NOAA Technical Memorandum NOS 20

TEST AND EVALUATION OF THE INTEROCEAN SYSTEMS, INC. MODEL 500 CTD/O_2 pH IN-SITU MONITOR SYSTEM

Washington, D.C.
August 1976

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NOS 12 Trends and Variability of Yearly Mean Sea Level 1893-1971. Steacy D. Hicks, March 1973. (COM-73-10670)

NOS 13 Trends and Variability of Yearly Mean Sea Level 1893-1972. Steacy D. Hicks and James E. Crosby, March 1974. (COM-74-11012)

NOS 14 Some Features of the Dynamic Structure of a Deep Estuary. Michael Devine, April 1974. (COM-74-10885)

NOS 15 An Average, Long-Period, Sea-Level Series for the United States. Steacy D. Hicks and James E. Crosby, September 1975. (COM-75-11463)

(Continued on inside back cover)

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TEST AND EVALUATION OF THE INTEROCEAN SYSTEMS, INC. MODEL 500 CTD/O_2 pH IN-SITU MONITOR SYSTEM

Barbara S. Pijanowski

National Oceanoraphic
Instrumentation Center
Washington, D. C.
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DEPARTMENT OF COMMERCE
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CONTENTS

ILLUSTRATIONS

TEST AND EVALUATION OF THE INTEROCEAN SYSTEMS, INC. MODEL 500 CTD/O_2 pH IN-SITU MONITOR SYSTEM

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National Ocean Survey, NOAA, Washington, D.C.

ABSTRACT. Test and evaluation results are reported for a system which is designed to measure temperature, conductivity, depth, dissolved oxygen, and pH to depths of 100 meters. The system is described and manufacturer's specifications are listed along with representative performance data such as accuracy, stability, power variation, and environmental effects for the five parameters. In addition, an extended performance summary is provided which details the history of the system, the modifications required during the course of the testing program, and a list of required replacement parts. General comments are offered for the benefit of potential and current users.

DESCRIPTION OF SYSTEM

The InterOcean Model 500 Monitor System is a marine instrument designed to measure *in-situ* and record conductivity, temperature, depth, dissolved oxygen, and pH. The system, which can operate to depths of 100 meters, consists of a Model 514A Readout, a Model 513D Probe, and an interconnecting cable.

The Model 514 Readout is a portable unit which incorporates four analog meters for continuous and simultaneous monitoring of conductivity, temperature, depth, and either pH or dissolved oxygen depending on the position of a selector switch. There is also a four-and-one-half-digit display for individual monitoring of any one of the parameters. The digital display incorporates automatic decimal point location, automatic polarity indication, and an illuminated indicator to show the parameter being displayed. The digital display can also be set to sequentially scan all parameters. Two output connectors are provided for use with (1) an analog recorder and (2) with either a digital printer or a paper tape punch.

The Model 513D Probe contains all five sensors to provide *in-situ* measurements of conductivity, temperature, depth, dissolved oxygen and pH. These and other combinations of sensors are available. The probe utilizes an internal electronics package with all circuitry required to convert the sensor signals to output signals for display directly in appropriate engineering units. Conductivity is measured by the inductive torroid coil technique, temperature by use of a linearized thermistor array, and depth by a bonded strain gauge pressure transducer. The dissolved oxygen sensor is a voltaic polarographic membrane type with a platinum/gold electrode combination, and the pH sensor incorporates reference and measuring electrodes into a single unit. The 100-meter interconnecting cable is a twelve-conductor, stranded cable covered by a neoprene jacket with a stainless steel braided strength member.

The manufacturer's performance specifications for the system are listed in Appendix A.

EXTENDED PERFORMANCE SUMMARY

History of Acquisition

The system evaluated in this report was originally purchased by the U.S. Coast Guard from InterOcean Systems, Inc. in early 1973. In February 1974, NOIC borrowed the unit for evaluation and, at that time, returned it to the manufacturer who indicated that the unit did not reflect recent modifications in units they were currently marketing. NOIC funded the appropriate modifications.

The modifications to make the model 513A probe equivalent to the Model 513D probe and the Model 514A readout unit equivalent to the models on the market at that time consisted of (1) replacement of pH sensor with updated unit, (2) interfacing new circuit boards into the unit for the pH and dissolved oxgyen probes, (3) modifying additional wiring on the mother circuit board in the underwater unit, and (4) adjustment of the readout unit to accommodate the modifications. Details concerning these modifications are included in Appendix B.

The modified unit[1] was returned to NOIC in May 1974 with revised manuals. The system was checked out in the laboratory using operational procedures detailed in the manual and was found to satisfy criteria for acceptable performance. Testing was then begun.

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[1]Model 513D Probe: S/N 2339052
Model 514D Readout Unit: S/N 2329080

Representative Performance Data[2,3]

Temperature

Test range: 0° to 40°C

Reading uncertainity

Analog meter: ±0.5°C

Digital display: ±0.01°C

Calibration errors
(Refer to figure 1.)

Nonrepeatability:
±0.02°C at 20°C

Nonlinearity: ±0.04°C

Long term stability (3 mo.)
(Refer to figure 1.)

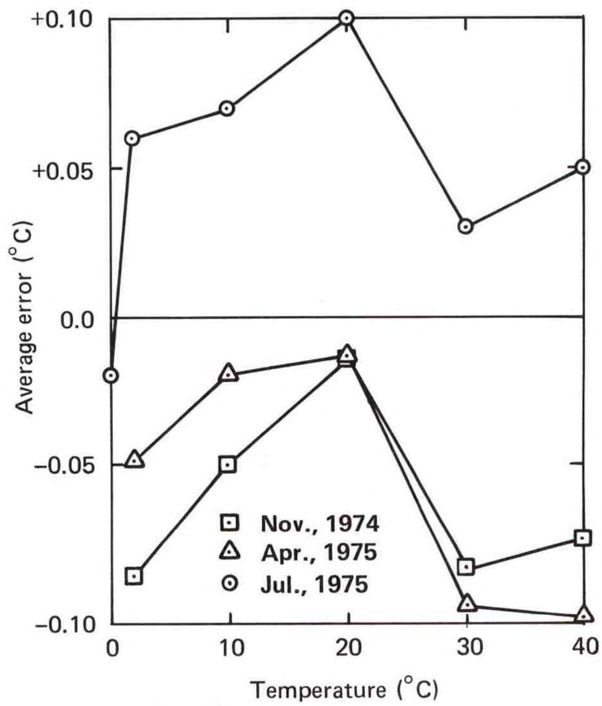

Figure 1.--Temperature calibration error.

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[2]All test results are worst case averages of three or more cycles unless otherwise specified.

[3]The impedance of the cable should be taken into account during calibration, i.e., the cable should be part of the system when calibration is carried out.

Conductivity

Test range	0 to 65 mmho/cm
Reading uncertainty	
Analog meter	±0.5 mmho/cm
Digital display	±0.01 mmho/cm
Calibration errors	Refer to figure 2.
Nonrepeatability	±0.04 mmho/cm at 2°, 20°, 40°C
Nonlinearity (at 20°C)	±0.01 mmho/cm
Long term stability (3 months)	Refer to figure 3.

Depth[4]

Test range	0 to 100 m
Reading uncertainty	
Analog meter	±1 m
Digital display	±0.1 m
Calibration errors	Refer to figure 4.
Nonrepeatability (at 20°C)	±0.35 m at 85.5 m
Nonlinearity (20°C)	±0.27 m
Hysteresis (at 20°C)	0.38 m
Long term stability	Refer to figure 5.

