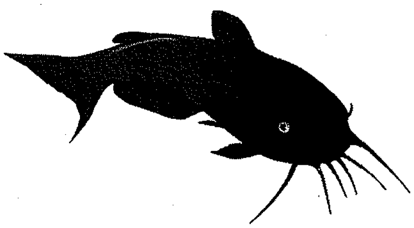
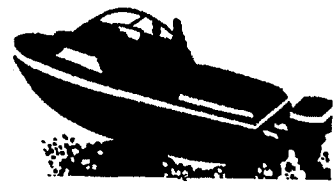
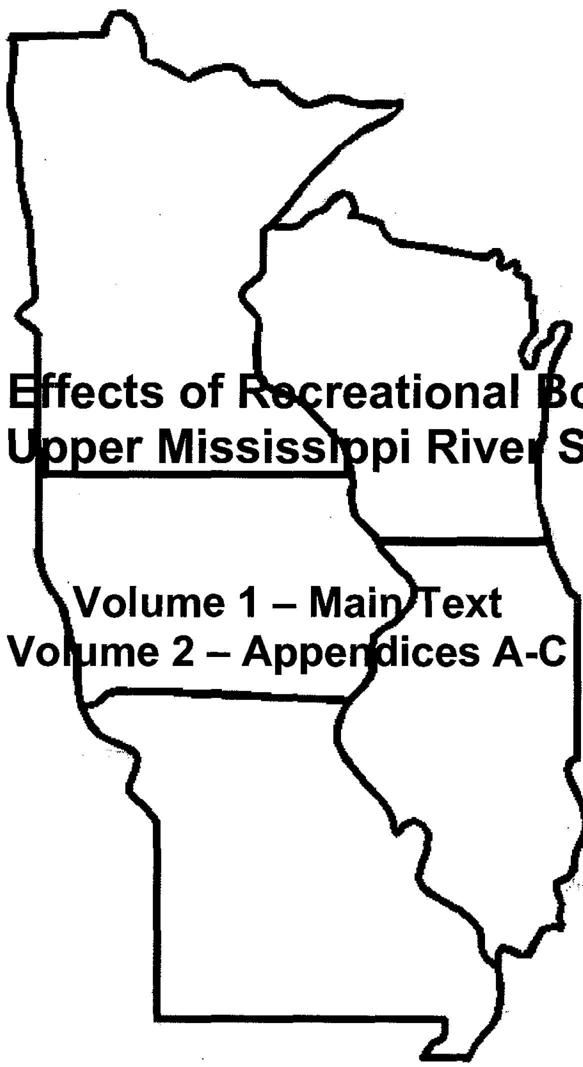
ENV Report 43

Interim Report For The Upper Mississippi River – Illinois Waterway System Navigation Study

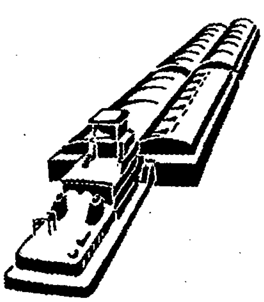






Hydraulic Effects of Recreational Boat Traffic on the Upper Mississippi River System

Volume 1 – Main Text
Volume 2 – Appendices A-C



September 2004

Rock Island District
St. Louis District
St. Paul District

US Army Corps of Engineers

Upper Mississippi River - Illinois Waterway
System Navigation Study

ENV Report 43
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Hydraulic Effects of Recreational Boat Traffic on the Upper Mississippi River System

Volume 1 – Main Text

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Final report

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ABSTRACT: Increased recreational boating traffic in the Upper Mississippi River will have an impact in conjunction with other stresses on the UMRS ecosystem. While the impact will consist of hydraulic, biologic and sediment disturbances, this report focuses on the effect of recreational traffic as related to wake waves and their potential for resuspending nearshore sediments. Field measurements were conducted in Pool 8 of the Upper Mississippi River near La Crosse, WI, to obtain data on wake waves and sediment resuspended in the nearshore zone and the results were used to validate numerical models. Potential maximum wave heights were assigned to vessel class and distance range from the sailing line. A generalized time-history wave response was developed for use in modeling sediment resuspension. Characteristics of field sediment were determined through laboratory tests. A new procedure was developed for sediment classification. A verified numerical model was used for making quantitative predictions of wake-wave-induced suspended sediment concentrations in the nearshore zone. Data on nearshore sediment characteristics were used as input to the model. Effect of wave height, wave period, vessel frequency, water depth, type of vessel, characteristics of vessel, and sediment properties were evaluated. Comparisons were made between effects of commercial tows versus recreational boats.

Contents

Volume 1

Volume 2[1]

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[1] Appendices A through C are provided on the enclosed CD as Volume 2 of this report.

Preface

The work reported herein was conducted as part of the Upper Mississippi River – Illinois Waterway (UMR – IWW) System Navigation Study. The information generated for this report will be considered as part of the plan formulation process for the System Navigation Study.

The U.S. Army Engineer Districts, Rock Island, St. Louis, and St. Paul, have been conducting the UMR – IWW System Navigation Study under the authority of Section 216 of the Flood Control Act of 1970. Commercial navigation traffic is increasing, and in consideration of existing system lock constraints, will result in traffic delays that will continue to grow in the future. The system navigation study scope includes examining the feasibility of navigation improvements to the Upper Mississippi River and Illinois Waterway to reduce delays to commercial navigation traffic. The study reported here is a part of the overall study that will determine the location and appropriate sequencing of potential navigation improvements on the system and prioritizing the improvements for the 50-year planning horizon from 2000 through 2050. The final product of the System Navigation Study will be a Feasibility Report, which will be the decision document submitted to Congress for processing.

Dr. Sandra K. Knight, Technical Director, and Dr. Trimbak M. Parchure, Sedimentation Engineering and Dredging Group, Estuarine Engineering Branch, Coastal and Hydraulics Laboratory (CHL), U.S. Army Engineer Research and Development Center (ERDC), were the principal investigators for the work described herein. They have prepared this report jointly. Mr. Timothy Fagerburg, CHL, and his team collected and analyzed the field data. Dr. Parchure conducted the work under general supervision of Dr. Robert T. McAdory, Chief, Estuarine Engineering Branch, and Mr. Thomas W. Richardson, Director, CHL.

This report was edited and published by the Information Technology Laboratory, ERDC. Mr. Robert C. Gunkel, Jr., Environmental Laboratory (EL), ERDC, was responsible for coordinating the necessary activities leading to publication. COL James R. Rowan, EN, was Commander and Executive Director of ERDC, and Dr. James R. Houston was Director.

Volume 1 of this report is the main report and Volume 2 includes all the appendices containing analysis of field data.

1 Introduction

Boating is the most popular and highly valued recreational activity on the Upper Mississippi River System (UMRS) (Carlson et al. 1995). Effects of recreational boating were assessed by the U.S. Army Corps of Engineers as part of the Upper Mississippi River – Illinois Waterway Navigation Study. Effects of recreational boating traffic were examined in order to better assess the effects of increased commercial navigation traffic in context of other stresses on the UMRS ecosystem. The primary hydraulic disturbances produced by recreational boating traffic include generation of wake waves, entrainment of water through propellers, and propeller jets. Secondary physical disturbances include sediment resuspension and bank erosion. Biological effects resulting from physical disturbances produced by recreational boat traffic include fragmentation of submerged aquatic plants by waves, suppression of submerged plant growth by resuspended sediment, and mortality of fish by propeller entrainment and impingement. The recreational boating study included a field study of the recreational boat fleet composition on the UMRS, traffic projections using an allocation and forecasting model, development of a navigated areas Geographic Information System (GIS), field studies to measure physical characteristics of wake waves and sediment resuspension by recreational vessels, a literature review of existing data and methodologies, development of aquatic plant growth models, and application of hydraulic and plant growth models to identify areas in the channel borders of the UMRS where recreational boat effects occur. This report focuses on the physical effects of recreational traffic as related to wake waves and the potential for resuspending nearshore sediments.

Objectives

The objectives of a physical effects study of recreational boat wake waves on the UMRS included:

a. Validation and/or modification, if practicable, of existing models for wake wave predictions specific to vessels on the UMRS.

b. Providing a method for quantification on a system-wide basis, expected wave heights for variable classes of recreational boats.

c. Providing a method for expressing the entire wave time series for evaluation of the secondary effects of sediment resuspension.

d. Developing a method for quantifying time-series suspended sediment concentrations in the nearshore based on estimated wake wave height and time series, frequency of boat passage events (multiple events) and sediment types. Consistent with the aquatic plant studies, these methodologies were limited to the effects of resuspension at the 1-m depth only.

Outputs from this study, specifically wave height and suspended sediment, were used to assess environmental impacts to submerged aquatic vegetation and are reported in the Environmental Impact Statement of the UMRS Navigation Feasibility Study (U.S. Army Corps of Engineers 2004). The successful evaluation of impacts over the entire UMRS was dependent upon: a (a) a simplified methodology for extrapolation of physical effects over the entire UMRS, and (b) a new sediment classification scheme, described by Parchure et al. (2001) in Chapter 4. The quantification of wake wave effects and the sediment classification was used in a GIS specifically developed for the UMRS that contained both projected recreational and commercial traffic forecasts to identify areas where both highly erodible fine sediments occur and where the magnitude of wake waves can cause resuspension.

Background

Supporting studies

Study parameters, data, and input requirements to meet the objectives were dependent upon results from other studies, described in the preceding section, in the UMRS recreational boating study. Seven types of vessel classes were identified for study in the UMRS analysis. These include sailboats, fishing boats, pontoon boats, jet skis, medium power boats, larger cruisers, and houseboats. The frequency distribution of these vessels at 10 specified locations in the study area, along with operational and physical characteristics, were provided in a report by a Corps of Engineers contactor (Rust Environmental and Infrastructure, Inc. 1996b). Disaggregation of annual data for the entire system to allocations by pool, by vessel category, to vessels per day, and to within-pool daily use was presented by Carlson, Bartell, and Campbell (2000). Based on the classes of vessels and their physical and operational characteristics, a field exercise was planned and conducted to obtain wave and sediment data in the nearshore zone. Controlled field experiments were conducted for six vessels representing five of the vessel classes (jet ski, fishing boat, two sizes of power boat, large cruiser, and houseboat) in November 1995, in Pool 8 of the Upper Mississippi River near La Crosse, WI, by Rust Environment and Infrastructure, Inc., and the U.S. Army Engineer Research and Development Center (ERDC), Coastal and Hydraulics Laboratory (CHL). These field experiments were conducted to obtain data on wake waves and sediment resuspended in the nearshore zone. Areas navigated by the different classes of recreational vessels on the UMRS were delineated by resource managers and digitized into a GIS.

Wave height prediction

The recreational boating study was initiated by conducting a thorough literature review of existing boat wave models and their relevance to UMRS vessels. Sorensen (1997) has provided the following information on wake waves:

"Wake waves are produced by recreational boats, depending on boat shape, size, weight, and speed. Vessels moving slowly through the water are operating in the displacement mode at or below "hull speed," and produce small wake waves. As boats operating in the displacement mode are pushed to higher speeds, bow, stern, and transverse waves develop, leaving a characteristic set of wake waves. The pattern consists of symmetrical sets of diverging bow and stern waves that move obliquely out from the sailing line, and a single set of transverse waves that move in the direction of the sailing line. The diverging waves propagate at an angle of 35° 16' in deep water. The transverse and diverging waves meet to form cusps that emanate at an angle of 19° 28' from the sailing line. The highest waves in the pattern are found along this cusp line. As boat speed increases, the wave lengths and celerities (wave speed) increase, but the pattern retains the same geometric shape. A similar pattern of stern waves, typically of much lower amplitude, is superimposed on the pattern propagating from the bow of the boat."

The intent of the literature study was to evaluate and select an existing predictive model for use in the system analysis of recreational traffic on the UMRS. The models varied in structure and required inputs. They were also based on a wide variation of vessel types and generally limited data sets. The recommended model was a complex algorithm developed by Weggel and Sorensen (1986), requiring a number of vessel characteristics and empirical coefficients based on each vessel type to provide meaningful predictive results. Predictive models, such as this, are typically based on the wave formed from a single vessel moving at constant speed along a fixed path above critical (or planing) speeds. Unlike commercial vessels and some large recreational craft that are confined to the main Upper Mississippi River navigation channel, most recreational craft can have variable origin and destination points, and can start/stop and navigate along variable paths in the main channel, in off-channel areas, and in channel borders. Hence, a wake wave model using steady-state vessel speeds and set sailing lines may not be realistic.

Vessel wake waves on the UMRS interact with other vessel wake waves, wind driven waves, and river currents to produce wave effects that further add to the complexity of developing a predictive model. The main purpose of the hydraulic analysis was to identify physical characteristics that have potential for causing environmental impacts. In this case, the most important outcome is associated with nearshore wake wave heights and sediment resuspension. Historical data indicate that suspended sediment solids concentrations in the nearshore zone are sustained at higher levels and for longer durations during peak recreational traffic conditions, such as on holidays. This suggests that at some traffic level in a given area a threshold is exceeded where you no longer can distinguish single vessel passages.

Sediment resuspension prediction

Sediment resuspension caused by both commercial and recreational boat traffic in the river was estimated to assess potential environmental impacts on the UMRS. The traffic pattern and the wave series generated by commercial barge traffic and recreational craft are different, and their impacts are considered separately. Parchure et al. (2001) have developed models and estimated sediment resuspension caused by towboat-generated waves and currents. A literature search revealed no standard procedure for estimating sediment resuspension by recreational boat wake waves. An analytical approach was therefore adopted for use with the recreational craft.

Parchure et al. (1996) described the effect of wave-induced resuspension of fine sediment on water quality in the nearshore zone. Fine sediment particles have a large specific surface area and the particle size is typically less than 4 microns. Hence, a few grams of fine sediment eroded from the bed may suspend millions of particles causing a greater underwater light attenuation than sand having the same total weight. Fine sediment particles are susceptible to erosion by relatively small shear forces. Once resuspended, fine particles may stay in suspension for days or weeks compared to seconds or minutes for resuspended sand particles. The adverse ecological effects of sediment resuspension by vessel wake waves primarily involve fine-grained sediment.

Approach

After evaluation of the literature and the available data, a determination was made that a wave height predictive model for each class vessel was beyond the needs of the UMRS Navigation feasibility study. The focus of the recreational boat wave task was turned toward establishing a table of maximum expected wave heights for each class vessel and providing a generic time series representation of the wake wave train. These inputs were then used in an analytical sediment resuspension model to evaluate the effects of different combinations of input parameters. Data gathered during the study along with other data sets from literature were analyzed. These data were used for the study to validate the analytical model developed to predict sediment resuspension by recreational boat wake waves.

A sediment classification scheme was developed to identify areas in the UMRS where highly erodible fine sediments occur (Parchure et al. 2001). That classification scheme was used in evaluation of both commercial and recreational boating impacts.

The recreational boating impacts evaluation was focused on wake wave effects only. In the case of some vessel types, such as small fishing boats, wake waves are not likely to be the source of sediment suspension in shallow nearshore zones. Because of their maneuverability and shallow draft, small fishing boats can navigate areas where their propellers can scour and resuspend sediments. Although most small boat operators avoid propeller dredging of sediment, it is a common occurrence in off-channel areas of the UMRS. Predicting this source of vessel-induced sediment resuspension would be difficult in the context of a UMRS study, but it is important to consider this type of impact, at least qualitatively.

2 Recreational Boat Data Pool 8

Overview

In addition to the literature review, wake wave data and resuspension data representative of the recreational boat fleet on the UMRS were needed to support the analysis required to meet the study objectives. A controlled full-scale field test was designed to obtain critical information while including as many parameters as economically feasible. In designing a field data collection program for vessel wake waves, many parameters must be considered. Based on previous field tests by Bhowmik et al. (1991) and Sorensen (1997). Field tests were designed to incorporate the most dominant variables. Boat speed, hull type, and distance from the vessel are generally considered dominant characteristics in forming wake waves. Additionally, boat loading (empty or light) can affect the wave pattern by: (a) effectively changing the shape of the hull below the water surface, and (b) can produce displacement effects under shallow water conditions. Since ambient currents can affect the relative speed of the vessel with respect to the water and the magnitude and propagation of vessel produced waves, tests conducted upbound and downbound may be considered. Gages for collection of suspended sediment and wave heights should be placed in proximity to each other in the nearshore zone to establish a correlation between suspended sediment data and wake waves.

On November 3 through 6, 1995, controlled experiments using recreational craft were performed in Pool 8, Mississippi River near La Crosse, WI (Figure 1a), along the left descending bank near Mormon Slough. A similar field study was conducted in Pool 8 to obtain data on the hydraulic effects of commercial vessels. A description of the instruments and analysis is provided by Fagerburg and Pratt (1998). For the recreational boat study, each test consisted of a vessel following, as accurately as practicable, a string of buoys marking a sailing line at a constant operating speed past a fixed set of instruments. Figure 1b shows a plan view identifying sailing lines and instrument locations. Both water levels, resulting from waves, and suspended sediment data, were collected. Ambient current conditions were monitored using an acoustic Doppler velocity meter. Six vessels were used in the testing, representing five of the seven vessel classes. Vessels used and general information regarding these vessels are shown in Table 1 (descriptions taken from Rust Environment and Infrastructure 1996a). Data were collected at two optical back scatter (OBS) sensors placed in the shallow nearshore zone and three wave gages placed at three depths and variable distances from the shores. In all, over 165 tests were completed for six vessels using variable boat speeds, upbound and downbound, loaded and unloaded conditions, and two sailing lines. This required analysis of over 700 time-histories of wave and sediment data. Tables 2 through 7 contain information regarding each experiment for each vessel type tested. The tables include the test number, real-time start, loading condition, direction, sailing line distance, boat speed, and engine rpm.

Wave Data

Wave data were collected at three wave gages perpendicular to the shoreline. Figure 2 shows wave gages and sailing line locations from shore. Actual plots of time-series wave data are found in Appendix A. Maximum wave heights were extracted from the time-series data in Appendix A. Table 8 provides the maximum wave heights at each gage by boat. Test numbers can be cross-referenced with Table 2 through Table 7 and used to identify time-series found in Appendix A. Wave gage recordings from the field data suggest that 2- to 4-cm fluctuations in readings can be attributed to electronic noise and minor wind-generated waves. Therefore, only events exceeding approximately 3 cm (0.1 ft) are included in Table 8. Test numbers not shown in Table 8 indicate that a significant response was not measured.

Suspended Sediment Data

During the field experiments in November 1995, water samples and time-series data on suspension concentrations were collected using an OBS each time a vessel passed by. The water samples were analyzed to determine suspended sediment concentration. These results were used for calibrating the OBS sensors. The OBS device does not physically measure suspension concentration. It measures optical properties. Water sample analysis provides a physical determination of suspension concentration in water, which is essential for calibration of OBS. The calibration gives correlation between optical measurement and the magnitude of suspension concentration. OBS device does not physically measure suspension concentration. It measures optical properties. Water sample analysis provides a physical determination of suspension concentration in water, which is essential for calibration of OBS. The calibration gives correlation between optical measurement and the magnitude of suspension concentration. Time-history suspended sediment data were collected using OBS sensors at two locations (Figure 3). OBS measurements were taken at 2.3, 2.0, 0.9, and 0.3 m (7.5, 6.5, 3.0 and 1.0 ft) above the bed. The results of these measurements are given in Appendix B. The results are summarized in Table B1 at the beginning of Appendix B.

Bed Sediment Data

Surface bed samples were collected at 112 locations in the controlled vessel passage study area to determine the physical and erosional characteristics of the bed. All the samples were analyzed to determine their particle-size distribution. Fagerburg and Pratt (1998) have given representative size gradation curves of bed material from each area. The results of particle-size distribution of samples collected in Pool 8 of the Mississippi River are given in Appendix C. Additional bed samples with predominantly clay contents were collected at nine locations in shallow-water areas very close to the riverbank in Mississippi River Pool 8 and Pool 9. The samples were analyzed to determine particle-size distribution, bulk density, and total organic contents. The samples were assigned erodibility labels based on the value of these three parameters. Locations, particle-size distribution curves, and details of erosion tests conducted on these samples are given in a report by Parchure et al. (2001).

3 Wave Data Analysis and Results

Introduction

Nearly 500 hundred wake-wave time-histories from the field study were analyzed along with data in the literature in an attempt to develop correlations between parameters such as vessel type, speed, draft, and sailing distance. While the field data collection program was fairly extensive, the analysis revealed that only approximately 90 tests produced wave heights that would be considered above the natural variability of the system and/or the noise from the instruments (approximately 3 cm), and only 32 tests resulted in wave heights greater than 10 cm. Furthermore, in the analysis of the sediments and their resuspension characteristics, waves of 10 cm or less did not cause appreciable increases in sediment concentrations even in the softest and most erodible sediments. Also, as described previously, most recreational craft can operate over a range of boat speeds, along variable sailing paths, both with and against the current, and with or without multiple passengers (loaded/unloaded) during any outing event. No further attempt was made to develop or modify a predictive equation for a single boat event as a function of vessel speed and draft. The peak wave data from all tests, including those in literature, were used to assign each class of vessels an expected maximum wave height. Given that at some distance from the vessel (see discussion that follows), the effects of the vessel are minimal, final maximum wave heights were presented as a function of distance from the vessel.

In the UMRS study of commercial traffic effects, attributes were assigned to polygons within a GIS for purposes of calculating wave impacts along the main channel borders of the Mississippi and Illinois River. These attributes included three vessel speeds, three sailing lines, direction of travel, origin and destination, and characteristics of the size and loading of the vessel. An algorithm was developed that related vessel speed to distance from the sailing line as a function of vessel loading, direction, and size (Knight 1999). For the recreational boating study areas were identified where each classification of vessel was observed to operate and are identified as fuzzy polygons in the same GIS. The final analysis and development of vessel wake-wave predictions for recreational craft focused on a method for extrapolating wave heights and suspended sediment impacts to these established polygons for each vessel class.

Analysis

Controlled tests, Pool 8

Table 8 contains a summary of data on vessel-induced wave heights greater than 3 cm for all tests in Pool 8 during controlled experiments. The following observations summarize the wave data presented in this table for each vessel class tested:

a. *Jet Ski, Type I.* Based on photos taken by Rust Environment and Infrastructure (1996a), jet skis produce a wake in the near vicinity of the vessel. The wake appears to dissipate at a relatively close distance from the vessel. Data collected at all gages (closest being 27 m (90 ft)) also show no significant waves. However, since jet skis can maneuver in circular patterns and in the very nearshore zone, a conservative value was assigned of 8 cm for areas within 31 m (100 ft) of the vessel.

b. *Starcraft FM-150, Type II.* A total of 24 tests were conducted for this fishing boat at variable speeds ranging from 6.1 to 59.4 km/h (3.8 to 36.9 mph) (Table 3). Three wave gages located within a distance from 27 to 78 m (90 to 255 ft) resulted in wave heights of 4 to 5 cm or less, with only one gage reading (1 out of the 72) having a wave of 8 cm.

c. *Crestliner, Type III.* A total of 34 tests were conducted with the Crestliner (Table 4), a small medium power boat (80 hp). At speeds from 5.6 to 57.1 km/h (3.5 to 35.5 mph) and for all data, except for one test at one gage, wave heights were 3 to 5 cm or less. Only Test #29 produced a higher maximum wave height of 10 cm.

d. *Four Winns, Type IV.* A total of 34 tests (Table 5) were conducted with the Four Winns, a larger medium power boat (205 hp). For speeds from 3.2 to 63.2 km/h (2 to 39.3 mph, only 13 of the possible 102 time-histories had wave heights in excess of 5 cm, the maximum being 14 cm.

e. *Luhrs Motoryacht, Type V.* The Luhrs was a large cabin cruiser (twin inboards, 340 hp each). A total of 32 tests were conducted with this vessel (Table 6) ranging in speed from 7.9 to 54.9 km/h (4.9 to 34.1 mph). In 48 of the 84 time-histories presented in Appendix A, wave heights exceeded 4 cm. The maximum wave height of 20.4 cm was recorded 53 m (175 ft) from the Luhrs while traveling upbound, loaded at 14.2 km/h (8.8 mph). This was the highest recorded wave height of all tests conducted for recreational craft during this field exercise. A distribution of wave heights from all 48 tests is provided in Figure 4. This represented enough data to conduct some tests to determine what, if any, correlations exist between parameters. While intuitively one would expect wave height to decrease with distance and increase with vessel speed, analysis of these tests did not support this theory. In fact, in tests 5, 6, and 7, the wave heights closest to the vessel are the smallest of the three. The maximum wave height occurred when the vessel was operating at 14.2 km/h (8.8 mph), while the maximum speed was recorded at 54.9 km/h (34.1 mph) (12.5 cm peak wave height). Several things could contribute to these results: (1) at lower speeds, the vessel could be displaying more water as opposed to riding the surface at higher speeds, forming a smaller wave; (2) the peak wave, occurring along the cusp line at the intersection of the transverse and diverging waves is forming away from the vessel and/or is not being captured because of the location of the wave gages; (3) perturbations in the operation of the boat along the sailing line can cause anomalies and variations in the results.

f. *Houseboat, Type VI.* A total of 23 tests were conducted with the houseboat (Table 7). Speed ranged from 4.2 to 15.1 km/h (2.6 to 9.4 mph). Like the jet skis, no waves exceeded the 3- to 5-cm range at distances from 27.4 to 77.7 m (90 to 255 ft) from the gages.

Other available data

Johnson (1968) presents data from controlled vessel passage events at an instrumented site that were taken for five vessel types at two sailing lines. One of the vessels was a cabin cruiser, 7 m (23 ft) long with a 2.5 m (8.25 ft) beam. Johnson reports that at a speed of 18.5 km/h (11.5 mph), the cabin cruise produced a maximum wave of 33.5 cm (1.1 ft) at 30.5 m (100 ft) from the sailing line and a height of 24 cm (0.8 ft) at a distance of 152 m (500 ft). He also stated that wave heights, in general, were less in shoaling water; however they did break. Sorensen (1973) presents similar data for a cabin cruiser. At 11.5 mph or less, the maximum wave was 33.5 cm (1.1 ft); while above 18.5 km/h (11.5 mph), the vessel planed and maximum wave height was reduced to 0.23 m (0.75 ft). From Sorensen's own observations, variations in wave height were small for different hull types and are mostly a function of speed above or below the planing speed of the vessel. Sorensen states that the maximum wave decreases the most between 30.5 and 91.4 m (100 and 300 ft) and is relatively constant for the next 61 m (200 ft).

Bhowmik et al. (1991) collected wave data from recreational vessels in controlled runs at two sites, the Illinois River near Havana and the Mississippi River near Red Wing. Summary tables of tests did not include all maximum wave heights. Wave heights in Table 9 were scaled from plots of tests presented in the report at the Havana site and Red Wing sites. Based on information given in tables in the report regarding length of vessel and hull shape, the vessels were assigned to one of the vessel classes used in this study.

From summary frequency distributions in the Bhowmik et al. (1991) report on maximum wave heights at the Havana site, the wave heights varied from 5 to 25 cm at wave Gage 1 and from 5 to 40 cm at Gage 2. Depending on the sailing line track used for the experiments, the vessel varied in distance at Gage 1 from 15.2 to 91.4 m (50 ft to 300 ft) and at Gage 2 from 7.6 to 83.8 m (25 ft to 275 ft). At Red Wing, the wave heights varied from 5 to 60 cm at Gage 1 (15.2 to 91.4 m (50 to 300 ft) from vessel and 5 to 50 cm at Gage 2 (7.6 to 83.8 m (25 to 275 ft)) from vessel. According to the data, duration of events was less than 1 min, the median being approximately 20 to 26 sec. Bhowmik et al. (1991) state "that a distance of about 100 meters is the outer limit where waves caused by an average recreational boat would have effects on the shoreline."

In addition to controlled run data collection to evaluate individual wake waves, Bhowmik et al. (1991) also collected and analyzed waves generated on a busy recreational boating day at the Red Wing site. They observed up to 120 boats in a single hour and concluded the following:

"The maximum observed wave heights for uncontrolled movements were 1.67 to 1.8 ft. Sustained movement of recreational boats can generate essentially continuous waves, giving the appearance of random waves at the shoreline." Higher waves (40 to 50 cm) can be sustained for prolonged periods. A more continuous wave history was observed when traffic levels reached approximately 50-60 boats per hour. It remained constant until traffic died off at the end of the day."

Results

Assignment of maximum wave heights to vessel classifications

Assignments of maximum wave height for each vessel class have been conservatively estimated (high) from the previous information and provided in Table 10. Distances represented in this table were used to create buffer zones extending from the edge of the navigation area GIS polygons assigned to each vessel type in each pool and river reach on the UMRS. This assumes that a vessel can operate near the circumference of the polygon and thereby generate a wave that propagates from the vessel through the buffer zones. Larger vessels such as cabin cruiser, houseboats, and pontoons are more likely to navigate down the main navigation channel toward the center of the river. This approach adds an imaginary buffer between the actual sailing line and the edge of the polygon. From the observations stated in the literature, waves drop the most in amplitude between 30.5 and 91.4 m (100 and 300 ft) (Sorensen 1973) or have little effect beyond 325 ft (Bhowmik et al. 1991). These observations were considered in setting wave heights for each of the buffer zones.

Jet skis do produce a wake in close proximity of the vessel, but by 100 ft from the vessel there is no apparent wake. Since no data were available near the vessel, and based on the photo in the Rust Environment & Infrastructure (1996a), a value of 8 cm was assigned to the area nearest the vessel.

For certain vessel classes, particularly pontoons and houseboats, no or very limited information was available. From Carlson et al. (2000), houseboats and pontoons have similar speeds and relative sizes. Their mean speed is 19 to 22.5 km/h (12 to 14 mph). Both vessel classes were assumed to have similar maximum wave heights. The only wave data available for this class vessel are presented in this report and the analysis indicated that nothing above 3 to 5 cm was measured. Vessel speeds associated with these tests were less than 10 mph and therefore lower than the reported speeds. To account for this, a wave height of 8 cm was assigned to both of these vessel classes for distances up to 30.5 m (100 ft) from the vessel.

From Bhowmik et al. (1991), two boats that were thought to be classified in the small powerboat or fishing boat categories produced waves at 15 m (50 ft) from 11 to 16 cm. From the UMRS data, the Starcraft fishing boat resulted in only one maximum wave of 8 cm at 195 ft from the vessel. All other tests produced values of 4 cm or less. The maximum value of 16 cm was selected for distance up to 30.5 m (100 ft) from the vessel, and an 8-cm value was selected at 30.5 to 91.4 m (100 to 300 ft) from the vessel.

From Bhowmik et al. (1991), data for medium powerboats ranged from 15 to 24 cm up to 30.5 m (100 ft) from the vessel and 12 to 22 cm at 30.5 to 91.4 m (100 to 300 ft). The UMRS field data suggested that waves did not exceed 14 cm at any distance. The maximum wave of 24 cm was used in the range closest to the vessel and was tapered to 14 cm at the 91.4- to 152.4-m (300- to 500-ft) range.

The maximum for cabin cruisers was 34 cm from Sorensen (1973) traveling at 18.5 km/h (11.5 mph), 45 cm from Bhowmik et al. (1991), and 20 cm from the UMRS field data (both traveling at 14.2 km/h (8.8 mph)) at distances up to 30.5 m (100 ft) from the vessel. In uncontrolled tests from Bhowmik et al. (1991), maximum waves were recorded from 25 to 60 cm at all distances from the vessel. There was no information that tied this to a specific vessel type, but because these were maximum waves that were observed, the author selected values on the high side for this category assuming that this vessel category likely contributed to these wave heights. At distances of 30.5 to 91.4 m (100 to 300 ft) from the vessel, the data suggested a range of 20 to 45 cm wave heights. For cabin cruisers, 50, 40, and 20 cm were selected for each buffer zone, respectively, with increasing distance from the vessel.

Generic wake wave time series

To evaluate potential resuspension of sediments resulting from vessel wake waves, a time series of the wake-wave event is needed. An example of the generic wake wave time series along with an actual time series of wake waves from the commercial towboat "Dixie Patriot" with barges is given in Figure 5 (Knight 1999.)

A generic time series pattern for recreational boat wake waves was developed similar to that done for commercial tows. A schematic pattern is shown in Figure 6. There were no apparent differences in the number of waves and their periods between classes of recreational vessels.

Based on Bhowmik et al. (1991), the average period of individual wake waves was 1 to 3 sec and duration of an individual wake wave train was on the order of 20 to 40 sec. Bhowmik et al. (1991) also observed that about 12 to 15 wake waves were generated by an individual recreational boat. The median duration of these events was 20 to 26 sec. A schematized wave series generated by recreational boats shown in Figure 6 has 12 waves of varying heights but a constant wave period of 2 sec. This wave series was used in computing wave-induced sediment suspension. Beginning with 2-cm waves, the peak height was attained in three waves, dropping to 4 cm over the next three waves and then continuing at 4 cm for the remainder of the six waves. The generic time-history presented in Figure 6 can represent all classes of vessels by changing only the maximum expected wave height. A typical response collected in the field from a cabin cruiser is shown in Figure 7.

4 Sediment Resuspension Modeling

General Methodology

Prior to a resuspension study conducted as part of the Upper Mississippi River Illinois Navigation Study (Parchure et al. 2001), a literature search was not successful in finding computational methods for predicting wave-induced resuspension. The following approach was developed:

a. Select a maximum value of wave height in a wave series.

b. Develop a need-specific wave series if several such consecutive events are to be considered.

c. Compute heights of individual waves in a series of waves generated in each boat passage event past the site of interest.

d. Assign appropriate values to parameters that define the erosional and depositional properties of bed sediment at site.

e. Use analytical model, VESTUNS, (Parchure et al. 2001), to compute sediment resuspension and deposition using the computed wave series as input. Outputs include the net amount of sediment in suspension.

Resuspension Algorithm

A commonly used form of erosion equation is

$$E = s\left(\frac{\tau_b - \tau_e}{\tau_e}\right) \tag{1}$$

where

E = erosion rate

s = erosion rate constant

τ_b = bed shear stress

τ_e = critical shear stress for erosion

The sediment suspension model, VESTUNS, uses a one-dimensional (vertical, 1DV) numerical solution of the convection diffusion equation to compute the vertical profile of sediment. It accounts for sediment settling and deposition plus erosion from the bed and upward diffusion by short period waves and/or a superimposed current. It considers the bed to be formed of mud with significant quantities of cohesive material. VESTUNS is based on the model VEST (Mehta and Li 1996).

The model solves the 1DV equation

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z}\left(K \frac{\partial C}{\partial z} + W_s C \right) \tag{2}$$

where

C = sediment mass concentration

t = time

z = vertical dimension

K = diffusion coefficient

W_s = sediment settling velocity, with the latter two parameters calculated from the following expressions

Equation 2 is solved by an implicit finite difference scheme.

$$K = \frac{\alpha_w H^2 \sigma \dfrac{\sin h^2(kz)}{2 \sin h^2(kh)} + \kappa u_* z \left(1 - \dfrac{z}{h}\right)}{(1 + \alpha_0 R_i)^{\beta_0}} \tag{3}$$

$$Ws = \begin{bmatrix} W_{sf} & C < C_{sf} \\ \dfrac{a \ C_{m1}}{\left(C^2 + b^2\right)^{m2}} & C > C_{sf} \end{bmatrix} \tag{4}$$

where

α_w = wave diffusion constant

H = wave height

σ = wave frequency

k = wave number, = $2\Pi/L$

L = wave length

h = water depth

κ = von Karman coefficient, taken to be 0.4

u_* = shear velocity

α_0, β_0 = empirical coefficients

W_{sf} = free settling velocity of sediment, determined by experiment

C_{sf} = upper concentration limit on free settling

a, b, m_1, m_2 = empirical coefficients

R_i = gradient Richardson number, given by:

$$R_i = \frac{-g \dfrac{\partial \rho}{\partial z}}{\rho \left(\dfrac{\partial u}{\partial z} \right)^2} \tag{5}$$

where

g = acceleration of gravity

ρ = fluid density

u = horizontal velocity (current plus wave)

The user specifies the initial concentration profile. Boundary conditions are zero concentration flux at the water surface and erosion/deposition flux at the bed, F_n, given by:

$$Fn = \begin{cases} -W_s C_{bed} \left(1 - \dfrac{\tau_b}{\tau_d}\right) & \tau_b \leq \tau_d \\ 0 & \tau_d < \tau_b < \tau_e \\ +s\ (\tau_b - \tau_e) & \tau_b > \tau_e \end{cases} \tag{6}$$

where

C_{bed} = sediment concentration just above the bed

τ_b = bed shear stress

τ_d = critical shear stress for deposition, determined by experiment

s = erosion rate constant

τ_e = critical shear stress for erosion, with the latter two given by:

$$s = s_{\max} e^{-a_r \tau_e b_r} \tag{7}$$

$$\tau_e = \alpha_e \ (\phi - \phi_e)^{\beta_e} \tag{8}$$

where

$s_{\max}$, a_r, b_r, β_e = empirical coefficients

ϕ = solids weight fraction, with ϕ_e the critical value below which the mud behaves like a fluid

The model allows for fluidization of the bed by waves, but that feature was not employed in this application.

The bed shear stress is calculated from:

$$\tau_b = \begin{cases} \dfrac{f_w}{2} \rho \ u_b^2 & \text{wave motion} \\ \dfrac{f_c}{2} \ \rho \ U^2 & \text{current} \end{cases} \tag{9}$$

where

f_w = wave friction factor

u_b = wave orbital velocity amplitude at the bed

U = depth averaged current velocity

f_c = current friction factor

$$\frac{1}{4 \ \sqrt{f_w}} + \log \frac{1}{4\sqrt{f_w}} = -0.08 + \log \frac{A_{ab}}{K_s} \tag{10}$$

where

K_s = Nikuradse roughness parameter

$$A_{ab} = \frac{H/_2 \ \cosh \ kh}{\sinh \ kh} \tag{11}$$

where

k = wave number, = $2\Pi/L$

L = wavelength

h = water depth

where

$$f_c = 2g\ \frac{n^2}{h^{1/3}} \tag{12}$$

where

n = Manning roughness coefficient

Characterization of Sediments

Characterization of sediments are determined by the following details.

Sediment shear strength

The shear strength of erodible cohesive sediment bed needs to be determined experimentally either in the field or in a laboratory (Mehta et al. 1982). Correlations such as that between the dry/bulk density and shear strength are sometimes established based on a large number of tests conducted on sediment samples from a study area. At present there is no analytical procedure available for obtaining the exact values of:

a. Critical shear stress for erosion.

b. Rate of erosion as a function of bed shear stress.

c. Erosion-rate-constant for any sediment, even if values of some of its properties are available.

A commonly used form of erosion equation is given earlier as Equation 1. The erosion rate constant is the proportionality constant in the erosion rate equation. It is a sediment-specific empirical coefficient, which needs to be determined through laboratory or field tests. The critical shear stress for erosion is a function of several parameters such as the clay mineral, chemistry of pore fluid and eroding fluid, percent organic contents, water content, etc. Therefore, it needs to be determined experimentally. The time series of waves is provided as input to the VESTUNS model. The wave-induced bed shear stress is calculated from Equation 9 given earlier. Erosion rate in Equation 1 is calculated by using values of bed shear stress, critical bed shear stress, and erosion rate constant. The erosion rate has units of grams per square centimeter per second. When the bed density is known, the thickness of layer eroded can be calculated, which is then used to calculate the volume of sediment brought in suspension per unit of time. During the initial period of time, the rate of erosion is higher than the rate of sediment deposition. Later on, the two rates balance each other and result in an equilibrium suspension concentration.

Laboratory testing of field sediment

Laboratory tests were conducted on sediment samples collected in Pool 8. The samples were assigned erodibility labels based on the values of particle-size distribution, bulk density, and total organic content. (See Appendix C for particle-size distributions). Nine surface sediment samples collected from the nearshore region were subjected to laboratory tests (Figure 8 shows location of samples in Pool 8). Particle-size distribution was determined by using Coulter Counter model LS100Q instrument.

Erosion tests were conducted by using the Particle Entrainment Simulator (PES) described by Tsai and Liek (1986). The sediment samples brought from the site were placed in the PES cylinder and tap water was used as the eroding fluid. The PES consists of a perforated disc placed horizontally in a Plexiglas cylinder containing sediment sample. Shear stress is imparted at the sediment-water interface by moving the disc vertically up and down by an electric motor.

Samples of sediment suspended within the water column were drawn periodically from the cylinder and its suspension concentration was determined. These data were used to compute the rate of erosion. By plotting the values of erosion rate E as a function of fluid-induced bed shear stress, the values of critical shear stress for erosion and erosion rate constant were determined. Each test provides two values of both the parameters, one in the lower range of bed shear stresses and the other in the higher range.

Nine samples from the Pool 8 Mississippi River study area were tested for critical shear stress and erosion rate constant using the PES. The samples were also analyzed to determine total organic content and bulk density. The results of the tests are summarized in Table 11. See Parchure et al. (2001) for more details.

Sediment classification

Sediments occurring in nature are often mixtures of inorganic and organic substances. The inorganic component consists of coarse sediments in particle sizes ranging from boulders to sand and fine sediments ranging from silt to clays. It is necessary to know the shear strength of soil for ascertaining its potential for erosion. The erosion processes of coarse and fine sediments are quite different when considered separately. Influence of organic matter depends upon the quantity and type. The only reliable way to measure shear strength in laboratory is by conducting erosion tests. To describe erodibility of Mississippi River bank under vessel-induced waves, you have to take into account several miles of reach. Sediment composition varies with water depth and location along the shore. It is impossible to tell how many samples per mile would be "representative" of the sediment in each reach. It is also expensive and time-consuming to conduct erosion tests on every sample. In view of the limited amount of time and money for any project, it became essential to develop a system of classification in which erosion strength of sediment samples can be estimated from measurement of a few properties determined by adopting quick and inexpensive laboratory methods.

The new sediment classification system has been used for predicting resuspension rates throughout the UMRS. Many samples from channel border areas throughout the UMRS were collected and analyzed for particle-size gradation, total organic content, and bulk density. These samples were considered representative of nearshore sediments in their respective river segments and were classified according to the following methods.

Relationships about sediment physical parameters reported in literature have been taken into account in developing the classification methodology used in this study:

a. Shear strength of cohesive sediment bed generally increases with increasing bulk density (Owen 1970)

b. Erosion rate constant generally decreases with increasing bulk density (Hwang 1989).

c. Settling velocity for cohesive sediments is a function of suspension concentration (Parchure and Long 1993) in addition to other factors. The settling velocity increases with increasing concentration of sediment in suspension between the range from about 50 mg/L to about 5,000 mg/L. For concentrations higher than about 5,000 mg/L, the settling velocity decreases with increasing concentration (Hwang 1989).

d. Erosion rate constant decreases with increasing bed shear strength (Lee and Mehta 1994).

e. Decreasing organic content generally correlates with increasing bed density (Lee and Mehta 1994). In other words, higher organic content decreases bed density.

f. Clay particles are smaller than 4-micron size and silt is finer than 62-micron size (Selley 1982).

g. Erosion rate of cohesive sediments is a function of flow-induced/wave-induced bed shear stress (Equation 1), among other factors. Laboratory tests on erosion of cohesive sediments often indicate two ranges of erosion rates and erosion rate constants, one in the lower range of bed shear stress and the other for the higher bed shear stress. Hence, the same sediment may have two values of these two parameters (Parchure 1980)

For purposes of erosion estimates, all samples were first classified under three groups, namely, Group 1-Cohesive, Group 2-Cohesive, and Noncohesive. Each sample under the Group 1-Cohesive and Group 2-Cohesive was then assigned one of three Erodibility Labels: viz. Soft, Medium, and Hard, based on criteria of bed density and percentage of organic matter. By definition, sediment bed labeled as soft is easier to erode than the bed labeled as medium bed. Similarly, sediment bed labeled as medium is easier to erode than the bed labeled as hard bed. In other words, a soft bed has a lower critical shear strength for erosion than that for the medium bed and a medium bed has a lower critical shear strength for erosion than that for the hard bed. For the present purpose, the use of these terms is indicative of only the relative erodibility of sediment.

In order to group and label bed samples, the following three-step approach was adopted.

- Step 1: The samples were first separated into three categories based on the relative percentages of clay, silt and sand obtained from particle-size distribution.

  <u>Group 1-Cohesive</u>
  When the sediment has 70 percent or more particles finer than 4-micron size ($D_{70} \leq 4$ microns).

  <u>Group 2-Cohesive</u>
  When the sediment has 70 percent or more particles finer than 62-micron size or when the sample has more than 16 percent clay ($D_{70} \leq 62$ microns or $D_{16} \leq 4$ microns).

  <u>Noncohesive</u>
  When the sediment contains more than 30 percent sand ($D_{70} \geq 62$ microns and $D_{16} \geq 4$ microns).

- Step 2: The sediments were next separated based on the percentage of total organic contents.

  <u>Low</u>
  When the total organic content is less than 5 percent.

  <u>Medium</u>
  When the total organic content is 5 to 10 percent.

  <u>High</u>
  When the total organic content is more than 10 percent.

- Step 3: The last separation was done based on the sediment bulk density.

The sediment classification procedure is explained in Figures 9, 10, and 11, respectively, for the Group 1-Cohesive sediments, Group 2-Cohesive sediments, and for the Noncohesive sediments. Based on the results of laboratory erosion tests conducted on the samples from the field, these three types of bed were assigned values of bulk density, critical shear strength, and erosion rate constant. These are shown in Table 12.

5 Results of Resuspension Modeling

Overview

As demonstrated in this chapter, the sediment resuspension and deposition study reinforces in a quantitative manner the qualitative results that might be expected as a vessel resuspends sediments in shallow nearshore zones. Sediment concentrations increase with higher wave heights, longer wave trains, and more vessels. As vessel frequency increases, there is less opportunity for deposition of sediments after each passage and the suspended sediment concentrations accumulate to an equilibrium level and are sustained for longer periods of time. The computer-generated results show that the time-averaged equilibrium concentrations are the most significant in the context of the present study.

To simplify and automate computations of sediment resuspension, a computer program was written to accept required wave inputs and sediment parameters into the VESTUNS sediment suspension model and generate outputs for analysis. Input parameters were selected based on results of the wave analysis and sediment classification studies. The analysis was conducted to provide a range of outputs for evaluation of recreational boating areas along the entire UMRS. Time-histories of suspended sediment concentrations from this modeling were used to provide inputs to ecological models evaluating impacts.

Model Verification

Field data collected in 1995 and1996 in the UMRS (Fagerburg and Pratt 1998) were used for model verification. The data were collected for towboat traffic. Parameters measured in the field included vessel type, vessel speed, vessel-induced sediment-suspensions concentration, wave heights, and sediment type. The data were collected in Pool 8, Pool 26, and La Grange Pool, Illinois River. Suspension concentrations recorded at three depths after the passage of towboats were within the following ranges: Pool 8: 50 to 70mg/L; Pool 26: 96 to 122 mg/L; La Grange: 180 to 400 mg/L. These data were collected at 53 locations, in different water depths and sediment compositions for a variety of vessels. The measured maximum wave height in uncontrolled tests of commercial vessels was 12 cm.

In spite of a very extensive field database, it was difficult to select field observations with conditions identical to those used in the model. A limitation was that the model wave heights extended up to 60 cm, whereas the field wave heights did not exceed 12 cm. Taking into account the sediment composition, which matched closer to the "soft" label, the model gave concentrations ranging from 13 to 241 mg/L for 10 cm heights. The desktop computational procedure is a simplified representation of natural conditions. It uses generalized wave series and generalized sediment properties and gives a depth-averaged suspension concentration. On the other hand, the site conditions may be different from the model in terms of wave pattern, sediment properties, and vertical distribution of sediment. Hence, the results obtained by the adopted procedure are considered comparable with the field observations within one order of magnitude of sediment concentration.

Input Data

The following details of wave data, traffic frequency-multiple events, channel and sediment-related parameters make up the input data.

Wave data

Recreational vessels are widely varied in their size, shapes of bow and keel, weight, width, configuration, etc. In the context of the present study, it was neither necessary nor practical to consider the unique wave pattern generated by all conceivable types of boats. Therefore, data from vessels representing six classifications were analyzed and a maximum expected wave height was selected for each class (Table 10). Passage of one recreational boat near a specific site under investigation is considered one event. Each event consists of a propagation of a series of waves of different heights. It was presumed that one wave in the series has the maximum wave height. The generalized time-history used in the model was adapted from Figure 6. The variable wave train is correlated to a single parameter, maximum wave height. Each wave is assumed to have a 2-sec wave period, and the total wave series consists of 12 waves. Figure 12 shows the schematized input used in the sediment resuspension model for both commercial towboats (200 waves) and recreational vessels (12 waves).

The maximum values of wave heights assigned to the six classes of recreational boats listed in Table 10 are 4, 8, 10, 16, 20, 24, 40, and 50 cm. Figure 13a and 13b show schematic wave series for maximum wave heights corresponding to these values. Preliminary studies showed no sediment resuspension for wave heights less than 10 cm in height. Hence, the maximum values of wave height used to develop the suspended concentration curves were 20, 30, 40, and 50 cm. The schematized wave series shown in Figure 12b was used as input to the model by suitably changing the value of maximum wave height.

Traffic frequency-multiple events

Evaluation of single events was practical in the studies of commercial tows on the UMRS, since there is a relatively low frequency of vessels passing a certain reach of river. On the other hand, in certain reaches of the river, which are very popular for recreation, the number of recreational boats in the area on popular summer holidays can be very high. In studies conducted by the Illinois State Water Survey (Bhowmik et al. 1991), up to 120 boats per hour were observed during a busy holiday at a recreational boating site on the UMRS. The authors also observed that 50 to 60 boats per hour gave a more continuous wave pattern resulting in sustained suspended sediment concentrations. The recreational boating traffic forecast and allocation model (Carlson et al. 2000) provides estimates of traffic rates in this range in some popular boating areas on the UMRS. Although the recreational boats are small in size, their higher frequency makes it imperative to evaluate the effects of multiple events.

In a real-life situation, the random arrival of different type vessels under different operating conditions would give a mix of multiple events with irregular wave heights. Also, the interarrival times for these events would be random as well, causing perhaps a few boats to arrive in a few minutes and then not have another for many minutes. The actual random combinations of vessel types and interarrival times would result in infinite combinations of wave series inputs. The study was simplified to look at a specified wave height occurring at even intervals.

Wave inputs were prepared for sequencing boats to pass a location at intervals of 1, 5, 10, 20, 30, and 60 min. Figure 14 shows suspension concentration resulting from passage of recreational boats at 1-min intervals. Figures 15 and 16 are examples of the wave inputs for a single event (1 boat) and multiple events (2, 5, and 40 boats) producing a 30-cm maximum wave passing a point in 1 hr. The wave series was used as input for computing sediment resuspension. Suspended sediment concentrations resulting from multiple events were calculated for durations up to 6 hr.

Since the model runs cover the entire range of anticipated wave heights and boat frequencies, results needed for other wave heights and/or frequencies can be obtained by interpolation techniques. Results for a selected combination of wave heights and duration can be obtained through linear interpolation computations using the results presented in Tables 13, 14, and 15.

Channel parameters

While the plan and profile shapes of the nearshore area contribute to the propagation, attenuation, and breaking characteristics of the wave and its effects on sediment resuspension, the VESTUNS model is an approximation based on one dimension (vertical) and therefore, only requires depth as an input. While the model is capable of accepting multiple depths, all computations were performed in this study for the nearshore conditions with a water depth of 1 m. The value of 1 m was a UMRS system parameter selected as a critical depth for aquatic habitat areas. Both submerged aquatic macrophytes and other benthic organisms in this zone are sensitive to light variations and thereby sediment resuspension. The depth of 1 m was used in the GIS to delineate these critical ecological areas along the entire UMRS.

Sediment-related parameters

The procedure described in Chapter 4, paragraph on sediment classification, was used for classifying sediments on the UMRS in terms of their erodibility. Polygons in the GIS having a Group 1-Cohesive classification were assigned one of the three labels, namely soft, medium and hard. Preliminary computations indicated that the relatively small wave heights and wave duration of the recreational boat waves could erode only the soft category of sediments, which included primarily fine sediments. All the computations using variable wave heights and frequencies assumed soft sediments. The GIS was used to identify sites along the banks of the Mississippi River where soft sediments predominate and recreational boating can occur.

Results of Modeling Sediment Resuspension by Recreational Boat Wake Waves

Suspended sediment concentration is determined by a variety of factors as discussed in the following text.

a. *Effects of wave height and vessel passage interval on equilibrium suspended sediment concentration.* Time-history of suspended sediment concentrations were computed for wave heights of 20, 30, 40, and 50 cm and for vessel passage frequencies (1, 5, 10, 20, 30, and 60 boat passages per hour) over a total duration of 6 hr. Results of computations are presented in graphical form in Figures 17 through 28.

   Mean equilibrium concentration as a function of recreational boat-induced waves at 1- to 60-min intervals for a maximum wave height of 30 cm are given in Table 13.

b. *Effect of wave height on suspended sediment concentration.* The effect of increasing wave heights on concentration of suspended sediment is illustrated in Figures 29, 30 and 31 for maximum wave heights of 10, 20, 30, 40, and 50 cm with 360 recreational boats passing at 1-min intervals over a period of 6 hr. It may be seen from these figures that after an initial increase in suspension concentration, the magnitude tends to stabilize at an equilibrium concentration. With higher wave heights, the time required to reach the equilibrium suspended sediment concentration declines. Peak sediment concentration resuspended by recreational boat wake waves of different heights occurring at one boat per minute vessel passage frequency is given in Table 14. The mean equilibrium sediment concentration resuspended by recreational boat wake waves of different heights occurring at one boat per minute vessel passage frequency is given in Table 15.

c. *Effect of boat passage frequency on suspended sediment concentration.* The effect of boat passage interval on sediment resuspension and deposition is illustrated in more detail in Figures 32, 33, and 34, which are plotted over only the initial 30-min duration. The wave height is constant at 30 cm in all these figures. The boat passage interval is changed from 1 min to 5, 10, 20, 30, and 60 min. Although predicted suspension concentration was about 80 mg/L at the first wave in each case, the net suspension concentration at the end of 30 min was lower with reduction in frequency of boat-passage. The maximum concentration resulting from a single event versus a series of 360 events at 1-min intervals is shown in Figure 35a. The maximum suspension concentration for any maximum wave height in the range of 10 cm to 50 cm and boat frequency from 1 per hour to 60 per hour will fall within the range defined by the two lines on Figure 35a. For comparison, Figure 35b illustrates the effect of wake wave height on the peak suspended sediment concentration generated by a single passage event.

   Figure 36a shows the time-averaged "mean equilibrium concentration" and Figure 36b shows peak concentration for different recreational boat passage frequencies from 1 to 60 boats per hour, assuming a 30-cm maximum wake wave height.

Sediment Settling

Fine sediments flocculate readily. At higher concentration, the particle collision frequency is higher, leading to larger flocs, which settle faster. Hence, suspension concentration drops rapidly under quiescent conditions and higher concentrations. This is shown in Figure 37 for initial concentrations of 1,500; 1,300; 1,100; 800; 430; 210; 110; and 55 mg/L. These results can be used to obtain reduction in suspension concentration during any length of time between both passage events.

Comparison of Resuspension Results

Commercial tows and recreational vessels have significantly different configurations and produce very different characteristic patterns of wake waves. A general comparison of the two wake wave patterns is shown in Figure 12. The wave pattern characteristics of towboat/barges and recreational boats are tabulated in Table 16. These differences in wake wave pattern can result in significant differences in the magnitudes of maximum suspension concentration.

Commercial traffic in the UMRS has a relatively very low frequency, generally less than 15 vessel passage events per day. On the other hand, in certain reaches of the river, the number of recreational boats in the area on summer holidays can be as high as 120 boats per hour. Although the recreational boats are considerably smaller than the commercial tows, the recreational boat traffic frequency and wake-wave generation characteristics may impose a wave regime much more significant than does the commercial traffic.

Peak concentration as a function of towboat-induced wake-wave heights of various magnitudes from single passage events is given in Table 17. By comparison, a series of recreational boat passage events (1-min intervals) produced the results in Table 14. Figure 35a shows maximum concentration of suspended sediment as a function of wave height generated by recreational boats. In comparison, Figure 35b shows similar results for towboats. It may be seen that for any wave height, the suspension concentration for a towboat is higher than that for the recreational boat. The reason for this is the number of waves generated by the two types of vessels in a single passage. The wave height plotted on the x-axis is the maximum wave height in a series of waves. The actual wave train generated by tows has 200 waves whereas the wave generated by the recreational boat has only 12 waves. Hence for any given maximum wave height, the suspension concentration caused by one tow is higher than a series of recreational boats with the same maximum wave height.

6 Summary

Wave Analysis Summary

The following are general conclusions regarding the study:

a. Recreational boats operating on the UMRS have a variety of hull, power, and operating characteristics and, therefore, have a wide range of wake-wave generating characteristics. Recreational vessels on the UMRS are operated in displacement, transitional, and planning modes over a wide range of speed. Boats generally produce low-amplitude wake waves when operating at lower speeds in the displacement mode, generate the highest wake waves when exceeding hull speed in a transitional mode, and tend to have lower wake waves when operating on plane. Many recreational boaters on the UMRS start and stop frequently, and do not necessarily navigate at steady operating speeds or along set sailing lines. All these factors make modeling of wake-wave generation difficult.

b. Literature suggests that wake-wave attenuation is not critical until the very nearshore. Most wave equations show a dissipation of wave height with distance. However, in the case of the field exercise conducted in Pool 8, a number of events were characterized with higher waves farther away from the vessel. This is probably attributed to the distance at which the wave crests intersect away from the vessel and may have been caused by wake-wave interaction with river current.

c. For purposes of system evaluation, potential maximum wave heights were assigned to vessel class and distance range from the sailing line. This method allowed developing GIS buffers around navigated area polygons to identify areas subject to different heights of recreational boat wake waves. Cabin cruisers and medium power boats appear to be the only two categories of vessels that can produce wake waves that could contribute to significant sediment resuspension and biological impacts. A generalized time-history wave response was developed for use in modeling sediment resuspension.

d. A number of assumptions and generalizations were made in assigning characteristic maximum wave heights by vessel class. Maximum wave heights that were observed in controlled vessel passage experiments were considered in developing the assignments of wave height by vessel class and distance from sailing line. For purposes of system modeling, the assumption is made that boats are operated at speeds that produce the maximum wake-wave height assigned to each vessel class. This means that the maximum wake-wave heights can be expected to occur anywhere in the navigated area polygons. Outside the navigated area polygons, maximum wake-wave height assignments were made to characterize typical attenuation of wake wave height with distance away from the sailing line. It is however assumed that maximum wave can occur anywhere inside the operating polygon. Attenuation in nearshore zone is assumed negligible. Dissipation of the wave is assumed at regions farther from the vessel. Wave data did not indicate any issues with wave reflection and, therefore, was assumed negligible.

Sediment Resuspension Analysis Summary

A new procedure was developed for estimating sediment resuspension resulting from the waves generated by recreational vessels in the UMRS. Quantitative predictions of wake-wave-induced suspended sediment concentrations in the nearshore zone were made using a verified numerical model. Data on nearshore sediment characteristics from throughout the UMRS were used as input to the model.

The procedure consists of the following steps:

a. Determine particle-size distribution, bulk density, and total organic contents of nearshore sediment.

b. Assign an erodibility label to each sediment sample.

c. Conduct erosion tests on the field samples to determine erosional characteristics and related coefficients.

d. Select the required wave time series using the wave data from site.

e. Run the model with appropriate input values of all the parameters.

The recreational boat wake-wave sediment resuspension model approach allows determining:

a. Whether or not the sediment at any given location is susceptible to erosion as a result of vessel-induced waves.

b. If the sediment is erodible, what is the expected value of maximum sediment concentration in suspension.

c. How long will the sediment remain in suspension.

The model is very versatile in its use. Effect of several relevant parameters such as wave height, wave period, time interval between consecutive vessels, water depth, type of vessel, characteristics of vessel, sediment properties, etc., can be evaluated from the use of this model. The effect of the following parameters on suspended sediment concentration in the nearshore zone have been evaluated:

a. Vessel-induced wave height.

b. Maximum suspended sediment concentration.

c. Background (ambient) suspension concentration.

d. Decrease in suspension concentration resulting from deposition without waves.

e. Time needed for the suspension concentration to drop back to the background magnitude of concentration.

f. Vessel passage frequency and timing of successive vessel passage events.

Sensitivity studies were conducted to assess sediment resuspension characteristics resulting from the recreational boat waves for single and multiple vessels. Comparisons were made between effects of commercial tows versus recreational boats. The results of these analyses of the hydraulic disturbances produced by recreational boat traffic will be used to assess the effects of boating traffic throughout the UMRS ecosystem.

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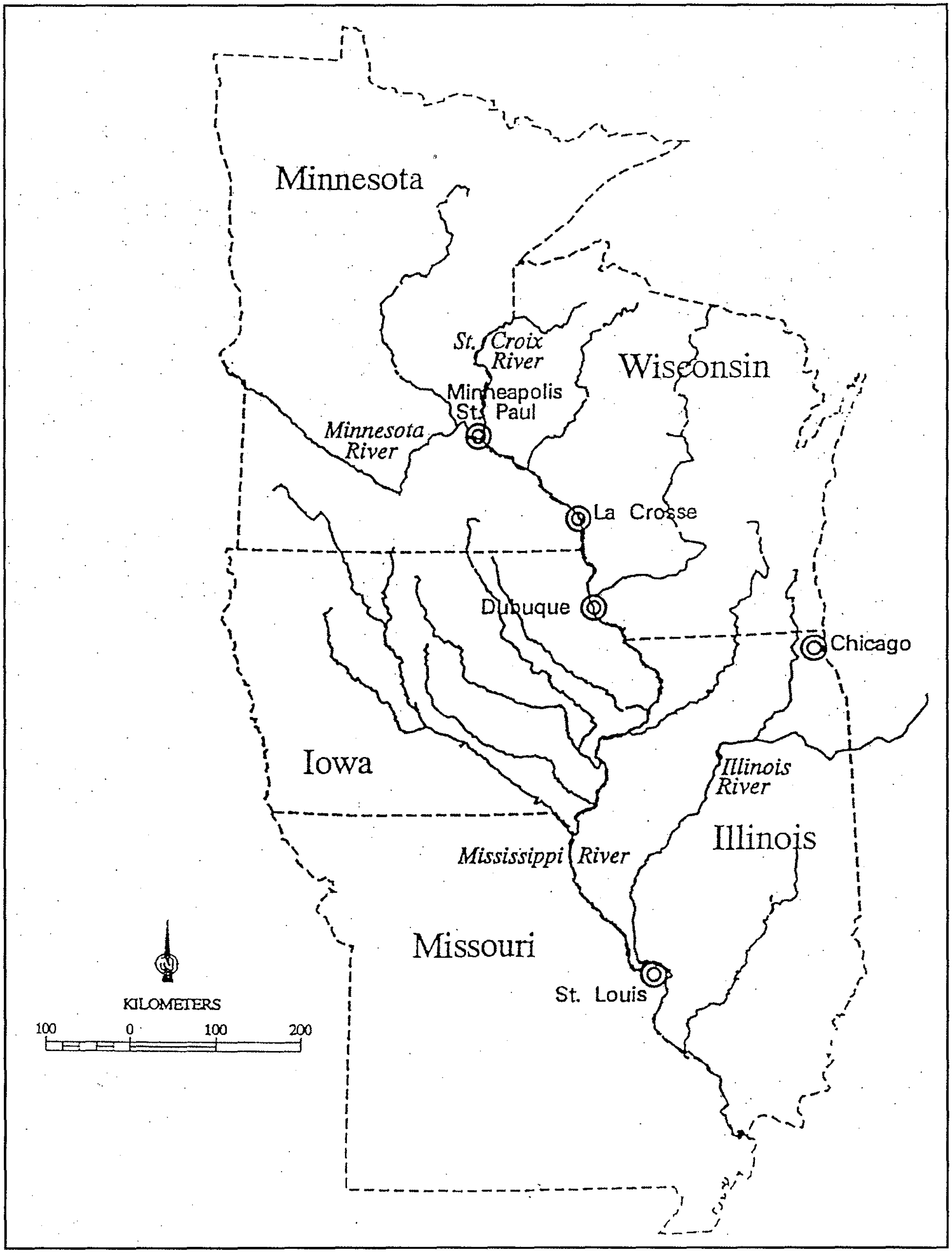


Figure 1a. Upper Mississippi River System showing La Crosse, WI

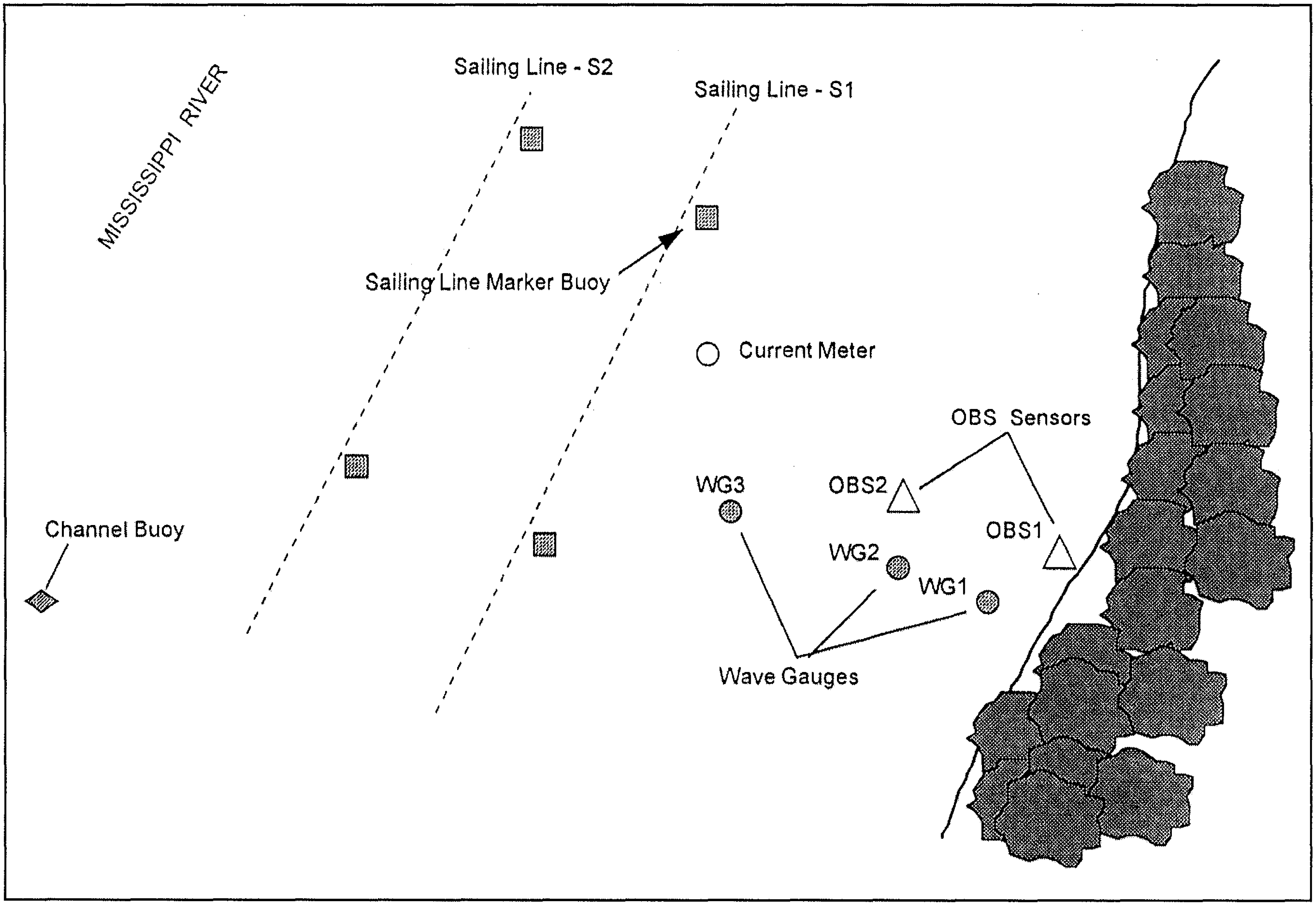


Figure 1b. Equipment deployment locations at data collection site

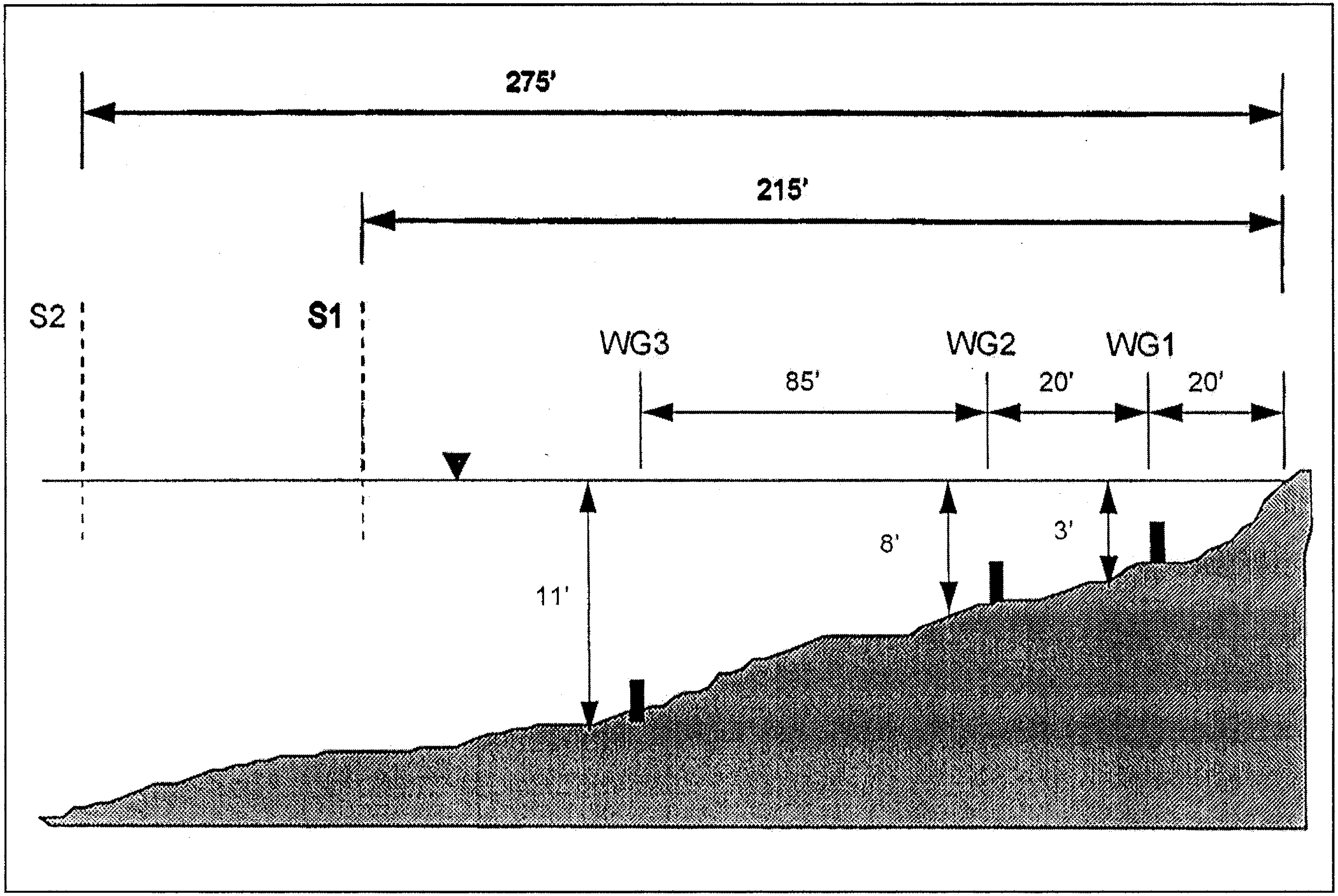


Figure 2. Wave gages and sailing line locations from shoreline

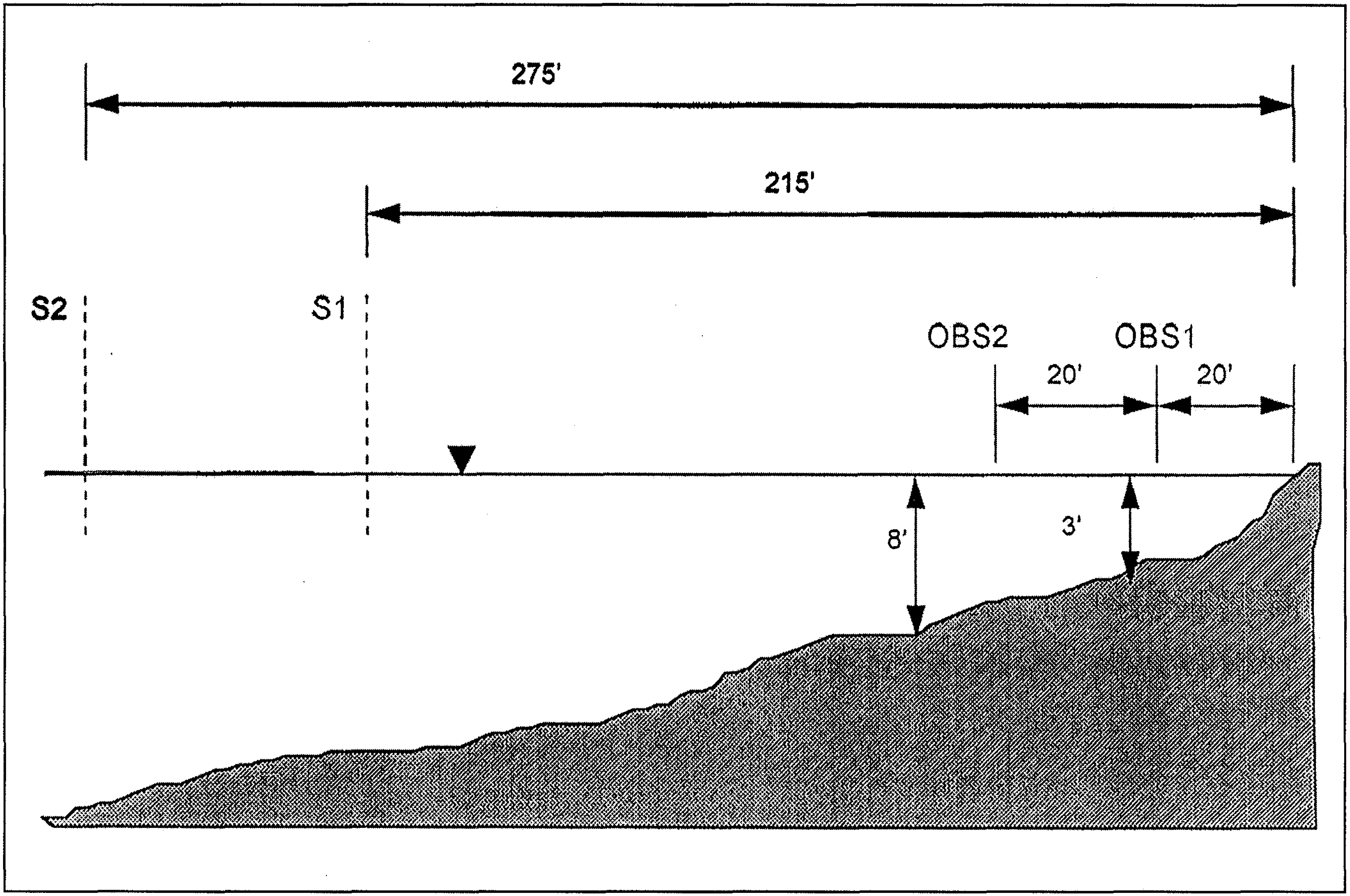


Figure 3. OBS sensors and sailing line locations from shoreline

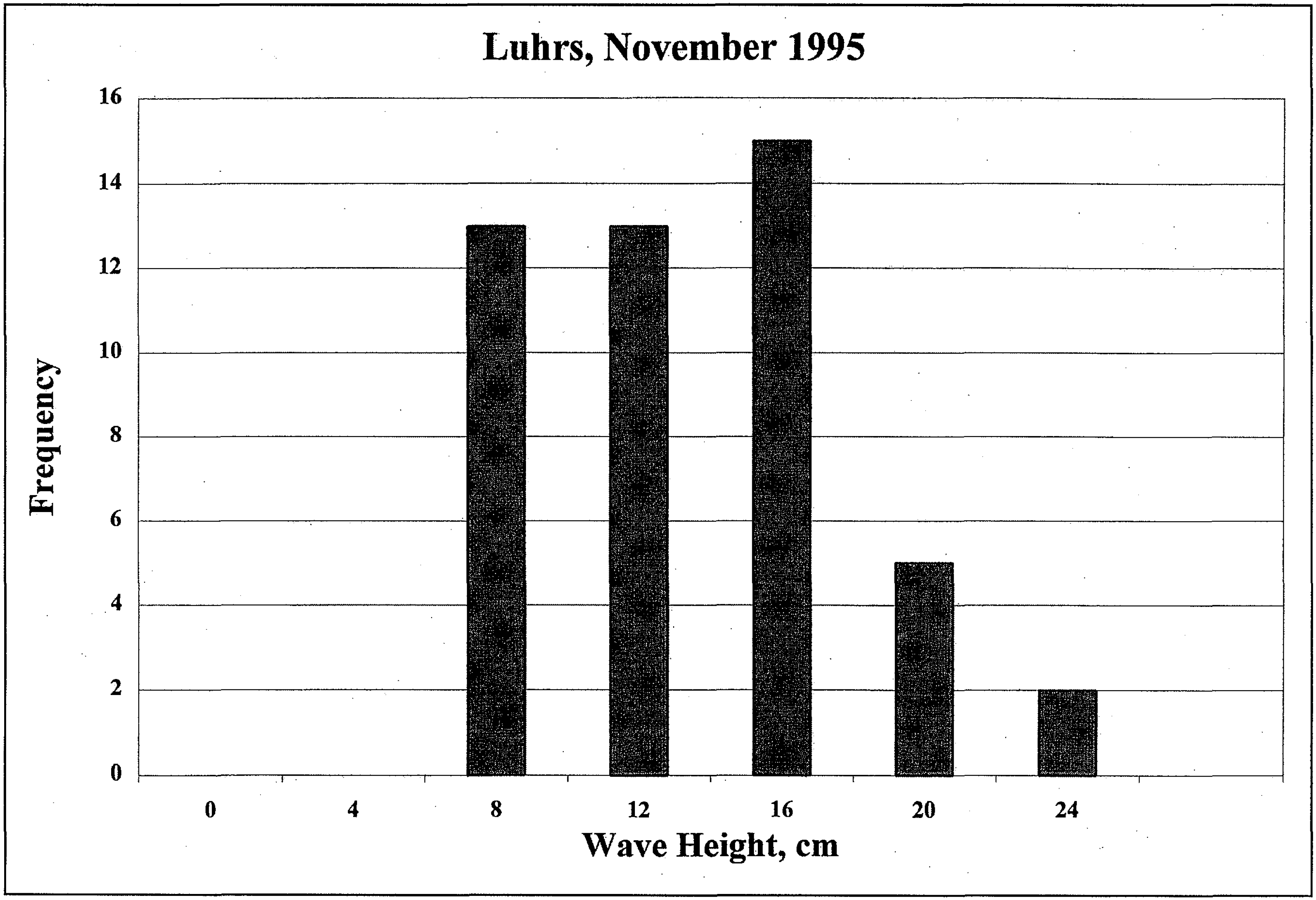


Figure 4. Histogram of wave heights greater than 4 cm from all tests conducted with cabin cruiser "Luhrs"

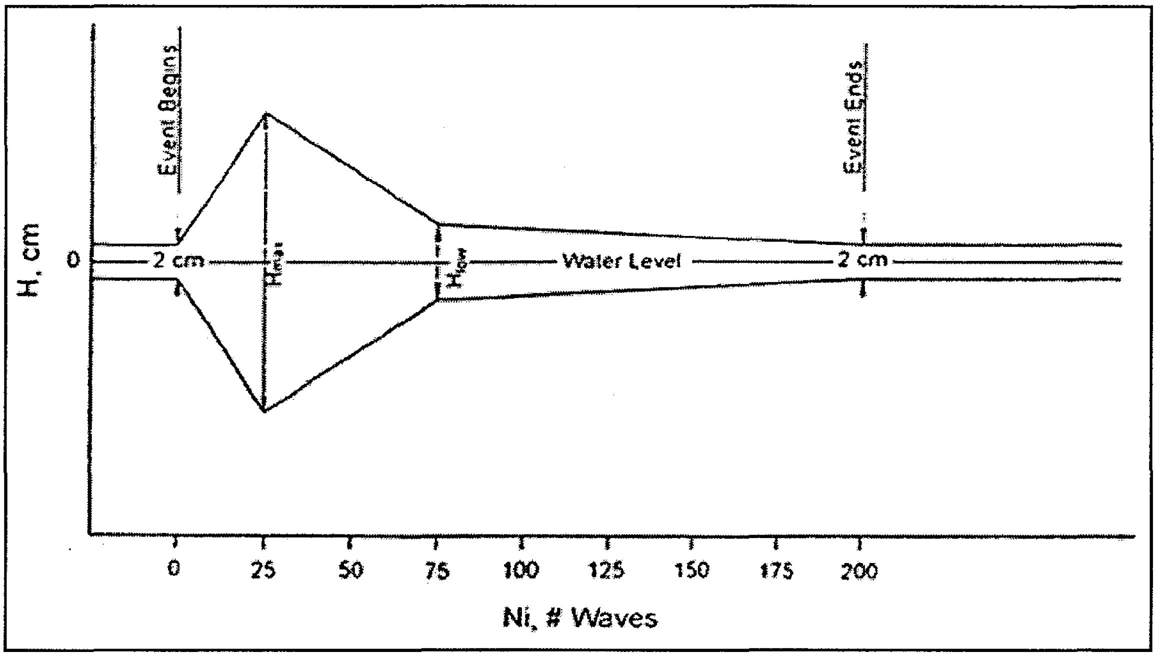


Figure 5a. Generic time-history based on Hmax

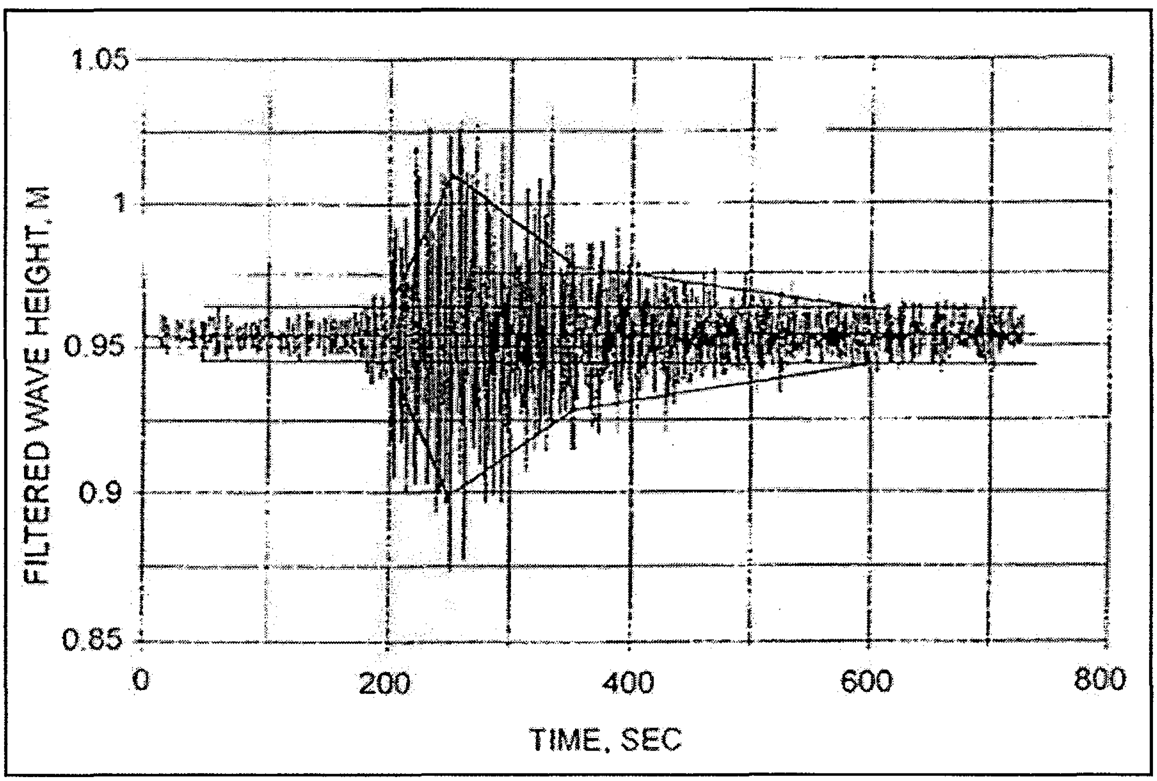


Figure 5b. Generic time-history along with actual time-history of events caused by "Dixie Patriot"

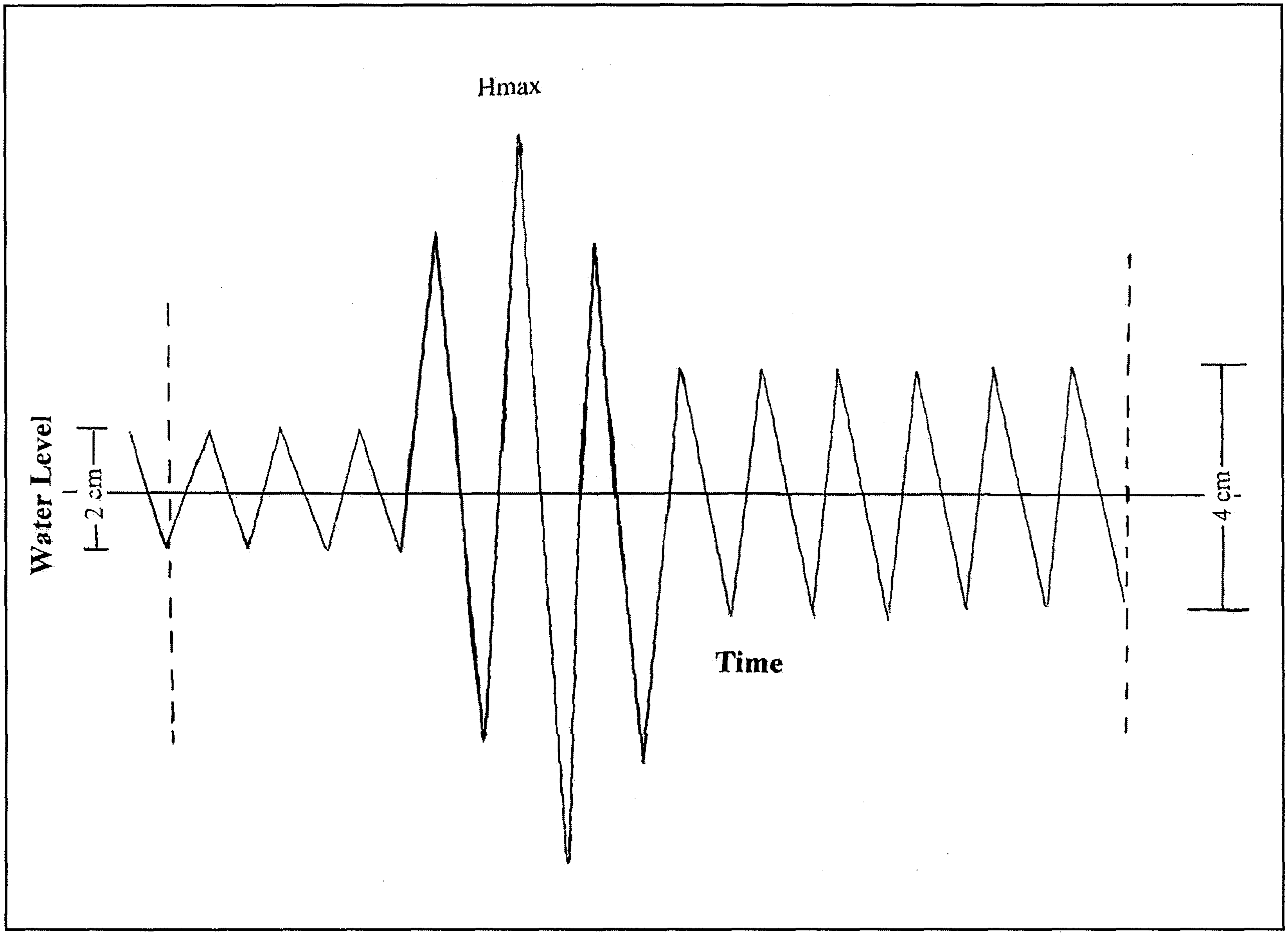


Figure 6. Schematized wave series for recreational boats

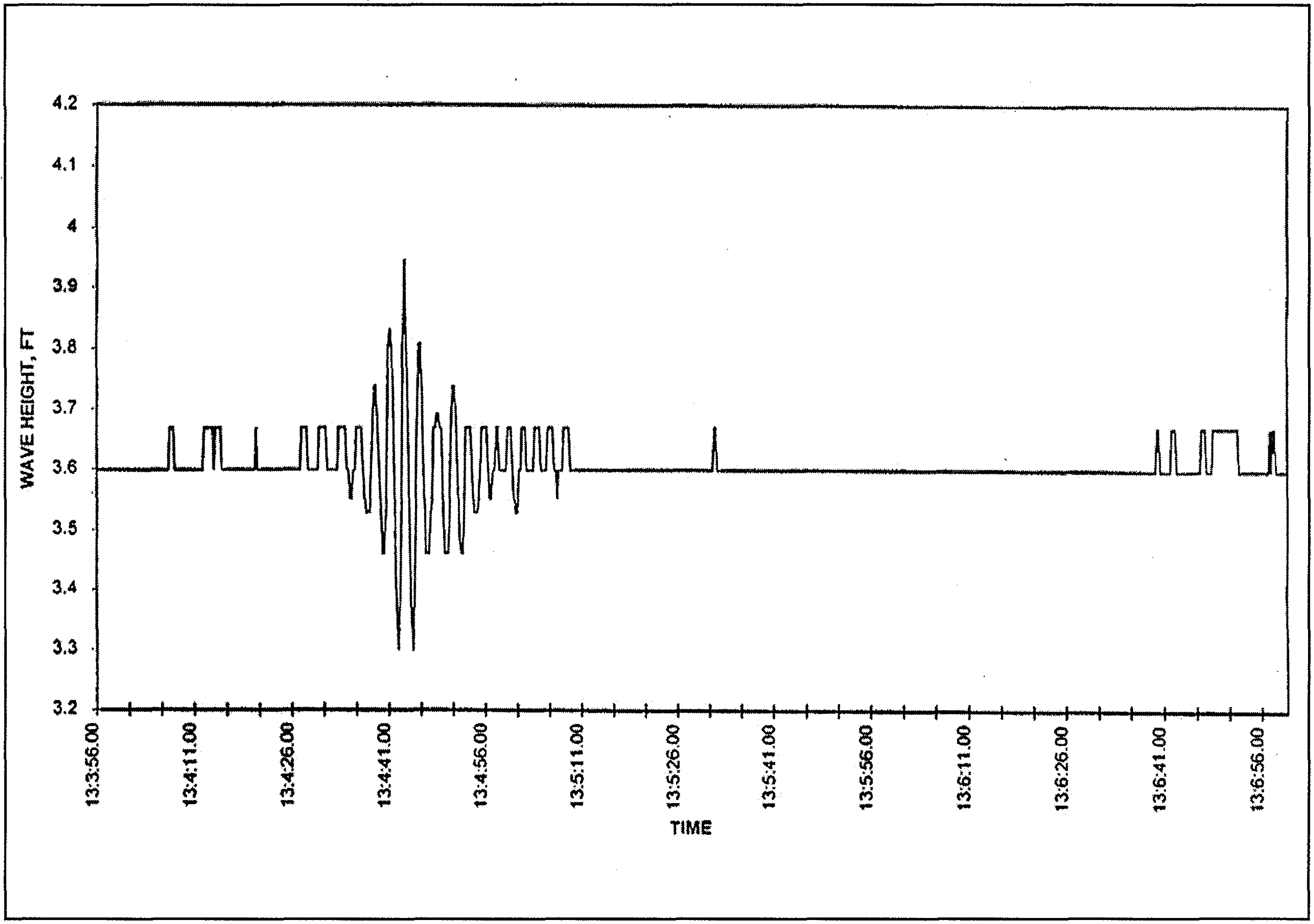


Figure 7. Wave heights measured on November 6, 1995 with boat type V (Test 5, sailing line S1, downstream, fully loaded, Gage WG2, 8-ft depth)

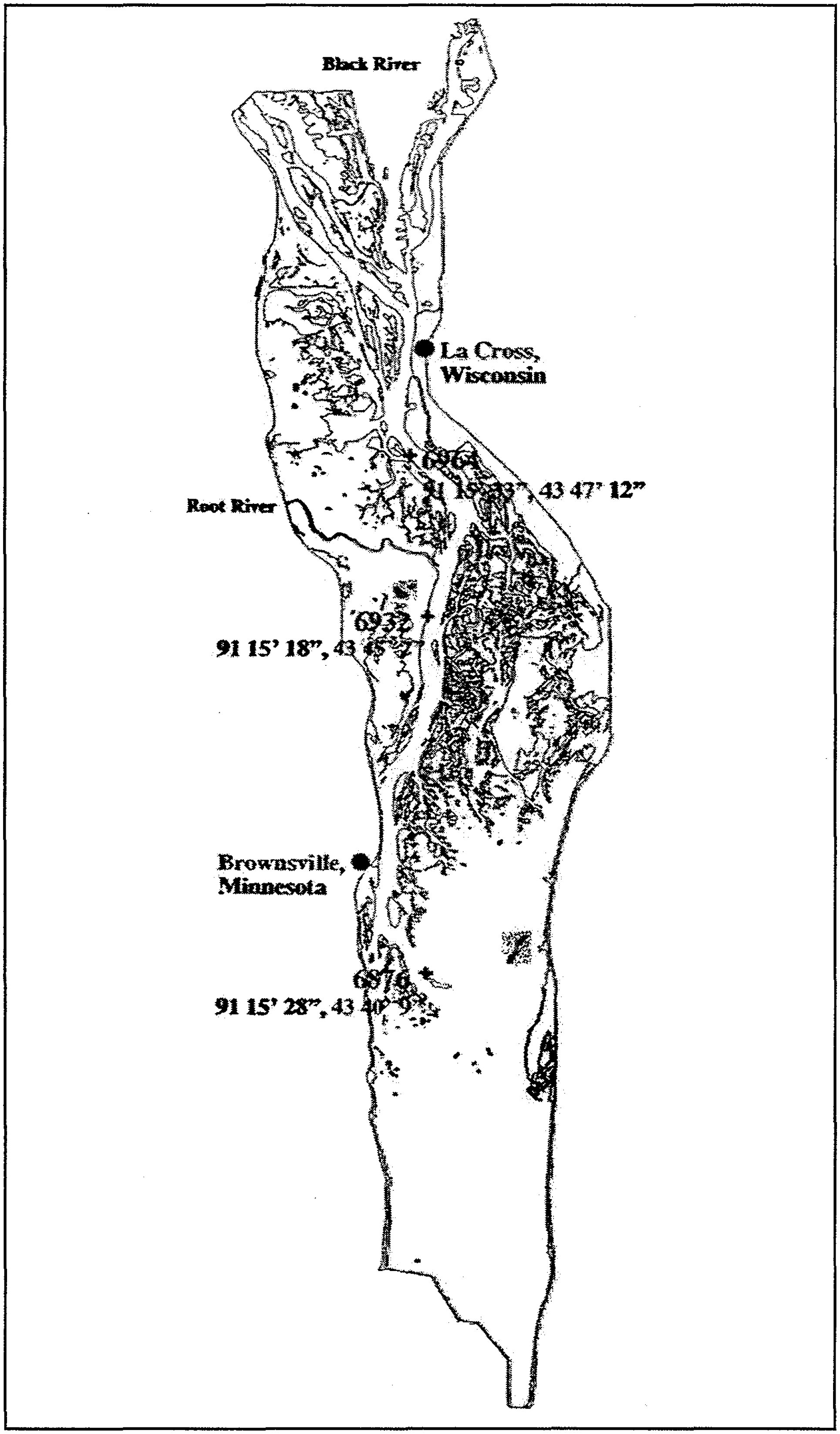


Figure 8. Locations of sediment samples (6964, 6932, 6876) in Pool 8

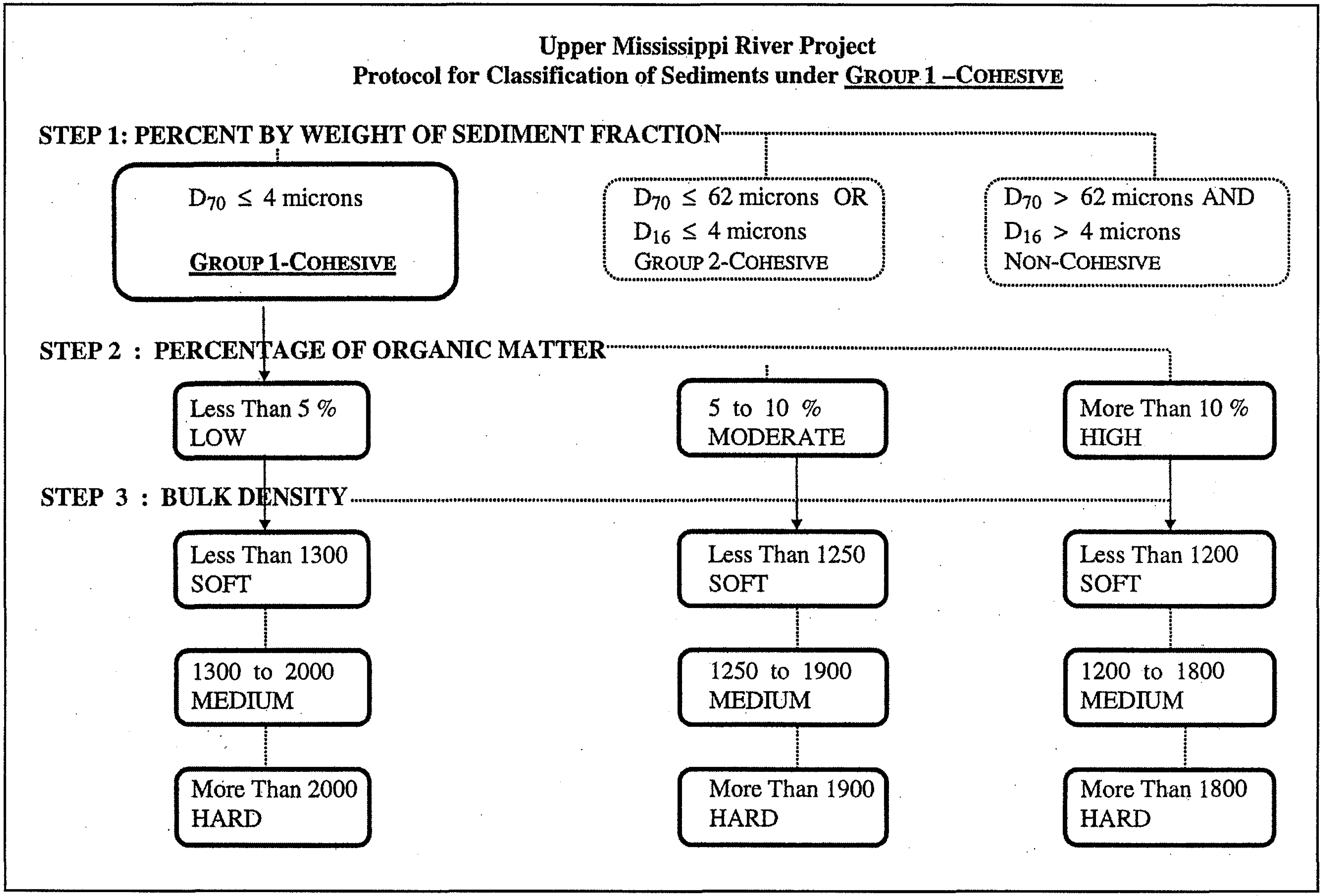


Figure 9. Protocol for classification of sediments under Group 1 - Cohesive

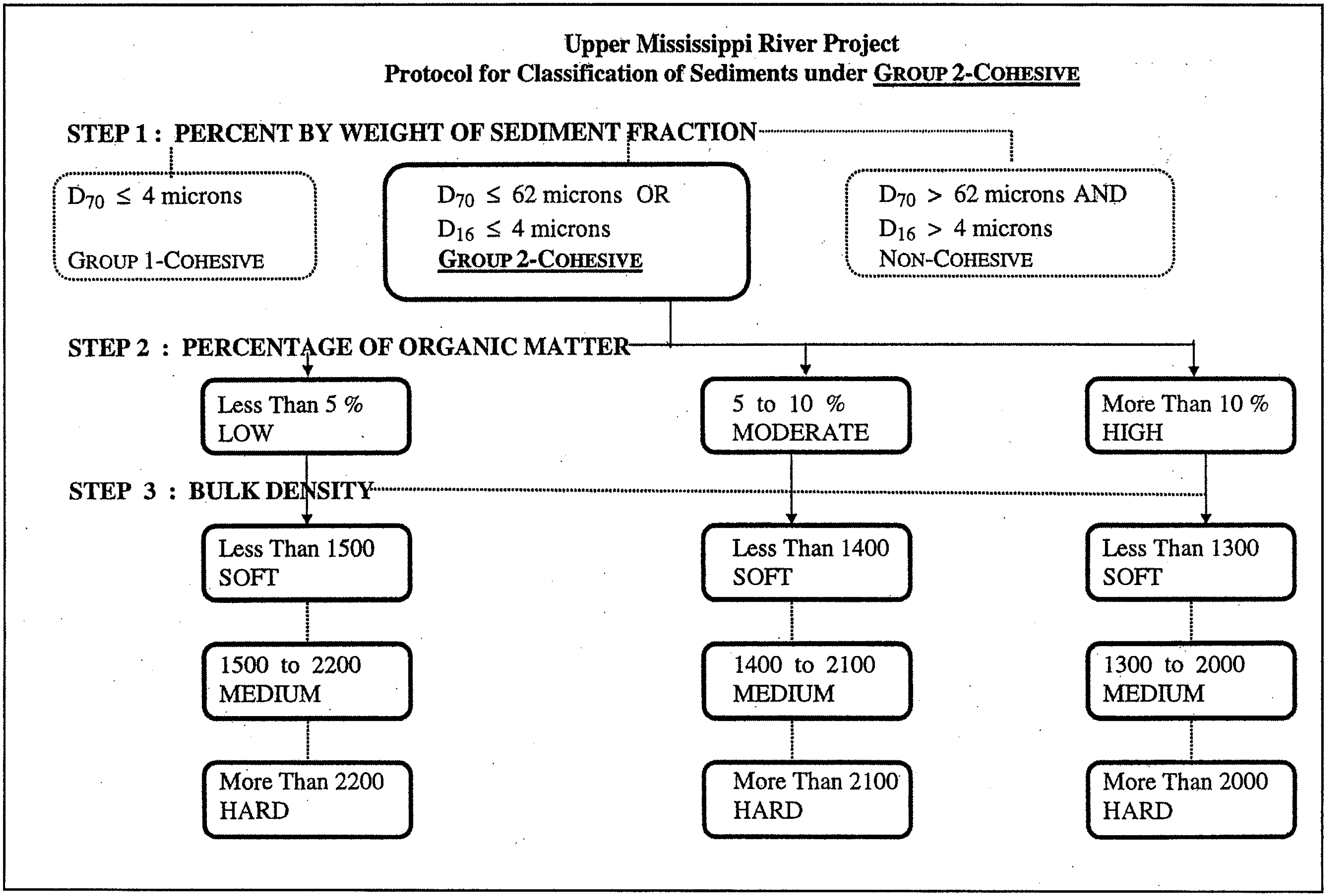


Figure 10. Protocol for classification of sediments under Group 2 - Cohesive

Upper Mississippi River Project
Protocol for Classification of NON-COHESIVE Sediments

STEP 1: PERCENT BY WEIGHT OF SEDIMENT FRACTION

$D_{70} \leq 4$ microns GROUP 1-COHESIVE	$D_{70} \leq 62$ microns OR $D_{16} \leq 4$ microns GROUP 2-COHESIVE	$D_{70} > 62$ microns AND $D_{16} > 4$ microns **NON-COHESIVE**

The only parameter that needs to be considered for treatment of "Non-Cohesive" sediments is the particle size. The other two parameters, viz. "Percentage of Total Organic Matter" and "Wet Bulk Density" may not be significant unless the sand mixture contains more than **10 %** of organic matter.

STEP 1 : PARTICLE SIZE SELECTION

Select a representative single value of grain diameter for a bed sample, e.g. D50 from the particle size distribution graph. If necessary, several sizes may be selected to represent different size classes.

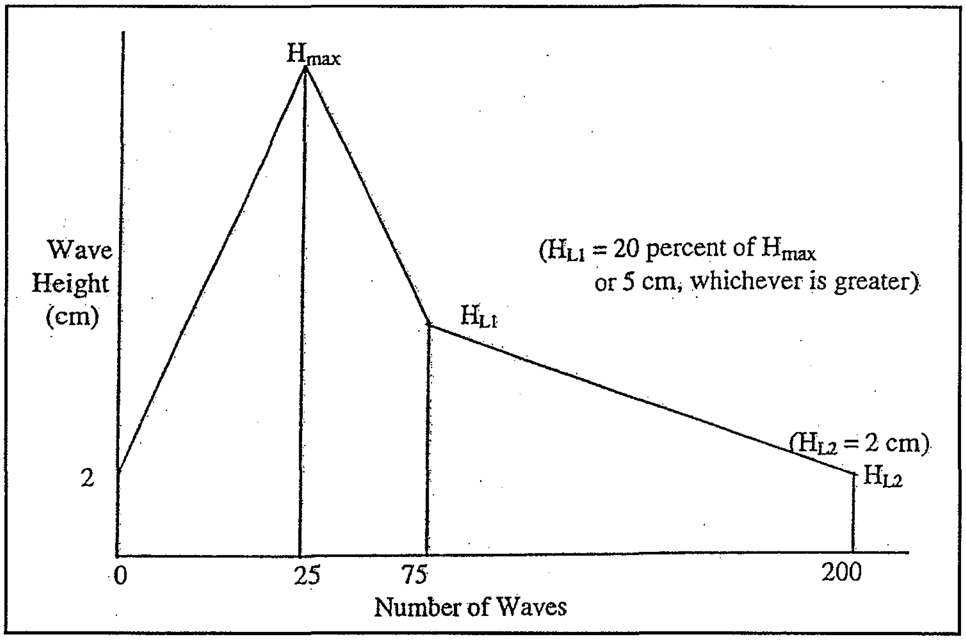
STEP 2: ENTRAINMENT AND DEPOSITION

Follow procedure described under the following two parts for further treatment.

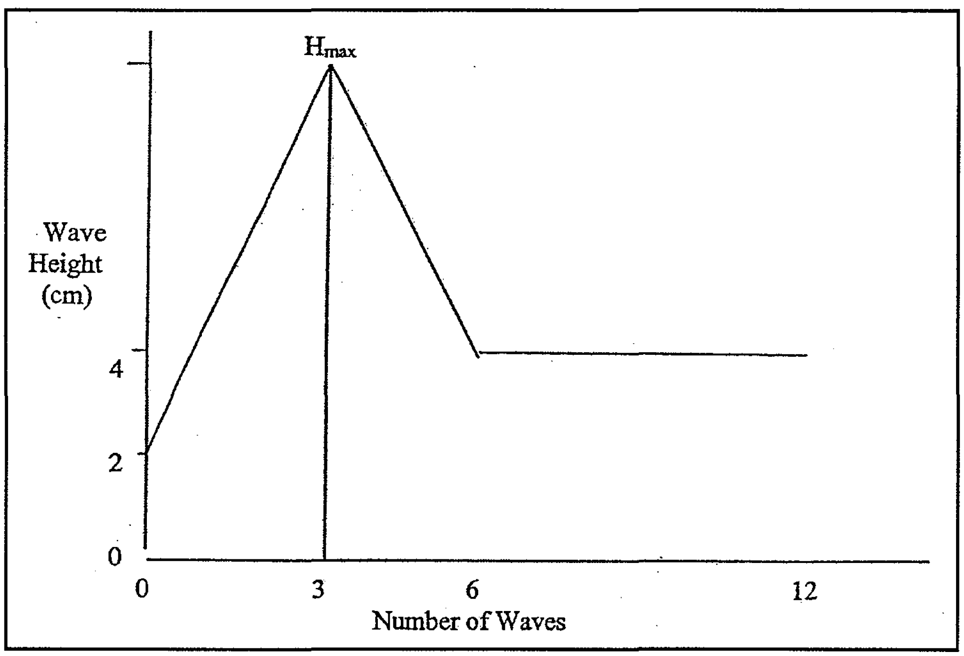
Part 8: Entrainment of Non-Cohesive Sediment

Part 9: Time required to settle sand particles

Figure 11. Protocol for classification of noncohesive sediments



a. Schematized wave series for towboats



b. Schematized wave series for recreational boats

Figure 12. Schematized wave series for tows and recreational boats

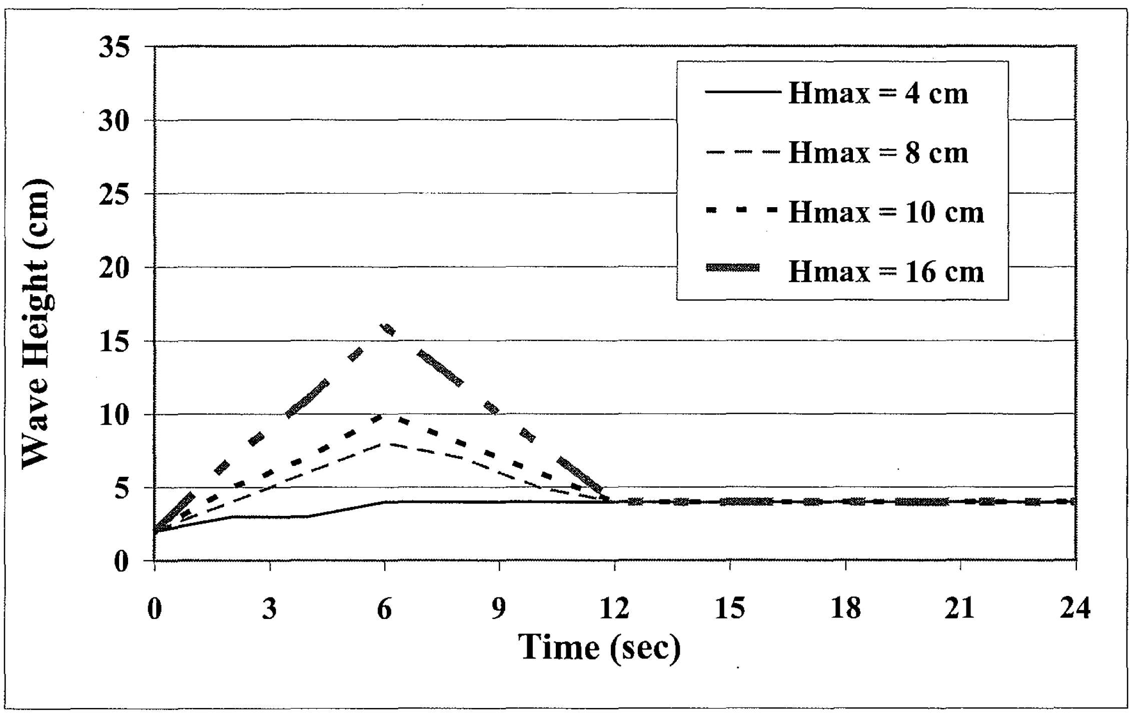


Figure 13a. Wave series generated by recreational boats for maximum wave heights: Hmax from 4 cm to 16 cm

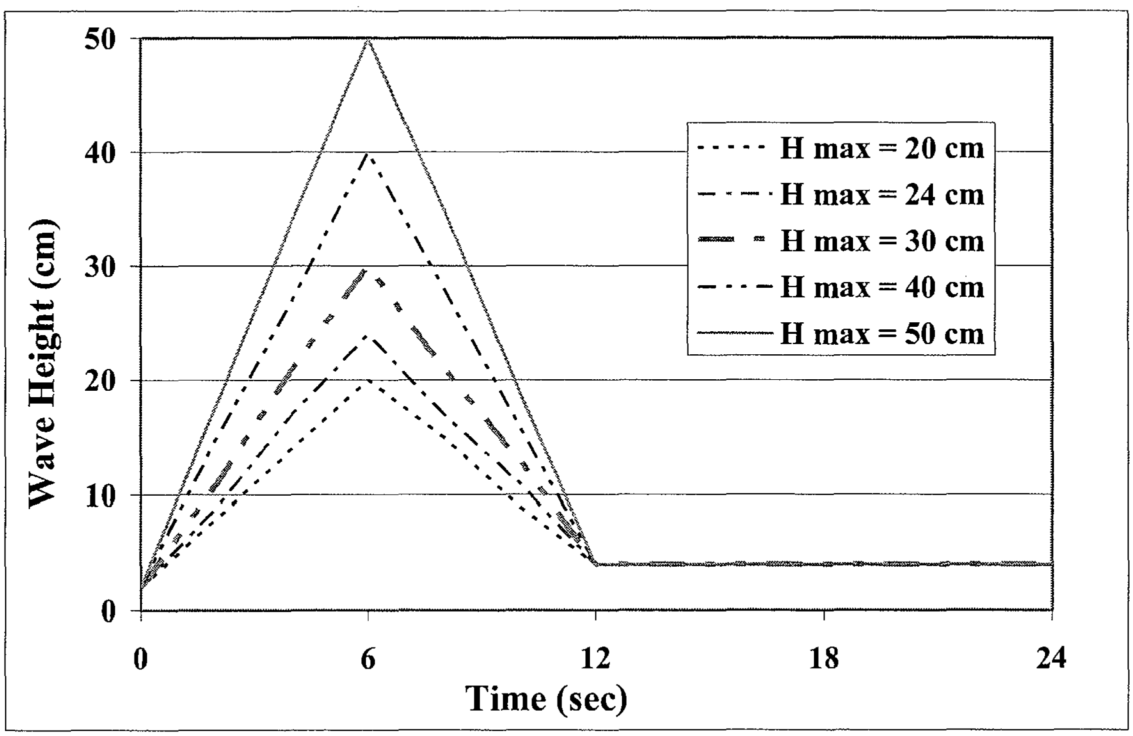


Figure 13b. Wave series generated by recreational boats for maximum wave heights: Hmax from 20 cm to 50 cm

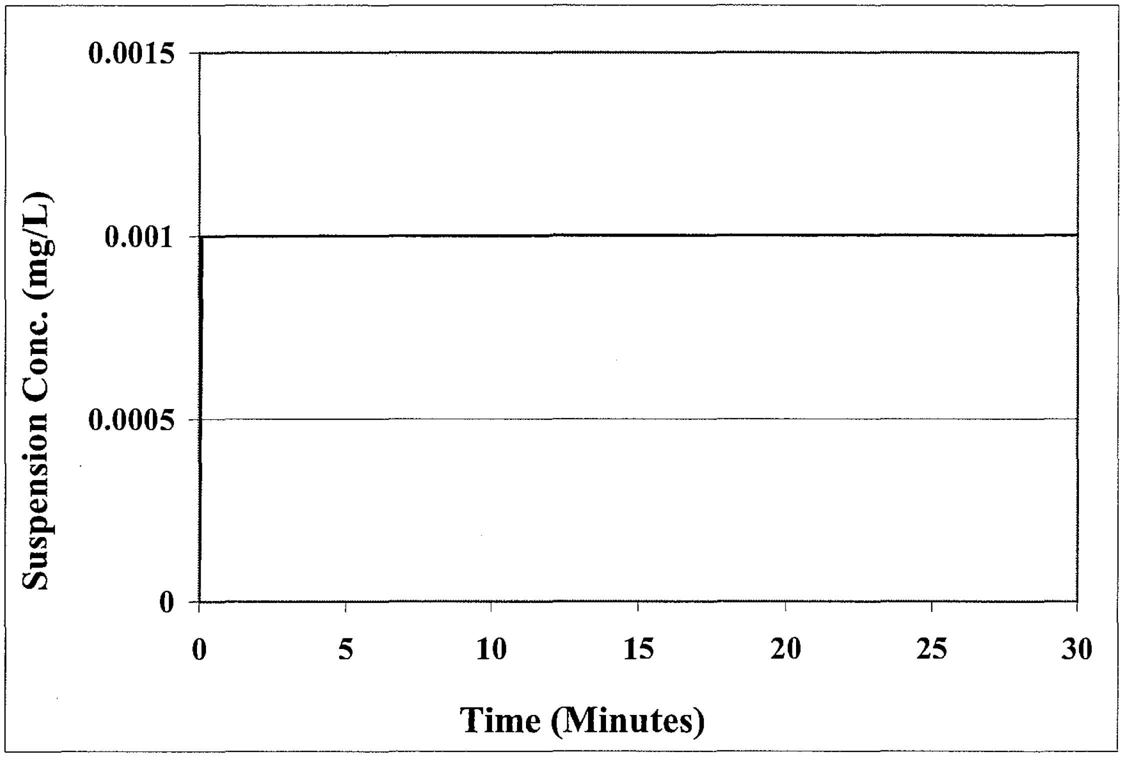


Figure 14. Suspension concentration with recreational boats at 1-min intervals, Hmax = 10 cm

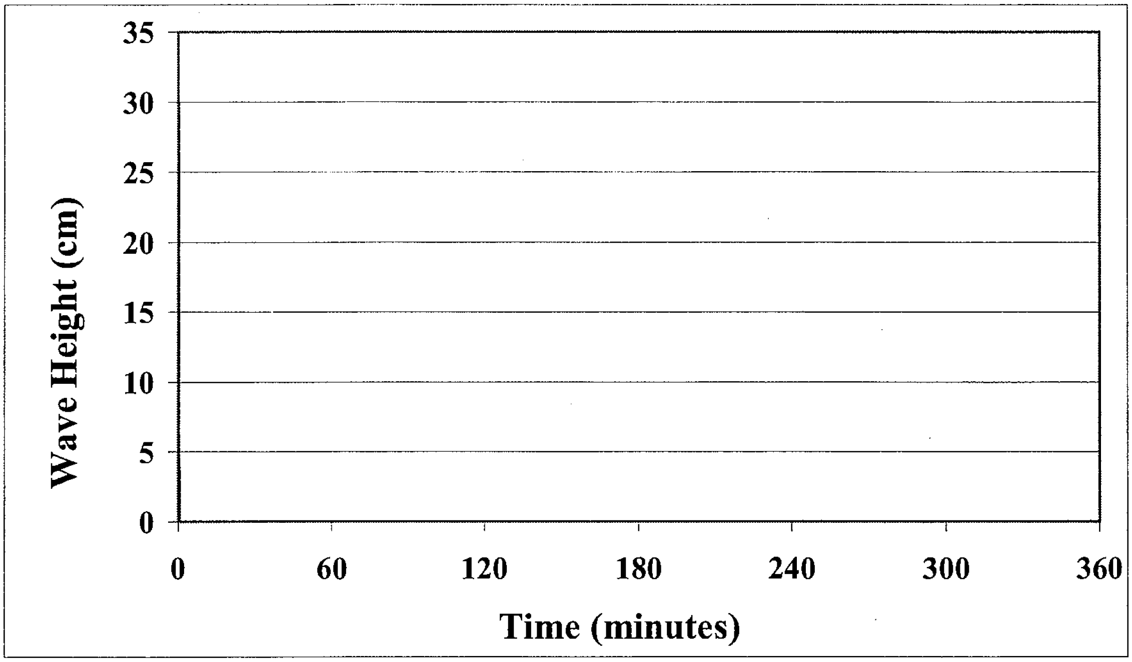


Figure 15a. Wave series for 1 recboat, Hmax = 30 cm

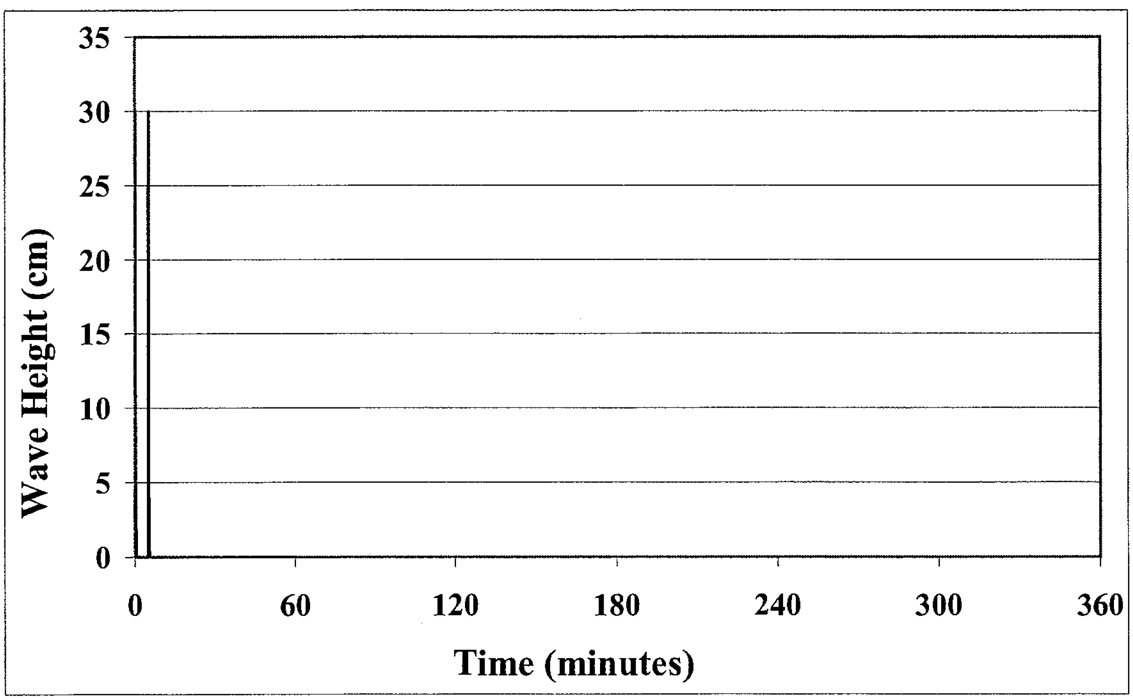


Figure 15b. Wave series for 2 recboats at 5-min intervals, Hmax = 30 cm

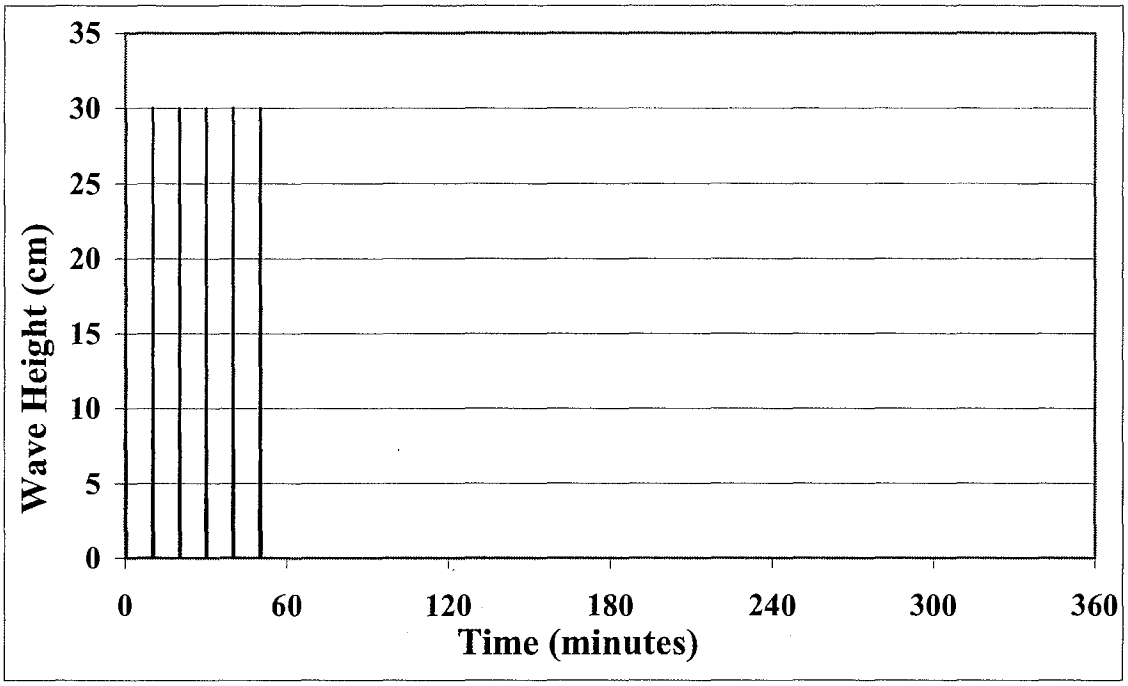


Figure 16a. Wave series for 5 recboats at 10-min intervals, Hmax = 30 cm

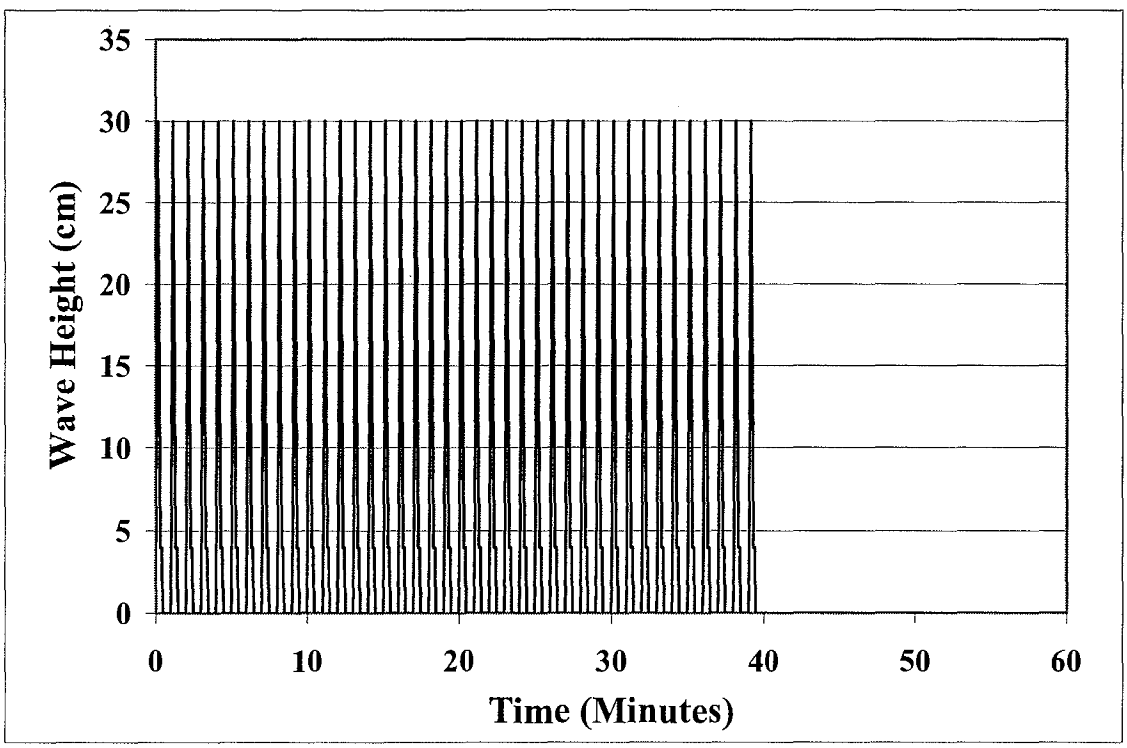


Figure 16b. Wave series for 40 recboats at 1-min intervals, Hmax = 30 cm

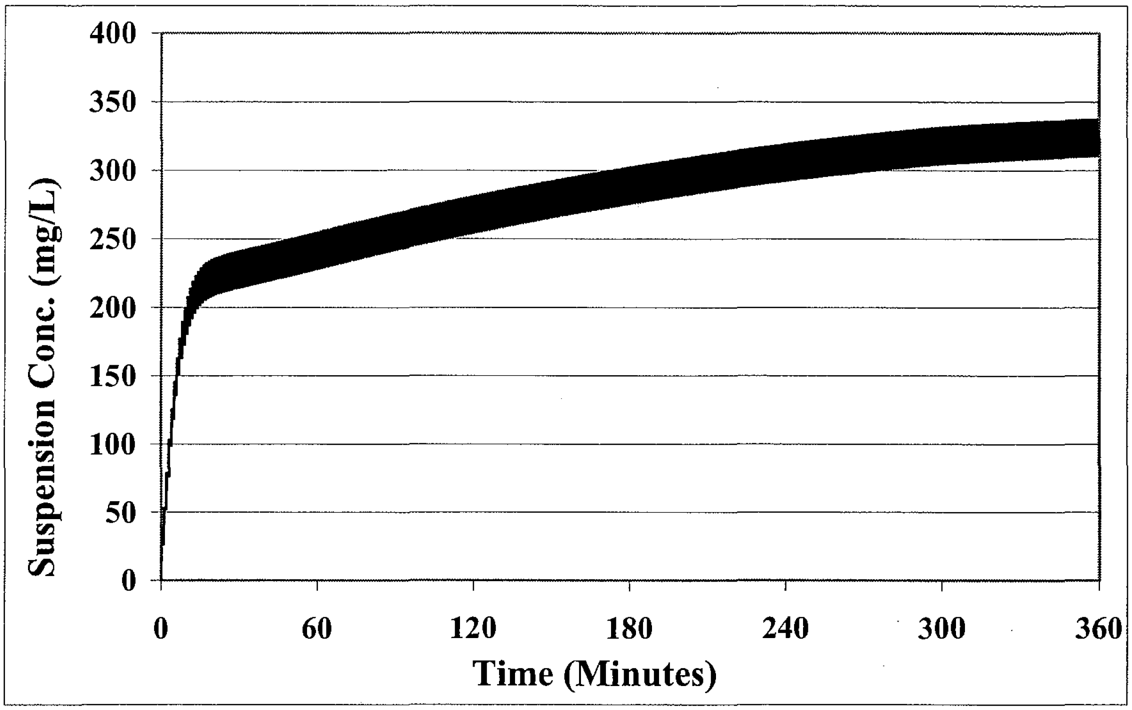


Figure 17a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 20 cm

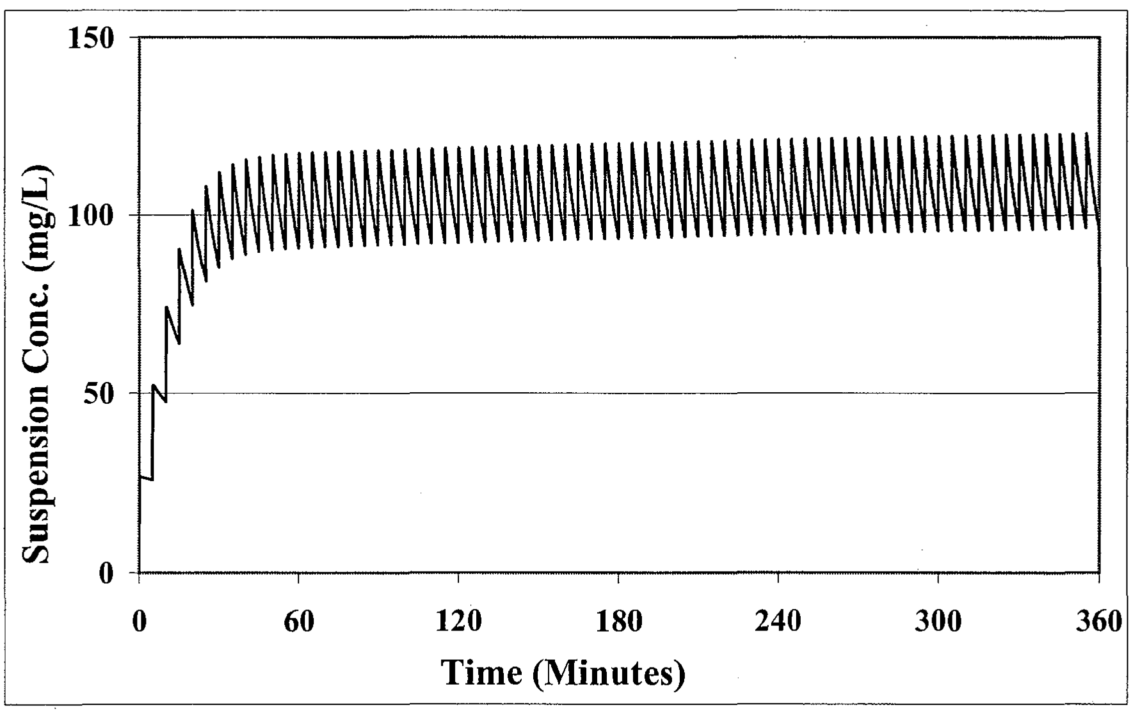


Figure 17b. Suspension concentration with 72 recboats at 5-min intervals, Hmax = 20 cm

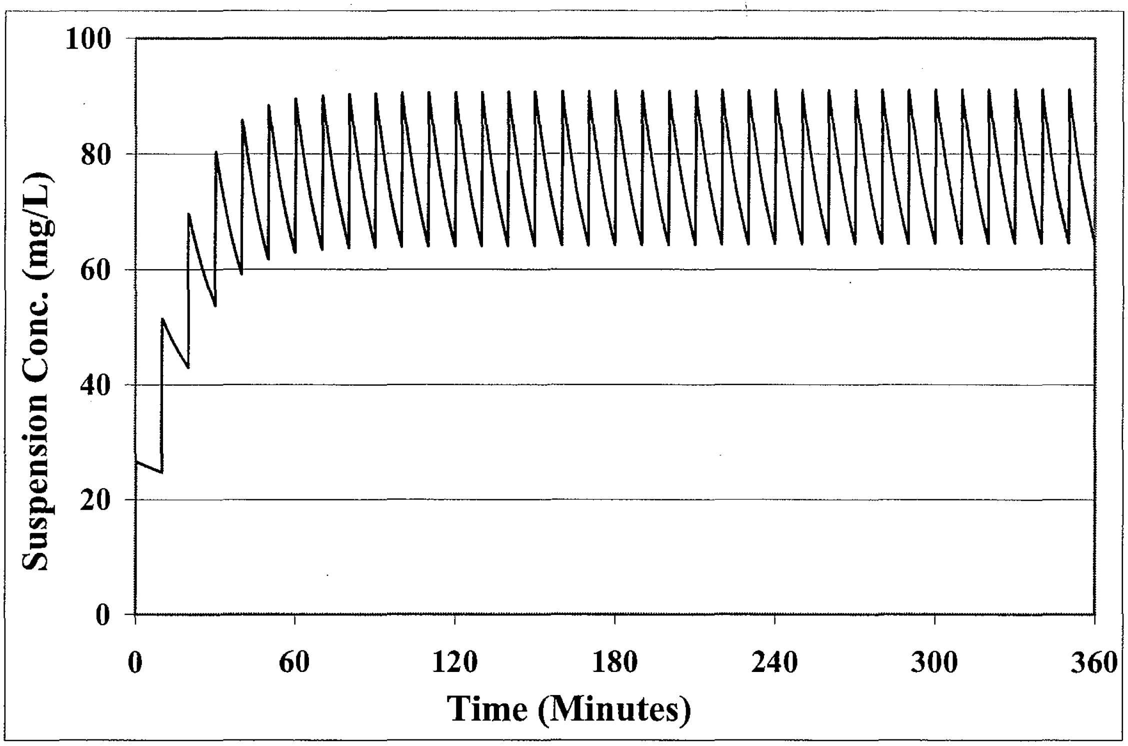


Figure 18a. Suspension concentration with 36 recboats at 10-min intervals, Hmax = 20 cm

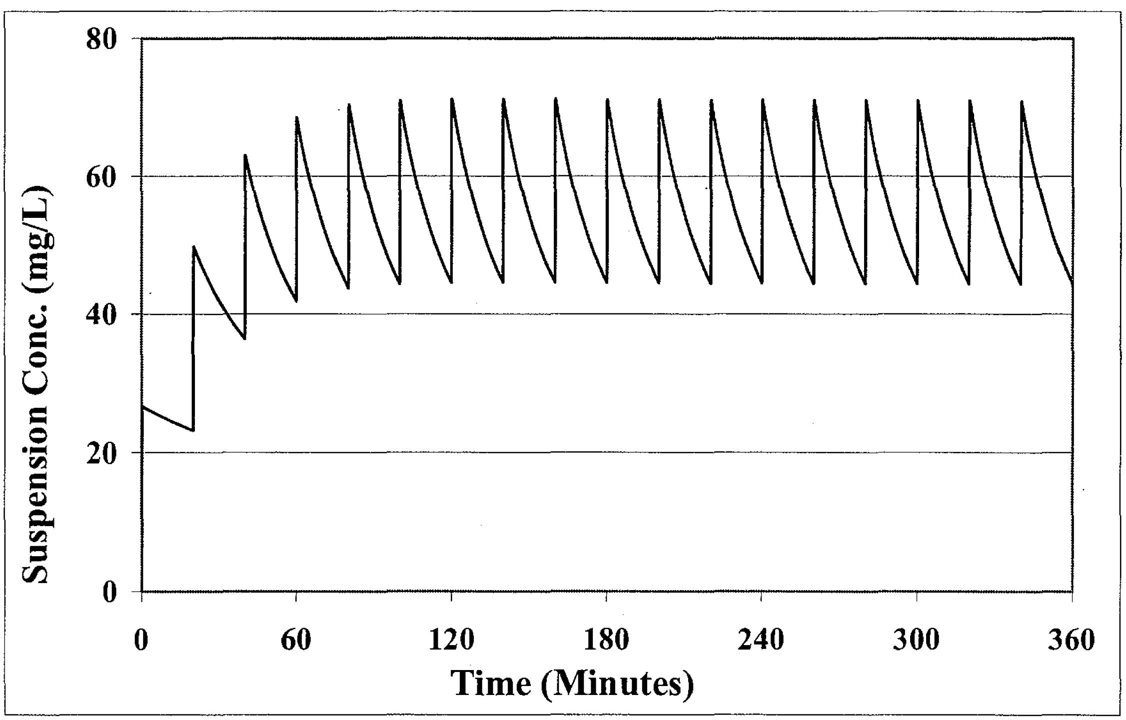


Figure 18b. Suspension concentration with 18 recboats at 20-min intervals, Hmax = 20 cm

