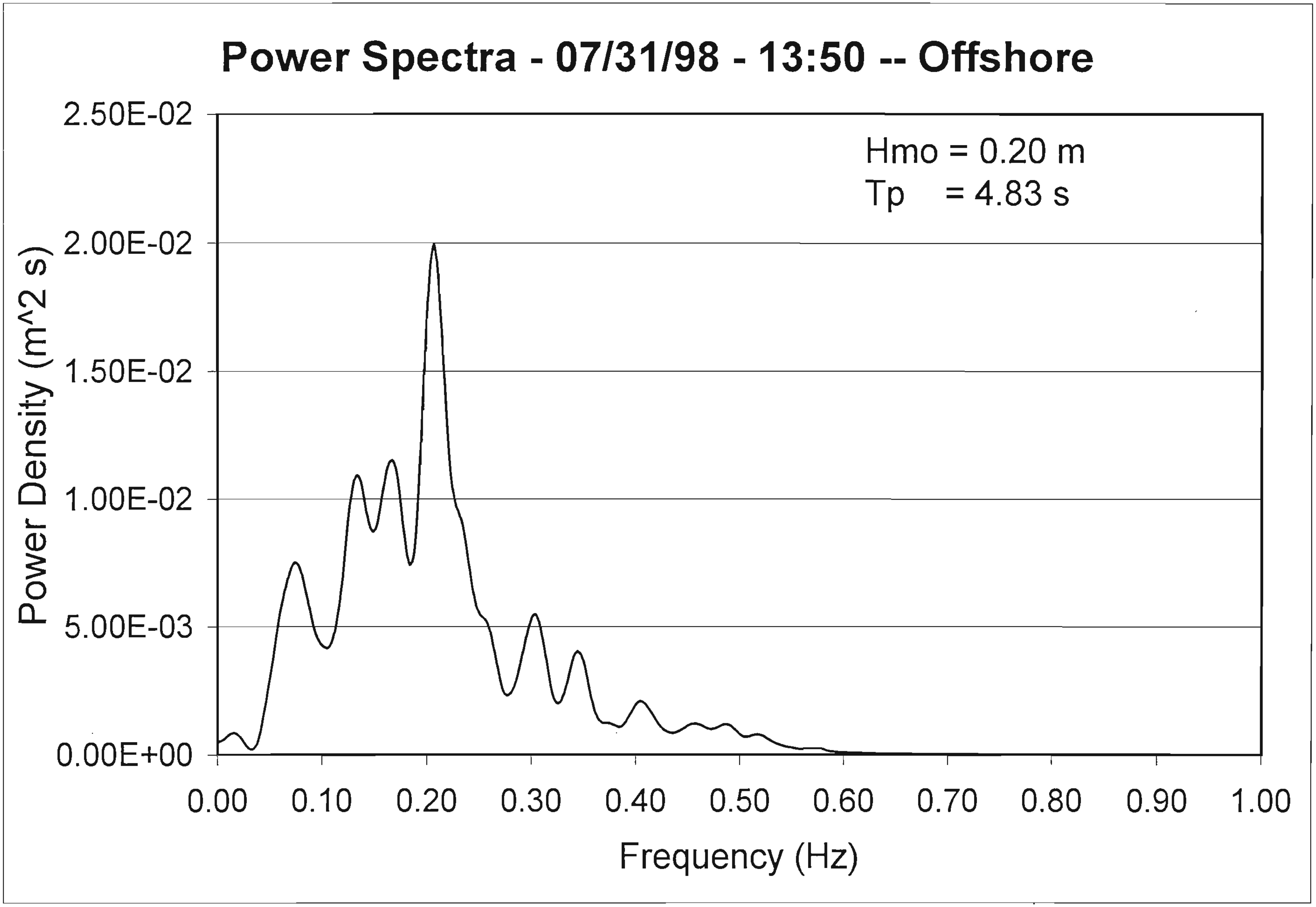

Power Spectra - 07/31/98 - 13:10 -- Offshore
Hmo = 0.20 m
Tp = 5.12 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

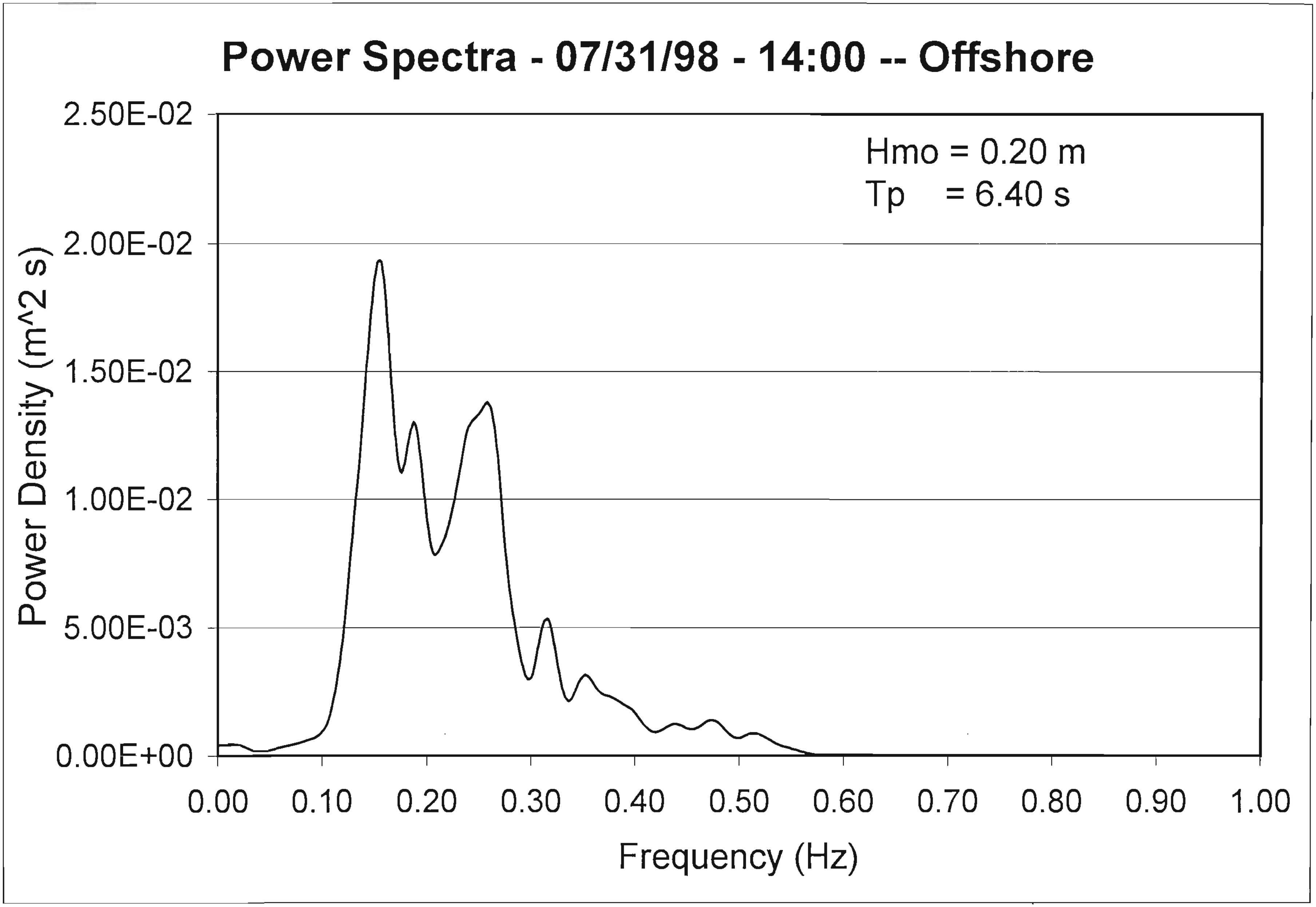

Power Spectra - 07/31/98 - 13:20 -- Offshore
Hmo = 0.19 m
Tp = 5.45 s
Power Density (m^2 s)
2.00E-02
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

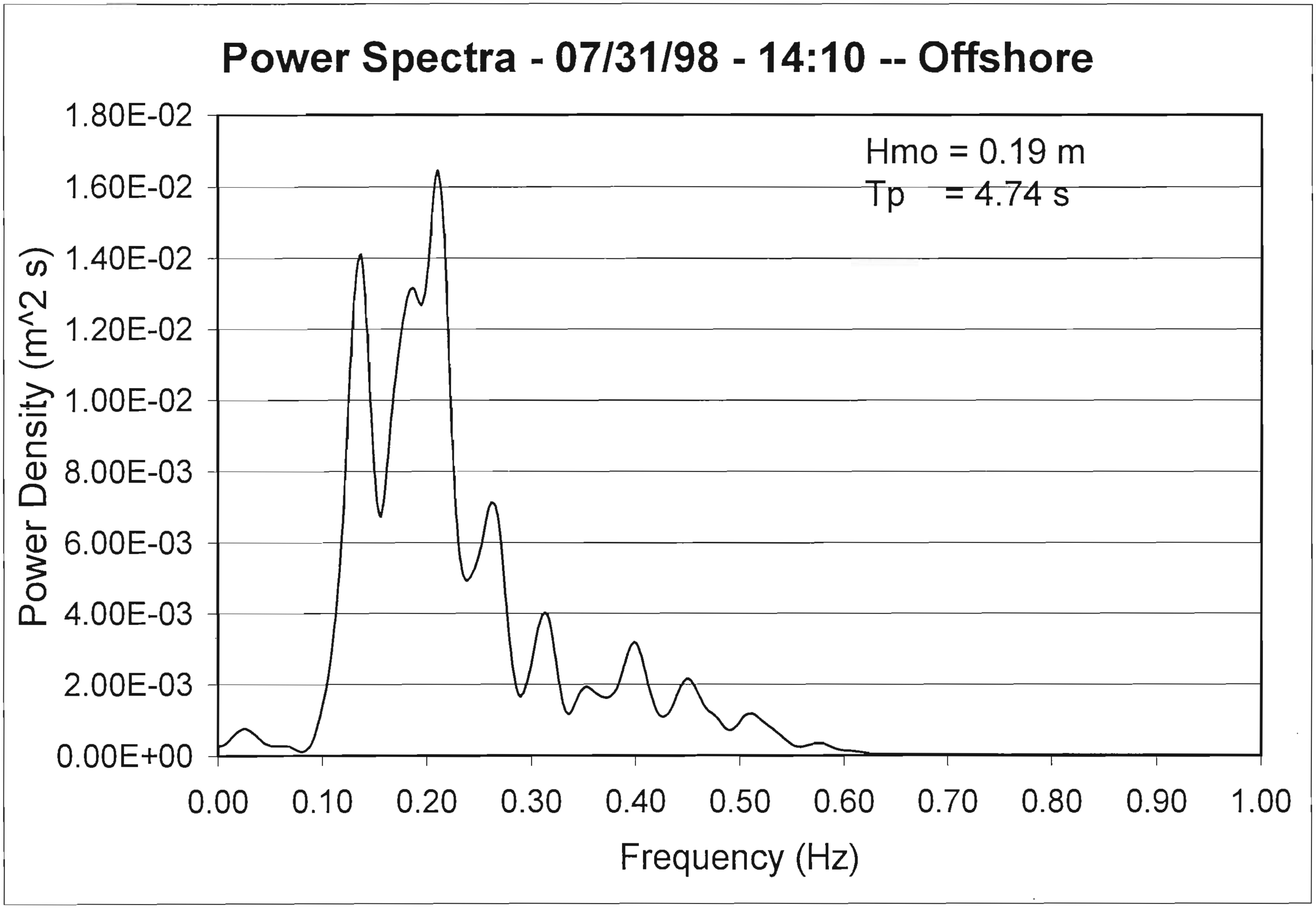

Power Spectra - 07/31/98 - 13:30 -- Offshore
Hmo = 0.24 m
Tp = 6.74 s
Power Density (m^2 s)
4.00E-02
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

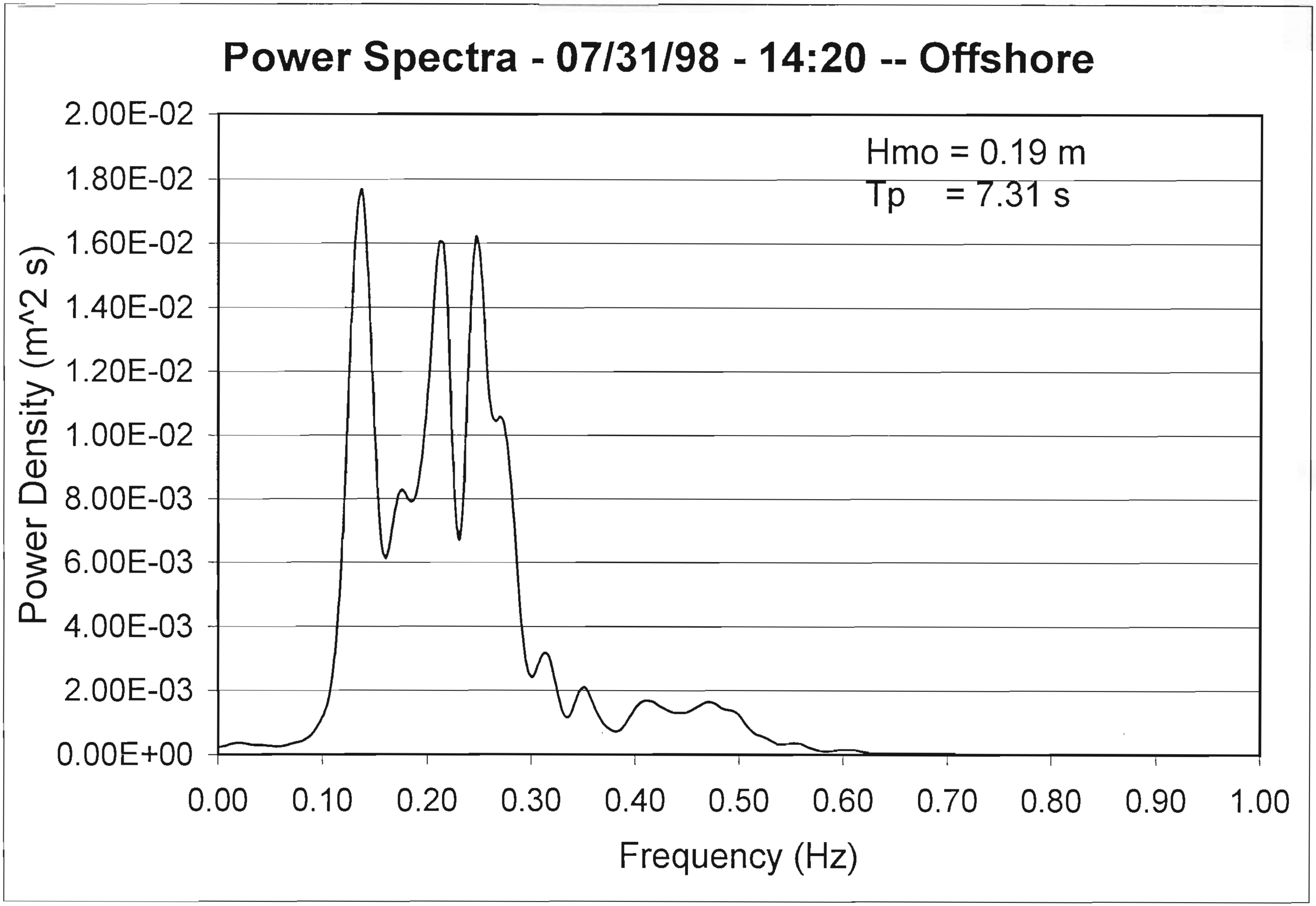


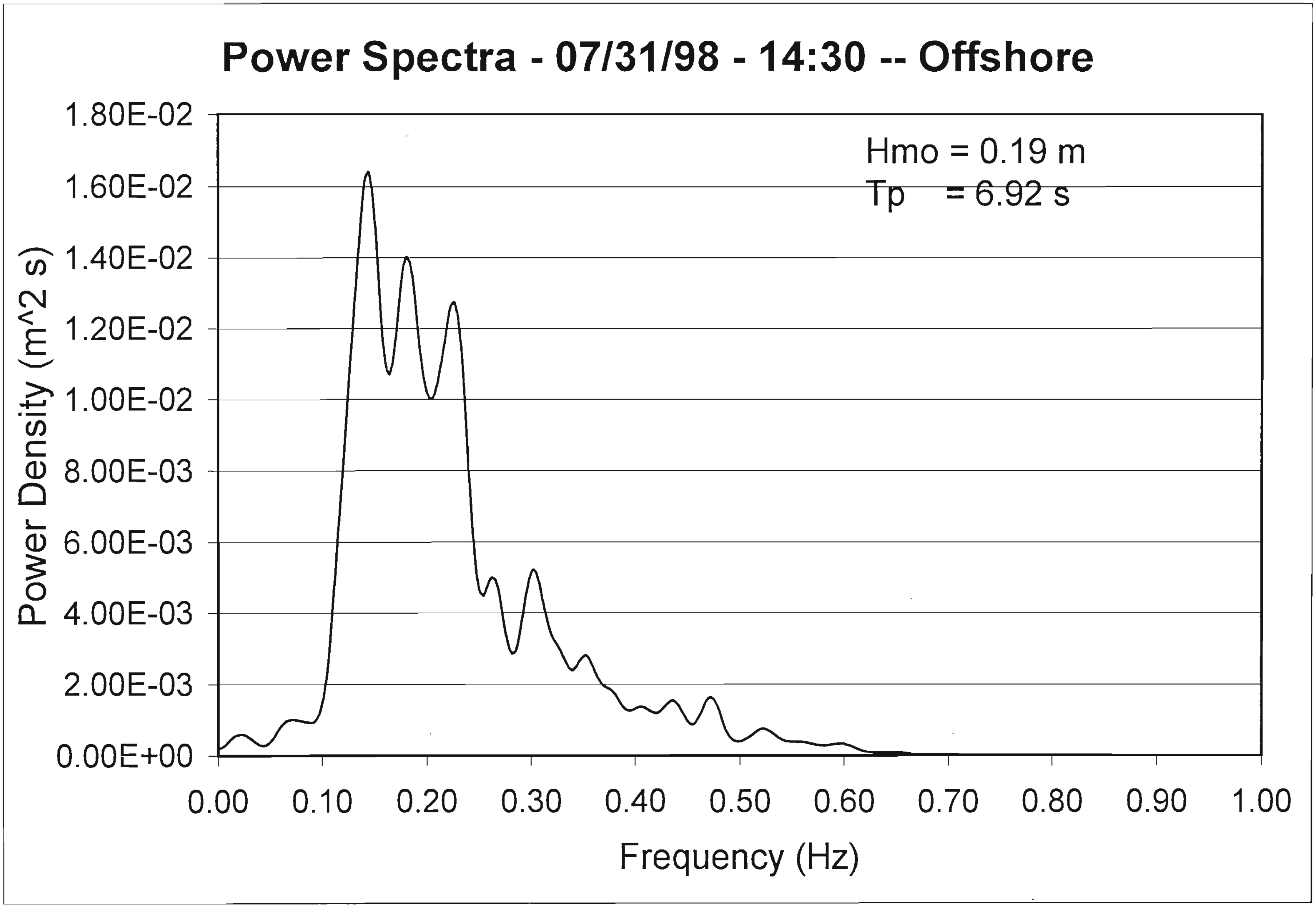
Power Spectra - 07/31/98 - 13:40 -- Offshore
Hmo = 0.23 m
Tp = 4.83 s
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

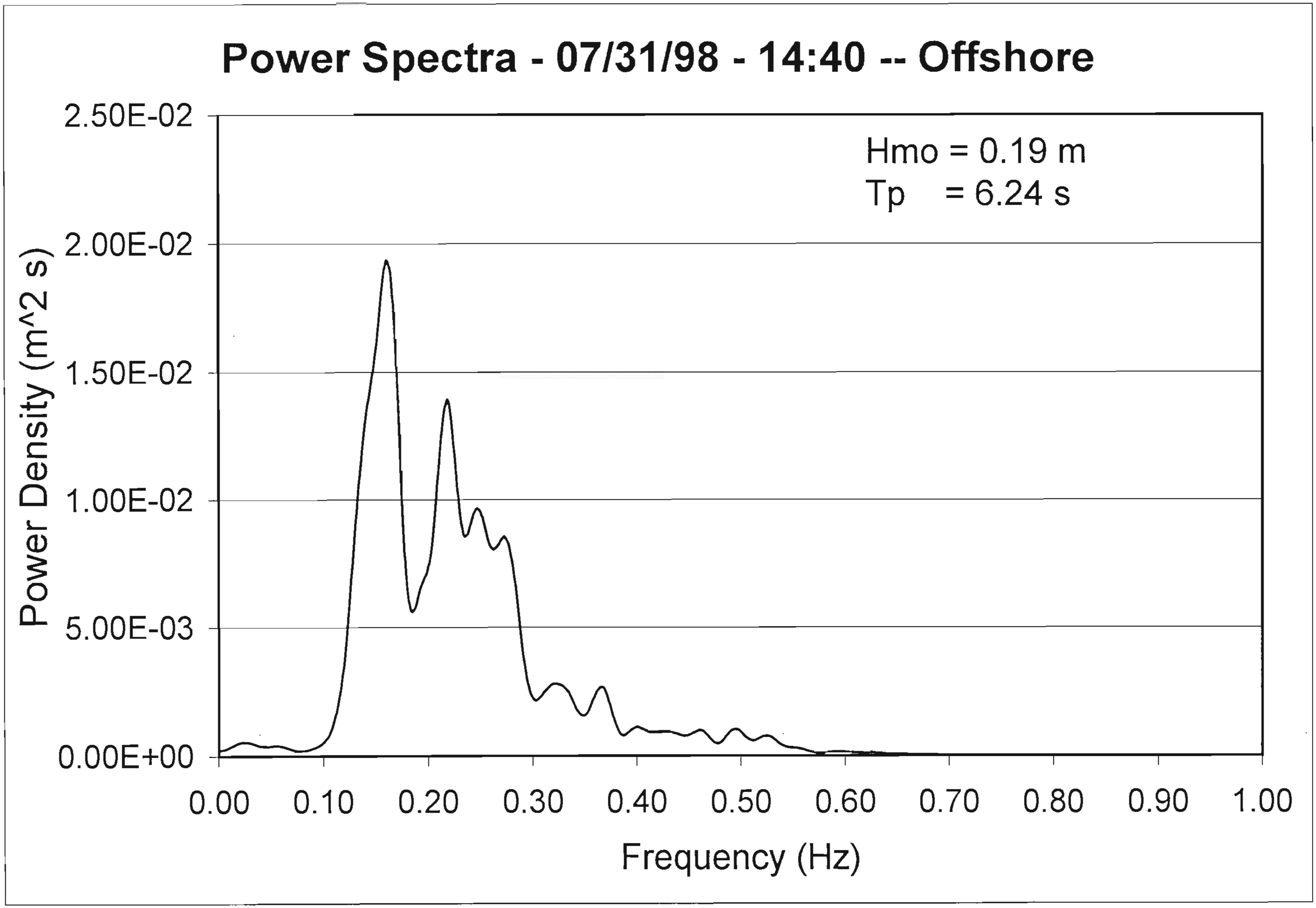

Power Spectra - 07/31/98 - 13:50 -- Offshore
Hmo = 0.20 m
Tp = 4.83 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

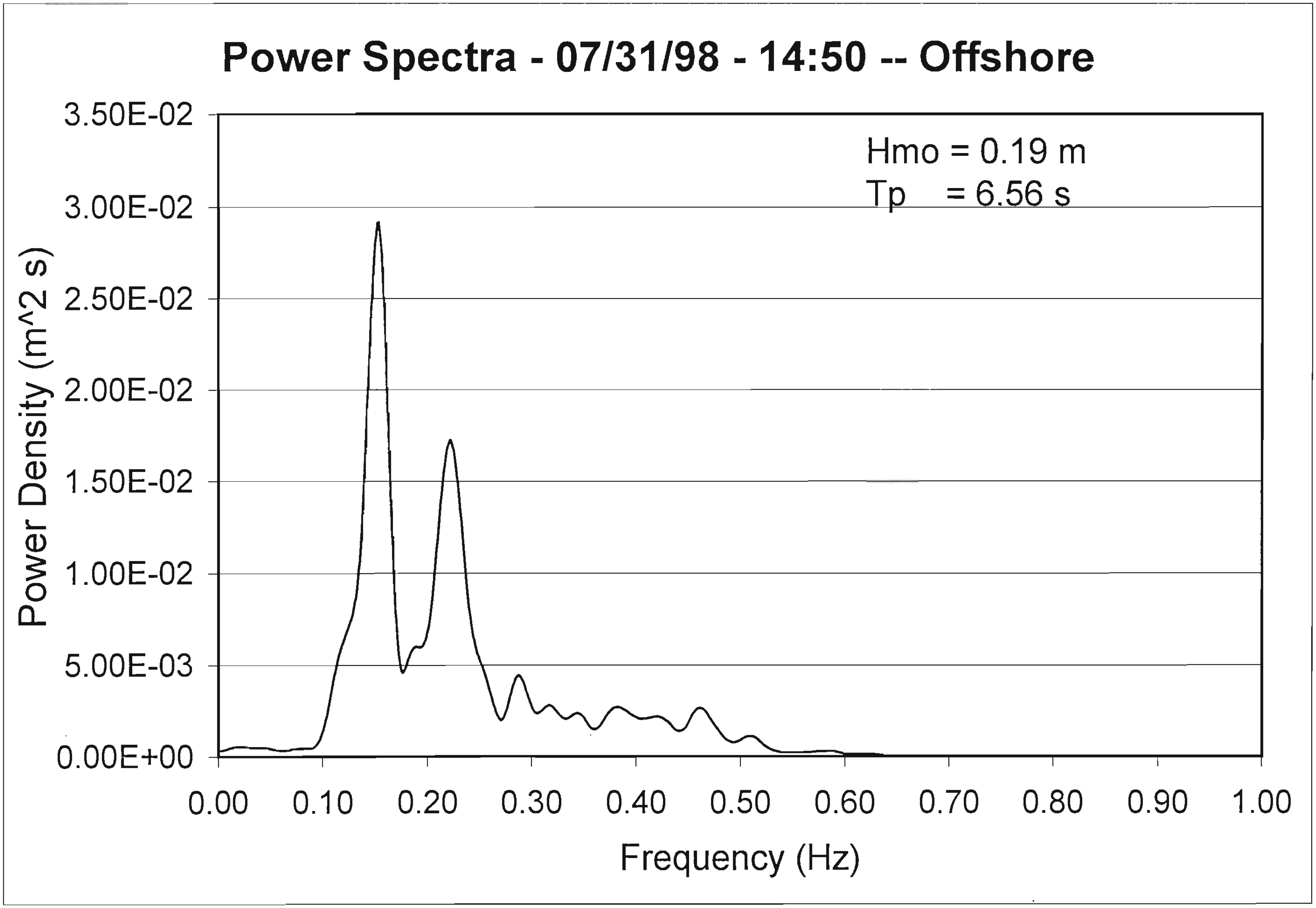

Power Spectra - 07/31/98 - 14:00 -- Offshore
Hmo = 0.20 m
Tp = 6.40 s
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