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[4] In these data, depth was converted to pressure by the following relationship: 1.462 psi = 1 m

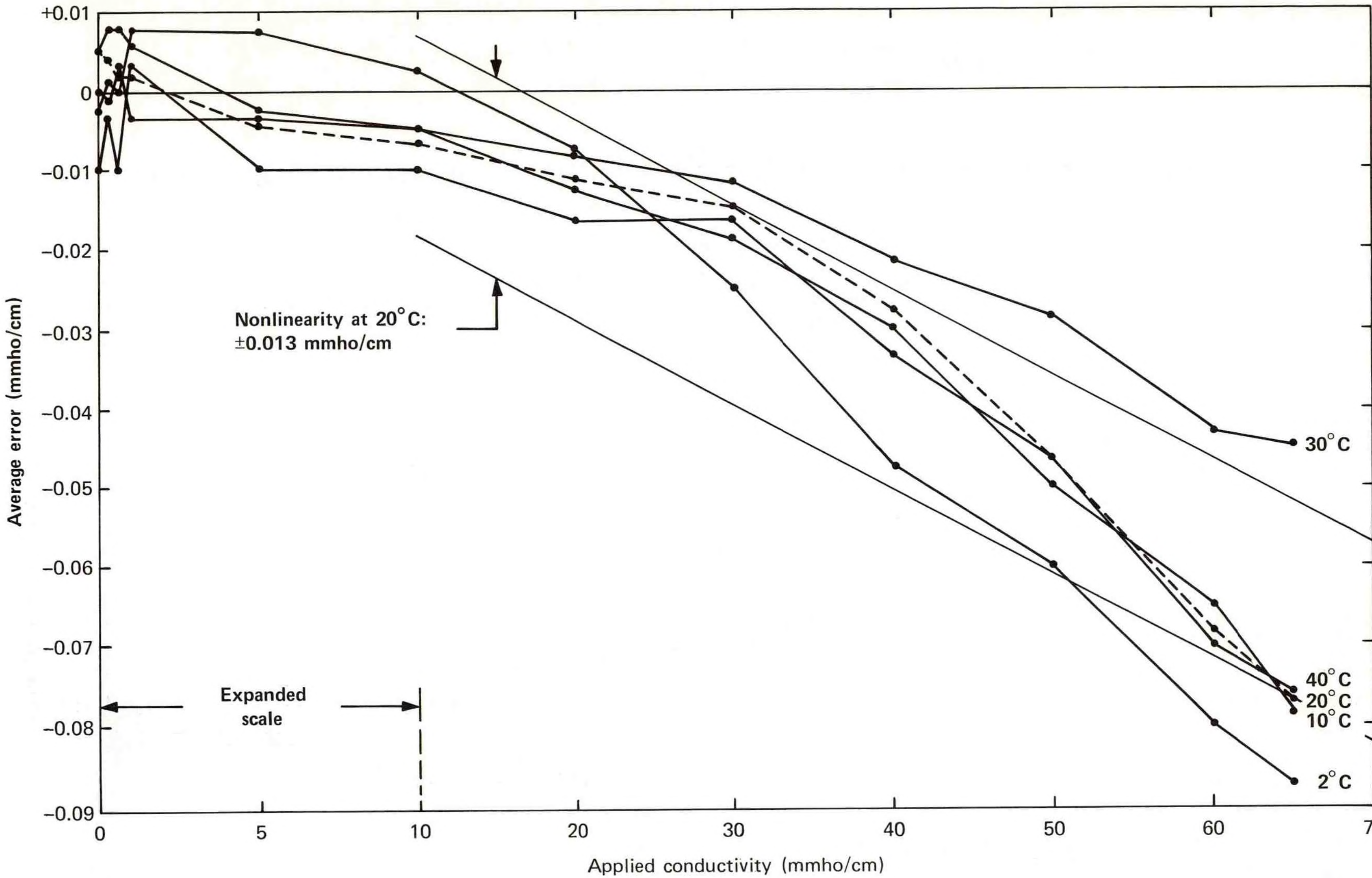

Figure 2.--Conductivity calibration error, wire-loop technique, April, 1975.

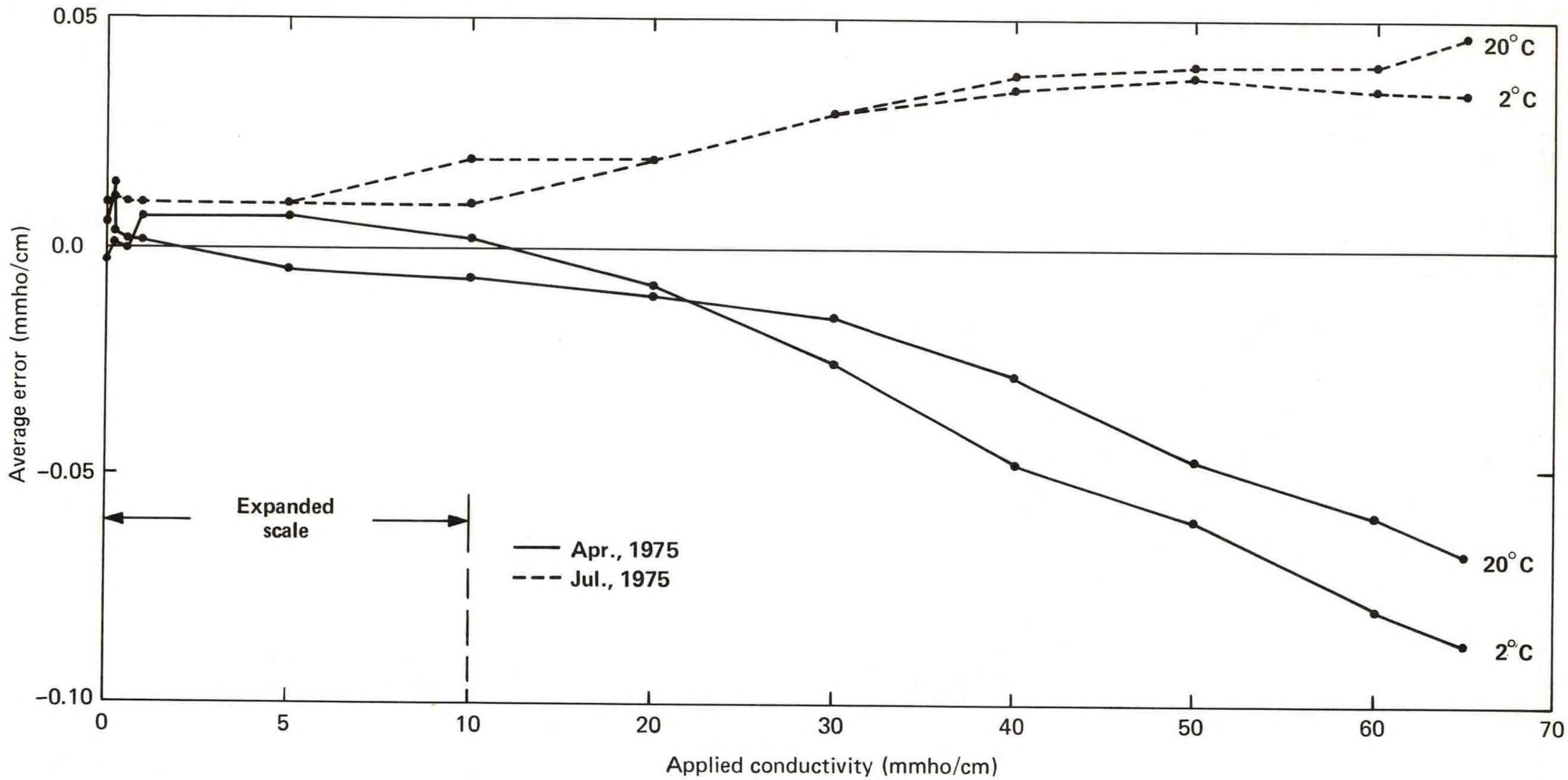

Figure 13.--Conductivity calibration error, long-term stability, wire-loop technique.

Dissolved Oxygen

Test range	0 to 14 ppm (0° to 40°C)
Reading uncertainty	
Analog meter	±0.25 ppm
Digital display	±0.01 ppm
Time constant	Refer to figure 6.
Calibration errors[5]	Refer to figure 7.
Nonrepeatability	
Saltwater average:	±0.1 ppm
Worst case:	±0.3 ppm at 0 and 28°C
Freshwater average:	±0.2 ppm
Worst case:	±0.4 ppm at 2°C

pH

Test range	pH 4 to 10
Reading uncertainty	
Analog meter	±0.25 pH
Digital display	±0.01 pH

---

[5]Dissolved oxygen calibration errors and nonrepeatability data were obtained from instrument readings in a bath where the concentration of dissolved oxygen was established as follows: A water bath was saturated with a gas mixture of O_2 and N_2 at temperatures of 0°, 10°, 20°, 30°, and 40°C; this saturation process and temperature cycling was repeated two or more times in baths of 0.5 - and 35 - ppt salinity. Three different gas mixtures (20.95, 4, and 8% of O_2 in N_2) were used to saturate baths which were temperature cycled in this manner to obtain a complete range of dissolved oxygen. Numerical values for dissolved oxygen in saturated seawater as functions of temperature and salinity were obtained from Gilbert, Pawley, and Park,1967: Carpenter's oxygen solubility table and nomography for seawater as a function of temperature and salinity. Oceanographical Society of Japan, 23(5) 252-255.