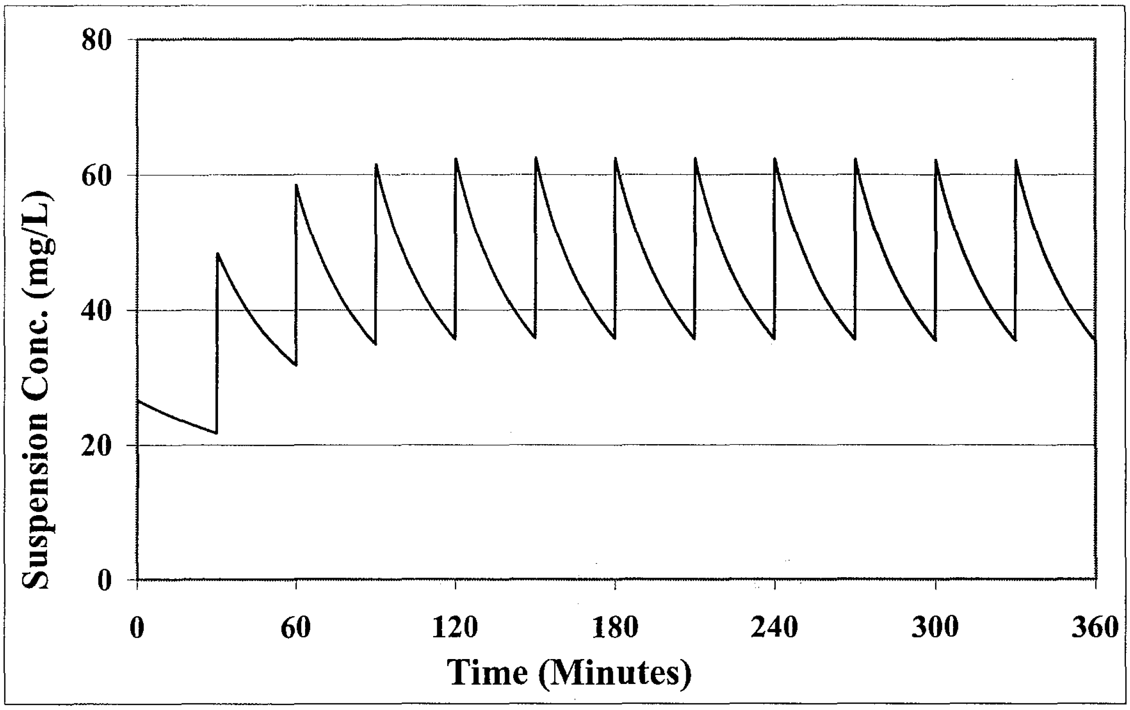


Figure 19a. Suspension concentration with 12 recboats at 30-min intervals, Hmax = 20 cm

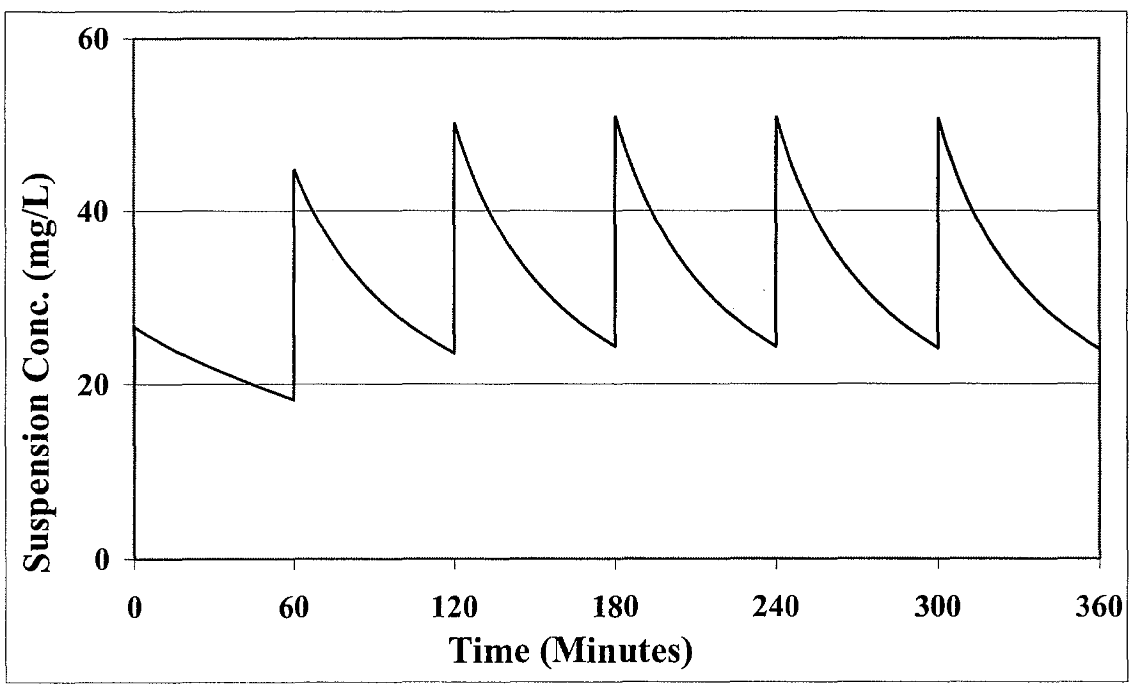


Figure 19b. Suspension concentration with 6 recboats at 60-min intervals, Hmax = 20 cm

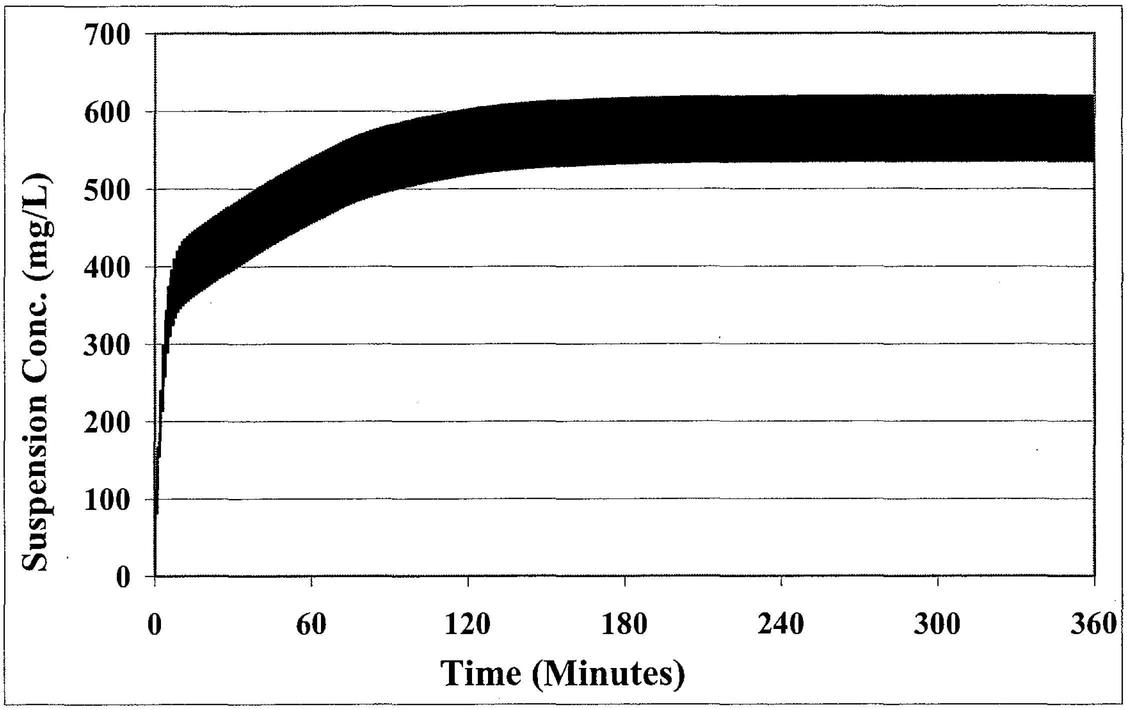


Figure 20a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 30 cm

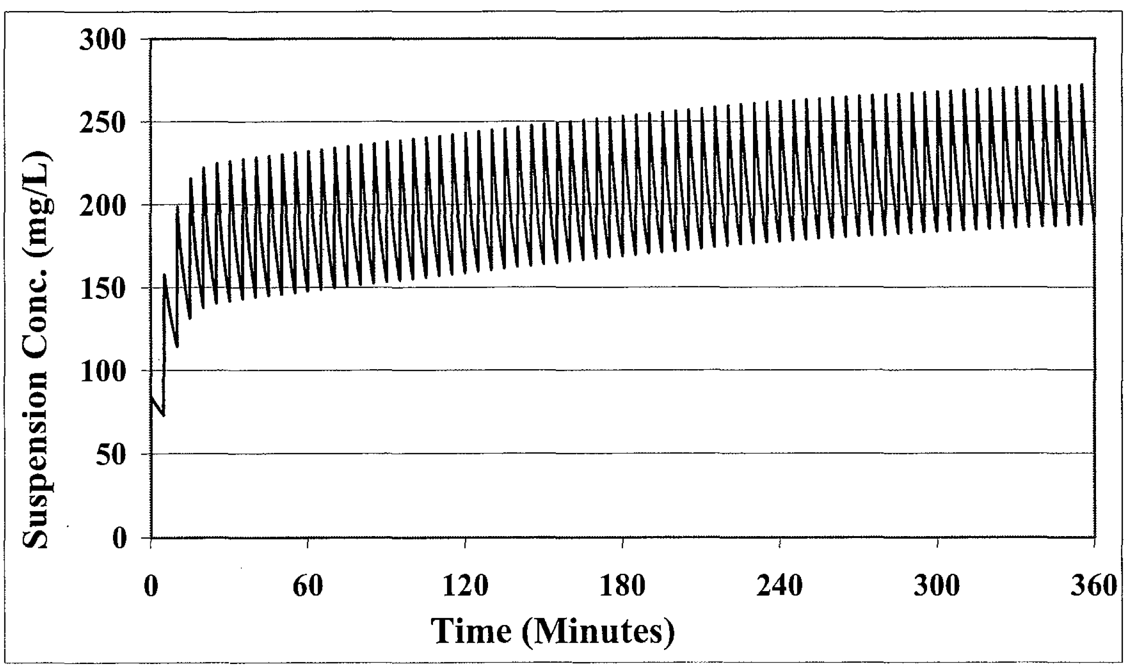


Figure 20b. Suspension concentration with 72 recboats at 5-min intervals, Hmax = 30 cm

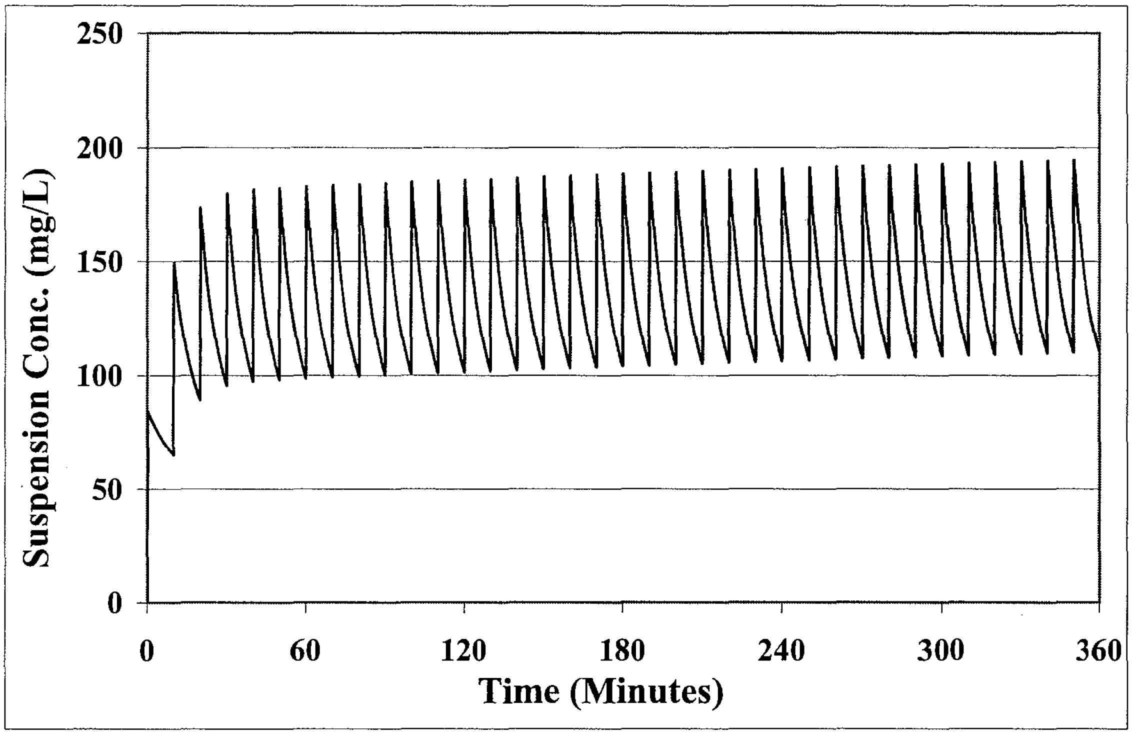


Figure 21a. Suspension concentration with 36 recboats at 10-min intervals, Hmax = 30 cm

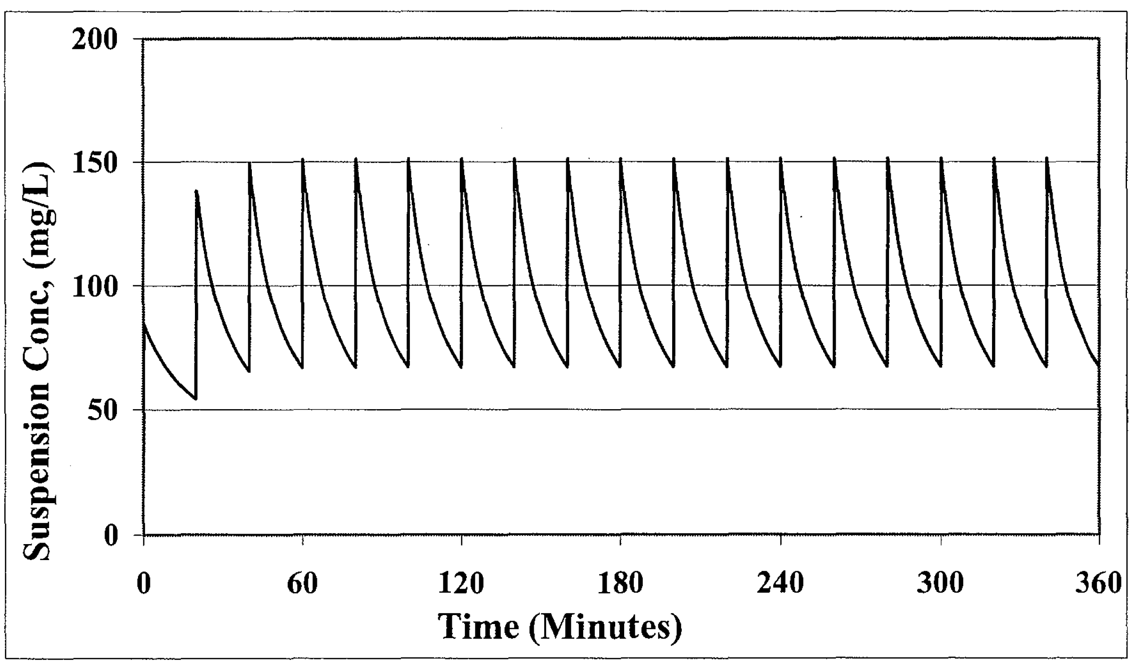


Figure 21b. Suspension concentration with 18 recboats at 20-min intervals, Hmax = 30 cm

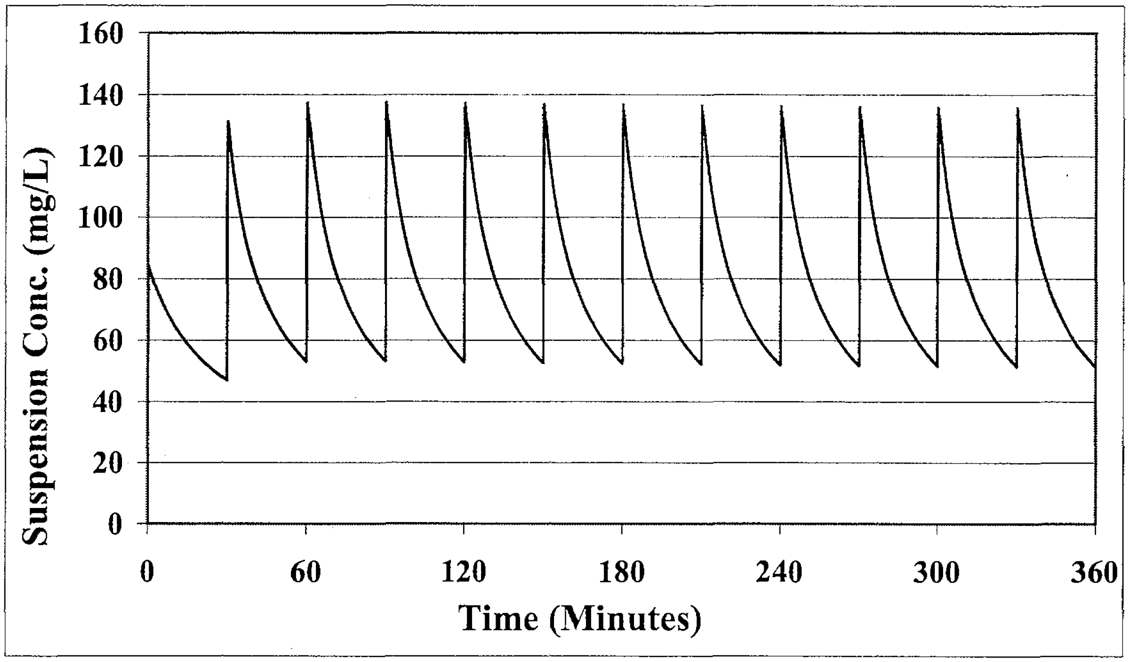


Figure 22a. Suspension concentration with 12 recboats at 30-min intervals, Hmax = 30 cm

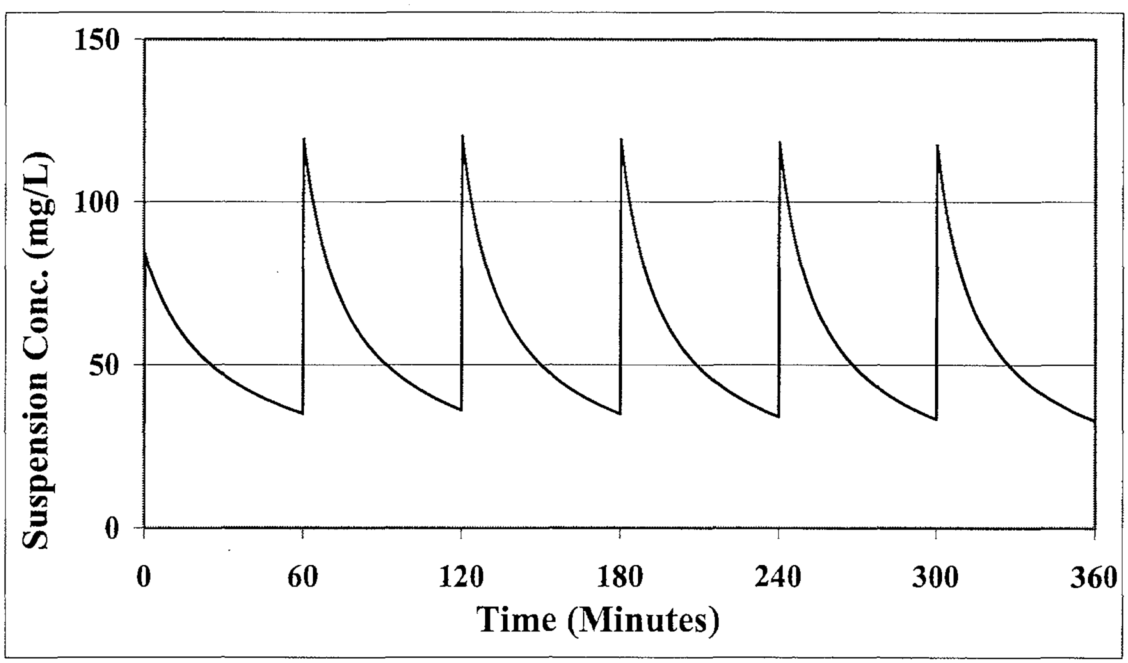


Figure 22b. Suspension concentration with 6 recboats at 60-min intervals, Hmax = 30 cm

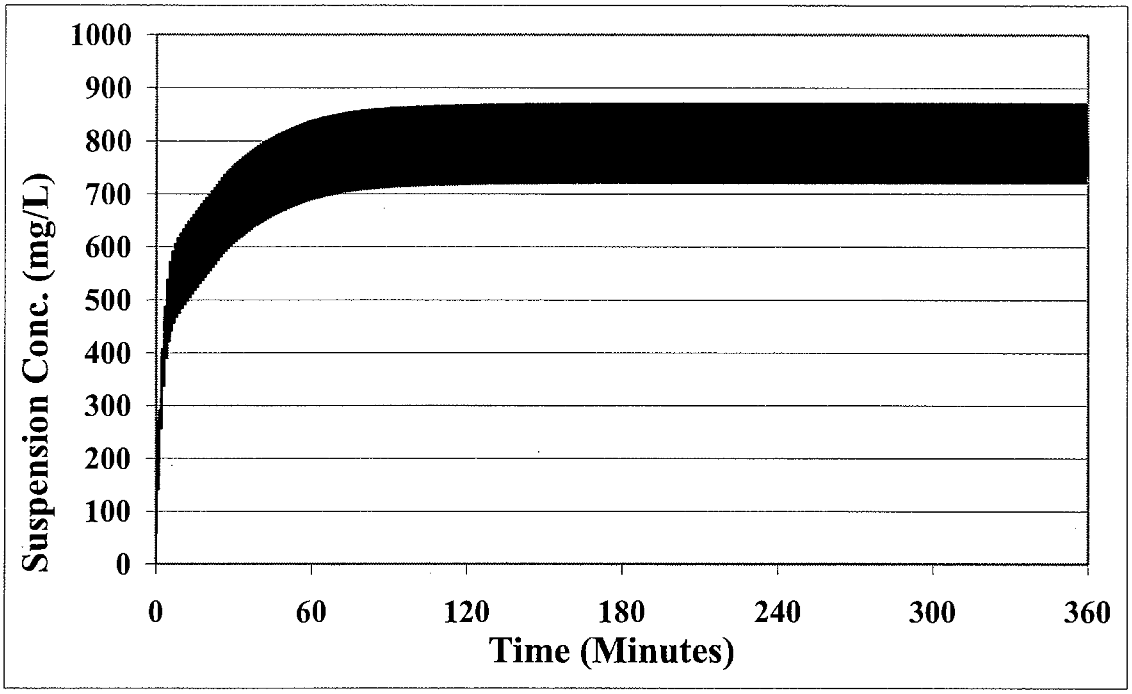


Figure 23a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 40 cm

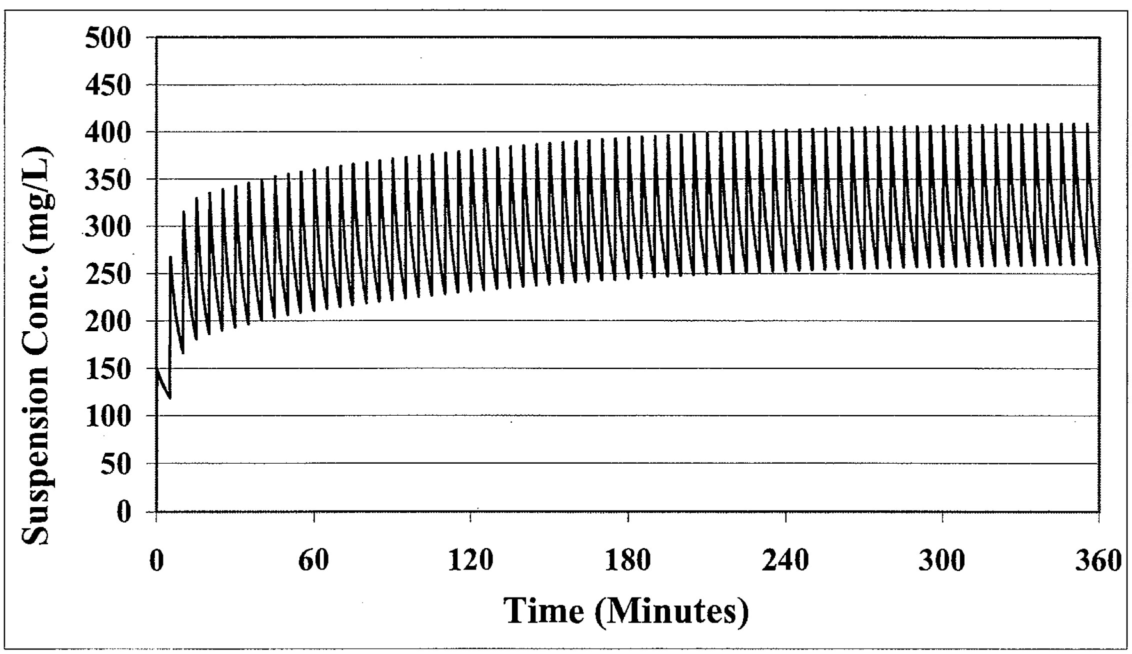


Figure 23b. Suspension concentration with 72 recboats at 5-min intervals, Hmax = 40 cm

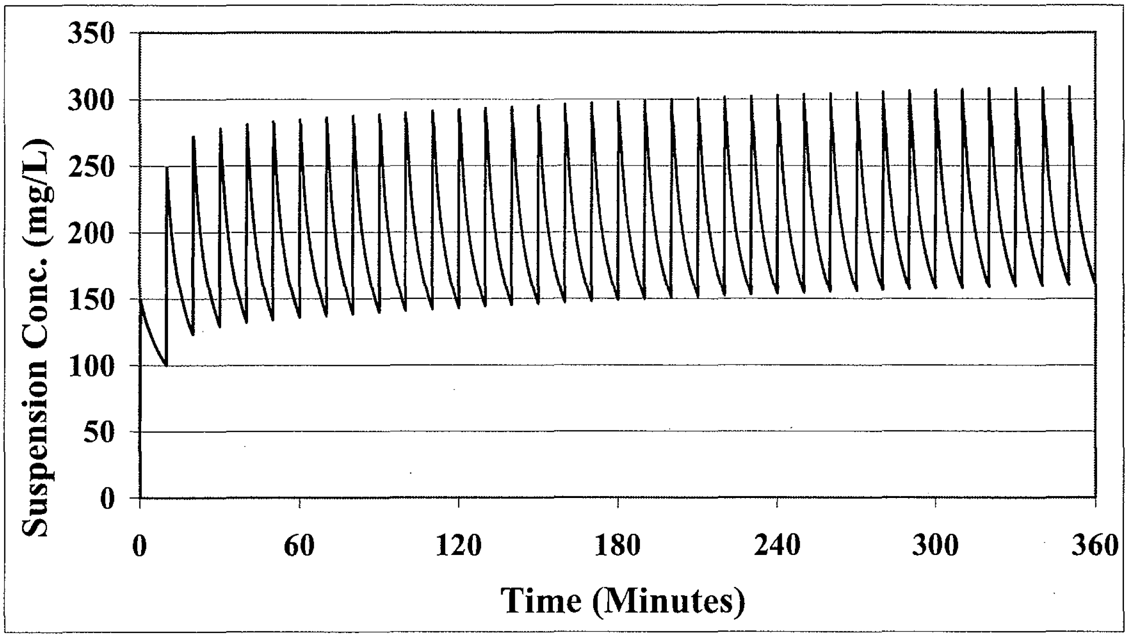


Figure 24a. Suspension concentration with 36 recboats at 10-min intervals, Hmax = 40 cm

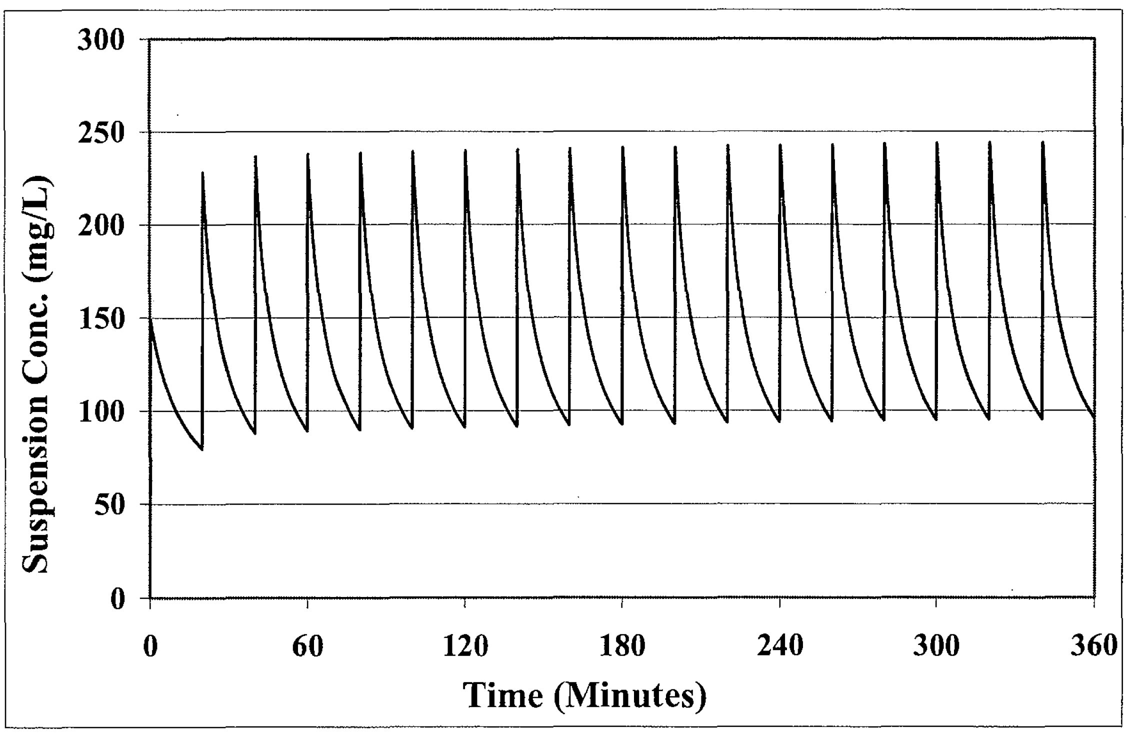


Figure 24b. Suspension concentration with 18 recboats at 20-min intervals, Hmax = 40 cm

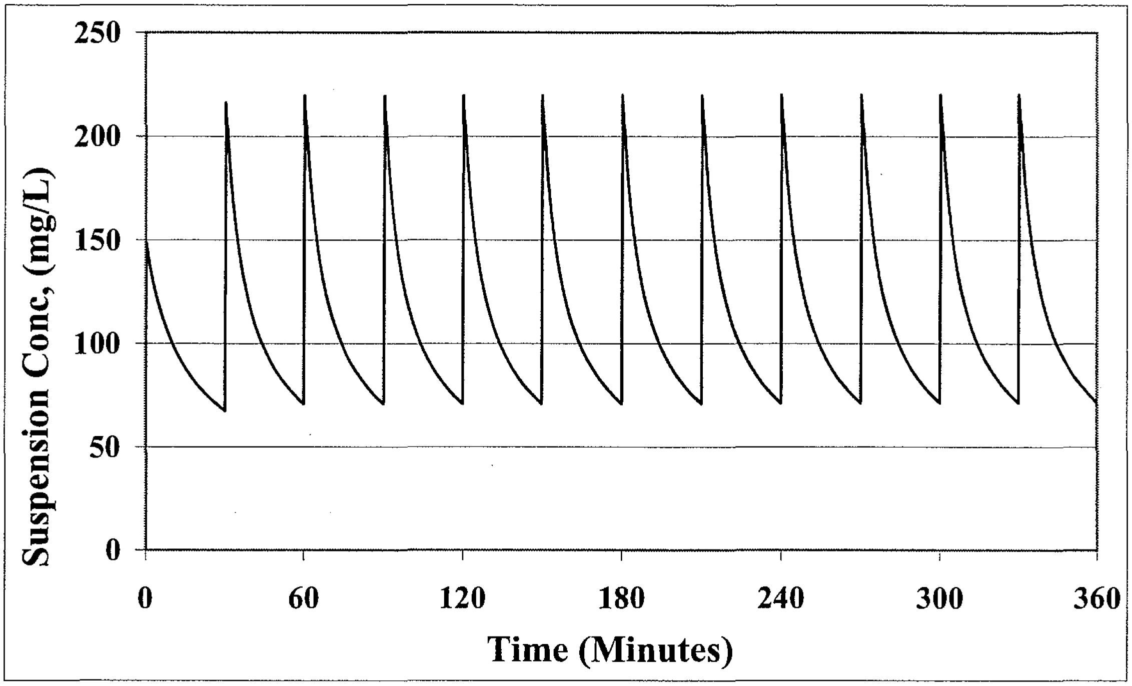


Figure 25a. Suspension concentration with 12 recboats at 30-min intervals, Hmax = 40 cm

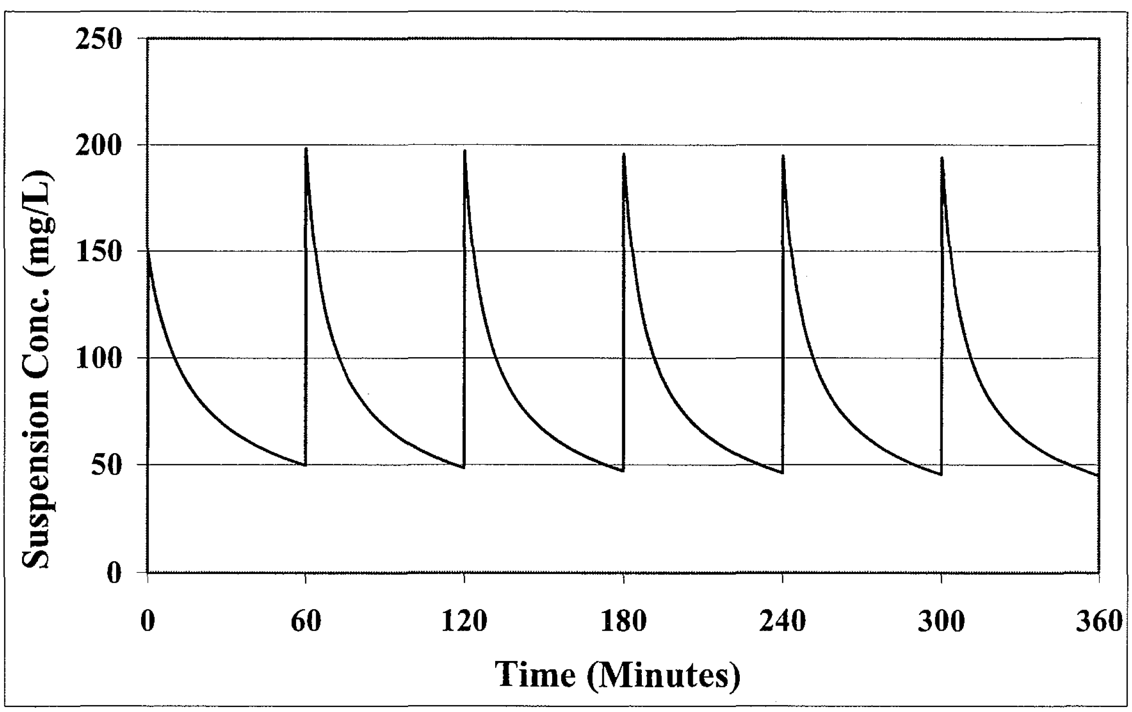


Figure 25b. Suspension concentration with 6 recboats at 60-min intervals, Hmax = 40 cm

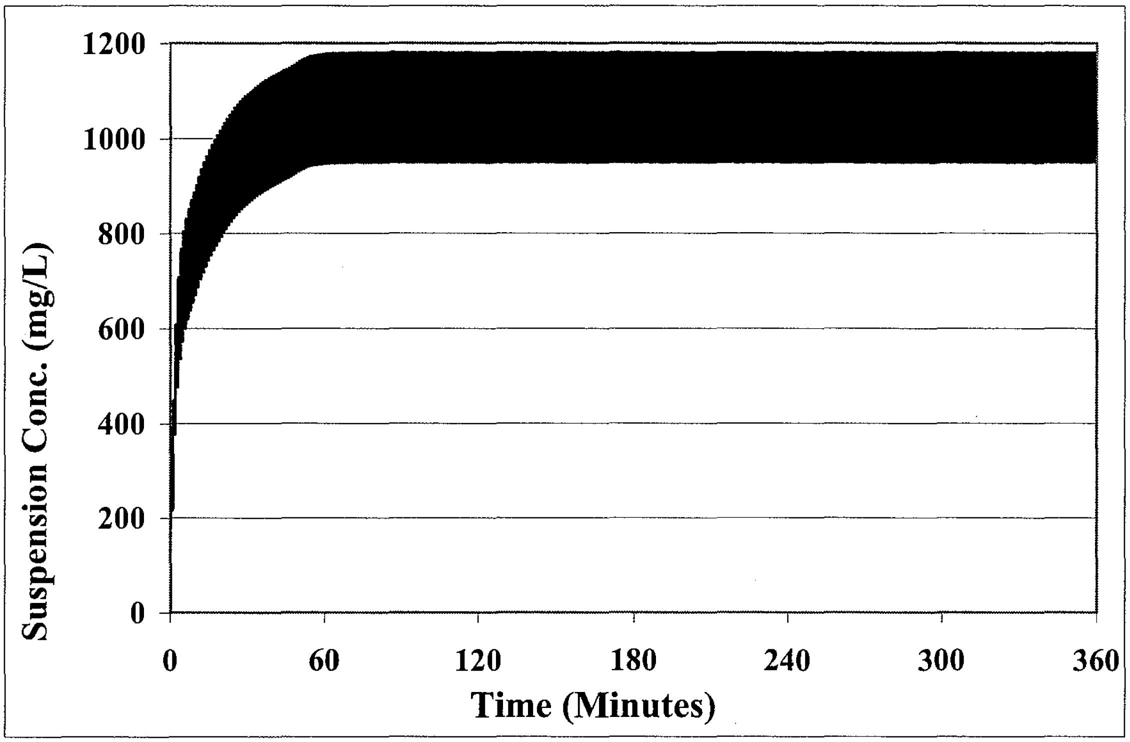


Figure 26a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 50 cm

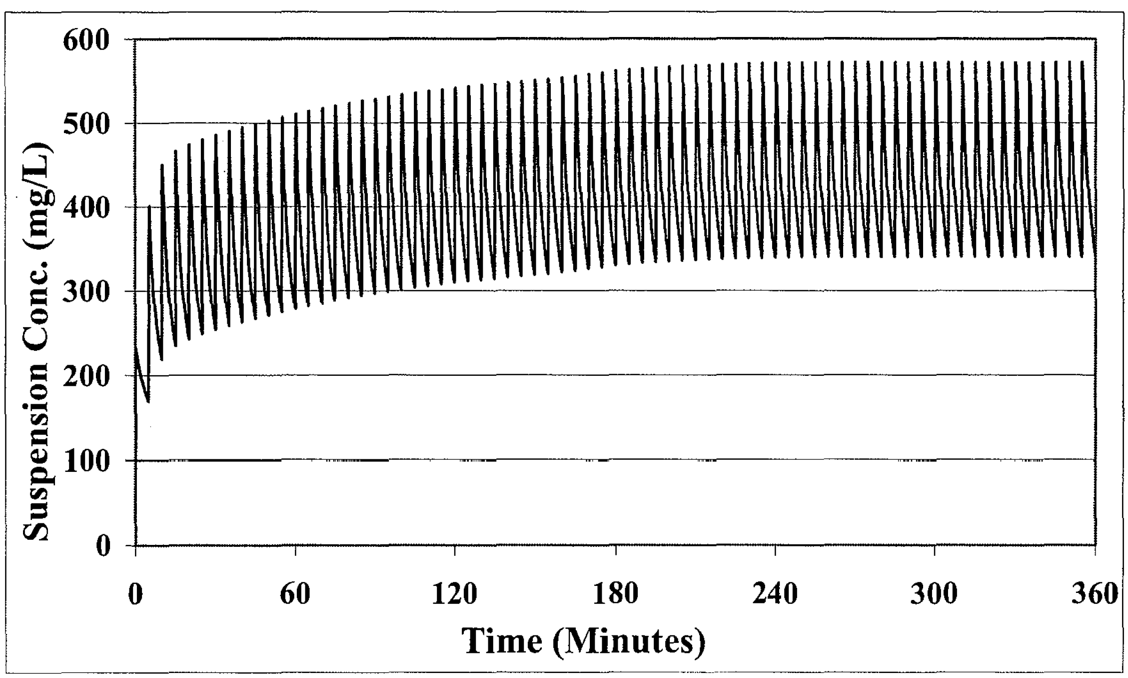


Figure 26b. Suspension concentration with 72 recboats at 5-min intervals, Hmax = 50 cm

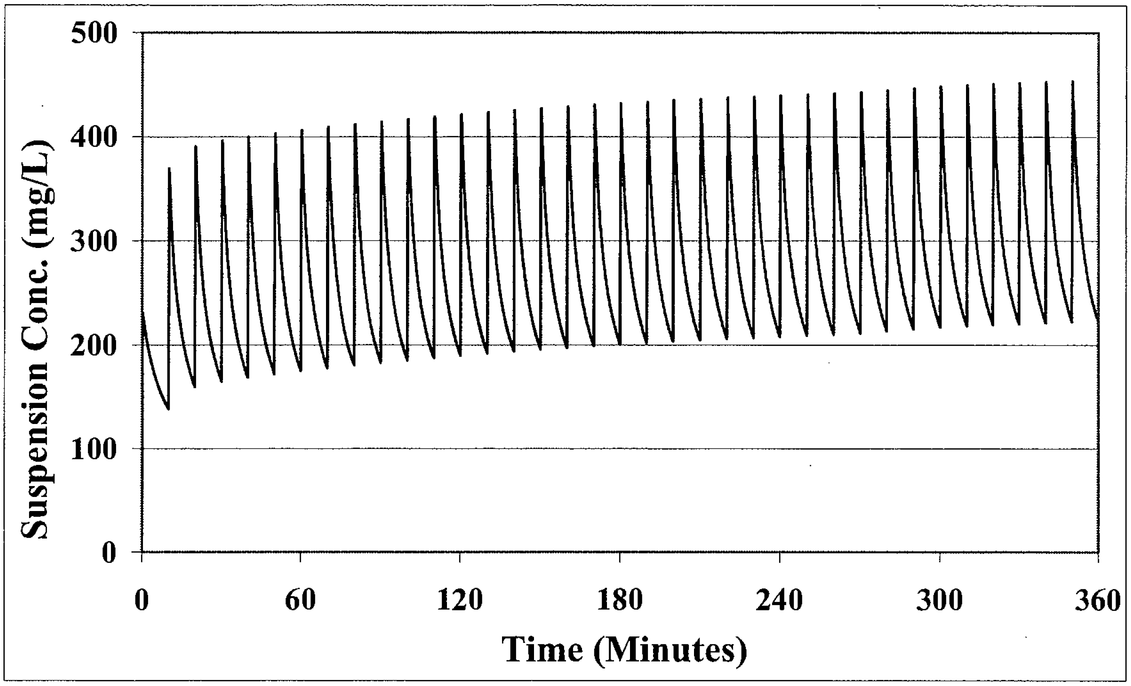


Figure 27a. Suspension concentration with 36 recboats at 10-min intervals, Hmax = 50 cm

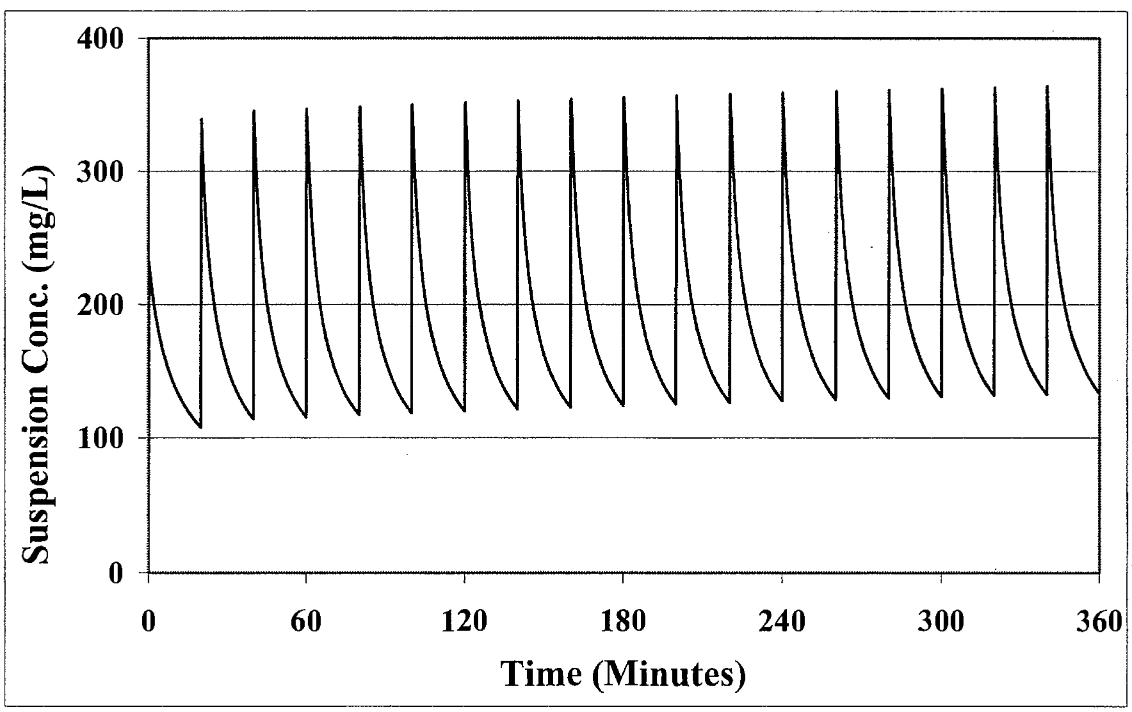


Figure 27b. Suspension concentration with 18 recboats at 20-min intervals, Hmax = 50 cm

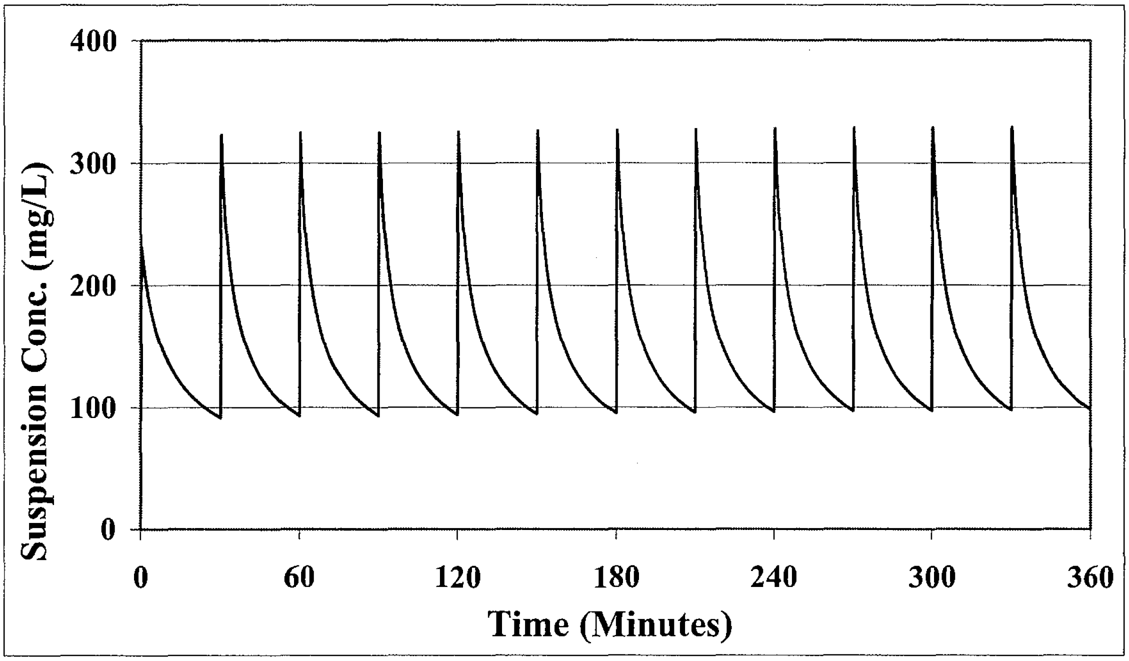


Figure 28a. Suspension concentration with 12 recboats at 30-min intervals, Hmax = 50 cm

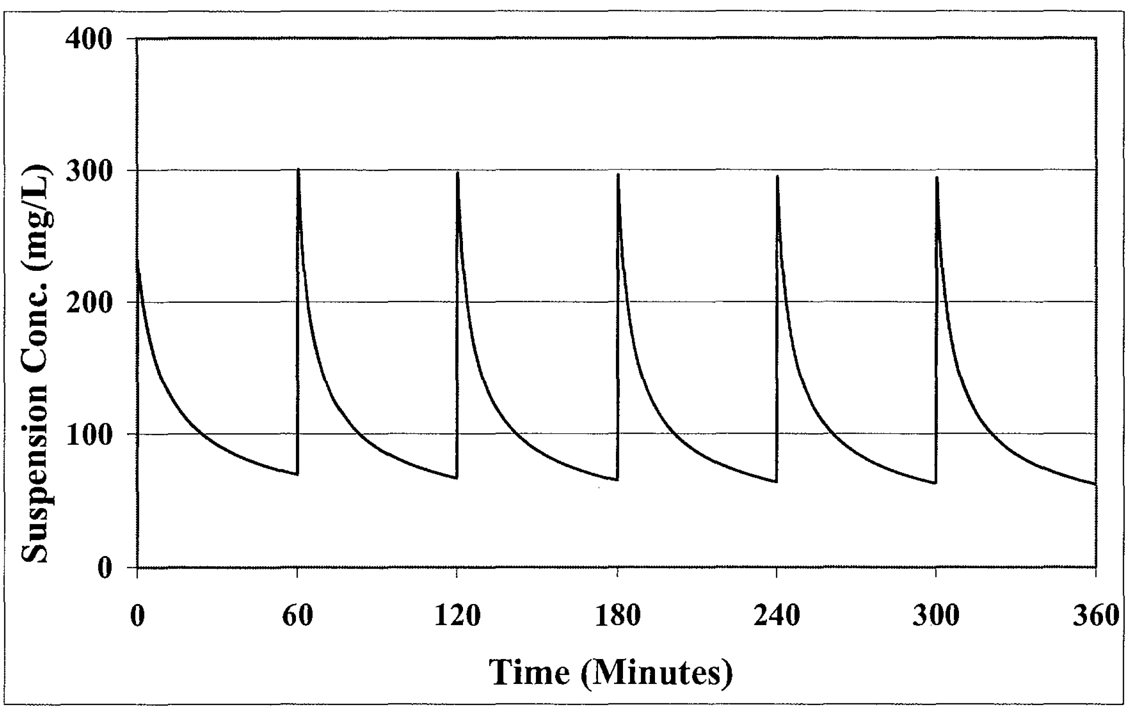


Figure 28b. Suspension concentration with 6 recboats at 60-min intervals, Hmax = 50 cm

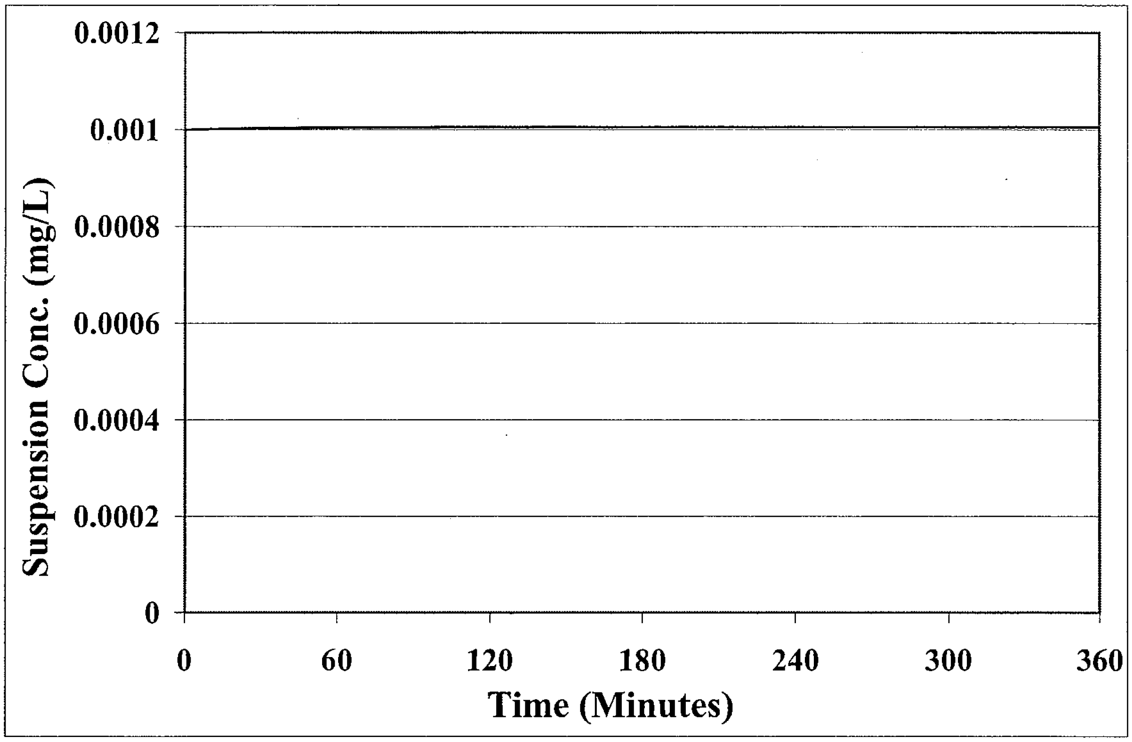


Figure 29a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 10 cm

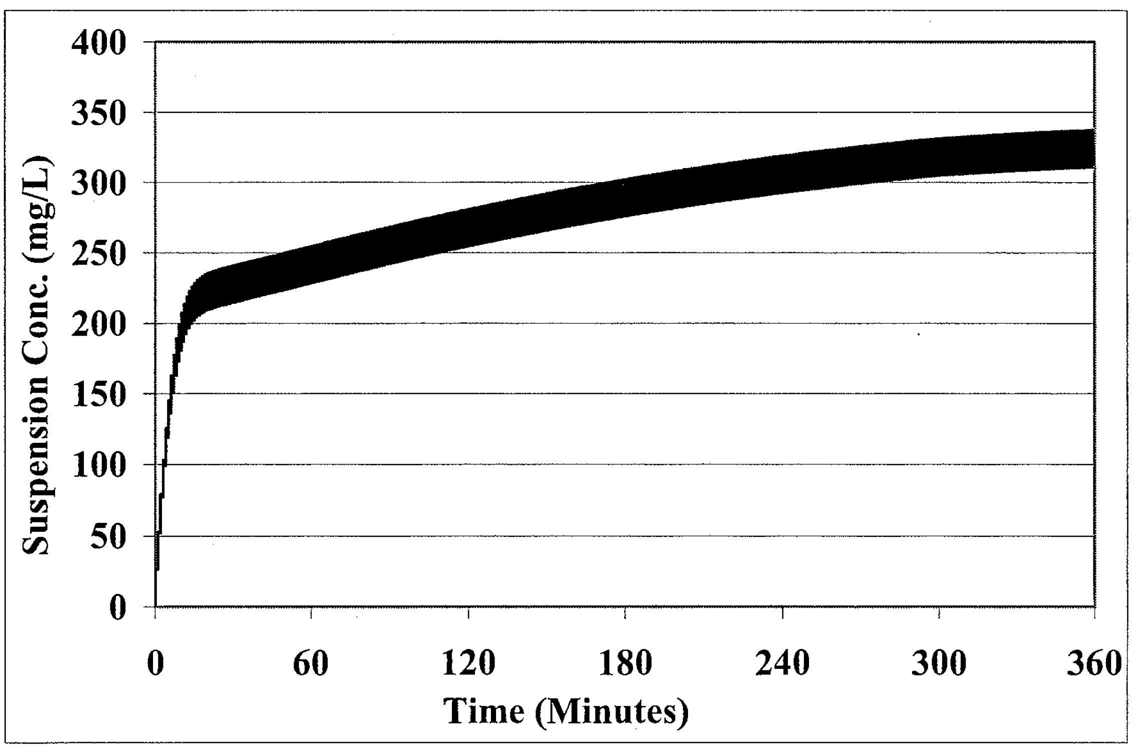


Figure 29b. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 20 cm

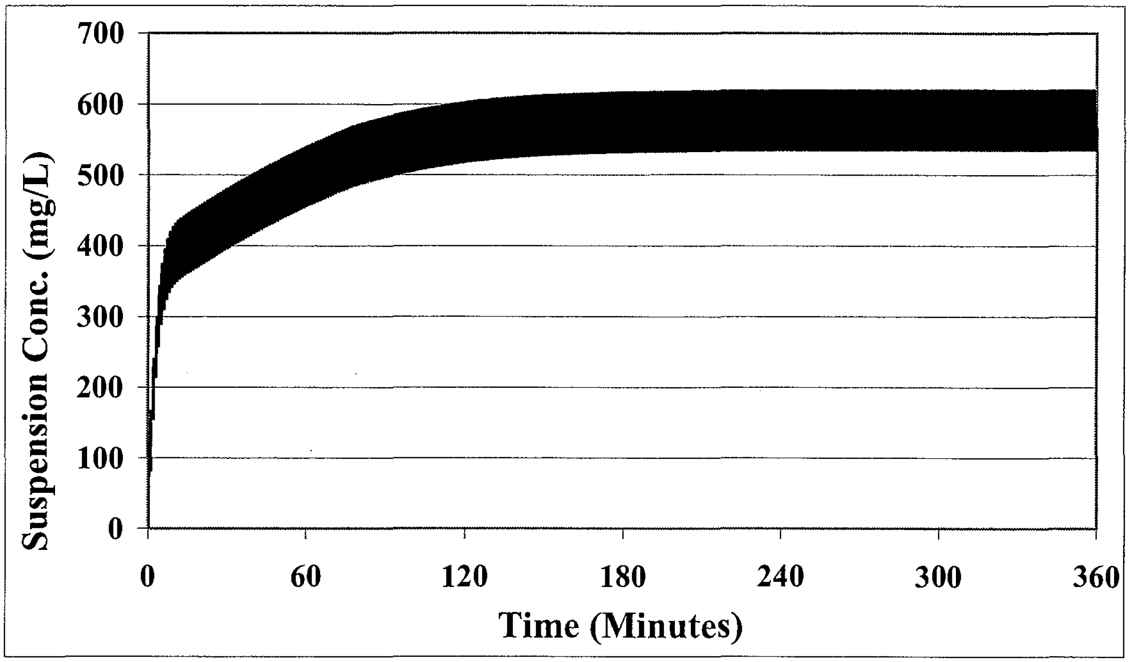


Figure 30a. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 30 cm

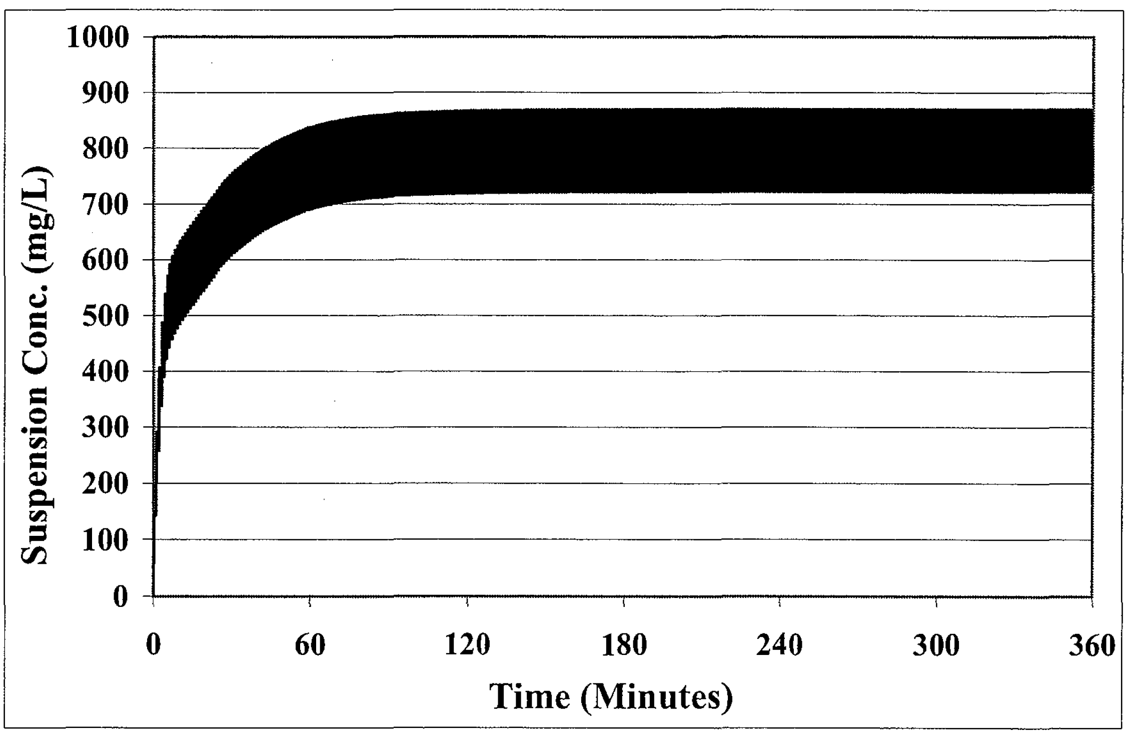


Figure 30b. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 40 cm

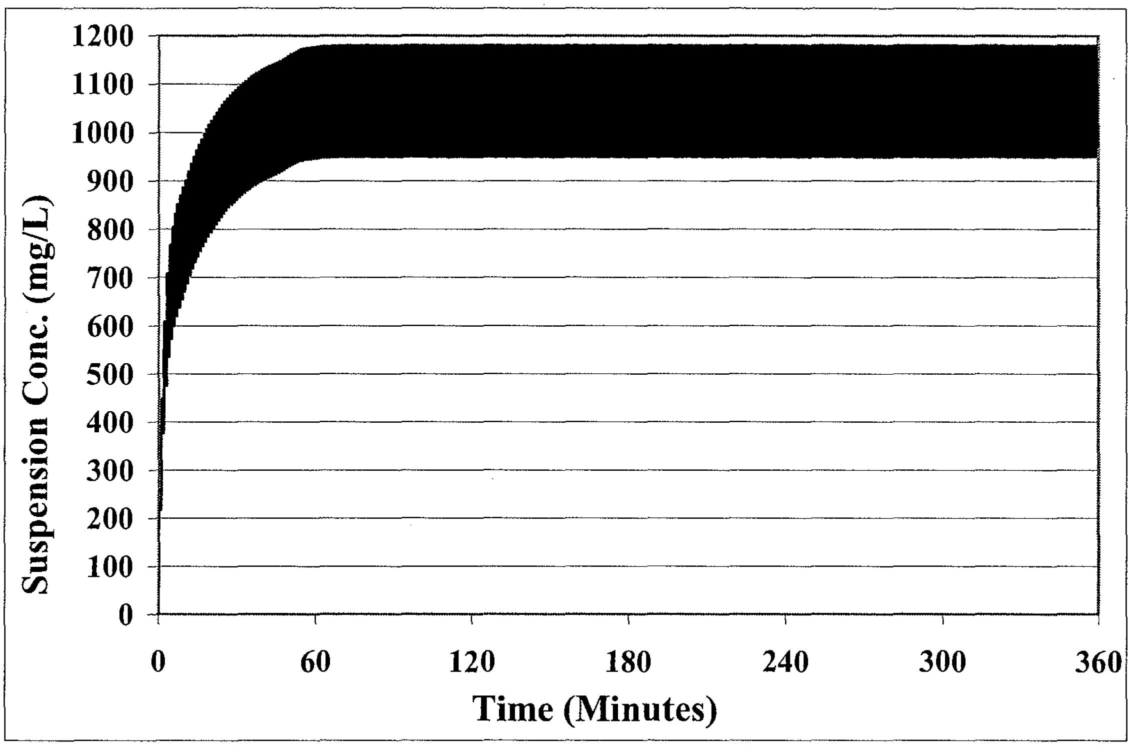


Figure 31. Suspension concentration with 360 recboats at 1-min intervals, Hmax = 50 cm

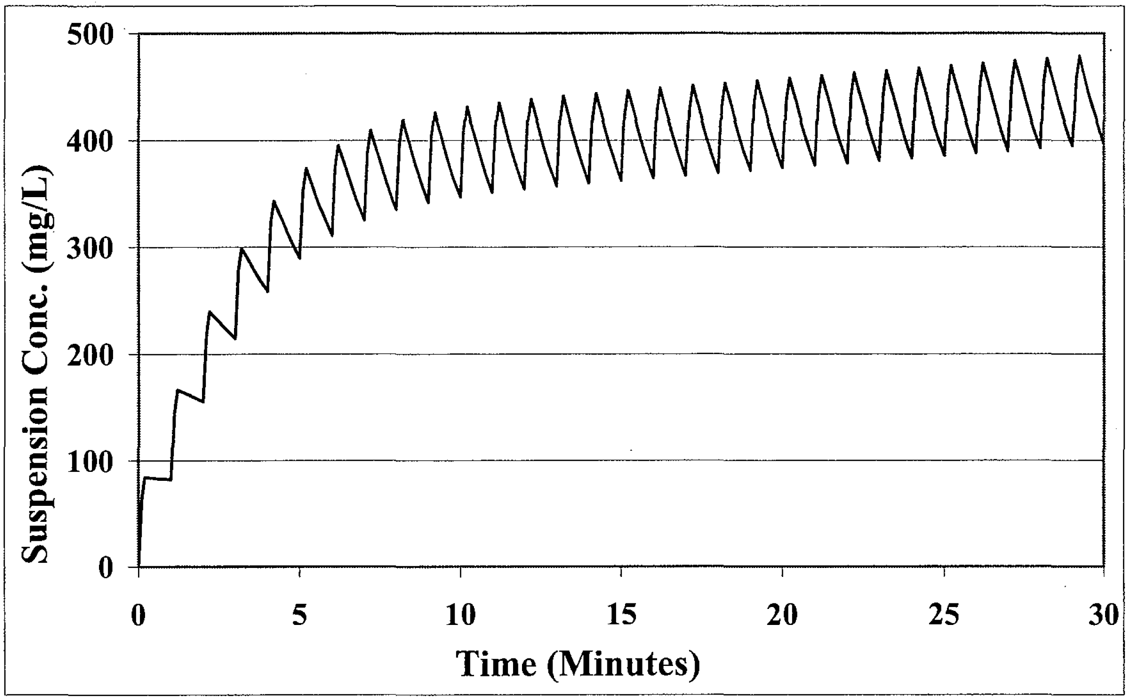


Figure 32a. Suspension concentration with recboats at 1-min intervals, Hmax = 30 cm

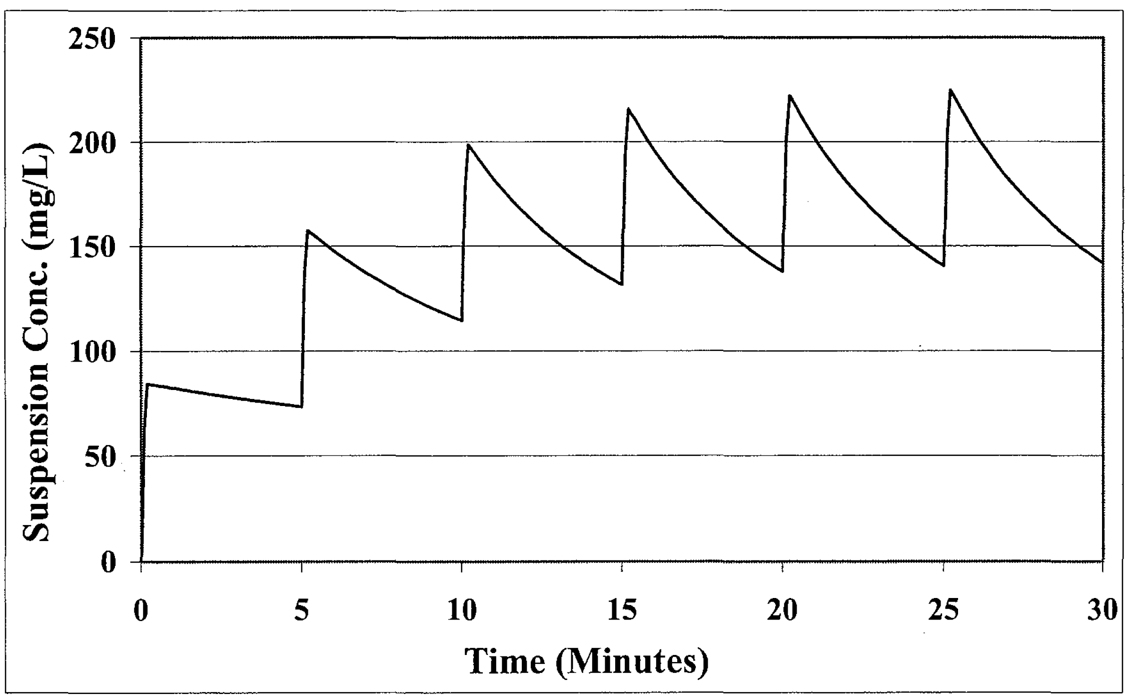


Figure 32b. Suspension concentration with recboats at 5-min intervals, Hmax = 30 cm

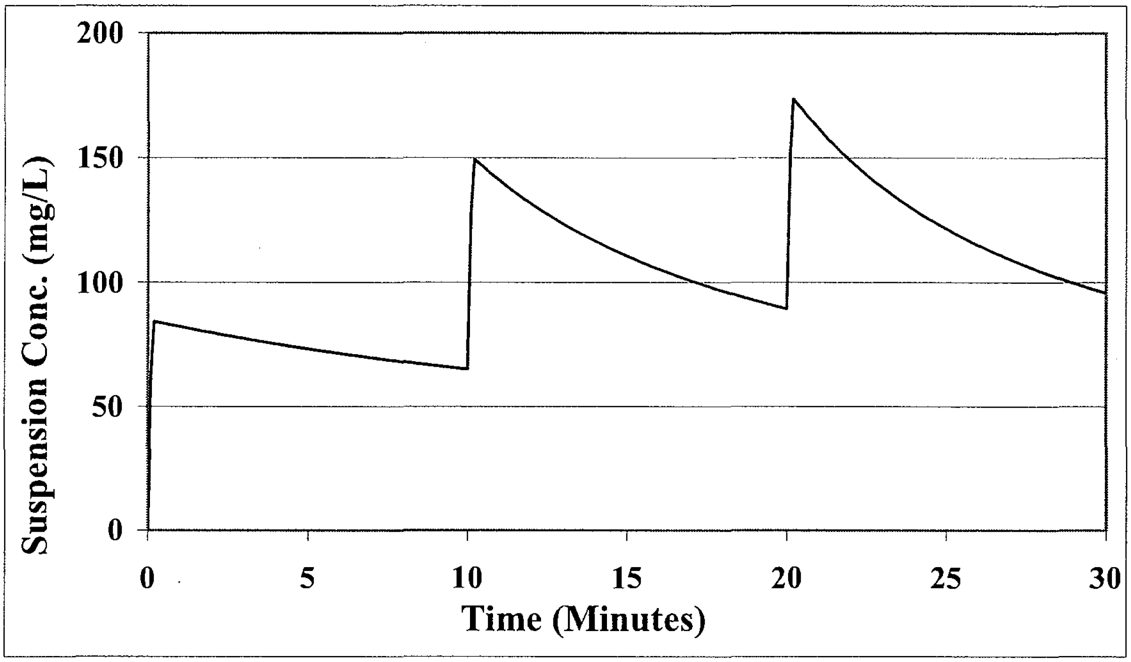


Figure 33a. Suspension concentration with recboats at 10-min intervals, Hmax = 30 cm

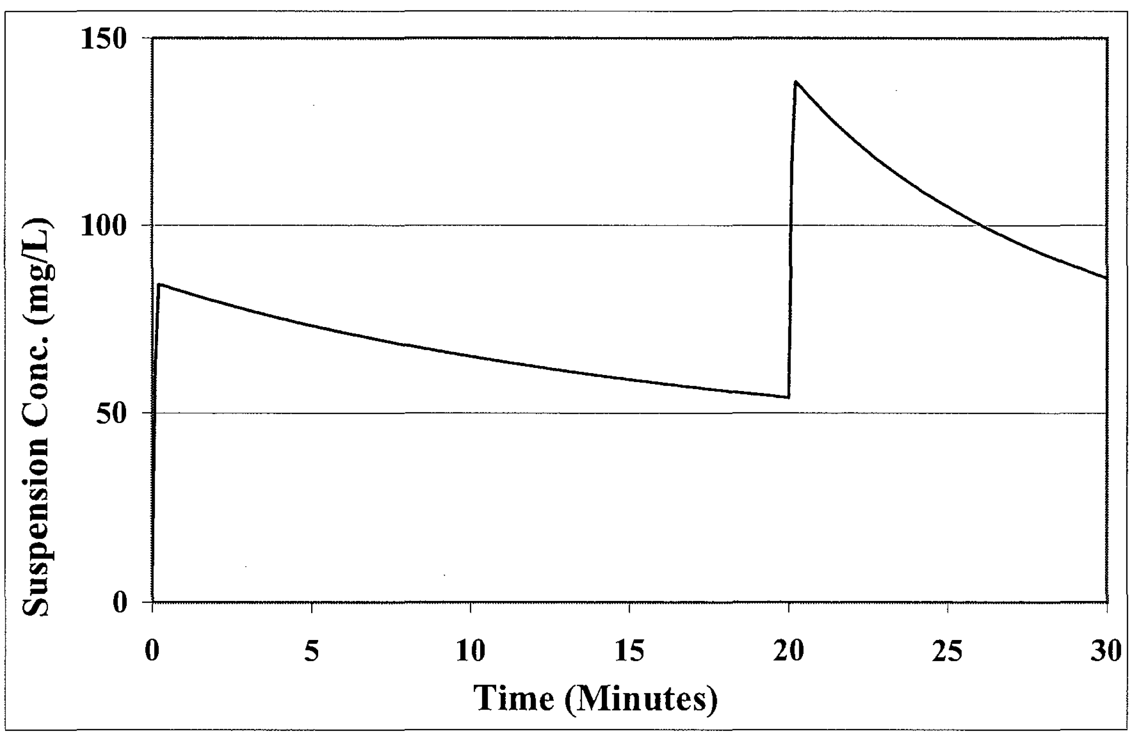


Figure 33b. Suspension concentration with recboats at 20-min intervals, Hmax = 30 cm

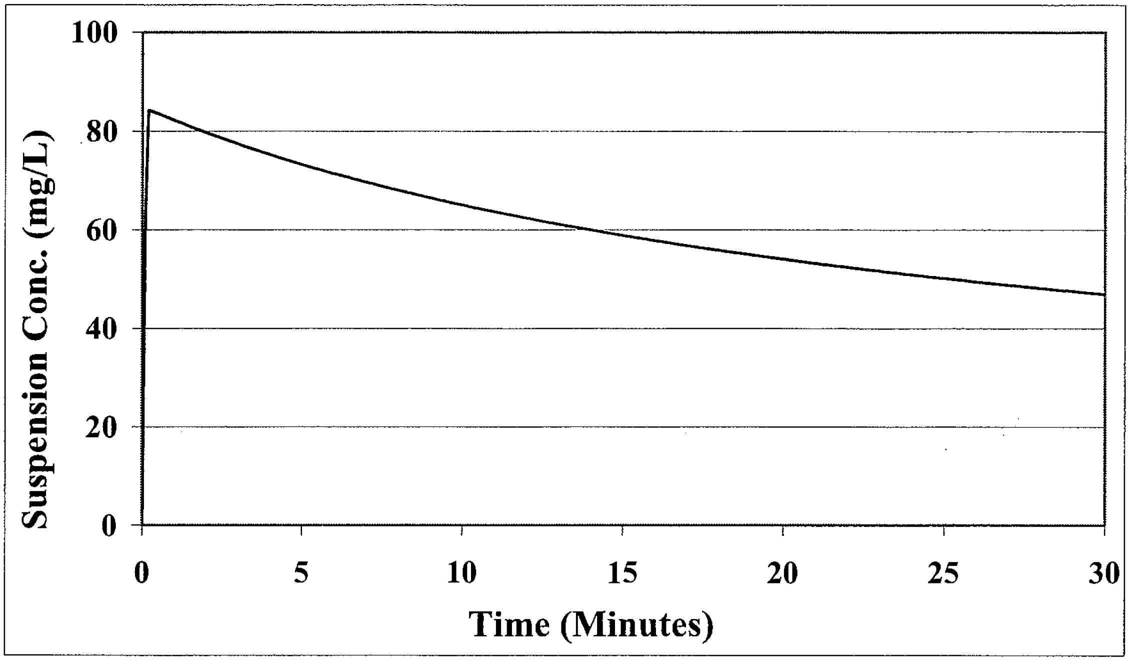


Figure 34a. Suspension concentration with recboats at 30-min intervals, Hmax = 30 cm

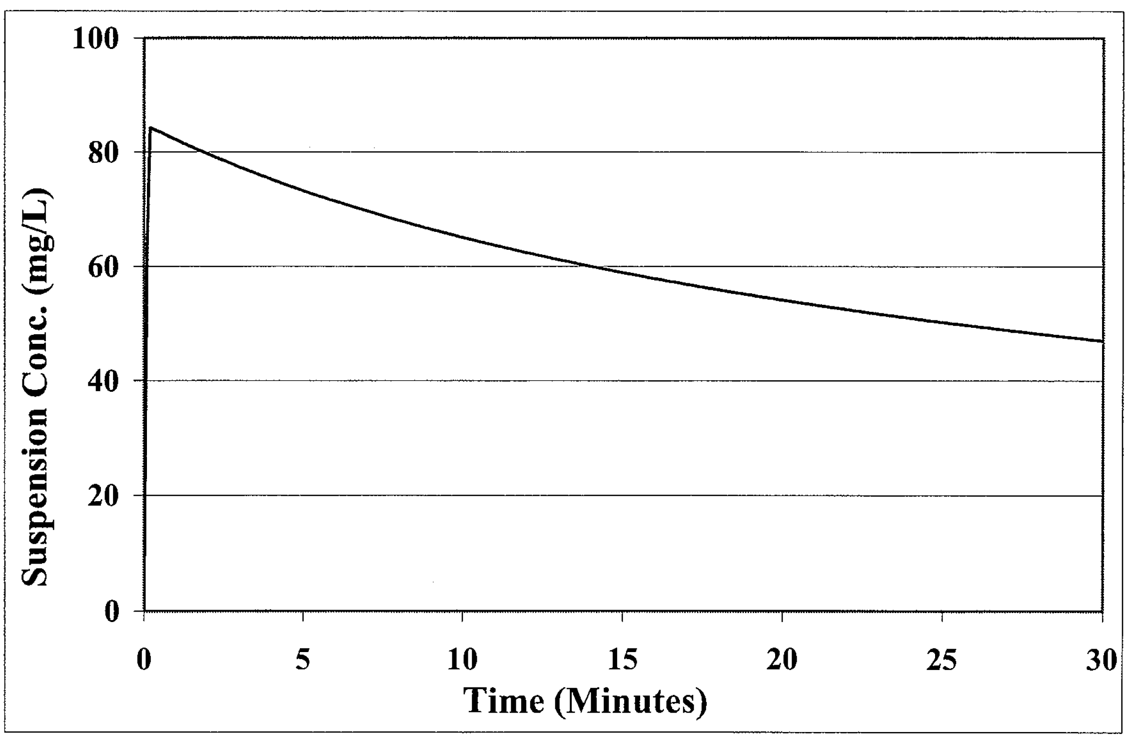


Figure 34b. Suspension concentration with recboats at 60-min intervals, Hmax = 30 cm

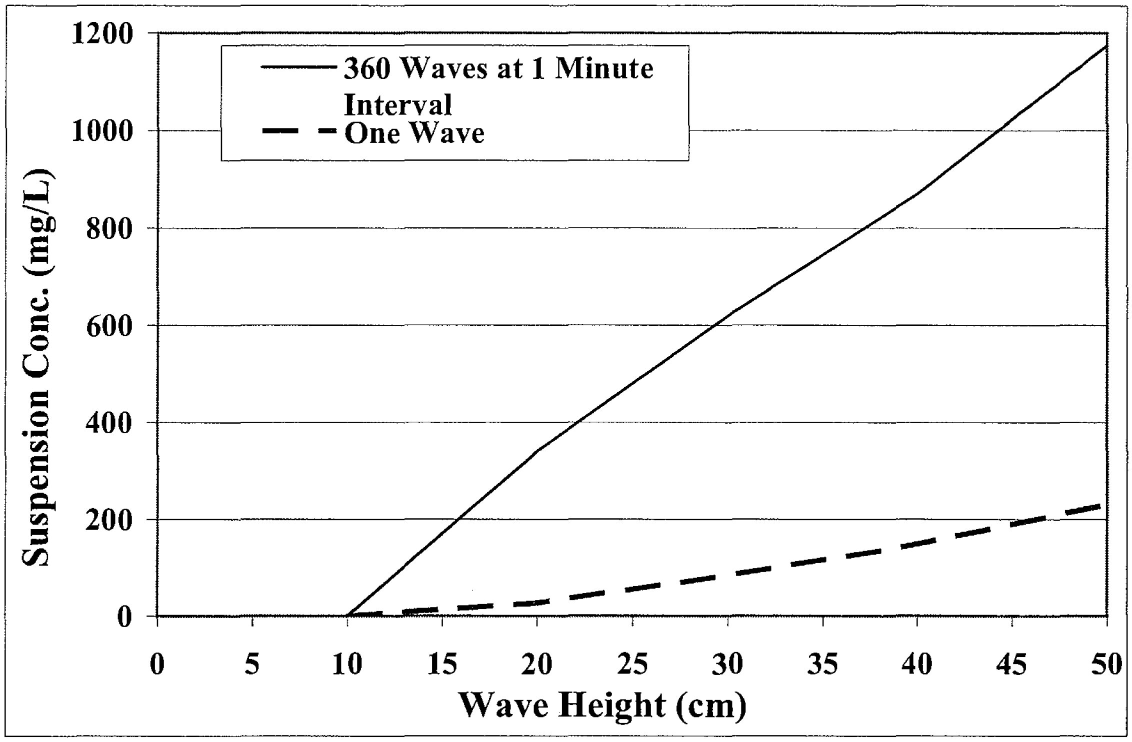


Figure 35a. Peak concentration as a function of recboat-induced waves (360 waves and 1 wave)

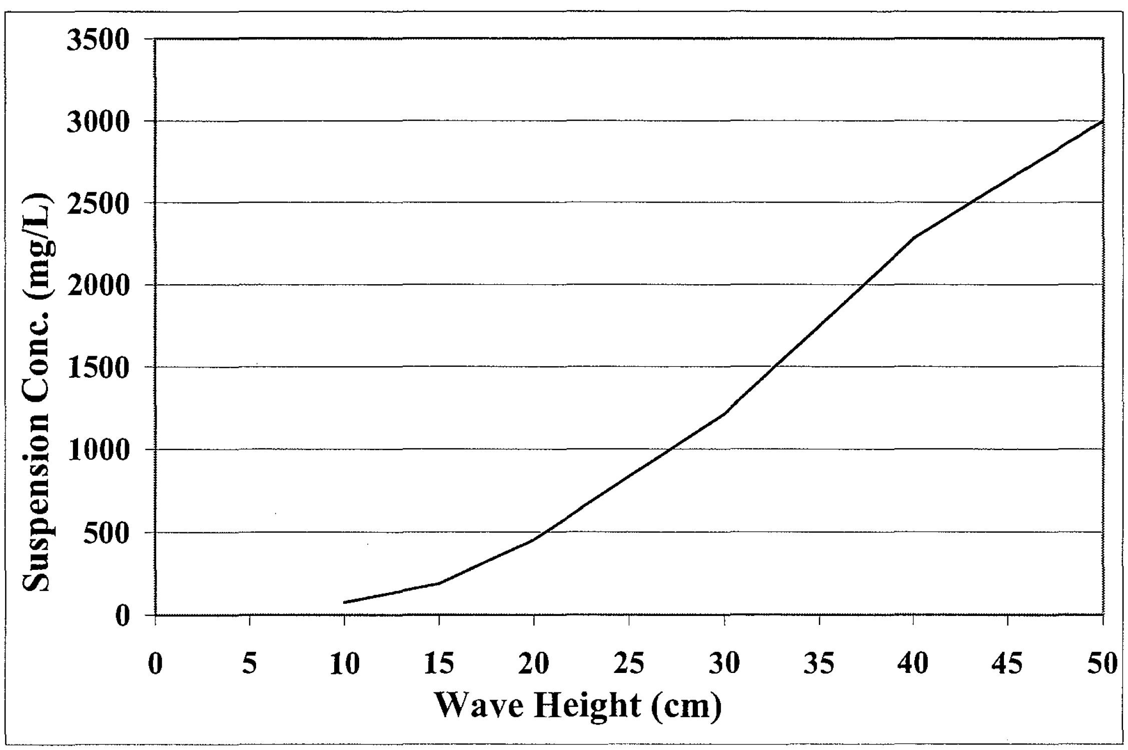


Figure 35b. Peak concentration as a function of one towboat-induced wave height

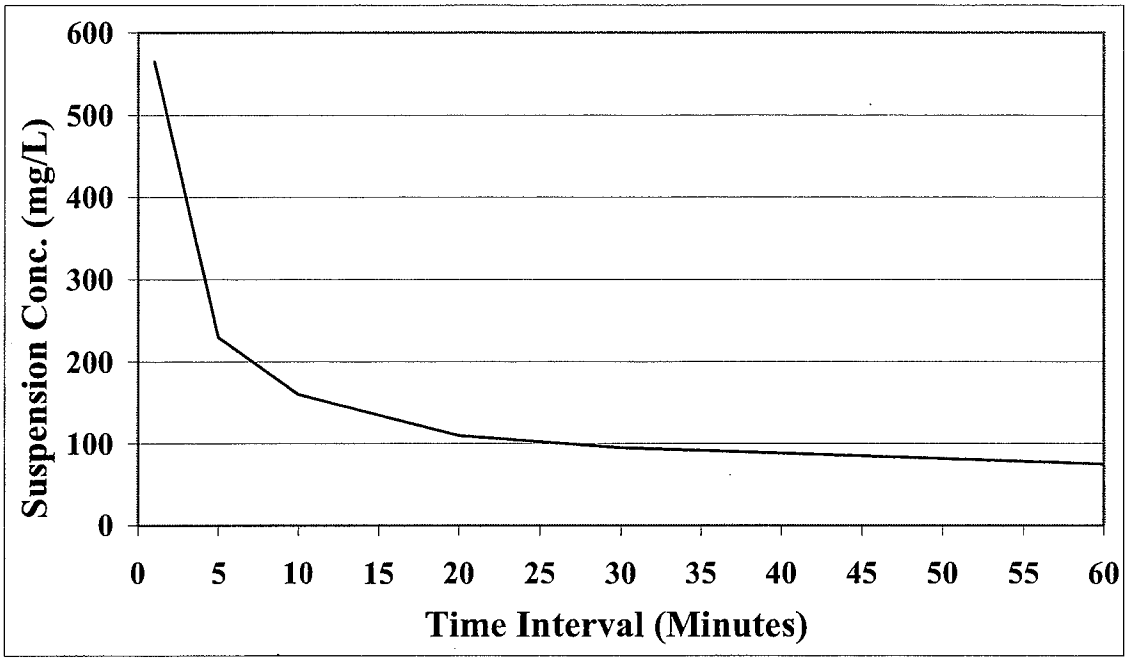


Figure 36a. Mean equilibrium concentration as a function of time interval between consecutive recboats, Hmax = 30 cm

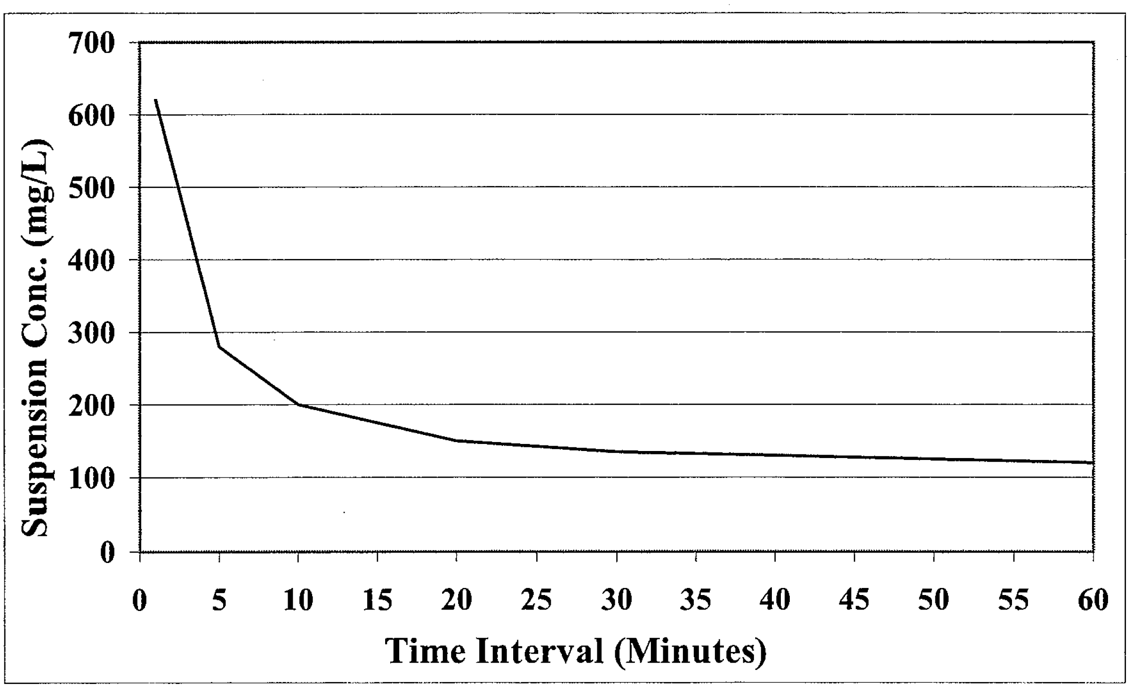


Figure 36b. Peak concentration as a function of time interval between consecutive recboats, Hmax = 30 cm

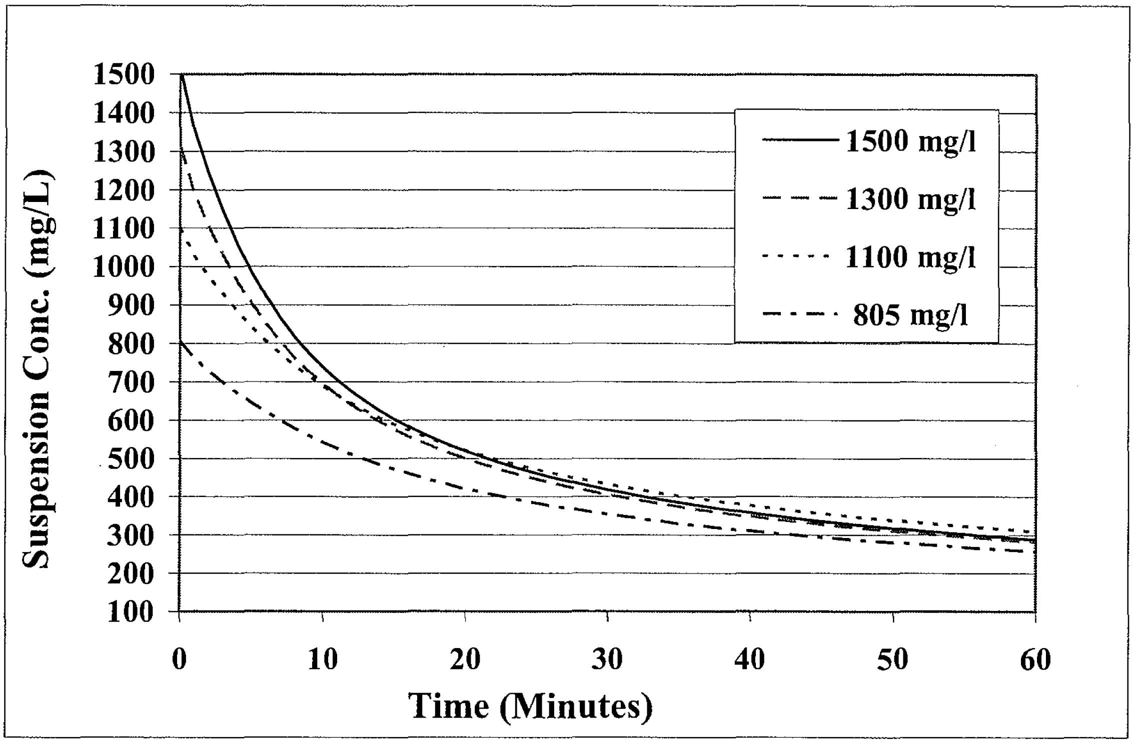


Figure 37a. Sediment deposition under zero waves with initial concentrations of 1,500, 1,300, 1,100, and 800 mg/L

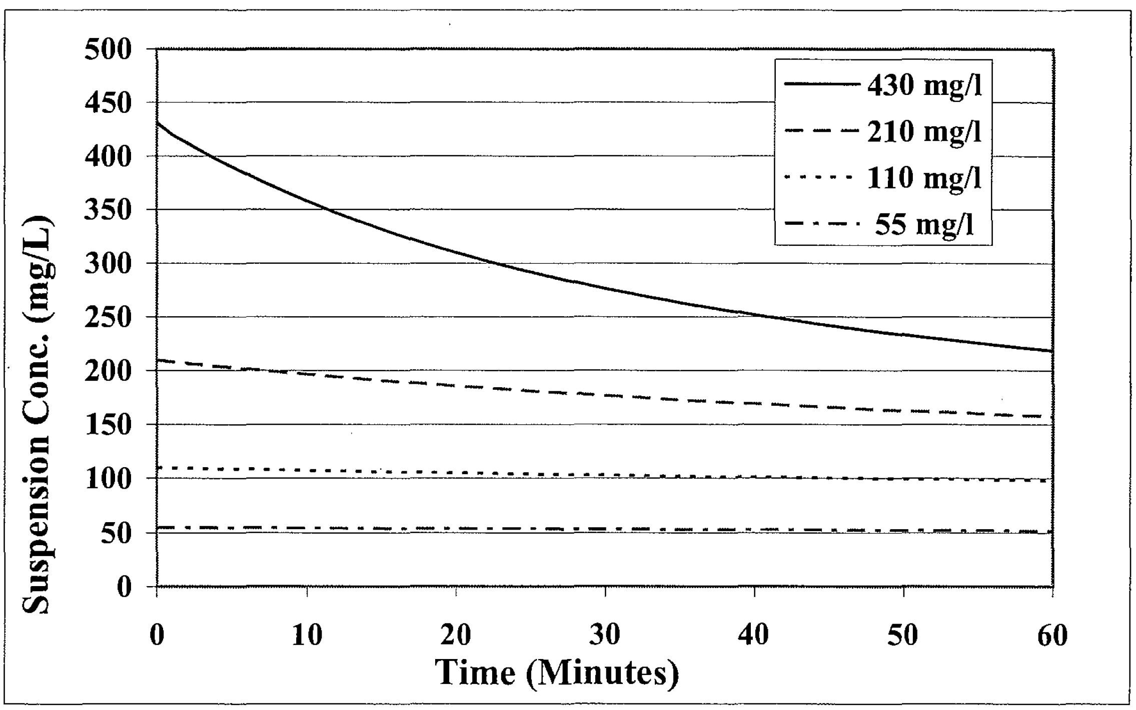


Figure 37b. Sediment deposition under zero waves for initial concentrations of 430, 210, 110, and 55 mg/L

Table 1
Vessels Used in UMRS Field Study (after Rust Environment and Infrastructure 1996a)

Vessel Classification	Make/ Model	Hull Type	Waterline Length	Width Stern	Propulsion
Jet ski	Yamaha	Planing	8 ft 6 in.	3 ft 7 in.	701 cc jet propulsion
Fishing boat	Starcraft FM-150	Nonplaning	13 ft	6 ft 5 in.	50 hp outboard
Medium powerboat	Crestliner	Deep V	14 ft 6 in.	7 in.	80 hp inboard/outboard
Medium powerboat	Four Winns 225 Sundower	Planing	17 ft	7 ft 2 in.	205 hp inboard/outboard
Large Cruiser	Luhrs Motor yacht 3400	Semiplaning	~30 ft	12 ft 6 in.	Twin/ 340 hp each inboard
Houseboat	Riverboat	Barge type/ Semi V	45 ft	12 ft	140 hp alpha drive

Table 2
Field Measurements Made on 6 November 1995 with Boat Type I, Jet Ski

Run #	Real Time	Load Status[1]	Direction	Sailing Line Distance[2] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
1	09:43:09	Unloaded	Downstream	215	0.47	6.1	NA
2	09:45:13	Unloaded	Upstream	215	0.47	NA	NA
3	09:48:16	Unloaded	Upstream	215	0.47	7.9	NA
4	09:49:47	Unloaded	Downstream	215	0.49	4.0	NA
5	09:51:30	Unloaded	Upstream	215	0.44	10.9	NA
6	09:52:56	Unloaded	Downstream	215	0.41	8.2	NA
7	09:54:06	Unloaded	Upstream	215	0.47	22.0	NA
8	09:55:07	Unloaded	Downstream	215	0.47	20.7	NA
9	09:56:03	Unloaded	Upstream	215	0.54	28.3	NA
10[3]	09:57:16	Unloaded	Downstream	215	0.47	25.2	NA
11[3]	09:59:17	Unloaded	Upstream	275	0.41	6.6	NA
12	10:01:45	Unloaded	Downstream	275	0.49	2.1	NA
13	10:04:08	Unloaded	Upstream	275	0.47	7.8	NA
14	10:05:43	Unloaded	Upstream	275	0.41	3.8	NA
15	10:07:37	Unloaded	Downstream	275	0.41	10.0	NA
16	10:09:00	Unloaded	Upstream	275	0.52	8.0	NA
17	10:10:16	Unloaded	Downstream	275	0.41	23.0	NA
18	10:11:24	Unloaded	Upstream	275	0.47	21.4	NA
19	10:12:38	Unloaded	Downstream	275	0.47	28.5	NA
20	10:13:39	Unloaded	Upstream	275	0.36	36.5	NA

[1] The loaded runs were not tested because of the instability of the jet ski with two riders.
[2] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[3] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore, there are no data for these test runs.

Table 3
Field Measurements Made in November 1995 with Boat Type II: Starcraft

Run #	Real Time	Load Status	Direction	Sailing Line Distance[1] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
11/03/1995							
1	15:34:26	Loaded	Downstream	215	0.57	7.6	NA
2[2]	15:38:00	Loaded	Upstream	215	0.49	3.8	NA
3	15:42:38	Loaded	Downstream	215	0.49	11.0	NA
4	15:47:00	Loaded	Upstream	215	0.47	6.8	NA
5	16:03:15	Loaded	Downstream	215	0.52	27.2	NA
6	16:05:35	Loaded	Upstream	215	0.44	28.0	NA
7	16:09:18	Loaded	Downstream	275	0.47	10.9	NA
8	16:14:55	Loaded	Upstream	275	0.41	4.4	NA
9[2]	16:18:15	Loaded	Downstream	275	0.52	14.0	NA
10	16:22:15	Loaded	Upstream	275	0.52	7.6	NA
11	16:26:50	Loaded	Downstream	275	0.47	36.9	NA
12	16:30:06	Loaded	Upstream	275	0.47	26.9	NA
13[2]	16:38:20	Unloaded	Downstream	215	0.52	8.7	NA
14	16:41:30	Unloaded	Upstream	215	0.47	4.4	NA
15	16:44:10	Unloaded	Downstream	215	0.49	21.9	NA
16	16:45:30	Unloaded	Upstream	215	0.62	15.1	NA
17	16:47:13	Unloaded	Downstream	215	0.47	27.6	NA
18	16:50:40	Unloaded	Upstream	215	0.47	21.9	NA
11/04/1995							
19[2]	08:36:28	Unloaded	Downstream	275	0.49	7.9	NA
20	08:41:34	Unloaded	Upstream	275	0.52	3.6	NA
21	08:53:25	Unloaded	Downstream	275	0.47	14.2	NA
22[2]	08:57:08	Unloaded	Upstream	275	0.49	11.4	NA
23	09:00:00	Unloaded	Downstream	275	0.44	29.6	NA
24	09:03:09	Unloaded	Upstream	275	0.52	24.9	NA

[1] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[2] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore there are no data.

Table 4
Field Measurements Made in November 1995 with Boat Type III: Crestliner

Run #	Real Time	Load Status	Direction	Sailing Line Distance[1] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
11/05/1995							
1[2]	---	---	Downstream	---		3.5	700
2[2]	---	---	Upstream	---		0.0	700
3[3]	13:19:12	Loaded	Downstream	215	0.54	7.8	1,600
4	13:21:30	Loaded	Upstream	215	0.52	5.7	1,600
5	13:23:57	Loaded	Downstream	215	0.52	10.9	2,500
6	13:25::44	Loaded	Upstream	215	0.57	7.2	2,500
7	13:28:10	Loaded	Downstream	215	0.41	26.3	3,300
8	13:29:47	Loaded	Upstream	215	0.47	21.7	3,300
9	13:31:49	Loaded	Downstream	215	0.52	32.6	4,200
10	13:33:30	Loaded	Upstream	215	0.47	28.9	4,200
11	13:36:04	Loaded	Downstream	275	0.52	8.9	1,600
12[3]	13:38:20	Loaded	Upstream	275	0.57	5.6	1,600
13	13:40:30	Loaded	Downstream	275	0.57	10.7	2,500
14	13:41:55	Loaded	Upstream	275	0.47	8.5	2,500
15	13:44:12	Loaded	Downstream	275	0.52	29.4	3,300
16	13:45:43	Loaded	Upstream	275	0.52	24.7	3,300
17	13:47:20	Loaded	Downstream	275	0.52	35.5	4,200
18	13:48:54	Loaded	Upstream	275	0.49	33.0	4,200
19	14:00:43	Unloaded	Downstream	215	0.57	9.1	1,600
20	14:04:09	Unloaded	Upstream	215	0.47	4.3	1,600
21	14:06:51	Unloaded	Downstream	215	0.47	20.4	2,500
22	14:08:43	Unloaded	Upstream	215	0.52	17.6	2,500
23	14:10:15	Unloaded	Downstream	215	0.47	29.4	3,300
24	14:11:30	Unloaded	Upstream	215	0.52	26.4	3,300
25	14:15:09	Unloaded	Downstream	215	0.62	35.3	4,200
26[3]	14:17:02	Unloaded	Upstream	215	0.52	31.2	4,200
27[3]	14:18:57	Unloaded	Downstream	275	0.47	8.2	1,600
28	14:20:53	Unloaded	Upstream	275	0.57	4.3	1,600
29	14:22:53	Unloaded	Downstream	275	0.57	22.3	2,500
30	14:24:27	Unloaded	Upstream	275	0.52	13.6	2,500
31	14:26:03	Unloaded	Downstream	275	0.52	29.9	3,300
32	14:27:38	Unloaded	Upstream	275	0.54	24.7	3,300
33	14:29;03	Unloaded	Downstream	275	0.47	34.5	4,200
34	14:30:32	Unloaded	Upstream	275	0.47	31.1	4,200

[1] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[2] The boat operator could not navigate the boat at the low rpms, therefore these test runs were scratched.
[3] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore there are no data for these test runs.

Table 5
Field Measurements Made in November 1995 with Boat Type IV: Four Winns

Run #	Real Time	Load Status	Direction	Sailing Line Distance[1] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
11/04/1995							
1	12:05:27	Loaded	Downstream	215	0.47	7.0	700
2	12:11:11	Loaded	Upstream	215	0.49	1.7	700
3[2]	12:17:32	Loaded	Downstream	215	0.52	9.6	1,400
4	12:22:22	Loaded	Upstream	215	0.54	5.5	1,400
5	12:28:05	Loaded	Downstream	215	0.47	12.3	2,200
6	12:32:04	Loaded	Upstream	215	0.57	7.0	2,200
7	12:45:54	Loaded	Downstream	275	0.57	29.2	3,000
8	12:50:42	Loaded	Upstream	275	0.57	13.7	3,000
9	12:55:06	Loaded	Downstream	275	0.47	36.9	3,800
10	13:02:17	Loaded	Upstream	275	0.57	34.2	3,800
11	13:06:05	Loaded	Downstream	275	0.57	9.7	1,400
12	13:11:57	Loaded	Upstream	275	0.57	5.4	1,400
13[2]	13:17:18	Loaded	Downstream	275	0.57	9.1	2,200
14	13:21:28	Loaded	Upstream	275	0.54	6.3	2,200
15	13:26:00	Loaded	Downstream	275	0.60	21.7	3,000
16	13:31:48	Loaded	Upstream	275	0.57	21.4	3,000
17	13:35:05	Loaded	Downstream	275	0.47	39.0	3,800
18[2]	13:38:20	Loaded	Upstream	275	0.62	34.2	3,800
19	14:41:28	Unloaded	Downstream	215	0.52	10.0	1,400
20	14:44:09	Unloaded	Upstream	215	0.47	5.3	1,400
21	14:46:54	Unloaded	Downstream	215	0.52	12.1	2,200
22	14:49:37	Unloaded	Upstream	215	0.52	8.9	2,200
23	14:51:49	Unloaded	Downstream	215	0.52	24.0	3,000
24	14:56:19	Unloaded	Upstream	215	0.54	23.2	3,000
25[2]	14:58:23	Unloaded	Downstream	215	0.57	42.8	4,400
26	15:00:54	Unloaded	Upstream	215	0.54	32.3	4,400
27	15:03:22	Unloaded	Downstream	275	0.62	9.7	1,400
28	15:05:49	Unloaded	Upstream	275	0.57	5.8	1,400
29	15:08:50	Unloaded	Downstream	275	0.52	13.4	2,200
30	15:12:24	Unloaded	Upstream	275	0.57	9.5	2,200
31	15:15:27	Unloaded	Downstream	275	0.57	26.7	3,000
32[2]	15:18:22	Unloaded	Upstream	275	0.62	22.6	3,000
33	15:21:45	Unloaded	Downstream	275	0.57	39.3	4,400
34	15:24:22	Unloaded	Upstream	275	0.62	35.7	4,400

[1] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[2] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore there are no data for these test runs.

Table 6
Field Measurements Made in November 1995 with Boat Type V: Luhrs

Run #	Real Time	Load Status	Direction	Sailing Line Distance[1] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
11/06/95							
1	12:50:51	Loaded	Downstream	215	0.44	7.7	1,250
2	12:54:36	Loaded	Upstream	215	0.47	5.8	1,250
3[2]	12:58:19	Loaded	Downstream	215	0.36	12.6	2,200
4	13:01:28	Loaded	Upstream	215	0.44	8.1	2,200
5	13:03:56	Loaded	Downstream	215	0.52	12.7	3,000
6	13:06:50	Loaded	Upstream	215	0.52	8.8	3,000
7	13:09:26	Loaded	Downstream	215	0.44	26.9	4,100
8	13:11:52	Loaded	Upstream	215	0.47	24.0	4,100
9	13:14:27	Loaded	Downstream	275	0.44	7.4	1,250
10[2]	13:17:30	Loaded	Upstream	275	0.41	6.4	1,250
11	13:20:31	Loaded	Downstream	275	0.52	13.0	2,200
12	13:23:39	Loaded	Upstream	275	0.47	9.4	2,200
13	13:26:16	Loaded	Downstream	275	0.52	15.3	3,000
14	13:29:16	Loaded	Upstream	275	0.47	9.8	3,000
15	13:31:59	Loaded	Downstream	275	0.47	26.9	4,100
16	13:34:47	Loaded	Upstream	275	0.52	24.3	4,100
17	14:14:37	Unloaded	Downstream	215	0.44	9.8	1,250
18[2]	14:17:40	Unloaded	Upstream	215	0.36	5.2	1,250
19	14:20:09	Unloaded	Downstream	215	0.52	12.6	2,200
20	14:23:19	Unloaded	Upstream	215	0.47	8.4	2,200
21	14:25:.30	Unloaded	Downstream	215	0.36	17.6	3,000
22	14:27:53	Unloaded	Upstream	215	0.44	13.7	3,000
23	14:30:10	Unloaded	Downstream	215	0.41	33.6	4,100
24	14:32:18	Unloaded	Upstream	215	0.47	28.3	4,100
25	14:34:24	Unloaded	Downstream	275	0.47	10.5	1,250
26[2]	14:37:45	Unloaded	Upstream	275	0.44	4.9	1,250
27	14:40:22	Unloaded	Downstream	275	0.47	11.1	2,200
28	14:43:04	Unloaded	Upstream	275	0.41	8.3	2,200
29	14:45:54	Unloaded	Downstream	275	0.36	17.9	3,000
30	14:48:09	Unloaded	Upstream	275	0.41	11.1	3,000
31	14:50:23	Unloaded	Downstream	275	0.41	34.1	4,100
32	14:52:34	Unloaded	Upstream	275	0.41	29.6	4,100

[1] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[2] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore there are no data for these test runs.

Table 7
Field Measurements Made in November 1995 with Boat Type VI: Houseboat

Run #	Real Time	Load Status	Direction	Sailing Line Distance[1] ft	Ambient Current Speed knots	Boat Speed mph	Motor Speed rpm
11/05/1995							
1[2]	08:15:29	Unloaded	Downstream	215	---	3.0	1,200
2[2]	08:19:55	Unloaded	Upstream	215	0.41	0.0	1,200
3	08:24:36	Unloaded	Upstream	215	0.52	3.2	1,650
4	08:28:29	Unloaded	Downstream	215	0.47	6.7	2,100
5	08:30:43	Unloaded	Upstream	215	0.49	2.6	2,100
6	08:34:56	Unloaded	Downstream	215	0.47	8.3	2,500
7[3]	08:37:45	Unloaded	Upstream	215	0.44	4.6	2,500
8	08:40:36	Unloaded	Downstream	215	0.57	9.4	3,000
9	08:43:01	Unloaded	Upstream	215	0.52	5.5	3,000
10	08:46:44	Unloaded	Downstream	275	0.49	4.4	2,500
11	08:49:09	Unloaded	Upstream	275	0.49	3.7	2,500
12	08:51:31	Unloaded	Downstream	275	0.49	9.2	3,000
13	08:53:50	Unloaded	Upstream	275	0.44	6.2	3,000
14	09:55:50	Loaded	Upstream	215	0.57	2.8	2,100
15[3]	09:58:27	Loaded	Downstream	215	0.52	7.1	2,100
16	10:00:41	Loaded	Upstream	215	0.62	5.2	2,500
17	10:03:40	Loaded	Downstream	215	0.52	7.3	2,500
18	10:05:50	Loaded	Upstream	215	0.47	6.1	3,000
19	10:08:02	Loaded	Downstream	215	0.52	8.0	3,000
20	10:10:01	Loaded	Upstream	275	0.52	4.4	2,500
21	10:15:49	Loaded	Downstream	275	0.57	7.9	2,500
22[3]	10:18:32	Loaded	Upstream	275	0.52	5.0	3,000
23	10:20:42	Loaded	Downstream	275	0.54	7.9	3,000

[1] The sailing line distance, 215 ft, is an inside course, and the sailing line distance, 275 ft, is an outside course.
[2] The boat operator could not navigate the boat at the low rpms, therefore these test runs were scratched.
[3] These test runs fell within the time frame in which the instruments were downloading data to storage, therefore there are no data for these test runs.

Table 8
Maximum Wave Height at Each Gage Listed with Boat Names

Recreational boating studies. Field data collected during November 1995. Data entered only for Hmax > 0.1 ft.

Vessel Type	Test #	Vessel Speed mph	Up/Down	Loaded/ Empty	Distance Bank to Boat	Distance Bank to Gage	Distance to Gage	Hmax ft	Hmax cm
Crestliner	4	5.7	u	l	215	20	195	0.14	4.27
Crestliner	5	10.9	d	l	215	20	195	0.16	4.88
Crestliner	6	7.2	u	l	215	20	195	0.14	4.27
Crestliner	10	28.9	u	l	215	20	195	0.16	4.88
Crestliner	16	24.7	u	l	275	40	235	0.12	3.66
Crestliner	29	22.3	d	e	275	20	255	0.34	10.36
Crestliner	29	22.3	d	e	275	40	235	0.14	4.27
Crestliner	30	13.6	u	e	275	40	235	0.14	4.27
Crestliner	31	29.9	d	e	275	40	235	0.13	3.96
Four Winns	5	12.3	d	l	215	20	195	0.47	14.32
Four Winns	5	12.3	d	l	215	40	175	0.19	5.79
Four Winns	6	7	u	l	215	20	195	0.14	4.27
Four Winns	7	29.2	d	l	275	20	255	0.26	7.92
Four Winns	7	29.2	d	l	275	40	235	0.12	3.66
Four Winns	8	13.7	u	l	275	20	255	0.14	4.27
Four Winns	8	13.7	u	l	275	40	235	0.14	4.27
Four Winns	9	36.9	d	l	275	20	255	0.23	7.01
Four Winns	10	34.2	u	l	275	20	255	0.14	4.27
Four Winns	10	34.2	u	l	275	40	235	0.12	3.66
Four Winns	14	6.3	u	l	275	20	255	0.14	4.27
Four Winns	14	6.3	u	l	275	40	235	0.14	4.27
Four Winns	15	21.7	d	l	275	20	255	0.28	8.53
Four Winns	15	21.7	d	l	275	40	235	0.14	4.27
Four Winns	16	21.4	u	l	275	20	255	0.14	4.27
Four Winns	17	39	d	l	275	20	255	0.28	8.53
Four Winns	21	12.1	d	e	215	20	195	0.33	10.06
Four Winns	21	12.1	d	e	215	40	175	0.14	4.27
Four Winns	22	8.9	u	e	215	20	195	0.23	7.01
Four Winns	22	8.9	u	e	215	40	175	0.15	4.57
Four Winns	22	8.9	u	e	215	125	90	0.16	4.88
Four Winns	23	24	d	e	215	20	195	0.27	8.23
Four Winns	24	23.2	u	e	215	20	195	0.14	4.27
Four Winns	26	32.3	u	e	215	20	195	0.14	4.27
Four Winns	28	5.8	u	e	275	20	255	0.14	4.27
Four Winns	29	13.4	d	e	275	20	255	0.2	6.10
Four Winns	30	9.5	u	e	275	40	235	0.14	4.27

(Sheet 1 of 3)

Note: All distances are in feet.

Table 8 (Continued)									
Vessel Type	Test #	Vessel Speed mph	Up/Down	Loaded/ Empty	Distance Bank to Boat	Distance Bank to Gage	Distance to Gage	Hmax ft	Hmax cm
Four Winns	30	9.5	u	e	275	125	150	0.19	5.79
Four Winns	31	26.7	d	e	275	20	255	0.23	7.01
Four Winns	31	26.7	d	e	275	40	235	0.14	4.27
Four Winns	33	39.3	d	e	275	20	255	0.18	5.49
Luhrs	5	12.7	d	l	215	20	195	0.61	18.59
Luhrs	5	12.7	d	l	215	40	175	0.66	20.12
Luhrs	5	12.7	d	l	215	125	90	0.4	12.19
Luhrs	6	8.8	u	l	215	20	195	0.56	17.07
Luhrs	6	8.8	u	l	215	40	175	0.67	20.42
Luhrs	6	8.8	u	l	215	125	90	0.5	15.24
Luhrs	7	26.9	d	l	215	20	195	0.43	13.11
Luhrs	7	26.9	d	l	215	40	175	0.4	12.19
Luhrs	7	26.9	d	l	215	125	90	0.18	5.49
Luhrs	8	24	u	l	215	20	195	0.35	10.67
Luhrs	8	24	u	l	215	40	175	0.26	7.92
Luhrs	8	24	u	l	215	125	90	0.19	5.79
Luhrs	12	9.4	u	l	275	125	150	0.19	5.79
Luhrs	13	15.3	d	l	275	20	255	0.4	12.19
Luhrs	13	15.3	d	l	275	40	235	0.14	4.27
Luhrs	14	9.8	u	l	275	40	235	0.27	8.23
Luhrs	14	9.8	u	l	275	125	150	0.46	14.02
Luhrs	15	26.9	d	l	275	20	255	0.42	12.80
Luhrs	15	26.9	d	l	275	40	235	0.29	8.84
Luhrs	16	24.3	u	l	275	20	255	0.43	13.11
Luhrs	16	24.3	u	l	275	40	235	0.29	8.84
Luhrs	17	9.8	d	e	215	20	195	0.21	6.40
Luhrs	19	12.6	d	e	215	20	195	0.21	6.40
Luhrs	19	12.6	d	e	215	40	175	0.16	4.88
Luhrs	20	8.4	u	e	215	125	90	0.28	8.53
Luhrs	21	17.6	d	e	215	20	195	0.63	19.20
Luhrs	21	17.6	d	e	215	40	175	0.59	17.98
Luhrs	21	17.6	d	e	215	125	90	0.47	14.32
Luhrs	22	13.7	u	e	215	20	195	0.43	13.11
Luhrs	22	13.7	u	e	215	40	175	0.47	14.32
Luhrs	22	13.7	u	e	215	125	90	0.65	19.81
Luhrs	23	33.6	d	e	215	20	195	0.43	13.11
Luhrs	24	28.3	u	e	215	20	195	0.43	13.11
Luhrs	24	28.3	u	e	215	40	175	0.35	10.67

(Sheet 2 of 3)

Table 8 (Concluded)									
Vessel Type	Test #	Vessel Speed mph	Up/Down	Loaded/ Empty	Distance Bank to Boat	Distance Bank to Gage	Distance to Gage	Hmax ft	Hmax cm
Luhrs	24	28.3	u	e	215	125	90	0.15	4.57
Luhrs	25	10.5	d	e	275	20	255	0.14	4.27
Luhrs	27	11.1	d	e	275	20	255	0.14	4.27
Luhrs	28	8.3	u	e	275	20	255	0.14	4.27
Luhrs	28	8.3	u	e	275	125	150	0.26	7.92
Luhrs	29	17.9	d	e	275	20	255	0.36	10.97
Luhrs	29	17.9	d	e	275	40	235	0.28	8.53
Luhrs	29	17.9	d	e	275	125	150	0.35	10.67
Luhrs	30	11.1	u	e	275	20	255	0.35	10.67
Luhrs	30	11.1	u	e	275	40	235	0.29	8.84
Luhrs	30	11.1	u	e	275	125	150	0.37	11.28
Luhrs	31	34.1	d	e	275	20	255	0.41	12.50
Luhrs	32	29.6	u	e	275	20	255	0.41	12.50
Luhrs	32	29.6	u	e	275	40	235	0.35	10.67
Starcraft	3	11	d	l	215	20	195	0.15	4.57
Starcraft	4	7.6	u	l	215	20	195	0.12	3.66
Starcraft	5	27.2	d	l	215	20	195	0.14	4.27
Starcraft	6	28	u	l	215	20	195	0.14	4.27
Starcraft	11	36.9	d	l	275	20	255	0.14	4.27
Starcraft	12	26.9	u	l	275	20	255	0.14	4.27
Starcraft	15	21.9	u	e	215	20	195	0.27	8.23
Starcraft	17	27.6	d	e	215	20	195	0.14	4.27
Starcraft	24	21	u	e	215	20	195	0.14	4.27
									(Sheet 3 of 3)

Table 9
Summary of Maximum Wave Height Data (from Bhowmik et al. 1991)

Type boat	Speed mph	Distance ft	Hmax ft	Hmax cm	UMRS Classification
Jon Boat	10.8	50	0.36	11	Fishing boat
NHS EEL	8.0	50	0.53	16	Fishing boat
Monitor	23.8	23	0.66	20	Medium Power
Queen Mary	21.8	173	0.72	22	Medium Power
Barracuda	8.7	23	0.78	24	Medium Power
Monitor	31.5	73	0.49	15	Medium Power
Barracuda	7.8	103	0.49	15	Medium Power
Barracuda	37.2	123	0.39	12	Medium Power
Propinquity	8.8	53	1.48	45	Cabin Cruiser
Propinquity	8.9	123	1.48	45	Cabin Cruiser
Sea Ray	18.3	103	1.07	33	Cabin Cruiser
Sheriff	9.7	78	0.95	29	Unknown

Table 10
Maximum Wave Heights Assigned to Each Vessel Class

Vessel Type	0 to 100 ft	100 to 300 ft	300 to 500 ft
Sailboats	N/A	N/A	N/A
Jet Skis - Type I	8 cm (0.26 ft)	4 cm (0.13 ft)	0
Fishing Boats - Type II	16 cm (0.52 ft)	8 cm (0.26 ft)	4 cm (0.13 ft)
Medium Power - Types III & IV	24 cm (0.79 ft)	20 cm (0.66 ft)	10 cm (0.33 ft)
Large Cruisers - Type V	50 cm (1.64 ft)	40 cm (1.31 ft)	20 cm (0.66 ft)
House boats/Pontoons - Type VI	8 cm (0.26 ft)	4 cm (0.13 ft)	4 cm (0.13 ft)

Table 11
Erosion Rate Parameters and Physical Properties of Bed Samples. Laboratory Measurements for Sediment Samples from Pool 8

Sample Number	Bulk Density kg/m^3	Organic Content %	% By Weight Finer Than 4 Micron	% By Weight Finer Than 62 Micron	Erosion Rate Constant M_1 $g/m^2/min$	Critical Shear Stress τ_2 Pa	Erosion Rate Constant M_2 $g/m^2/min$	Erodibility Label
6606	1873	3.18	20.85	77.2	*	*	*	Medium
6701	1840	2.60	13.18	53.5	0.1	*	*	Medium
6702	1731	4.25	25.97	81.3	0.2	0.378	4.457	Medium
6932	1966	1.71	6.19	24.7	0.1	0.46	*	Medium
6759	1638	3.36	12.82	52.4	0.2	0.371	5.9	Medium
6876	1625	3.54	8.09	40.6	0.1	0.46	*	Medium
6556	1547	4.40	21.46	79.3	1.0	*	1.0	Medium
6704	1807	3.12	21.63	61.8	0.03	0.55	*	Medium
6964	*	3.91	24.71	80.2	0.15	0.52	5.0	*

Note: See next page for an explanation of notations used in this table.
* Values of these could not be determined.

Explanation of Laboratory Results Reported in Table 11.

A commonly used form of erosion equation is

$$E = M\left[\frac{\tau_b - \tau_e}{\tau_e}\right] \quad (1)$$

where

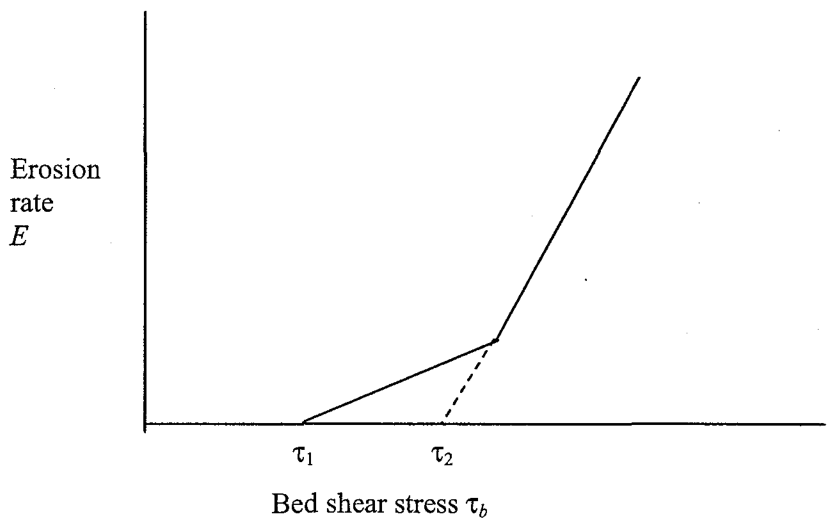
E = erosion rate

M = erosion rate constant

τ_b = bed shear stress

τ_e = critical shear stress for erosion.

The erosion rate constant M is the proportionality constant in the erosion rate equation. Typical results of laboratory tests are shown in the following figure.



In this figure,

τ_1 and τ_2 show the two values of critical shear stress.

M_1 and M_2 represent the two values of Erosion Rate Constant associated with τ_1 and τ_2.

Table 11 gives the results of laboratory tests giving values of M1, τ_2 and M2 for the samples tested.

Table 12
Values Assigned to Bed Parameters

Erodibility Label	Bulk Density kg/m^3	Critical Shear Stress τ Pa	Erosion Rate Constant M $g/m^2/min$
Soft	1,600	0.021	6.27
Medium	1,900	0.147	2.06
Hard	2,000	0.458	0.53

Table 13
Mean Equilibrium Concentration as a Function of Recreational Boat-Induced Waves at 1- to 60-min Intervals; Hmax = 30 cm

Interval min	Mean Equilibrium Concentration mg/L	Peak Suspension Concentration mg/L
1	565	620
5	230	280
10	160	200
20	110	150
30	95	135
60	75	120

Conditions: (a) Soft Bed, (b) 1 m depth of water, (c) Varying time interval between passing of successive boats (1 min to 60 min), (d) Wave Height = 30 cm

Table 14
Peak Concentration as a Function of a Series of Recreational Boat-Induced Wave Heights at 1-min Intervals

Maximum Wave Height, cm	Peak Suspension Concentration, mg/L
10	0.001
20	340
30	620
40	870
50	1,175

Conditions: (a) Soft Bed, (b) 1 m depth of water, (c) 1 min fixed time interval between passing of successive boats, (d) Varying wave heights, (e) Duration = 6 hr (360 rec boats).

Table 15
Mean Equilibrium Concentration as a Function of Series of Recreational Boat-Induced Varying Wave Heights at 1-min Intervals

Maximum Wave Height, cm	Mean Equilibrium Concentration, mg/L
10	0.001
20	325
30	580
40	800
50	1,060
Conditions: (a) Soft bed, (b) 1 m depth of water, (c) 1 min fixed time interval between passing of successive boats, (d) Varying wave heights, (e) Duration = 6 hr	

Table 16
Comparison of Characteristics of Waves Generated by Towboats and Recreational Boats

Parameter	Towboat	Recreational Boat
Duration of a single event	400 sec or about 7 min	24 sec
Number of waves in one event	200	12
Initial wave height	2 cm	2 cm
Occurrence of maximum wave height	Wave # 25	Wave # 3
Intermediate wave height	Wave # 75	Wave # 6
Ending wave height	2 cm	4 cm
Period of each wave	2 sec	2 sec

Table 17
Peak Concentration as a Function of One Towboat-Induced Wave Height

Maximum Wave Height, cm	Peak Suspension Concentration, mg/L
10	75
15	188
20	454
30	1214
40	2280
50	3000
60	3000
Conditions: (a) Soft bed, (b) 1 m depth of water, (c) Only one towboat (200 waves over 7 min), (d) Varying wave heights, (e) Effect of 0.4 m/s return current is included.	

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Volume 2 of this report containing Appendices A, B, and C is provided on enclosed CD.

14. ABSTRACT

Increased recreational boating traffic in the Upper Mississippi River will have an impact in conjunction with other stresses on the UMRS ecosystem. While the impact will consist of hydraulic, biologic and sediment disturbances, this report focuses on the effect of recreational traffic as related to wake waves and their potential for resuspending nearshore sediments. Field measurements were conducted in Pool 8 of the Upper Mississippi River near La Crosse, WI, to obtain data on wake waves and sediment resuspended in the nearshore zone and the results were used to validate numerical models. Potential maximum wave heights were assigned to vessel class and distance range from the sailing line. A generalized time-history wave response was developed for use in modeling sediment resuspension. Characteristics of field sediment were determined through laboratory tests. A new procedure was developed for sediment classification. A verified numerical model was used for making quantitative predictions of wake-wave-induced suspended sediment concentrations in the nearshore zone. Data on nearshore sediment characteristics were used as input to the model. Effect of wave height, wave period, vessel frequency, water depth, type of vessel, characteristics of vessel, and sediment properties were evaluated. Comparisons were made between effects of commercial tows versus recreational boats.

