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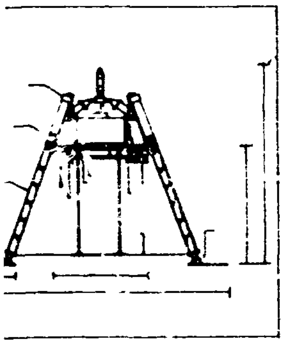

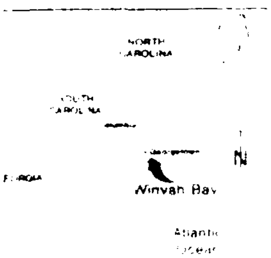

HYDRAULICS
LABORATORY

IMPROVEMENT OF OPERATIONS AND MAINTENANCE TECHNIQUES

TECHNICAL REPORT HL-90-10

NEAR-BED OPTICAL BACKSCATTER SENSOR AND VECTOR-MEASURING VELOCITY METER CALIBRATION

by

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This report summarizes the procedures used to calibrate a Vector-Measuring Velocity Meter and an Optical Backscatter Turbidity Meter. Descriptions of facilities used in these calibration procedures are given, but they in no way limit the possibility of using other similar type facilities. Sensor thresholds and sensing limits are given to ensure accurate data collection.

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Vector-Measuring Velocity Meters
Velocity meter calibration

PREFACE

The calibration of the Optical Backscatter (OBS) sensor and the Vector-Measuring Velocity Meter was conducted during a research effort under the Improvement of Operations and Maintenance Techniques (IOMT) research program sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), under IOMT Work Unit No. 32385, "Accurate Measurements of Near-Bed Velocities and Sediment Concentrations."

This analysis was conducted in the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) during the period 29 January to 1 May 1989 under the general supervision of Messrs. Frank A. Herrmann, Jr., Chief, HL; Richard A. Sager, Assistant Chief, HL; William H. McAnally, Jr., Chief, Estuaries Division (ED), HL; George M. Fisackerly, Chief, Estuarine Processes Branch (EPB), ED, and Robert F. Athow, Estuarine Engineering Branch, ED, IOMT Program Manager. Mr. Jim Gottesman was HQUSACE Technical Monitor.

The study was conducted and this report prepared by Mr. Thad C. Pratt, EPB. Messrs. Larry G. Caviness and Billy G. Moore, both of EPB, provided sample analysis assistance. Mrs. Marsha C. Gay, Information Technology Laboratory, WES, edited this report.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

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

Multiply	By	To Obtain
cubic feet	0.02831685	cubic metres
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
feet	0.3048	metres
gallons (US liquid)	3.785412	cubic decimetres
inches	2.540	centimetres

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

NEAR-BED OPTICAL BACKSCATTER SENSOR AND VECTOR-MEASURING VELOCITY METER CALIBRATION

PART I: INTRODUCTION

Background

1. Measuring near-bed phenomena has troubled researchers for many years. The problem with making these measurements is that in obtaining them, the environment is disturbed by the measurement process. The most accurate measurement is obtained when the environment is disturbed the least. By making more accurate near-bed velocity and suspended sediment concentration measurements, the researcher will be able to better understand the physical processes he is trying to predict.

2. The electromagnetic velocity meter has been used to make near-bed measurements in flumes and field investigations. Signal interference caused by suspended solids, metallic objects, electromagnetic fields, and density variations is one of the reasons that led to the development of the Vector-Measuring Velocity Meter (VMVM).

3. The Optical Backscatter (OBS) sensor is small so that it minimizes the disturbance in the testing area. This sensor uses reflected light as a means of sensing suspended solids. Since light does not disturb the test medium, the OBS sensor is very attractive for taking near-bed measurements. The OBS sensor has a very linear output, which makes calibration and data analysis much easier.

4. The objective of the work unit was to evaluate methods of measuring near-bed velocities, bottom shear stresses, and sediment concentrations. These evaluations would be critical in preparation for designing a complete measurement system for making near-bed measurements in estuarine and inland waterways. Upon identifying deployment and operational problems associated with the electromagnetic velocity meters, it was decided to design and build a VMVM in an attempt to reduce these problems. The OBS sensor was chosen because it performed in the near-bed environment and it was easy to calibrate and deploy. In addition, its data output was easy to reduce.

Objective

5. The objective of this report is to give operational guidelines and calibration techniques for the OBS sensor and the VMVM.

PART II: OPTICAL BACKSCATTER SENSOR

Sensor Operation

6. The OBS sensor contains a high-intensity infrared light-emitting diode (IRED) (Figure 1). Four silicon photodiodes were mounted around the IRED along with a linear solid-state temperature transducer. All of the components were molded into a polycarbonate housing encased in a stainless steel jacket for easy deployment. The surface of the sensor was coated with a gelatin filter and optical-grade epoxy resin.

7. The IRED emits a conical-shaped infrared beam directed perpendicular to the sensor surface. The photodiodes were mounted so that they measured scattered light through angles greater than 150 deg.* The gelatin filter over the sensor face reduced the effects of ambient light from the surface. The signal output from the photodiodes was in volts, and this was equated to concentration of suspended solids. The temperature transducer was used to measure heat generated by the sensor components, thus improving the quality of signal by compensating for this heat in the signal-conditioning. The sensitivity range for the sensor in mud was 5 to 5,000 mg/ℓ and in sand, 100 to 100,000 mg/ℓ.

8. Since different materials absorb and scatter light differently, calibration curves had to be developed for each sediment type. The results of calibration work showed that the same sensor output could represent concentrations varying from 1,000 to 3,000 ppm depending upon sediment type.

Setup

9. Calibration of the OBS sensor using sediment from a test location was a relatively simple process. The first consideration was to determine how to monitor the sensor output. The manufacturer's instruction manual** provided a detailed step-by-step method for connection of the sensor to the

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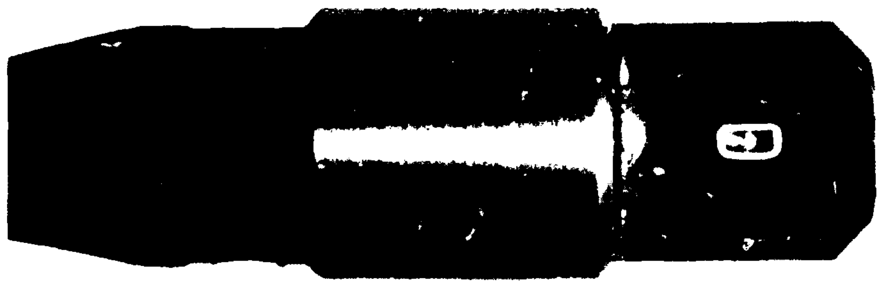
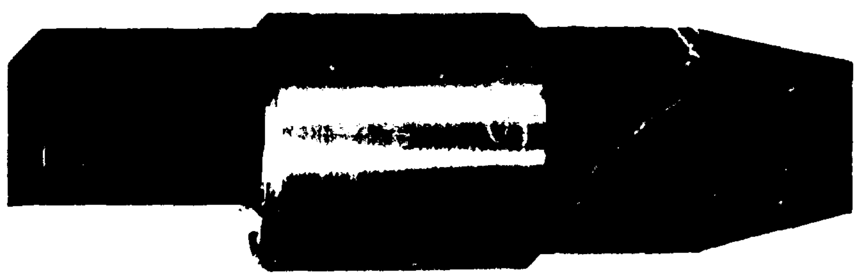
* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

** J. Downing. 1987. "Instruction Manual, OBS-1 Optical Backscatterance Turbidity and Suspended Solids Monitor," Downing and Associates, Washington, DC.



a. Front



b. Side

Figure 1. OBS turbidity sensor

signal-processing board. The instruction manual also recommended that a voltmeter be used to measure sensor output. A calibration curve was then developed from the voltage readings. During the calibration tests, the OBS sensor was also connected to a Tattle Tale V data logger. The data logger converted the voltage output into bits. The data logger had 10-bit resolution, so full-scale sensor output was equal to 1,023 bits. The two data sets were identical; therefore, all results and data presented herein are in the form of the data logger output, i.e., bits.

Test tank

10. There were several considerations in choosing a test tank. In clear water, the sensing range was almost 20 cm; therefore, all objects or mixing devices had to be 20 cm from the sensor surface. These criteria dictated that the tank be at least 10 in. deep and 12 in. in diameter. A 5-gal paint bucket adequately served as a test tank, but in order to reduce the reflective effects caused by the walls of the tank, the bucket walls were painted with black paint. The sensor instruction manual* recommended the use of a black Teflon bucket. Since the test medium had to remain homogeneous, a mixing device was used. The instruction manual recommended a drill-powered paint stirrer, but a small recirculation pump was used because it kept the mixture more evenly mixed.

11. This tank gave accurate results for sensor calibration, but a second tank design developed by Downing and Beach was a more elaborate facility.** Detailed studies were conducted by Downing and Beach in determining the performance of this new tank. If funds are available and time permits, the construction of a tank similar to Downing's might prove to be a better facility.

Sensor mounting

12. The sensor should be mounted to be stationary at least 3 in. from the bottom of the tank with at least 5 in. of water over the sensor. It should face away from the walls and surface of the tank. Reflections from the walls and the surface will be minimized with this configuration. For this testing, the effects of ambient light were minimized with the protective film

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* Downing, op. cit.

** J. P. Downing and R. A. Beach. 1989. "Laboratory Apparatus for Calibrating Optical Suspended Solids Sensor," Marine Geology, Vol 86, pp 243-249.

that coats the sensor face, but to further eliminate the effects of ambient light, the top of the tank could be covered with a black cloth or plastic material. The circulation pump should be at least 20 cm from the face of the sensor.

Sediment slurry

13. A slurry was made from the sediment sample taken at the test location to develop a calibration curve over the sensor range. A portion of the sediment sample was placed into a sealable container and distilled water was added to make approximately 400 ml of slurry. This slurry was added to the test medium in measured amounts to limit the concentration, so that the tank concentration would not greatly exceed values expected in the field. The reason for this limit was that for the most accurate calibration curve, more points need to be collected in the expected measuring range. Before a measured volume was added to the test medium, the slurry was mixed to maintain homogeneity. A sealable container allowed easy mixing by shaking the container. To obtain maximum sensor resolution, during predeployment preparations, the gain on the sensor output was set to give a voltage output 70 percent of full scale with the maximum sediment concentration expected at a particular site.

Setting sensor gain

14. The full-scale output of the sensor was 5 v. If the maximum expected concentration to be observed in the field did not give an output 70 percent of full scale, the gain on the signal-processing board needed to be increased to maximize the resolution. A detailed description for setting the gain on the signal-processing board was presented in the instruction manual.* The gain was set using the maximum concentration expected to be observed in the field and the calibration was continued.

Calibration Procedure

15. These steps should be followed to calibrate the OBS sensor:

a. Mount the sensor in the tank as described in paragraph 12.

b. Fill the tank, covering the sensor with at least 5 in. of water. Remove air bubbles from the walls of the tank by brushing them with a stirring rod. Place a dark cover over the top of the tank to reduce any surface interference.

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* Downing, op. cit.

c. Record clear-water offset for at least 5 min to measure output signal drift.

d. Add a measured sediment sample to the test medium and start the circulating pump. Sensor output readings should be taken for at least 5 min or until the output reaches a level of equilibrium. Depending on sediment type and particle size, the state of equilibrium could be reached instantly or could take as long as 10 min. The concentrations of the sediment in the test medium should be in the same range as expected in the field.

e. Take a sample from the test medium for gravimetric analysis when the sensor reaches a level of equilibrium.

f. Repeat procedure in d and e above until all of the points for the desired concentration range have been obtained.

g. Fit a polynomial curve to the analog and sediment concentration data.

16. After these calibration steps were completed, the OBS sensor was ready for deployment at the test location.

Sediment Sample Collection and Analysis

17. A field deployment of the OBS sensor was conducted at three locations in Winyah Bay, South Carolina (Figure 2). Sediment samples were taken using a shallow-water push-core sampler at each test site. These samples were returned to the US Army Engineer Waterways Experiment Station for use in calibration procedures. Since the sediment types were different, a good representative picture can be drawn regarding the operation of the OBS sensor.

Site 1

18. Site 1 sample was composed of silt, fine sands with shell, and some fine organic material giving the sediment a slight organic odor. Sixty percent of the sample passed a No. 200 sieve.

Site 2

19. Site 2 sample was fine sand and silt, but clay balls were present. This test location was directly below an operating dredge. Seventy percent of the sample passed a No. 200 sieve.

Site 3

20. Site 3 sample was mostly silt and clay. Some fine organic material was present with a slight odor. Eighty-five percent of the sample passed a No. 200 sieve.

