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DESIGN, DEVELOPMENT, AND FIELD DEMONSTRATION OF A REMOTE DEPLOYABLE WATER QUALITY MONITORING SYSTEM

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SUMMARY

This research and application project was initiated under an interagency agreement between the National Aeronautics and Space Administration (NASA), Langley Research Center (Langley) and the Environmental Protection Agency (EPA), Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

Under this agreement, NASA developed and tested an automated, multiparameter Water Quality Monitoring System that offers almost continuous in situ water monitoring capability. The two-man portable system features include the following:

- a microprocessor controlled central processing unit which allows preprogrammed sampling schedules and reprogramming in situ;
- a subsurface unit for multiple depth capability and security from vandalism;
- an acoustic data link for communications between the subsurface unit and the surface control unit;
- eight water quality parameter sensors;
- a nonvolatile magnetic bubble memory which prevents data loss in the event of power interruption;
- a rechargeable power supply sufficient for 2 weeks of unattended operation;
- a water sampler which can collect 16 samples for laboratory analysis;
- data output in direct engineering units on printed tape or through a computer compatible RS232C link;
- internal electronic calibration eliminating external sensor adjustment; and
- acoustic location and recovery systems.

Langley personnel conducted a 1-week field test of the WQMS during August 1980 in Saginaw Bay, Lake Huron. All functional aspects of the system performed satisfactorily. The system was calibrated, preprogrammed, and

deployed. After 3 days of operation, the system was reprogrammed through a hardwire link and operated 2 more days before being reprogrammed through the acoustic link for the final 2 days of operation. During the test, the subsurface unit was located via the acoustic system and the acoustic link was used to release the unit from the anchor for recovery. Recalibration of the sensors showed little drift.

This report was submitted in fulfillment of Interagency Agreement D6-0053 between NASA Langley Research Center and EPA, Environmental Monitoring Systems Laboratory, Las Vegas. This report covers a period from June 1976 to August 1980; work was completed as of August 15, 1980.

CONTENTS

TABLES

FIGURES

LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATONS

CPU	-	central processing unit
d.c.	-	direct current
D.O.	-	dissolved oxygen
EPROM	-	erasable programmable read only memory
FSK	-	frequency shift keyed
I/O	-	input/output
LCD	-	liquid crystal digital
MBM	-	magnetic bubble memory
NTU	-	nephelometric turbidity units
ORP	-	oxidation reduction potential
PC	-	printed circuit
SCU	-	surface control unit
SIC	-	sensor interface circuit
SSU	-	subsurface unit
WQMS	-	Water Quality Monitoring System

SYMBOLS

cm	-	centimeter
^{o}C	-	degree Celsius
ℓ	-	liter

mg	-	milligram
mℓ	-	milliliter
mV	-	millivolt
V	-	Volt
μ mho	-	micromho

INTRODUCTION

The NASA/EPA Water Quality Monitoring System (WQMS) described in this report is an automated, multiparameter system. It is designed to operate in situ, unattended for periods up to 2 weeks, collecting sensor data and water samples.

The system was designed and fabricated by the National Aeronautics and Space Administration (NASA), Langley Research Center (Langley) under an interagency agreement with the Environmental Protection Agency (EPA), Environmental Monitoring Systems Laboratory, Las Vegas, Nevada.

The purpose was to develop a small, lightweight, automated water monitoring system that could be deployed by one or two people from a small boat, or possibly a helicopter, for extended self-powered operation. Multiple sensors and sample collecting capability were desired, for collecting data at selectable frequencies. A subsurface system was desired for multiple depth capability as well as security from vandalism. The system was needed for unattended monitoring of remote waters, such as lakes, bays, or marshes, as well as for trend or pollution episode monitoring in streams. Internal data storage and retrieval capability were also desired.

The WQMS is a two-man portable system that offers almost continuous in situ water quality monitoring capability. When deployed, the system collects data from eight sensors and stores the data in a nonvolatile magnetic bubble memory (MBM). A microprocessor controls the system and is normally preprogrammed with the data and sample collection schedules. Reprogramming of the system can be performed through an acoustic link or through a data cable without disturbing the system. The system will operate in water depths to 30 meters and ambient temperatures from 0° to $35^{\circ}C$.

Langley personnel field tested the WQMS during August 1980 in Saginaw Bay, Lake Huron. All functional aspects of the system were tested and operated satisfactorily. Operational support and field verification data were provided by the EPA Large Lakes Research Station (LLRS), Grosse Ile, Michigan. Upon completion of the field tests, the system was turned over the LLRS for operational use.

We gratefully acknowledge the contribution to system definition and development of Mr. Clifford Risley, of the U.S. Environmental Protection Agency, Region V, Chicago. His continued interest and support throughout the project provided valuable EPA input.

CONCLUSIONS

The Water Quality Monitoring System described here is a prototype and hence not a production model. It has the potential to become one of the most useful water quality monitoring tools developed. Future operational use of this prototype will further define the strong and weak points of the system. The scientist in the field can determine the most useful and the least useful features.

The system is somewhat larger and heavier than originally planned, but can be transported and deployed with little difficulty by two persons. The size watercraft used to deploy the system is determined more by the deployment site than by the size of the system. During preliminary in-water tests, a 14-foot rowboat was used for deployment in a local reservoir.

A tremendous capability is offered by the system electronics with the nonvolatile memory, the acoustic communication link, and the programmable microprocessor. Versatility is exemplified by the capability of the system to collect data and samples on command, by schedule, and on alert from a sensor, and by the ability to reprogram the system through the acoustic link without disturbing it physically.

Although the electronics are quite sophisticated, operation of the system is straightforward with some prompting of the operator by the surface control unit. Field personnel should not have any difficulty operating the system.

The power supply is sufficient for the design goal of 2 weeks operation, with a margin of 50 percent. Biofouling could cause degradation in some of the sensors over extended periods. Approximately 3 to 4 hours would be required to refurbish the system in the field for extended use.

SYSTEM DESCRIPTION

The WQMS consists basically of two units, a submersible data and sample collection unit and a surface control unit (SCU). The subsurface unit (SSU) houses the system electronics, the sensors, and the water sampler. The SCU contains a set of electronics similar to the SSU electronics and is used to program and retrieve data from the SSU.

STRUCTURE

The WQMS is shown in figure 1. With the anchor attached, the buoy is 1.5 meters tall, 0.57 meter in diameter, and has a mass of 59 kilograms. All of the structural material in the SSU is aluminum. The electronics housing is fabricated with 0.63 centimeter-thick aluminum plate with welded seams. A flat rubber gasket is used to seal the housing which has been pressure tested to 4.48×10^5 Newtons/meter^2 or an equivalent water depth of 45 meters. The lifting structure and the anchor support structure are 0.93 cm diameter tubing. The battery box was machined from a block and underwent the same pressure tests as the electronics housing. It is also sealed with a flat rubber gasket.

Pressure relief valves are integral parts of the electronics housing and battery box. In addition to preventing large pressure buildups, the valves are used to purge and fill the interiors with dry nitrogen.

The anchor is a polypropylene form which is filled with lead shot and cement to the desired weight. It is attached to the anchor support structure with 1330-Newton capacity line and two swivels.

BUOY ELECTRONICS

The SSU electronics unit is shown in figure 2(a). The heart of the SSU electronics is the central processing unit (CPU), which is a microprocessor-based subsystem. The microprocessor is an RCA 1802 CMOS unit, which uses a 10,000-step software package to control all SSU operations. The microprocessor is shown on the printed-circuit (PC) board in figure 2(b). CPU communications with all other portions of the SSU is through input/output (I/O) ports.

Operation of the system begins when the CPU receives the measurement and sampling schedule from the SCU. The CPU stores the schedule in the MBM and then examines it for the time of the first operation. The time is set in a clock register. The CPU then shuts the SSU power off except for maintenance operations. When the clock reaches the time set in the register, the CPU resumes operation and signals the appropriate sensor to take a measurement. Additional sensors required to correct the measurement (i.e., temperature corrections) are also signaled. True values of sensor measurements are computed by the software and stored in the MBM along with the time and number of days since launch.

This procedure is repeated for each measurement, including water sample collection, during the deployment. Daily self-tests are performed for each sensor channel with the results stored in the MBM.

MAGNETIC BUBBLE MEMORY

The magnetic bubble memory subsystem performs the nonvolatile storage function for the SSU in four 92-kilobit chips. This subsystem contains its own central processing unit and other peripherals which control data entry and retrieval from the MBM chips. The MBM chips are shown on the PC board in figure 2(c). The MBM CPU receives the data and operational instructions from the main CPU and responds accordingly, keeping track of the page numbers corresponding to data entries.

A 1,000-step software program is used by MBM CPU to control the generation of the magnetic bubbles which make this data storage system such a valuable tool. These magnetic bubbles are not affected by the state of the power supply, so no data are lost if the system should lose power.

SENSORS

The WQMS is designed to handle ten data channels with eight sensors provided on the SSU. A ninth channel is occupied by the water sampler while the tenth channel currently is unused.

All of the sensors are commercially available products. Their selection was based on a survey of the literature and discussions with users in government and industry. Criteria considered most significant included successful in situ operation, modest size, and lack of a requirement for complex manipulation or maintenance of the sensor. Table 1 lists the sensors, their manufacturers, and specifications, however, this is not an endorsement of these sensors.

Associated with each sensor is an interface PC board with an erasable programmable read only memory (EPROM). The EPROM contains the sensor characteristics, including equations needed by the CPU to provide corrected, linearized data in direct engineering units. An EPROM is shown in figure 2(d) on the PC board for the sensor.

Three of the sensors, temperature, pressure, and conductivity, which are used for all measurements, are mounted on the top of the SSU. The remaining sensors are mounted around the sides of the electronics canister. Figure 3(a) and 3(b) shows the sensors mounted on the SSU.

Parameter values stored in the MBM are final true values. All necessary secondary corrections have been made using a mathematics software package and the temperature, pressure, and conductivity readings which have been taken simultaneously with each measurement. Brief descriptions of the sensors are as follows:

Temperature

The temperature sensor uses a thermistor to make measurements. There are no corrections required and the sensor interfaces directly with the sensor interface circuit (SIC), which presents linear temperature data to the CPU.

Pressure

The pressure sensor uses a resistive bridge technique which produces a voltage differential with pressure. No corrections are required and input to the sensor interface circuit is direct. Linear pressure data are presented to the CPU.

Conductivity

The conductivity sensor uses a four-electrode system which forms a bridge with one path measuring the resistance of the return through water. Conductivity is corrected for temperature and inputs direct to the SIC. The SIC presents logarithmic data to the CPU.

pH

pH is a Nernstian measurement. The sensor measures the electrochemical potential of the hydrogen ions in the water, giving a voltage output. Buffer electronics make a correction and condition the signal before it is input to the SIC. The SIC presents linear data to the CPU.

Oxidation-Reduction Potential (ORP)

The ORP sensor measures redox or electrochemical potential of the water. The measurement is buffered and a proportional voltage is input to the SIC. There are no corrections. Linear data are presented to the CPU.

Dissolved Oxygen (DO)

The DO sensor measures oxygen migration through a polarographic membrane to an electrode. A custom buffer converts the low current output into a voltage proportional to the DO. Corrections are necessary for temperature, pressure, and conductivity. The SIC presents linear data to the CPU.

Fluoride

Fluoride is a Nernstian measurement which uses a specific ion probe to measure the electrochemical potential of fluoride ions. The measurement is corrected for temperature and buffered for input to the SIC unit which presents logarithmic data to the CPU.

Turbidity

The turbidity sensor is a sidescatter measuring instrument. A light detector measures the amount of light scattered at a 90° angle from a beam produced by the instrument. A voltage proportional to the amount of scattering material in the water is input to the SIC which presents linear data to the CPU. No corrections are made.

Schematics for all of the electronics are included in the system operating manual which is provided with the WQMS.

SENSOR CALIBRATION

The electronics in the sensor buffers and the sensor interface are designed for a minimum of drift. When the SSU is operating in situ, a self-test feature periodically checks drift of the sensor electronics. This drift is small compared to that which normally may be expected from the sensors.

Calibration of the sensors is performed from the SCU using software, with no internal adjustments needed. The procedure is outlined below using pH as an example.

Prepare two buffer solutions, one a high pH (10.0) and one a low pH (4.0).

Immerse the pH sensor in the pH 10.0 solution and instruct the buoy to read pH.

The SCU will show a measured value and then ask if this is a true value.

Enter the true value if different from the measured value.

Follow this procedure with the pH 4.0 solution and after the true values have been entered, instruct the SSU to calibrate. If two buffer solutions have been used, the system will internally adjust both the slope and the offset of the calibration curve. Calibration with one sample results in adjustment of the offset only.

WATER SAMPLER

The water sampler is located below the electronics housing (figure 1). It is controlled by the CPU and can collect up to sixteen 500 mℓ samples. Samples are collected under three modes; on a preprogrammed basis, on command from the surface control unit, or on an alert basis where a specified parameter exceeds predefined boundaries.

The sampler is a rosette which holds 16 sampling frames. Each frame is loaded with a plastic bag which has the top rolled to form a seal. Inside the center post of the rosette is a stepping motor which drives a rotating cam to activate the sampling frames. When a frame is activated, the top of the bag is unrolled and the frame mechanically expands the bag, drawing in the water sample. The bag is then resealed by rolling the top.

POWER SUPPLY

The battery box is located between the electronics housing and the water sampler (figure 1). It contains a rechargeable Nickel-Cadmium (NiCd) battery pack which provides the primary power supply of 20 volts to the SSU. A number of secondary voltages (+24 V, +15 V, +12 V, +5 V, -5 V, -12 V) are generated by the power supply circuit in the SSU to operate the different subsystems. Two switching regulators are used for the d.c. to d.c. conversion. The +5 V, which supplies the logic circuits, is always needed and has one of the regulators dedicated to it. The second regulator is turned on and off as needed for power conservation, and provides the voltages needed to operate the MBM, sensor circuitry, and other peripherals.

LOCATION AIDS

There are two acoustic transmitters (pingers) located on top of the electronics canister as shown in figure 4. One serves as the primary location aid while the other serves as an emergency signal and location aid.

The locator pinger produces an omnidirectional signal burst or "ping" every 2 seconds. This pinger is turned on during normal operation of the SSU and operates continuously. A directional surface hydrophone can detect the signal at distances of up to 1 mile, permitting exact SSU location.

The emergency pinger is a duplicate of the location pinger except the repetition rate is one ping every second. This pinger is turned on when the primary battery voltage drops below 17.5 V, or if a water leak into the electronics canister is detected. When the emergency pinger is on, the SSU will not respond to any commands or take measurements.

Each pinger has an independent battery power supply which allows continuous operation for approximately 30 days.

DEPLOYMENT AND RETRIEVAL

The SSU is equipped with two class "C" pyrotechnic cable cutters (figure 1) to facilitate deployment and retrieval. Each pyrotechnic requires two coded commands before it can be activated. The CPU must receive and recognize the two commamds within 30 seconds of each other or the pyrotechnic will not be activated.

Both cable cutters are used with two cables if the SSU and anchor are to be close-coupled during deployment. Once anchored, the short cable would be cut allowing the SSU to float to a predetermined height above the bottom for operation. The same procedure would be used if data were desired from two heights in the same water column. The SSU would be deployed at the lower height, and after a given period, the cable would be cut allowing the SSU to float to the second height for the remainder of the operation.

To recover the SSU, the second cable is cut and the SSU floats to the surface. If only one cable is used for deployment, then one cable cutter is used unless the operator desires redundancy in the recovery system.

DATA LINK

Communications between the SSU and the surface control unit is through the data link. When the SSU is in operation in open waters, an acoustic link is used. If the SSU is to be deployed in an acoustically unfavorable site, a direct cable link is used. Reflected signals cause interference with transmission and even in open waters limit use of the acoustic link to a 45° half angle cone above the SSU.

A data link canister with two hemispherical hydrophones is attached to the top of the SSU. These hydrophones are shown in figure 4. Each hydrophone transmits and receives on one of two frequencies used in the frequency shift keyed (FSK) system of digital data transmission. The FSK system uses one frequency (230 kHz) to represent logical 1's state and the other frequency (153 kHz) to represent logical 0's state, shifting frequencies as necessary to transmit the digital data stream. An identical hydrophone system is used at the surface to handle data transmission and reception for the SCU.

The acoustic link transmits data at 2.88 kilobits/second, which is a significant increase in the state of the art in this discipline. Prior technology limited data rates to less than 100 bits/second.

SURFACE CONTROL UNIT

The surface control unit shown in figure 5 is the operator interactive part of the Water Quality Monitoring System. It is used by the operator to program the SSU data collection schedule, to issue commands, to initiate data retrieval, to store data, and to present the data either through a thermal printer or through a computer compatible link.

Circuitry in the SCU is, to a large extent, identical to circuitry in the SSU. The MBM system, the CPU hardware, the data link, and the power supply circuits are identical. The principal difference is control of keyboard, display, and printer functions in the SCU in lieu of sensor control in the SSU.

The SCU is packaged in a waterproof attaché case made of corrosion-resistant materials. The case is suitable for use as a shipping container. All openings, operating controls, displays, and connectors are of splash-proof design.

Input/Output Elements

Located on the face of the SCU are the input/output elements: the keyboard, display, thermal printer, and connectors. Input to the system is through a 64-character ASCII keyboard plus six special-purpose keys. Commands, data collection schedules, and comments are typed on the keyboard and entered through one of the special purpose keys.

A 16-character liquid crystal display (LCD) shows the information being entered into the system. It also displays data as commanded and displays CPU prompting for the operator.

Hard copy records of measurements, schedules, data identification, commands, and/or any operator entry may be obtained with the 16-character-per-line thermal printer. The printer is activated by one of the special-purpose keys.

The connectors on the SCU are for the SSU data link, the computer compatible RS-232C output link, and external power and battery recharging for the SCU. Grouped with the connectors is a system on/off switch.

OPERATION

In operation, the CPU initially scans the keyboard for entries. As entries are made, the CPU stores them in its buffer memory until an operational instruction is defined. The CPU then executes the instruction. If, for example, the instruction is to obtain an immediate measurement from a specific sensor the command is transmitted to the SSU. The SSU CPU receives the command, activates the required sensor, obtains the measurement, performs any secondary corrections, and transmits the value to the SCU. The surface CPU receives the value and displays it for the operator.

When entering an operating schedule, the entries are held in the buffer memory until the entire schedule has been entered. On command, the schedule is then stored in the permanent bubble memory. The schedule may be recalled at any time and transmitted to the SSU. This capability allows the operator to enter, edit, and/or change the program at any convenient time or place and then transmit the program to the SSU on site.

FIELD TEST

The Water Quality Monitoring System was field tested with EPA support in Saginaw Bay, Lake Huron during August 1980. Saginaw Bay is freshwater, and is a large, relatively shallow finger of Lake Huron which protrudes into the State of Michigan. The operations base for the test was Bay City, Michigan. The test site was 24 kilometers from the mouth of the Saginaw River and 1.6 kilometers southeast of the entrance channel buoy number 3. Water depth at the site was approximately 9 meters. Location of the test site is shown in figure 6.

The SSU was deployed as shown in figure 7. Physical location and recovery aids were added to the system as a precaution since this was a prototype system. Once the SSU was deployed, a 15.3-meter recovery line attached to the base of the SSU was extended along the bottom, and the free end anchored. In the event a normal recovery could not be made, a grappling hook would be used to snare the recovery line and pull the SSU to the surface. Small international orange buoys were anchored beyond each extremity of the recovery line as an aid to grappling for the line and also as a location aid for the system should hydrophone location fail. Anchors separate from the SSU were used to prevent unwanted retrieval of the SSU.

CHRONOLOGY

The WQMS was transported to Bay City, Michigan, by NASA Langley personnel. The system was assembled, checked out, and calibrated on August 4th and 5th. On August 6th, the system was loaded on the EPA vessel BLUE WATER and transported to the deployment site. The system was deployed with the sensor height set at 1.5 meters above the bottom, and began operation at 1500 hours on August 6th. Figure 8 shows the SSU being deployed. After obtaining field verification data and ascertaining that the system was operating properly, the BLUE WATER returned to port.

The system was checked daily as a precaution to make certain all systems were operating properly. Daily checks will not be necessary when the system is put into operational use. The system will be unattended until a data dump is wanted or until the system is to be recovered. Field verification data were also collected daily during the depoyment.

On August 9th, during an attempt to interrogate the SSU, there was a momentary power loss, resulting in automatic shutdown of the SSU electronics and activation of the emergency pinger. The power loss was thought to be a result of the near orange buoy line becoming entangled with the SSU and flexing the external power cable from the battery box to the electronics housing. Using the grappling hook and recovery line, the SSU was retrieved and placed on the BLUE WATER. The SSU was checked to make sure that water-tight integrity had been maintained and then the data in the SSU memory were dumped and the data schedule was changed through the direct link. Ten water samples which had been collected were removed and analyzed and the frames were reloaded. The SSU was then redeployed about 100 meters from the original site.

On August 11th, using the acoustic link, a data dump was made, and a new schedule was transmitted to the SSU. Figure 9 shows a system operator with the SCU. The system continued to operate satisfactorily and the field test was ended on August 13th. The pyrotechnic release was used to recover the SSU. The release commands were transmitted over the acoustic link and the cable cutter activated as scheduled. The buoy floated to the surface and was placed aboard the BLUE WATER. Before returning to port the sensors were recalibrated.