15. SUBJECT TERMS

Bank erosion	Inland navigation	Upper Mississippi River
Environmental impact	Recreational boating	Vessel-generated waves
	Sediment resuspension	Wave-induced erosion

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Upper Mississippi River
Waves Generated by Recreational Vessels (November 1995 Data)
Log of Electronic Data Files in Appendix A

File Name	Figure Name	Final Fig. #	Test #	Boat Type	Sailing Line	Direction	Loading	Wave Gage	Water Depth (ft)	Beginning Time	Date
Jetski_WG1.xls	Sheet 1	1	1	Jetski	S1	Downstream	Lightly	1	3	9:43:09	11/6/1995
Jetski_WG1.xls	Sheet 2	2	2		S1	Upstream	Lightly	1	3	9:45:13	11/6/1995
Jetski_WG1.xls	Sheet 3	3	3		S1	Downstream	Lightly	1	3	9:48:16	11/6/1995
Jetski_WG1.xls	Sheet 4	4	4		S1	Upstream	Lightly	1	3	9:49:47	11/6/1995
Jetski_WG1.xls	Sheet 5	5	5		S1	Downstream	Lightly	1	3	9:51:30	11/6/1995
Jetski_WG1.xls	Sheet 6	6	6		S1	Upstream	Lightly	1	3	9:52:56	11/6/1995
Jetski_WG1.xls	Sheet 7	7	7		S1	Downstream	Lightly	1	3	9:54:06	11/6/1995
Jetski_WG1.xls	Sheet 8	8	8		S1	Upstream	Lightly	1	3	9:55:07	11/6/1995
Jetski_WG1.xls	Sheet 9	9	9		S1	Downstream	Lightly	1	3	9:56:03	11/6/1995
Jetski_WG1.xls	Sheet 10	10	12		S2	Upstream	Lightly	1	3	10:01:45	11/6/1995
Jetski_WG1.xls	Sheet 11	11	13		S2	Downstream	Lightly	1	3	10:04:08	11/6/1995
Jetski_WG1.xls	Sheet 12	12	14		S2	Upstream	Lightly	1	3	10:05:43	11/6/1995
Jetski_WG1.xls	Sheet 13	13	15		S2	Downstream	Lightly	1	3	10:07:37	11/6/1995
Jetski_WG1.xls	Sheet 14	14	16		S2	Upstream	Lightly	1	3	10:09:00	11/6/1995
Jetski_WG1.xls	Sheet 15	15	17		S2	Downstream	Lightly	1	3	10:10:16	11/6/1995
Jetski_WG1.xls	Sheet 16	16	18		S2	Upstream	Lightly	1	3	10:11:24	11/6/1995
Jetski_WG1.xls	Sheet 17	17	19		S2	Downstream	Lightly	1	3	10:12:38	11/6/1995
Jetski_WG1.xls	Sheet 18	18	20		S2	Upstream	Lightly	1	3	10:13:39	11/6/1995
Jetski_WG2.xls	Sheet 19	19	1	Jetski	S1	Downstream	Lightly	2	8	9:43:09	11/6/1995
Jetski_WG2.xls	Sheet 20	20	2		S1	Upstream	Lightly	2	8	9:45:13	11/6/1995
Jetski_WG2.xls	Sheet 21	21	3		S1	Downstream	Lightly	2	8	9:48:16	11/6/1995
Jetski_WG2.xls	Sheet 22	22	4		S1	Upstream	Lightly	2	8	9:49:47	11/6/1995
Jetski_WG2.xls	Sheet 23	23	5		S1	Downstream	Lightly	2	8	9:51:30	11/6/1995
Jetski_WG2.xls	Sheet 24	24	6		S1	Upstream	Lightly	2	8	9:52:56	11/6/1995
Jetski_WG2.xls	Sheet 25	25	7		S1	Downstream	Lightly	2	8	9:54:06	11/6/1995
Jetski_WG2.xls	Sheet 26	26	8		S1	Upstream	Lightly	2	8	9:55:07	11/6/1995
Jetski_WG2.xls	Sheet 27	27	9		S1	Downstream	Lightly	2	8	9:56:03	11/6/1995
Jetski_WG3.xls	Sheet 28	28	12	Jetski	S2	Upstream	Lightly	3	11	10:01:45	11/6/1995
Jetski_WG3.xls	Sheet 29	29	13		S2	Downstream	Lightly	3	11	10:04:08	11/6/1995

Jetski_WG3.xls	Sheet 30	30	14		S2	Upstream	Lightly	3	11	10:05:43	11/6/1995
Jetski_WG3.xls	Sheet 31	31	15		S2	Downstream	Lightly	3	11	10:07:37	11/6/1995
Jetski_WG3.xls	Sheet 32	32	16		S2	Upstream	Lightly	3	11	10:09:00	11/6/1995
Jetski_WG3.xls	Sheet 33	33	17		S2	Downstream	Lightly	3	11	10:10:16	11/6/1995
Jetski_WG3.xls	Sheet 34	34	18		S2	Upstream	Lightly	3	11	10:11:24	11/6/1995
Jetski_WG3.xls	Sheet 35	35	19		S2	Downstream	Lightly	3	11	10:12:38	11/6/1995
Jetski_WG3.xls	Sheet 36	36	20		S2	Upstream	Lightly	3	11	10:13:39	11/6/1995
Starcraft_WG1.xls	Sheet 37	37	1	Starcraft	S1	Downstream	Fully	1	3	15:34:26	11/3/1995
Starcraft_WG1.xls	Sheet 38	38	2		S1	Upstream	Fully	1	3	15:40:00	11/3/1995
Starcraft_WG1.xls	Sheet 39	39	3		S1	Downstream	Fully	1	3	15:42:38	11/3/1995
Starcraft_WG1.xls	Sheet 40	40	4		S1	Upstream	Fully	1	3	15:47:00	11/3/1995
Starcraft_WG1.xls	Sheet 41	41	5		S1	Downstream	Fully	1	3	16:03:15	11/3/1995
Starcraft_WG1.xls	Sheet 42	42	6		S1	Upstream	Fully	1	3	16:05:55	11/3/1995
Starcraft_WG1.xls	Sheet 43	43	7		S2	Downstream	Fully	1	3	16:09:18	11/3/1995
Starcraft_WG1.xls	Sheet 44	44	8		S2	Upstream	Fully	1	3	16:14:55	11/3/1995
Starcraft_WG1.xls	Sheet 45	45	9		S2	Downstream	Fully	1	3	16:20:00	11/3/1995
Starcraft_WG1.xls	Sheet 46	46	10		S2	Upstream	Fully	1	3	16:22:15	11/3/1995
Starcraft_WG1.xls	Sheet 47	47	11		S2	Downstream	Fully	1	3	16:26:50	11/3/1995
Starcraft_WG1.xls	Sheet 48	48	12		S2	Upstream	Fully	1	3	16:30:06	11/3/1995
Starcraft_WG1.xls	Sheet 49	49	14		S1	Upstream	Lightly	1	3	16:41:30	11/3/1995
Starcraft_WG1.xls	Sheet 50	50	15		S1	Downstream	Lightly	1	3	16:44:10	11/3/1995
Starcraft_WG1.xls	Sheet 51	51	16		S1	Upstream	Lightly	1	3	16:45:30	11/3/1995
Starcraft_WG1.xls	Sheet 52	52	17		S1	Downstream	Lightly	1	3	16:47:13	11/3/1995
Starcraft_WG1.xls	Sheet 53	53	18		S1	Upstream	Lightly	1	3	16:50:40	11/3/1995
Starcraft_WG1.xls	Sheet 54	54	20		S2	Downstream	Lightly	1	3	8:41:34	11/4/1995
Starcraft_WG1.xls	Sheet 55	55	21		S2	Upstream	Lightly	1	3	8:50:25	11/4/1995
Starcraft_WG1.xls	Sheet 56	56	22		S2	Downstream	Lightly	1	3	8:53:25	11/4/1995
Starcraft_WG1.xls	Sheet 57	57	24		S2	Downstream	Lightly	1	3	9:00:00	11/4/1995
Starcraft_WG1.xls	Sheet 58	58	24		S2	Upstream	Lightly	1	3	9:03:09	11/4/1995
Starcraft_WG1.xls	Sheet 59	59	25		S2	Upstream	Lightly	1	3	9:03:09	11/4/1995
Starcraft_WG2.xls	Sheet 60	60	1	Starcraft	S1	Downstream	Fully	2	8	15:34:26	11/3/1995
Starcraft_WG2.xls	Sheet 61	61	3		S1	Downstream	Fully	2	8	15:42:38	11/3/1995
Starcraft_WG2.xls	Sheet 62	62	4		S1	Upstream	Fully	2	8	15:47:00	11/3/1995
Starcraft_WG2.xls	Sheet 63	63	5		S1	Downstream	Fully	2	8	16:03:15	11/3/1995
Starcraft_WG2.xls	Sheet 64	64	6		S1	Upstream	Fully	2	8	16:05:35	11/3/1995

Starcraft_WG2.xls	Sheet 65	65	7		S2	Downstream	Fully	2	8	16:09:00	11/3/1995
Starcraft_WG2.xls	Sheet 66	66	8		S2	Upstream	Fully	2	8	16:14:00	11/3/1995
Starcraft_WG2.xls	Sheet 67	67	10		S2	Upstream	Fully	2	8	16:22:15	11/3/1995
Starcraft_WG2.xls	Sheet 68	68	11		S2	Downstream	Fully	2	8	16:26:00	11/3/1995
Starcraft_WG2.xls	Sheet 69	69	12		S2	Upstream	Fully	2	8	16:30:00	11/3/1995
Starcraft_WG2.xls	Sheet 70	70	14		S1	Upstream	Lightly	2	8	16:41:30	11/3/1995
Starcraft_WG2.xls	Sheet 71	71	15		S1	Downstream	Lightly	2	8	16:44:00	11/3/1995
Starcraft_WG2.xls	Sheet 72	72	16		S1	Upstream	Lightly	2	8	16:45:30	11/3/1995
Starcraft_WG2.xls	Sheet 73	73	17		S1	Downstream	Lightly	2	8	16:47:00	11/3/1995
Starcraft_WG2.xls	Sheet 74	74	18		S1	Upstream	Lightly	2	8	16:50:00	11/3/1995
Starcraft_WG2.xls	Sheet 75	75	20		S2	Upstream	Lightly	2	8	8:41:00	11/4/1995
Starcraft_WG2.xls	Sheet 76	76	21		*	Downstream	Lightly	2	8	8:50:00	11/4/1995
Starcraft_WG2.xls	Sheet 77	77	22		S2	Downstream	Lightly	2	8	8:53:24	11/4/1995
Starcraft_WG2.xls	Sheet 78	78	24		S2	Downstream	Lightly	2	8	9:00:00	11/4/1995
NA	NA	79	25		S2	Upstream	Lightly	2	8	9:03:09	11/4/1995
					*	Center of channel					
Starcraft_WG3.xls	Sheet 80	80	1	Starcraft	S1	Downstream	Fully	3	11	15:34:26	11/3/1995
Starcraft_WG3.xls	Sheet 81	81	3		S1	Downstream	Fully	3	11	15:42:38	11/3/1995
Starcraft_WG3.xls	Sheet 82	82	4		S1	Upstream	Fully	3	11	15:47:00	11/3/1995
Starcraft_WG3.xls	Sheet 83	83	5		S1	Downstream	Fully	3	11	16:03:15	11/3/1995
Starcraft_WG3.xls	Sheet 84	84	6		S1	Upstream	Fully	3	11	16:05:35	11/3/1995
Starcraft_WG3.xls	Sheet 85	85	7		S2	Downstream	Fully	3	11	16:09:18	11/3/1995
Starcraft_WG3.xls	Sheet 86	86	8		S2	Upstream	Fully	3	11	16:14:55	11/3/1995
Starcraft_WG3.xls	Sheet 87	87	10		S2	Upstream	Fully	3	11	16:22:15	11/3/1995
Starcraft_WG3.xls	Sheet 88	88	11		S2	Downstream	Fully	3	11	16:26:50	11/3/1995
Starcraft_WG3.xls	Sheet 89	89	12		S2	Upstream	Fully	3	11	16:30:06	11/3/1995
Starcraft_WG3.xls	Sheet 90	90	14		S2	Upstream	Lightly	3	11	16:41:12	11/3/1995
Starcraft_WG3.xls	Sheet 91	91	15		S1	Downstream	Lightly	3	11	16:44:10	11/3/1995
Starcraft_WG3.xls	Sheet 92	92	16		S1	Upstream	Lightly	3	11	16:45:30	11/3/1995
Starcraft_WG3.xls	Sheet 93	93	17		S1	Downstream	Lightly	3	11	16:47:13	11/3/1995
Starcraft_WG3.xls	Sheet 94	94	18		S1	Upstream	Lightly	3	11	16:50:40	11/3/1995
Starcraft_WG3.xls	Sheet 95	95	20		S2	Upstream	Lightly	3	11	8:41:34	11/4/1995
Starcraft_WG3.xls	Sheet 96	96	21		S2	Downstream	Lightly	3	11	8:50:25	11/4/1995
Starcraft_WG3.xls	Sheet 97	97	22		S2	Downstream	Lightly	3	11	8:53:25	11/4/1995
Starcraft_WG3.xls	Sheet 98	98	24		S2	Downstream	Lightly	3	11	9:00:00	11/4/1995
Starcraft_WG3.xls	Sheet 99	99	25		S2	Upstream	Lightly	3	11	9:03:00	11/4/1995

Crestliner_WG1.xls	Sheet 100	100	4	Crestliner	S1	Upstream	Fully	1	3	13:21:30	11/5/1995
Crestliner_WG1.xls	Sheet 101	101	5		S1	Downstream	Fully	1	3	13:23:57	11/5/1995
Crestliner_WG1.xls	Sheet 102	102	6		S1	Upstream	Fully	1	3	13:25:44	11/5/1995
Crestliner_WG1.xls	Sheet 103	103	7		S1	Downstream	Fully	1	3	13:28:10	11/5/1995
Crestliner_WG1.xls	Sheet 104	104	8		S1	Upstream	Fully	1	3	13:29:47	11/5/1995
Crestliner_WG1.xls	Sheet 105	105	9		S1	Downstream	Fully	1	3	13:31:49	11/5/1995
Crestliner_WG1.xls	Sheet 106	106	10		S1	Upstream	Fully	1	3	13:33:30	11/5/1995
Crestliner_WG1.xls	Sheet 107	107	11		S2	Downstream	Fully	1	3	13:36:04	11/5/1995
Crestliner_WG1.xls	Sheet 108	108	13		S2	Downstream	Fully	1	3	13:40:30	11/5/1995
Crestliner_WG1.xls	Sheet 109	109	14		S2	Upstream	Fully	1	3	13:41:55	11/5/1995
Crestliner_WG1.xls	Sheet 110	110	15		S2	Downstream	Fully	1	3	13:44:12	11/5/1995
Crestliner_WG1.xls	Sheet 111	111	16		S2	Upstream	Fully	1	3	13:45:43	11/5/1995
Crestliner_WG1.xls	Sheet 112	112	17		S2	Downstream	Fully	1	3	13:47:20	11/5/1995
Crestliner_WG1.xls	Sheet 113	113	18		S2	Upstream	Fully	1	3	13:48:54	11/5/1995
Crestliner_WG1.xls	Sheet 114	114	19		S1	Downstream	Lightly	1	3	14:00:43	11/5/1995
Crestliner_WG1.xls	Sheet 115	115	20		S1	Upstream	Lightly	1	3	14:04:09	11/5/1995
Crestliner_WG1.xls	Sheet 116	116	21		S1	Downstream	Lightly	1	3	14:06:51	11/5/1995
Crestliner_WG1.xls	Sheet 117	117	22		S1	Upstream	Lightly	1	3	14:08:43	11/5/1995
Crestliner_WG1.xls	Sheet 118	118	23		S1	Downstream	Lightly	1	3	14:10:15	11/5/1995
Crestliner_WG1.xls	Sheet 119	119	24		S1	Upstream	Lightly	1	3	14:11:30	11/5/1995
Crestliner_WG1.xls	Sheet 120	120	25		S1	Downstream	Lightly	1	3	14:15:09	11/5/1995
Crestliner_WG1.xls	Sheet 121	121	28		S2	Upstream	Lightly	1	3	14:20:53	11/5/1995
Crestliner_WG1.xls	Sheet 122	122	29		S2	Downstream	Lightly	1	3	14:22:53	11/5/1995
Crestliner_WG1.xls	Sheet 123	123	30		S2	Upstream	Lightly	1	3	14:24:27	11/5/1995
Crestliner_WG1.xls	Sheet 124	124	31		S2	Downstream	Lightly	1	3	14:26:03	11/5/1995
Crestliner_WG1.xls	Sheet 125	125	32		S2	Upstream	Lightly	1	3	14:27:38	11/5/1995
Crestliner_WG1.xls	Sheet 126	126	33		S2	Downstream	Lightly	1	3	14:29:03	11/5/1995
Crestliner_WG1.xls	Sheet 127	127	34		S2	Upstream	Lightly	1	3	14:30:32	11/5/1995
Crestliner_WG2.xls	Sheet 128	128	4	Crestliner	S1	Upstream	Fully	2	8	13:21:00	11/5/1995
Crestliner_WG2.xls	Sheet 129	129	5		S1	Downstream	Fully	2	8	13:23:57	11/5/1995
Crestliner_WG2.xls	Sheet 130	130	6		S1	Upstream	Fully	2	8	13:25:44	11/5/1995
Crestliner_WG2.xls	Sheet 131	131	7		S1	Downstream	Fully	2	8	13:28:10	11/5/1995
Crestliner_WG2.xls	Sheet 132	132	8		S1	Upstream	Fully	2	8	13:29:47	11/5/1995
Crestliner_WG2.xls	Sheet 133	133	9		S1	Downstream	Fully	2	8	13:31:49	11/5/1995
Crestliner_WG2.xls	Sheet 134	134	10		S1	Upstream	Fully	2	8	13:33:30	11/5/1995

Crestliner_WG2.xls	Sheet 135	135	11		S2	Downstream	Fully	2	8	13:36:00	11/5/1995
Crestliner_WG2.xls	Sheet 136	136	13		S2	Downstream	Fully	2	8	13:40:00	11/5/1995
Crestliner_WG2.xls	Sheet 137	137	14		S2	Upstream	Fully	2	8	13:41:00	11/5/1995
Crestliner_WG2.xls	Sheet 138	138	15		S2	Downstream	Fully	2	8	13:44:00	11/5/1995
Crestliner_WG2.xls	Sheet 139	139	16		S2	Upstream	Fully	2	8	13:45:43	11/5/1995
Crestliner_WG2.xls	Sheet 140	140	17		S2	Downstream	Fully	2	8	13:47:07	11/5/1995
Crestliner_WG2.xls	Sheet 141	141	18		S1	Upstream	Fully	2	8	13:48:54	11/5/1995
Crestliner_WG2.xls	Sheet 142	142	19		S1	Downstream	Lightly	2	8	14:00:00	11/5/1995
Crestliner_WG2.xls	Sheet 143	143	20		S1	Upstream	Lightly	2	8	14:04:00	11/5/1995
Crestliner_WG2.xls	Sheet 144	144	21		S1	Downstream	Lightly	2	8	14:06:00	11/5/1995
Crestliner_WG2.xls	Sheet 145	145	22		S1	Upstream	Lightly	2	8	14:08:00	11/5/1995
Crestliner_WG2.xls	Sheet 146	146	23		S1	Downstream	Lightly	2	8	14:10:00	11/5/1995
Crestliner_WG2.xls	Sheet 147	147	24		S1	Upstream	Lightly	2	8	14:11:00	11/5/1995
Crestliner_WG2.xls	Sheet 148	148	25		S1	Downstream	Lightly	2	8	14:15:00	11/5/1995
Crestliner_WG2.xls	Sheet 149	149	26		S1	Upstream	Lightly	2	8	14:17:00	11/5/1995
Crestliner_WG2.xls	Sheet 150	150	28		S2	Upstream	Lightly	2	8	14:20:00	11/5/1995
Crestliner_WG2.xls	Sheet 151	151	29		S2	Downstream	Lightly	2	8	14:22:53	11/5/1995
Crestliner_WG2.xls	Sheet 152	152	30		S2	Upstream	Lightly	2	8	14:24:27	11/5/1995
Crestliner_WG2.xls	Sheet 153	153	31		S2	Downstream	Lightly	2	8	14:26:00	11/5/1995
Crestliner_WG2.xls	Sheet 154	154	32		S2	Upstream	Lightly	2	8	14:27:38	11/5/1995
Crestliner_WG2.xls	Sheet 155	155	33		S2	Downstream	Lightly	2	8	14:29:00	11/5/1995
Crestliner_WG2.xls	Sheet 156	156	34		S2	Upstream	Lightly	2	8	14:30:32	11/5/1995
Crestliner_WG3.xls	Sheet 157	157	4	Crestliner	S1	Upstream	Fully	3	11	13:21:30	11/5/1995
Crestliner_WG3.xls	Sheet 158	158	5		S1	Downstream	Fully	3	11	13:23:57	11/5/1995
Crestliner_WG3.xls	Sheet 159	159	6		S1	Upstream	Fully	3	11	13:25:44	11/5/1995
Crestliner_WG3.xls	Sheet 160	160	7		S1	Downstream	Fully	3	11	13:28:10	11/5/1995
Crestliner_WG3.xls	Sheet 161	161	8		S1	Upstream	Fully	3	11	13:29:47	11/5/1995
Crestliner_WG3.xls	Sheet 162	162	9		S1	Downstream	Fully	3	11	13:31:49	11/5/1995
Crestliner_WG3.xls	Sheet 163	163	10		S1	Upstream	Fully	3	11	13:33:30	11/5/1995
Crestliner_WG3.xls	Sheet 164	164	11		S2	Downstream	Fully	3	11	13:36:00	11/5/1995
Crestliner_WG3.xls	Sheet 165	165	13		S2	Downstream	Fully	3	11	13:40:30	11/5/1995
Crestliner_WG3.xls	Sheet 166	166	14		S2	Upstream	Fully	3	11	13:41:55	11/5/1995
Crestliner_WG3.xls	Sheet 167	167	15		S2	Downstream	Fully	3	11	13:44:12	11/5/1995
Crestliner_WG3.xls	Sheet 168	168	16		S2	Upstream	Fully	3	11	13:45:43	11/5/1995
Crestliner_WG3.xls	Sheet 169	169	17		S2	Downstream	Fully	3	11	13:47:20	11/5/1995
Crestliner_WG3.xls	Sheet 170	170	18		S2	Upstream	Fully	3	11	13:48:54	11/5/1995

Crestliner_WG3.xls	Sheet 171	171	19		S2	Downstream	Lightly	3	11	14:00:43	11/5/1995
Crestliner_WG3.xls	Sheet 172	172	20		S1	Upstream	Lightly	3	11	14:04:00	11/5/1995
Crestliner_WG3.xls	Sheet 173	173	21		S1	Downstream	Lightly	3	11	14:06:51	11/5/1995
Crestliner_WG3.xls	Sheet 174	174	22		S1	Upstream	Lightly	3	11	14:08:43	11/5/1995
Crestliner_WG3.xls	Sheet 175	175	23		S1	Downstream	Lightly	3	11	14:10:00	11/5/1995
Crestliner_WG3.xls	Sheet 176	176	24		S1	Upstream	Lightly	3	11	14:11:30	11/5/1995
Crestliner_WG3.xls	Sheet 177	177	25		S1	Downstream	Lightly	3	11	14:15:00	11/5/1995
Crestliner_WG3.xls	Sheet 178	178	26		S1	Upstream	Lightly	3	11	14:17:00	11/5/1995
Crestliner_WG3.xls	Sheet 179	179	28		S1	Upstream	Lightly	3	11	14:20:53	11/5/1995
Crestliner_WG3.xls	Sheet 180	180	29		S2	Downstream	Lightly	3	11	14:22:53	11/5/1995
Crestliner_WG3.xls	Sheet 181	181	30		S2	Upstream	Lightly	3	11	14:24:27	11/5/1995
Crestliner_WG3.xls	Sheet 182	182	31		S2	Downstream	Lightly	3	11	14:26:00	11/5/1995
Crestliner_WG3.xls	Sheet 183	183	32		S2	Upstream	Lightly	3	11	14:27:38	11/5/1995
Crestliner_WG3.xls	Sheet 184	184	33		S2	Downstream	Lightly	3	11	14:29:00	11/5/1995
Crestliner_WG3.xls	Sheet 185	185	34		S2	Upstream	Lightly	3	11	14:30:32	11/5/1995
FourWinns_WG1.xls	Sheet 186	186	1	Four Winns	S1	Downstream	Fully	1	3	12:05:27	11/4/1995
FourWinns_WG1.xls	Sheet 187	187	2		S1	Upstream	Fully	1	3	12:11:11	11/4/1995
FourWinns_WG1.xls	Sheet 188	188	4		S1	Upstream	Fully	1	3	12:22:22	11/4/1995
FourWinns_WG1.xls	Sheet 189	189	5		S1	Downstream	Fully	1	3	12:28:05	11/4/1995
FourWinns_WG1.xls	Sheet 190	190	6		S1	Upstream	Fully	1	3	12:32:04	11/4/1995
FourWinns_WG1.xls	Sheet 191	191	7		S1	Downstream	Fully	1	3	12:45:54	11/4/1995
FourWinns_WG1.xls	Sheet 192	192	8		S1	Upstream	Fully	1	3	12:50:42	11/4/1995
FourWinns_WG1.xls	Sheet 193	193	9		S1	Downstream	Fully	1	3	12:55:06	11/4/1995
FourWinns_WG1.xls	Sheet 194	194	10		S1	Upstream	Fully	1	3	13:02:17	11/4/1995
FourWinns_WG1.xls	Sheet 195	195	11		S2	Downstream	Fully	1	3	13:06:05	11/4/1995
FourWinns_WG1.xls	Sheet 196	196	12		S2	Upstream	Fully	1	3	13:11:57	11/4/1995
FourWinns_WG1.xls	Sheet 197	197	14		S2	Upstream	Fully	1	3	13:21:58	11/4/1995
FourWinns_WG1.xls	Sheet 198	198	15		S2	Downstream	Fully	1	3	13:26:00	11/4/1995
FourWinns_WG1.xls	Sheet 199	199	16		S2	Upstream	Fully	1	3	13:31:48	11/4/1995
FourWinns_WG1.xls	Sheet 200	200	17		S2	Downstream	Fully	1	3	13:35:05	11/4/1995
FourWinns_WG1.xls	Sheet 201	201	19		S1	Downstream	Lightly	1	3	13:41:28	11/4/1995
FourWinns_WG1.xls	Sheet 202	202	20		S1	Upstream	Lightly	1	3	14:44:09	11/4/1995
FourWinns_WG1.xls	Sheet 203	203	21		S1	Downstream	Lightly	1	3	14:46:54	11/4/1995
FourWinns_WG1.xls	Sheet 204	204	22		S1	Upstream	Lightly	1	3	14:49:37	11/4/1995
FourWinns_WG1.xls	Sheet 205	205	23		S1	Downstream	Lightly	1	3	14:51:49	11/4/1995
FourWinns_WG1.xls	Sheet 206	206	24		S1	Upstream	Lightly	1	3	14:56:19	11/4/1995

FourWinns_WG1.xls	Sheet 207	207	26		S1	Upstream	Lightly	1	3	15:00:54	11/4/1995
FourWinns_WG1.xls	Sheet 208	208	27		S2	Downstream	Lightly	1	3	15:03:22	11/4/1995
FourWinns_WG1.xls	Sheet 209	209	28		S2	Upstream	Lightly	1	3	15:05:49	11/4/1995
FourWinns_WG1.xls	Sheet 210	210	29		S2	Downstream	Lightly	1	3	15:08:50	11/4/1995
FourWinns_WG1.xls	Sheet 211	211	30		S2	Upstream	Lightly	1	3	15:12:24	11/4/1995
FourWinns_WG1.xls	Sheet 212	212	31		S2	Downstream	Lightly	1	3	15:15:27	11/4/1995
FourWinns_WG1.xls	Sheet 213	213	33		S2	Downstream	Lightly	1	3	15:21:45	11/4/1995
FourWinns_WG1.xls	Sheet 214	214	34		S2	Upstream	Lightly	1	3	15:24:22	11/4/1995
FourWinns_WG2.xls	Sheet 215	215	1	Four Winns	S1	Downstream	Fully	2	8	12:05:25	11/4/1995
FourWinns_WG2.xls	Sheet 216	216	2		S1	Upstream	Fully	2	8	12:11:00	11/4/1995
FourWinns_WG2.xls	Sheet 217	217	3		S1	Downstream	Fully	2	8	12:17:00	11/4/1995
FourWinns_WG2.xls	Sheet 218	218	4		S1	Upstream	Fully	2	8	12:22:00	11/4/1995
FourWinns_WG2.xls	Sheet 219	219	5		S1	Downstream	Fully	2	8	12:28:00	11/4/1995
FourWinns_WG2.xls	Sheet 220	220	6		S1	Upstream	Fully	2	8	12:32:00	11/4/1995
FourWinns_WG2.xls	Sheet 221	221	7		S1	Downstream	Fully	2	8	12:45:54	11/4/1995
FourWinns_WG2.xls	Sheet 222	222	8		S1	Upstream	Fully	2	8	12:50:42	11/4/1995
FourWinns_WG2.xls	Sheet 223	223	9		S1	Downstream	Fully	2	8	12:55:00	11/4/1995
FourWinns_WG2.xls	Sheet 224	224	10		S1	Upstream	Fully	2	8	13:02:00	11/4/1995
FourWinns_WG2.xls	Sheet 225	225	11		S2	Downstream	Fully	2	8	13:06:00	11/5/1995
FourWinns_WG2.xls	Sheet 226	226	12		S2	Upstream	Fully	2	8	13:11:00	11/4/1995
FourWinns_WG2.xls	Sheet 227	227	13		S2	Downstream	Fully	2	8	13:17:00	11/4/1995
FourWinns_WG2.xls	Sheet 228	228	14		S2	Upstream	Fully	2	8	13:21:00	11/4/1995
FourWinns_WG2.xls	Sheet 229	229	15		S2	Downstream	Fully	2	8	13:26:00	11/4/1995
FourWinns_WG2.xls	Sheet 230	230	16		S2	Upstream	Fully	2	8	13:31:00	11/4/1995
FourWinns_WG2.xls	Sheet 231	231	17		S2	Downstream	Fully	2	8	13:35:00	11/4/1995
FourWinns_WG2.xls	Sheet 232	232	19		S1	Downstream	Lightly	2	8	14:41:00	11/4/1995
FourWinns_WG2.xls	Sheet 233	233	20		S1	Upstream	Lightly	2	8	14:44:00	11/4/1995
FourWinns_WG2.xls	Sheet 234	234	21		S1	Downstream	Lightly	2	8	14:46:00	11/4/1995
FourWinns_WG2.xls	Sheet 235	235	22		S1	Upstream	Lightly	2	8	14:49:37	11/4/1995
FourWinns_WG2.xls	Sheet 236	236	23		S1	Downstream	Lightly	2	8	14:51:49	11/4/1995
FourWinns_WG2.xls	Sheet 237	237	24		S1	Upstream	Lightly	2	8	14:56:19	11/4/1995
FourWinns_WG2.xls	Sheet 238	238	26		S1	Upstream	Lightly	2	8	15:00:00	11/4/1995
FourWinns_WG2.xls	Sheet 239	239	27		S2	Downstream	Lightly	2	8	15:03:00	11/4/1995
FourWinns_WG2.xls	Sheet 240	240	28		S2	Upstream	Lightly	2	8	15:05:00	11/4/1995
FourWinns_WG2.xls	Sheet 241	241	29		S2	Downstream	Lightly	2	8	15:08:00	11/4/1995
FourWinns_WG2.xls	Sheet 242	242	30		S2	Upstream	Lightly	2	8	15:12:00	11/4/1995

FourWinns_WG2.xls	Sheet 243	243	31		S2	Downstream	Lightly	2	8	15:15:27	11/4/1995
FourWinns_WG2.xls	Sheet 244	244	33		S2	Downstream	Lightly	2	8	15:21:45	11/4/1995
FourWinns_WG2.xls	Sheet 245	245	34		S2	Upstream	Lightly	2	8	15:24:22	11/4/1995
FourWinns_WG3.xls	Sheet 246	246	1	Four Winns	S1	Downstream	Fully	3	11	12:05:27	11/4/1995
FourWinns_WG3.xls	Sheet 247	247	2		S1	Upstream	Fully	3	11	12:11:11	11/4/1995
FourWinns_WG3.xls	Sheet 248	248	4		S1	Upstream	Fully	3	11	12:22:22	11/4/1995
FourWinns_WG3.xls	Sheet 249	249	5		S1	Downstream	Fully	3	11	12:28:00	11/4/1995
FourWinns_WG3.xls	Sheet 250	250	6		S1	Upstream	Fully	3	11	12:32:00	11/4/1995
FourWinns_WG3.xls	Sheet 251	251	7		S1	Downstream	Fully	3	11	12:45:54	11/4/1995
FourWinns_WG3.xls	Sheet 252	252	8		S1	Upstream	Fully	3	11	12:50:42	11/4/1995
FourWinns_WG3.xls	Sheet 253	253	9		S1	Downstream	Fully	3	11	12:55:00	11/4/1995
FourWinns_WG3.xls	Sheet 254	254	10		S1	Upstream	Fully	3	11	13:02:17	11/4/1995
FourWinns_WG3.xls	Sheet 255	255	11		S2	Downstream	Fully	3	11	13:06:05	11/4/1995
FourWinns_WG3.xls	Sheet 256	256	12		S2	Upstream	Fully	3	11	13:11:57	11/4/1995
FourWinns_WG3.xls	Sheet 257	257	14		S2	Upstream	Fully	3	11	13:21:28	11/4/1995
FourWinns_WG3.xls	Sheet 258	258	15		S2	Downstream	Fully	3	11	13:26:00	11/4/1995
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FourWinns_WG3.xls	Sheet 260	260	17		S2	Downstream	Fully	3	11	13:35:05	11/4/1995
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FourWinns_WG3.xls	Sheet 262	262	20		S1	Upstream	Lightly	3	11	14:44:00	11/4/1995
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Luhrs_WG1.xls	Sheet 279	279	6		S1	Upstream	Fully	1	3	13:06:50	11/6/1995
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Luhrs_WG1.xls	Sheet 283	283	11		S2	Downstream	Fully	1	3	13:20:31	11/6/1995
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Luhrs_WG1.xls	Sheet 290	290	19		S1	Downstream	Lightly	1	3	14:20:09	11/6/1995
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Luhrs_WG2.xls	Sheet 308	308	7		S1	Downstream	Fully	2	8	13:09:26	11/6/1995
Luhrs_WG2.xls	Sheet 309	309	8		S1	Upstream	Fully	2	8	13:11:52	11/6/1995
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Luhrs_WG3.xls	Sheet 336	336	6		S1	Upstream	Fully	3	11	13:06:50	11/6/1995
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Upper Mississippi River

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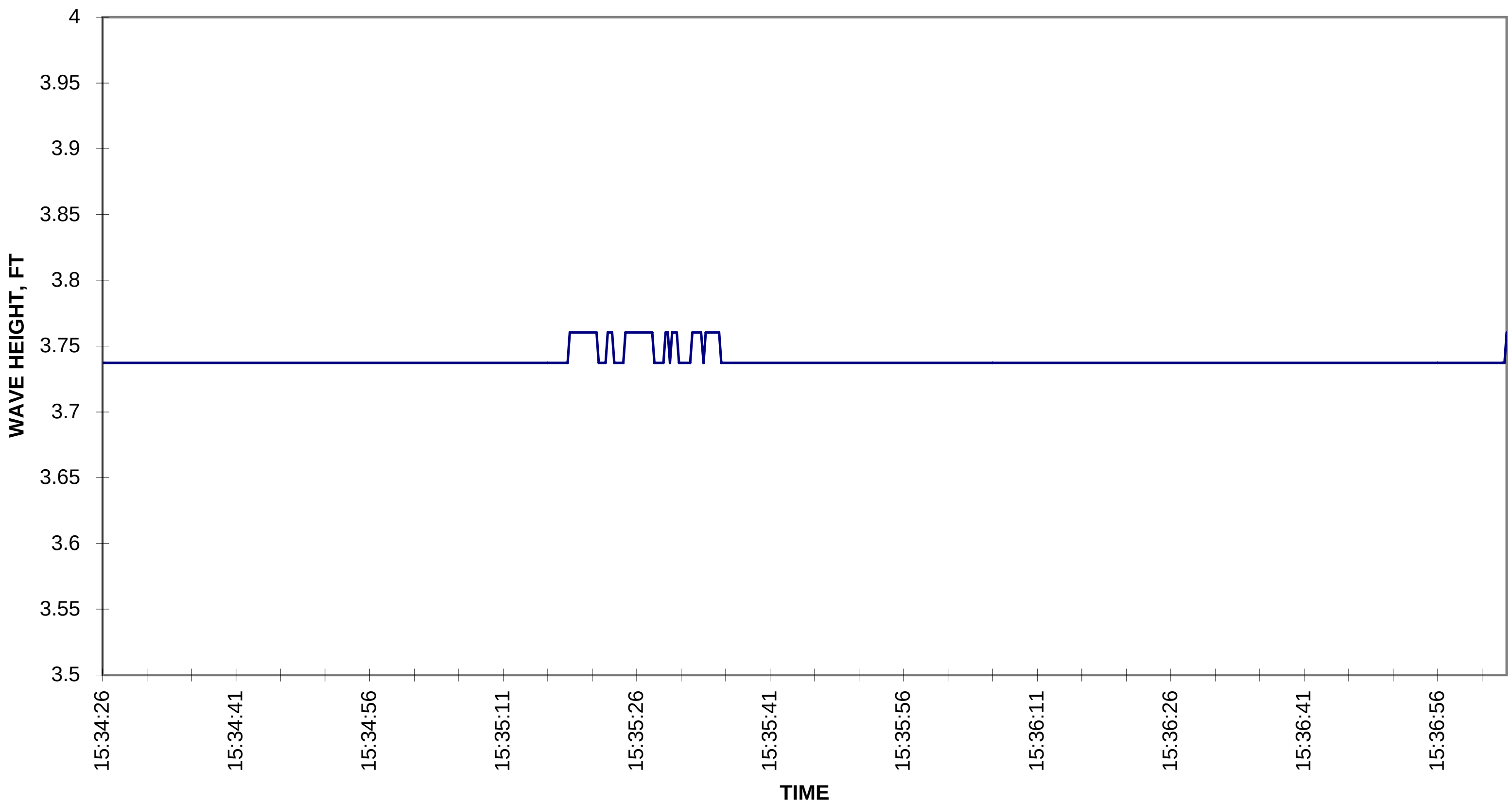
B.27	OBS Data at 3.0 feet, Pool 8 Type 4 Loaded 11/04/95
B.28	OBS Data at 1.0 feet, Pool 8 Type 4 Loaded 11/04/95
B.29	OBS Data at 7.5 feet, Pool 8 Type 4 Empty 11/04/95
B.30	OBS Data at 6.5 feet, Pool 8 Type 4 Empty 11/04/95
B.31	OBS Data at 3.0 feet, Pool 8 Type 4 Empty 11/04/95
B.32	OBS Data at 1.0 feet, Pool 8 Type 4 Empty 11/04/95
B.33	OBS Data at 7.5 feet, Pool 8 Type 5 Loaded 11/06/95
B.34	OBS Data at 6.5 feet, Pool 8 Type 5 Loaded 11/06/95
B.35	OBS Data at 3.0 feet, Pool 8 Type 5 Loaded 11/06/95
B.36	OBS Data at 1.0 feet, Pool 8 Type 5 Loaded 11/06/95
B.37	OBS Data at 7.5 feet, Pool 8 Type 5 Empty 11/06/95
B.38	OBS Data at 6.5 feet, Pool 8 Type 5 Empty 11/06/95
B.39	OBS Data at 3.0 feet, Pool 8 Type 5 Empty 11/06/95
B.40	OBS Data at 1.0 feet, Pool 8 Type 5 Empty 11/06/95
B.41	OBS Data at 7.5 feet, Pool 8 Type 6 Empty 11/06/95
B.42	OBS Data at 6.5 feet, Pool 8 Type 6 Empty 11/06/95
B.43	OBS Data at 3.0 feet, Pool 8 Type 6 Empty 11/06/95
B.44	OBS Data at 1.0 feet, Pool 8 Type 5 Empty 11/06/95
B.45	OBS Data at 7.5 feet, Pool 8 Type 6 Loaded 11/06/95
B.46	OBS Data at 6.5 feet, Pool 8 Type 6 Loaded 11/06/95
B.47	OBS Data at 3.0 feet, Pool 8 Type 6 Loaded 11/06/95
B.48	OBS Data at 1.0 feet, Pool 8 Type 6 Loaded 11/06/95

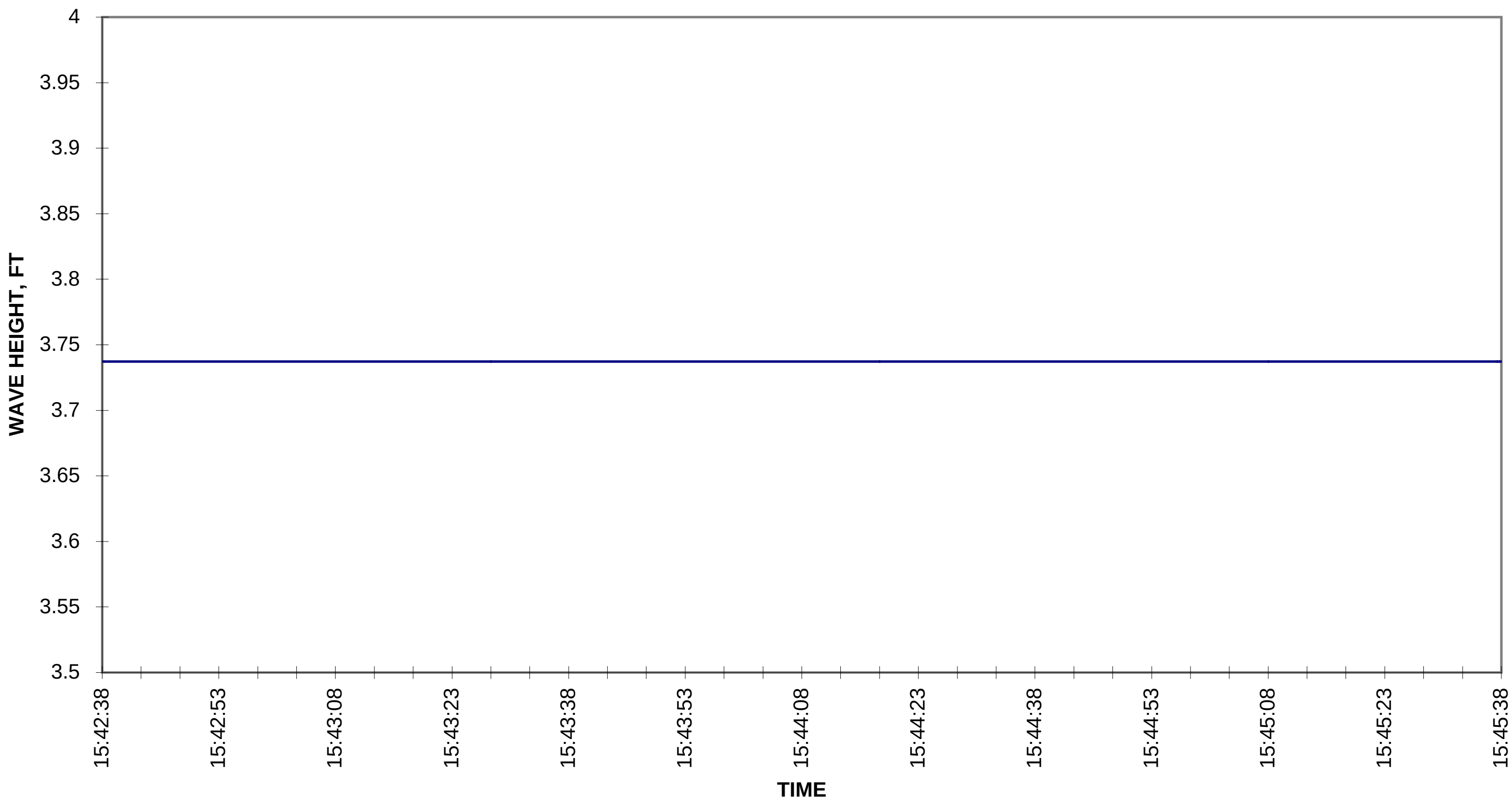
Upper Mississippi River

Log of Electronic Files in Appendix C

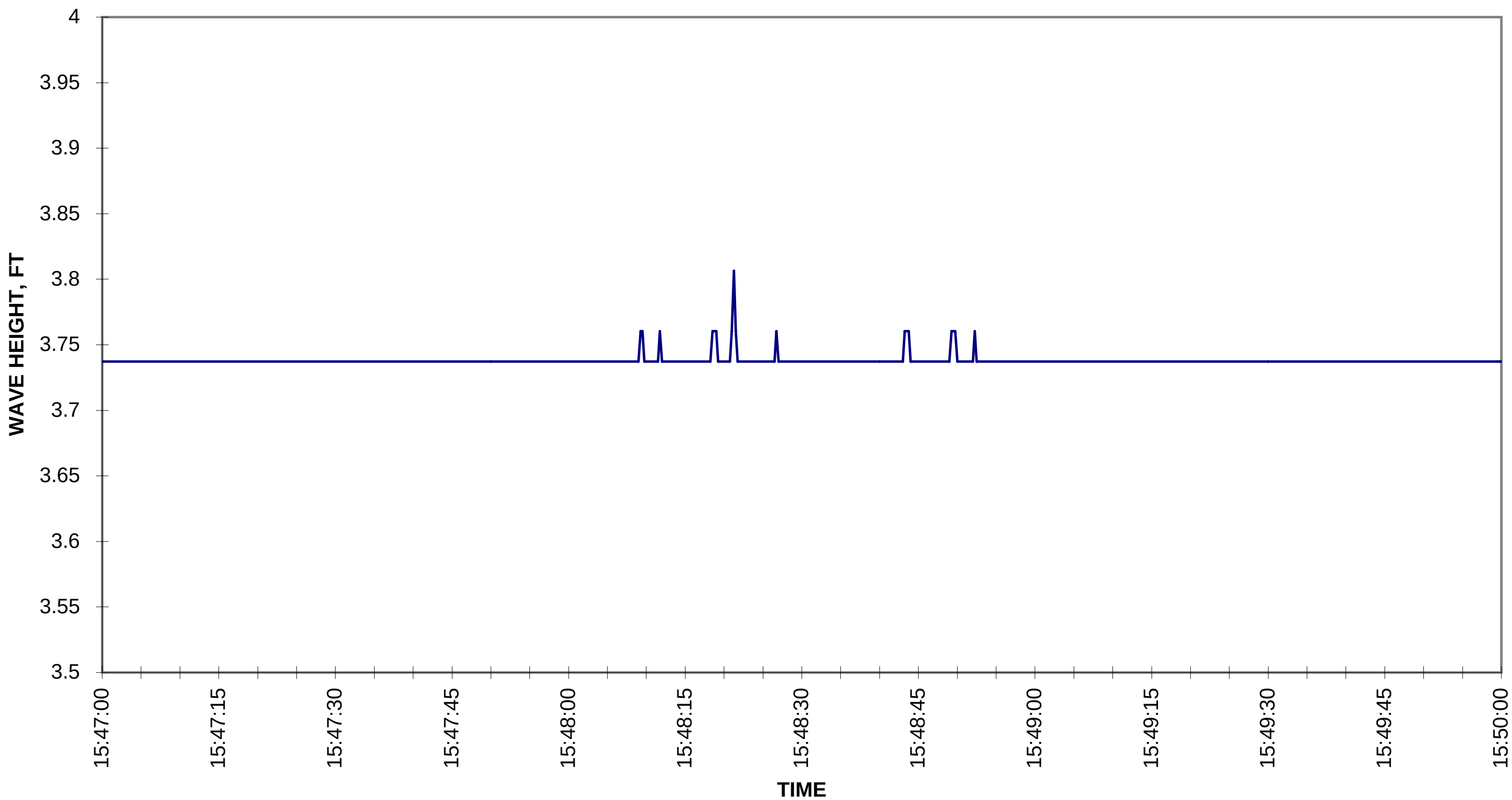
Sheet #	Contents
1	Title: Appendix C
2	Bed Material Characteristics
3	Bed Material Characteristics
4	Bed Material Characteristics
5	Sediment Analysis Pool 8 All Data
6	Bed Sediment Analysis Pool 8 #'s 1-20
7	Bed Sediment Analysis Pool 8 #'s 21-40
8	Bed Sediment Analysis Pool 8 #'s 41-60
9	Bed Sediment Analysis Pool 8 #'s 61-80
10	Bed Sediment Analysis Pool 8 #'s 81-100



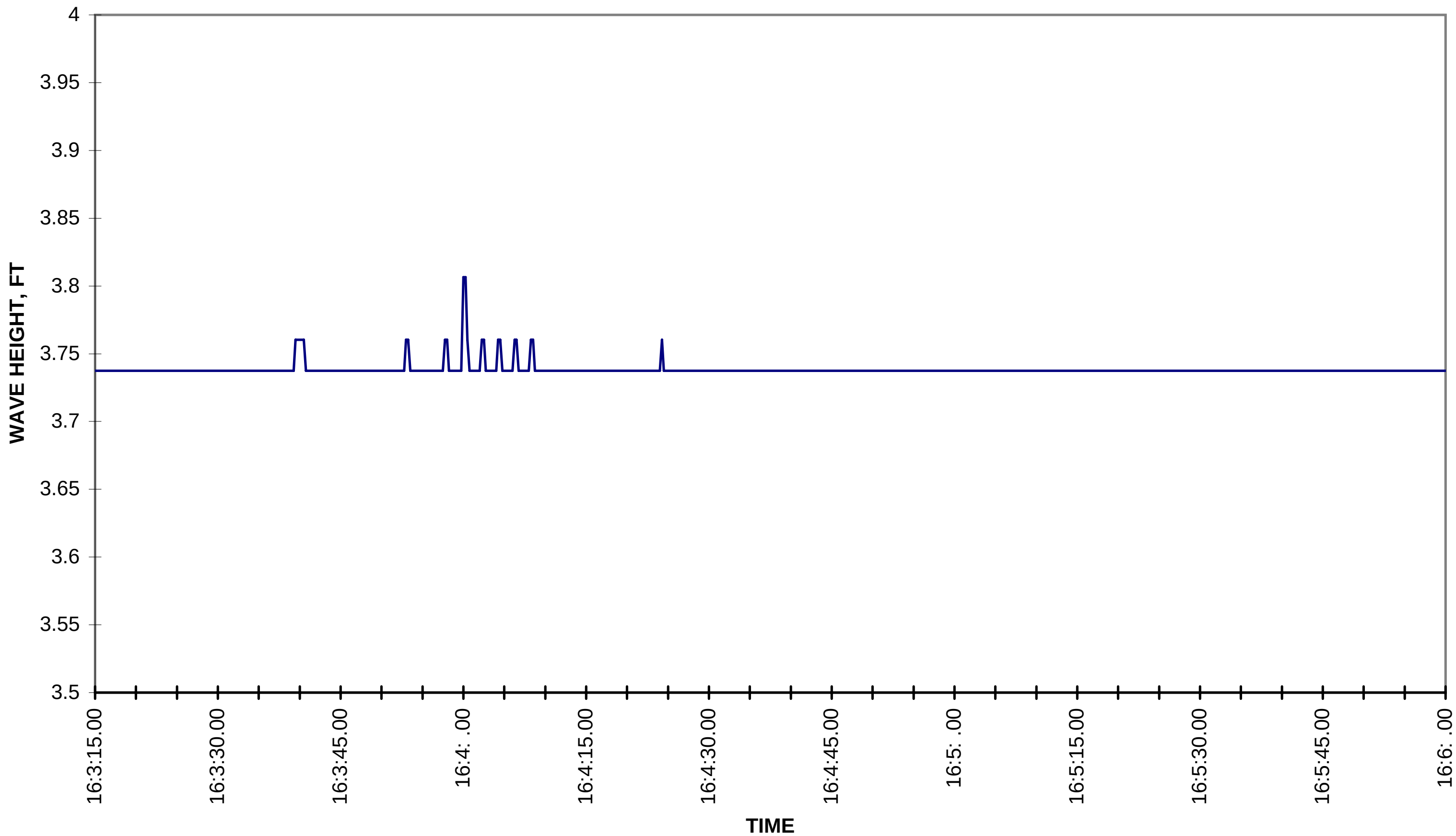
WAVE HEIGHTS
TEST 1, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



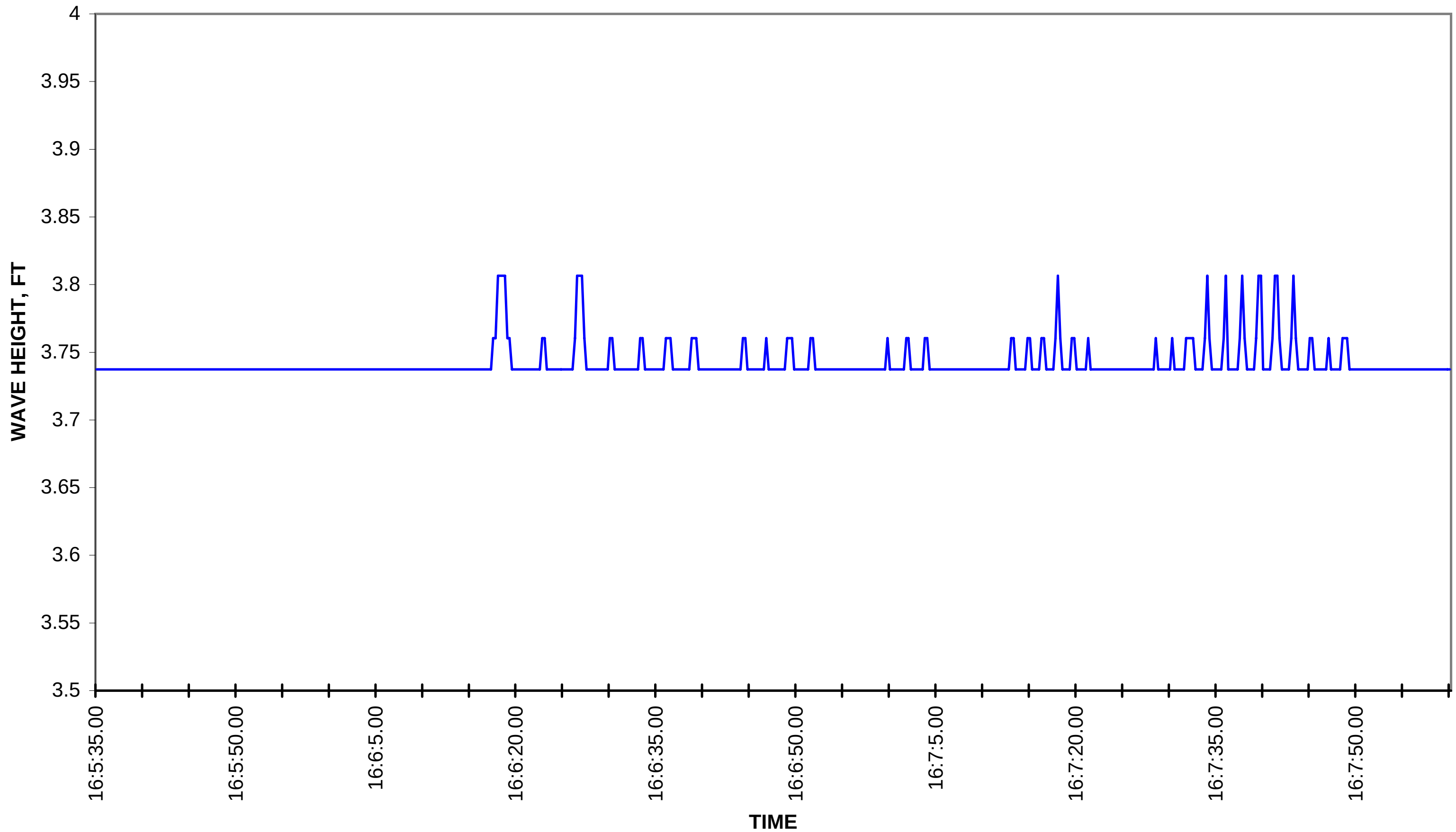
WAVE HEIGHTS
TEST 3, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 4, BOAT TYPE II
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 5, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



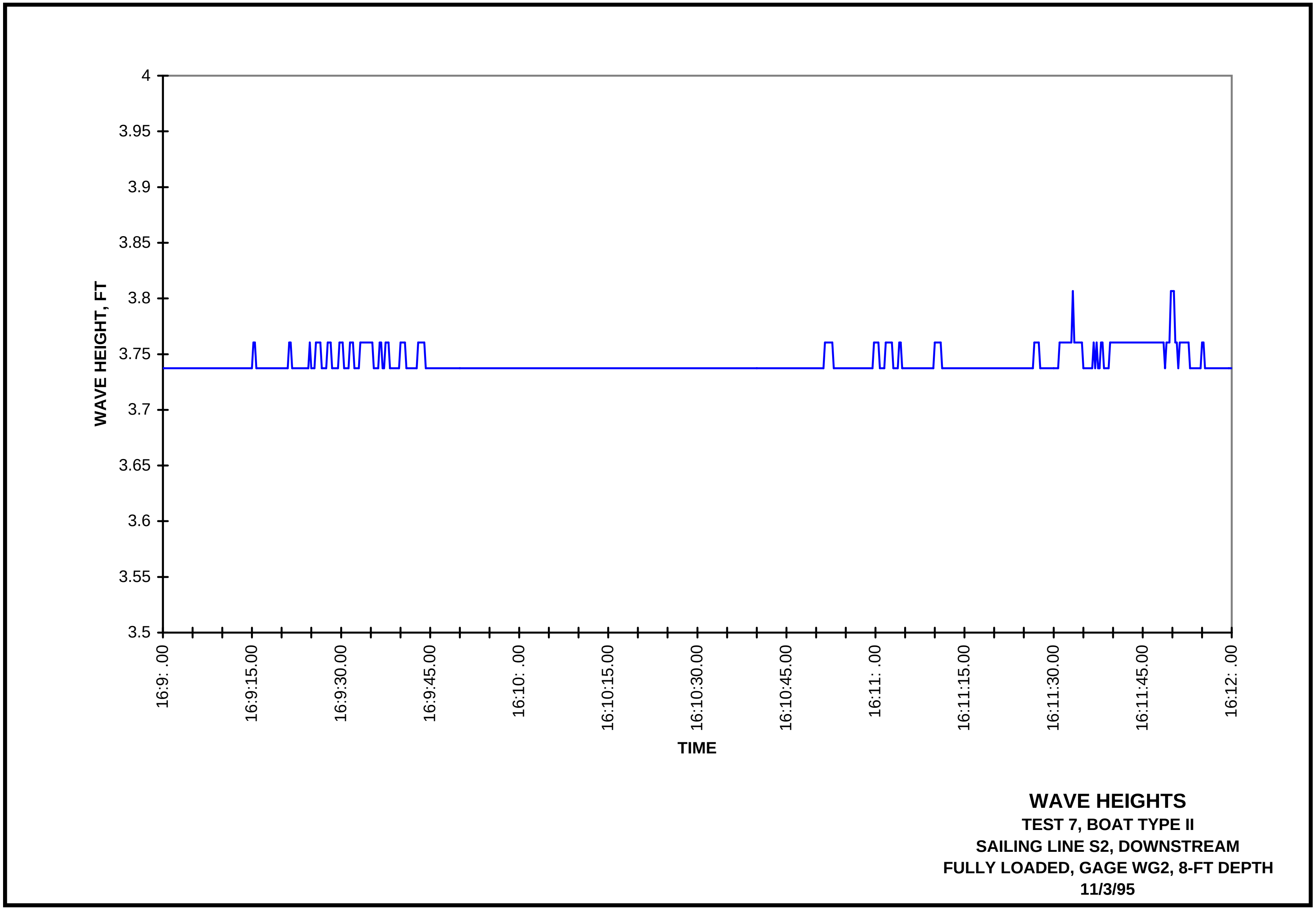
WAVE HEIGHTS

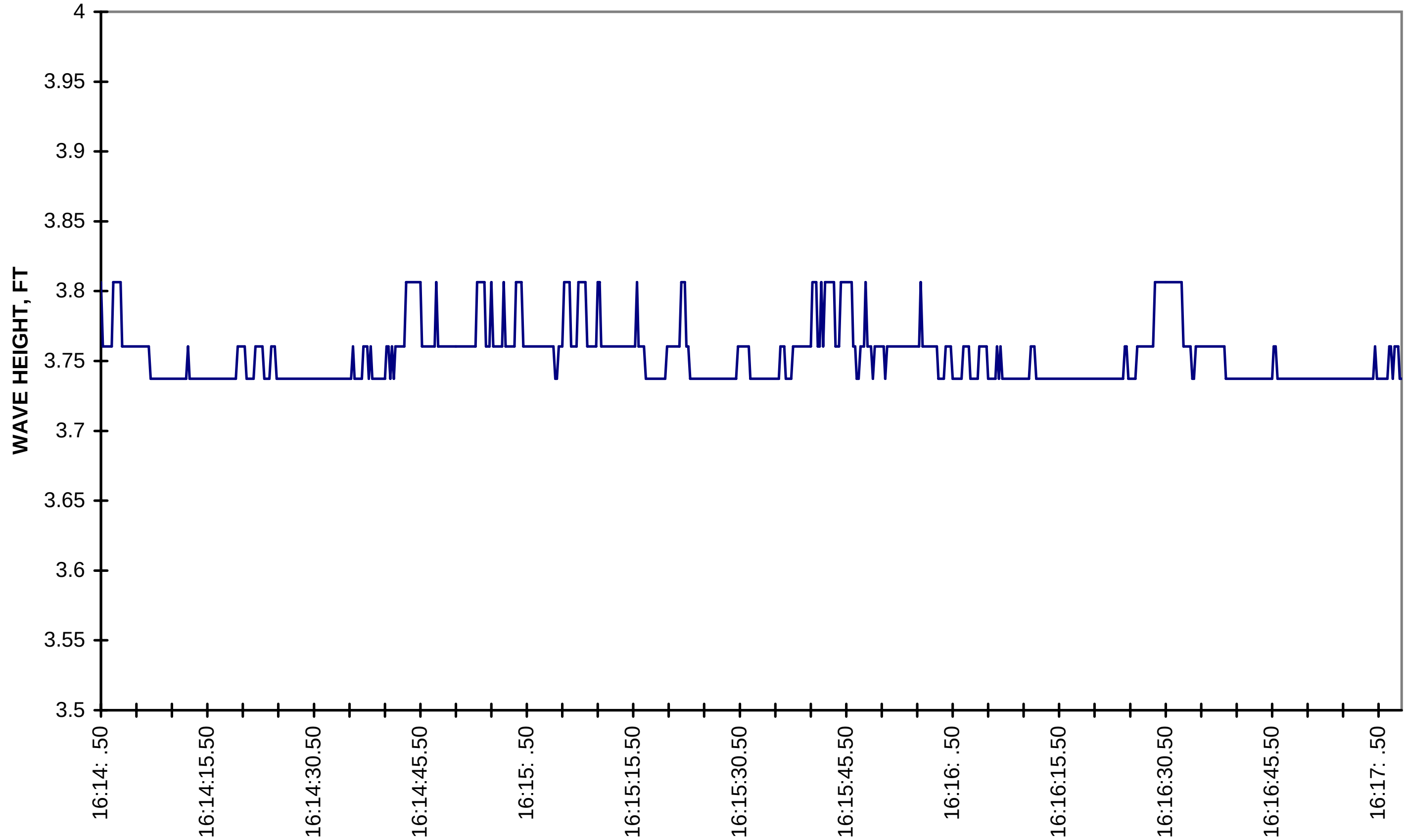
TEST 6, BOAT TYPE II

SAILING LINE S1, UPSTREAM

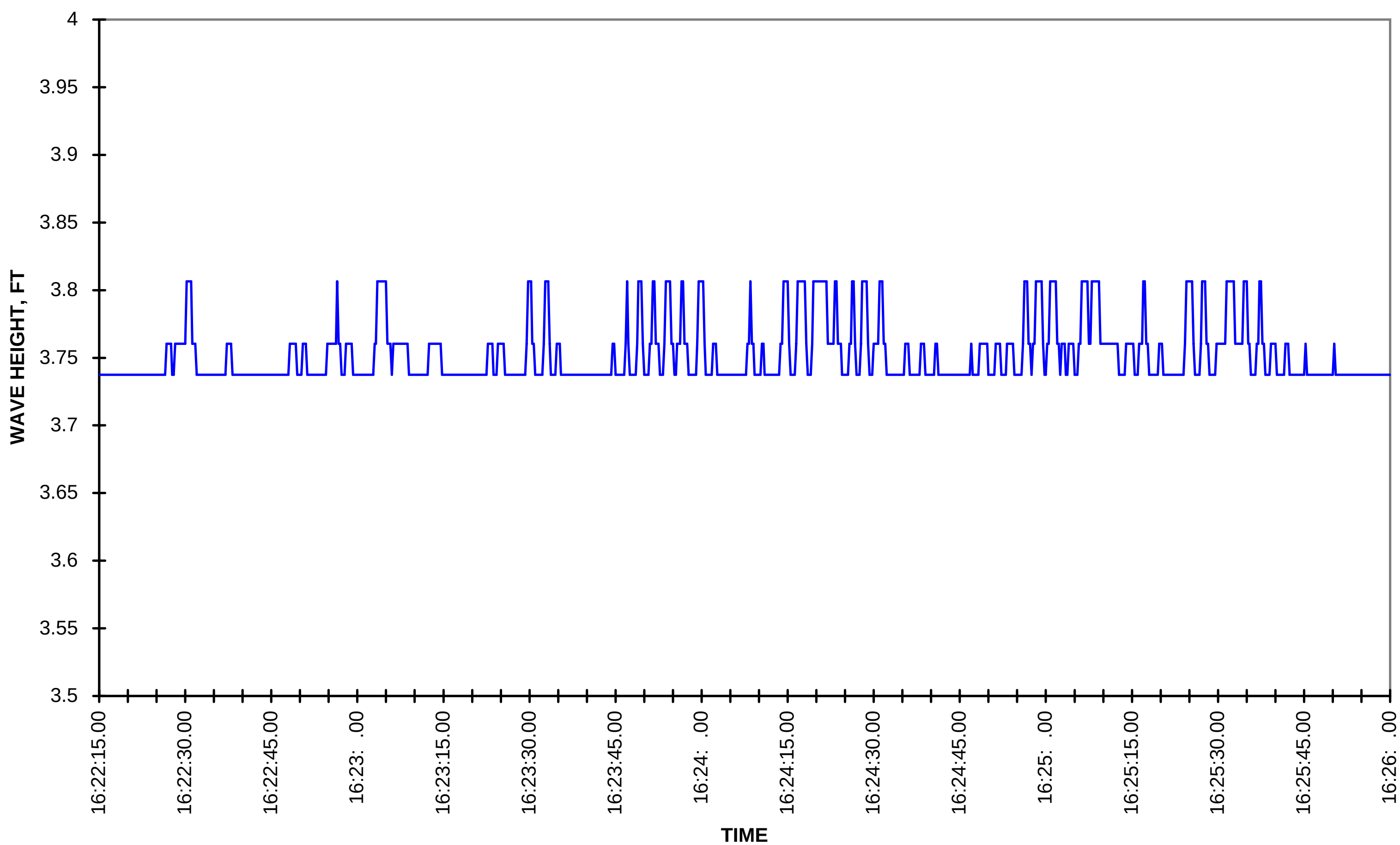
FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/3/95

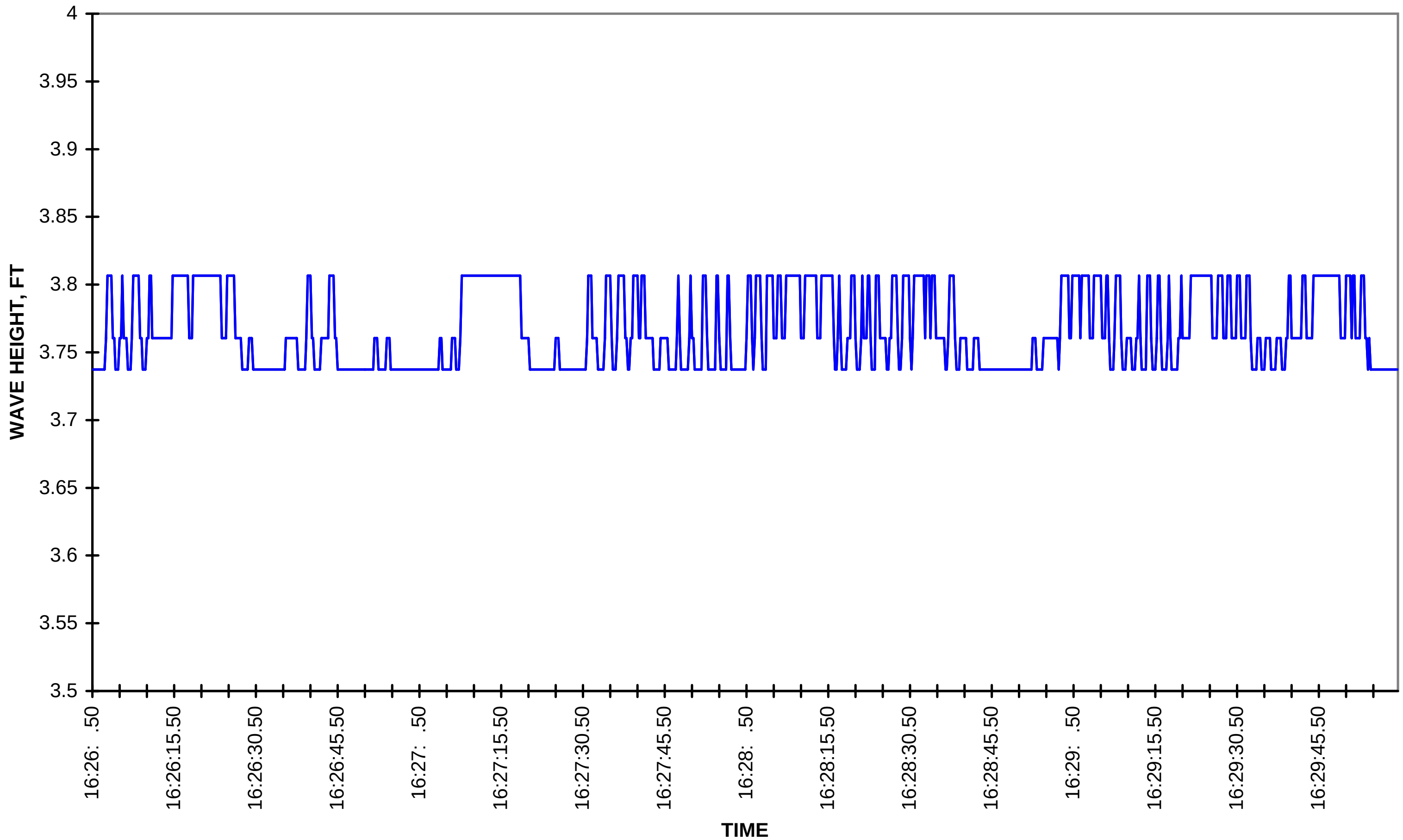

4
3.95
3.9
3.85
3.8
3.75
3.7
3.65
3.6
3.55
3.5
WAVE HEIGHT, FT
16:9: .00
16:9:15.00
16:9:30.00
16:9:45.00
16:10: .00
16:10:15.00
16:10:30.00
16:10:45.00
16:11: .00
16:11:15.00
16:11:30.00
16:11:45.00
16:12: .00
TIME
WAVE HEIGHTS
TEST 7, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 8, BOAT TYPE II
SAILING LINES2, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 10, BOAT TYPE II
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



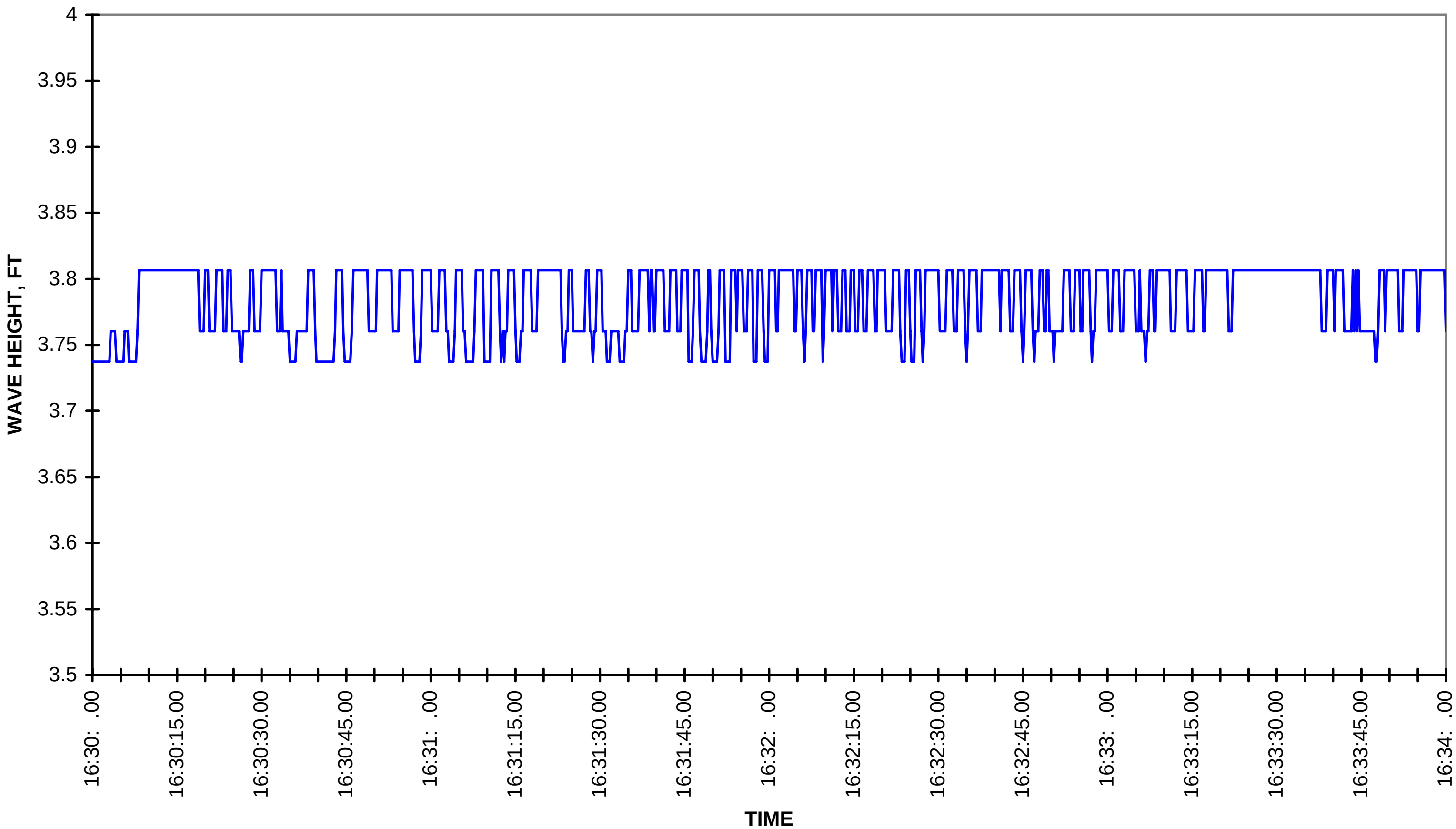
WAVE HEIGHTS

TEST 11, BOAT TYPE II

SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/3/95



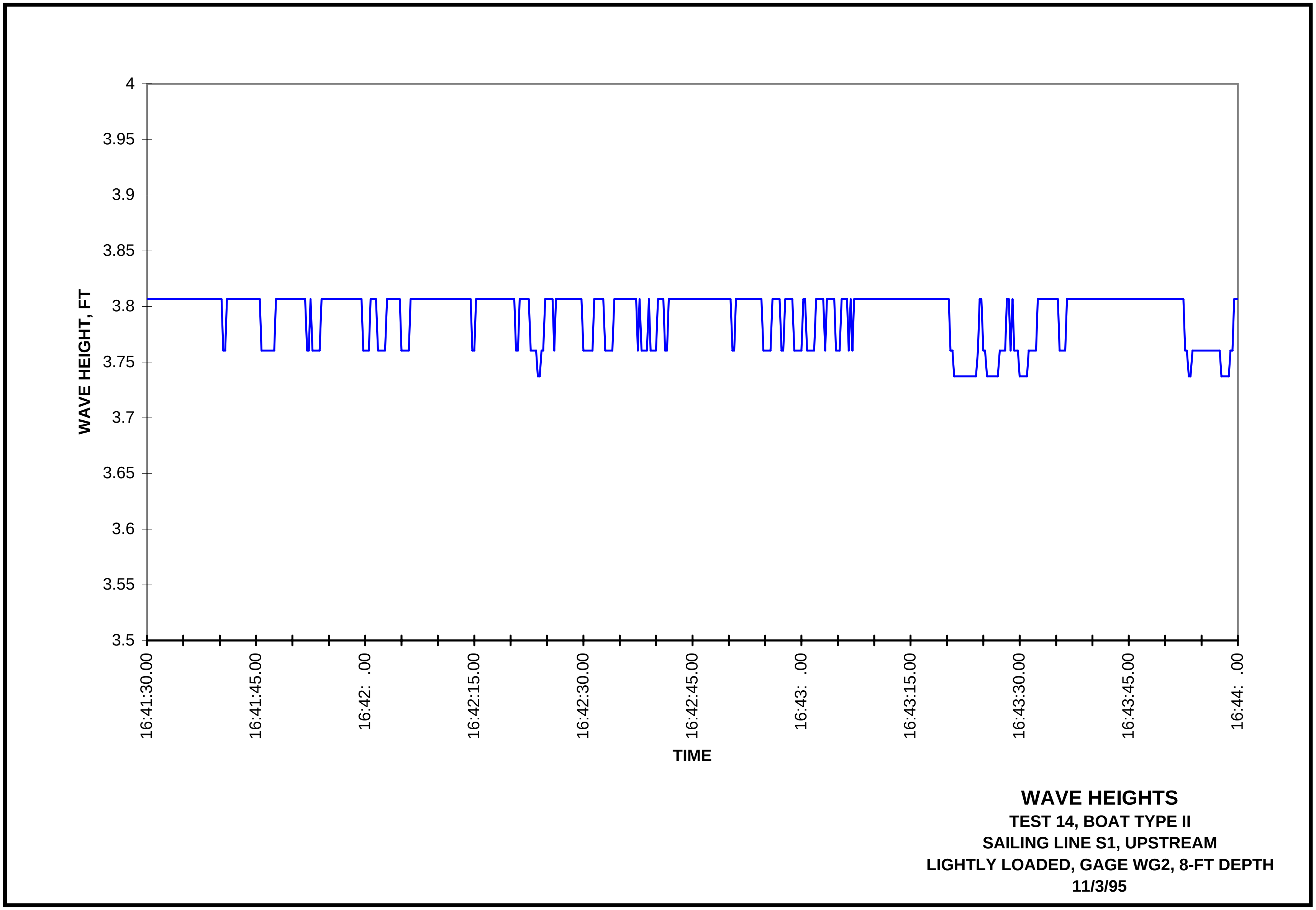
WAVE HEIGHTS

TEST 12, BOAT TYPE II

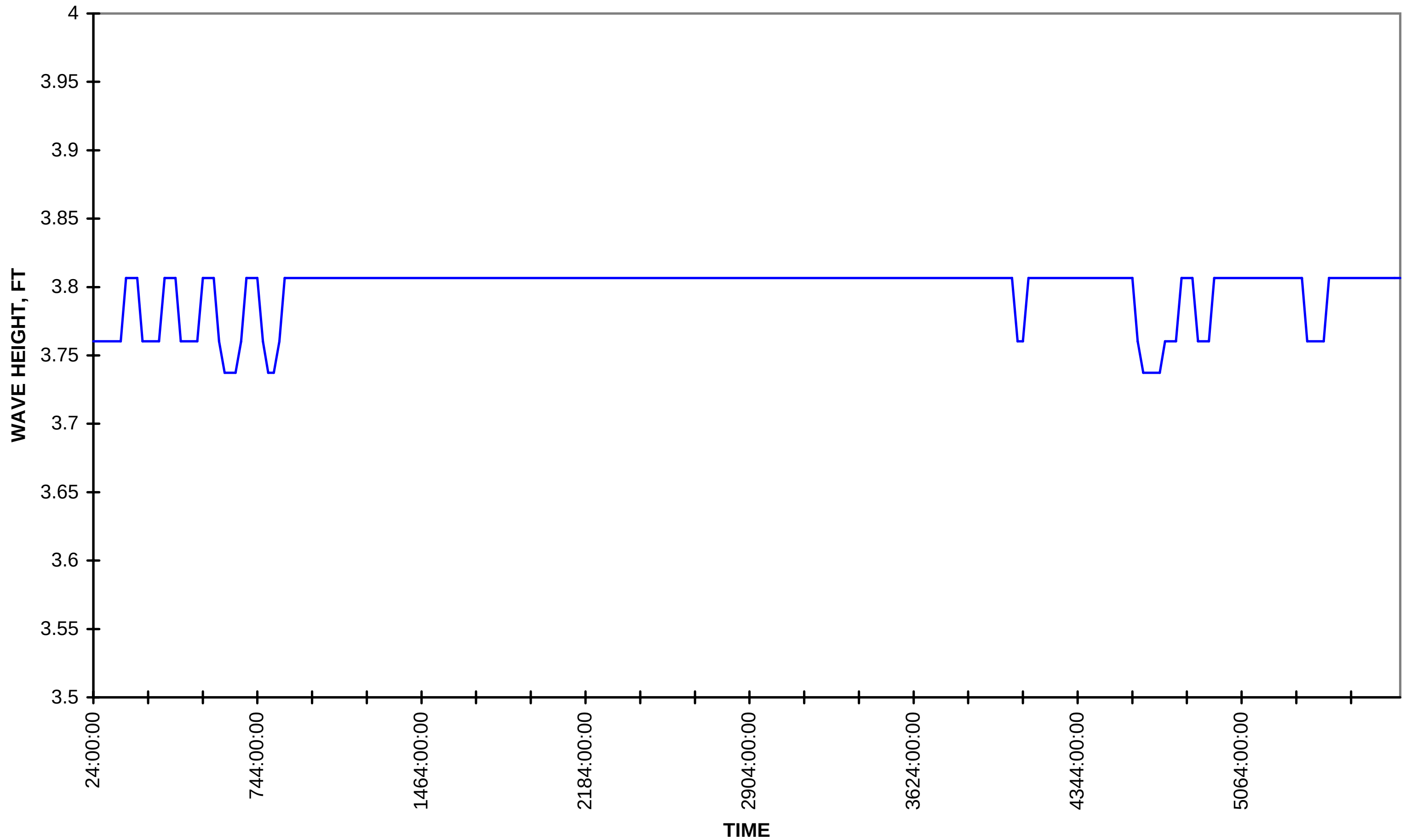
SAILING LINE S2, UPSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

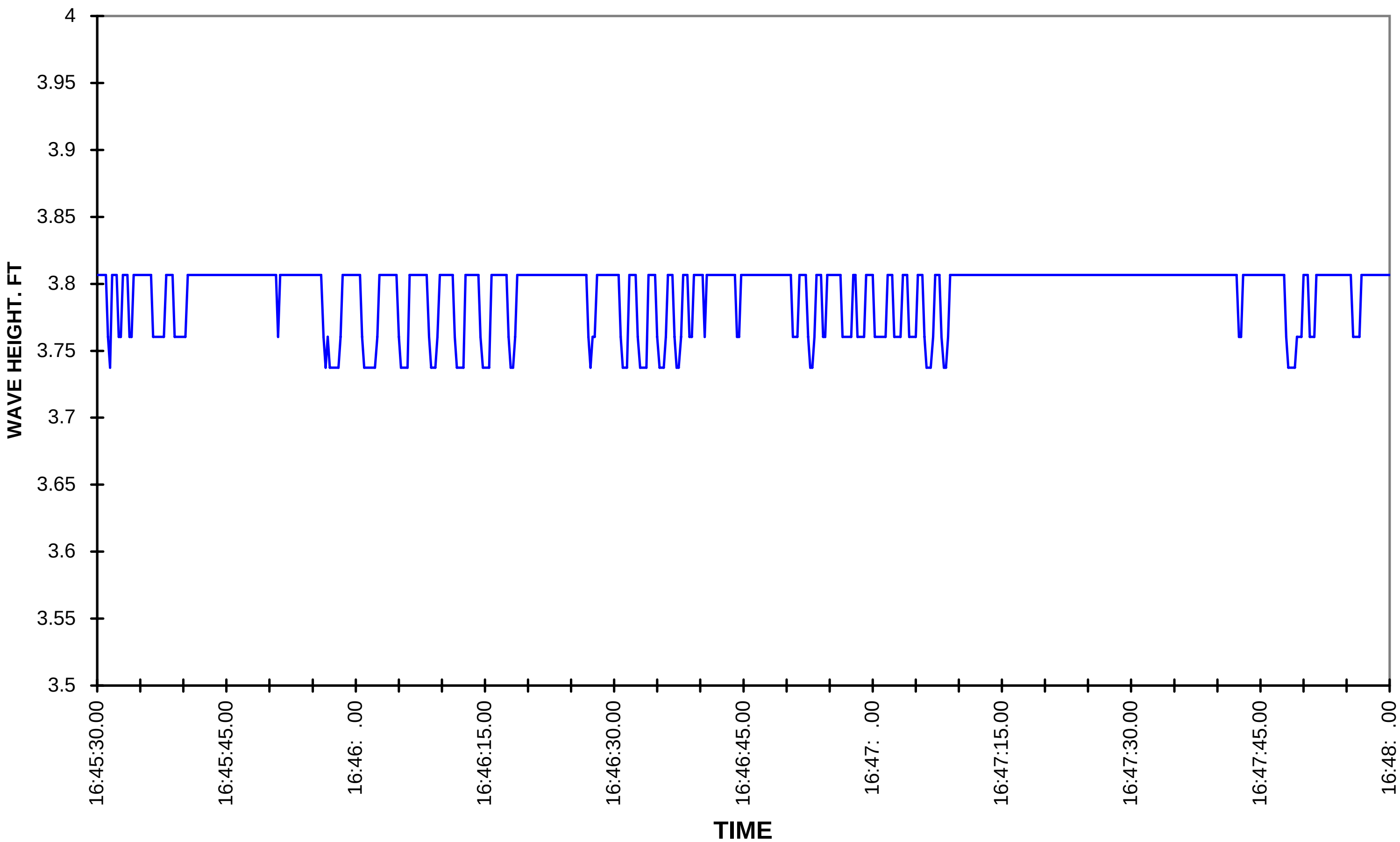
11/3/95



WAVE HEIGHT, FT
4
3.95
3.9
3.85
3.8
3.75
3.7
3.65
3.6
3.55
3.5
16:41:30.00
16:41:45.00
16:42: .00
16:42:15.00
16:42:30.00
16:42:45.00
16:43: .00
16:43:15.00
16:43:30.00
16:43:45.00
16:44: .00
TIME
WAVE HEIGHTS
TEST 14, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 15, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



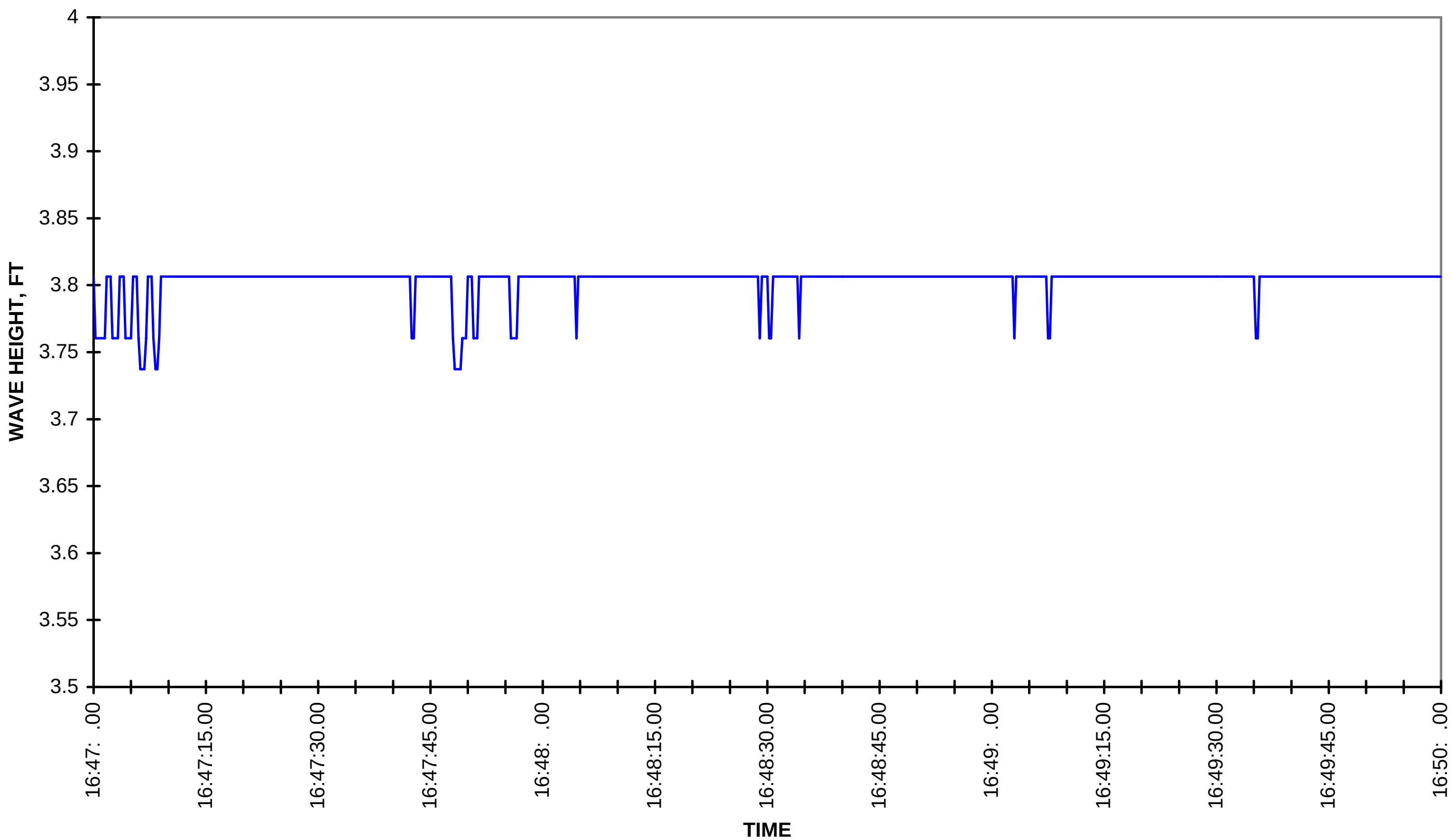
WAVE HEIGHTS

TEST 16, BOAT TYPE II

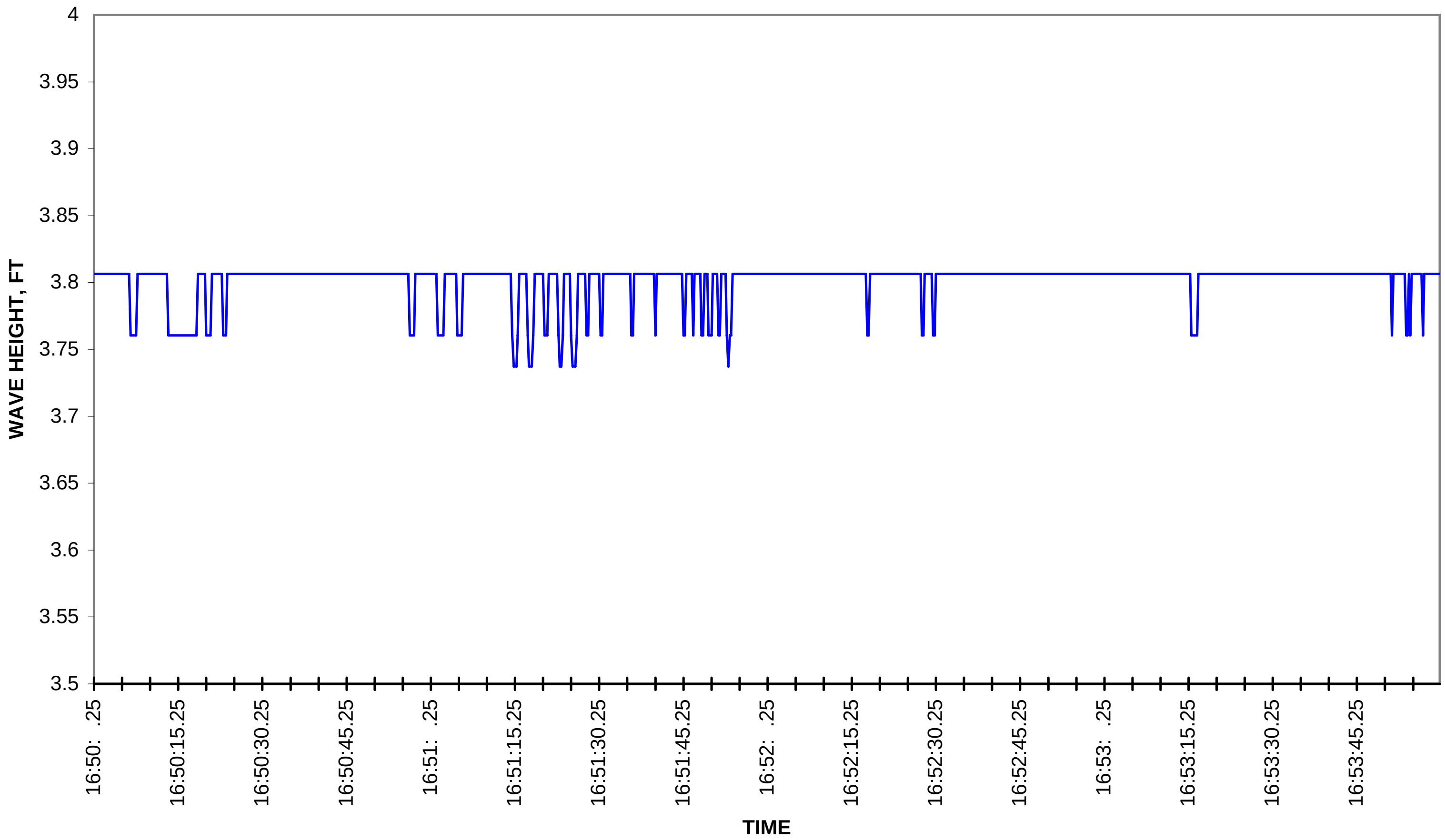
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

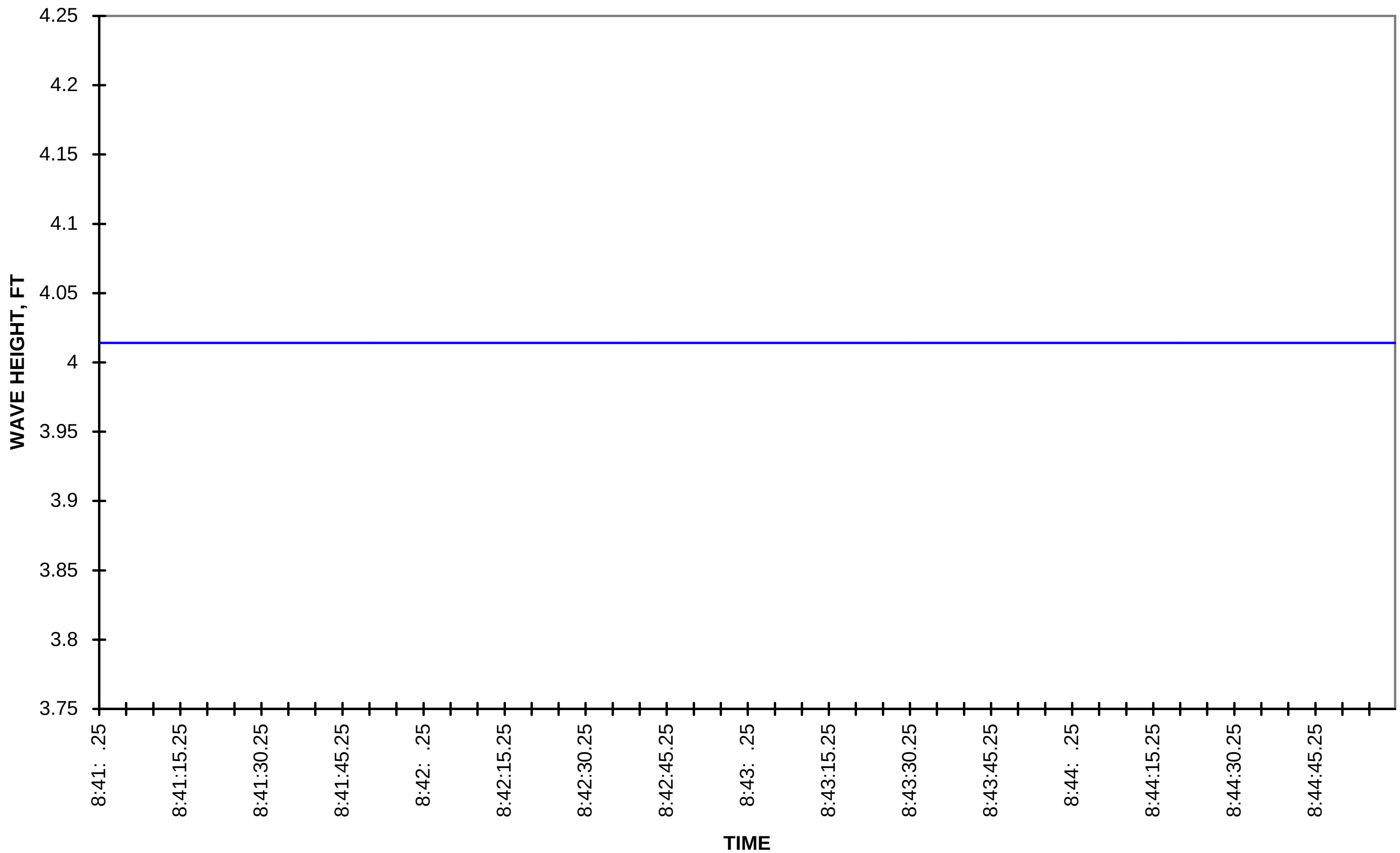
11/3/95



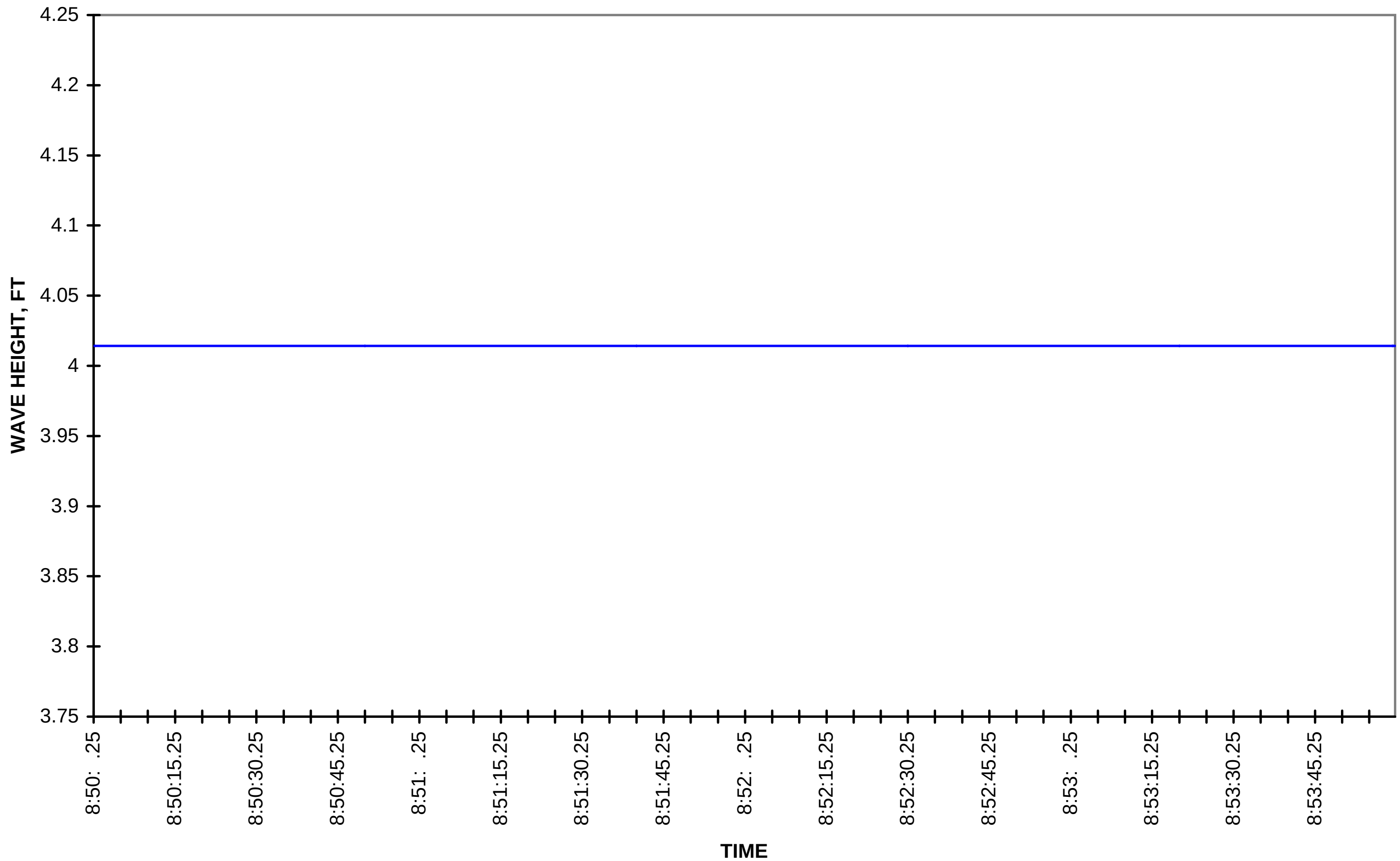
WAVE HEIGHTS
TEST 17, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, WAGE WG2, 8-FT DEPTH
11/3/95



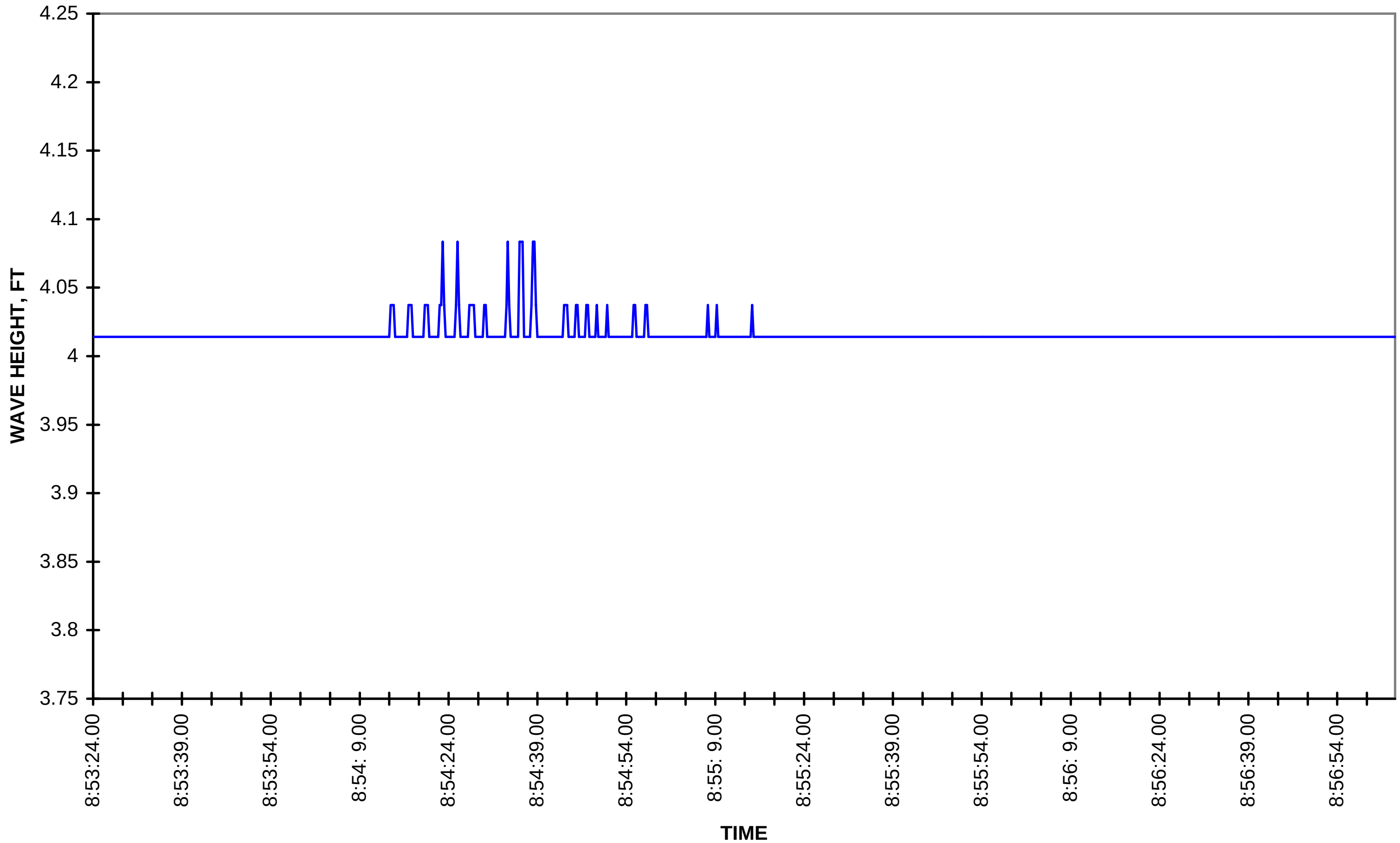
WAVE HEIGHTS
TEST 18, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/3/95



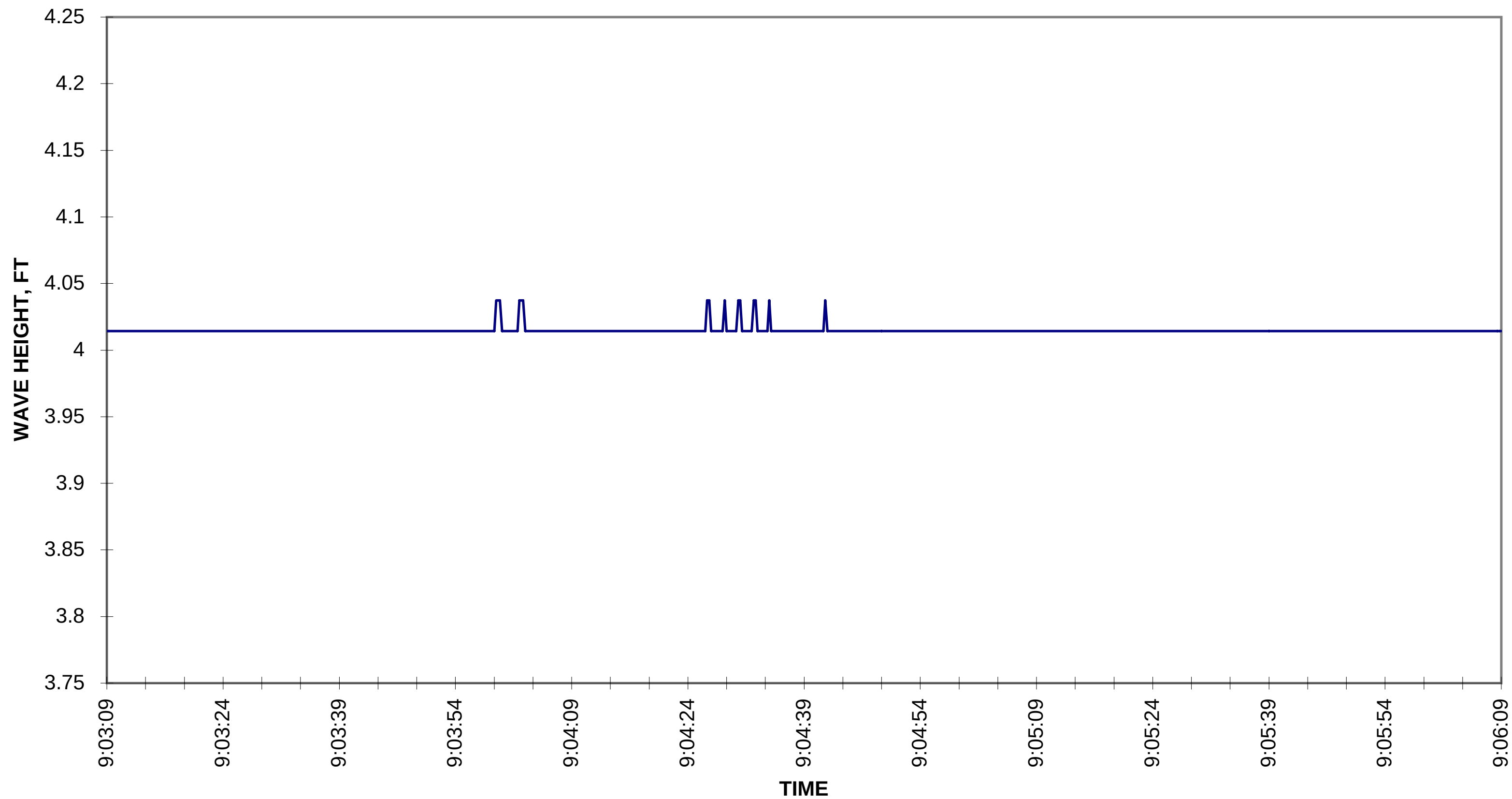
WAVE HEIGHTS
TEST 20, BOAT TYPE II
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/4/95



WAVE HEIGHTS
TEST 21, BOAT TYPE II
CENTER OF CHANNEL, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/4/95



WAVE HEIGHTS
TEST 22, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/4/95



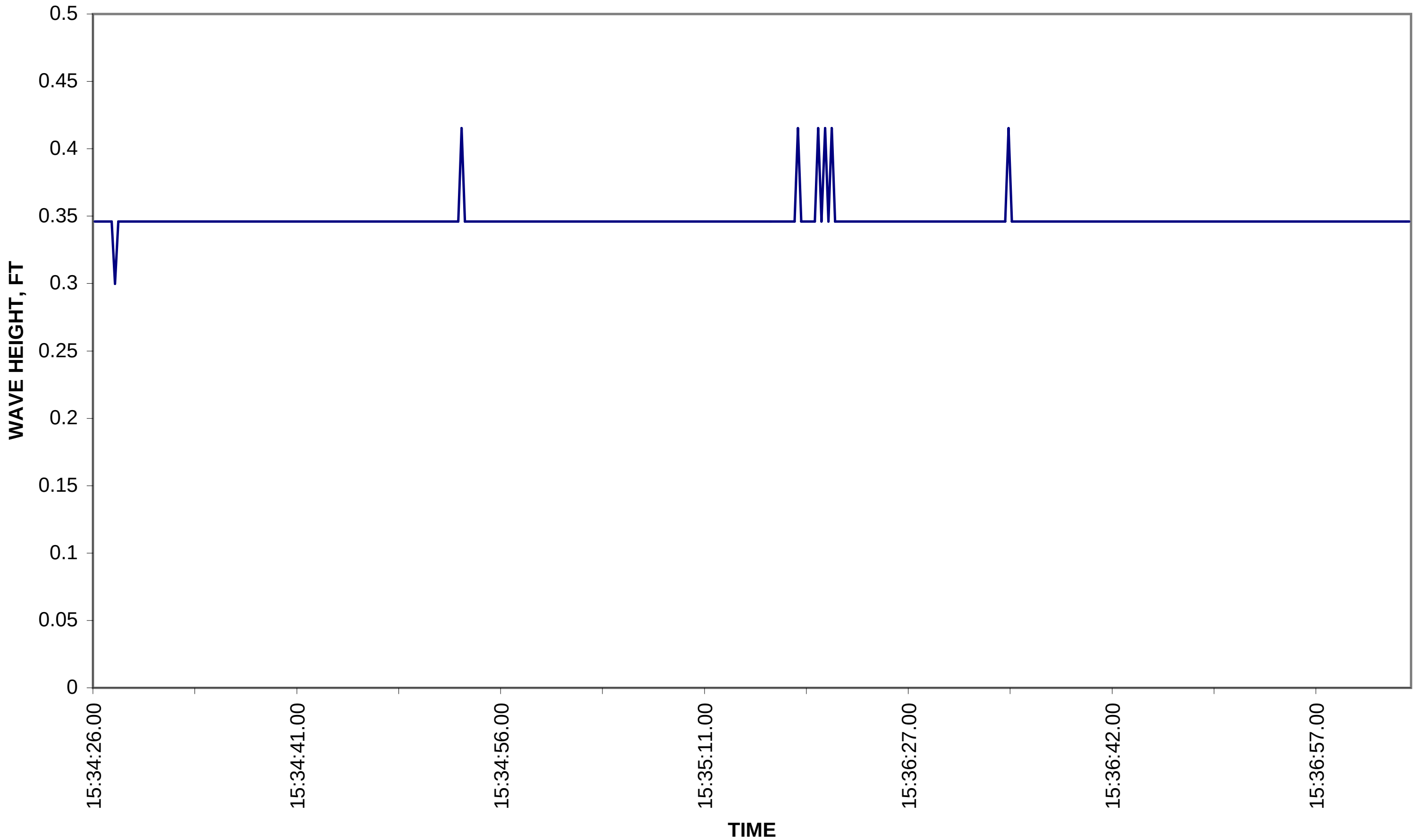
WAVE HEIGHTS

TEST 24, BOAT TYPE II

SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/4/95



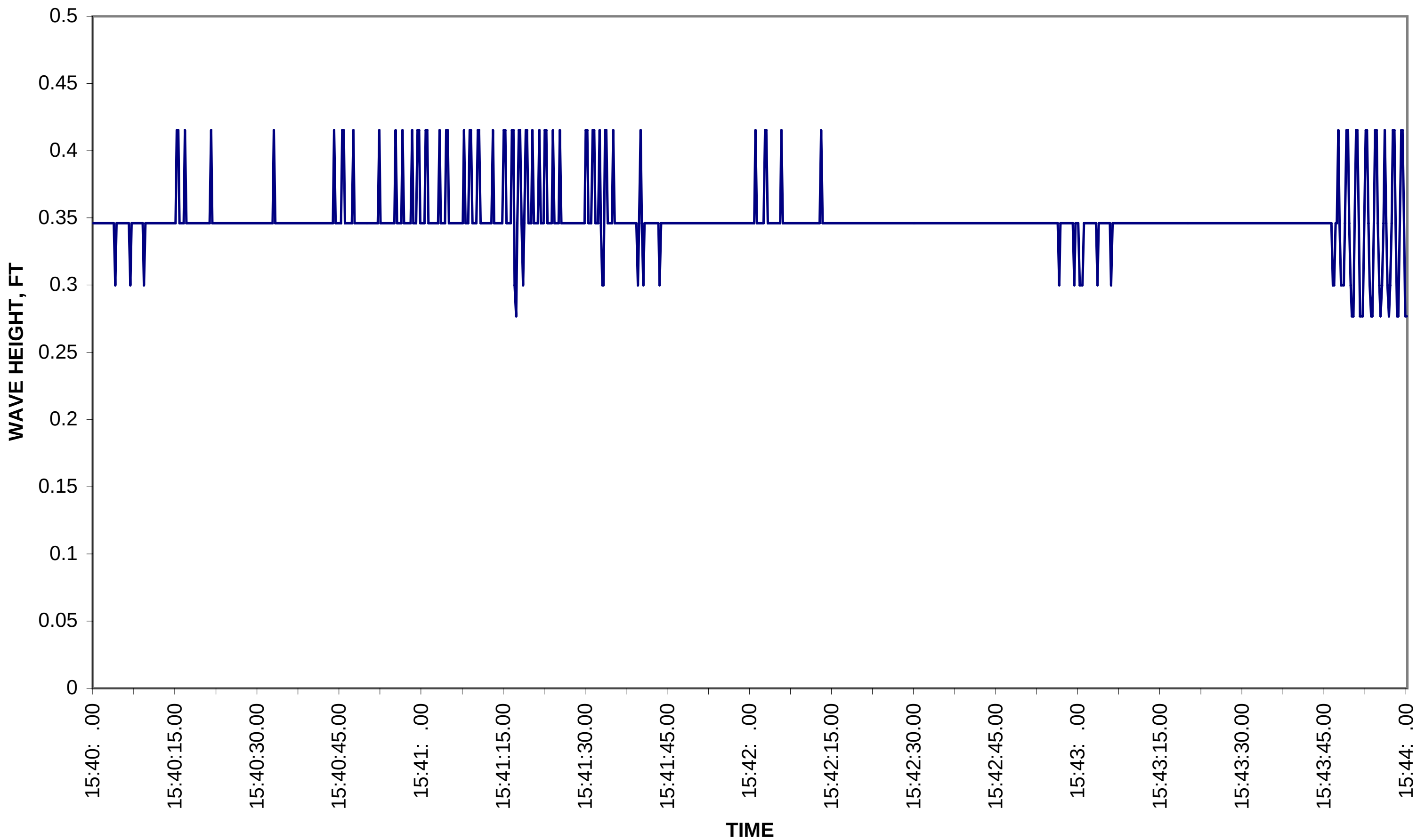
WAVE HEIGHTS

TEST 1, BOAT TYPE II

SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



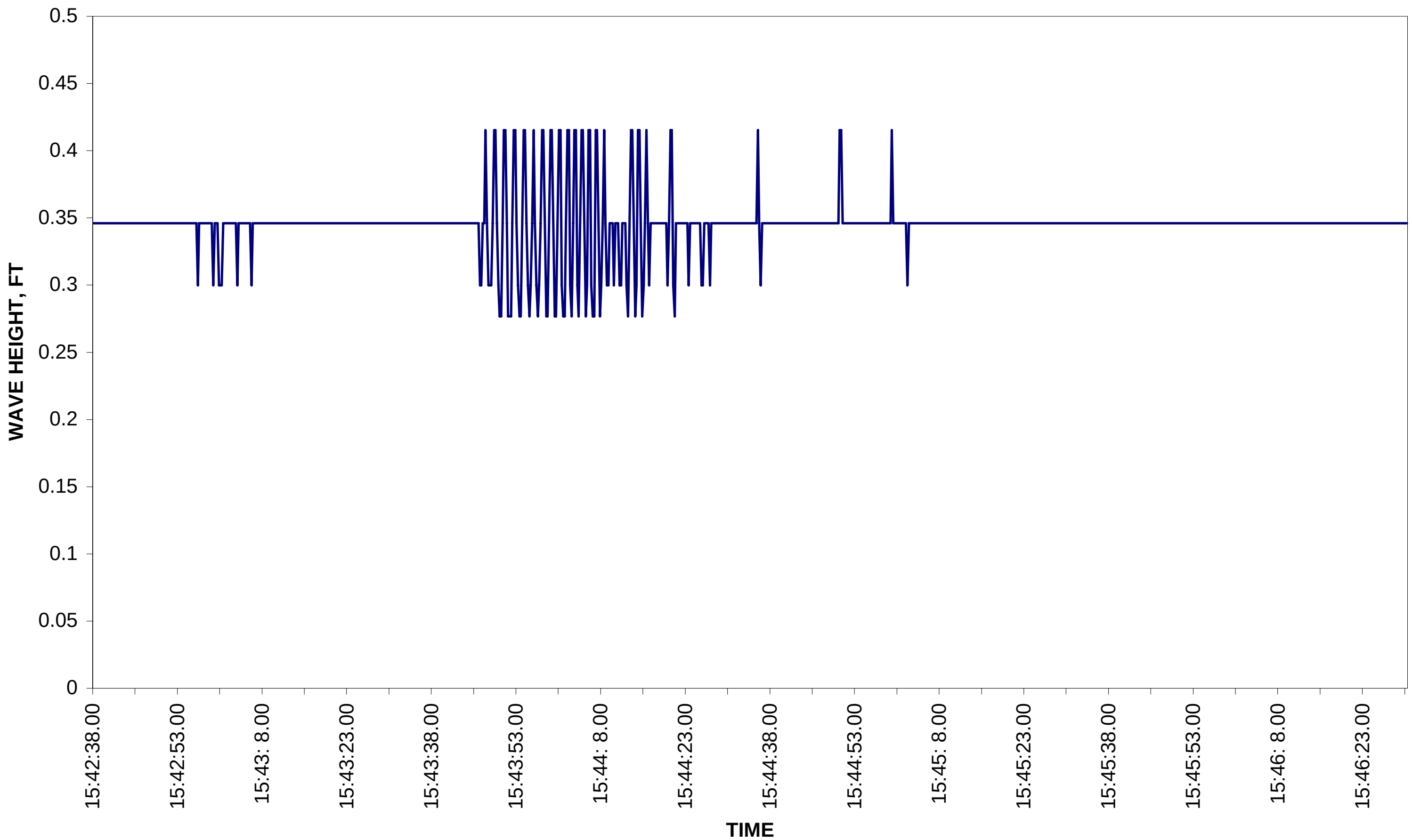
WAVE HEIGHTS

TEST 2, BOAT TYPE II

SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



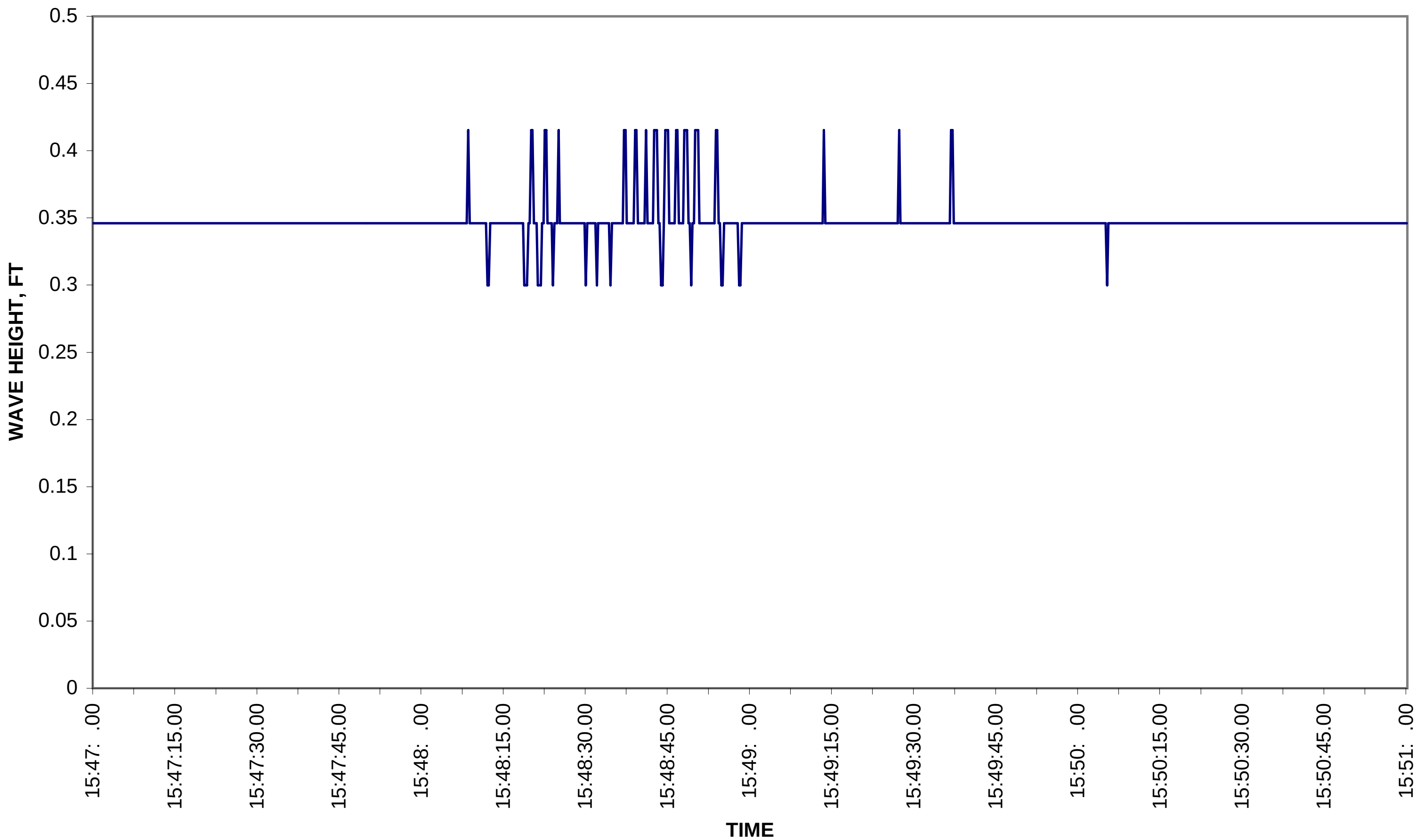
WAVE HEIGHTS

TEST 3, BOAT TYPE II

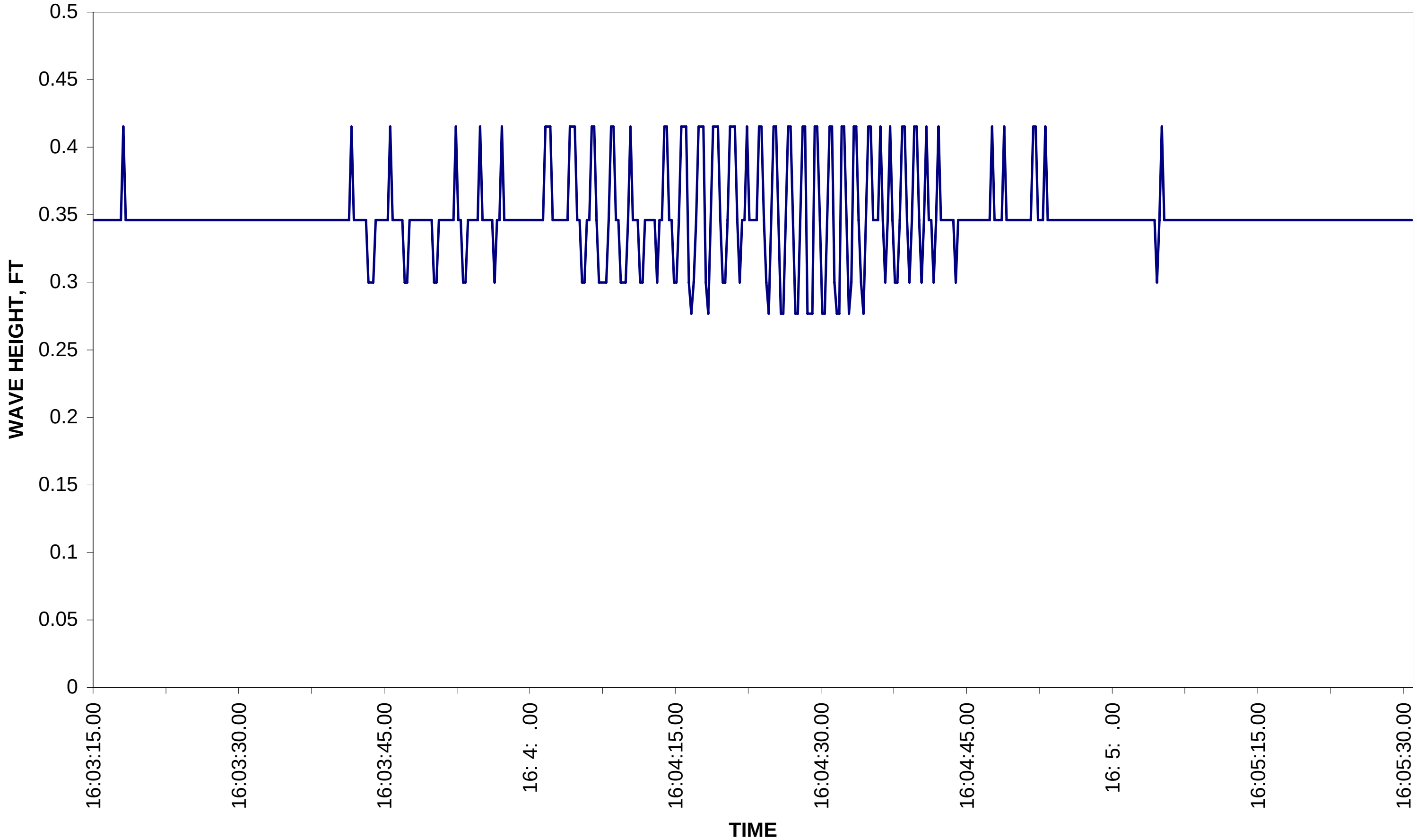
SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

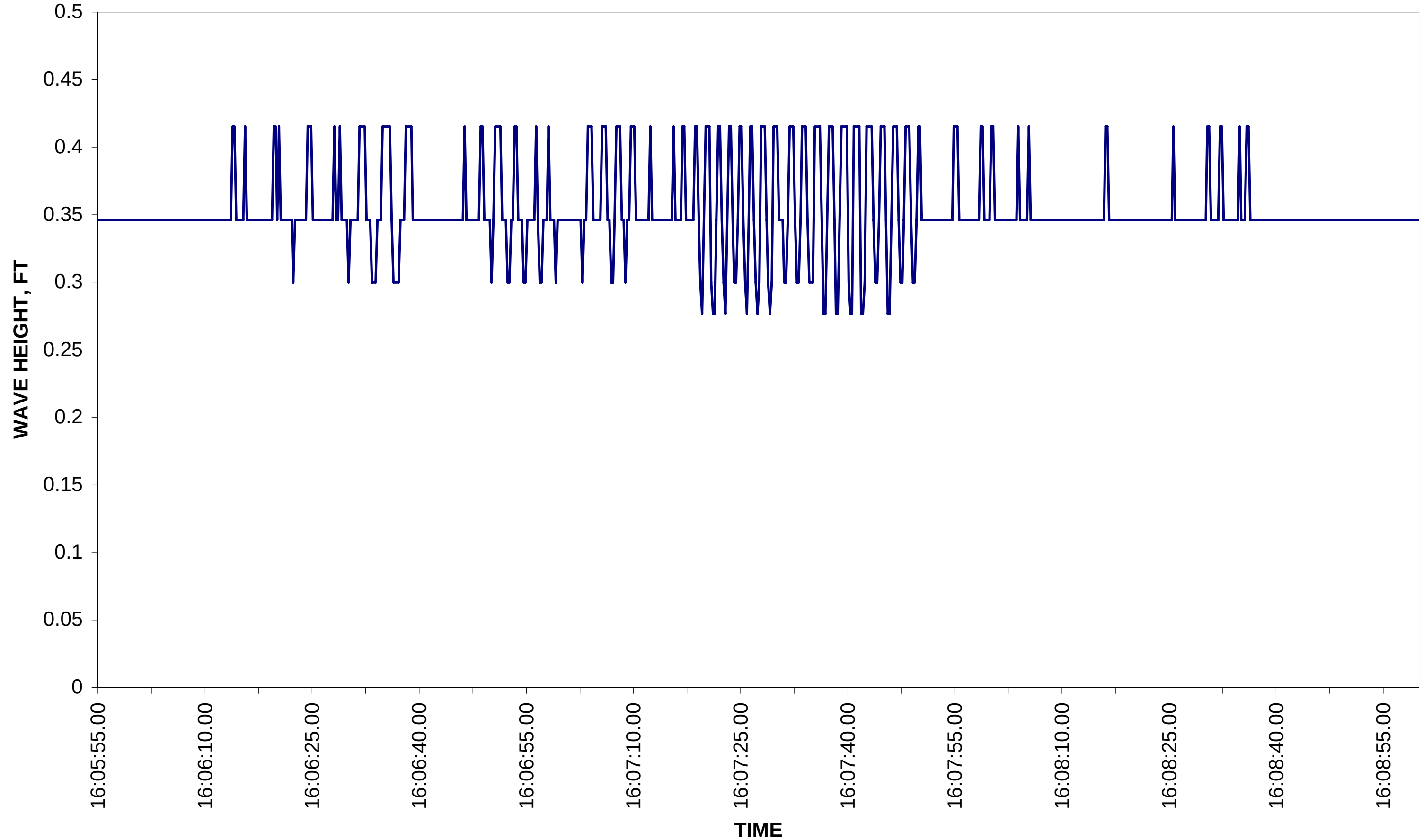
11/3/95



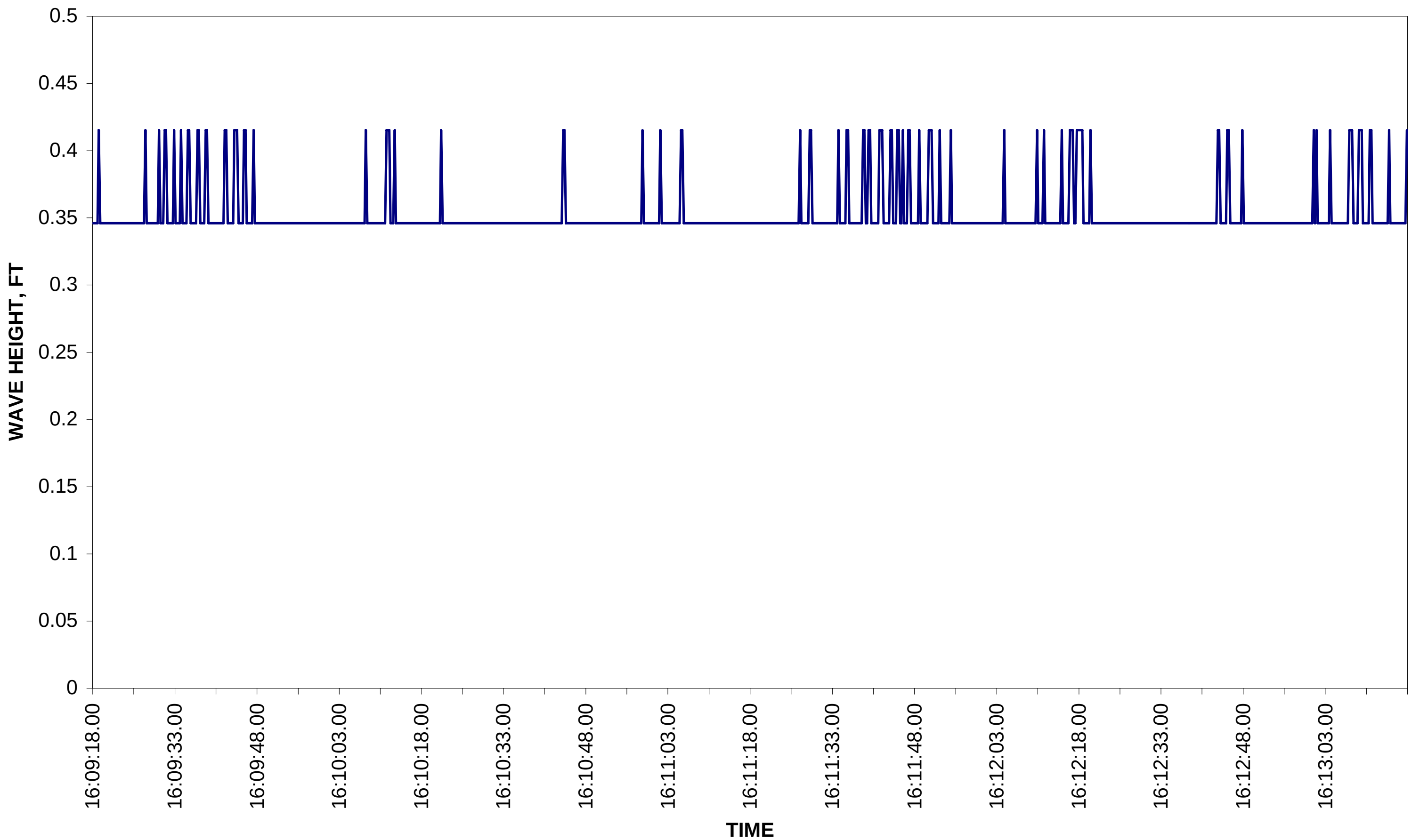
WAVE HEIGHTS
TEST 4, BOAT TYPE II
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 5, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 6, BOAT TYPE II
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95



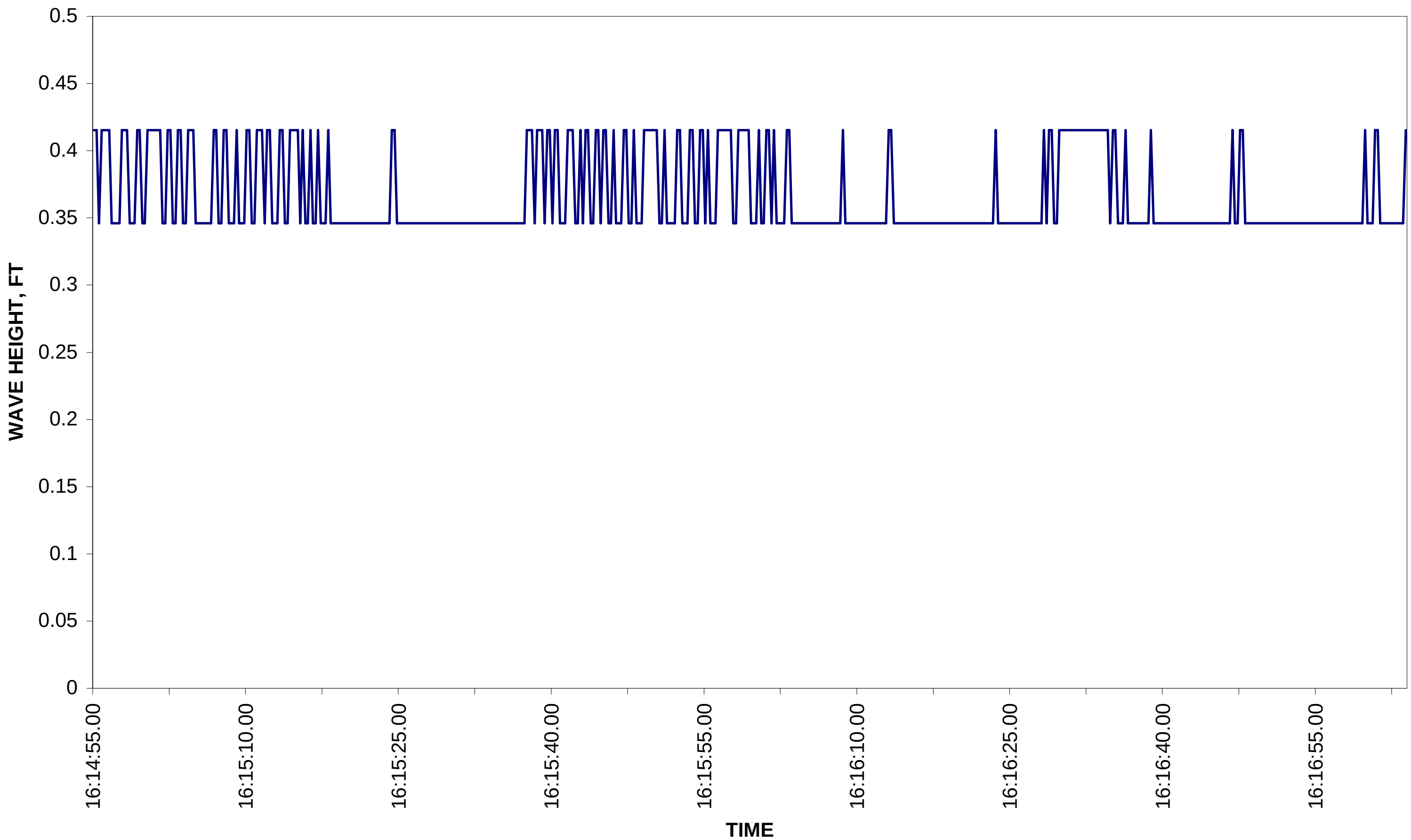
WAVE HEIGHTS

TEST 7, BOAT TYPE II

SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



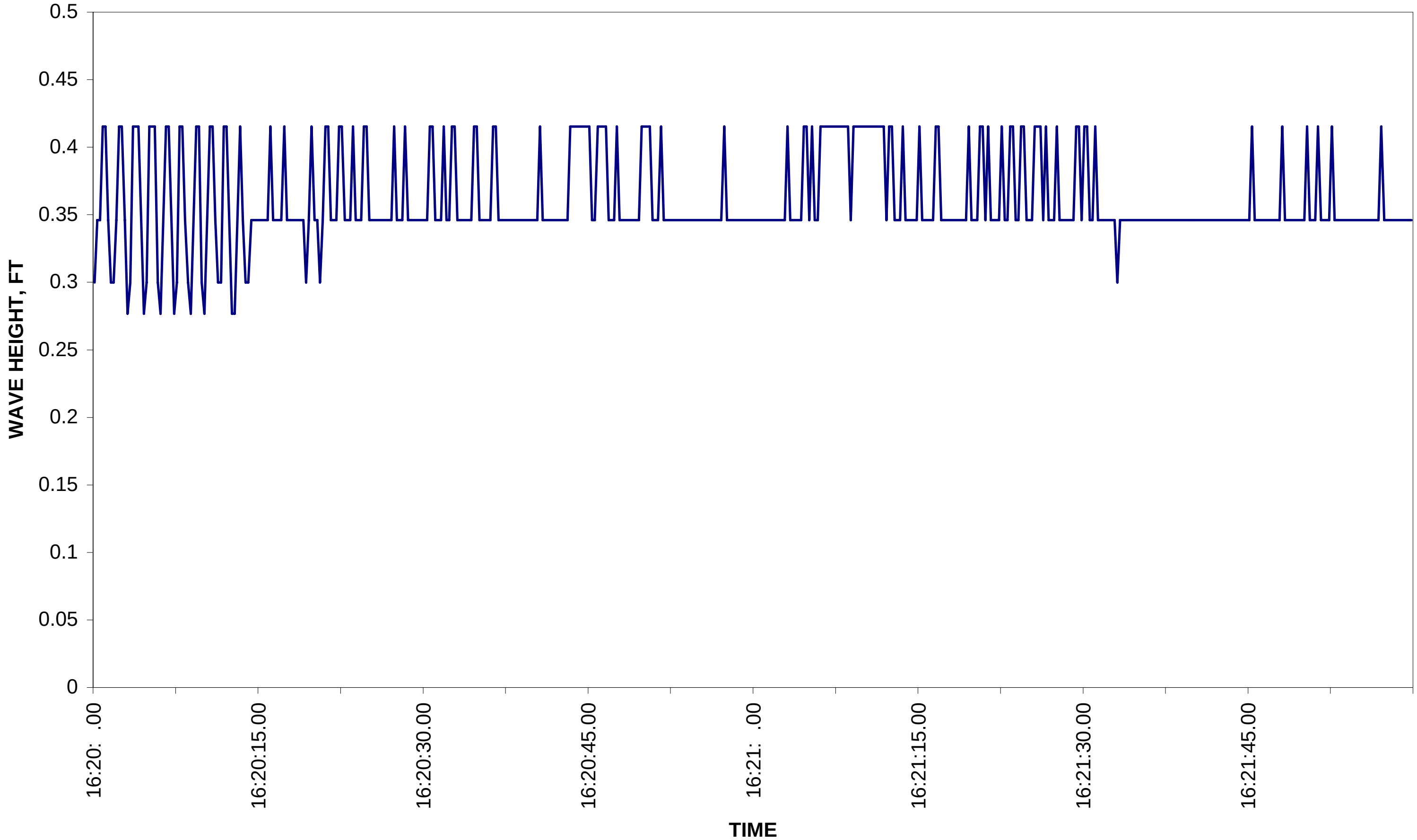
WAVE HEIGHTS

TEST 8, BOAT TYPE II

SAILING LINE S2, UPSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



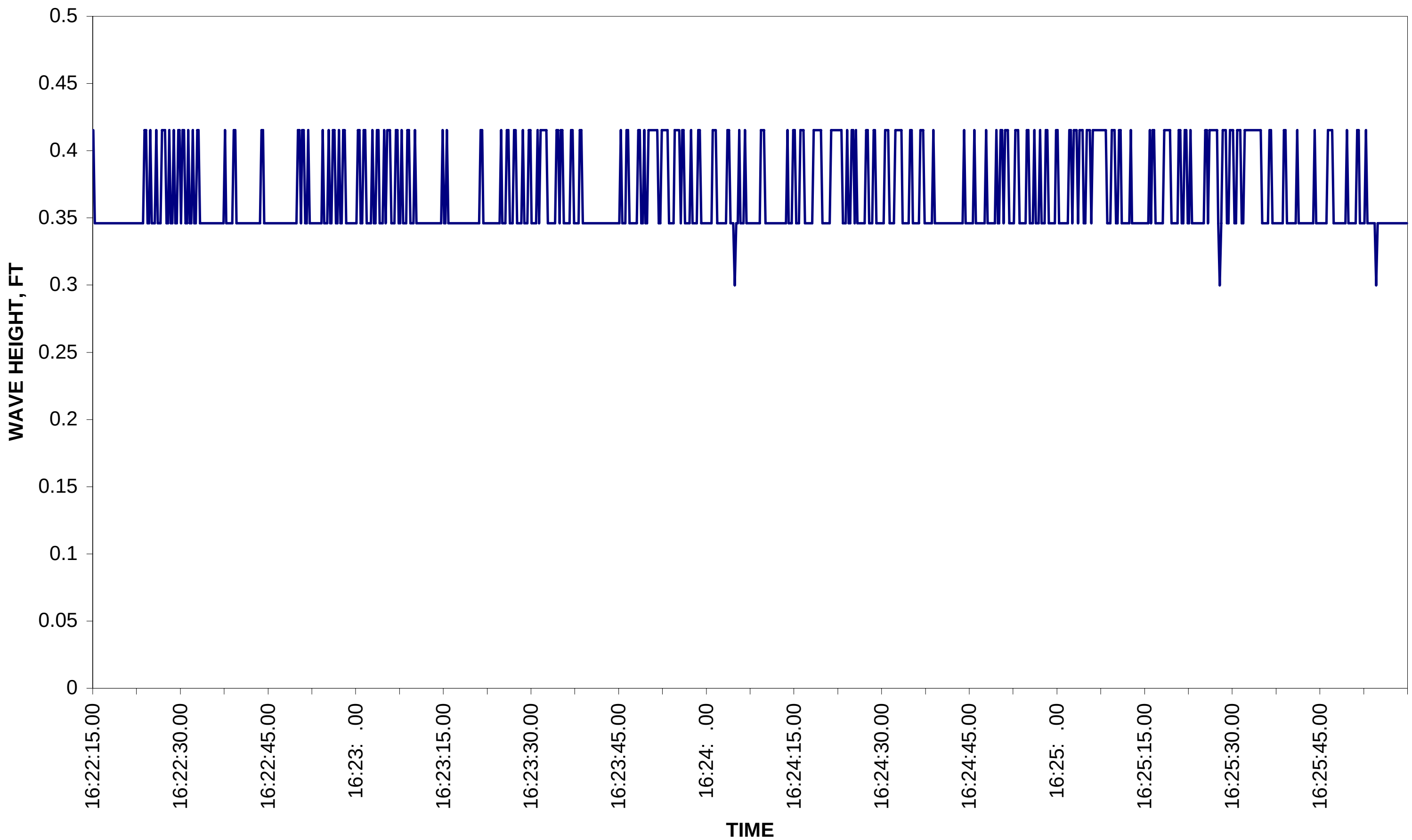
WAVE HEIGHTS

TEST 9, BOAT TYPE II

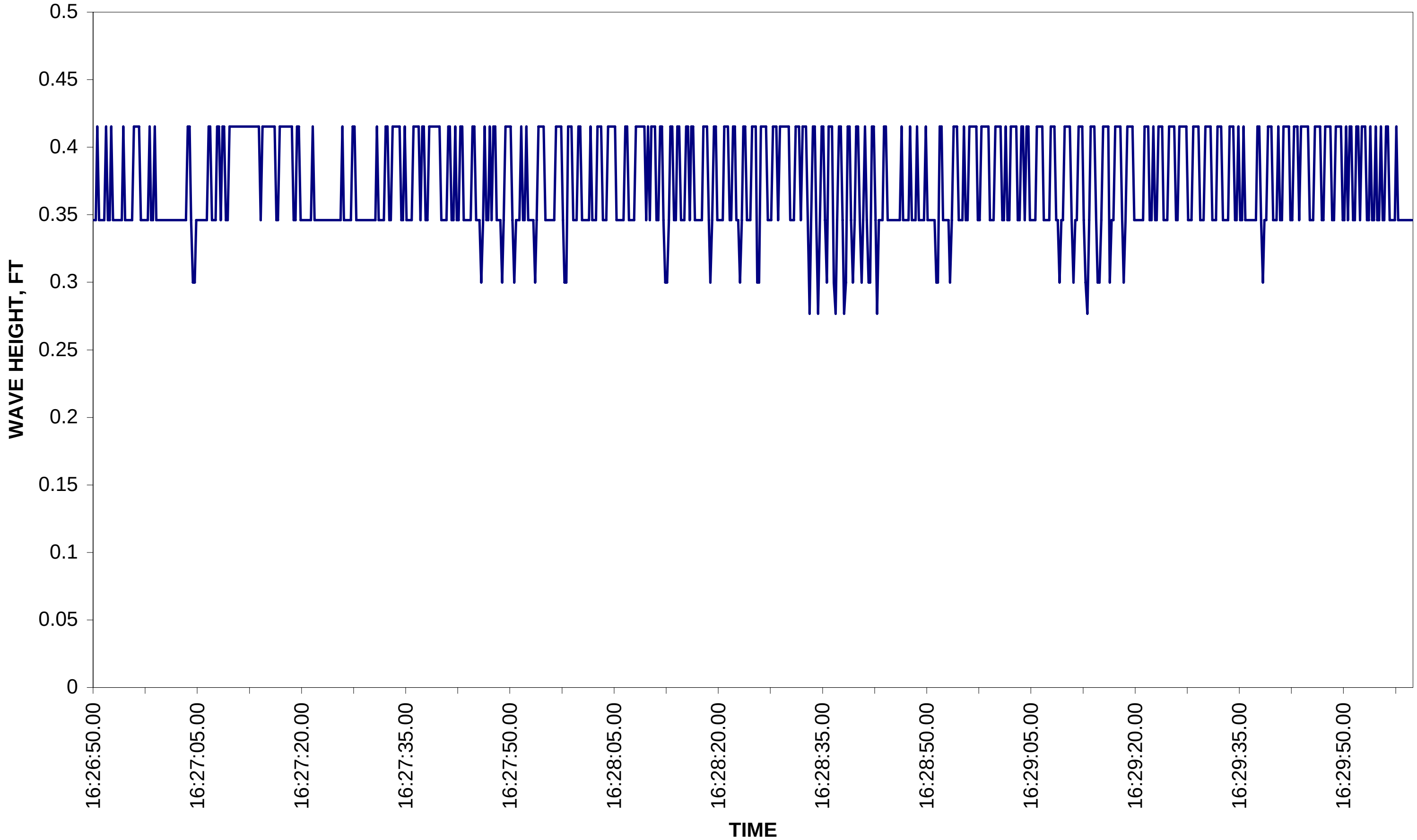
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



