ECONOMIC COMPARISON OF TWO TYPES OF AUTOMATIC WATER-QUALITY MONITORS

By Max S. Katzenbach

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 87-4232

Columbus, Ohio

1988

DEPARTMENT OF THE INTERIOR

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	By	To obtain metric unit
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by the following equation:

$$F = 1.8(^{\circ}C) + 32$$

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ABSTRACT

A comparison of the U.S. Geological Survey's minimonitor system with a self-contained, "packaged-sensor" system indicates that the packaged-sensor system requires less servicing time. The U.S. Geological Survey minimonitor is powered by an external battery and is housed in a weatherproof shelter. This instrument measures temperature, specific conductance, dissolved oxygen, and pH by means of sensors with extension cables having underwater connectors; data are recorded in binary coded decimal form on a 16-channel punched-paper-tape recorder that is housed in a shelter. The packaged-sensor system also measures temperature, specific conductance, dissolved oxygen, and pH by means of sensors housed in a package that is submerged in the stream. It has an internal power supply, no moving parts, and does not require a weatherproof shelter; data are stored in solid-state memory.

Minimonitors were installed at four sites in Ohio where U.S. Geological Survey flowthrough monitors already were in operation. Two packaged-sensor systems also were assigned to each site and alternated every 2 weeks. Detailed records were kept of (1) time involved in operation and maintenance of the systems, and (2) equipment problems during the test period, which lasted from October 1985 through September 1986. Equipment costs were not considered in the economic evaluation.

Results of the comparisons show that the packaged-sensor system required less time to install, operate, and maintain than the minimonitor system.

INTRODUCTION

The U.S. Geological Survey conducts a nationwide program of water-resources surveys, investigations, and research. Over the years, the need for water-quality information has led the U.S. Geological Survey to establish a nationwide network of water-quality data-collection stations on rivers, canals, streams, lakes, and reservoirs. Various systems have been used for automatically measuring and recording water-quality data such as temperature, specific conductance, pH, and dissolved oxygen.

The two systems currently being used by the U.S. Geological Survey are the flowthrough monitor (fig. 1) and the minimonitor (fig. 2), which gather data electronically and record the data in digital form on perforated tape. In the flowthrough system, water is pumped from the stream to a heated shelter in which a sampling chamber, sensors and associated electronics, and recording devices are housed. An 110-volt alternating current (AC) power supply is required. The battery-powered minimonitor has sensors that are connected to long cables and submerged in the stream. No AC power or pumping equipment is necessary, and associated electronics and recording devices can be housed in a smaller, unheated shelter in remote locations. Both systems require maintenance and calibration of sensors in the field.

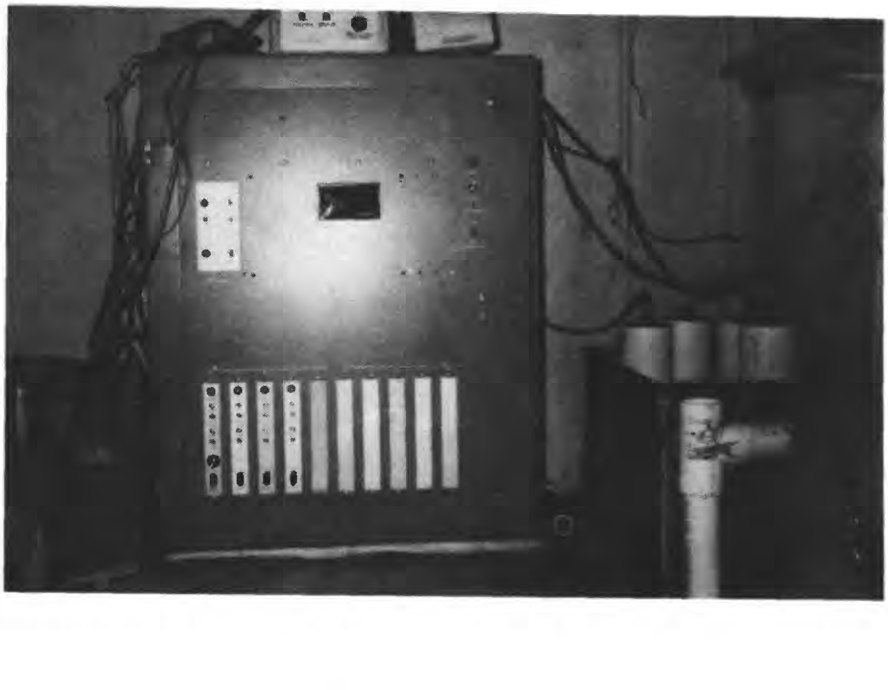

Figure 1.— Flowthrough monitor system.

Figure 2.—Minimonitor system.

A more recently developed system makes use of "packaged sensors" (fig. 3). All components in this system--including microprocessor-controlled solid-state data storage, sensors, and power supply--are contained in a sensor package that is submerged in the stream. The sensor package has no external wires, and requires no land-based instrumentation or shelter. The system can be maintained and calibrated in an office setting after being exchanged with a spare unit in the field. Although not currently being used by the U.S. Geological Survey, the submersible system shows potential for meeting U.S. Geological Survey data-collection requirements.

In October 1985, a study was begun at the request of and with support from the U.S. Geological Survey's Hydrologic Instrumentation Facility at Bay St. Louis, Miss., to determine whether a packaged-sensor system might be more economical to operate than a system requiring maintenance and calibration in the field, such as the U.S. Geological Survey's minimonitor.

Purpose and Scope

This report provides descriptions of the minimonitor and packaged-sensor systems tested, and presents the results of the economic evaluations. Special emphasis is given to time involved in calibration and maintenence of the test systems.