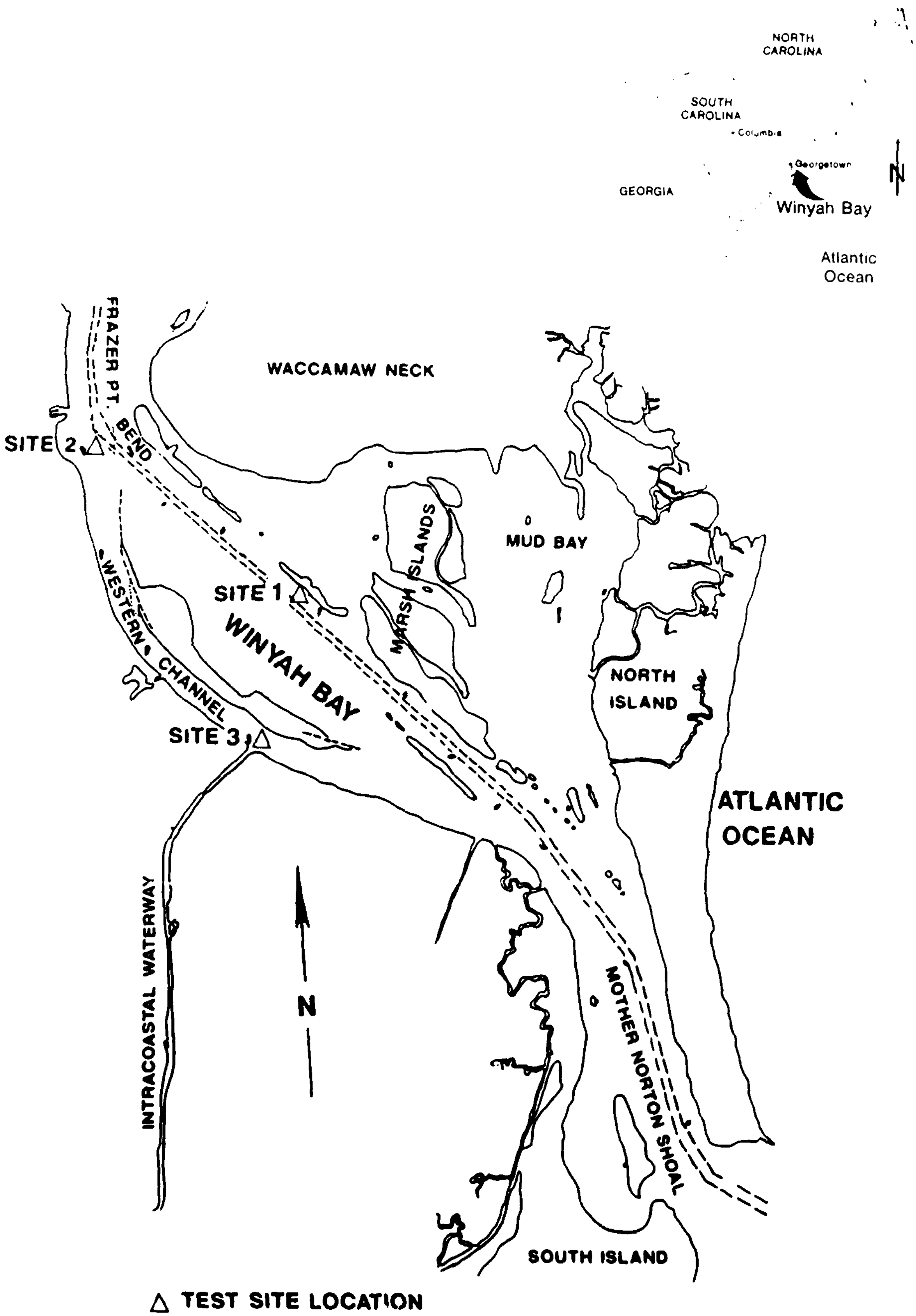

Figure 2. Test site locations

Data Analysis

21. The procedure described in paragraph 15 was used to develop calibration curves for each of the test sites. A slurry mixture was made from the sediment samples that, when added to the test tank, did not greatly exceed the concentration values expected in the field. Using this slurry, 50-ml increments were added to the distilled water in the test tank. Voltage output as well as bit output was recorded for comparison. The data logger output was directly proportional to voltage output from the sensor. The full-scale output from the sensor was equal to the computer's full-scale output, 1,023 bits. From this value, a scale factor of bits per volt was determined. Eight samples in the upper concentration region were taken for gravimetric analysis. A second slurry was mixed to be added to a clean test tank in 50-ml increments to give sensor output values in the lower concentration region. The sampling procedure was repeated, and eight samples were taken in the lower region for analysis. Table 1 is a listing of the OBS calibration data.

22. The OBS output from Site 1 calibration tests reached an equilibrium level after approximately 60 sec. A polynomial curve was fit to the complete data set, and the best fit was a second-order polynomial. Residual values (sensor output values calculated using the calibration curve) for Site 1 data are presented in Table 2. The points for the lower concentrations were removed from the data set, and a second curve was fit to the upper concentration data. Using this new curve-fit equation to calculate values in the lower concentration region would generate erroneous concentration values. Thus, the importance of collecting data points in the expected concentration range was demonstrated. Plate 1 is a plot of sediment concentration versus sensor output using the sediment sample from Site 1. The polynomial function that fits the concentration data is overlayed in Plate 1, and it is noted in the legend.

23. Site 2 calibration was very similar to that for Site 1 in that the OBS sensor output reached an equilibrium level within 60 sec. The sediment contained more fine material than did Site 1; therefore, the calibration curve was different. Data points were collected in the upper range and the lower range as before and are presented in Table 3. The best fit to the concentration data was a second-order polynomial. Residual values for Site 2 data are shown in Table 4. Plate 2 is a plot of Site 2 upper and lower concentration data and corresponding polynomial calibration curve.

24. Site 3 calibration was performed using the same procedure as for Site 1, but the time required for the sensor to reach an equilibrium output level, 5-10 min, was considerably different. The addition of incremental volumes of sediment slurry to the test medium initially produced minimum changes in the sensor's output. The output gradually increased over the next several minutes. Once the circulation pump had mixed enough to approach a homogeneous mixture, the sensor output seemed to reach an equilibrium level.

25. Attempting to fit a curve to these data (Table 5) was difficult. If all the data points were used for the upper and lower concentrations, a second-order polynomial would not fit the data very closely. Residual values for Site 3 data are shown in Tables 6 and 7. A large negative y-intercept would result with the inclusion of all the points. A curve fit the data much closer when the polynomial regression was performed on the data from the upper and lower concentration ranges separately. The y-intercept of the curve for the lower concentrations was much closer to zero, which is desired. It is apparent from a plot of the data (Plate 3) that there is a noticeable break in the graph at 75 bits. The data were divided at this point for the generation of two separate calibration curves. Calibration curves for the lower and upper concentrations are shown in Plates 4 and 5, respectively.

Results

26. From the different curves developed, it can be seen that predeployment calibration is necessary. If calibration were not performed prior to field deployment, sample rates might not be of sufficient length. With Site 3, the sample duration at one level would need to be several minutes for the most accurate measurement. Tank size should be at least the size described in paragraph 10 if not larger to remove signal contamination from wall and surface reflections. A good sediment circulation system is important in keeping the sediment suspended in the test tank. Plate 6 shows a scatter plot of the different data sets collected during calibration procedures of Sites 1, 2, and 3.

27. Further study is required to determine the effects of salt on the calibration of the OBS sensor. Nothing is mentioned in any of the instruction manuals about salt effects, but it is well known that salt affects the way sediment particles aggregate. It is also apparent that sediment particle size

affects the OBS output. The sediments from Sites 1 and 2 both contained larger sand and organic particles than Site 3, causing the sensor to respond faster. Further studies may show that the salt concentration of the test medium must be similar to that of the field sampling site to generate the most accurate calibration curve. Sediment profile data from the three sites are presented in Table 8. Profiles of the data are shown in Plates 7-9.

PART III: VECTOR-MEASURING VELOCITY METER

Sensor Description

28. The VMVM consists of two meters mounted 90 deg apart as shown in Figure 3 with two impellers fixed to an axle that runs through the mounting hub. The axle has machined slots on each end that are 22 deg out of phase. Two proximity switches located in the mounting hub sense the rotation of the axle. Two identical pulse trains are produced by the switches, but one pulse train is shifted because the slots are 22 deg out of phase. Depending on which signal train from the two switches is the leading signal train, direction of rotation and revolutions per minute can be obtained from the signal.

29. With this measurement, the magnitude and direction of the velocity component can be resolved. The direction of the velocity is then corrected using the angle resolved from the two component vectors and the angle in relation to due north of the entire instrument system.

Facility Description

30. The facility consists of a two-chamber tank, a constant-head tank, and associated piping as shown in Figure 4. The calibration tank is divided into upper and lower chambers by a partition containing a 2.5-in. plastic Verein Deutscher Ingeneiure nozzle.* Water introduced into the upper chamber flows through the nozzle into the lower chamber and over a brass 45-deg V-notch weir into a waste pit. Discharge, and thus nozzle flow velocity, are determined by measuring head over the weir. Current meters are calibrated by placing them in the nozzle jet on the lower chamber side of the partition. The calibration tank is that designed by Brown** but with several minor modifications.

31. The constant-head tank (Figure 5) consists of concentric cylindrical barrels on a stand above the calibration tank. Water flows into the center barrel from an overhead freshwater supply line. The lip of the center

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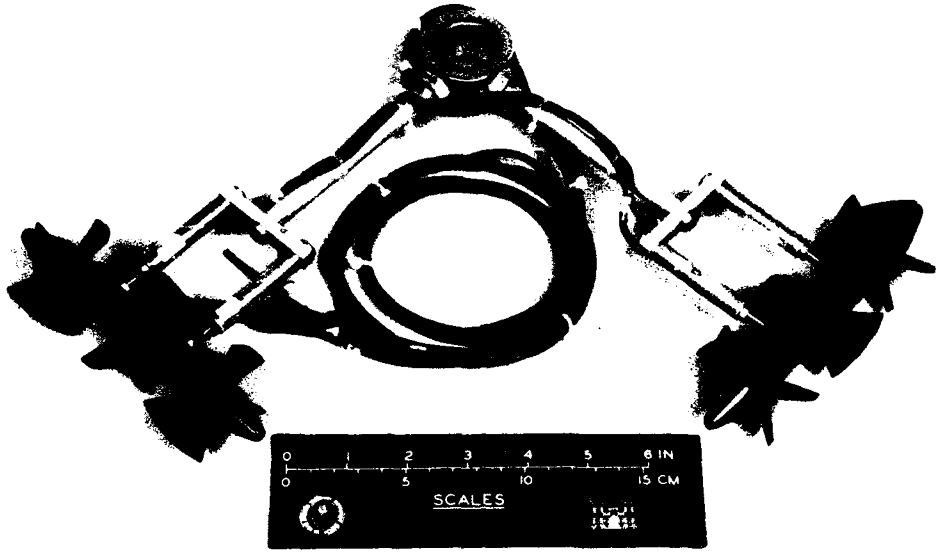
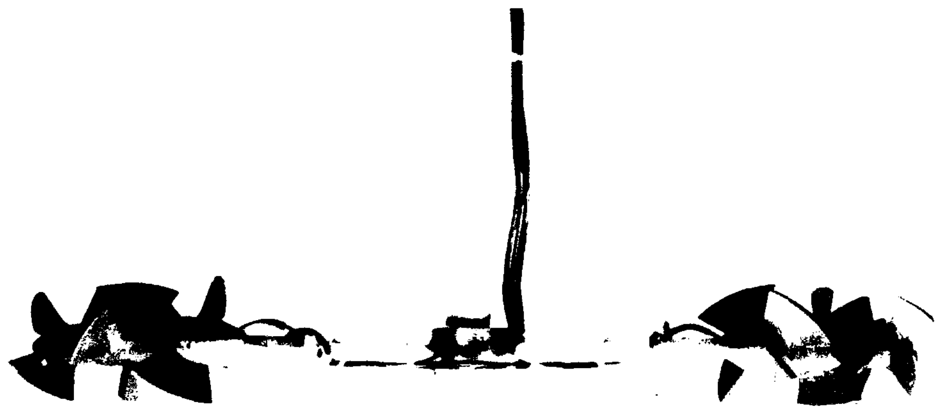
* V. L. Streeter. 1962. Fluid Mechanics, McGraw Hill, New York.