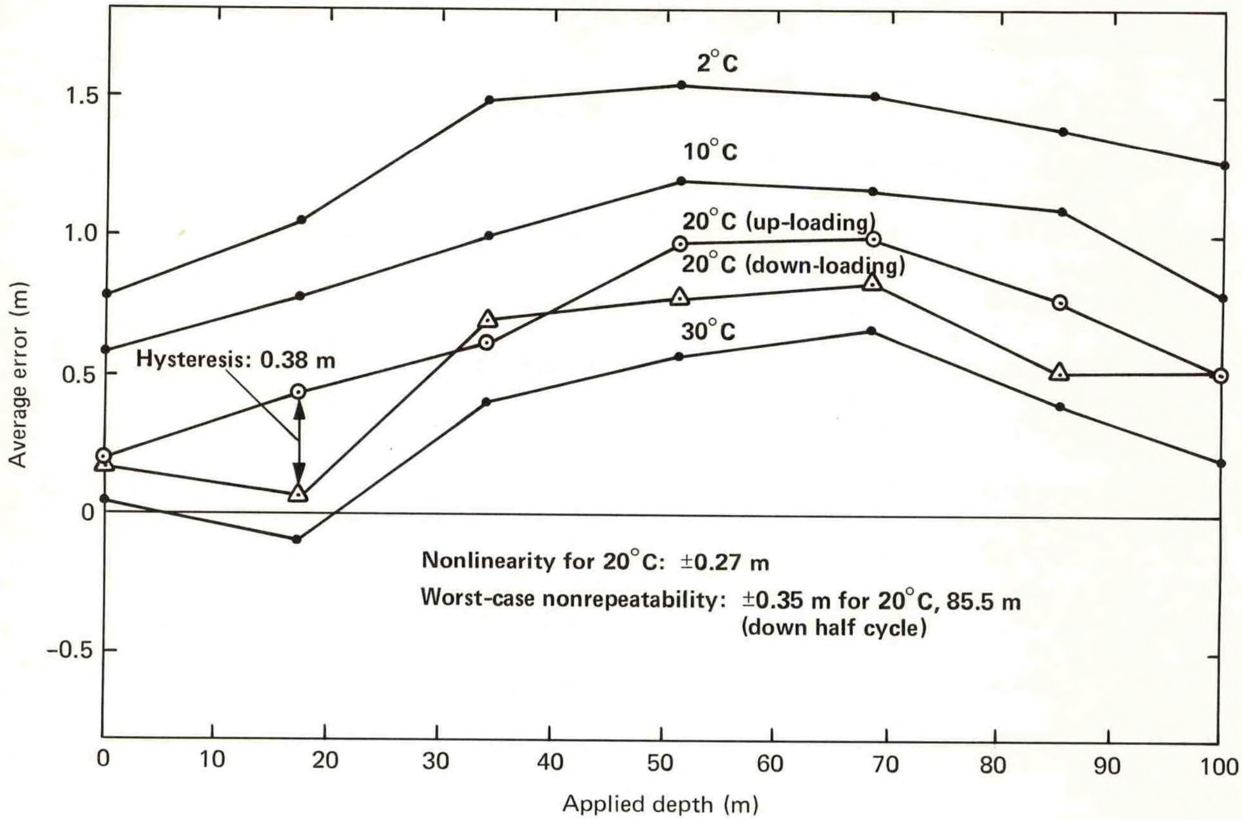

Figure 4.--Depth calibration error.

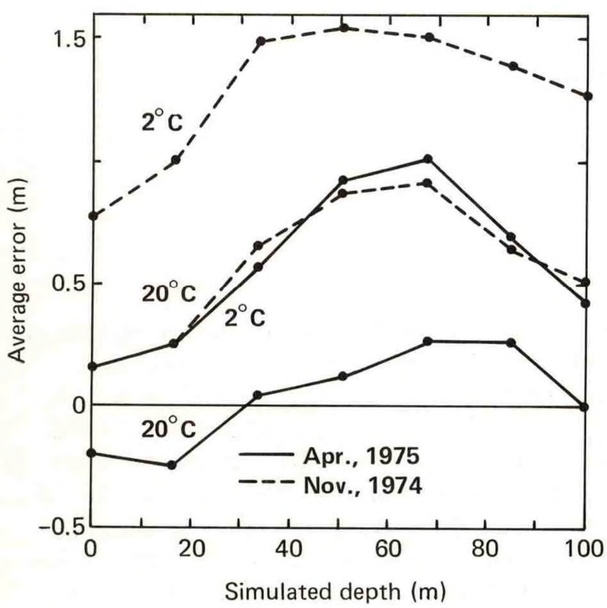

Figure 5.--Depth calibration error, long-term stability.

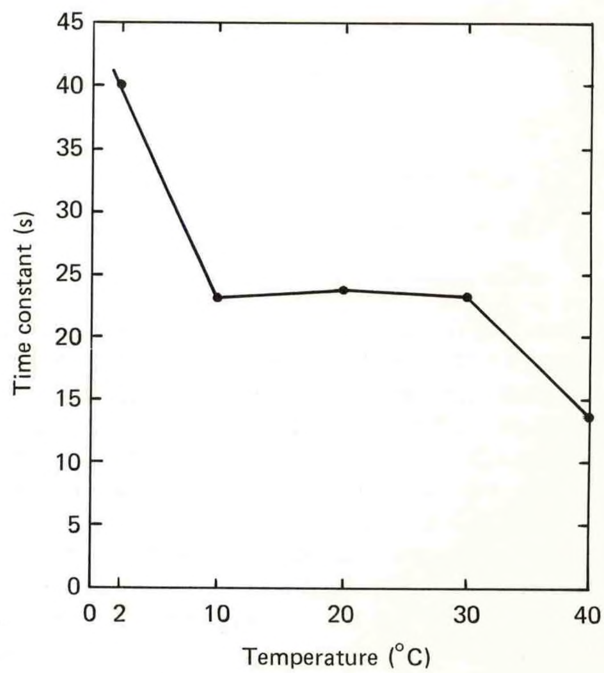

Figure 6.--Dissolved oxygen time constant.