SENSOR CALIBRATION DURING TEST

Temperature

The temperature sensor was calibrated prior to launch and after retrieval by comparing air temperature measurements with an independent temperature probe. Field verification data were collected with A YSI telethermometer using water samples collected in the vicinity of the SSU. Calibration of the sensor was maintained throughout the test.

Pressure

A one-point calibration was performed prior to launch using atmospheric pressure as the standard. After deployment, a discrepancy of 1.6 meters was noted between the sensor and depth measured by depth sounder and plumb line. After retrieval a two-point calibration of the sensor provided the proper slope and offset for the sensor. Subsequent data analysis showed no system problem and determined that the sensor read low by a factor of 1.224. This correction has not been applied to the data presented here.

Conductivity

Two standard solutions were used to calibrate the sensor prior to deployment and after retrieval. Calibration was maintained throughout the deployment. Sensor data compared favorably with field verification data measured with a Beckman model RC-19 conductivity meter.

pH

The pH sensor was calibrated using two standard buffer solutions before deployment and three solutions after retrieval. The SSU measured the buffer solutions correctly as did the field verification instrument, a Fisher model 520 pH meter. However, in situ SSU measurements were consistently lower than the field verification data by a pH of 2. The manufacturer has attributed this anomaly to a defect in the probe.

ORP

A one-point calibration was performed before and after the deployment period and showed no drift. The SSU measurements showed little variation and their accuracy is not known since no field verification data were collected.

Dissolved Oxygen

Calibration of the dissolved oxygen sensor before and after the deployment period was performed by saturating water with air for the upper end point and purging the water with nitrogen gas for the lower end point. The lower end point read the same before and after but the upper end point read 8.4 mg/ℓ before versus 7.1 mg/ℓ after. This difference might be partially attributed to uncertainty in the total saturation of the sample. Field verification data obtained by Winkler Analysis compared reasonably well with the SSU measurements.

The D.O. data presented in figure 15 must be divided by a factor of 1.477 to eliminate an inadvertent double correction for pressure. The buoy program corrects the data for pressure, but the manufacturer has indicated that the D.O. sensor self-corrects for pressure.

Fluoride

Two-point calibrations of the fluoride sensor before and after deployment showed no drift. The apparently large variations in the data are small when compared to the six-decade range of the sensor. Field verification data were not collected.

Turbidity

The turbidity sensor was not calibrated. Prior to launch, the system measured 4.3 nephelometric turbidity units (NTU) with the sensor covered and 100 NTU when exposed to ambient light. A light shield was not used around the sensor and consequently during daylight hours the sensor measurements were saturated. Turbidity of samples collected during daytime and measured with a Hach 2100A turbidimeter was in the same range as the nighttime readings of the SSU.

Water Sampler

During schedule I the water sampler collected 10 samples, one immediately on command, six on alert from the D.O. sensor, and three at scheduled times. Five samples were collected on schedule during the remainder of the deployment.

FIELD TEST RESULTS

During the test period, a total of 3720 data points were measured and recorded by the system. Table 2 lists the three data collection schedules used during the tests. Using schedule I, 1426 data points were collected. One thousand one hundred and two (1102) data points were collected with schedule II and 1192 were collected with schedule III. Tables 3 through 10 present all of the data collected, by parameter, while figures 10 through 17 are graphical representations of the hourly averages for each parameter. Because this was a system demonstration test only, no attempt is made here to interpret the data. Table II presents the field verification data provided by EPA during the test. These data points are represented by the circles on the SSU data graphs.

Conductivity, pH, and turbidity of the first 10 water samples were measured using the field verification instruments. These data are presented in table 12 and represented by the triangles in figures 12, 13, and 17.

After the proper corrections were made, the SSU sensor measurements all fell within ranges that showed reasonable agreement with the field verification data.

Overall, the Water Quality Monitoring System performed as expected and the field test was a success. Although there were several sensor problems, all functions of the WQMS were tested and operated as designed. The SSU was preprogrammed and deployed and then reprogrammed several days later through the acoustic link, while submerged. The SSU collected and stored data from all eight sensors and transmitted the stored data over the acoustic link on command from the surface control unit. When a buoy power interruption occurred, the memory retained all the stored information and the emergency pinger was automatically activated. The system exercised the water sampler, collecting samples by schedule, by alert, and on command from the SCU. The recovery system released the SSU on command for an easy recovery.

During the 1-week exercise only one-third of the battery capacity was used and less than one-third of the SSU storage capability was used. There was some biofouling present on the sensors but it did not appear to affect the measurements.

For the daily checks of the system, the SSU was normally located visually by the marker buoys. On one check the SSU was located successfully using the acoustic locator system. The weather encountered had little effect on the ability to acquire the pinger's acoustic signal, but rougher sea states shortened the periods of communication with the SSU via the acoustic data links.

After recovery, the system was transported to Grosse Ille, Michigan, where it was turned over to EPA's Large Lakes Research Station personnel. All of the data collected, a preliminary assessment of the field test, and the operators manual were included with the WQMS.

RECOMMENDATIONS

A redesign study should be conducted, aimed at streamlining the system both physicallly and operationally. Redesign of the system could result in a reduction in the size, weight, and cost, as well as reinforcement of the strong points and elimination of the weak points.

Though not under the scope of this project, the improvement of existing sensors or the development of new, more accurate sensors would improve the accuracy of the system. Improved calibration procedures would also help in this respect as the electronics have been shown to be stable and reliable.

Specific recommendations include the following:

SENSOR INTERCHANGEABILITY

At present, the SSU electronics and sensor interfaces confine a specific sensor to a specific channel. Changing the type of sensor on a channel requires a printed circuit board change inside the SSU. The system would be more versatile if sensors or sensor modules could be interchanged at the plug-in point.

COMPUTER COMPATIBLE LINK

The RS-232C link in the current surface control unit is not a fast-dump comparable to the SSU-to-SCU acoustic link. Data output to a computer is at the same rate as the line printer, requiring several hours to dump a full memory. The SCU software should be changed to make this a fast-dump, on the order of 1 to 3 minutes.

TURBIDITY SENSOR

A light shield should be fabricated and placed around the turbidity sensor to eliminate ambient light interference.

DISSOLVED OXYGEN SENSOR

Considerations should be given to installing a circulator for the D.O. sensor. If water is not circulated around the sensor the oxygen at the sensor membrane is depleted and results in an artificially low D.O. reading.

APPENDIX

TABLES AND FIGURES

The data presented here are the raw data as they are output from the system. No corrections or other attempts at refinement have been made. The hourly averages presented in the graphs are intended only to give interested parties a quick look at the data. The only use of the data has been to judge the satisfactory operation of the system.

TABLE 1. LIST OF SENSORS

PARAMETER	MANUFACTURER	UNITS	RANGE MEASURED	RESOLUTION
Temperature	YSI thermistor probe 710	$^{\circ}$C	-2 to 35	0.2° C
Pressure	Bell & Howell CEC1000	kg/cm^2	0 to 5 absolute	2%
Conductivity	Neil Brown - four electrode	µmho/cm	0 to 100,000	3%
pH	Great Lakes Instr. - pH 60	pH	2 to 12	0.1
ORP (redox)	Great Lakes Instr. - ORP 60	mV	-1000 to +1000	5 mV
Dissolved Oxygen	Beckman Fieldlab 39552	mg/ℓ	0 to 20	2%
Specific ion-fluoride	Beckman 39600 with permaprobe reference	mg/ℓ	activity to 10^3	10%
Turbidity	Ecologic 204A	NTU*	0 - 100	0.2 NTU

*Nephelometric Turbidity Units

TABLE 2. SSU DATA SCHEDULES

Schedule I 8/6 - 8/9	Points/Day	Schedule II 8/9 - 8/11	Points/Day	Schedule III 8/11 - 8/13	Points/Day
Do Sampler		Do Sampler		Do Sampler	
Start 08:25		Start 09:50		Start 09:50	
24:00 Intervals	1	18:00 Intervals	1.5	18:00 Intervals	1.5
Alert D.O.					
<2.0					
Do Temperature		Do Temperature		Do Temperature	
Start 08:00		Start 09:00		Start 09:00	
00:10 Intervals	144	00:12 Intervals	120	00:12 Intervals	120
Do Pressure		Do Pressure		Do Pressure	
Start 08:15		Start 09:45		Start 09:30	
01:00 Intervals	24	00:40 Intervals	36	00:30 Intervals	48
Do 2 Conductivity		Do Conductivity		Do Conductivity	
02 Min. Apart		Start 09:30		Start 09:45	
Start 08:30		00:30 Intervals	48	00:40 Intervals	36
01:00 Intervals	48	Do 2 pH		Do 2 pH	
Do pH		2 Min. Apart		2 Min Apart	
Start 07:45		Start 09:15		Start 09:15	
00:30 Intervals	48	00:20 Intervals	144	00:20 Intervals	144
Do ORP		Do ORP		Do ORP	
Start 07:45		Start 10:25		Start 09:25	
00:20 Intervals	72	00:30 Intervals	48	00:45 Intervals	32
Do Fluoride		Do Fluoride		Do Fluoride	
Start 07:55		Start 08:55		Start 08:55	
00:30 Intervals	24	00:15 Intervals	96	00:15 Intervals	96
Do D.O.		Do D.O.		Do D.O.	
Start 08:00		Start 09:10		Start 09:10	
00:20 Intervals	72	00:30 Intervals	48	00:30 Intervals	48
Do Turbidity		Do Turbidity		Do Turbidity	
Start 09:35		Start 09:35		Start 10:25	
01:00 Intervals	24	00:45 Intervals	32	00:30 Intervals	48
TOTALS:	457		573.5		573.5

TABLE 3. TEMPERATURE, °C

Date	Time	Temp oC	Date	Time	Temp oC
08/06	1520	22.0	08/06	2300	21.4
	1530	22.0		2310	21.4
	1540	22.0		2320	21.4
	1550	22.0		2330	21.4
	1610	22.0		2340	21.4
	1616	22.0		2350	21.4
	1630	22.0	08/07	0001	21.1
	1640	22.0		0010	21.2
	1650	22.0		0020	21.4
	1700	22.0		0040	20.8
	1710	22.0		0050	21.4
	1720	22.0		0100	21.4
	1730	22.0		0110	21.7
	1740	22.0		0120	21.7
	1750	22.0		0130	21.7
	1800	22.0		0140	21.7
	1810	22.0		0150	21.7
	1820	22.0		0200	21.8
	1830	21.9		0210	21.7
	1840	22.0		0230	21.7
	1850	22.0		0240	21.7
	1900	22.0		0250	21.8
	1910	22.0		0300	22.0
	1920	22.0		0310	22.0
	1930	20.8		0320	22.0
	1940	22.0		0330	22.0
	1950	22.0		0340	22.0
	2000	22.0		0350	22.0
	2010	22.0		0400	20.8
	2020	22.0		0410	21.8
	2030	22.0		0420	21.7
	2040	20.8		0430	21.7
	2050	22.0		0440	21.7
	2110	22.0		0450	21.7
	2120	22.0		0500	21.9
	2130	22.0		0510	21.7
	2140	21.9		0520	21.6
	2150	21.7		0530	21.7
	2200	21.7		0540	21.4
	2210	21.7		0550	21.4
	2220	21.6		0600	20.9
	2230	21.2		0610	21.7
	2240	21.5		0620	21.7
	2250	21.2			

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/07	0630	21.2	08/07	1350	20.1
	0640	21.1		1400	19.6
	0650	21.1		1410	20.8
	0700	21.1		1420	20.8
	0710	21.1		1430	19.0
	0720	20.8		1440	19.3
	0730	20.5		1450	19.6
	0740	21.4		1500	19.0
	0750	21.4		1510	19.3
	0800	20.8		1520	19.3
	0810	20.9		1530	19.6
	0820	20.8		1540	19.3
	0830	20.9		1550	19.9
	0840	20.8		1600	19.9
	0850	20.9		1610	20.3
	0900	20.8		1620	20.5
	0920	20.3		1630	20.8
	0930	20.5		1640	20.8
	0940	20.8		1650	20.3
	0946	18.0		1700	20.1
	1000	22.1		1720	21.4
	1010	22.1		1730	16.0
	1020	21.6		1740	20.8
	1030	21.9		1750	20.8
	1040	21.7		1800	20.8
	1050	21.6		1810	20.9
	1100	21.5		1820	20.8
	1110	22.0		1840	21.2
	1120	21.6		1850	21.7
	1130	21.6		1900	21.4
	1140	21.2		1910	21.6
	1150	20.8		1920	21.4
	1200	20.9		1930	21.6
	1210	19.0		1940	22.0
	1220	18.3		1950	22.0
	1230	18.7		2000	22.0
	1240	19.1		2010	22.0
	1250	19.6		2020	22.1
	1300	19.6		2030	22.0
	1310	19.6		2040	21.4
	1320	18.3		2050	21.4
	1330	18.3		2100	20.8
	1340	19.0		2110	20.9

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/07	2120	20.8	08/08	0502	20.9
	2130	21.2		0440	20.3
	2140	21.5		0450	19.6
	2150	21.4		0500	19.4
	2200	21.5		0510	19.3
	2210	21.7		0520	19.3
	2220	20.8		0530	19.0
	2230	22.0		0540	19.1
	2240	22.0		0550	19.0
	2250	22.0		0600	19.0
	2300	22.3		0610	21.1
	2310	22.0		0630	21.2
	2320	22.0		0640	21.1
	2330	21.4		0650	21.6
	2340	21.1		0700	22.0
	2350	20.3		0710	21.9
08/08	0001	20.8		0720	22.0
	0010	20.2		0730	21.6
	0020	20.5		0740	21.1
	0030	20.5		0750	21.4
	0040	20.1		0810	21.4
	0050	20.2		0820	20.8
	0100	20.3		0830	21.2
	0110	20.2		0840	19.8
	0120	19.9		0850	21.4
	0130	19.3		0900	20.8
	0140	20.1		0910	20.1
	0150	19.9		0920	20.1
	0200	19.6		0940	20.5
	0210	19.6		0950	18.8
	0220	19.8		1000	19.1
	0230	20.8		1010	18.7
	0240	19.9		1020	18.7
	0250	20.2		1030	18.7
	0300	19.6		1040	18.7
	0310	23.3		1050	18.7
	0320	20.5		1100	18.5
	0330	21.4		1110	18.5
	0340	21.1		1120	18.3
	0350	21.1		1130	18.3
	0400	21.4		1140	18.3
	0410	21.1		1150	18.7
	0420	21.4		1200	19.0

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/80	1210	19.3	08/08	1950	22.6
	1220	20.1		2000	22.6
	1230	20.1		2010	22.3
	1240	19.9		2020	22.6
	1250	19.3		2030	22.6
	1300	19.0		2040	22.0
	1320	19.0		2050	20.8
	1330	19.0		2100	20.0
	1340	18.7		2110	20.1
	1350	18.7		2120	20.1
	1400	18.7		2130	20.1
	1410	18.5		2140	20.3
	1420	18.5		2150	20.7
	1430	18.7		2200	20.8
	1440	18.7		2210	20.8
	1500	19.8		2220	21.7
	1510	18.8		2230	20.8
	1520	19.0		2240	31.0
	1530	19.0		2250	21.1
	1540	19.0		2300	20.5
	1550	19.1		2310	20.8
	1600	19.9		2320	20.8
	1610	20.8		2330	20.1
	1620	19.6		2340	20.5
	1630	20.8		2350	20.1
	1640	19.9	08/09	0833	19.8
	1650	20.5		0010	19.0
	1700	19.1		0020	19.0
	1710	19.6		0030	19.0
	1720	20.1		0040	19.0
	1730	22.0		0050	19.1
	1740	21.7		0100	19.0
	1750	22.0		0120	20.8
	1800	22.1		0130	19.1
	1810	22.3		0140	19.8
	1820	22.0		0150	18.8
	1830	21.7		0200	18.8
	1840	21.7		0210	18.7
	1850	22.3		0220	18.7
	1900	23.2		0230	19.0
	1910	22.0		0240	19.0
	1921	22.6		0250	19.9
	1930	22.3		0300	20.5
	1940	22.3		0310	19.8

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/09	0330	19.8	08/09	1027	22.7
	0340	20.8		1040	22.9
	0350	20.3		1050	22.6
	0400	22.0		1100	22.9
	0410	20.8		1110	23.4
	0420	22.9	SCHEDULE CHANGE		
	0430	22.3		1336	22.9
	0440	22.6		1348	22.9
	0450	22.9		1400	22.9
	0500	22.3		1412	22.9
	0510	22.6		1424	22.9
	0520	20.8		1436	22.9
	0530	22.6		1448	22.9
	0540	21.1		1500	22.9
	0550	22.1		1512	22.9
	0600	22.3		1524	22.9
	0610	22.0		1536	22.9
	0620	21.2		1548	22.9
	0630	22.3		1600	22.9
	0640	22.4		1612	22.9
	0650	21.1		1624	22.9
	0700	21.4		1636	23.0
	0710	16.0		1648	22.9
	0720	22.7		1700	22.9
	0746	21.7		1712	22.9
	0740	22.3		1724	22.9
	0750	22.7		1736	22.9
	0800	22.9		1748	22.9
	0810	22.7		1800	22.9
	0820	22.0		1812	22.2
	0830	21.2		1824	22.9
	0840	20.1		1836	22.9
	0850	21.2		1848	22.9
	0900	22.7		1900	22.9
	0910	22.7		1912	22.9
	0920	22.9		1924	22.9
	0930	22.7		1936	22.9
	0937	22.6		1948	22.9
	0946	22.6		2000	22.9
	0953	22.7		2012	23.2
	1010	22.7		2024	23.2
	1020	22.7			

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/09	2036	23.2	08/10	0524	23.3
	2048	23.2		0536	23.1
	2100	23.2		0548	22.9
	2112	23.2		0600	22.9
	2124	23.2		0612	23.0
	2136	23.2		0624	22.9
	2148	23.2		0636	22.9
	2200	23.2		0648	22.9
	2224	23.2		0700	22.9
	2236	23.2		0712	22.9
	2248	23.2		0724	22.9
	2300	23.2		0736	22.9
	2312	23.2		0748	22.9
	2324	23.2		0800	22.9
	2336	23.2		0812	22.9
	2348	23.2		0824	22.9
08/10	0001	23.2		0836	22.9
	0012	23.2		0850	22.9
	0024	23.2		0901	22.9
	0036	20.8		0912	22.9
	0048	23.2		0924	22.9
	0100	23.2		0936	22.9
	0112	23.2		0948	22.9
	0124	23.2		1000	22.9
	0136	23.2		1012	22.9
	0148	23.2		1024	22.9
	0200	23.2		1036	22.9
	0212	23.2		1048	22.9
	0224	23.2		1100	22.9
	0236	23.2		1112	22.9
	0248	23.2		1124	22.9
	0300	23.2		1136	22.9
	0312	23.2		1148	22.9
	0324	23.2		1200	22.9
	0336	23.2		1420	22.9
	0348	23.2		1224	22.9
	0400	23.2		1236	22.9
	0412	23.2		1248	22.9
	0424	20.8		1300	22.9
	0436	23.1		1312	22.9
	0448	23.0		1324	22.9
	0500	23.2			
	0512	22.9			

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/10	1336	22.9	08/10	2212	22.6
	1348	22.9		2224	22.6
	1400	22.9		2236	22.7
	1412	22.9		2248	22.7
	1424	22.9		2300	22.7
	1436	22.9		2312	22.6
	1448	22.9		2356	22.6
	1500	22.9		2336	22.6
	1512	22.9		2348	22.6
	1524	22.9	08/11	0002	22.6
	1536	22.9		0012	22.7
	1548	22.9		0024	22.7
	1600	22.9		0036	22.7
	1612	22.9		0048	22.7
	1624	22.9		0100	22.7
	1636	22.7		0112	22.7
	1648	22.9		0124	22.7
	1700	22.9		0136	22.7
	1712	22.9		0148	22.7
	1724	22.6		0200	22.6
	1736	22.7		0212	22.7
	1748	22.7		0224	22.7
	1800	22.7		0236	22.7
	1812	22.7		0248	22.6
	1824	22.7		0300	22.6
	1836	23.4		0312	22.7
	1848	22.7		0324	22.7
	1900	22.7		0336	22.7
	1912	22.7		0348	22.6
	1924	22.7		0400	22.6
	1936	22.7		0516	22.6
	1948	22.7		0424	22.7
	2000	22.7		0436	22.7
	2012	22.7		0448	22.6
	2024	22.7		0500	22.6
	2036	22.6		0512	22.7
	2048	22.7		0524	22.6
	2100	22.7		0536	22.7
	2112	22.7		0548	22.6
	2124	22.7		0600	22.6
	2136	22.6		0612	22.6
	2148	22.6		0624	22.6
	2200	22.6			