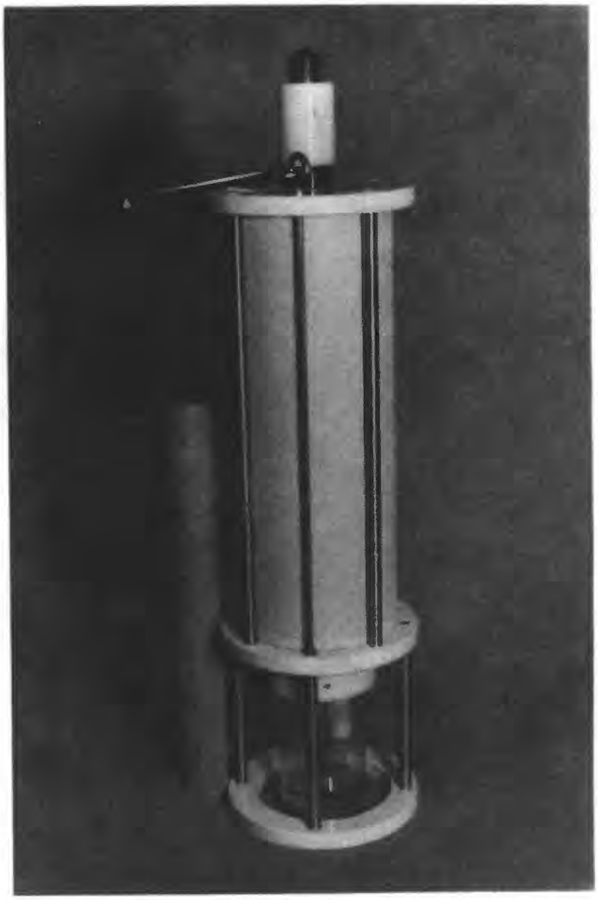

Figure 3.—Packaged-sensor system.

Instruments were installed at four flowthrough-monitor sites previously established in northeastern Ohio (fig. 4; table 1). The evaluations are based on detailed records of (1) time involved in operation and maintenance of the systems and (2) equipment problems. Comparisons of completeness and quality of the data obtained from the two systems were beyond the scope of this study. The systems were tested from October 1985 through September 1986.

Acknowledgment

The author wishes to thank Stuart Garner of Hydrolab, Inc.[1] for his advice and cooperation in solving equipment problems.

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[1]Use of brand and firm names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

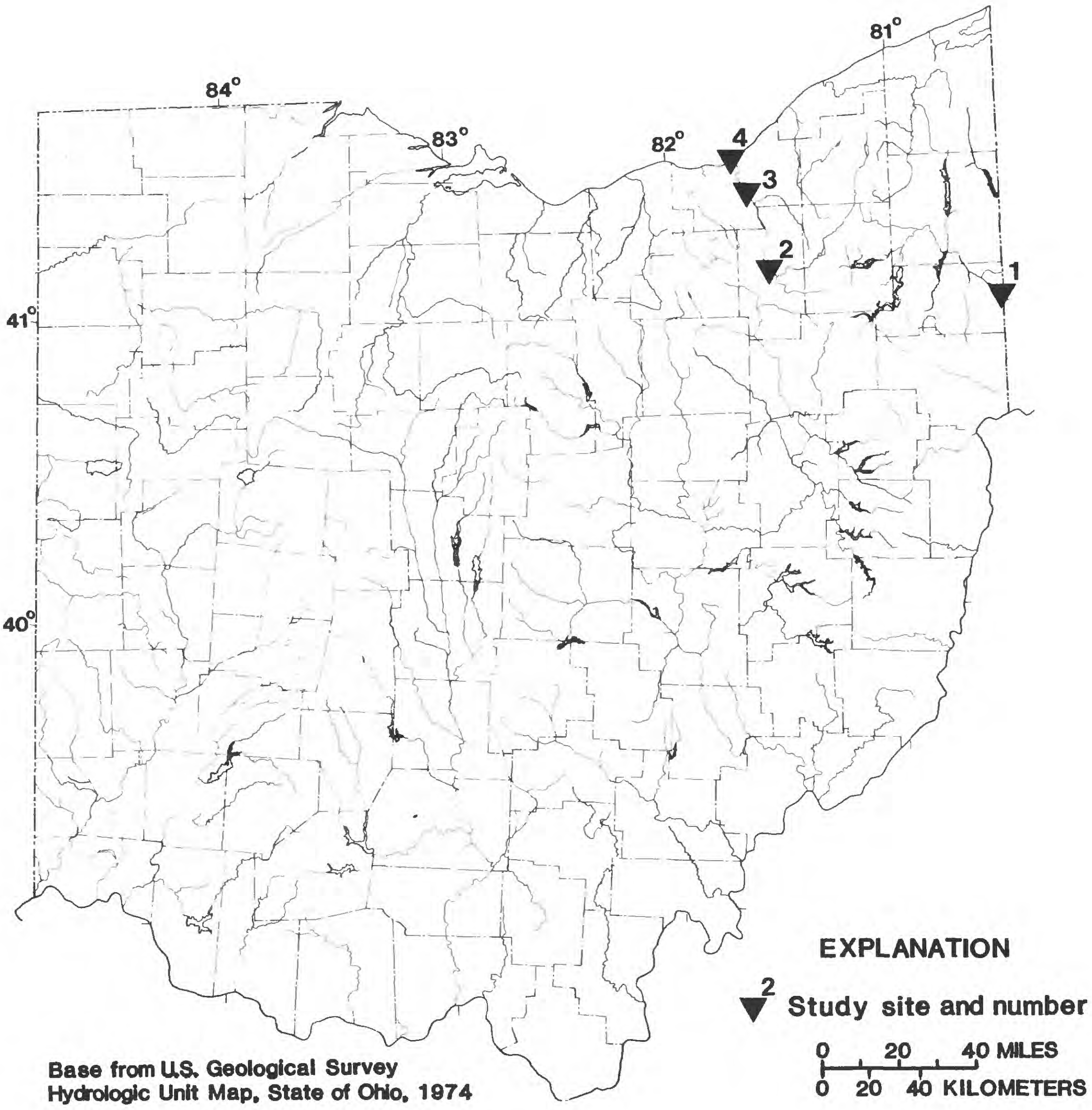

Figure 4.—Location of test sites (see table 1 for additional site data).