** B. J. Brown. 1970 (20 Jan). "Calibration Facility for Laboratory Current Meters," Memorandum for Record, US Army Engineer Waterways Experiment Station, Vicksburg, MS.



a. Top view



b. Front view

Figure 3. Vector-measuring velocity meter

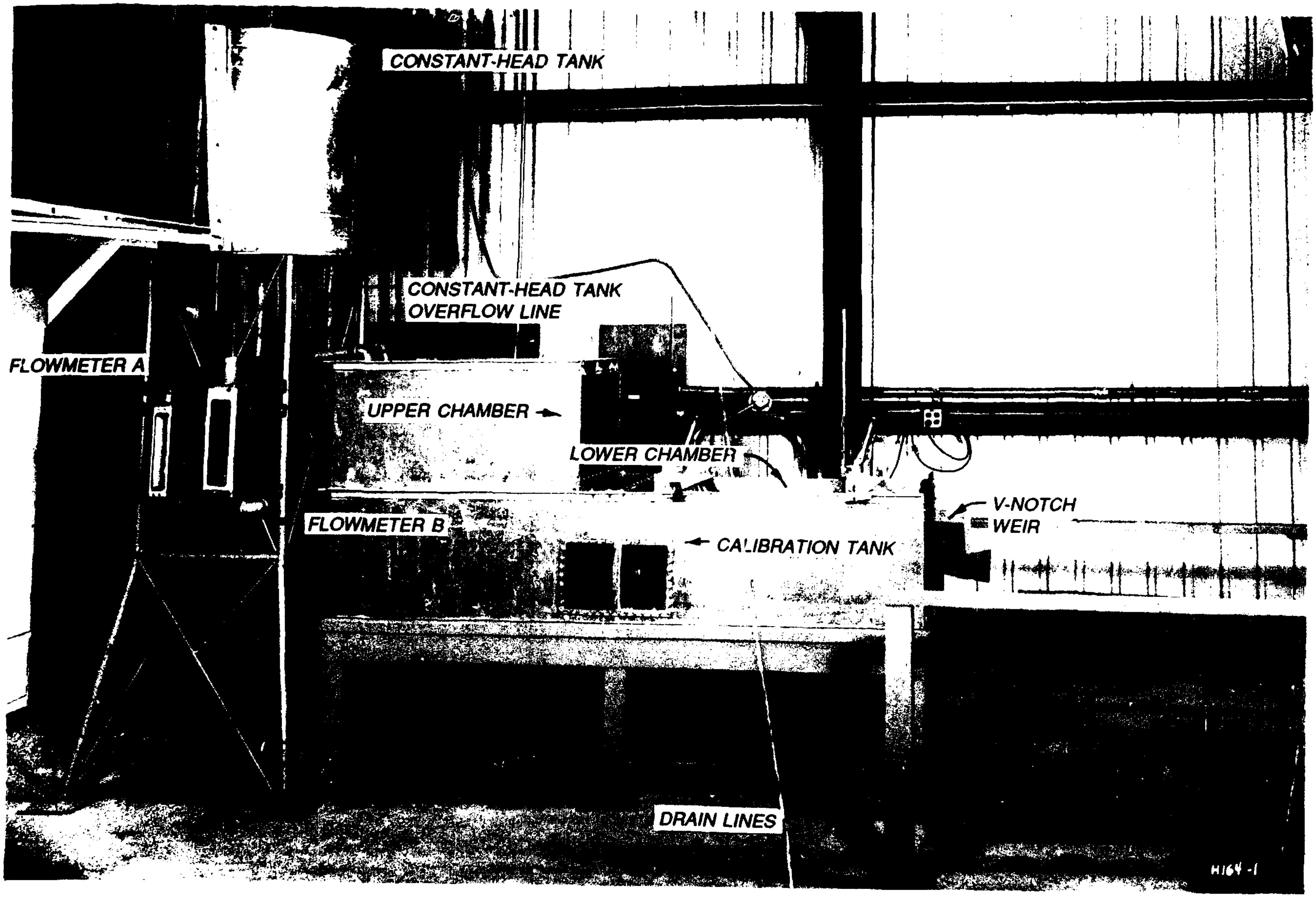


Figure 4. Calibration facility

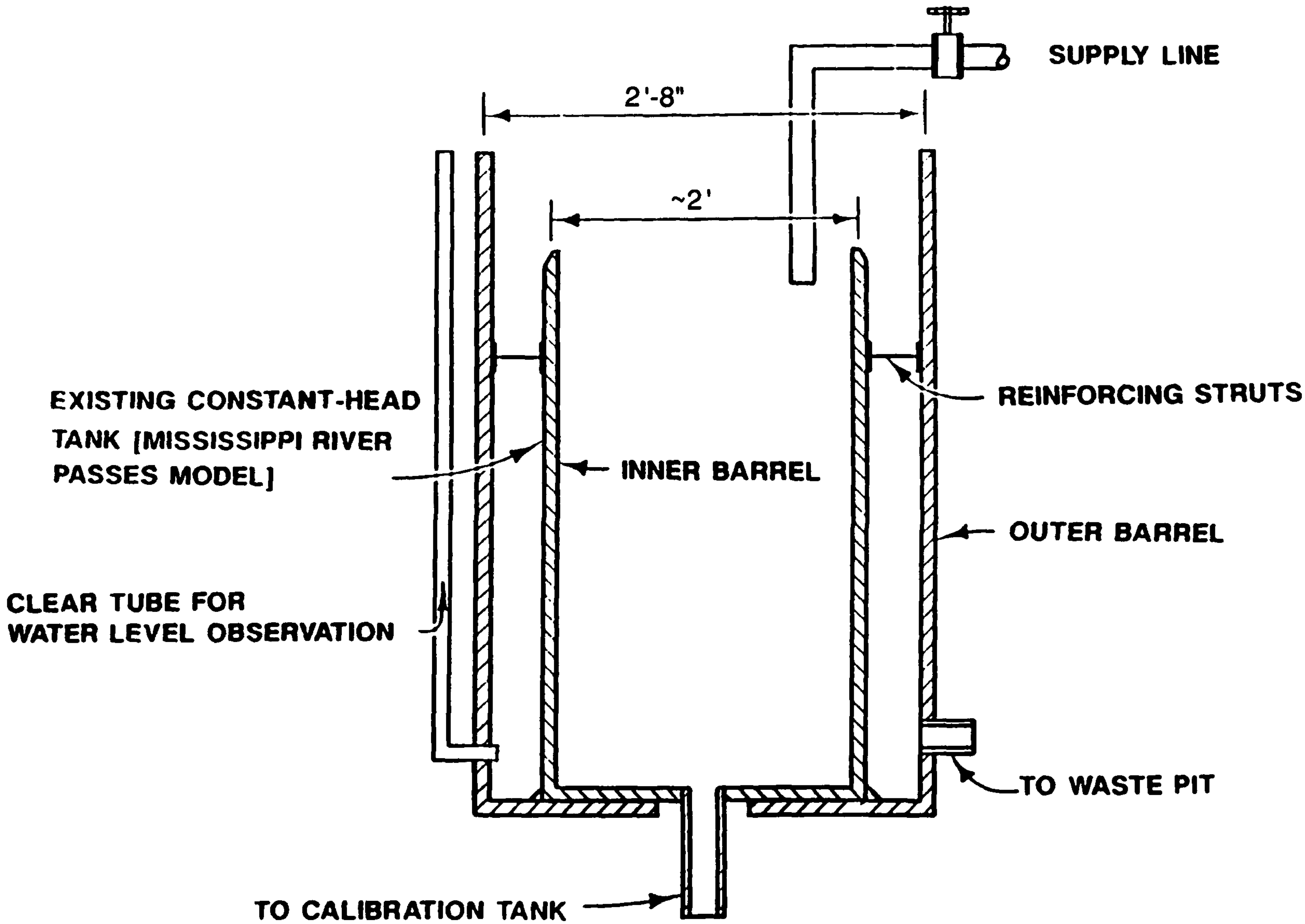


Figure 5. Constant-head tank

barrel acts as a long (6.3-ft) sharp-crested weir and maintains a nearly constant water level in the barrel for a given flow. Water flowing over the lip falls into the outer barrel and is wasted. Water for the calibration tank is withdrawn through a tap in the bottom of the inner barrel, where it flows into the upper chamber of the calibration tank.

Calibration Procedures

32. Calibration of the facility consists of measuring the time required to fill a 1.01-cu-ft plastic box from the V-notch weir overflow from a given head. The resulting volumetric flow rate is converted to an average velocity through the nozzle. The average velocity is then converted to an actual velocity that corrects for the velocity profile near the nozzle boundary. The correction factor is given by Brown.* Two quadratic equations are fit to the calibration data points by the least squares method. Separate equations are fit to the upper and lower portions of the curve with the dividing point being a head of 0.09 ft, the point at which the weir nappe looses aeration. The curve in Plate 10 and the values in Table 9 represent the best-fit quadratic equation.

Accuracy**

33. The point gage used to measure head on the weir is read directly to the nearest 0.001 ft and can be interpolated to ±0.0005 ft. An average error of 0.001 ft due to miszeroing or misreading the point gage will result in a current speed error of 0.002 fps at 0.05 fps and 0.01 fps at 1.0 fps. The volume of the calibration cube has been computed from measurements of the inside dimensions to be 1.011 cu ft. Measuring the volume of water required to fill it showed a volume of 1.014 cu ft. For volumetric computations, it is assumed to have a volume of 1.01 cu ft. Variation of ±0.005 cu ft in actual volume would result in an error of 0.5 percent in the flow rate and calculated flow speed.

34. The most significant source of error in calibrating the flume is

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* Op. cit.

** Paragraphs 34 and 35 of this discussion were extracted from the following source: W. H. McAnally, Jr., and C. A. Buford. 1977 (22 Mar). "Calibration Facility for Laboratory Current Meters," Memorandum for Record, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

measuring the time required to fill the calibration cube. Time is measured with a stopwatch graduated to 0.1 sec. Tests of several individuals timing the duration of a timed light have shown variations of up to 0.5 sec under optimum conditions. If 1.0 sec is taken to be the maximum error in time measurement, the resultant flow speed error is about 0.2 percent at 0.05 fps and about 4.0 percent at 1.0 fps.

35. The correction factor used to compute a center-line speed from the average flow speed is a function of the flow Reynolds number. The calibration curve (Plate 10) is based on a water temperature of 70° F, but the error due to change in viscosity for a temperature range of 60°-90° F is about 0.002 fps at 0.1 fps and less for higher flow speeds. The correction factor has not been measured for flow speeds of less than about 0.05 fps and must therefore be extrapolated. From the data presented by Brown,* the error in the factor could be as much as 3 percent at 0.02 fps, or ±0.0006 fps, which is well within the other errors.

Equipment

36. The equipment required for VMVM calibration consisted of a digital voltmeter, a storage oscilloscope, a variable DC power supply, and a two-channel magnetic signal recorder (Teac Recorder).

Procedure

37. These steps should be followed to calibrate the velocity meter:

a. The VMVM uses two proximity switches to measure rotation of the propellers. Each switch has three conductors: brown, black, and blue. The black conductor is the signal output, the brown is power, and the blue is ground. The reason for two switches per velocity meter is to determine direction of rotation of the propeller. For determining velocity thresholds and VMVM calibration curves, only one switch is needed for data collection because the velocity meter will be mounted parallel to flow and the direction of rotation will be constant.

b. Using the variable power supply, set the voltage output to be 8 v. Check the voltage output level with the digital voltmeter as a safety precaution before connecting the power supply to the proximity switch. Connect the leads of the oscilloscope to the proper conductors on the proximity meter to measure signal output. When the propellers are spun, a pulse train should be displayed on the oscilloscope if proper connection has been made. Once the proper working order has been established, then connect the magnetic tape recorder between the switch and the oscilloscope. A hard copy of the switch output signals can be

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* Op. cit.

made from this tape for future analysis.

c. Check connections on the tape recorder and oscilloscope to ensure proper working order.

d. Mount the velocity meter on a point gage (Figure 6) and place it in front of the nozzle in the lower chamber. The meter should be plumb, not more than 2 in. from the end of the nozzle and as near to the center line as possible.

e. Flow to the calibration chambers from the constant-head tank is controlled by a valve leading into the upper chamber. The flow must be determined by measuring the head over the V-notch weir in the lower chamber (Figure 6). The point gage should be positioned to measure water elevation at a point 1.11 ft from the weir in the center of the tank. Zero water-surface elevation is defined as being 0.64 ft below the engraved cross on the top surface of the aluminum reference bar. The reference bar must be securely clamped into the proper position before zeroing the point gage. The relationship between head over the weir and nozzle velocity is shown in Plate 10 and Table 9. The equation of the polynomial in Plate 10 is

$$V = 0.109 - 1.98H + 24.34H^2$$

where

V = velocity, fps

H = head, ft

f. Flow should be allowed to stabilize before readings are taken. Head should then be measured before and after each meter calibration to ensure that the flow rate has not changed. Under normal conditions, the flow rate will fluctuate very little once stability has been reached.

g. Press "Record" on the tape recorder once the flow rate has stabilized. Press "Store" on the oscilloscope to store a screen of data. Using the cursor on the oscilloscope, measure the period in seconds of four complete pulses. Since the meter outputs four pulses for one revolution, this period needs to be recorded as the time for one revolution at the present flow rate.

h. If several velocity meters are to be calibrated, it is advisable to interchange the different meters before the valve settings are changed.

i. Values for a period of revolution should be recorded for the complete range of the calibration tank, which is about 1.5 fps.