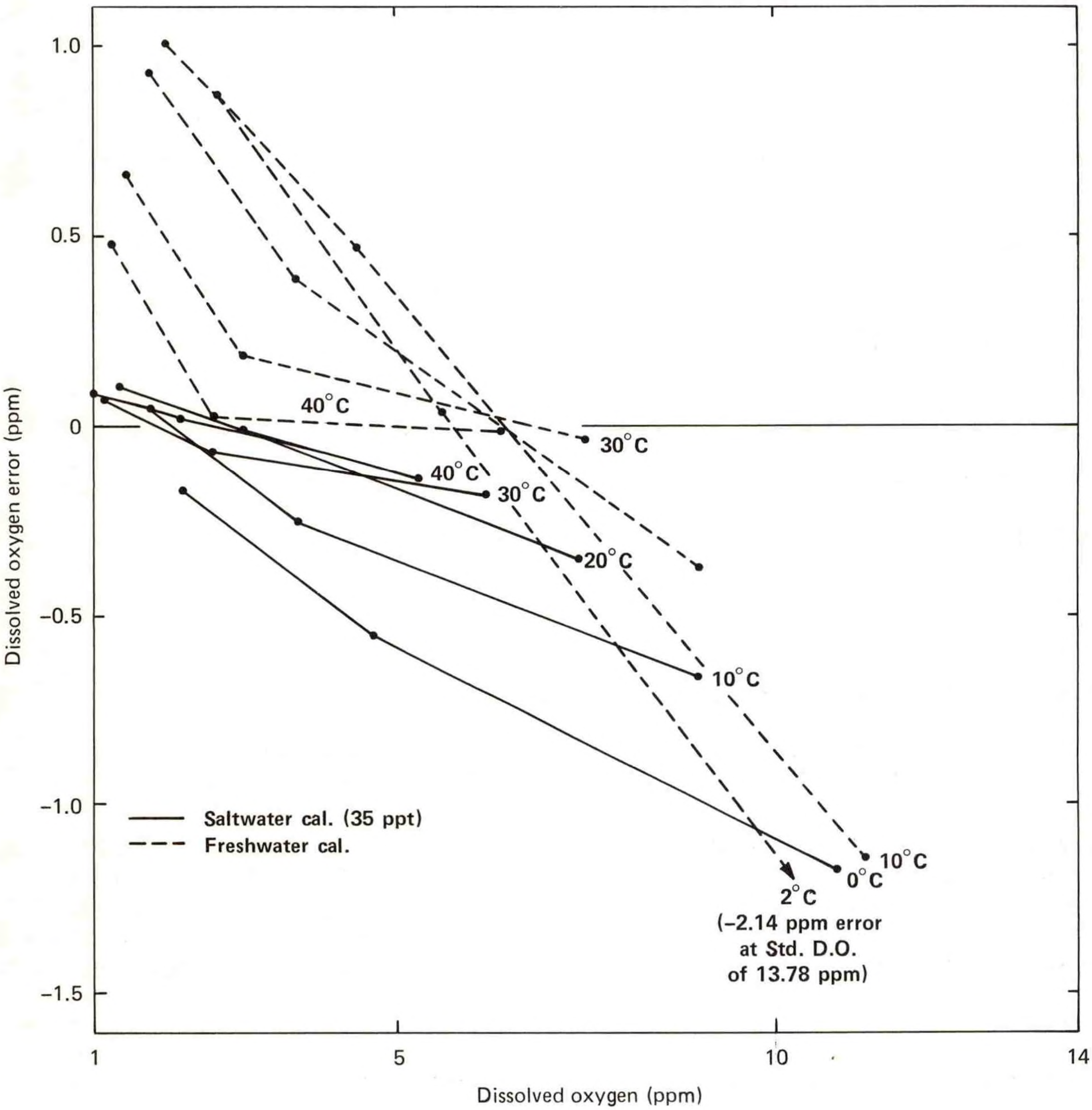

Figure 7.--Dissolved oxygen calibration error, original sensor

Time constant

(Refer to figure 8.)

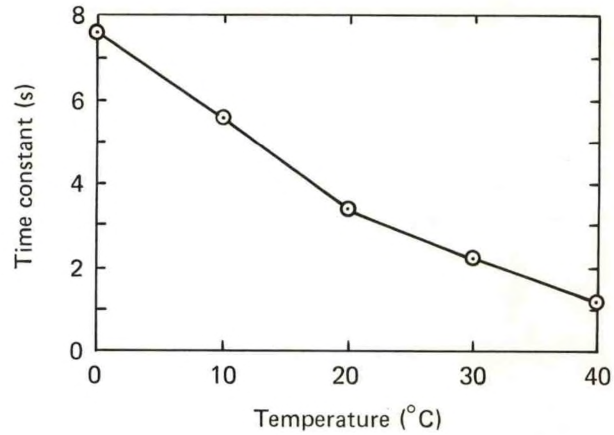

Figure 8.--pH time constant

Calibration errors[6,7]

(Refer to figure 9.)

Nonrepeatability	
Average at pH 7	+0.06 pH
Worst case at pH 7	±0.12 pH at 20°C
Pressure effect[6]	Refer to figure 10.
Effect of power supply variation[6] (12 VDC ± 20%)	Refer to figure 11.

Environmental Effects on the readout unit (digital display)[8]

Temperature (0° to 70°C)

Cond.	-0.06 mmho/cm at 49°C
Temp.	-0.09°C at 70°C
D.O.	+1.00 ppm at 0°C
pH	-0.08 pH at 49°C
Depth	-0.08 m at 49°C

Relative humidity (R.H.) (0-to 95-% R.H. referenced to 54°C, 0% R.H.)

Cond.	+0.03 mmho/cm at 20°C,95% R.H.
Temp.	+0.17°C at 20°C, 95% R.H.
D.O.	+1.3 ppm at 20°C, 50%, R.H.
pH.	+0.03 pH at 20°C, 50% & 90% R.H.
Depth	+0.9 m at 20°C, 50% R.H.

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[6] Refer to General Comments section for additional information.

[7] For greatest accuracy, the unit was calibrated with buffers of pH 7 and 4 to establish curves 1, 2 and 3 and buffers of pH 7 and 10 to establish curve 4.

[8] Environmental tests were run by substituting fixed inputs in place of the sensors and subjecting the deck unit to various environmental conditions according to a slightly modified verision of MIL SPEC 810C. (Worst case errors are cited.)

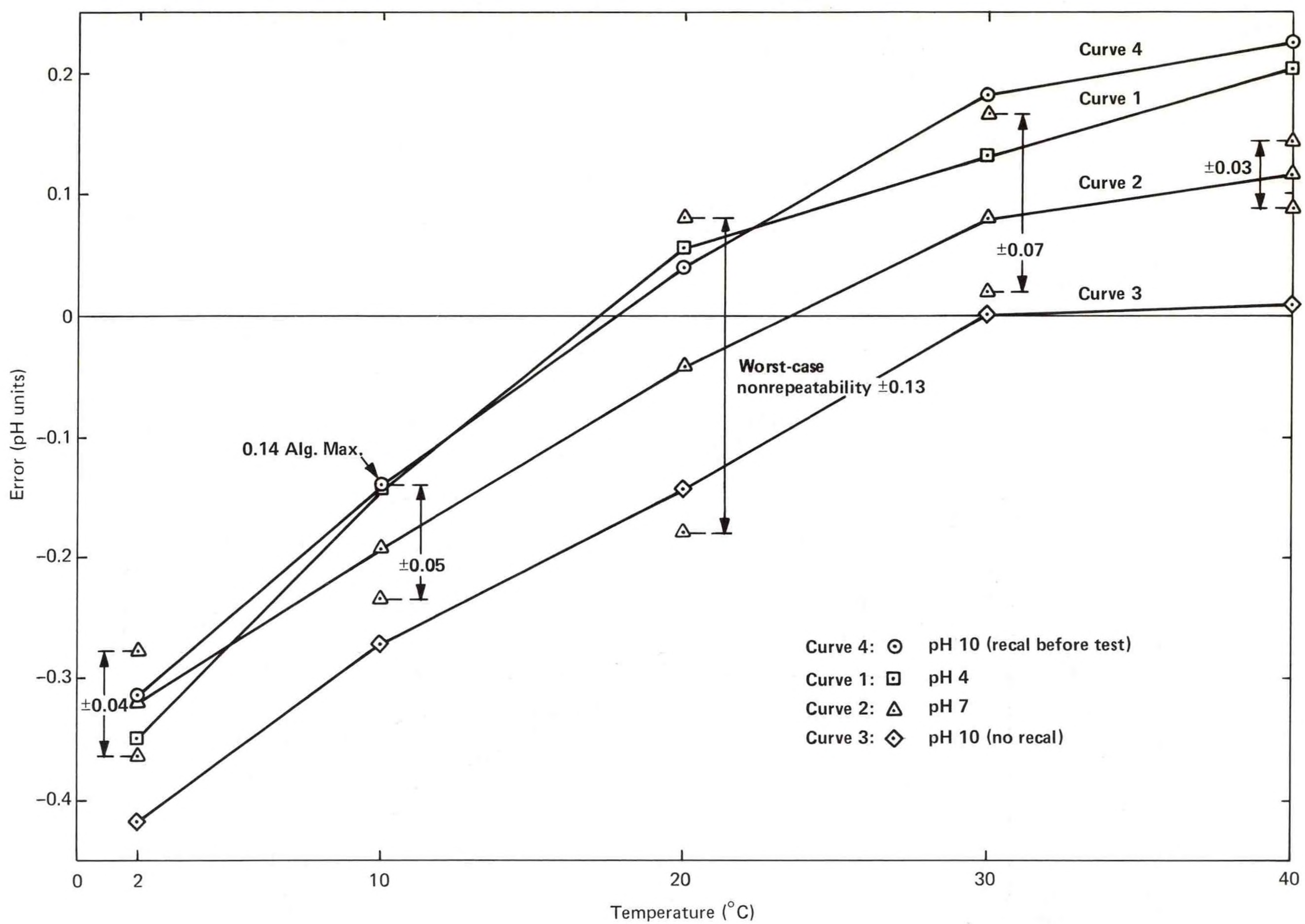

Figure 9.--pH calibration error.