Table 1.--Site names and station identification numbers

Site no.	Site name	Type of system	Station ID
1	Mahoning. River at Lowellville, Ohio	Flowthrough----	03099510
		Minimonitor----	03099511
		Packaged-sensor	03099512
2	Cuyahoga River at Old Portage, Ohio	Flowthrough----	04206000
		Minimonitor----	04206001
		Packaged-sensor	04206002
3	Cuyahoga River at Independence, Ohio	Flowthrough----	04208000
		Minimonitor----	04208001
		Packaged-sensor	04208002
4	Cuyahoga River at West Third Street	Flowthrough----	04208506
	Bridge in Cleveland, Ohio	Minimonitor----	04208507
		Packaged-sensor	04208508

DESCRIPTION OF INSTRUMENT SYSTEMS TESTED

Brief descriptions of the minimonitor and packaged-sensor systems are presented below. Features of both systems are summarized in table 2.

U.S. Geological Survey Minimonitor

The minimonitor (fig. 2) consists of a battery-powered electronic package that is controlled by an internal crystal clock. At each recording interval, the unit scans, measures, and then records the data in binary-coded decimal (BCD) form on a 16-channel punched-paper-tape recorder. The instrument measures temperature, specific conductance, dissolved oxygen, and pH through sensors ("probes") that are submerged in the stream. The sensors typically are submerged in the stream in 6-inch plastic pipe (fig. 5) having 1-inch-diameter holes staggered on 6-inch centers; extension cables with underwater connectors link the sensors to the electronics package, which is housed in a weatherproof shelter.

Figure 5.—Test-site shelter with PVC housing pipes for minimonitor and packaged sensors.

Table 2.--Comparison of instrument features

[ADR, automatic data recorder; ATC, automatic temperature compensation; µS/cm, microsiemens per centimeter at 25 °C; NBS, National Bureau of Standards; ppm, parts per million; VDT, video display terminal; N/A, not applicable.]

Instrument features	USGS flow-through monitor	Minimonitor	Packaged-sensor system
Shelter required?	Yes	Yes	No
Power	120	12v,120v	[a]6v
Pump required?	Yes	No	No
Probes in stream?	No	Yes	Yes
Monitor in stream?	No	No	Yes
Where is calibration done?	Field	Field	Office
Internal data memory?	No	No	Yes
Data output to:	ADR	ADR	ASCII into VDT, printer, or computer
	Temperature		
Range	0-50 °C	0-50 °C	-2 to 50 °C
Sensor type	Linear thermistor	Linear thermistor	Linear thermistor
Calibration	Potentiometer (cold & warm solution)	Potentiometer (cold & warm solution)	NBS, factory
Temperature compensation	N/A	N/A	N/A
	Specific conductance		
Range (µS/cm)	0-2000	0-10,000	0-10,000
Sensor type	6-electrode cell	4-electrode cell	6-electrode cell
Calibration	Potentiometer with sensor imersed in KCl	Potentiometer with sensor imersed in KCl	Keyboard entry with sensor imersed in KCl
Temperature compensation	Automatic 25 °C reference	Automatic 25 °C reference	Automatic 25 °C reference
	Dissolved oxygen		
Range (ppm)	0-20	0-20	0-20
Sensor type	Galvanic	Polarographic	Polarographic
Calibration	Potentiometer with sensor in saturated air at barometric pressure	Potentiometer with sensor in saturated air at barometric pressure	Keyboard entry of barometric pressure with sensor in saturated air or water
Temperature compensation	ATC	ATC	ATC
Stirrer on dissolved oxygen probe?	No	Yes	No
	pH		
Range (units)	0-10	0-10	0-14
Sensor type	Glass-electrode sealed reference, refillable flowing junction	Combination glass with non refillable wood junction	Glass-electrode sealed reference refillable flowing junction
Calibration	Potentiometer with probe in; pH 4, 7, or 10	Potentiometer with probe in; pH 7 and 4 or 10	Keyboard entry with probe in pH 7 and 4 or 10
Temperature compensation	ATC	ATC	ATC

[a]Four "D"-cell disposable batteries

The minimonitor is calibrated by making manual adjustments to the readings that show on the digital readout after the sensors are placed in solutions of known concentration (Gordon and Katzenbach, 1983, p. 60-75). All calibrations are based on a field person's knowledge of the system.

Routine Maintenance and Calibration

During a typical site visit for this study, specific-conductance, dissolved-oxygen, temperature, and pH data were first read on the minimonitor panel display and compared to measurements made with portable field instruments. The minimonitor sensors then were removed from the stream, serviced, and calibrated if necessary by placing the sensors in standard solutions of known concentration. The specific-conductance sensor was serviced by removing the shield covering the electrodes (fig. 6) and cleaning them; electrodes periodically were polished with crocus cloth.