WAVE HEIGHTS
TEST 10, BOAT TYPE II
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95



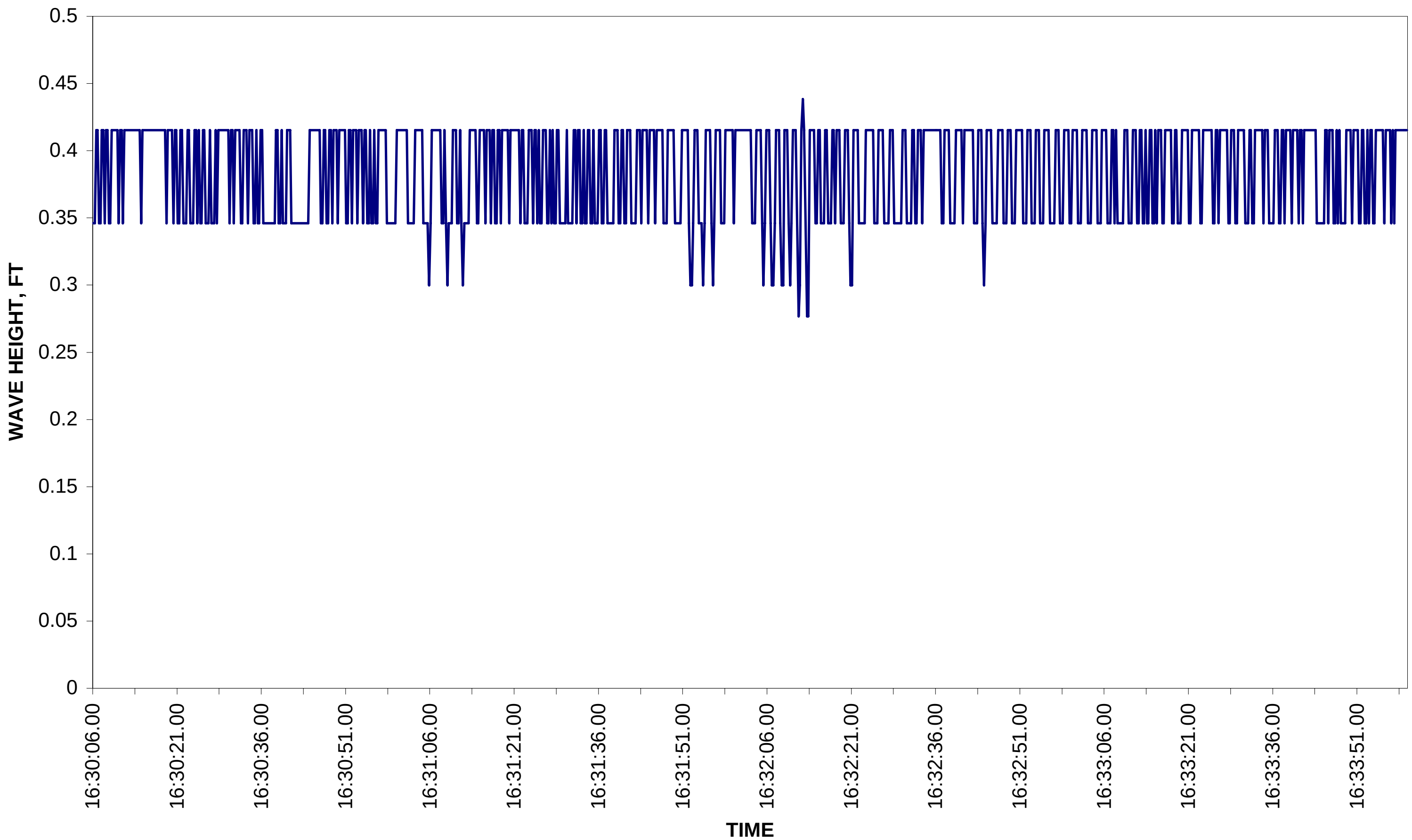
WAVE HEIGHTS

TEST 11, BOAT TYPE II

SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



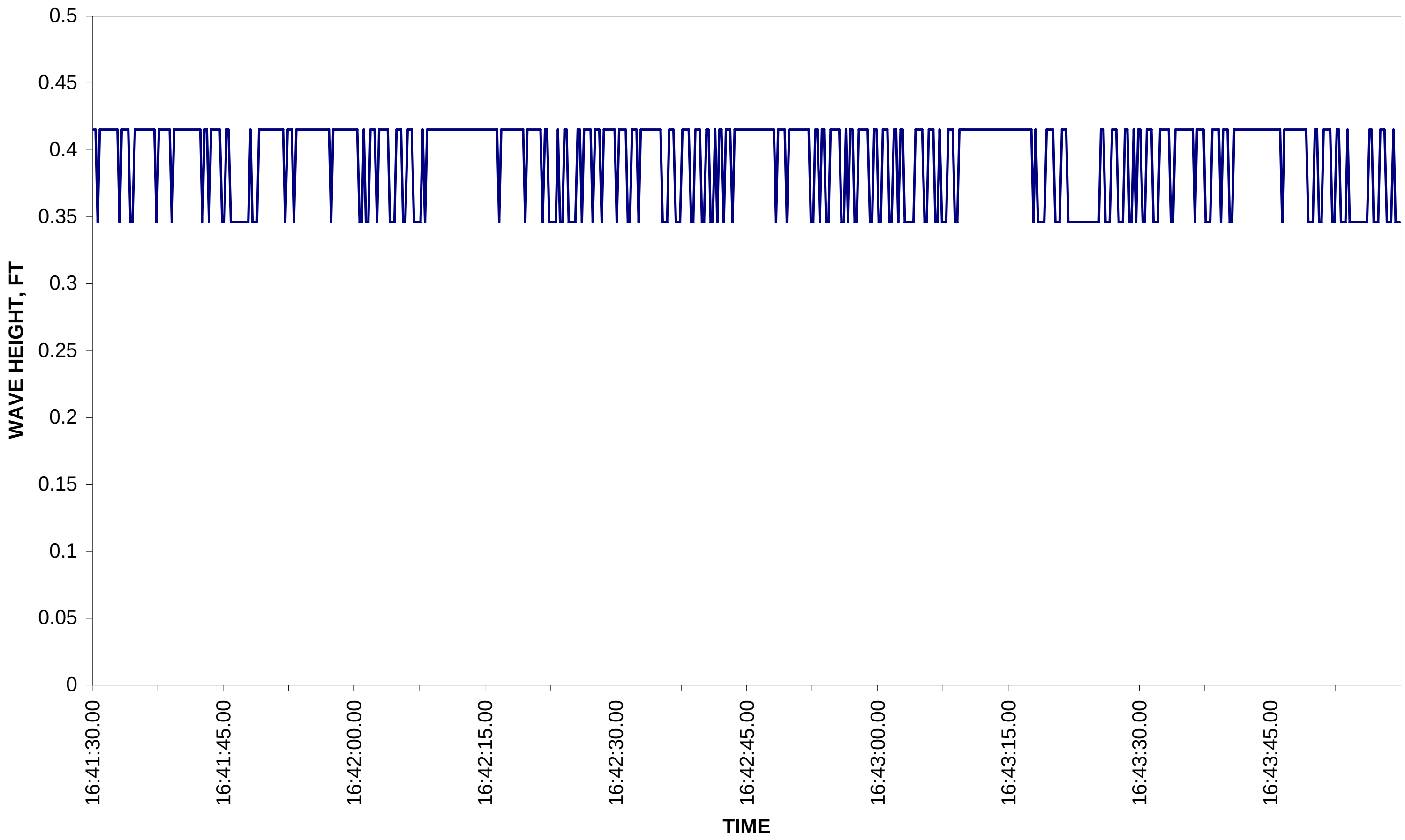
WAVE HEIGHTS

TEST 12, BOAT TYPE II

SAILING LINE S2, UPSTREAM

FULLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



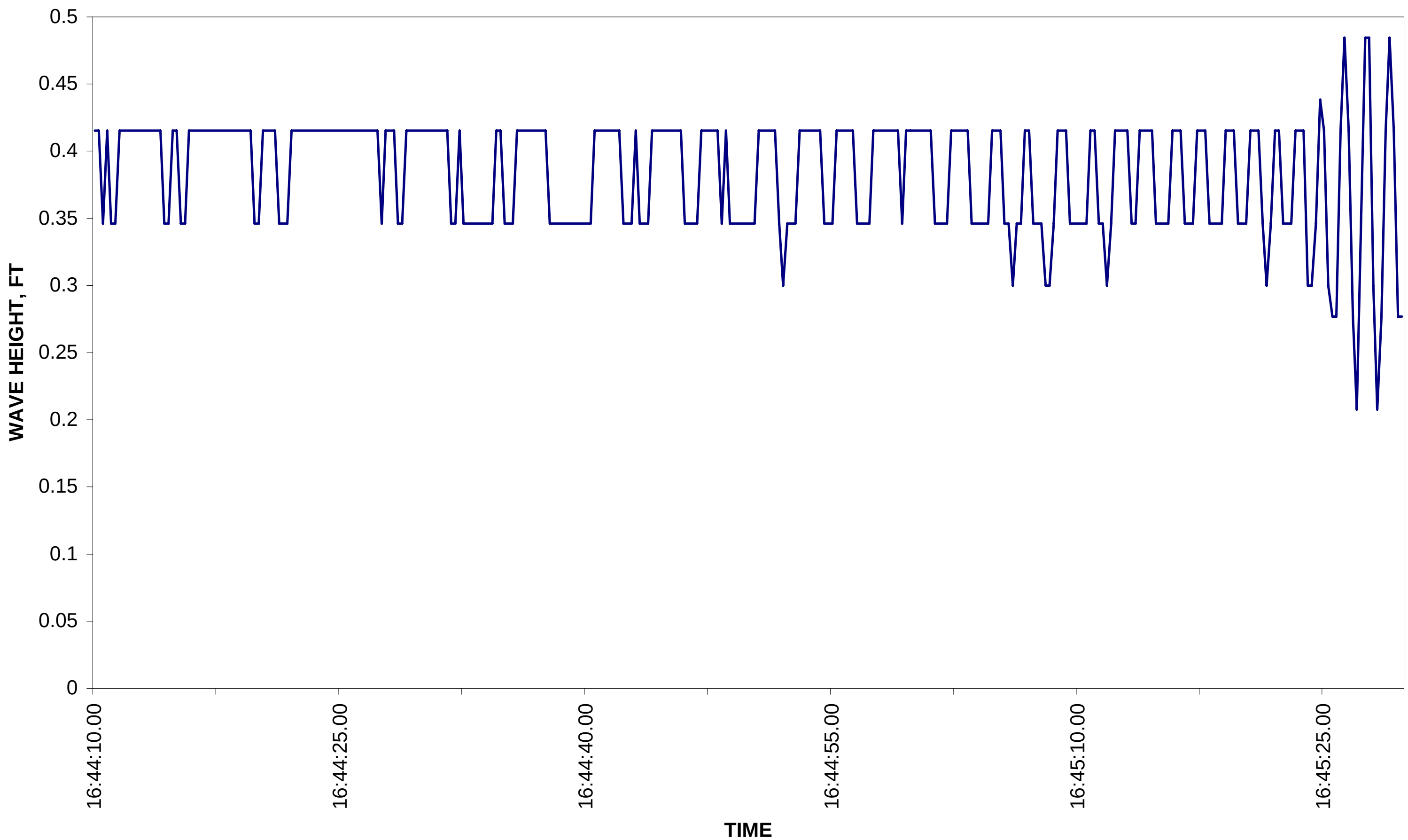
WAVE HEIGHTS

TEST 14, BOAT TYPE II

SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



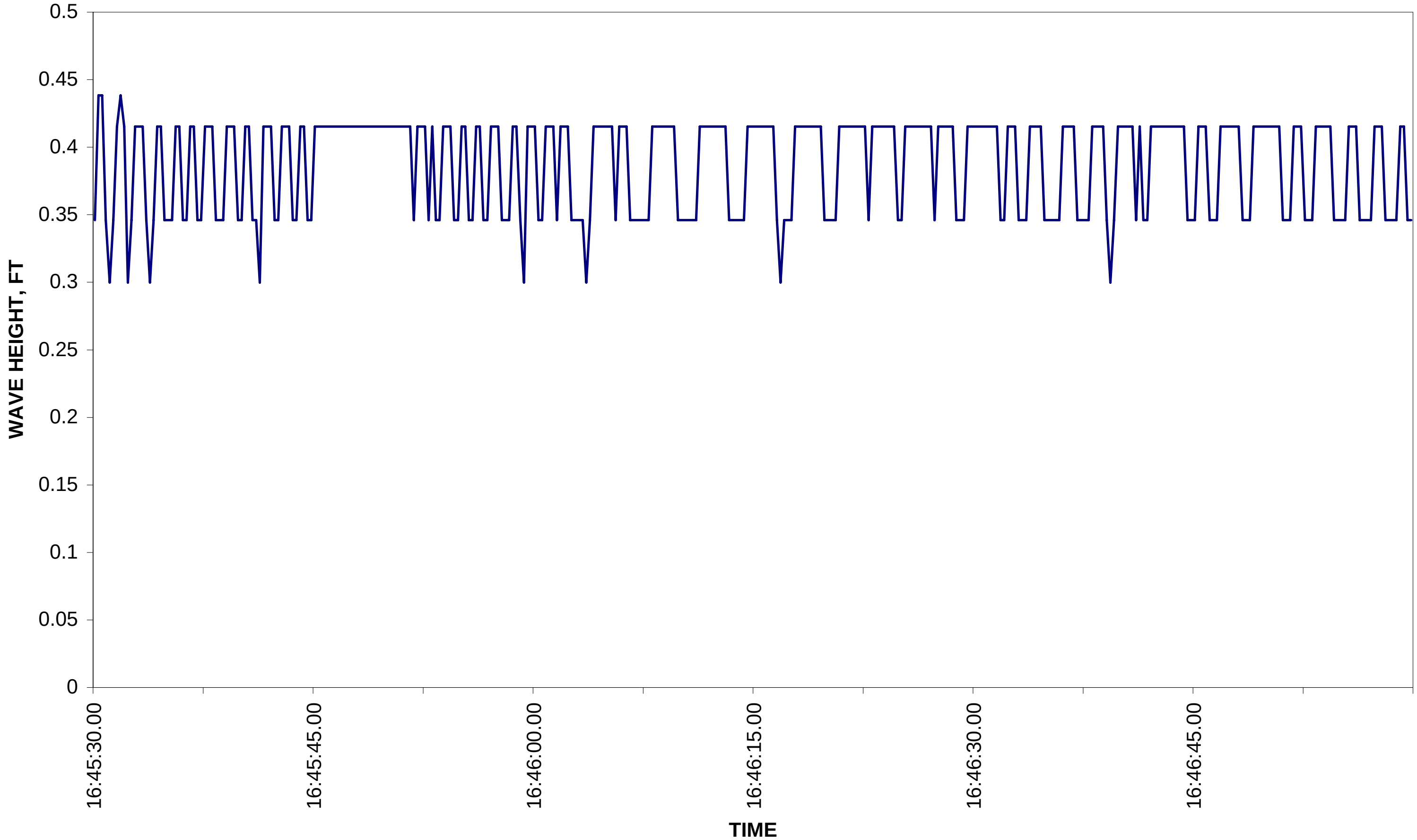
WAVE HEIGHTS

TEST 15, BOAT TYPE II

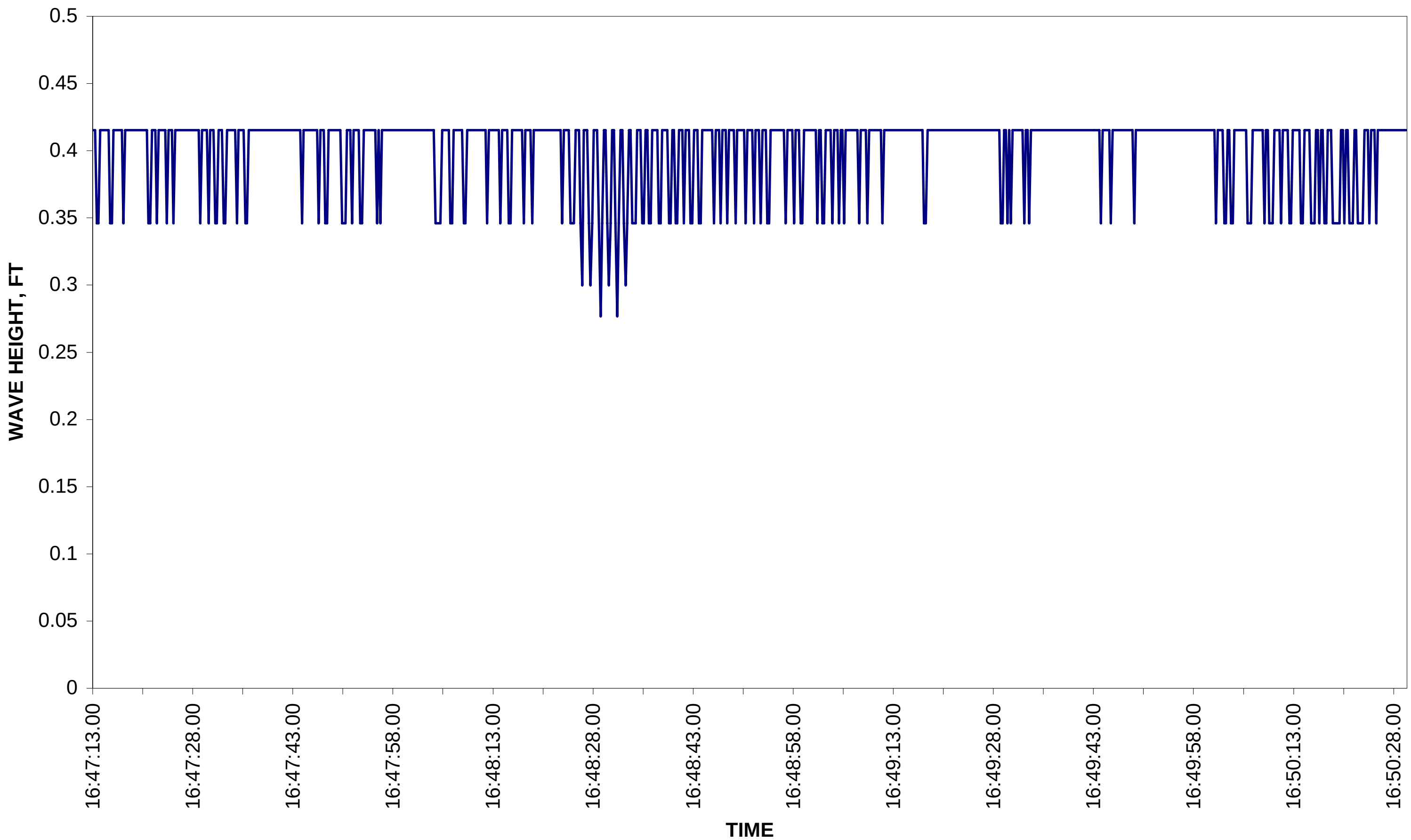
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

11/3/95



WAVE HEIGHTS
TEST 16, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95



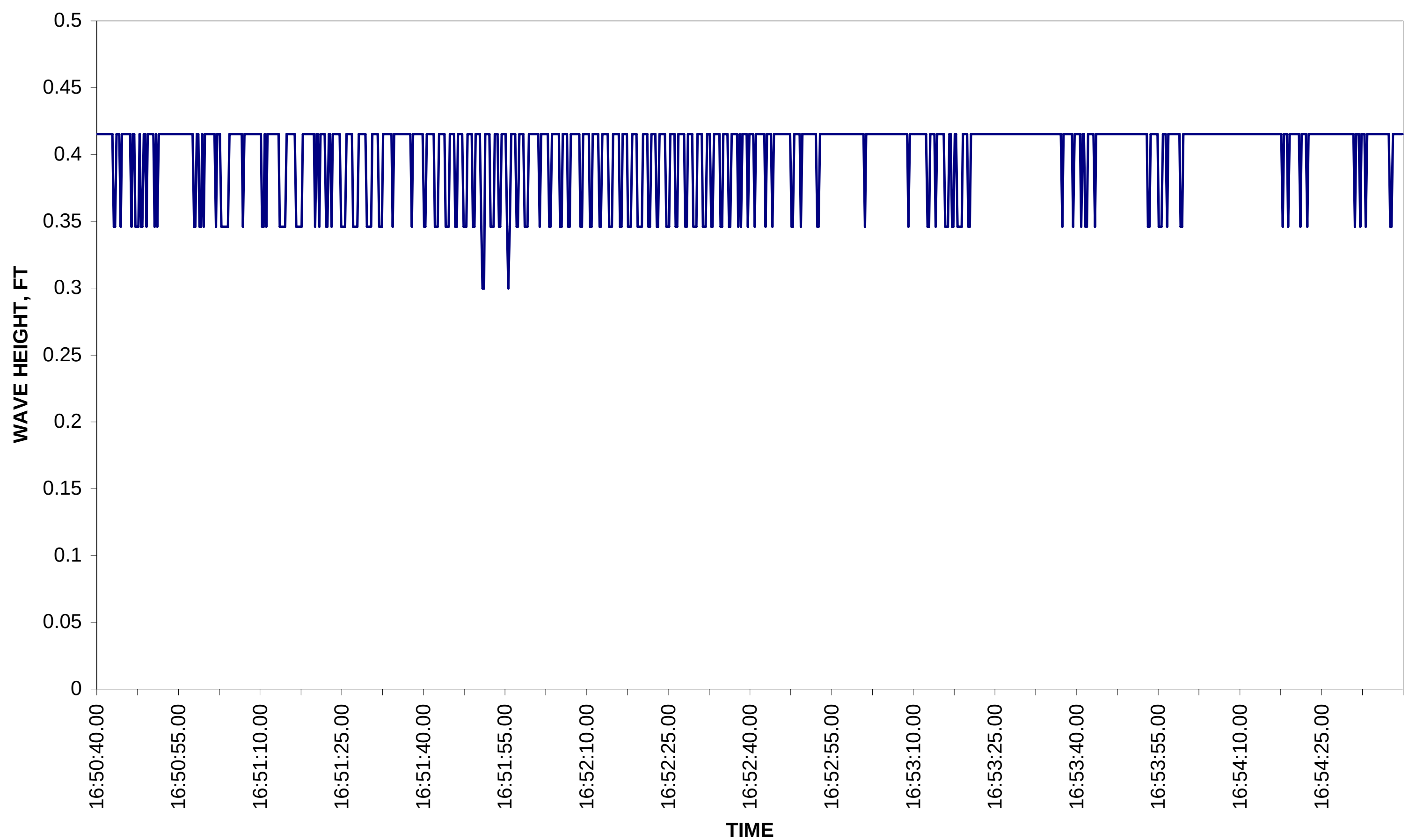
WAVE HEIGHTS

TEST 17, BOAT TYPE II

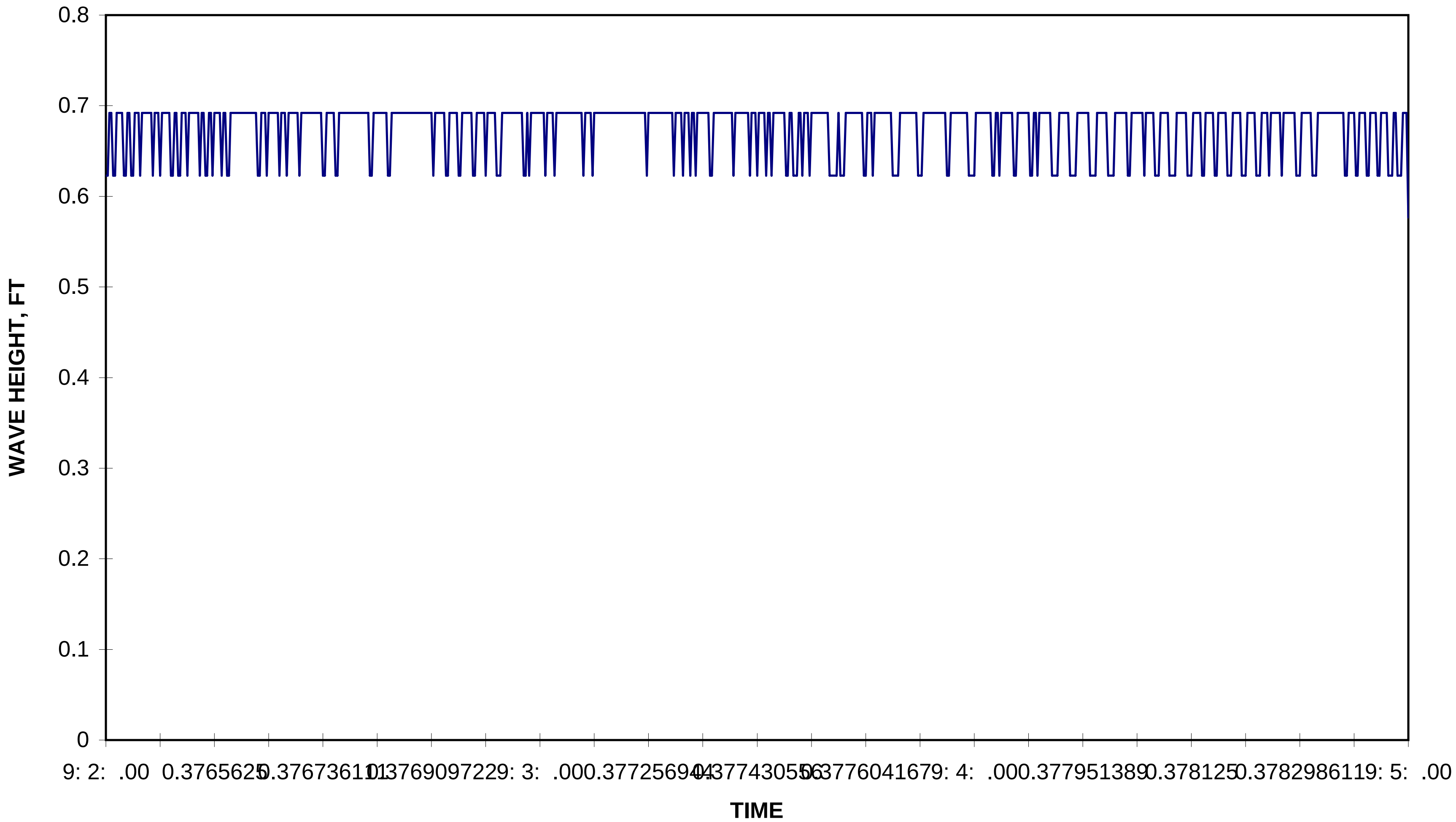
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

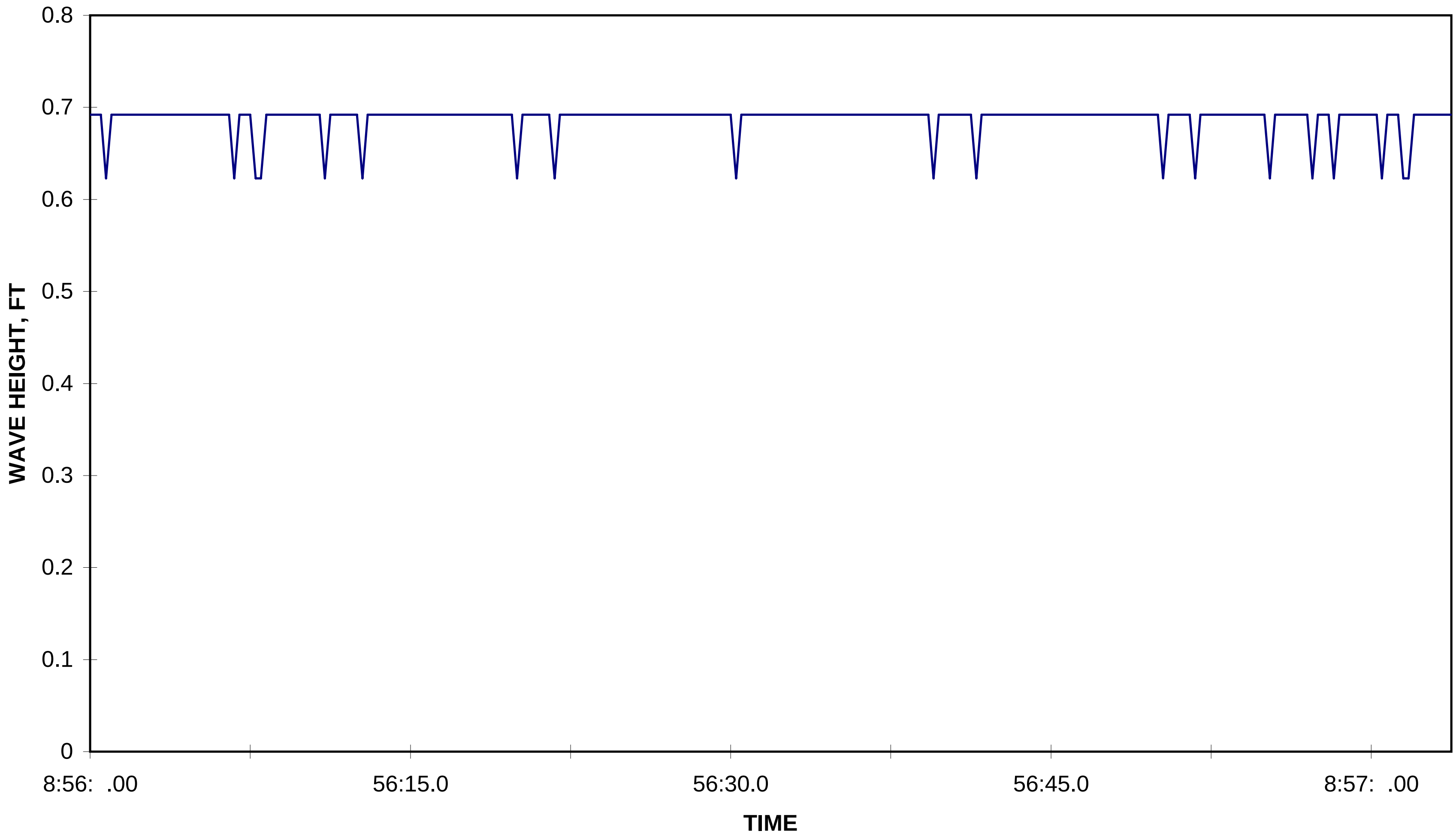
11/3/95



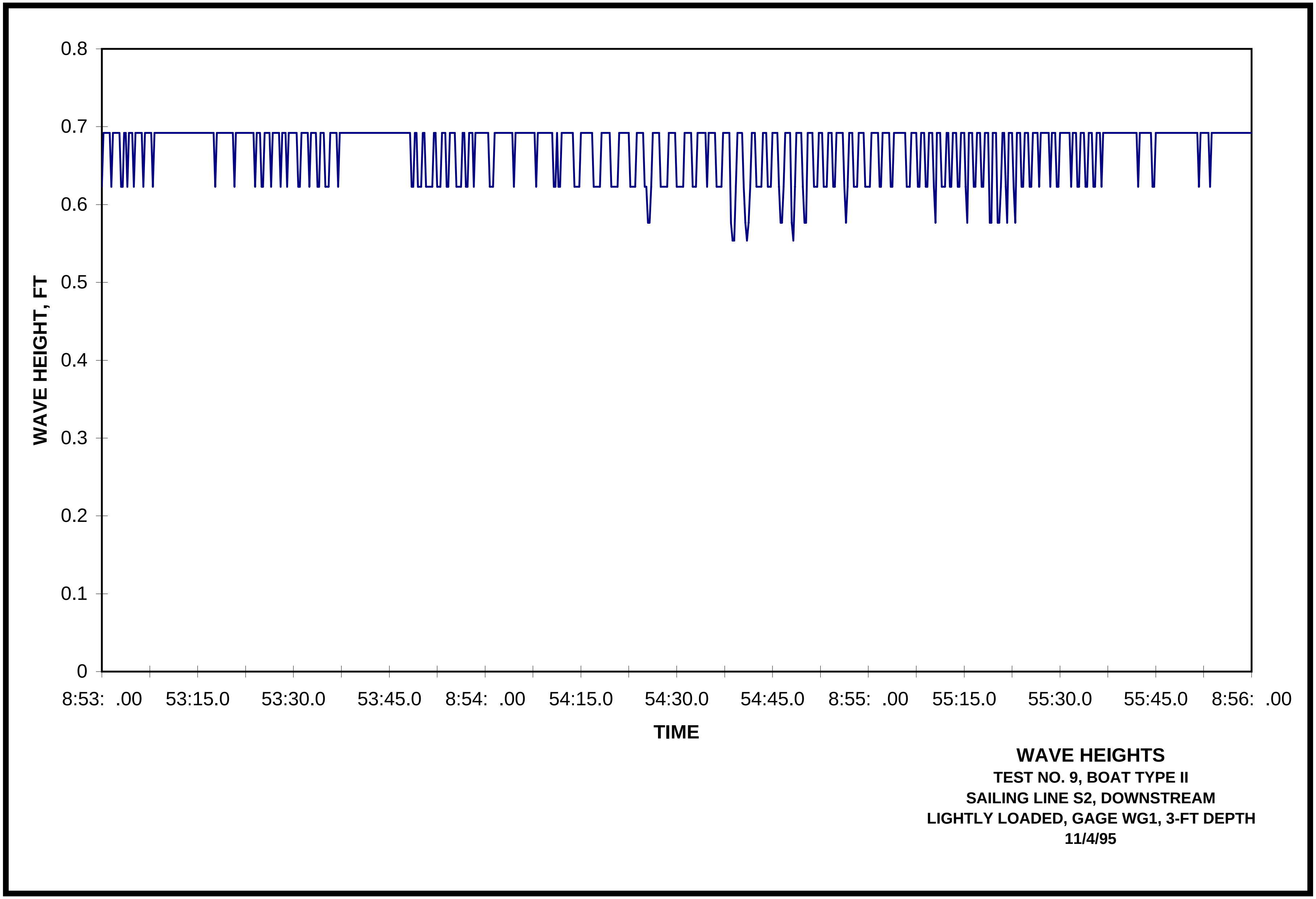
WAVE HEIGHTS
TEST 18, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/3/95

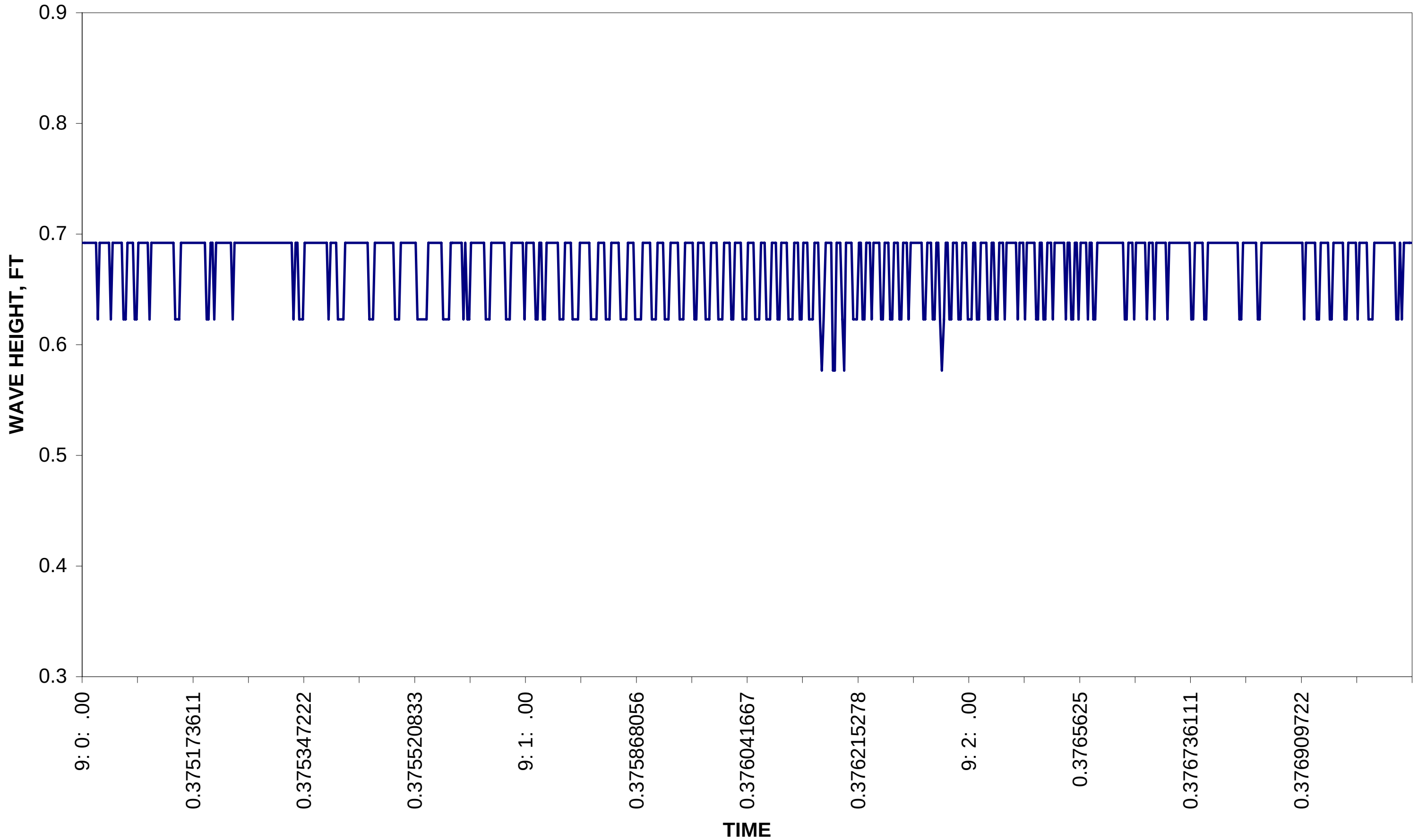


WAVE HEIGHTS
TEST NO. 11, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/4/95



WAVE HEIGHTS
TEST NO. 10, BOAT TYPE II
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/4/95


0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WAVE HEIGHT, FT
8:53: .00
53:15.0
53:30.0
53:45.0
8:54: .00
54:15.0
54:30.0
54:45.0
8:55: .00
55:15.0
55:30.0
55:45.0
8:56: .00
TIME
WAVE HEIGHTS
TEST NO. 9, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/4/95



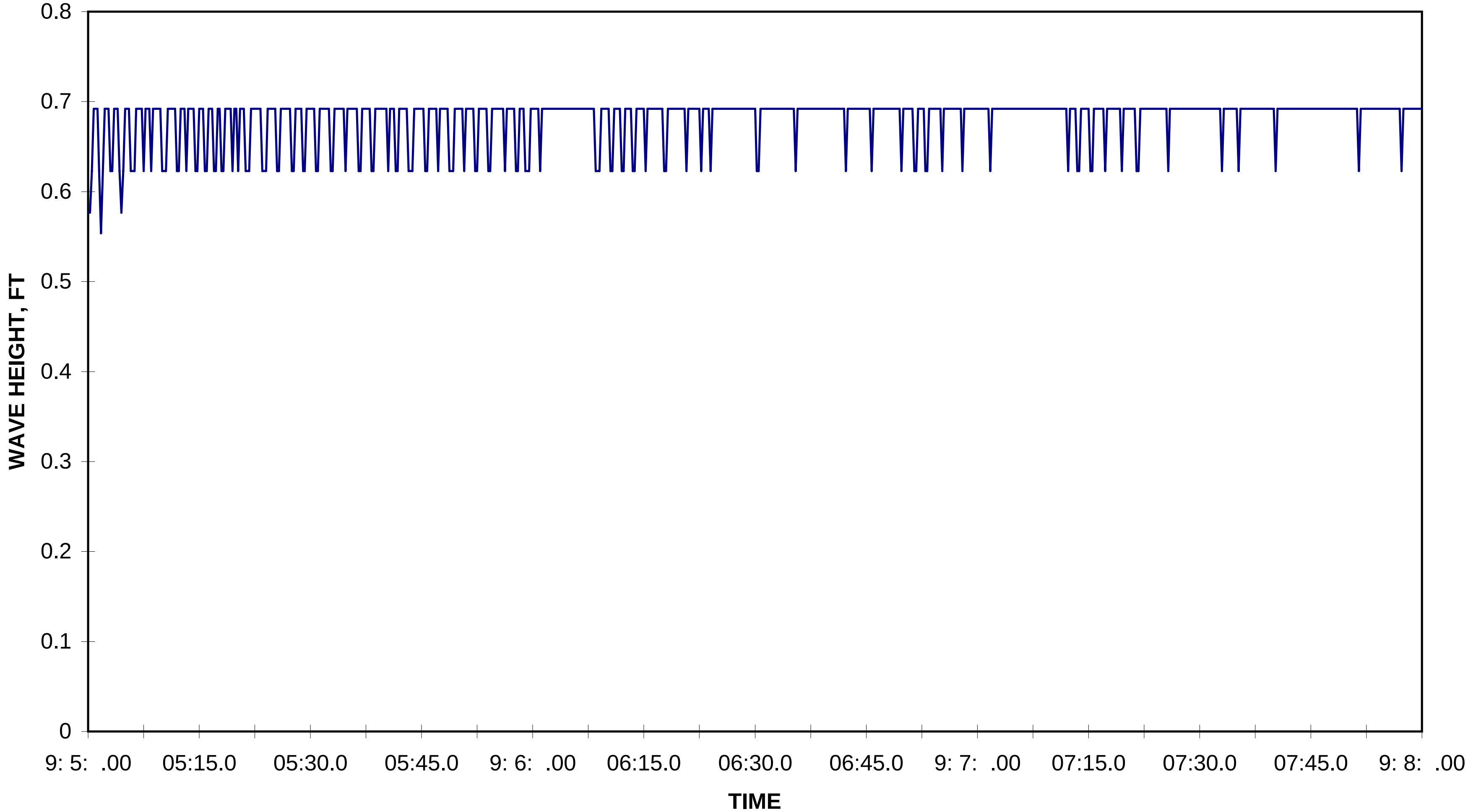
WAVE HEIGHTS

TEST 23, BOAT TYPE II

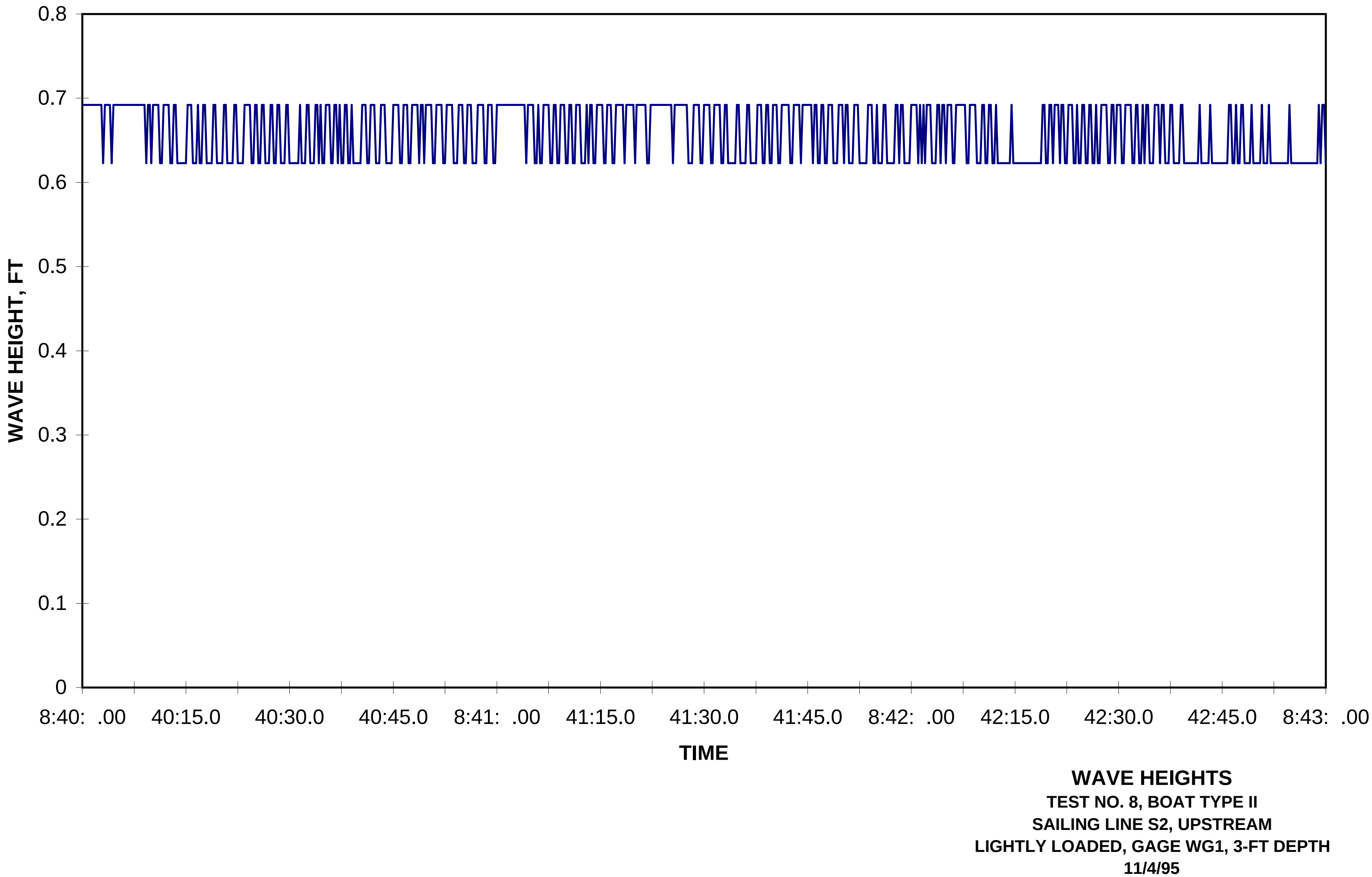
SAILING LINE S2, DOWNSTREAM

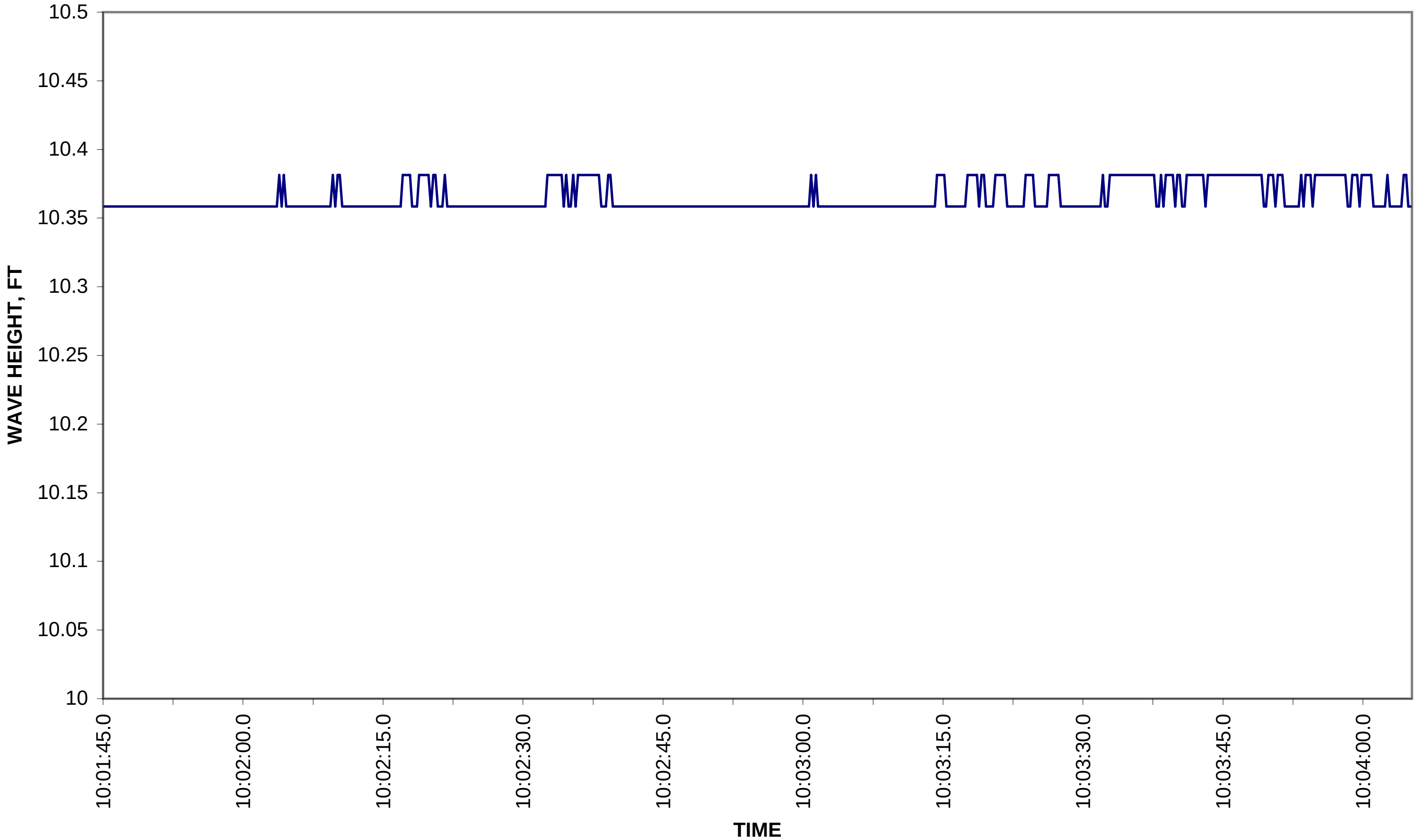
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

11/4/95

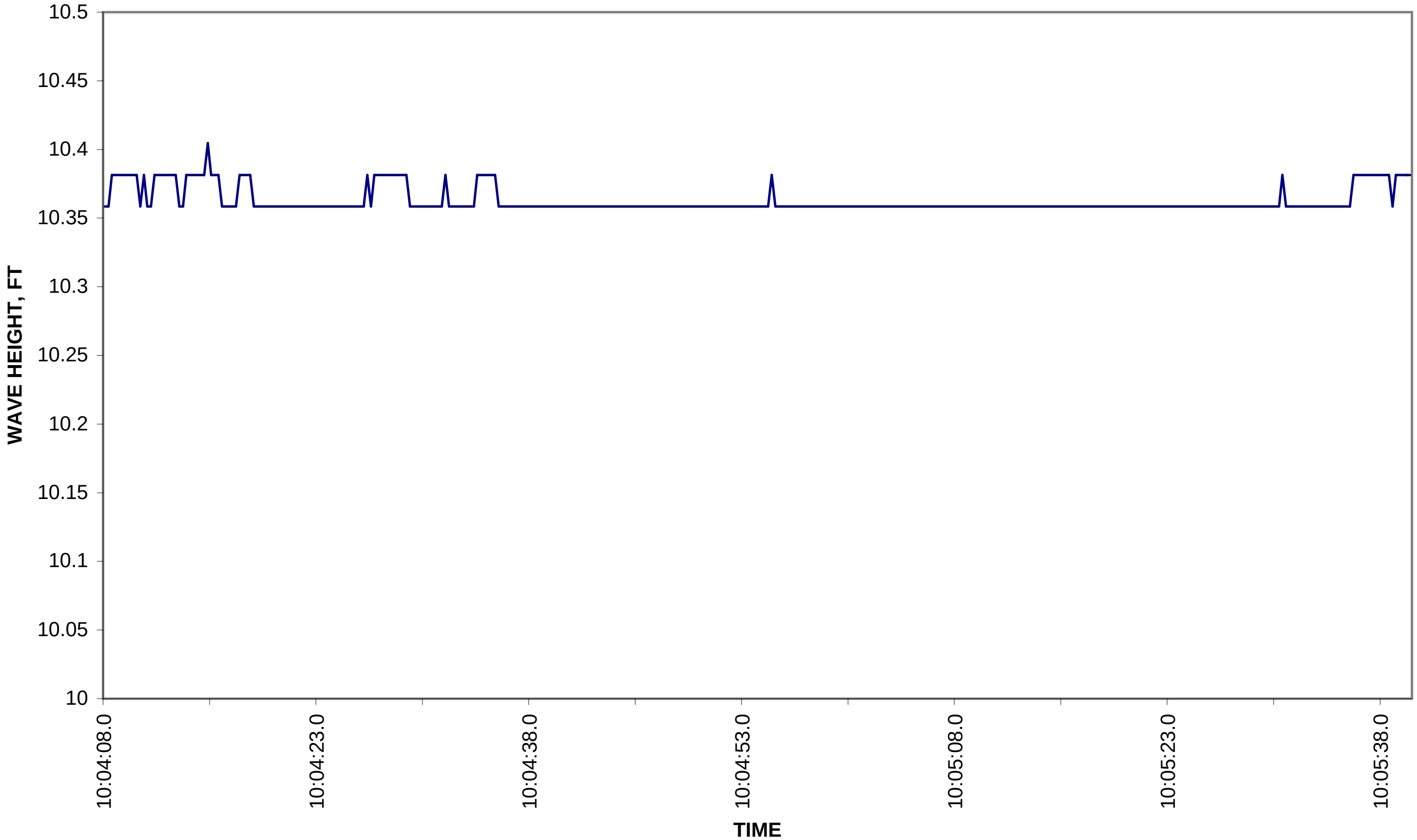


WAVE HEIGHTS
TEST NO. 12, BOAT TYPE II
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/4/95

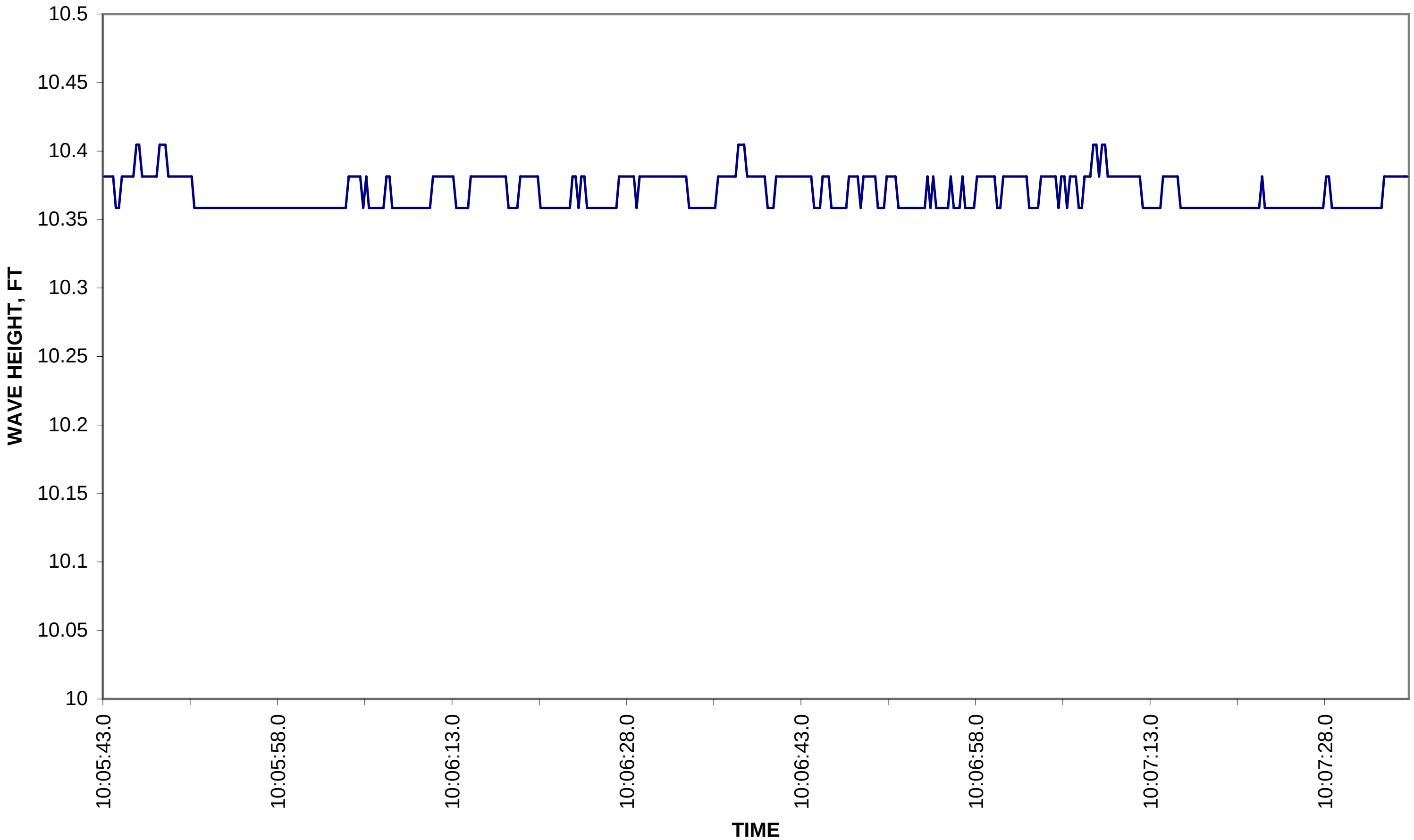

0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
WAVE HEIGHT, FT
8:40: .00
40:15.0
40:30.0
40:45.0
8:41: .00
41:15.0
41:30.0
41:45.0
8:42: .00
42:15.0
42:30.0
42:45.0
8:43: .00
TIME
WAVE HEIGHTS
TEST NO. 8, BOAT TYPE II
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/4/95



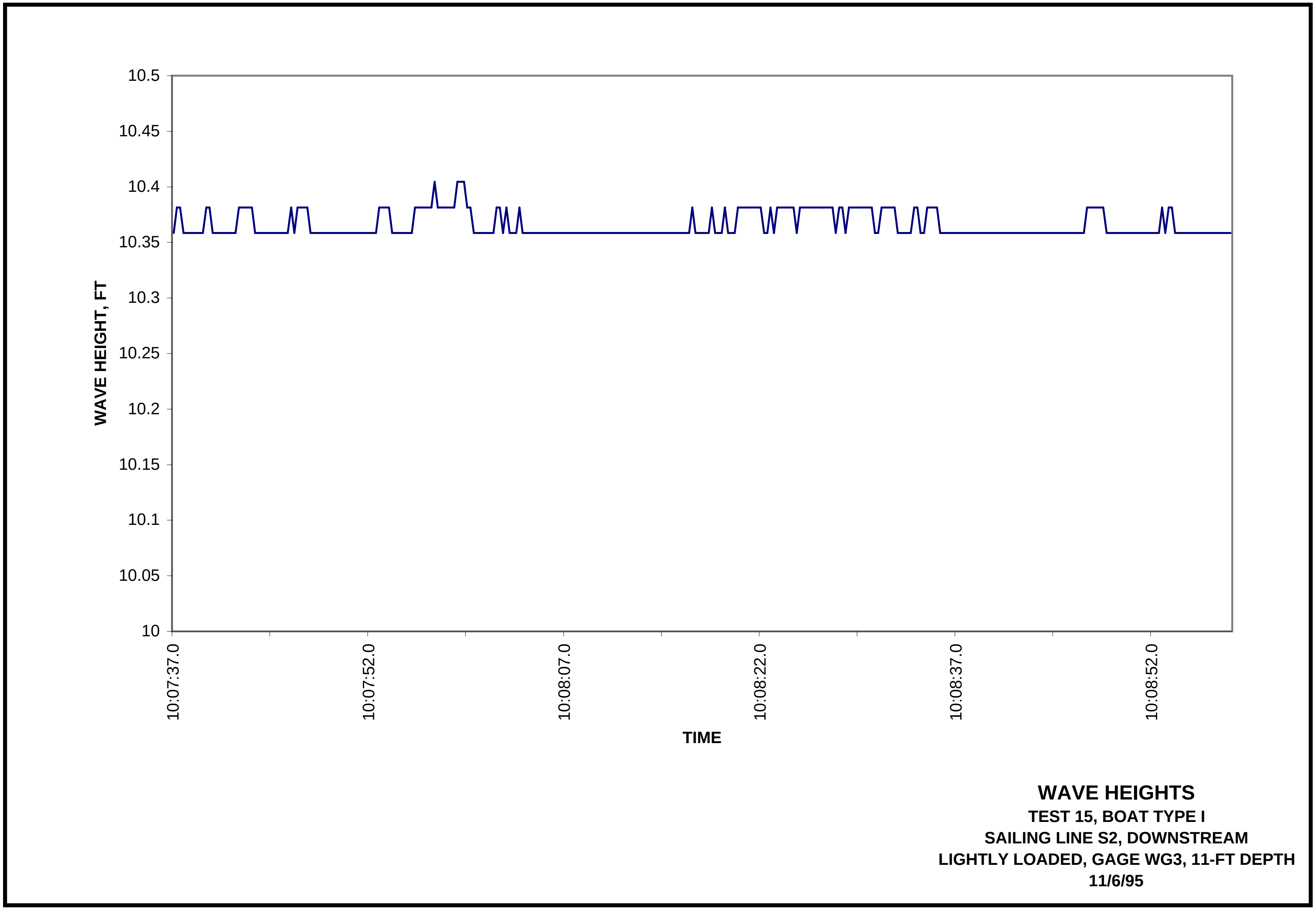
WAVE HEIGHTS
TEST 12, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



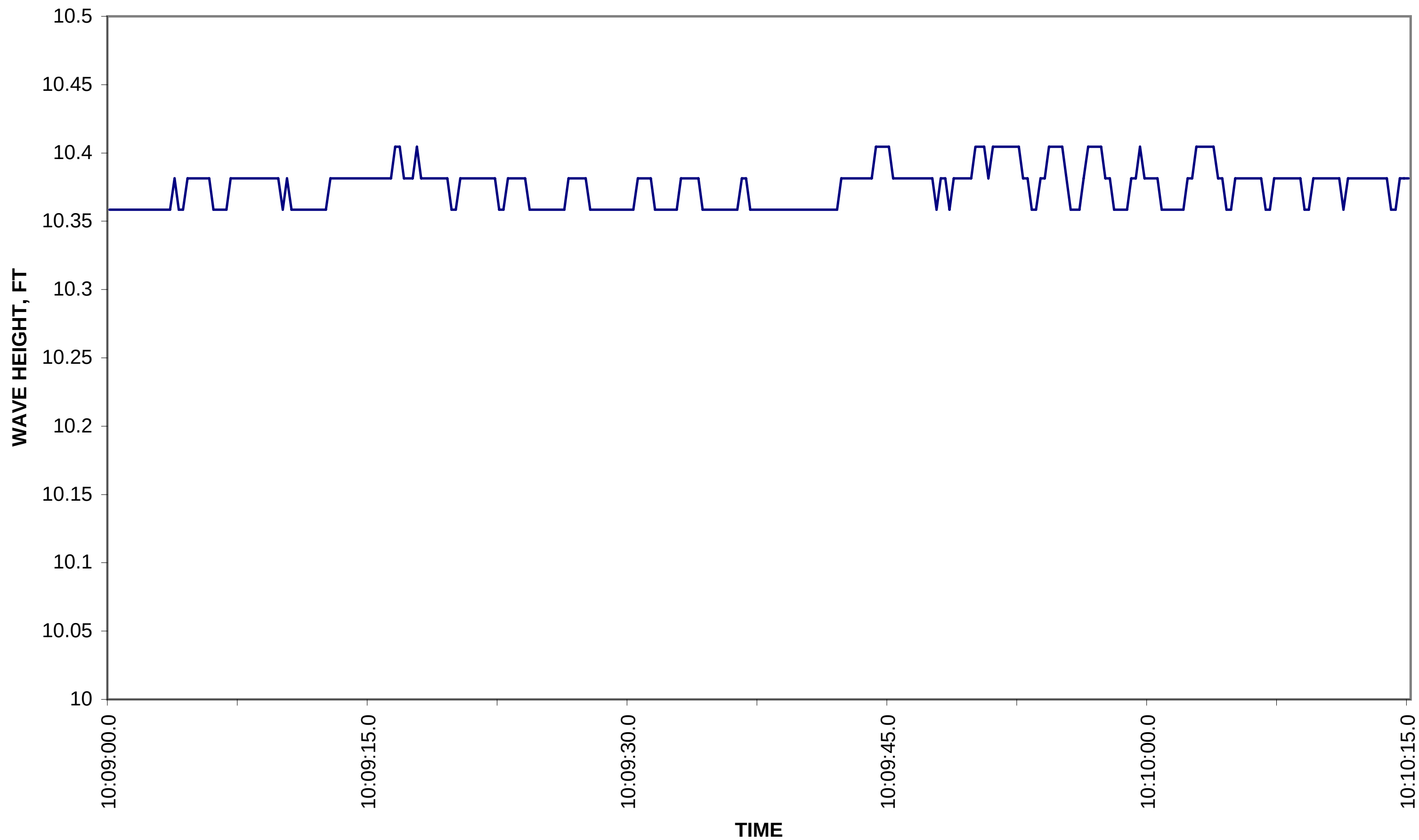
WAVE HEIGHTS
TEST 13, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



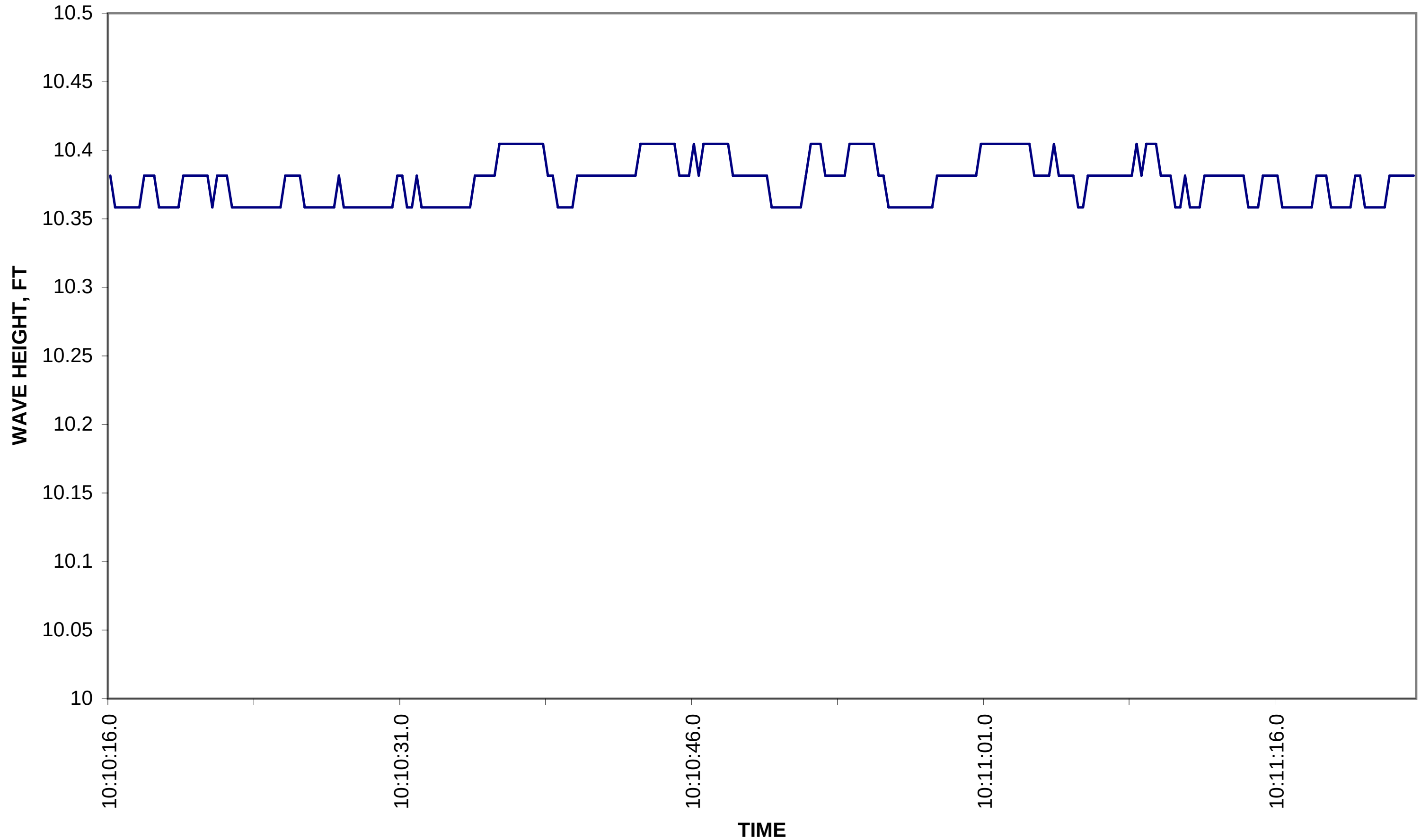
WAVE HEIGHTS
TEST 14, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



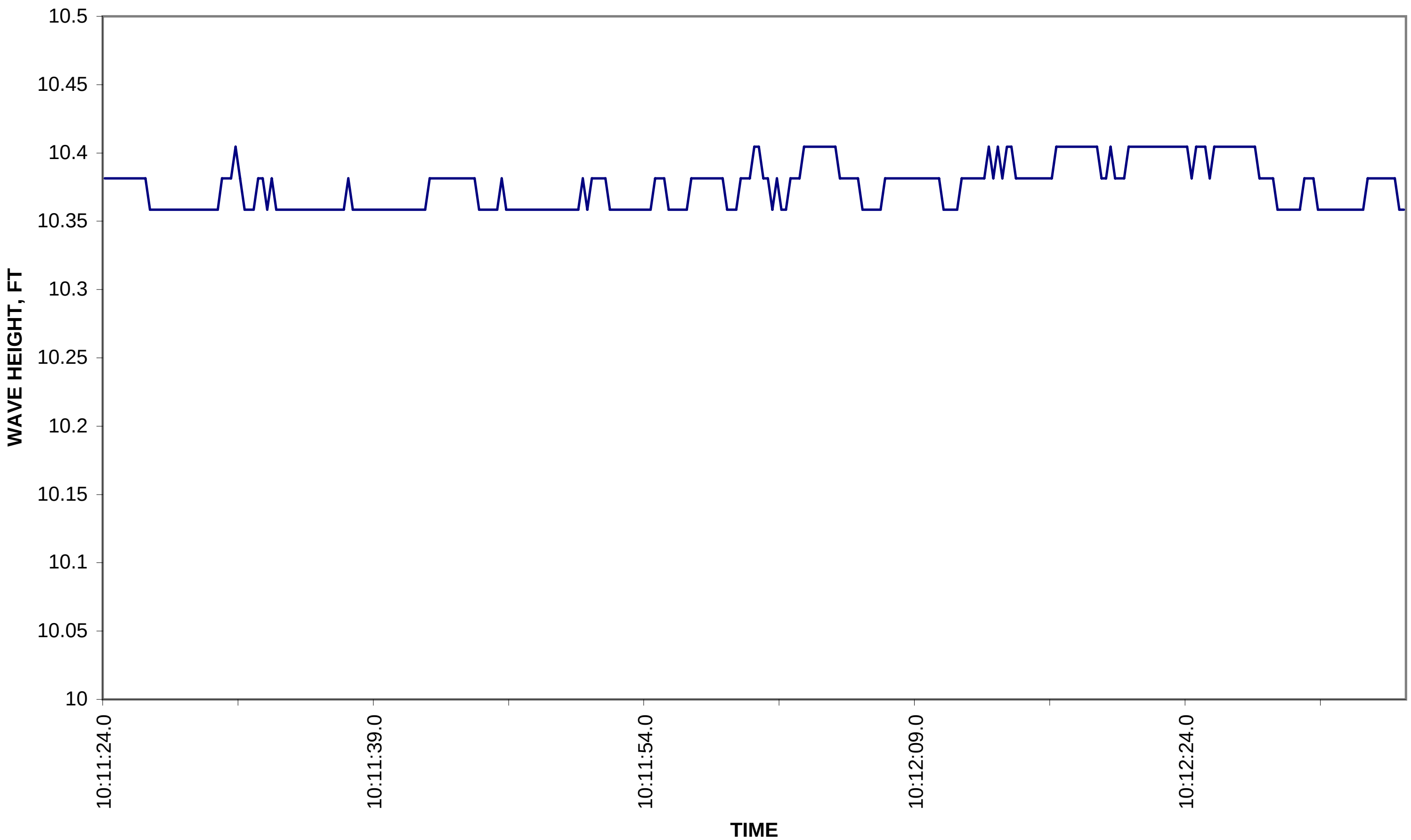
10.5
10.45
10.4
10.35
10.3
10.25
10.2
10.15
10.1
10.05
10
WAVE HEIGHT, FT
10:07:37.0
10:07:52.0
10:08:07.0
10:08:22.0
10:08:37.0
10:08:52.0
TIME
WAVE HEIGHTS
TEST 15, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 16, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 17, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



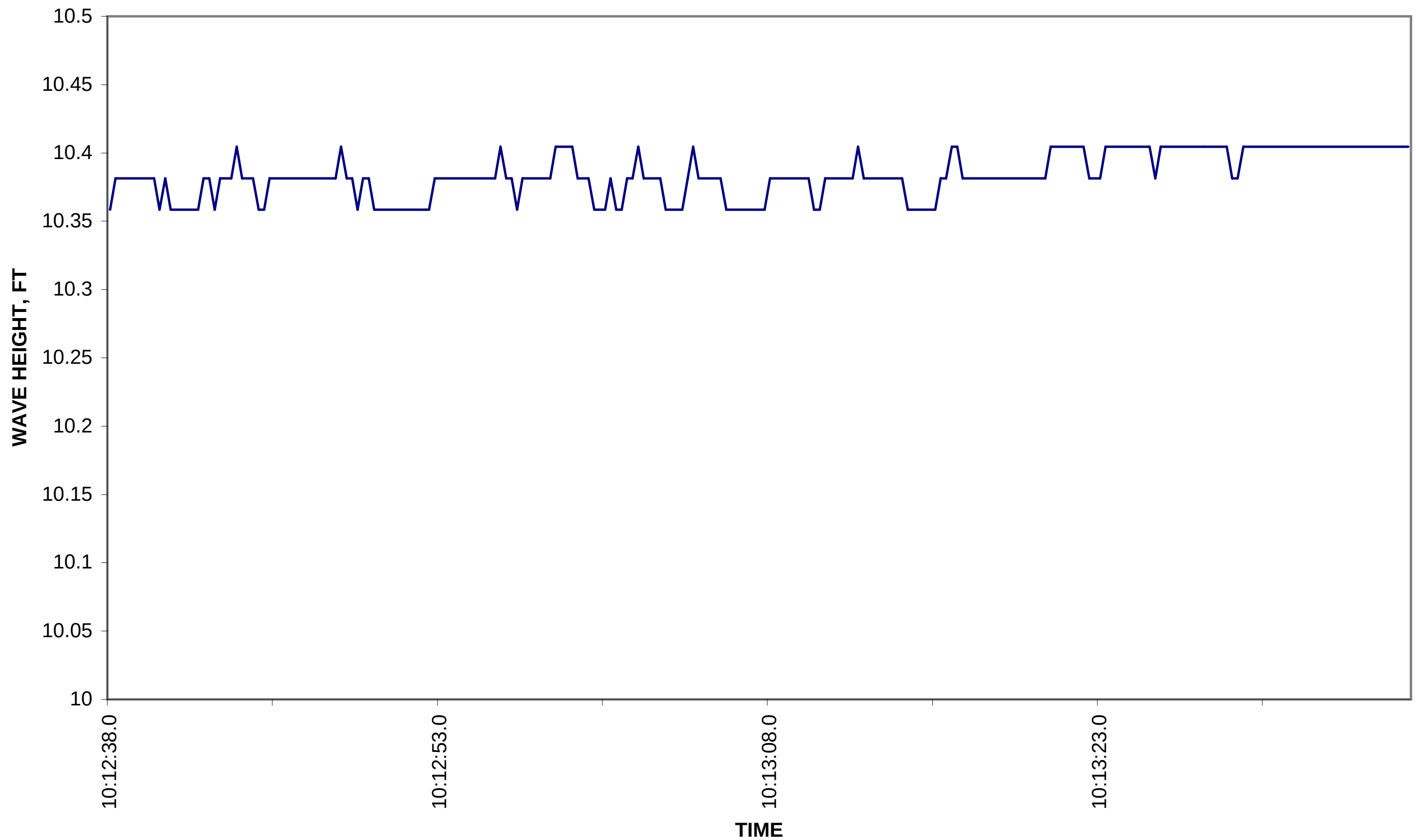
WAVE HEIGHTS

TEST 18, BOAT TYPE I

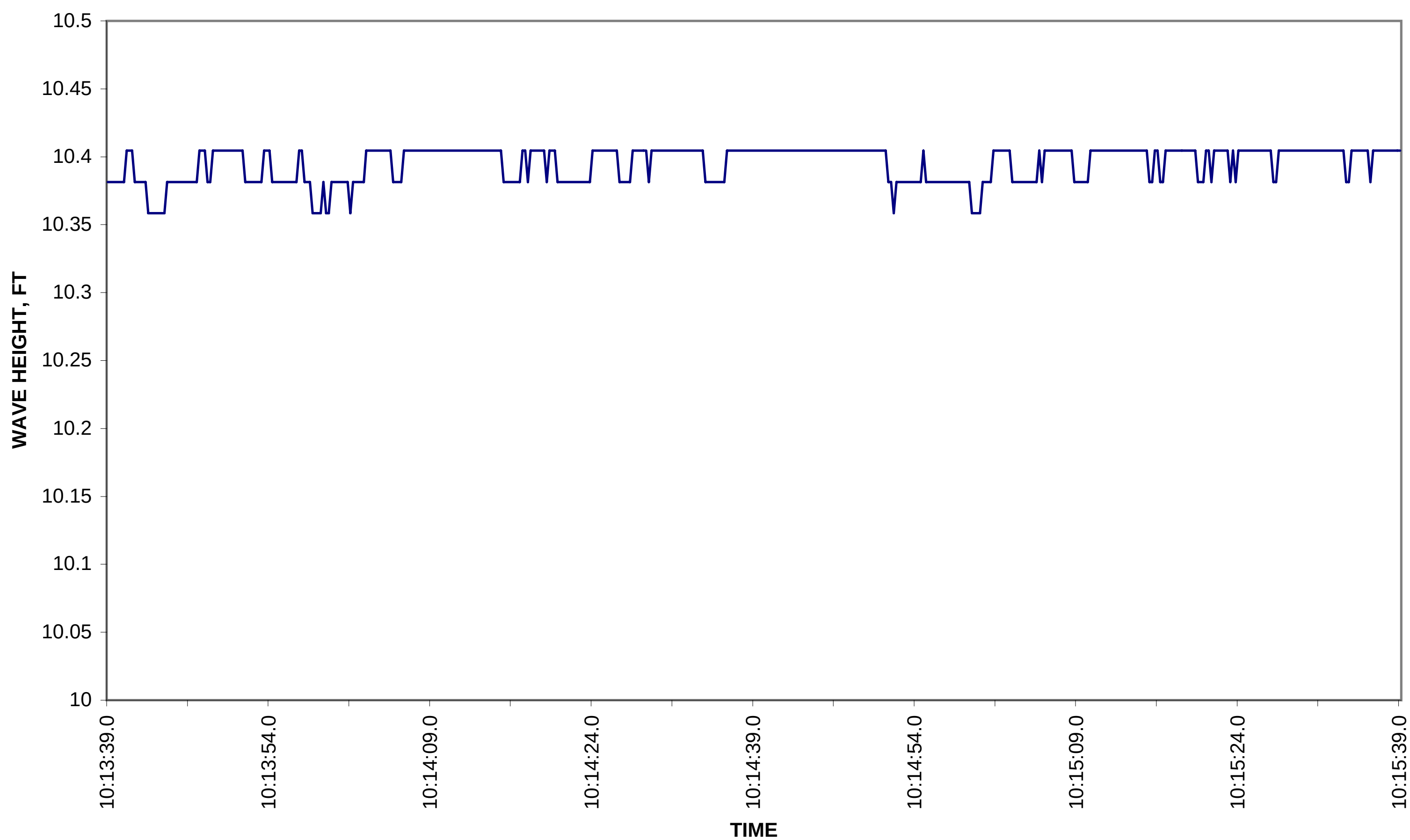
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

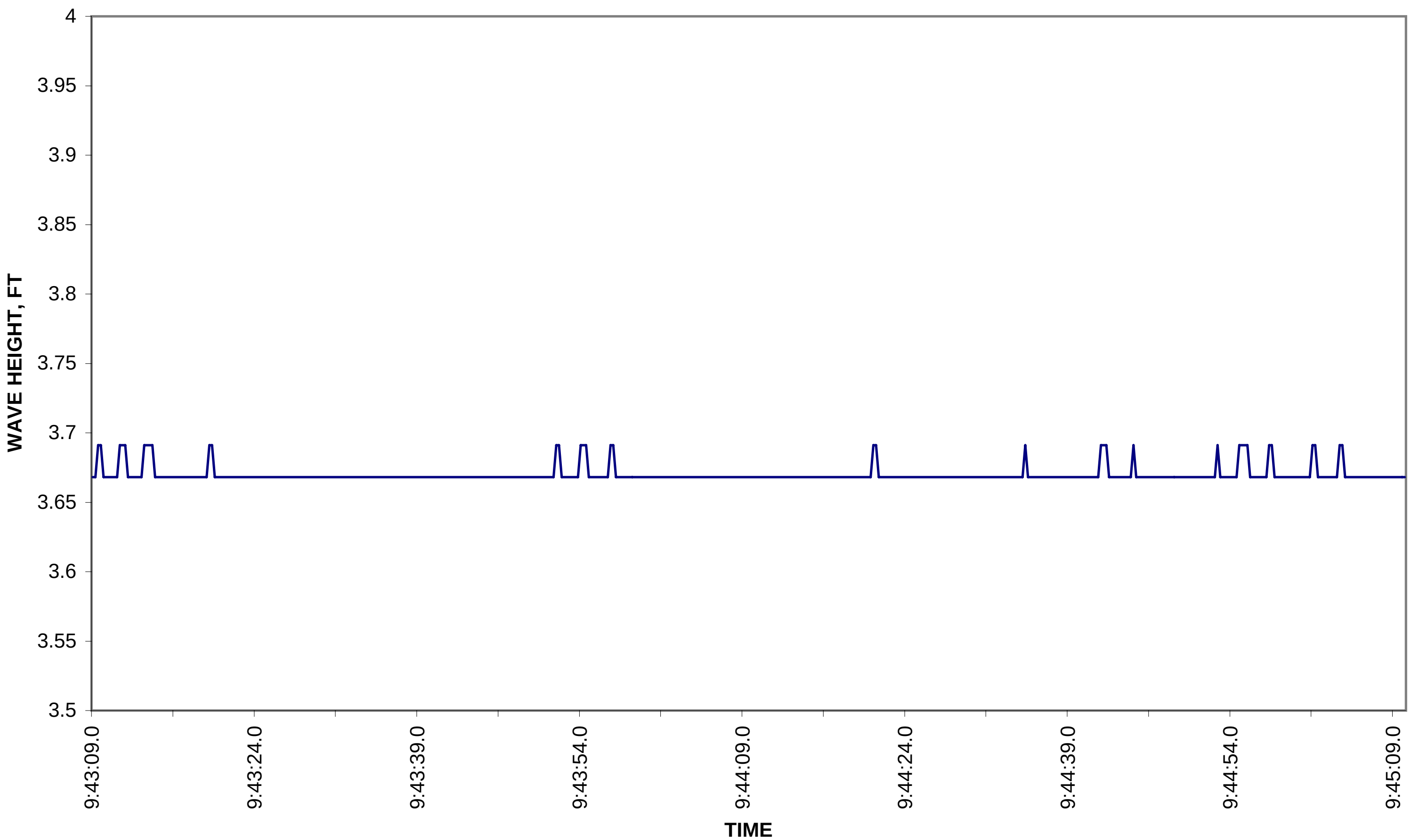
11/6/95



WAVE HEIGHTS
TEST 19, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 20, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/6/95



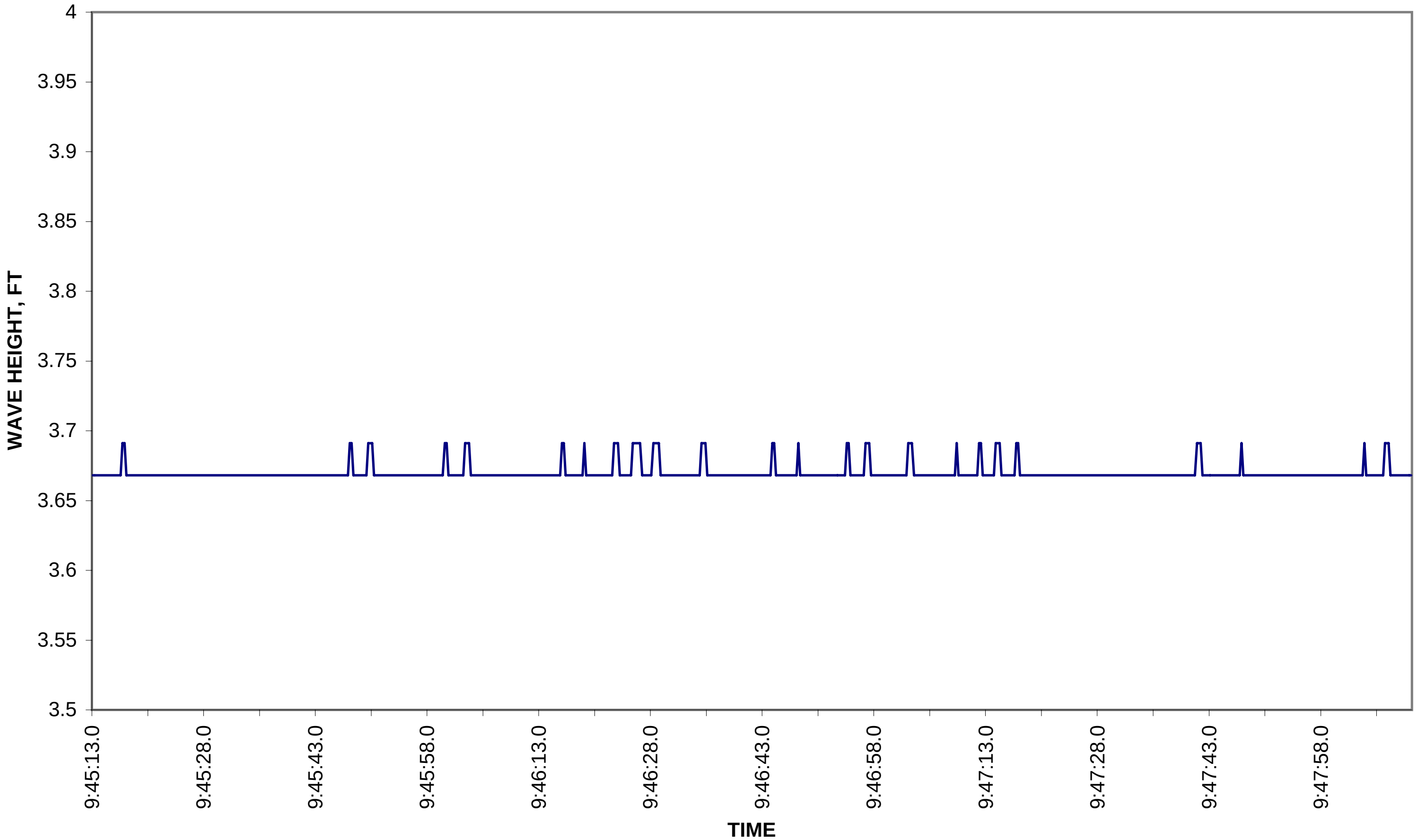
WAVE HEIGHTS

TEST 1, BOAT TYPE I

SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/6/95



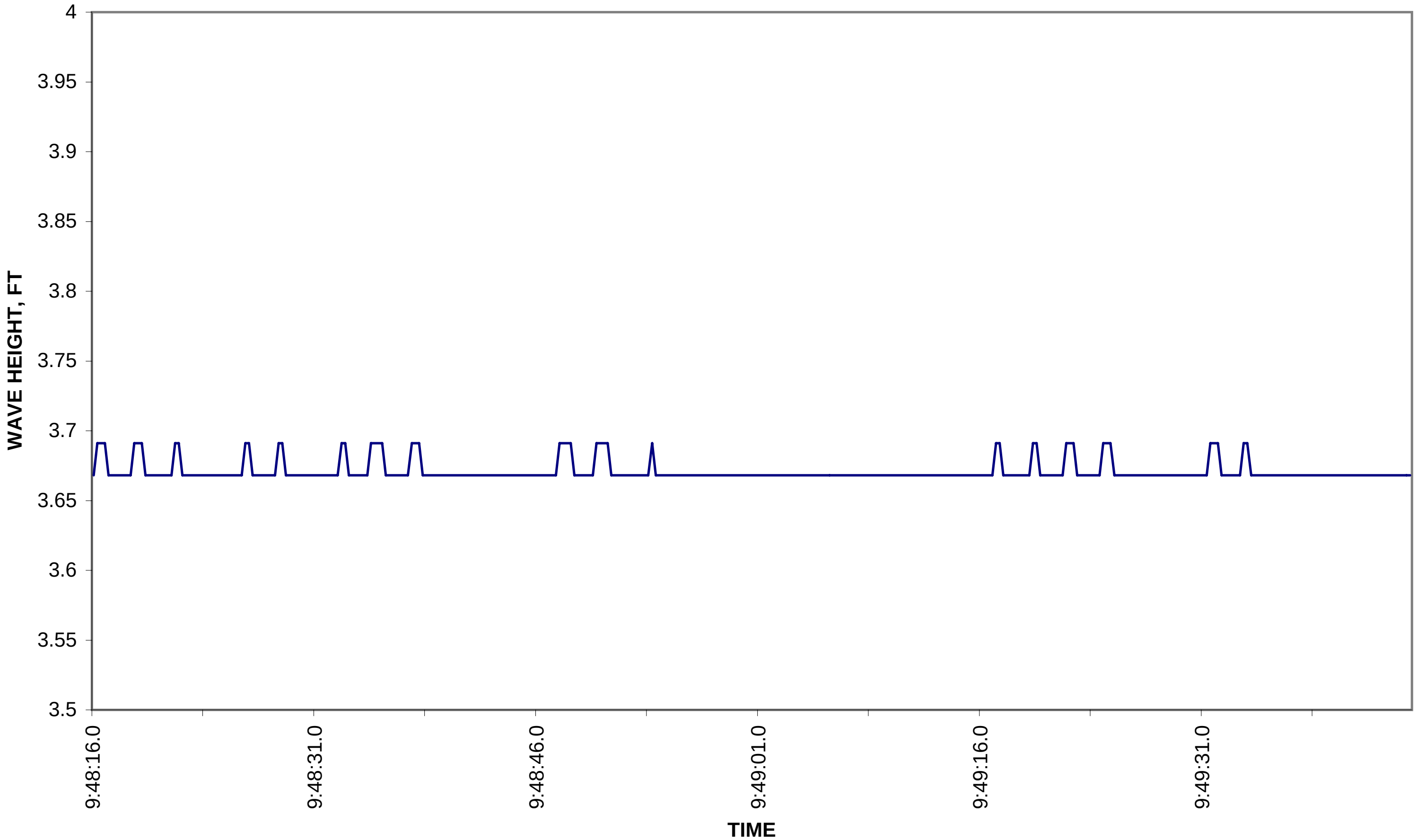
WAVE HEIGHTS

TEST 2, BOAT TYPE I

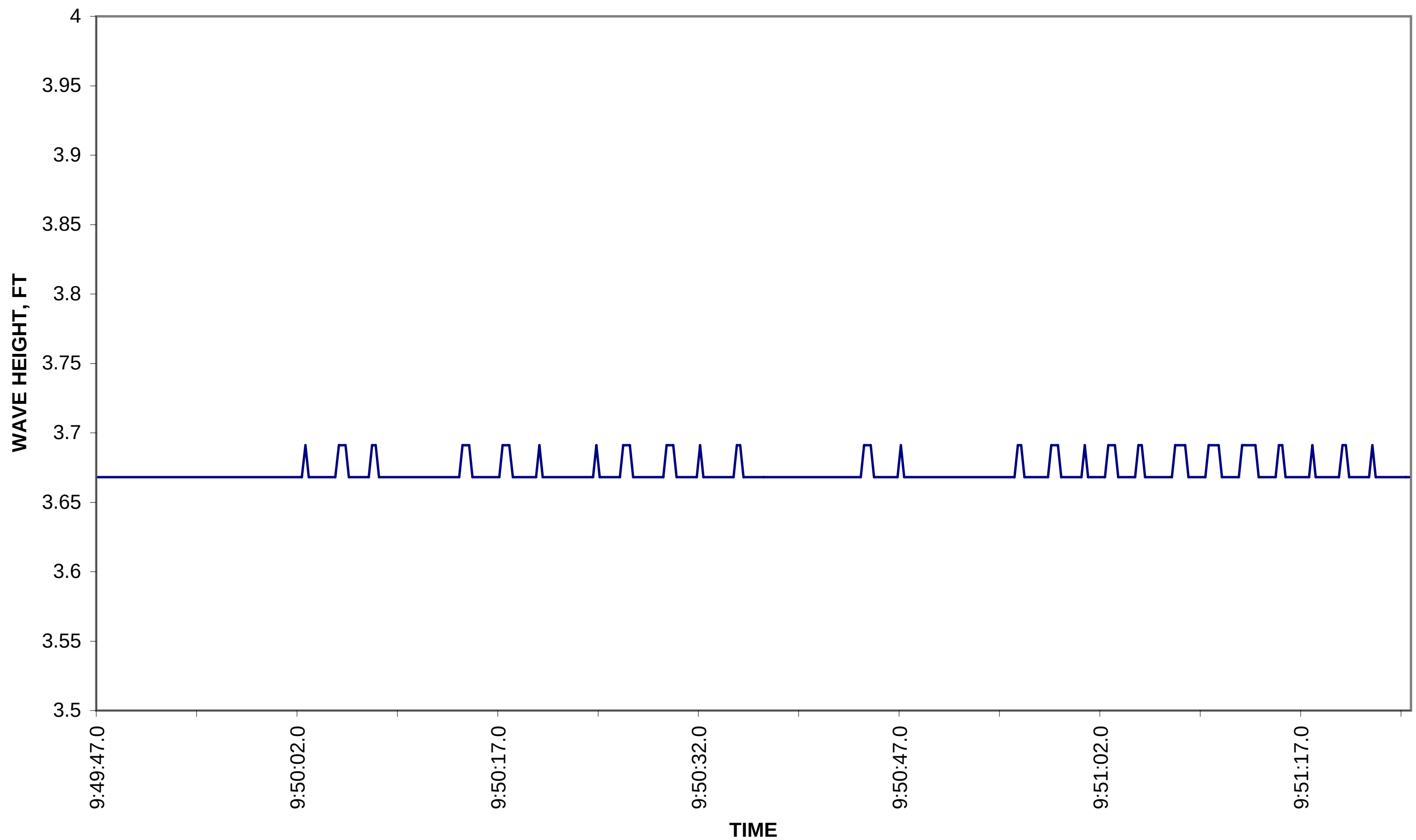
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/6/95



WAVE HEIGHTS
TEST 3, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/6/95



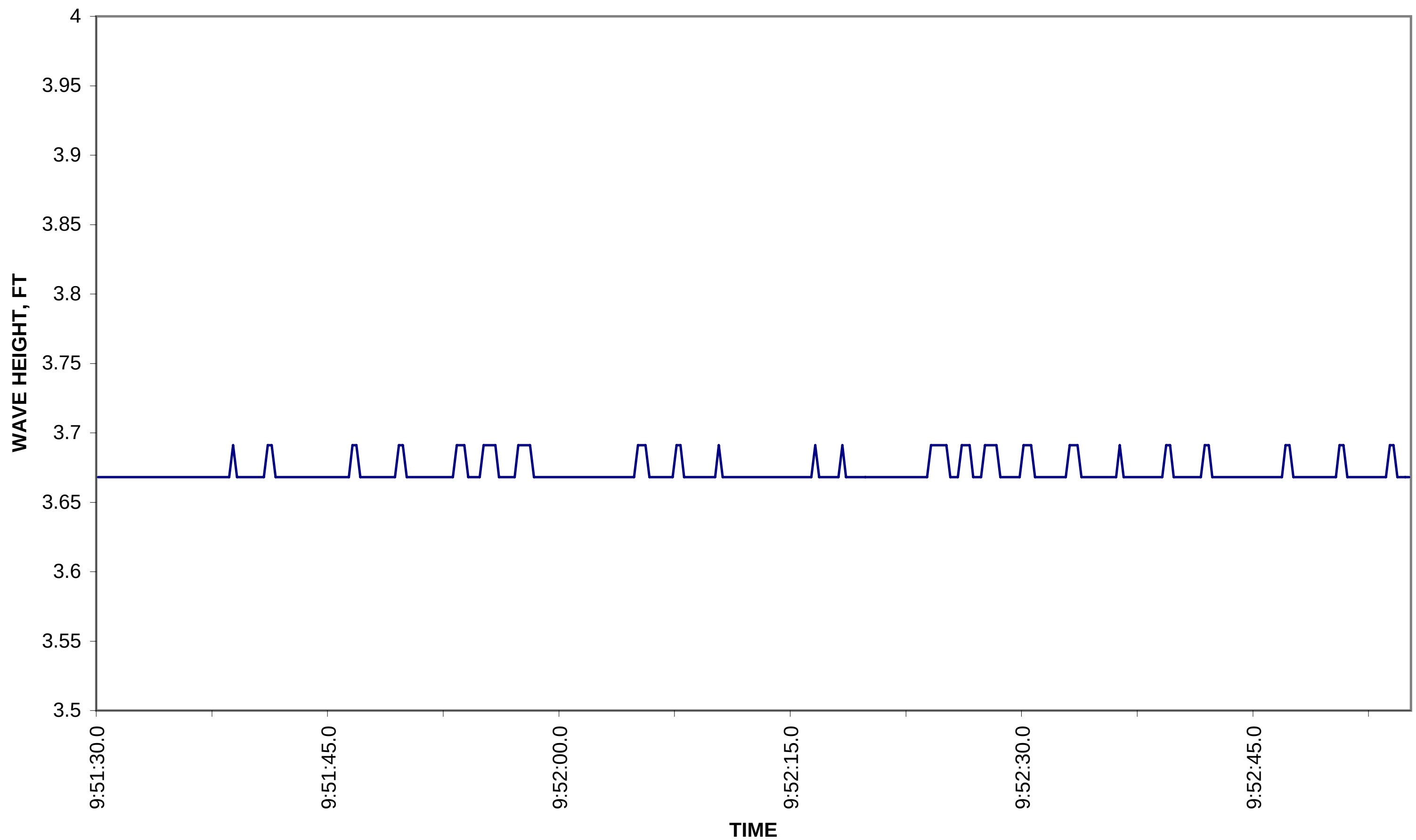
WAVE HEIGHTS

TEST 4, BOAT TYPE I

SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/6/95



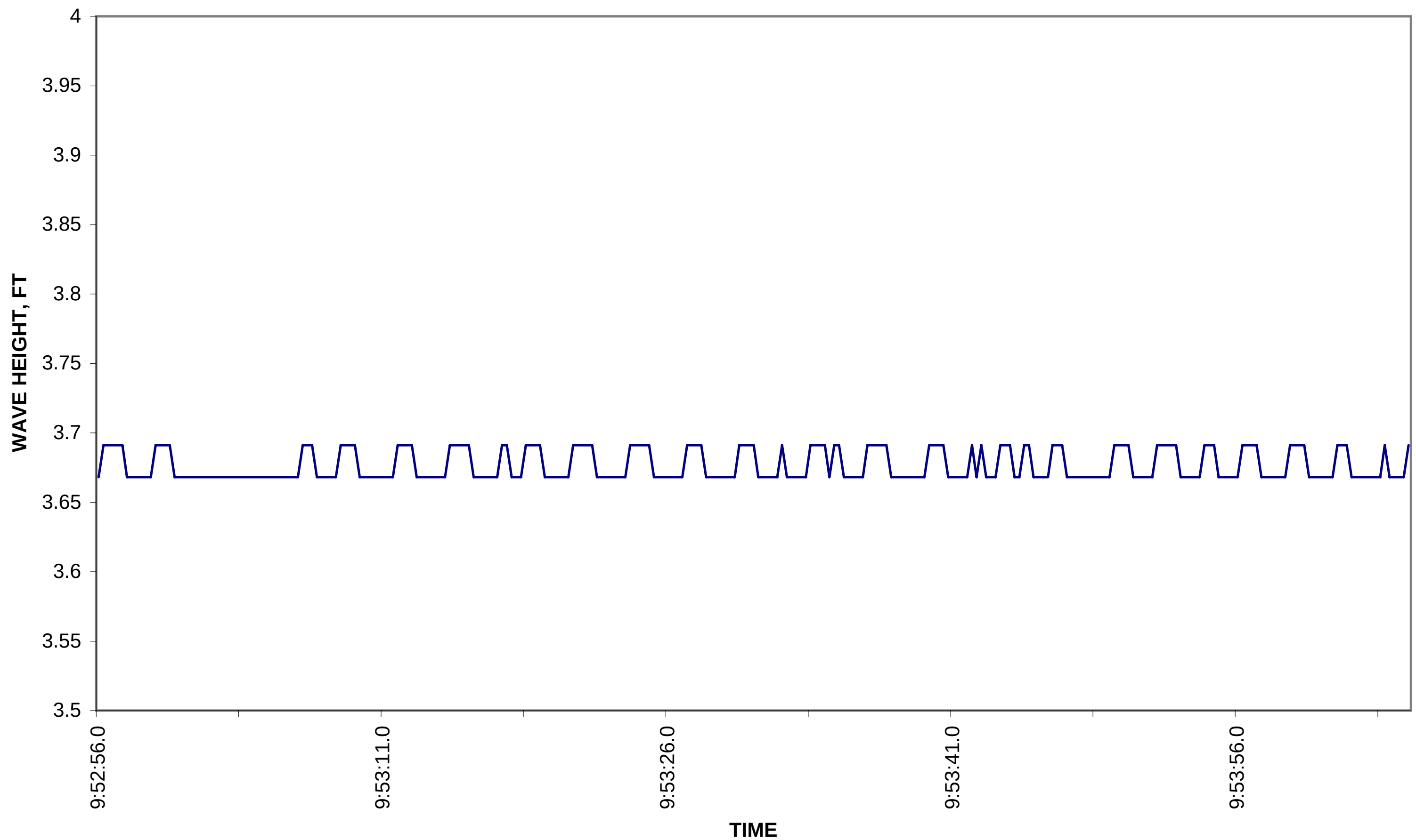
WAVE HEIGHTS

TEST 5, BOAT TYPE I

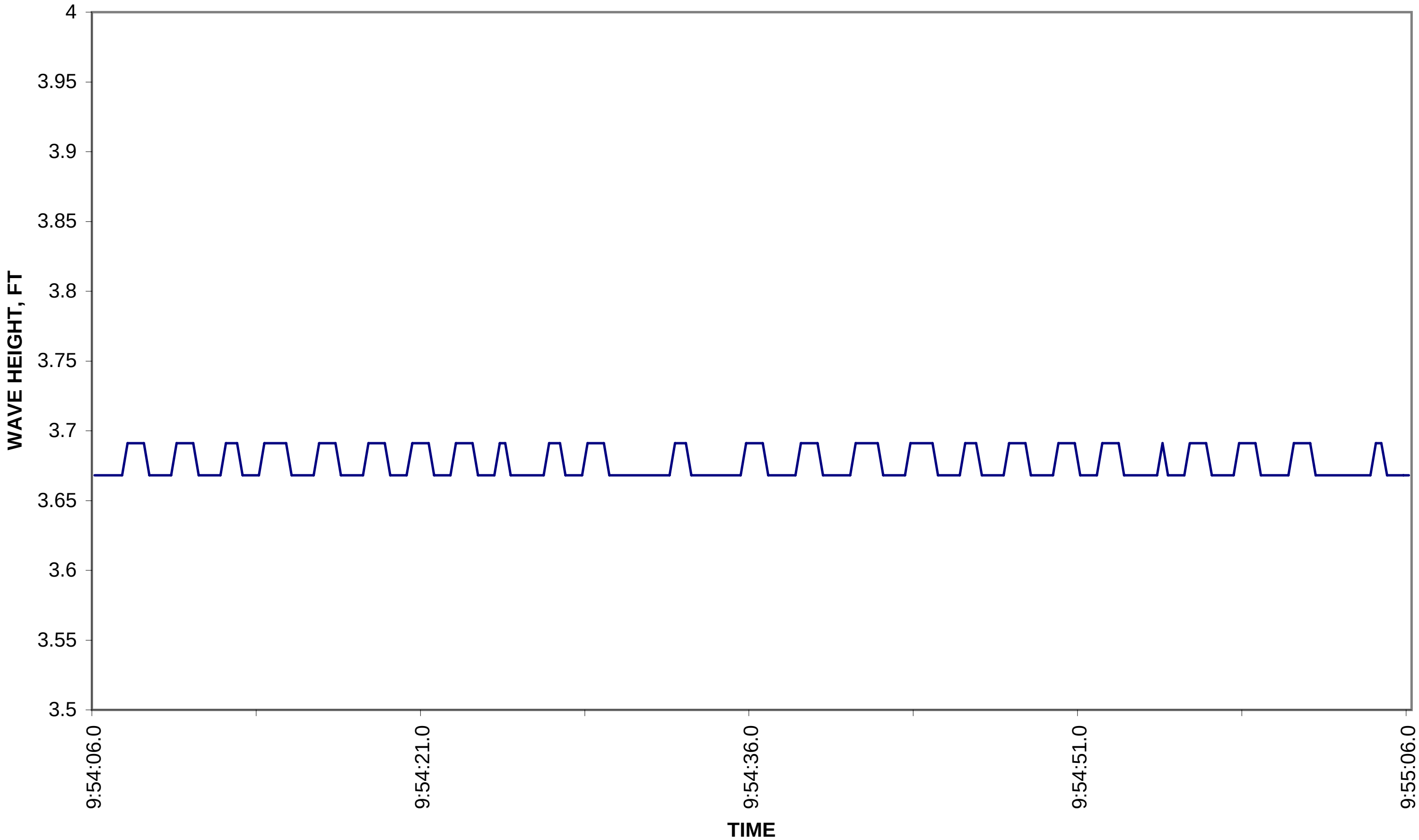
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/6/95



WAVE HEIGHTS
TEST 6, BOAT TYPE I
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/6/95



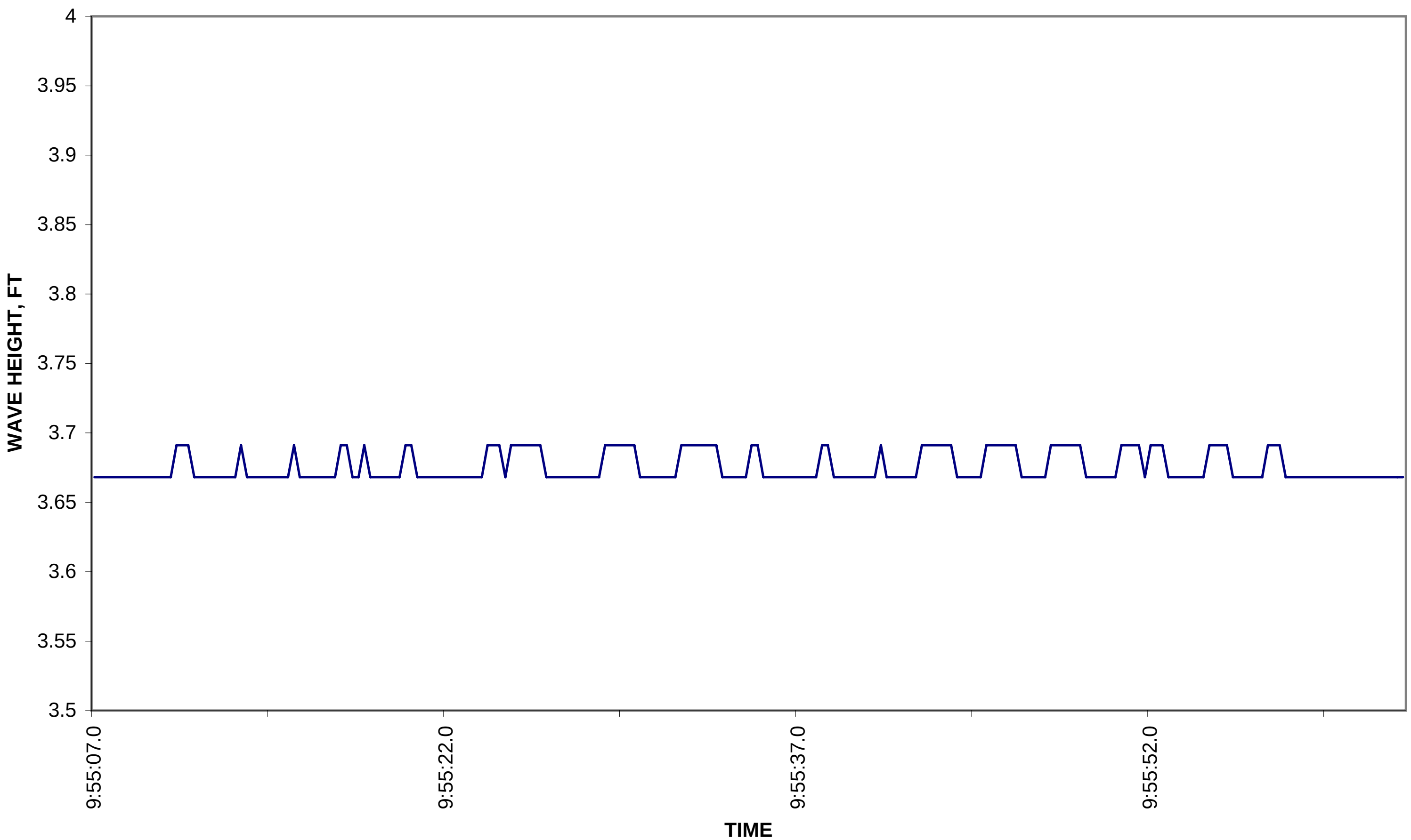
WAVE HEIGHTS

TEST 7, BOAT TYPE I

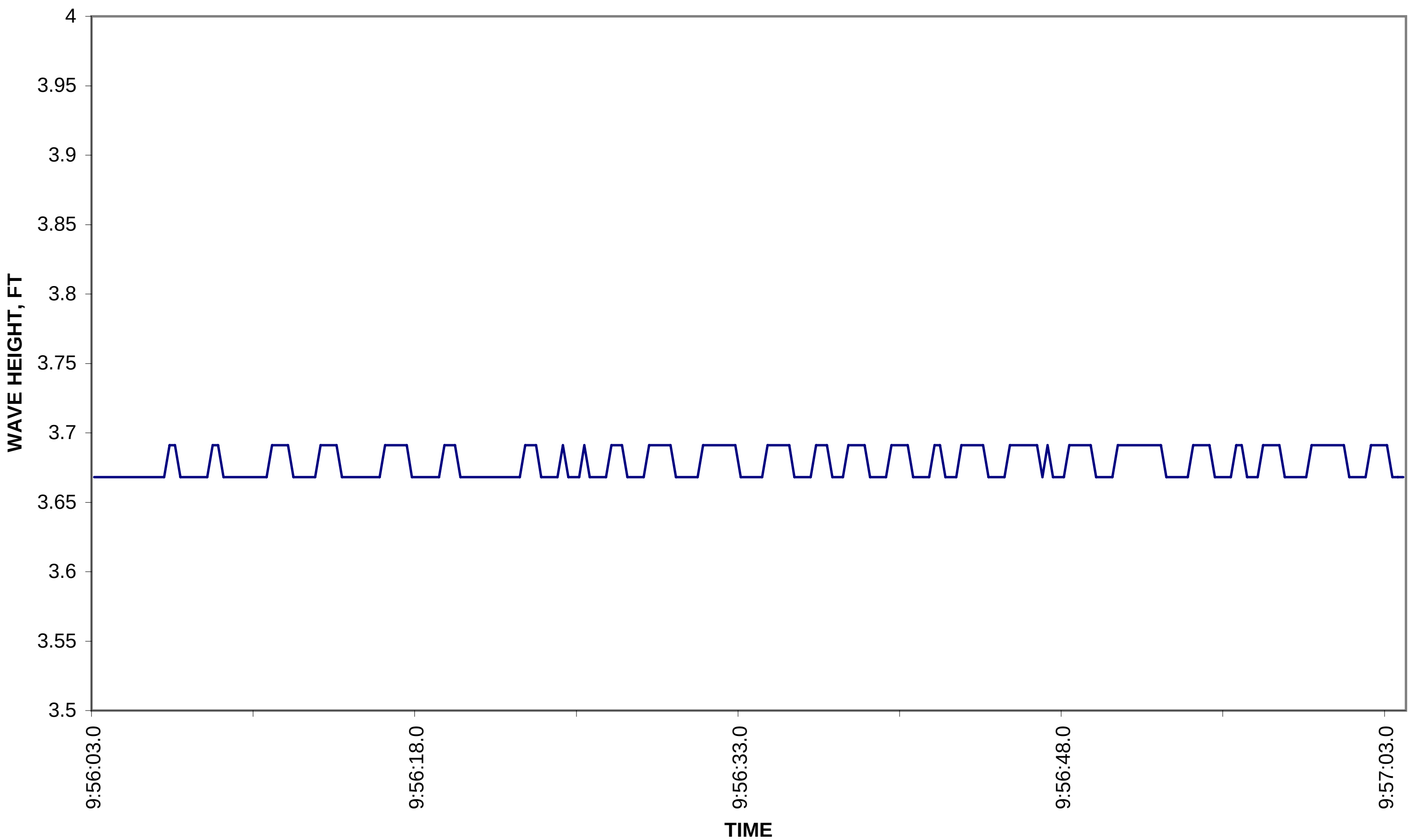
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

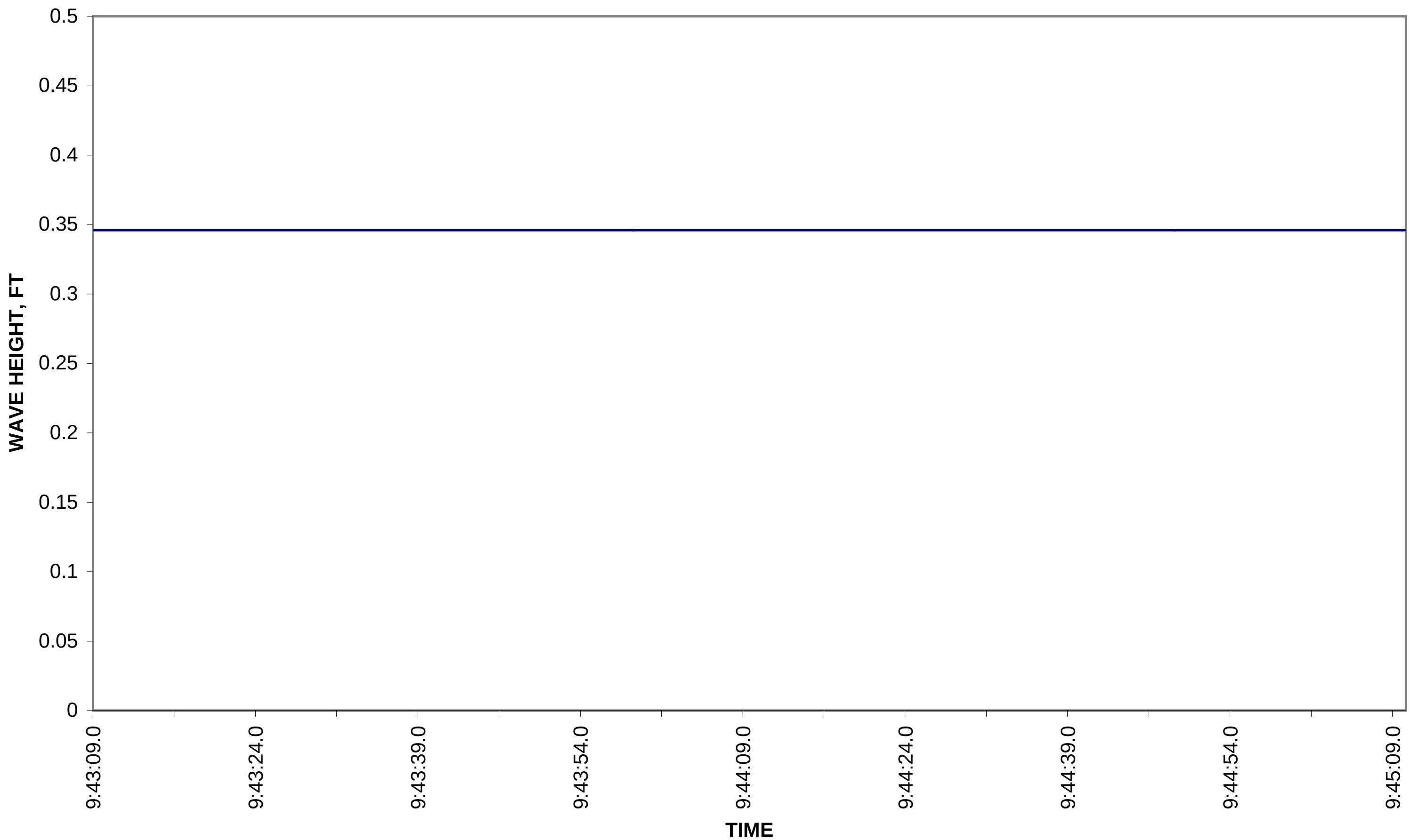
11/6/95



WAVE HEIGHTS
TEST 8, BOAT TYPE I
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 9, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/6/95



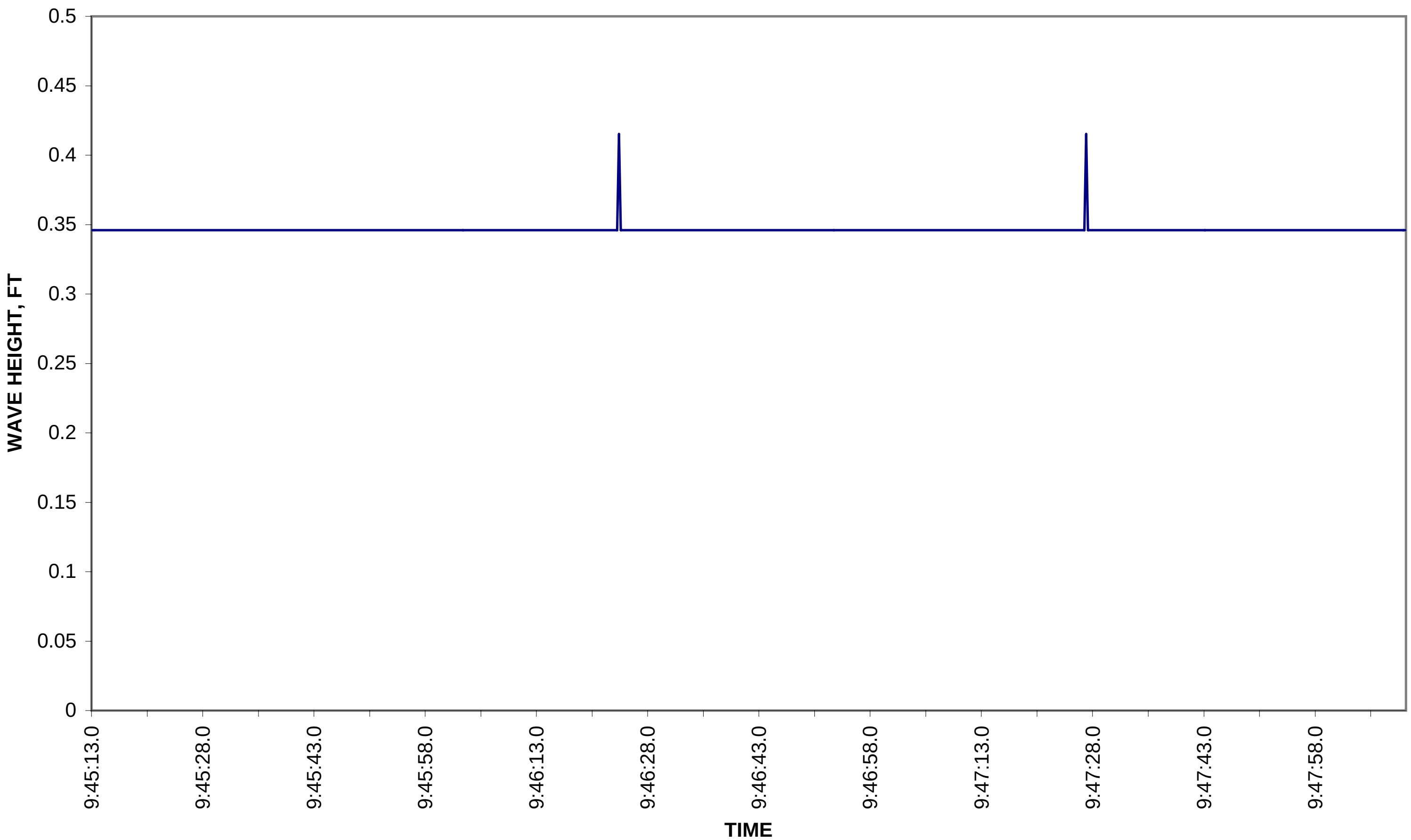
WAVE HEIGHTS

TEST 1, BOAT TYPE I

SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

11/6/95



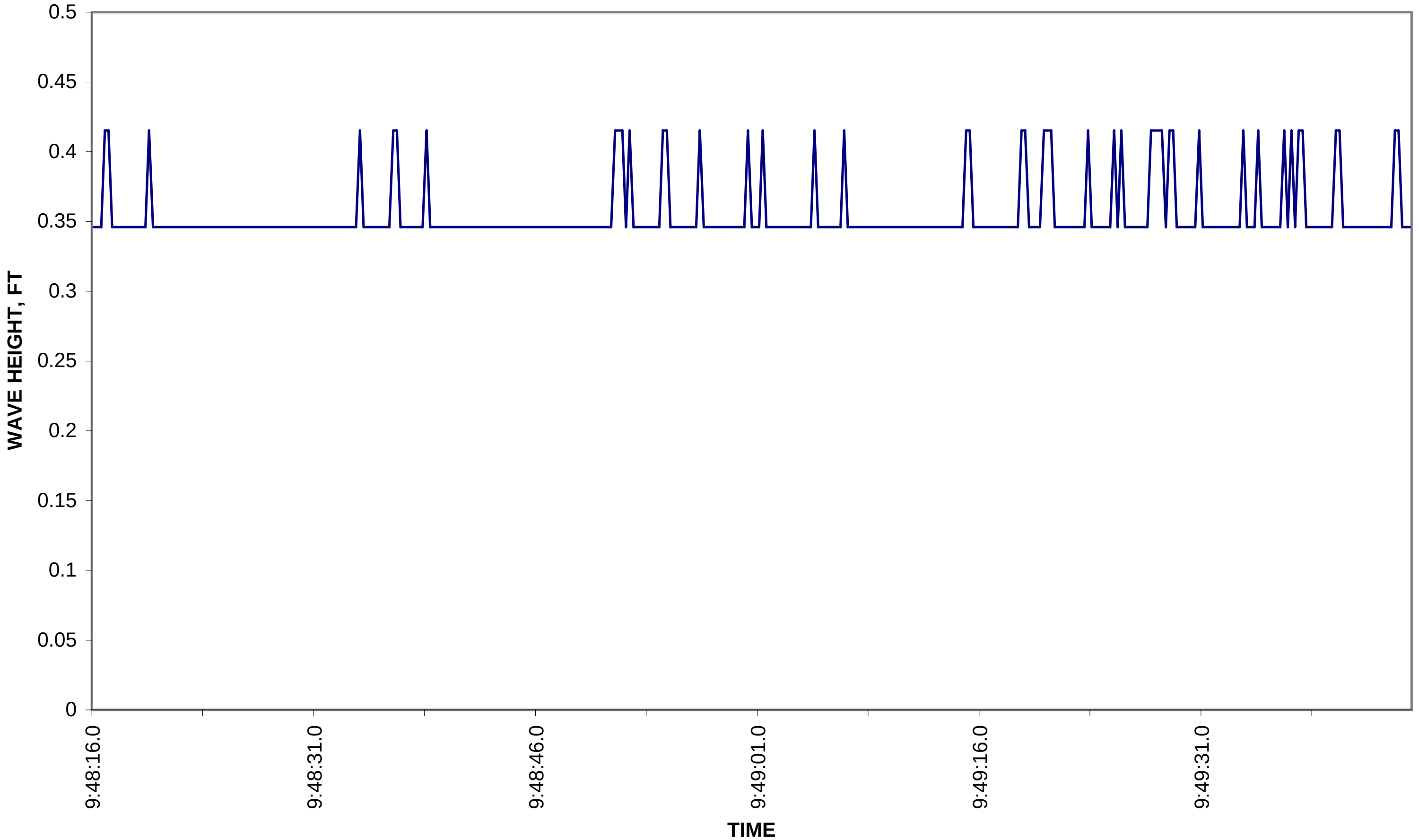
WAVE HEIGHTS

TEST 2, BOAT TYPE I

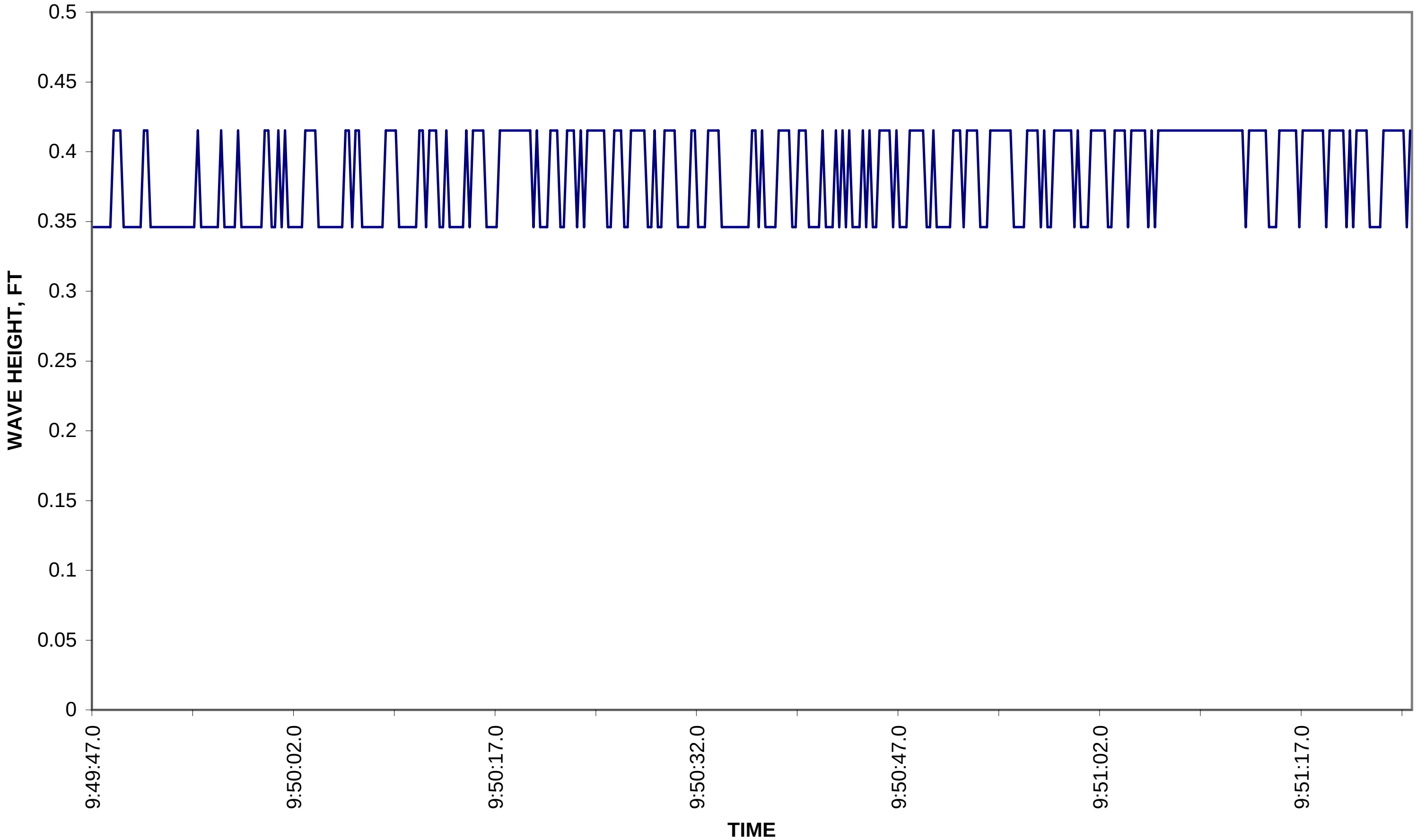
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

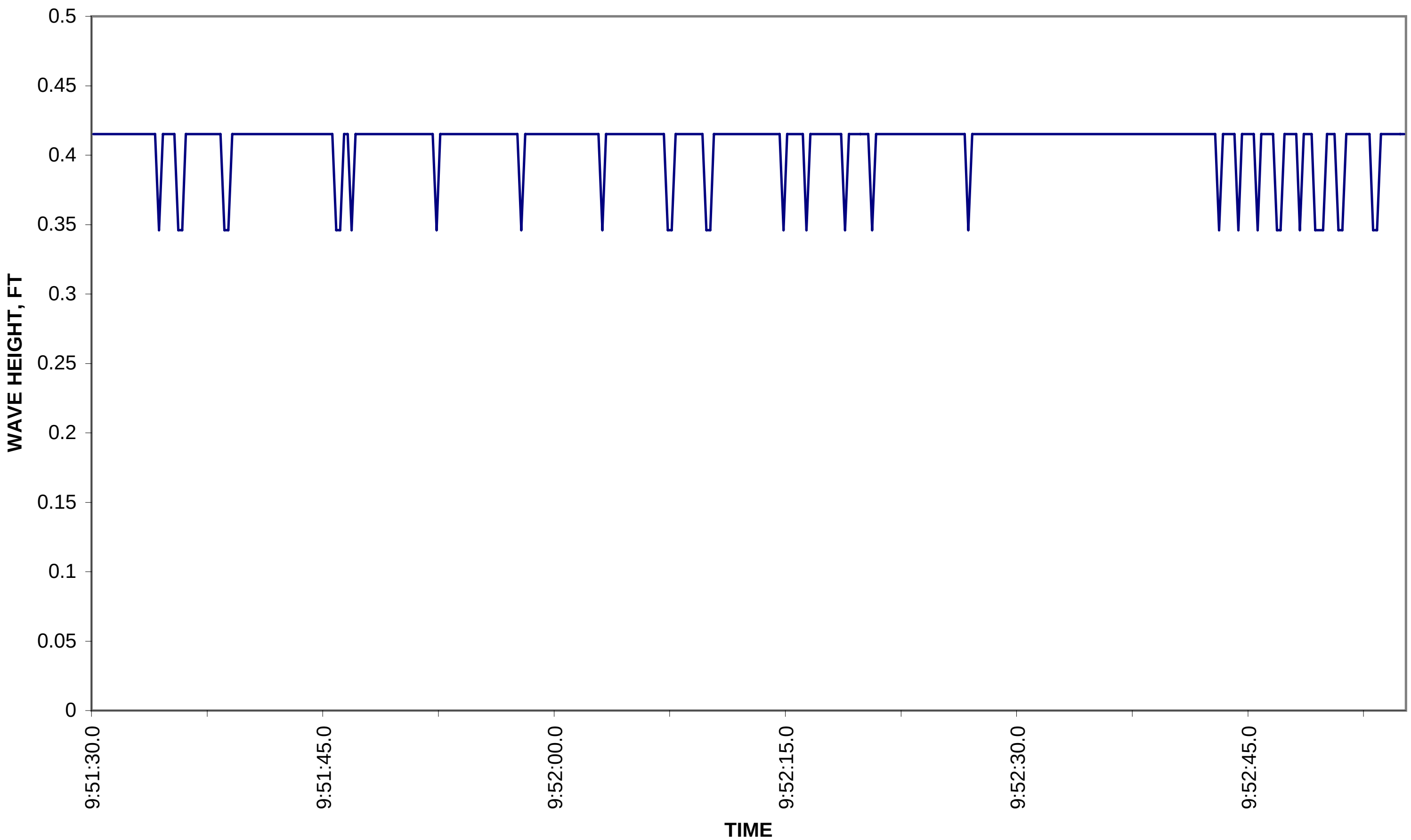
11/6/95



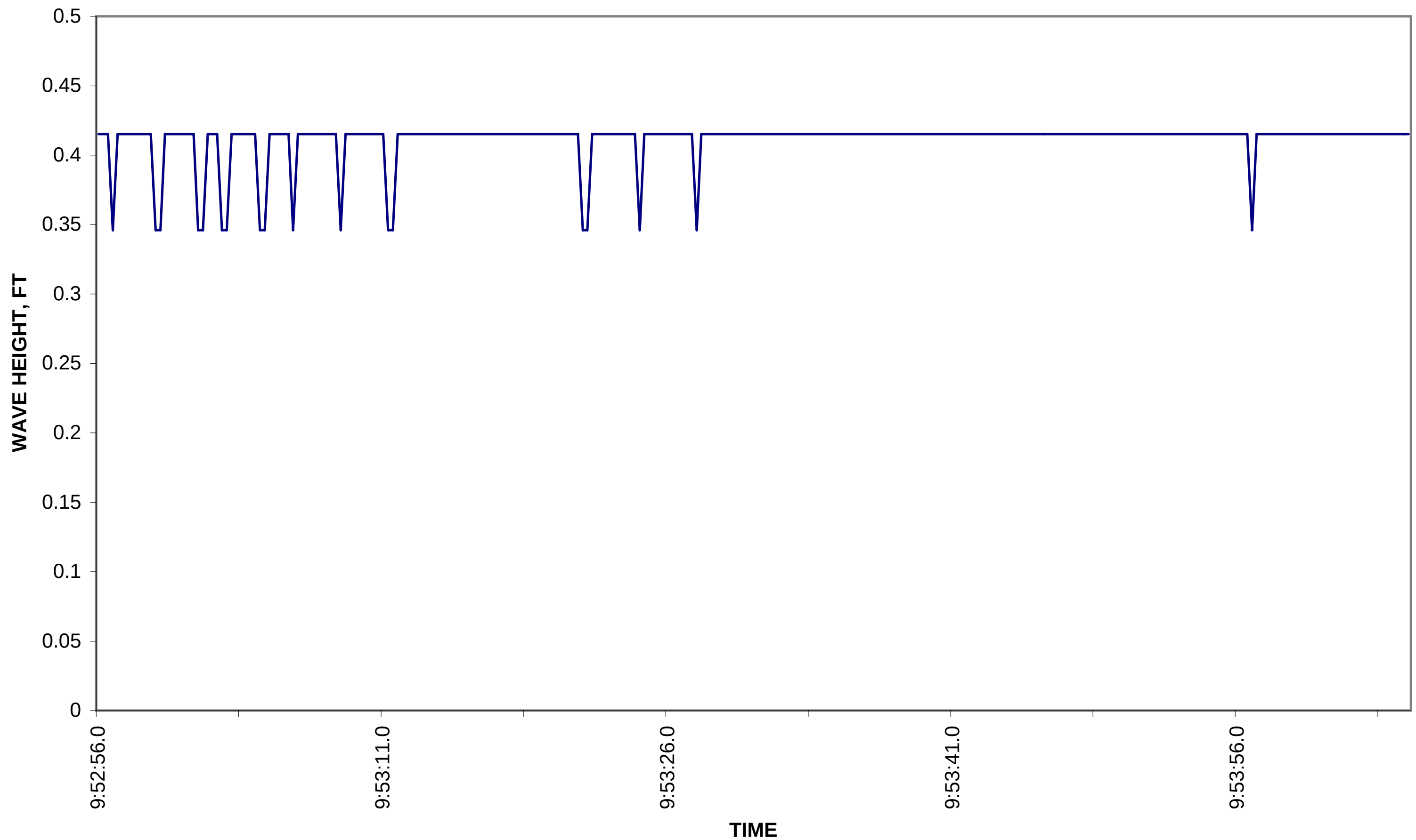
WAVE HEIGHTS
TEST 3, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 4, BOAT TYPE I
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 5, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