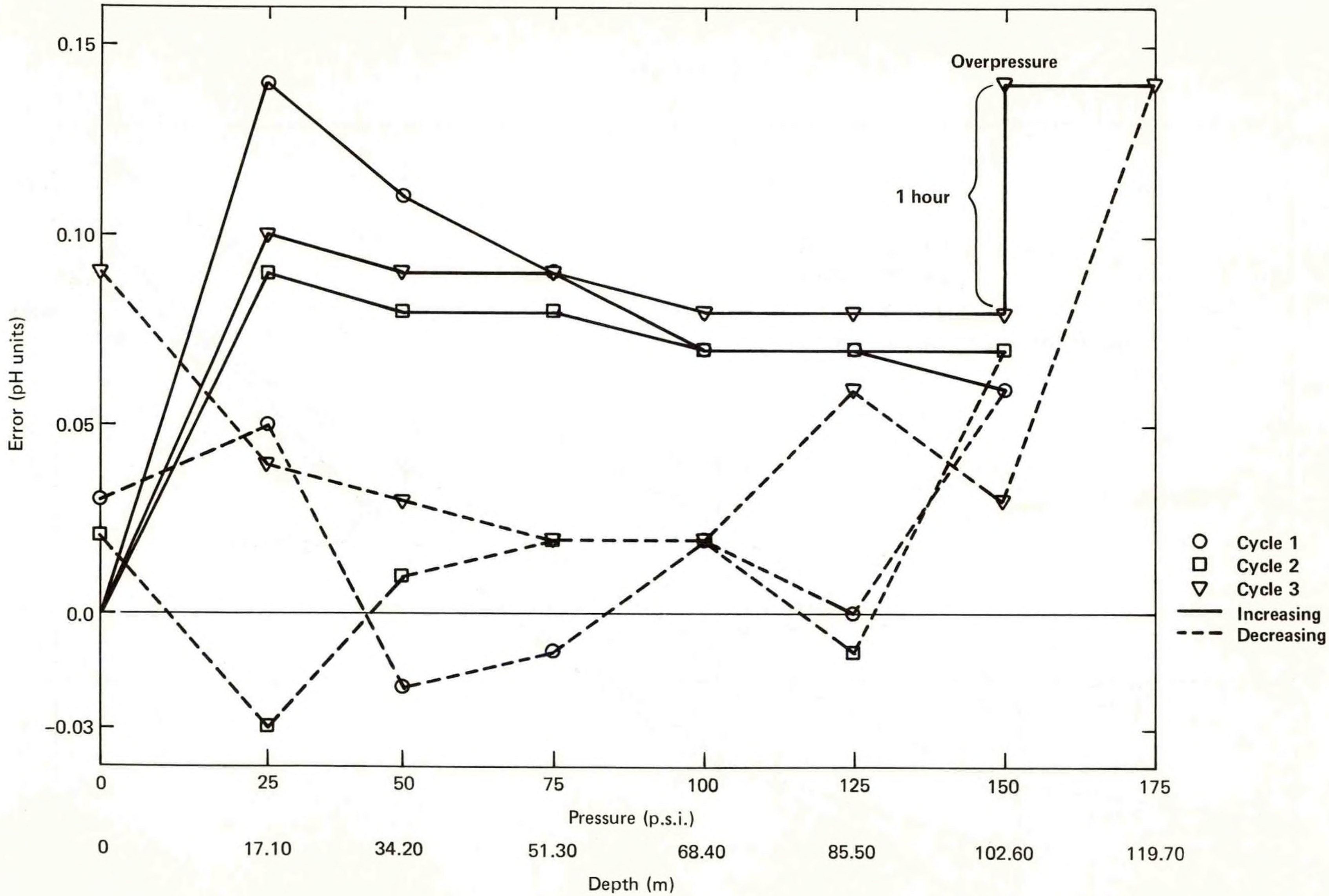

Figure 10.--Pressure effect on pH sensor.

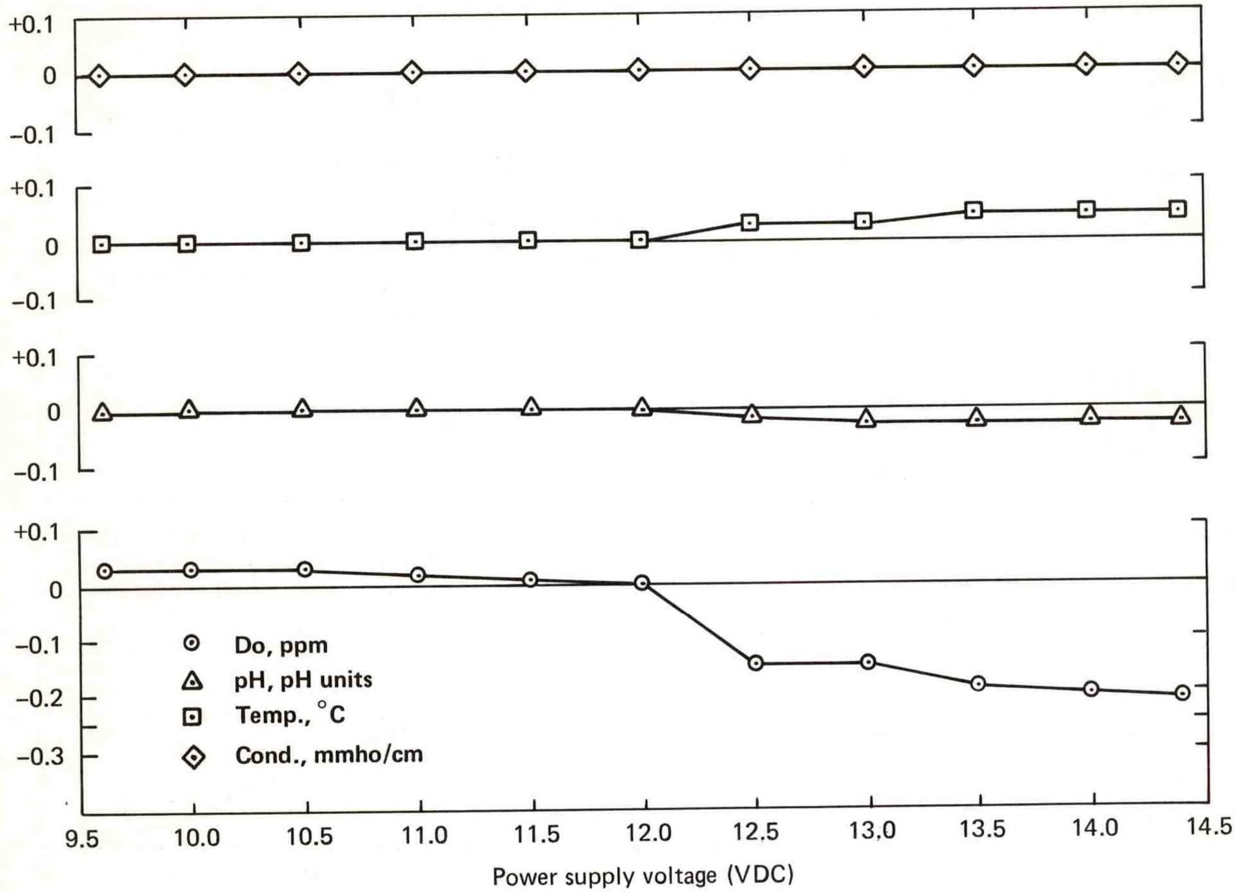

Figure 11.--Effect of power supply variation.

Dimensions and weights

Readout unit:	17 in. W X 10 7/8 in. D X 12 7/8 in. H, 20.21b (43.18 cm W X 27.62 cm D X 32.70 cm H, 9.16 kg)
Probe:	31 1/2 in. H, 15 15/16 in. diameter, 20.2 lb (80.01 cm H, 40.48 cm diameter, 9.16 kg)
Cable:	100 m long, 5/8-in. diameter, 75 lb (100 m long, 1.59 cm diameter, 32.02 kg)

History of Testing

Conductivity and Temperature Testing

Conductivity and temperature testing was originally started in September, 1974. Using a wire loop technique for simulating conductivity (appendix C), the data obtained in figure 12 for conductivity and figure 1 for temperature were obtained.