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/11	0636	22.6	08/11	1512	22.6
	0648	22.6		1524	22.6
	0700	22.6		1536	22.6
	0712	22.6		1548	22.6
	0724	22.6		1600	22.6
	0736	22.6		1612	22.6
	0748	22.6		1624	22.6
	0800	22.6		1636	22.6
	0812	22.6		1648	22.6
	0824	22.6		1700	22.6
	0836	22.6		1712	22.6
	0848	22.6		1724	22.6
	0900	22.6		1736	22.6
	0912	22.6		1748	22.6
	0924	22.6		1800	22.6
	0932	22.6		1812	22.6
SCHEDULE CHANGE				1824	22.6
				1836	22.6
	0936	22.6		1848	22.6
	1020	22.6		1900	22.6
	1036	22.6		1912	22.3
	1048	22.6		1924	22.3
	1100	22.6		1936	22.3
	1112	22.6		1948	22.3
	1124	22.6		2000	22.3
	1136	22.6		2012	22.3
	1148	22.6		2024	22.3
	1200	22.6		2036	22.0
	1212	22.6		2048	22.0
	1224	22.0		2100	21.7
	1236	22.6		2112	21.6
	1248	22.6		2124	21.8
	1300	22.6		2136	21.9
	1312	22.6		2148	22.3
	1324	22.6		2200	22.3
	1336	22.6		2212	22.1
	1348	22.6		2224	22.3
	1400	22.6		2236	22.3
	1412	22.6		2248	22.3
	1424	22.6		2300	22.3
	1436	22.6		2300	22.3
	1448	22.6		2312	22.3
	1500	22.6		2324	22.3

TABLE 3. CONTINUED

Date	Time	Temp °C	Date	Time	Temp °C
08/11	2336	22.3	08/12	0900	22.0
	2348	22.3		0912	22.0
08/12	0002	22.3		0924	22.1
	0012	22.4		0936	22.0
	0024	22.3		0948	22.1
	0036	22.3		1000	22.0
	0048	22.4		1012	22.0
	0100	22.4		1024	22.0
	0124	22.4		1036	22.0
	0136	22.3		1048	22.0
	0148	22.3		1100	22.0
	0200	22.3		1112	22.0
	0212	22.3		1124	22.0
	0224	22.3		1136	22.0
	0236	22.3		1148	22.0
	0248	22.1		1200	22.0
	0300	22.3		1224	22.0
	0312	22.1		1236	22.0
	0324	22.1		1248	22.0
	0336	22.3		1300	22.0
	0348	22.0		1312	22.0
	0400	22.3		1325	22.0
	0412	22.0		1336	22.1
	0424	22.1		1348	22.0
	0436	22.1		1412	22.0
	0448	22.0		1436	22.1
	0500	22.1		1448	22.1
	0536	22.1		1500	22.0
	0548	22.1		1512	22.0
	0600	22.2		1524	22.1
	0612	22.1		1536	22.1
	0624	22.1		1548	22.1
	0648	22.1		1600	22.1
	0700	22.0		1612	22.1
	0712	22.0		1624	22.1
	0028	22.0		1636	22.0
	0736	22.0		1648	22.1
	0748	22.0		1700	22.1
	0800	22.0		1712	22.1
	0812	22.1		1724	22.1
	0824	22.0		1736	22.1
	0836	22.0		1748	22.1
	0848	22.0		1800	22.1

TABLE 3. CONCLUDED

Date	Time	Temp °C	Date	Time	Temp °C
08/12	1812	22.1	08/13	0248	22.3
	1824	22.1		0300	22.3
	1836	22.1		0312	22.3
	1900	22.1		0324	22.3
	1912	22.1		0336	22.3
	1924	22.1		0348	22.2
	1936	22.1		0400	22.0
	1948	22.1		0412	22.0
	2000	22.1		0424	22.0
	2012	22.1		0436	22.1
	2024	22.1		0448	22.1
	2036	22.1		0500	22.1
	2048	22.1		0512	22.1
	2100	22.1		0524	22.0
	2112	22.1		0536	22.1
	2124	22.1		0548	22.1
	2136	22.1		0600	22.1
	2148	22.1		0612	22.1
	2200	22.1		0624	22.1
	2212	22.1		0636	22.1
	2224	22.0		0648	22.1
	2236	22.1		0700	22.1
	2248	22.1		0712	22.1
	2300	22.1		0724	22.1
	2312	22.1		0736	22.0
	2324	22.1		0748	22.1
	2336	22.1		0800	22.1
	2348	22.0		0812	22.0
08/13	0001	22.2		0824	22.1
	0012	22.3		0836	22.1
	0024	22.3		0848	22.0
	0036	22.3		0900	22.0
	0048	22.3		0912	22.0
	0100	22.3		0924	22.0
	0112	22.3		0936	22.0
	0124	22.3		0948	22.0
	0136	22.3			
	0148	22.3			
	0200	22.3			
	0212	22.3			
	0224	22.3			
	0236	22.3			

TABLE 4. PRESSURE

Date	Time	P kg/cm^2	Date	Time	P kg/cm^2
08/06	1615	1.509	08/08	1315	1.493
	1715	1.509		1415	1.493
	1815	1.509		1515	1.493
	1915	1.509		1615	1.493
	2015	1.509		1715	1.493
	2115	1.509		1815	1.509
	2215	1.509		1915	1.493
	2315	1.509		2015	1.493
08/07	0015	1.509		0547	1.493
	0115	1.509		2215	1.493
	0215	1.509		2315	1.493
	0315	1.509	08/09	0015	1.493
	0415	1.509		0115	1.509
	0515	1.509		0215	1.493
	0615	1.493		0315	1.509
	0715	1.493		0415	1.509
	0815	1.493		0515	1.509
	0915	1.493		0615	1.509
	1015	1.493		0715	1.509
	1115	1.493		0815	1.509
	1315	1.493		0915	1.509
	1415	1.493		1015	1.509
	1515	1.493	SCHEDULE CHANGE		
	1615	1.493	08/09	1345	1.509
	1715	1.509		1425	1.509
	1815	1.493		1505	1.509
	1915	1.493		1545	1.509
	2015	1.493		1625	1.509
	2115	1.493		1705	1.509
	2215	1.493		0353	1.509
	2315	1.493		1825	1.509
08/08	0015	1.493		1905	1.509
	0115	1.493		1945	1.493
	0215	1.493		2025	1.493
	0415	1.493		2105	1.509
	0515	1.493		2145	1.509
	0615	1.493		2225	1.509
	0715	1.493		2305	1.493
	0815	1.493		2345	1.493
	0915	1.493	08/10	0025	1.493
	1015	1.493		0105	1.493
	1115	1.493		0145	1.493
	1215	1.493		0225	1.493

TABLE 4. CONTINUED

Date	Time	P kg/cm^2	Date	Time	P kg/cm^2
			SCHEDULE CHANGE		
08/10	0305	1.493	08/11	0935	1.493
	0345	1.493		1027	1.493
	0425	1.493		1100	1.493
	0505	1.509		1130	1.493
	0545	1.509		1200	1.493
	0625	1.509		1230	1.493
	0705	1.493		1300	1.493
	0745	1.493		1330	1.493
	0825	1.509		1400	1.493
	0905	1.493		1430	1.493
	0945	1.493		1500	1.493
	1025	1.493		1530	1.493
	1105	1.493		1600	1.493
	1145	1.493		1630	1.493
	1305	1.493		1700	1.493
	1345	1.493		1730	1.493
	1425	1.493		1800	1.493
	1505	1.556		1830	1.493
	1545	1.493		1900	1.493
	1625	1.493		2000	1.493
	1705	1.493		2030	1.493
	1745	1.493		2100	1.493
	1825	1.493		2130	1.493
	1905	1.509		2200	1.493
	1945	1.509		2230	1.493
	2025	1.509		2300	1.493
	2105	1.509		2330	1.493
	2145	1.493	08/12	0002	1.493
	2225	1.493		0030	1.493
	2305	1.493		0100	1.493
	2345	1.493		0130	1.493
08/11	0025	1.493		0200	1.493
	0105	1.493		0230	1.493
	0145	1.493		0300	1.493
	0225	1.493		0330	1.493
	0305	1.493		0400	1.493
	0345	1.493		0430	1.493
	0425	1.493		0530	1.493
	0505	1.493		0600	1.493
	0545	1.493		0630	1.493
	0625	1.493		0700	1.509
	0705	1.493		0834	1.509
	0745	1.493		0800	1.493
	0825	1.493		0830	1.493
	0905	1.493		0900	1.493

TABLE 4. CONCLUDED

Date	Time	P kg/cm^2	Date	Time	P kg/cm^2
08/12	0930	1.493	08/12	2200	1.509
	1000	1.493		2230	1.509
	1030	1.493		2300	1.509
	1100	1.493		2330	1.509
	1130	1.493	08/13	0001	1.509
	1200	1.493		0030	1.493
	1230	1.493		0100	1.493
	1330	1.493		0130	1.493
	1400	1.493		0200	1.509
	1430	1.509		0230	1.493
	1500	1.509		0300	1.509
	1530	1.509		0330	1.509
	1600	1.509		0400	1.509
	1630	1.509		0430	1.509
	1700	1.509		0500	1.509
	1730	1.509		0530	1.509
	1800	1.509		0600	1.509
	1830	1.509		0630	1.509
	1900	1.509		0700	1.509
	1930	1.509		0730	1.509
	2000	1.509		0800	1.509
	2030	1.509		0830	1.493
	2100	1.509		0900	1.493
	2130	1.572		0930	1.493

TABLE 5. CONDUCTIVITY

Date	Time	Cond µmho/cm	Date	Time	Cond µmho/cm
08/06	1530	217	08/07	1330	205
	1532	217		1332	209
	1630	205		1430	205
	1632	162		1432	209
	1730	217		1530	217
	1732	217		1532	209
	1830	209		1630	221
	1832	209		1632	217
	1930	205		1710	3780
	2030	195		1730	217
	2032	195		1732	221
	2130	188		1830	221
	2132	184		1832	221
	2230	184		1930	229
	2232	188		1932	221
	2330	188		2030	229
	2332	188		2032	229
08/07	0030	198		2130	221
	0032	195		2132	221
	0130	205		2230	229
	0132	205		2232	229
	0334	217		2330	221
	0232	217		2332	229
	0330	217	08/08	0030	217
	0332	221		0032	217
	0430	221		0130	217
	0432	221		0132	217
	0530	221		0230	217
	0532	221		0232	217
	0630	217		0330	221
	0632	217		0332	217
	0730	217		0430	221
	0732	217		0434	217
	0830	217		0530	209
	0832	217		0532	209
	0930	290		0630	221
	0932	217		0632	221
	1030	221		0730	229
	1032	221		0732	229
	1130	221		0830	221
	1132	217		0832	221
	1230	205		0930	217
	1232	205		0932	217

TABLE 5. CONTINUED

Date	Time	Cond µmho/cm	Date	Time	Cond µmho/cm
08/08	1030	209	08/09	0830	229
	1032	209		0832	233
	1130	205		0930	233
	1132	205		0932	290
	1230	209		1030	233
	1232	217		1032	233
	1330	209	SCHEDULE CHANGE		
	1332	209	08/09	1400	290
	1430	205		1430	290
	1432	274		1500	290
	1530	209		1530	290
	1532	209		1600	290
	1630	217		1630	290
	1632	217		1700	290
	1732	221		1730	290
	1830	221		1800	290
	1832	229		1830	290
	1930	233		1900	290
	1932	233		1930	290
	2030	233		2000	290
	2032	233		2030	290
	2146	217		2100	290
	2132	217		2130	290
	2230	221		2200	233
	2232	221		2230	233
	2330	221		2300	290
	2332	217		2330	233
08/09	0030	205	08/10	0001	233
	0032	209		0030	233
	0130	209		0100	233
	0132	209		0130	233
	0230	209		0200	233
	0232	217		0230	233
	0330	217		0300	233
	0332	209		0330	233
	0430	229		0400	233
	0432	233		0430	233
	0530	233		0530	233
	0532	221		0600	233
	0630	233		0630	233
	0632	233		0700	233
	0730	229		0730	233
	0732	233		0800	233

TABLE 5. CONTINUED

Date	Time	Cond µmho/cm	Date	Time	Cond µmho/cm
08/10	0830	233	08/11	0630	233
	0900	233		0700	233
	0930	233		0730	233
	1000	233		0800	233
	1030	233		0830	233
	1100	233		0900	233
	1130	233		0930	233
	1200	233	SCHEDULE	CHANGE	
	1230	233	08/11	1025	233
	1300	233		1105	233
	1330	233		1145	233
	1400	233		1225	233
	1430	233		1305	233
	1500	233		1345	233
	1530	233		1425	233
	1600	233		1505	233
	1630	233		1545	233
	1700	233		1625	233
	1730	233		1705	233
	1800	233		1745	233
	1830	233		1825	233
	1900	233		1905	233
	1930	233		1945	233
	2000	233		2025	233
	2030	233		2105	229
	2100	233		2145	229
	2130	233		2225	233
	2200	233		2305	233
	2230	233		2345	233
	2300	233	08/12	0025	233
	2330	233		0105	233
08/11	0002	233		0145	233
	0030	233		0225	233
	0100	233		0305	233
	0130	233		0345	233
	0200	233		0425	233
	0230	233		0505	233
	0300	233		0545	233
	0330	233		0625	233
	0430	233		0705	233
	0500	233		0745	233
	0530	233		0825	233
	0600	233		0905	233

TABLE 5. CONCLUDED

Date	Time	Cond µmho/cm	Date	Time	Cond µmho/cm
08/12	0945	233	08/12	2225	233
	1025	233		2305	233
	1105	233		2345	233
	1145	233		0025	233
	1225	233		0105	233
	1305	233		0145	233
	1345	233		0225	233
	1425	233		0305	233
	1545	233		0345	233
	1625	233		0425	233
	1705	233		0505	233
	1745	233		0545	233
	1825	233		0625	233
	1905	233		0705	233
	1945	233		0745	233
	2025	233		0825	229
	2137	233		0945	229
	2145	233			

TABLE 6. pH

Date	Time	pH	Date	Time	pH
08/06	1515	6.8	08/07	1315	5.6
	1545	6.7		1345	5.5
	1615	6.5		1415	5.6
	1645	6.6		1445	5.5
	1715	6.6		1515	5.6
	1745	6.6		1545	4.6
	0423	6.6		1615	5.9
	1845	6.6		1645	5.6
	1915	6.5		1715	5.8
	1945	6.4		1745	5.8
	2015	6.3		1815	5.8
	2045	5.7		1845	5.9
	2115	6.3		1915	5.9
	2145	6.2		1945	6.1
	2245	6.0		2015	6.0
	2315	5.9		2045	5.9
	2345	5.8		2115	5.9
08/07	0015	5.8		2145	5.9
	0045	5.7		2215	5.7
	0115	5.9		2245	5.9
	0145	5.9		2315	6.0
	0215	5.9		2345	5.9
	0245	6.1	08/08	0045	5.7
	0315	6.3		0115	5.7
	0345	6.3		0145	5.7
	0415	6.2		0215	5.6
	0445	6.0		0245	5.6
	0515	6.2		0315	5.6
	0545	5.9		0345	5.6
	0615	5.9		0415	5.7
	0645	5.6		0445	5.6
	0715	5.6		0515	5.6
	0745	5.4		0545	5.6
	0815	5.6		0615	5.7
	0845	5.6		0645	5.9
	0915	5.6		0715	6.0
	0944	5.6		0745	5.8
	1015	5.6		0815	5.9
	1045	5.6		0845	5.6
	1115	5.6		0915	5.6
	1145	5.6		0945	5.6
	1215	5.5		1015	5.6
	1245	5.5		1045	5.5

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/08	1115	5.5	08/09	0915	5.6
	1145	5.4		0944	5.7
	1215	5.6		1015	5.7
	1245	5.6		1045	5.7
	1315	5.6	SCHEDULE CHANGE		
	1345	5.6	08/09	1335	6.5
	1415	5.6		1337	6.5
	1445	5.6		1355	6.5
	1515	5.5		1357	6.5
	1545	5.5		1415	6.4
	1615	5.6		1417	6.4
	1715	5.6		1435	6.3
	1745	5.6		1437	6.4
	1815	5.7		1455	6.4
	1845	5.7		1457	6.3
	1915	5.7		1515	6.5
	1945	6.2		1517	6.5
	2015	6.0		1535	6.3
	2045	5.7		1537	6.3
	2115	5.6		1555	6.4
	2145	5.6		1557	6.4
	2215	5.7		1615	6.4
	2245	5.6		1617	6.4
	2315	5.6		1635	6.3
	2345	5.5		1637	6.3
08/09	0015	5.5		1655	6.4
	0045	5.5		1657	6.4
	0115	5.5		1715	6.4
	0145	5.5		1717	6.4
	0215	5.5		1735	6.4
	0245	5.5		1737	6.4
	0315	5.5		1755	6.4
	0345	5.5		1757	6.3
	0415	5.6		1815	6.4
	0445	5.7		1817	6.4
	0515	5.5		1835	6.5
	0545	5.5		1837	6.3
	0615	5.5		1855	6.3
	0645	5.5		1857	6.5
	0715	5.5		1915	13.3
	0745	5.6		1917	6.5
	0815	5.6		1937	6.4
	0845	12.6		1955	6.4

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/09	1957	6.3	08/10	0315	6.5
	2015	13.5		0317	6.5
	2017	6.5		0335	6.5
	2035	6.4		0337	6.5
	2037	6.5		0355	6.5
	2055	6.5		0357	6.5
	2057	6.5		0415	6.5
	2115	6.4		0417	6.5
	2117	6.3		0435	6.5
	2135	6.5		0437	6.5
	2137	6.5		0455	6.5
	2155	6.5		0457	6.5
	2157	6.5		0515	6.5
	2215	6.5		0517	6.5
	2217	6.5		0535	6.5
	2235	6.5		0537	6.5
	2237	6.5		0559	6.5
	2255	6.5		0557	6.5
	2257	6.5		0615	6.5
	2315	6.5		0617	6.4
	2317	6.5		0635	6.4
	2335	6.5		0637	6.4
	2337	6.5		0655	6.4
	2355	6.5		0657	6.4
	2357	6.5		0715	6.4
08/10	0015	6.5		0717	6.4
	0017	6.5		0735	6.4
	0035	6.3		0737	6.4
	0037	6.5		0755	6.4
	0055	6.5		0757	6.4
	0057	6.5		0815	6.4
	0115	6.5		0817	6.4
	0117	6.5		0835	6.4
	0135	6.5		0837	6.4
	0137	6.5		0855	6.4
	0155	6.5		0857	6.4
	0157	6.5		0915	6.4
	0215	6.5		0917	6.4
	0217	6.5		0935	6.4
	0235	6.5		0937	6.4
	0237	6.5		0955	6.4
	0255	6.5		0957	6.4
	0257	6.5		1015	6.4

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/10	1017	6.4	08/10	1735	6.4
	1035	6.4		1737	6.4
	1037	6.4		1755	6.4
	1055	6.4		1757	6.4
	1057	6.4		1815	6.4
	1115	6.4		1817	6.4
	1117	6.4		1835	6.4
	1135	6.4		1837	6.4
	1137	6.4		1855	6.4
	1155	6.4		1857	6.4
	1157	6.4		1915	6.4
	1215	6.4		1935	6.4
	1217	6.4		1937	6.4
	1235	6.4		1955	6.4
	1237	6.4		1957	6.4
	1255	6.4		2015	6.4
	1257	6.4		2017	6.4
	1315	6.3		2035	6.4
	1317	6.4		2037	6.4
	1335	6.4		2055	6.4
	1337	6.4		0113	6.4
	1355	6.4		2115	6.4
	1357	6.4		2117	6.4
	1415	6.5		2135	6.4
	1417	6.4		2137	6.3
	1435	6.4		2155	6.4
	1437	6.4		2157	6.4
	1455	6.4		2215	6.4
	1457	6.4		2217	6.4
	1515	6.4		2235	6.4
	1517	6.4		2237	6.4
	1535	6.4		2255	6.4
	1537	6.4		2257	6.4
	1555	6.3		2315	6.4
	1557	6.3		2317	6.4
	1615	6.5		2335	6.4
	1617	6.4		2337	6.4
	1635	6.4		2355	6.4
	1637	6.3		2357	6.4
	1655	6.4	08/11	0015	6.4
	1657	6.4		0017	6.4
	1715	6.4		0035	6.4
	1717	6.4			

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/11	0037	6.4	08/11	0755	6.3
	0055	6.4		0757	6.4
	0057	6.4		0815	6.4
	0115	6.4		0817	6.4
	0117	6.4		0835	6.4
	0135	6.4		0837	6.4
	0137	6.4		0855	9.1
	0155	6.4		0855	6.4
	0157	6.4		0857	6.3
	0215	6.4		0915	6.3
	0217	6.4		0917	6.4
	0235	6.4		0931	6.3
	0237	6.4		0933	6.4
	0255	6.4	SCHEDULE CHANGE		
	0257	6.4	08/11	1030	6.4
	0315	6.4		1037	6.3
	0317	6.4		1055	6.4
	0335	6.4		1057	6.3
	0337	6.4		1115	6.3
	0355	6.4		1117	6.3
	0357	6.4		1135	6.3
	0415	6.4		1137	6.3
	0417	6.4		1155	6.3
	0435	6.4		1157	6.3
	0437	6.4		1215	6.2
	0455	6.4		1217	6.2
	0457	6.4		1235	5.7
	0515	6.4		1237	6.3
	0517	6.4		1255	6.2
	0535	6.4		1257	6.2
	0537	6.4		1315	6.3
	0559	6.4		1317	6.3
	0557	6.4		1335	6.3
	0615	6.4		1337	6.3
	0617	6.4		1355	5.7
	0635	6.4		1357	6.3
	0637	6.4		1415	6.3
	0655	6.4		1417	6.3
	0657	6.4		1435	6.3
	0715	6.3		1437	6.3
	0717	6.4		1455	6.3
	0735	6.4		1457	6.3
	0737	6.4			