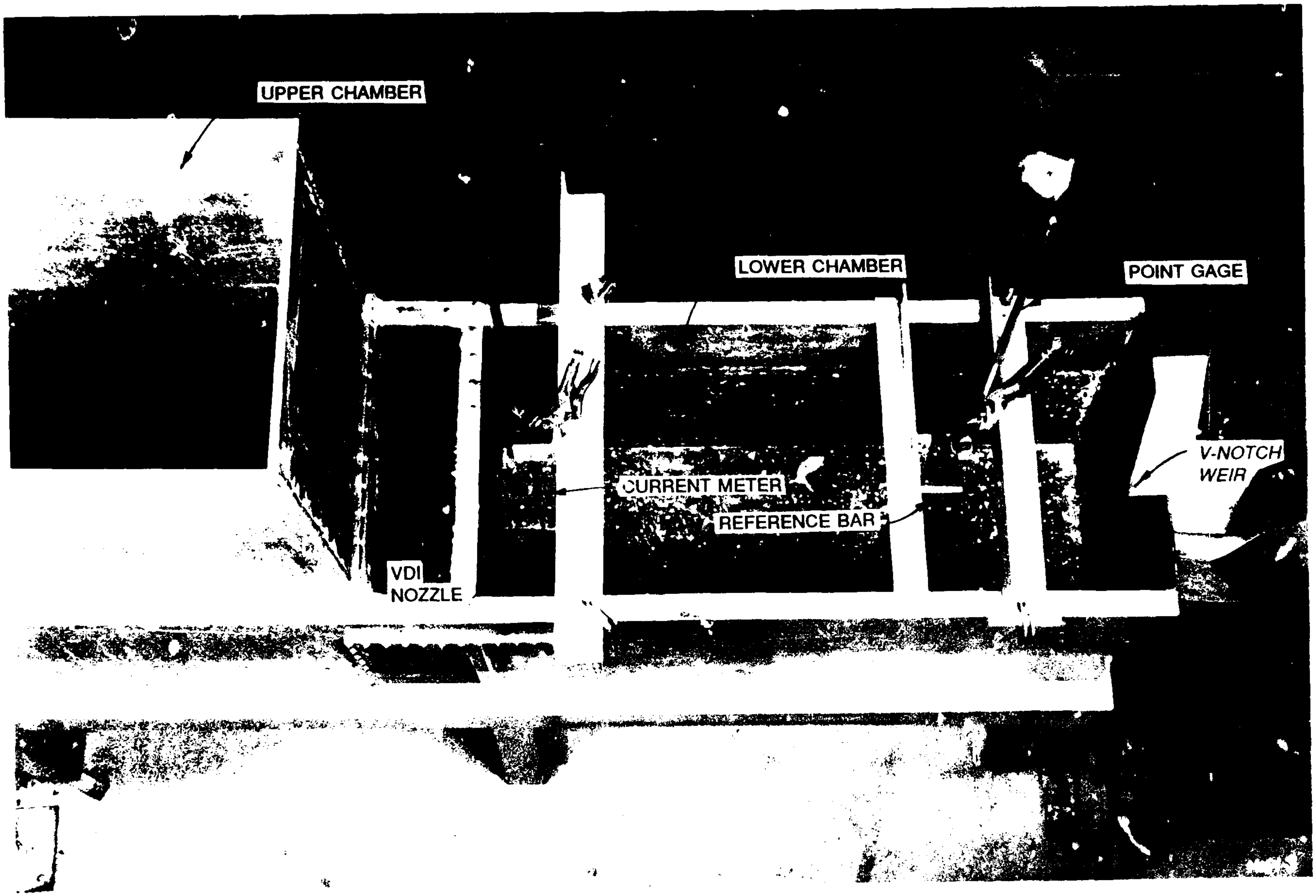


Figure 6. Calibration tank

Results

38. After data have been collected for all the velocity meters, a calibration curve must be fit to the data points. A power function was found to be the closest fit to the data. Use the period of revolution as the dependent variable and the current as the independent variable when running the nonlinear regression on the data. Tables 10 and 11 are example calibration data sets for VMVM's A and B, respectively. Tables 12 and 13 are residual tables and constant values for the calibration curves developed for these data sets. Scatter plots with calibration curve overlays for VMVM's A and B are in Plates 11 and 12.

39. A limitation of the VMVM is that the meter had to be small and exhibit cosine response in taking measurements in fluid mud regions close to the bed. Further calibration work is needed to determine the response of the velocity meter to incident velocities from 0 to 360 deg. At present, the facilities are not available for this type of testing. Another area of further interest is to test the meters in unison to get a verification of their operation in the field. The results of the tests run to date show that the threshold of the present VMVM is 0.10 fps. These meters were designed to operate where electromagnetic velocity meters fail, but to be able to get more precise measurements, the threshold needs to be reduced further.

PART IV: CONCLUSIONS

40. As a result of the calibration exercise of the VMVM velocity meters and the OBS turbidity meters, important sensor characteristics were noted. Response time, sensing thresholds, and sensor limitations were identified. It was apparent as a result of the OBS calibration work that calibration over the expected operating range produces more accurate calibration curves compared to curves generated for the entire range of the OBS sensor. Salinity effects were identified as a major consideration for further work with the OBS sensors.

41. The velocity meters were evaluated as well as calibrated. The major limitation of the VMVM meters was that they exhibited a high threshold (0.1 fps) of operation. A threshold level of 0.05 fps would have been preferred to improve sensor sensitivity. They would be best suited for use in a high suspension zone where electromagnetic meters fail. The most important lesson to be learned from this exercise was that becoming familiar with sensor operation is absolutely paramount before deployment on a field study.

Table 1

OBS Calibration Data, Winyah Bay

Site 1

Sample Number	Sediment Concentration mg/ℓ	Logger Output bits
1	0.0	0
2	19.0	3
3	26.0	5
4	33.0	7
5	41.0	9
6	50.0	11
7	72.0	15
8	128.0	27
9	382.0	76
10	732.0	138
11	1,230.0	194
12	1,660.0	252
13	2,200.0	298
14	2,760.0	347
15	3,170.0	381
16	3,470.0	437
17	4,250.0	467

Table 2

Residuals, Site 1

Sample Number	Observed Y bits	Predicted Y bits	Residual	Standardized Residual
1	0.00	-2.52454	2.52454	0.02777
2	19.00	10.97747	8.02253	0.08824
3	26.00	20.07242	5.92758	0.06520
4	33.00	29.24226	3.75774	0.04133
5	41.00	38.48700	2.51300	0.02764
6	50.00	47.80662	2.19338	0.02412
7	72.00	66.67055	5.32945	0.05862
8	128.00	125.05970	2.94030	0.03234
9	382.00	391.46323	-9.46323	-0.10408
10	732.00	792.97026	-60.97026	-0.67059
11	1,230.00	1,217.48175	12.51825	0.13768
12	1,660.00	1,719.05179	-59.05179	-0.64949
13	2,200.00	2,161.63355	38.36645	0.42198
14	2,760.00	2,676.65655	83.34345	0.91667
15	3,170.00	3,060.43726	109.56274	1.20504
16	3,470.00	3,739.72800	-269.72800	-2.96665
17	4,250.00	4,127.78611	122.21389	1.34419

Note: Degree of Regression = 2
R^2 = 0.99655
Standard error of estimate = 90.9200786337
The following regression coefficients were determined at a 95 percent confidence interval:

Coefficient	Value	Lower Limit	Upper Limit
Constant	-2.52454	-75.13372	70.08465
X1	4.47258	3.36731	5.57786
X2	0.00936	0.00678	0.01194

Table 3

OBS Calibration Data, Winyah Bay

Site 2

Sample Number	Sediment Concentration mg/ℓ	Logger Output bits
1	0.0	0
2	14.0	4
3	22.0	6
4	40.0	12
5	78.0	18
6	80.0	24
7	100.0	29
8	118.0	35
9	150.0	42
10	532.0	123
11	1,020.0	217
12	1,810.0	314
13	2,210.0	373
14	2,710.0	435
15	3,530.0	494
16	4,020.0	555

Table 4

Residuals, Site 2

Sample Number	Observed Y bits	Predicted Y bits	Residual	Standardized Residual
1	0.00	1.72120	-1.72120	-0.03325
2	14.00	14.89995	-0.89995	-0.01739
3	22.00	21.57710	0.42290	0.00817
4	40.00	41.95963	-1.95963	-0.03786
5	78.00	62.86878	15.13122	0.28232
6	80.00	84.30456	-4.30456	-0.08316
7	100.00	102.57000	-2.57000	-0.04965
8	118.00	124.97126	-6.97126	-0.13468
9	150.00	151.77166	-1.77166	-0.03423
10	532.00	514.02657	17.97343	0.34722
11	1,020.00	1,054.74056	-34.74056	-0.67114
12	1,810.00	1,748.22247	61.77753	1.19346
13	2,210.00	2,237.35141	-27.35141	-0.52839
14	2,710.00	2,806.22281	-96.22281	-1.85890
15	3,530.00	3,399.78460	130.21540	2.51559
16	4,020.00	4,067.00743	47.00743	-0.90812

Note: Degree of Regression = 2
$R^2 = 0.99878$
Standard error of estimate = 51.7632985858
The following regression coefficients were determined at a 95 percent confidence interval:

Coefficient	Value	Lower Limit	Upper Limit
Constant	1.72120	-40.43247	43.87486
X1	3.26543	2.66567	3.86519
X2	0.00731	0.00613	0.00850

Table 5

OBS Calibration Data, Winyah Bay

Site 3

Sample Number	Sediment Concentration mg/ℓ	Logger Output bits
1	0.0	0
2	16.0	6
3	28.0	12
4	42.0	17
5	55.0	22
6	83.0	32
7	112.0	42
8	141.0	52
9	194.0	70
10	508.0	95
11	1,016.0	143
12	1,590.0	174
13	2,440.0	218
14	2,750.0	239
15	3,210.0	269
16	3,680.0	300
17	4,290.0	364

Table 6

Residuals, Site 3

Lower Sediment Concentrations

Sample Number	Observed Y bits	Predicted Y bits	Residual	Standardized Residual
1	0.00	0.22490	-0.22490	-0.22351
2	16.00	14.55477	1.44523	1.43627
3	28.00	29.39821	-1.39821	-1.38954
4	42.00	42.16005	-0.16005	-0.15906
5	55.00	55.27855	-0.27855	-0.27682
6	83.00	82.58547	0.41453	0.41196
7	111.00	111.31898	0.68102	0.67680
8	141.00	141.47907	-0.47907	-0.47610

Note: Degree of Regression = 2
$R^2 = 0.99970$
Standard error of estimate = 1.00624112075
The following regression coefficients were determined at a 95 percent confidence interval:

Coefficient	Value	Lower Limit	Upper Limit
Constant	0.22490	-1.86197	2.31177
X1	2.34551	2.14810	2.54292
X2	0.00713	0.00349	0.01078

Table 7

Residuals, Site 3

Upper Sediment Concentrations

Sample Number	Observed Y bits	Predicted Y bits	Residual	Standardized Residual
9	194.00	73.36229	120.63771	0.81631
10	508.00	481.04882	26.95118	0.18237
11	1,016.00	1,243.67238	-227.67238	-1.54057
12	1,590.00	1,722.12773	-132.12773	-0.89406
13	2,440.00	2,382.26328	57.73672	0.39068
14	2,750.00	2,689.48446	60.51554	0.40948
15	3,210.00	3,119.58021	90.41979	0.61183
16	3,680.00	3,553.14649	126.85351	0.85837
17	4,290.00	4,413.31435	-123.31435	-0.83442

Note: Degree of Regression = 2
R^2 = 0.99210
Standard error of estimate = 147.784703115
The following regression coefficients were determined at a 95 percent confidence interval:

Coefficient	Value	Lower Limit	Upper Limit
Constant	-1106.37202	-1,719.72092	-493.02312
X1	17.25558	10.88333	23.62783
X2	-0.00575	-0.02052	0.00903

Table 8

Sediment Profile Data, Winyah Bay

Distance from Bottom, in.	Sediment Concentration, mg/ℓ		
	Site 1	Site 2	Site 3
0	17.17	133.50	25.22
3	15.52	144.03	22.74
6	15.52	150.47	21.09
9	15.52	158.25	19.45
12	15.52	204.79	17.48
15	19.16	353.30	16.99
18	15.52	274.73	16.99
21	12.79	290.66	16.99
24	11.73	287.75	16.99
27	11.88	237.85	16.99
30	12.97	246.26	15.77
33	12.47	229.50	13.34
36	10.98	221.20	12.94

Table 9

Head on Weir Versus Flow Velocity Through Nozzle Velocity Meter Calibration Facility Calibration, February 1976

Head ft	Velocity fps	Head ft	Velocity fps	Head ft	Velocity fps
0.030	0.015	0.106	0.172	0.182	0.554
0.032	0.017	0.108	0.179	0.184	0.568
0.034	0.019	0.110	0.185	0.186	0.582
0.036	0.022	0.112	0.192	0.188	0.596
0.038	0.024	0.114	0.199	0.190	0.611
0.040	0.027	0.116	0.206	0.192	0.625
0.042	0.029	0.118	0.214	0.194	0.640
0.044	0.032	0.120	0.221	0.196	0.655
0.046	0.035	0.122	0.229	0.198	0.671
0.048	0.038	0.124	0.237	0.200	0.686
0.050	0.041	0.126	0.245	0.202	0.702
0.052	0.044	0.128	0.254	0.204	0.717
0.054	0.048	0.130	0.262	0.206	0.733
0.056	0.051	0.132	0.271	0.208	0.750
0.058	0.055	0.134	0.280	0.210	0.766
0.060	0.059	0.136	0.289	0.212	0.783
0.062	0.062	0.138	0.299	0.214	0.799
0.064	0.066	0.140	0.308	0.216	0.816
0.066	0.070	0.142	0.318	0.218	0.833
0.068	0.074	0.144	0.328	0.220	0.851
0.070	0.079	0.146	0.338	0.222	0.868
0.072	0.083	0.148	0.349	0.224	0.886
0.074	0.088	0.150	0.359	0.226	0.904
0.076	0.092	0.152	0.370	0.228	0.922
0.078	0.097	0.154	0.381	0.230	0.940
0.080	0.102	0.156	0.392	0.232	0.959
0.082	0.106	0.158	0.403	0.234	0.978
0.084	0.111	0.160	0.415	0.236	0.997
0.086	0.117	0.162	0.426	0.238	1.016
0.088	0.122	0.164	0.438	0.240	1.035
0.090	0.128	0.166	0.450	0.242	1.055
0.092	0.132	0.168	0.463	0.244	1.074
0.094	0.138	0.170	0.475	0.246	1.094
0.096	0.143	0.172	0.488	0.248	1.114
0.098	0.148	0.174	0.501	0.250	1.135
0.100	0.154	0.176	0.514	0.252	1.156
0.102	0.160	0.178	0.527	0.254	1.176
0.104	0.166	0.180	0.541	0.256	1.197

Table 10

Calibration Data, Velocity Meter A

Time per Revolution sec	Linear Displacement ft	Current Speed fps	Head on Weir ft
6.100	0.781	0.128	0.090
3.870	0.620	0.160	0.102
3.490	0.648	0.185	0.110
3.340	0.678	0.203	0.115
2.420	0.575	0.238	0.124
1.930	0.524	0.272	0.132
1.710	0.536	0.314	0.141
1.180	0.518	0.439	0.164
1.200	0.534	0.445	0.165
1.250	0.611	0.489	0.172
0.980	0.537	0.548	0.181
0.920	0.523	0.569	0.184
0.600	0.490	0.817	0.216
0.540	0.513	0.950	0.231
0.500	0.494	0.988	0.235
0.438	0.480	1.090	0.246
0.380	0.483	1.270	0.263
0.378	0.493	1.300	0.266
0.337	0.477	1.420	0.276
0.331	0.488	1.470	0.281
0.308	0.472	1.530	0.286
0.289	0.471	1.630	0.294
0.259	0.465	1.800	0.307
0.180	0.421	2.340	0.346