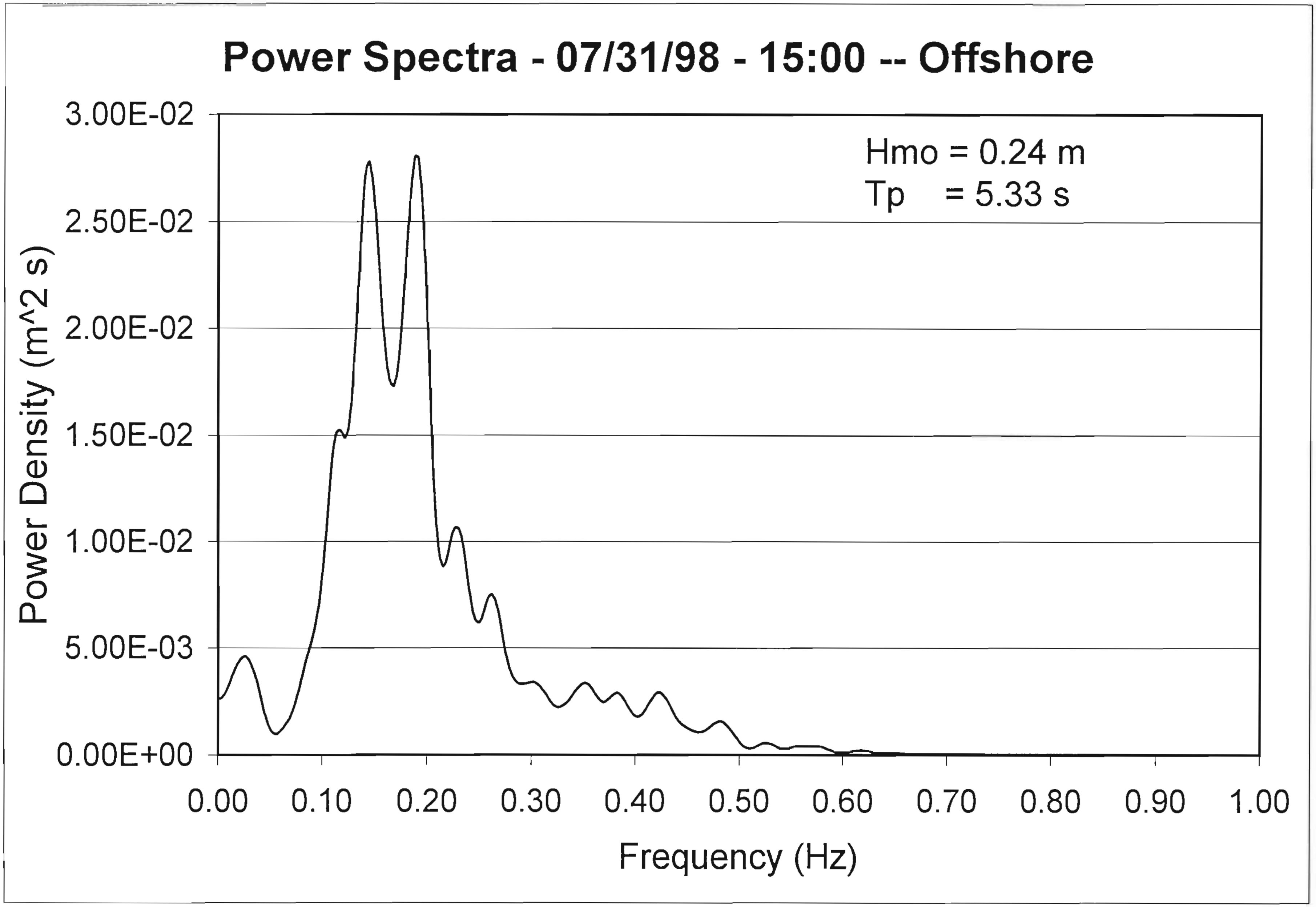

Power Spectra - 07/31/98 - 14:10 -- Offshore
Hmo = 0.19 m
Tp = 4.74 s
Power Density (m^2 s)
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

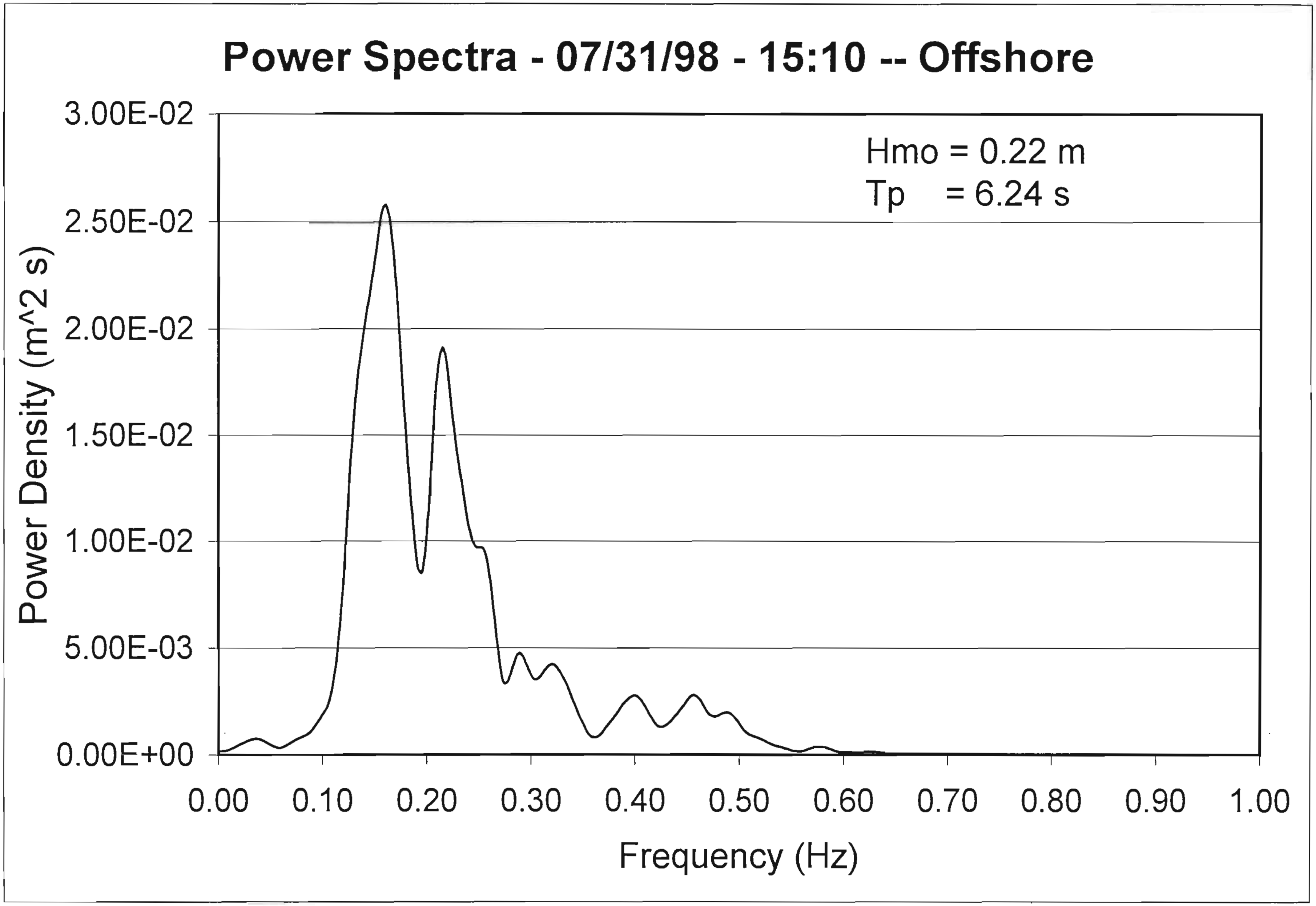

Power Spectra - 07/31/98 - 14:20 -- Offshore
Hmo = 0.19 m
Tp = 7.31 s
Power Density (m^2 s)
2.00E-02
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

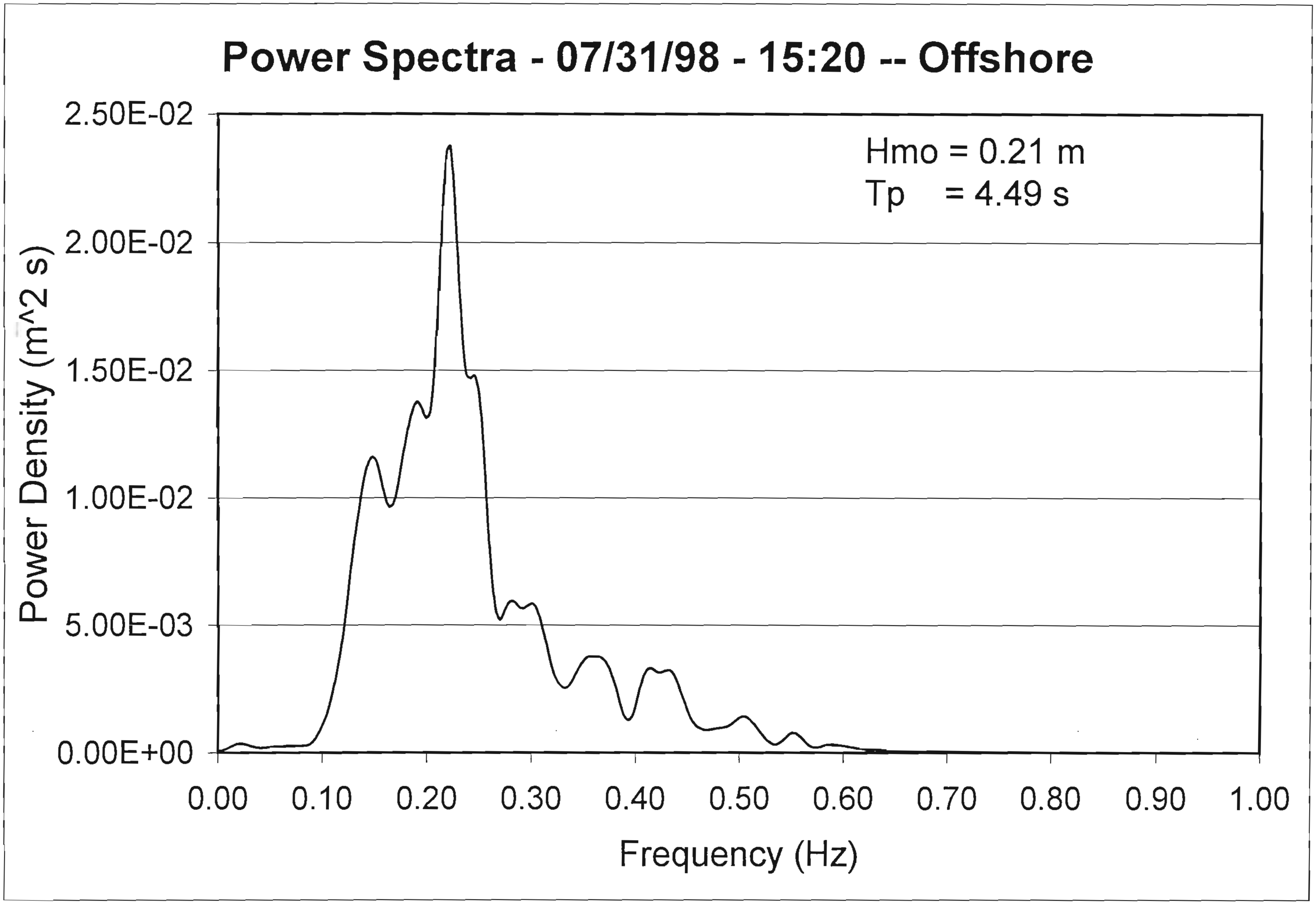

Power Spectra - 07/31/98 - 14:30 -- Offshore
Hmo = 0.19 m
Tp = 6.92 s
Power Density (m^2 s)
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

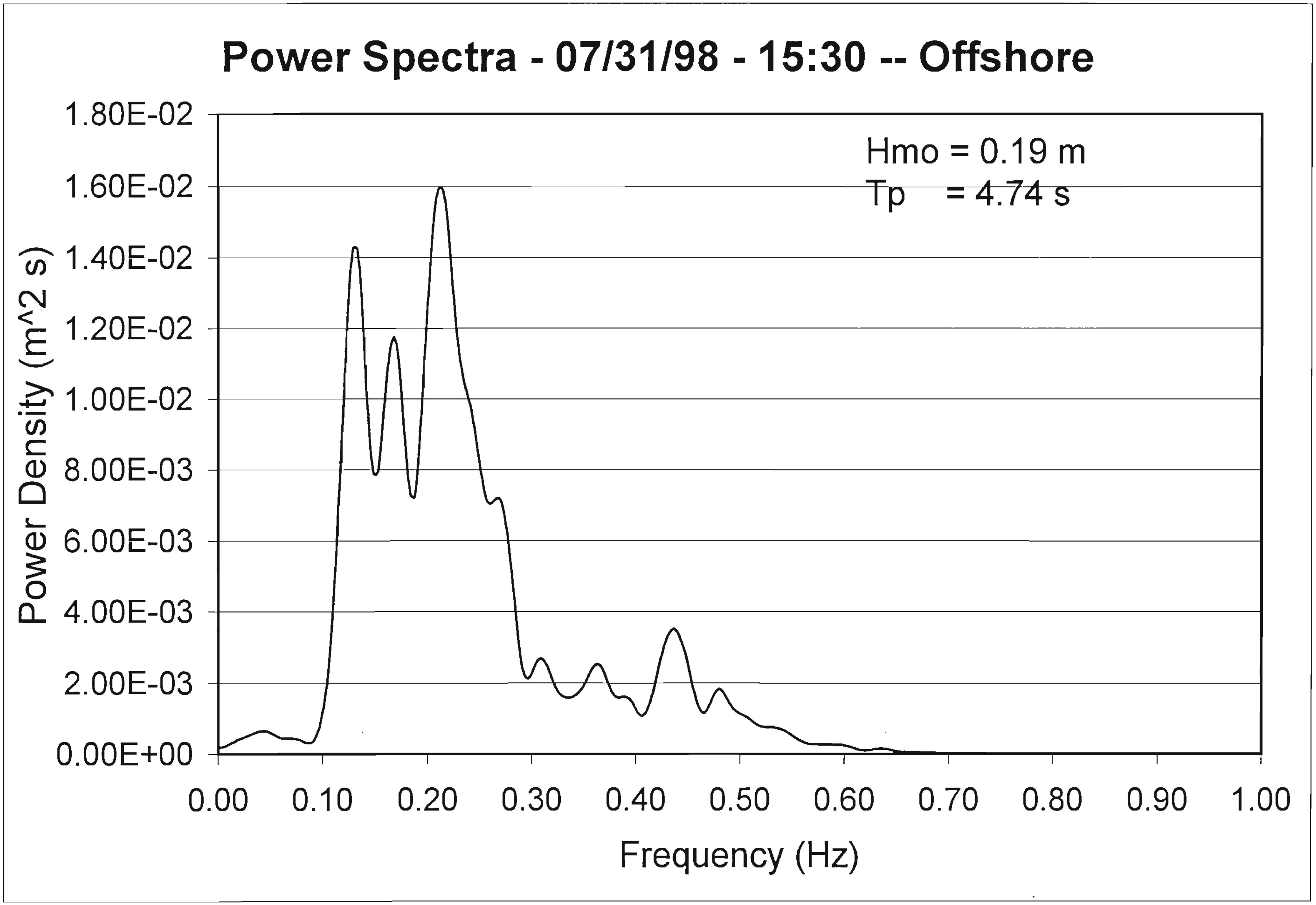

Power Spectra - 07/31/98 - 14:40 -- Offshore
Hmo = 0.19 m
Tp = 6.24 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

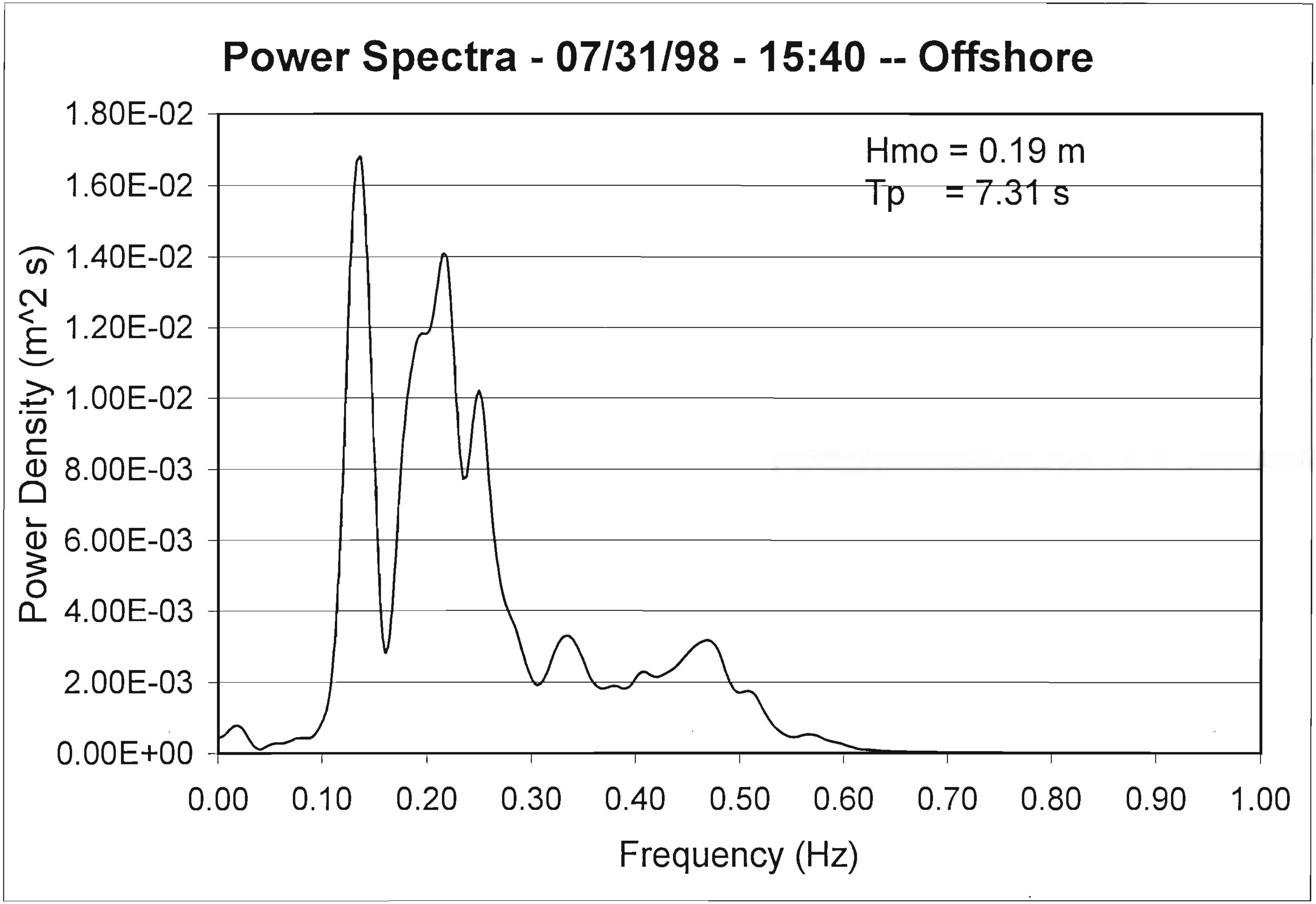

Power Spectra - 07/31/98 - 14:50 -- Offshore
Hmo = 0.19 m
Tp = 6.56 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

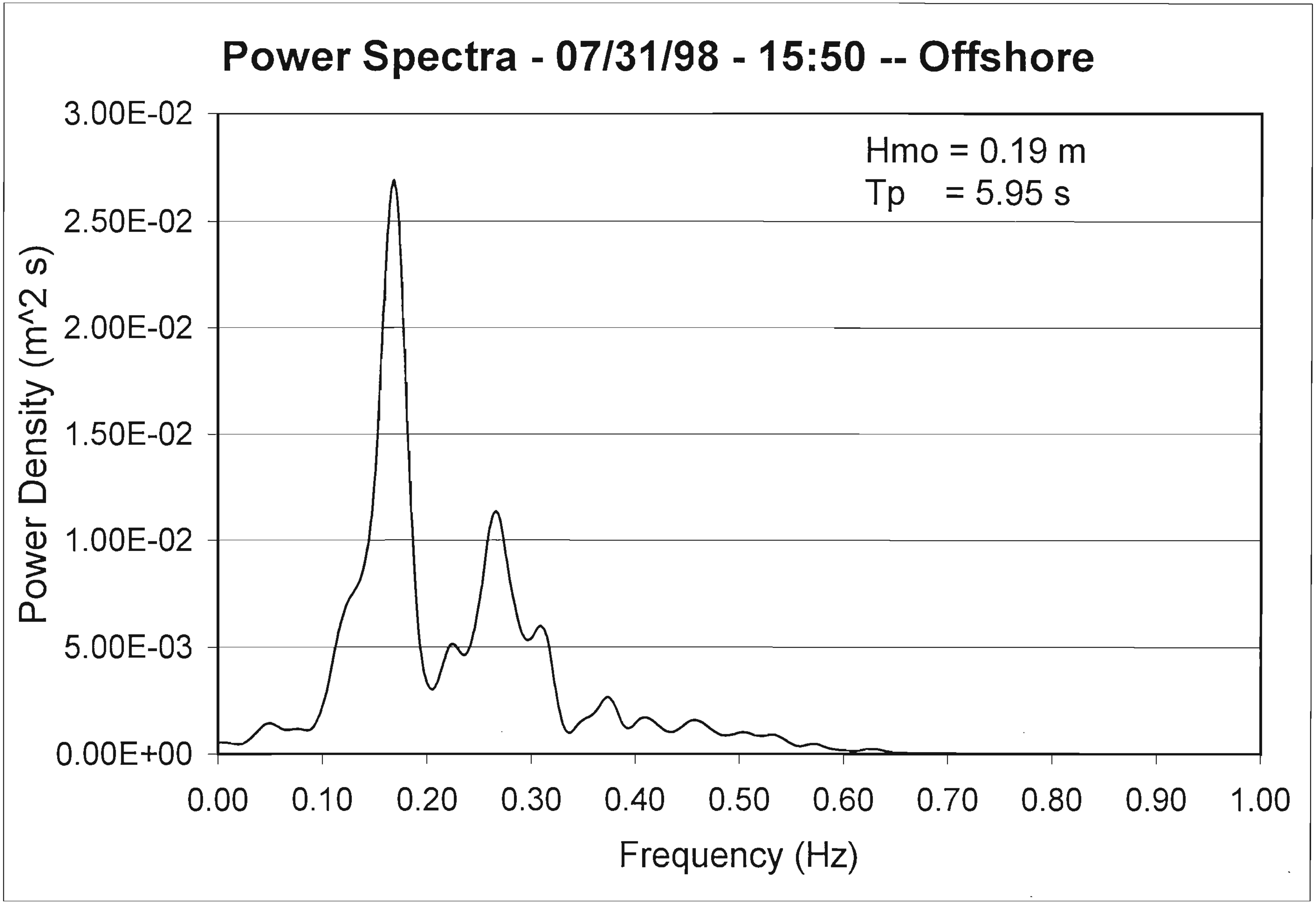

Power Spectra - 07/31/98 - 15:00 -- Offshore
Hmo = 0.24 m
Tp = 5.33 s
Power Density (m^2 s)
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

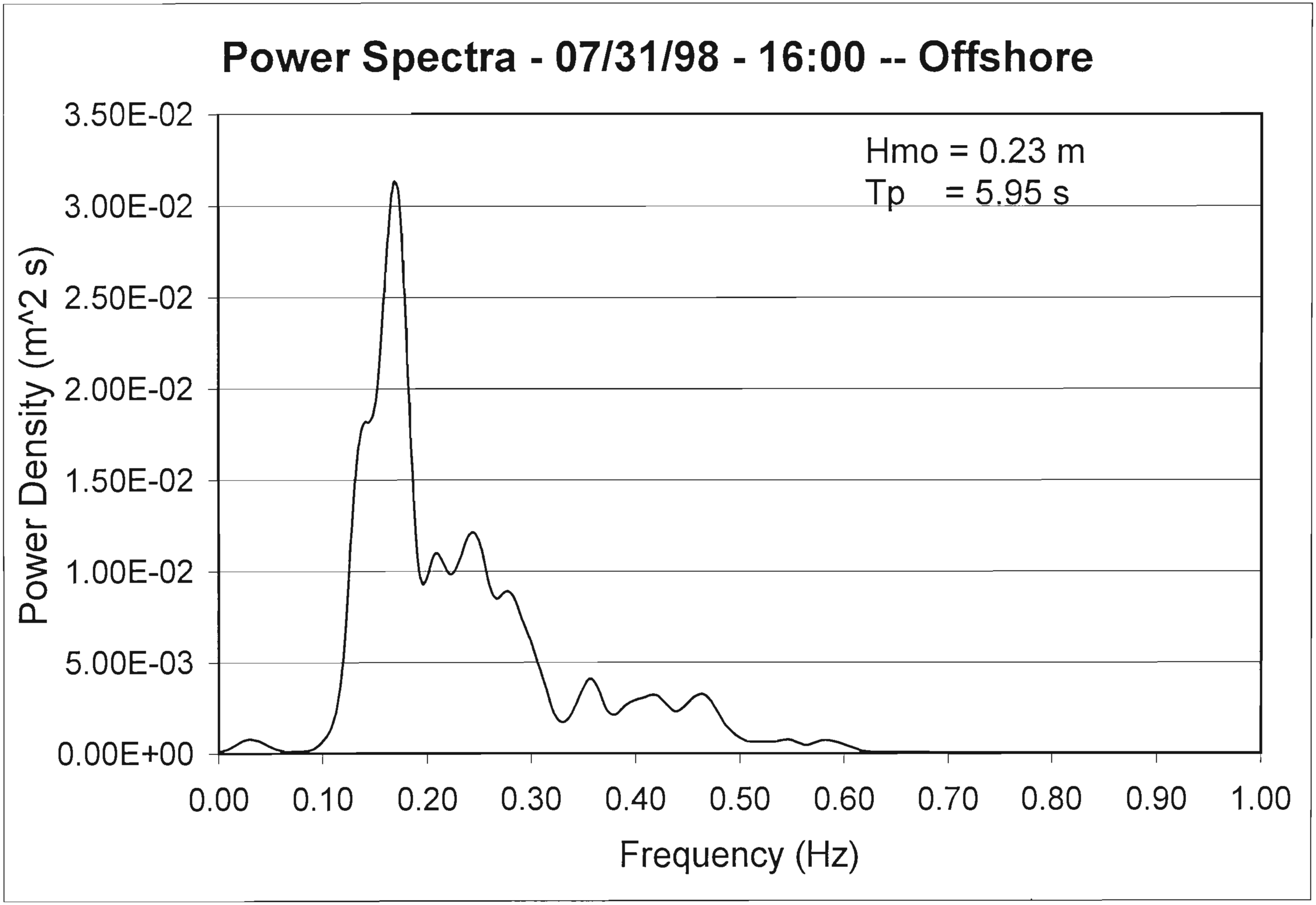

Power Spectra - 07/31/98 - 15:10 -- Offshore
Hmo = 0.22 m
Tp = 6.24 s
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