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/11	1515	6.3	08/11	2217	5.9
	1517	6.3		2235	6.2
	1535	6.3		2237	6.3
	1537	6.3		2255	6.2
	1555	6.3		2257	6.3
	1557	5.7		2315	6.3
	1615	6.4		2317	6.4
	1617	6.4		2335	6.3
	1635	6.4		2337	6.4
	1637	6.4		2355	6.4
	1655	6.3		2357	6.4
	1657	6.3	08/12	0015	6.3
	1715	6.4		0017	6.3
	1717	6.4		0035	6.3
	1735	6.4		0037	6.3
	1737	6.4		0055	6.3
	1755	6.3		0057	6.3
	1757	6.4		0115	6.3
	1815	6.4		0117	6.4
	1817	6.4		0135	6.3
	1835	6.4		0137	6.4
	1837	6.4		0155	6.2
	1855	6.3		0157	6.1
	1857	6.3		0215	6.2
	1915	6.1		0217	6.2
	1917	6.1		0235	6.1
	1935	5.8		0237	6.1
	1937	5.9		0255	6.0
	1955	5.8		0257	6.2
	1957	5.7		0315	5.9
	2015	5.9		0317	6.0
	2017	5.7		0335	6.2
	2035	5.9		0337	6.2
	0645	5.8		0355	6.2
	2055	5.4		0357	6.3
	2057	5.5		0415	6.1
	2115	5.6		0417	6.2
	2117	5.7		0435	6.2
	2135	5.7		0437	6.2
	2137	5.6		0455	6.2
	2155	5.7		0457	6.3
	2157	5.9		0515	6.2
	2215	6.0		0517	6.2

TABLE 6. CONTINUED

Date	Time	pH	Date	Time	pH
08/12	0535	6.2	08/12	1257	6.3
	0537	6.3		1315	6.3
	0555	6.3		1317	6.3
	0557	6.3		1335	6.3
	0615	6.2		1337	6.3
	0617	6.2		1355	6.3
	0635	6.2		1357	6.3
	0637	6.2		1415	6.3
	0655	6.2		1417	6.3
	0657	6.2		1437	6.3
	0715	6.2		1455	6.3
	0717	6.3		1457	6.3
	0735	6.2		1515	6.3
	0737	6.2		1517	6.3
	0755	6.3		1535	6.3
	0757	6.3		1537	6.3
	0815	6.3		1555	6.3
	0817	6.3		1557	6.3
	0835	6.3		1615	6.3
	0837	6.3		1617	6.3
	0855	6.3		1635	5.7
	0857	6.3		1637	6.3
	0917	6.3		1655	5.7
	0935	6.3		1657	5.7
	0937	13.3		1715	5.7
	0955	6.3		1717	5.7
	0957	6.3		1735	5.7
	1015	6.3		1737	5.7
	1017	6.3		1755	5.7
	1035	6.3		1757	6.3
	1037	6.3		1815	5.7
	1055	5.7		1817	5.7
	1057	6.3		1835	6.3
	1115	6.3		1837	6.3
	1117	6.3		1855	6.3
	1135	5.7		1857	6.3
	1137	6.3		1915	6.3
	1155	6.3		1917	6.3
	1157	6.3		1935	6.3
	1215	6.3		1937	6.3
	1217	6.3		1955	6.3
	1235	6.3		1957	6.3
	1237	6.3		2015	6.3
	1255	6.3		2017	6.3

TABLE 6. CONCLUDED

Date	Time	pH	Date	Time	pH
08/12	2035	5.7	08/13	0317	6.3
	2037	5.7		0335	6.3
	2055	5.7		0337	6.3
	2057	5.7		0355	5.7
	2115	6.3		0357	6.3
	2135	6.3		0417	6.5
	2137	6.3		0435	6.3
	2155	6.3		0437	6.3
	2157	6.3		0455	6.3
	2215	5.7		0457	6.3
	2217	6.3		0515	6.3
	2235	6.3		0517	6.3
	2237	6.3		0535	6.3
	2255	6.3		0537	6.3
	2257	6.3		0555	6.3
	2315	6.3		0557	6.3
	2317	6.3		0615	6.3
	2335	6.3		0617	6.3
	2337	6.3		0635	6.3
	2355	6.3		0637	6.3
	2357	6.3		0655	6.3
08/13	0015	6.3		0657	6.3
	0017	6.3		0715	6.3
	0035	6.3		0717	6.3
	0037	6.3		0735	6.3
	0055	6.3		0737	6.3
	0057	6.3		0755	6.3
	0115	6.3		0757	6.3
	0117	6.3		0815	6.3
	0135	6.3		0817	6.3
	0137	6.3		0835	6.3
	0155	6.3		0837	6.3
	0157	6.3		0855	6.3
	0215	6.3		0857	6.3
	0217	6.3		0915	6.3
	0235	6.3		0917	6.3
	0237	6.3		0935	6.3
	0255	6.3		0937	6.3
	0257	6.3		0955	6.2
	0315	6.3			

TABLE 7. OXIDATION-REDUCTION POTENTIAL

Date	Time	ORP mv	Date	Time	ORP mv
08/06	1545	324	08/07	0625	328
	1605	328		0645	328
	1645	320		0705	328
	1705	324		0725	324
	1725	316		0745	324
	1745	312		0805	324
	1805	308		0825	320
	1825	556		0845	442
	1845	305		0905	316
	1905	308		0925	312
	1925	312		0945	312
	1945	316		1005	312
	2005	316		1025	312
	2025	316		1045	312
	2045	316		1125	312
	2105	316		1145	312
	2125	316		1205	308
	2145	320		1225	308
	2205	320		1305	308
	2225	320		1325	308
	2245	324		1345	312
	2305	328		1405	312
	2325	332		1425	686
	2345	332		1445	312
08/07	0005	332		1505	308
	0025	336		1525	308
	0045	332		1545	308
	0105	332		1605	308
	0125	332		1625	308
	0145	340		1645	312
	0205	332		1705	312
	0225	336		1725	312
	0245	332		1745	312
	0305	328		1805	312
	0325	316		1825	312
	0401	316		1845	312
	0405	316		1905	312
	0425	320		1925	312
	0445	324		2005	312
	0505	316		2025	312
	0525	320		2045	312
	0545	324		2105	312
	0605	328		2125	312

TABLE 7. CONTINUED

Date	Time	ORP mv	Date	Time	ORP mv
08/07	2145	312	08/08	1205	308
	2205	312		1225	308
	2225	312		1245	305
	2245	312		1305	305
	2305	308		1325	308
	2325	312		1345	308
	2345	312		1405	308
08/08	0005	324		1425	686
	0025	316		1445	312
	0045	312		1505	312
	0105	312		1525	312
	0125	312		1545	312
	0145	316		1605	312
	0205	316		1625	312
	0225	316		1645	308
	0245	316		1705	312
	0305	316		1725	308
	0325	316		1745	308
	0345	316		1805	308
	0405	316		1825	308
	0425	316		1845	312
	0445	316		1905	312
	0505	316		1925	308
	0525	316		1945	308
	0545	316		2005	301
	0605	316		2025	301
	0625	316		2045	308
	0645	312		2105	312
	0705	686		2125	312
	0725	316		2145	312
	0745	312		2205	312
	0805	312		2225	312
	0825	316		2245	316
	0845	312		2305	316
	0905	312		2325	312
	0925	312		2345	324
	0945	312	08/09	0005	312
	1005	312		0025	312
	1025	312		0045	312
	1045	312		0113	312
	1105	312		0125	312
	1125	312		0145	312
	1145	312		0205	312

TABLE 7. CONTINUED

Date	Time	ORP mv	Date	Time	ORP mv
08/09	0225	312	08/09	2125	285
	0245	312		2155	285
	0305	312		2225	285
	0325	312		2255	411
	0345	316		2325	285
	0405	316		2355	285
	0425	690	08/10	0025	285
	0445	316		0055	285
	0505	316		0125	289
	0525	316		0155	289
	0545	312		0225	293
	0605	312		0255	289
	0625	312		0325	289
	0645	324		0355	289
	0705	316		0425	289
	0725	316		0455	289
	0745	316		0525	289
	0805	312		0555	674
	0825	312		0625	289
	0845	686		0655	289
	0905	312		0725	293
	0925	312		0755	308
	0945	312		0825	293
	1005	308		0855	293
	1025	308		0925	293
	1045	305		0955	293
	1104	301		1025	293
SCHEDULE CHANGE				1055	293
08/09	1348	261		1125	293
	1425	269		1155	293
	1455	273		1225	293
	1525	308		1255	293
	1555	277		1325	293
	1625	281		1355	293
	1655	285		1425	293
	1725	285		1455	293
	1755	411		1525	293
	2241	285		1555	293
	1855	285		1625	293
	1925	285		1655	297
	1955	285		1725	297
	2025	289		1755	293
	2055	285		1825	293

TABLE 7. CONTINUED

Date	Time	ORP mv	Date	Time	ORP mv
08/10	1855	293	08/11	1835	301
	1925	297		1921	301
	1955	293		2005	308
	2233	293		2050	308
	2055	297		2135	312
	2229	297		0237	308
	2155	297		2305	301
	2225	297		2350	301
	2255	297	08/12	0035	301
	2325	301		0121	305
	2355	301		0205	305
08/11	0025	301		0250	305
	0055	297		0335	305
	0125	297		0421	308
	0155	297		0505	308
	0225	297		0550	305
	0255	297		0635	305
	0325	297		0721	308
	0355	297		0805	305
	0425	297		0850	308
	0455	301		0935	305
	0525	297		1021	308
	0555	297		1105	308
	0625	297		1150	308
	0655	297		1235	305
	0725	301		1321	305
	0755	301		1405	305
	0825	297		1450	308
	0855	297		1535	308
	0925	301		1621	556
SCHEDULE CGABGE				1705	556
08/11	0938	308		1750	308
	1020	301		1835	312
	1105	301		1921	312
	1150	297		2005	308
	1235	301		2050	312
	1321	297		2135	312
	1405	301		2221	316
	1450	301		2305	312
	1535	301		2350	312
	1621	301	08/13	0035	808
	1705	301		0121	308
	1750	297		0205	308

TABLE 7. CONCLUDED

Date	Time	ORP mv	Date	Time	ORP mv
08/13	0250	308	08/13	0635	312
	0335	312		0721	312
	0425	312		0805	312
	0505	312		0850	312
	0550	312		0935	316

TABLE 8. DISSOLVED OXYGEN

Date	Time	D.O. mg/ℓ	Date	Time	D.O. mg/ℓ
08/06	1520	13.9	08/06	0600	12.3
	1540	13.6		0620	13.1
	1600	13.6		0640	12.5
	1640	13.6		0700	12.1
	1700	13.7		0720	9.5
	1720	11.1		0740	11.0
	1740	13.7		0800	10.8
	1800	13.7		0820	9.9
	1820	0.0		0840	10.0
	1840	14.0		0900	9.5
	1900	0.0		0920	10.2
	1920	0.0		0941	8.2
	1940	13.8		1000	12.7
	2000	13.9		1020	8.6
	2020	0.0		1040	11.8
	2040	0.0		1100	8.0
	2100	0.0		1120	9.7
	2120	13.9		1140	7.5
	2140	13.8		1616	7.2
	2201	13.9		1220	7.6
	2220	13.6		1240	8.1
	2240	13.6		1300	8.8
	2300	13.4		1340	12.1
	2320	13.2		1420	8.8
	2340	13.0		1440	9.1
08/07	0002	12.8		1500	8.6
	0020	13.1		1520	9.1
	0040	13.0		1540	10.0
	0100	13.4		1600	10.5
	0120	14.0		1620	12.2
	0140	14.0		1640	12.5
	0200	14.3		1700	11.7
	0220	14.3		1720	11.8
	0240	15.1		1740	11.2
	0300	14.5		1800	11.7
	0320	14.5		1820	10.6
	0340	14.6		1840	12.6
	0400	14.5		1900	13.0
	0420	0.0		1920	12.9
	0440	14.7		1940	14.0
	0500	15.2		1955	8.4
	0520	13.3		2000	13.5
	0540	13.8		2020	14.6

TABLE 8. CONTINUED

Date	Time	D.O. mg/ℓ	Date	Time	D.O. mg/ℓ
08/07	2040	13.1	08/08	1120	8.5
	2100	12.4		1140	8.6
	2120	13.1		1208	8.4
	2140	13.3		1220	8.2
	2200	13.4		1240	8.5
	2220	14.0		1300	8.9
	2240	14.5		1320	9.1
	2300	15.1		1340	8.8
	2340	0.0		1400	8.8
08/08	0002	10.4		1420	8.8
	0020	10.8		1440	8.8
	0040	9.6		1500	9.0
	0100	10.2		1520	8.9
	0120	9.5		1540	8.7
	0140	9.7		1600	8.8
	0200	10.1		1620	9.4
	0220	9.9		1640	9.4
	0240	9.6		1700	9.0
	0300	9.3		1720	9.1
	0320	10.2		1740	11.0
	0340	10.6		1800	12.1
	0400	11.3		1820	10.7
	0420	9.9		1840	12.3
	0440	9.0		1900	12.7
	0500	9.2		1920	15.5
	0520	9.4		1940	14.1
	0540	8.9		2000	15.5
	0600	9.0		2020	15.0
	0620	11.4		2040	0.0
	0640	12.5		2100	0.0
	0700	13.4		2120	9.7
	0720	12.9		2140	10.4
	0740	12.5		2200	11.7
	0800	12.1		2220	12.1
	0820	10.5		2240	10.5
	0840	9.8		2300	9.9
	0900	8.9		2320	10.4
	0920	8.6		2340	9.0
	0940	8.2	08/09	0002	8.4
	1000	8.6		0020	8.7
	1020	8.8		0040	8.9
	1040	12.3		0100	8.7
	1100	12.5		0120	8.6

TABLE 8. CONTINUED

Date	Time	D.O. mg/ℓ	Date	Time	D.O. mg/ℓ
08/09	0140	8.4	08/09	2041	16.7
	0200	12.3		2110	17.1
	0220	12.3		2141	17.0
	0240	12.2		2210	17.1
	0320	8.5		2240	16.7
	0340	8.2		2310	16.9
	0400	9.1		2340	0.0
	0420	9.5	08/10	0010	16.8
	0440	11.7		0041	16.9
	0500	11.6		0110	16.9
	0520	9.2		0140	19.1
	0540	8.6		0314	16.5
	0600	8.9		0240	16.5
	0620	8.1		0310	16.5
	0640	11.6		0341	16.3
	0700	9.7		0410	16.4
	0724	8.8		0440	16.5
	0740	10.1		0510	18.2
	0800	13.0		0540	16.5
	0820	13.6		0610	16.6
	0840	10.5		0641	16.4
	0900	12.0		0710	16.4
	0920	15.3		0740	16.5
	0941	13.4		0810	16.4
	1000	14.0		0840	16.5
	1020	0.0		0910	16.4
	1040	14.7		0941	16.7
	1100	0.0		1010	16.7
SCHEDULE CHANGE				1040	16.5
08/09	1341	16.0		1110	16.2
	1410	16.0		1140	16.3
	1440	16.0		1210	16.3
	1510	16.0		1241	16.4
	1541	16.5		1310	16.5
	1610	16.5		1340	16.3
	1625	8.1		1410	16.3
	1710	16.7		1440	16.2
	1740	16.7		1510	0.0
	1810	16.7		1541	16.5
	1841	16.5		1610	0.0
	1910	16.6		1640	16.6
	1941	16.6		1710	16.4
	2010	16.6		1740	16.8

TABLE 8. CONTINUED

Date	Time	D.O. mg/ℓ	Date	Time	D.O. mg/ℓ
08/10	1810	16.3	08/11	1541	15.4
	1841	16.2		1610	15.9
	1910	16.2		1640	16.3
	1940	15.9		1740	15.8
	2010	16.9		1810	16.2
	2040	16.8		1841	15.1
	2110	16.9		1910	14.0
	2141	16.8		1940	14.3
	2210	16.5		2010	13.0
	2240	16.6		2040	0.0
	2310	16.6		2110	7.8
	2340	16.7		2141	8.0
08/11	0010	16.7		2210	9.6
	0041	16.7		2240	0.0
	0110	16.5		2310	15.5
	0140	16.3	08/12	0010	15.8
	0210	16.4		0041	16.0
	0240	16.3		0110	16.2
	0310	16.5		0140	15.8
	0341	16.4		0210	15.8
	0410	16.1		0240	12.1
	0440	16.2		0310	11.4
	0510	15.8		0341	13.7
	0540	16.1		0410	13.2
	0610	16.0		0440	0.0
	0641	15.9		0510	0.0
	0710	16.0		0540	0.0
	0740	15.7		0610	0.0
	0810	15.7		0641	0.0
	0840	15.9		0710	0.0
	0910	15.9		0740	0.0
SCHEDULE CHANGE				0810	0.0
08/11	0934	15.9		0840	0.0
	1040	15.4		0910	0.0
	1110	15.2		0941	0.0
	1140	15.0		1010	0.0
	1210	14.7		1040	0.0
	1241	14.5		1110	16.1
	1310	16.0		1140	0.0
	1340	16.2		1210	0.0
	1410	16.0		1241	15.8
	1440	15.3		1310	0.0
	1510	15.1		1340	0.0

TABLE 8. CONCLUDED

Date	Time	D.O. mg/ℓ	Date	Time	D.O. mg/ℓ
08/12	1410	0.0	08/13	0010	0.0
	1440	0.0		0041	16.3
	1510	16.4		0110	16.5
	1541	16.3		0140	16.5
	1610	0.0		0210	16.6
	1640	16.2		0240	16.3
	1710	0.0		0310	16.5
	1740	16.4		0341	16.5
	1810	16.3		0410	0.0
	1841	0.0		0510	16.3
	1910	0.0		0540	0.0
	1941	0.0		0610	0.0
	2010	16.5		0641	0.0
	2040	0.0		0710	0.0
	2110	0.0		0740	0.0
	2141	16.5		0810	0.0
	2210	16.4		0840	16.6
	2240	1.2		0910	0.0
	2310	0.0		0941	0.0
	2340	0.0			

TABLE 9. FLUORIDE

Date	Time	Fℓ mg/ℓ	Date	Time	Fℓ mg/ℓ
08/06	1525	0.247	08/07	1325	0.515
	1555	.324		1355	.425
	1600	11.3		1425	.462
	1655	.291		1455	.450
	1725	.247		1525	.437
	1755	.261		1555	.462
	1825	.247		1625	.543
	1855	.247		1655	.450
	1925	.210		1725	.425
	1955	.199		1755	.393
	2025	.183		1825	.371
	2055	.183		1855	.343
	2125	.156		1925	.371
	2155	.178		2025	.324
	2225	.210		2055	.371
	2255	.228		2125	.361
	0933	.228		2155	.343
	2355	.228		2225	.343
08/07	0025	.247		2255	.393
	0055	.222		2325	.324
	0125	.222		2355	.393
	0155	.228	08/08	0025	.361
	0225	.291		0055	.393
	0255	.216		0125	.450
	0325	.199		0155	.543
	0355	.199		0225	.414
	0425	.199		0255	.450
	0455	.216		0325	.450
	0525	.216		0355	.393
	0555	.228		0425	.393
	0655	.261		0455	.462
	0725	.247		0525	.462
	0755	.291		0555	.474
	0825	.343		0625	.393
	0855	.361		0655	.543
	0925	.315		0725	.462
	0950	.393		0755	.393
	1025	.210		0825	.474
	1055	.291		0855	.529
	1125	.291		0925	.501
	1155	.343		0955	.543
	1225	.361		1025	.622
	1255	.425		1055	.622

TABLE 9. CONTINUED

Date	Time	Fℓ mg/ℓ	Date	Time	Fℓ mg/ℓ
08/09	2325	0.393	08/10	1025	0.501
	2340	.543		1040	.543
	2355	.403		1055	.414
08/10	0010	.414		1110	.403
	0025	.462		1125	.403
	0040	.425		1140	.403
	0055	.462		1155	.425
	0110	.403		1210	.450
	0125	.352		1225	.462
	0140	.343		1240	.425
	0155	.343		1255	.425
	0210	.343		1310	.543
	0225	.343		1325	.403
	0240	.343		1340	.371
	0255	.35		1355	.403
	0310	.403		1410	.403
	0325	.403		1425	.403
	0340	.382		1440	.371
	0355	.393		1455	.371
	0410	.343		1510	.382
	0425	.343		1525	.403
	0440	.343		1540	.393
	0511	.343		1555	.414
	0510	.352		1610	.393
	0525	.352		1625	.382
	0540	.371		1640	.371
	0555	.403		1655	.403
	0610	.403		1710	.403
	0625	.393		1725	.371
	0640	.425		1740	.393
	0655	.565		1755	.403
	0710	.425		1810	.462
	0725	.425		1825	.450
	0740	.403		1840	.437
	0810	.371		1855	.462
	0825	.328		1910	.425
	0840	.403		1925	.462
	0855	.382		1940	.462
	0910	.450		1955	.462
	0925	.486		2010	.543
	0940	.543		2025	.529
	0955	.501		2040	.543
	1010	.515		2055	.543