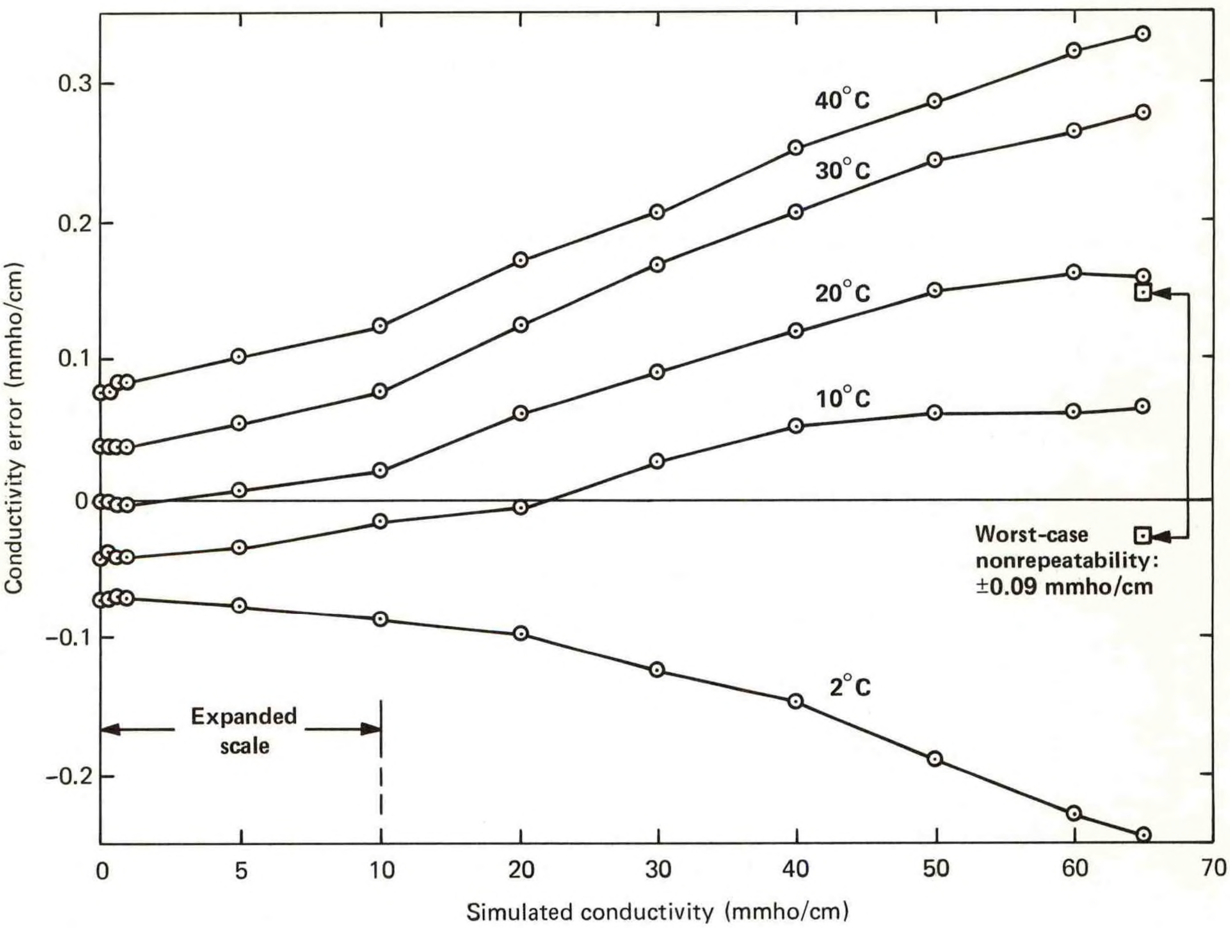

Figure 12.--Conductivity calibration error, wire-loop technique, November, 1974.

After discussion of these data with the manufacturer in December 1974, he indicated that the system could not be functioning properly and must have a serious failure since the data was not within specifications. At the manufacturer's request, the unit was returned for inspection.

In January, 1975, the system was returned to NOIC. A new temperature sensor had been provided, and InterOcean indicated that they could find no failures that would account for the poor performance indicated by our testing. An internal examination of the underwater probe by NOIC revealed some wiring modifications and the addition of a thermistor to the conductivity circuit board. Repeated requests by NOIC for clarification of these modifications resulted in the following explanation dated October 4, 1975:

Upon return of the probe to InterOcean, conductivity was recalibrated and was found to be working properly with nonrepeatability less than ± 0.01 mmho. We were thus totally baffled by your report of ± 0.09 mmho. It was also apparent at the time that you were assuming that the conductivity sensor was ordered with temperature compensation whereas in truth it was not. We thus took it upon ourselves to install temperature compensation at no charge.

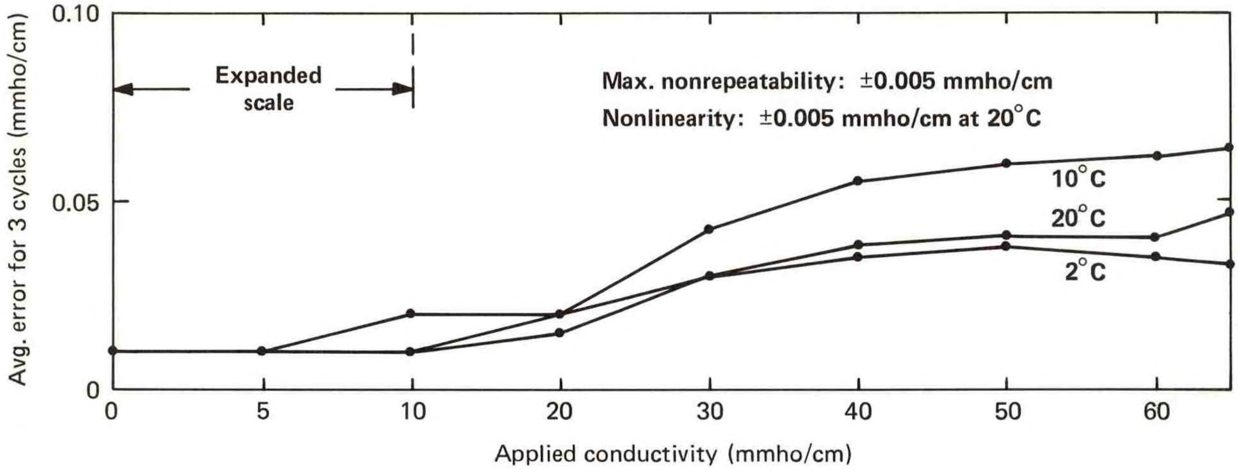

Figure 13.--Conductivity calibration error, wire-loop technique, November, 1975.

Note that the temperature compensation is designed to compensate for variation in the electronics as well as the conductivity head cell constant as a function of temperature. In your mode of testing conductivity using a wire loop, a change in the cell constant of the head is neglected hence the compensation will not work to its fullest advantage.

It was pointed out in a subsequent letter to InterOcean that, to our knowledge, they were the only manufacturer who did not supply automatic temperature compensation as an integral part of the basic instrument. Without such compensation, the system is of little value to the average user.

Conductivity and temperature tests were repeated on the modified system; these data are illustrated in figures 1 and 2. To examine calibration stability, tests were repeated after 90 days and data are presented in figures 1 and 13.

As a result of InterOcean's questioning of the validity of the wire loop technique used in testing their instrument, additional testing was performed using water sampling calibration procedures released by NOIC's Metrology Division in July, 1975. These procedures are described in appendix D, and figure 14 illustrates the conductivity calibration errors found when this testing approach was taken. Note that because of the nature of the C-S-T relationship, it was not possible to span the full temperature-conductivity range of the instrument with a test bath of 35 ppt salinity. For this reason, the wire loop technique for simulating conductivity is often used as a testing technique since conductivities covering the entire instrument range (0 to 65 mmho/cm) can be simulated over the specified temperature range (0 to 40°C).