Table 11

Calibration Data, Velocity Meter B

Time per Revolution sec	Linear Displacement ft	Current Speed fps	Head on Weir ft
5.400	0.691	0.128	0.090
4.770	0.763	0.160	0.100
3.540	0.655	0.185	0.110
3.640	0.739	0.203	0.115
2.420	0.576	0.238	0.124
1.940	0.545	0.281	0.134
1.660	0.521	0.314	0.141
1.880	0.627	0.334	0.145
1.140	0.500	0.439	0.164
1.280	0.569	0.445	0.165
1.060	0.518	0.489	0.172
0.912	0.500	0.548	0.181
0.935	0.532	0.569	0.184
0.620	0.507	0.817	0.216
0.540	0.513	0.950	0.231
0.822	0.804	0.978	0.234
0.500	0.494	0.988	0.235
0.436	0.475	1.090	0.246
0.380	0.483	1.270	0.263
0.363	0.472	1.300	0.266
0.328	0.466	1.420	0.276
0.316	0.465	1.470	0.281
0.305	0.467	1.530	0.286
0.287	0.468	1.630	0.294
0.255	0.459	1.800	0.307
0.180	0.421	2.340	0.346

Table 12

Residuals, Meter A

Calibration Data

Sample Number	Observed Y	Predicted Y	Residual	Standardized Residual
1	6.10000	4.06440	2.03560	3.04129
2	3.87000	5.04374	-1.17374	-1.75363
3	3.49000	2.86357	0.62643	0.93592
4	3.34000	2.62161	0.71839	1.07331
5	2.42000	2.26365	0.16635	0.24853
6	1.93000	1.98495	-0.05495	-0.08210
7	1.71000	1.73164	-0.02164	-0.03233
8	1.18000	1.25917	-0.07917	-0.11829
9	1.20000	1.24303	-0.04303	0.06428
10	1.25000	3.06898	-1.81898	-2.71764
11	0.98000	1.01979	-0.03979	-0.05945
12	0.92000	0.98397	-0.06397	-0.09557
13	0.60000	0.69760	-0.09760	-0.14582
14	0.54000	0.60440	-0.06440	-0.09622
15	0.50000	0.58228	-0.08228	-0.12293
16	0.43800	0.53035	-0.09235	-0.13798
17	0.38000	0.45862	-0.07862	-0.11746
18	0.37800	0.44855	-0.07055	-0.10541
19	0.33700	0.41243	-0.07543	-0.11270
20	0.33100	0.39908	-0.06808	-0.10172
21	0.30800	0.38419	-0.07619	-0.11383
22	0.28900	0.36175	-0.07275	-0.10868
23	0.25900	0.32918	-0.07018	-0.10486
24	0.18000	0.25651	-0.07651	-0.11431

Note: Nonlinear Regression model: $Y = A \times X^B$

where
- Y = dependent variable, time/rev
- A = parameter value, 0.5756347
- X = independent variable (current, fps)
- B = parameter value, -0.9507830

Table 13

Residuals, Meter B

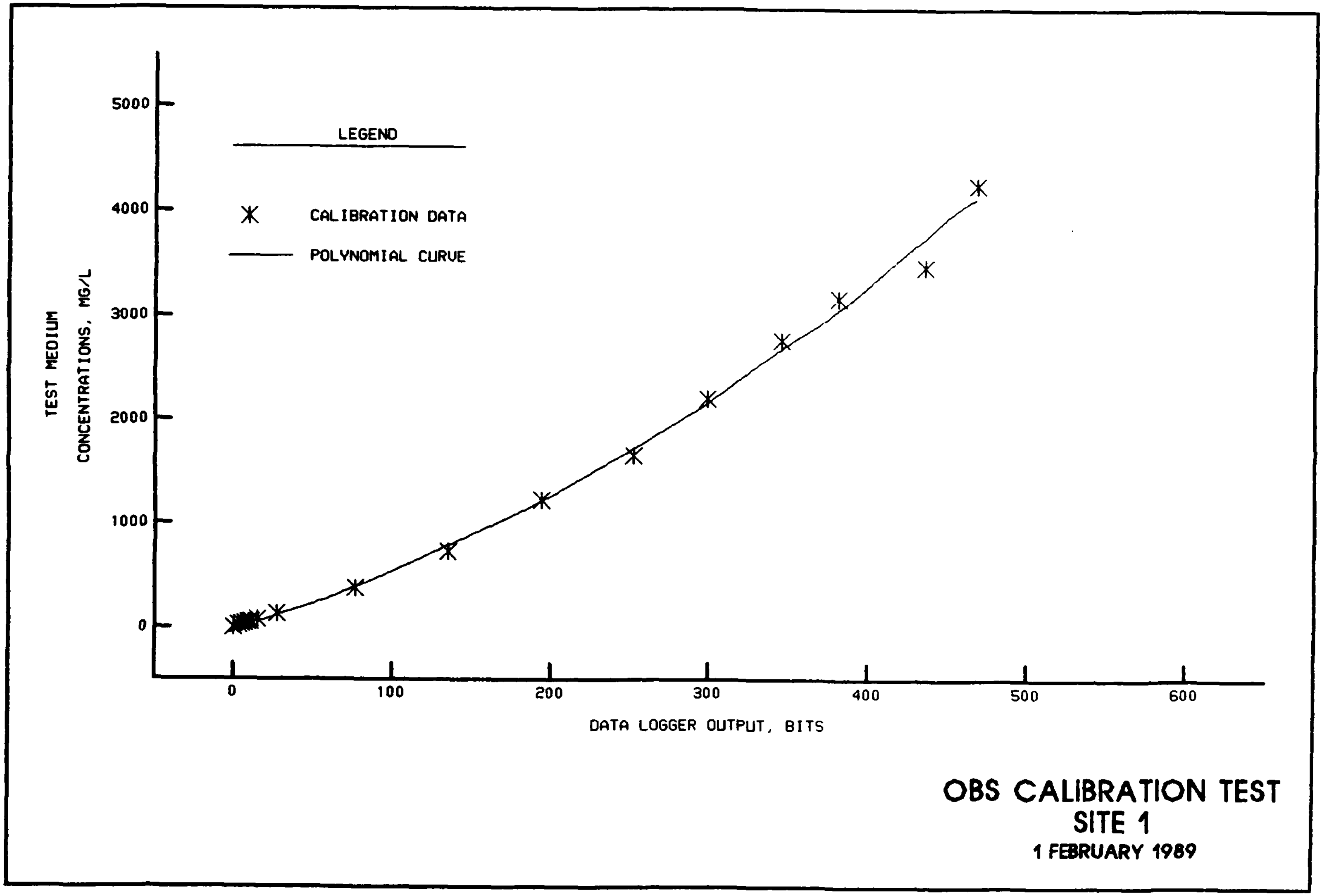
Calibration Data

Sample Number	Observed Y	Predicted Y	Residual	Standardized Residual
25	5.40000	5.50915	-0.10915	-0.23052
26	4.77000	4.12697	0.64303	1.35802
27	3.54000	3.41986	0.12014	0.25373
28	3.64000	3.03254	0.60746	1.28289
29	2.42000	2.46819	-0.04819	-0.10177
30	1.94000	1.99069	-0.05069	-0.10706
31	1.66000	1.72416	-0.06416	-0.13550
32	1.88000	1.59170	0.28830	0.60886
33	1.14000	1.11732	0.02268	0.04790
34	1.28000	1.09785	0.18215	0.38467
35	1.06000	0.97171	0.08829	0.18647
36	0.91200	0.83848	0.07352	0.15527
37	0.93500	0.79864	0.13636	0.28799
38	0.62000	0.49999	0.12001	0.25344
39	0.54000	0.56544	0.02544	0.27753
40	0.50000	0.39095	0.10905	0.23031
41	0.43600	0.34426	0.09174	0.19375
42	0.38000	0.28246	0.09754	0.20600
43	0.36300	0.27405	0.08895	0.18786
44	0.32800	0.24445	0.08355	0.17645
45	0.31600	0.23374	0.08226	0.17372
46	0.30500	0.22194	0.08306	0.17541
47	0.28700	0.20448	0.08252	0.17428
48	0.25500	0.17983	0.07517	0.15874
49	0.18000	0.12805	0.05195	0.10972

Note: Nonlinear Regression model: $Y = A \times X^B$

where

- Y = dependent variable, time/rev
- A = parameter value, 0.3848861
- X = independent variable (current, fps)
- B = parameter value, -1.2945403



LEGEND
CALIBRATION DATA
POLYNOMIAL CURVE
TEST MEDIUM
CONCENTRATIONS, MG/L
5000
4000
3000
2000
1000
0
100
200
300
400
500
600
DATA LOGGER OUTPUT, BITS
OBS CALIBRATION TEST
SITE 1
1 FEBRUARY 1989

PLATE 1

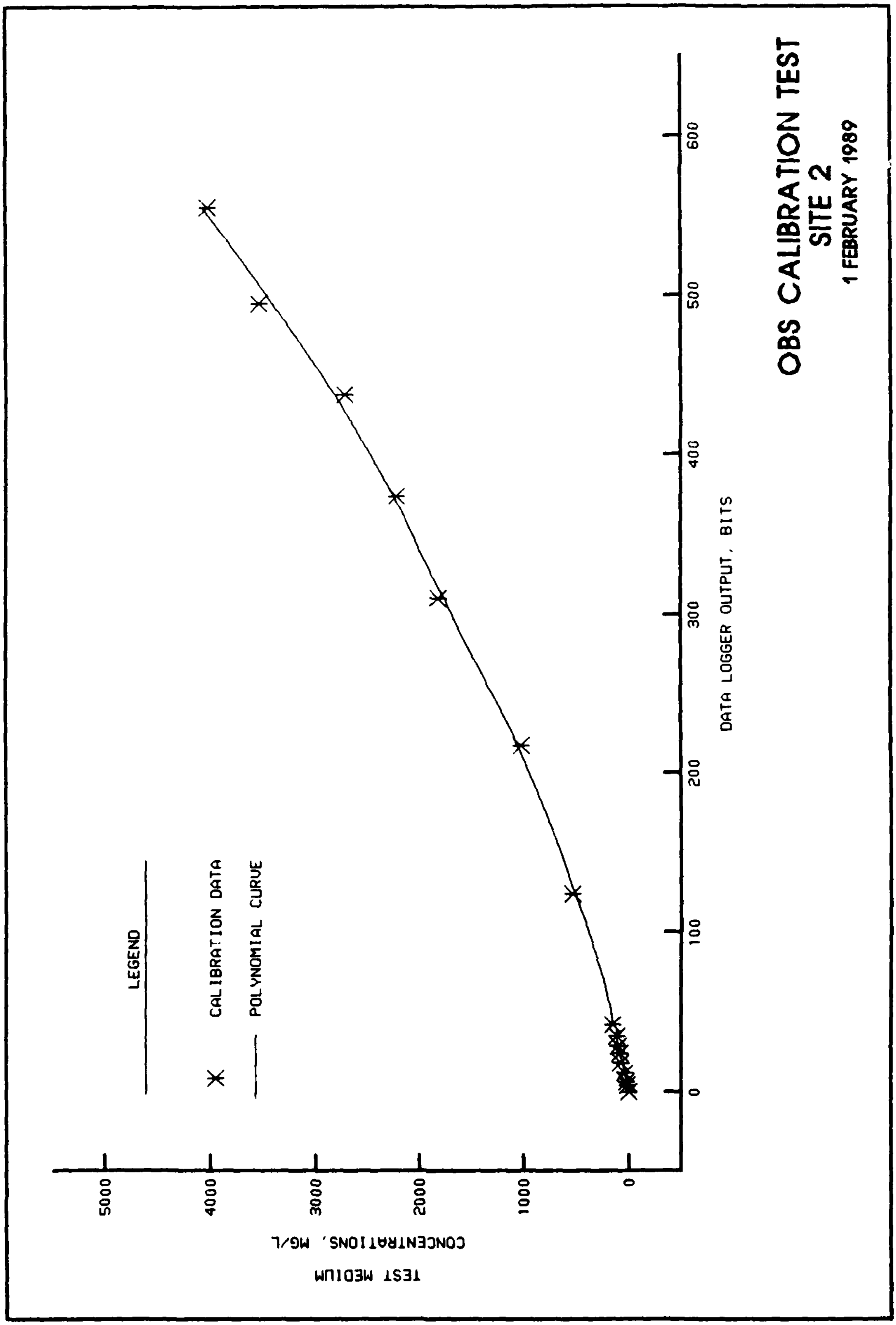

OBS CALIBRATION TEST
SITE 2
1 FEBRUARY 1989
LEGEND
CALIBRATION DATA
POLYNOMIAL CURVE
DATA LOGGER OUTPUT, BITS
TEST MEDIUM
CONCENTRATIONS, MG/L
0
100
200
300
400
500
600
1000
2000
3000
4000
5000