TABLE 9. CONTINUED

Date	Time	Fℓ mg/ℓ	Date	Time	Fℓ mg/ℓ
08/10	2110	0.543	08/11	0810	0.590
	2125	.543		0825	.606
	2140	1.0		0840	.732
	2155	.557		0855	.732
	2210	.501		0910	.590
	2225	.543		0925	.543
	2240	1.0	SCHEDULE CHANGE		
	2255	1.0	08/11	0933	.515
	2310	1.0		1025	.543
	2325	.543		1040	.515
	2340	.543		1055	.529
	2355	.501		1110	1.0
08/11	0010	.543		1125	.639
	0025	.501		1140	.590
	0040	.501		1155	.590
	0055	.557		1210	.557
	0110	.543		1225	.543
	0125	.590		1255	.529
	0140	.529		1310	.529
	0155	.486		1325	.543
	0210	.501		1340	.543
	0225	.543		1355	.543
	0240	.529		1410	.529
	0255	.590		1425	.529
	0310	.590		1440	.543
	0325	.639		1455	.543
	0340	.606		1510	.486
	0355	.639		1525	.462
	0425	.543		1540	.515
	0440	.501		1555	.501
	0455	.543		1610	.501
	0510	.486		1625	1.0
	0525	.501		1640	.501
	0540	.501		1655	.501
	0555	.543		1710	.501
	0610	.529		1725	.501
	0625	.501		1740	.462
	0640	.543		1755	.543
	0655	.529		1810	.590
	0710	.543		1825	.590
	0725	.543		1840	.557
	0740	.543		1855	.656
	0755	.543		1910	.639

TABLE 9. CONTINUED

Date	Time	Fℓ mg/ℓ	Date	Time	Fℓ mg/ℓ
08/11	1925	0.590	08/12	0610	0.639
	1941	.501		0625	.590
	1955	.606		0640	.639
	2010	.639		0655	.639
	2025	.639		0710	.590
	2040	.639		0725	.639
	2055	.557		0740	.639
	2110	.590		0755	.639
	2125	.590		0810	.732
	2140	.694		0825	.694
	2155	.656		0840	.732
	2210	.639		0855	.694
	2225	.622		0910	.694
	2240	.606		0925	.656
	2255	.639		0940	.694
	2310	.590		0955	.694
	2325	.573		1010	.656
	2340	.590		1025	.694
	2355	.732		1040	.694
08/12	0010	.732		1055	.732
	0025	.557		1110	.694
	0040	.543		1125	.694
	0055	.501		1140	.713
	0110	.501		1155	.732
	0125	.543		1210	.732
	0140	.543		1225	.732
	0155	.557		1240	.694
	0210	.639		1255	.694
	0225	.639		1310	.694
	0240	.694		1325	.732
	0255	.639		1340	.656
	0310	.639		1355	.694
	0325	.639		1410	.732
	0340	.543		1425	.713
	0355	.590		1440	.732
	0410	1.0		1455	.732
	0425	1.0		1510	.773
	0440	.543		1525	.773
	0455	1.0		1540	.732
	0510	.590		1555	.732
	0525	.694		1610	.732
	0540	.639		1625	1.0
	0555	.639		1640	.732

TABLE 9. CONCLUDED

Date	Time	Fℓ mg/ℓ	Date	Time	Fℓ mg/ℓ
08/12	1655	0.694	08/13	0125	0.639
	1710	.694		0140	.639
	1725	.656		0155	.639
	1740	.639		0210	.639
	1755	.639		0225	.732
	1810	.606		0240	.732
	1825	.639		0255	.732
	1840	.639		0310	.732
	1855	.639		0325	.732
	1910	.606		0340	.732
	1925	.622		0355	.732
	1940	.732		0410	.639
	1955	.639		0425	.639
	2010	.639		0440	.732
	2025	.732		0455	.694
	2040	.639		0510	.732
	2055	.639		0525	.732
	2110	.639		0540	.732
	2125	.606		0610	.795
	2140	.639		0625	1.0
	2155	.606		0640	.795
	2210	.639		0655	.795
	2225	.639		0710	1.0
	2240	.606		0725	.732
	2255	.639		0740	.795
	2310	.606		0755	.839
	2325	.639		0810	.795
	2340	.732		0825	.732
	2355	.639		0840	762.0
08/13	0010	.694		0855	.713
	0025	.656		0910	.739
	0040	.656		0925	.795
	0055	.694		0940	.839
	0110	.639		0955	.910

TABLE 10. TURBIDITY

Date	Time	Turb NTU	Date	Time	Turb NTU
08/06	1535	100.0	08/08	1035	76.0
	1635	100.0		1135	100.0
	1735	100.0		1235	100.0
	1835	100.0		1335	100.0
	1935	100.0		1435	100.0
	2035	46.2		1535	100.0
	2135	7.9		1635	100.0
	2235	9.0		1735	100.0
	2335	7.9		1835	100.0
08/07	0035	8.3		1935	100.0
	0135	8.1		2243	28.5
	0235	7.7		2135	20.8
	0335	7.1		2235	19.5
	0435	7.5		2335	18.3
	0535	9.0	08/09	0035	25.0
	0635	22.2		0135	24.2
	0735	100.0		0235	18.9
	0835	100.0		0335	18.7
	0935	100.0		0435	18.1
	1035	100.0		0635	23.4
	1135	100.0		0735	100.0
	1235	100.0		0835	100.0
	1335	100.0		0935	100.0
	1435	100.0		1035	100.0
	1535	100.0	SCHEDULE CHANGE		
	1635	100.0	08/09	1405	100.0
	1735	100.0		1450	100.0
	1835	100.0		1621	100.0
	1935	100.0		1705	100.0
	2035	32.0		1750	100.0
	2135	12.4		1835	100.0
	2235	14.0		1921	88.2
	2335	16.5		2005	46.2
08/08	0035	24.8		2050	16.7
	0135	24.4		2135	9.2
	0235	20.2		2221	8.7
	0335	19.3		2305	8.6
	0435	18.7		2350	9.4
	0535	23.4	08/10	0035	8.8
	0635	18.7		0121	8.4
	0735	32.0		0205	8.4
	0835	42.8		0250	8.8
	0935	100.0		0335	9.8

TABLE 10. CONTINUED

Date	Time	Turb NTU	Date	Time	Turb NTU
08/10	0421	8.3	08/11	1125	100.0
	0505	8.4		1155	100.0
	0550	8.3		1225	100.0
	0635	11.6		1255	100.0
	0721	61.7		1325	100.0
	0805	56.2		1355	100.0
	0850	46.0		1425	100.0
	0935	83.3		1455	25.9
	1021	100.0		1525	100.0
	1105	100.0		1555	100.0
	1150	100.0		1625	100.0
	1235	100.0		1655	100.0
	1321	100.0		1725	100.0
	1405	100.0		1755	100.0
	1450	100.0		1825	84.9
	1535	100.0		1855	72.3
	1621	100.0		1925	96.7
	1705	77.2		1955	46.6
	1750	43.4		2025	25.3
	1835	55.4		2055	17.5
	1921	69.6		2125	12.8
	2005	28.9		2155	12.6
	2050	9.2		2225	11.4
	2135	9.8		2255	10.2
	2221	9.0		2325	9.2
	2305	9.0		2355	9.0
	2350	9.8	08/12	0025	8.8
08/11	0035	9.0		0055	9.2
	0121	9.4		0125	9.0
	0205	9.0		0155	9.8
	0250	9.4		0225	12.0
	0335	8.6		0255	12.0
	0421	8.4		0325	11.6
	0505	9.6		0355	11.0
	0550	9.8		0425	11.6
	0635	12.2		0455	13.8
	0721	40.3		0525	14.1
	0805	96.3		0555	9.2
	0850	100.0		0625	12.4
	0932	100.0		0655	18.3
SCHEDULE CHANGE				0725	38.1
08/11	1025	100.0		0755	64.6
	1055	100.0		0825	58.6

TABLE 10. CONCLUDED

Date	Time	Turb NTU	Date	Time	Turb NTU
08/12	0855	100.0	08/12	2155	8.8
	0925	100.0		2225	9.2
	0955	100.0		2255	9.0
	1025	100.0		2325	8.8
	1055	100.0		2355	9.0
	1125	100.0	08/13	0025	10.0
	1155	100.0		0055	9.2
	1225	100.0		0125	9.4
	1255	100.0		0155	9.4
	1325	100.0		0225	9.4
	1355	100.0		0255	8.6
	1425	100.0		0325	8.6
	1455	100.0		0355	9.0
	1525	100.0		0425	9.0
	1555	100.0		0455	9.0
	1625	100.0		0525	8.3
	1655	100.0		0555	8.6
	1755	59.7		0625	9.8
	1825	100.0		0655	23.4
	1855	100.0		0725	56.2
	1925	76.4		0755	100.0
	1955	37.7		0825	100.0
	2025	17.9		0855	100.0
	2055	9.2		0925	100.0
	2125	8.6		0955	100.0

TABLE 11. FIELD VERIFICATION DATA

Date	Temp °C	Conductivity, µmho/cm	pH	Turbidity, NTU	Dissolved Oxygen, mg/ℓ	Depth, meters
08/06	17.6	244.0	7.33	6.6	2.1	8.1
08/07	22.0	254.5	8.54	1.3	8.0	4.9
08/08	22.9	246.6	8.64	1.5	7.8	4.9
08/09	23.2	262.0	8.62	1.6	8.0	7.0
08/10	22.5	236.2	8.54	1.6	7.4	7.0
08/11	22.5	251.2	8.44	1.8	7.86	7.0
08/12	22.0	250.2	8.44	2.1	7.5	7.0
08/13	22.0	243.8	8.59	2.0	7.52	7.0

TABLE 12. MEASUREMENTS OF WATER SAMPLES

Date	Time	Conductivity, μmho/cm	Turbidity, NTU	pH
08/06	1500	239.5	1.3	7.88
	1700	238.3	1.8	7.55
	1900	227.4	1.2	7.71
08/07	0400	233.4	2.2	7.60
	0800	231.4	4.5	7.47
	2400	250.4	8.5	7.62
08/08	0800	246.4	4.6	7.61
	2000	240.0	4.8	7.70
08/09	0800	247.2	3.6	7.93
	1100	246.0	3.6	8.33

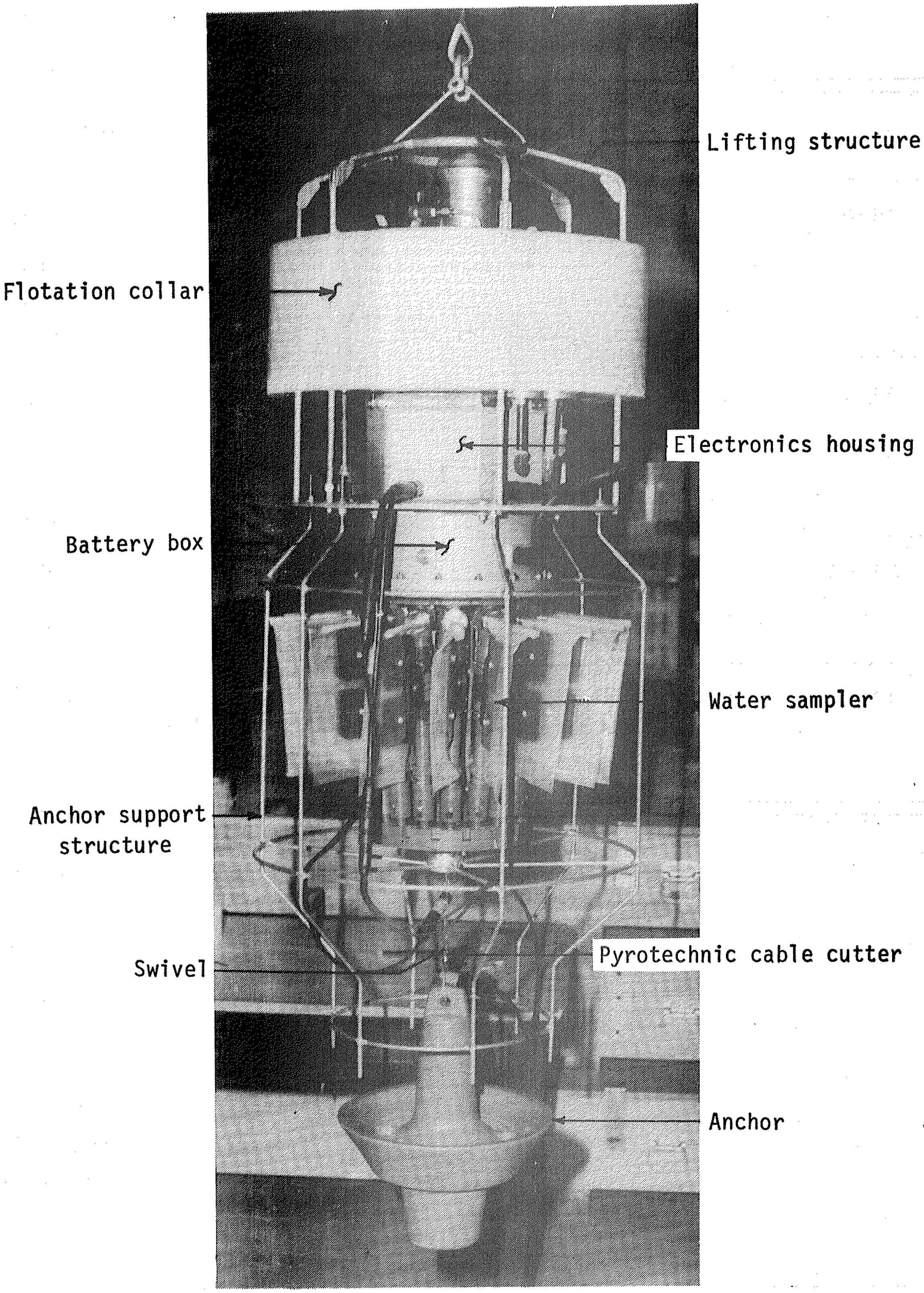

Figure 1.- Water Quality Monitoring System subsurface unit.

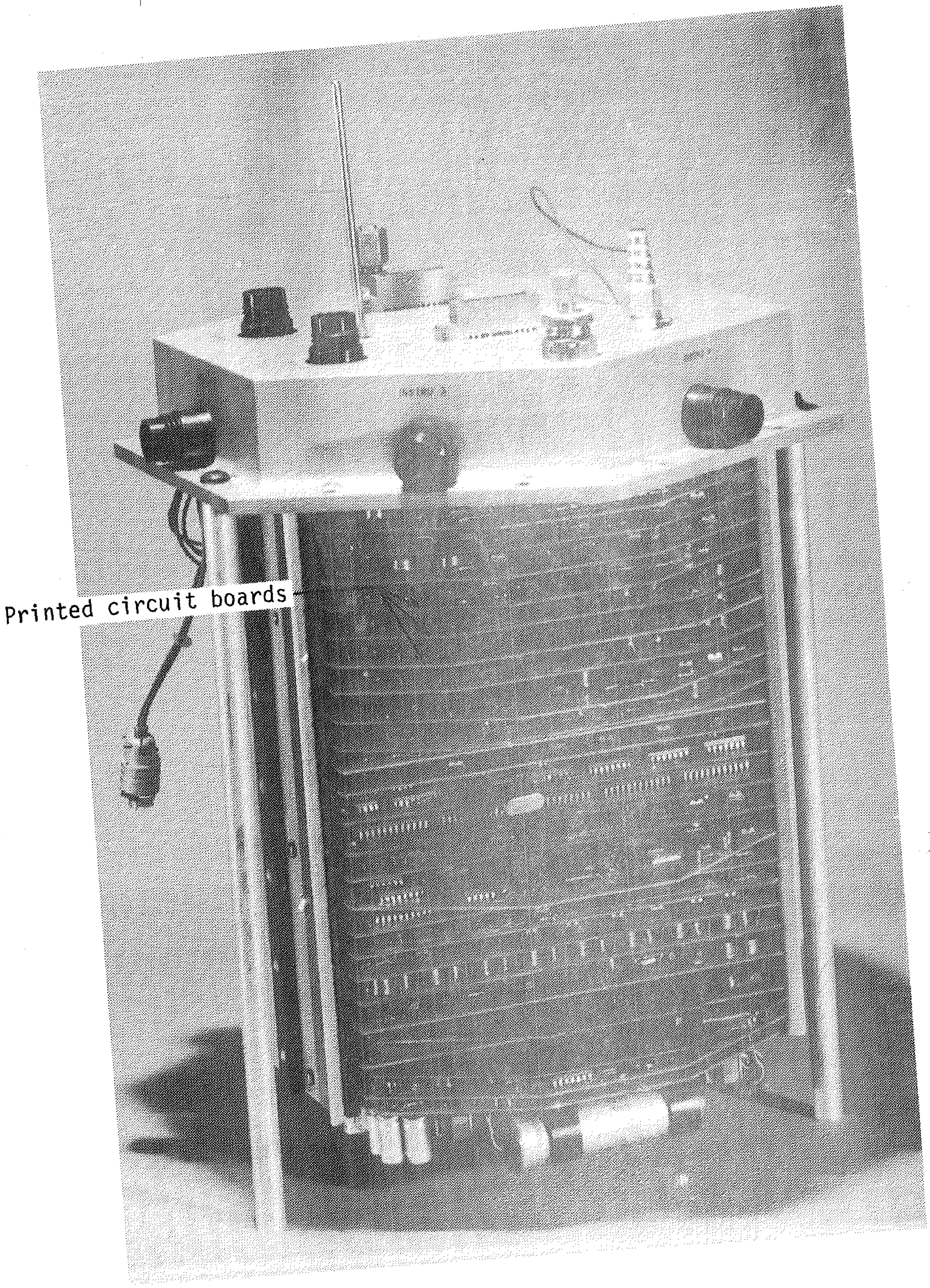

Figure 2.- WQMS SSU electronics.

(a) Assembled electronics.

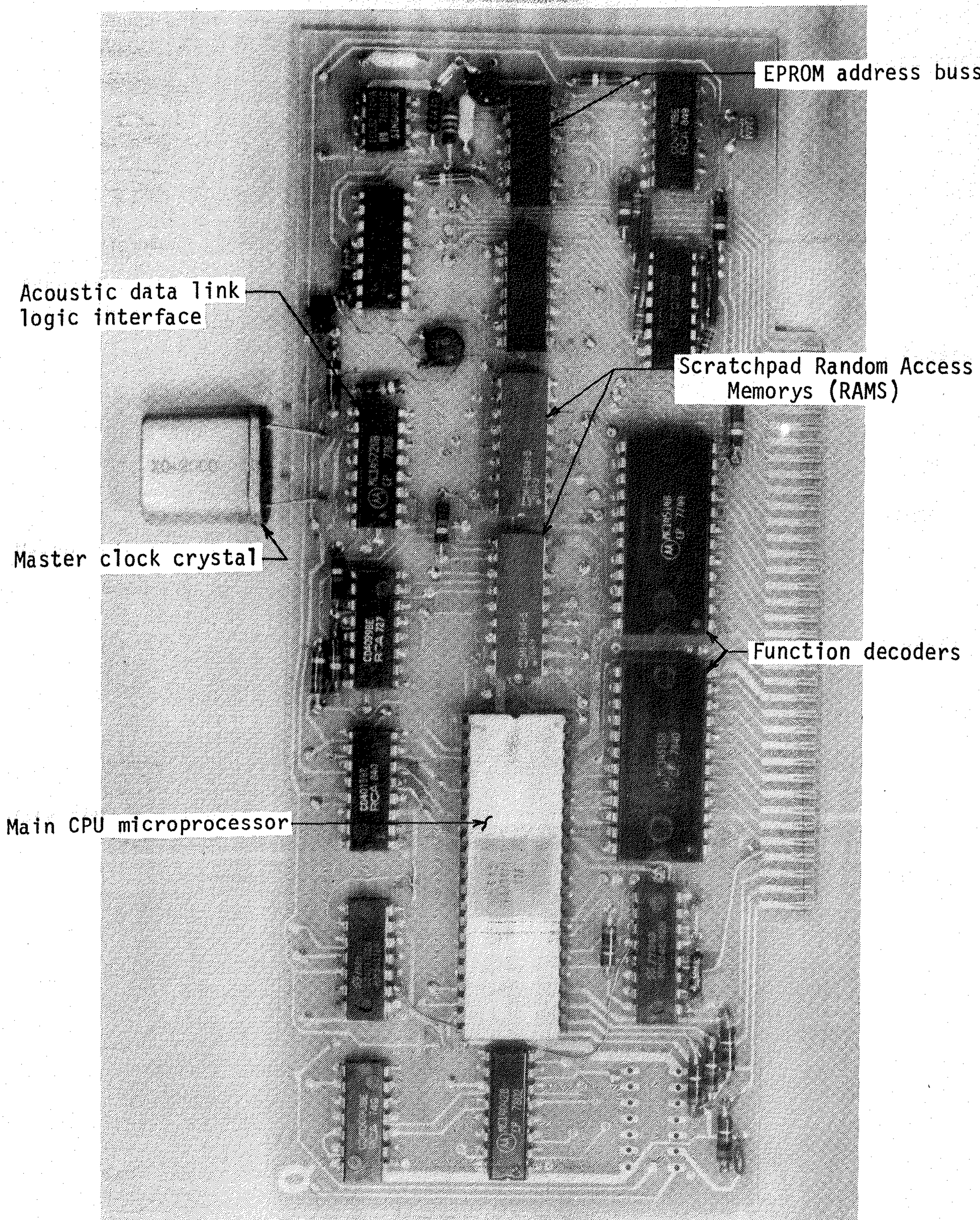

Figure 2.- Continued.

(b) Main Central Processor Unit (CPU) card (one of three).