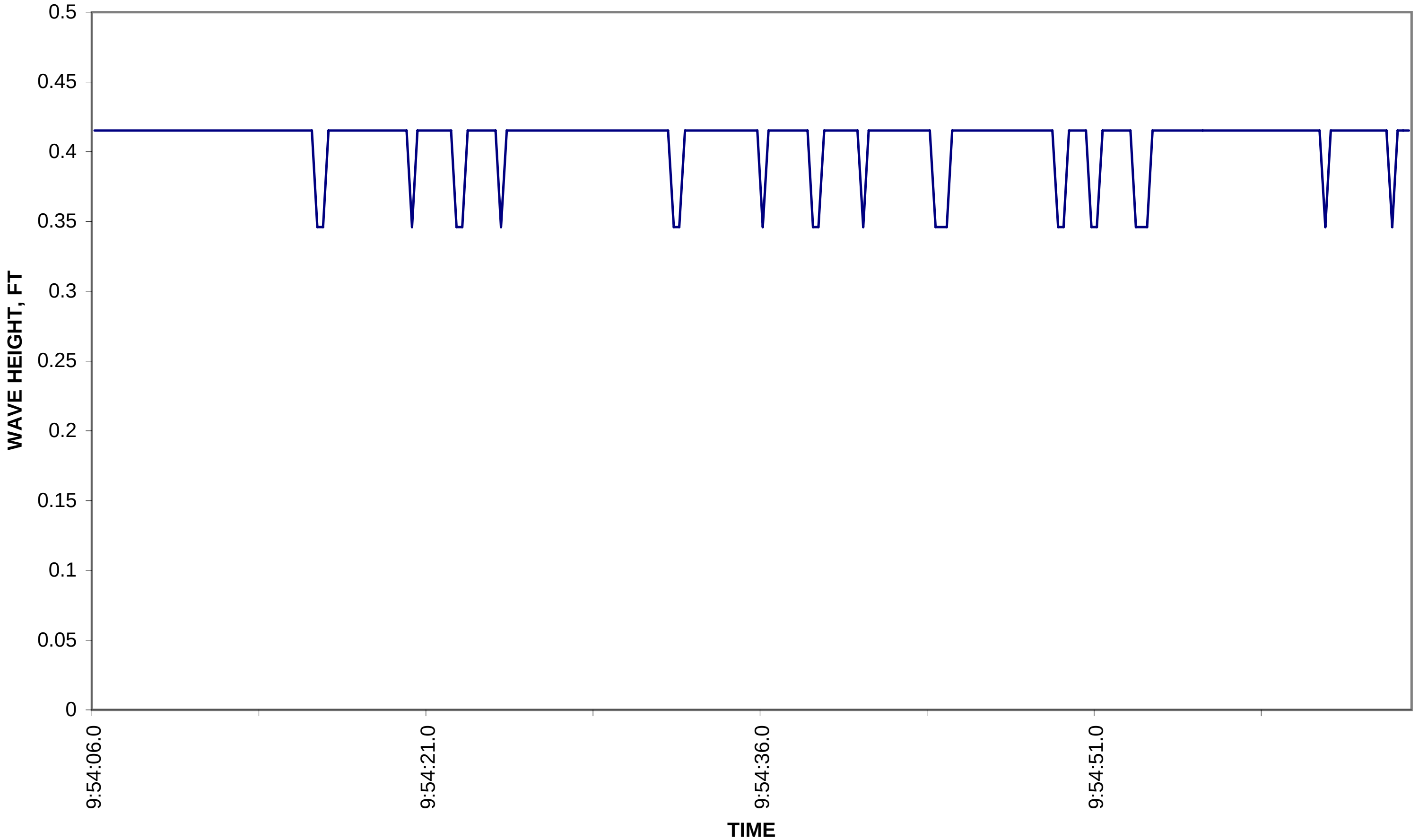
WAVE HEIGHTS

TEST 6, BOAT TYPE I

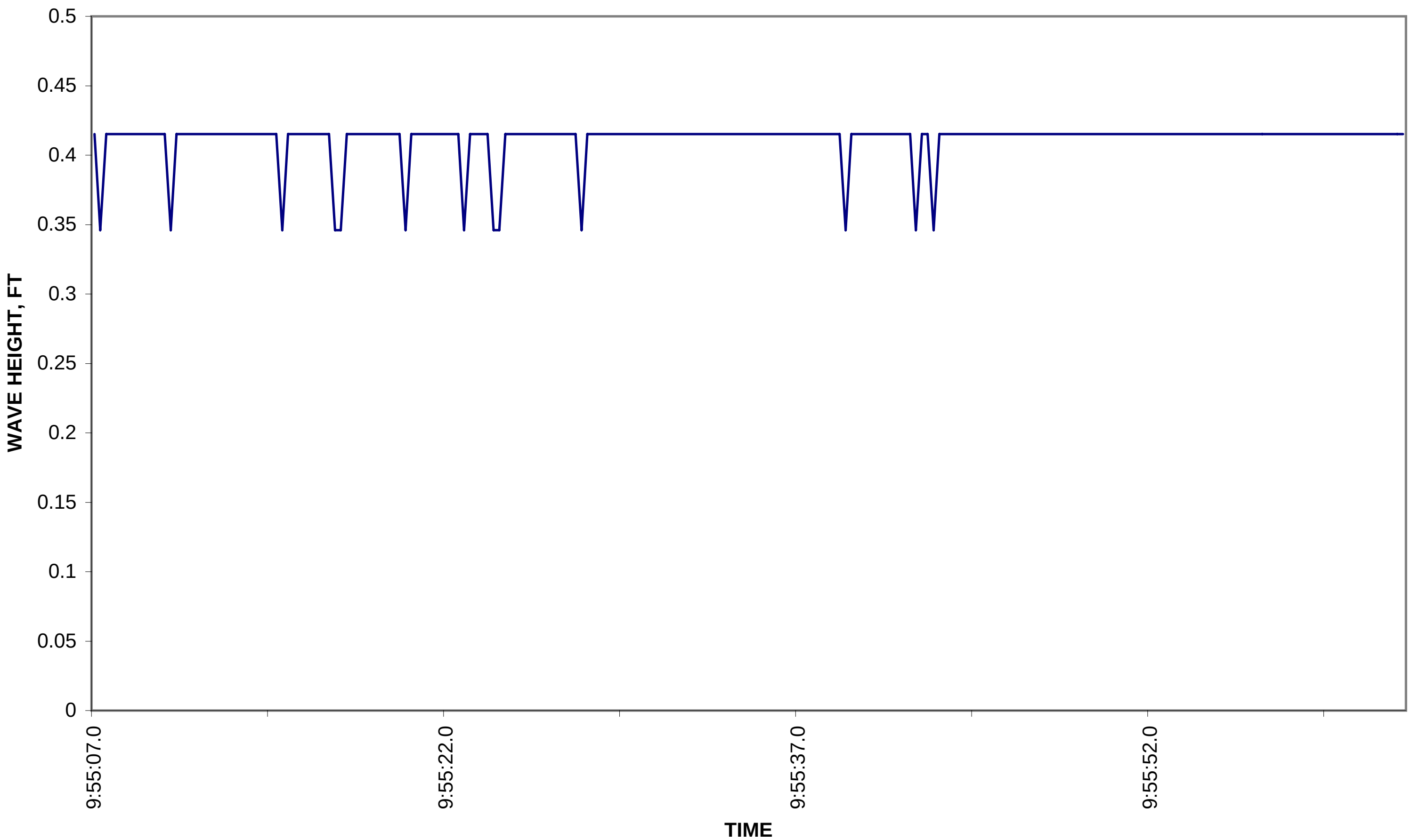
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

11/6/95



WAVE HEIGHTS
TEST 7, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



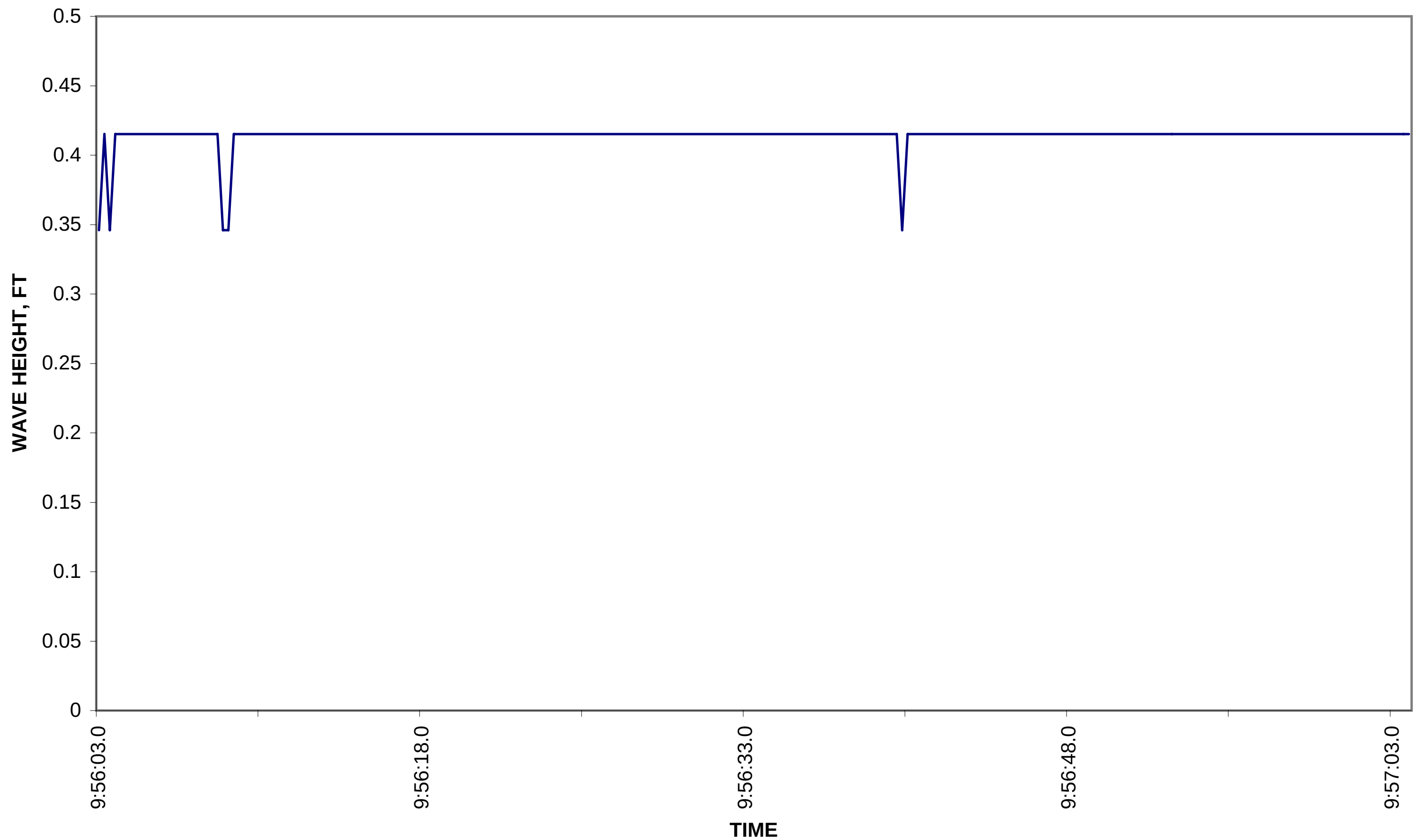
WAVE HEIGHTS

TEST 8, BOAT TYPE I

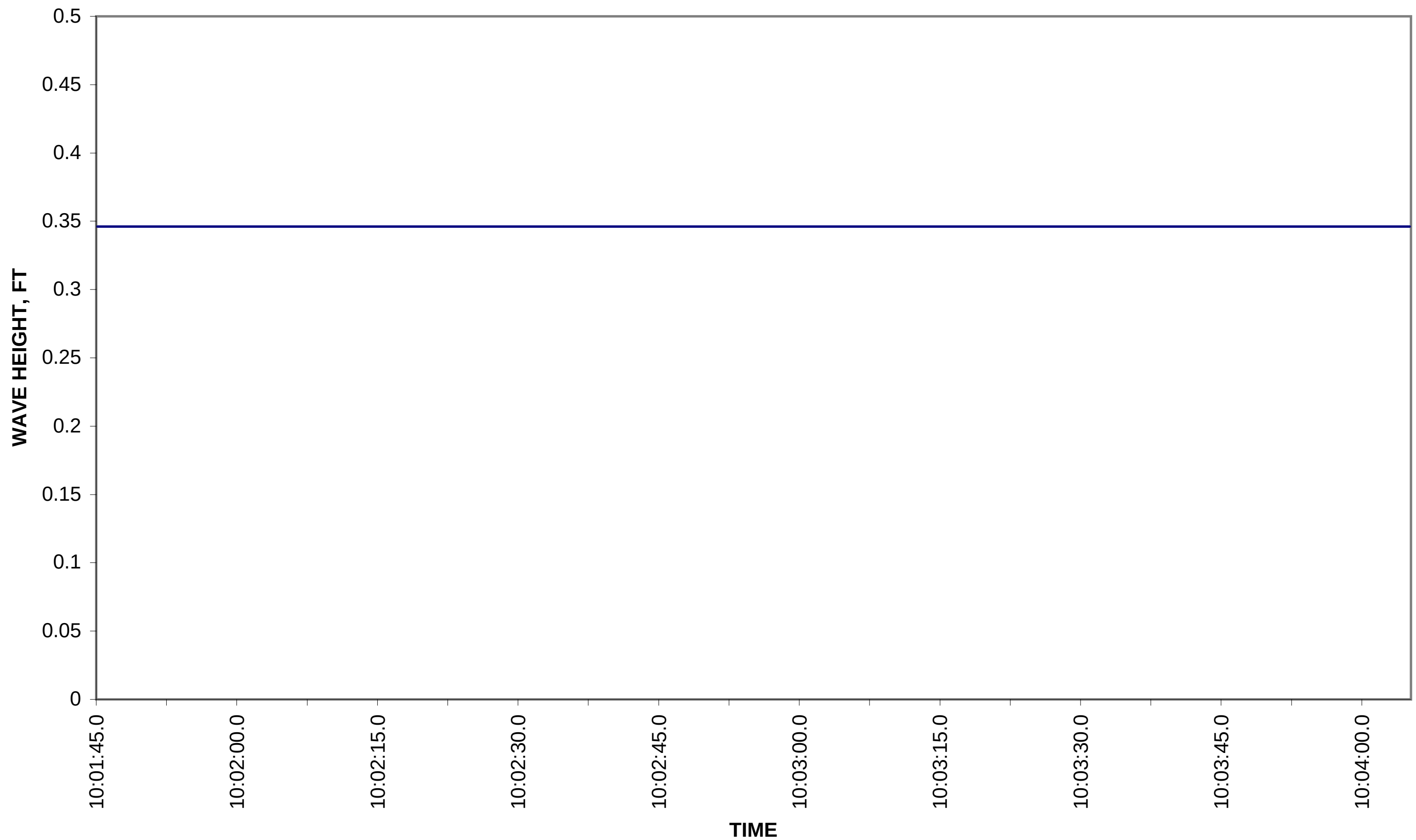
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

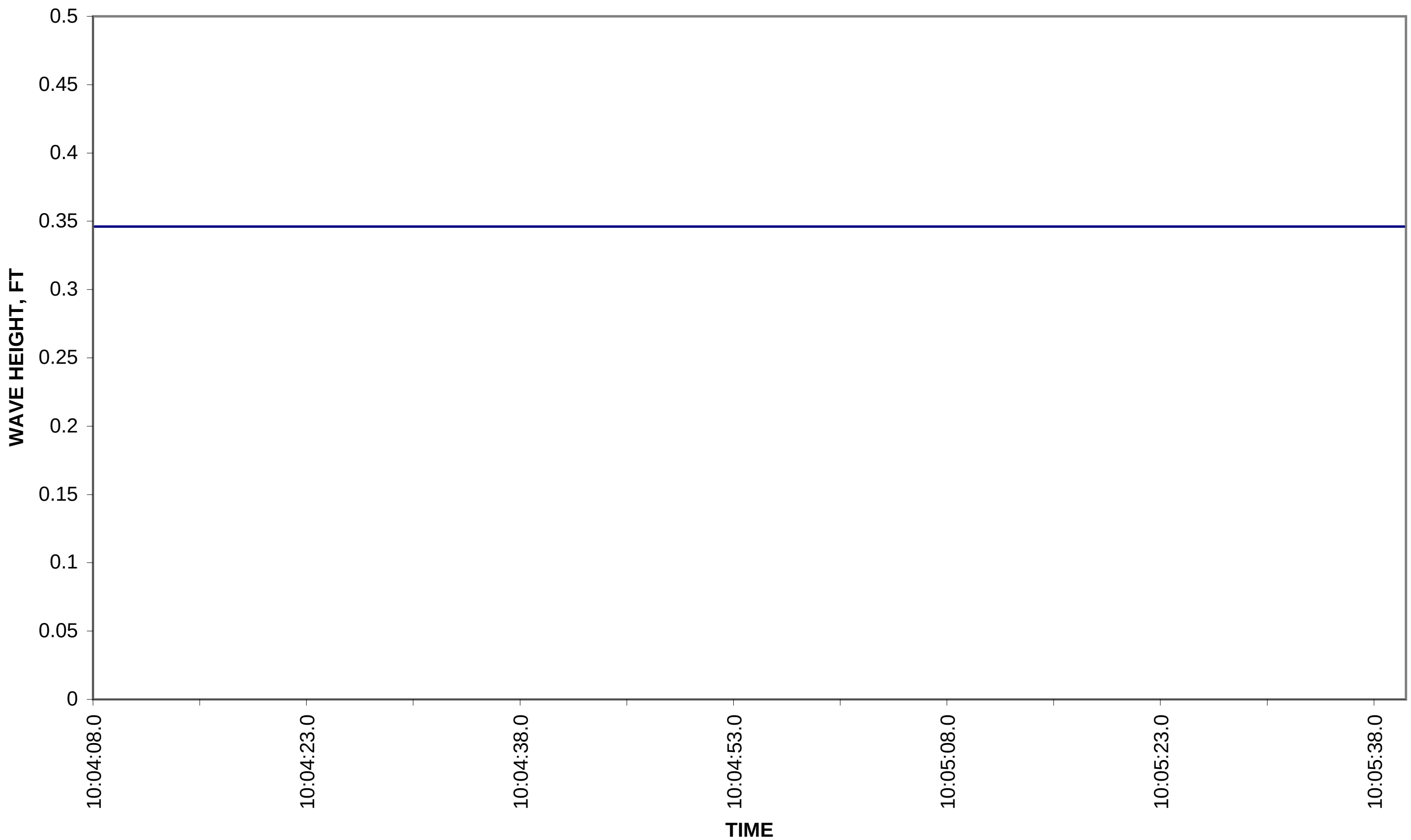
11/6/95



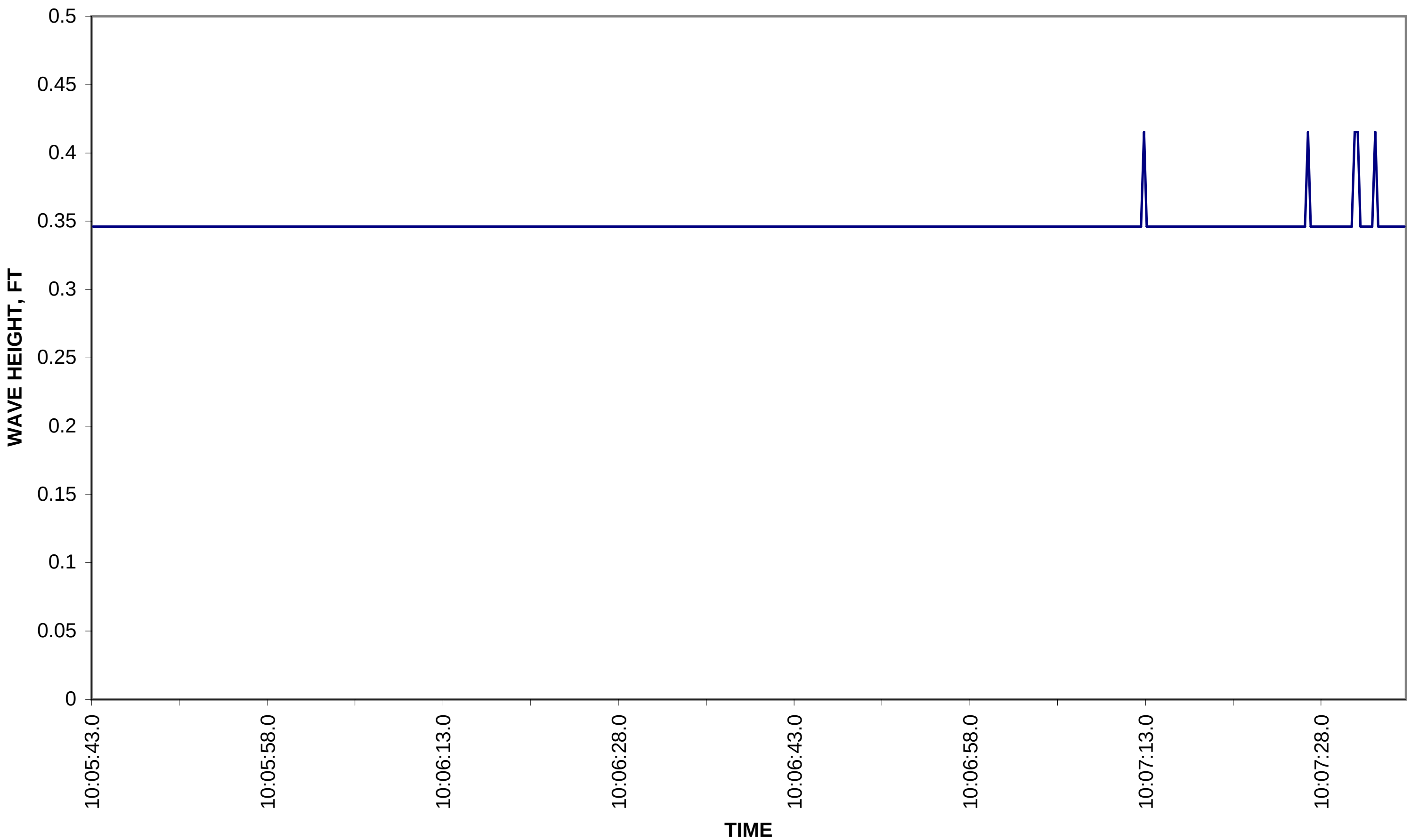
WAVE HEIGHTS
TEST 9, BOAT TYPE I
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



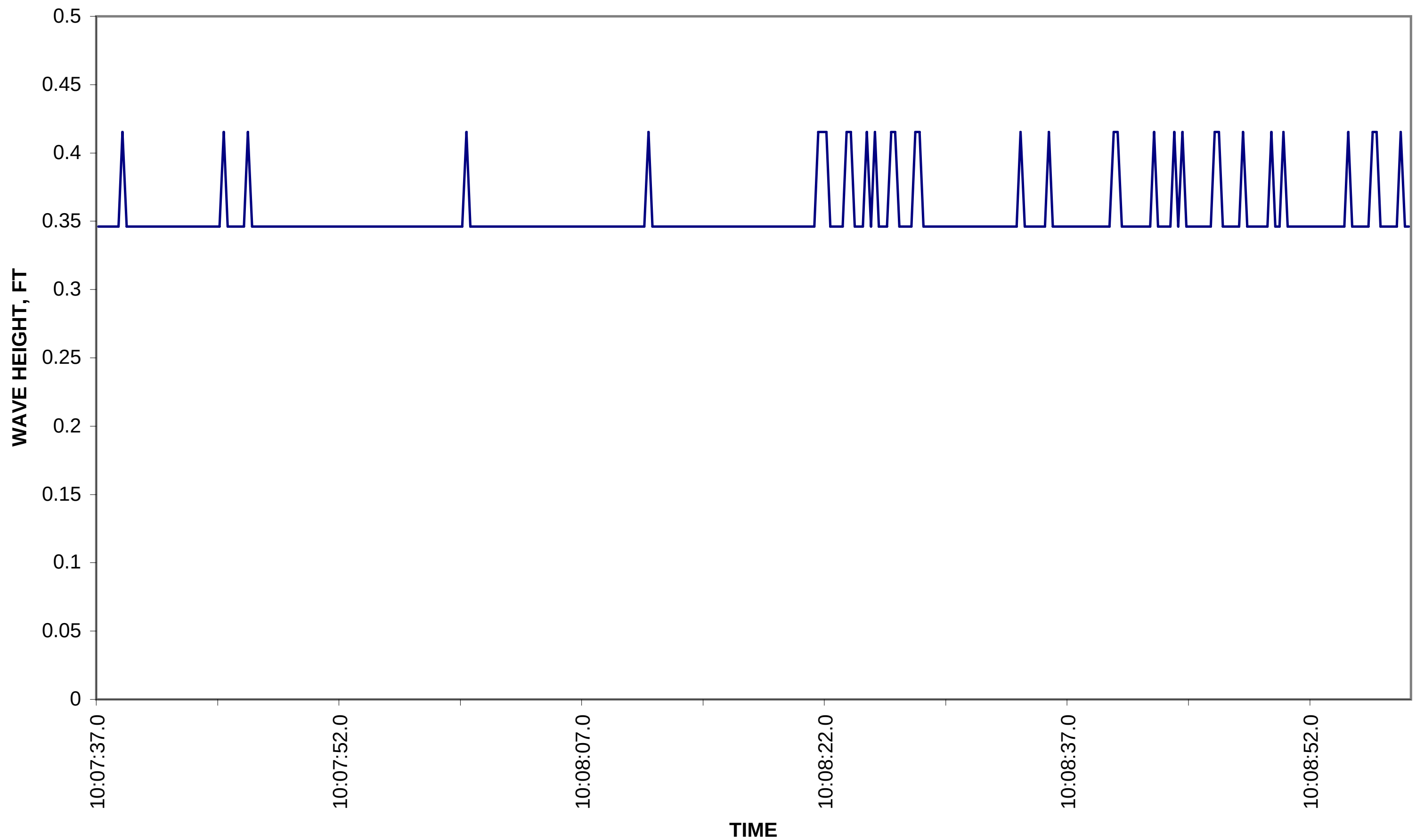
WAVE HEIGHTS
TEST 12, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



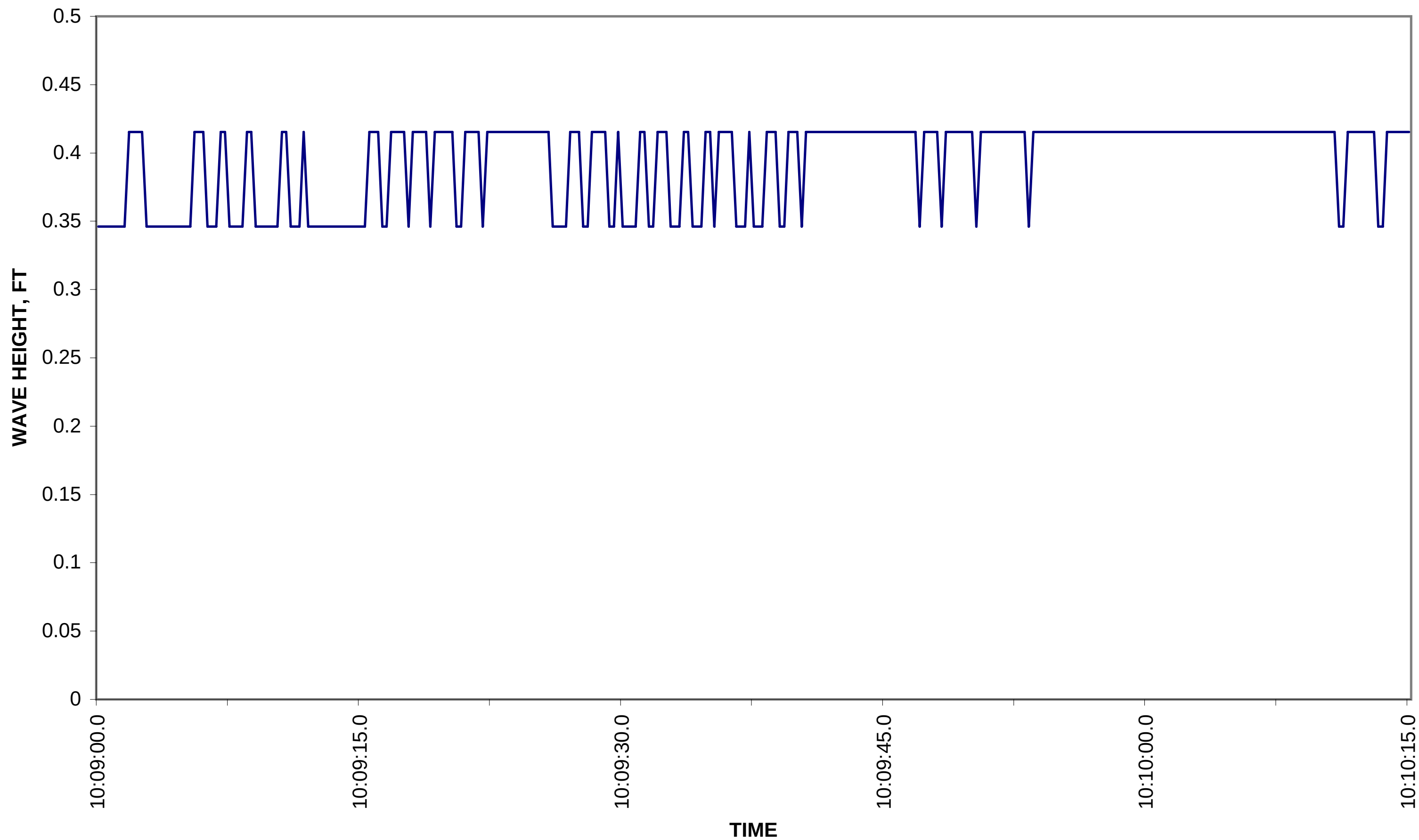
WAVE HEIGHTS
TEST 13, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 14, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 15, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



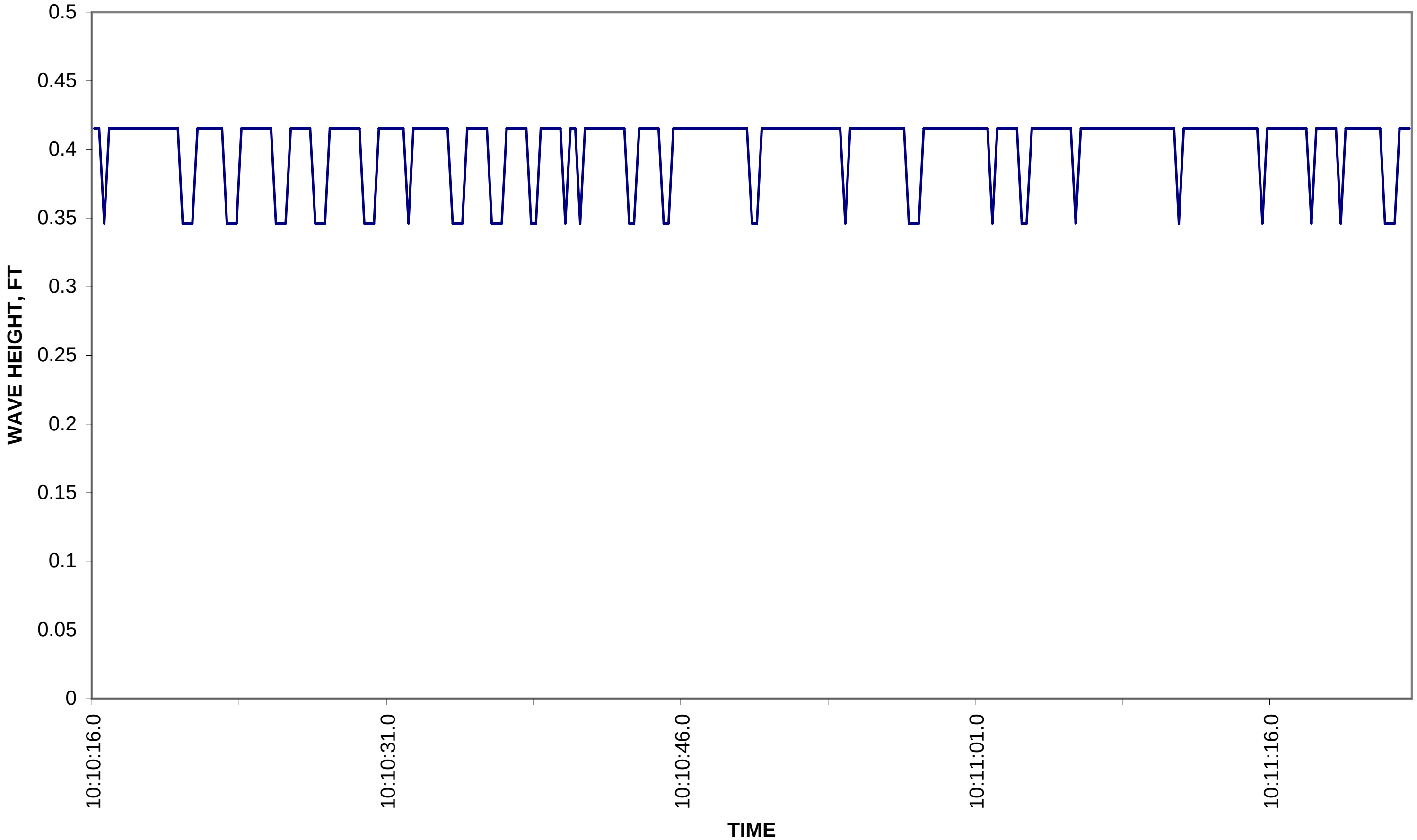
WAVE HEIGHTS

TEST 16, BOAT TYPE I

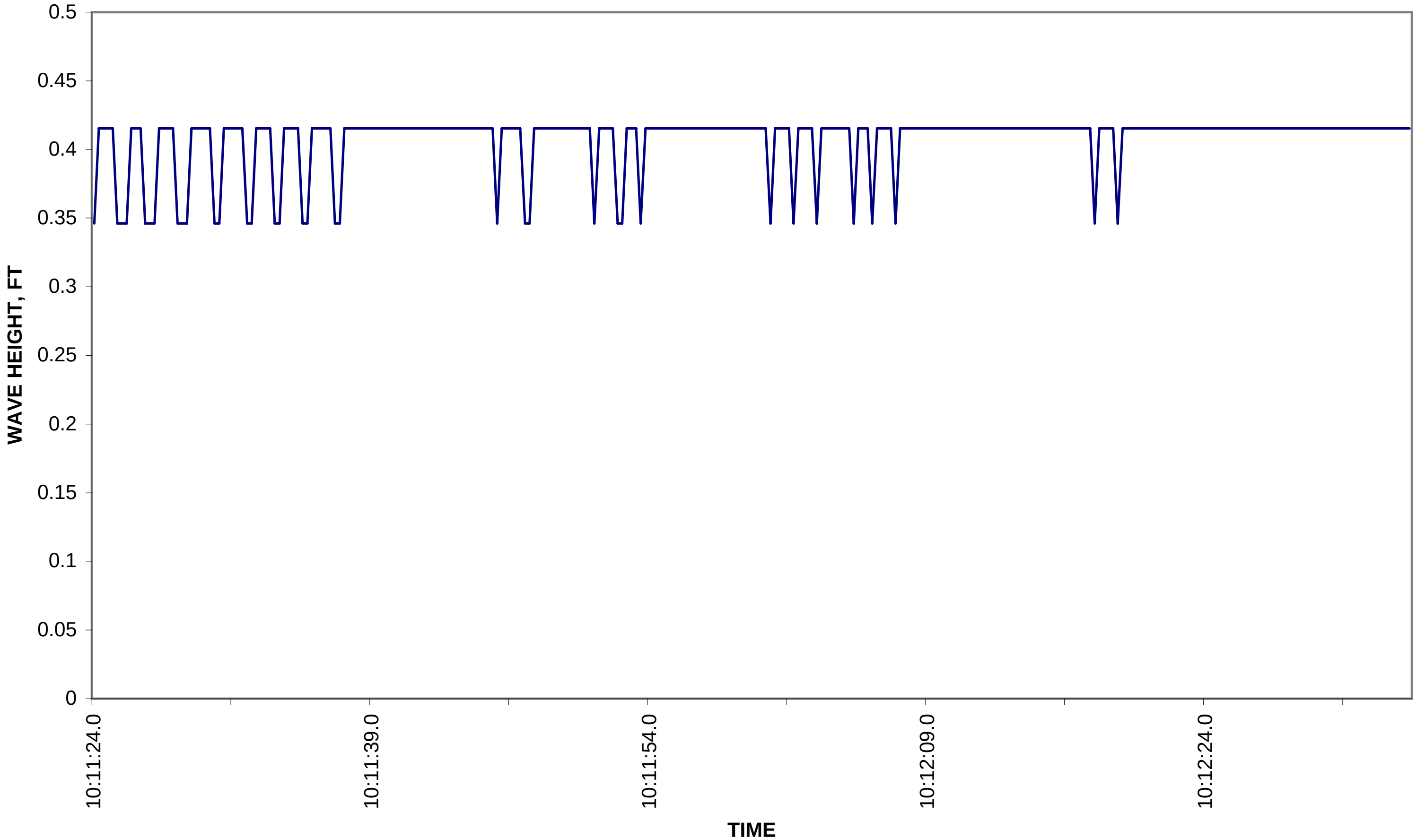
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

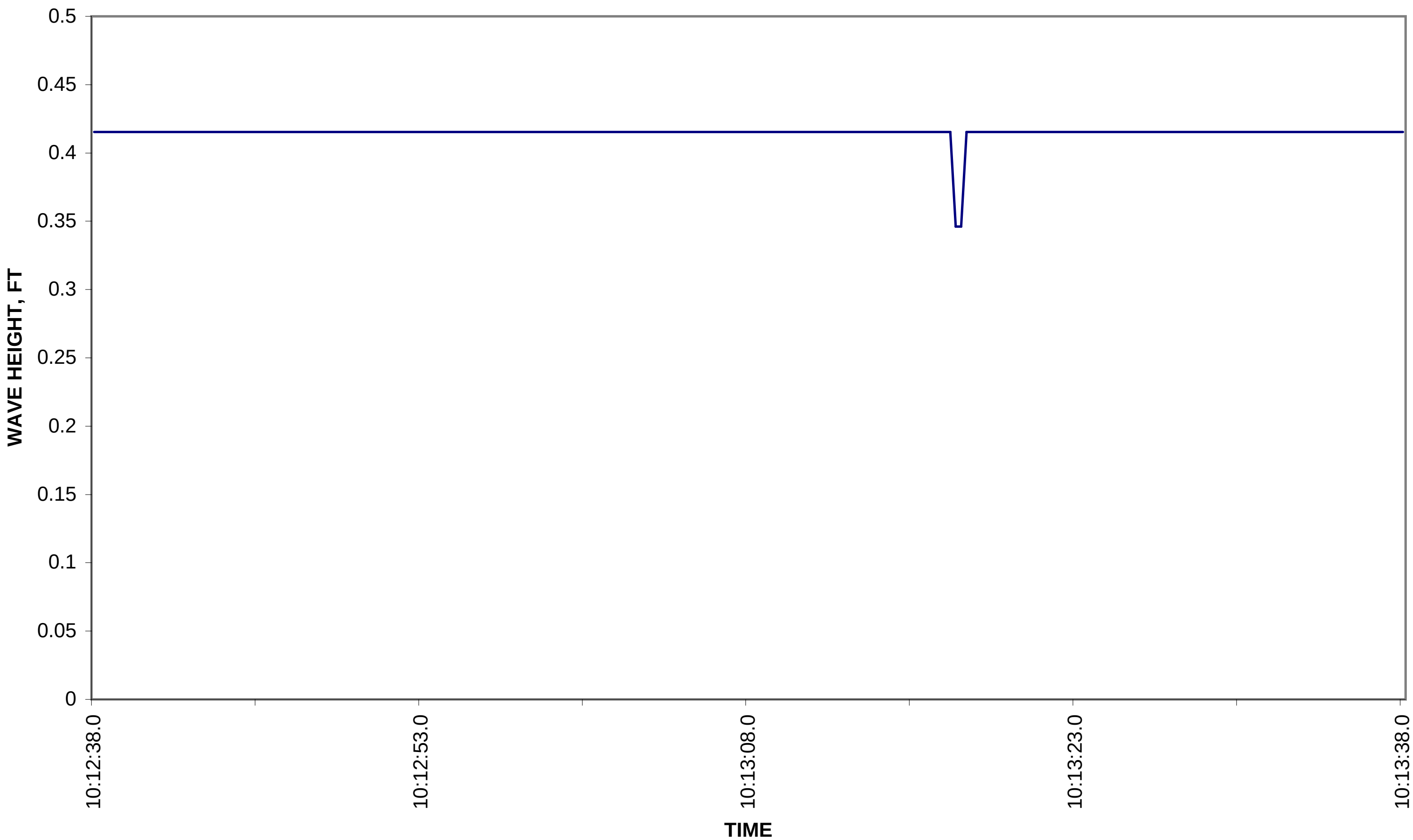
11/6/95



WAVE HEIGHTS
TEST 17, BOAT TYPE I
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHTS
TEST 18, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



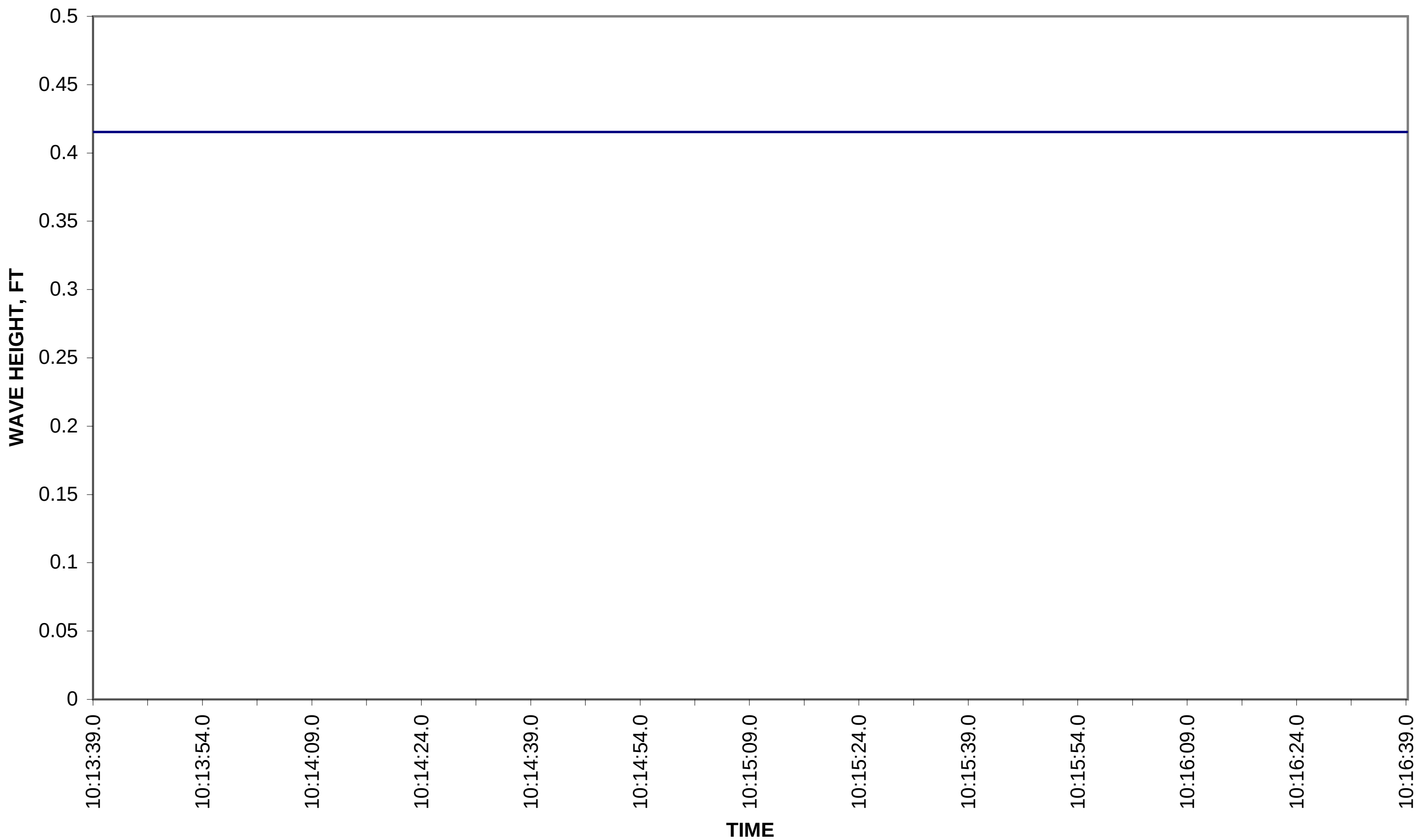
WAVE HEIGHTS

TEST 19, BOAT TYPE I

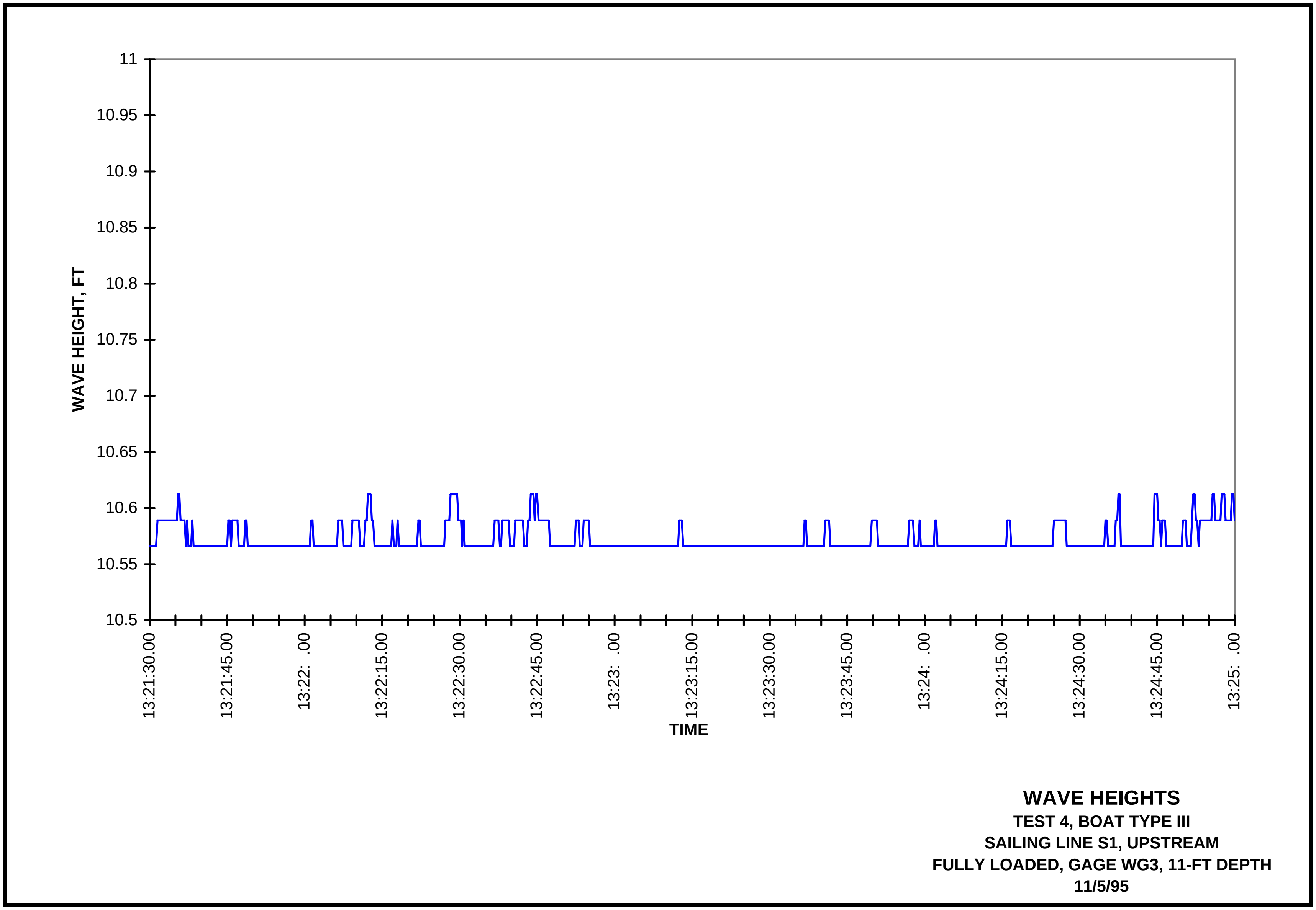
SAILING LINE S2, DOWNSTREAM

LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH

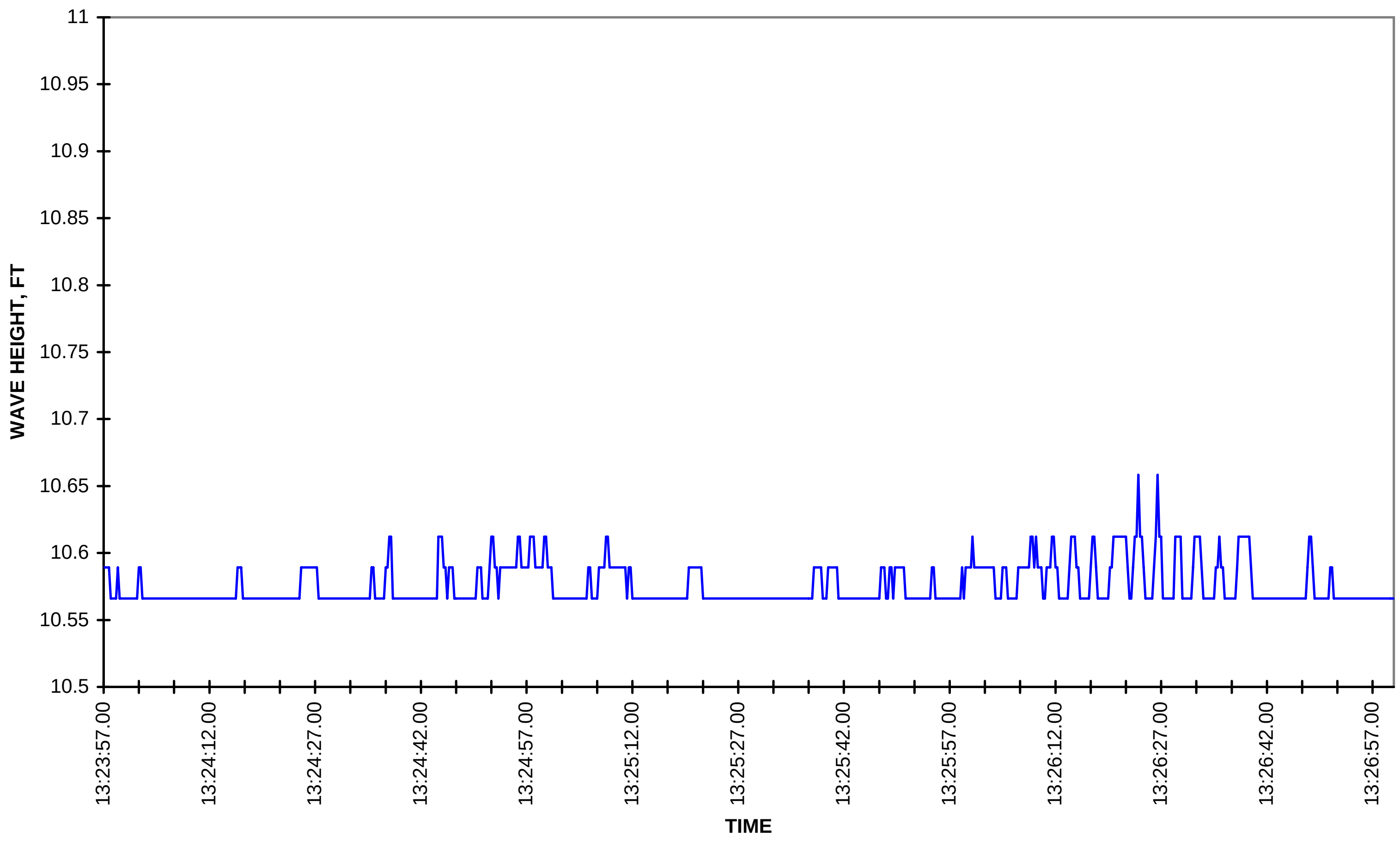
11/6/95



WAVE HEIGHTS
TEST 20, BOAT TYPE I
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG1, 3-FT DEPTH
11/6/95



WAVE HEIGHT, FT
11
10.95
10.9
10.85
10.8
10.75
10.7
10.65
10.6
10.55
10.5
13:21:30.00
13:21:45.00
13:22: .00
13:22:15.00
13:22:30.00
13:22:45.00
13:23: .00
13:23:15.00
13:23:30.00
13:23:45.00
13:24: .00
13:24:15.00
13:24:30.00
13:24:45.00
13:25: .00
TIME
WAVE HEIGHTS
TEST 4, BOAT TYPE III
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



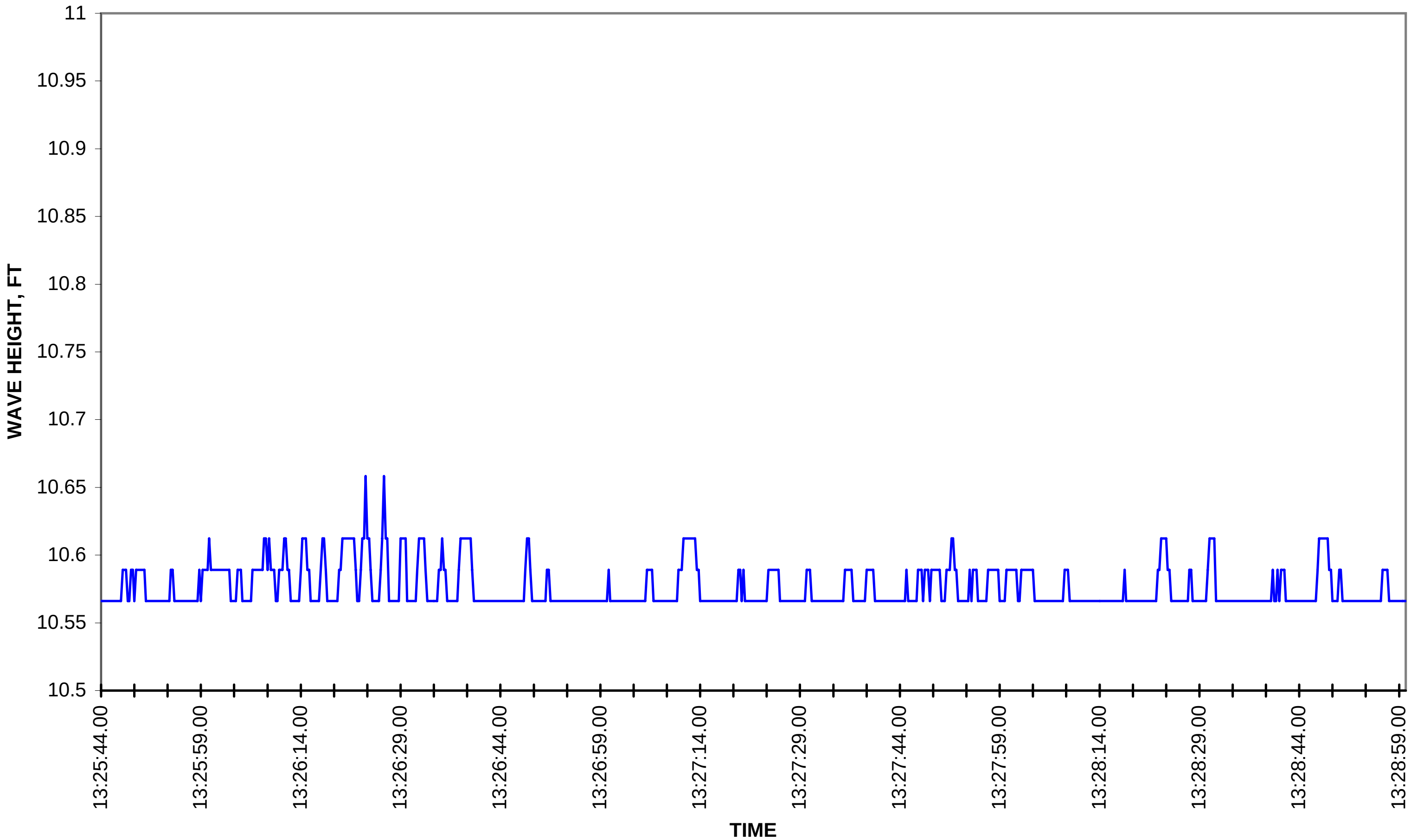
WAVE HEIGHTS

TEST 5, BOAT TYPE III

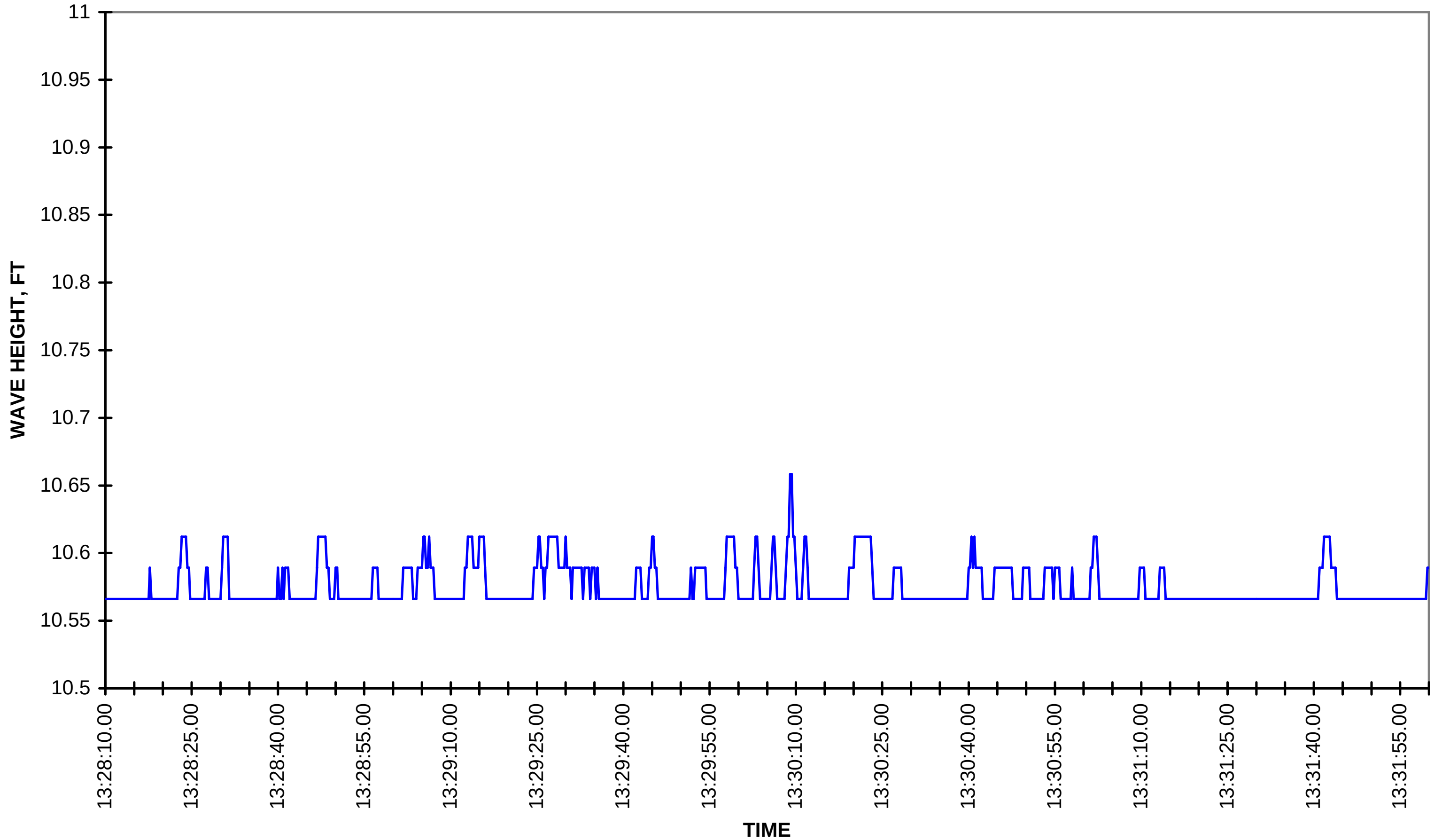
SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



WAVE HEIGHTS
TEST 6, BOAT TYPE III
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



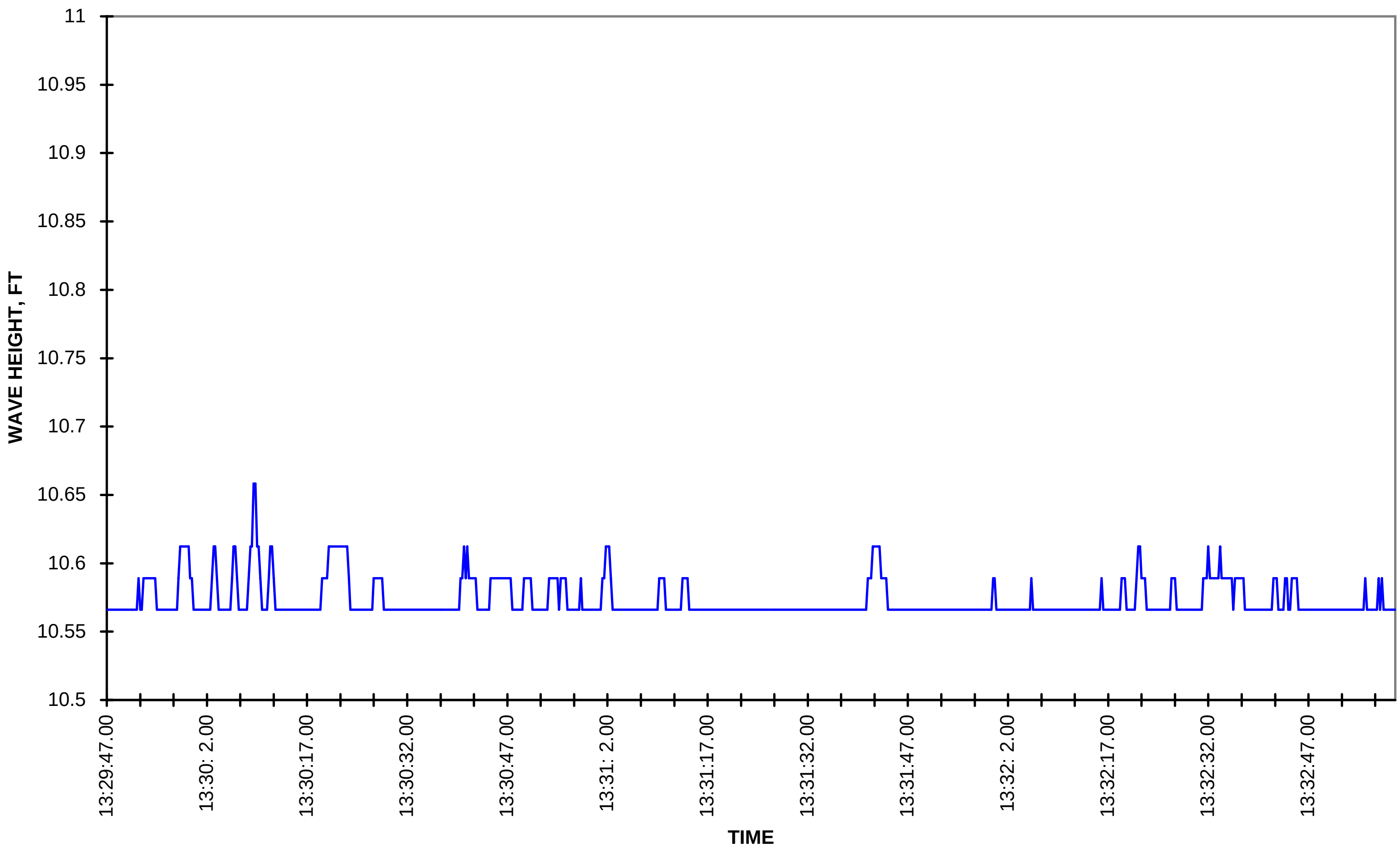
WAVE HEIGHTS

TEST 7, BOAT TYPE III

SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



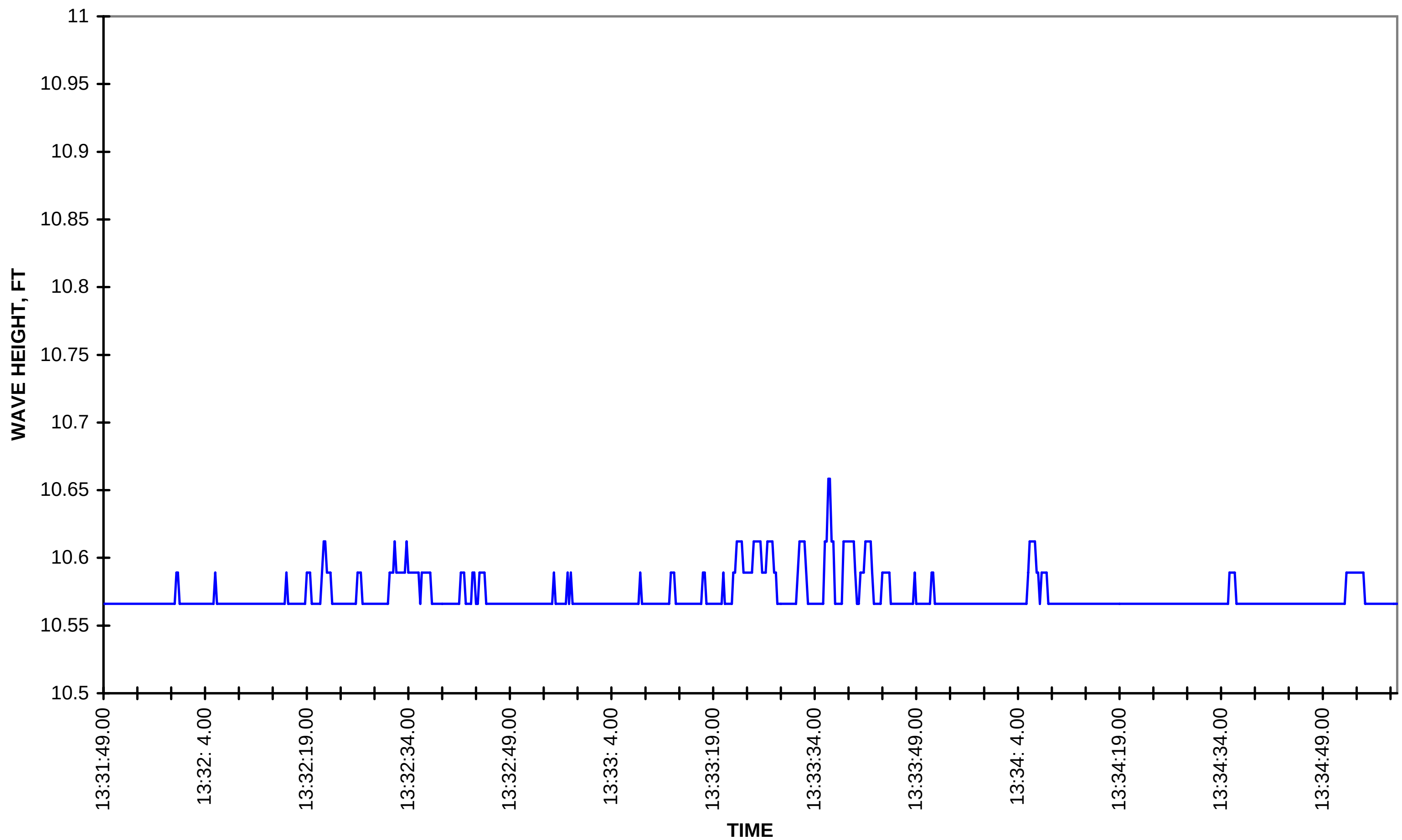
WAVE HEIGHTS

TEST 8, BOAT TYPE III

SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



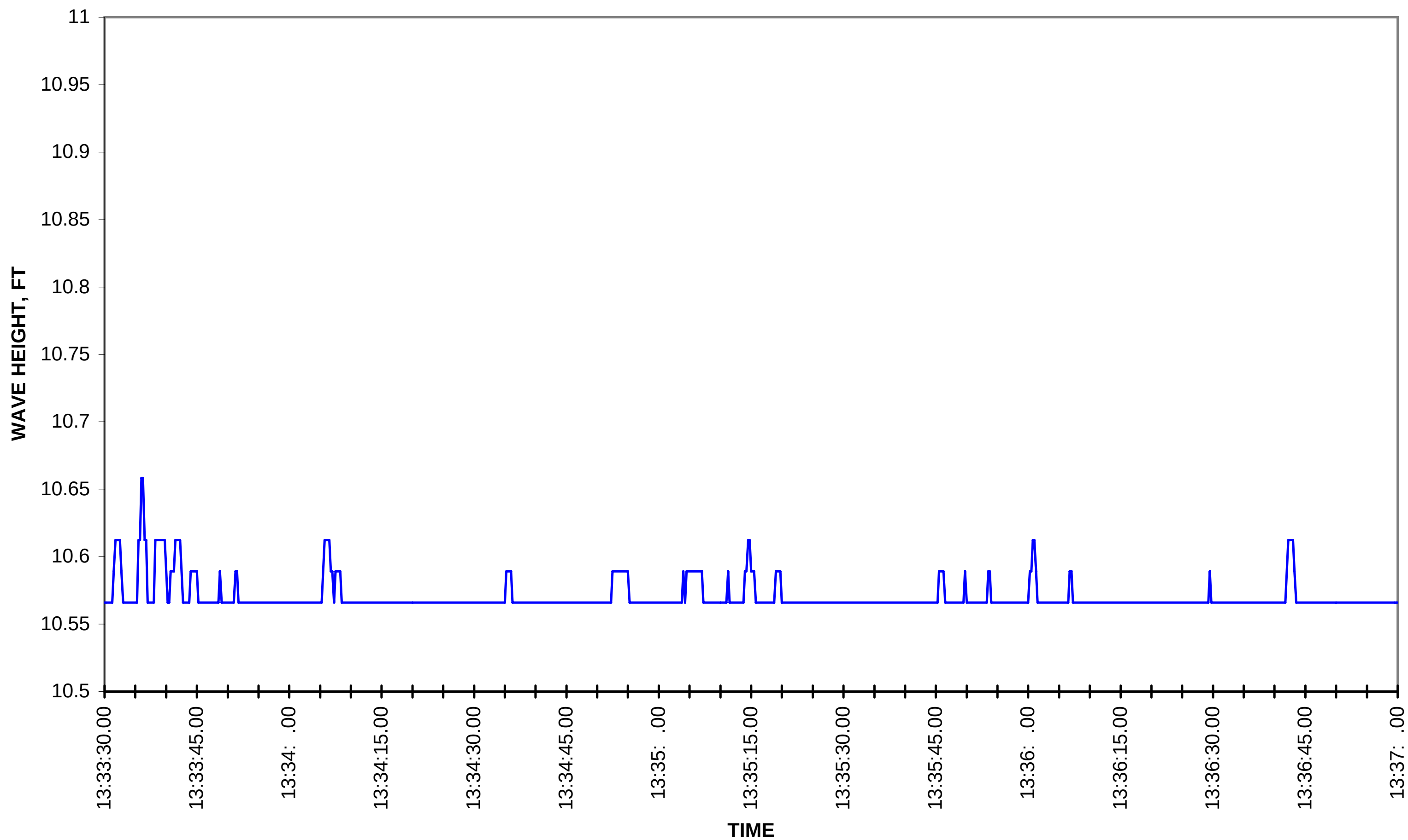
WAVE HEIGHTS

TEST 9, BOAT TYPE III

SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



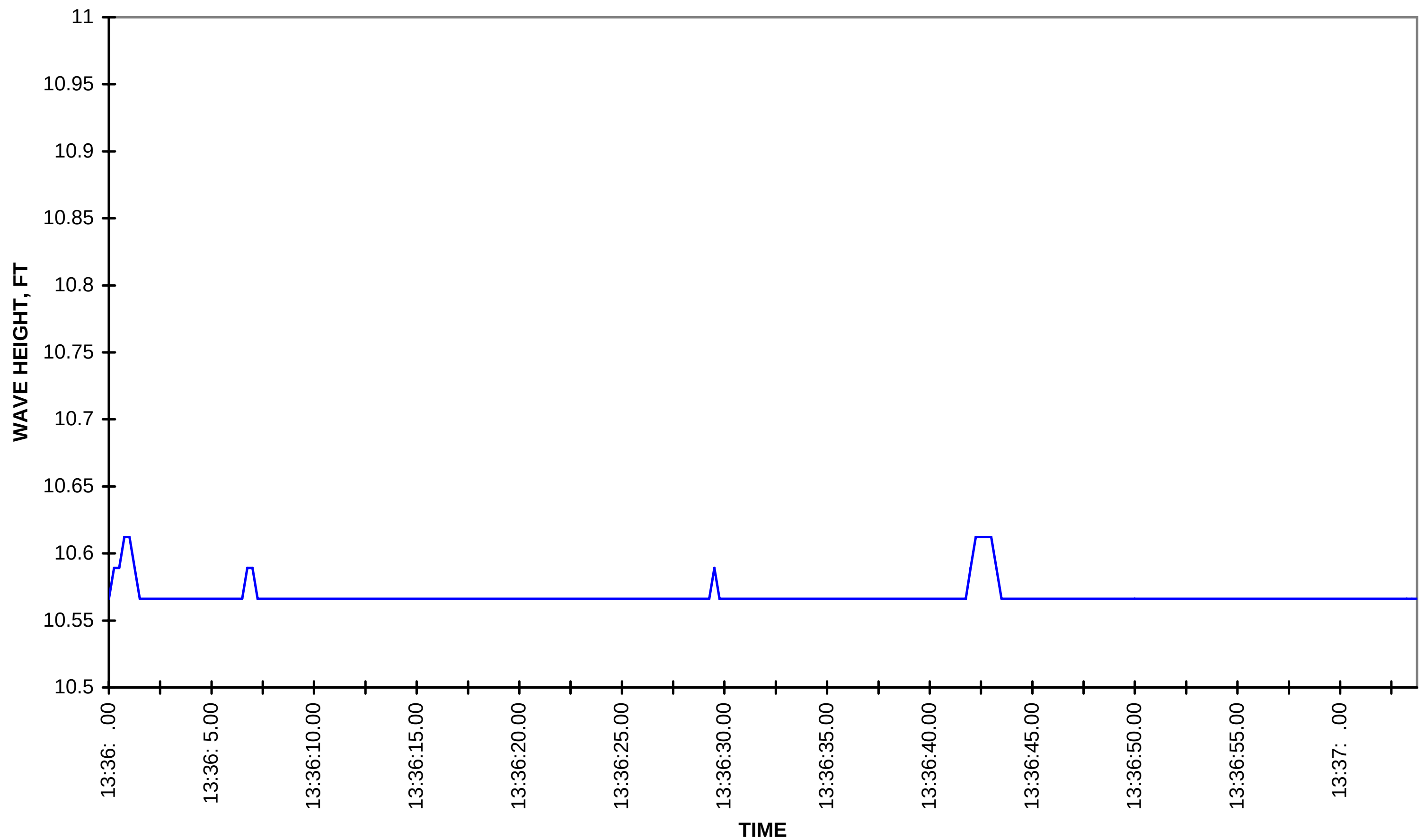
WAVE HEIGHTS

TEST 10, BOAT TYPE III

SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



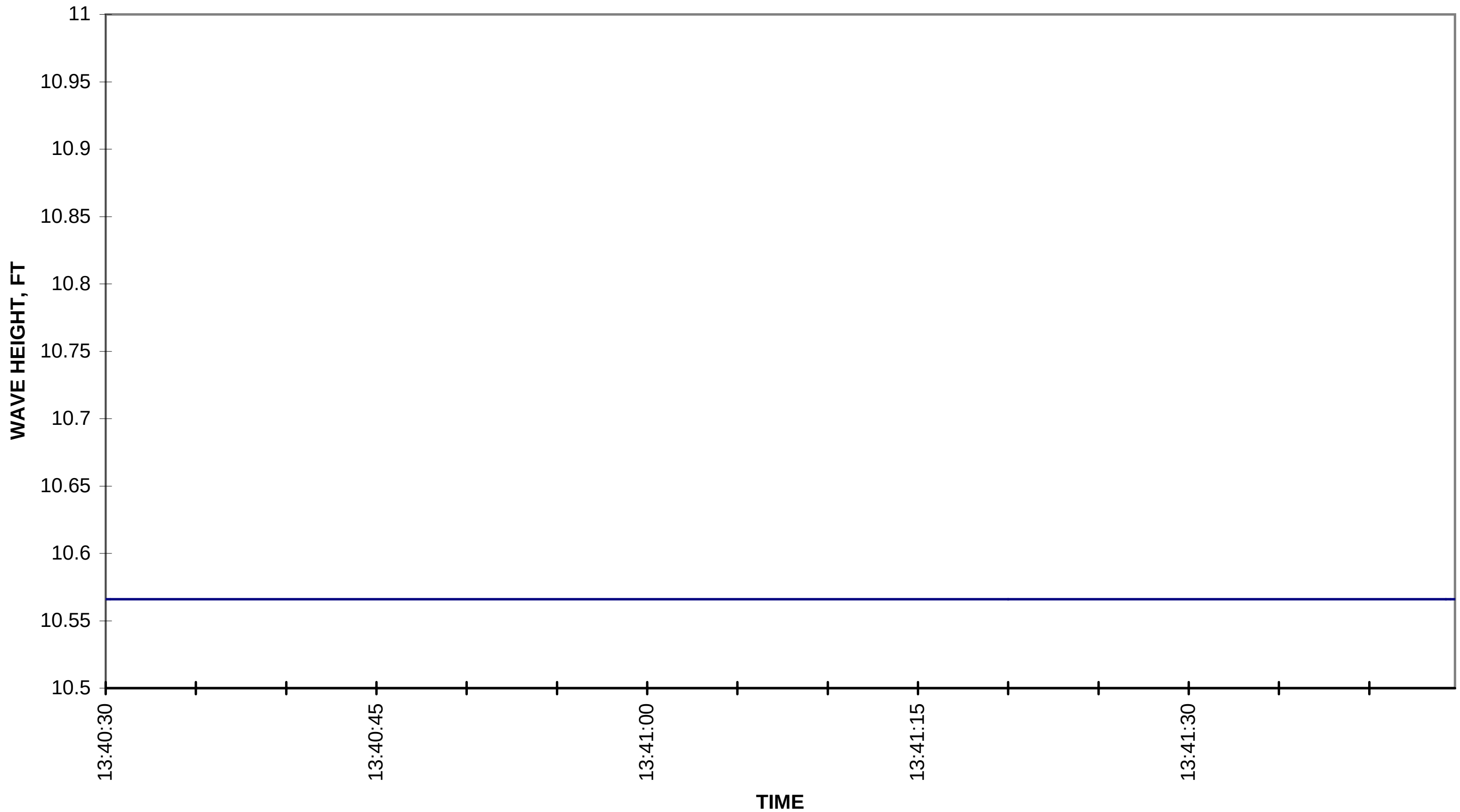
WAVE HEIGHTS

TEST 11, BOAT TYPE III

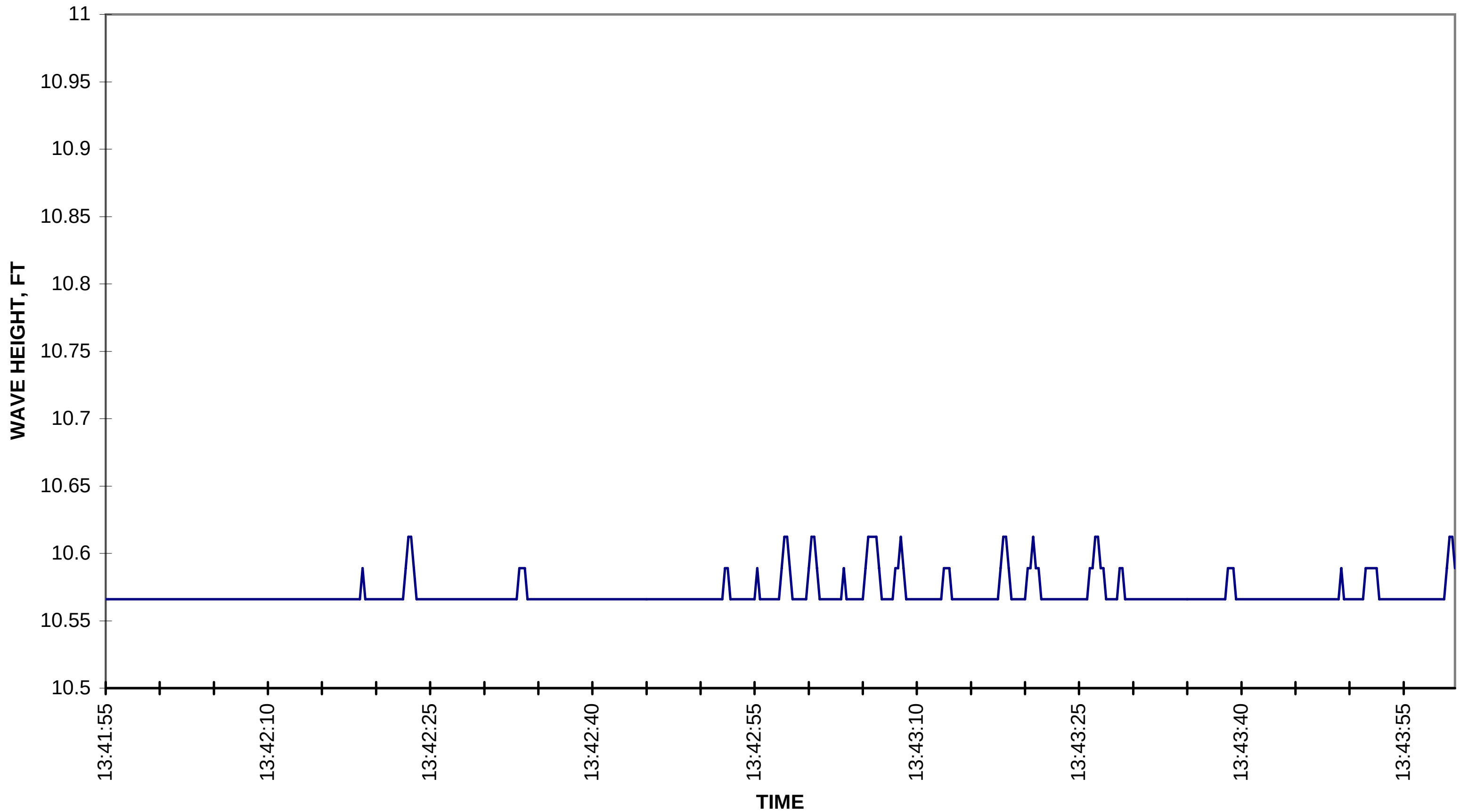
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

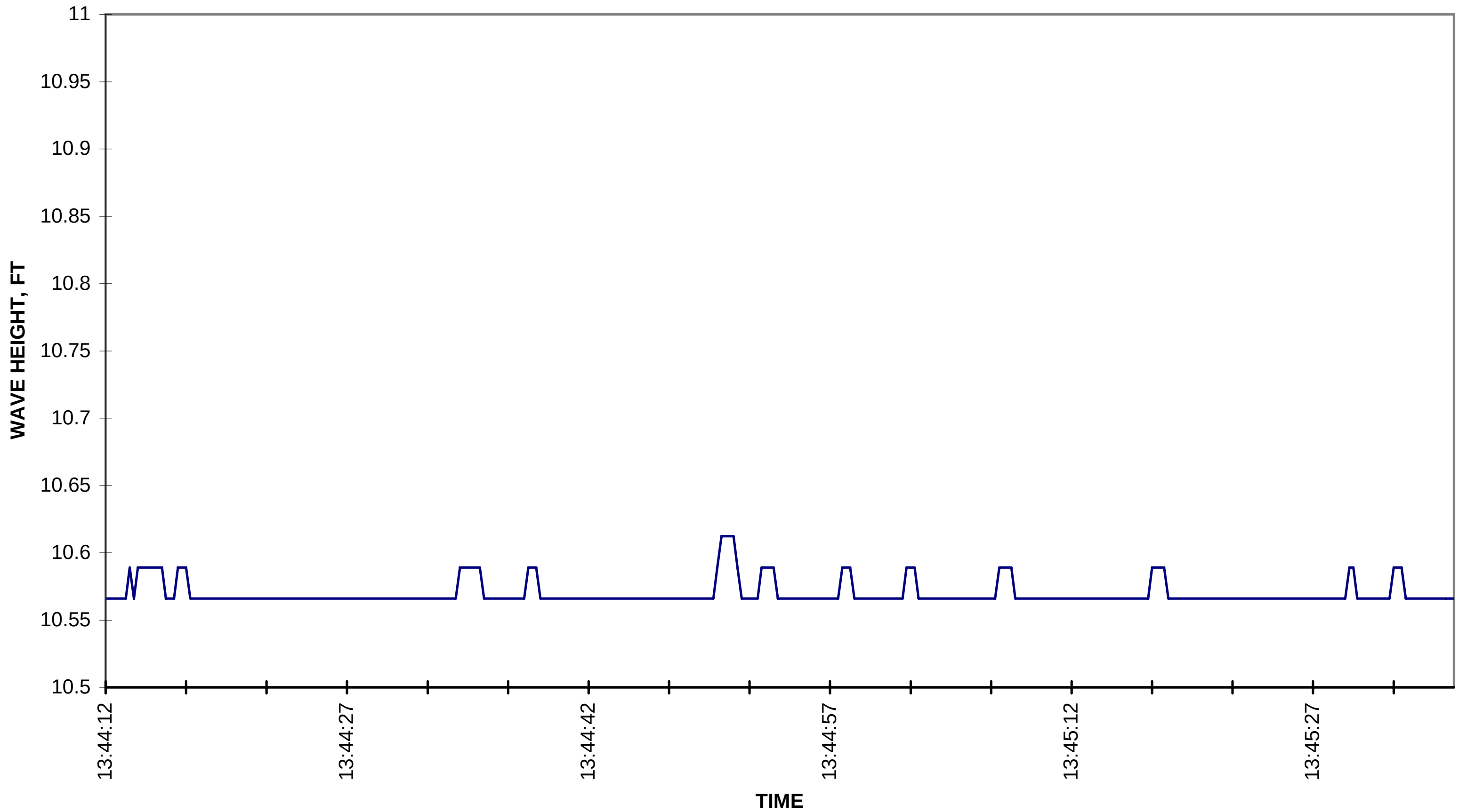
11/5/95



WAVE HEIGHTS
TEST 13, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 14, BOAT TYPE III
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



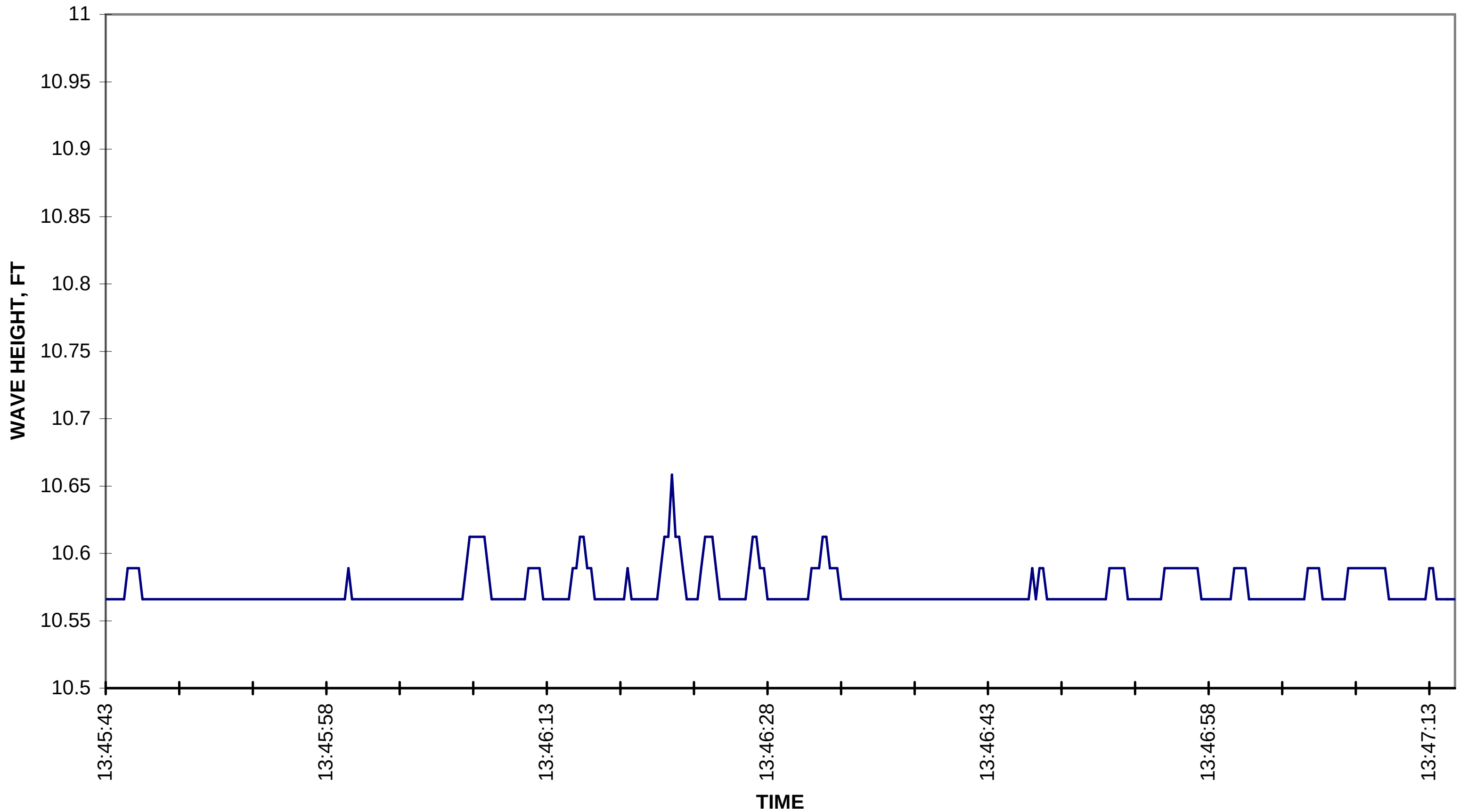
WAVE HEIGHTS

TEST 15, BOAT TYPE III

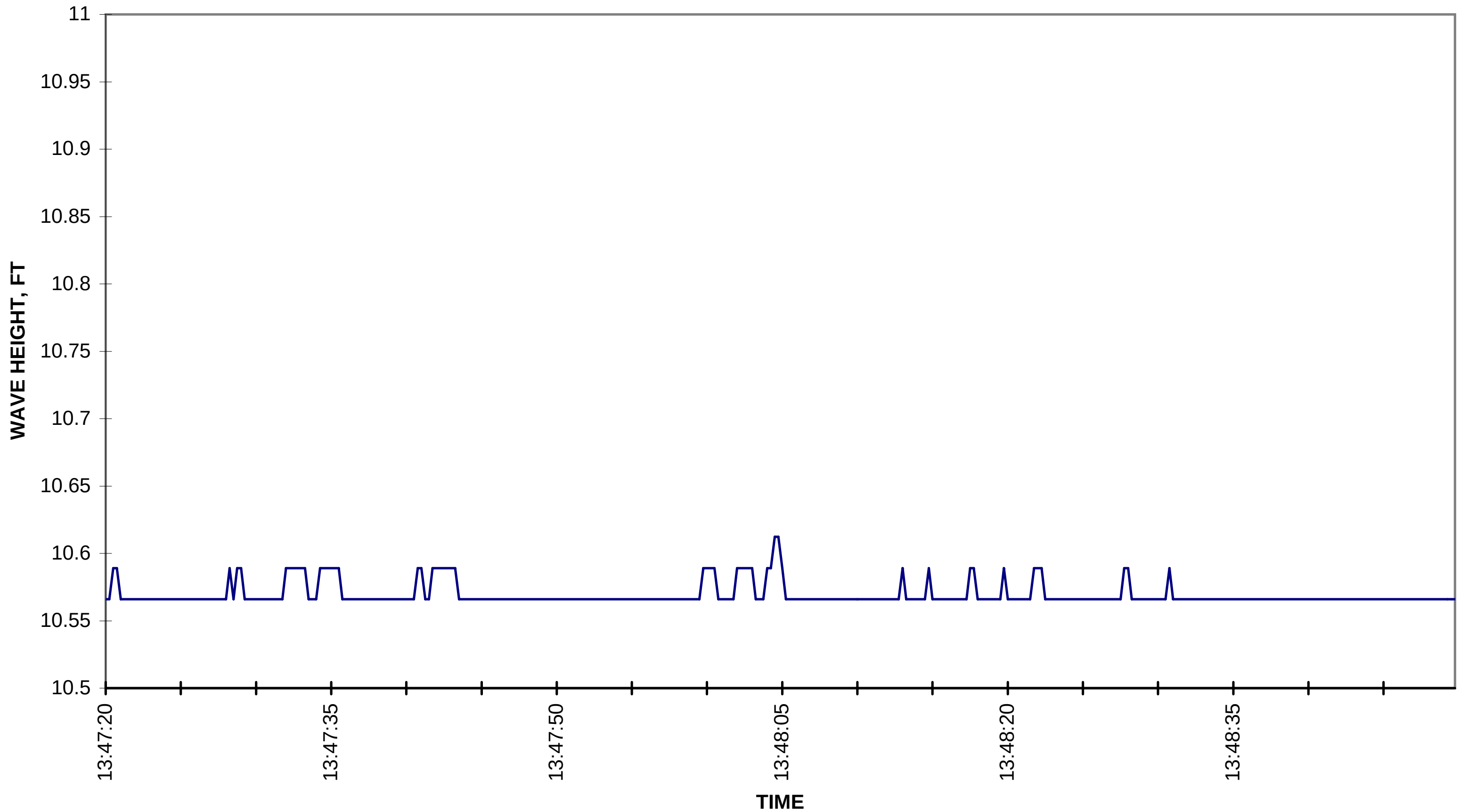
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

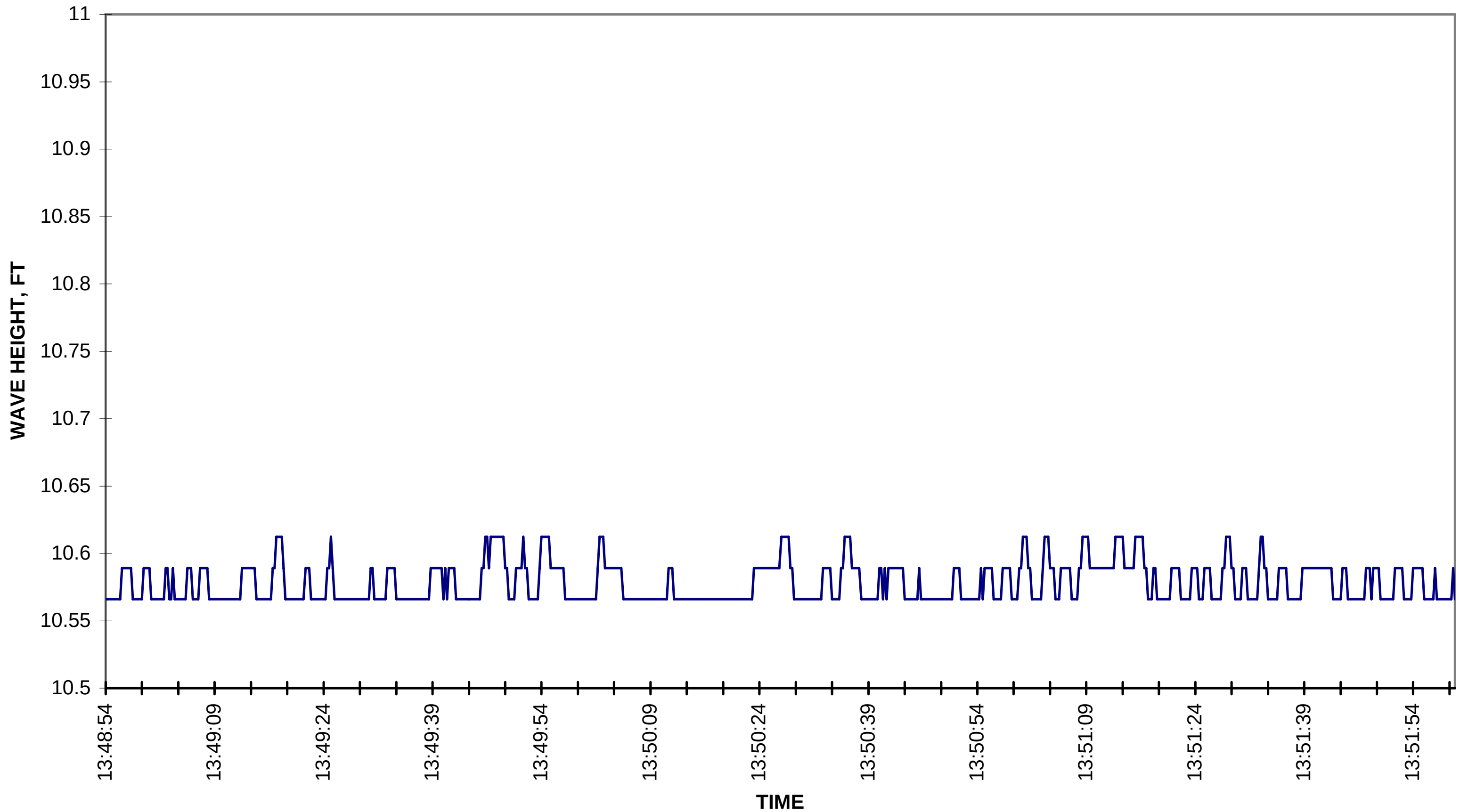
11/5/95



WAVE HEIGHTS
TEST 16, BOAT TYPE III
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 17, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



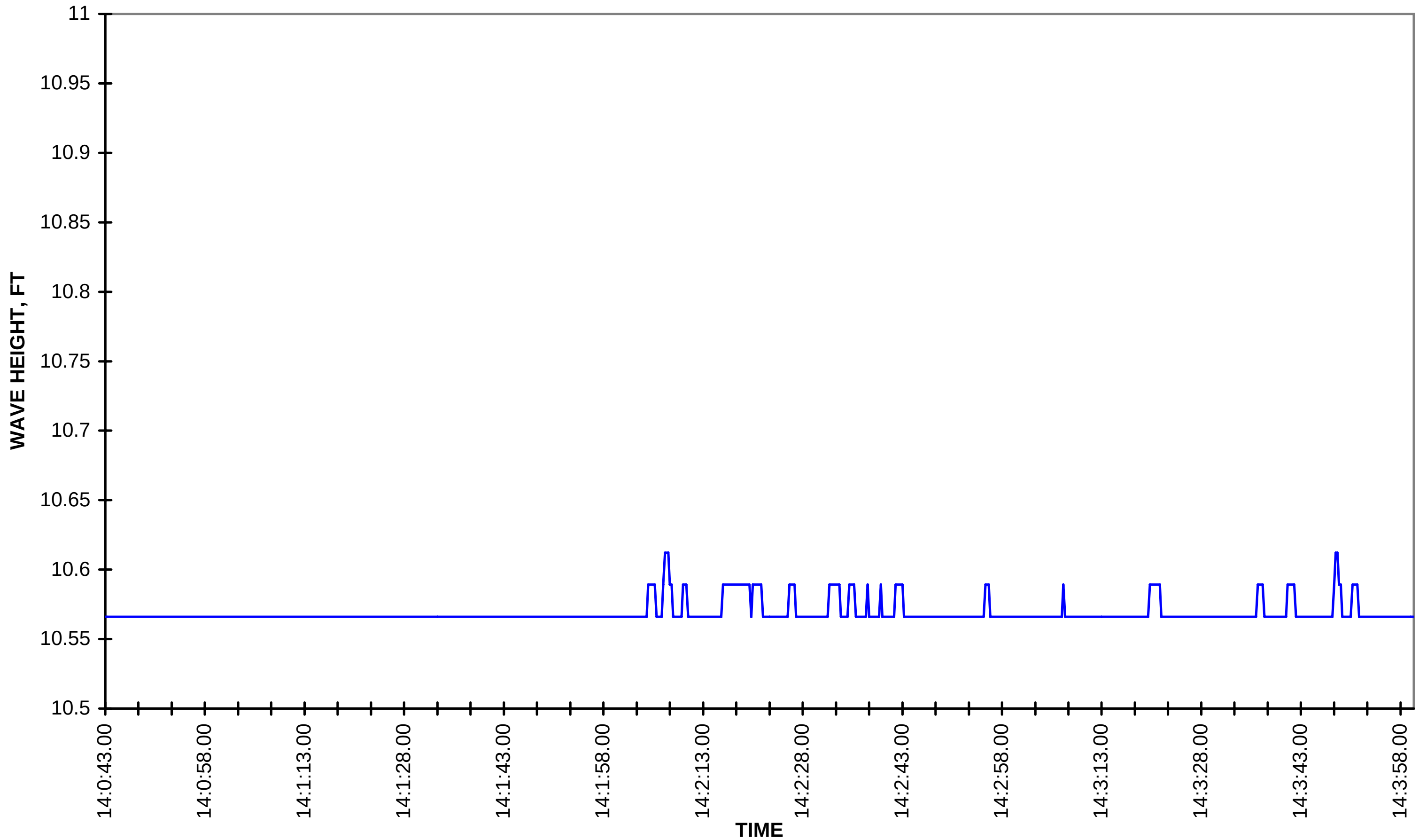
WAVE HEIGHTS

TEST 18, BOAT TYPE III

SAILING LINE S2, UPSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



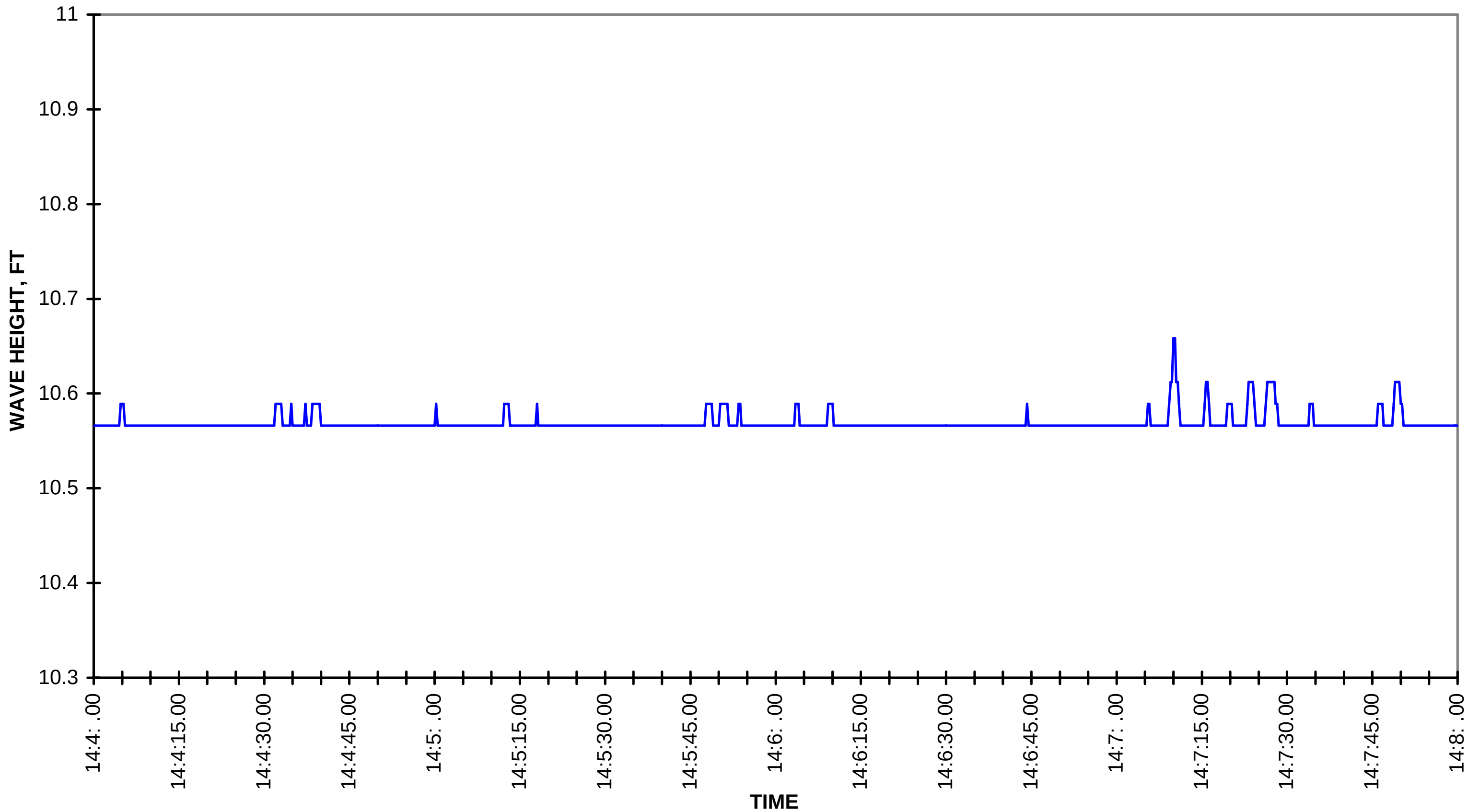
WAVE HEIGHTS

TEST 19, BOAT TYPE III

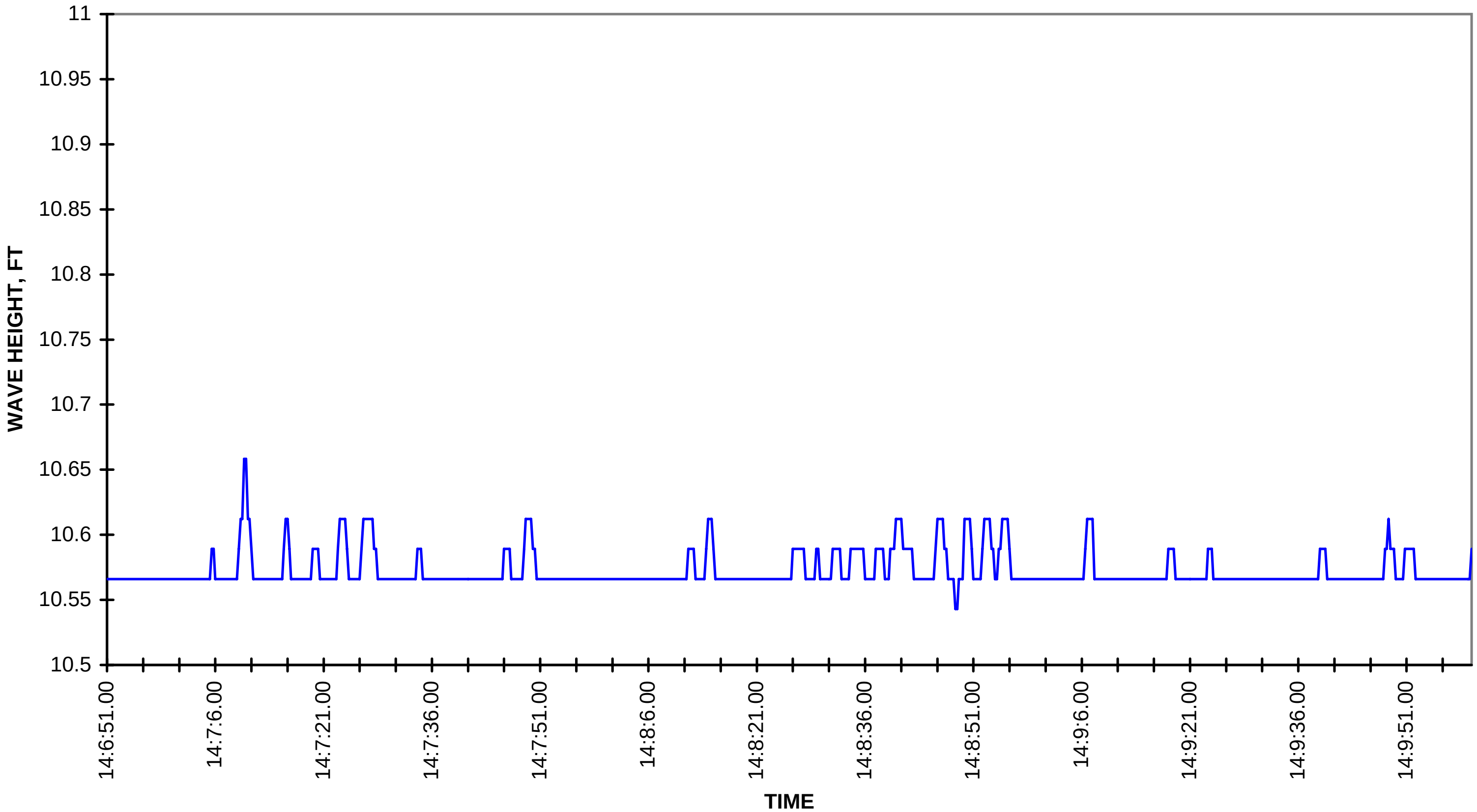
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



WAVE HEIGHTS
TEST 20, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



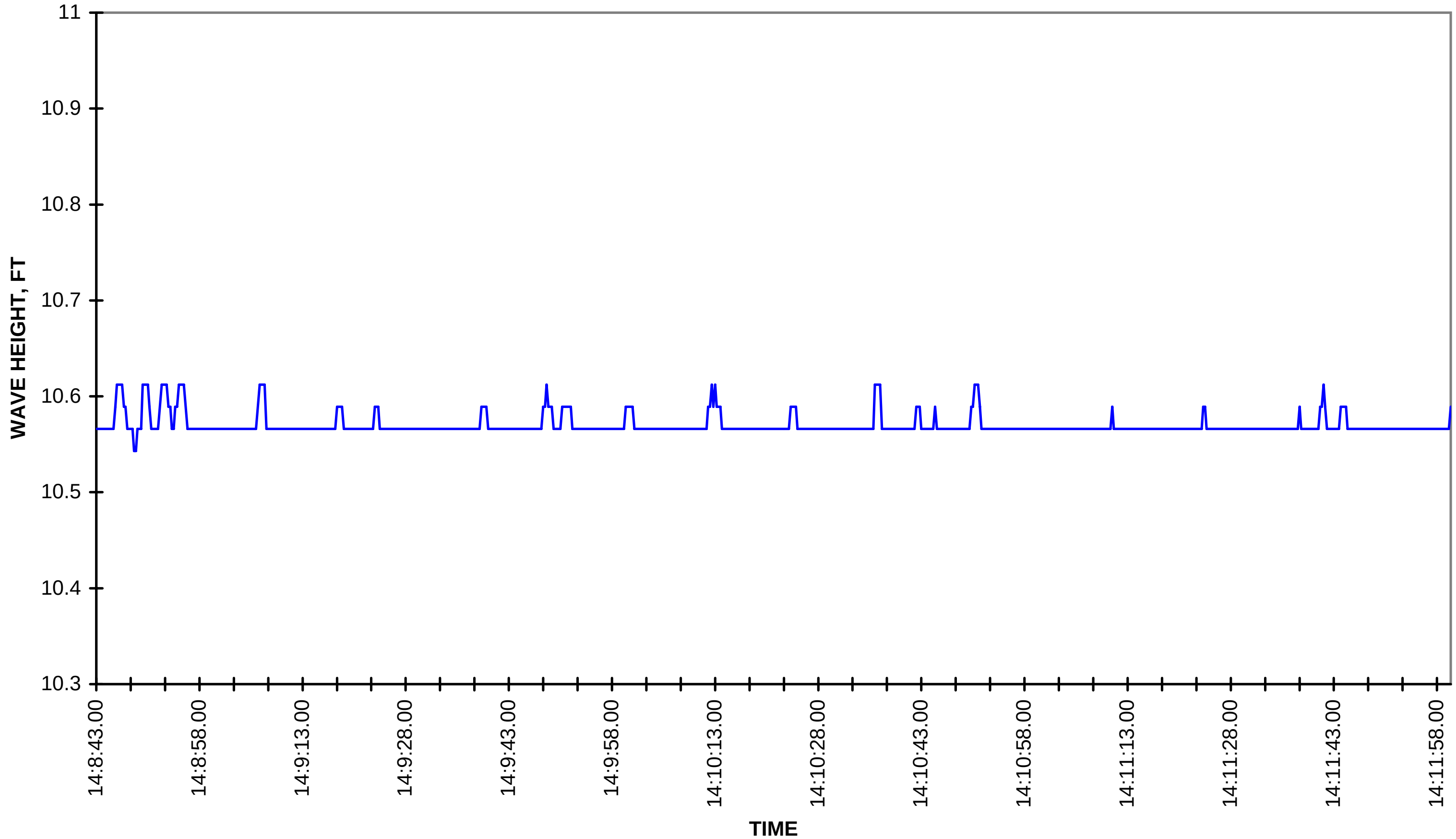
WAVE HEIGHTS

TEST 21, BOAT TYPE III

SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



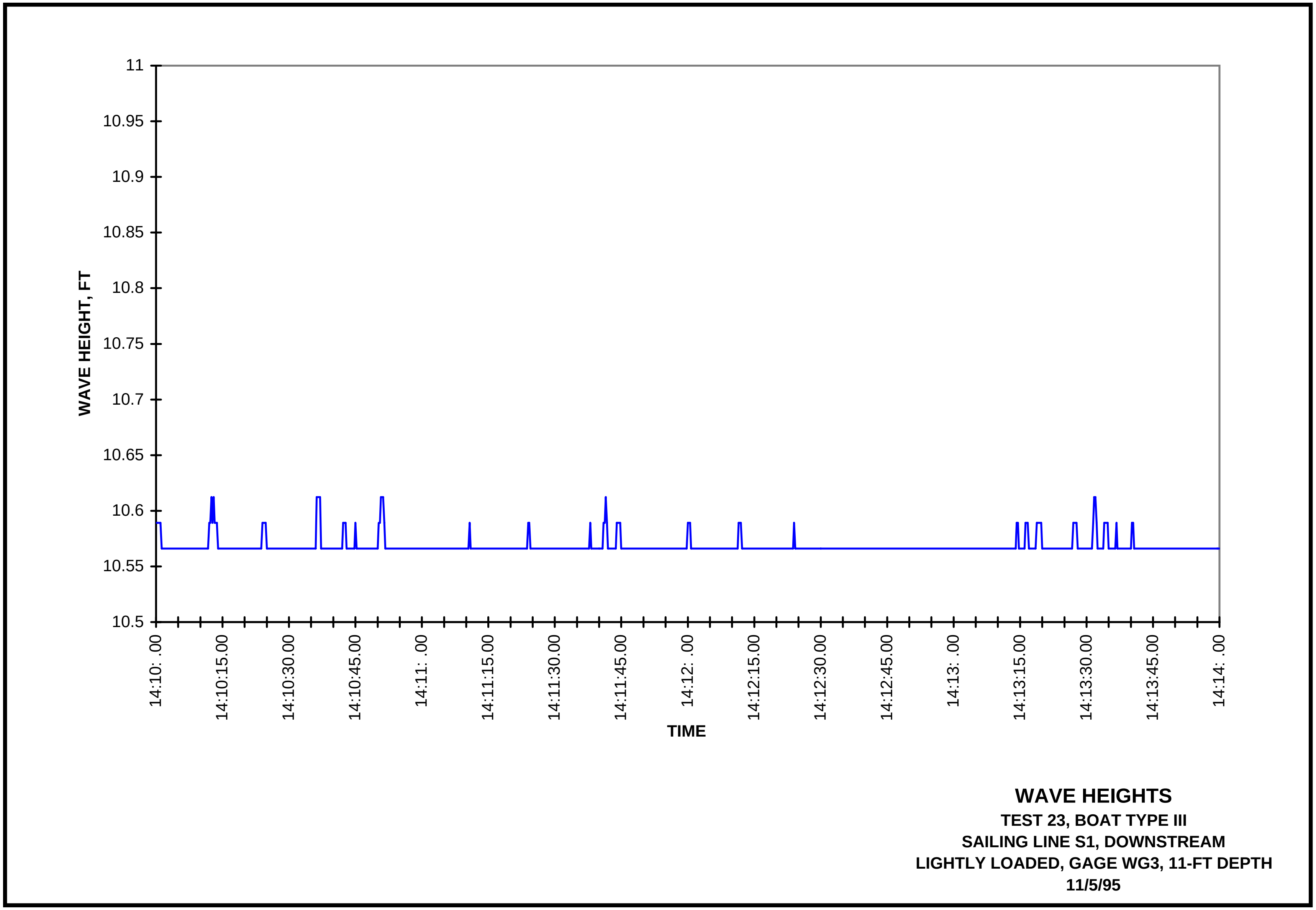
WAVE HEIGHTS

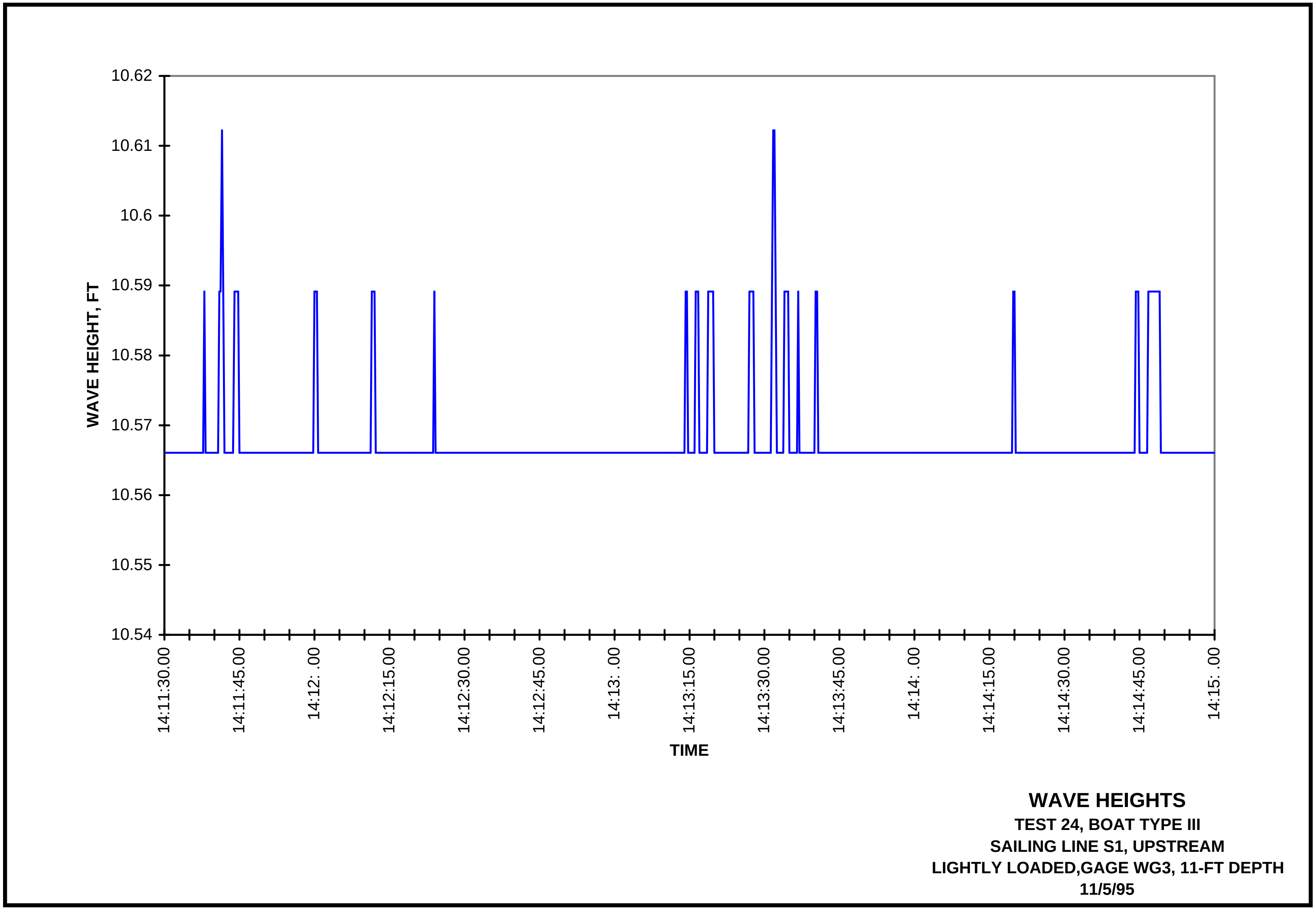
TEST 22, BOAT TYPE III

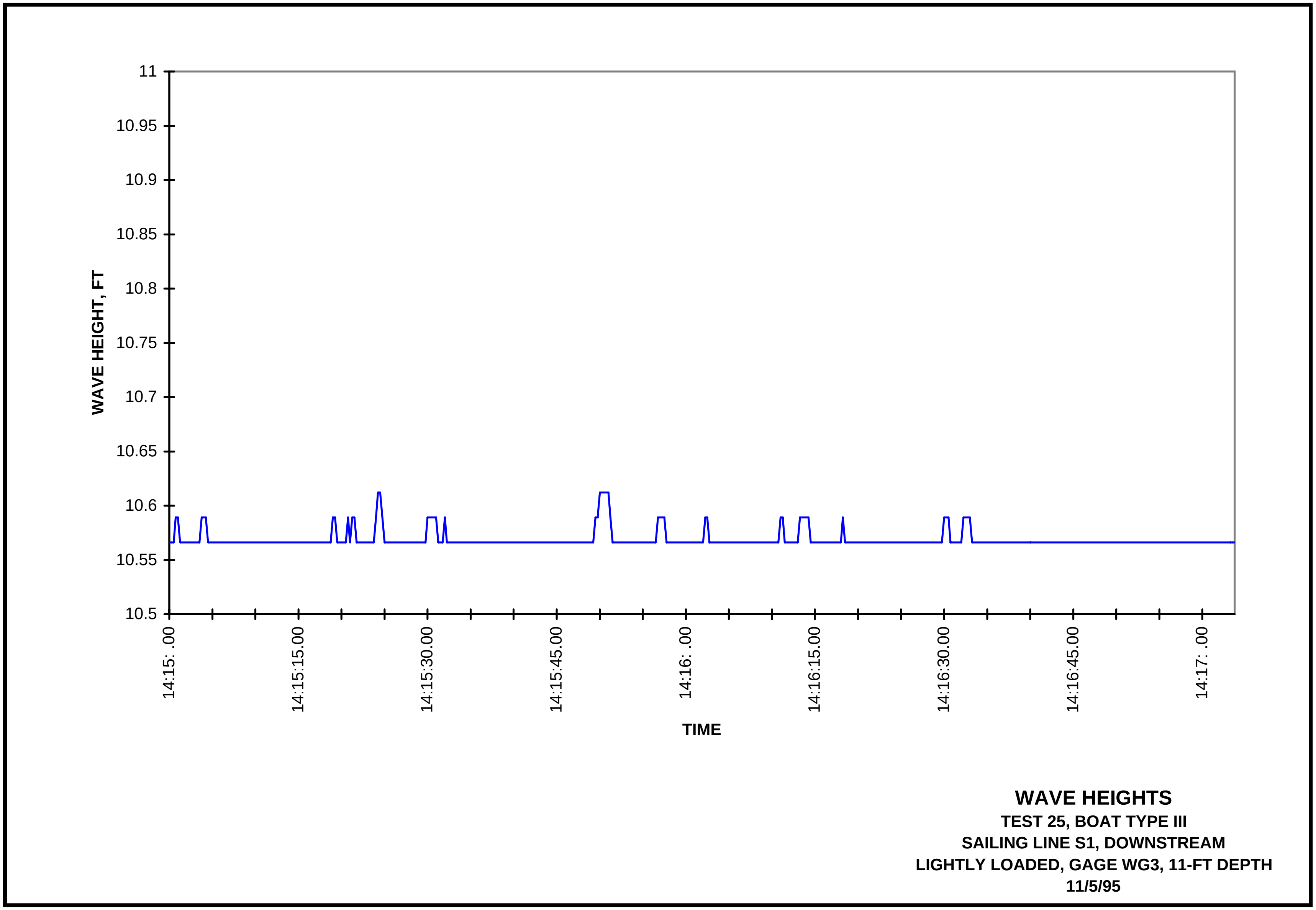
SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

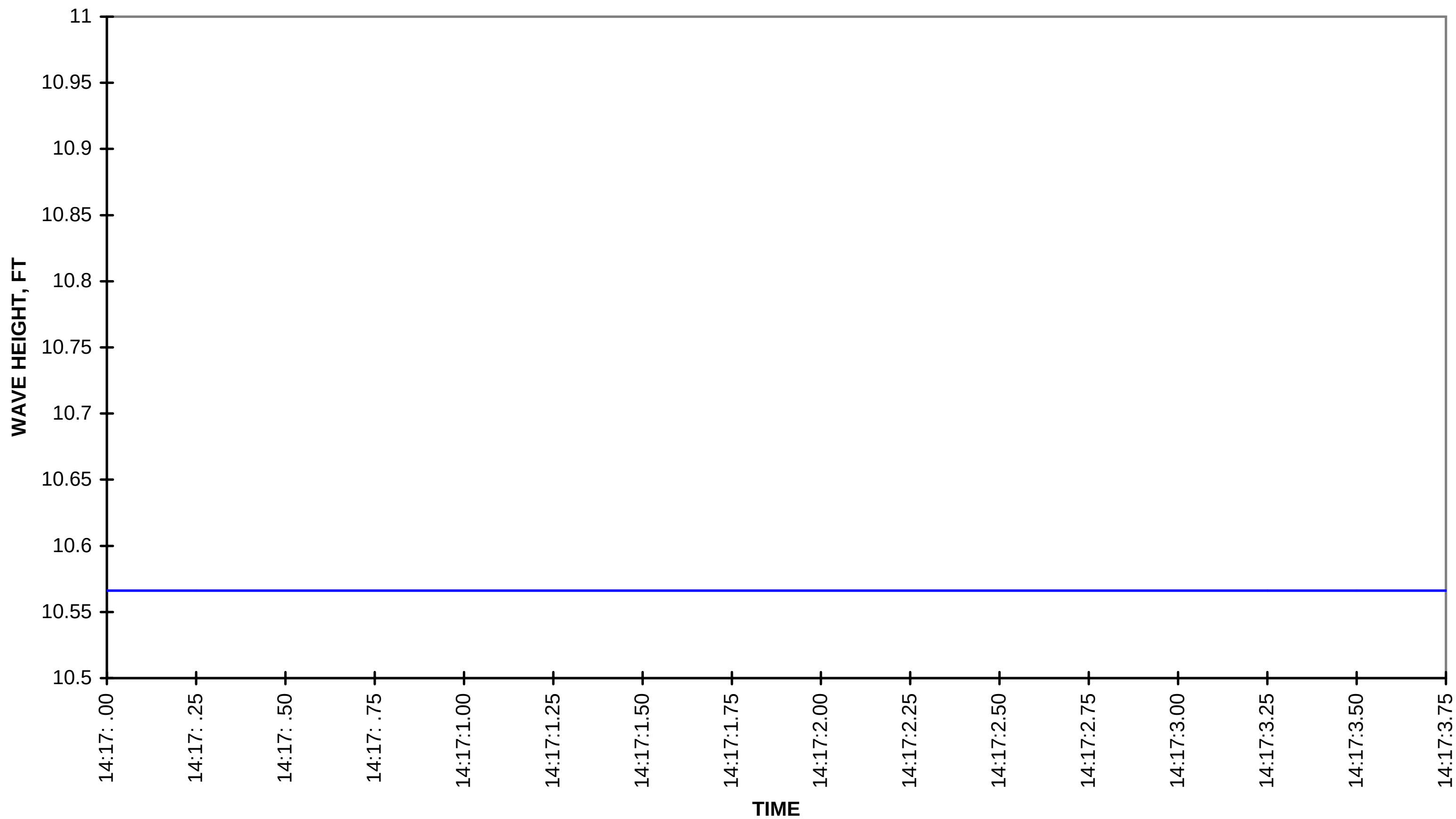
11/5/95


WAVE HEIGHT, FT
11
10.95
10.9
10.85
10.8
10.75
10.7
10.65
10.6
10.55
10.5
14:10: .00
14:10:15.00
14:10:30.00
14:10:45.00
14:11: .00
14:11:15.00
14:11:30.00
14:11:45.00
14:12: .00
14:12:15.00
14:12:30.00
14:12:45.00
14:13: .00
14:13:15.00
14:13:30.00
14:13:45.00
14:14: .00
TIME
WAVE HEIGHTS
TEST 23, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95

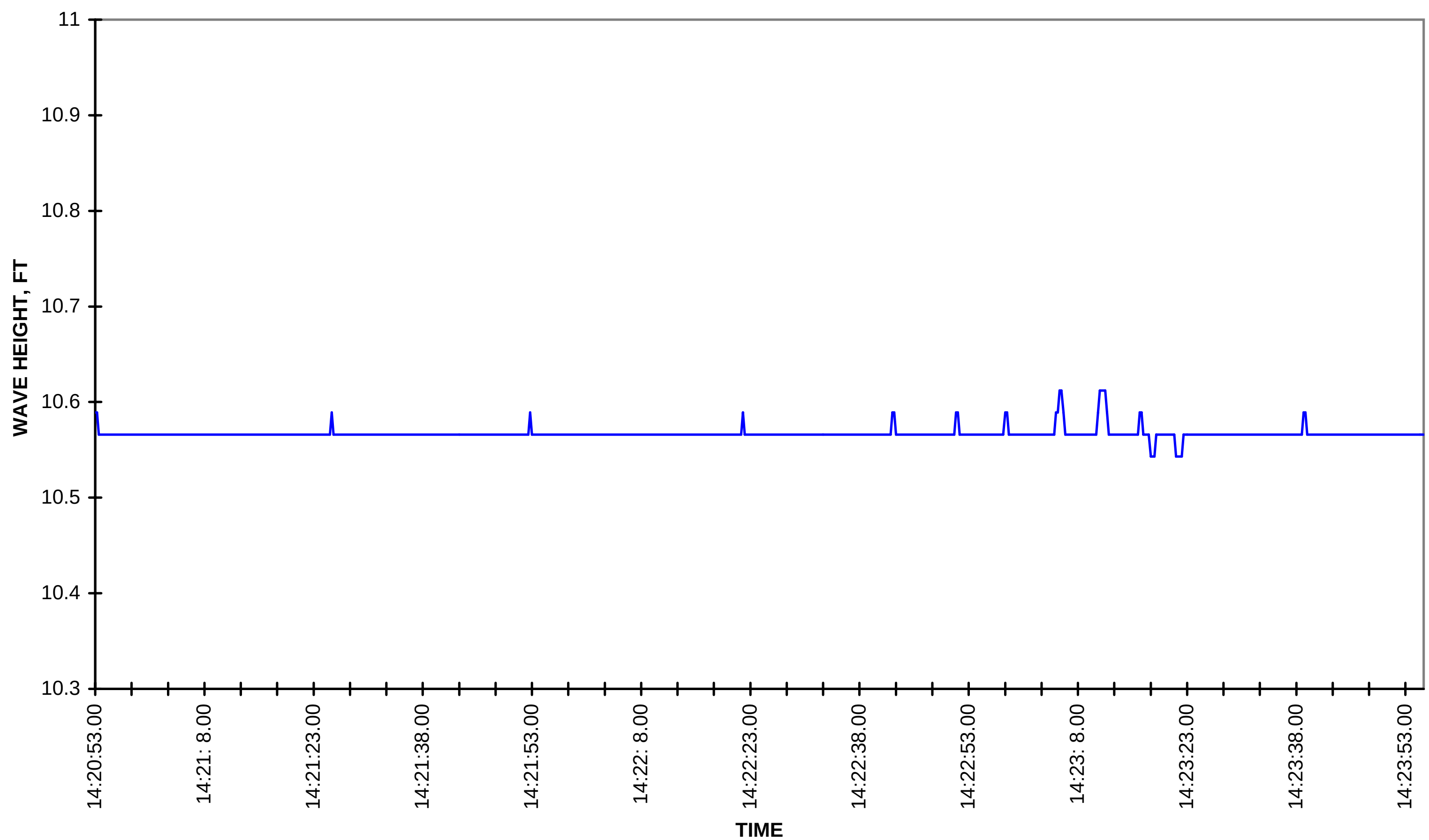

10.62
10.61
10.6
10.59
10.58
10.57
10.56
10.55
10.54
WAVE HEIGHT, FT
14:11:30.00
14:11:45.00
14:12: .00
14:12:15.00
14:12:30.00
14:12:45.00
14:13: .00
14:13:15.00
14:13:30.00
14:13:45.00
14:14: .00
14:14:15.00
14:14:30.00
14:14:45.00
14:15: .00
TIME
WAVE HEIGHTS
TEST 24, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED,GAGE WG3, 11-FT DEPTH
11/5/95