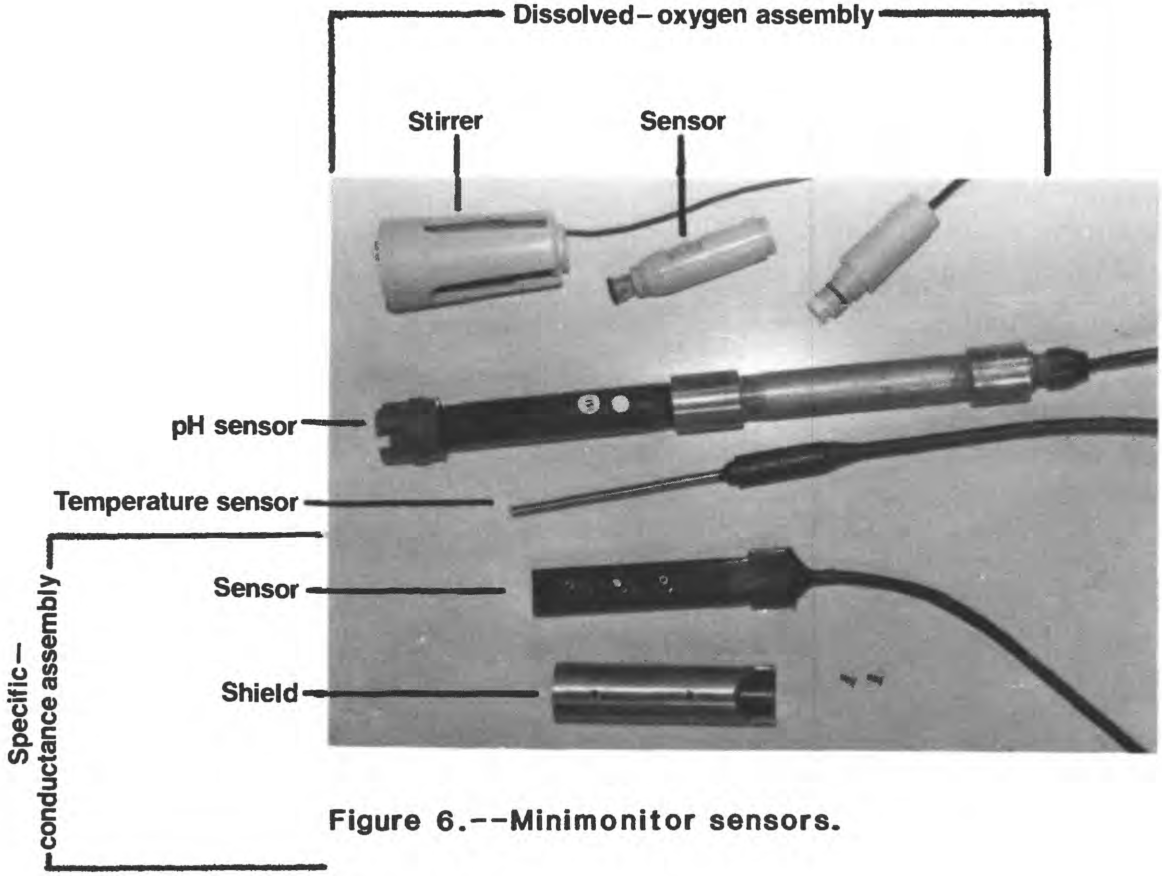

Figure 6.--Minimonitor sensors.

The sensor shield also was cleaned and then replaced. The dissolved-oxygen sensor (fig. 6) was serviced by cleaning the membrane, checking the stirrer assembly, and sometimes replacing the membrane and electrolyte. Generally, the membrane was replaced only when it was damaged or when readings were unstable.

Temperature sensors (fig. 6) require no field maintenance other than replacement in case of failure or recalibration if readings exceed allowable error. The pH sensor (fig. 6), which is a combination of a glass pH electrode and a wood-junction reference electrode, was serviced periodically by cleaning the electrodes' surfaces with a nonscratching cloth or soft brush.

After servicing, the sensors were returned to their original position in the stream and allowed to stabilize before final data were read from the panel meter. While the sensors were stabilizing, field-instrument measurements again were made and recorded. If the difference between these measurements and the equivalent panel-meter values for each water-quality characteristic were within allowable limits, servicing was complete (Gordon and Katzenbach, 1983, p. 84-86).

Additional maintenance was necessary if the difference between the panel meter and field-instrument reading was not within allowable limits for one or more characteristics (Gordon and Katzenbach, 1983, p. 85-86). If the problem was determined to be in the calibration, then the instrument was recalibrated with standards (Gordon and Katzenbach, 1983, p. 60-74). If the problem was a failed or malfunctioning sensor, the sensor was replaced and recalibrated with standard solutions. If the problem was determined to be in the electronics, the appropriate electronic part was replaced.

Data Output

The data were recorded on 16-channel punched-paper tape and removed at regular intervals for processing. The data were transferred from tape to temporary computer files at the office by means of a Mitron model MDTS-2 data translator. The data were then edited and transferred to permanent storage for analysis.

Packaged-Sensor System

The packaged-sensor system (a Hydrolab DataSonde, model 2000 series) consists of solid-state electronic circuitry powered by internal batteries and controlled by a quartz clock. It is a self-contained unit that measures temperature, specific conductance, dissolved oxygen, and pH without moving parts, land-based instrumentation, or cable attachments for direct readout. A microprocessor controls all necessary measuring circuits, processing, and data storage.

The package-sensor system was fully submerged in the stream in a housing of 6-inch plastic pipe (fig. 5) having 1-inch-diameter holes on 6-inch centers.

Routine Maintenance and Calibration

The packaged-sensor system (fig. 7) was exchanged with a spare unit at every visit, serviced entirely in the office, and made ready for the next visit. Routine maintenance of the specific-conductance components entailed polishing the six nickel electrodes with crocus cloth and wiping the electrodes clean with alcohol. Maintenance of the dissolved-oxygen sensor (fig. 8) consisted of cleaning the membrane; generally, the membrane and electrolyte needed to be replaced only when calibration was not possible or when the membrane had been damaged. The temperature sensor (fig. 8), which was calibrated at the factory, has no user-serviceable components. Maintenance of the pH sensor (fig. 8), consisted of cleaning the glass electrode and reference electrode with a nonscratching cloth; generally, the reference filling solution (KCl electrolyte) or Teflon junction was replaced if the instrument failed calibration checks. Batteries were replaced each time the packaged-sensor system was serviced in the office.

Figure 7.—Packaged-sensor system being replaced in the field.