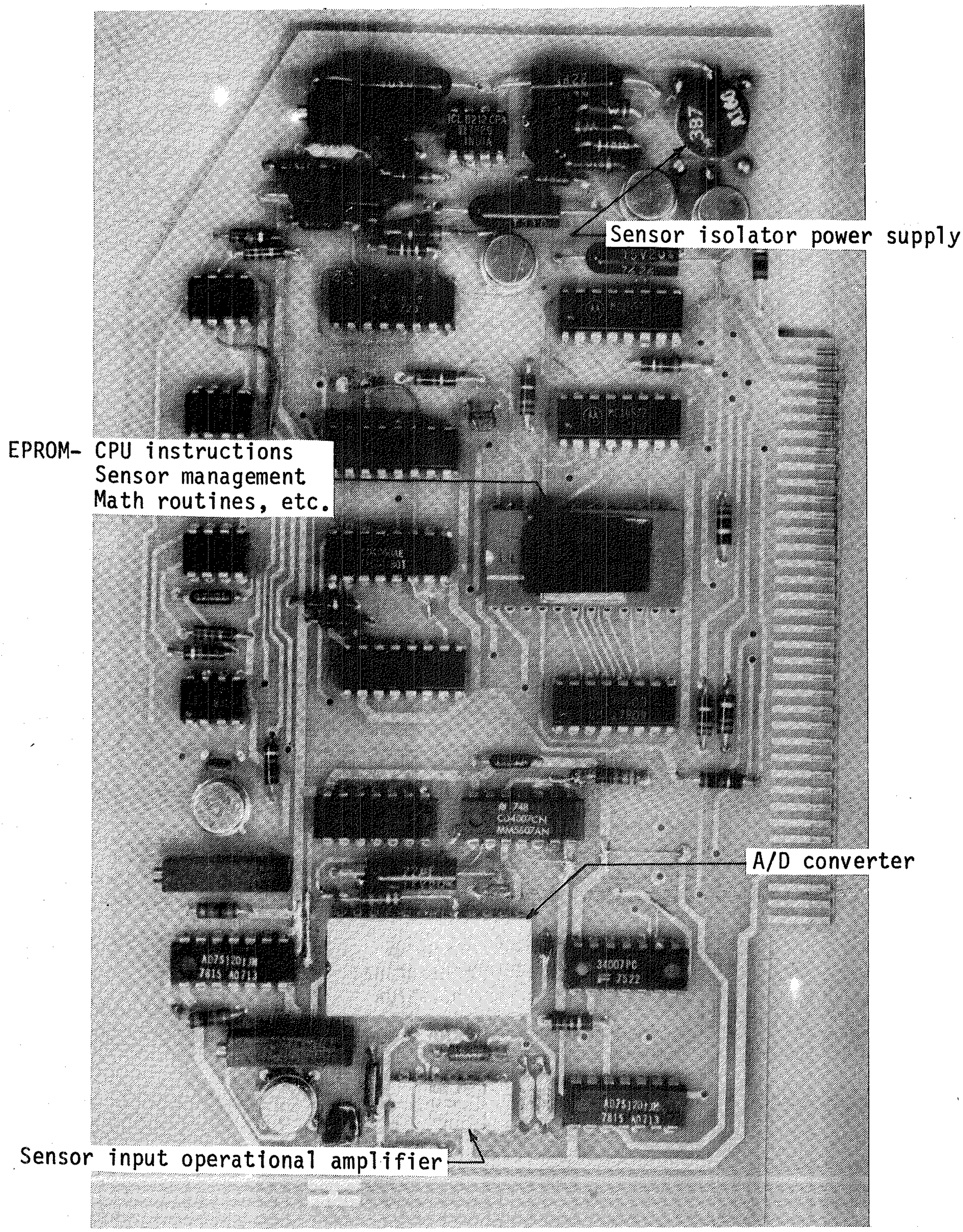

Figure 2.- Continued.

(c) Sensor interface card (one for each sensor).

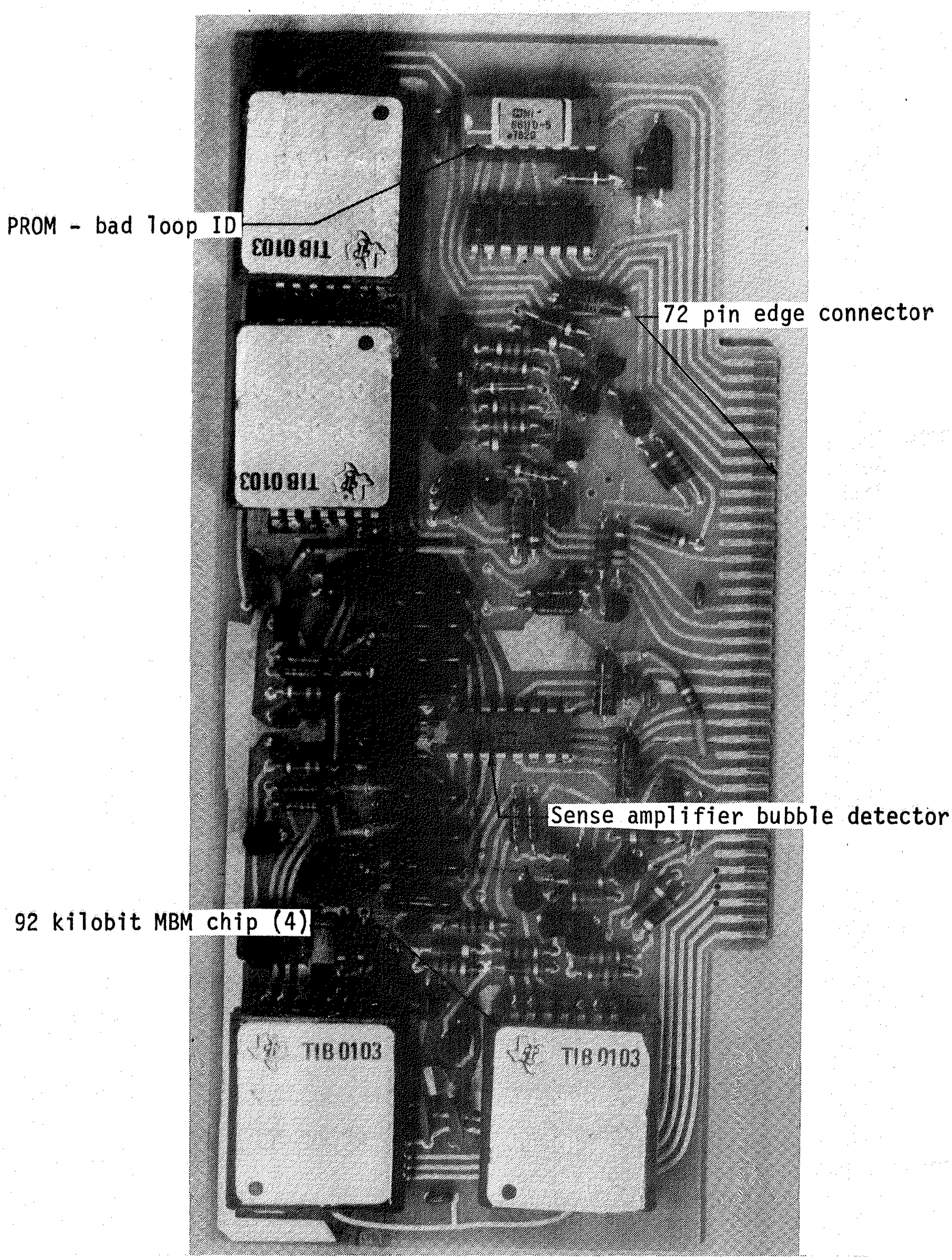

Figure 2.- Continued.

(d) Magnetic domain bubble memory card (one of six).

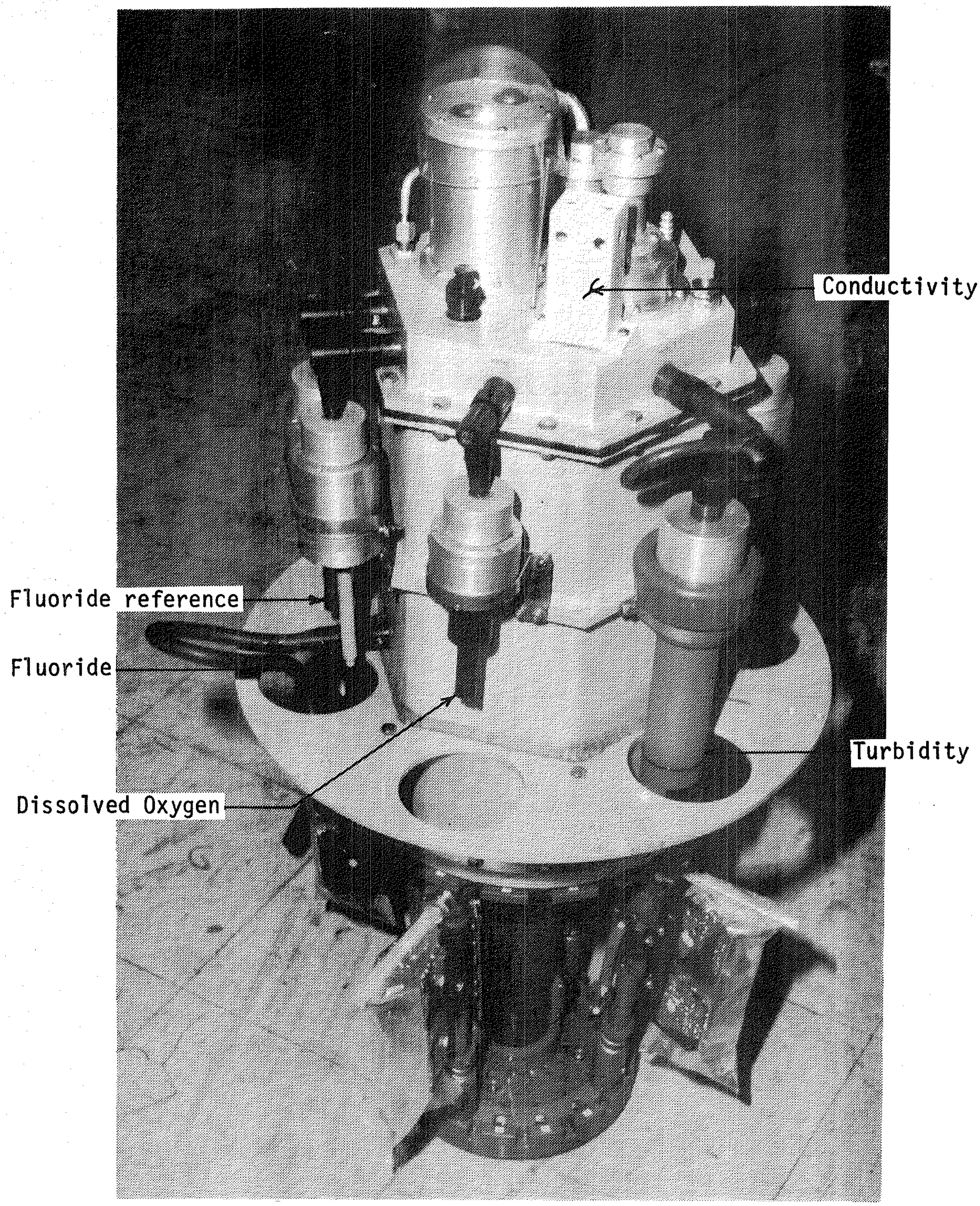

Figure 3.- SSU sensor mounting.

(a) First side view.

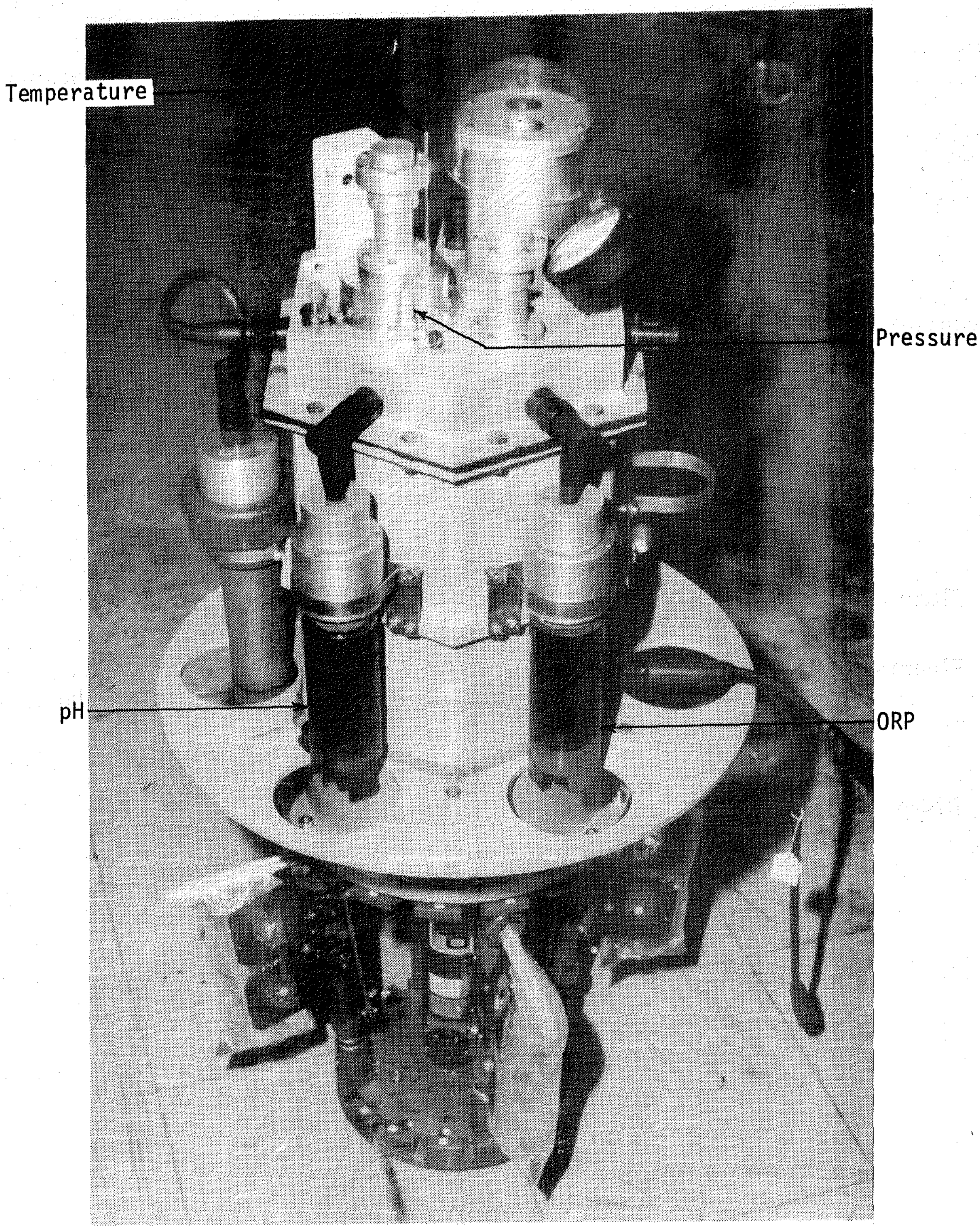

Figure 3.- Continued.

(b) Second side view.

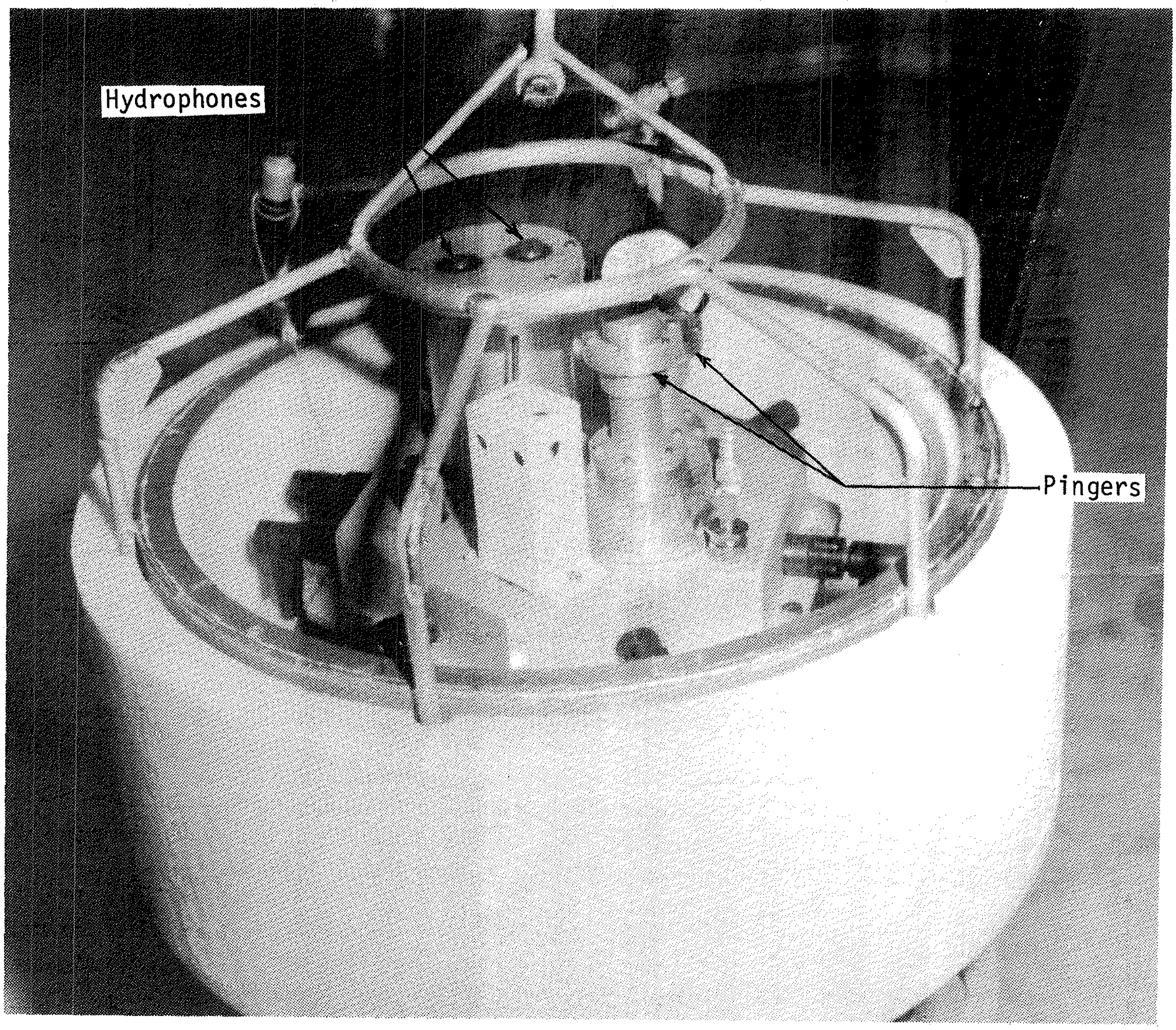

Figure 4.- Communication and location aids on SSU.

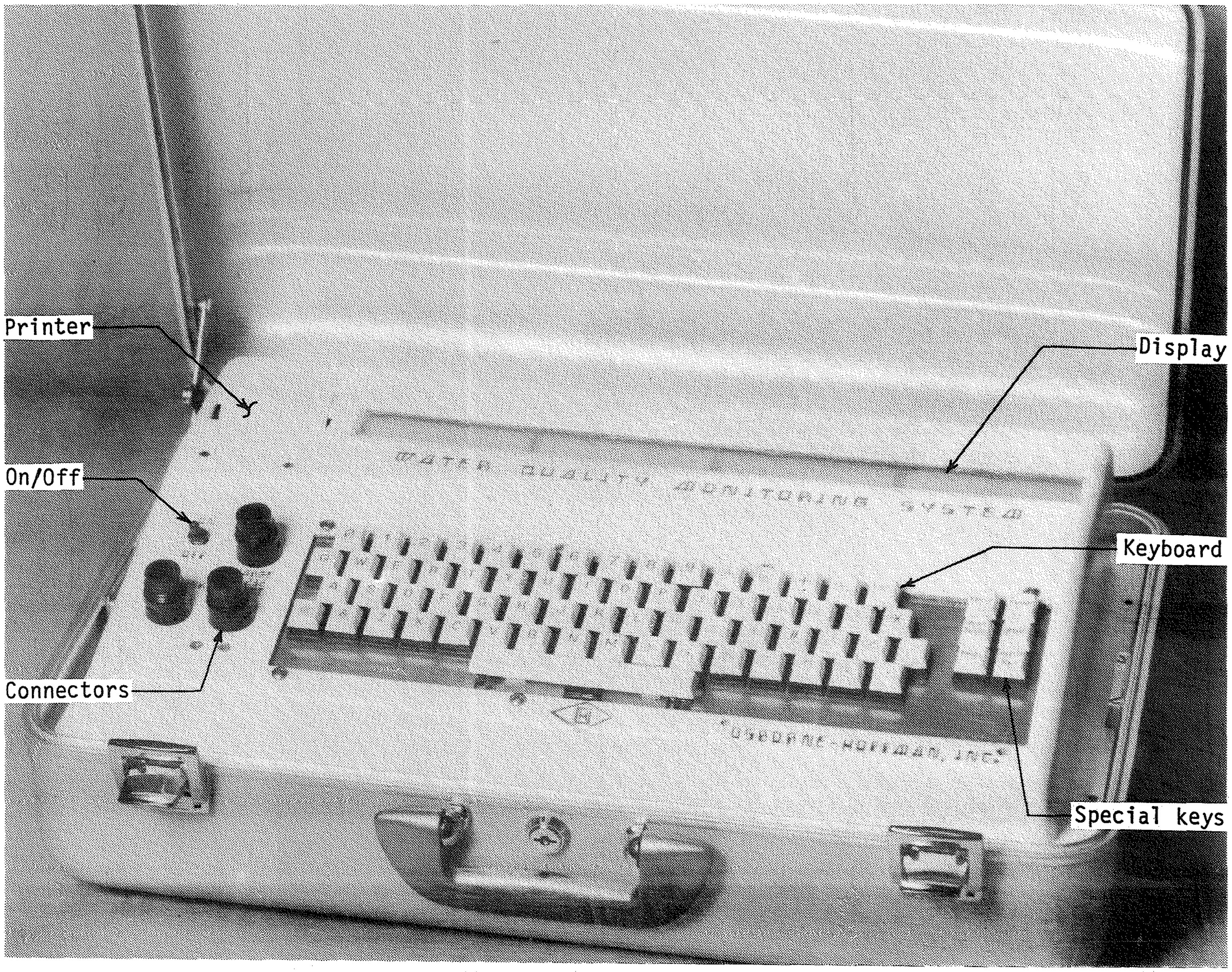

Figure 5.- WQMS Surface Control Unit.