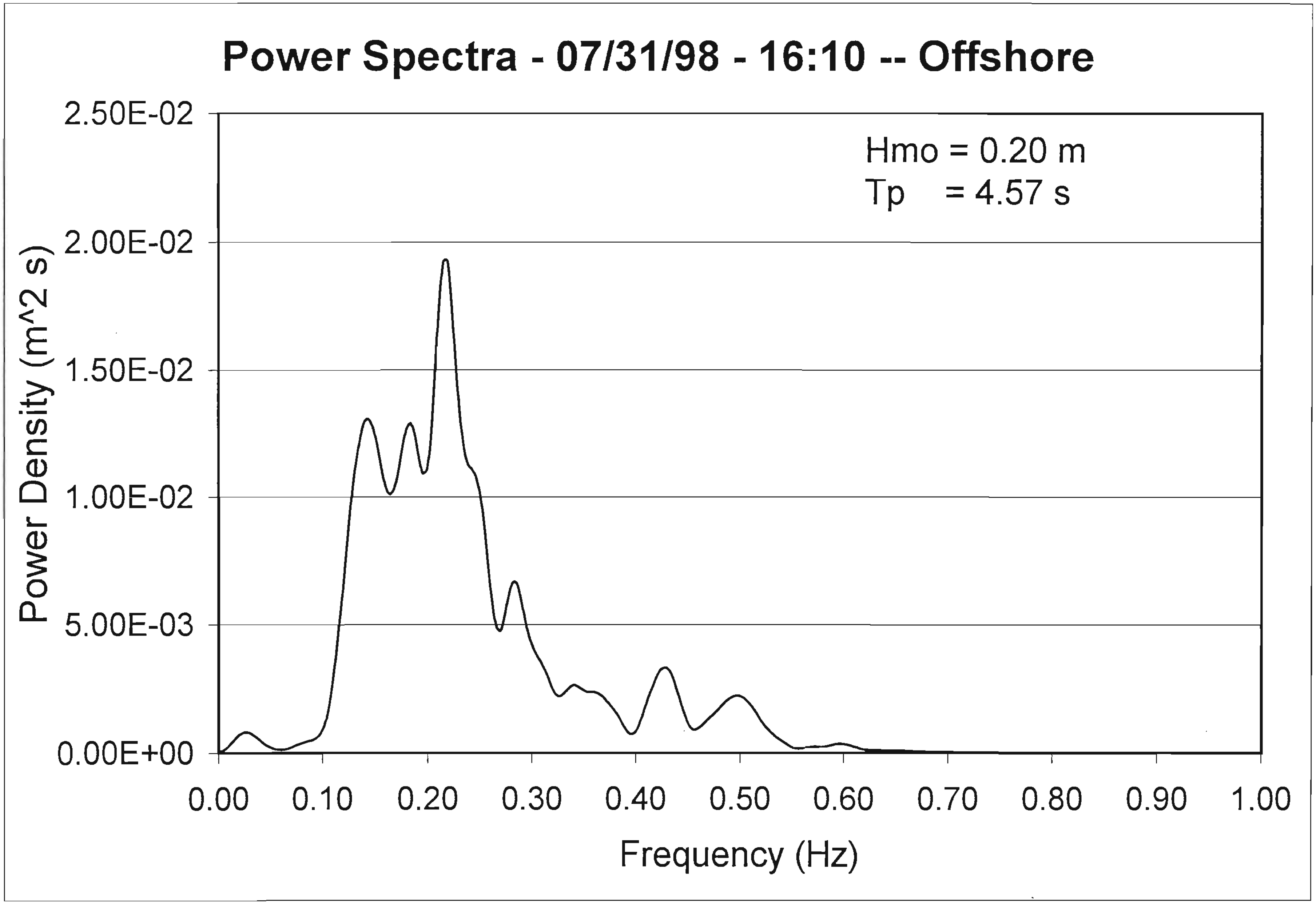

Power Spectra - 07/31/98 - 15:20 -- Offshore
Hmo = 0.21 m
Tp = 4.49 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

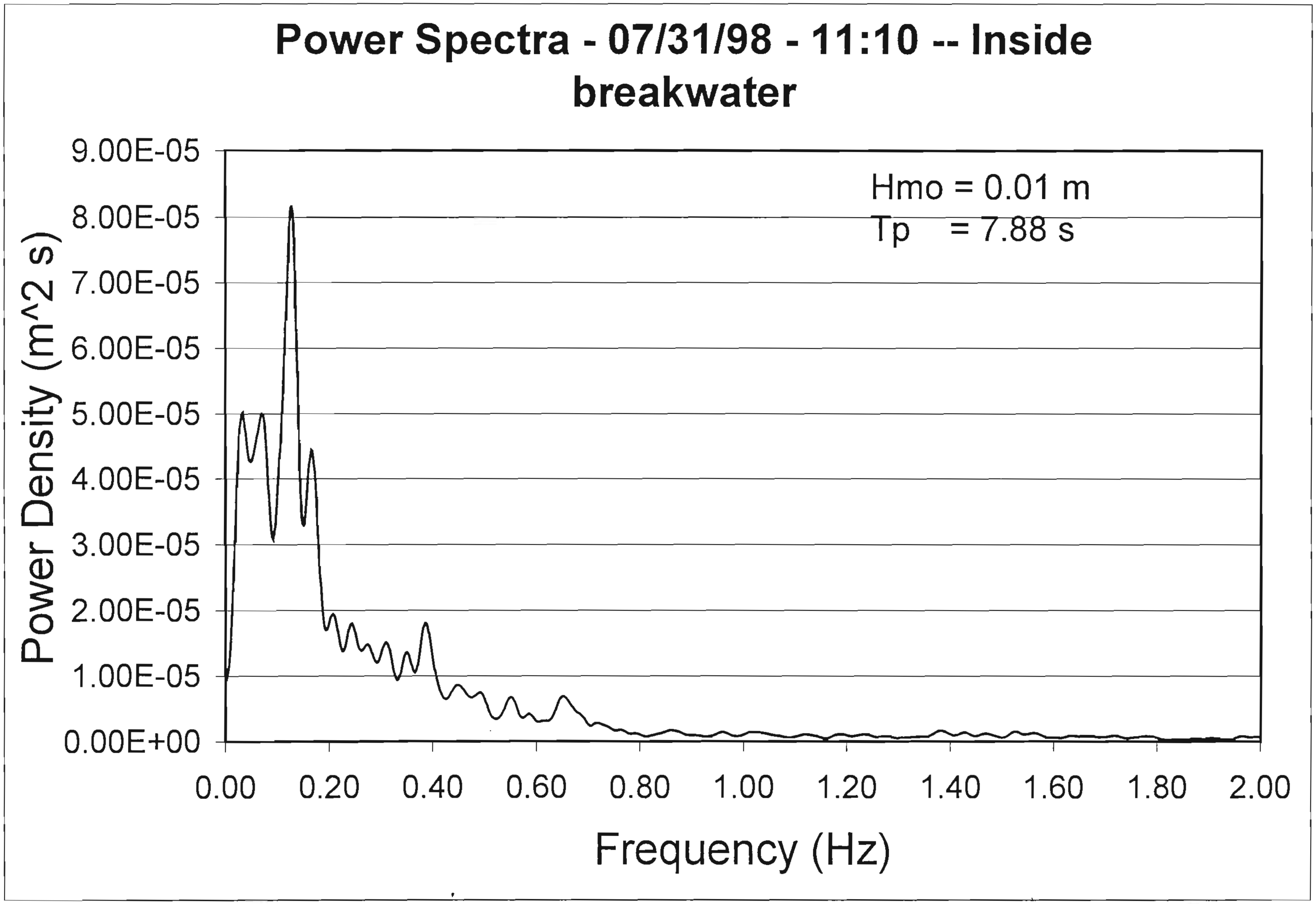

Power Spectra - 07/31/98 - 15:30 -- Offshore
Hmo = 0.19 m
Tp = 4.74 s
Power Density (m^2 s)
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

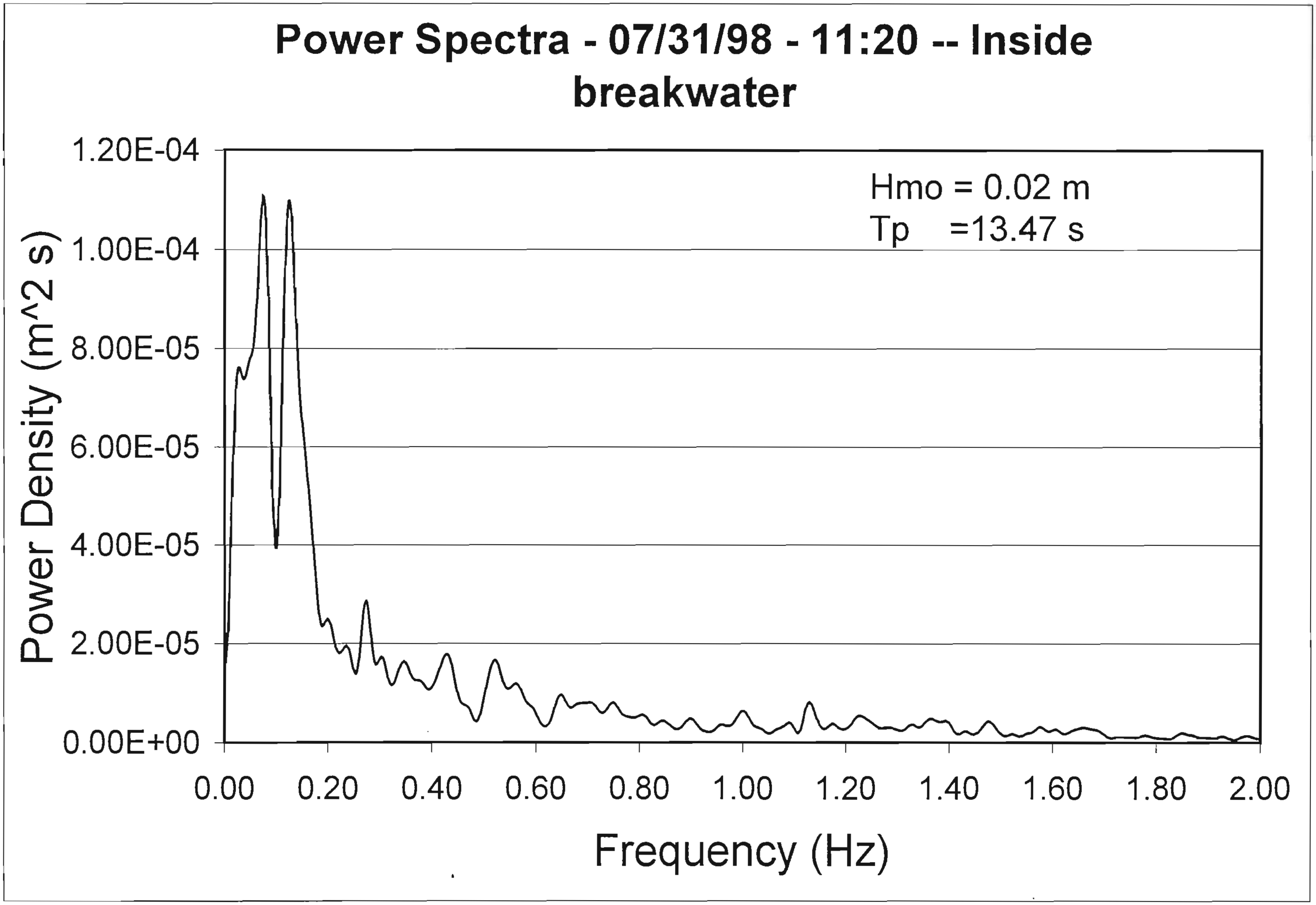

Power Spectra - 07/31/98 - 15:40 -- Offshore
Hmo = 0.19 m
Tp = 7.31 s
Power Density (m^2 s)
1.80E-02
1.60E-02
1.40E-02
1.20E-02
1.00E-02
8.00E-03
6.00E-03
4.00E-03
2.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

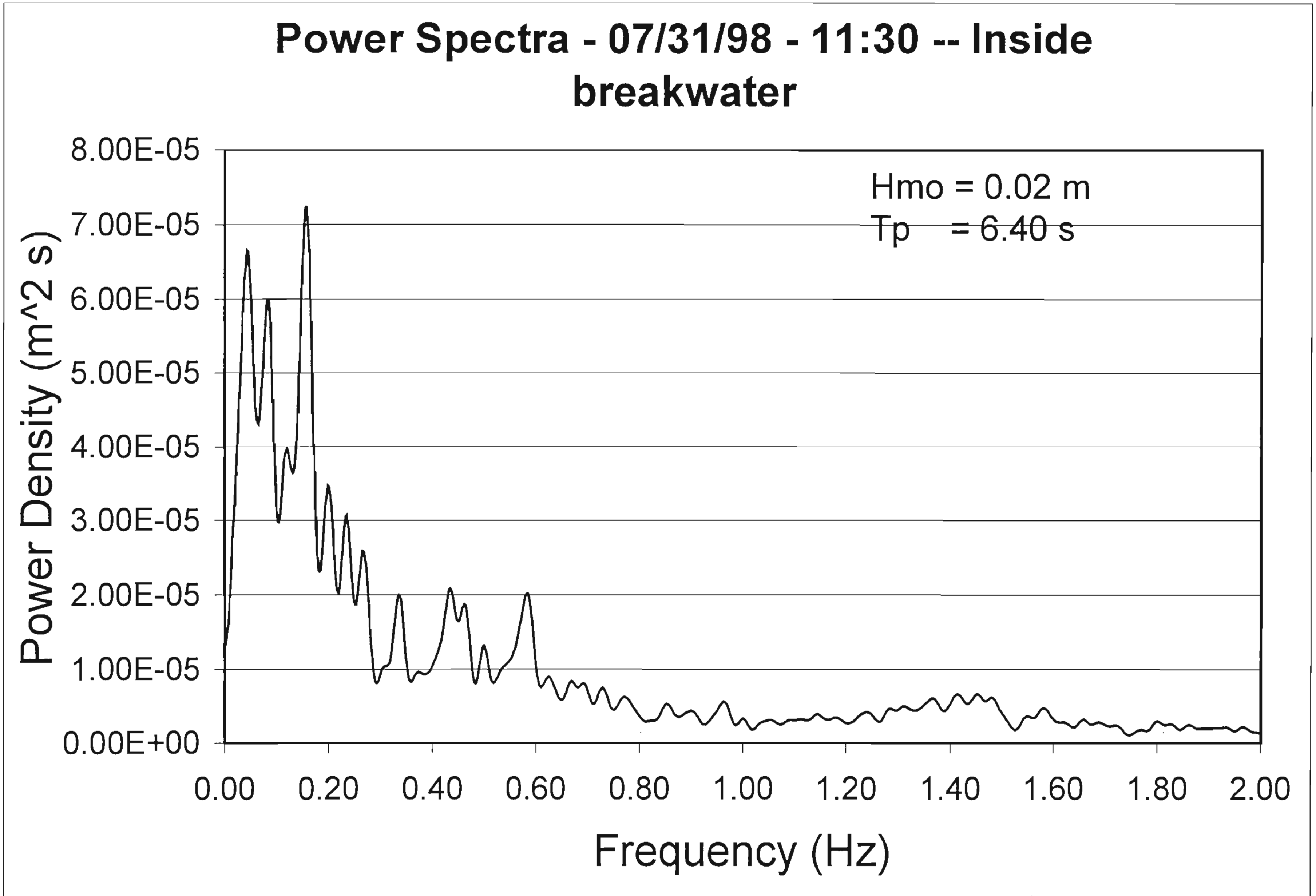

Power Spectra - 07/31/98 - 15:50 -- Offshore
Hmo = 0.19 m
Tp = 5.95 s
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
Power Density (m^2 s)
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)


Power Spectra - 07/31/98 - 16:00 -- Offshore
Hmo = 0.23 m
Tp = 5.95 s
Power Density (m^2 s)
3.50E-02
3.00E-02
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

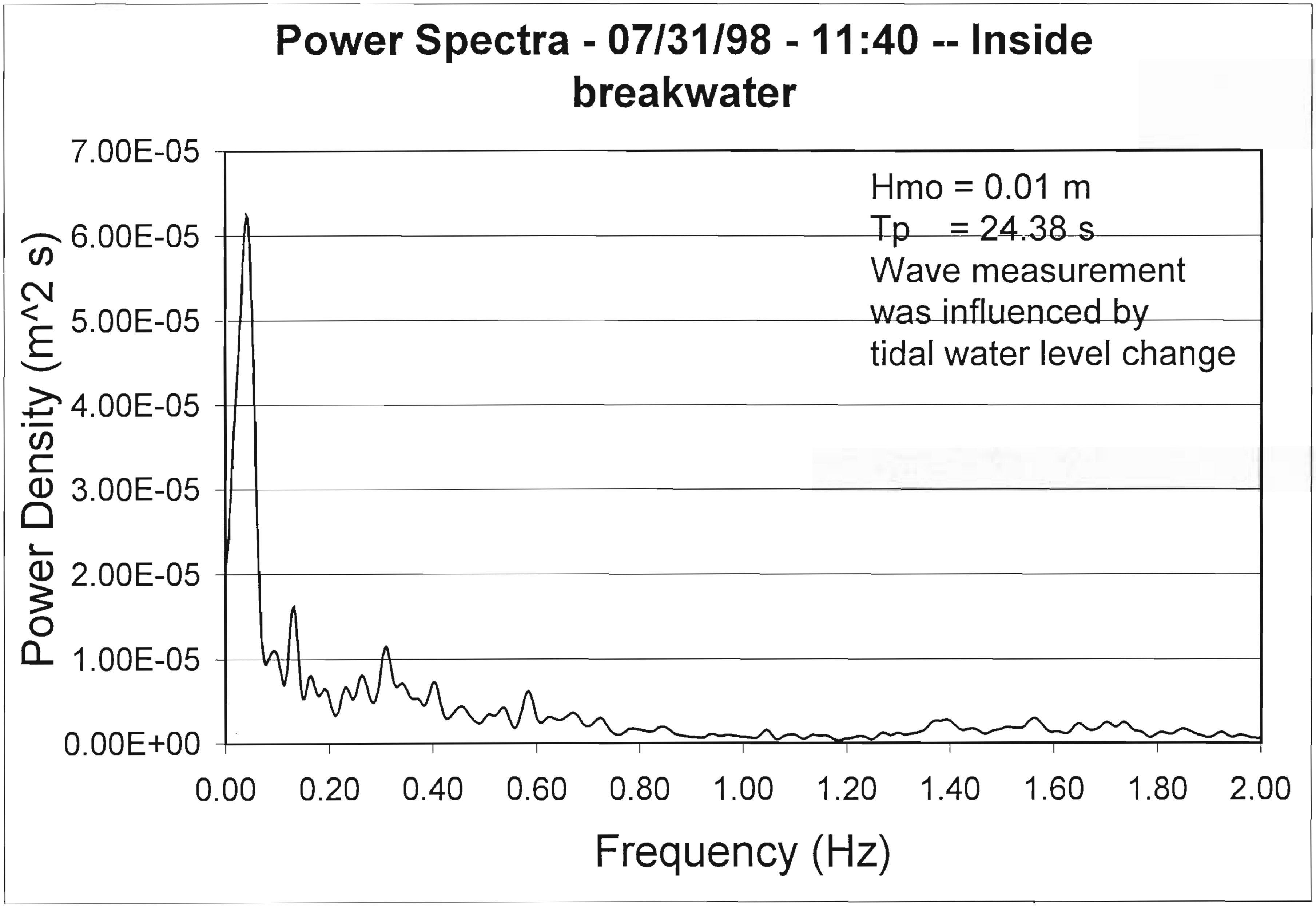

Power Spectra - 07/31/98 - 16:10 -- Offshore
Hmo = 0.20 m
Tp = 4.57 s
Power Density (m^2 s)
2.50E-02
2.00E-02
1.50E-02
1.00E-02
5.00E-03
0.00E+00
0.00
0.10
0.20
0.30
0.40
0.50
0.60
0.70
0.80
0.90
1.00
Frequency (Hz)

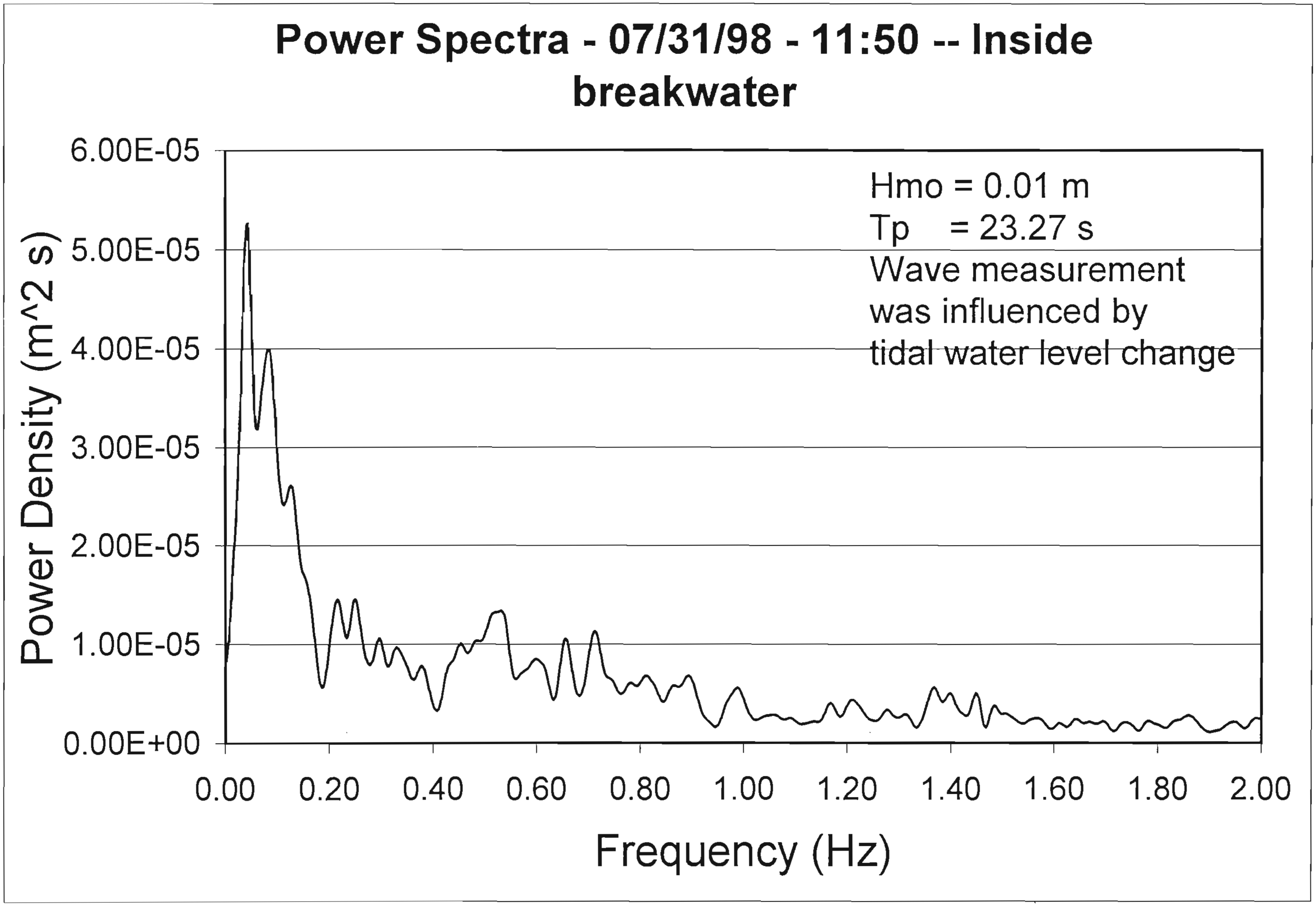

Power Spectra - 07/31/98 - 11:10 -- Inside breakwater
Hmo = 0.01 m
Tp = 7.88 s
Power Density (m^2 s)
9.00E-05
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