PLATE 2

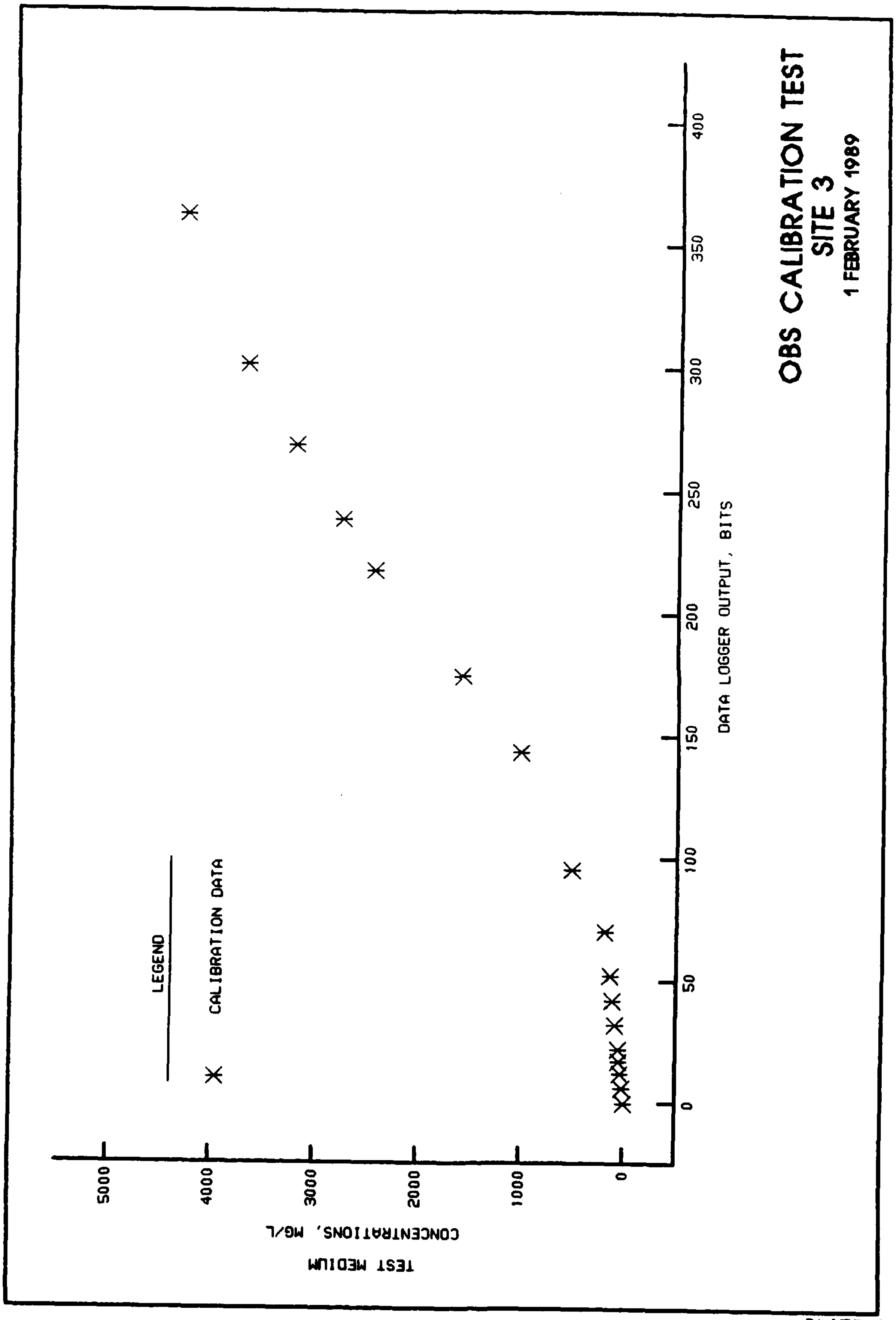

OBS CALIBRATION TEST
SITE 3
1 FEBRUARY 1989
LEGEND
CALIBRATION DATA
DATA LOGGER OUTPUT, BITS
0
50
100
150
200
250
300
350
400
TEST MEDIUM
CONCENTRATIONS, MG/L
0
1000
2000
3000
4000
5000

PLATE 3

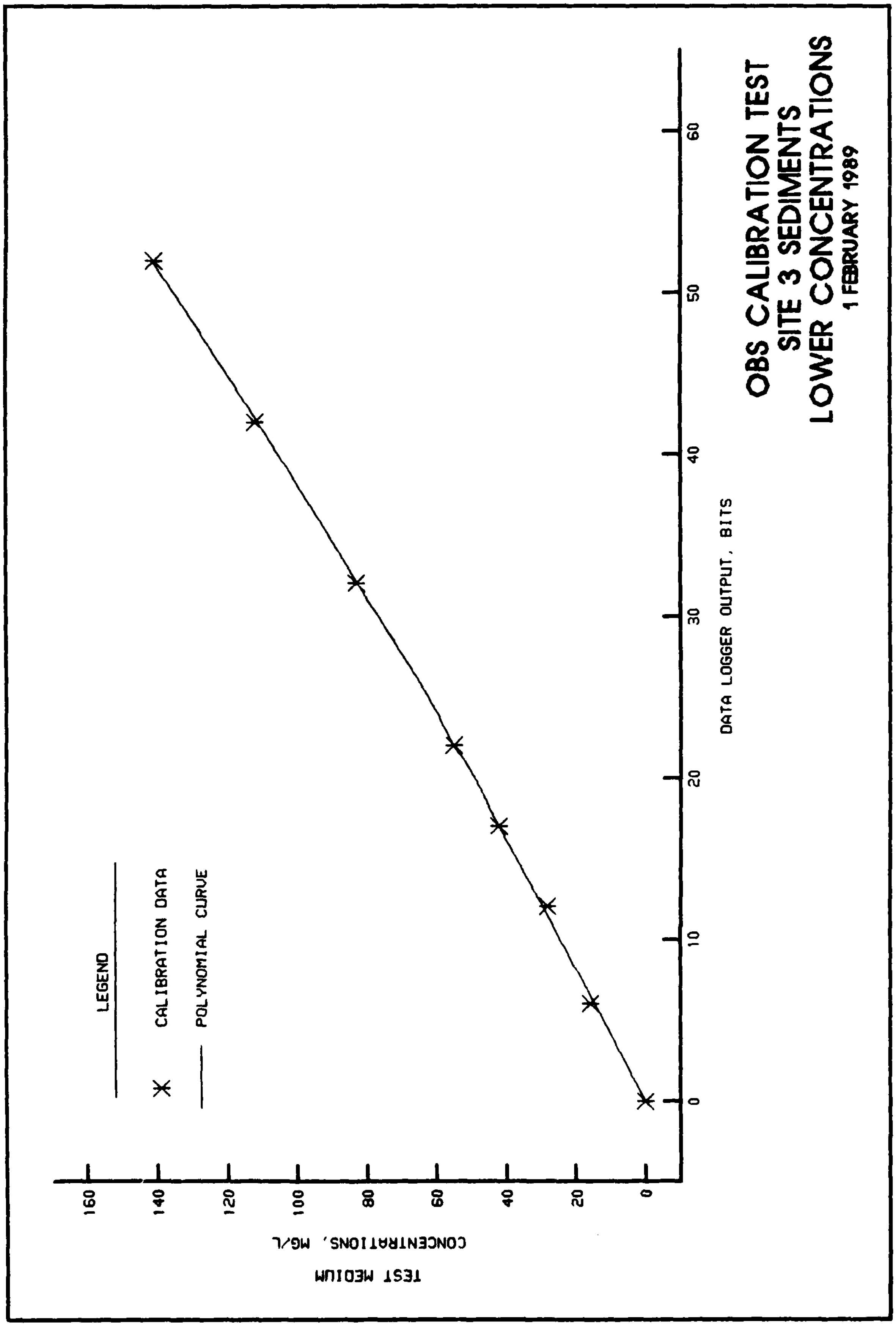
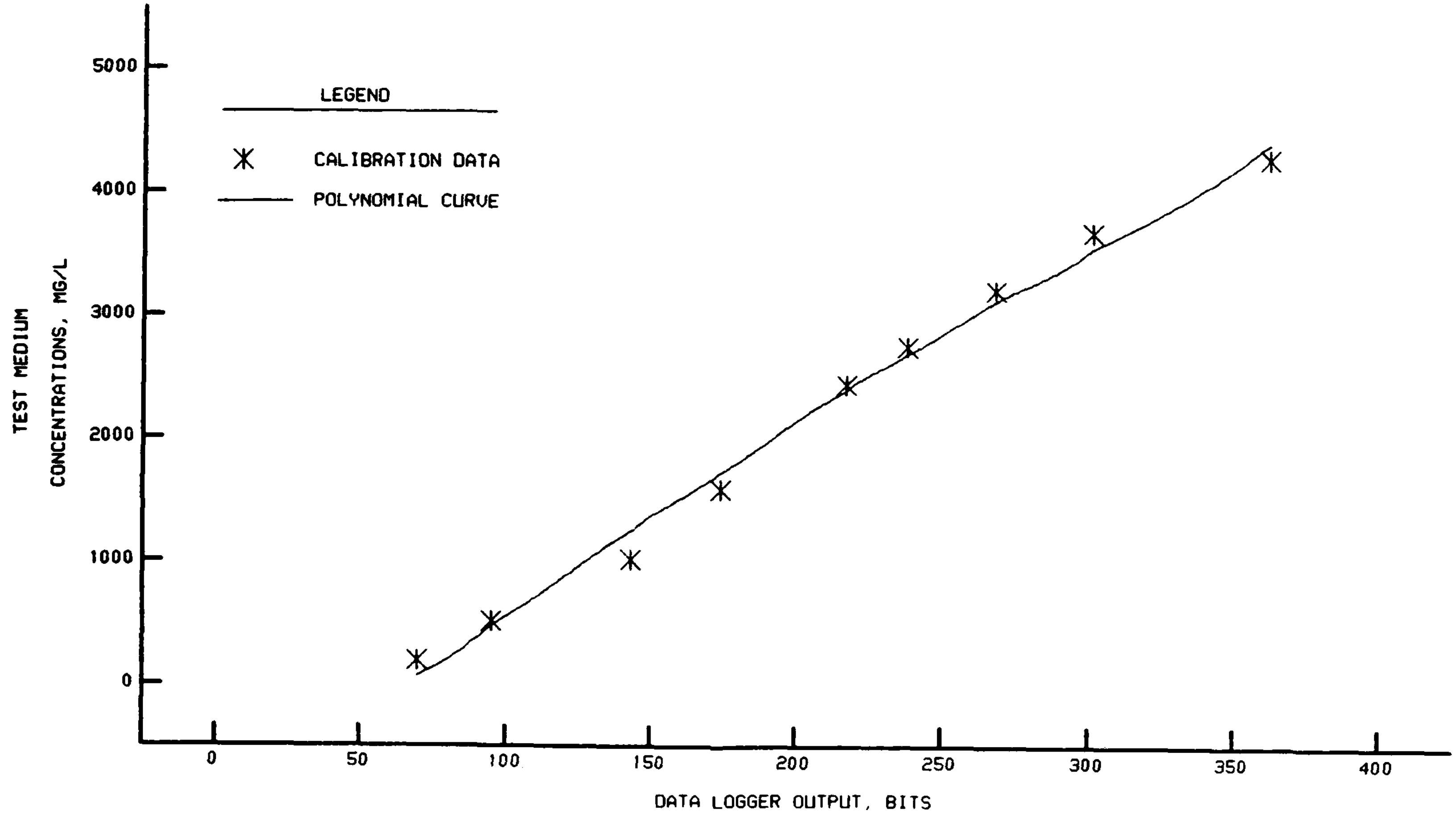

OBS CALIBRATION TEST
SITE 3 SEDIMENTS
LOWER CONCENTRATIONS
1 FEBRUARY 1989
LEGEND
CALIBRATION DATA
POLYNOMIAL CURVE
DATA LOGGER OUTPUT, BITS
0
10
20
30
40
50
60
TEST MEDIUM
CONCENTRATIONS, MG/L
0
20
40
60
80
100
120
140
160