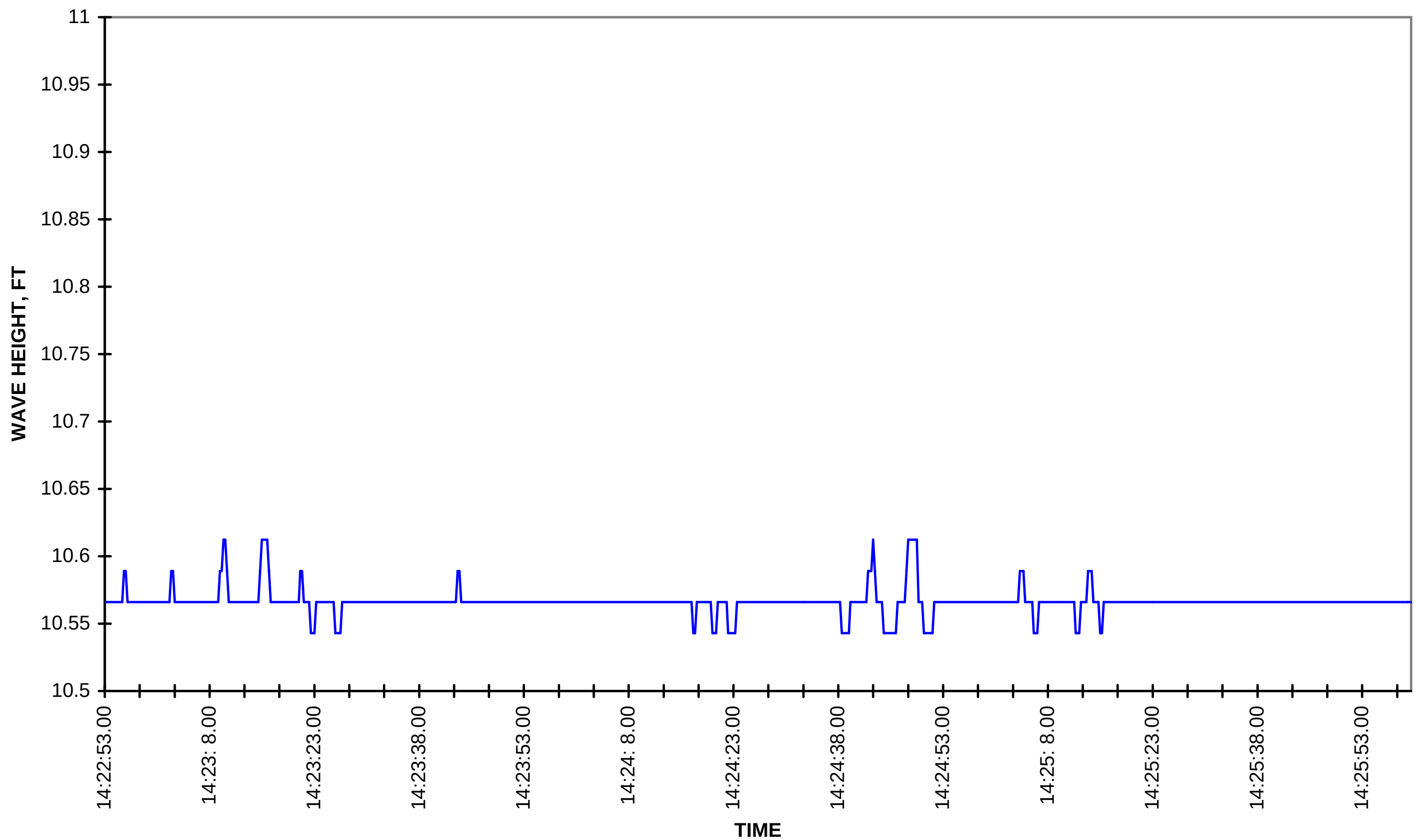
WAVE HEIGHT, FT
11
10.95
10.9
10.85
10.8
10.75
10.7
10.65
10.6
10.55
10.5
14:15: .00
14:15:15.00
14:15:30.00
14:15:45.00
14:16: .00
14:16:15.00
14:16:30.00
14:16:45.00
14:17: .00
TIME
WAVE HEIGHTS
TEST 25, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 26, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 28, BOAT TYPE III
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



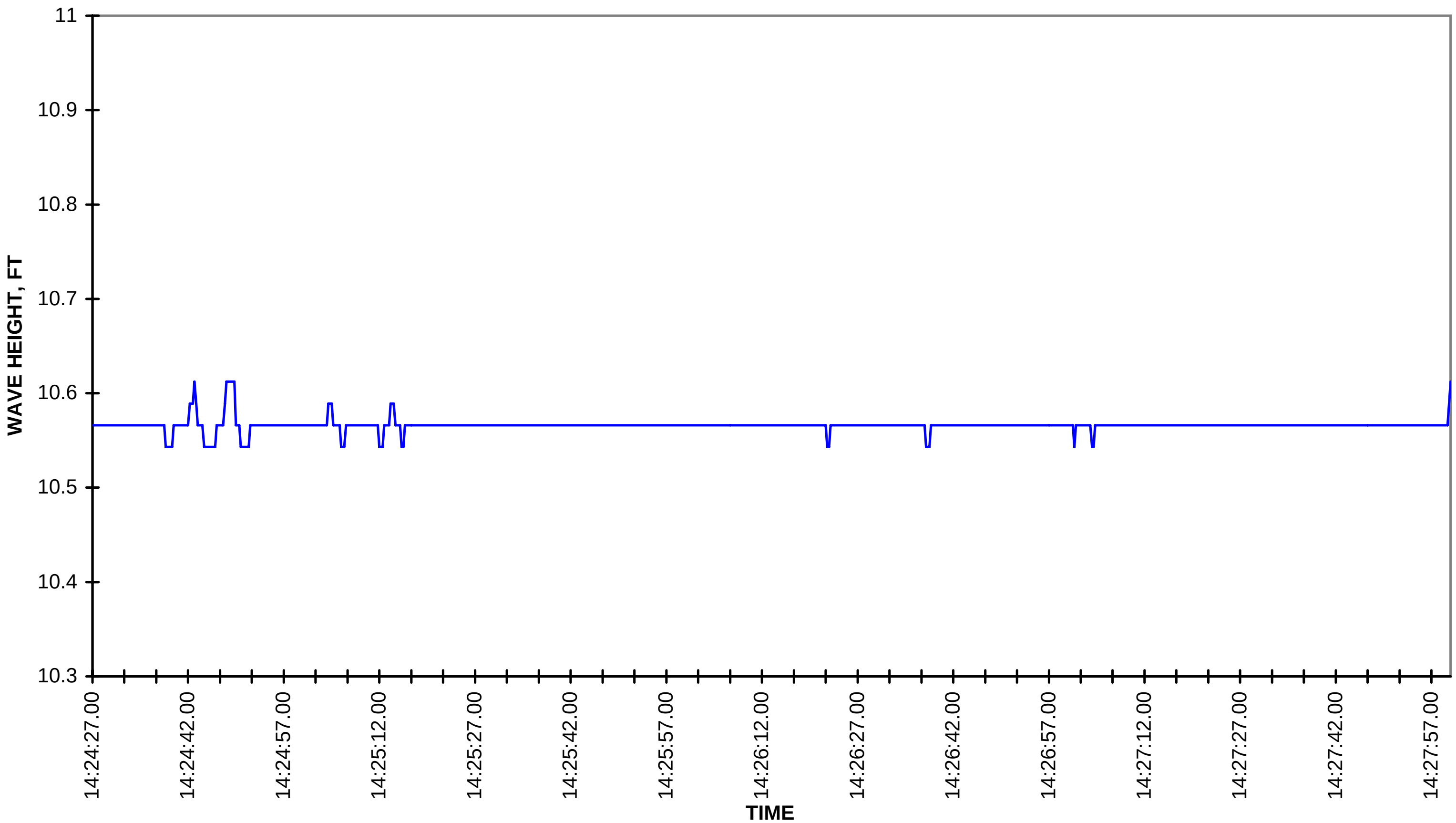
WAVE HEIGHTS

TEST 29, BOAT TYPE III

SAILING LINE S2, DOWNSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



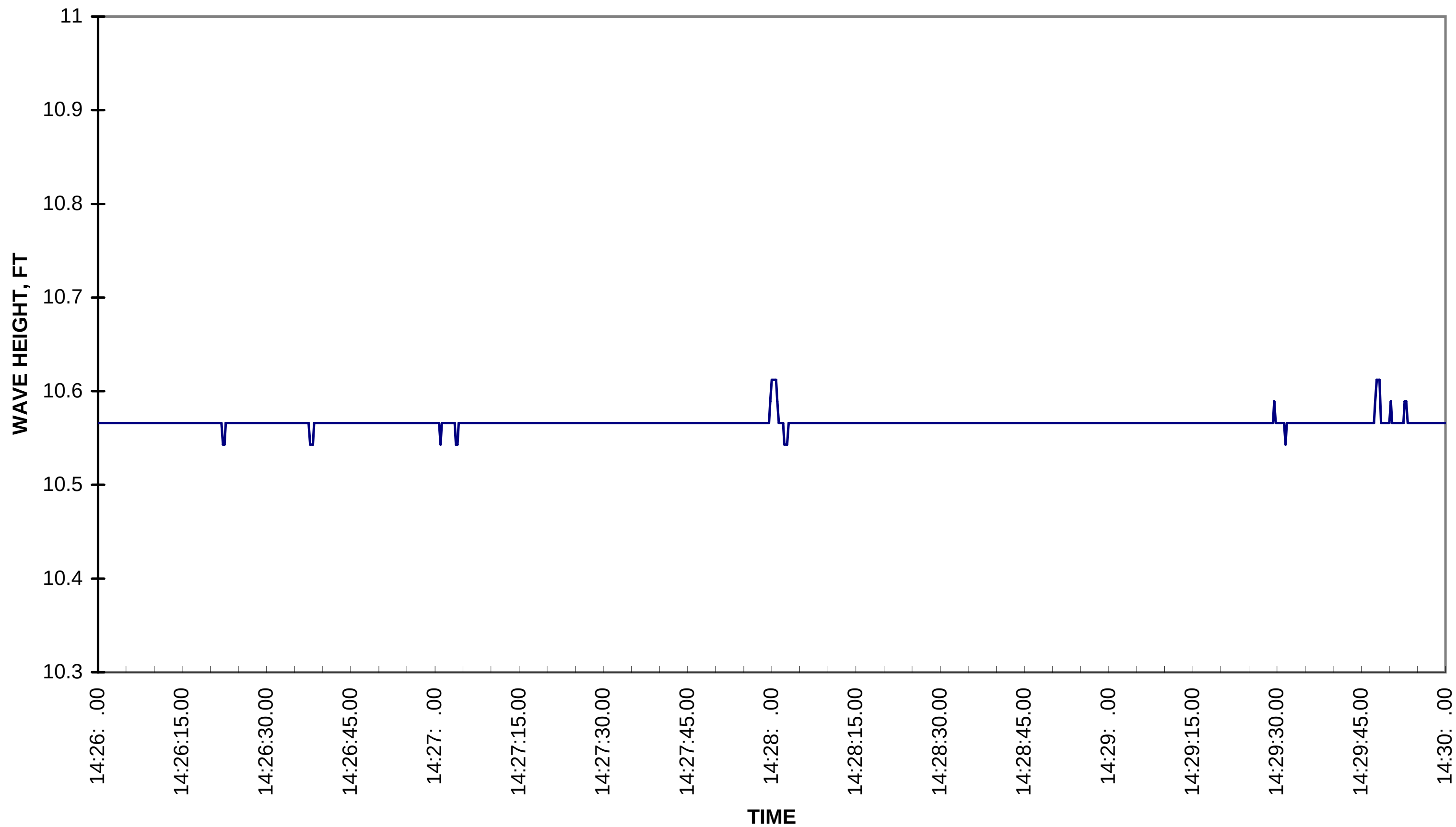
WAVE HEIGHTS

TEST 30, BOAT TYPE III

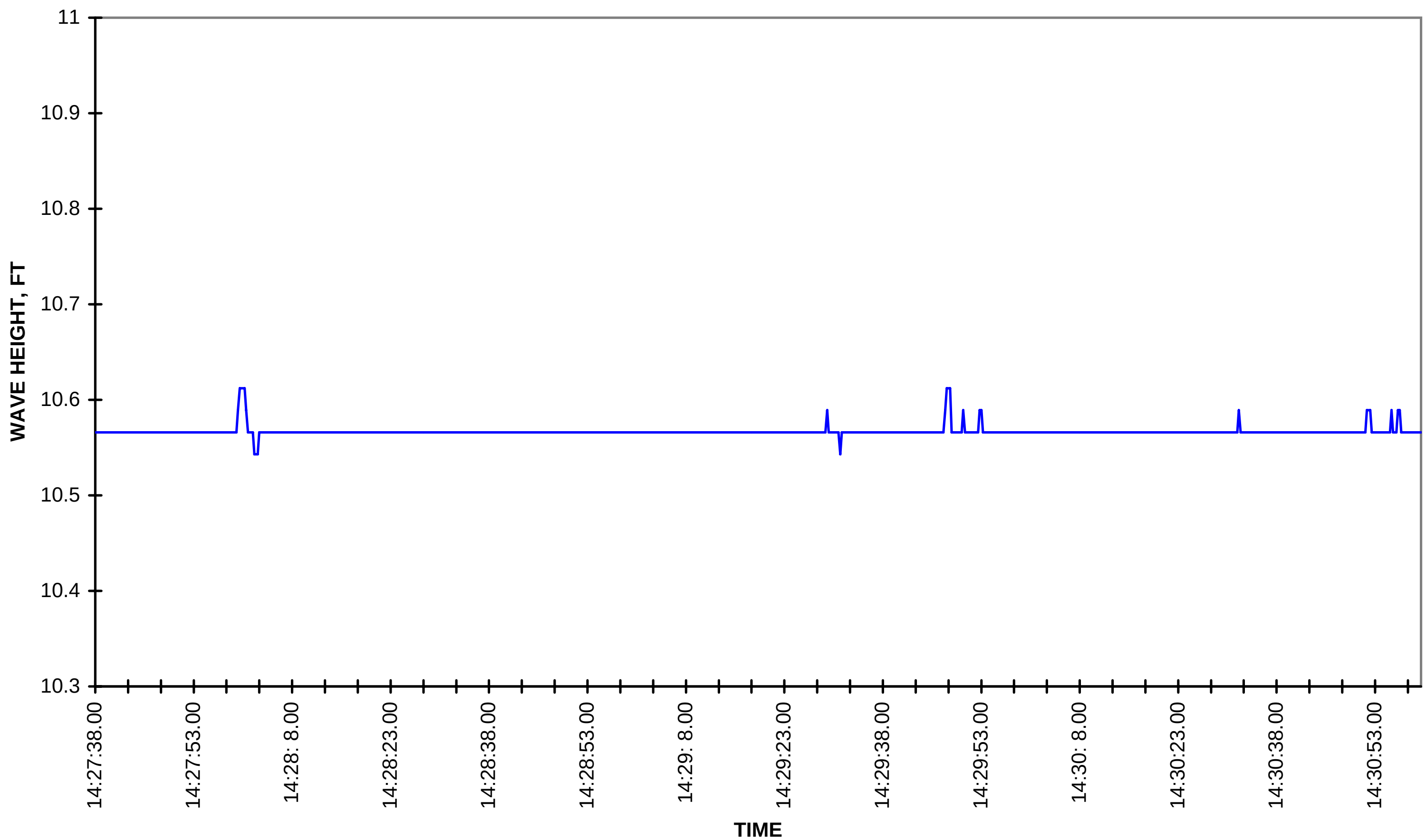
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



WAVE HEIGHTS
TEST 31, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



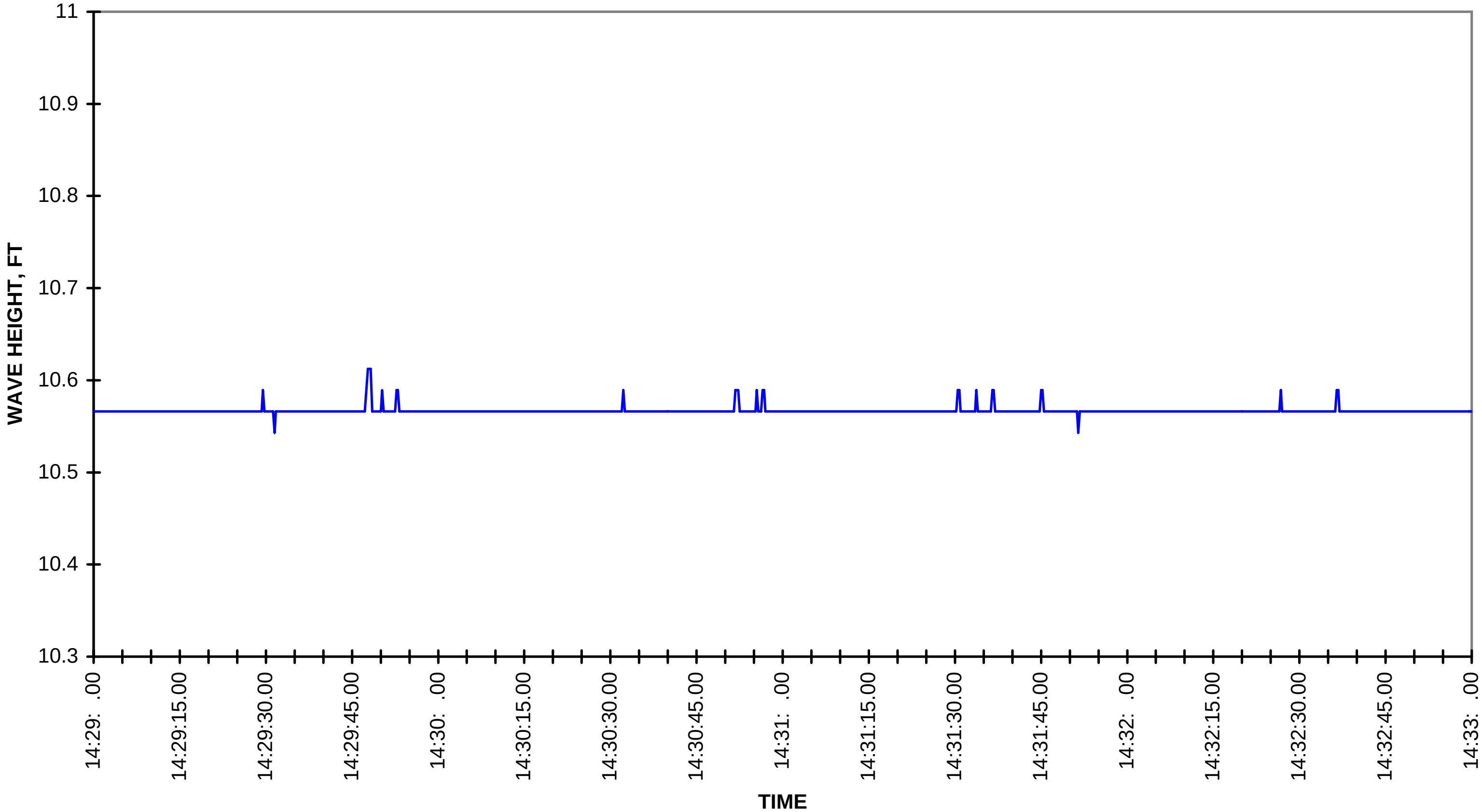
WAVE HEIGHTS

TEST 32, BOAT TYPE III

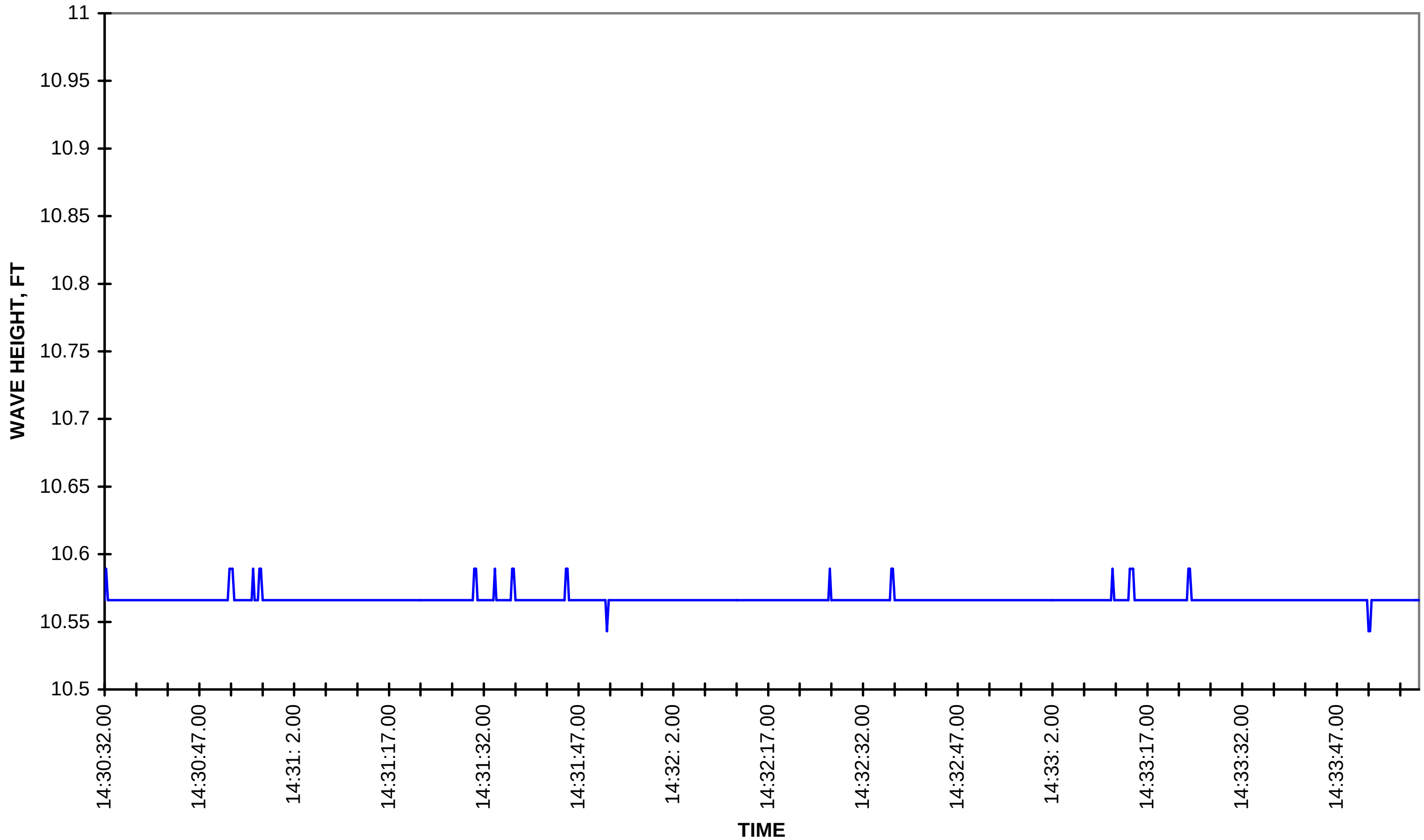
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



WAVE HEIGHTS
TEST 33, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/5/95



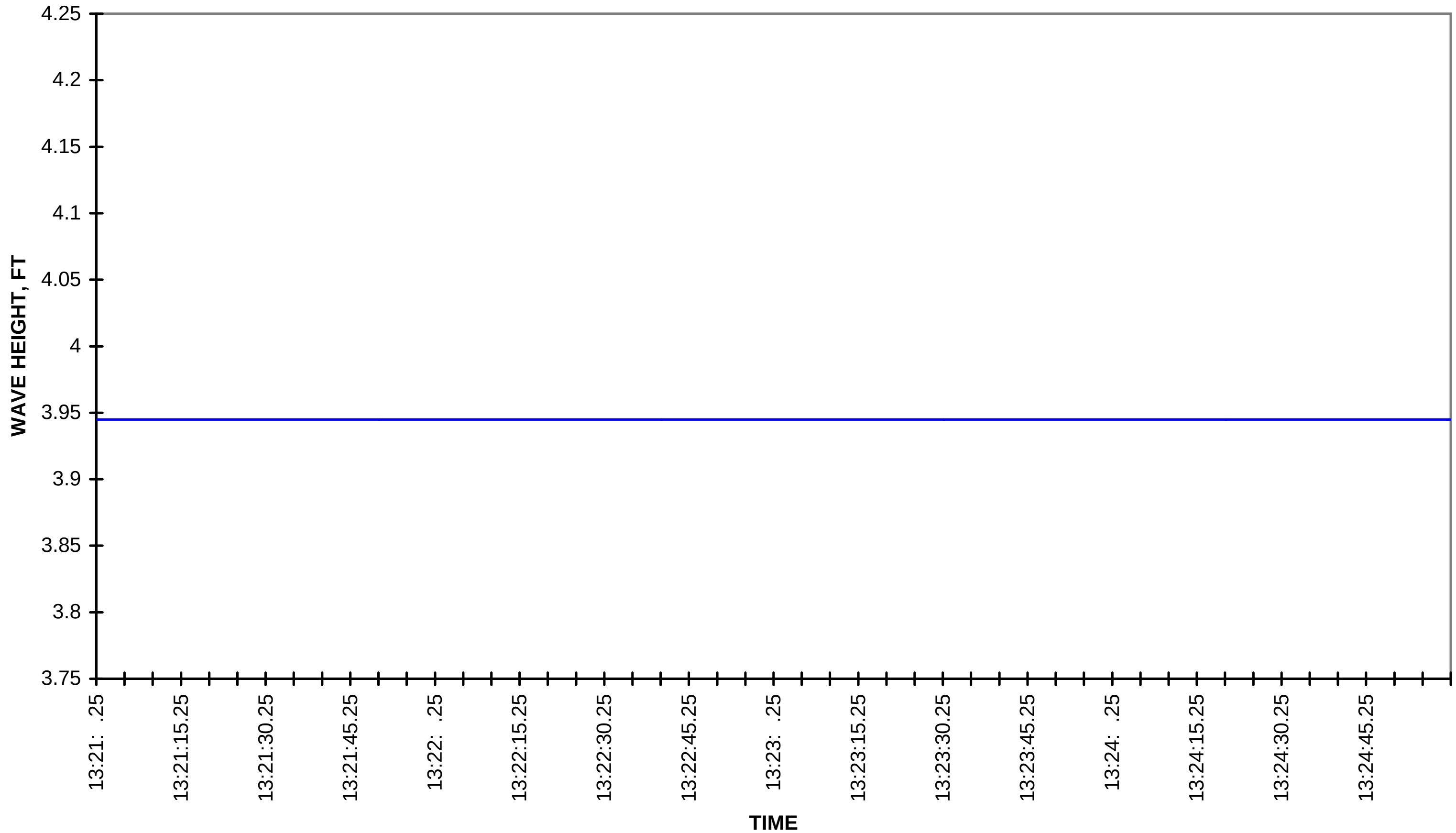
WAVE HEIGHTS

TEST 34, BOAT TYPE III

SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/5/95



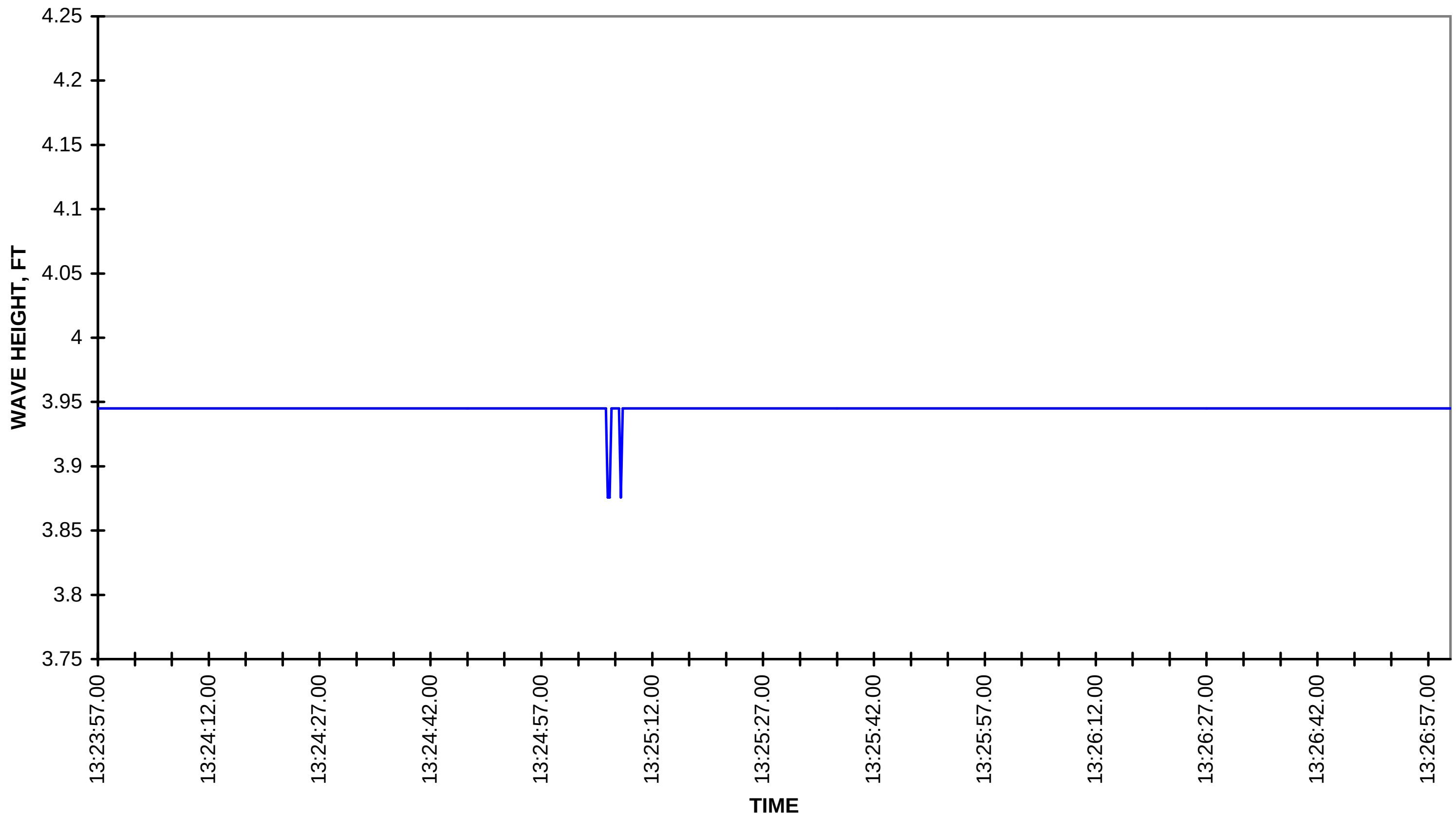
WAVE HEIGHTS

TEST 4, BOAT TYPE III

SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



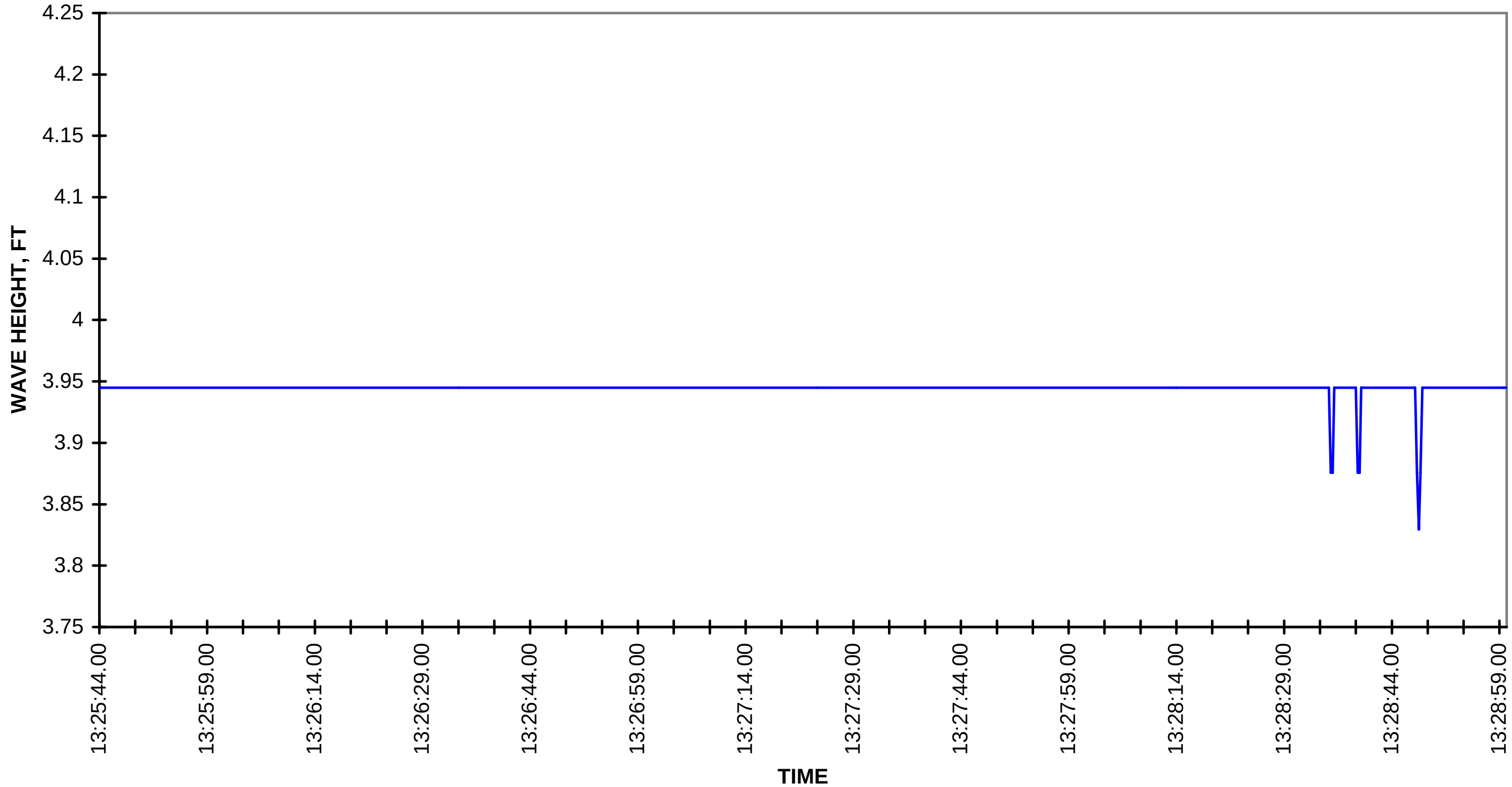
WAVE HEIGHTS

TEST 5, BOAT TYPE III

SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



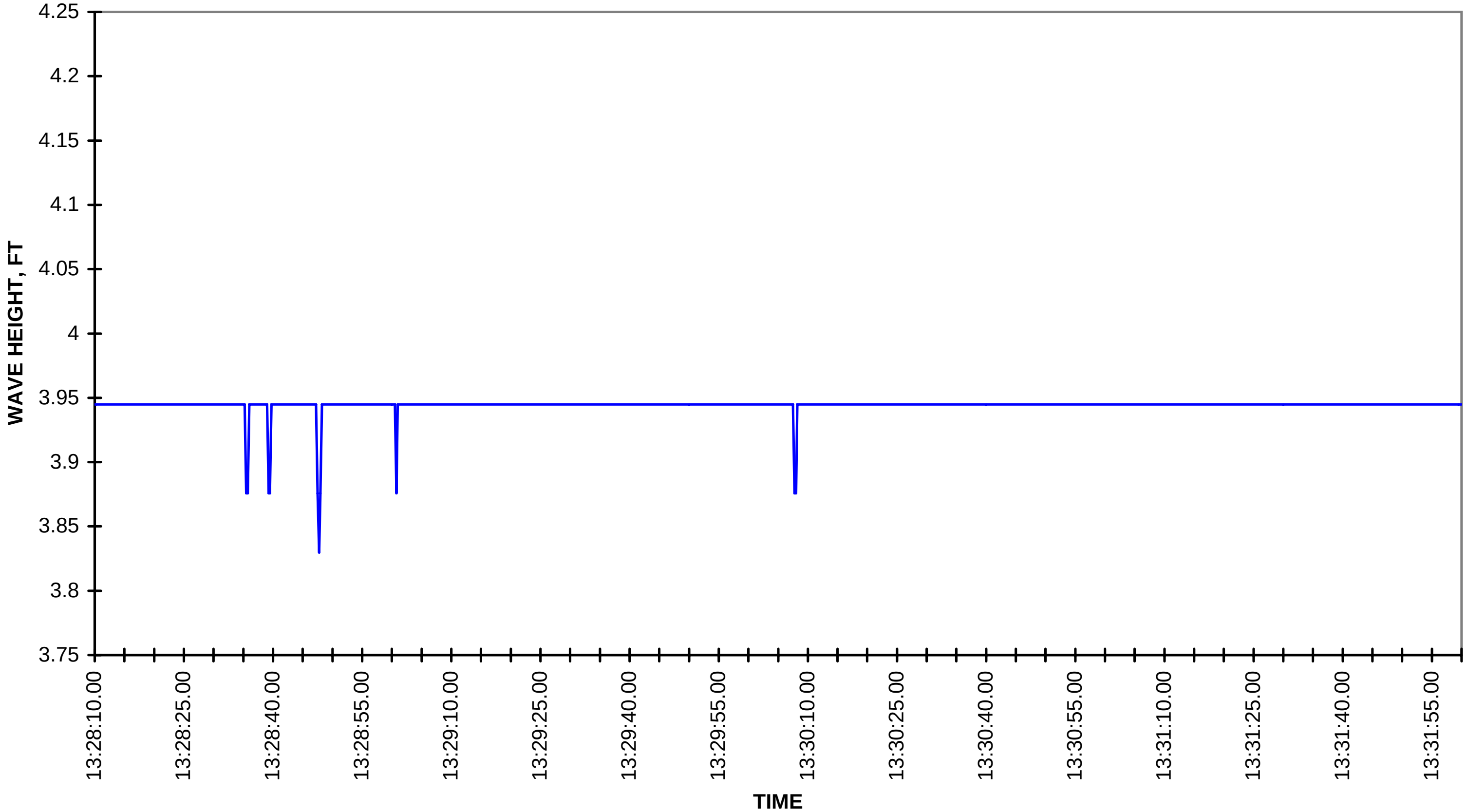
WAVE HEIGHTS

TEST 6, BOAT TYPE III

SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



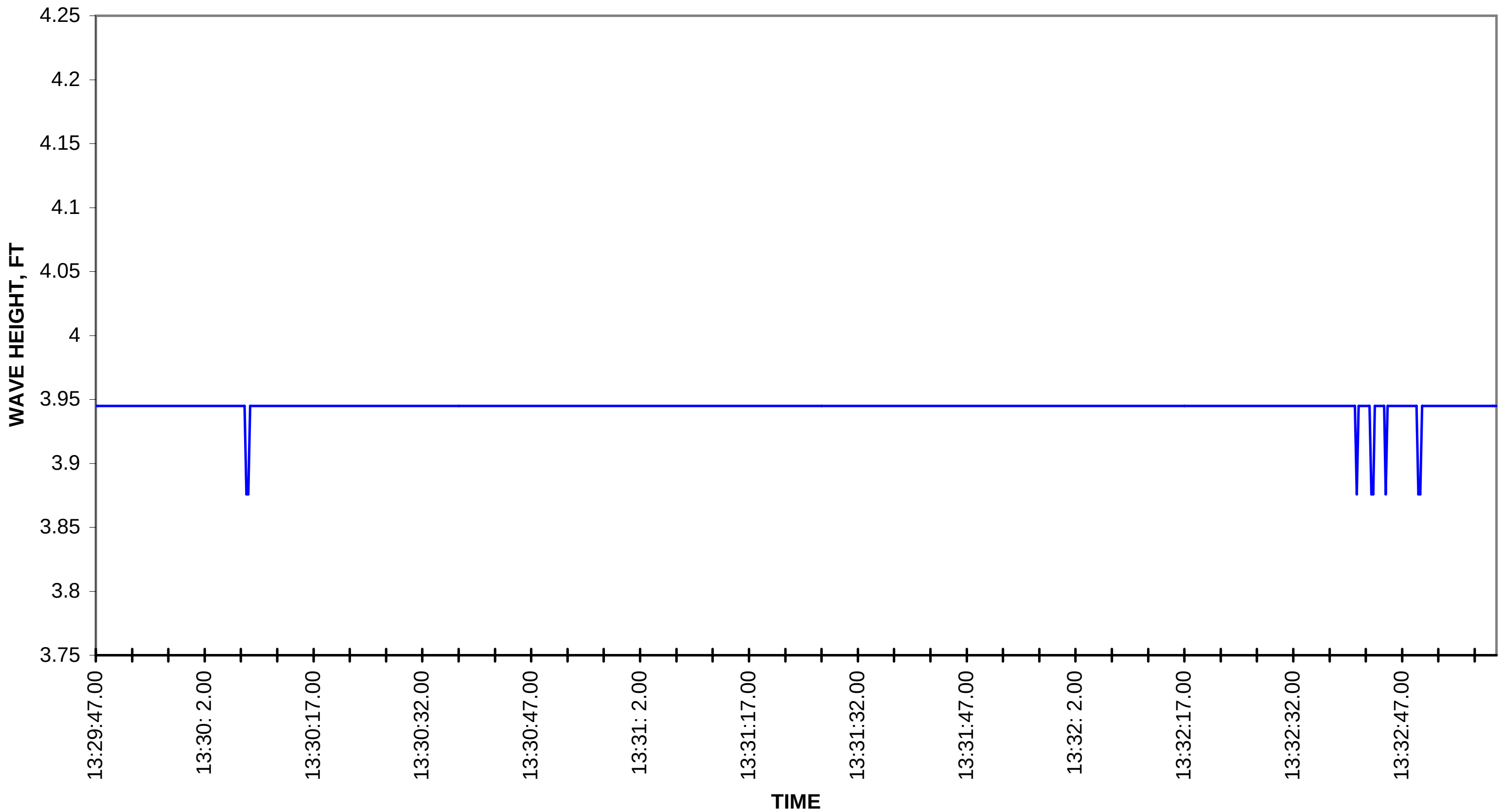
WAVE HEIGHTS

TEST 7, BOAT TYPE III

SAILING LINE S1, DOWNSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



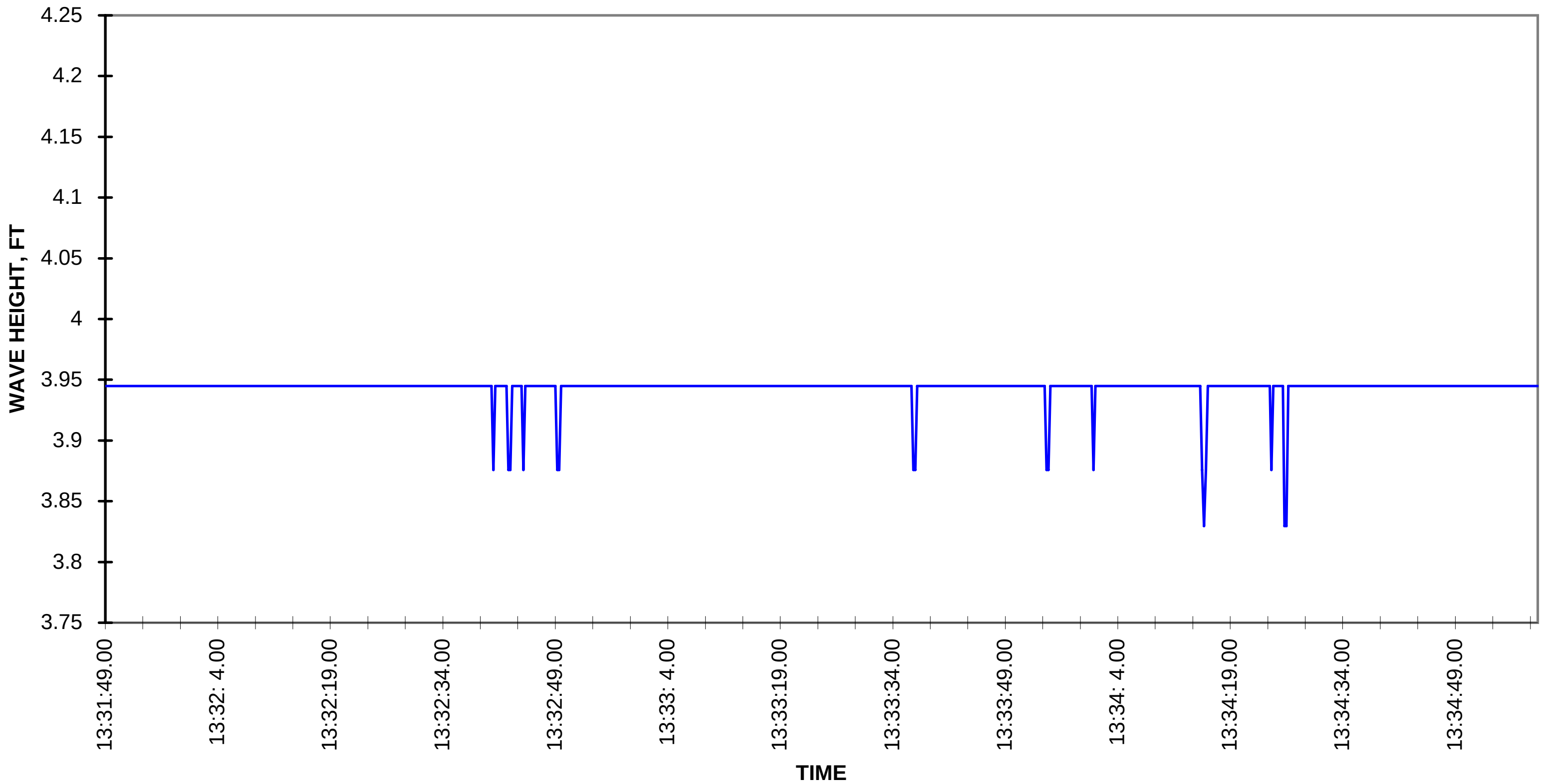
WAVE HEIGHTS

TEST 8, BOAT TYPE III

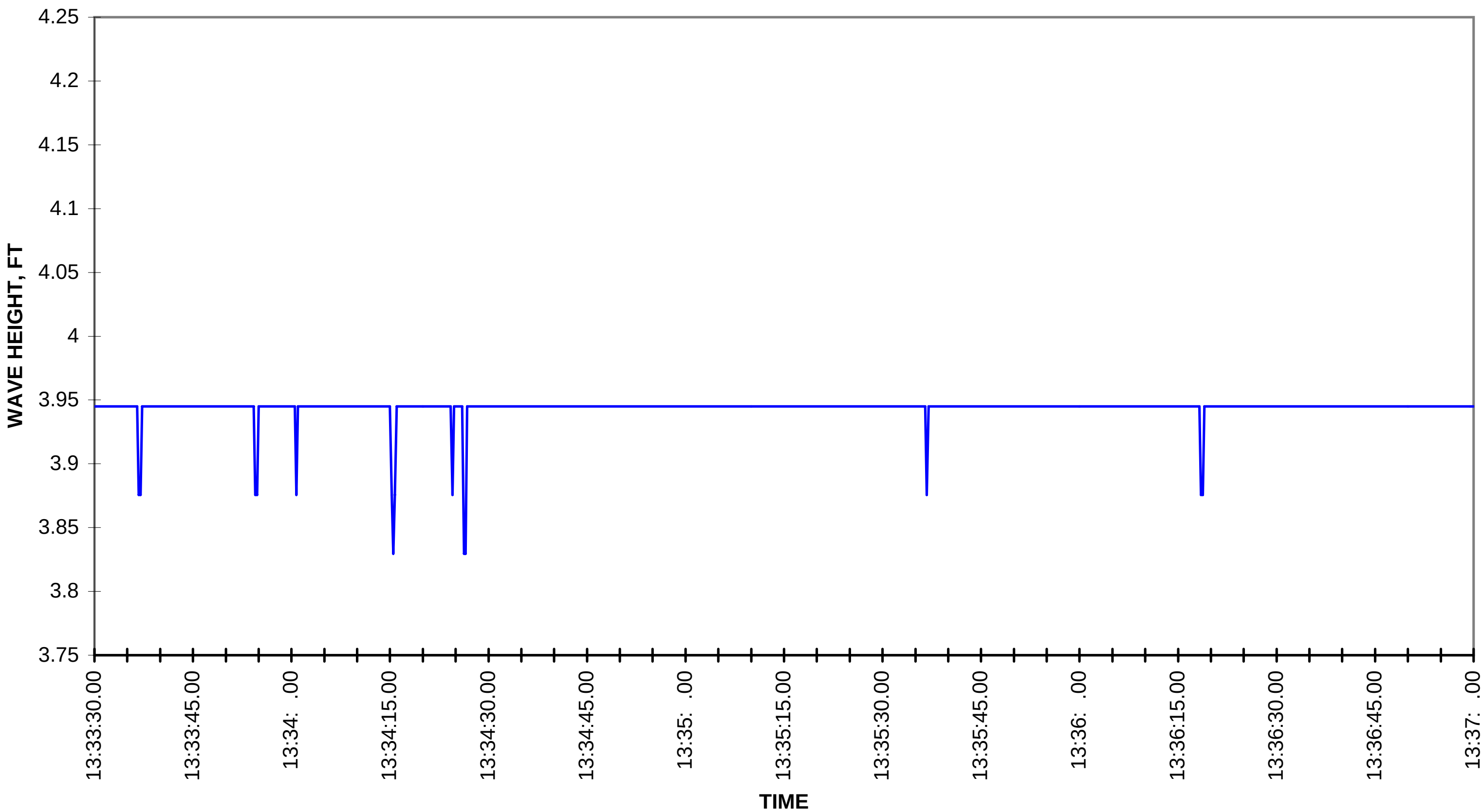
SAILING LINE S1, UPSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

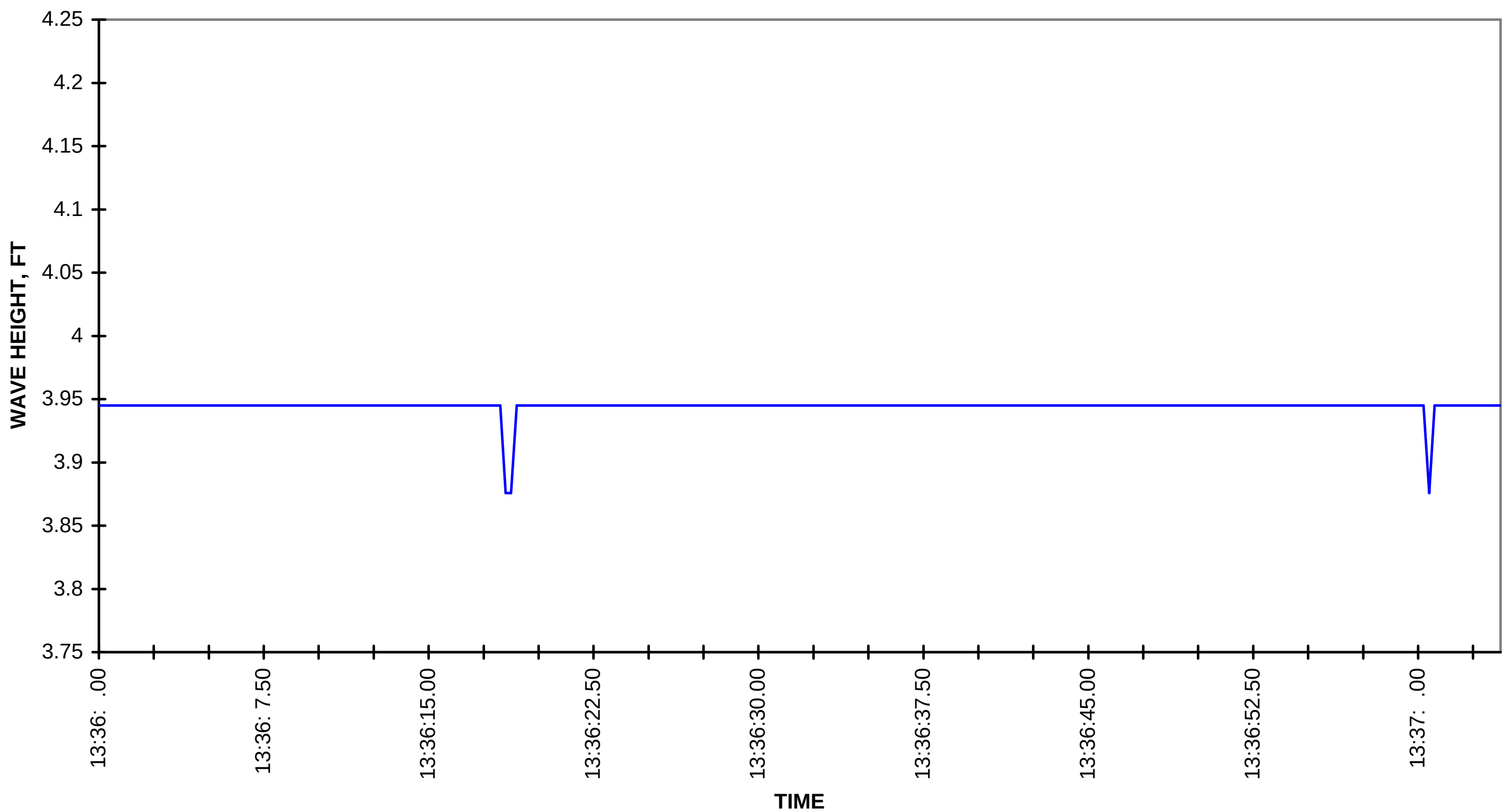
11/5/95



WAVE HEIGHTS
TEST 9, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 10, BOAT TYPE III
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



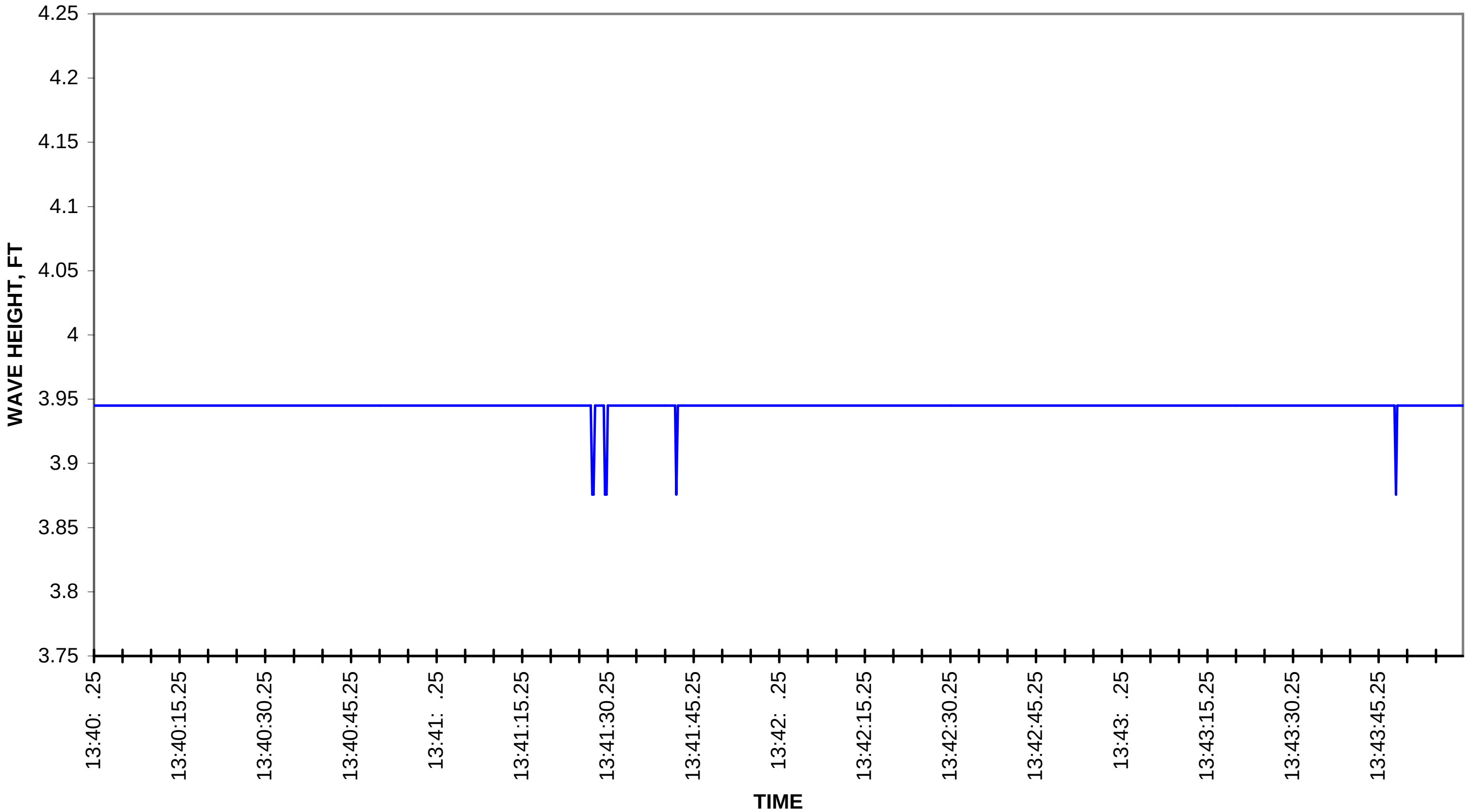
WAVE HEIGHTS

TEST 11, BOAT TYPE III

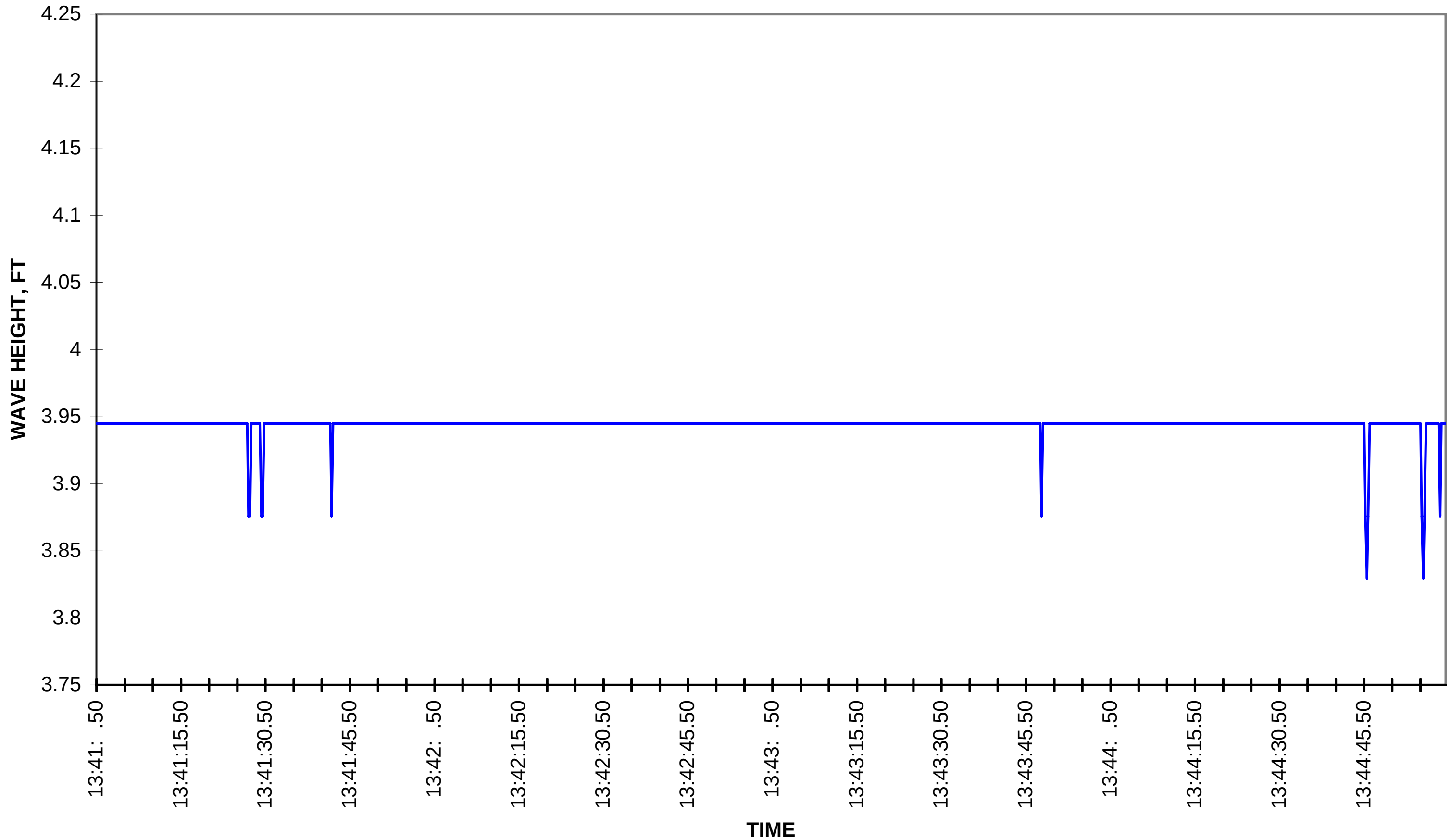
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

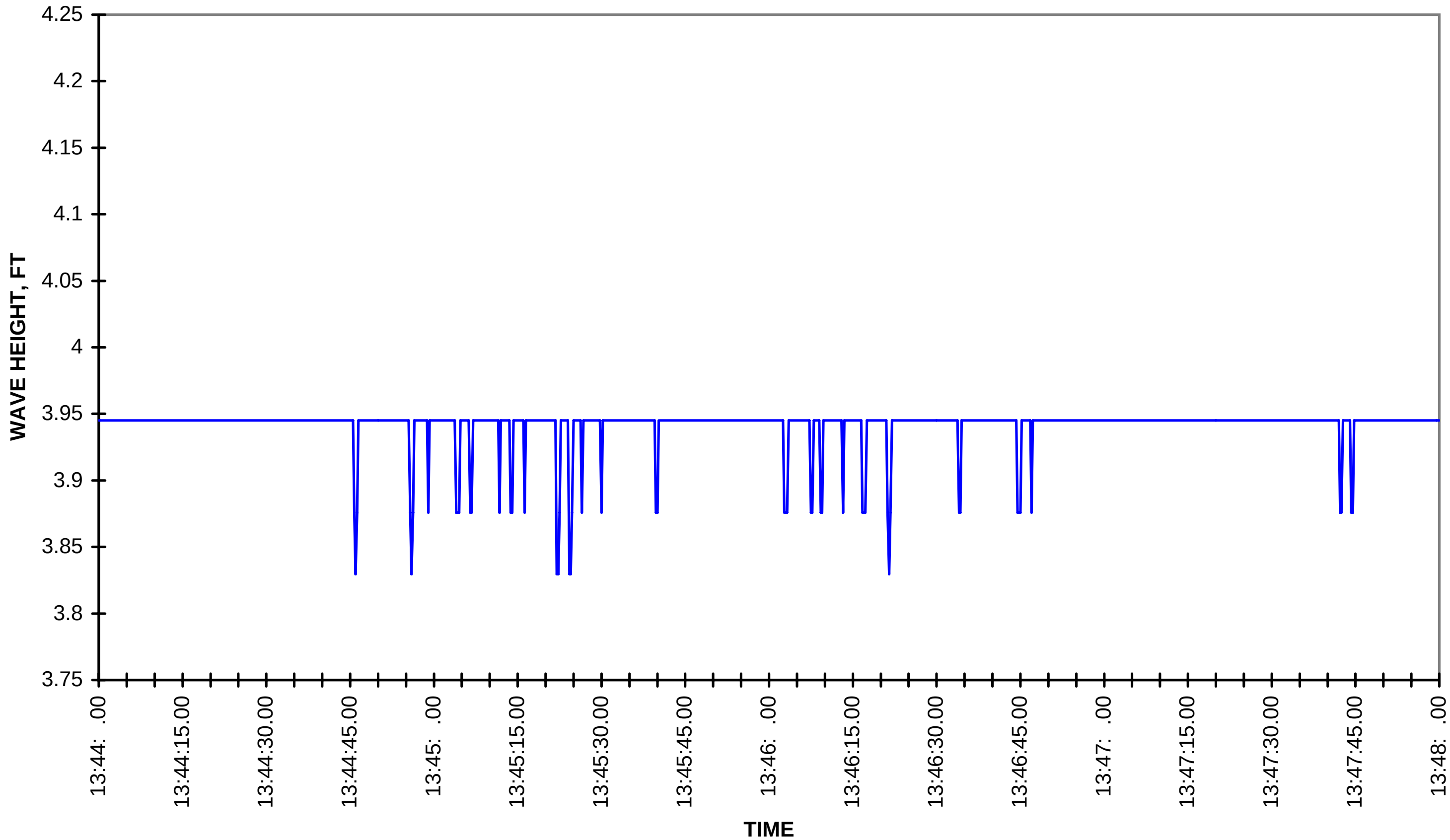
11/5/95



WAVE HEIGHTS
TEST 13, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 14, BOAT TYPE III
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



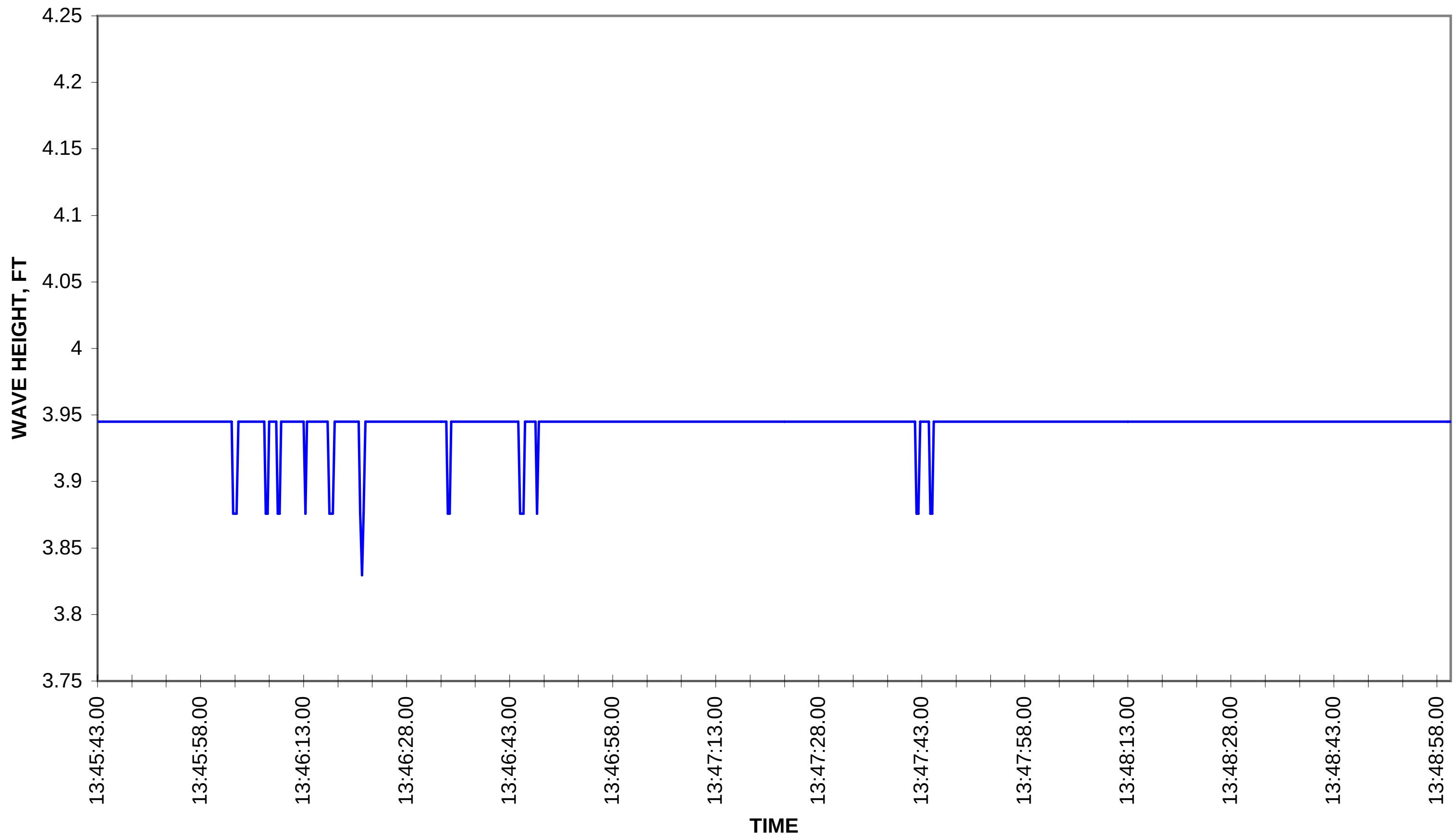
WAVE HEIGHTS

TEST 15, BOAT TYPE III

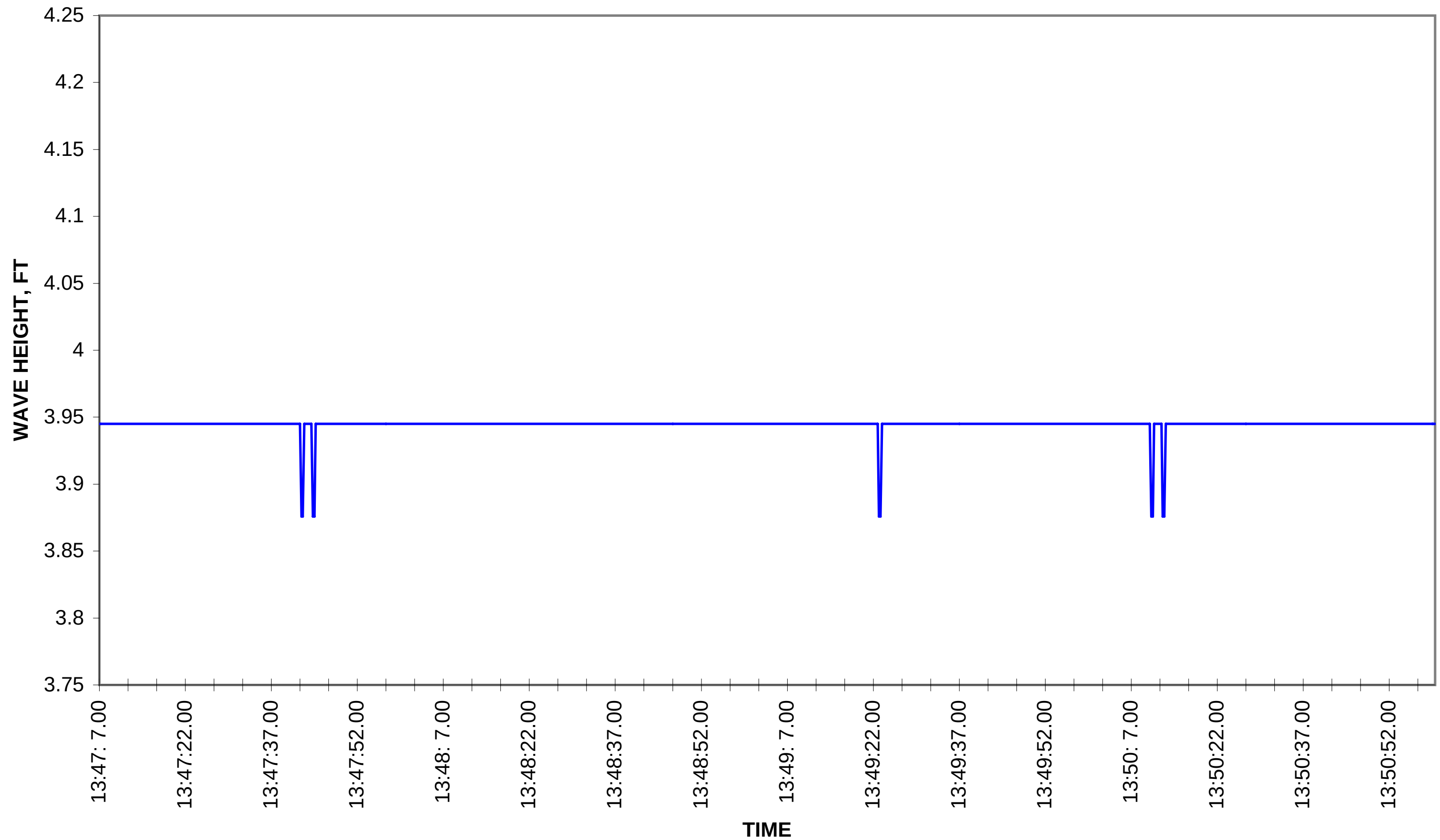
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG2, 8-FT DEPTH

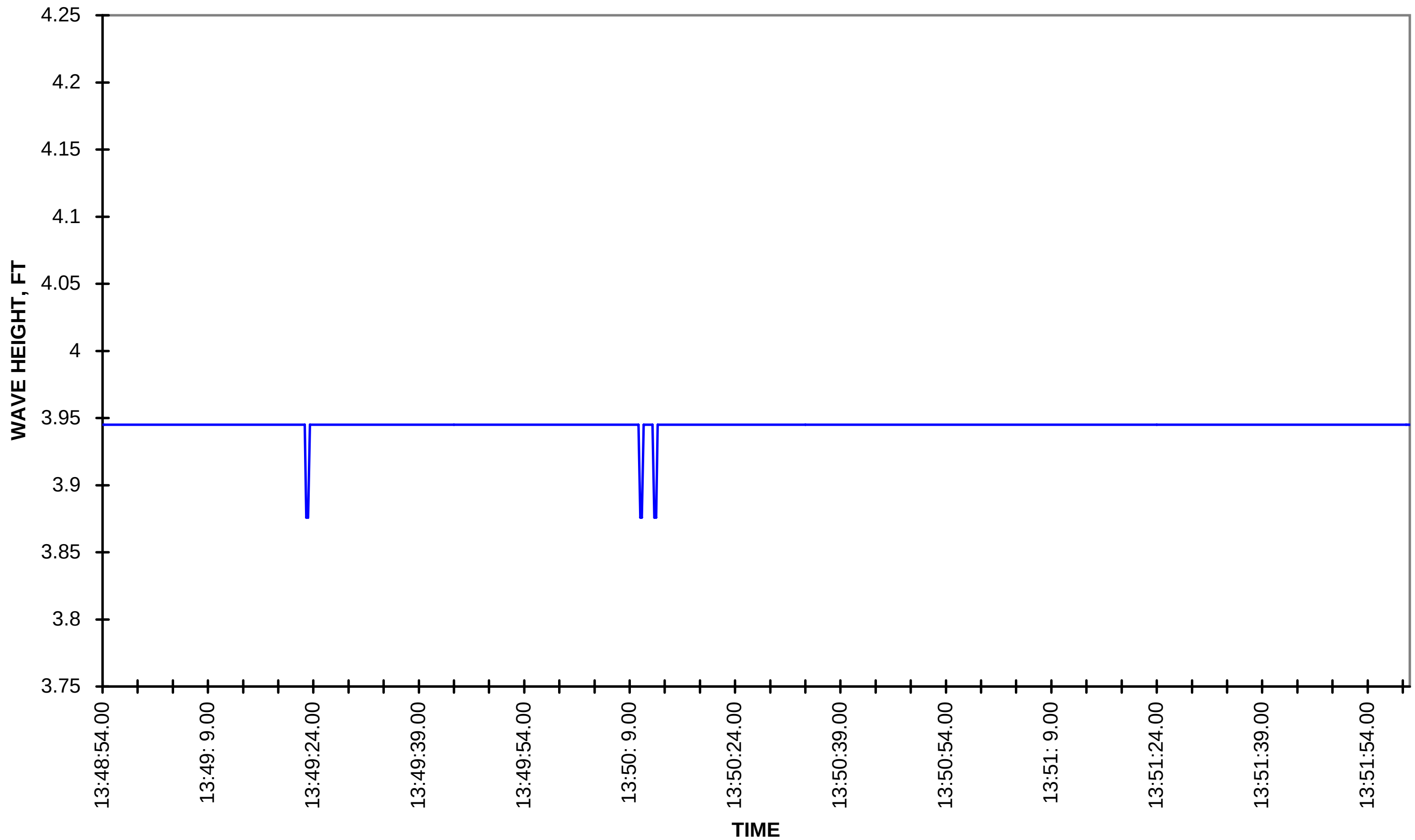
11/5/95



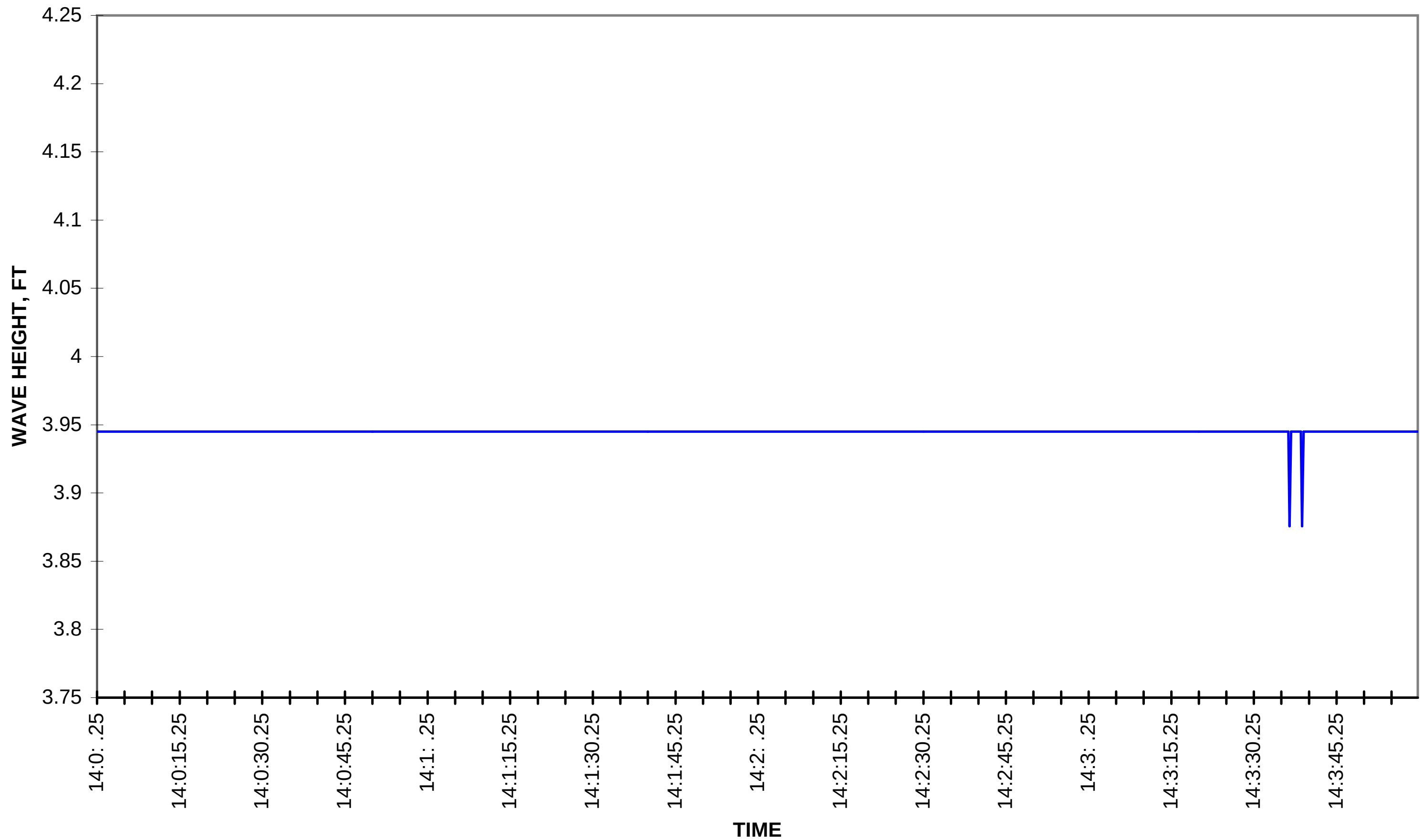
WAVE HEIGHTS
TEST 16, BOAT TYPE III
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 17, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 18, BOAT TYPE III
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



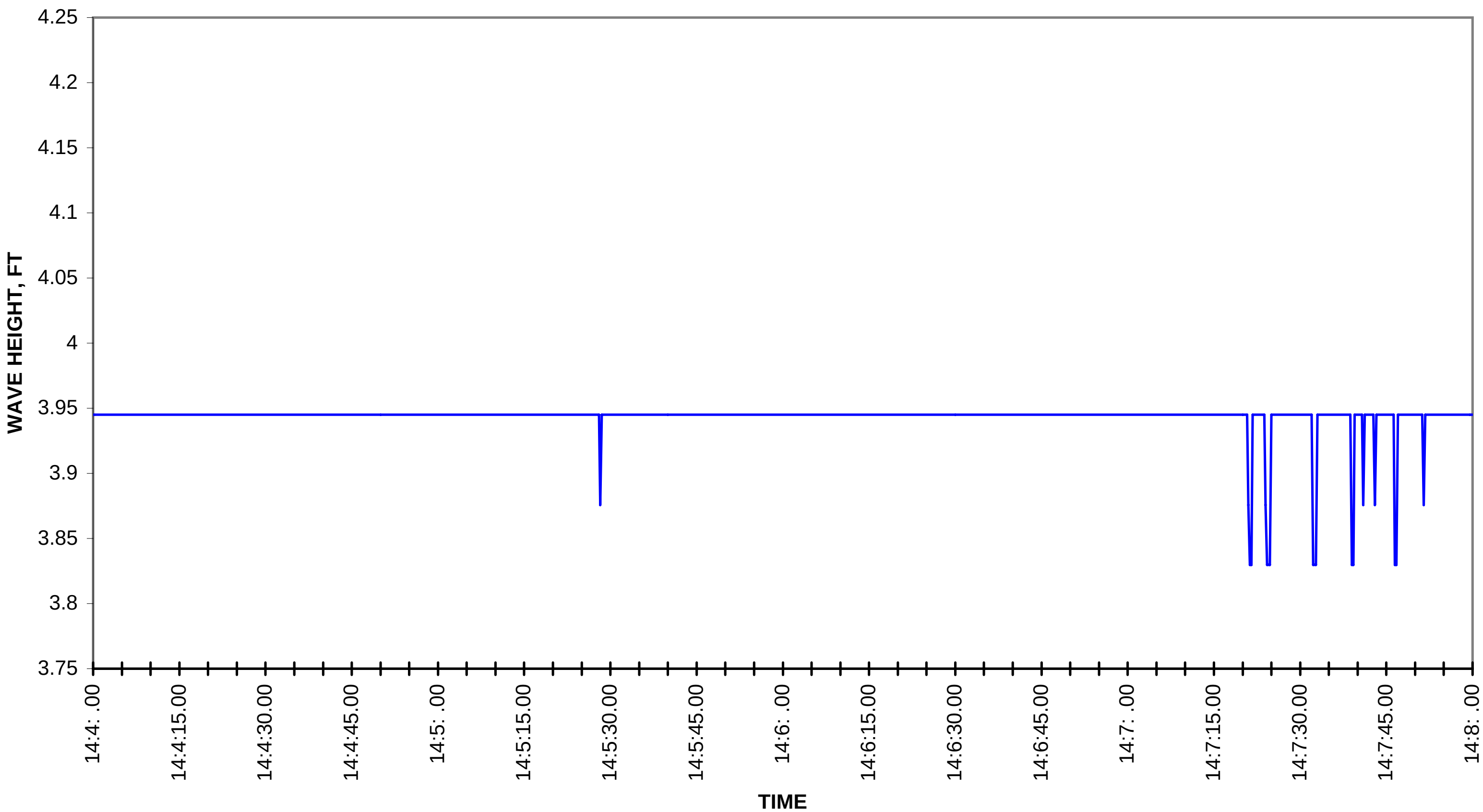
WAVE HEIGHTS

TEST 19, BOAT TYPE III

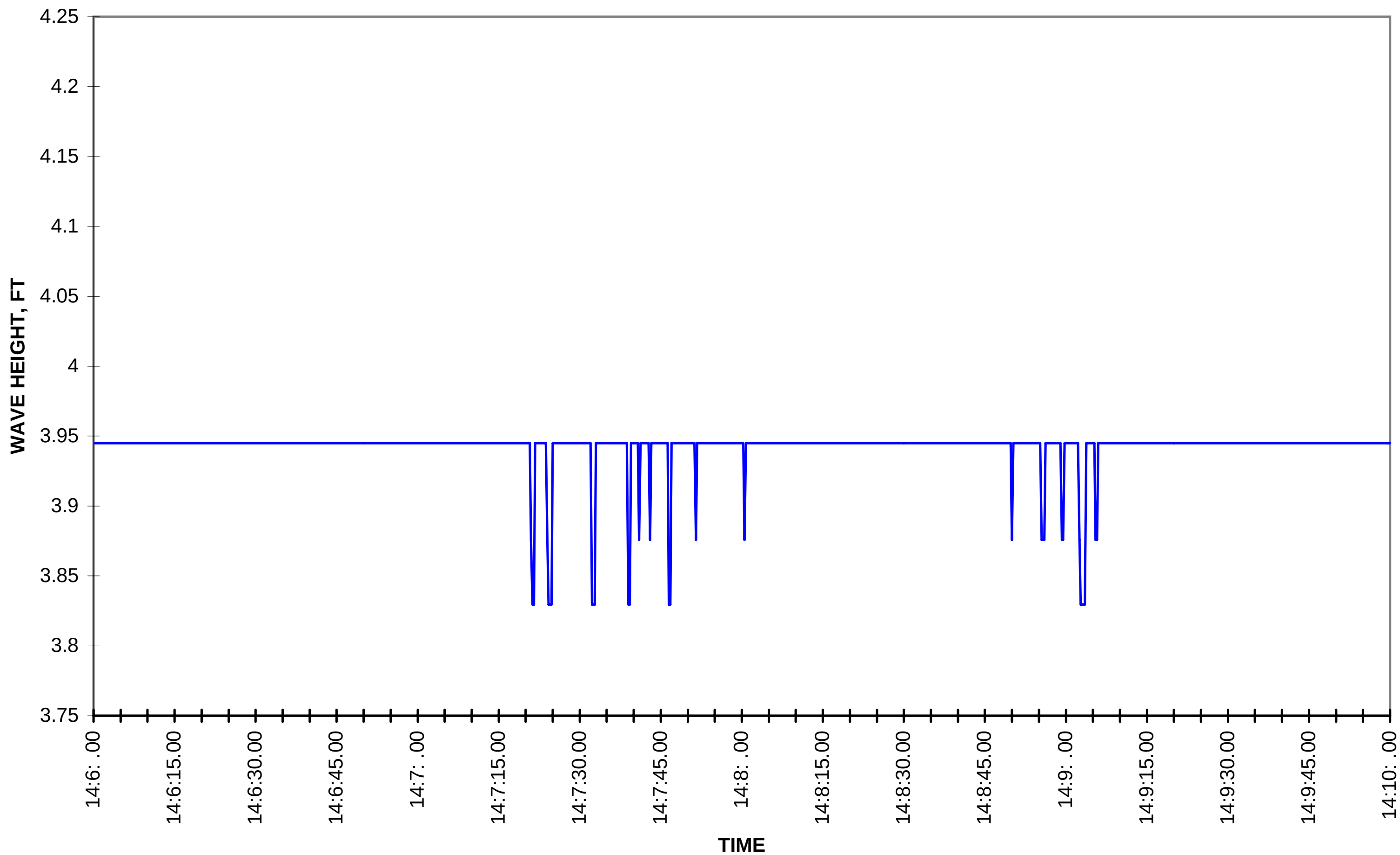
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

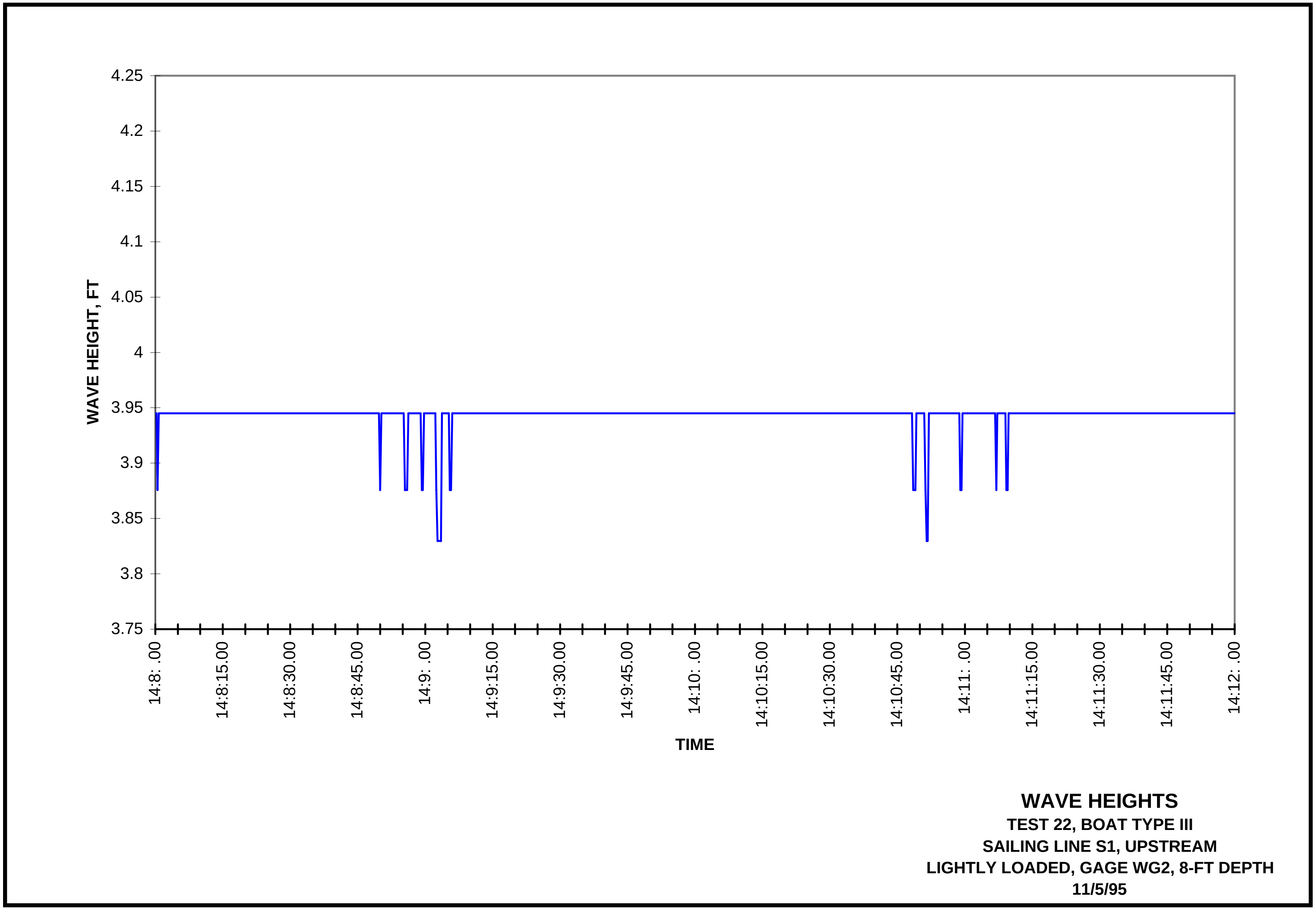
11/5/95



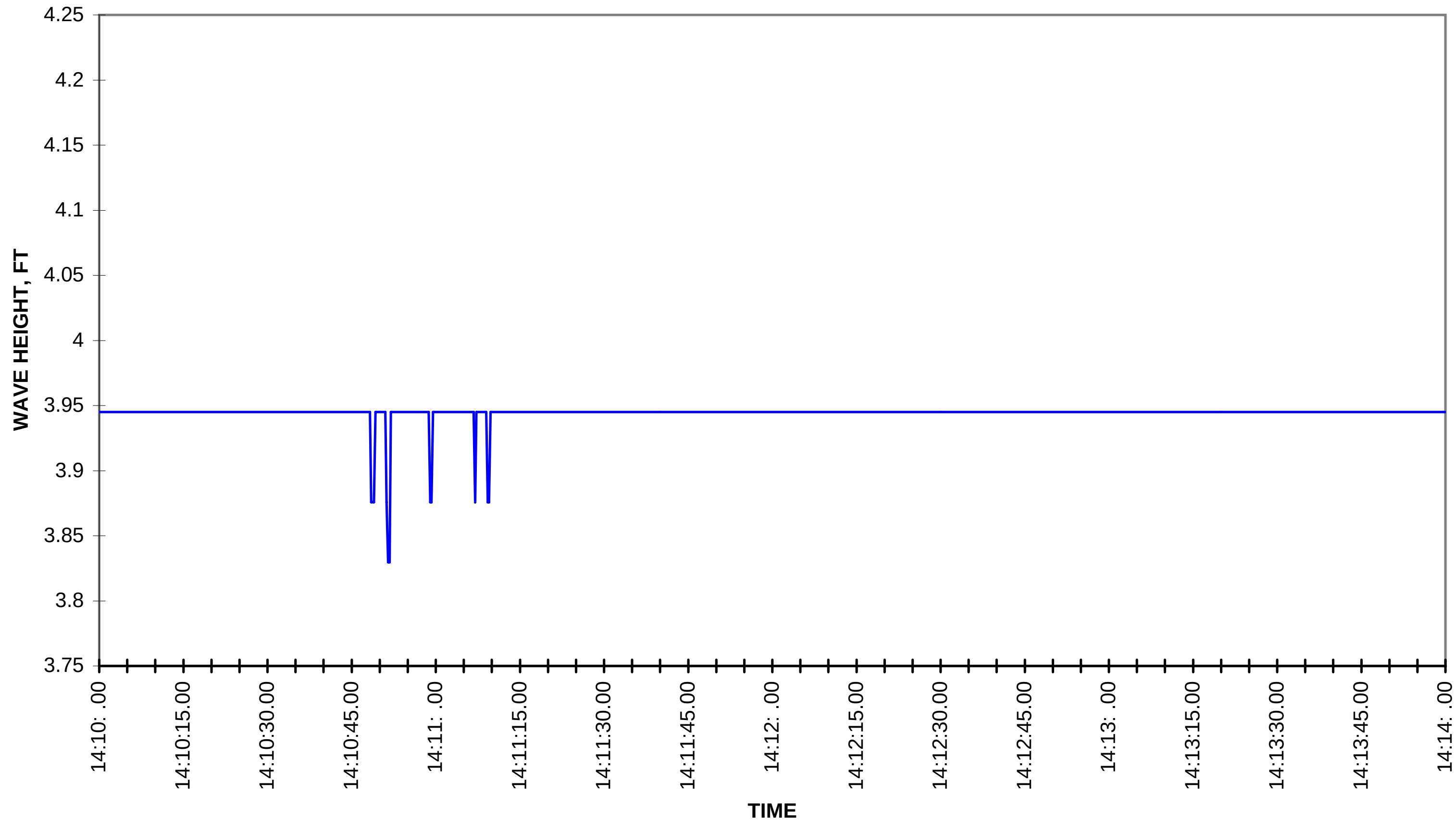
WAVE HEIGHTS
TEST 20, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



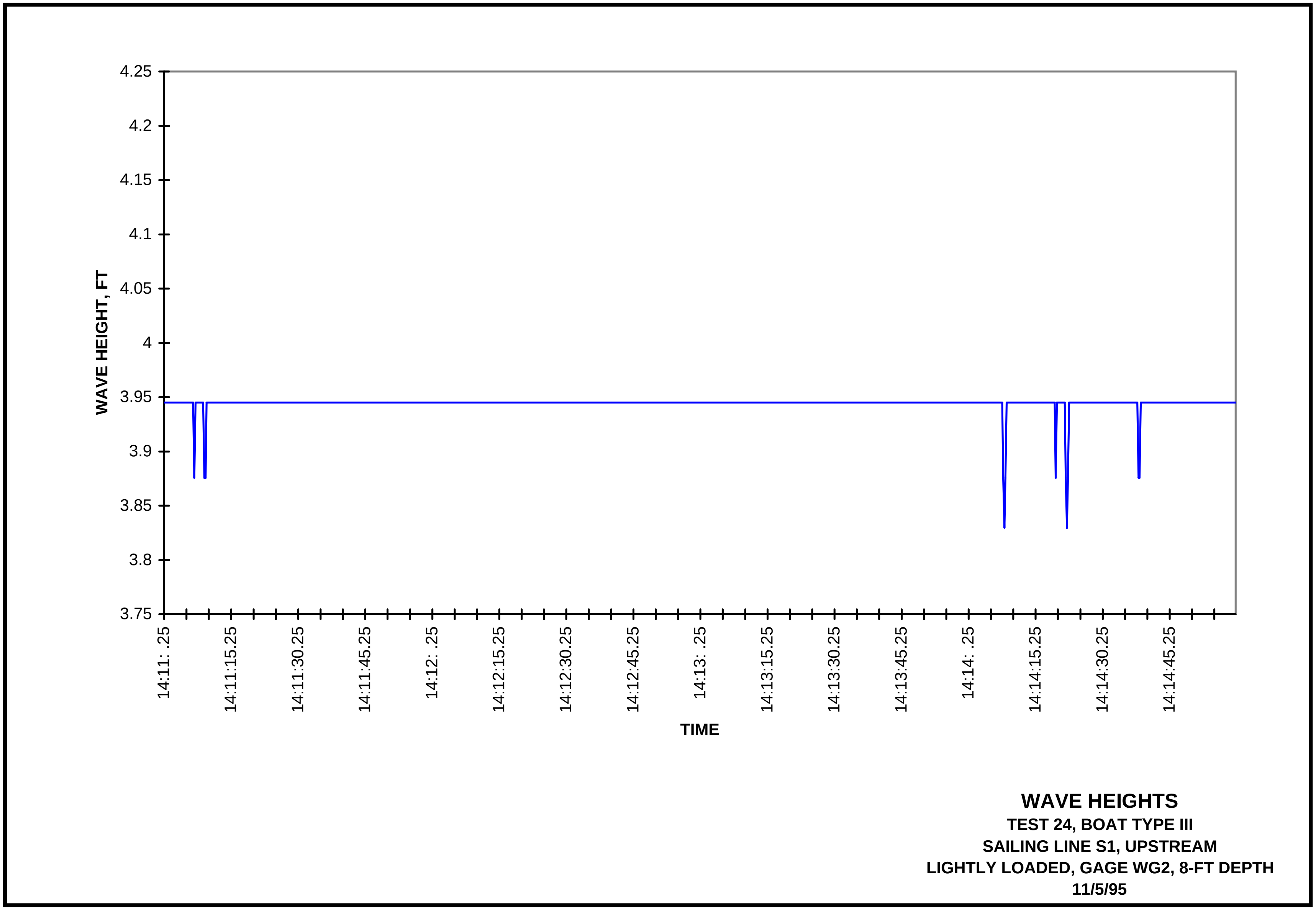
WAVE HEIGHTS
TEST 21, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



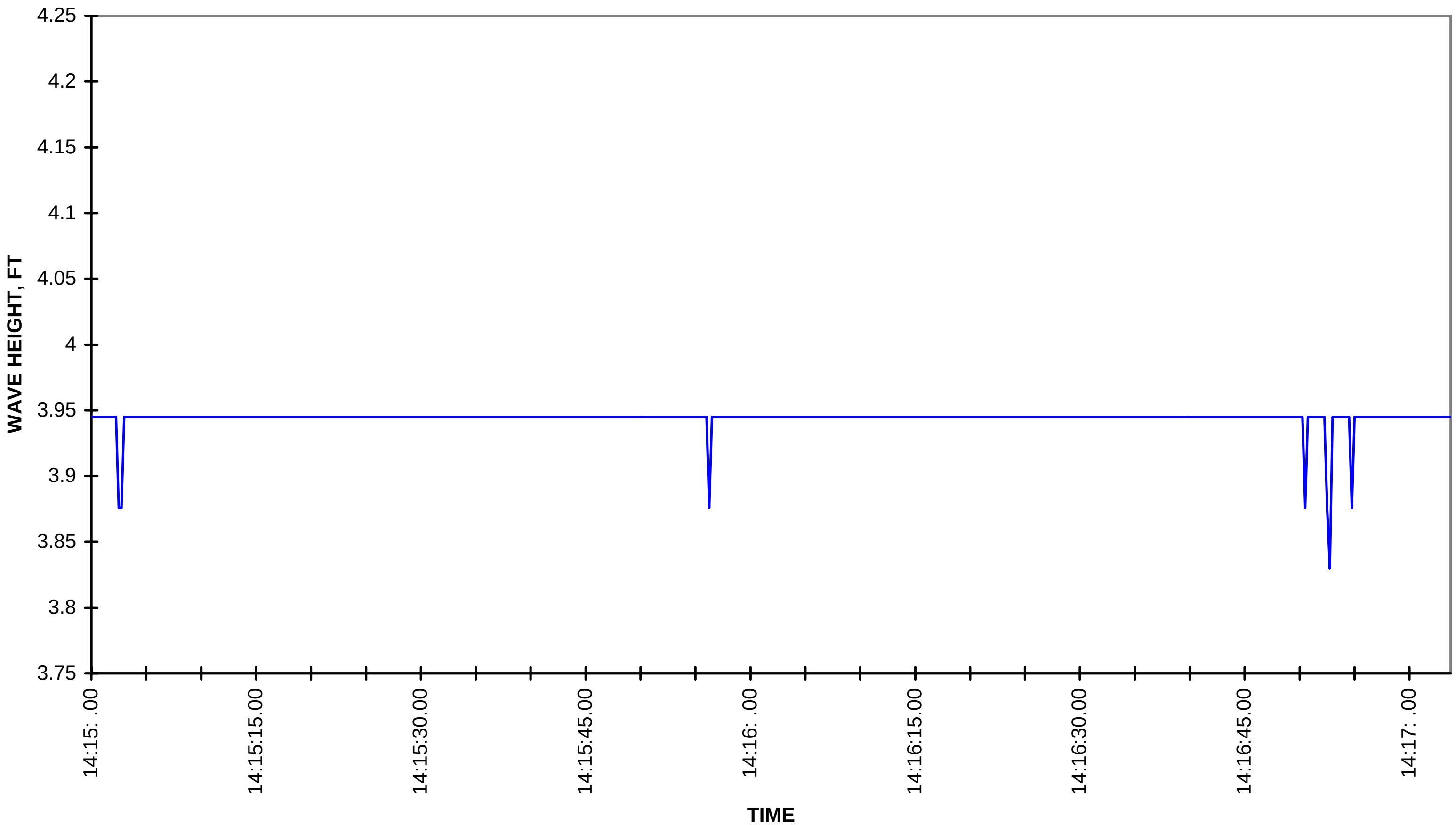
WAVE HEIGHT, FT
4.25
4.2
4.15
4.1
4.05
4
3.95
3.9
3.85
3.8
3.75
14:8: .00
14:8:15.00
14:8:30.00
14:8:45.00
14:9: .00
14:9:15.00
14:9:30.00
14:9:45.00
14:10: .00
14:10:15.00
14:10:30.00
14:10:45.00
14:11: .00
14:11:15.00
14:11:30.00
14:11:45.00
14:12: .00
TIME
WAVE HEIGHTS
TEST 22, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



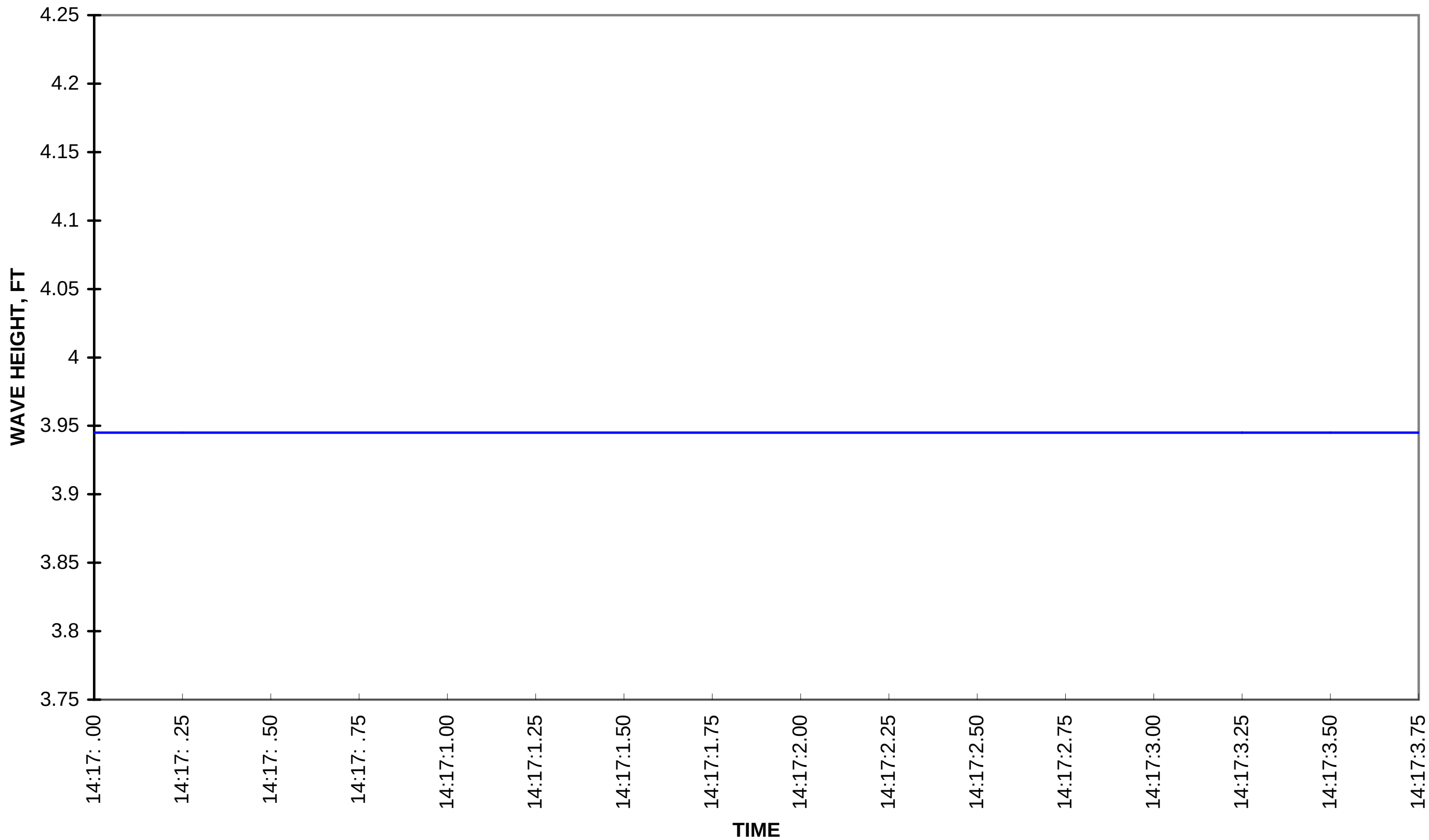
WAVE HEIGHTS
TEST 23, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHT, FT
4.25
4.2
4.15
4.1
4.05
4
3.95
3.9
3.85
3.8
3.75
14:11: .25
14:11:15.25
14:11:30.25
14:11:45.25
14:12: .25
14:12:15.25
14:12:30.25
14:12:45.25
14:13: .25
14:13:15.25
14:13:30.25
14:13:45.25
14:14: .25
14:14:15.25
14:14:30.25
14:14:45.25
TIME
WAVE HEIGHTS
TEST 24, BOAT TYPE III
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



WAVE HEIGHTS
TEST 25, BOAT TYPE III
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



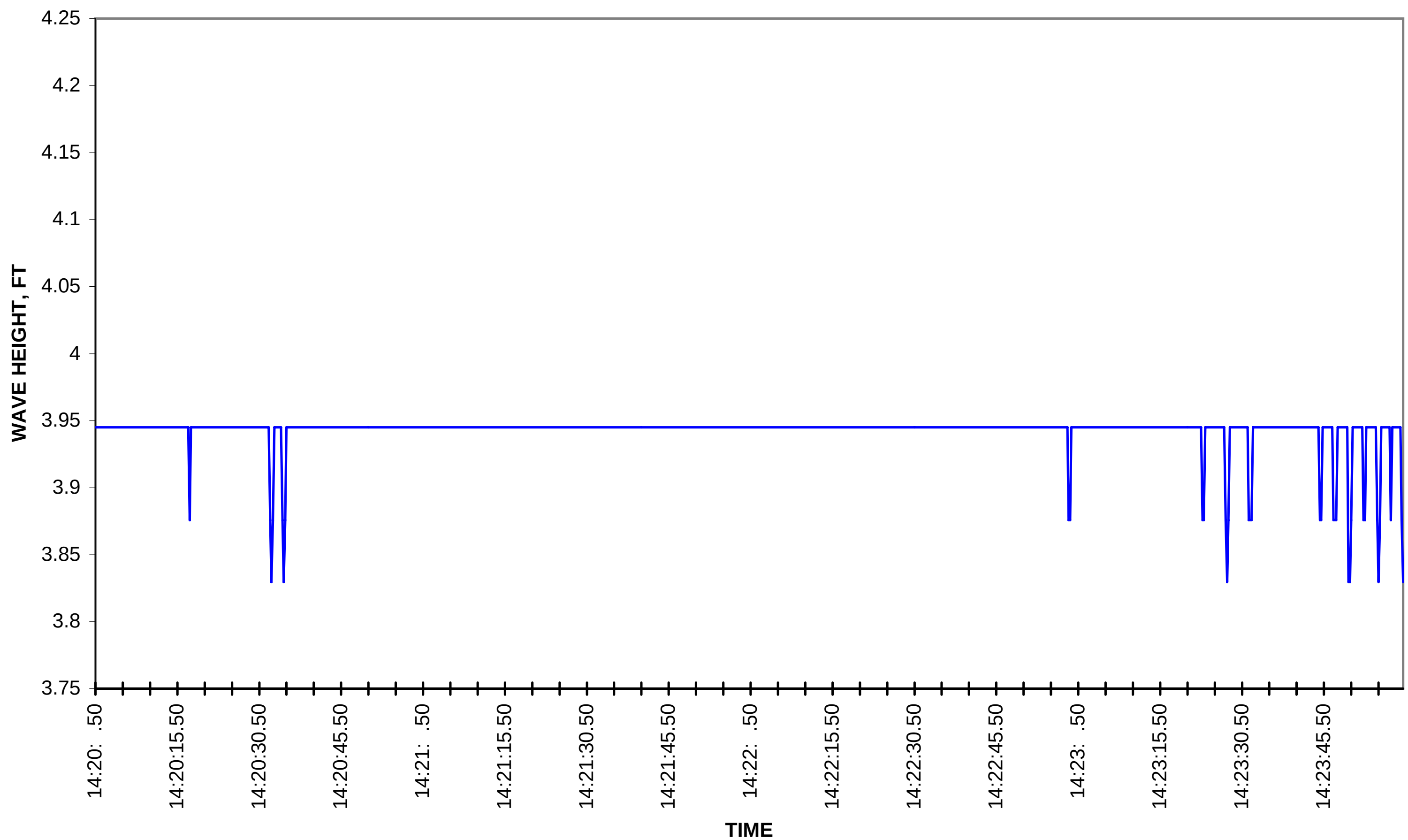
WAVE HEIGHTS

TEST 26, BOAT TYPE III

SAILING LINE S1, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



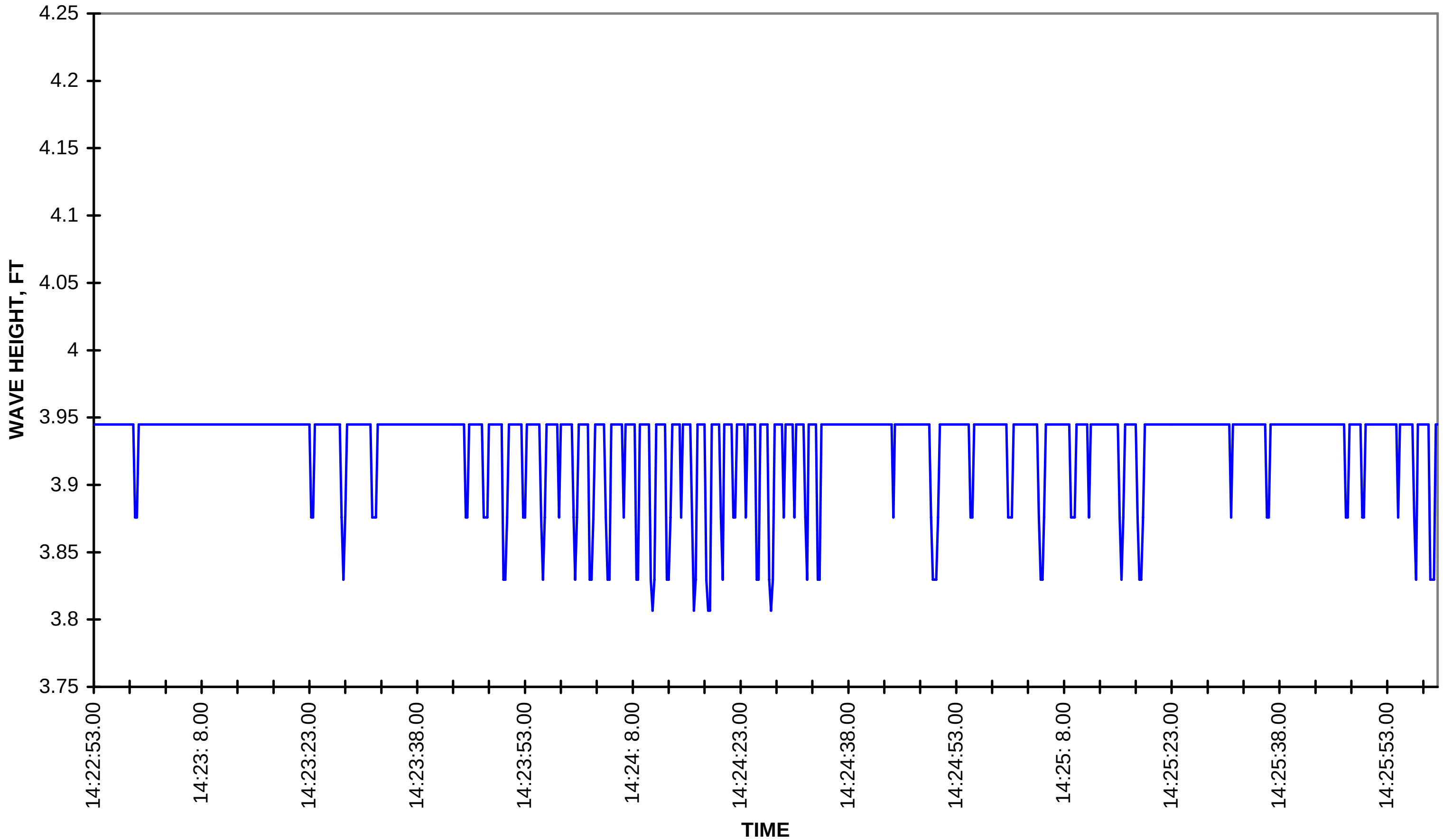
WAVE HEIGHTS

TEST 28, BOAT TYPE III

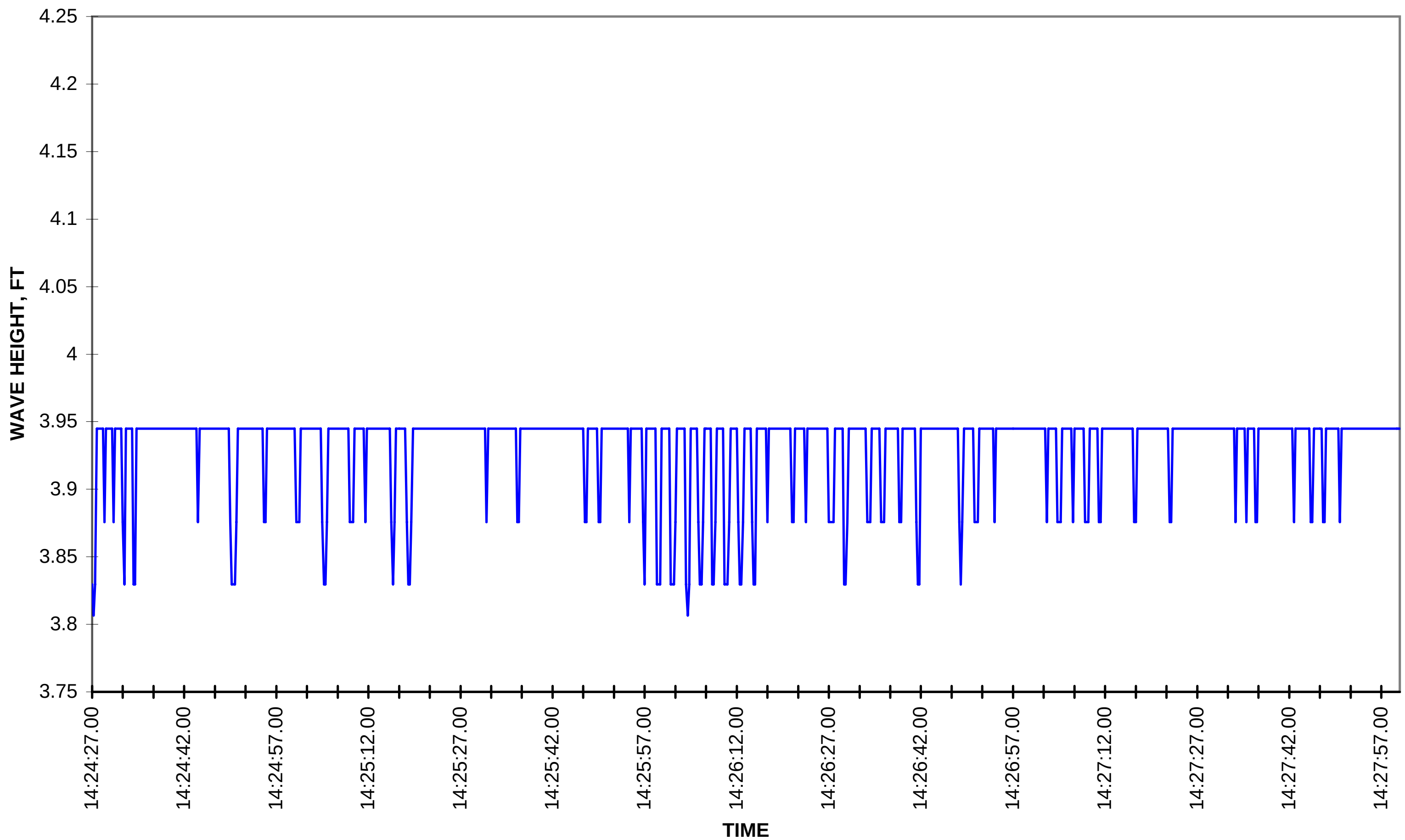
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

11/5/95



WAVE HEIGHTS
TEST 29, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



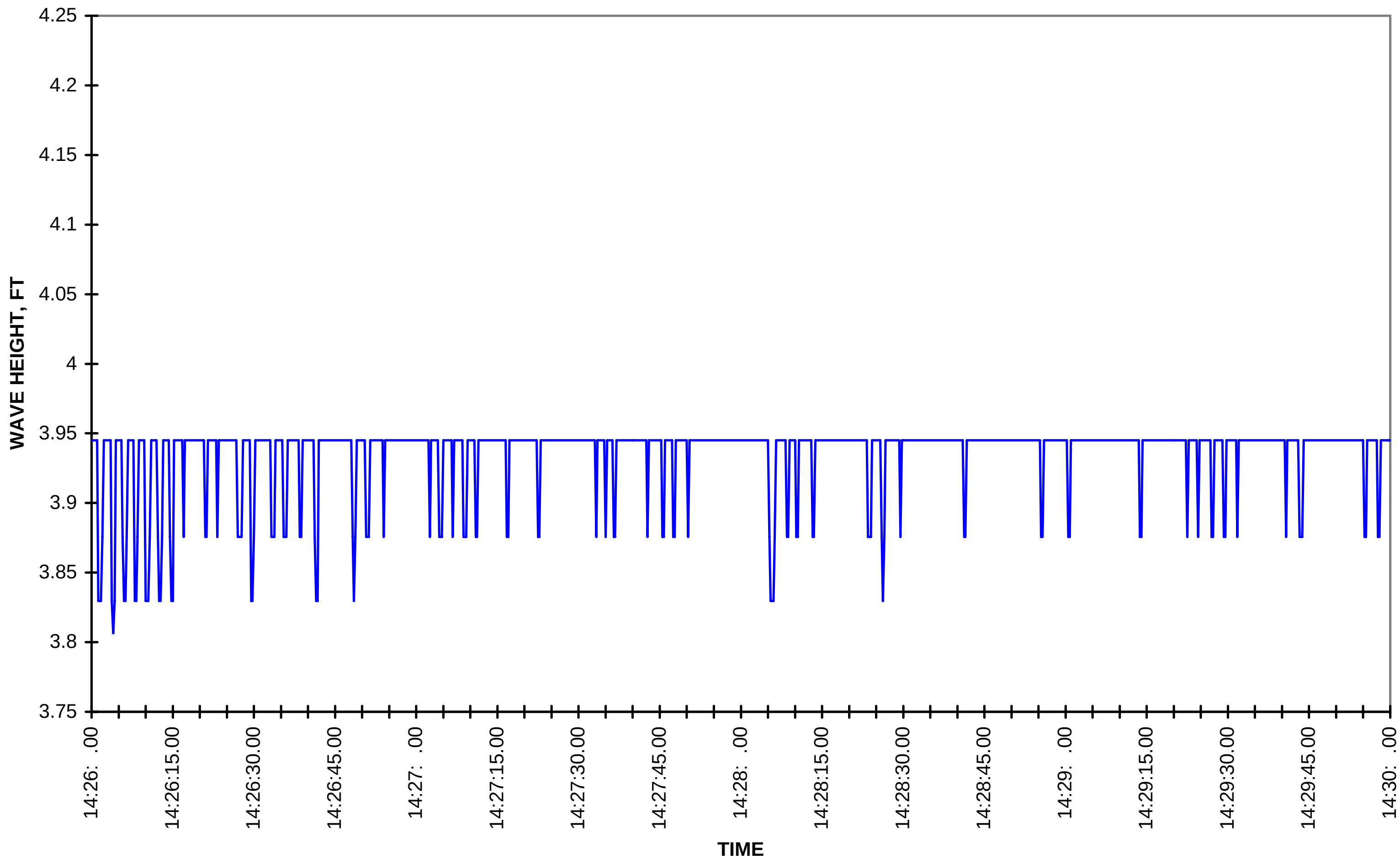
WAVE HEIGHTS

TEST 30, BOAT TYPE III

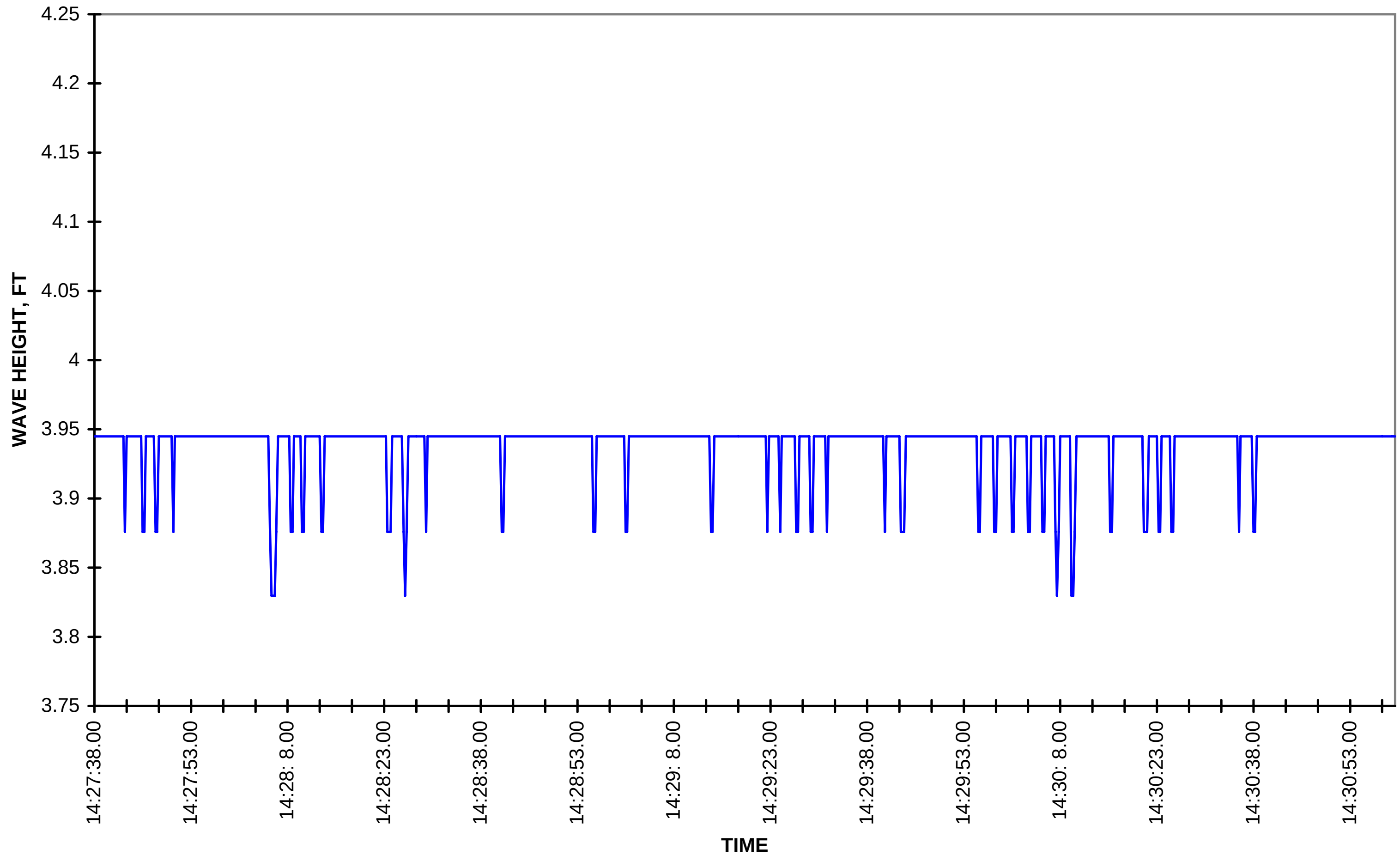
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH

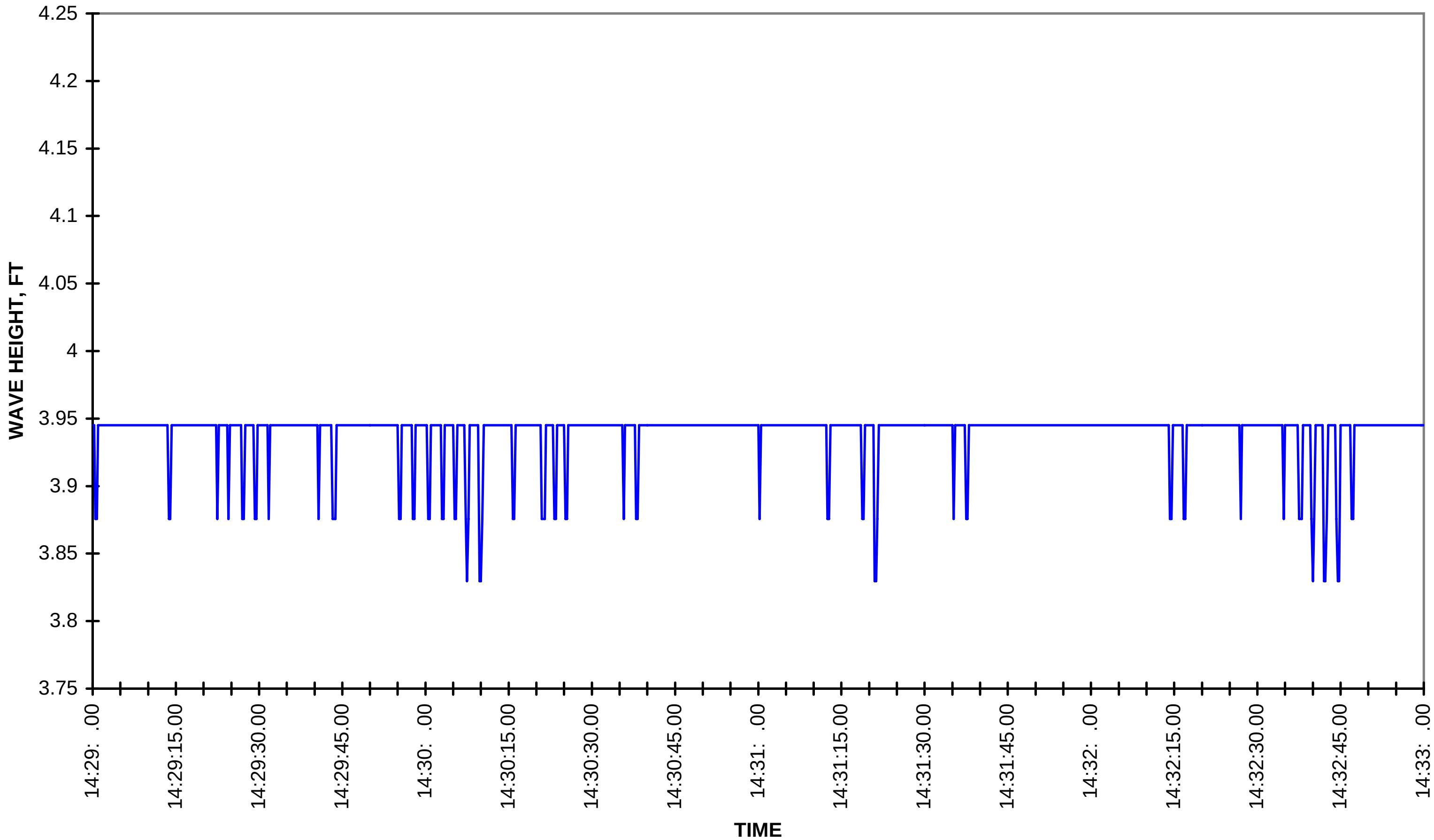
11/5/95



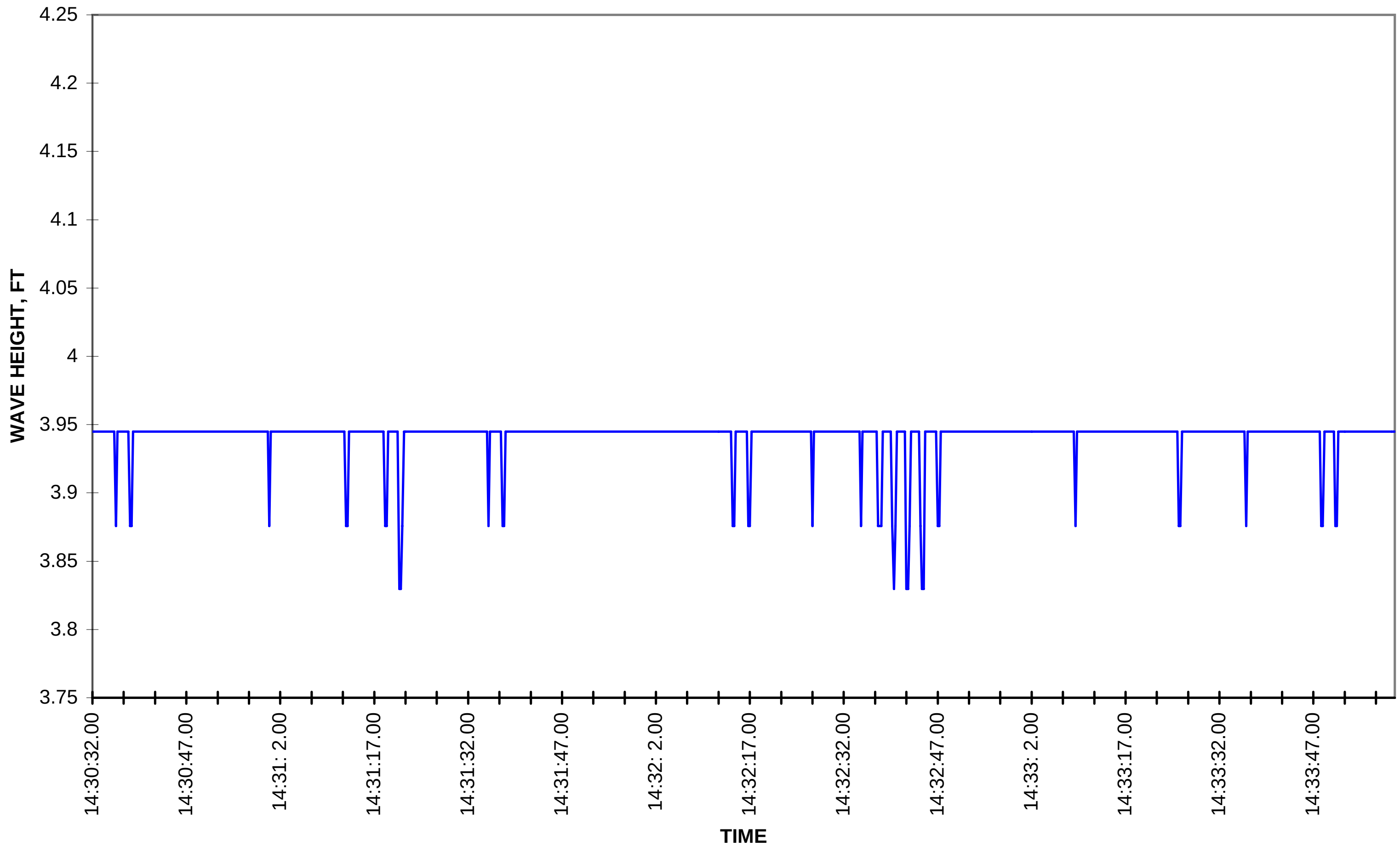
WAVE HEIGHTS
TEST 31, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



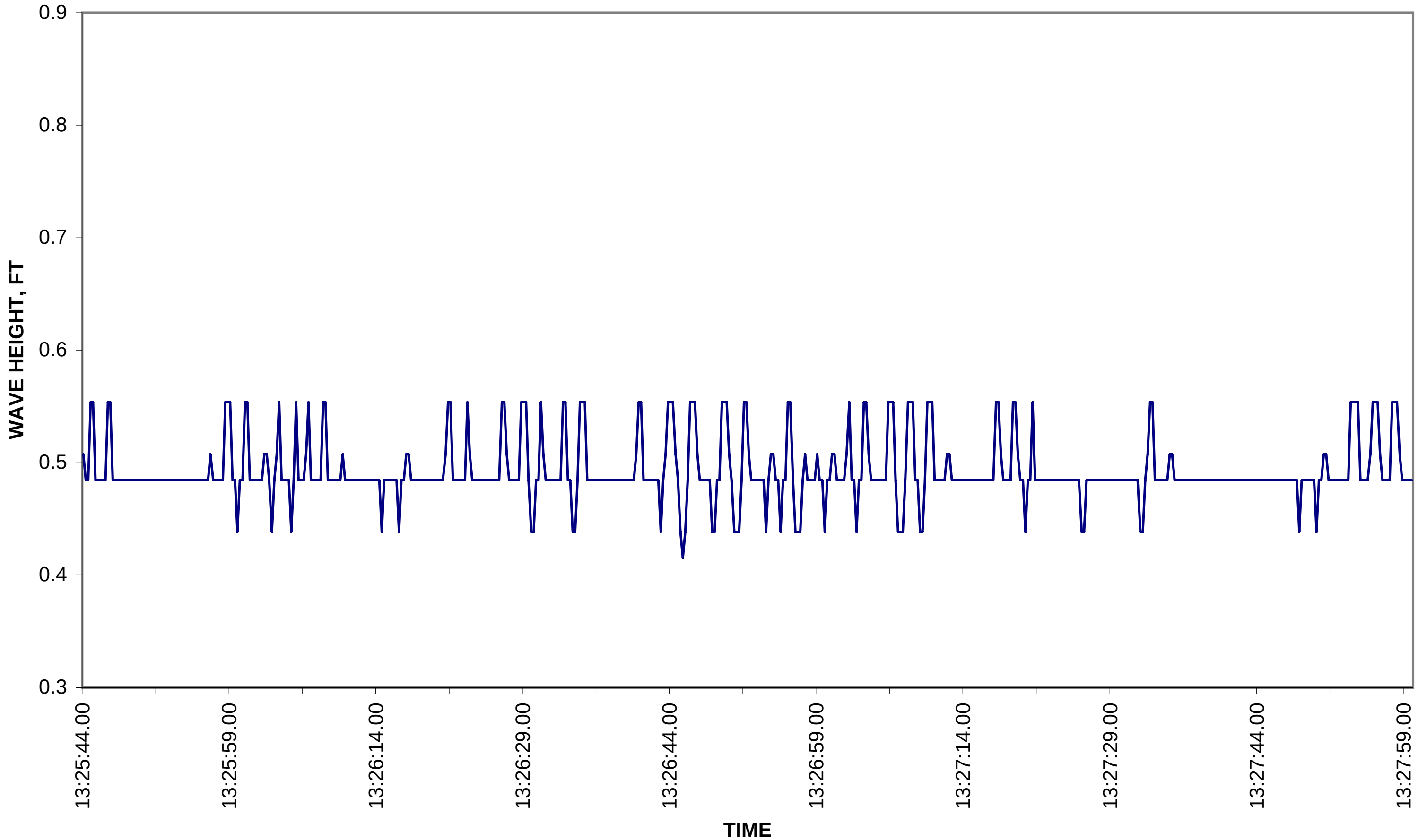
WAVE HEIGHTS
TEST 32, BOAT TYPE III
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