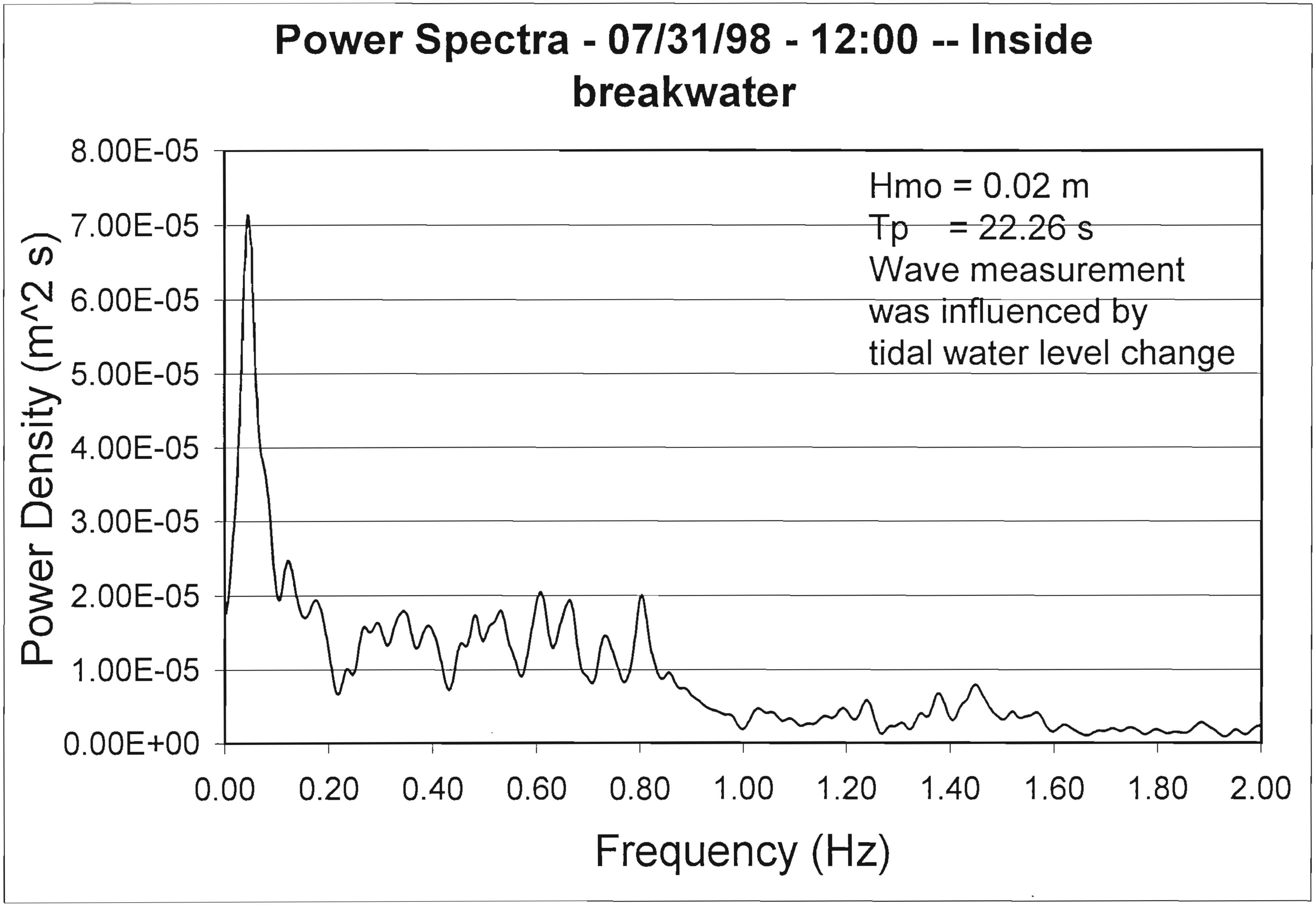

Power Spectra - 07/31/98 - 11:20 -- Inside breakwater
Hmo = 0.02 m
Tp =13.47 s
Power Density (m^2 s)
1.20E-04
1.00E-04
8.00E-05
6.00E-05
4.00E-05
2.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

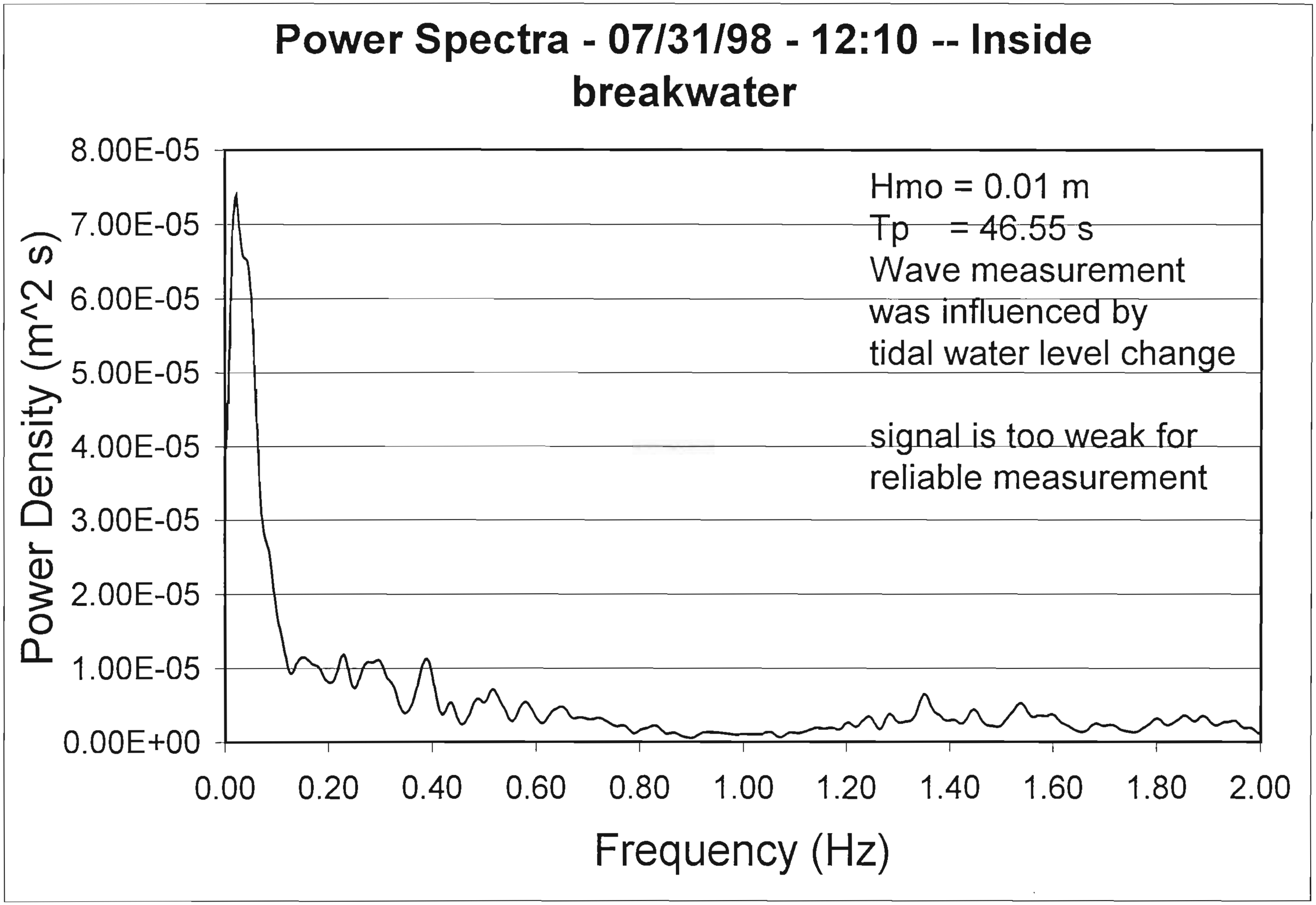


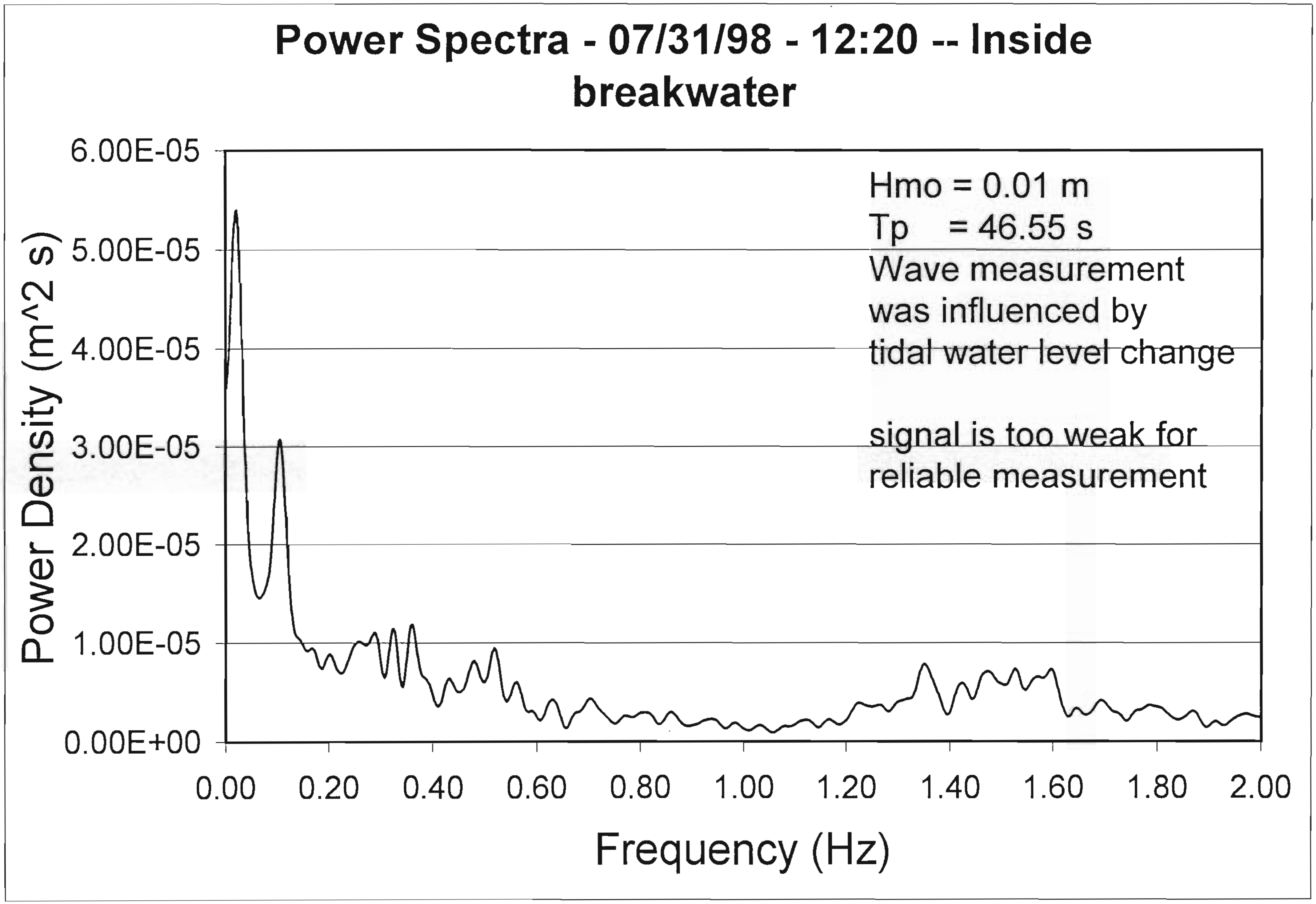
Power Spectra - 07/31/98 - 11:30 -- Inside breakwater
Hmo = 0.02 m
Tp = 6.40 s
Power Density (m^2 s)
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

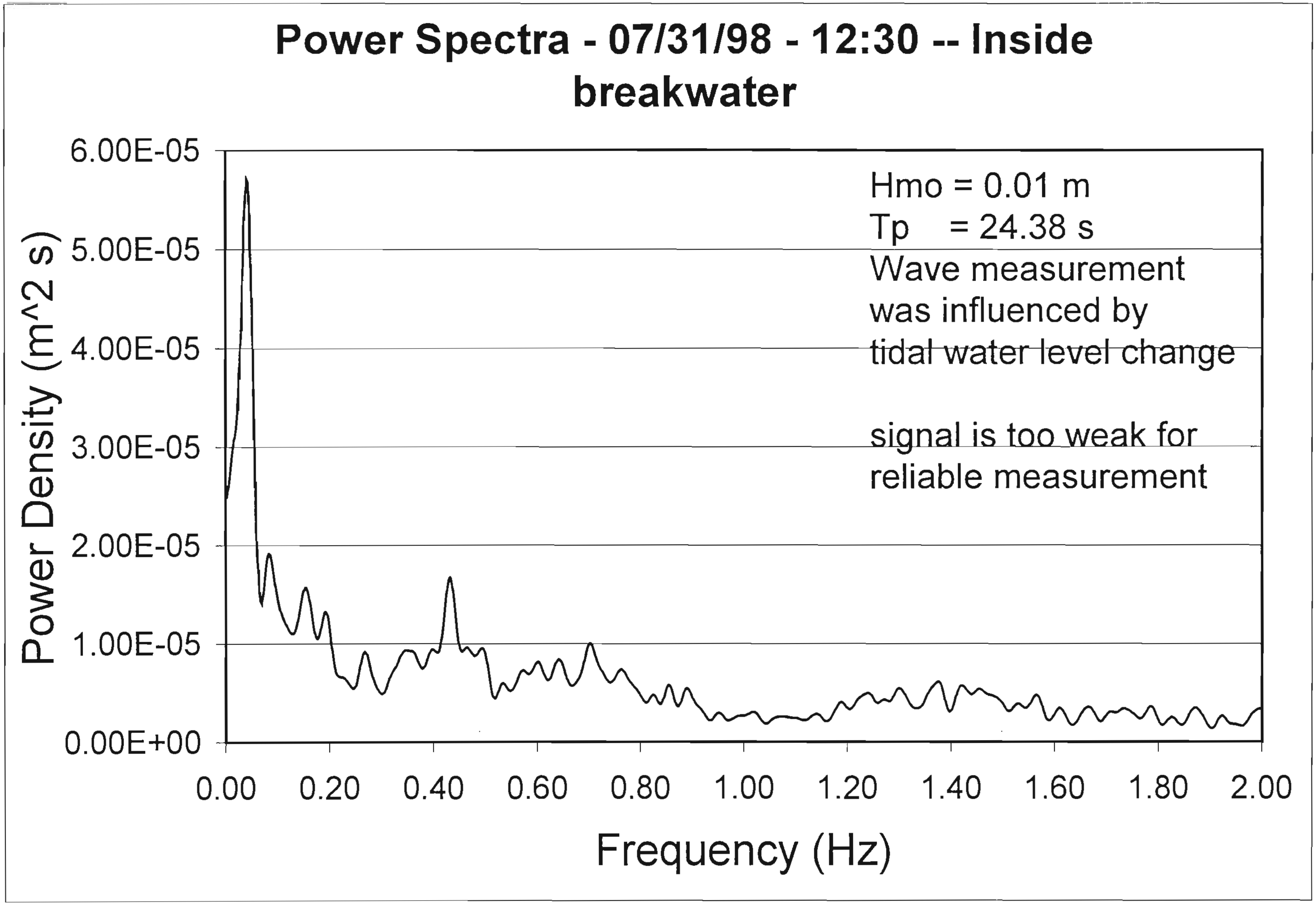

Power Spectra - 07/31/98 - 11:40 -- Inside breakwater
Hmo = 0.01 m
Tp = 24.38 s
Wave measurement was influenced by tidal water level change
Power Density (m^2 s)
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

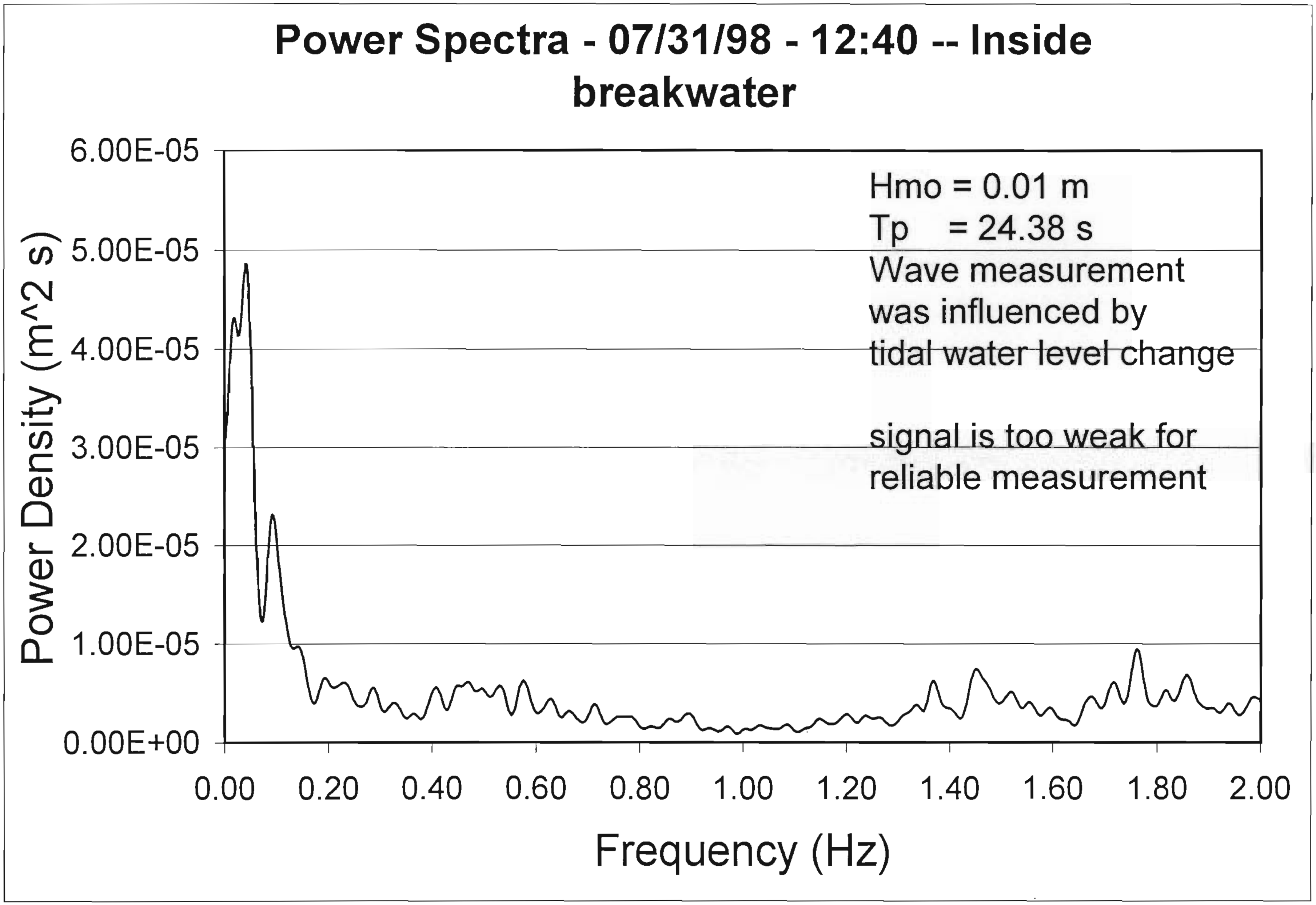

Power Spectra - 07/31/98 - 11:50 -- Inside breakwater
Hmo = 0.01 m
Tp = 23.27 s
Wave measurement was influenced by tidal water level change
Power Density (m^2 s)
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 07/31/98 - 12:00 -- Inside breakwater
Hmo = 0.02 m
Tp = 22.26 s
Wave measurement
was influenced by
tidal water level change
Power Density (m^2 s)
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

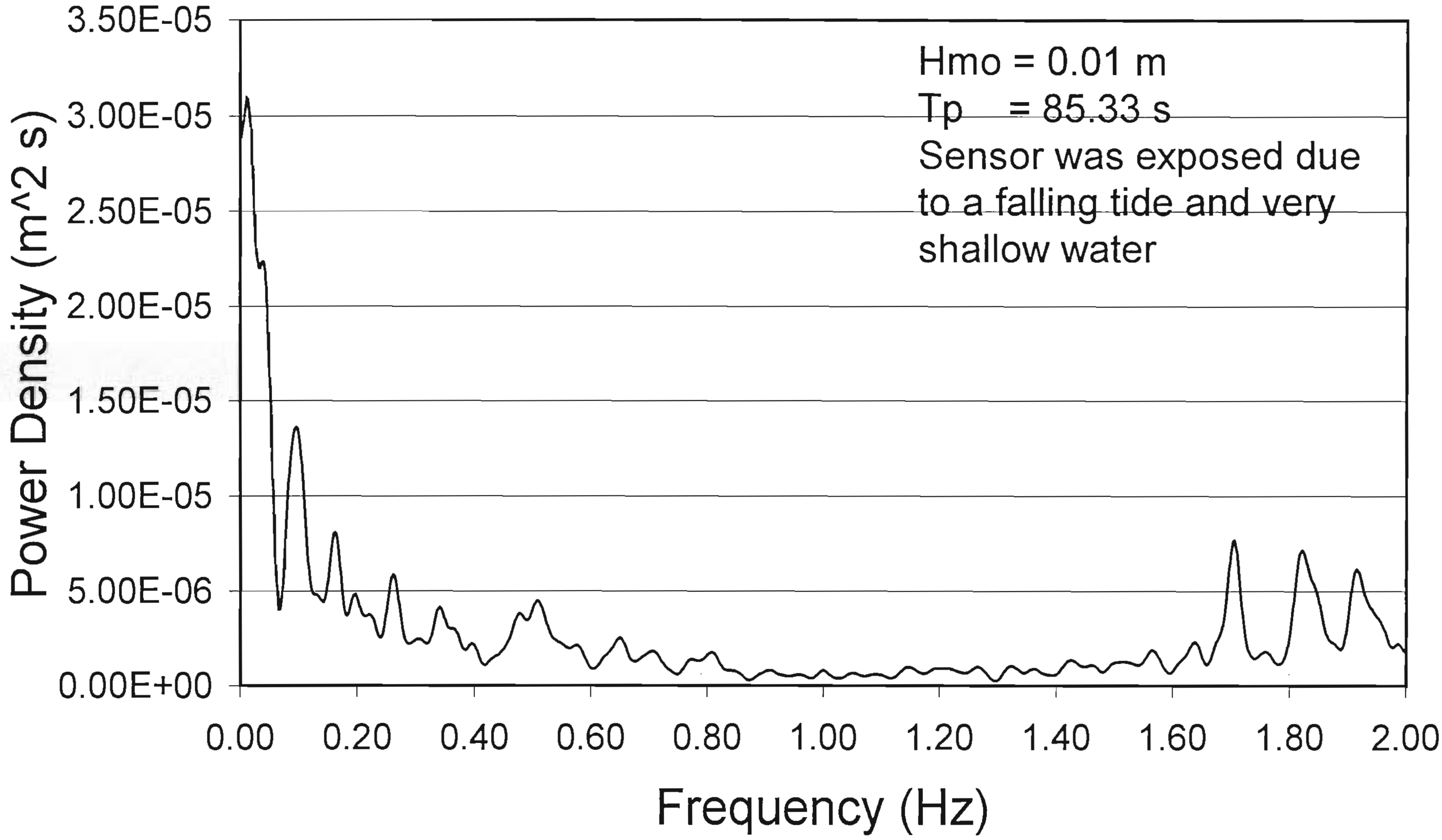

Power Spectra - 07/31/98 - 12:10 -- Inside breakwater
Hmo = 0.01 m
Tp = 46.55 s
Wave measurement was influenced by tidal water level change
signal is too weak for reliable measurement
Power Density (m^2 s)
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

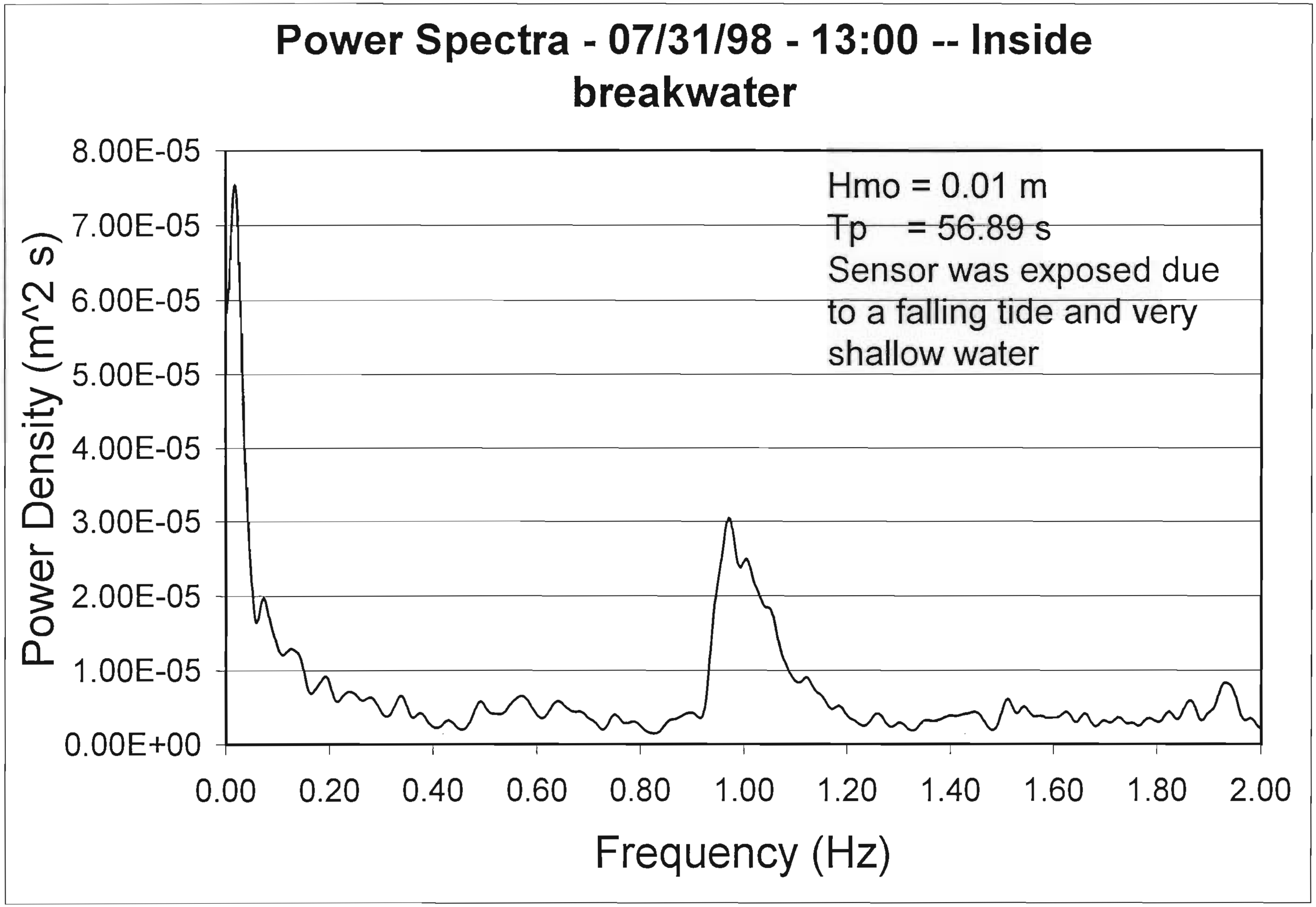

Power Spectra - 07/31/98 - 12:20 -- Inside breakwater
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)
Hmo = 0.01 m
Tp = 46.55 s
Wave measurement
was influenced by
tidal water level change
signal is too weak for
reliable measurement