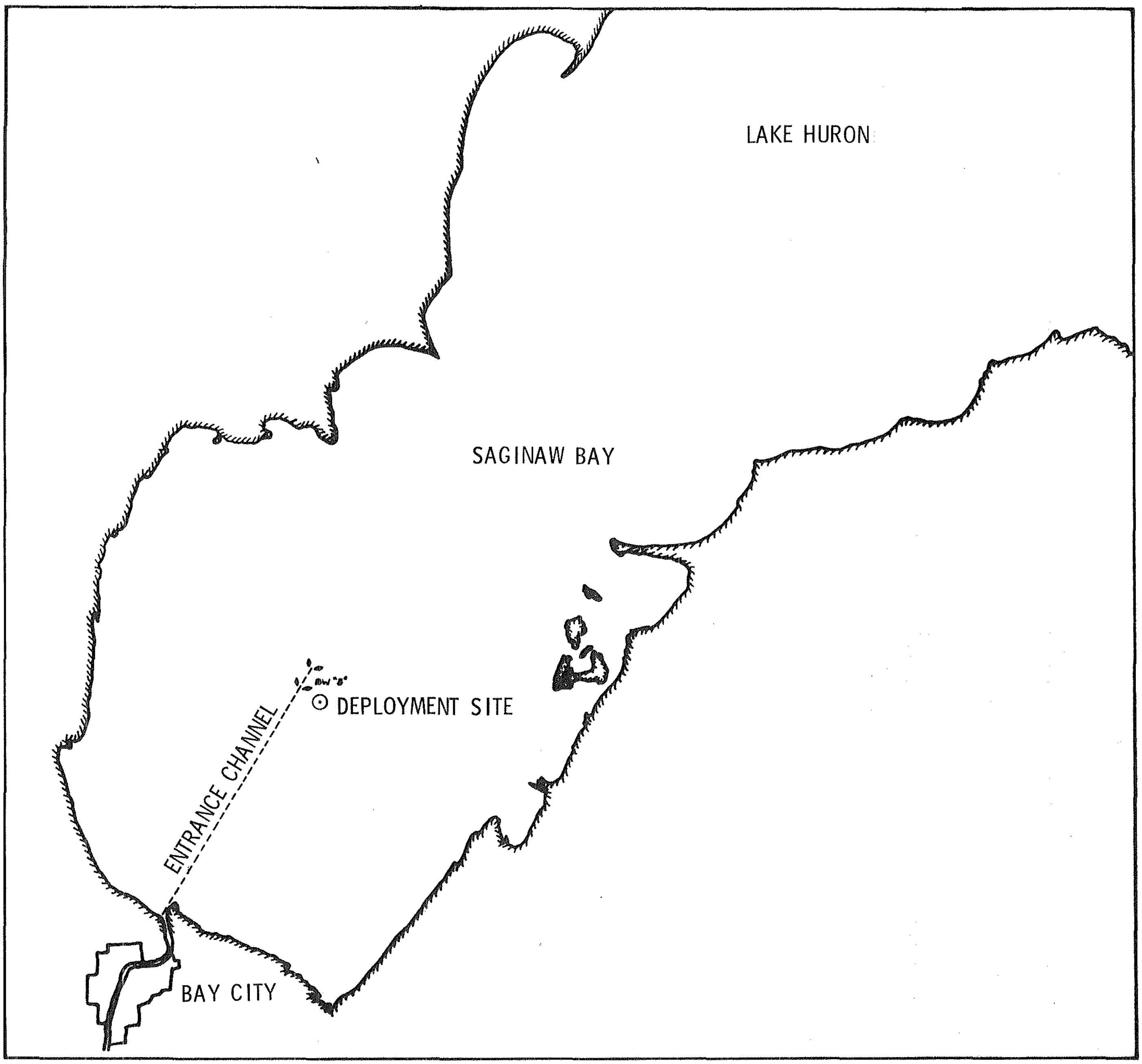

FIGURE 6. - SSU deployment site.

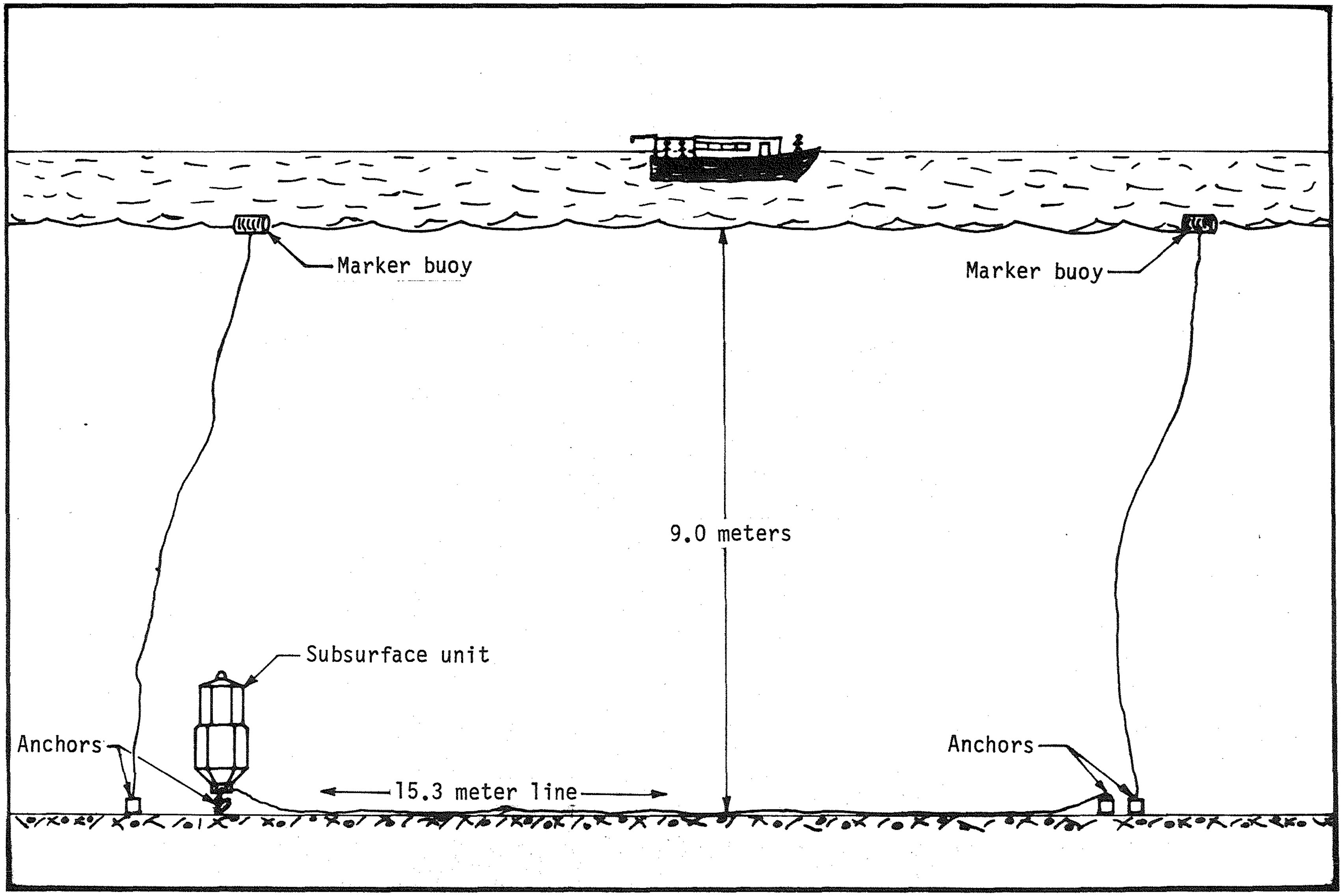

Figure 7.- SSU deployment arrangement.

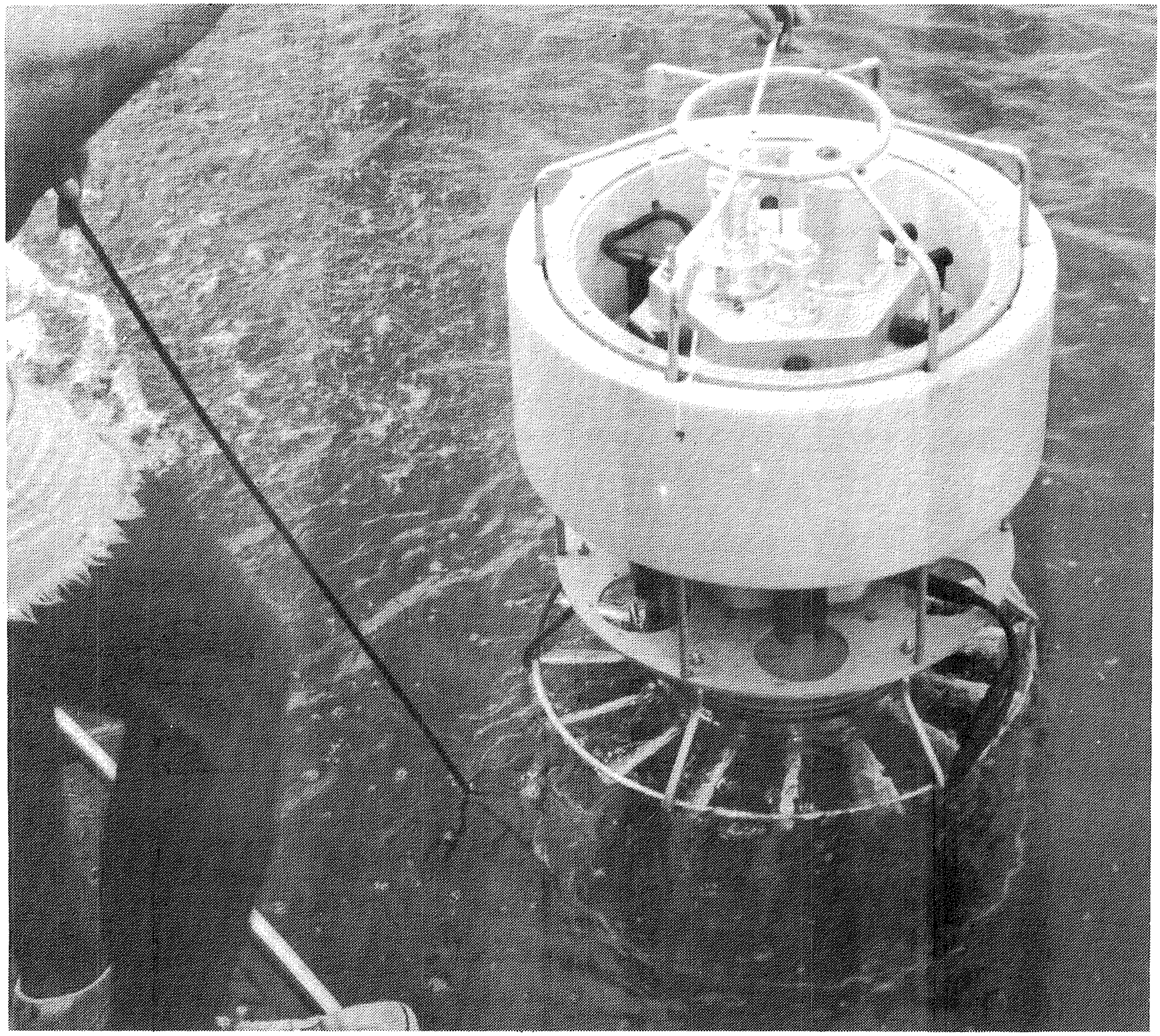

Figure 8.- SSU being lowered into waters of Saginaw Bay.

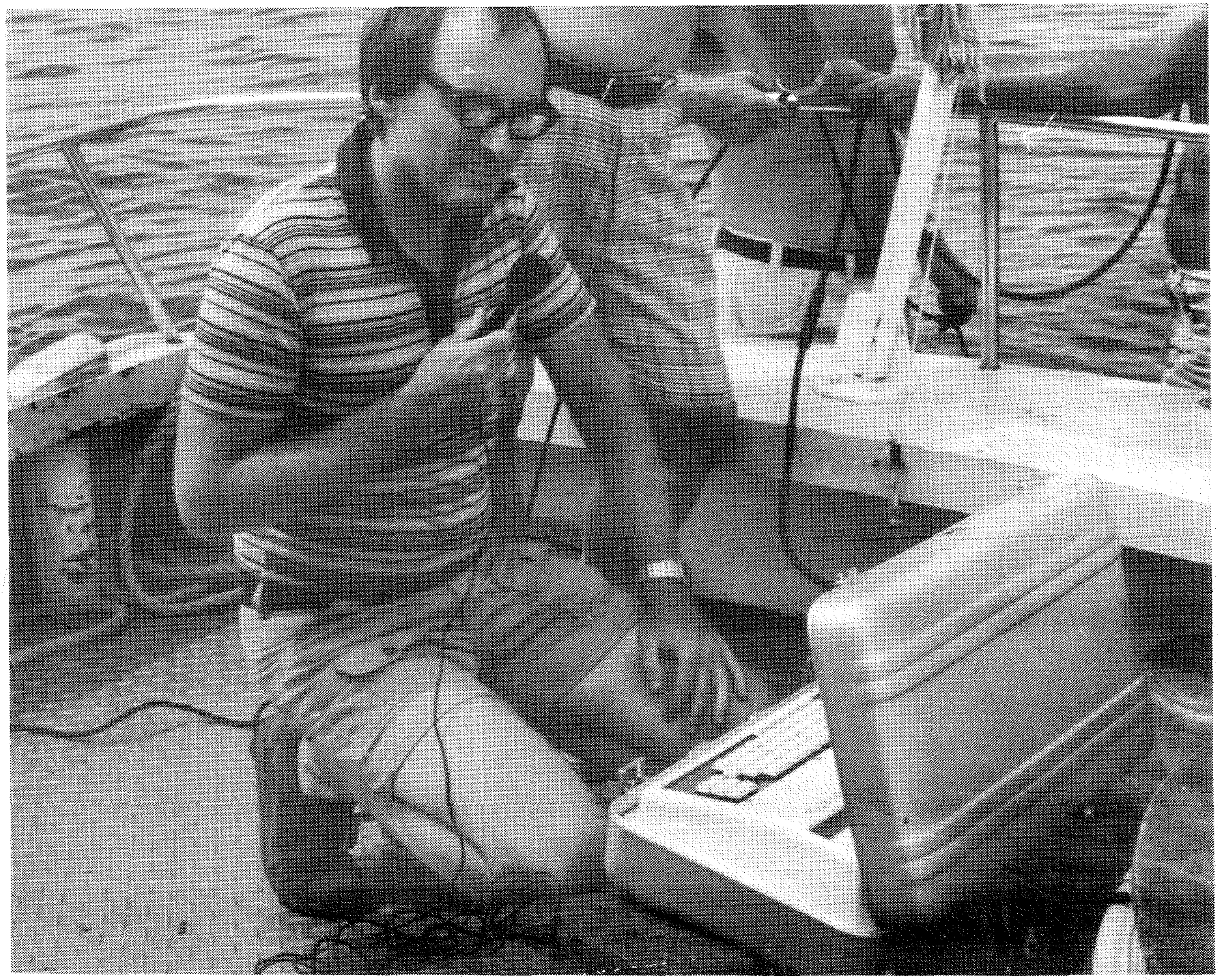

Figure 9.- Operator with SCU during daily operational
check of SSU.

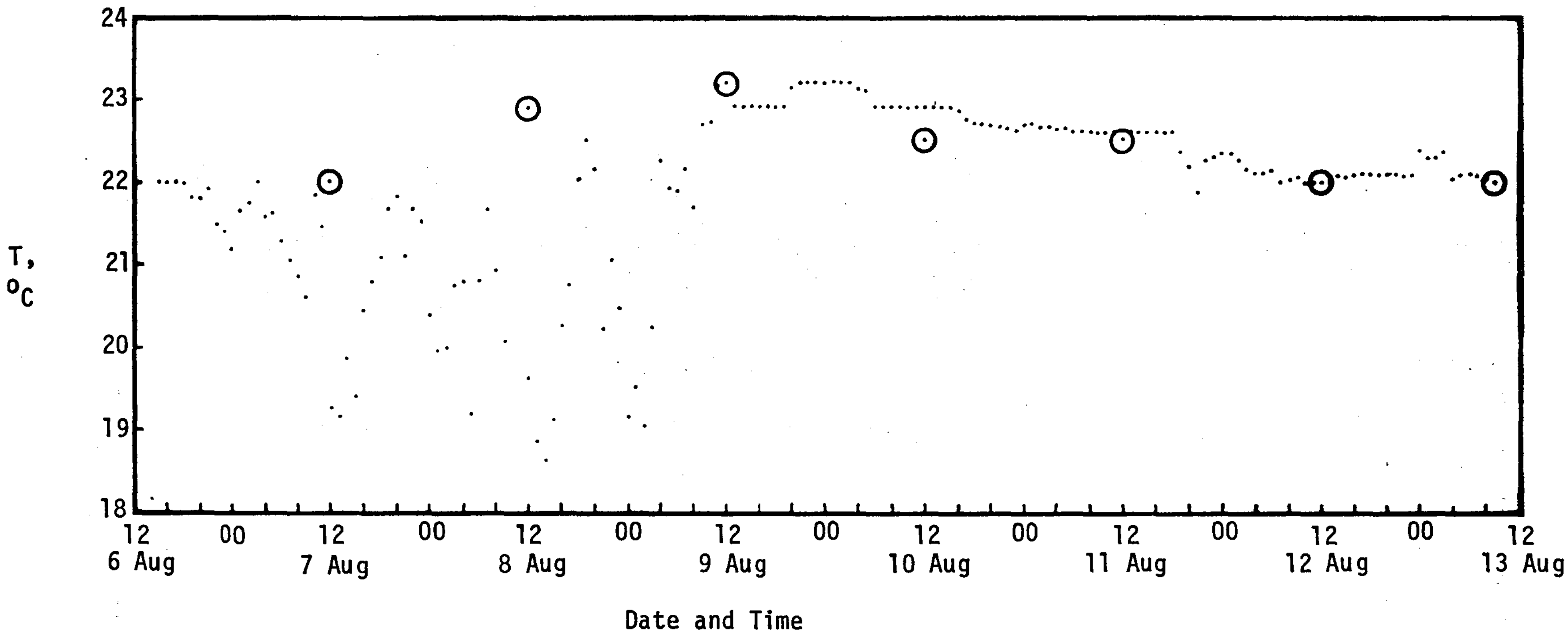

Figure 10.- Hourly averages of temperature.

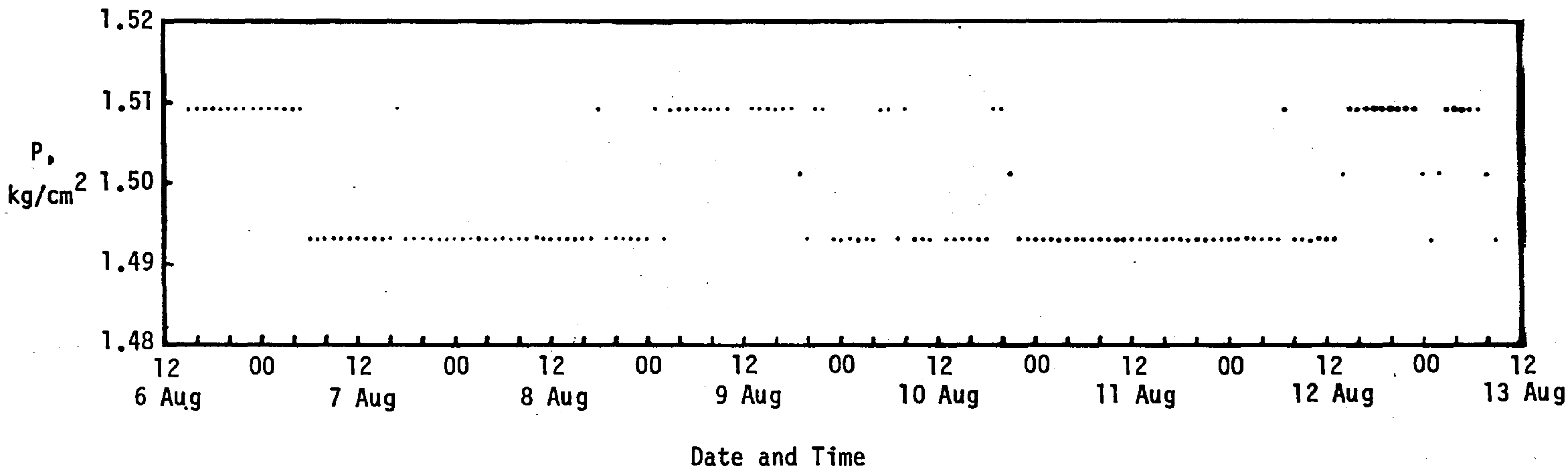

Figure 11.- Hourly averages of pressure.