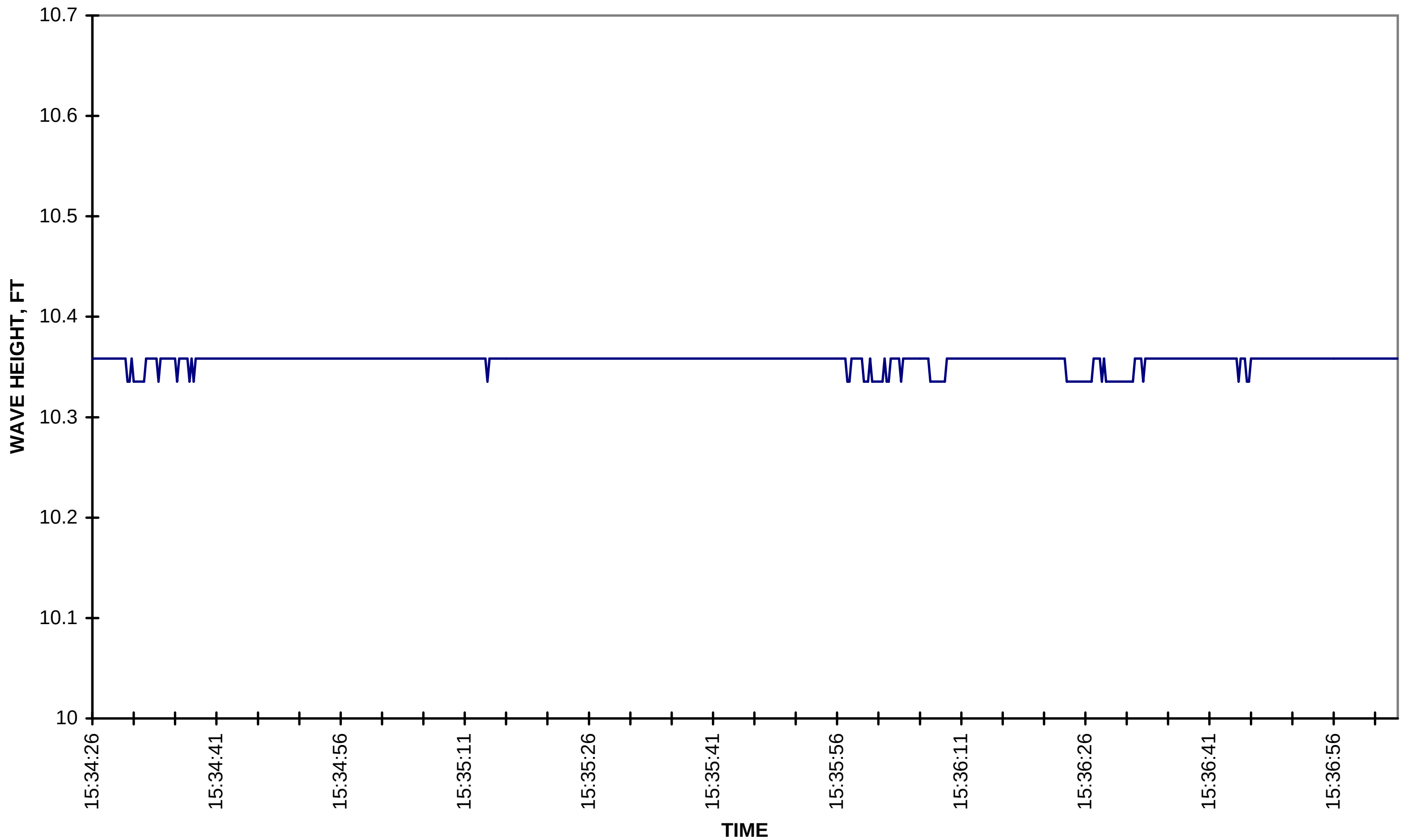
WAVE HEIGHTS
TEST 33, BOAT TYPE III
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



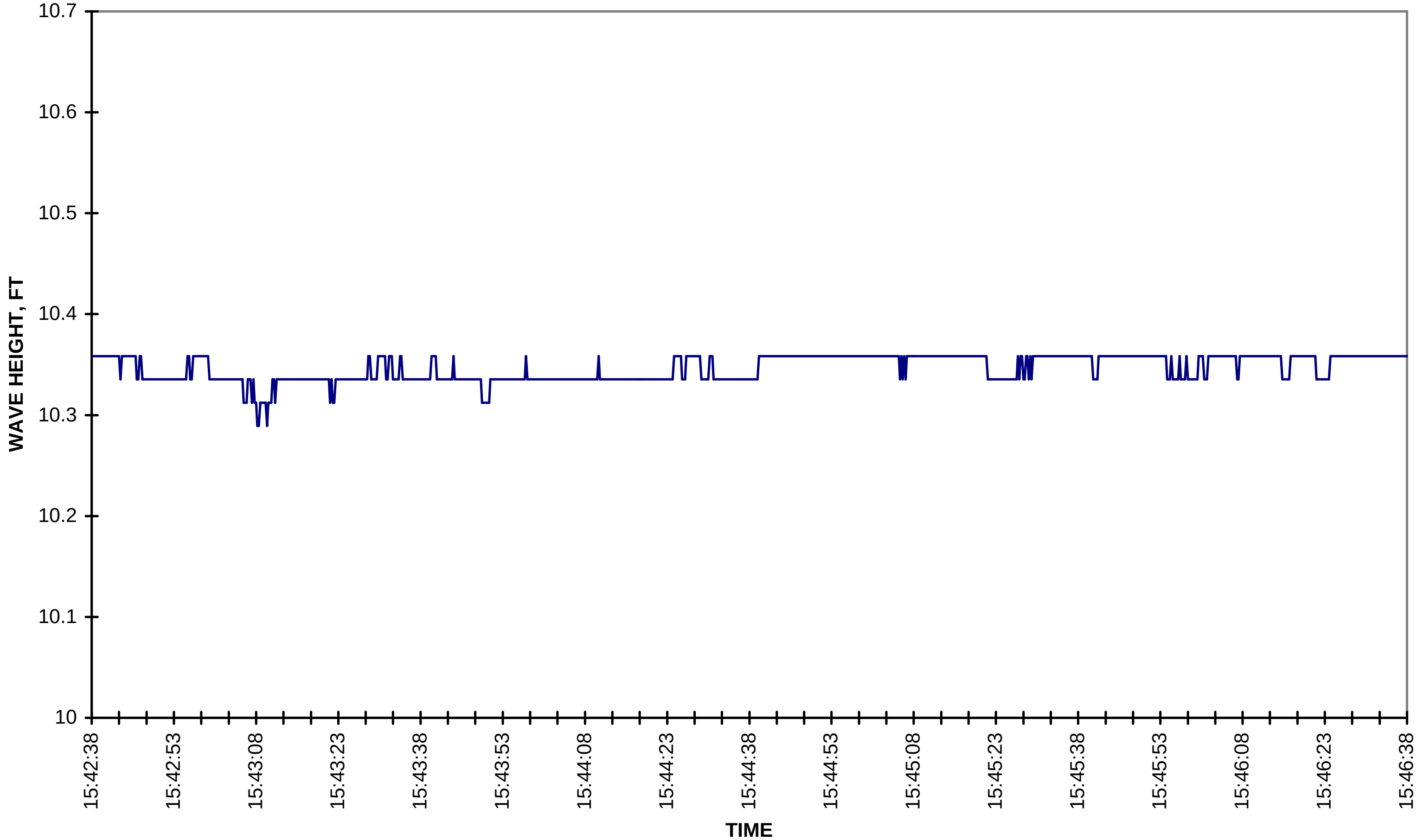
WAVE HEIGHTS
TEST 34, BOAT TYPE III
SAILING LINE S2, UPSTREAM
LIGHTLY LOADED, GAGE WG2, 8-FT DEPTH
11/5/95



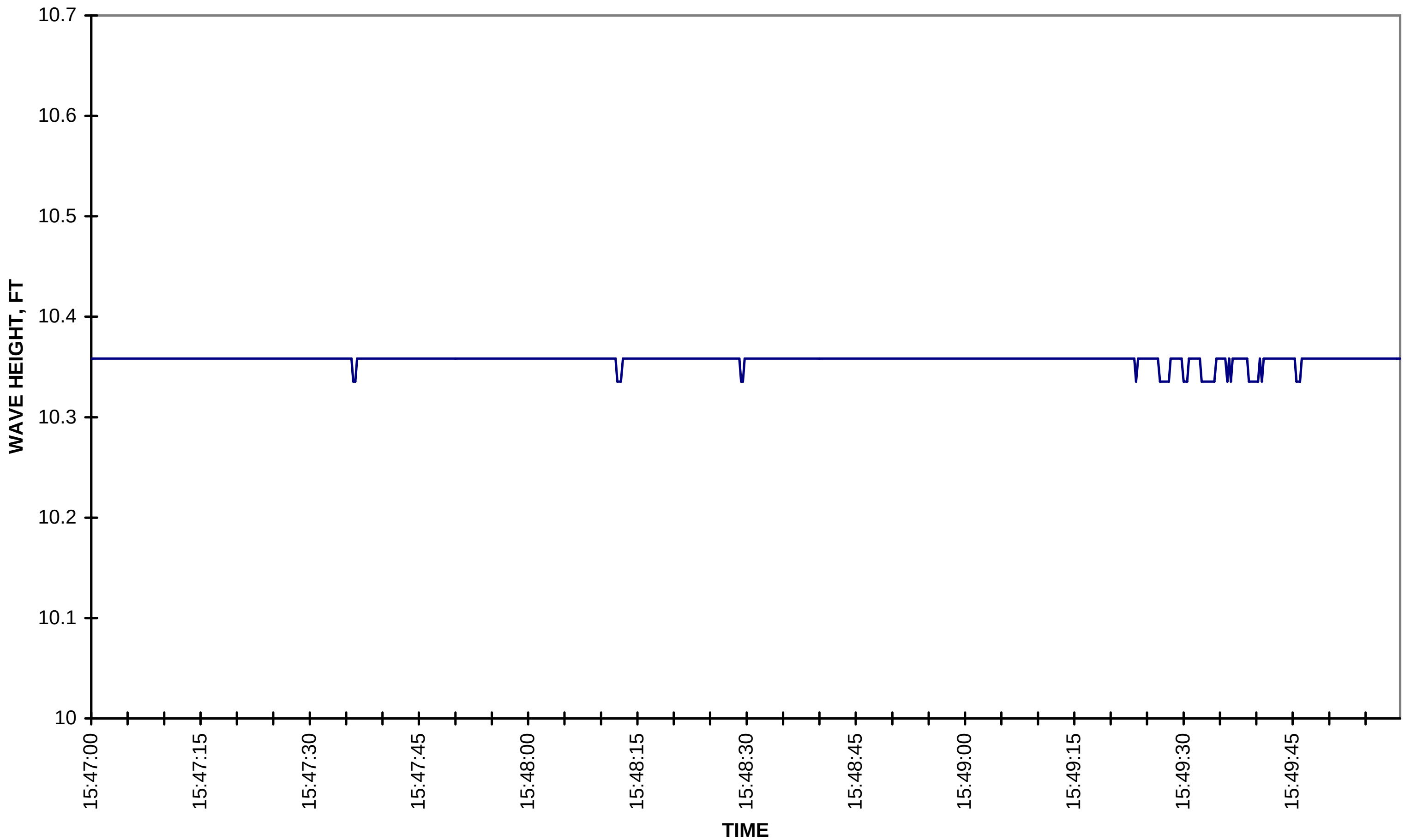
WAVE HEIGHTS
TEST 6, BOAT TYPE III
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG1, 3-FT DEPTH
11/5/95



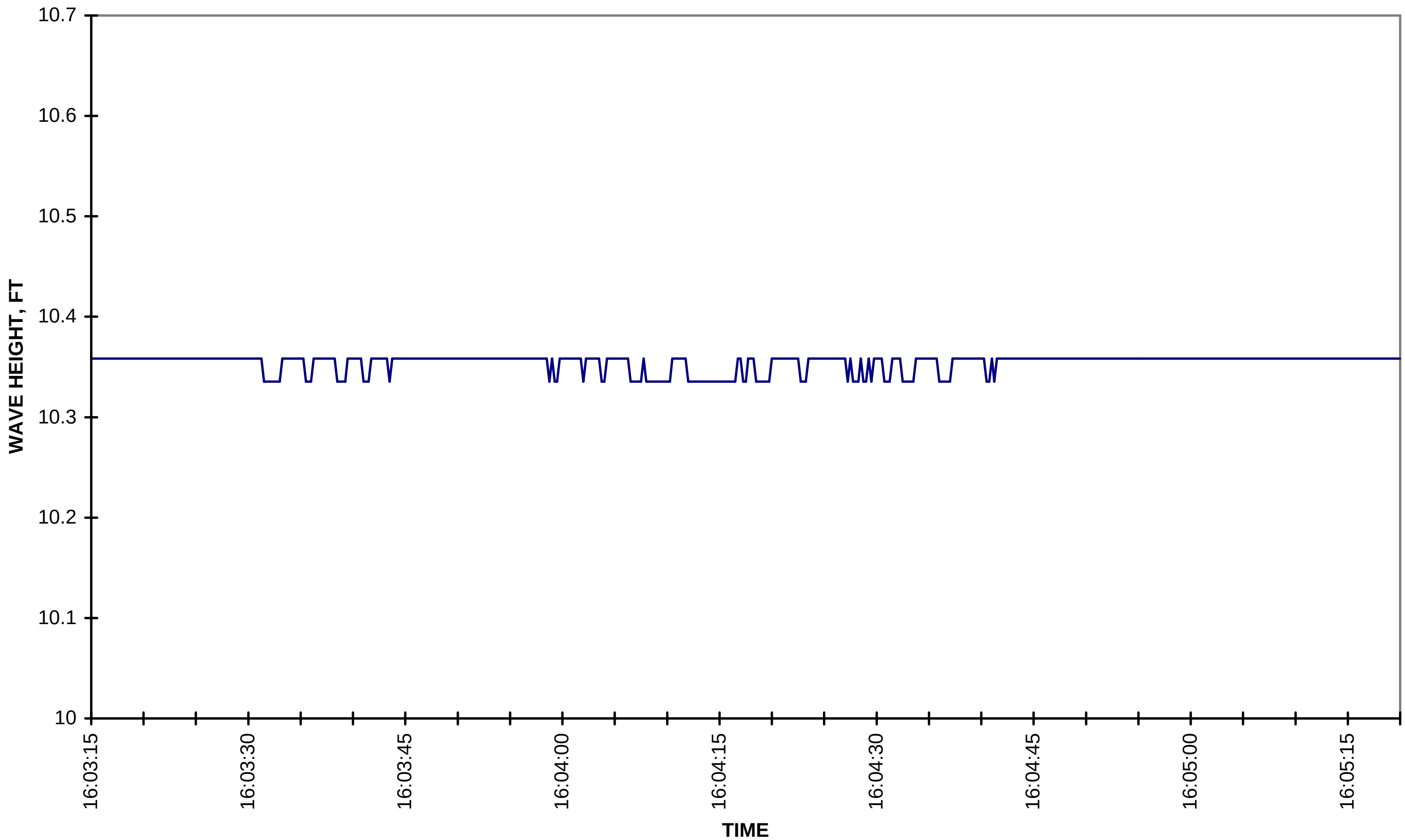
WAVE HEIGHTS
TEST 1, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



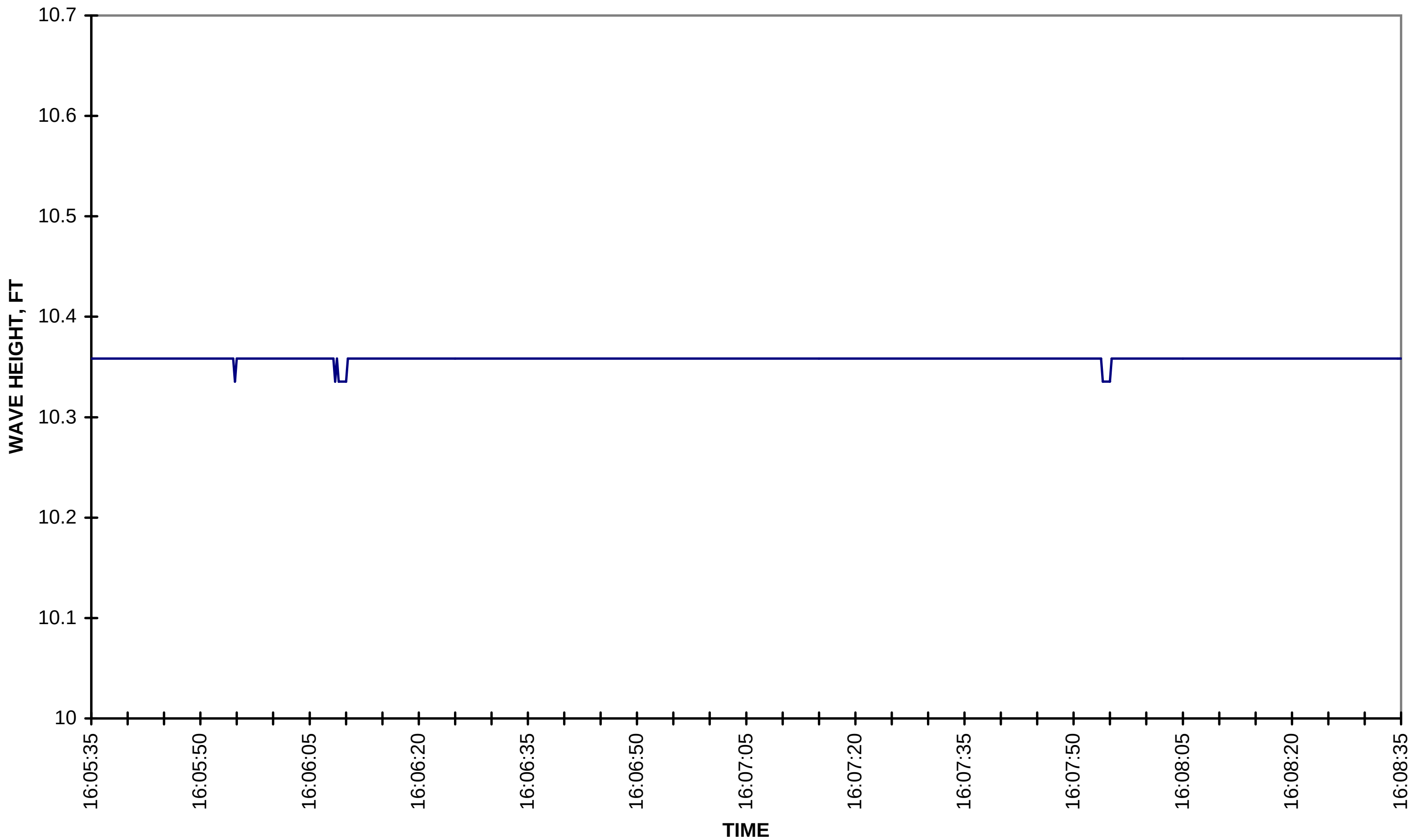
WAVE HEIGHTS
TEST 3, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



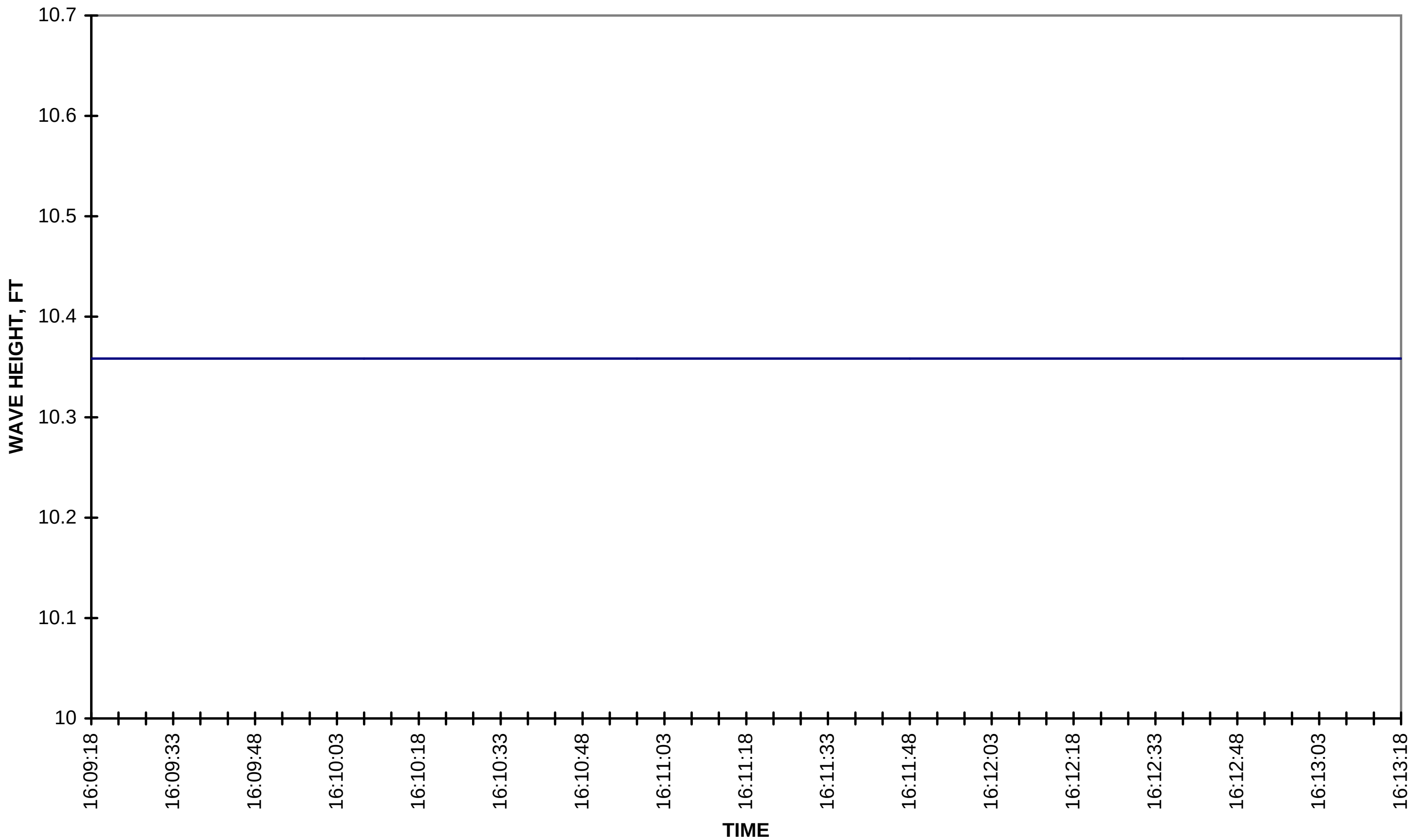
WAVE HEIGHTS
TEST 4, BOAT TYPE II
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 5, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 6, BOAT TYPE II
SAILING LINE S1, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



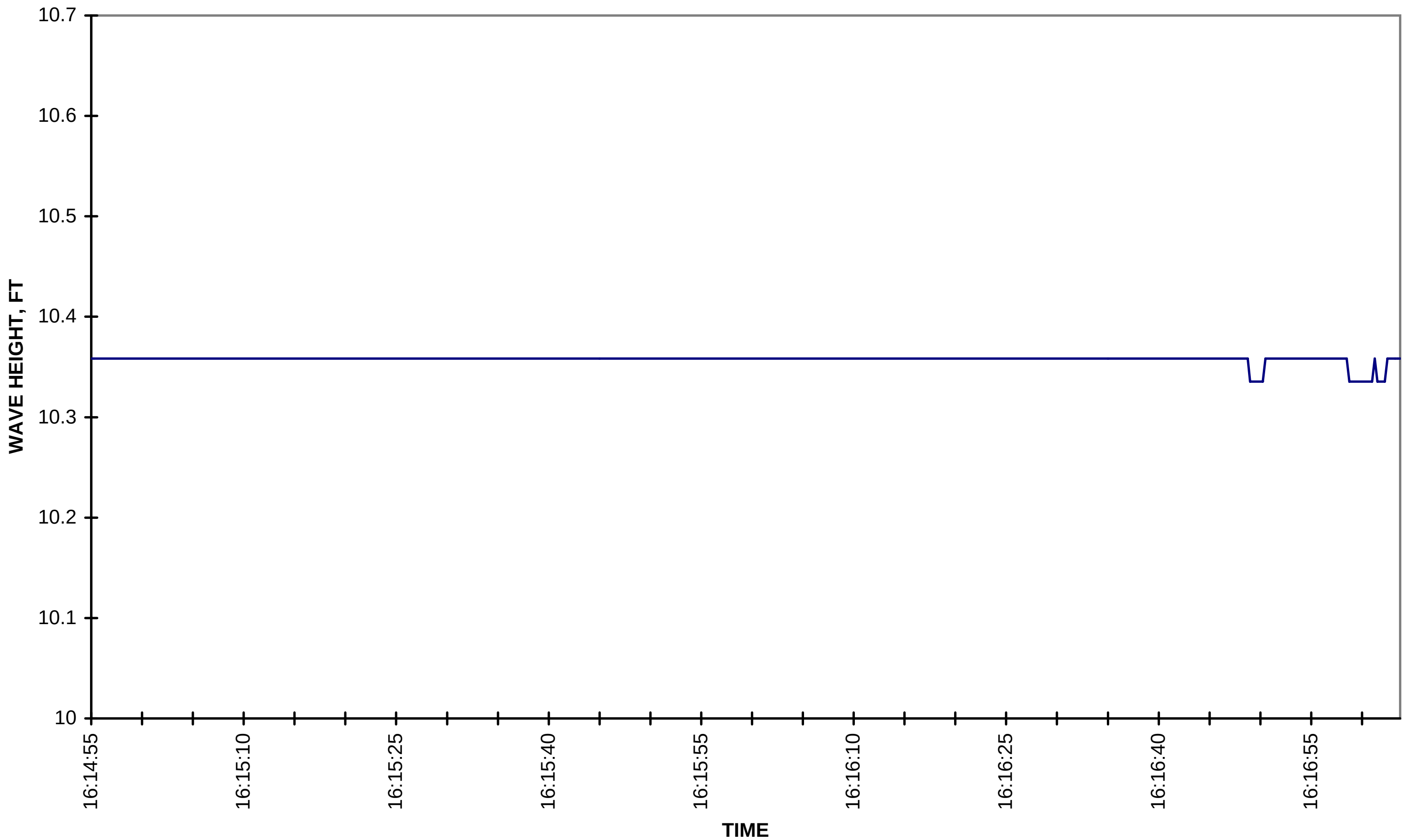
WAVE HEIGHTS

TEST 7, BOAT TYPE II

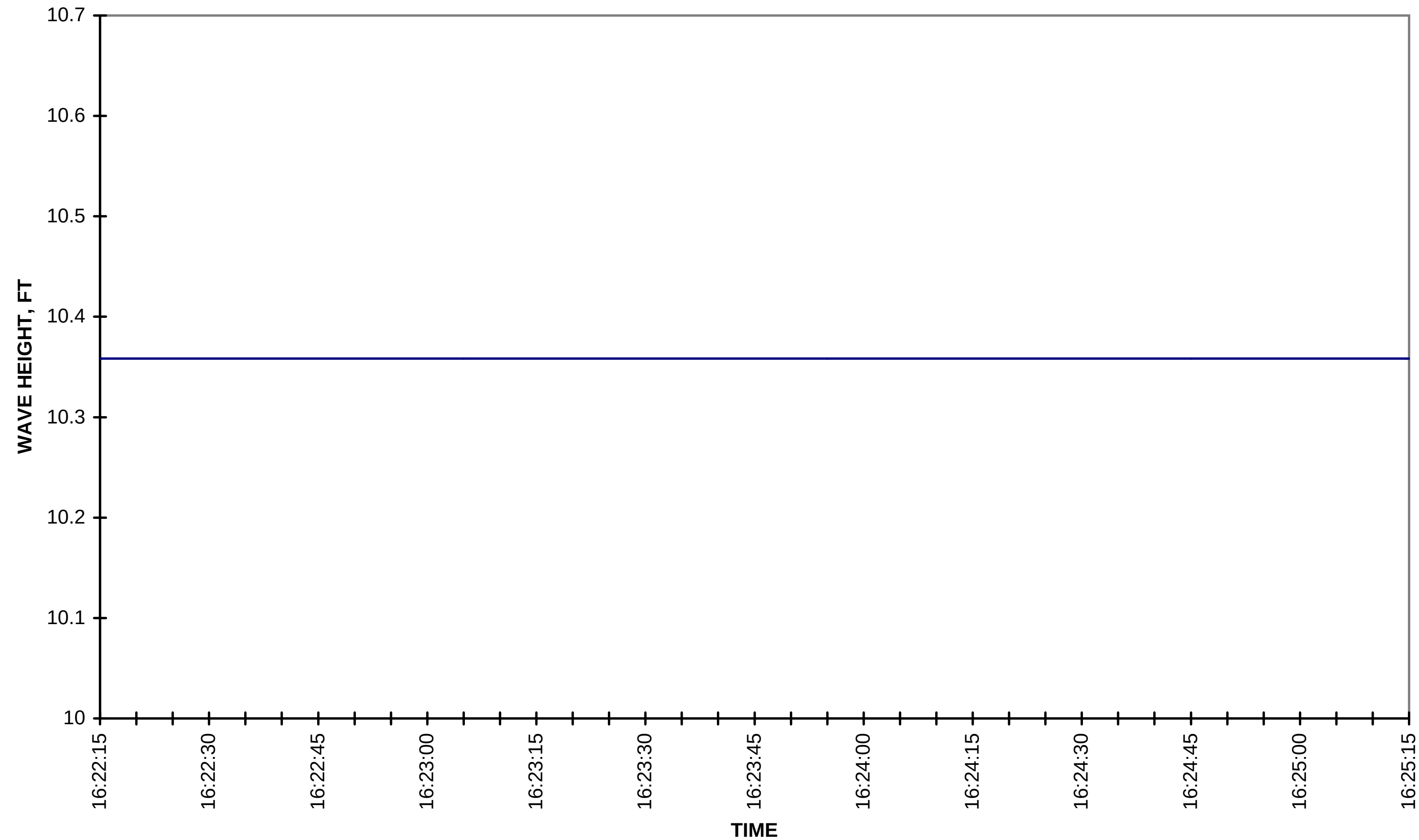
SAILING LINE S2, DOWNSTREAM

FULLY LOADED, GAGE WG3, 11-FT DEPTH

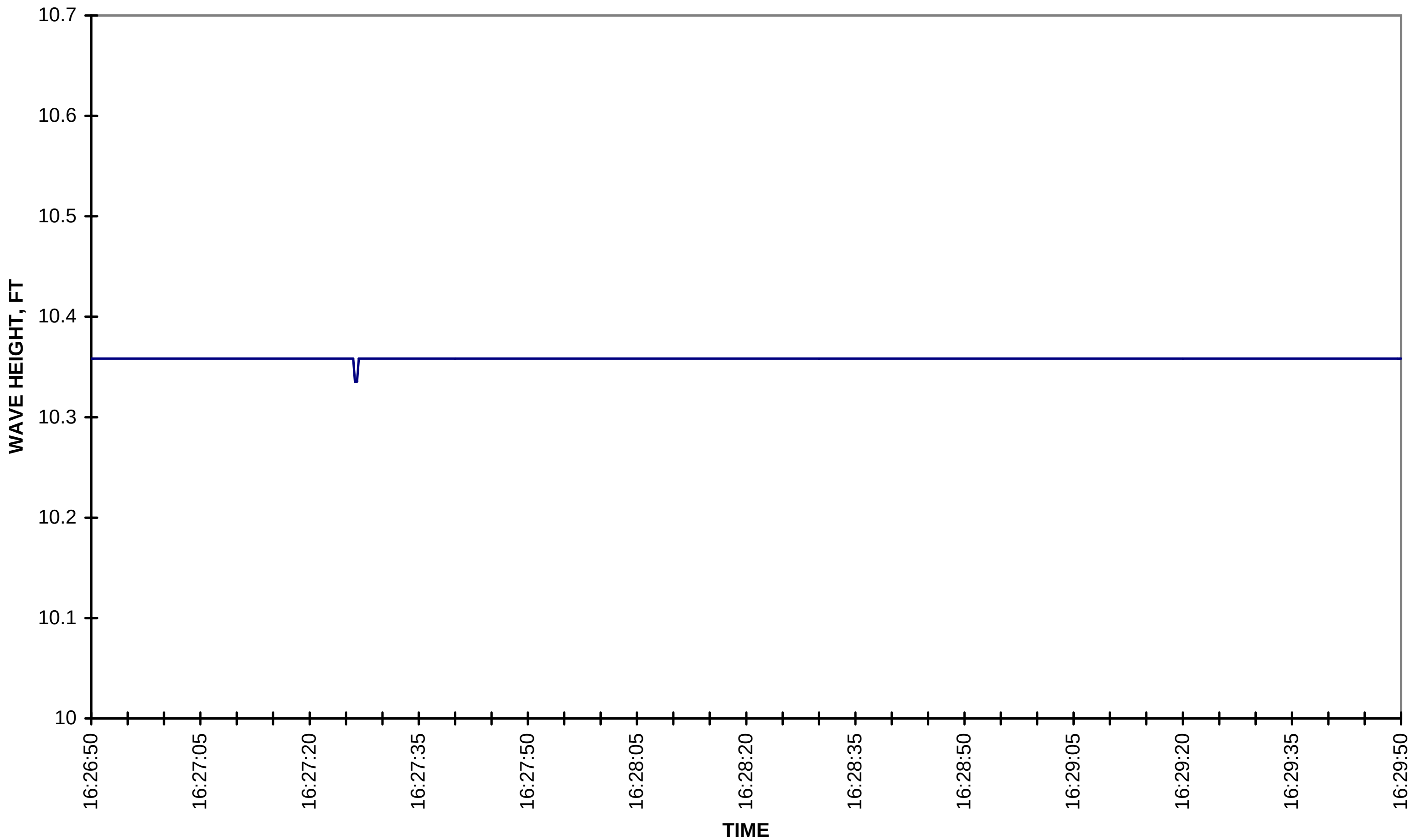
11/3/95



WAVE HEIGHTS
TEST 8, BOAT TYPE II
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95

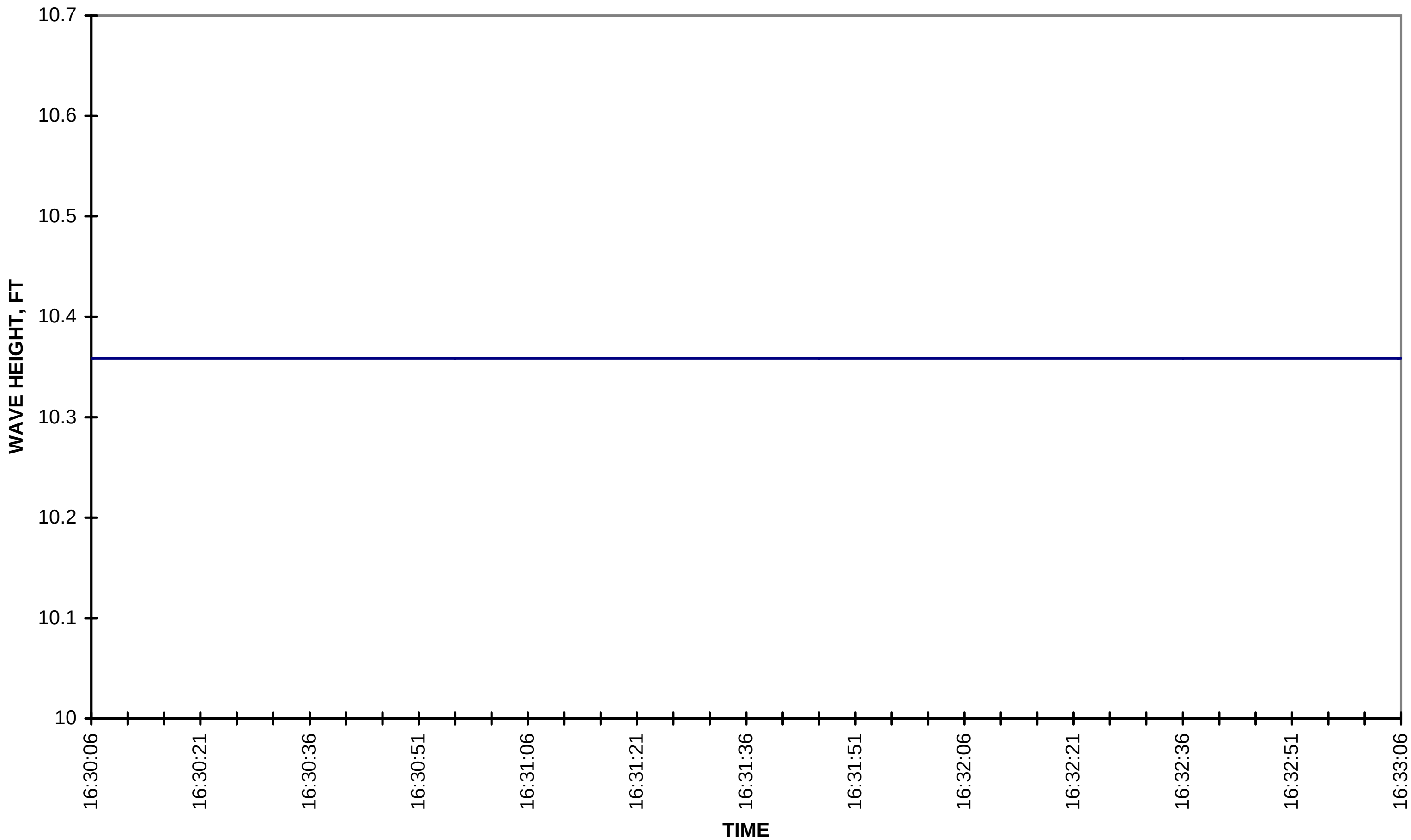


WAVE HEIGHTS
TEST 10, BOAT TYPE II
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95

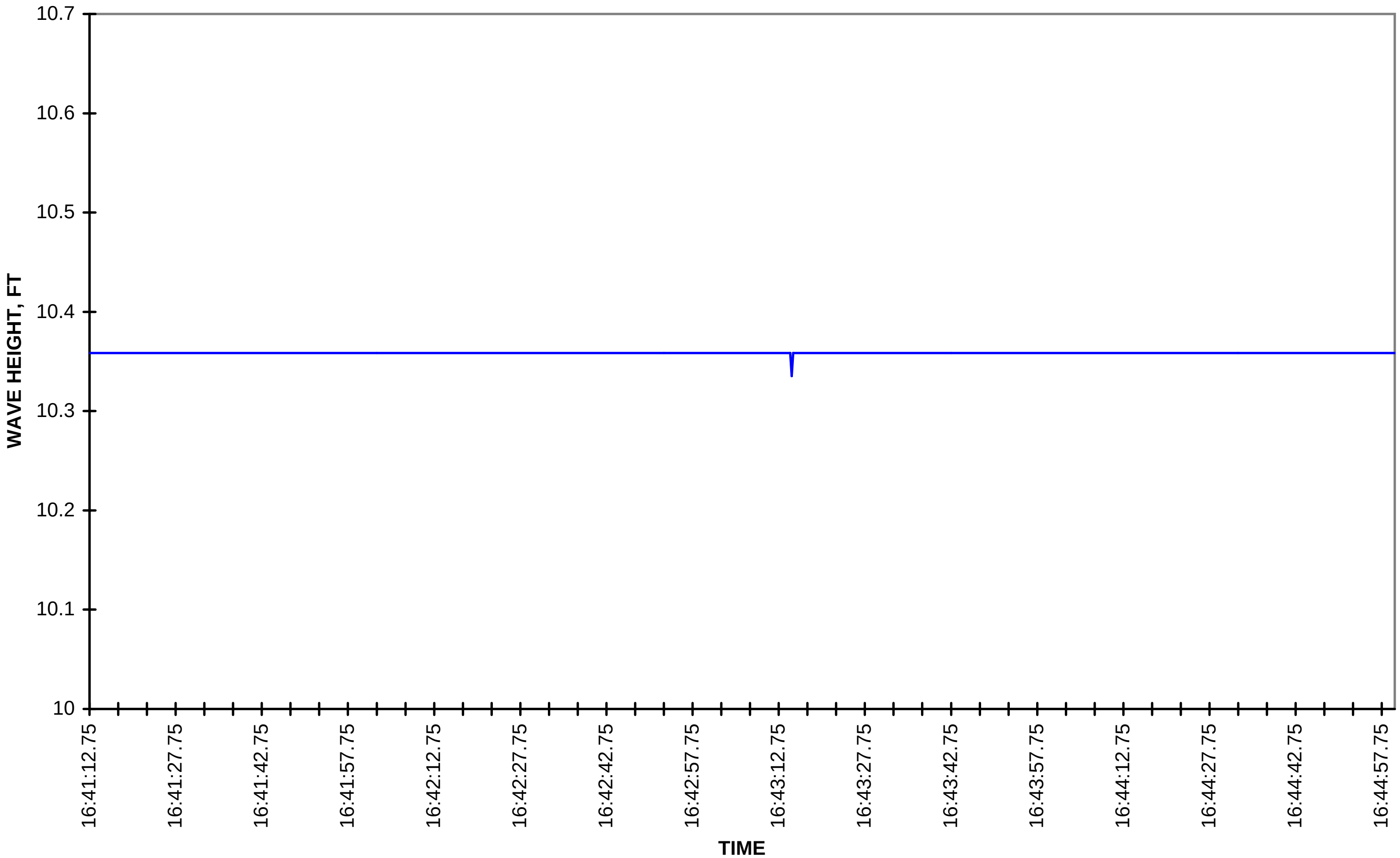


WAVE HEIGHTS

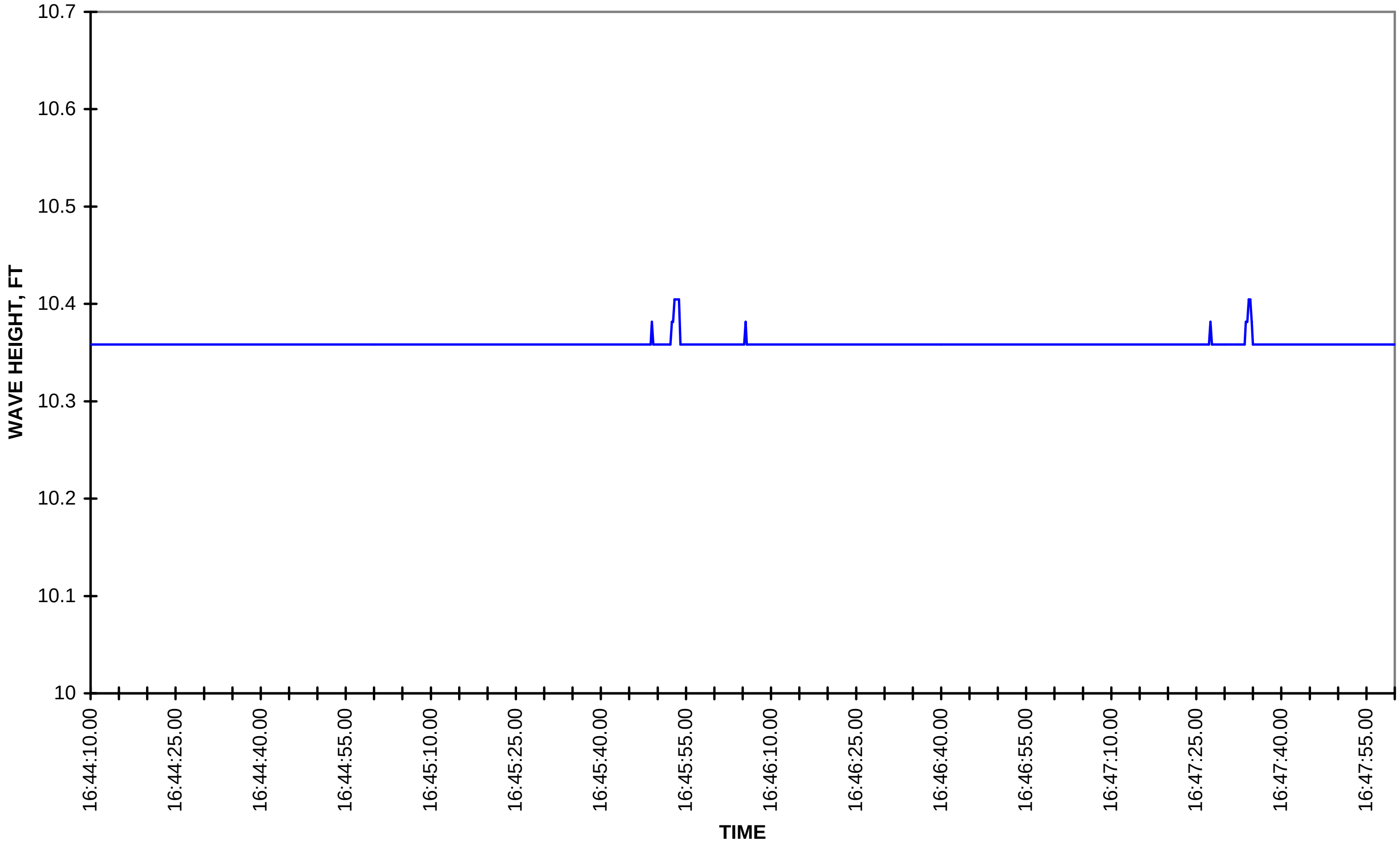
TEST 11, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 12, BOAT TYPE II
SAILING LINE S2, UPSTREAM
FULLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 14, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



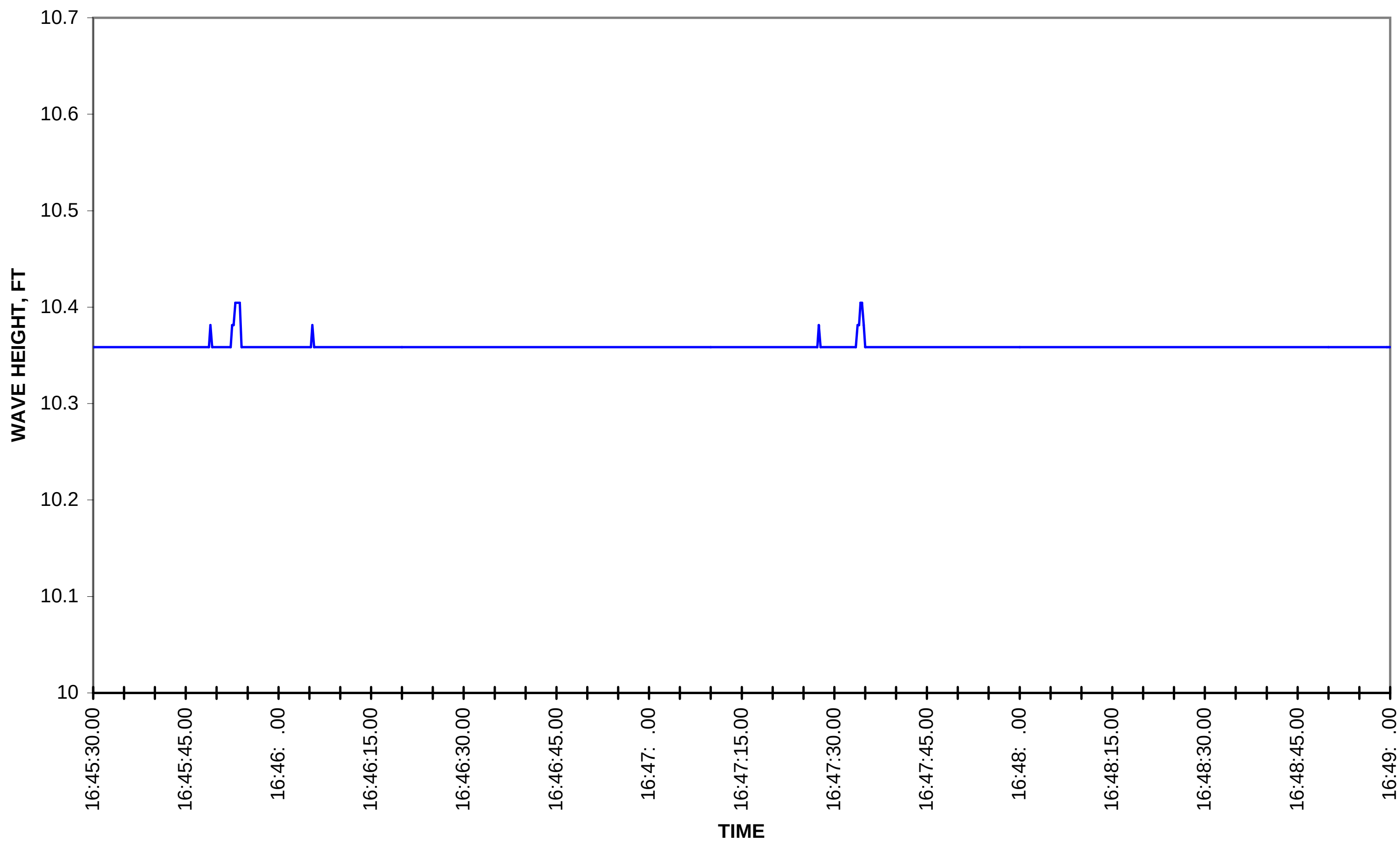
WAVE HEIGHTS

TEST 15, BOAT TYPE II

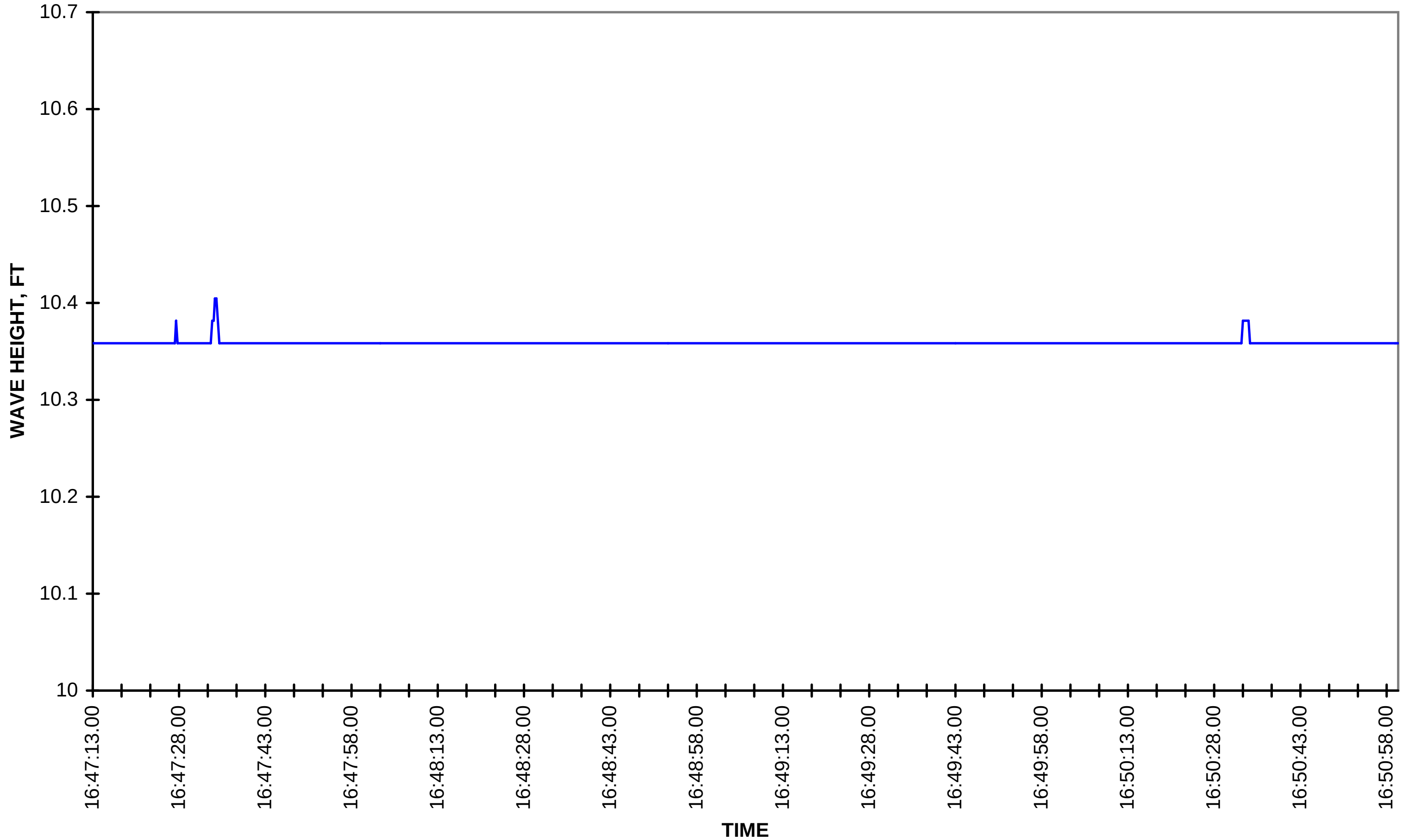
SAILING LINE S1, DOWNSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

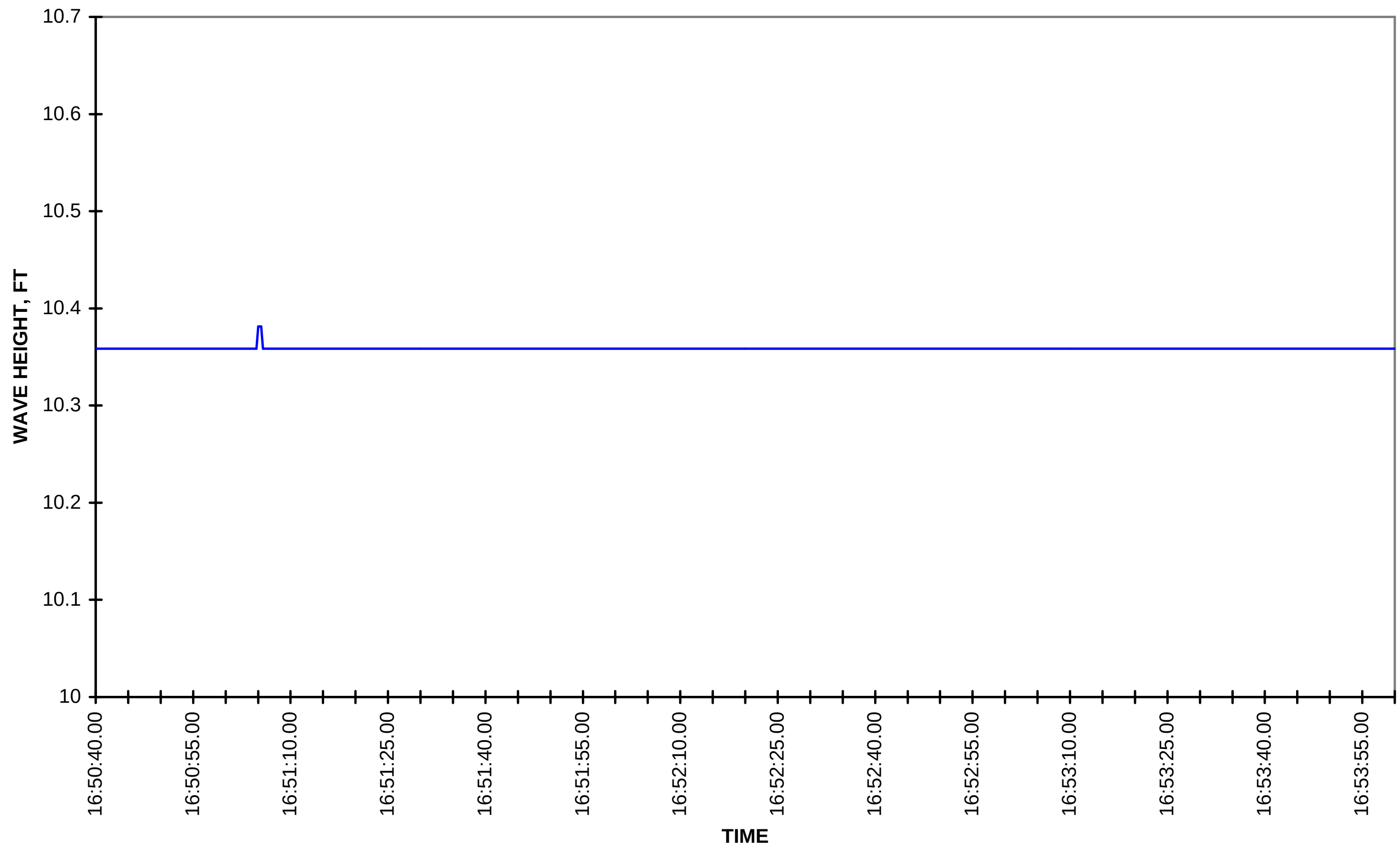
11/3/95



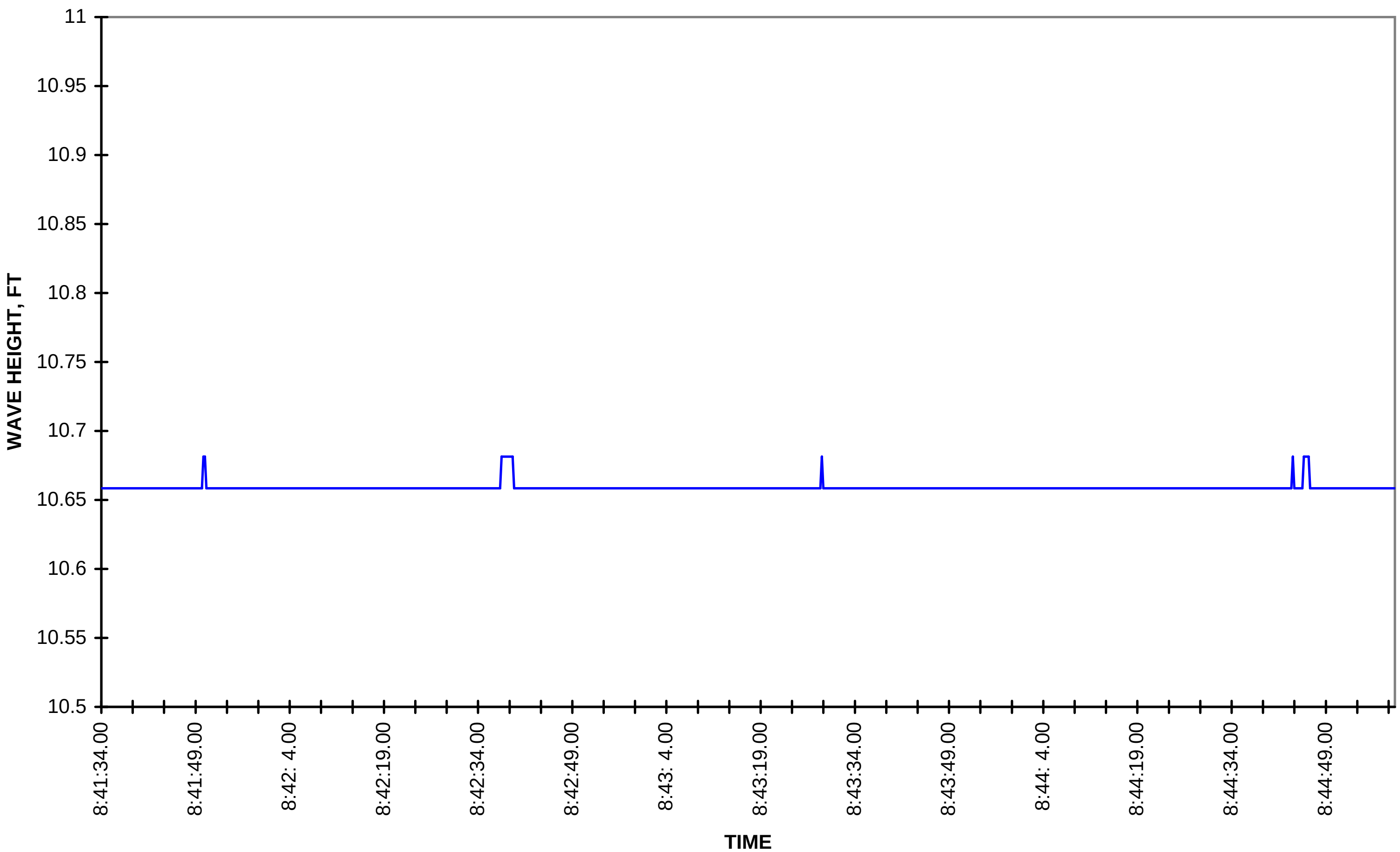
WAVE HEIGHTS
TEST 16, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 17, BOAT TYPE II
SAILING LINE S1, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



WAVE HEIGHTS
TEST 18, BOAT TYPE II
SAILING LINE S1, UPSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/3/95



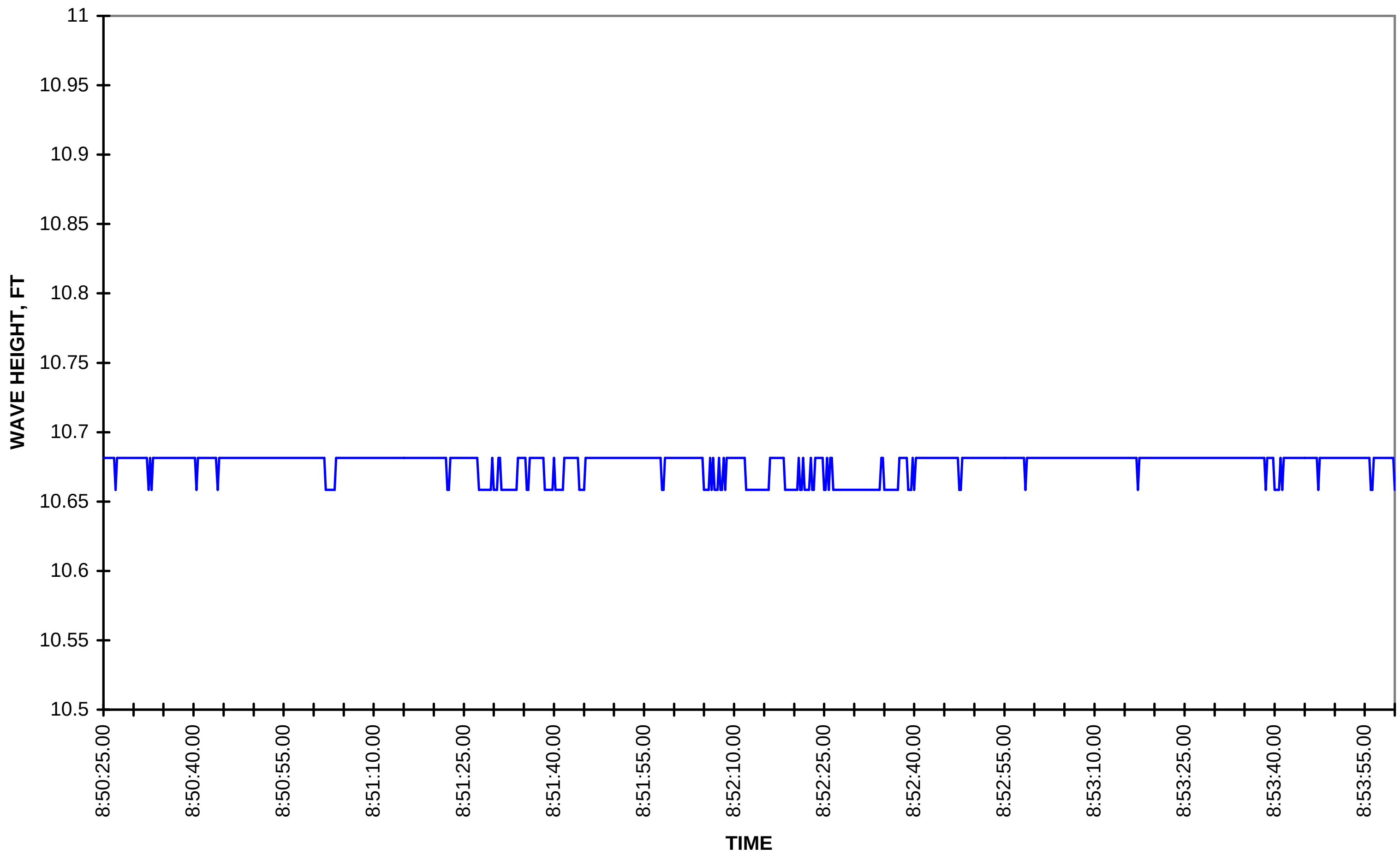
WAVE HEIGHTS

TEST 20, BOAT TYPE II

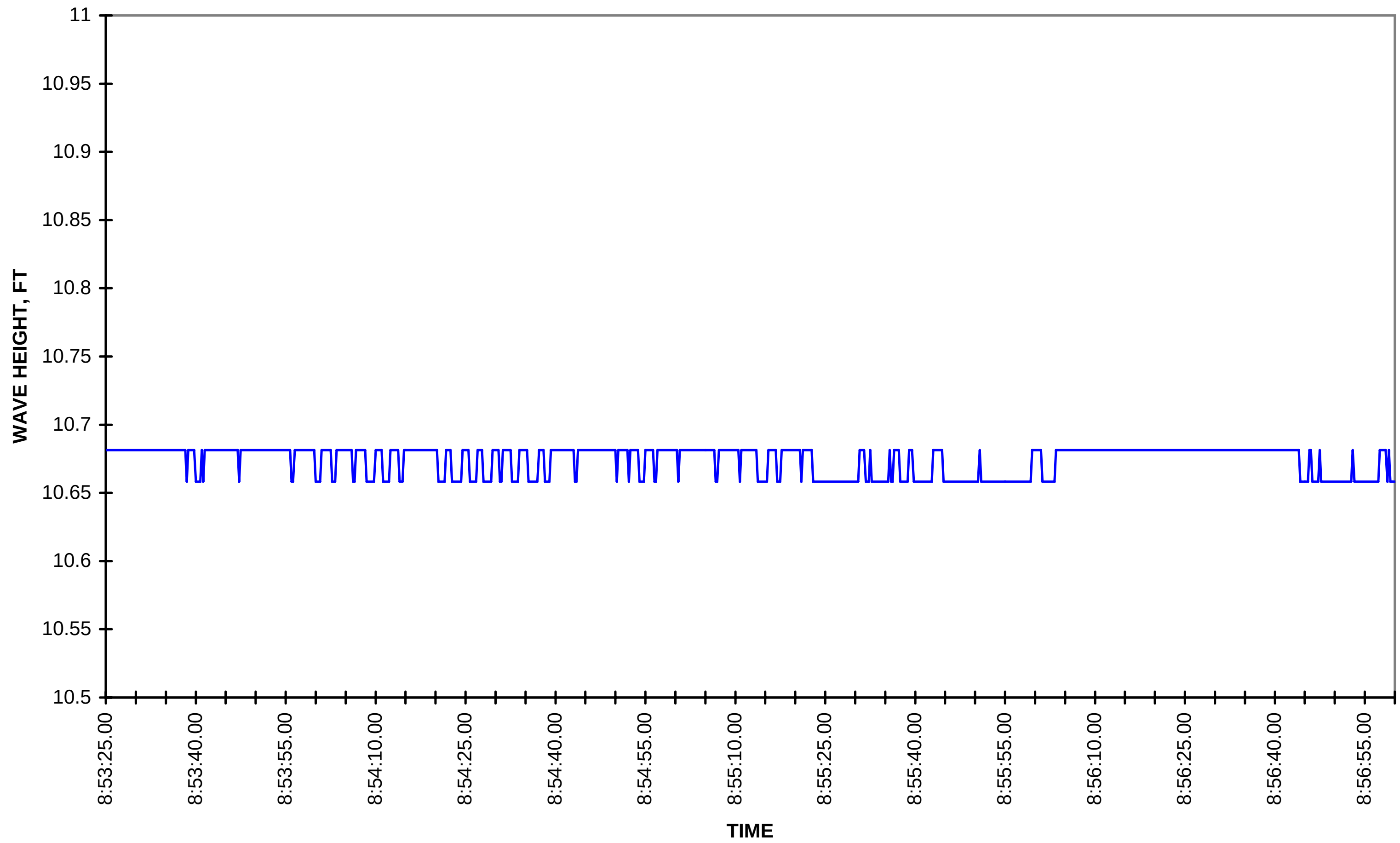
SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

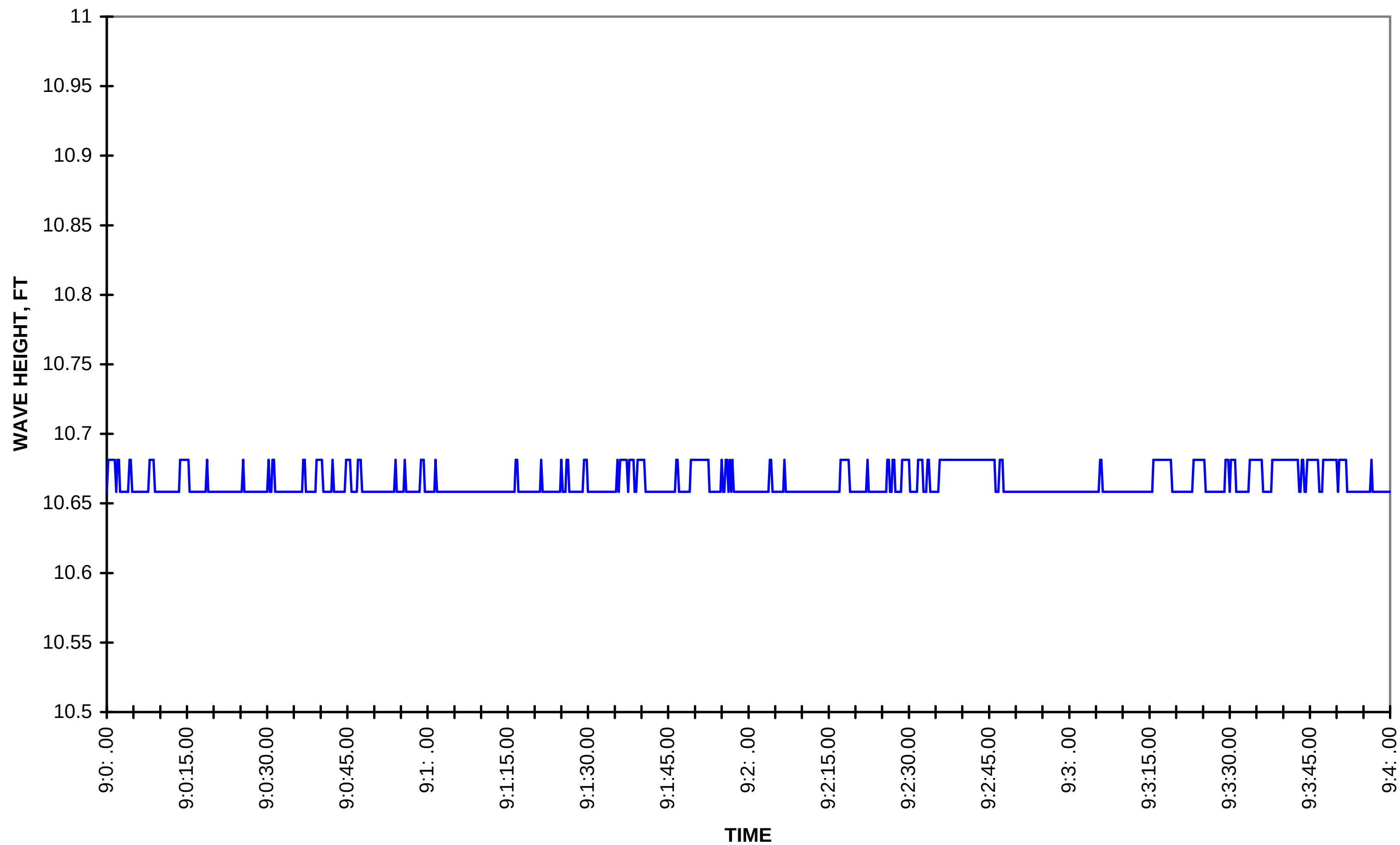
11/4/95



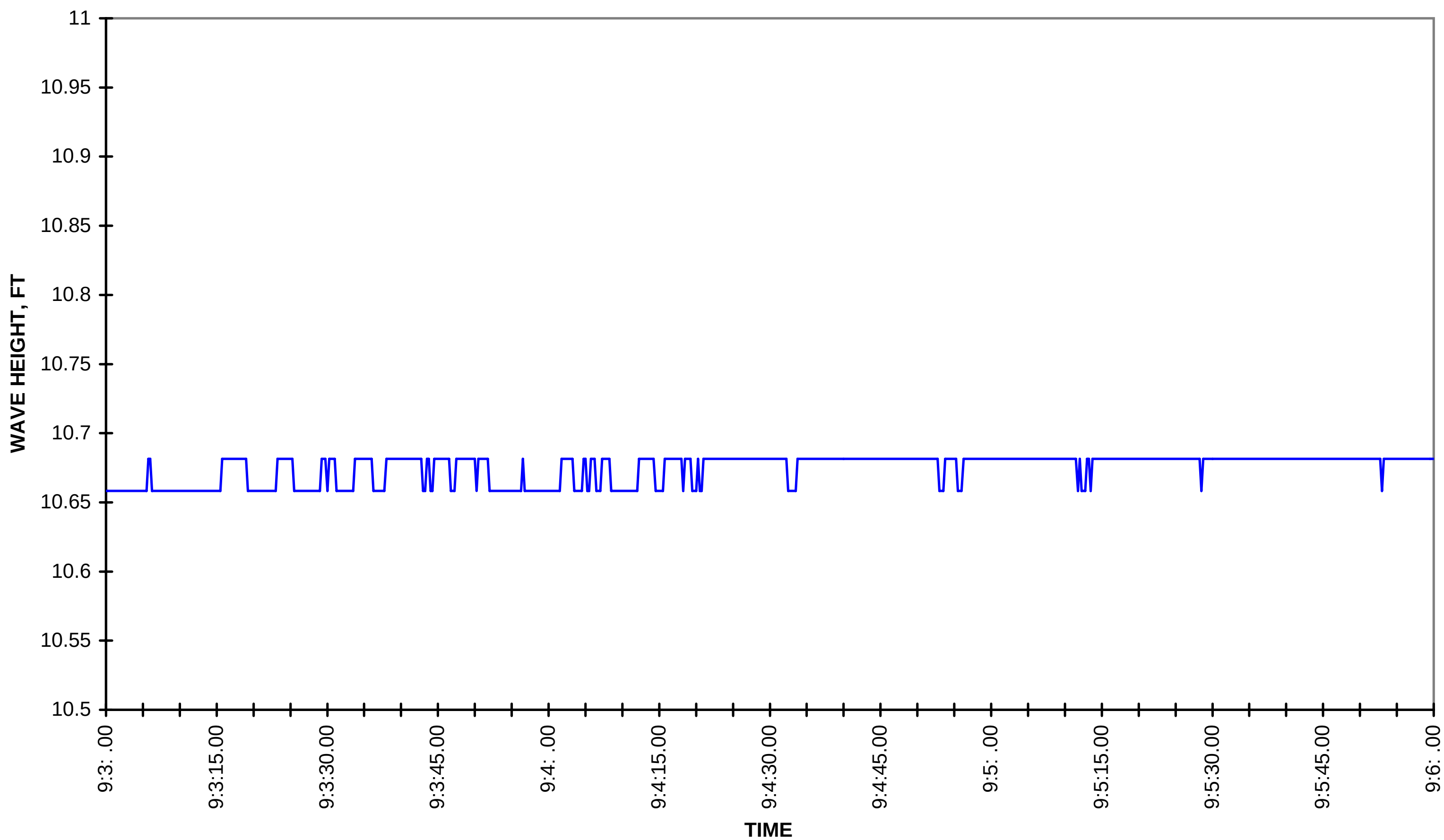
WAVE HEIGHTS
TEST 21, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/4/95



WAVE HEIGHTS
TEST 22, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/4/95



WAVE HEIGHTS
TEST 23, BOAT TYPE II
SAILING LINE S2, DOWNSTREAM
LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH
11/4/95



WAVE HEIGHTS

TEST 24, BOAT TYPE II

SAILING LINE S2, UPSTREAM

LIGHTLY LOADED, GAGE WG3, 11-FT DEPTH

11/4/95

Appendix B

Suspended Sediment Concentration, Pool 8

Appendix B

Suspended Sediment Concentration
Pool 8

Notes:

1. **Observations were taken at 7.5, 6.5, 3.0, and 1.0 feet above bed during November 3 - 6, 1995.**

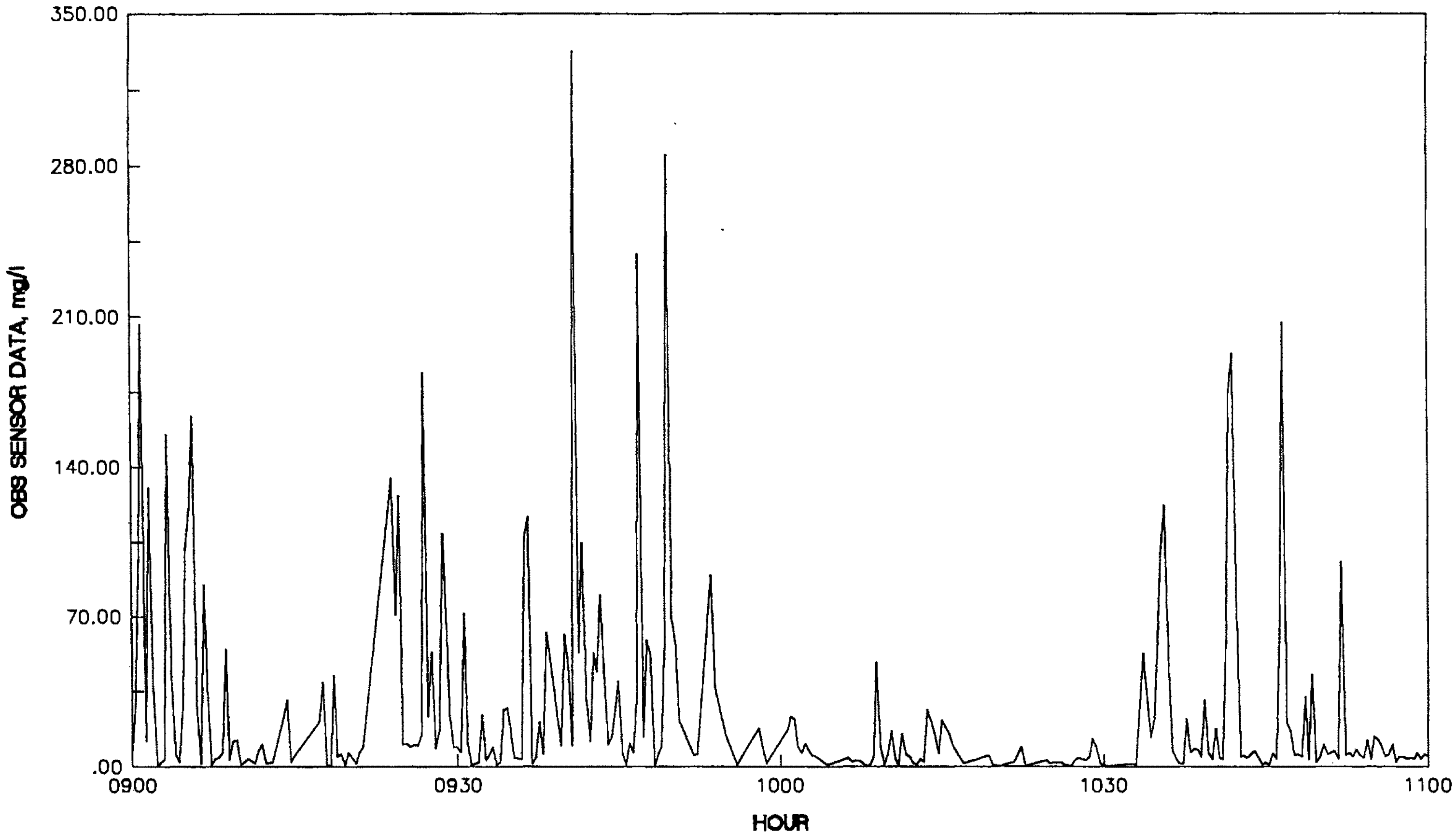
Page #	Vessel Type	Empty/Loaded
B1 – B4	1	Empty
B5 – B8	2	Loaded/Empty
B9 – B12	2	Empty
B13 – B16	3	Loaded
B17 – B20	3	Empty
B21 – B24	4	Loaded
B25 – B28	4	Empty
B29 – B32	5	Loaded
B33 – B36	5	Empty
B37 – B40	6	Empty
B41 – B44	6	Loaded

Field Data on Suspended Sediment Concentration
Mississippi River Project
Location: Pool 8

#	Date	Type	Empty / Loaded	Depth (Feet)	Suspension Concentration mg/l		
					Event 1 Peak	Event 2 Peak	General, Ignoring Peaks
1	11/06/95	1	Empty	7.5	340	210	50
2				6.5	590	200	80
3				3.0	65	68	25
4				1.0	23	-	19.5
5	11/03/95	2	Loaded	7.5	950	400	80
6				6.5	360	330	60
7				3.0	58	-	20
8				1.0	52	-	20
9	11/04/95	2	Empty	7.5	700	950	300
10				6.5	290	-	30
11				3.0	890	-	500
12				1.0	890	720	400
13	11/05/95	3	Loaded	7.5	670	660	140
14				6.5	200	-	-
15				3.0	38	27	20
16				1.0	-	-	20
17	11/05/95	3	Empty	7.5	890	720	360
18				6.5	810	850	450
19				3.0	26	-	20
20				1.0	280	-	-
21	11/04/95	4	Loaded	7.5	580	480	60
22				6.5	225	150	75
23				3.0	-	-	20
24				1.0	-	-	20
25	11/04/95	4	Empty	7.5	200	75	70
26				6.5	33	-	20
27				3.0	-	-	20
28				1.0	-	-	20
29	11/06/95	5	Loaded	7.5	930	800	200
30				6.5	850	350	200
31				3.0	550	-	30
32				1.0	-	-	-20
33	11/06/95	5	Empty	7.5	870	870	180
34				6.5	750	540	120
35				3.0	580	-	-

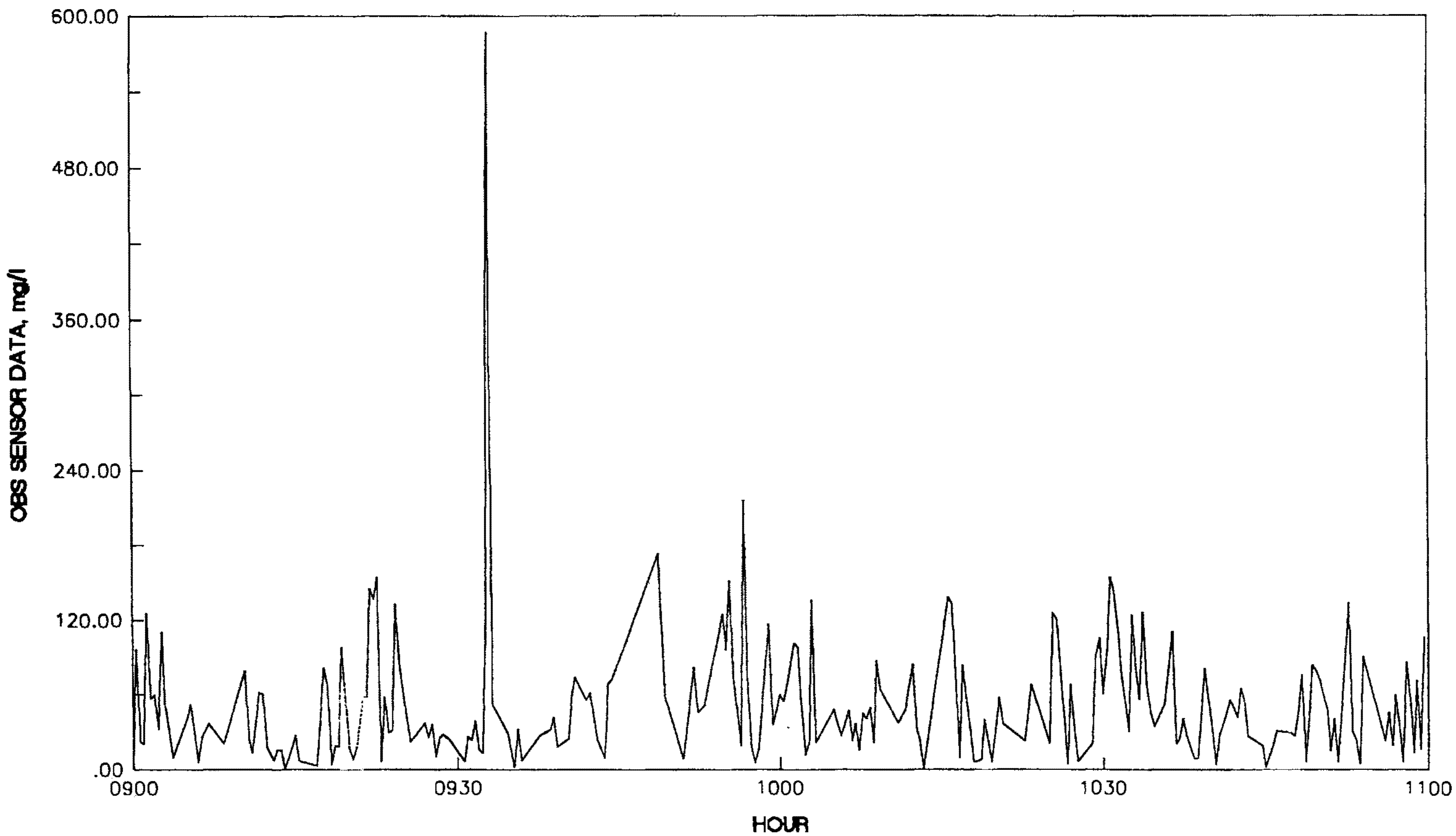
Field Data on Suspended Sediment Concentration
Mississippi River Project
Location: Pool 8

36				**1.0**	**-**	**-**	**-**
37	**11/05/95**	**6**	**Empty**	**7.5**	**660**	**520**	**80**
38				**6.5**	**540**	**750**	**200**
39				**3.0**	**-**	**-**	**20**
40				**1.0**	**-**	**-**	**20**
41	**11/05/95**	**6**	**Loaded**	**7.5**	**360**	**360**	**160**
42				**6.5**	**520**	**700**	**140**
43				**3.0**	**-**	**-**	**20**
44				**1.0**	**-**	**-**	**20**



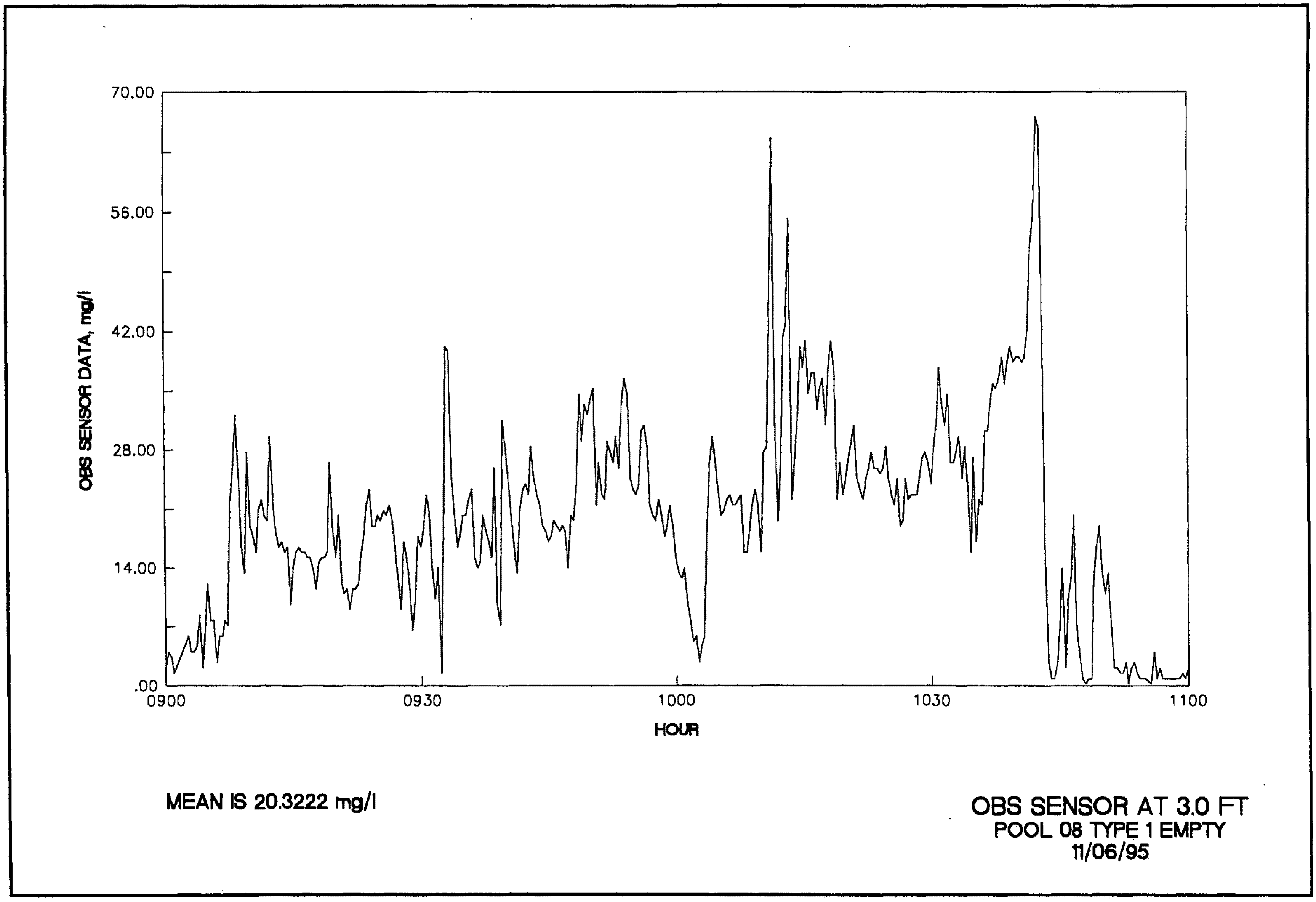
MEAN IS 26.4114 mg/l

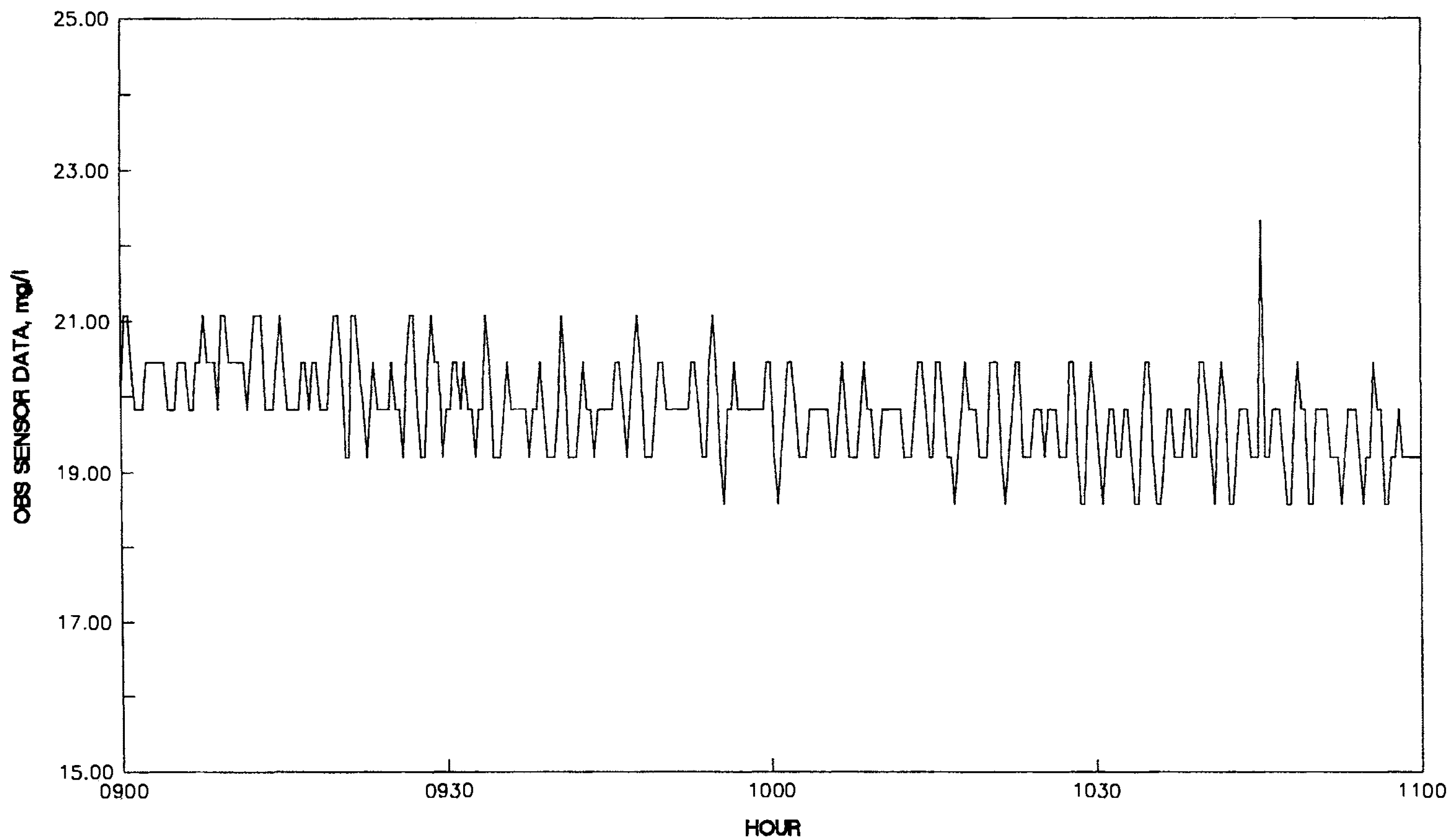
OBS SENSOR AT 7.5 FT
POOL 08 TYPE 1 EMPTY
11/06/95



MEAN IS 51.6960 mg/l

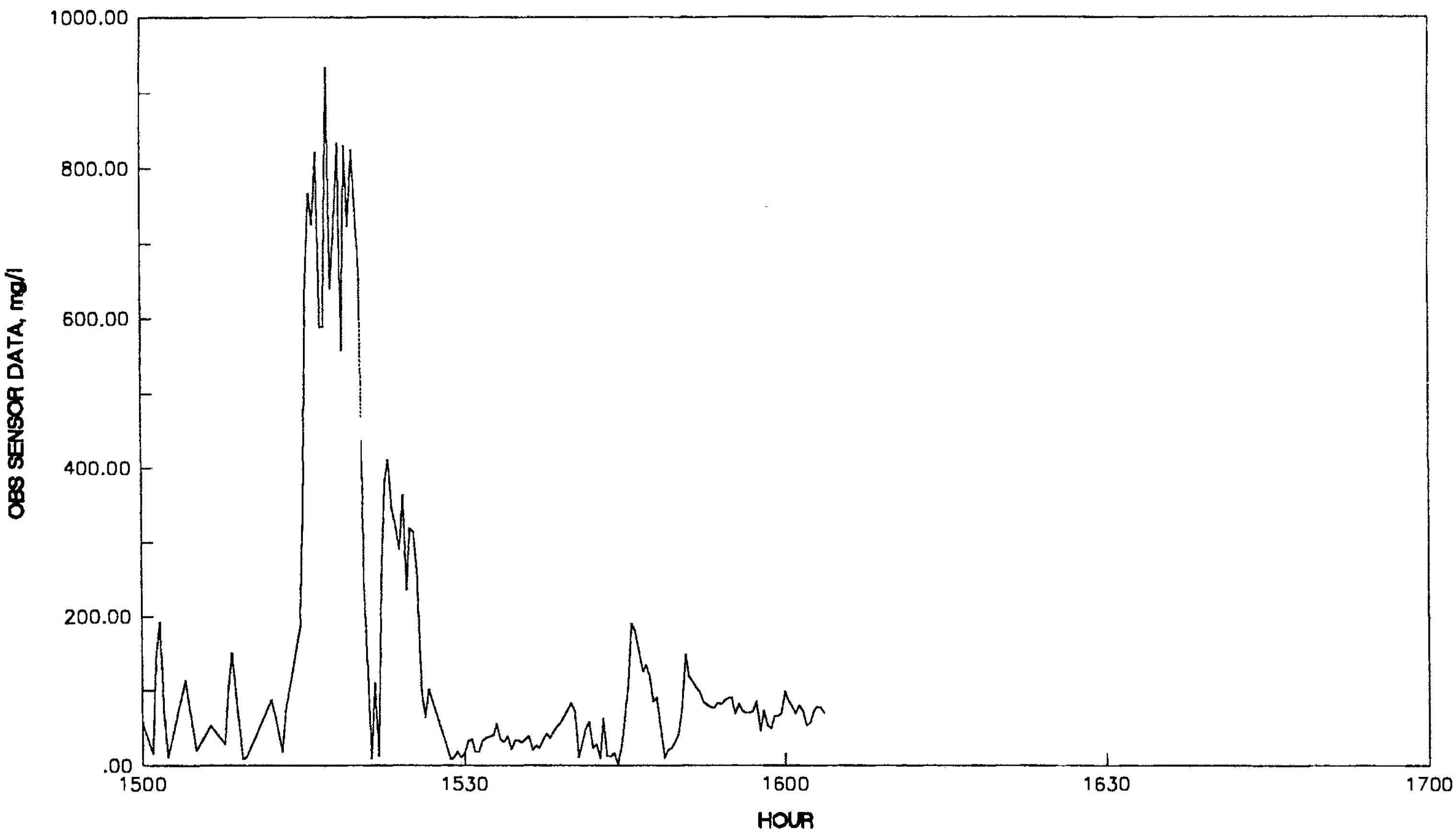
OBS SENSOR AT 6.5 FT
POOL 08 TYPE 1 EMPTY
11/06/95


70.00
56.00
42.00
28.00
14.00
.00
OBS SENSOR DATA, mg/l
0900
0930
1000
1030
1100
HOUR
MEAN IS 20.3222 mg/l
OBS SENSOR AT 3.0 FT
POOL 08 TYPE 1 EMPTY
11/06/95



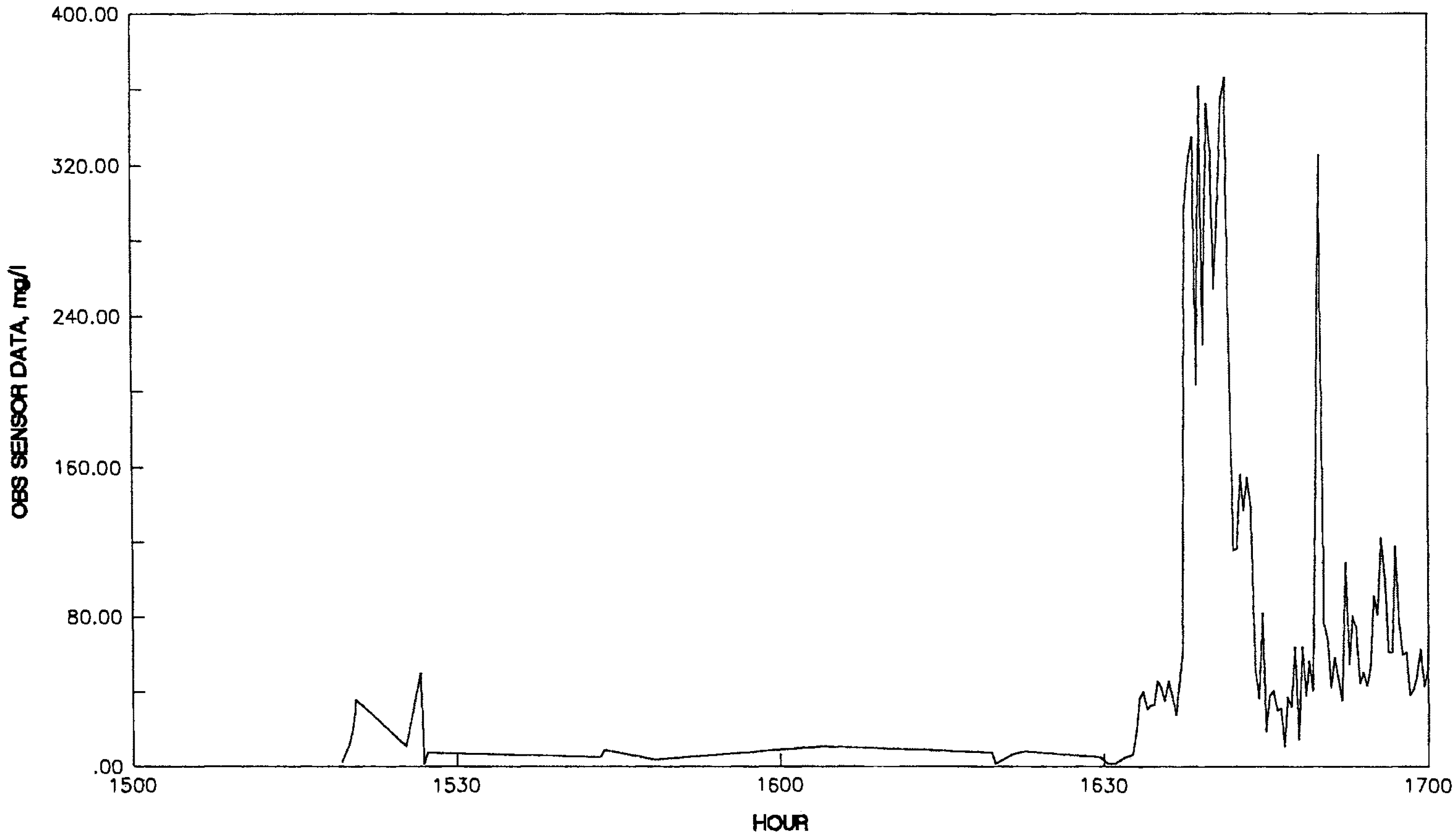
MEAN IS 19.7999 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 1 EMPTY
11/06/95



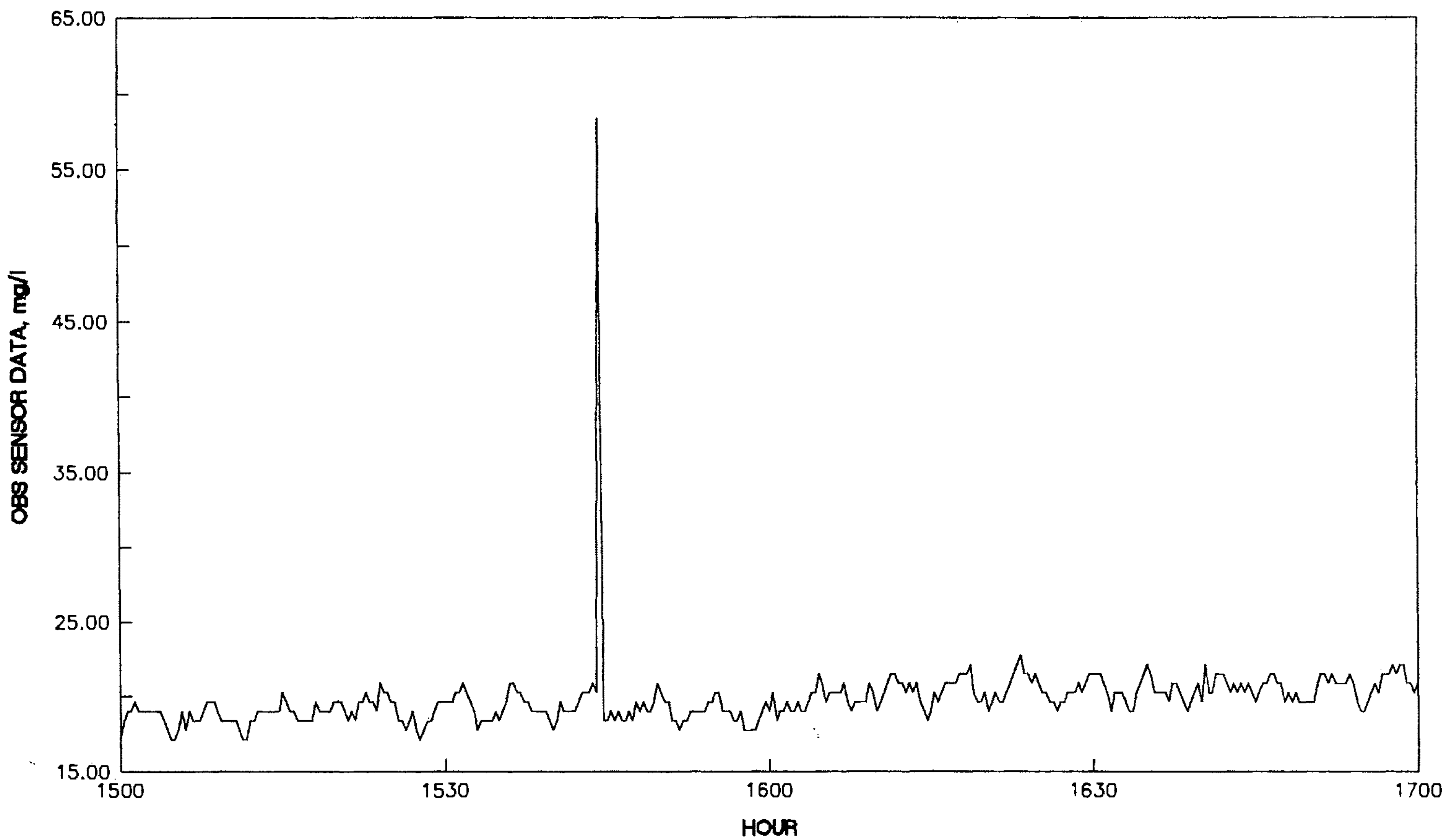
MEAN IS 145.5777 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 2
LOADED: 1500-1630 UNLOADED: 1630-1700
11/03/95



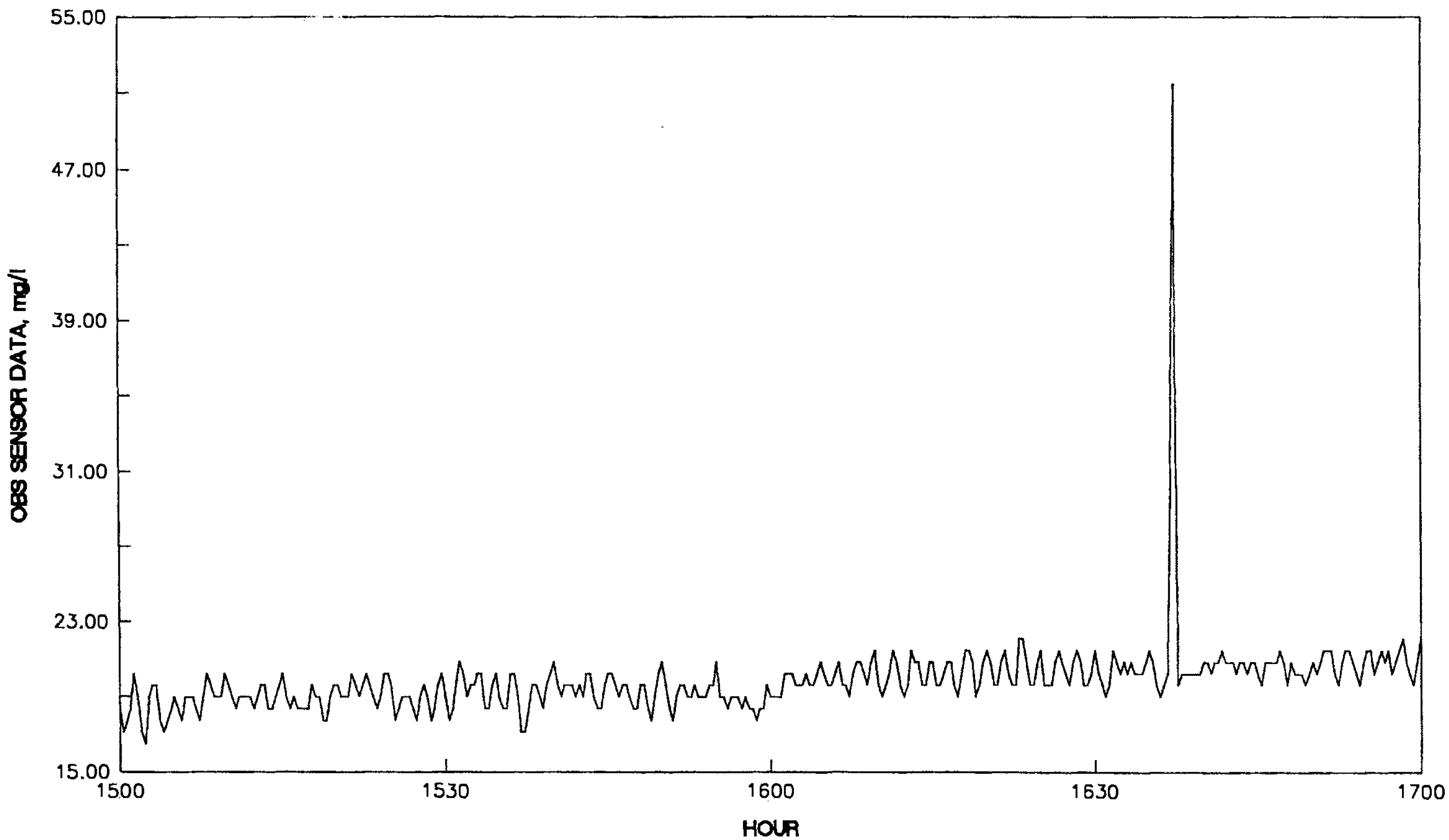
MEAN IS 84.1550 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 2
LOADED: 1500-1630 UNLOADED: 1630-1700
11/03/95



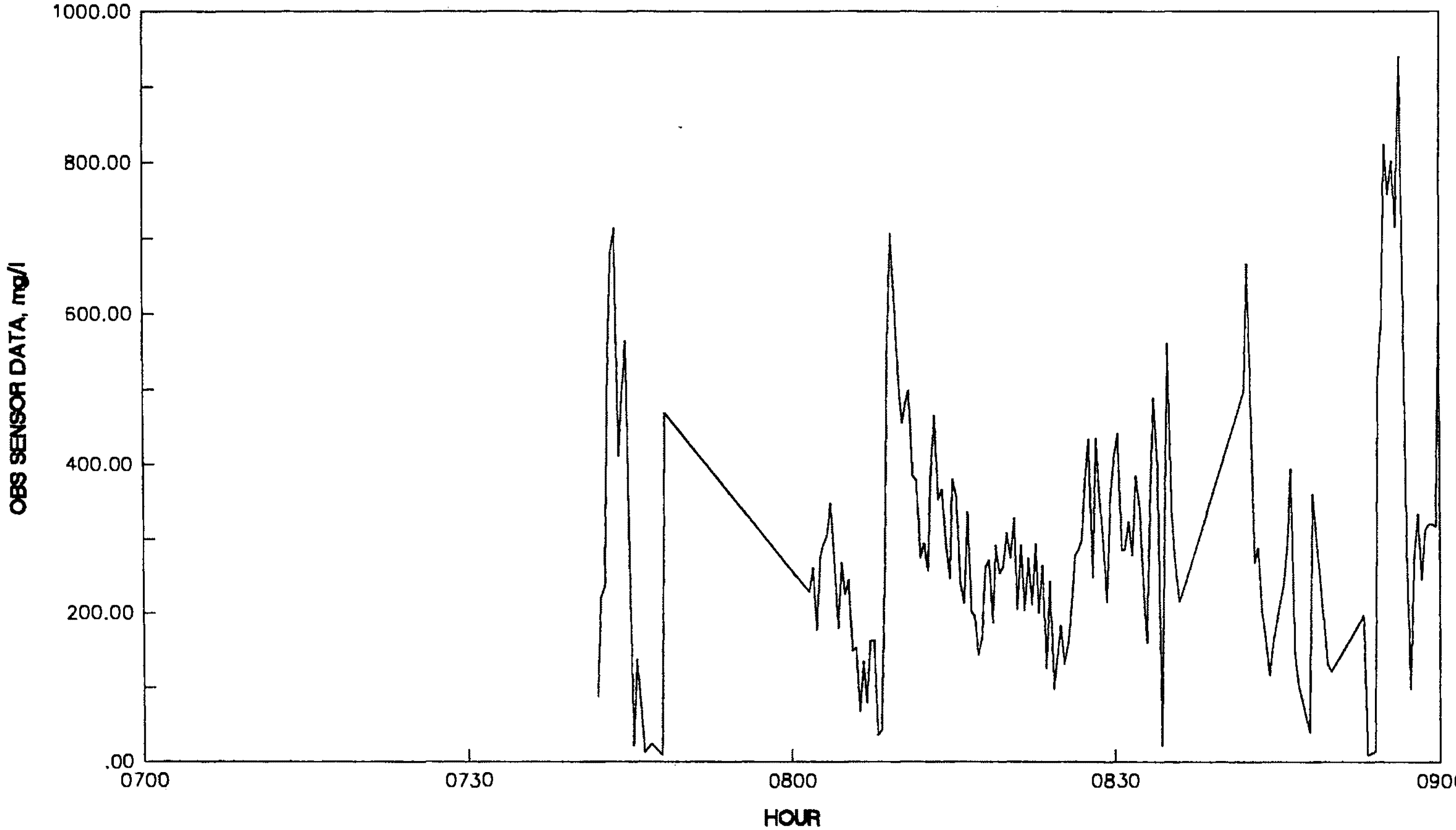
MEAN IS 19.8001 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 2
LOADED: 1500-1630 UNLOADED: 1630-1700
11/03/95



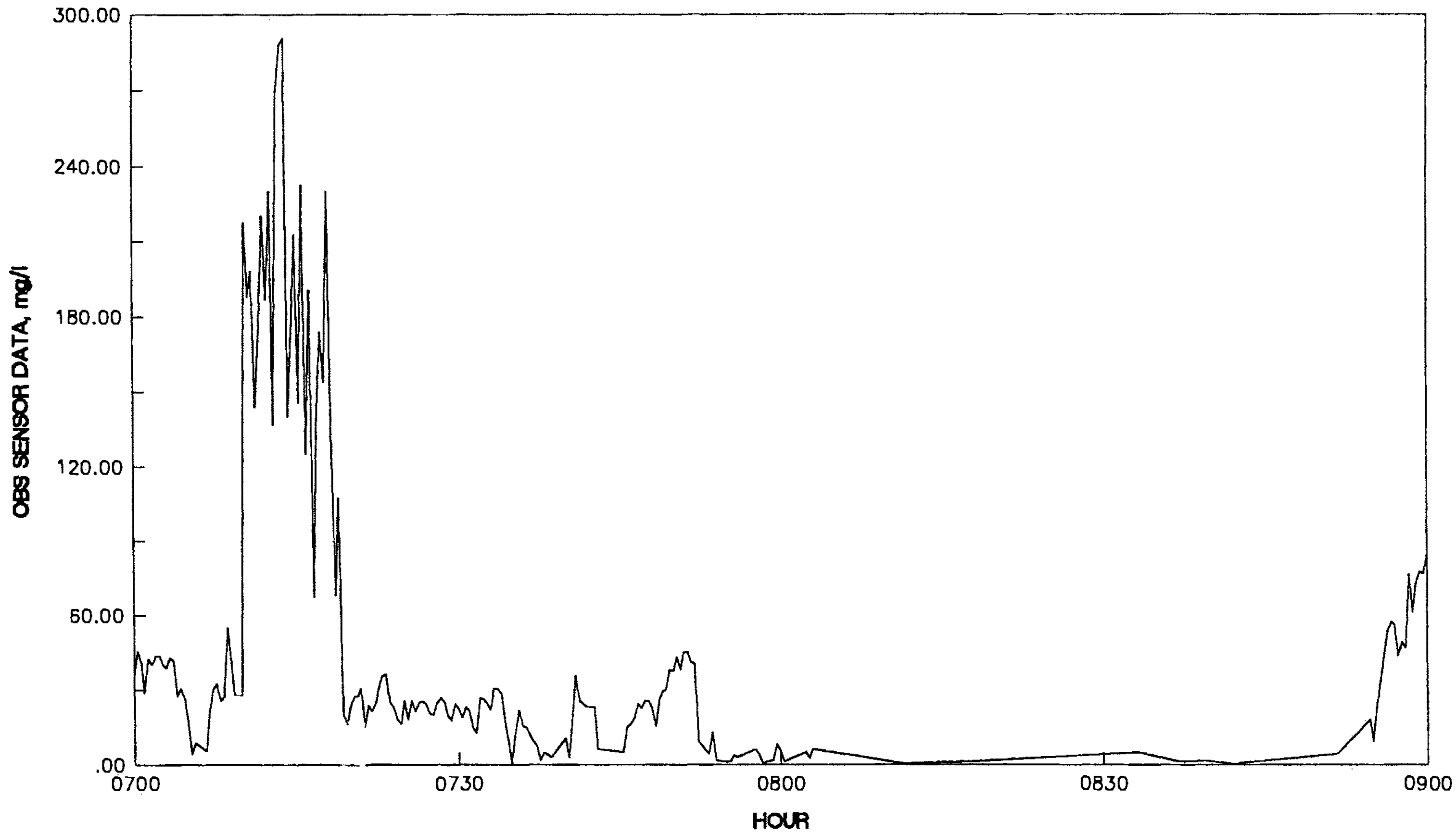
MEAN IS 19.8000 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 2
LOADED: 1500-1630 UNLOADED: 1630-1700
11/03/95



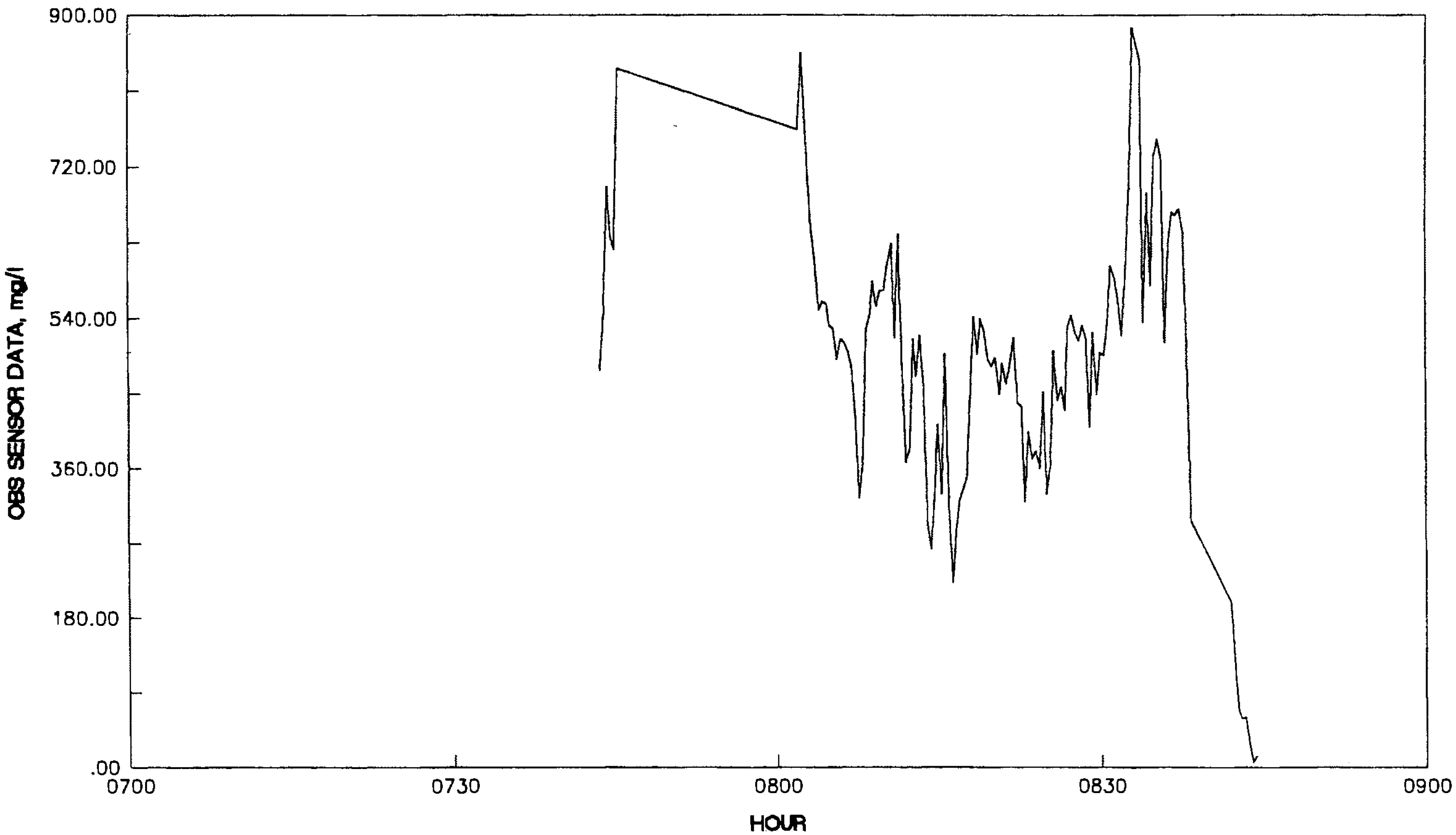
MEAN IS 304.1664 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 2 EMPTY
11/04/95



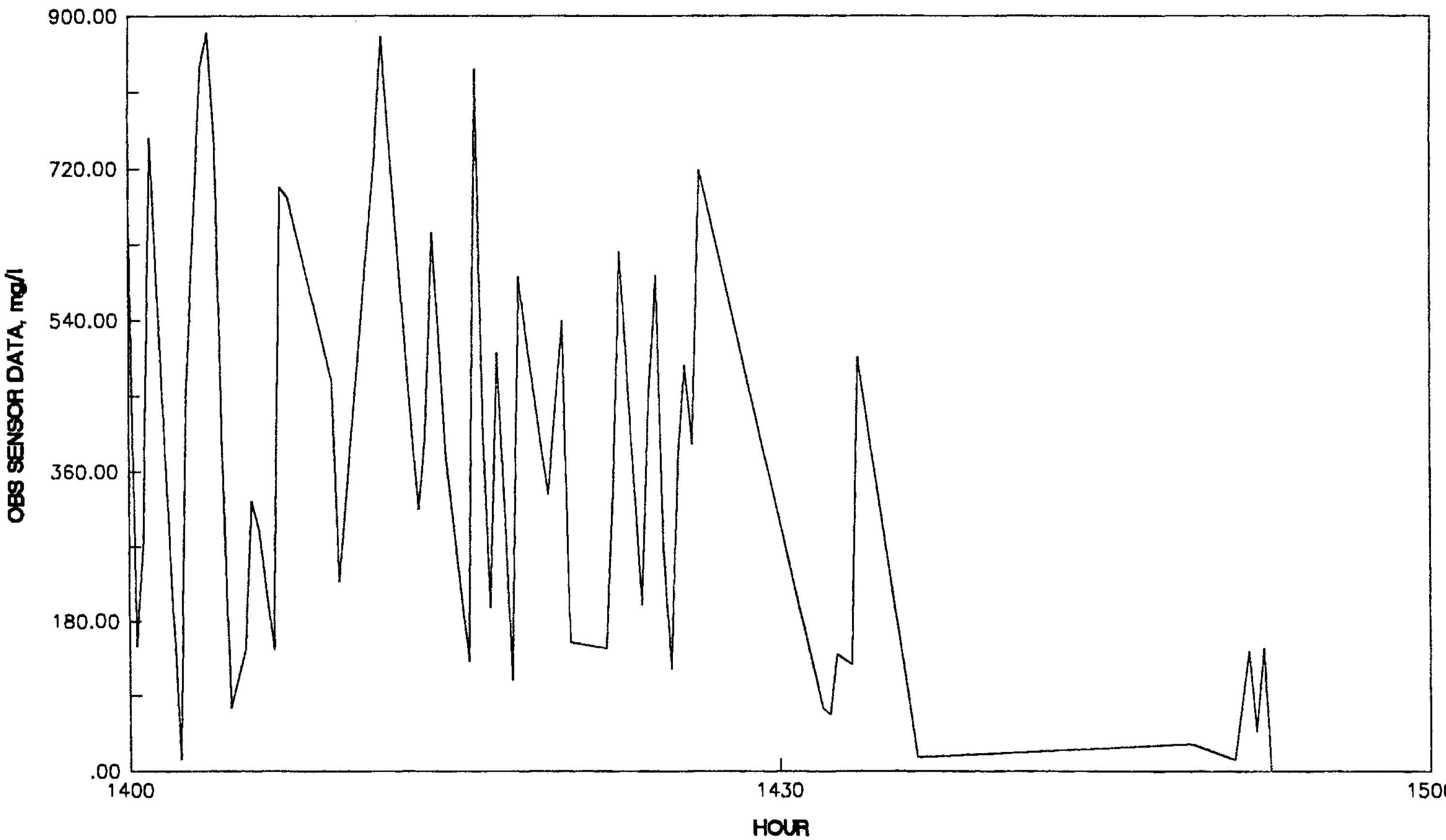
MEAN IS 46.2610 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 2 EMPTY
11/04/95



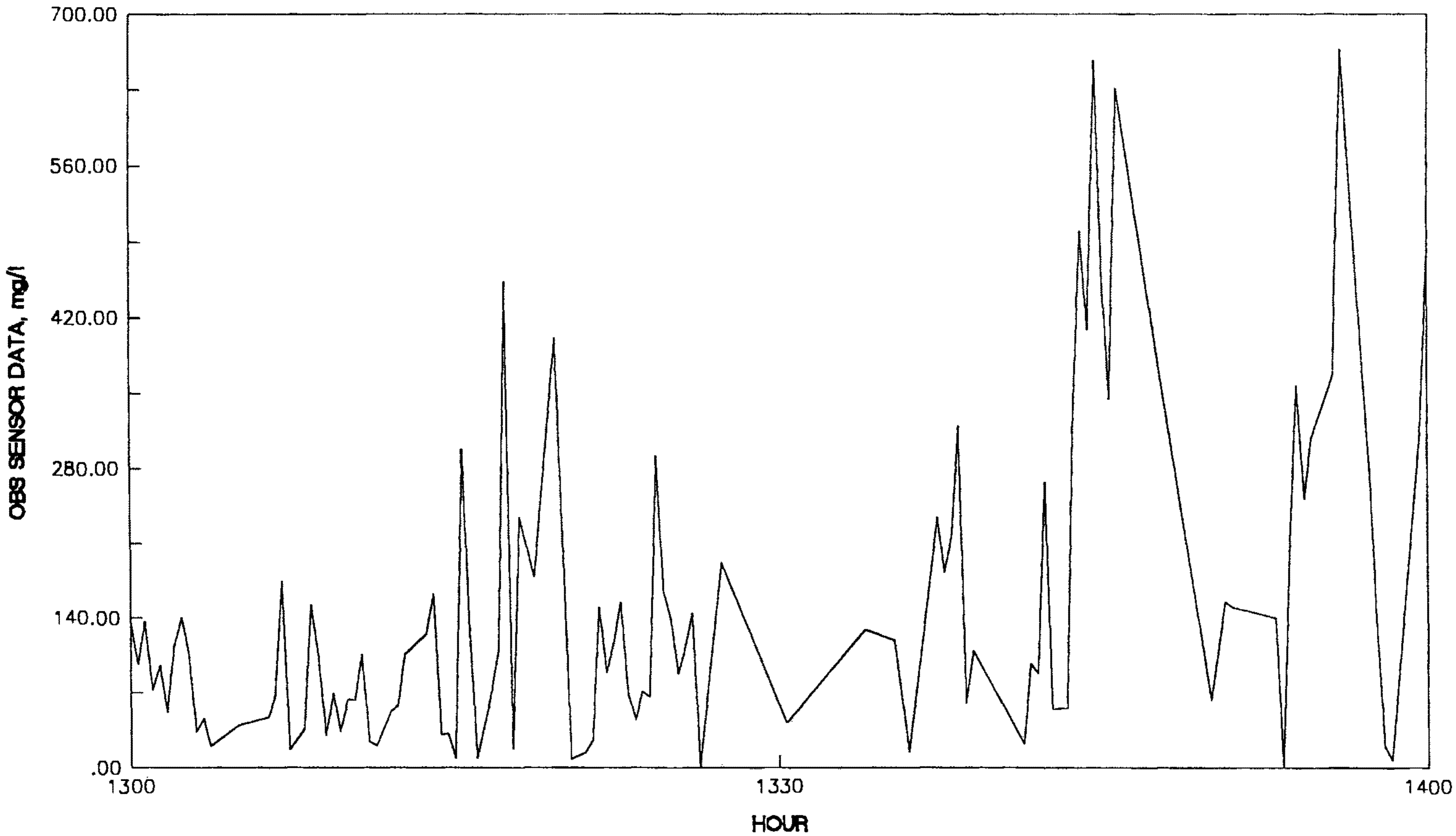
MEAN IS 487.9804 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 2 EMPTY
11/04/95



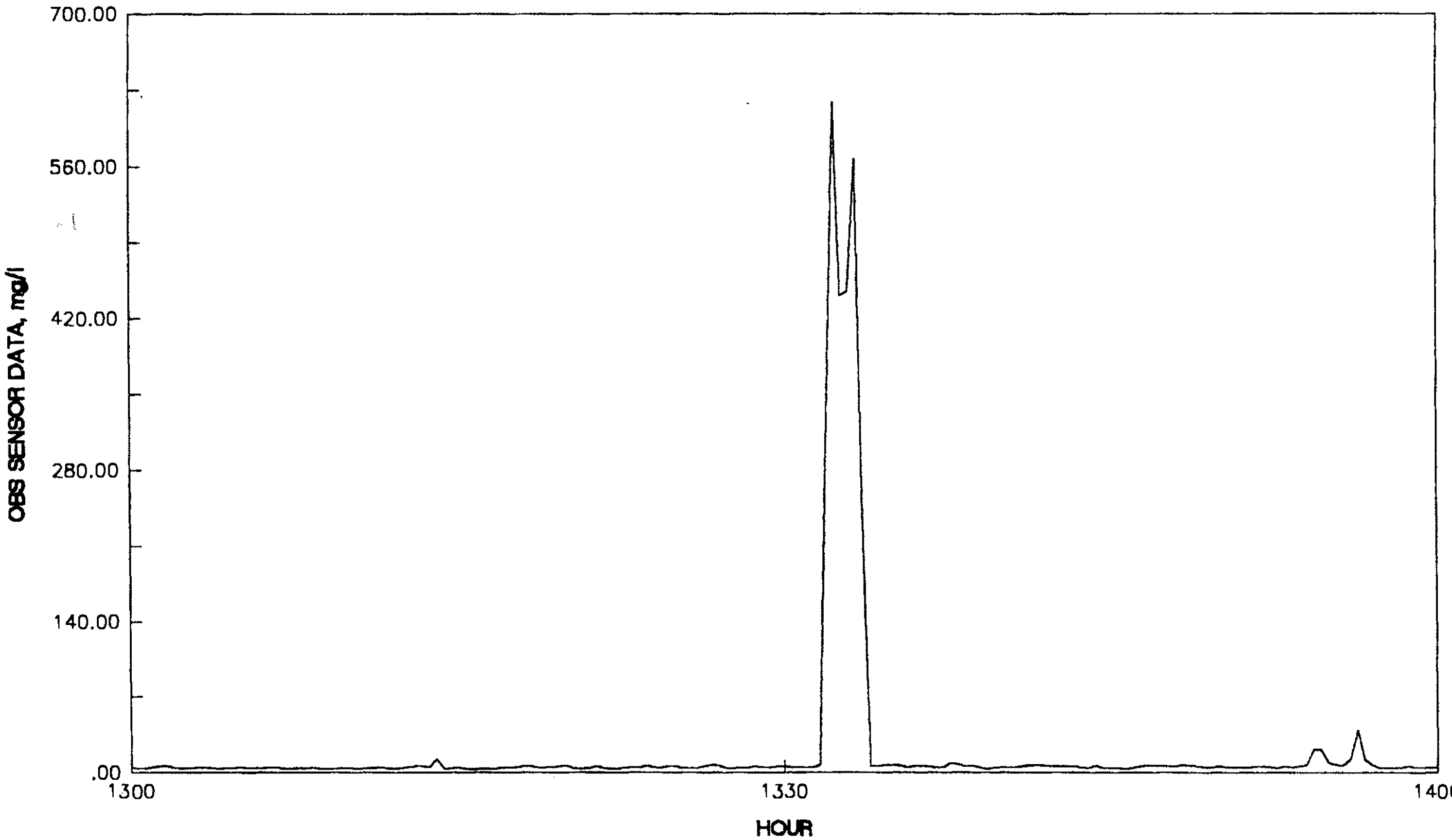
MEAN IS 363.0020 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 2 EMPTY
11/04/95



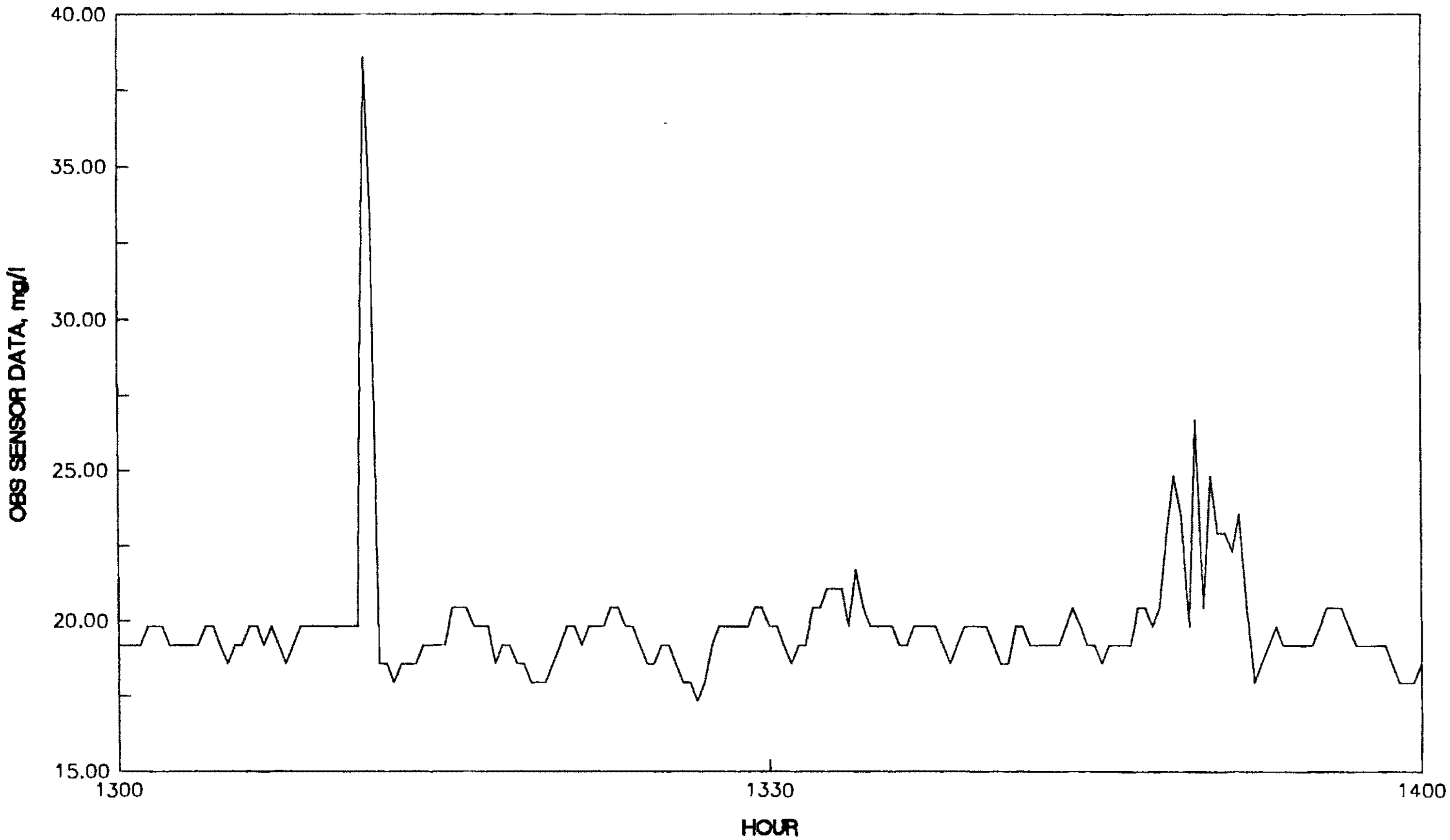
MEAN IS 149.7495 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 3 LOADED
11/05/95



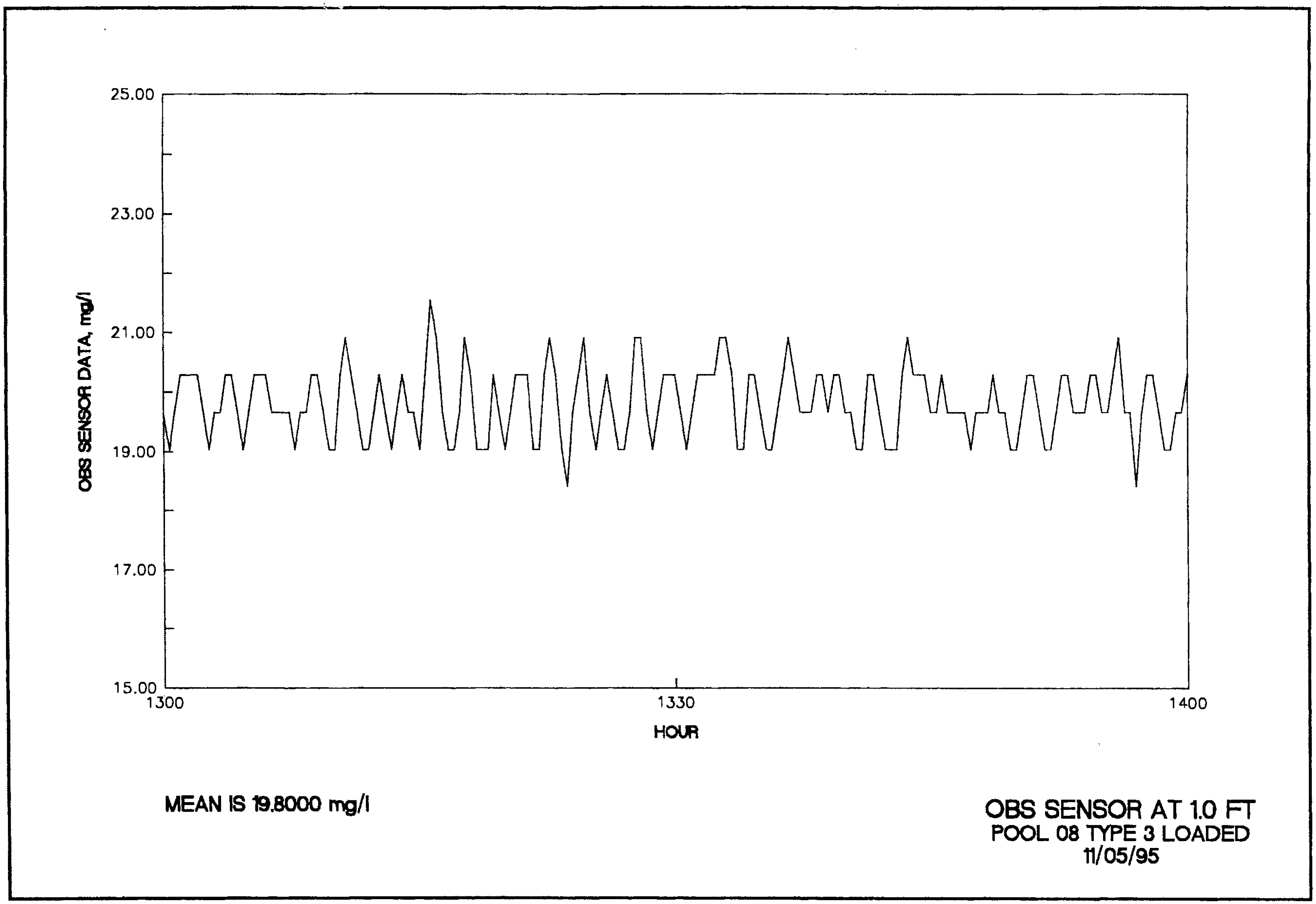
MEAN IS 19.8000 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 3 LOADED
11/05/95