Power Spectra - 07/31/98 - 12:30 -- Inside breakwater
Hmo = 0.01 m
Tp = 24.38 s
Wave measurement
was influenced by
tidal water level change
signal is too weak for
reliable measurement
Power Density (m^2 s)
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

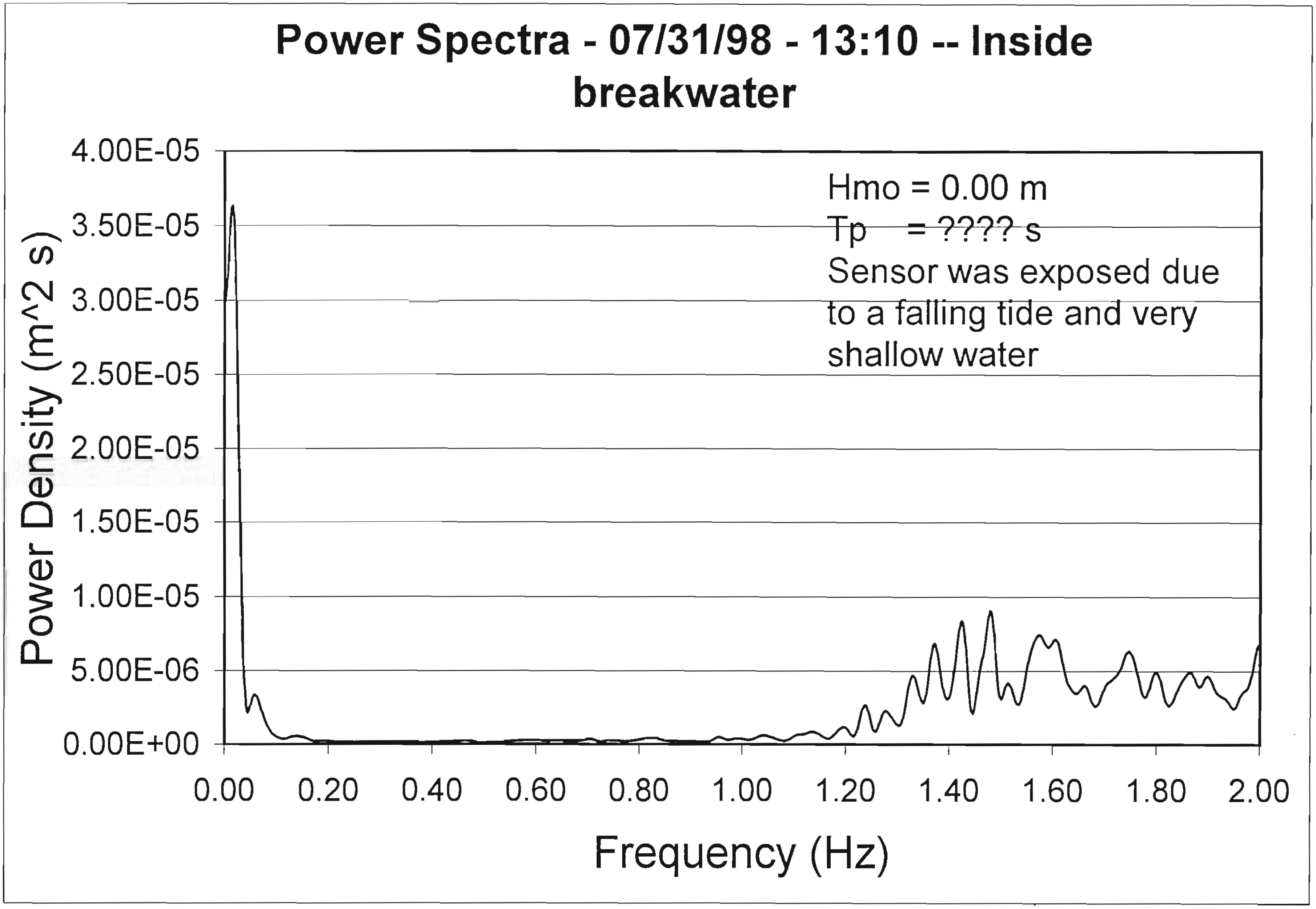

Power Spectra - 07/31/98 - 12:40 -- Inside breakwater
Hmo = 0.01 m
Tp = 24.38 s
Wave measurement was influenced by tidal water level change
signal is too weak for reliable measurement
Power Density (m^2 s)
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

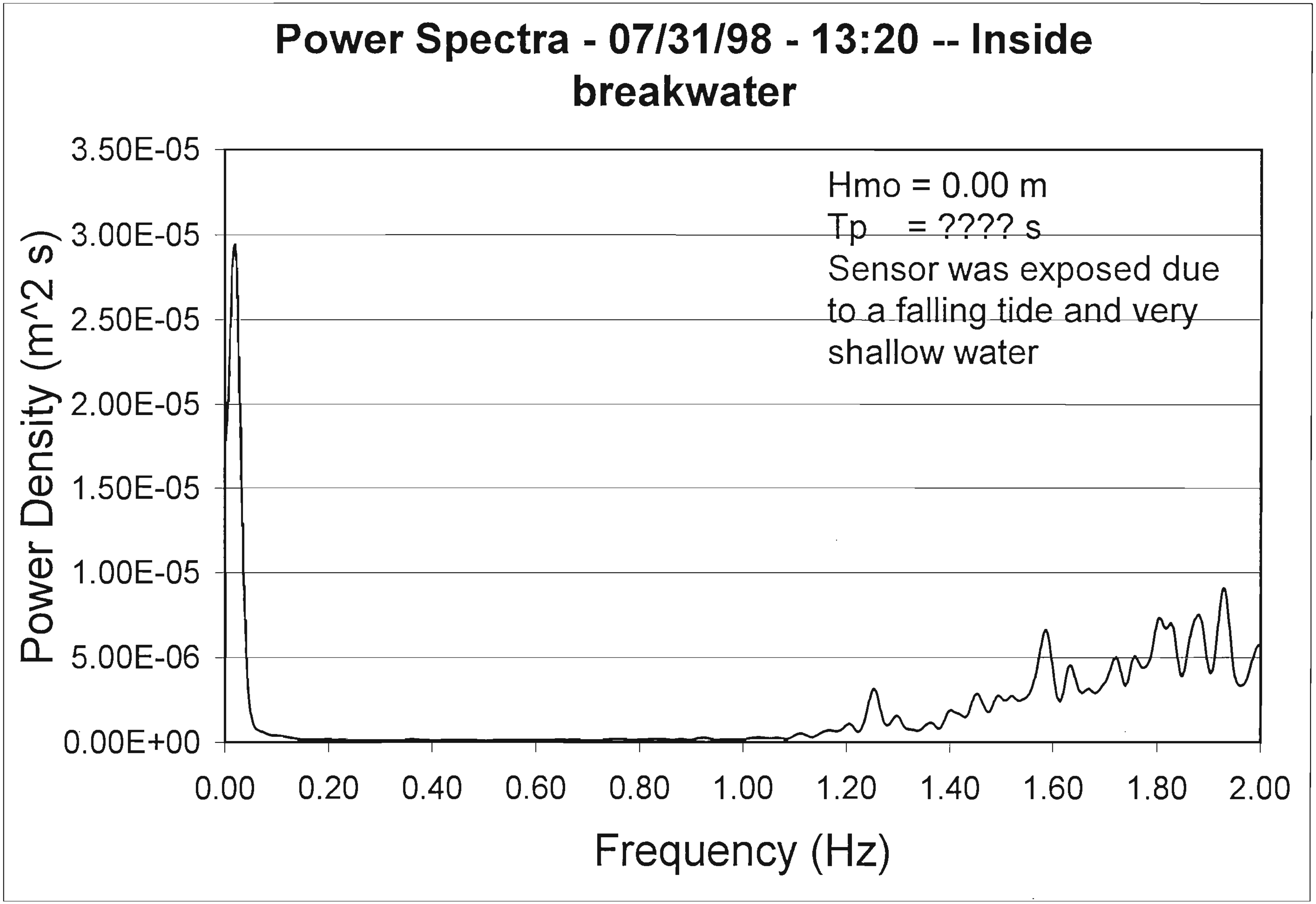
Power Spectra - 07/31/98 - 12:50 -- Inside breakwater

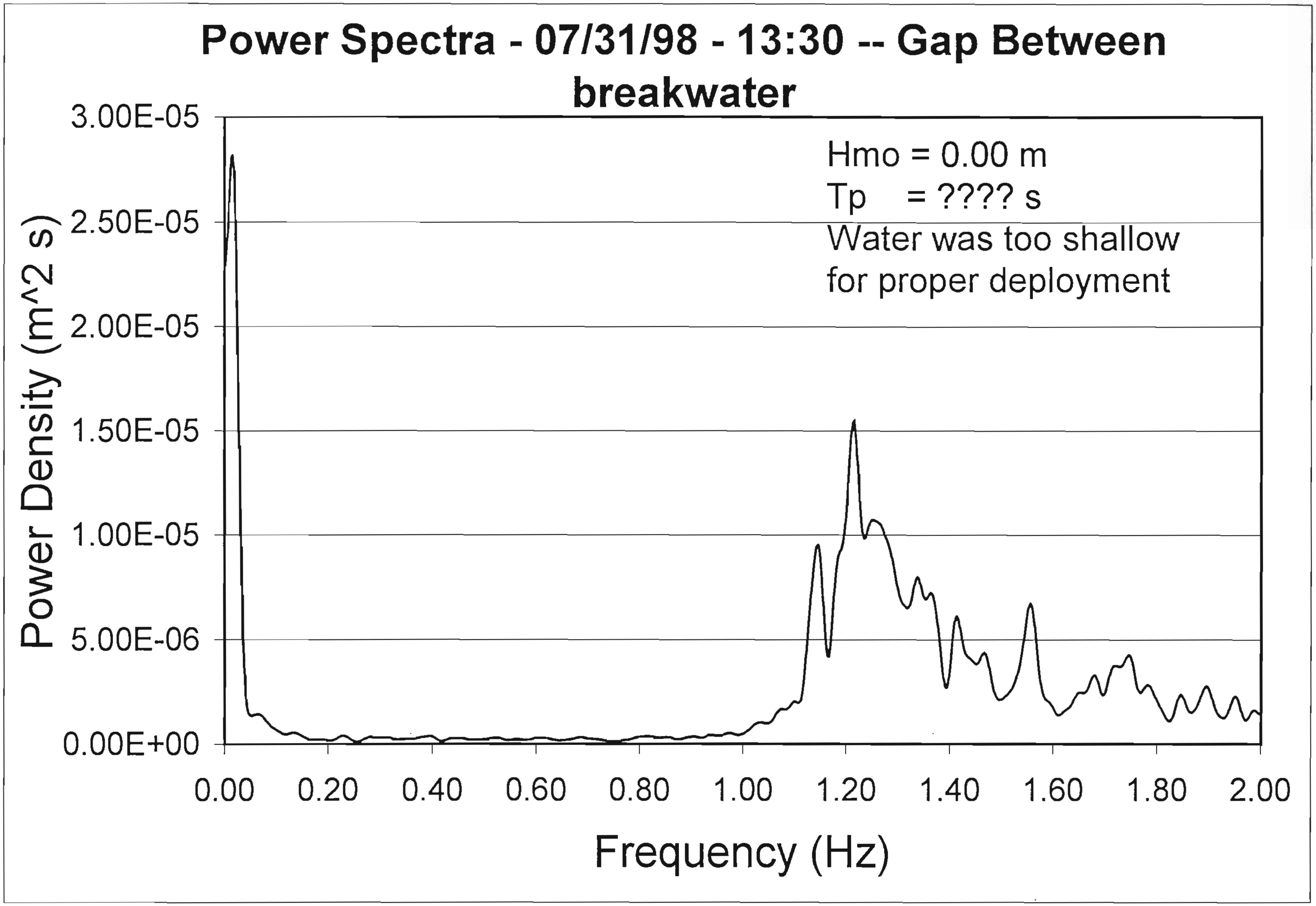


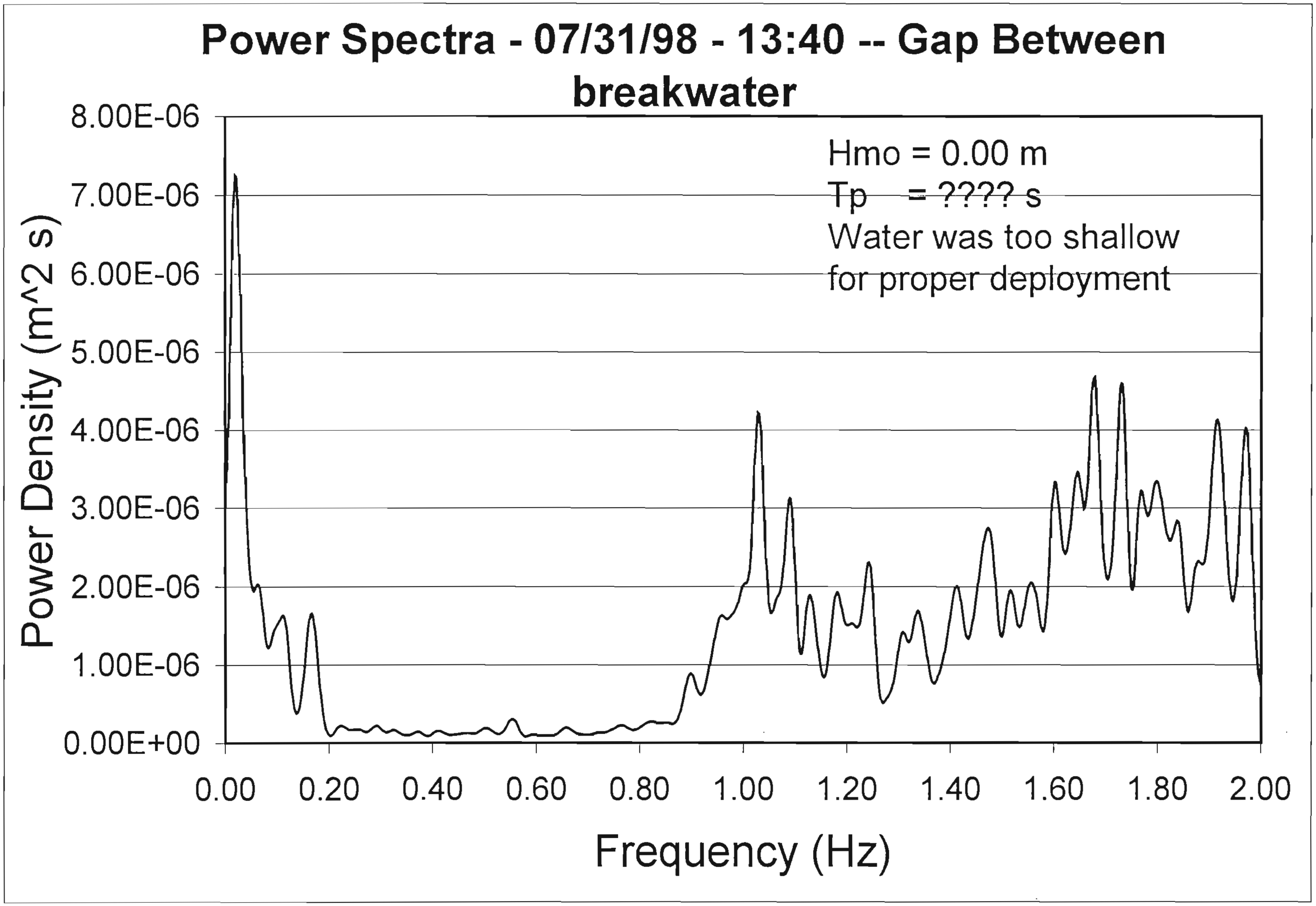


Power Spectra - 07/31/98 - 13:00 -- Inside breakwater
Hmo = 0.01 m
Tp = 56.89 s
Sensor was exposed due to a falling tide and very shallow water
Power Density (m^2 s)
8.00E-05
7.00E-05
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

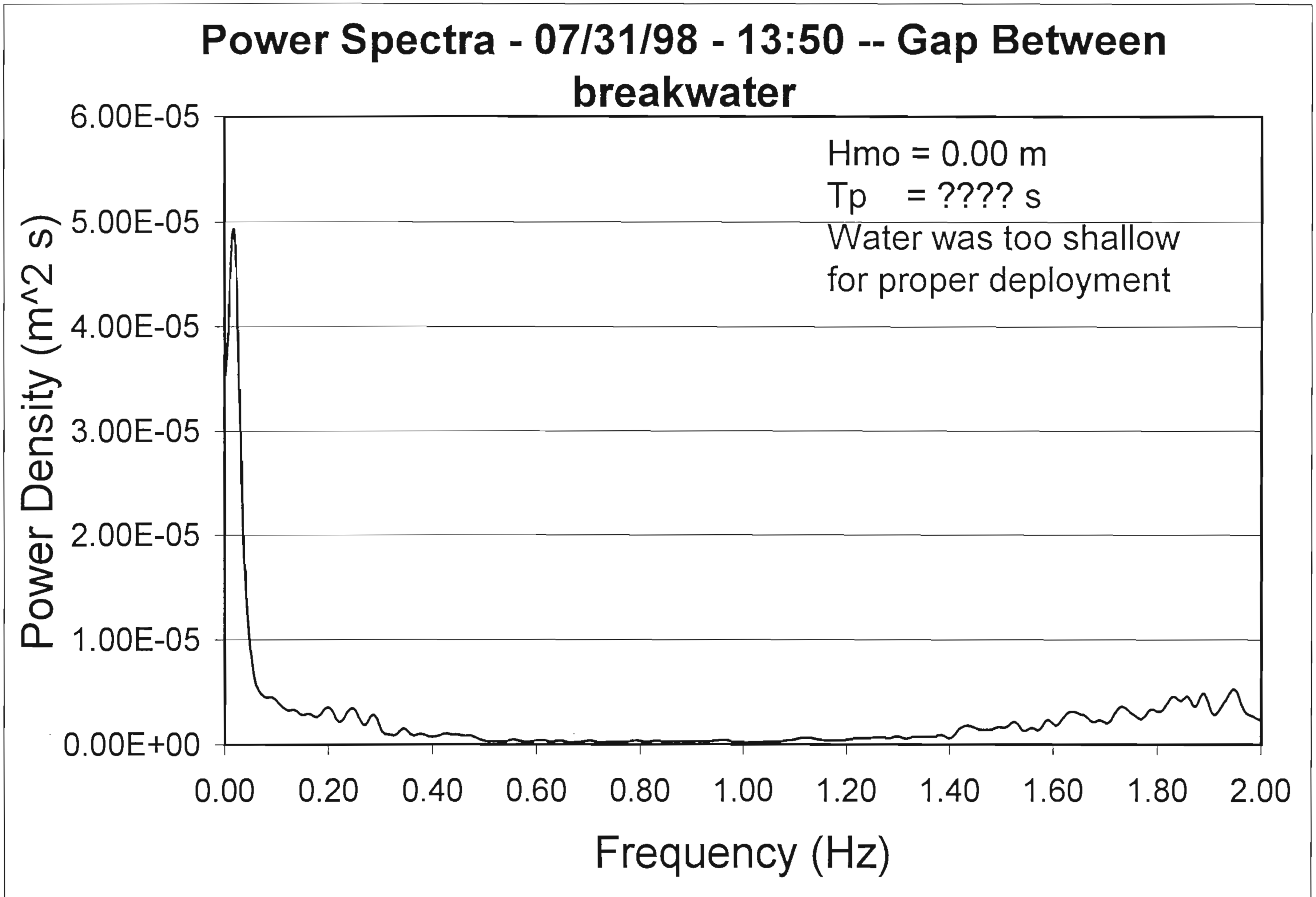

Power Spectra - 07/31/98 - 13:10 -- Inside breakwater
Hmo = 0.00 m
Tp = ???? s
Sensor was exposed due to a falling tide and very shallow water
4.00E-05
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

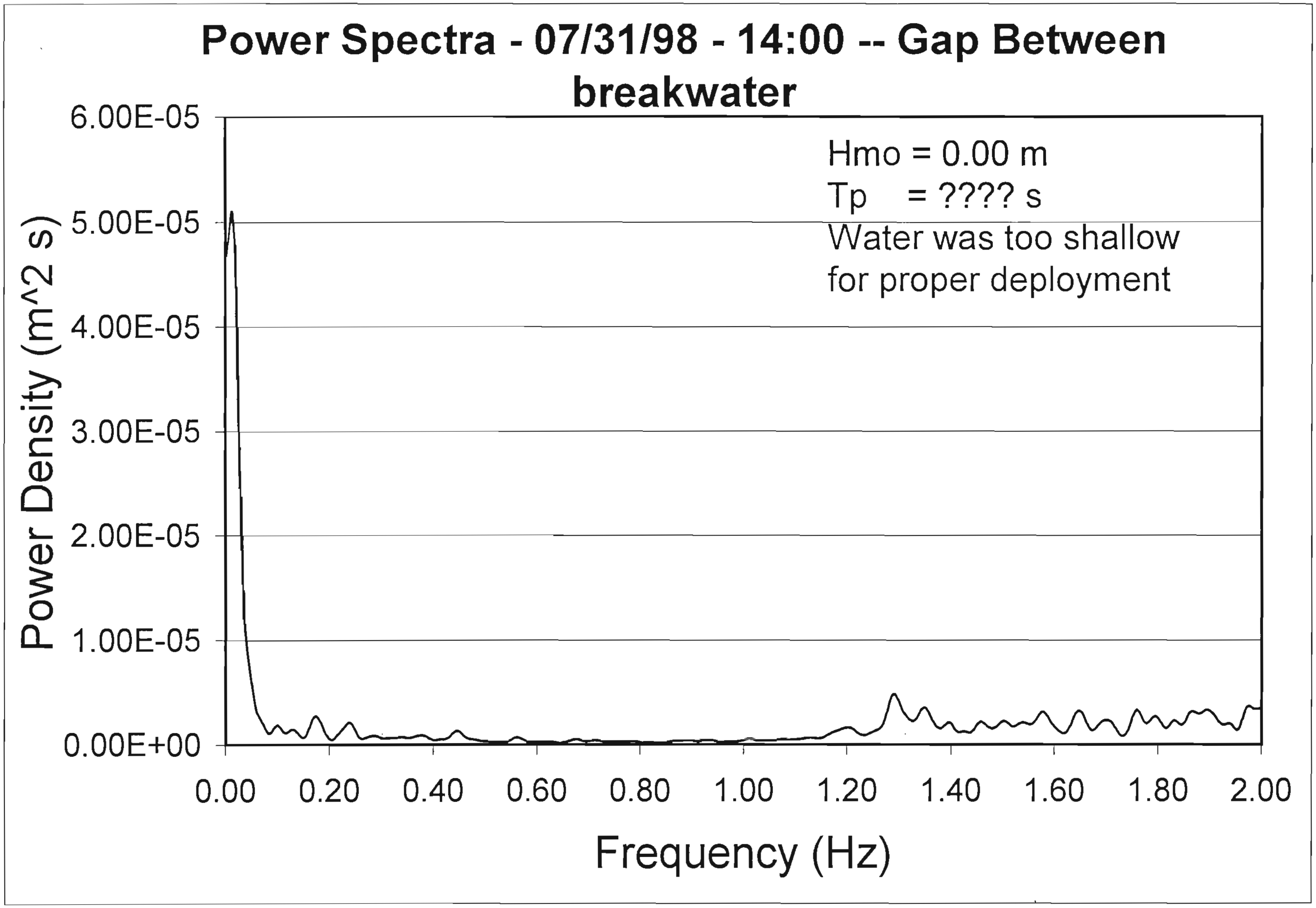

Power Spectra - 07/31/98 - 13:20 -- Inside breakwater
Hmo = 0.00 m
Tp = ???? s
Sensor was exposed due to a falling tide and very shallow water
Power Density (m^2 s)
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

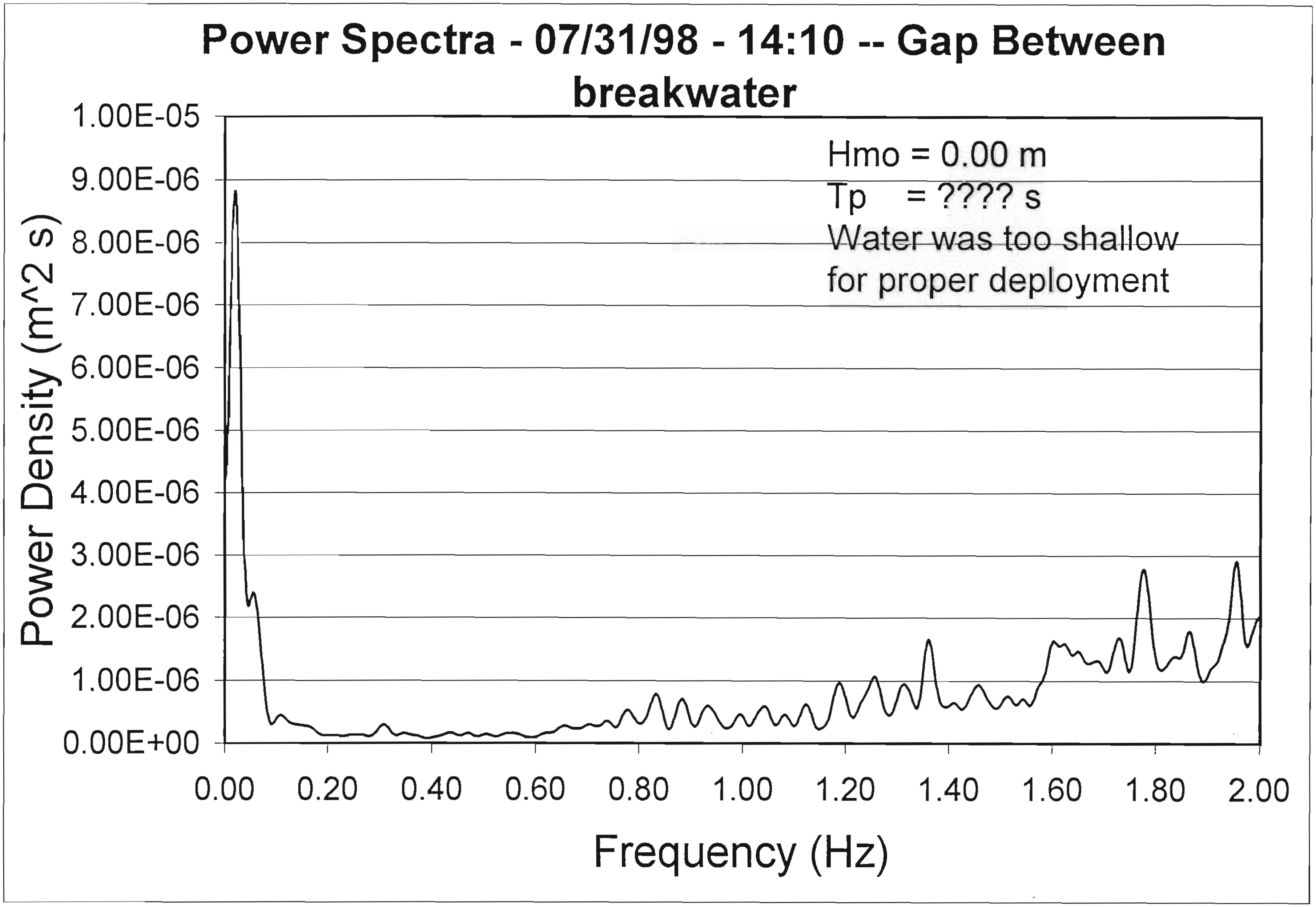

Power Spectra - 07/31/98 - 13:30 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