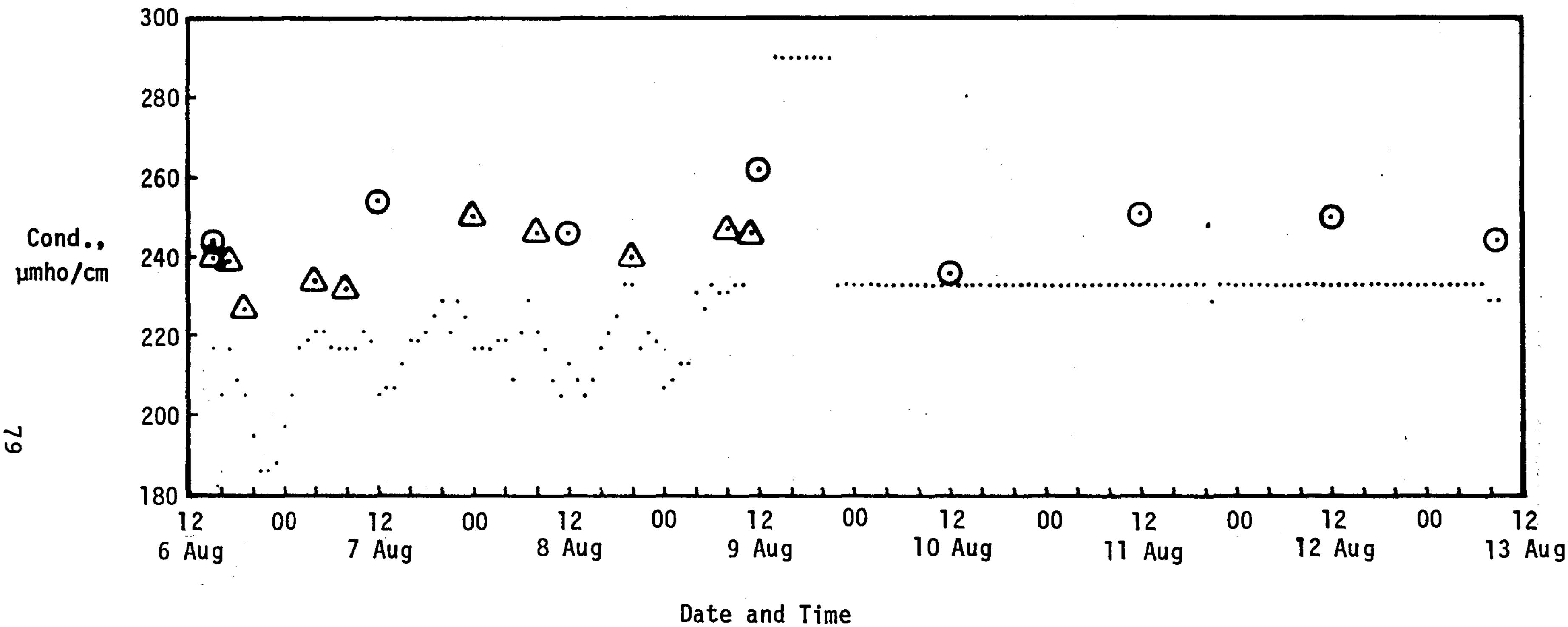

Figure 12.- Hourly averages of conductivity.

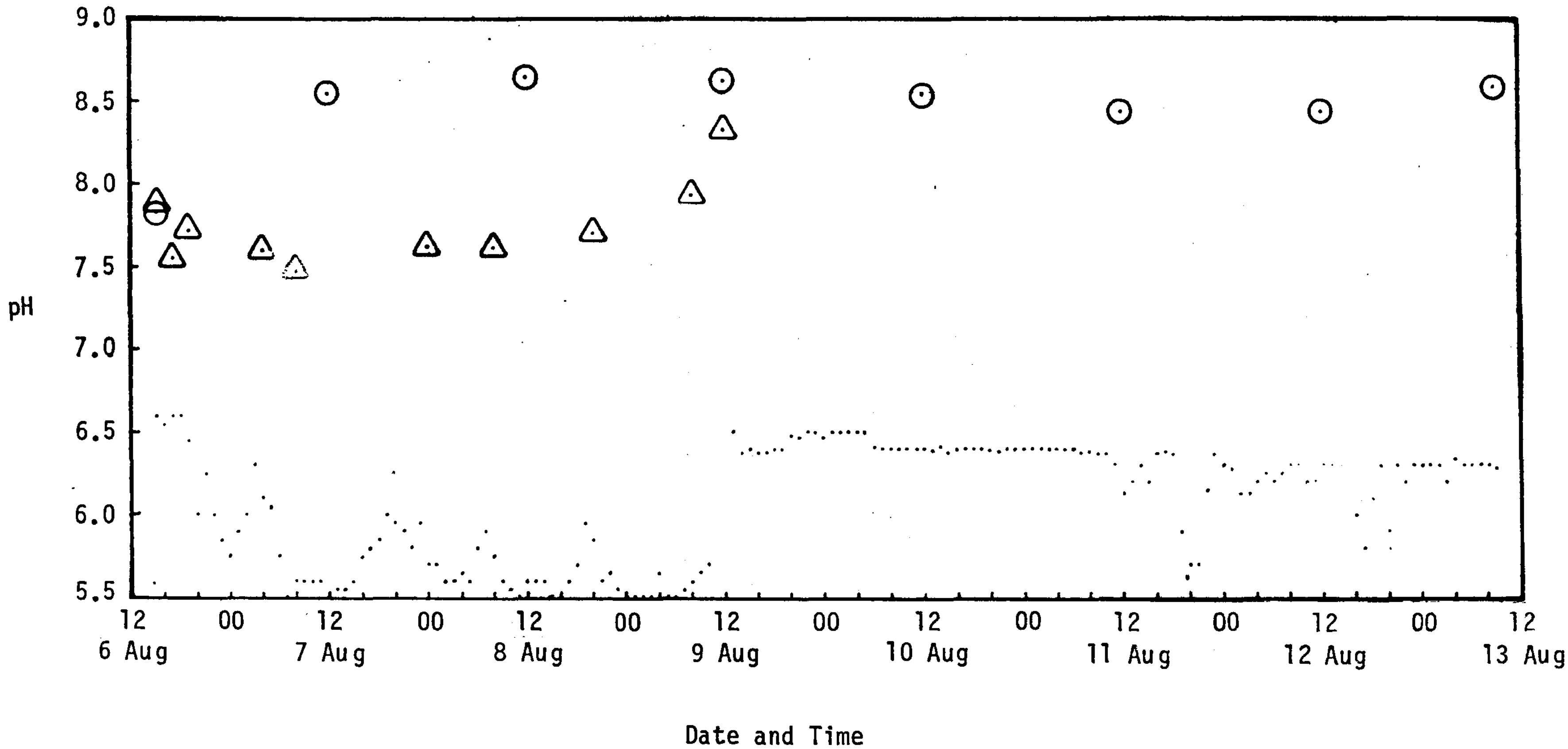

Figure 13.- Hourly averages of pH.

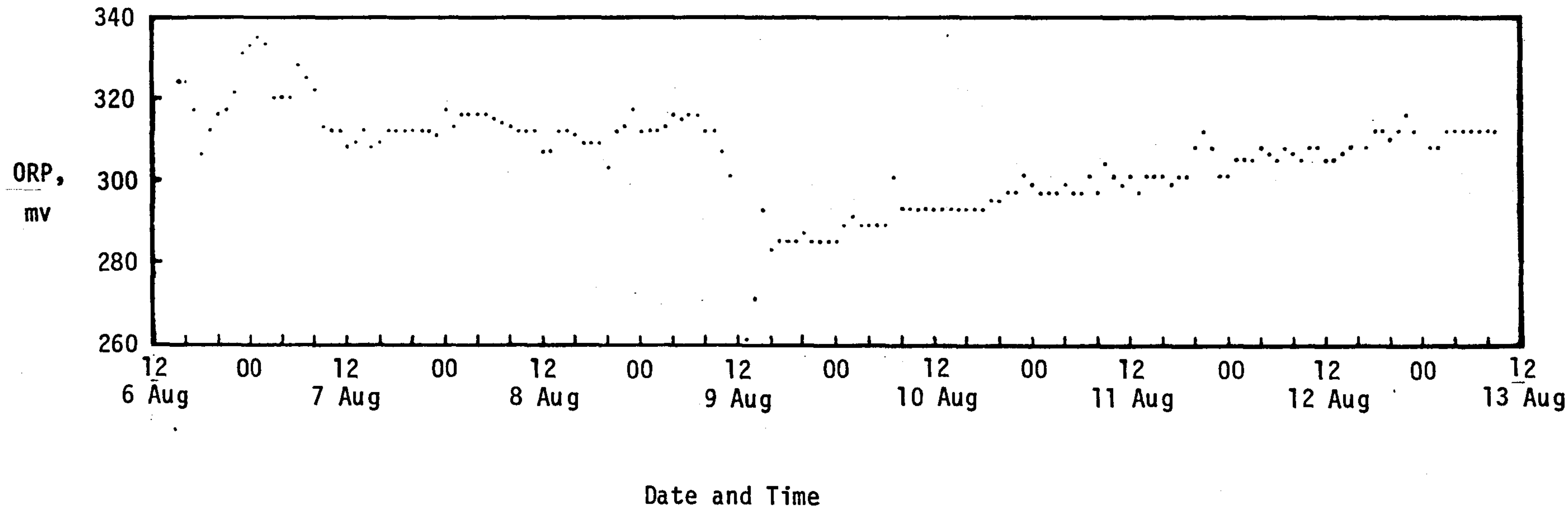

Figure 14.- Hourly averages of redox (ORP).

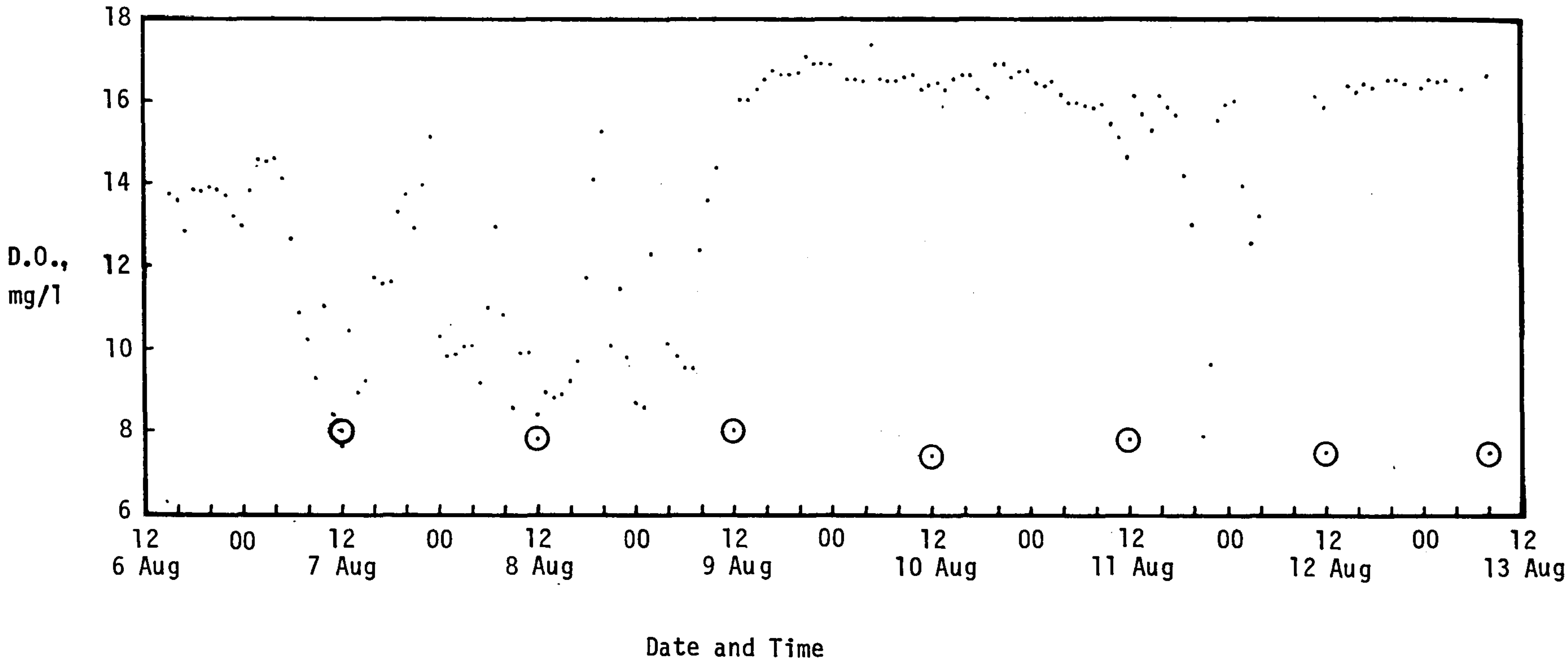

Figure 15.- Hourly averages of dissolved oxygen.

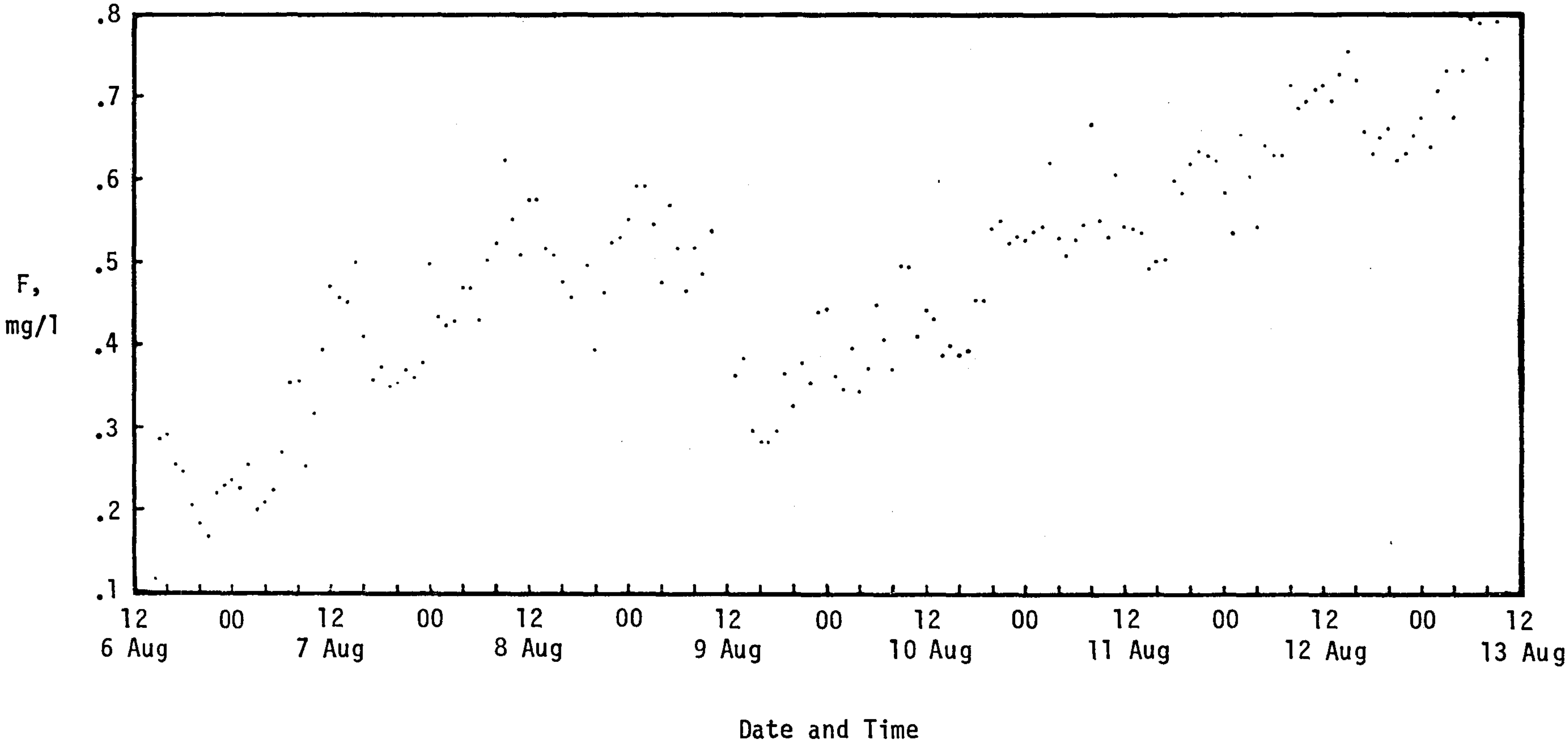

Figure 16.- Hourly averages of fluoride.

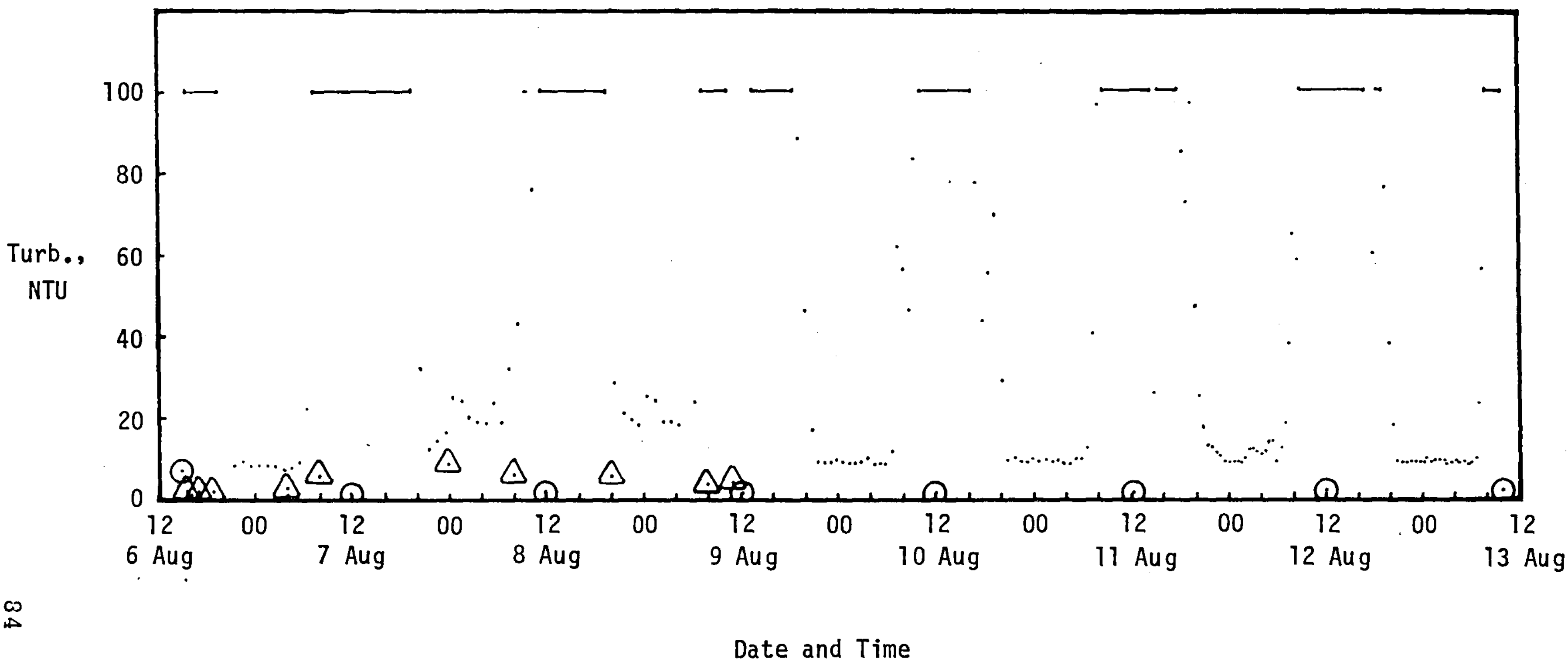

Figure 17.- Hourly averages of turbidity.

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16. Abstract

This report describes an automated, multiparameter Water Quality Monitoring System that offers almost continuous in situ water monitoring capability. This system was developed and tested under an interagency agreement between the National Aeronautics and Space Administration, Langley Research Center, and the U.S. Environmental Protection Agency, Environmental Monitoring Systems Laboratory.

Details of the electronic and mechanical subsystems' design and operation are presented, as well as a description of the field demonstration of the system. Data collected during the field demonstration are presented without any attempt at interpretation.

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Measuring instrumentation

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