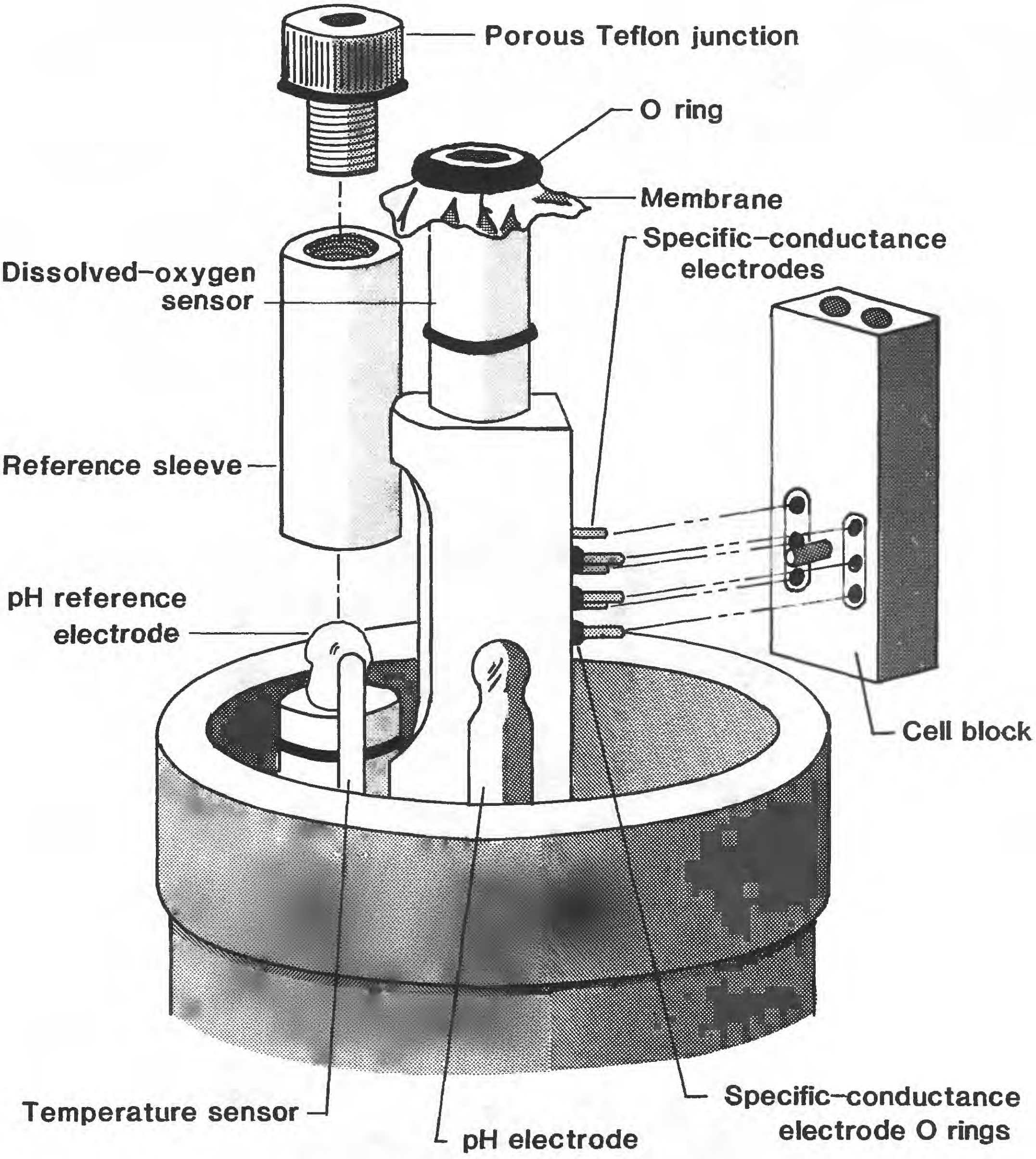

Figure 8.--Exploded diagram of packaged sensors.

The packaged sensors were calibrated and programmed in the office by means of a data-management unit (DMU) linked to an external printer-keyboard terminal (fig. 9) or computer terminal. The keyboard operator was prompted by the DMU to immerse the sensors in particular standard solutions. The unit self-tested and calibrated if the discrepancy between the reading for the standard solution and the value for the standard entered by the field person was within allowable limits[2]. If the discrepancy was greater than allowable limits, the unit rejected calibration. Rejection of calibration indicated either a malfunctioning sensor or that an incorrect or contaminated standard solution was being used. If the problem was a malfunctioning sensor, the sensor was replaced and the unit was recalibrated. If the problem was determined to be in the electronics, the unit was sent back to the manufacturer.

If no calibration problems were encountered, the keyboard operator entered a "quit" code. The DMU then would test the packaged-sensor unit's battery and memory, and, finally, would prompt the operator to enter a station identification code and dates and time to begin and end collection of data.

Figure 9.—Packaged-sensor system attached to data-management unit and printing keyboard.

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[2]Each of the four water-quality characteristics to be measured (specific conductance, pH, temperature, and dissolved oxygen) was calibrated in the ranges shown in table 2.

Data Output

Data stored in the packaged-sensor unit's solid-state memory were retrieved in the office during servicing. The output of each unit was organized and formatted by the DMU and, in this study, was transmitted through a modem to a computer located in another office for temporary storage. The data were then edited and transfered to permanent storage for analysis.

ECONOMIC COMPARISON

Procedure

Four minimonitors and eight packaged sensors were sent from the Hydrologic Instrumentation Facility to the U.S. Geological Survey's District office in Columbus, Ohio, to be tested at four flowthrough monitor sites in Ohio for 1 year (October 1985 through September 1986). Upon receipt, each system was unpacked, inspected for shipping damage, and set up and calibrated in an office environment.

A minimonitor was installed at each of four sites where flowthrough monitors already were in operation (fig. 10); two packaged-sensor systems were assigned to each site and alternated every 2 weeks.