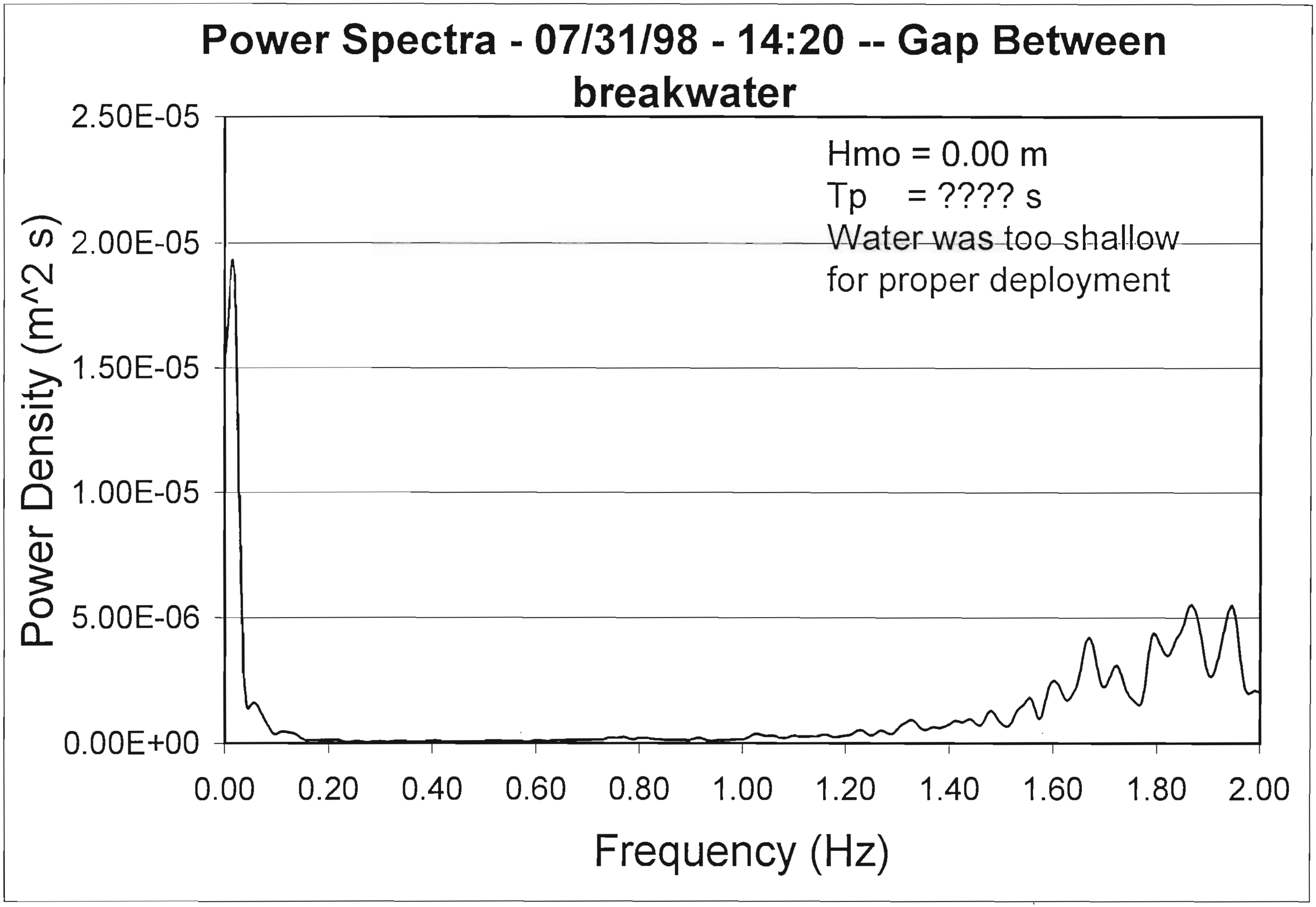


Power Spectra - 07/31/98 - 13:40 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

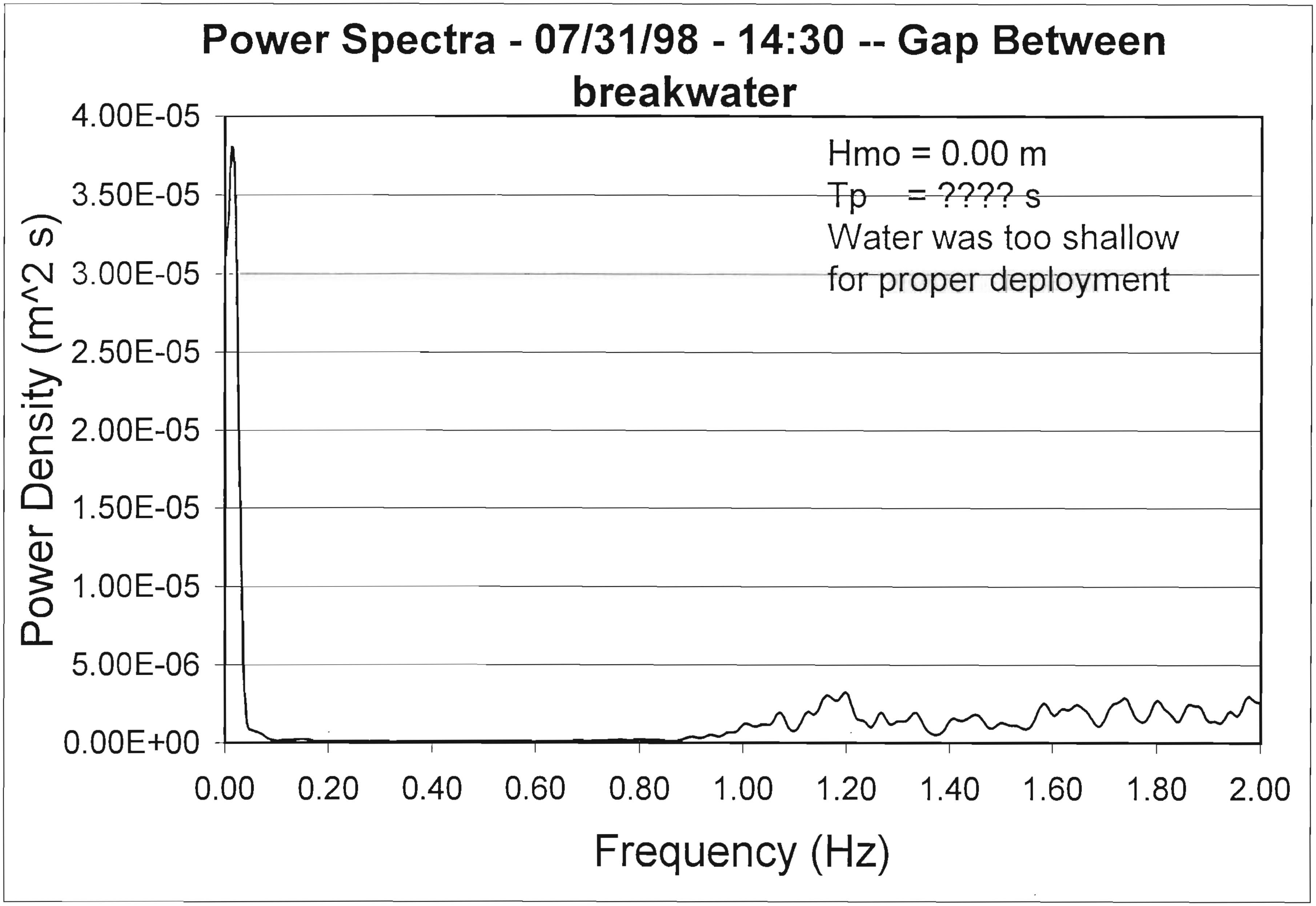

Power Spectra - 07/31/98 - 13:50 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

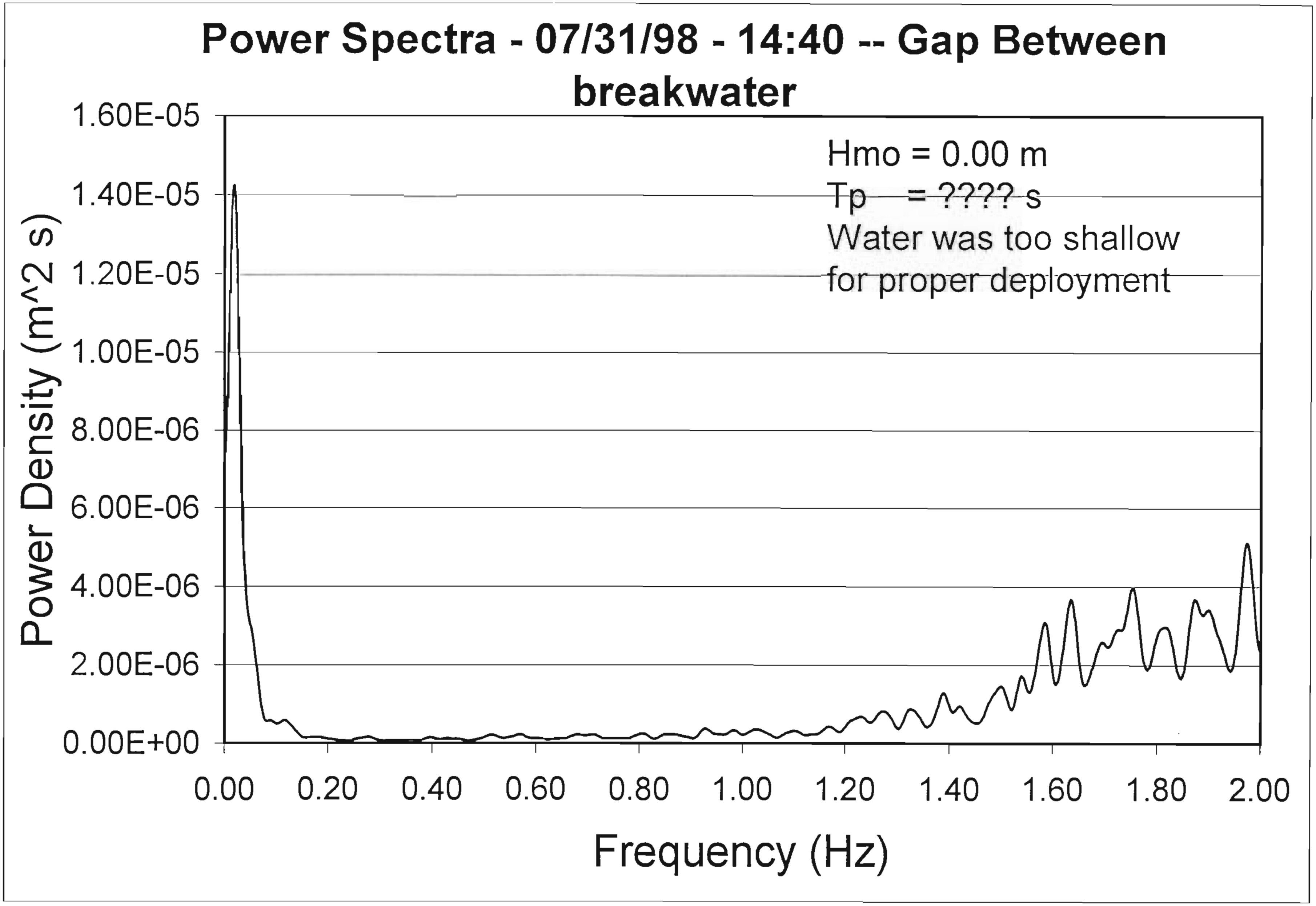

Power Spectra - 07/31/98 - 14:00 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
6.00E-05
5.00E-05
4.00E-05
3.00E-05
2.00E-05
1.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

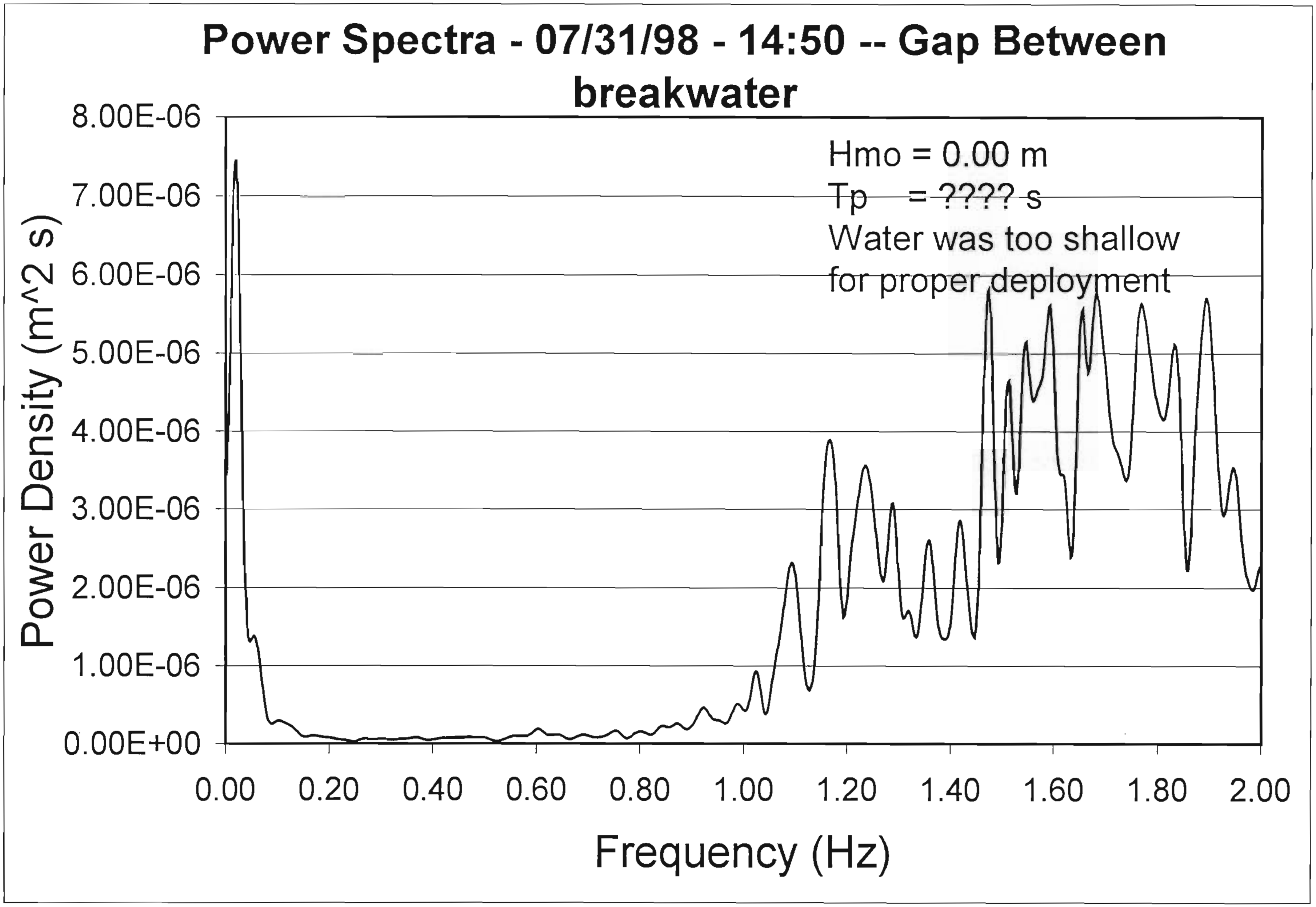

Power Spectra - 07/31/98 - 14:10 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
1.00E-05
9.00E-06
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)



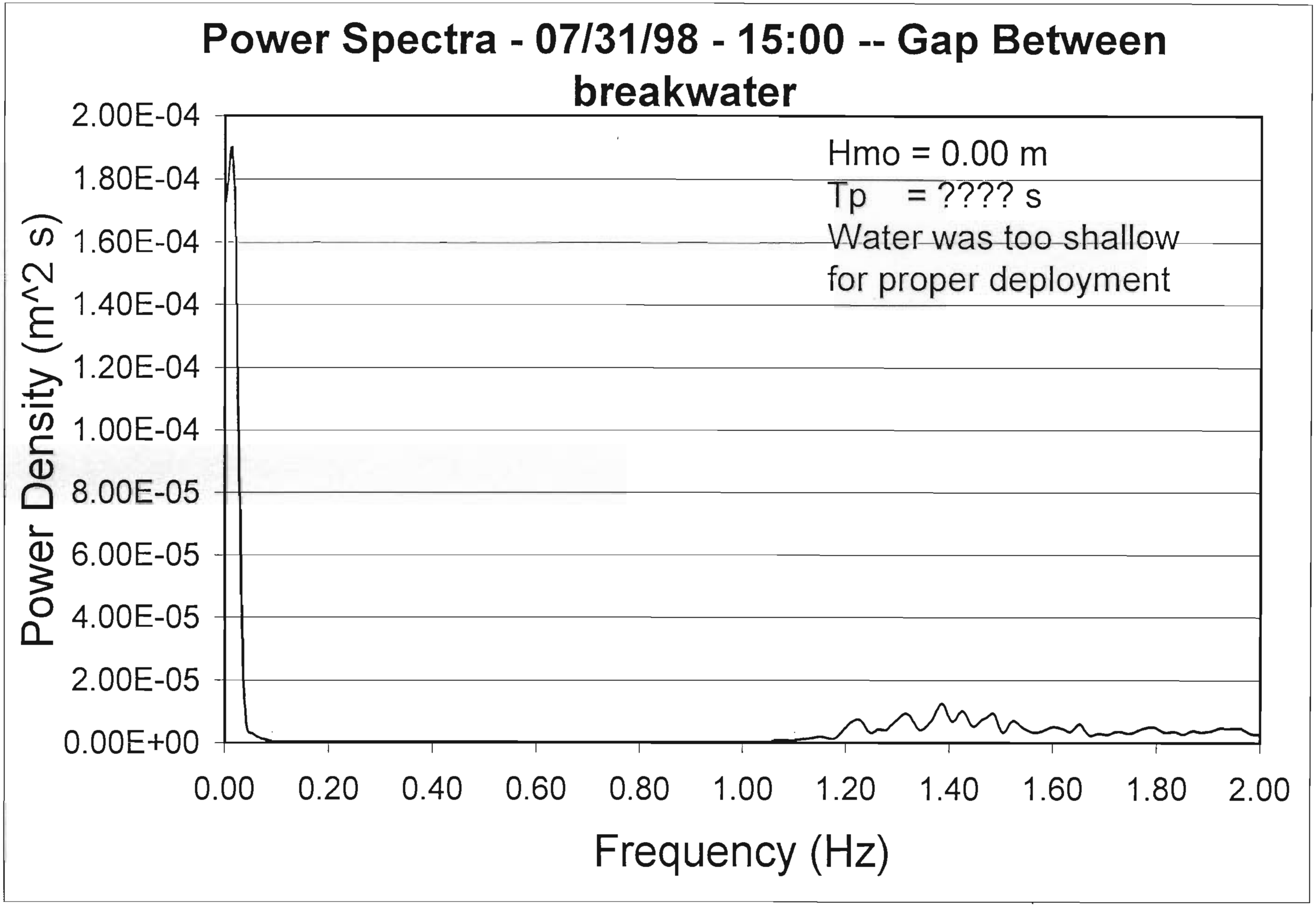
Power Spectra - 07/31/98 - 14:20 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

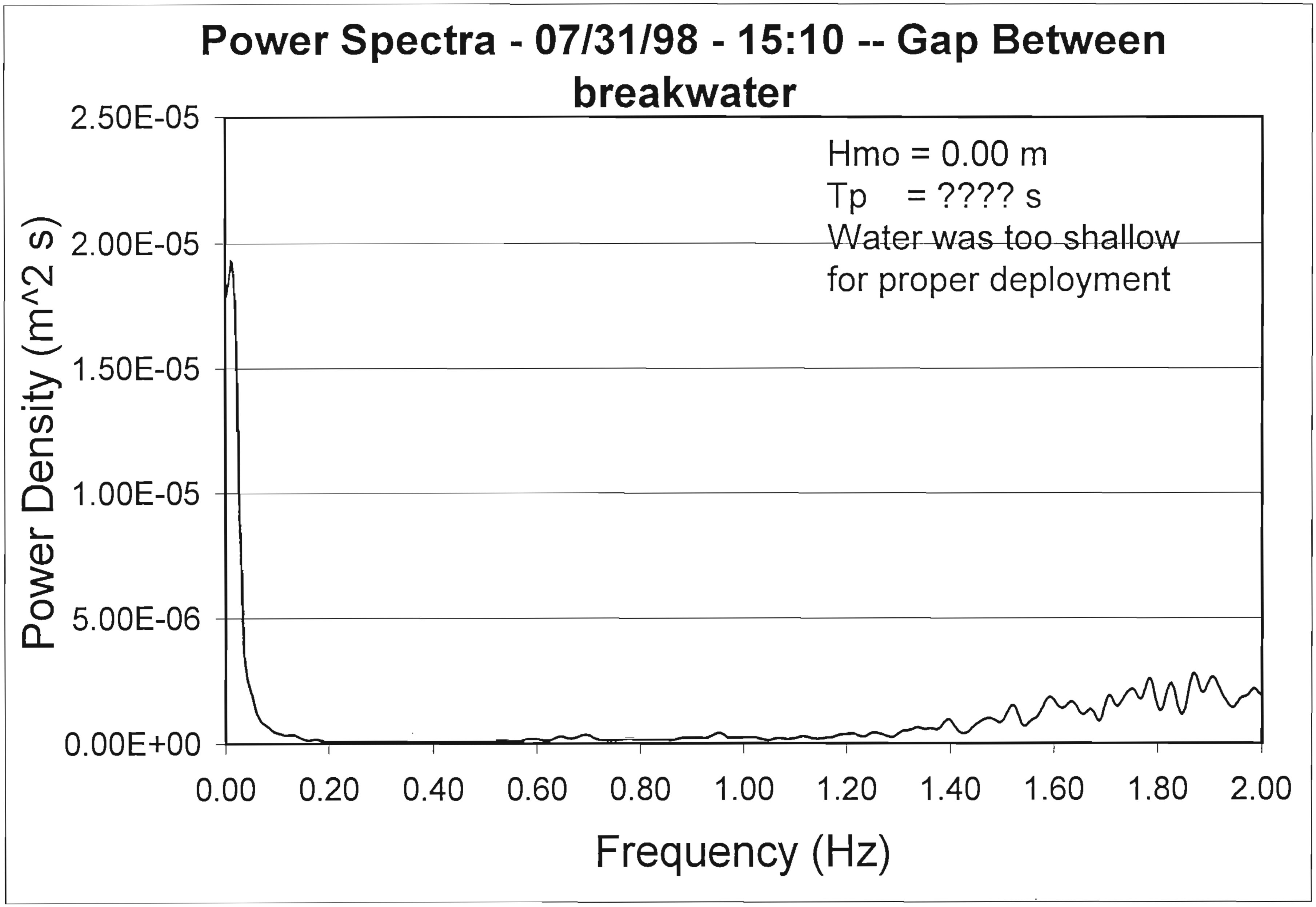

Power Spectra - 07/31/98 - 14:30 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
4.00E-05
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