PLATE 4



OBS CALIBRATION TEST
SITE 3 SEDIMENTS
UPPER CONCENTRATIONS
1 FEBRUARY 1989

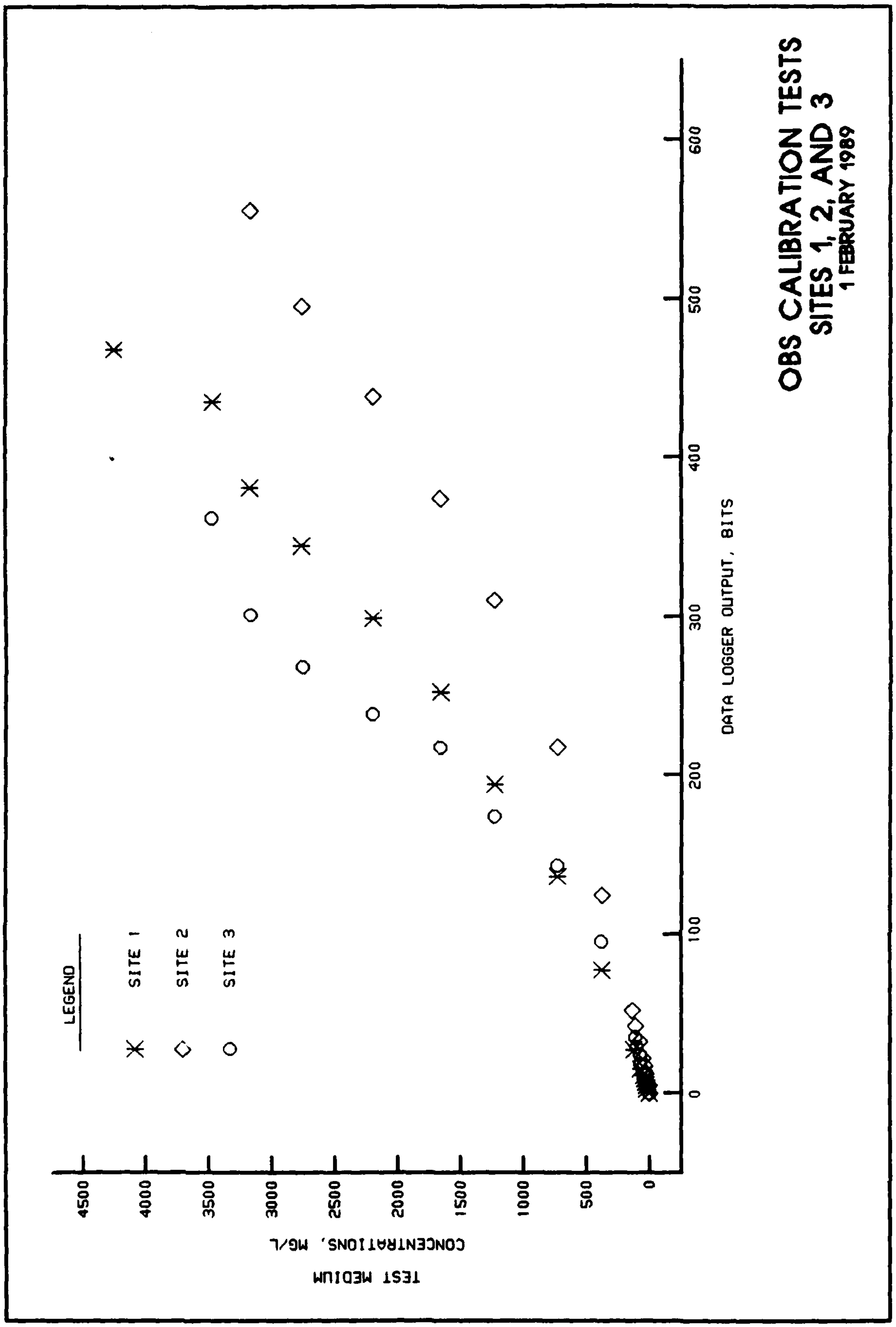
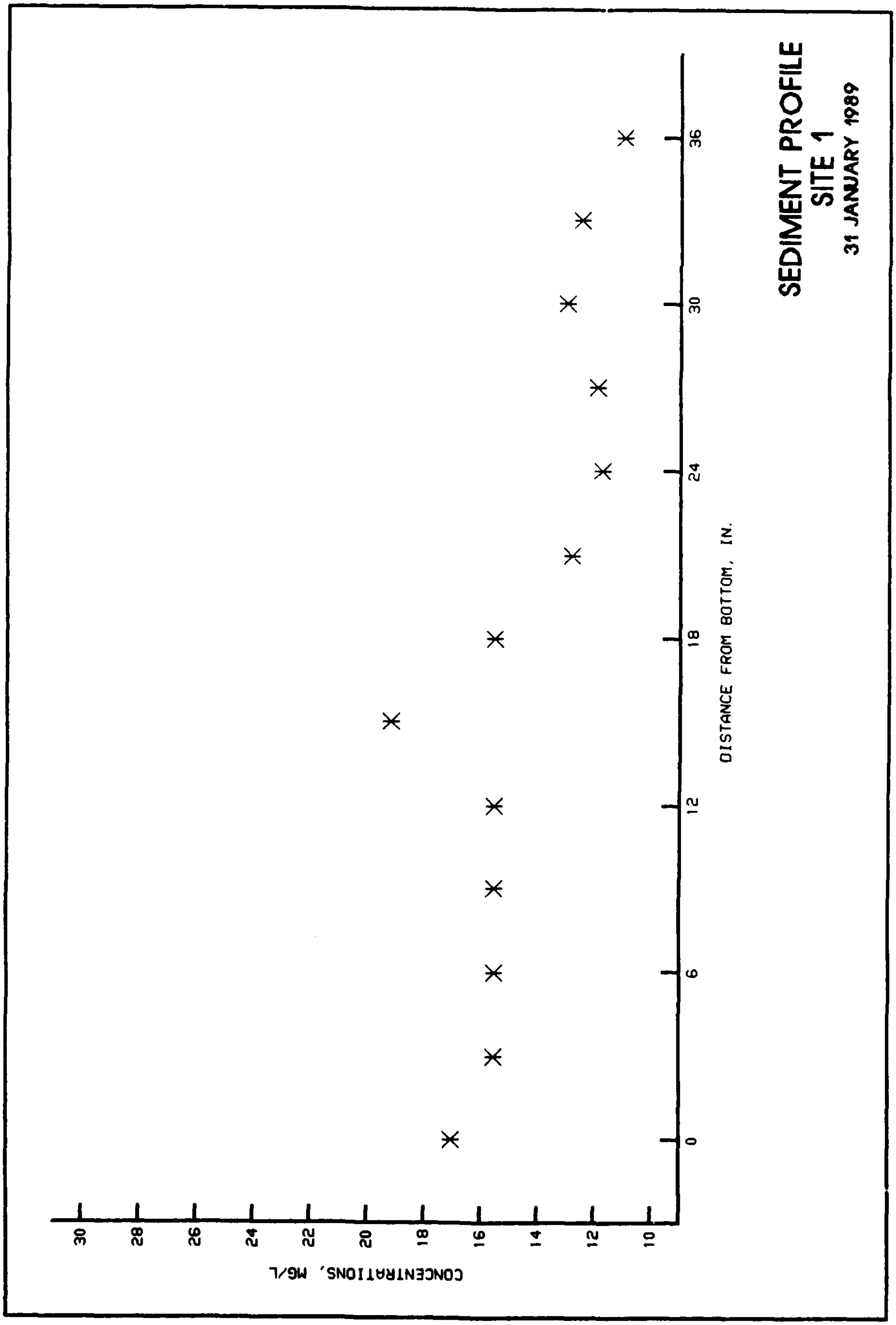

OBS CALIBRATION TESTS
SITES 1, 2, AND 3
1 FEBRUARY 1989
LEGEND
SITE 1
SITE 2
SITE 3
TEST MEDIUM
CONCENTRATIONS, MG/L
DATA LOGGER OUTPUT, BITS
0
500
1000
1500
2000
2500
3000
3500
4000
4500
100
200
300
400
500
600

PLATE 6


SEDIMENT PROFILE
SITE 1
31 JANUARY 1989
DISTANCE FROM BOTTOM, IN.
0
6
12
18
24
30
36
CONCENTRATIONS, MG/L
10
12
14
16
18
20
22
24
26
28
30

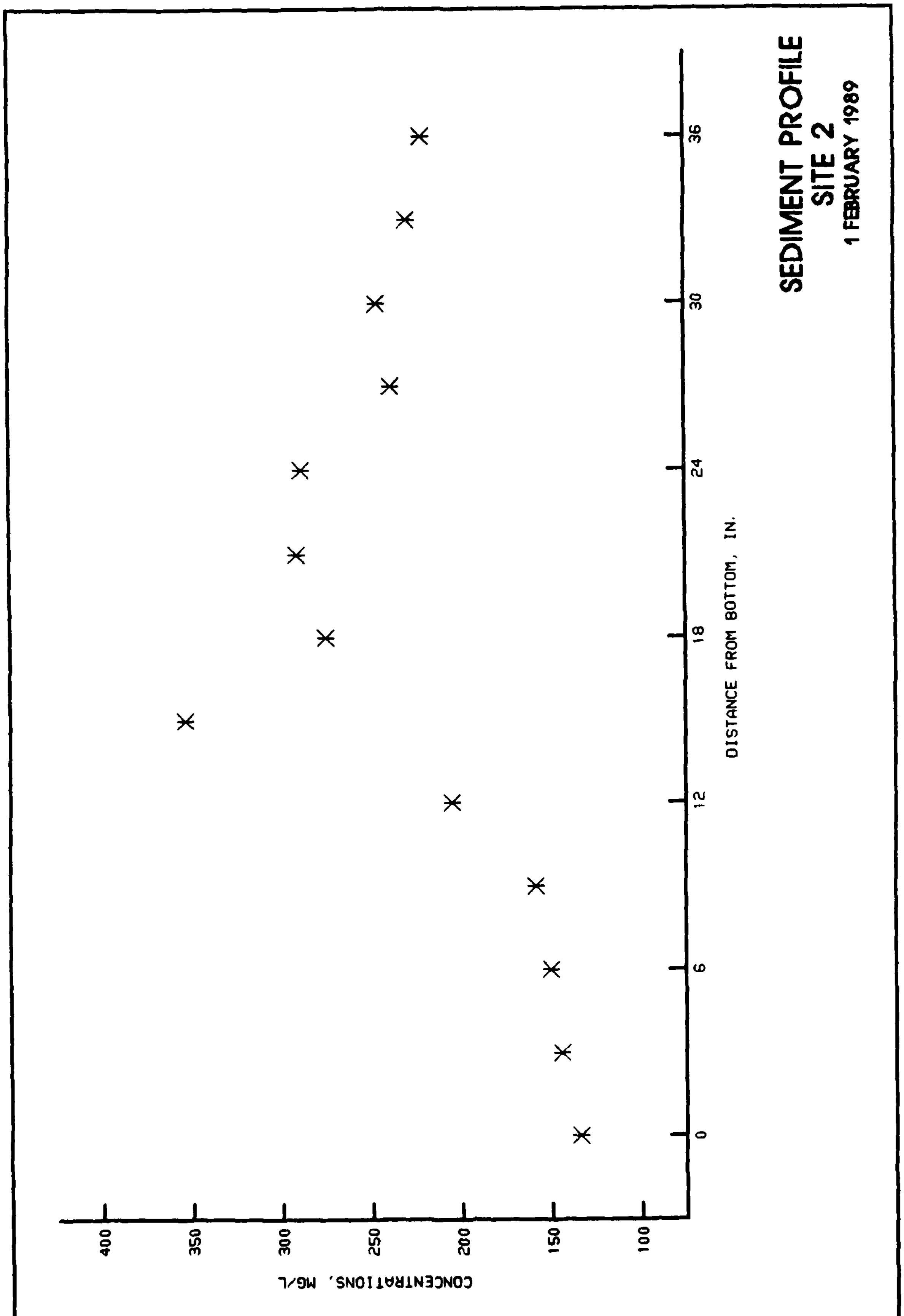

SEDIMENT PROFILE
SITE 2
1 FEBRUARY 1989
DISTANCE FROM BOTTOM, IN.
0
6
12
18
24
30
36
CONCENTRATIONS, MG/L
100
150
200
250
300
350
400

PLATE 8

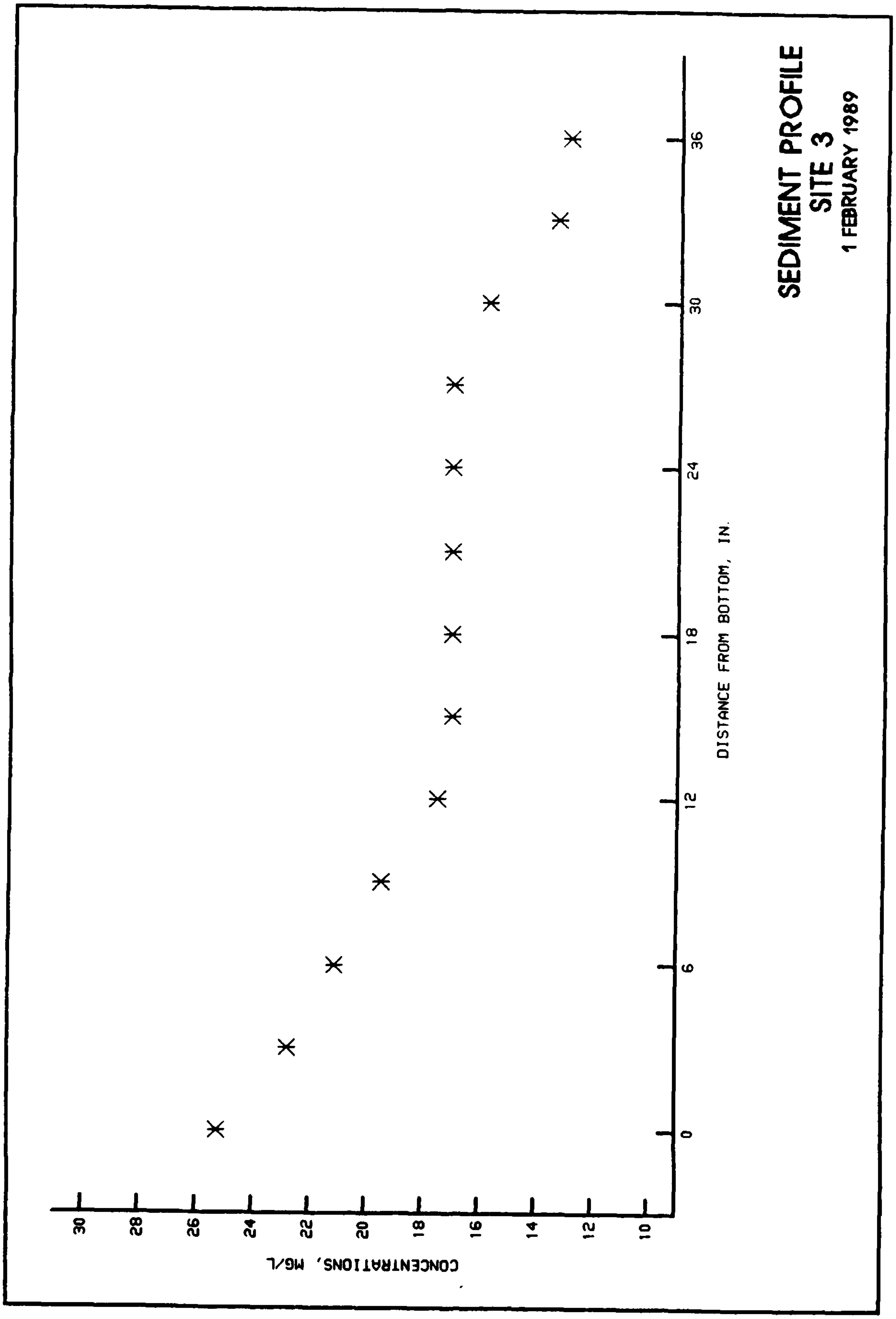

SEDIMENT PROFILE
SITE 3
1 FEBRUARY 1989
CONCENTRATIONS, MG/L
30
28
26
24
22
20
18
16
14
12
10
DISTANCE FROM BOTTOM, IN.
0
6
12
18
24
30
36