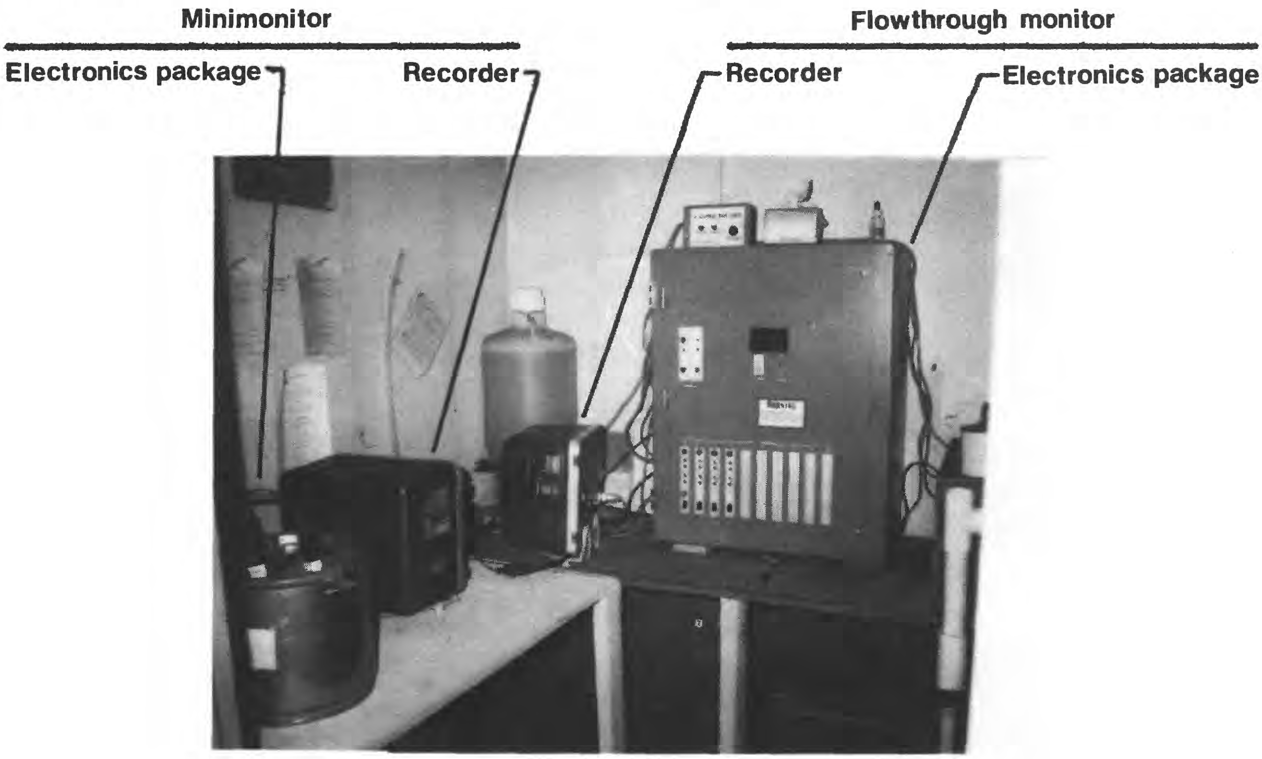

Figure 10.--Minimonitor equipment in typical flowthrough-monitor shelter.

Detailed records were kept of (1) time involved in operation and maintenance of the systems and (2) equipment problems. These records are the basis for the comparisons discussed in the following sections of this report.

Time Required for Servicing

Time required for servicing each type of system (in total man-hours) was tabulated from October 1, 1985, through September 30, 1986, to evaluate the economic aspects of system operation. Time required to clean, check, and calibrate each system at each site is summarized in figure 11; total time required for service and maintenance of the systems at all four sites is shown in figure 12.

Because the minimonitors were located in heated flowthrough-monitor shelters, servicing of the minimonitors was easier and faster than would be expected at a typical minimonitor site. If the smaller, unheated shelters normally used with minimonitors had been used in this study, the total time required to service each minimonitor would have increased by an estimated 20 hours per year per site, owing to the problems associated with checking, calibrating, and (or) repairing equipment in cold or rainy weather. The estimated additional time also is shown in figures 11 and 12. It should be noted that the streams never froze solid at any site during the test period, thus, presence of ice never interfered with removal of sensors.

Times required for field measurements and for travel to and from the office were not recorded, as they would be the same for both systems.

Other Economic Considerations

Travel and Construction Costs

Because established flowthrough monitor sites were selected as test sites in this study, there was no opportunity to assess differences in field-trip travel costs or system-installation costs that might be incurred for a network of minimonitors compared with a network of packaged-sensor systems. Differences in travel costs (reimbursement for meals and lodging) would depend largely on how many units were in a given network and how far apart the sites were. However, because an average of 30 minutes of field time is required for the packaged-sensor system as compared with about 2.5 hours for a minimonitor (not including extra time due to cold weather), it appears that the packaged-sensor system has a definite advantage over the minimonitor in the number of sites that could be serviced per day and, therefore, potentially less travel cost associated with each unit.