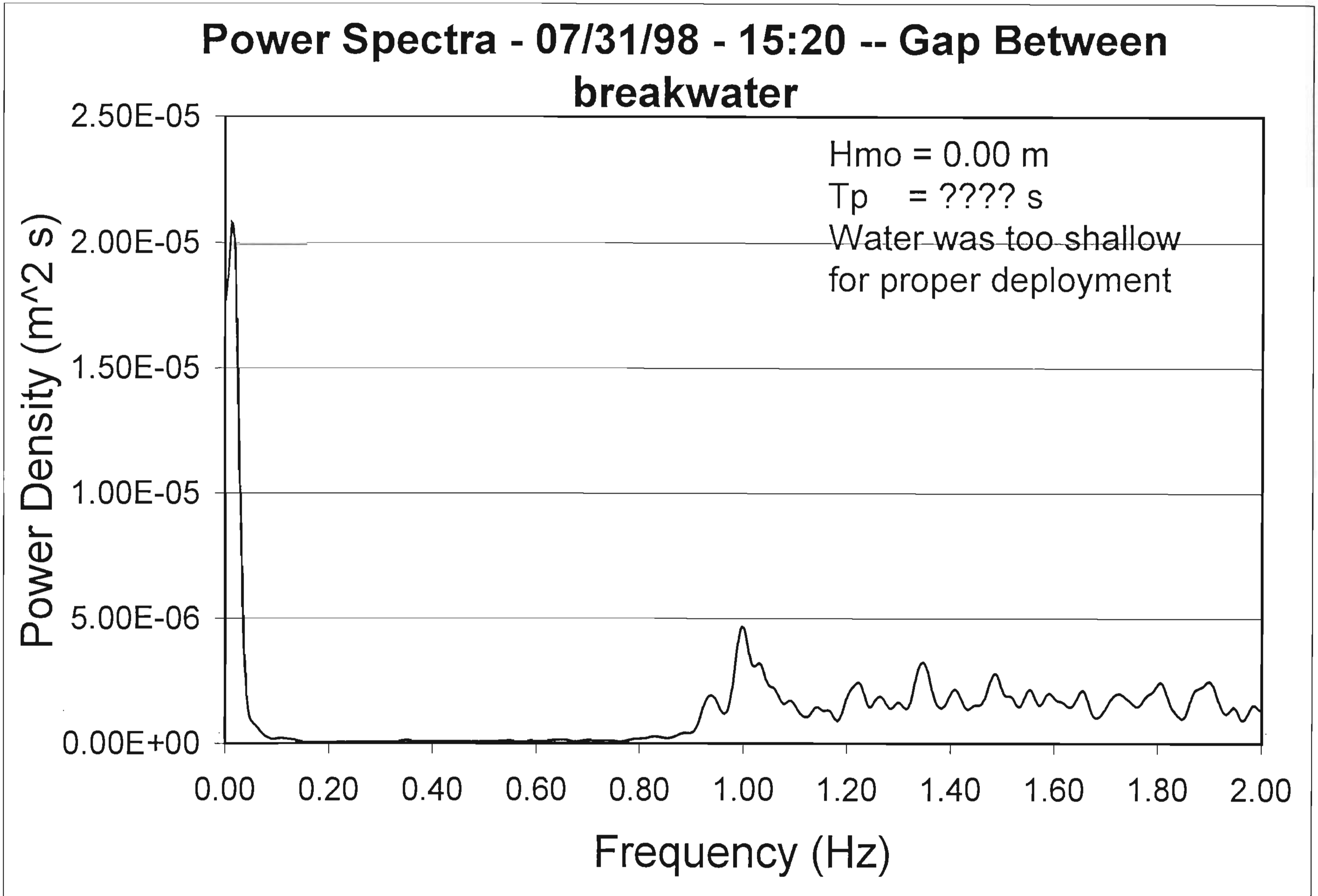

Power Spectra - 07/31/98 - 14:40 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
1.60E-05
1.40E-05
1.20E-05
1.00E-05
8.00E-06
6.00E-06
4.00E-06
2.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

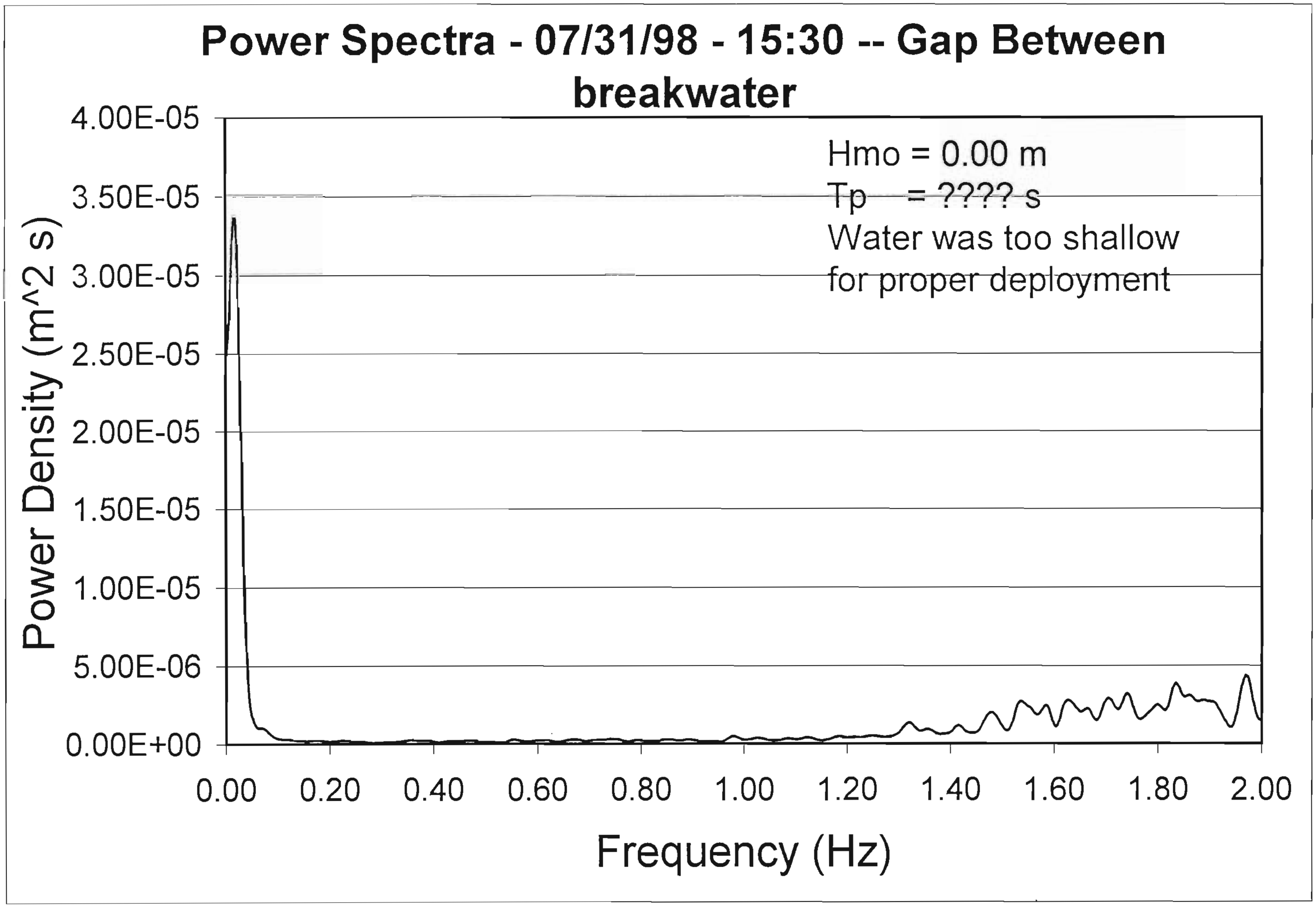


Power Spectra - 07/31/98 - 14:50 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
8.00E-06
7.00E-06
6.00E-06
5.00E-06
4.00E-06
3.00E-06
2.00E-06
1.00E-06
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)


Power Spectra - 07/31/98 - 15:00 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow for proper deployment
Power Density (m^2 s)
2.00E-04
1.80E-04
1.60E-04
1.40E-04
1.20E-04
1.00E-04
8.00E-05
6.00E-05
4.00E-05
2.00E-05
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

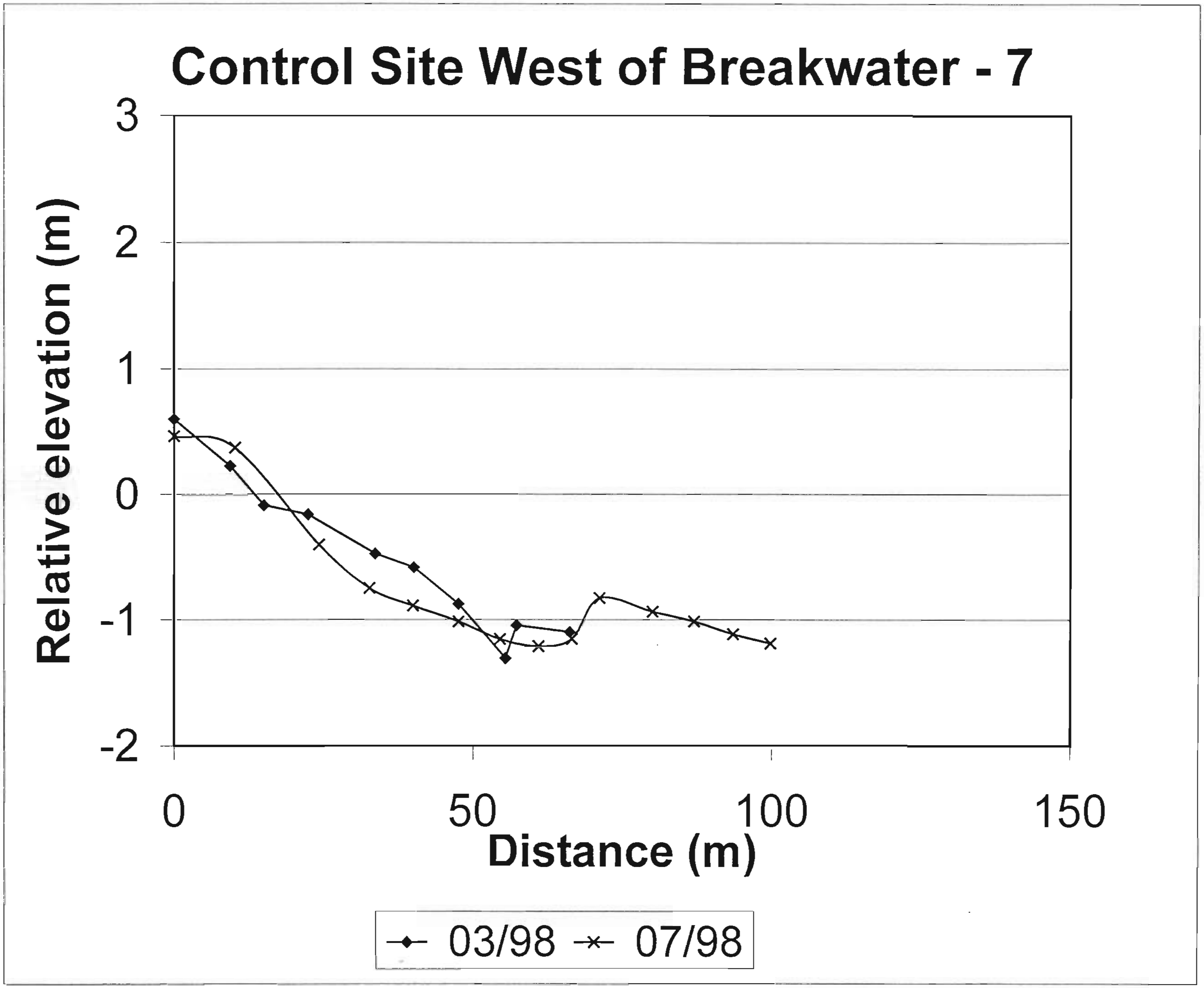

Power Spectra - 07/31/98 - 15:10 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

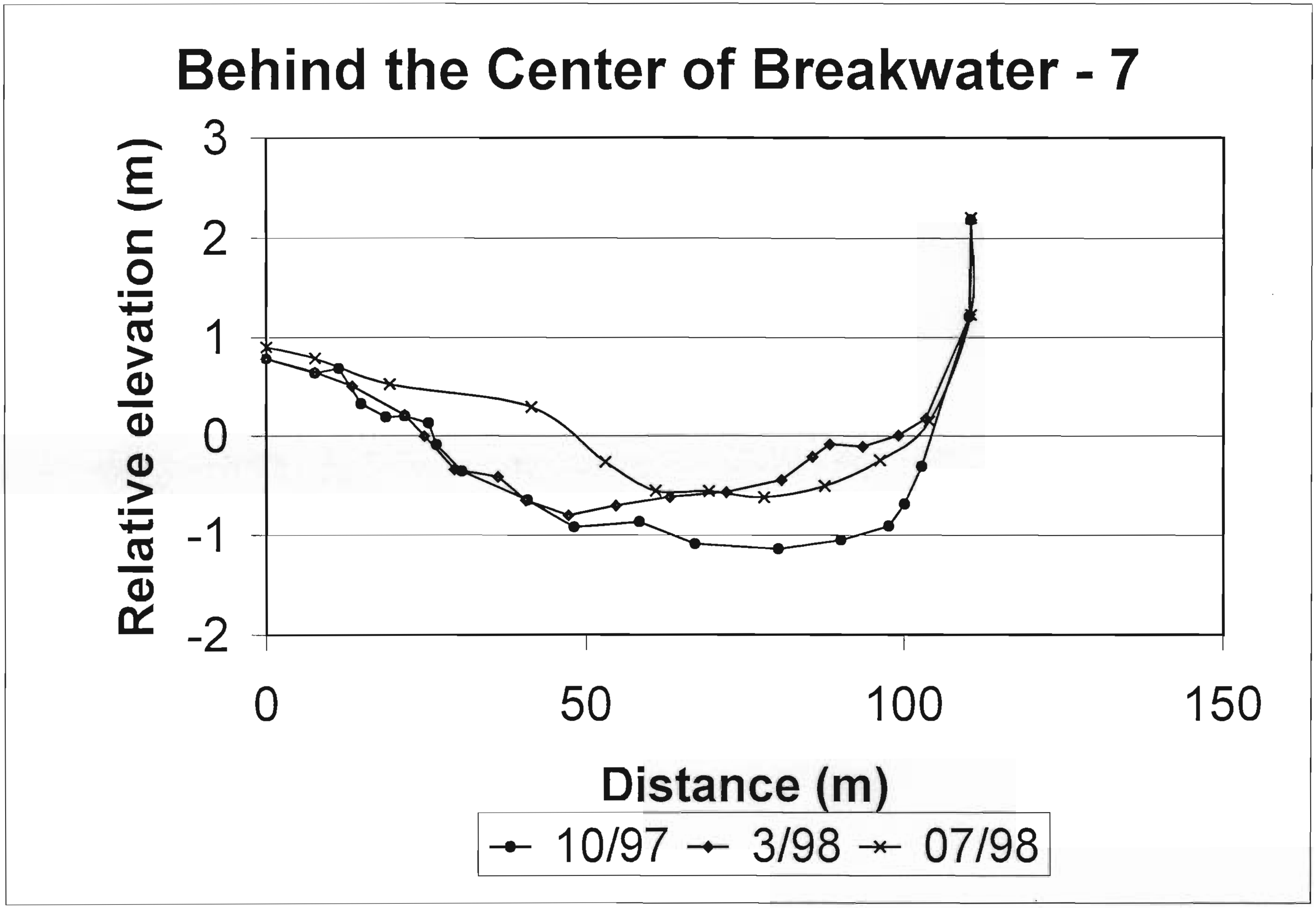

Power Spectra - 07/31/98 - 15:20 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
Power Density (m^2 s)
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

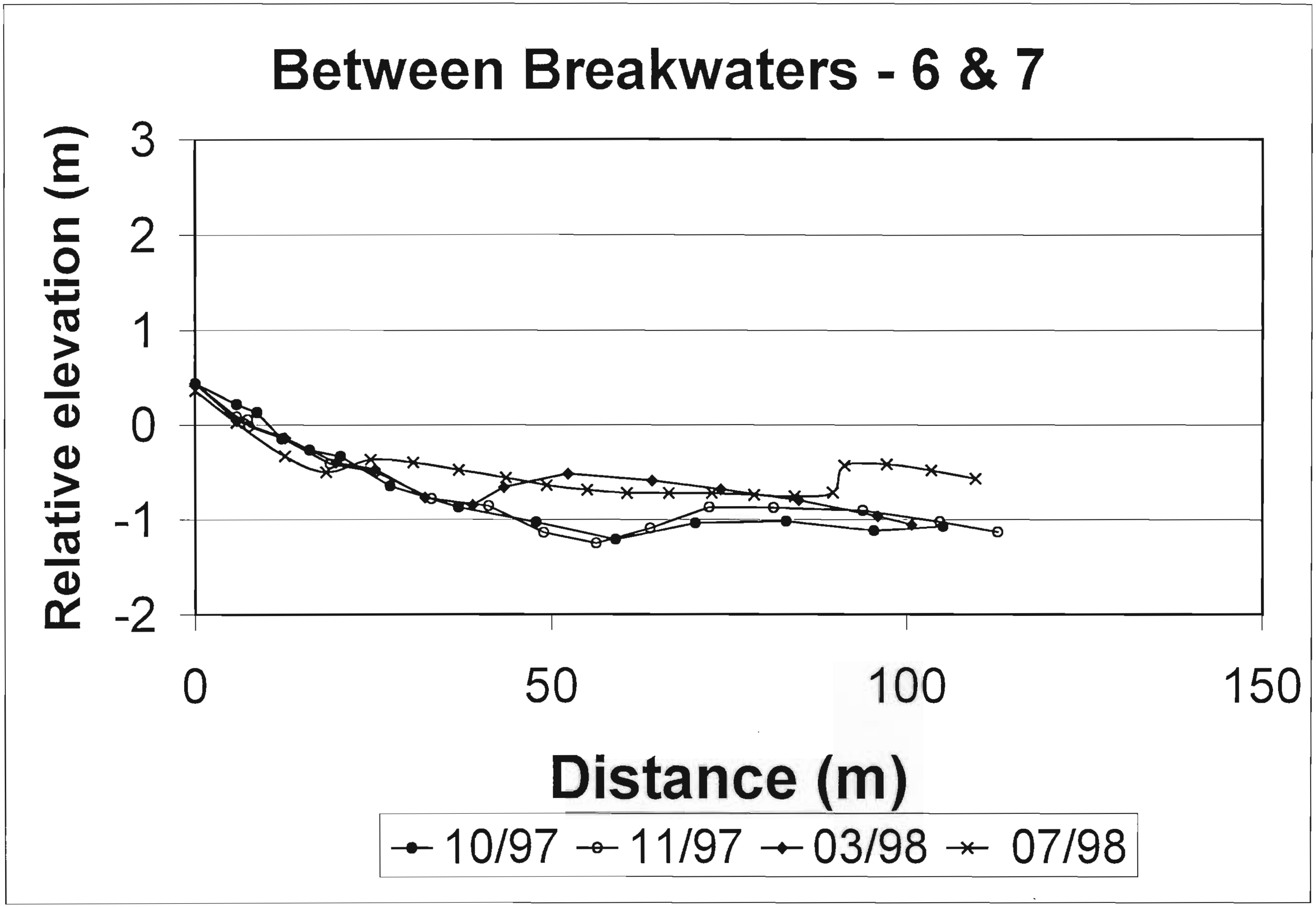

Power Spectra - 07/31/98 - 15:30 -- Gap Between breakwater
Hmo = 0.00 m
Tp = ???? s
Water was too shallow
for proper deployment
4.00E-05
3.50E-05
3.00E-05
2.50E-05
2.00E-05
1.50E-05
1.00E-05
5.00E-06
0.00E+00
Power Density (m^2 s)
0.00
0.20
0.40
0.60
0.80
1.00
1.20
1.40
1.60
1.80
2.00
Frequency (Hz)

APPENDIX 3

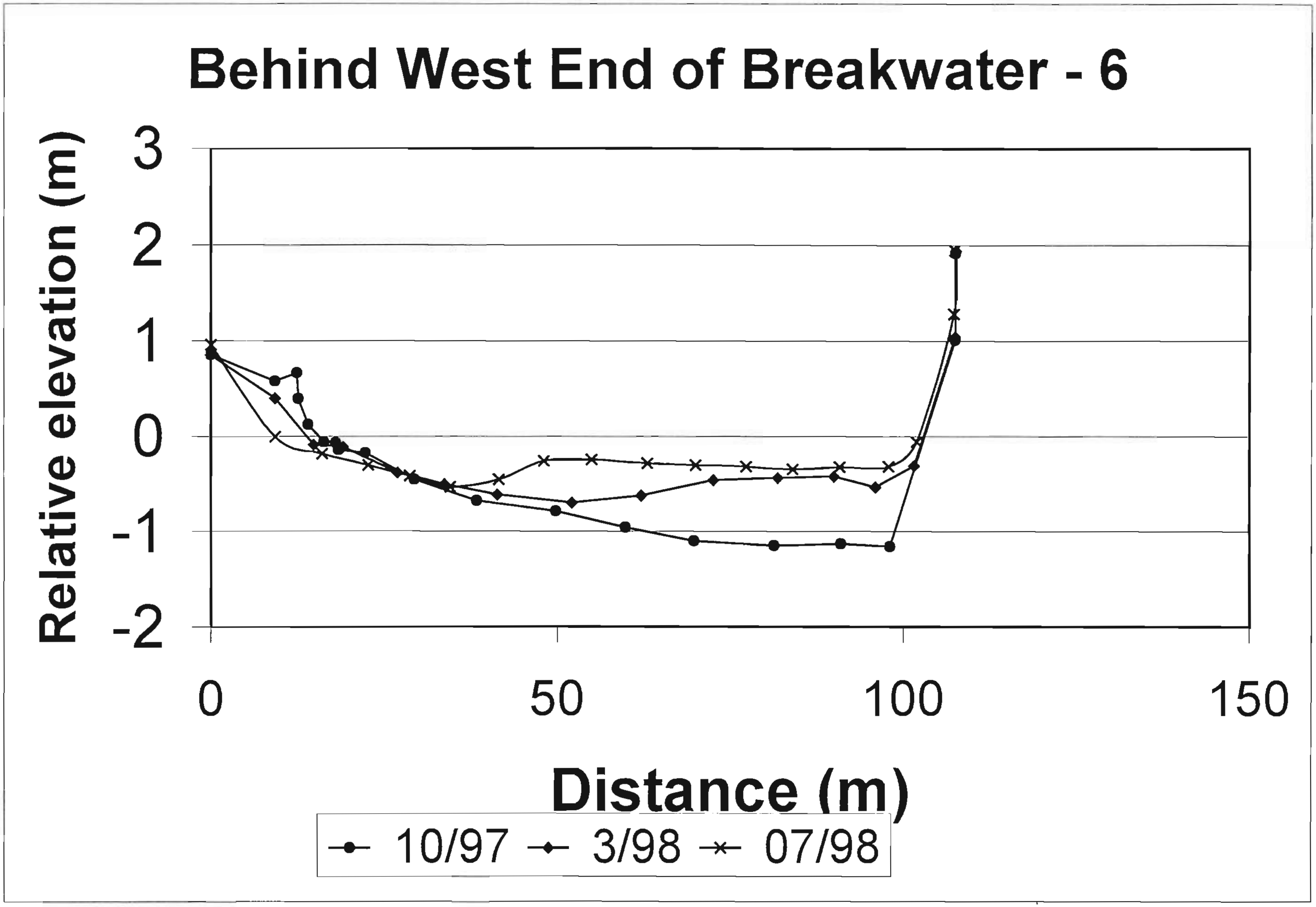
Time-series of beach profiles (profile locations are shown in Figure 1): Upper figures are in metric units; lower figures are in English units.

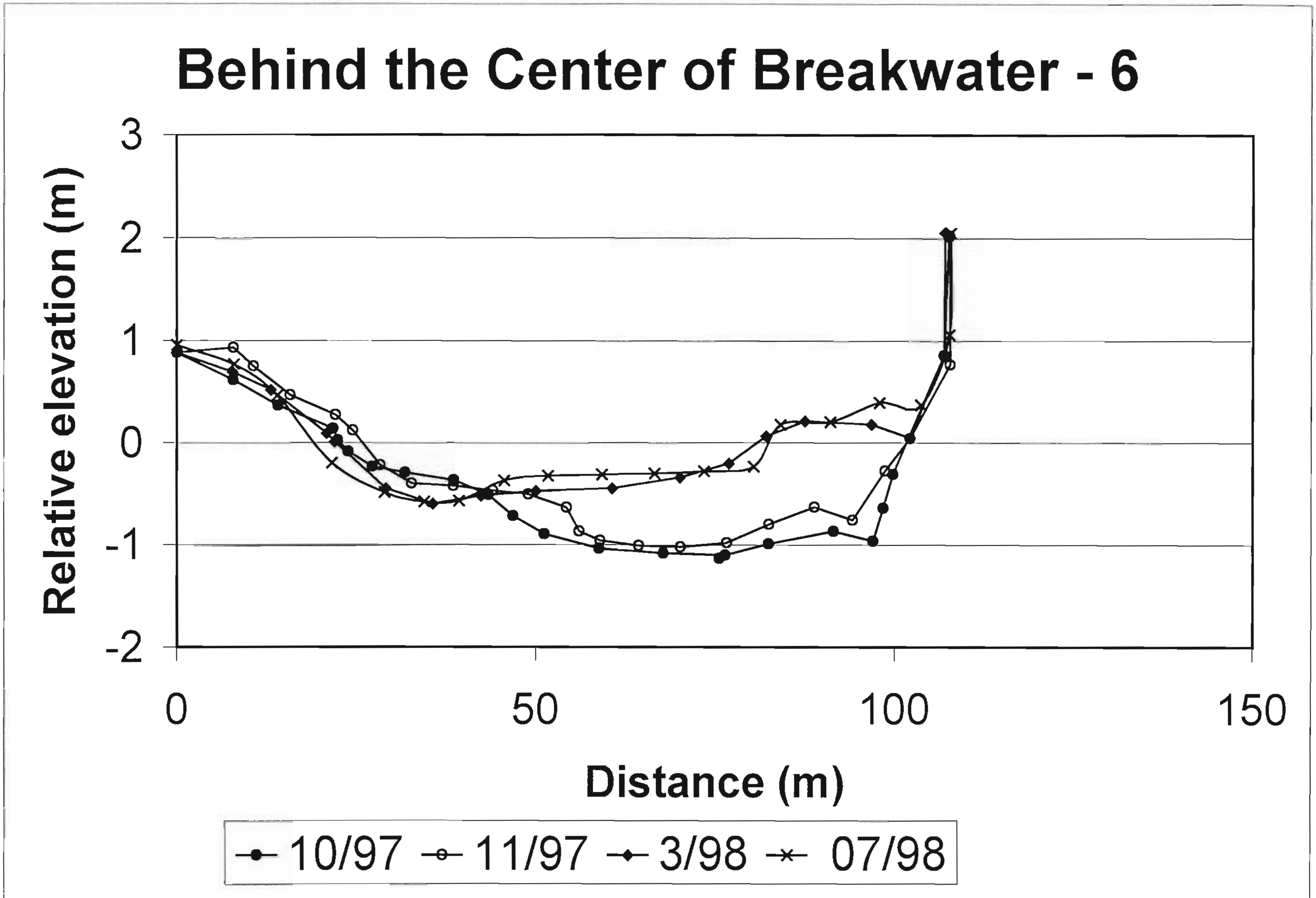

Control Site West of Breakwater - 7
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
03/98
07/98