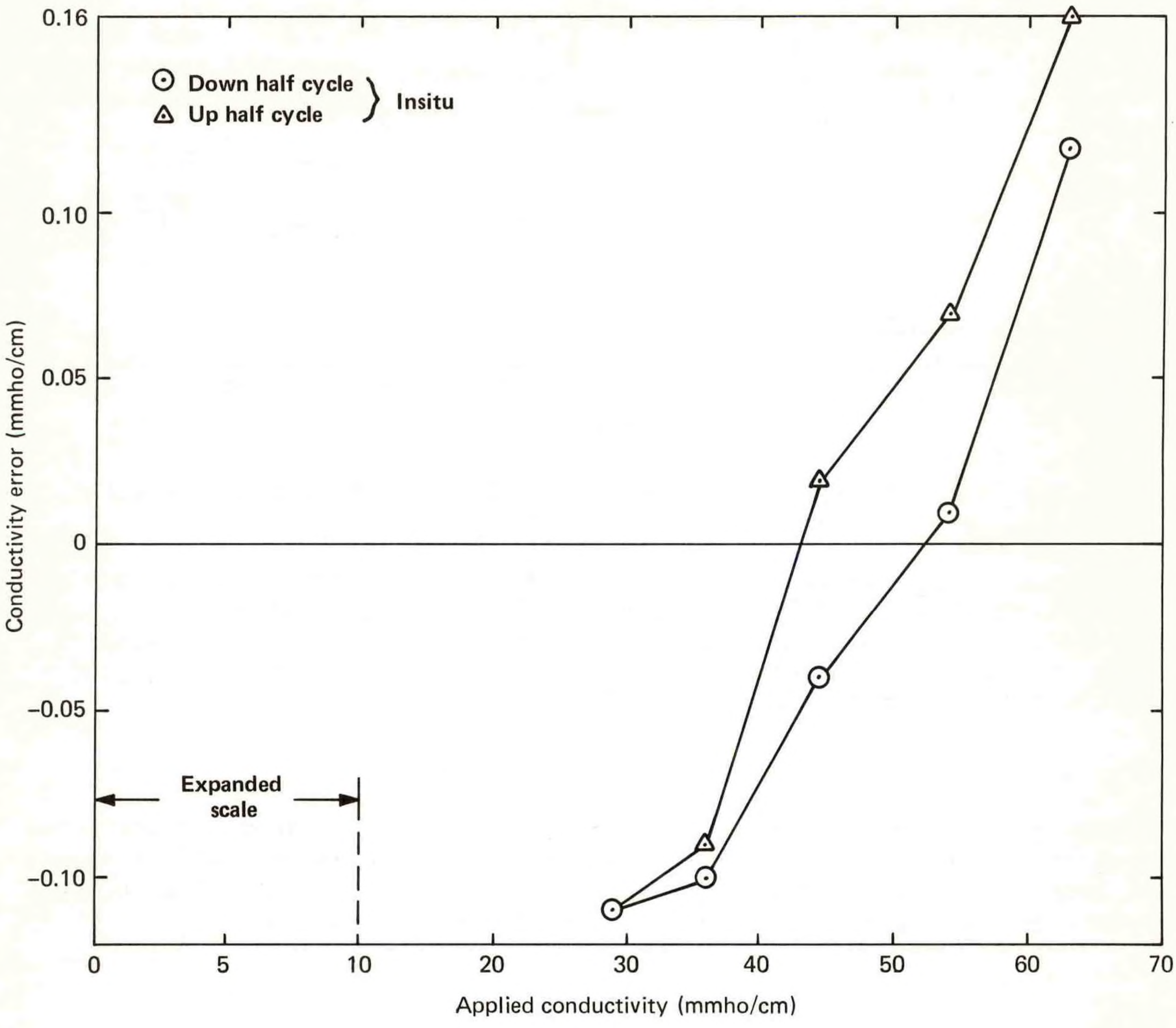

Figure 14.--Conductivity calibration error, water sampling technique.

If data from the previously described test are used to calculate the conductivity probe's cell constant at each test temperature, and these corrected cell constants are used in the wire loop technique, the calibration errors illustrated in figure 15 are obtained. Note that these calibration errors include calibration drift over a nine-month period. The cell constant were calculated and are shown in tabular form adjacent to figure 15.

Nonrepeatability was found to be high (+0.03 mmho/cm)(fig. 14) even though the stabilization time allowed in the test bath should have been sufficient to equilibrate the conductivity cell dimensions.

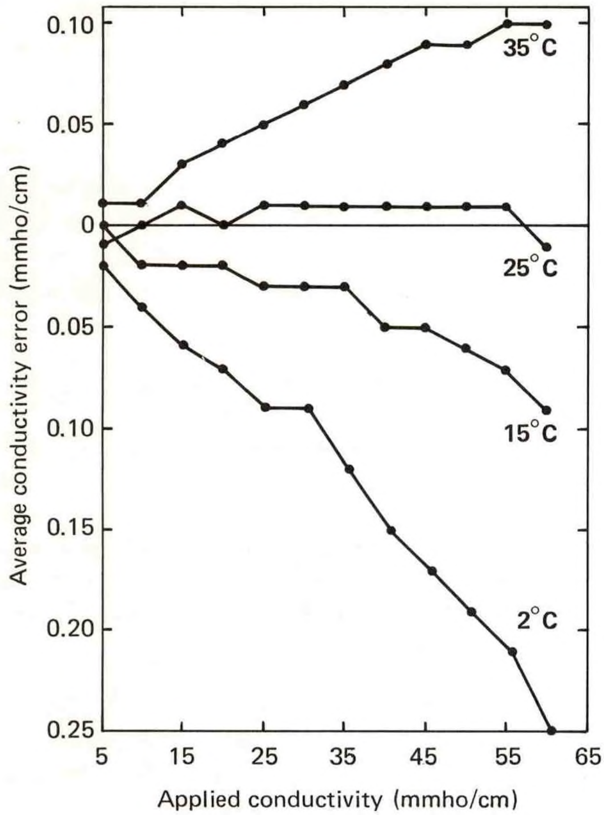

Figure 15.--Conductivity calibration error, wire-loop technique with adjustment for temperature effect on cell constant.

Temperature (°C)	Cell Constant ($x\ 10^{-4}$)
2	4.19862
15	4.20699
25	4.21136
35	4.21825

Dissolved Oxygen Testing

Dissolved Oxygen calibration testing was started in May 1975, and data (figure 7) were obtained. Near the end of the testing, the sensor displayed unstable readings, sensitivity to flow, and the inability to be properly adjusted for calibration. It was decided that the sensor had expired after its normally expected lifetime and a new sensor was purchased to replace it. InterOcean had recently begun marketing a new type probe into which they had designed several modifications to improve performance. The new probe was tested with the results illustrated in figure 16.

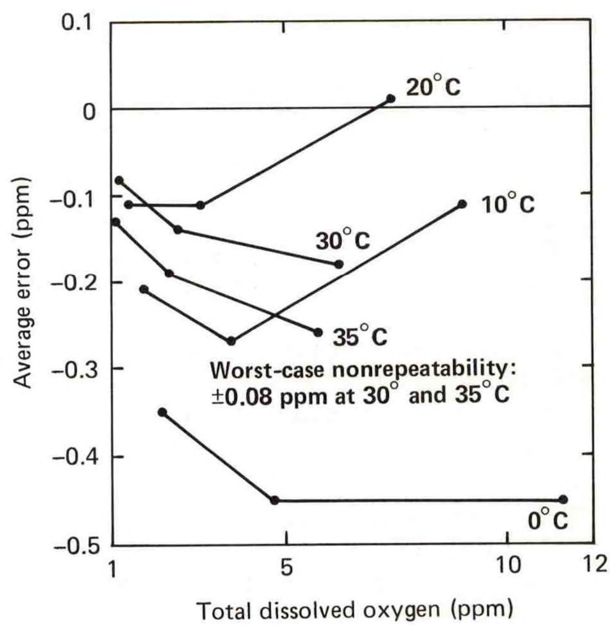

Figure 16.--Dissolved oxygen calibration error, new sensor.

pH Testing

The first pH sensor to undergo pressure testing failed. The replacement provided by the manufacturer performed as illustrated in Figure 10.

REPLACEMENT PARTS REQUIRED

July 1974 - temperature sensor failed.

Since this was the original sensor, and had not been replaced as part of the recent modifications, a new sensor was purchased for a cost of $322.

August 1974 - pH sensor failed after low temperature testing and was replaced by the manufacturer under warranty.

September 1974 - temperature sensor failed and was replaced under warranty.

November 1974 - temperature and pH sensors failed and were replaced by manufacturer's representative under warranty.

December 1974 - the entire system was returned to the manufacturer at his request since conductivity test data did not meet his specifications. During that time, the temperature sensor was again replaced and several modifications were made. (Refer to Appendix B for details.)

March 1975 - the cable was returned to the manufacturer for repair. Field testing had resulted in the application of unusual strain near the probe connector and several wires in the cable were broken. NOIC paid for repair costs of $357.

April 1975 - operational amplifier on pH circuit board failed and was replaced under warranty.

May 1975 - dissolved oxygen sensor failed. This was the original sensor. A new sensor of improved design then offered for sale by the company was purchased by NOIC for $2,085.

GENERAL COMMENTS

The following comments are offered by this office as an aid to individuals contemplating use of the InterOcean series 500 system.

1. The instruction manual for the system is excellent. It provides information on theory of operation, calibration, and operating instructions. Troubleshooting procedures are also provided along with schematics and parts lists.

2. The system can best be used in situations where a trained operator or technician can be made responsible for operation of the system. It is an extremely complex system with many idiosyncracies, and use by many different

operators may not allow each user to obtain maximum performance in terms of data and/or operation. Use by personnel unskilled in the maintenance and handling of the system is not recommended in spite of the fact that a detailed manual is provided.

3. If precise conductivity data is required, this InterOcean system offers a less costly alternative to the highly sophisticated STD systems provided that conductivity calibration is performed often, either by adjustment in the laboratory or routine water sampling during the measuring program.