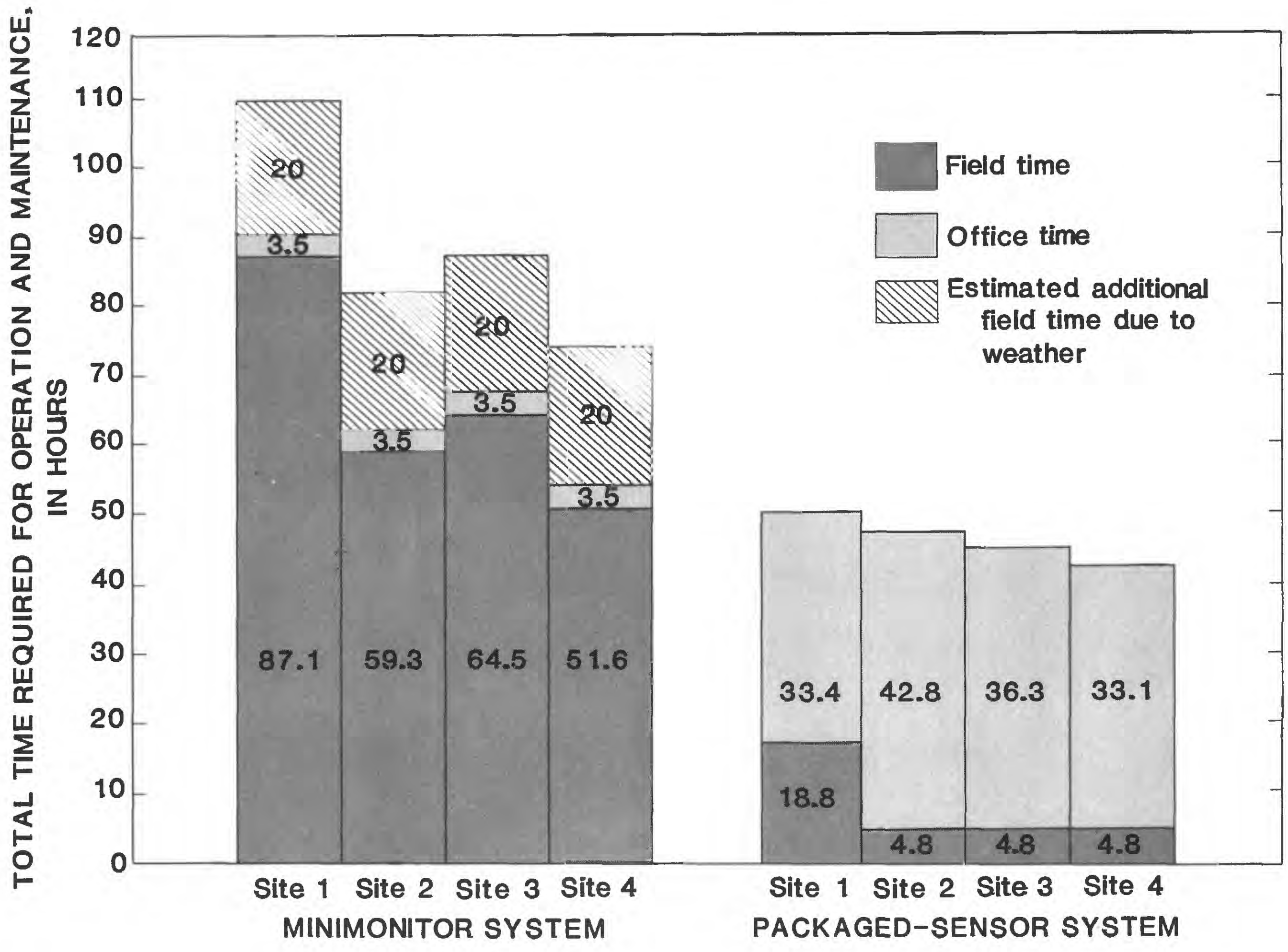

Figure 11.--Total time required for operation and maintenance of minimonitor and packaged-sensor systems, by site.

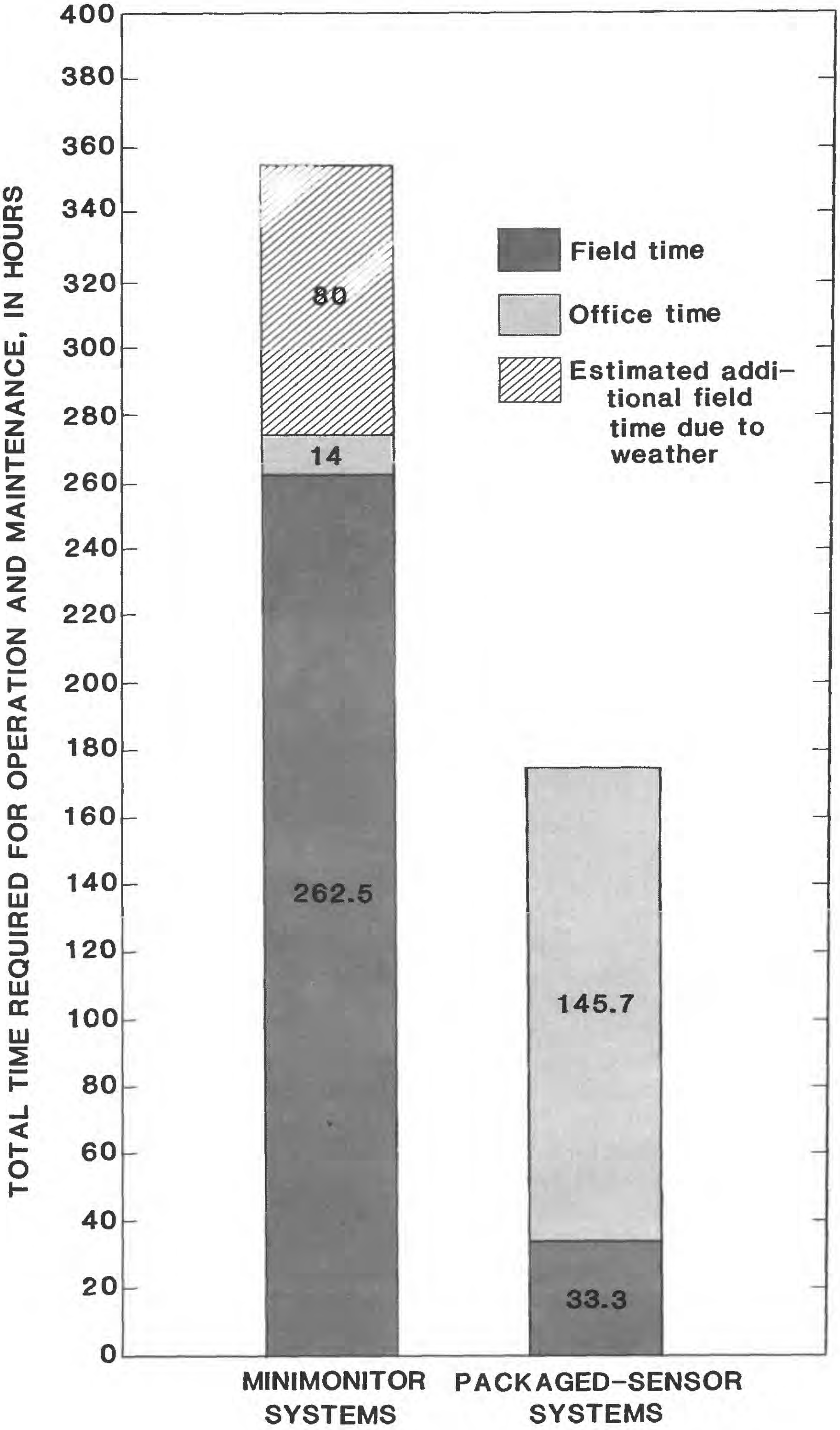

Figure 12.--Total time required for operation and maintenance of minimonitor and packaged-senor systems, all sites .