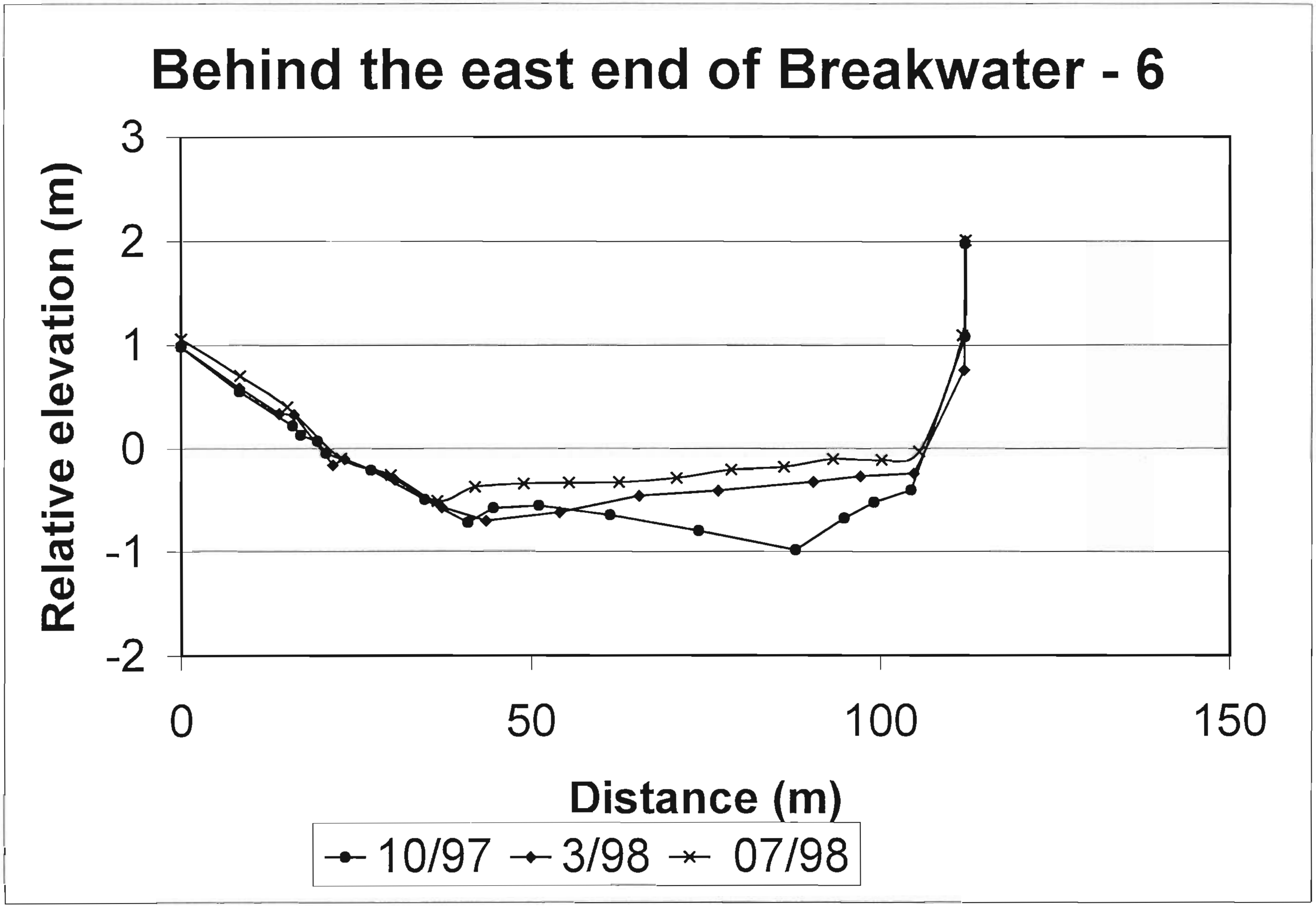

Behind the Center of Breakwater - 7
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
3/98
07/98

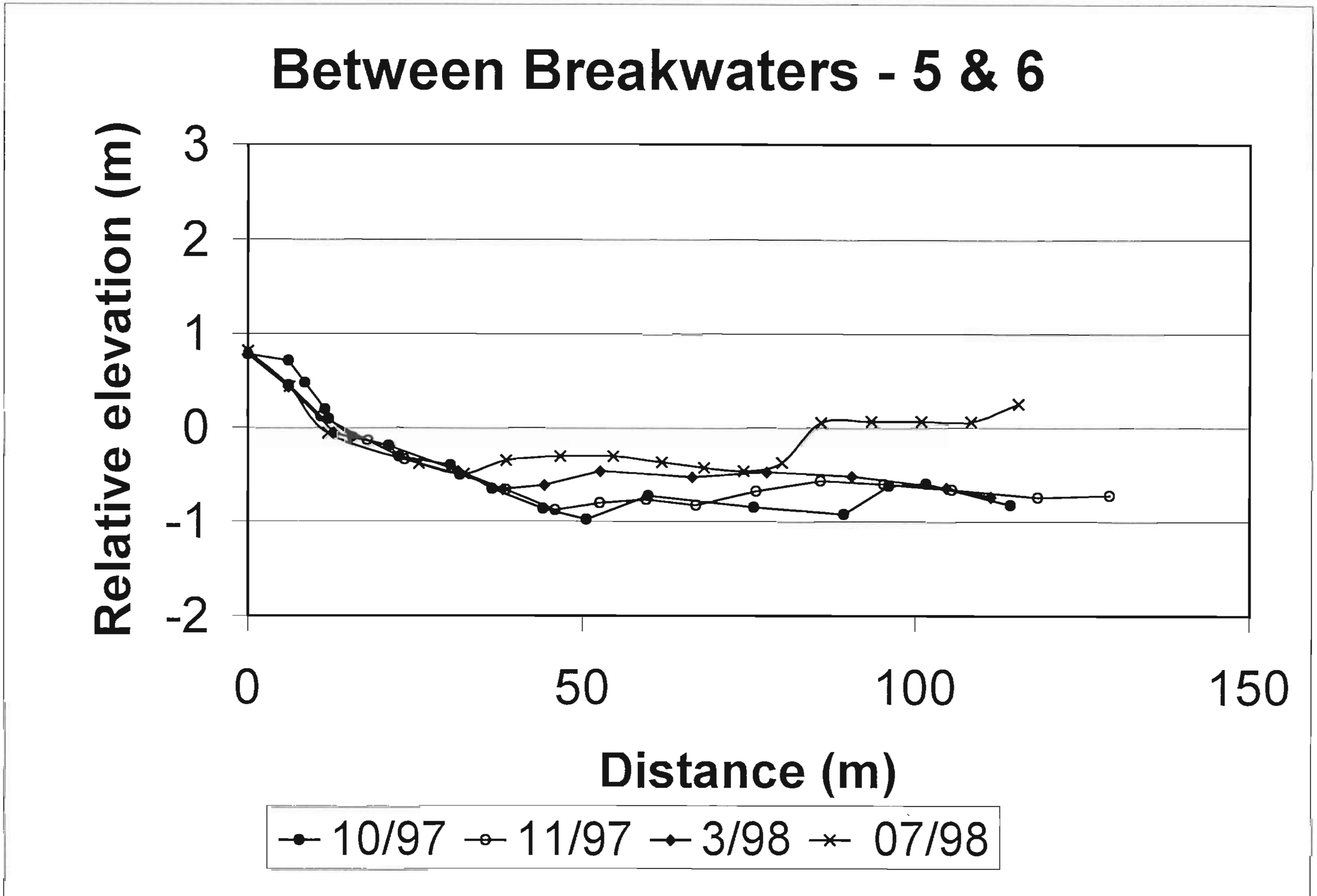


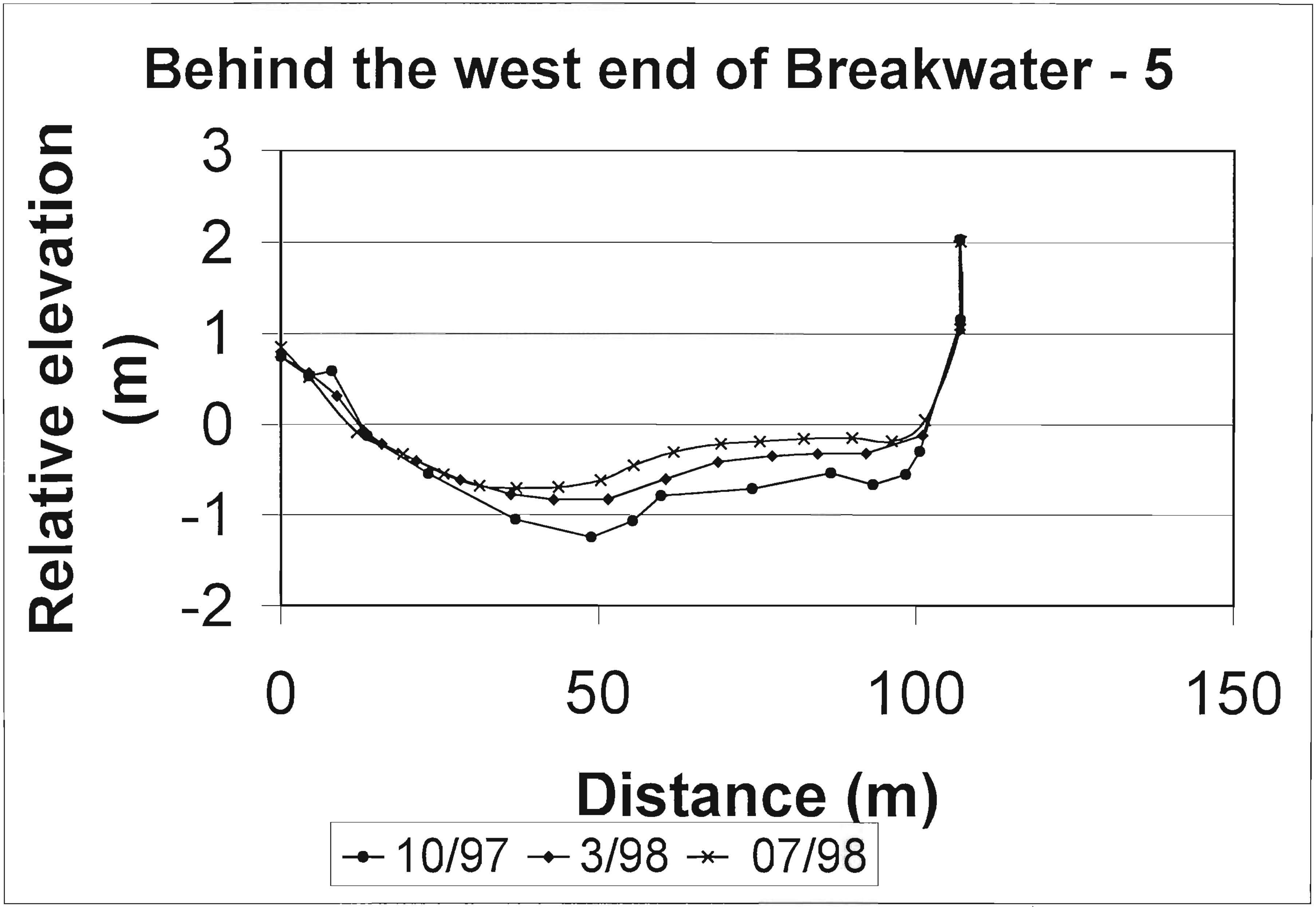
Between Breakwaters - 6 & 7
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
11/97
03/98
07/98

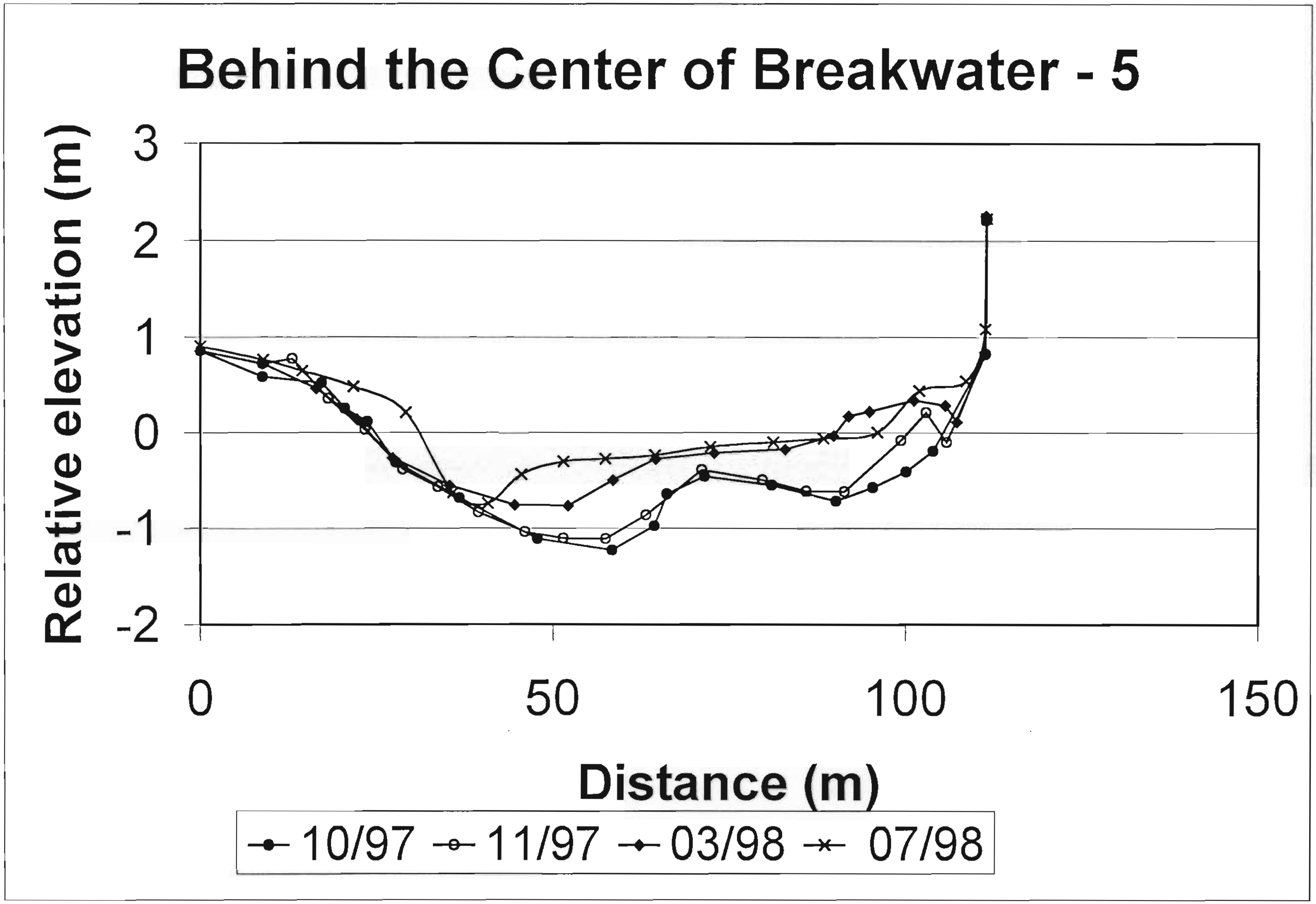

Behind West End of Breakwater - 6
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
3/98
07/98


Behind the Center of Breakwater - 6
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
11/97
3/98
07/98

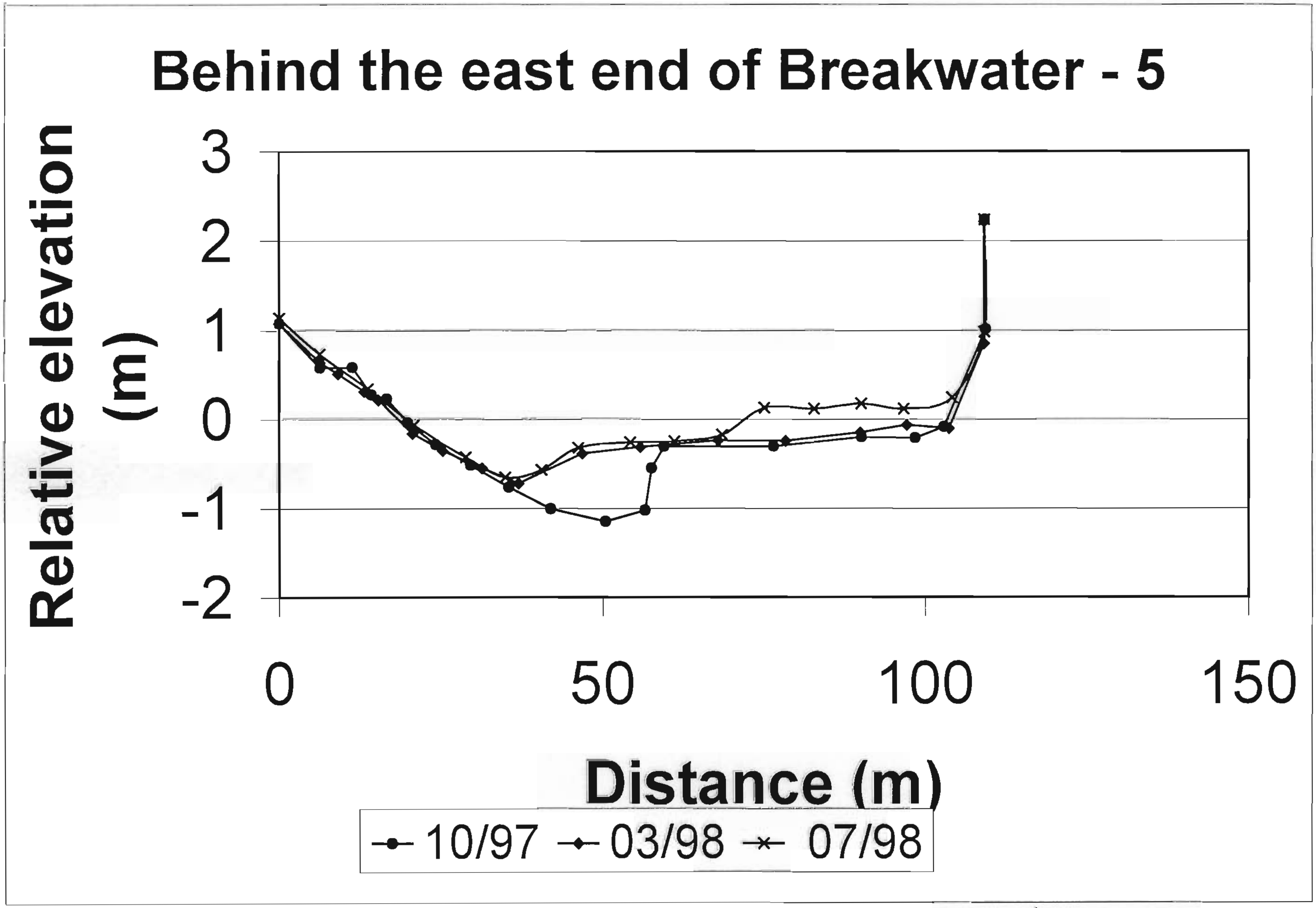

Behind the east end of Breakwater - 6
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
3/98
07/98

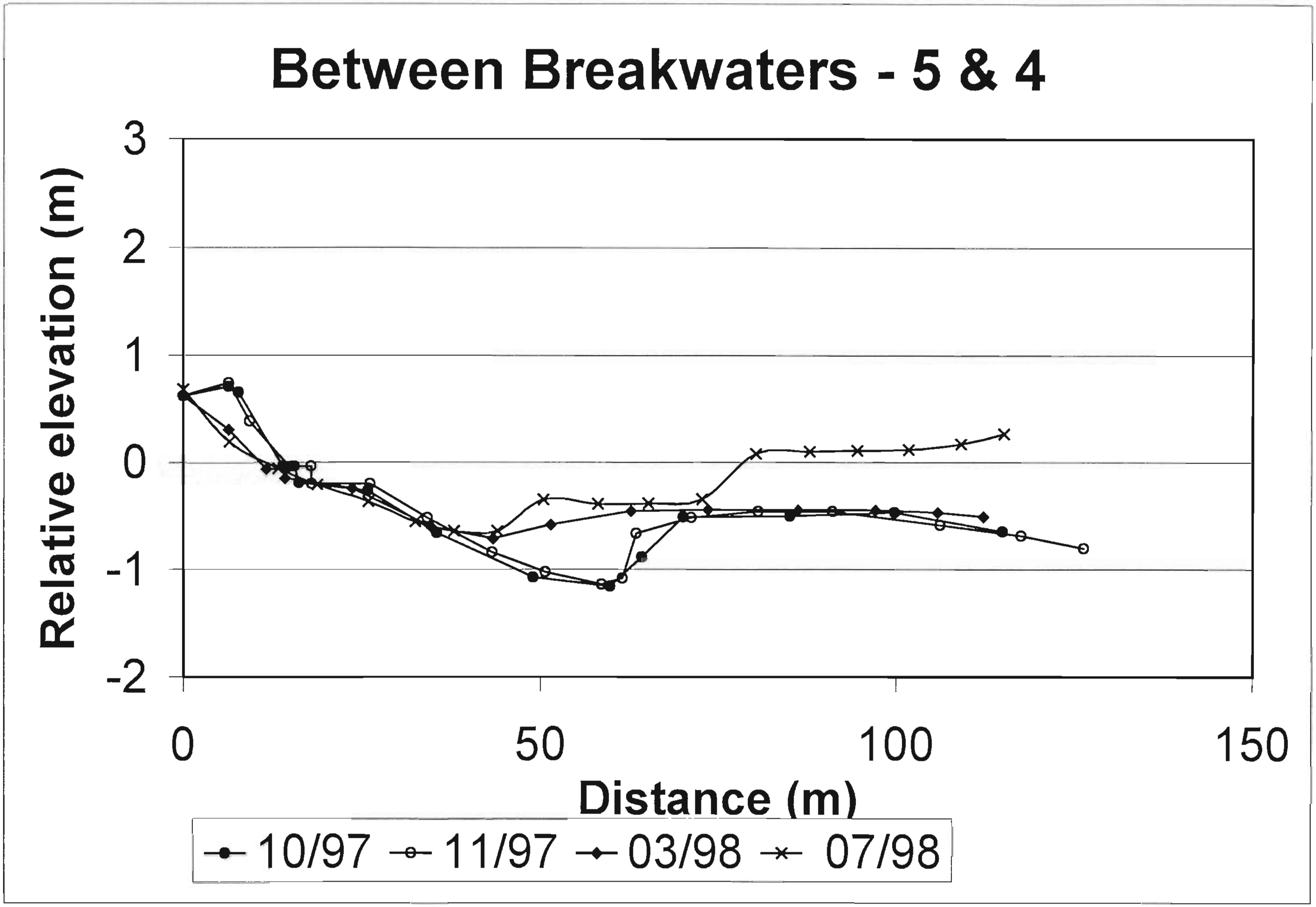

Between Breakwaters - 5 & 6
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
11/97
3/98
07/98

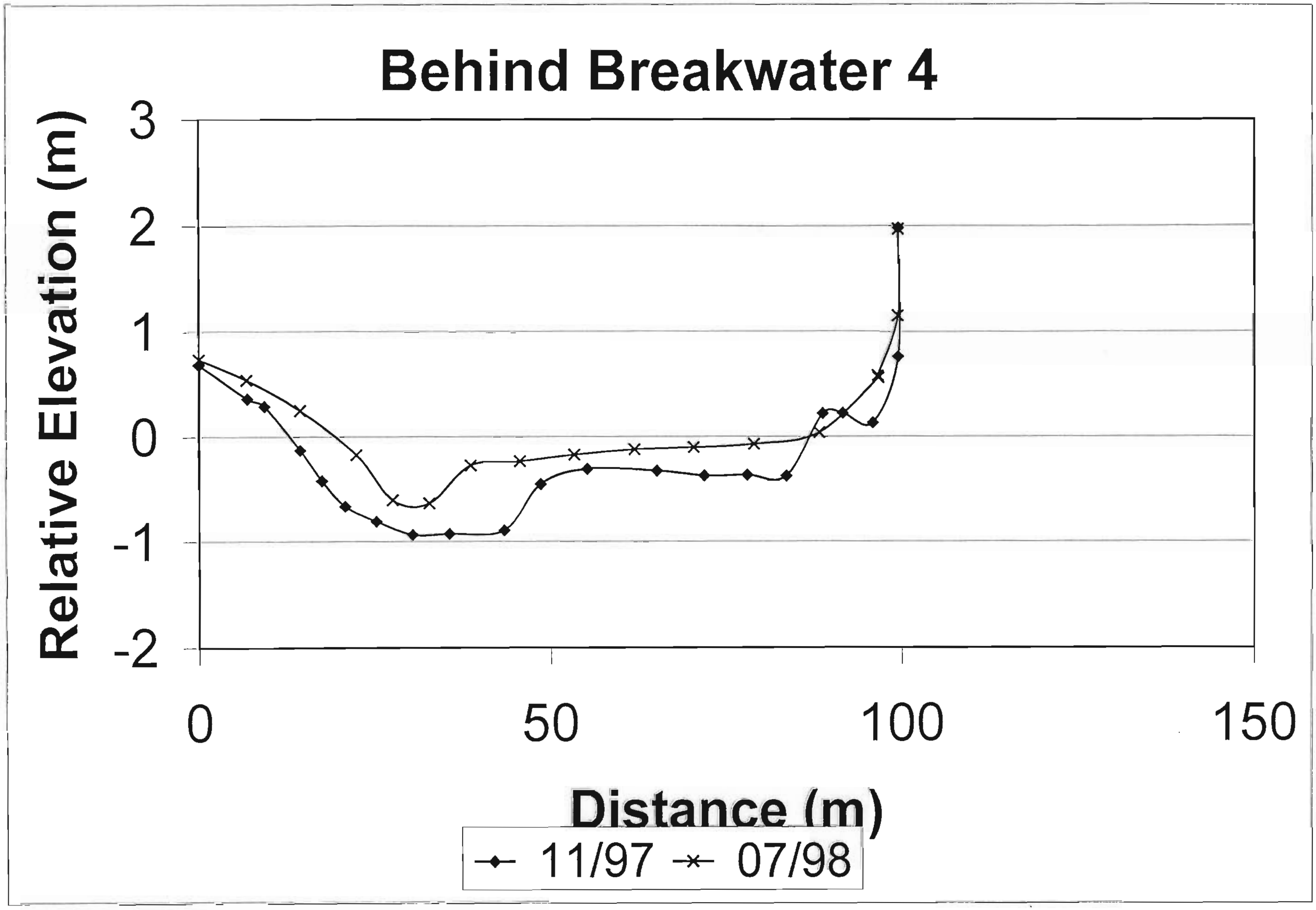

Behind the west end of Breakwater - 5
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
3/98
07/98



Behind the Center of Breakwater - 5
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
11/97
03/98
07/98


Behind the east end of Breakwater - 5
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
03/98
07/98


Between Breakwaters - 5 & 4
Relative elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
10/97
11/97
03/98
07/98


Behind Breakwater 4
Relative Elevation (m)
3
2
1
0
-1
-2
0
50
100
150
Distance (m)
11/97
07/98