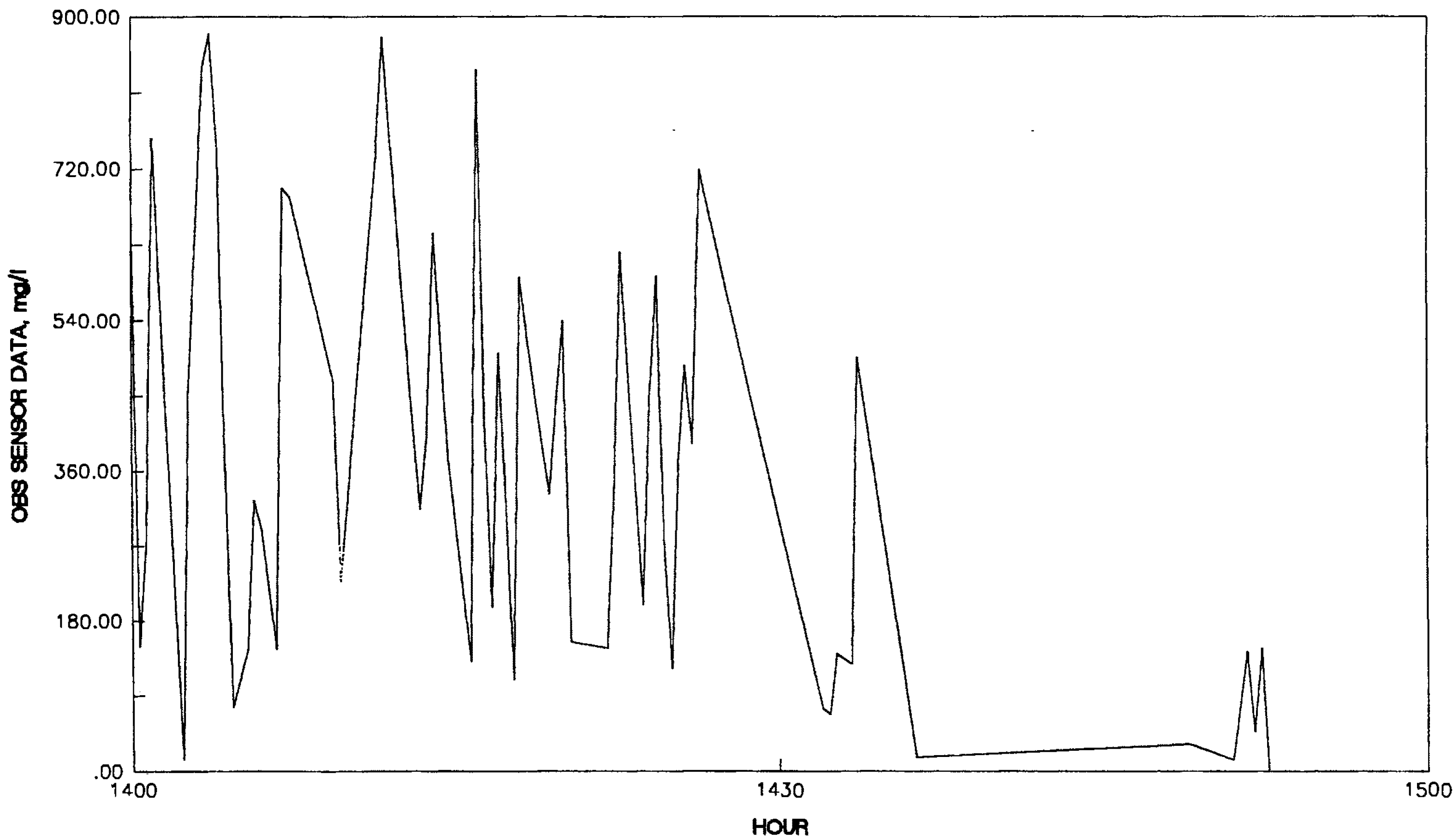


MEAN IS 19.8000 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 3 LOADED
11/05/95

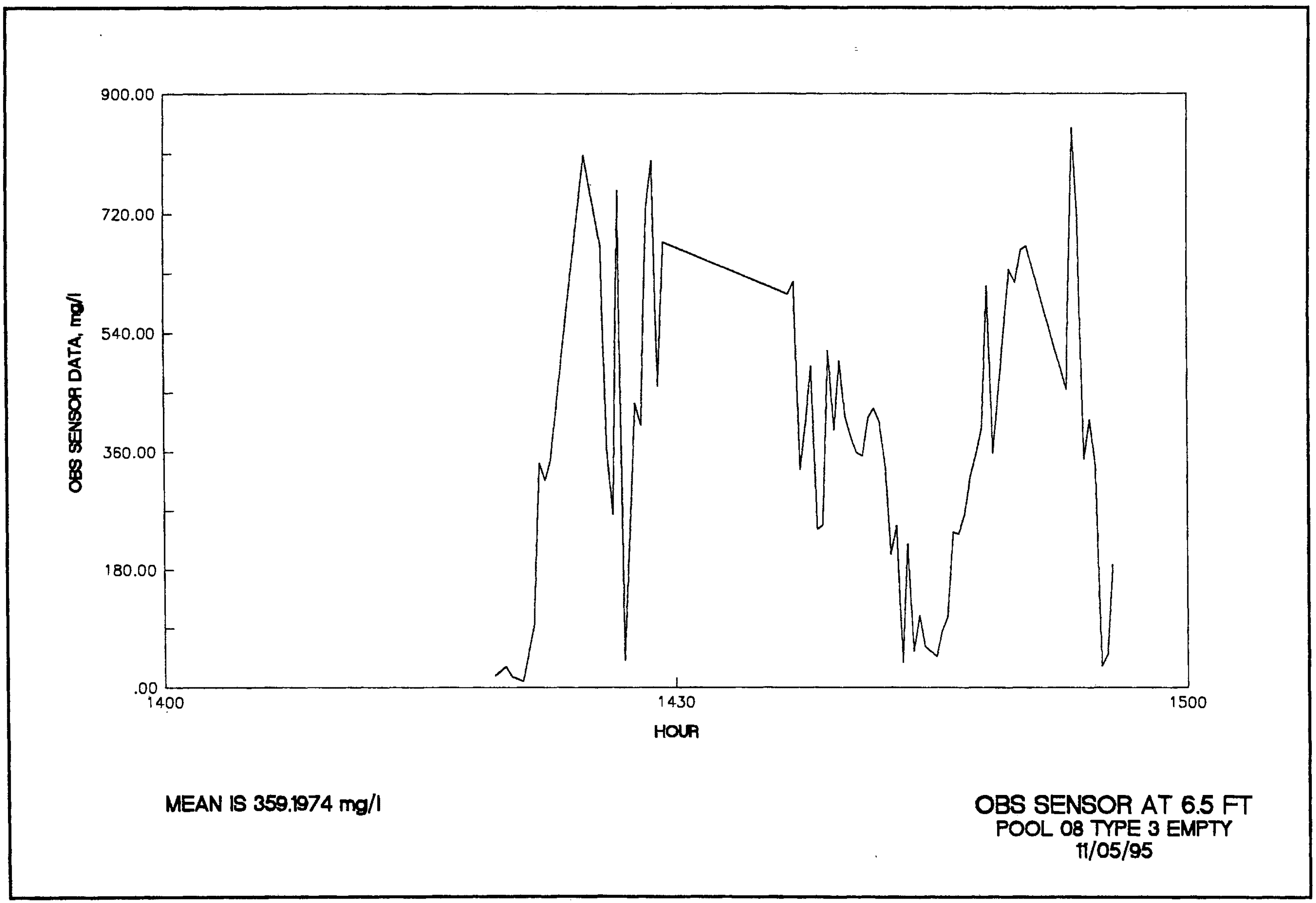


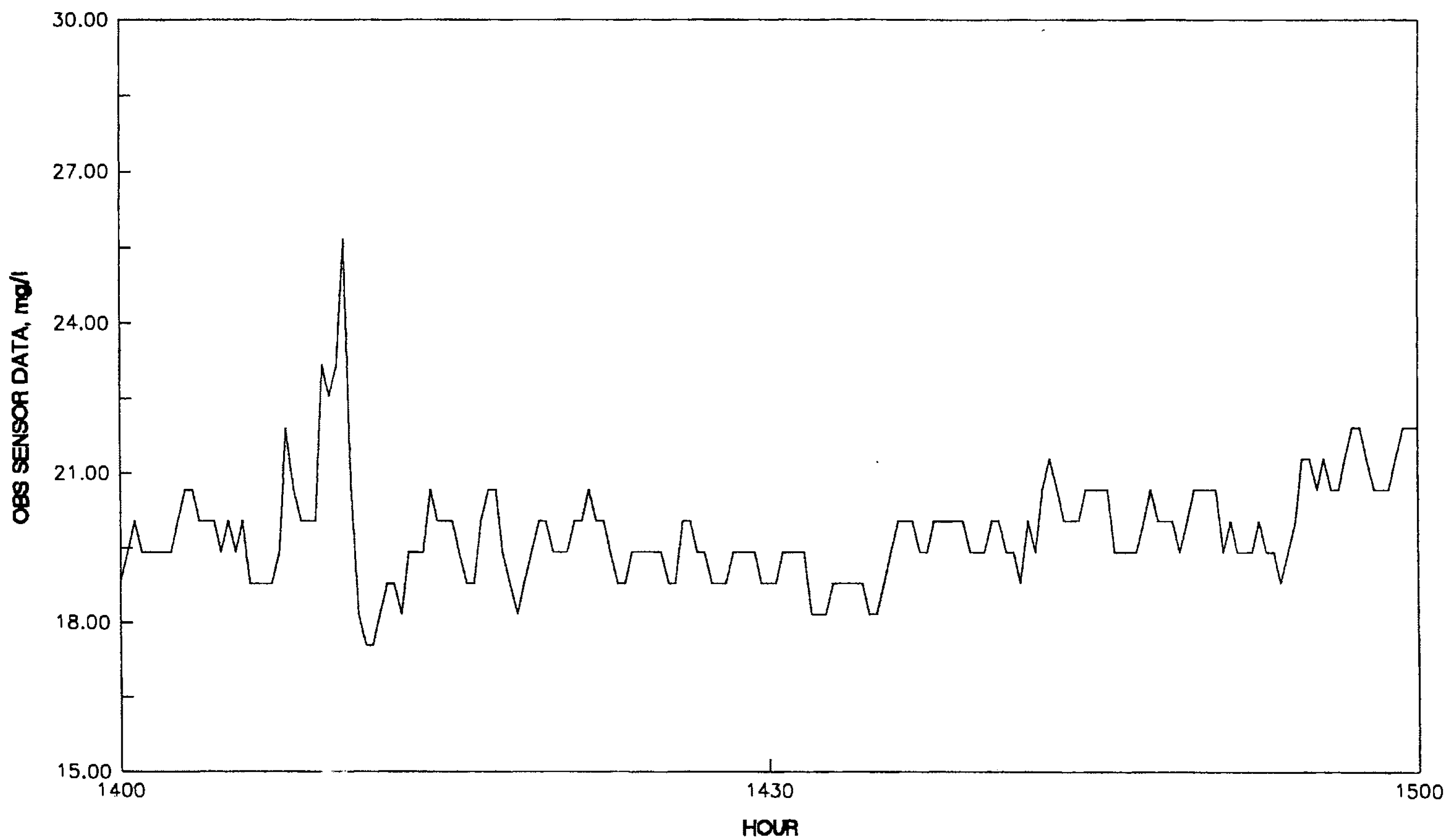
25.00
23.00
21.00
19.00
17.00
15.00
OBS SENSOR DATA, mg/l
1300
1330
1400
HOUR
MEAN IS 19.8000 mg/l
OBS SENSOR AT 1.0 FT
POOL 08 TYPE 3 LOADED
11/05/95



MEAN IS 363.0020 mg/l

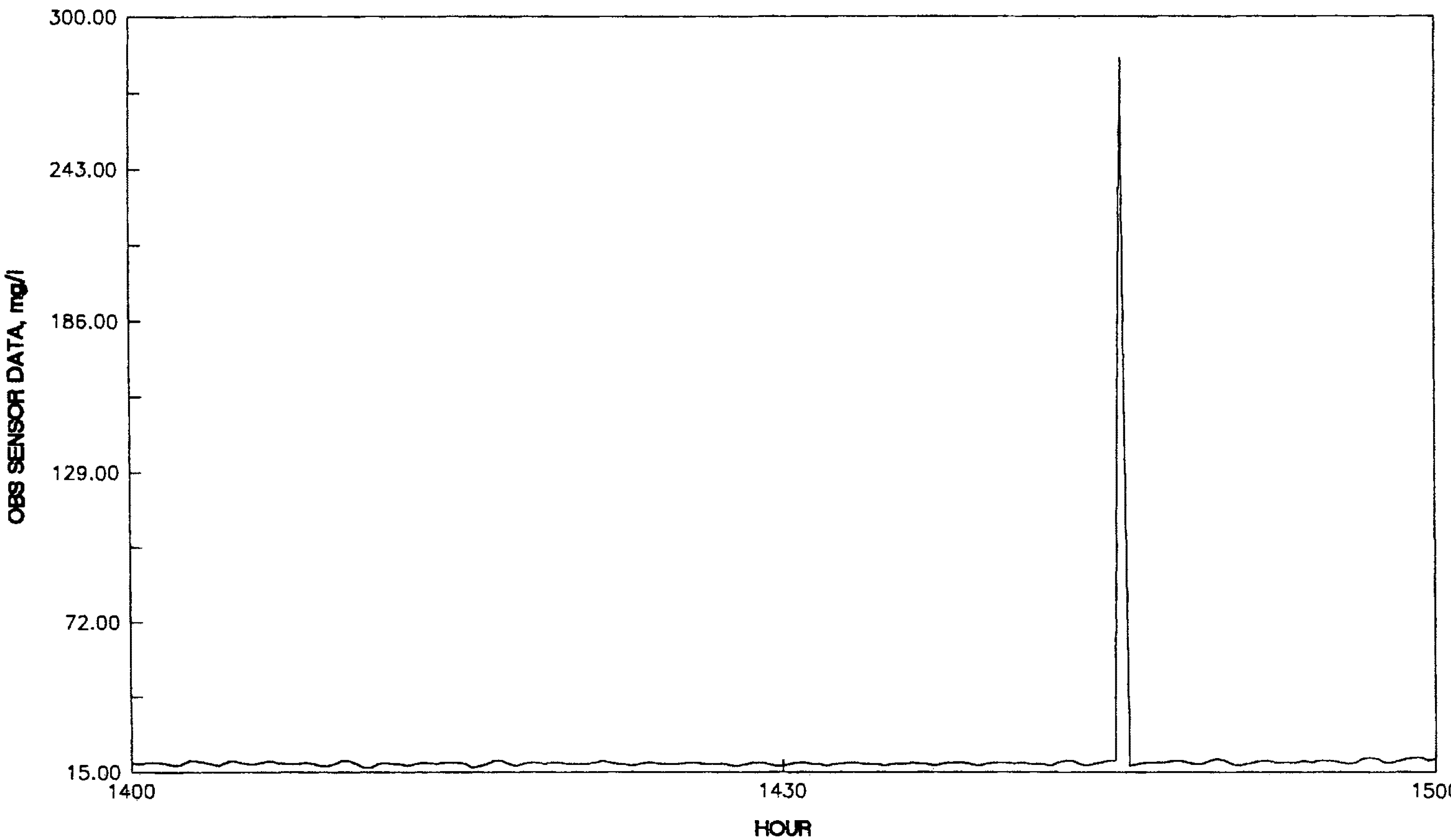
OBS SENSOR AT 7.5 FT
POOL 08 TYPE 3 EMPTY
11/05/95


900.00
720.00
540.00
360.00
180.00
.00
OBS SENSOR DATA, mg/l
1400
1430
1500
HOUR
MEAN IS 359.1974 mg/l
OBS SENSOR AT 6.5 FT
POOL 08 TYPE 3 EMPTY
11/05/95



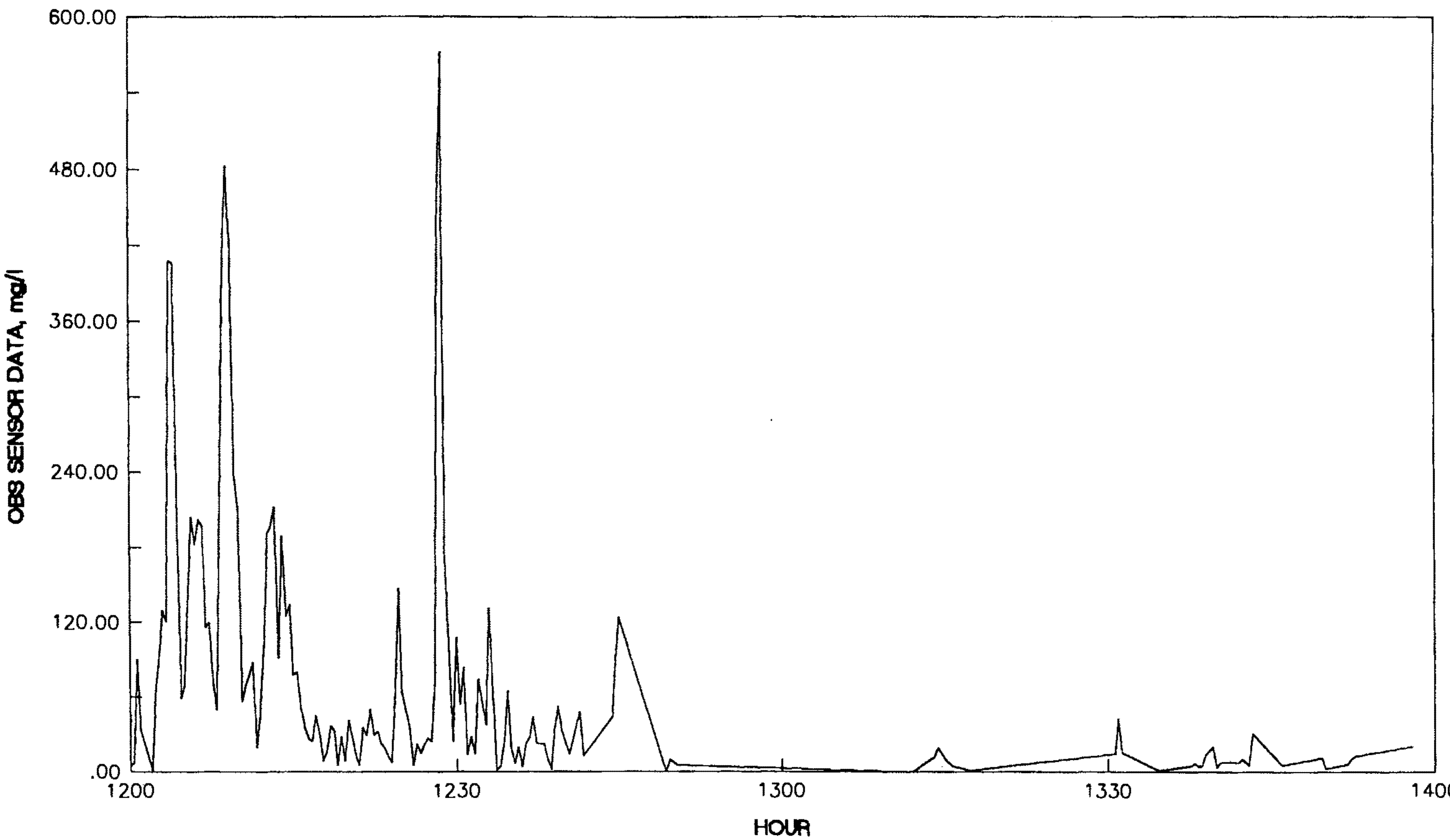
MEAN IS 19.8000 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 3 EMPTY
11/05/95



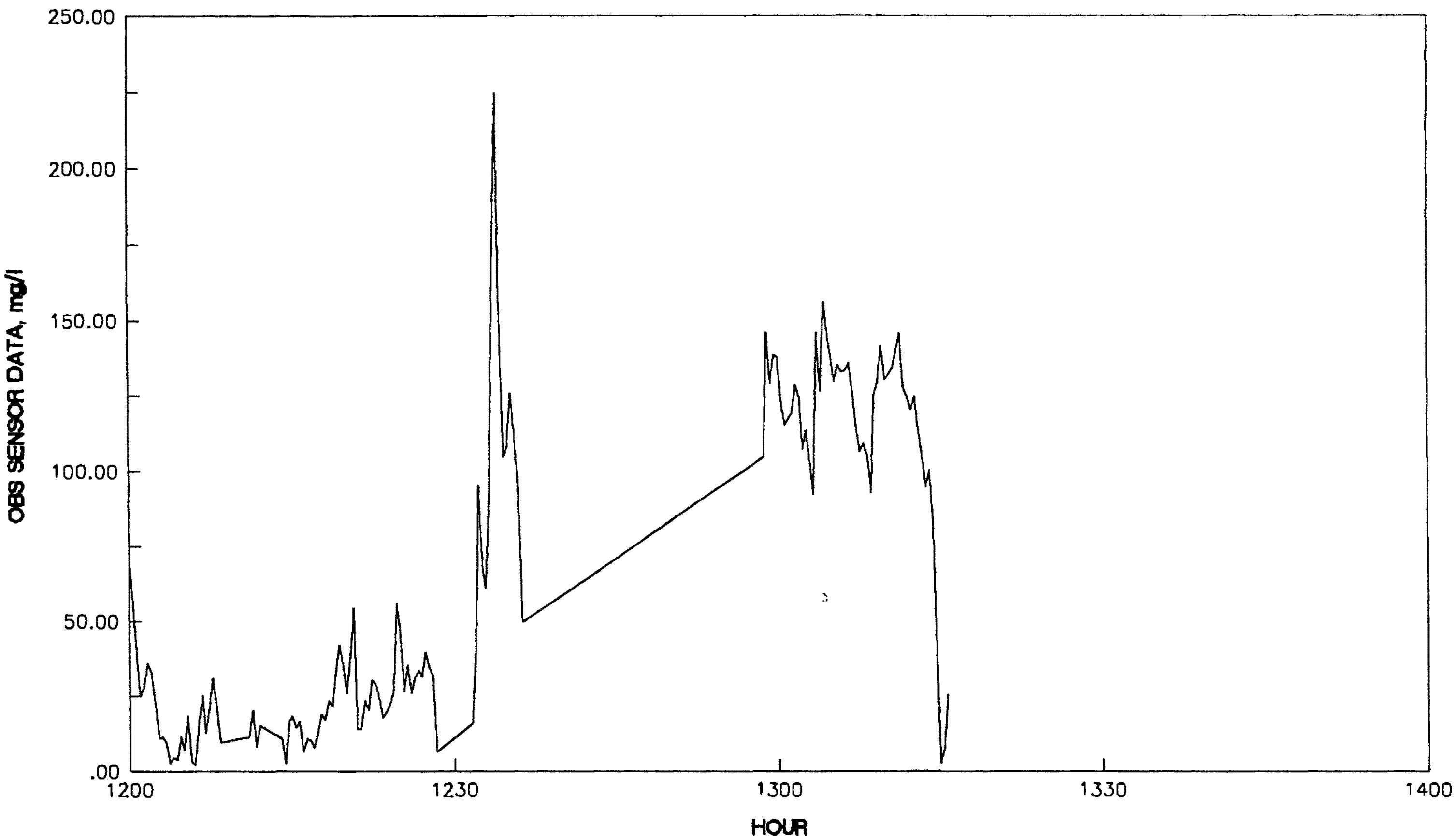
MEAN IS 19.8000 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 3 EMPTY
11/05/95



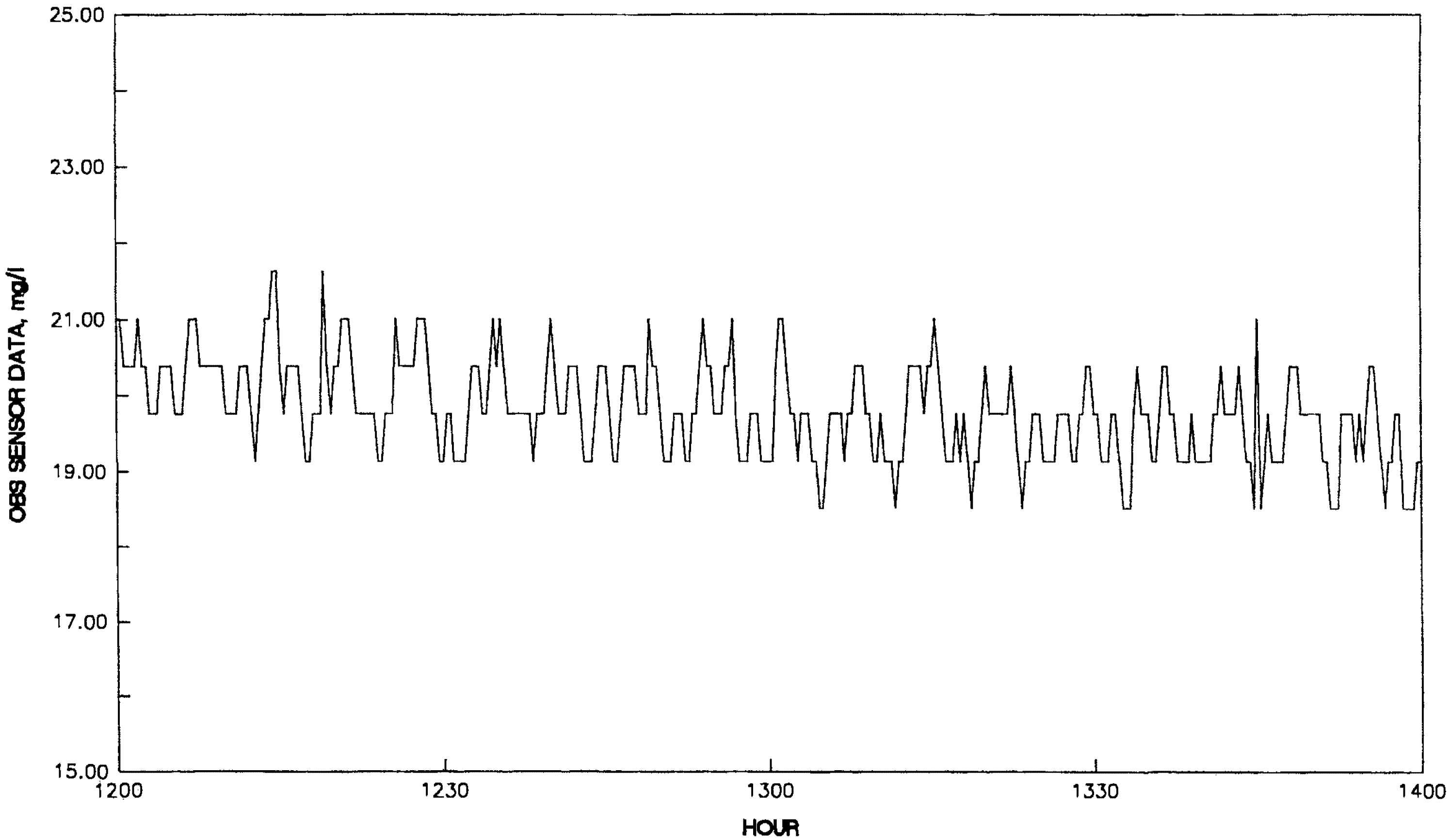
MEAN IS 68.7835 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 4 LOADED
11/04/95



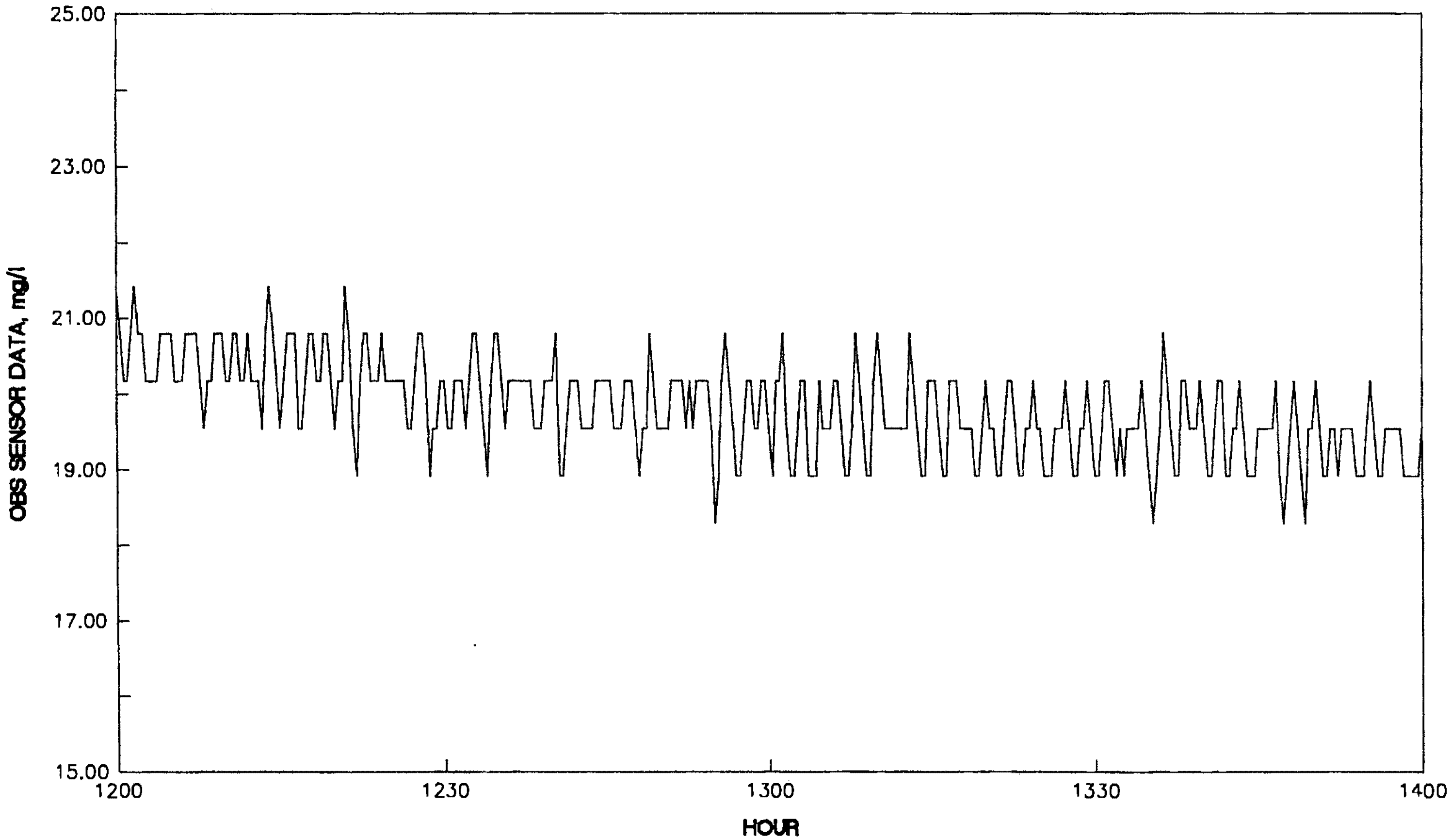
MEAN IS 64.4158 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 4 LOADED
11/04/95



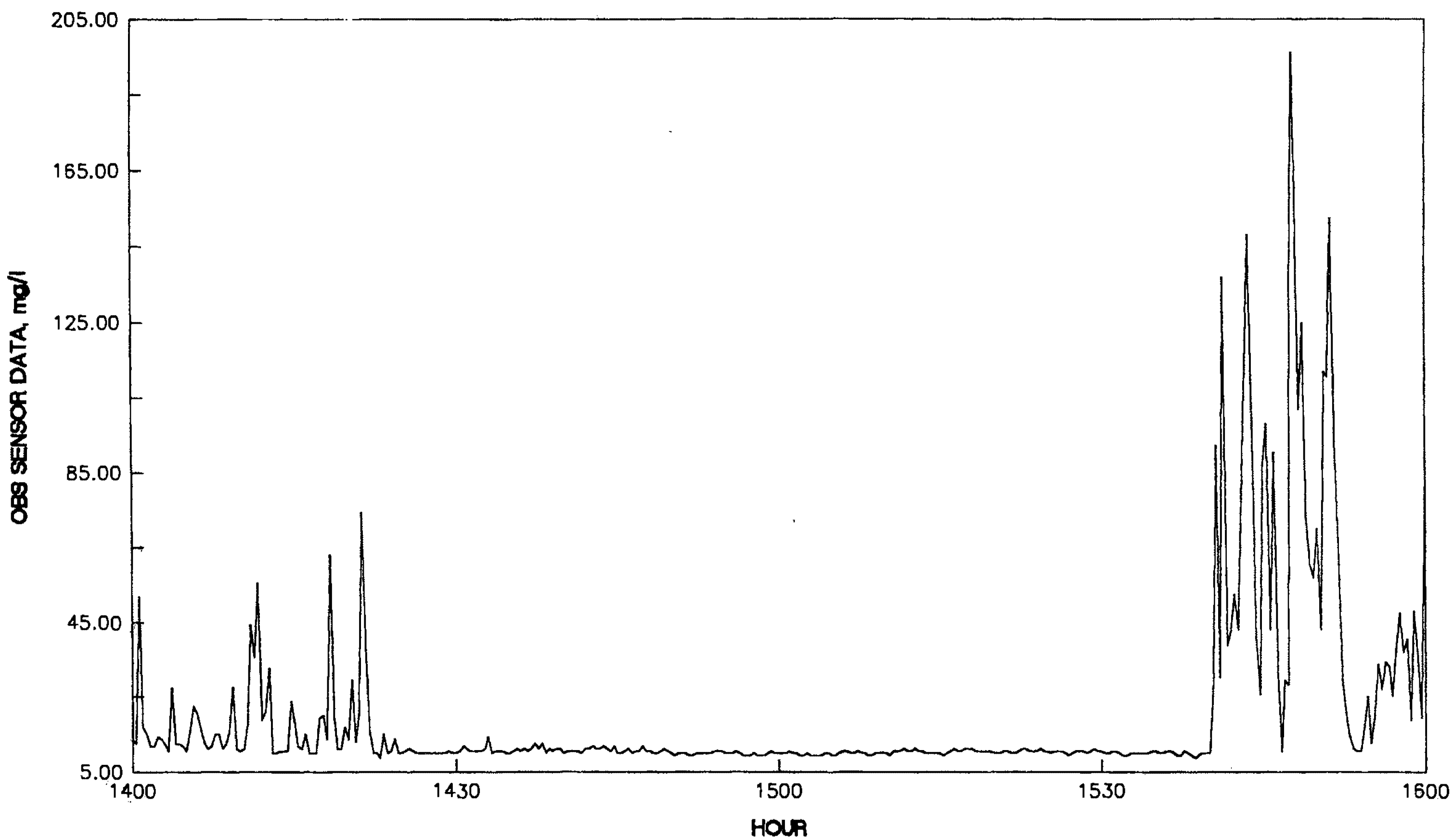
MEAN IS 19.8000 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 4 LOADED
11/04/95



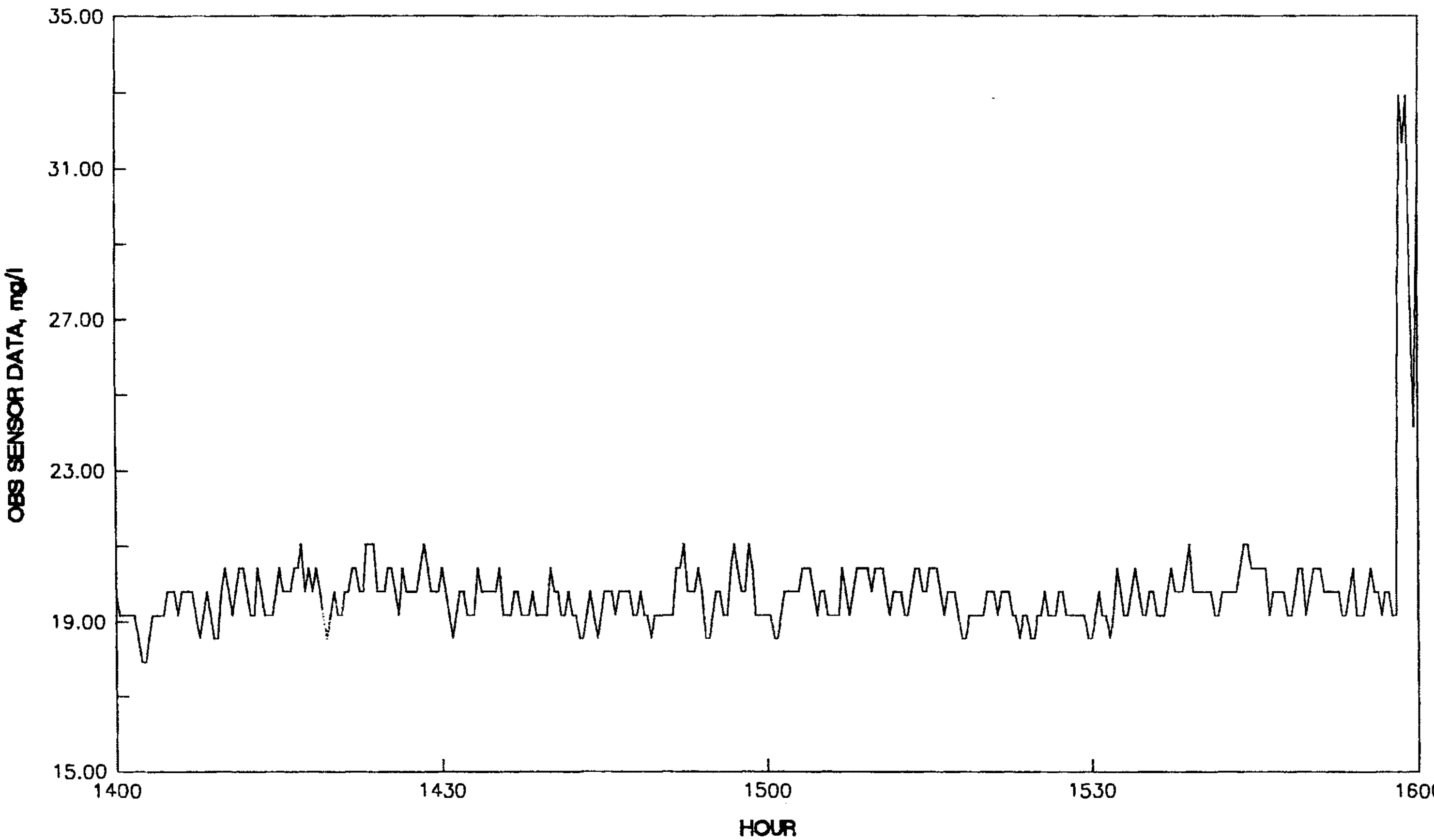
MEAN IS 19.8000 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 4 LOADED
11/04/95



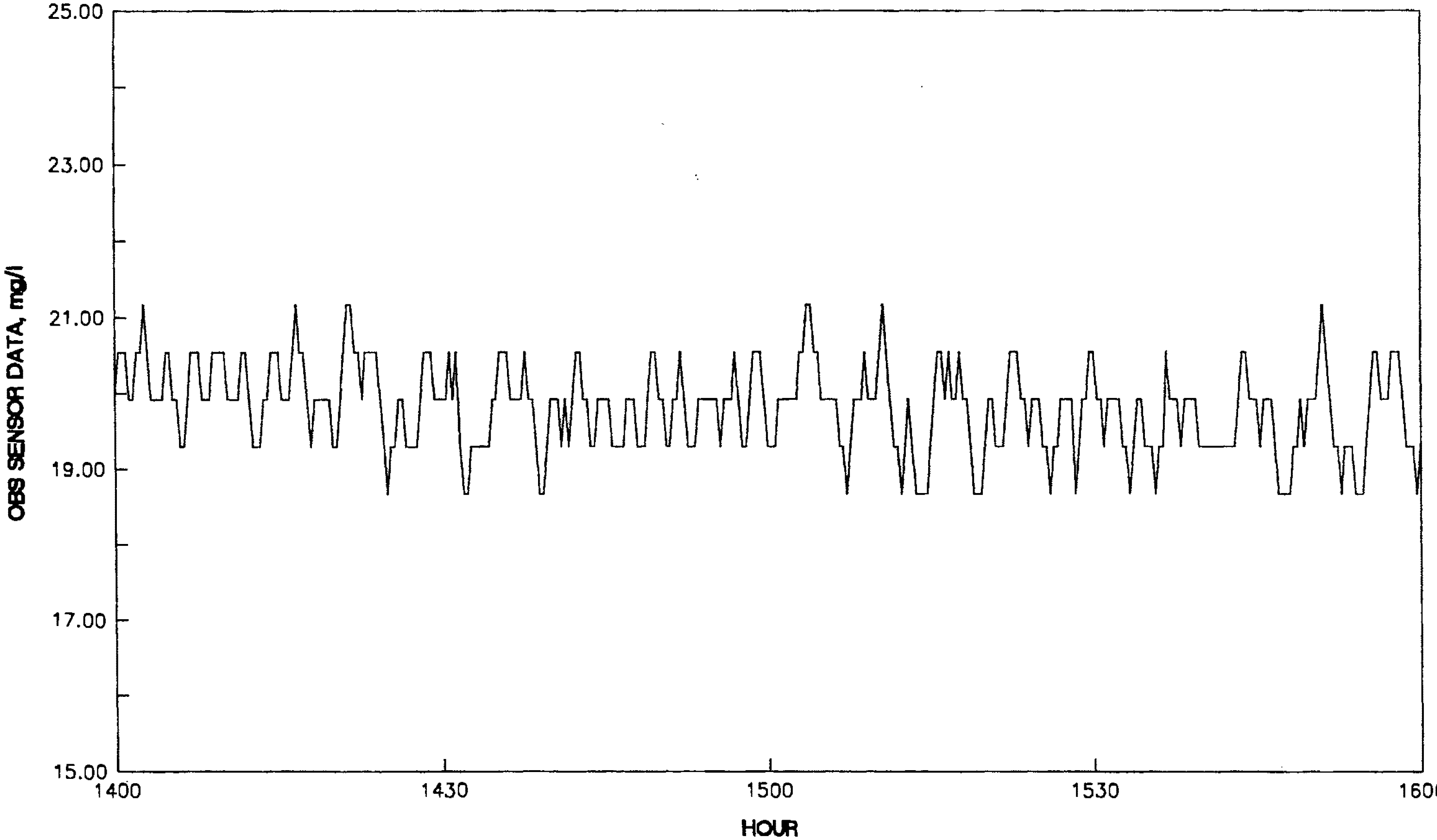
MEAN IS 19.8001 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 4 EMPTY
11/04/95



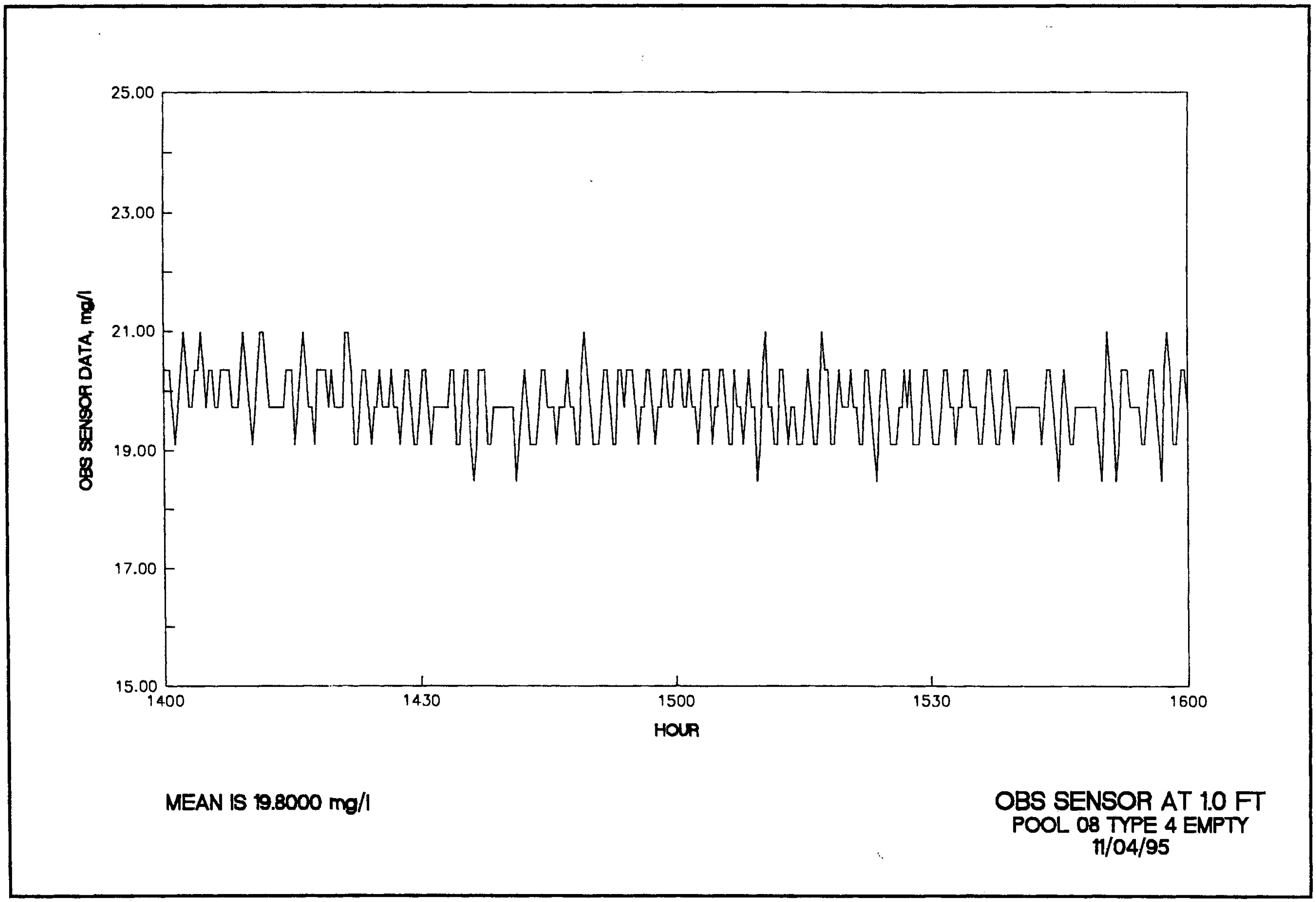
MEAN IS 19.7999 mg/l

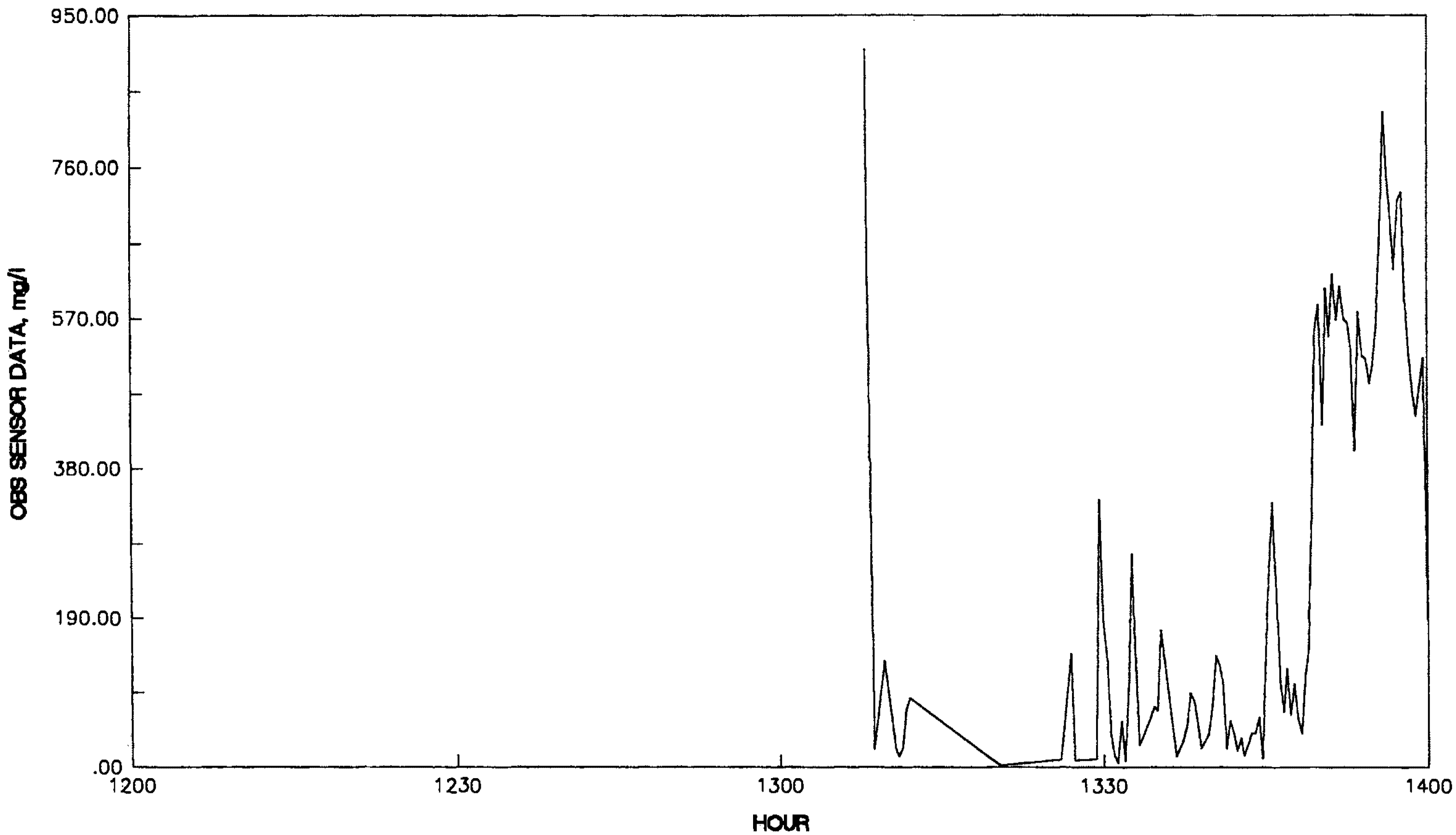
OBS SENSOR AT 6.5 FT
POOL 08 TYPE 4 EMPTY
11/04/95



MEAN IS 19.8000 mg/l

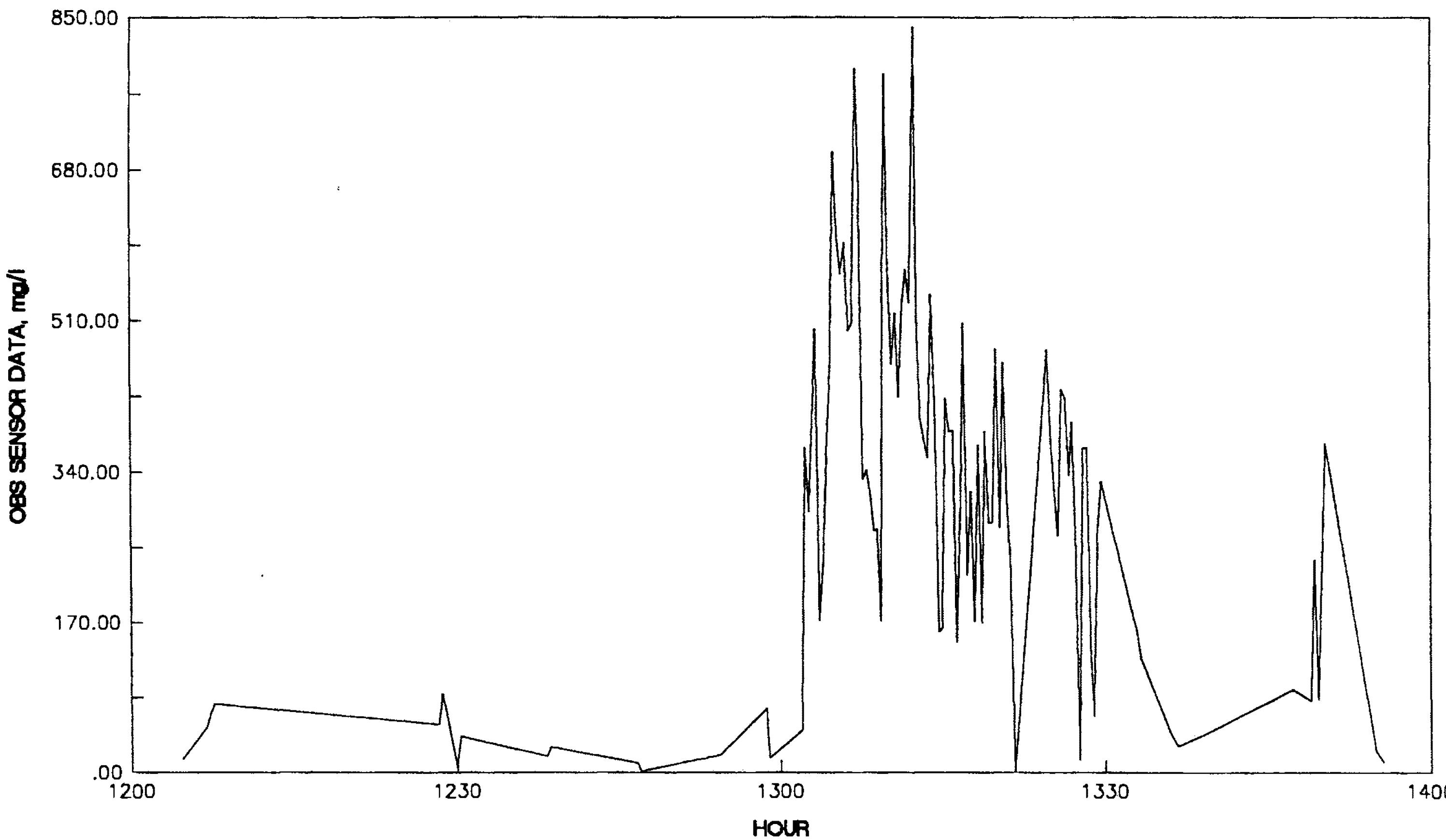
OBS SENSOR AT 3.0 FT
POOL 08 TYPE 4 EMPTY
11/04/95


25.00
23.00
21.00
19.00
17.00
15.00
OBS SENSOR DATA, mg/l
1400
1430
1500
1530
1600
HOUR
MEAN IS 19.8000 mg/l
OBS SENSOR AT 1.0 FT
POOL 08 TYPE 4 EMPTY
11/04/95



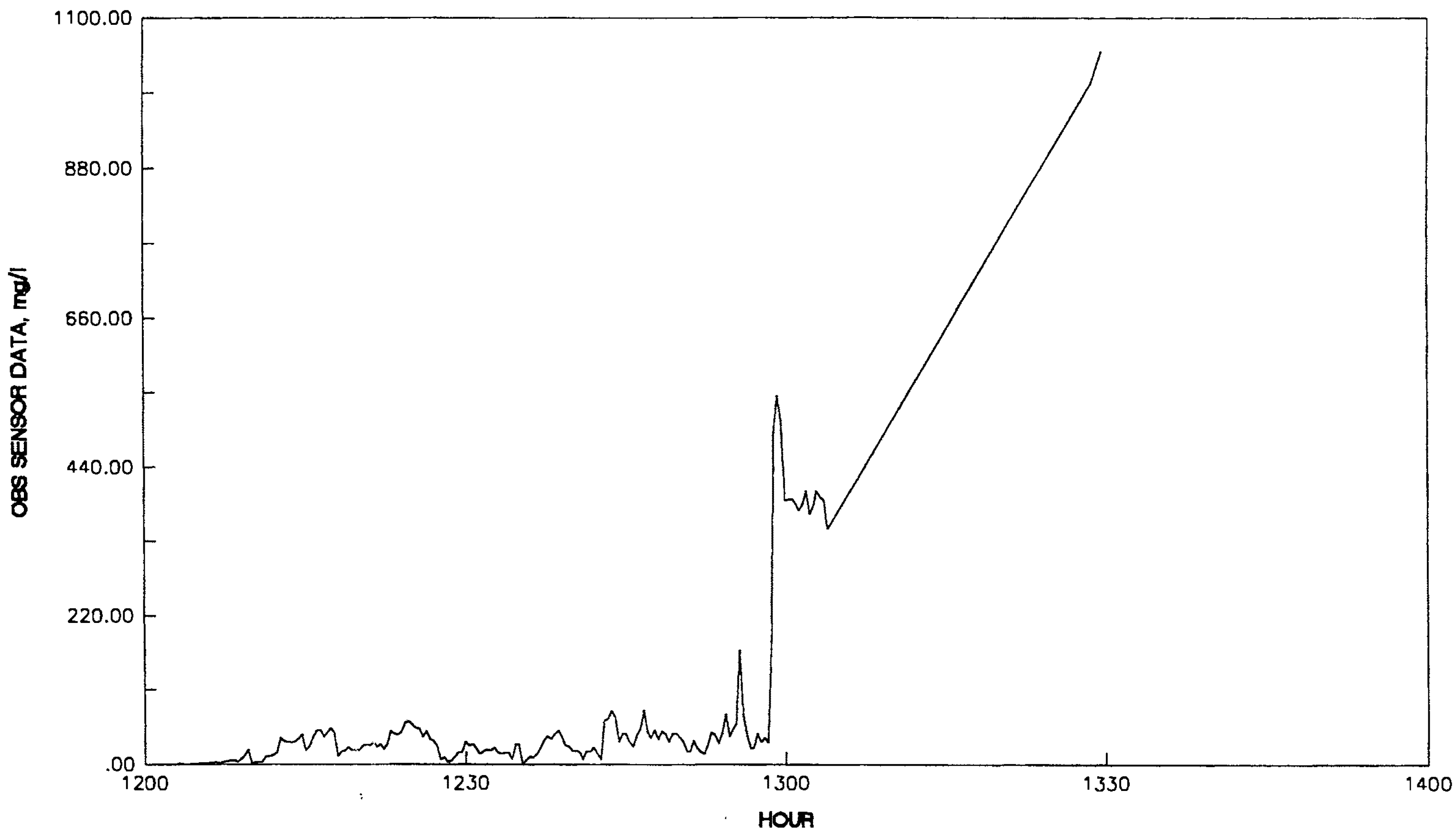
MEAN IS 250.2891 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 5 LOADED
11/06/95



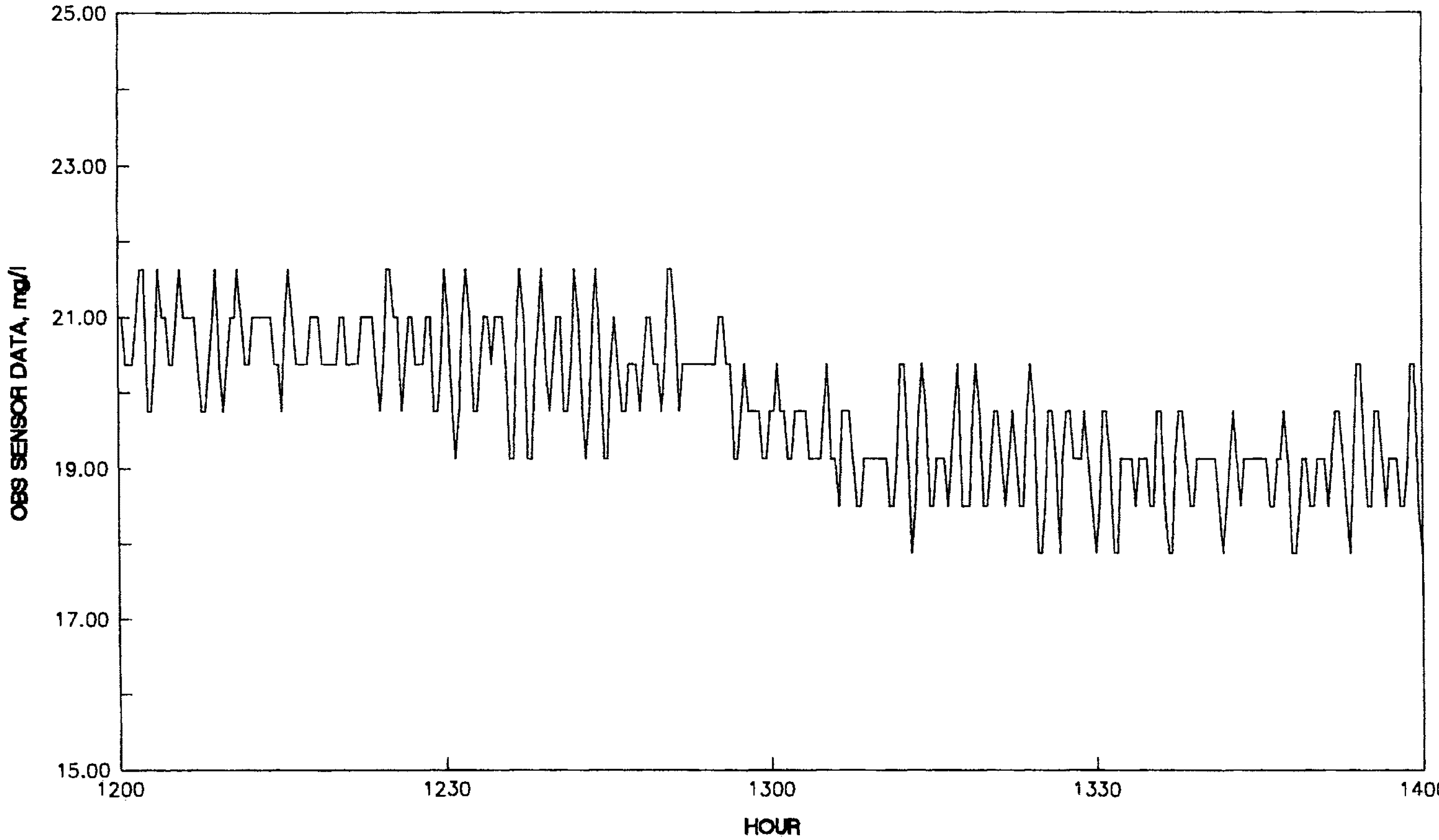
MEAN IS 294.6763 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 5 LOADED
11/06/95



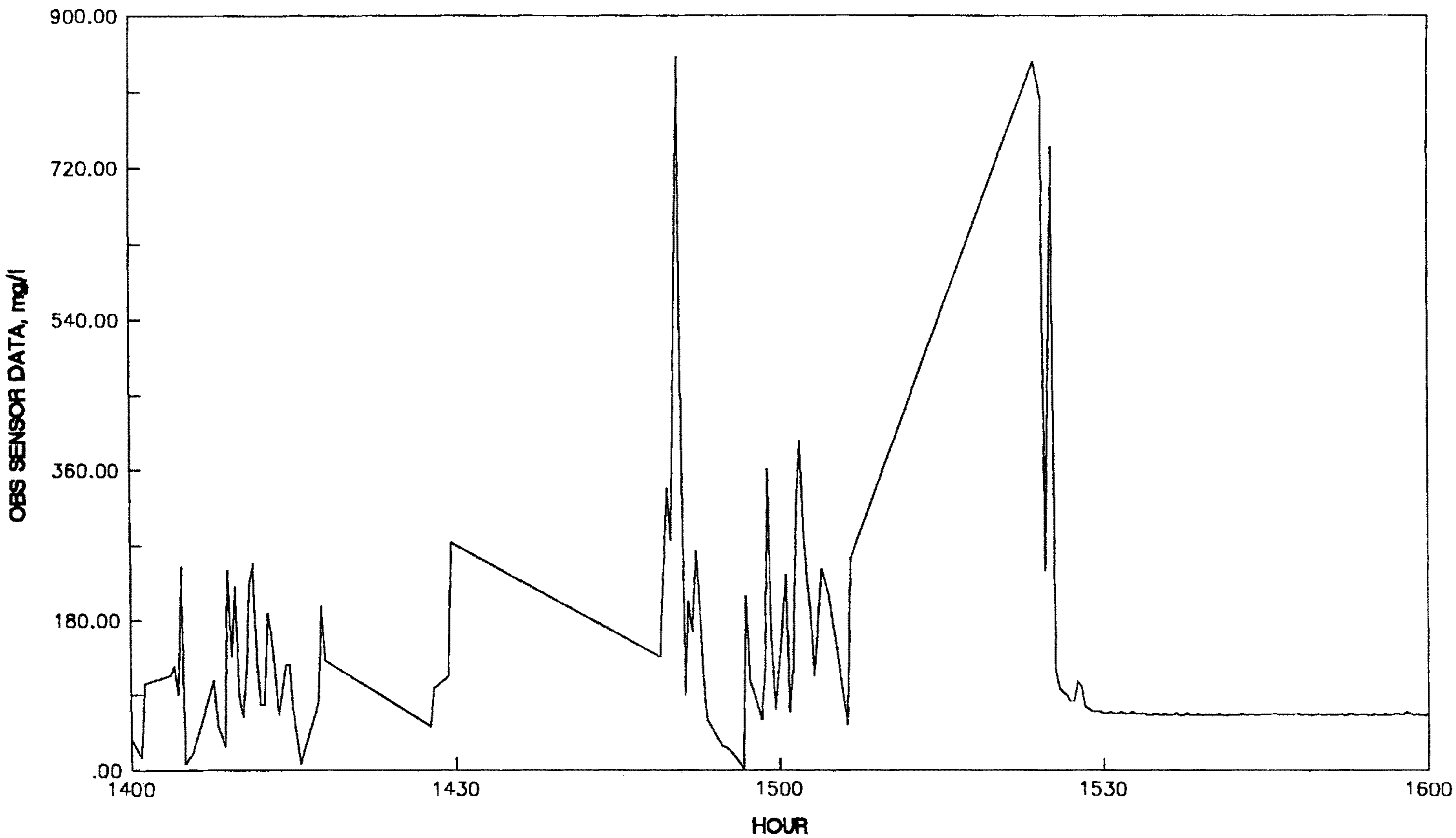
MEAN IS 79.1392 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 5 LOADED
11/06/95



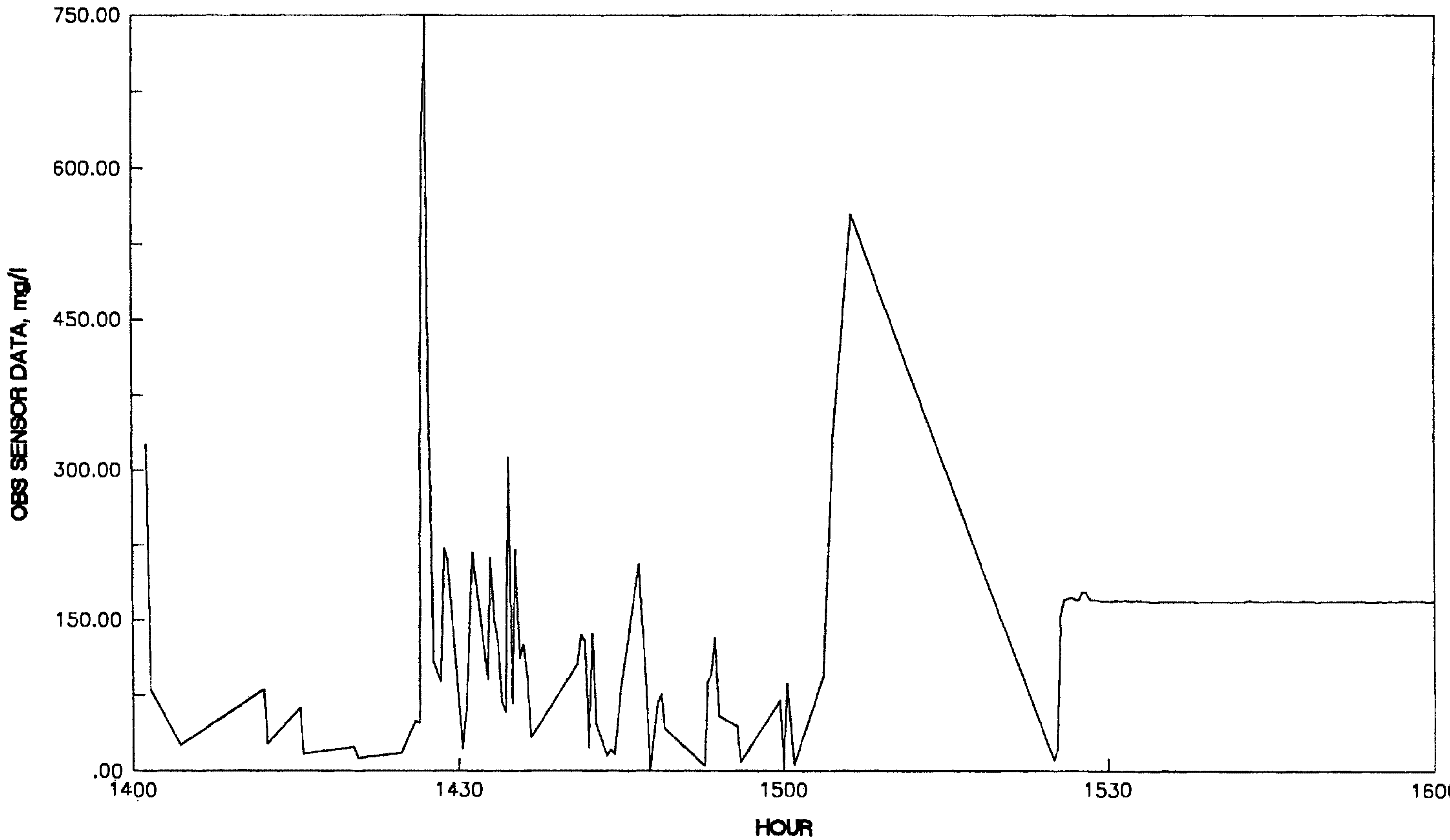
MEAN IS 19.7999 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 5 LOADED
11/06/95



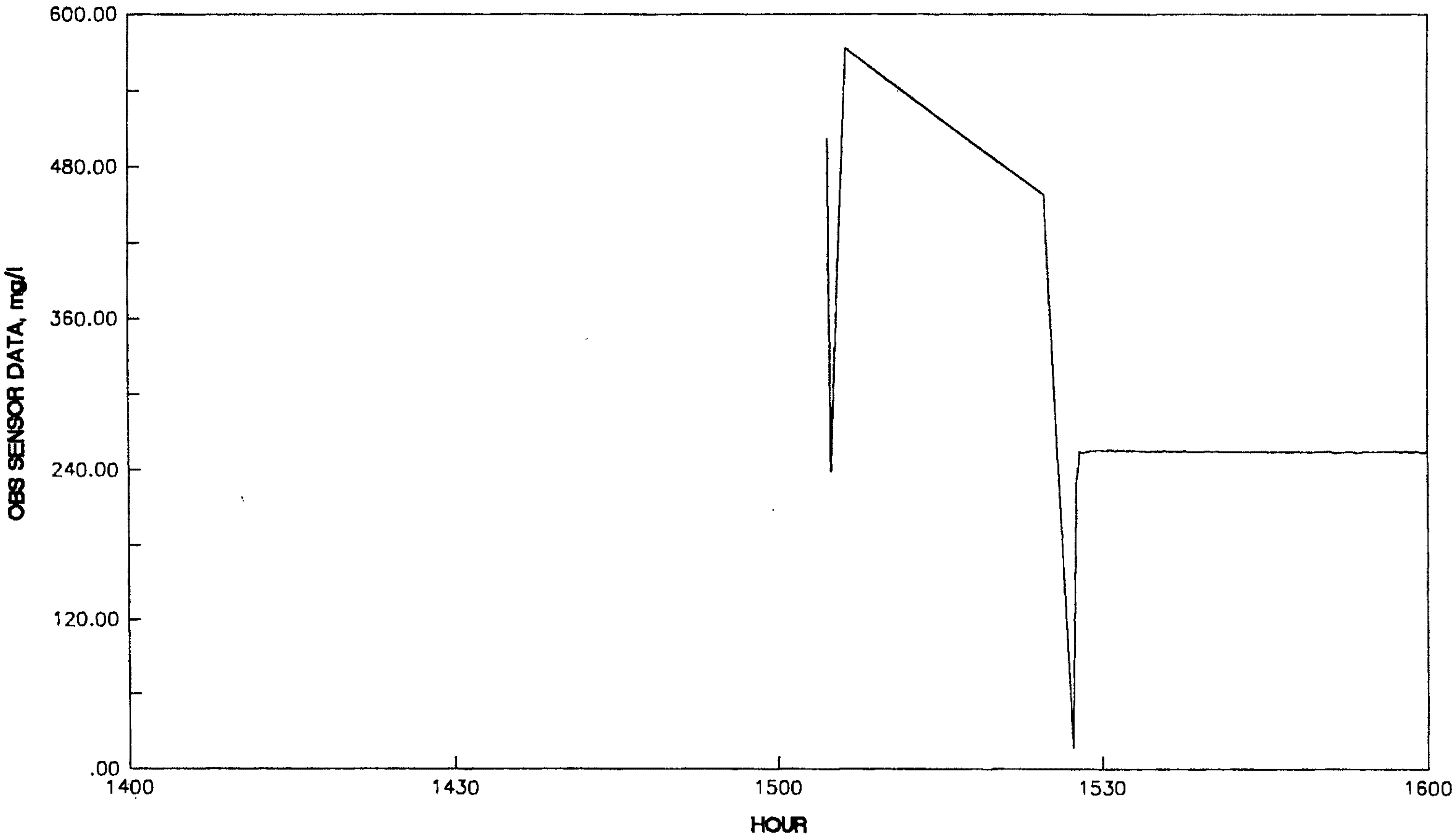
MEAN IS 118.5462 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 5 EMPTY
11/06/95



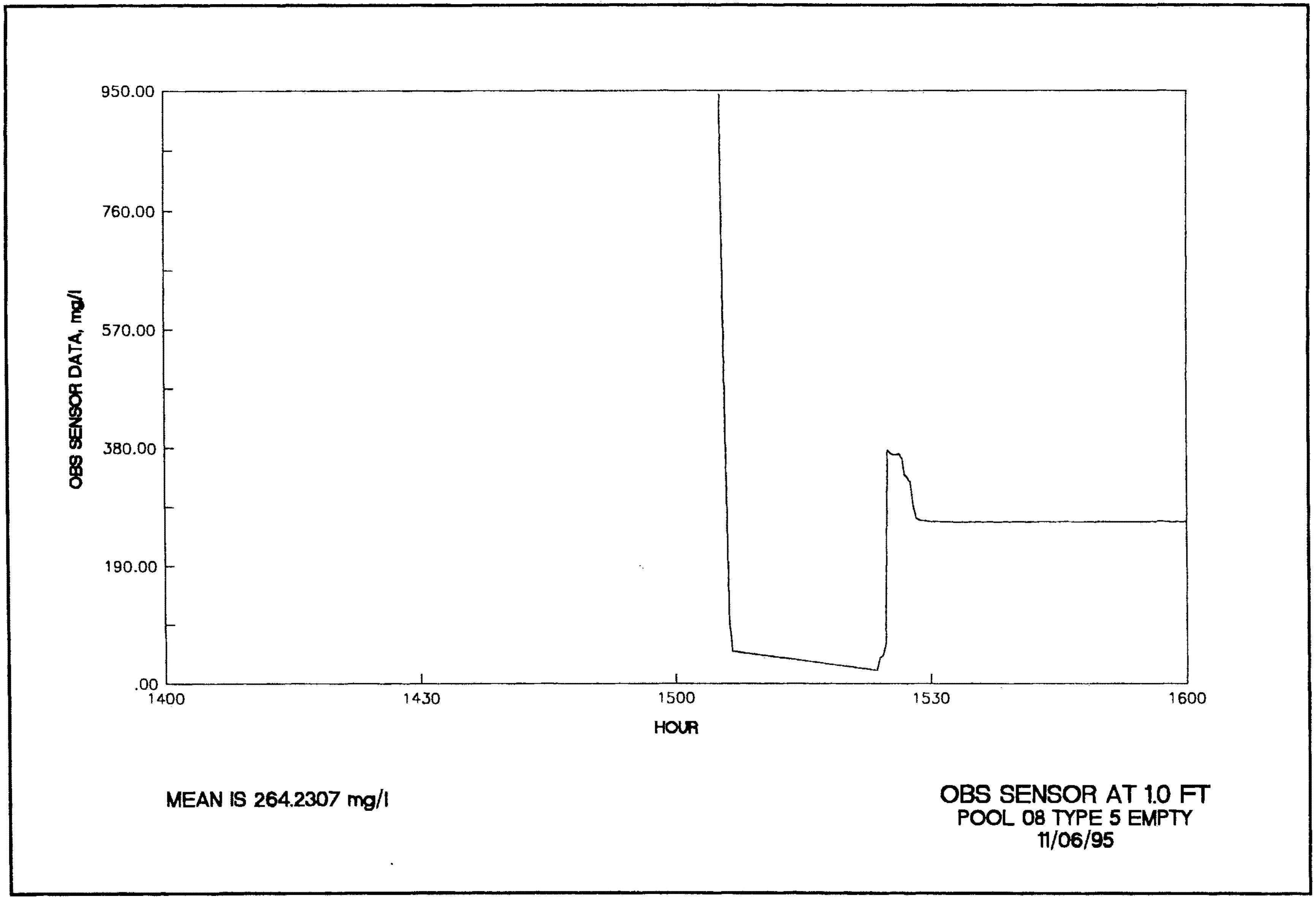
MEAN IS 149.3376 mg/l

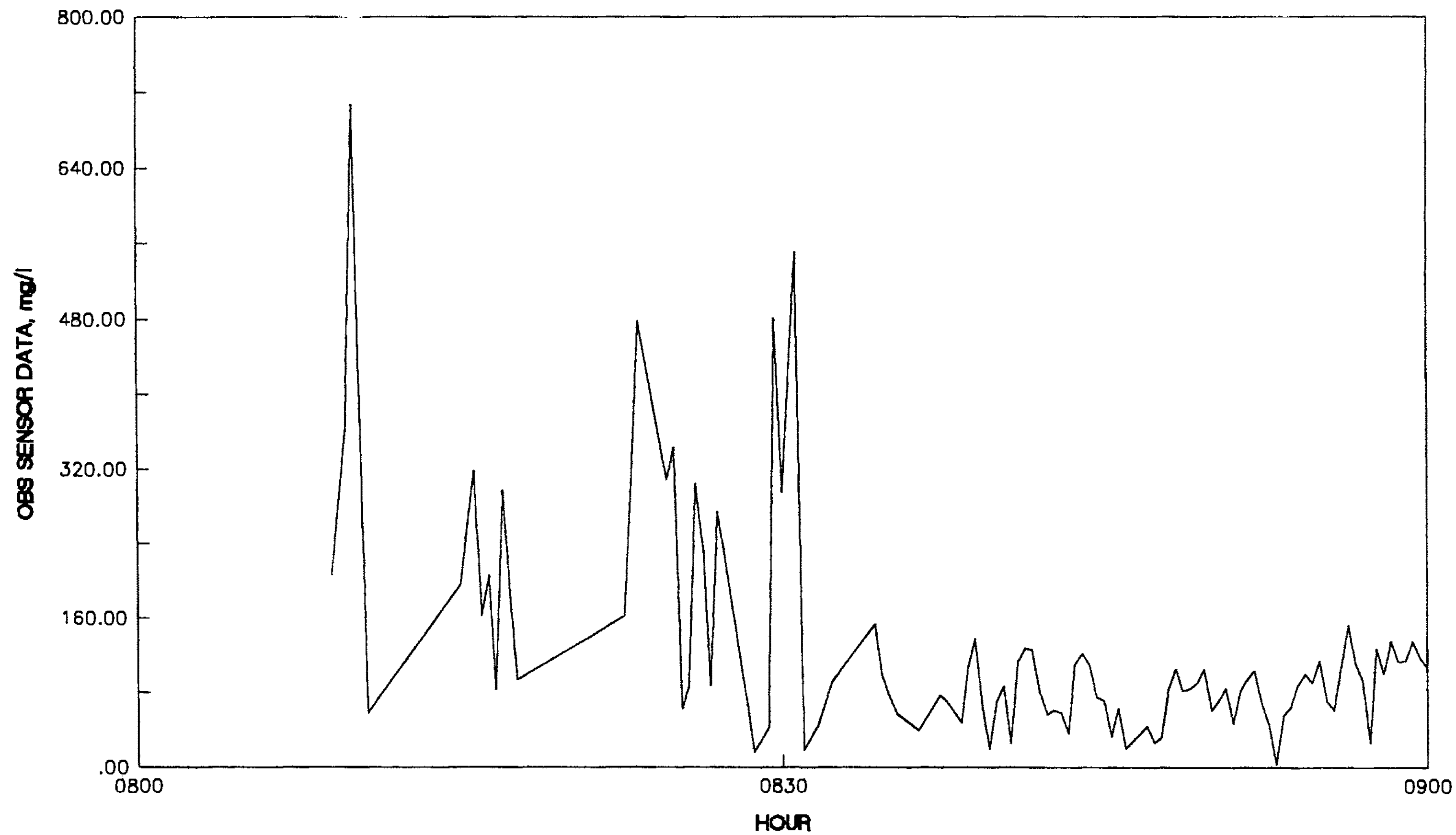
OBS SENSOR AT 6.5 FT
POOL 08 TYPE 5 EMPTY
11/06/95



MEAN IS 259.1649 mg/l

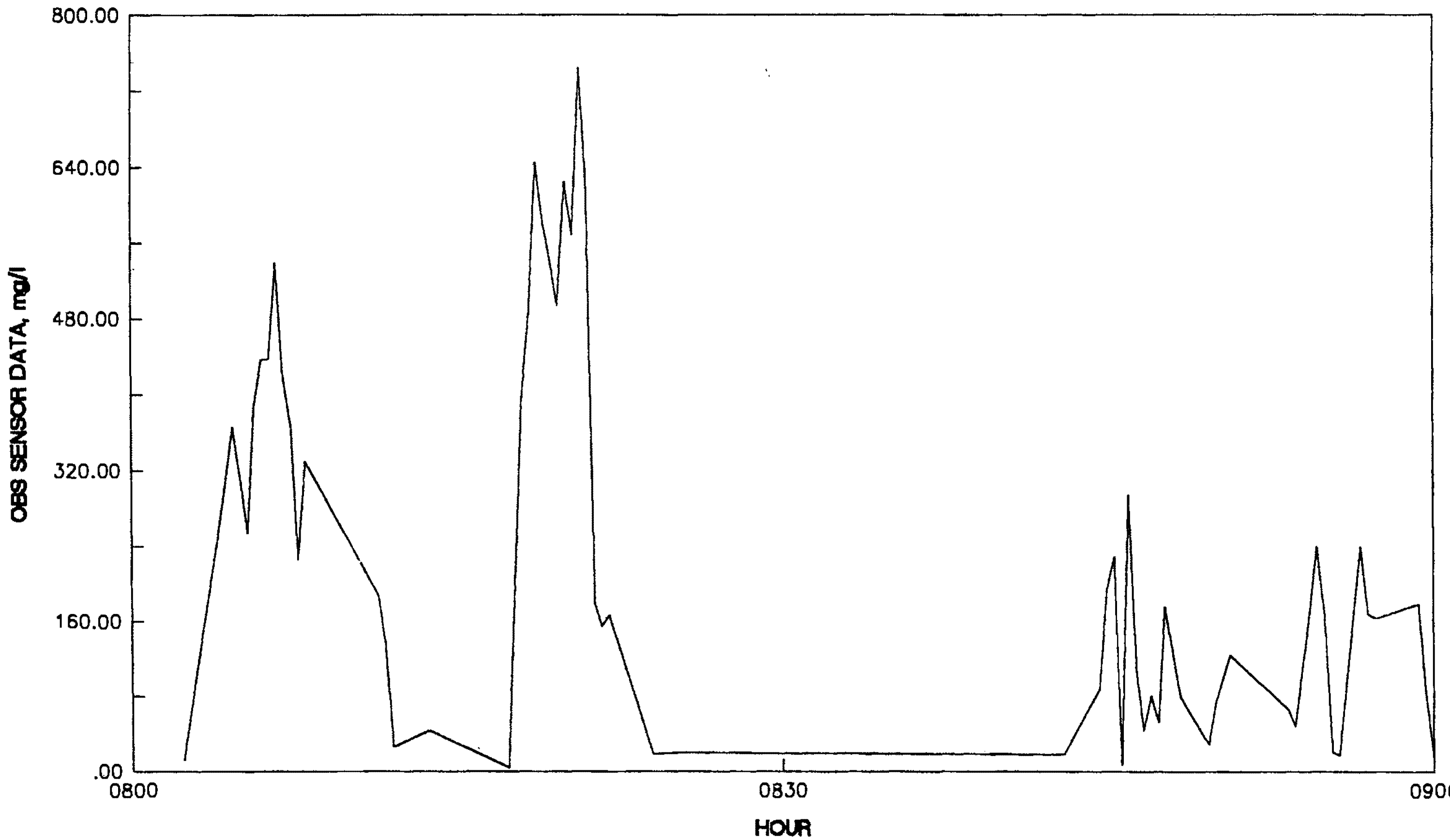
OBS SENSOR AT 3.0 FT
POOL 08 TYPE 5 EMPTY
11/06/95


950.00
760.00
570.00
380.00
190.00
.00
OBS SENSOR DATA, mg/l
1400
1430
1500
1530
1600
HOUR
MEAN IS 264.2307 mg/l
OBS SENSOR AT 1.0 FT
POOL 08 TYPE 5 EMPTY
11/06/95



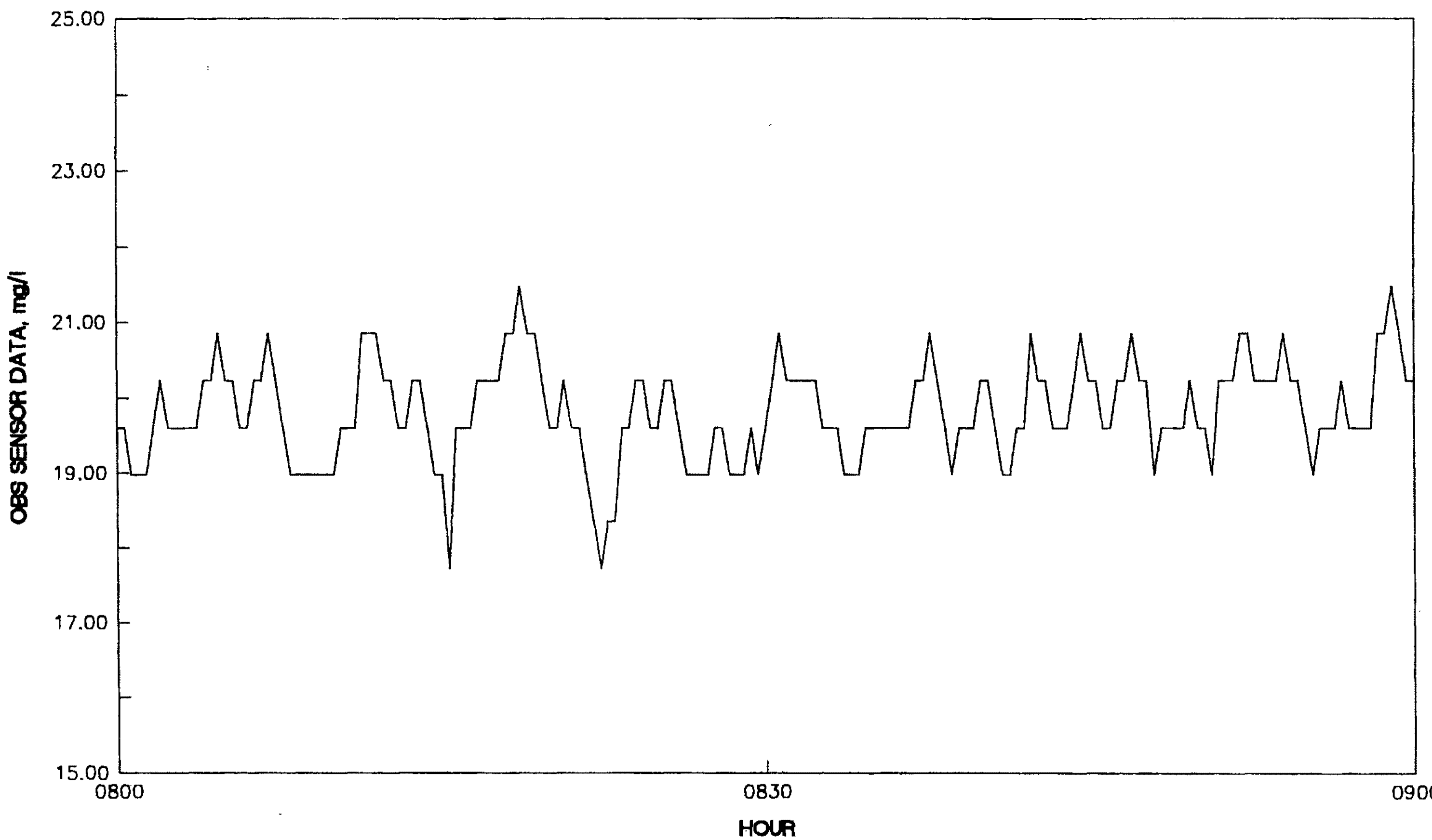
MEAN IS 127.1217 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 6 EMPTY
11/05/95



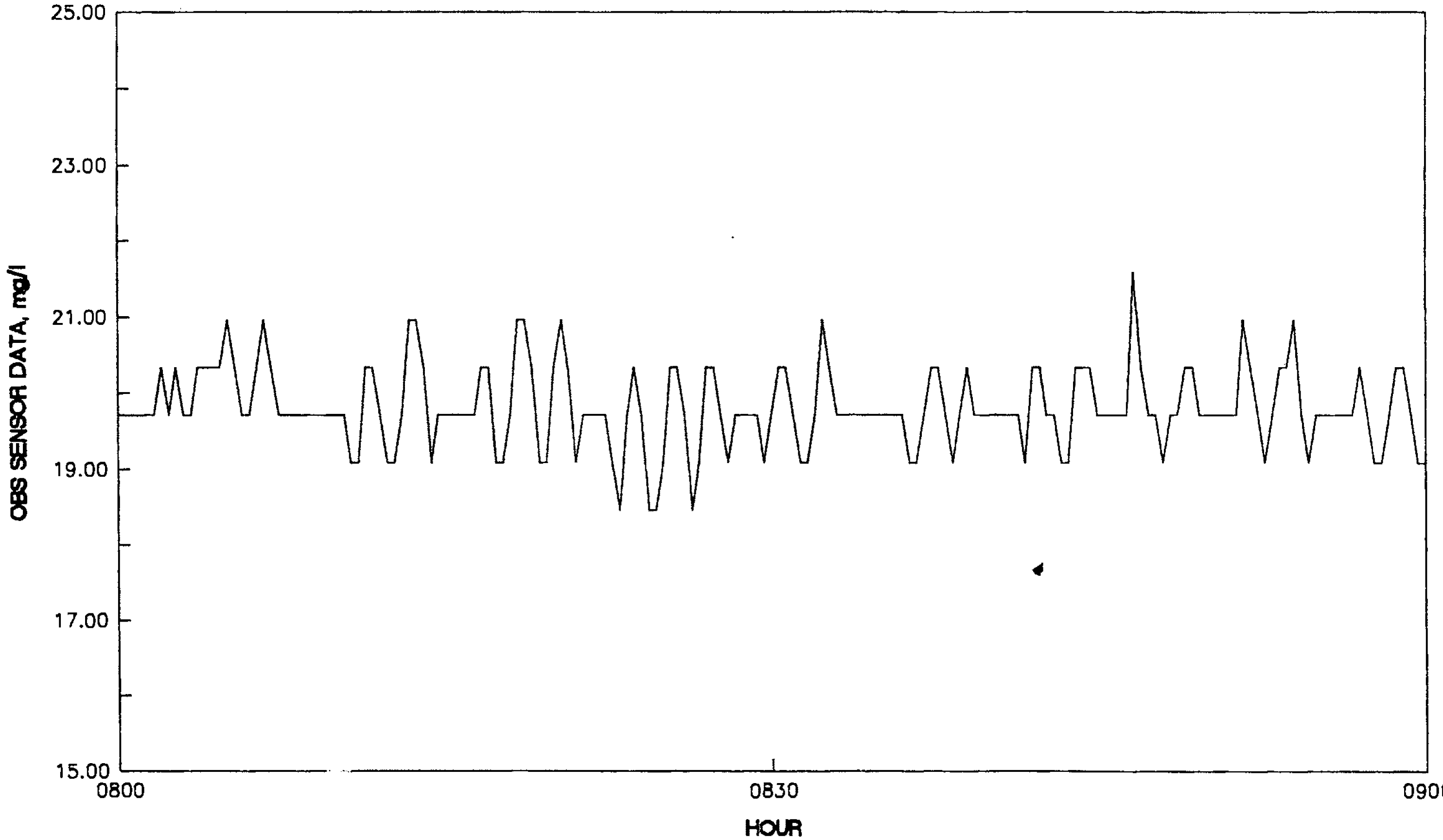
MEAN IS 231.3988 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 6 EMPTY
11/06/95



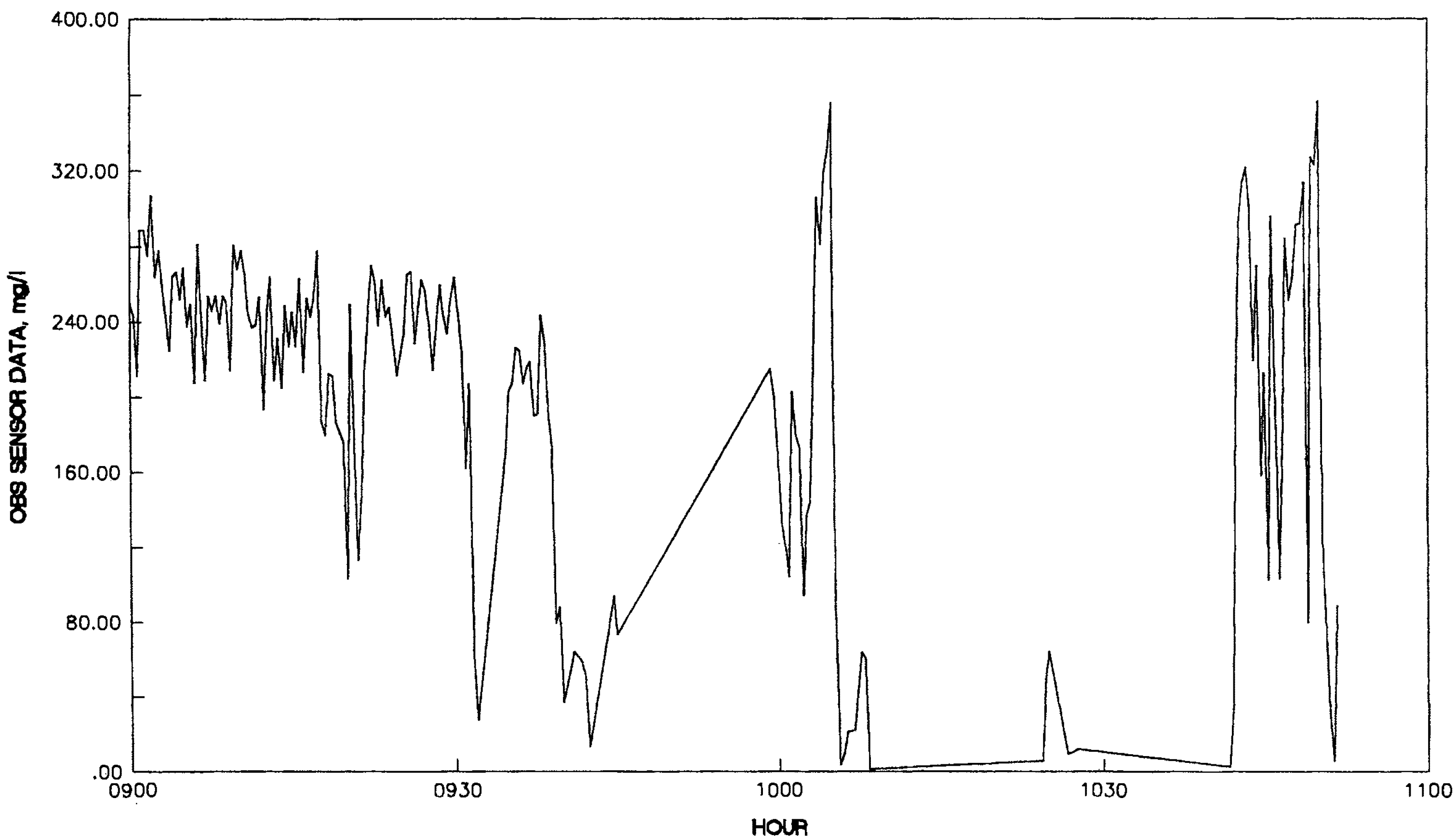
MEAN IS 19.8000 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 6 EMPTY
11/06/95



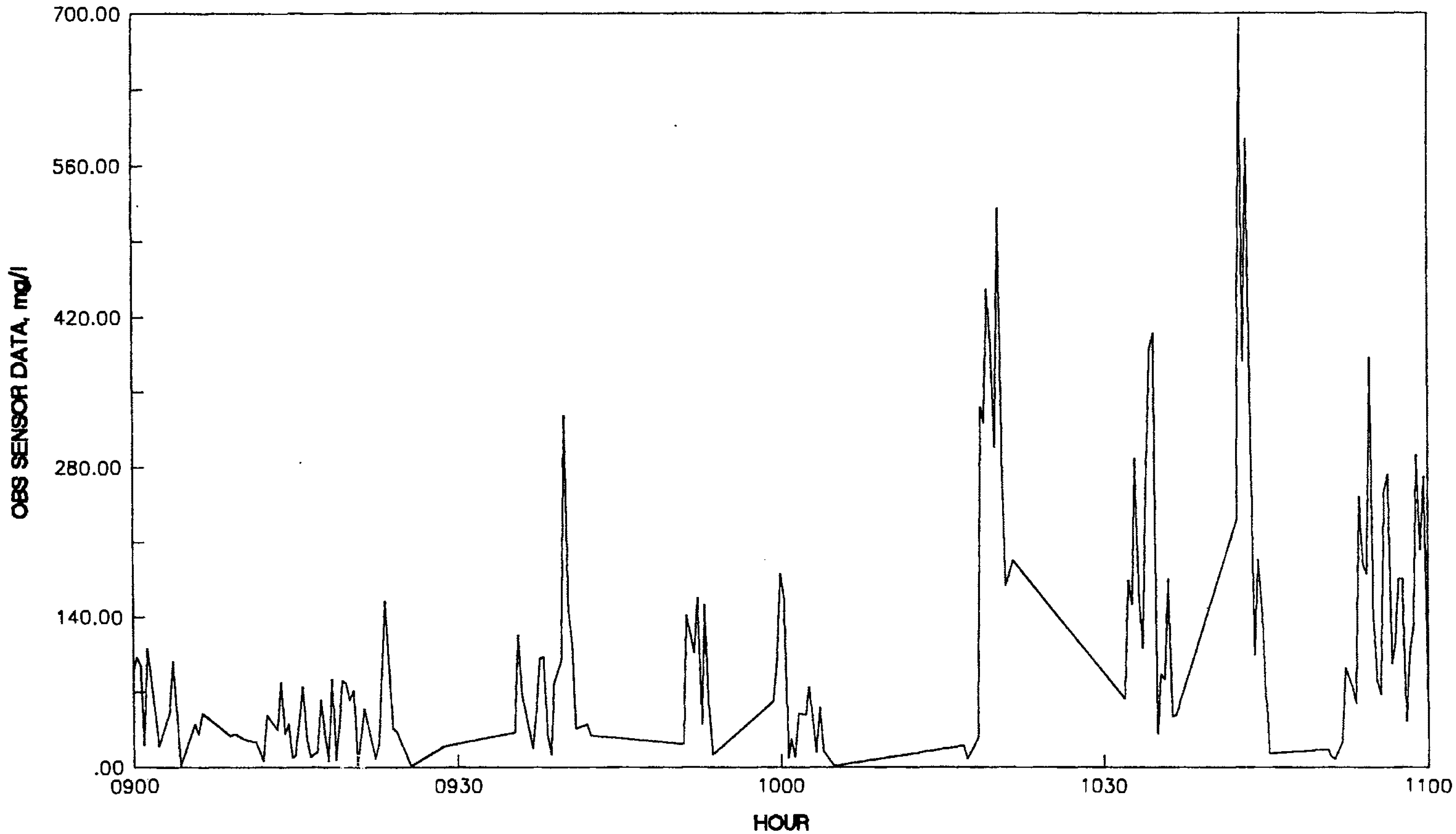
MEAN IS 19.8000 mg/l

OBS SENSOR AT 1.0 FT
POOL 08 TYPE 6 EMPTY
11/06/95



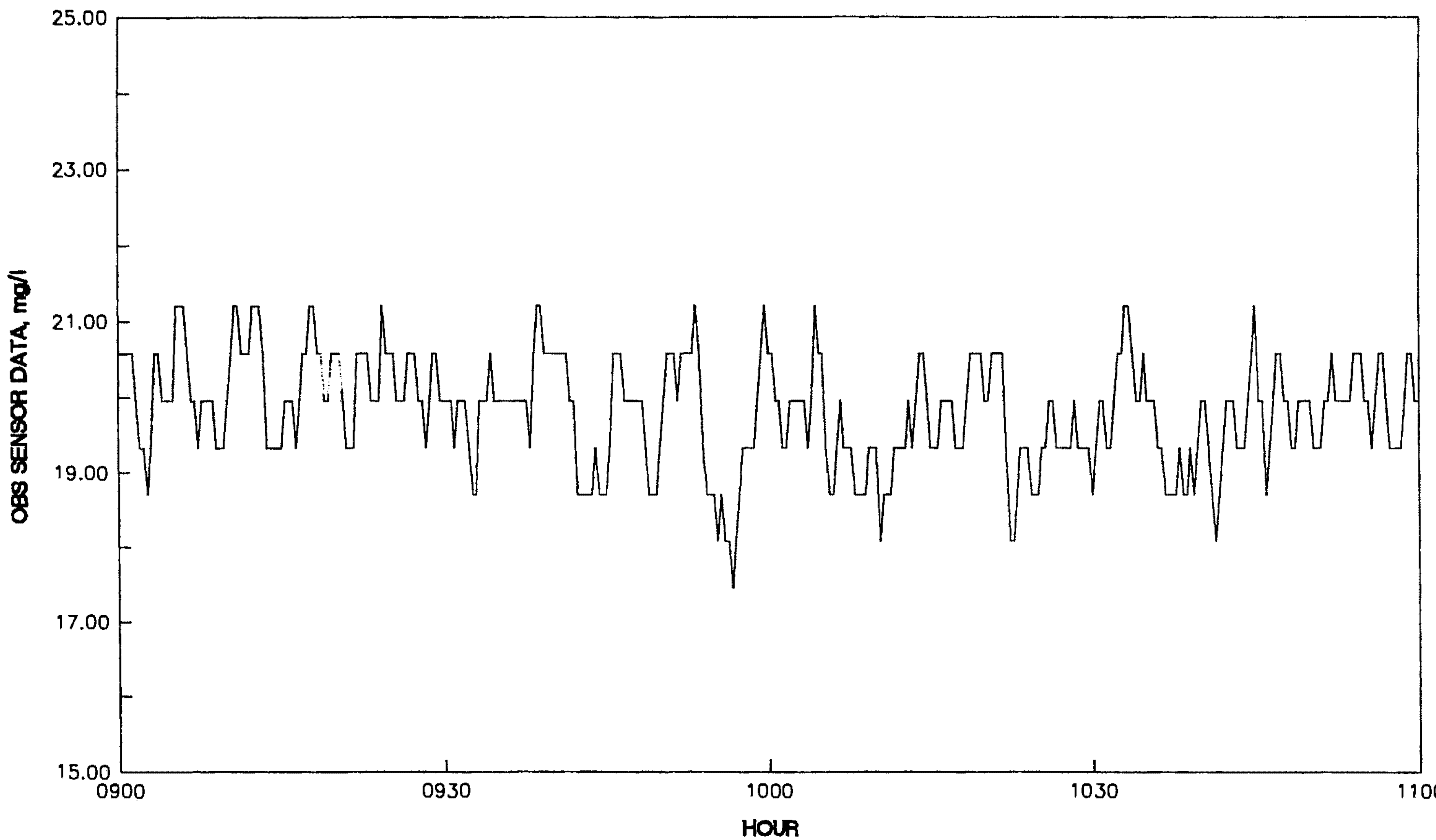
MEAN IS 200.6795 mg/l

OBS SENSOR AT 7.5 FT
POOL 08 TYPE 6 LOADED
11/06/95



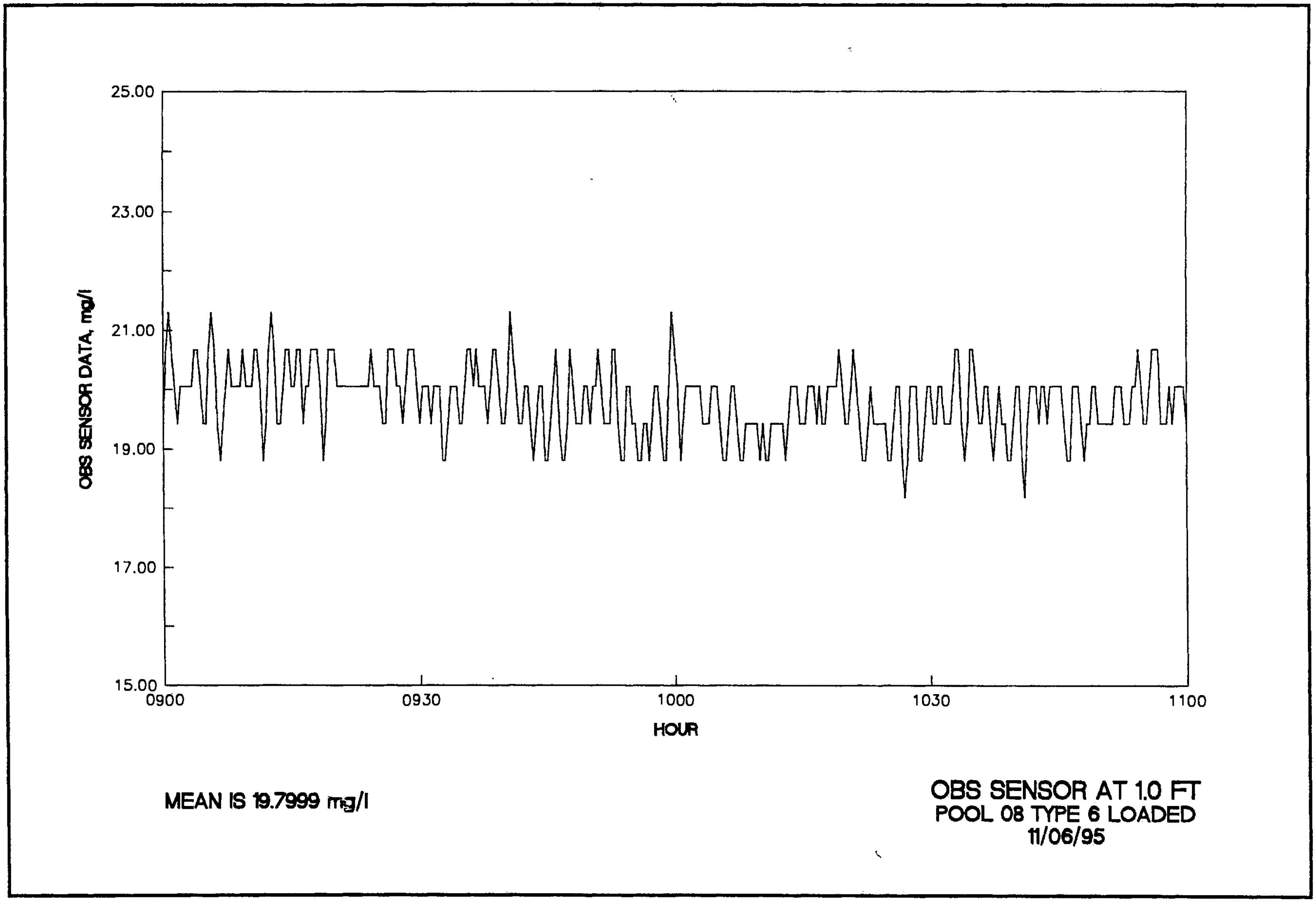
MEAN IS 112.5328 mg/l

OBS SENSOR AT 6.5 FT
POOL 08 TYPE 6 LOADED
11/06/95



MEAN IS 19.7999 mg/l

OBS SENSOR AT 3.0 FT
POOL 08 TYPE 6 LOADED
11/06/95


25.00
23.00
21.00
19.00
17.00
15.00
OBS SENSOR DATA, mg/l
0900
0930
1000
1030
1100
HOUR
MEAN IS 19.7999 mg/l
OBS SENSOR AT 1.0 FT
POOL 08 TYPE 6 LOADED
11/06/95

Appendix C

Particle Size Distribution of Surface Sediment Samples Collected in Pool 8

Bed Material Characteristics
Summer of 1995
Pool 8

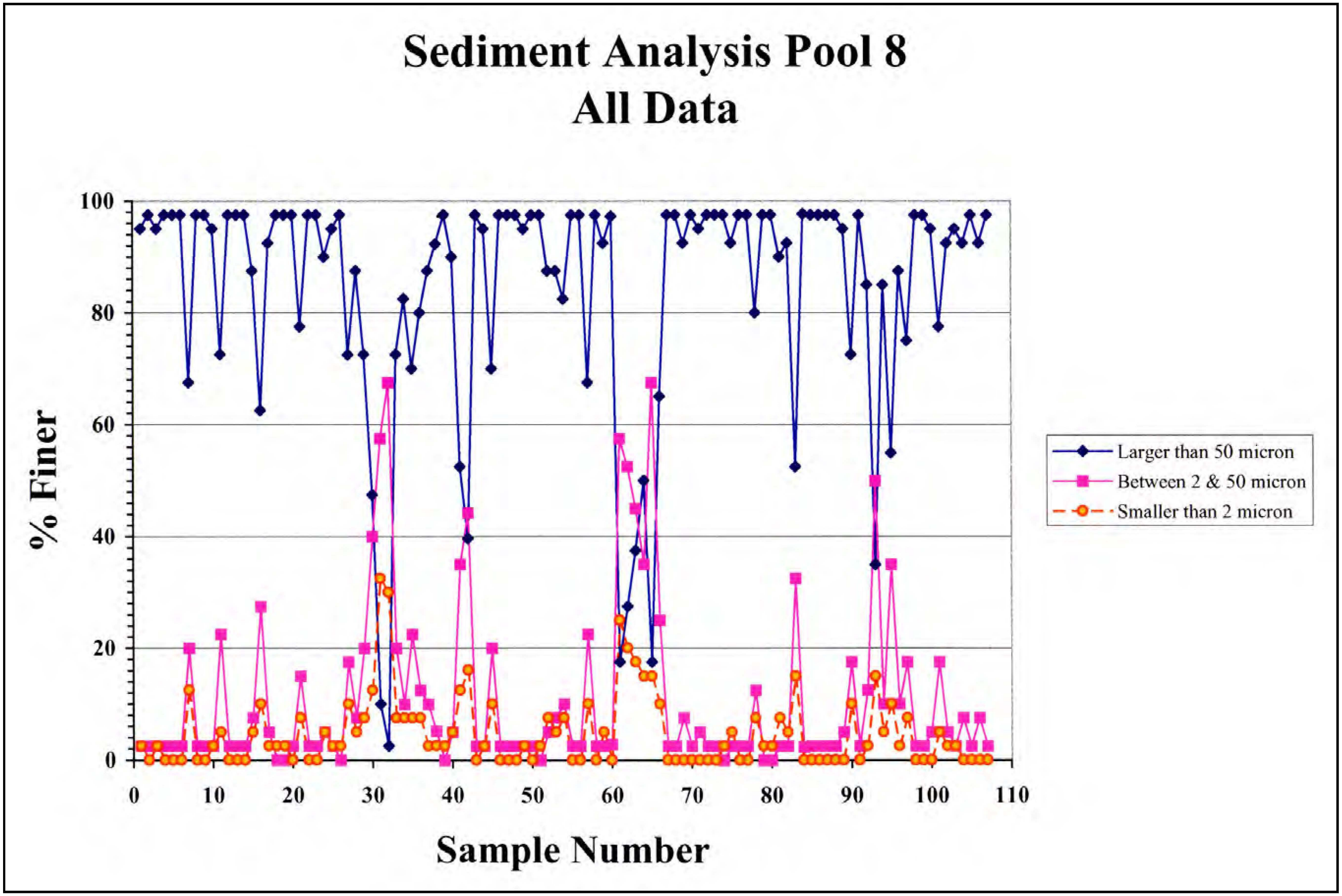
Sample ID	% of Sediment >50µ	% of Sediment 2µ<X<50µ	% of Sediment <2µ
MC 1	95	2.5	2.5
MC 2	97.5	2.5	0
MC 3	95	2.5	2.5
MC 4	97.5	2.5	0
MC 5	97.5	2.5	0
MC 6	97.5	2.5	0
MC 7	67.5	20	12.5
MC 8	97.5	2.5	0
MC 9	97.5	2.5	0
MC 9B	95	2.5	2.5
RR 1	72.5	22.5	5
RR 2	97.5	2.5	0
RR 3	97.5	2.5	0
RR 4	97.5	2.5	0
RR 5	87.5	7.5	5
RR 6	62.5	27.5	10
LA 1	92.5	5	2.5
LA 2	97.5	0	2.5
LA 3	97.5	0	2.5
LA 4	97.5	2.5	0
LA 5	77.5	15	7.5
LM 2	97.5	2.5	0
LM 1	97.5	2.5	0
LB			
LC	90.0	5.0	5.0
LD 1	95	2.5	2.5
LD 2	97.5	0	2.5
LD 3	72.5	17.5	10
LD 4	87.5	7.5	5
LD 5	72.5	20	7.5
BW1A	47.5	40	12.5
BW1B	9.99	57.5	32.5
BW1C	2.5	67.5	30
BW1D 1	72.5	20	7.5
BW1D 2	82.5	10	7.5
BW1D 3	70	22.5	7.5
BW1D 4	80	12.5	7.5
LE 1	87.49	10.01	2.5
LE 2	92.29	5.14	2.57

Bed Material Characteristics
Summer of 1995
Pool 8

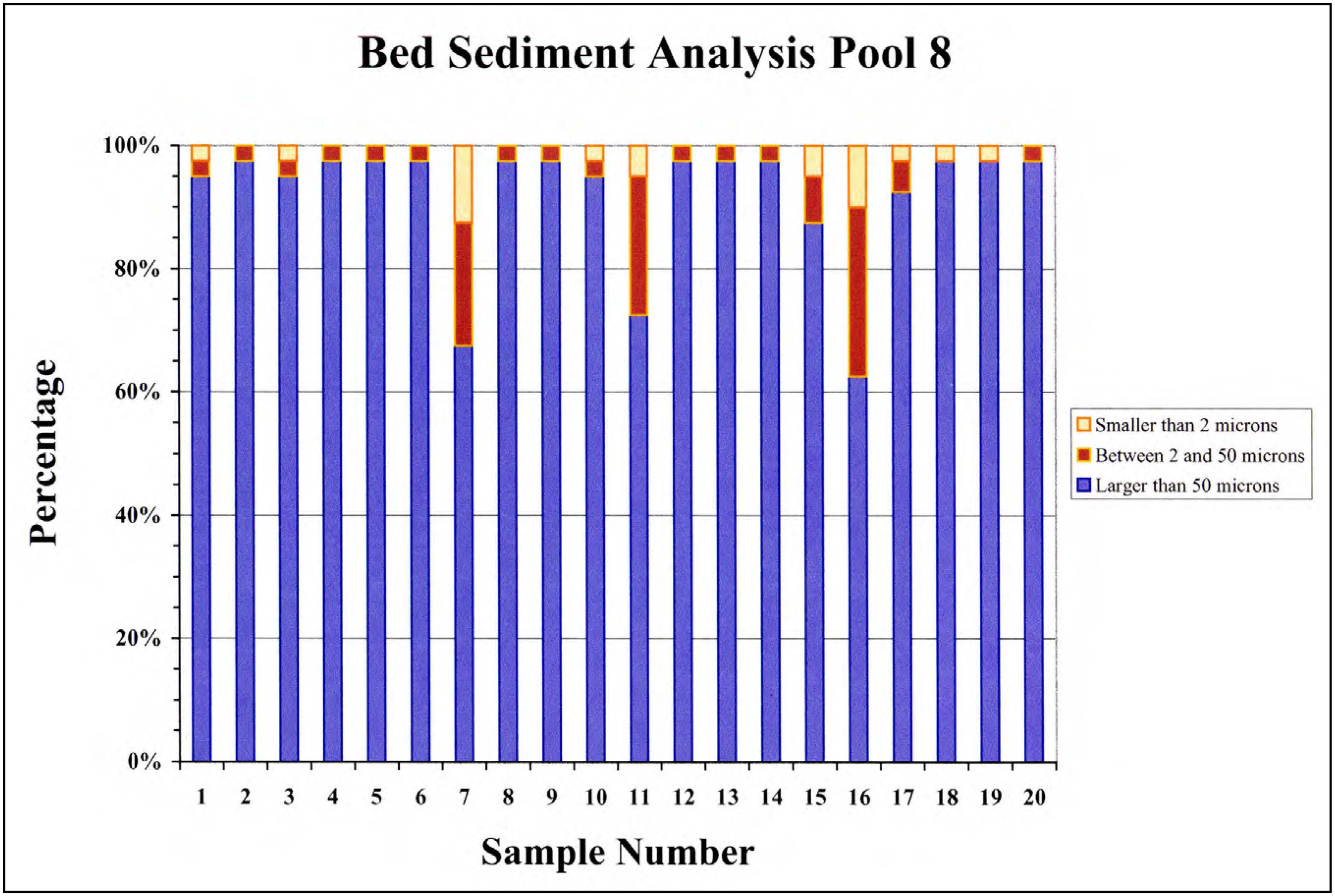
LE 3	97.5	0	2.5
LE 4	90	5	5
LE 5 TOP	12.5	52.5	35
LE 5 SAN	16.09	39.68	44.23
LF	97.5	2.50	0
LG	95.0	2.5	2.5
LH 1	70.01	20	10
LH 2	97.5	2.5	0
LH 3	97.5	2.5	0
LH 4	97.5	2.5	0
LH 5	95	2.5	2.5
LRA	97.5	2.5	0
LRB	97.5	0	2.5
LRC 1	87.5	5	7.5
LRC 2	87.5	7.5	5
LRC 3	82.5	10	7.5
LRD	97.5	2.5	0
LRE	97.5	2.5	0
LI 1	67.5	22.5	10
LI 2	97.5	2..5	0
LI 3	92.5	2.5	5
LLA	97.28	2.72	0
BW2A	17.51	57.49	25
BW2B	27.5	52.5	20
BW2C	37.5	45	17.5
BW2D 1	5.	35	15
BW2D 2	17.5	67.5	15
BWED 3	65	25	10
LLB	97.5	2.5	0
LLC	2.5	0	0
LLD 1	92.5	7.5	0
LLD 2	97.5	2.5	0
LLD 3	95	5	0
LLE	97.5	2.5	0
LLF	97.5	2.5	0
LLG	97.5	0	2.5
LLH	92.5	2.5	5
RM 1	97.5	2.5	0
RM 2	97.52	2.48	0
CBA 1	80	12.5	7.5
CBA 2	97.5	0	2.5

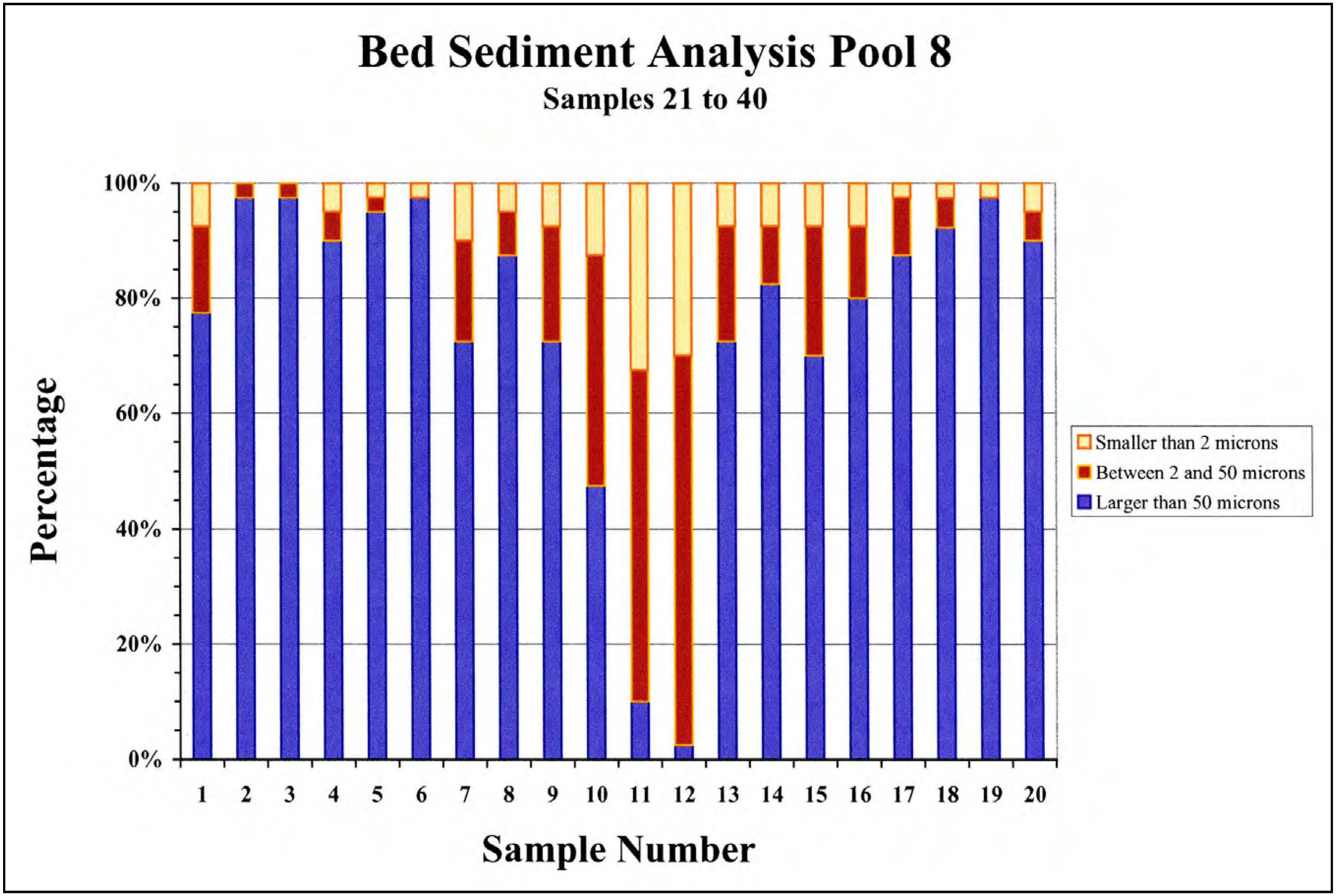
Bed Material Characteristics
Summer of 1995
Pool 8

CBA 3	97.5	0	2.5
CBA 4	90	2.5	7.5
CBA 5	92.5	2.5	5
RA 1	52.5	32.5	15
RA 2	97.69	2.31	0
RA 3	97.5	2.5	0
RA 4	97.5	2.5	0
RA 5	97.5	2.5	0
RB	97.5	2.5	0
RC	95.0	2.5	0
RD	TOO	MANY	ROCKS
RE 1	72.5	17.5	10
RE 2	97.5	2.5	0
RE 3	85	12.5	2.5
BW3A	35	50	15
BW3B	85	10	5
BW3C	55	35	10
BW3D	76.5	21.0	2.5
BW3E	75	17.5	7.5
RH			
RI	97.5	2.5	0
RJ			
SCA	97.5	2.5	0
RK	95.0	5	0
RL			
SC2C	77.5	17.5	5
RM			
RN 1	92.5	5	2.5
RN 2	95	2.5	2.5
RN 3	92.5	7.5	0
RN 4	97.5	2.5	0
RN 5	92.5	7.5	0

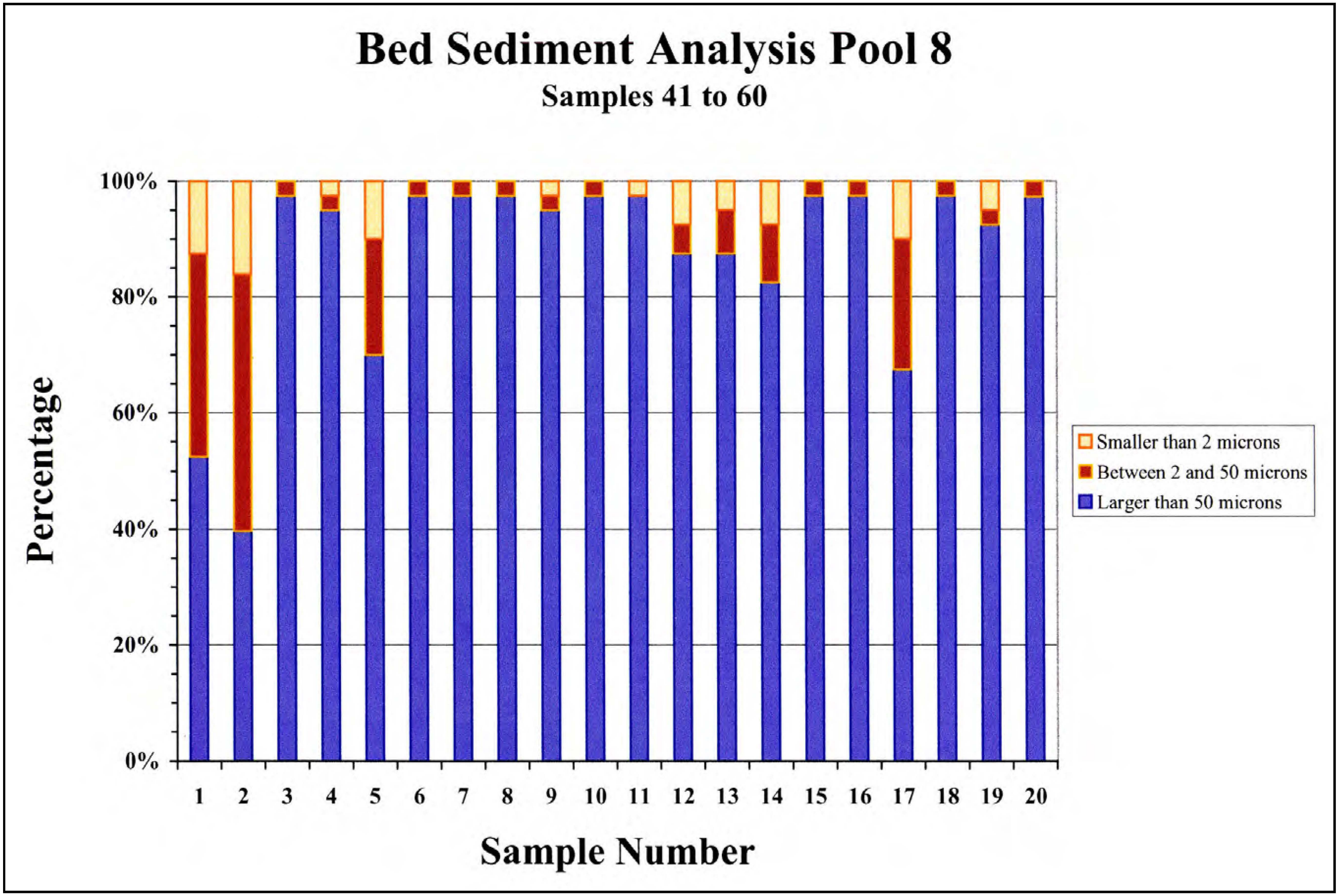


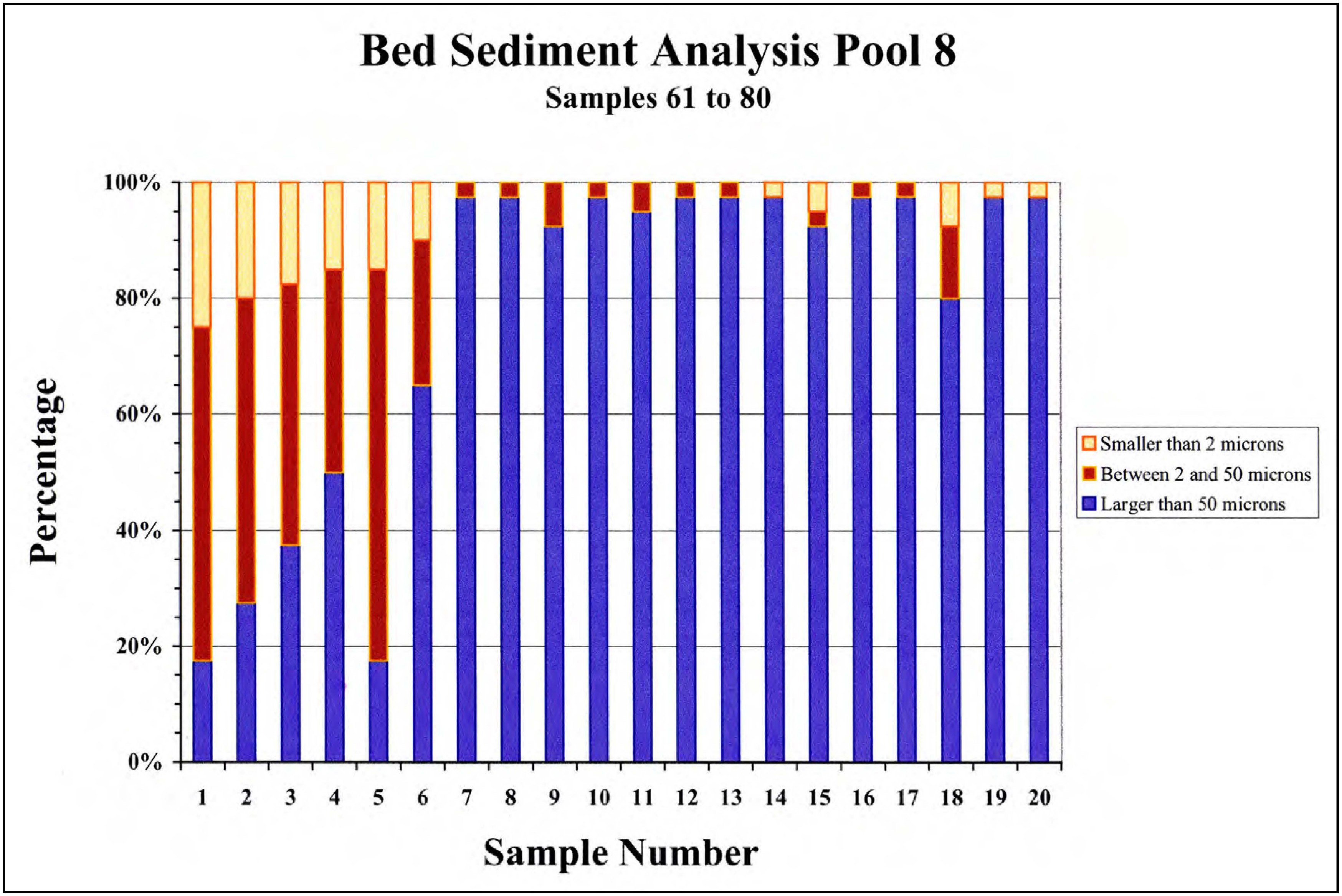
Sediment Analysis Pool 8
All Data
% Finer
100
80
60
40
20
0
0
10
20
30
40
50
60
70
80
90
100
110
Sample Number
Larger than 50 micron
Between 2 & 50 micron
Smaller than 2 micron

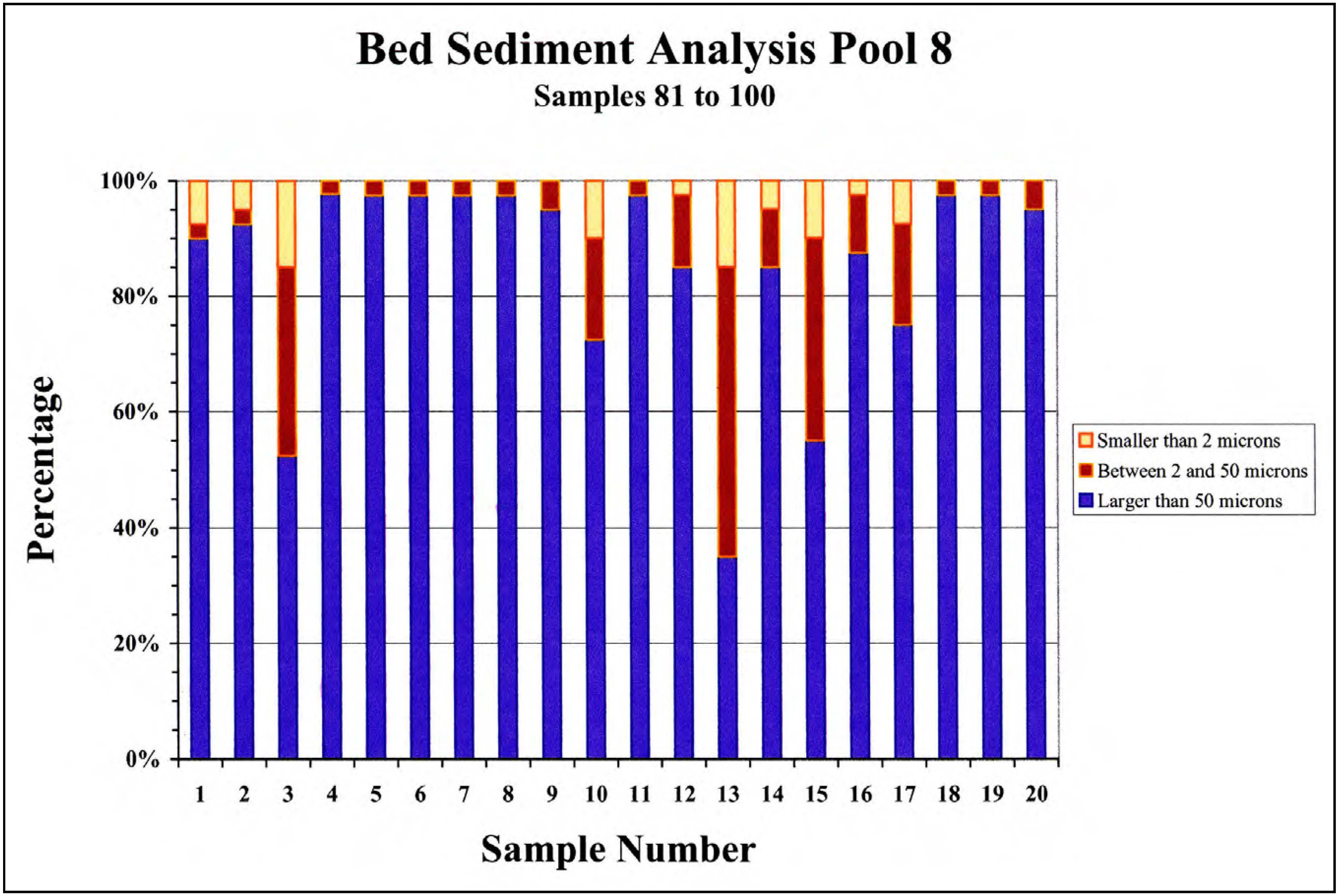

Bed Sediment Analysis Pool 8
Percentage
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sample Number
Smaller than 2 microns
Between 2 and 50 microns
Larger than 50 microns



Bed Sediment Analysis Pool 8
Samples 21 to 40
Percentage
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Sample Number
Smaller than 2 microns
Between 2 and 50 microns
Larger than 50 microns


Bed Sediment Analysis Pool 8
Samples 41 to 60
Percentage
100%
80%
60%
40%
20%
0%
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Sample Number
Smaller than 2 microns
Between 2 and 50 microns
Larger than 50 microns


Bed Sediment Analysis Pool 8
Samples 61 to 80
Percentage
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sample Number
Smaller than 2 microns
Between 2 and 50 microns
Larger than 50 microns



Bed Sediment Analysis Pool 8
Samples 81 to 100
Percentage
100%
80%
60%
40%
20%
0%
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Sample Number
Smaller than 2 microns
Between 2 and 50 microns
Larger than 50 microns