PLATE 9

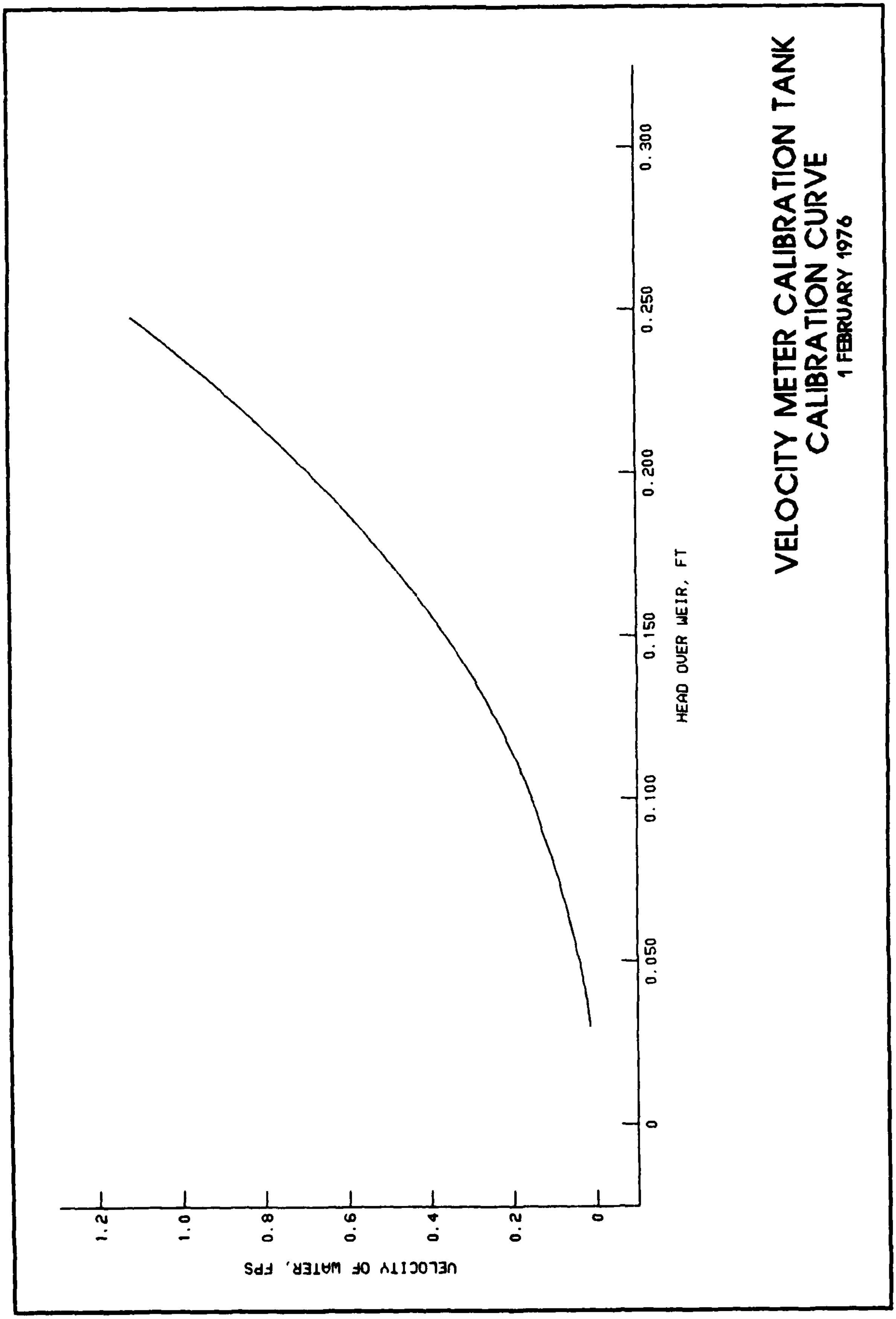
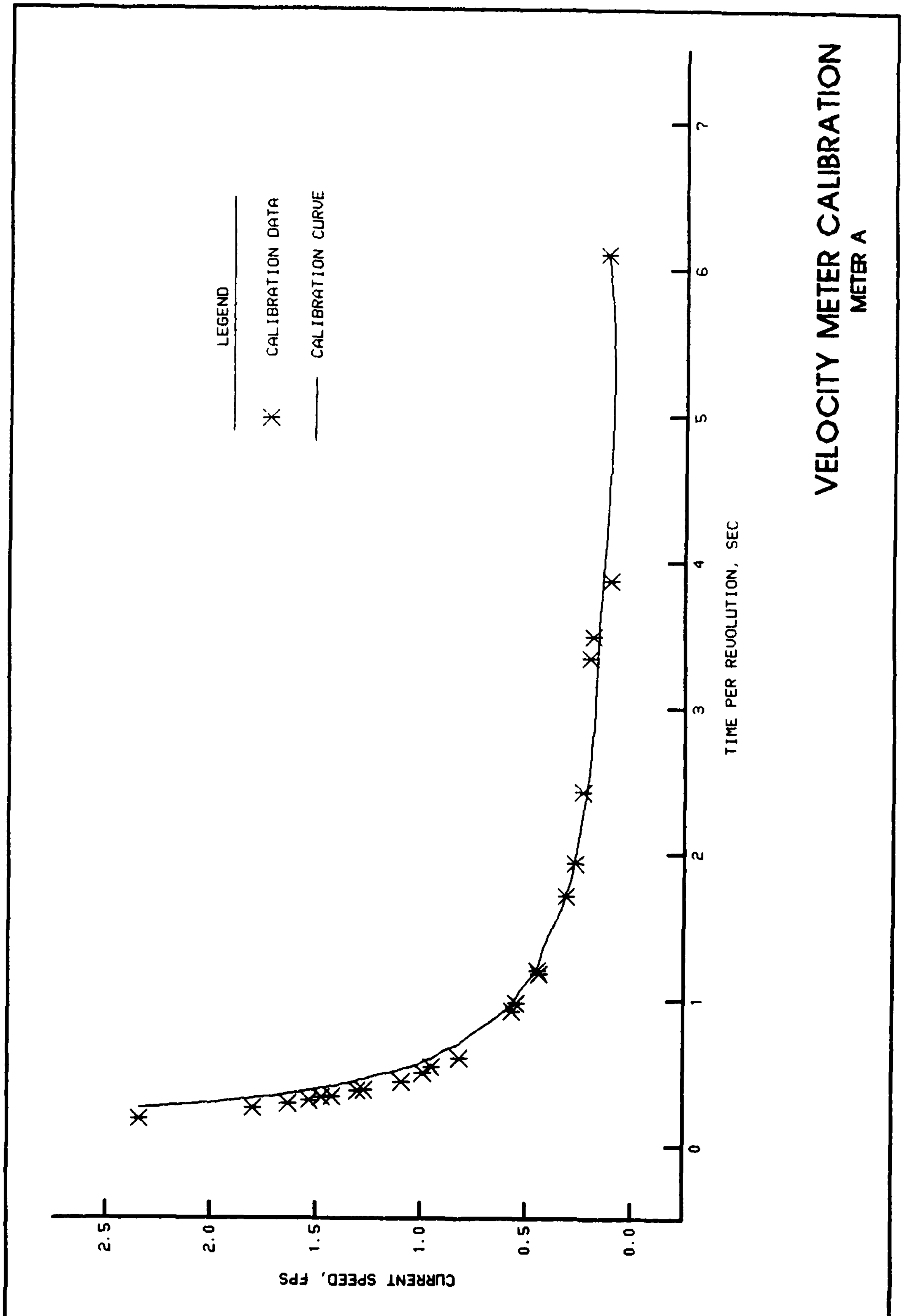

VELOCITY METER CALIBRATION TANK
CALIBRATION CURVE
1 FEBRUARY 1976
HEAD OVER WEIR, FT
0
0.050
0.100
0.150
0.200
0.250
0.300
VELOCITY OF WATER, FPS
0
0.2
0.4
0.6
0.8
1.0
1.2

PLATE 10


VELOCITY METER CALIBRATION
METER A
LEGEND
CALIBRATION DATA
CALIBRATION CURVE
CURRENT SPEED, FPS
0.0
0.5
1.0
1.5
2.0
2.5
TIME PER REVOLUTION, SEC
0
1
2
3
4
5
6
7

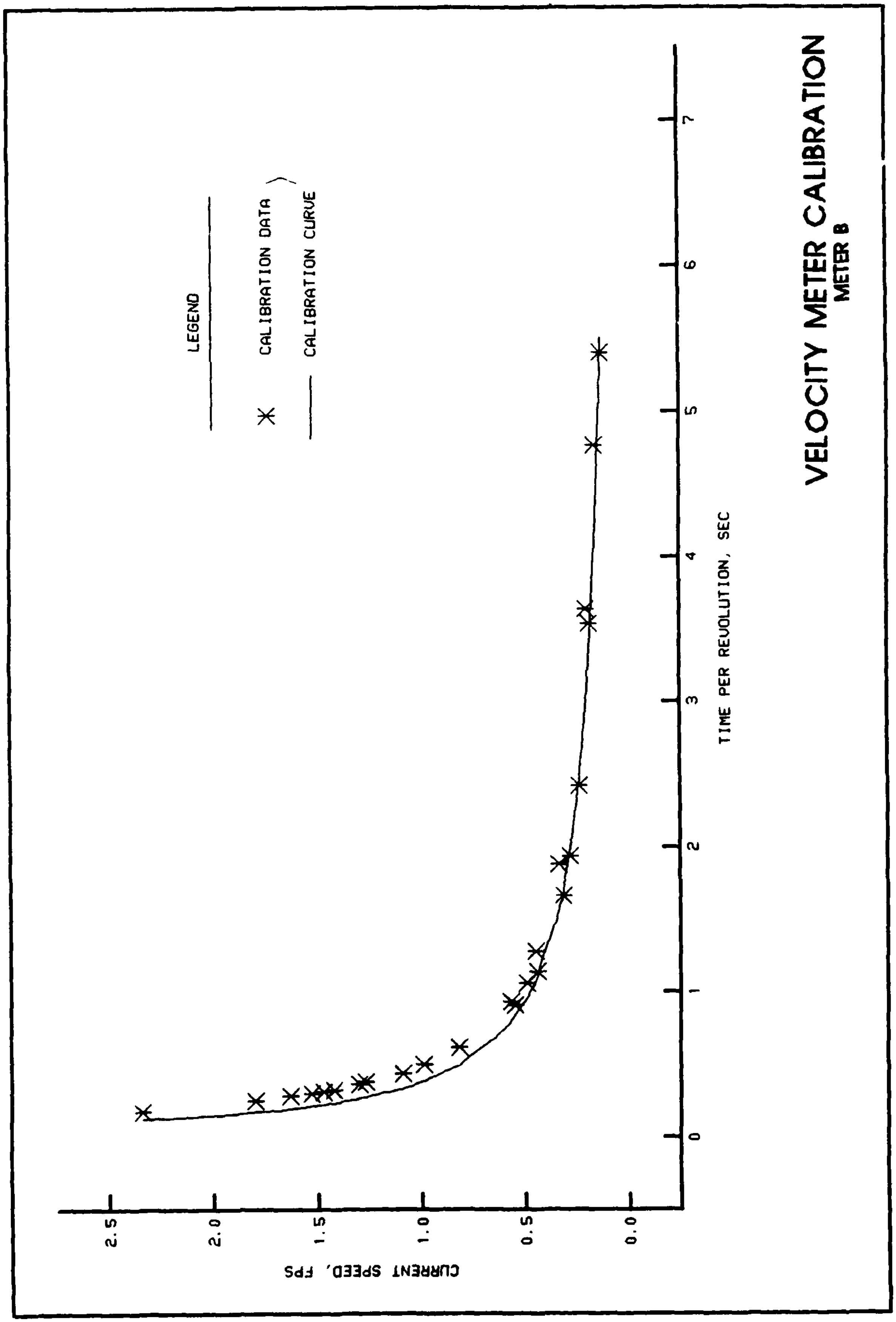

VELOCITY METER CALIBRATION
METER B
LEGEND
CALIBRATION DATA
CALIBRATION CURVE
TIME PER REVOLUTION, SEC
0
1
2
3
4
5
6
7
CURRENT SPEED, FPS
0.0
0.5
1.0
1.5
2.0
2.5

PLATE 12