4. The system is difficult to use for accurate pH and dissolved oxygen measurements in situations where stray electrical currents or ground loops occur. The unit is designed to operate with a seawater ground, and this has been found to cause problems under certain conditions. For example, it was necessary to use a separate 12V automotive battery as a power supply during laboratory testing because stray currents were a problem even when an isolated AC transformer was utilized.

5. As with any water quality system, it is useful to have on hand a spare set of sensors for dissolved oxygen and pH so that they can be substituted quickly when required.

6. Calibration of the unit can be carried out only by removing the housing on the underwater probe. This is time consuming and an inconvenience.

ACKNOWLEDGEMENTS

The author wishes to acknowledge the dedicated efforts of Charles White and Paul Eichelberger, project technicians. Without their expertise, perseverance, and attention to testing detail, the data in this report could not have been gathered.

APPENDIX A--MANUFACTURER'S PERFORMANCE SPECIFICATIONS

	MODEL 514A READOUT	MODEL 513D PROBE
Conductivity		
Range	0-65 mmhos/cm	0-65 mmhos/cm
Accuracy	0.01% ± 1 digit	±0.05 mmhos/cm
Repeatability		0.02 mmhos/cm
Time constant		10 ms
Resolution	0.01 mmho/cm	Continuous
Output		1 volt/10 mmhos
Temperature		
Range	-5° to 45°C	-5° to 45°C
Accuracy	0.01% ± 1 digit	±0.05°C
Repeatability		0.02°C
Time constant		1.4 s
Resolution	0.01°C	Continuous
Output		1 volt/10°C
Depth		
Range	0 to 100 m	0 - 100 m
Accuracy	0.01%± 1 digit	±1%
Repeatability		0.5%
Time constant		50 msec
Resolution	0.1 m	Continuous
Output		1 volt/100 m Transducer depth limit: 25% over range

Dissolved Oxygen		
Range	0 to 20 ppm	0 to 20 ppm
Accuracy	0.01% ± 1 digit	± 1%
Time constant		5 - 10 s
Resolution	0.01 ppm	
Output		1V/10 ppm
pH		
Range	2 to 12 pH units	2 to 12 pH units
Accuracy	0.01% ± 1 digit	±0.05 pH
Time constant		40 ms
Resolution	0.01 pH unit	
Output		0.1 V/pH

Scan Rate: Variable, from 1 to 5 s for each reading

Power Requirements: External 12 VDC ± 10%, 2.5A maximum. Optional internal rechargeable battery with full protection built in charger from 110 VAC.

APPENDIX B--SYSTEM MODIFICATIONS

In a letter from InterOcean, dated January 16, 1974, the following comments were offered with respect to differences between the model 513A and the 513D probes:

1. The pH sensor is a completely new assembly. It is somewhat larger due to the fact that heavier gauge glass is now used. The sensor is much more resistant to mechanical and thermal stress. Recovery time after drying out is much less (complete drying out, however, is still to be avoided if possible).

2. The electronic circuits on the pH board have been modified. It is now almost completely immune to "ground loops" of small magnitude which could be caused by non-ideal system installation or deployment.

3. The mother board and pH board layout has been redone to change the circuit path spacing to minimize stray offset currents which might get into the pH amplifier circuit. Electostatic guard paths around the sensitive input paths are provided.

4. Previously (Model 513A), power was interrupted to the DO sensor when pH was activated. This was necessary to avoid cross-talk between the two sensors. This arrangement was somewhat inconvenient on survey systems because of the DO settling time and was impossible for ultra high speed data interrogation and telemetry as is done on the NASA ERTS project. In the Model 513D, both the pH and DO sensors are powered and received simultaneously and continuously. This feature was made possible by circuit changes in the DO and pH electronics boards.

5. The mother board is now Humiseal sprayed.

6. Moisture repellent is used on pH, DO and mother board and unsealed connector areas.

7. The cable which is now used is of different material and construction. Required bend radius is reduced. The number of conductors are increased, outside diameter is reduced, and resistance to cuts and mechanical damage is much greater.

8. The design of the molded connector in the cable has been changed. Strain relief from the solder point to the flexible part of the cable is accomplished gradually over a four inch section. We have not experienced a single connector failure since this design change was made (approximately six months ago).

To convert a Model 513A probe which has C/S/T/D/DO and pH, one would have to: 1. exchange pH circuit board, 2. exchange DO circuit board, 3. modify mother board wiring, and 4. exchange pH sensor.

I believe that the units purchased by the Coast Guard in November 1972 are usable field monitoring systems. In view of the significant modifications that have been made, I believe that the current Model 514D should be selected for testing and evaluation.

(signed by representative of InterOcean Systems, Inc.)

APPENDIX C--WIRE-LOOP CONDUCTIVITY CALIBRATION PROCEDURE

The wire loop technique for conductivity calibration assumes that the cell constant is constant with temperature:

1. Determine constant at 20°C:

   (a) Place sensor in bath of known conductivity (35 ± 0.2 ppt, 20° ± 0.1°C) and determine bath conductivity by running sample through a laboratory salinometer. This will provide C_{KNOWN}.

   (b) While sensor is in known bath, record instrument output. This will provide C_{INSTR}.

   (c) Place sensor in a freshwater, deionized bath (0.0 ppt, 20° ± 0.1°C) and run wire loop through cell bore, plugging bore if necessary. Connect to decade box.

   (d) Adjust decade box, R_{DECADE}, until instrument output is equal to C_{instr} as determined in (b).

   (e) Calculate cell constant, K_{20}:

   $$K_{20} = CR = (C_{KNOWN})(R_{DECADE}).$$

2. Using the cell constant, K, calculate the resistances required to simulate conductivities of 0.2, 0.5, 1, 5, 10, 20, 30, 40, 50, 60, and 65 mmho/cm.

3. Place sensor in distilled water bath (20° ± 0.1°C).

4. Run three simulated conductivity cycles (0 to 65 mmho/cm) and record R_{DECADE}, C_{SIM}, C_{INSTR}, T_{INSTR}, and T_{STD}.

5. Run three additional cycles at bath temperatures of 0°, 10°, 30°, and 40°C.

6. Calculate conductivity calibration errors at each temperature:

   $$\text{Error} = C_{INSTR} - C_{SIM}.$$

APPENDIX D*-WATER SAMPLING CONDUCTIVITY CALIBRATION PROCEDURE

The water sampling technique for conductivity calibration does not assume that the cell constant is constant with temperature:

1. Place sensor in 35 $\pm$0.1 ppt bath. Determine conductivity by running bath sample through a laboratory salinometer. This will provide C_{STD}.

2. In-situ run: Cycle bath through temperatures of 35°, 26°, 17°, 8°, and -1°C recording T_{INSTR} (°C), true bath temperature T_{STD}, and C_{INSTR}. This provides part of the data required.

3. Simulated conductivity run: Place a wire loop connected to a variable conductance (decade resistance box) through the hole in the conductivity sensor. The bore is plugged with rubber stoppers if necessary. Place the instrument in a temperature controlled bath at 25°C.

   a. Adjust the decade resistance box for a conductivity readout of 30 mmho/cm. By use of table I in the calibration procedure, find a multiplier corresponding to 30 mmho/cm. By using other multipliers in table I to obtain resistances, R, simulated conductances can be found from 5 to 60 mmho/cm.

   b. Simulated conductivity cycles are run at 35°, 26°, 17°, 8° and -1°C recording instrument conductivity $(C_{INSTR})_T$ for all simulated conductivities.

4. Determine cell constant for each temperature,

$$K_T = \frac{1}{R(C_{INSTR})}.$$

5. True conductivity can then be determined from

$$C_{TRUE} = \frac{1}{RK_T}.$$

6. Instrument error can then be determined from

$$\text{Error} = (C_{INSTR})_T - (C_{TRUE})_T.$$

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*From Calibration Procedure for CTD and STD Sensors, NOIC-CP-04A.

(Continued from inside front cover)

NOS 16 Deep Sea Tide and Current Observations in the Gulf of Alaska and Northeast Pacific. Carl A. Pearson, December 1975.

NOS 17 Deep Sea Tide Observations Off the Southeastern United States. Carl A. Pearson, December 1975.

NOS 18 Performance Evaluation of Guildline Model 8400 Laboratory Salinometer. James E. Boyd, July 1976.

NOS 19 Test Results on an Electromagnetic Current Sensor With an Open Design. David R. Crump, August 1976.