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, multi-parameter 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 sub-surface 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.

This report has been reviewed by the Environmental Monitoring Systems Laboratory, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.
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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

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
°C             - degree Celsius
L              - liter
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<td>mg</td>
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<td>m\ell</td>
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<td>mV</td>
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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°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 x 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 builds, 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 commands 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 $45^\circ$ 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 attache 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 deployment.

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 teletetherometer 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 physically 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.
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## TABLE 12. MEASUREMENTS OF WATER SAMPLES

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<th>pH</th>
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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 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.
DESIGN, DEVELOPMENT, AND FIELD DEMONSTRATION OF A REMOTELY DEPLOYABLE WATER QUALITY MONITORING SYSTEM

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This research and application project was initiated under Interagency Agreement IAG D6-0053 between NASA Langley Research Center and the Environmental Protection Agency, Environmental Monitoring Systems Laboratory. The EPA Project Officer was Donald T. Wruble.

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.

Remote sensors
Measuring instrumentation

Unclassified - Unlimited
Subject Category 35

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