Estimates for time and materials required for a typical minimonitor installation and a packaged-sensor installation like that used in this study are presented below:

Item	Construction costs: Minimonitor	Construction costs: Packaged sensor
Recorder shelter (4 ft x 5 ft x 3 ft).........	$3,285	(None)
Sensor housing.....	6-in. pipewell, $125	6-in. pipewell, $125
Field time	160 man-hours	18 man-hours
Travel cost........	$900	$50
Total............	160 man-hours plus $4,310	18 man-hours plus $175

Diagnosis of Equipment Problems

Although human error in the field can result in data loss for both systems, extra field time for diagnosis of equipment problems would be required for the minimonitor system because (1) sensors are remote from the electronics package, (2) the field person may encounter unfavorable weather, and (3) access to spare parts and consultation is limited while in the field. The diagnostic routine that checks calibration of the packaged-sensor system is performed at the office and requires about 60 minutes if the unit needs complete calibration. The diagnostic routine yields a complete record of parameter checks and (or) failures, as well as prompts that suggest possible remedies for apparent equipment problems. As mentioned previously, a built-in diagnostics check can detect whether calibration values keyed in by the field person are reasonable. Unlike the packaged-sensor unit, the operation of the minimonitor is handled entirely in the field and leaves many decisions to the field person. It requires the field person to diagnose problems, carry spare parts to fix problems, and recalibrate to ensure data reliability. Misdiagnosis can result in an extra field trip to the station, loss of data, and (or) longer time spent in the field to correct the problem. Effects of misdiagnosis are reflected to a certain extent in the greater total time required to service the minimonitors compared with the packaged sensors at each of the four sites.

Data Processing

As far as data processing was concerned, the all-electronic transfer of data from the packaged-sensor memory to computer files was easier than the transfer of data from 16-channel punched-paper tape generated by the minimonitor. Because the packaged-sensor system is downloaded directly to computer files through the DMU, none of the time-consuming problems associated with handling and processing paper tape (such as correcting for punch errors) were encountered. Some problems were encountered with downloading data from the packaged-sensor systems during the first few months of data collection, before the package sensors were modified to record continuous data for 2 weeks. Data were lost three times between the time a unit was removed in field and the time it was to be downloaded to computer files. These data had to be hand entered into computer files from a hard copy that was printed at the site when the packaged-sensor was removed, and this required about 3 extra hours of data handling. Once the equipment modifications had been made, data processing took much less time for the packaged-sensor systems; however, because detailed records were not kept, it is impossible to estimate how much of a difference there actually was for processing data generated by the two systems tested.

EQUIPMENT PROBLEMS AND HUMAN ERRORS

Numerous equipment problems occurred during the test period. However, most of the problems were minor, and some of the data loss was due to malfunctions of the recording equipment. A complete history of equipment problems at each of the four sites is presented in tables 3 and 4.

Problems with the minimonitor occurred sporadically throughout the test period (table 3), although more data loss occurred during the first half of the period owing to an insufficient supply of spare parts. There were two failures each for specific conductance and temperature sensors. Problems with the dissolved-oxygen sensors were primarily confined to dirty or damaged membranes; however, at least four dissolved-oxygen sensors appear to have failed, as well as three stirrer assemblies. Problems with the pH sensors were numerous, and the malfunctioning sensors were replaced whenever spares were available. In addition, nine recorders had to be replaced during the test period, three that failed to advance tape and six that punched erroneous data. In one instance, high water washed away a sensor housing with the sensors inside. Other problems include a monitor that was not left in operating mode, a punch tape that was not secured to the take-up spool, interruptions in data collection when minimonitors were sent back to the Hydrologic Instrumentation Facility for modification, and data loss because the field person could not diagnose an electronic problem.

Table 3.--History of equipment problems, minimonitor systems

Site number and date	Any data loss?	Characteristic affected: Specific conductance	Dissolved oxygen	Temperature	pH	Remarks
Site 1						
10/20 to 10/29	Yes	X	X	X	X	Tape stuck in punch block (recorder repaired).
11/10 to 12/11	Yes	X	X	X	X	High water removed sensor-protector pipes, damaged sensors and circuit board.
11/29----------	No------------------------------					Replaced recorder.
12/11 to 1/6	No------------------------------					Recorder dropping 0100 punch (replaced).
1/6------------	No		X			Replaced sensor.
1/22 to 2/6	Yes	X	X	X	X	Removed minimonitor for modification by HIF.
2/6------------	No		X			Replaced sensor.
2/6 to 2/12	Yes				X	Faulty sensor; no spare.
4/24-----------	No		X			Replaced sensor.
5/22 to 6/5	No------------------------------					Recorder dropping 0400 punch (replaced).
6/5 to 7/22	No------------------------------					Recorder dropping 0100 punch (replaced).
6/18 to 7/2	Yes	X	X	X	X	Removed monitor; power fuse kept blowing (faulty capacitor on pH; human error).
9/11-----------	No		X			Replaced membrane and solution.
Site 2						
10/1 to 10/3	Yes	X	X	X	X	Paper tape would not advance (recorder replaced).
12/6 to 12/11	Yes	X	X	X	X	Paper tape put on wrong (human error).
12/13 to 1/23	Yes		X			Troubleshooting problem (malfunctioning instrument).
1/24 to 2/6	Yes	X	X	X	X	Removed monitor for modification by HIF.
3/10 to 3/20	Yes				X	Faulty pH sensor; spare also faulty.
4/17-----------	No		X			Replaced sensor.
6/26 to 7/8	No------------------------------					Recorder dropping 0020 (replaced).
6/29 to 7/8	Yes	X				Faulty conductance sensor (replaced).
Site 3						
10/10 to 10/22	Yes	X	X	X	X	Switch on "hold" (human error).
11/4 to 11/7	Yes	X	X	X	X	Paper tape stuck in punch block (recorder replaced).
11/7 to 11/20	Yes				X	Sensor did not work after being cleaned and put back in water (had water inside); no spare.
11/7 to 11/25	No------------------------------					Recorder dropping punches (replaced).

Table 3.--History of equipment problems, minimonitor systems

Site number and date	Any data loss?	Characteristic affected: Specific conductance	Dissolved oxygen	Temperature	pH	Remarks
Site 3--Continued						
12/30 to 1/15	Yes				X	Faulty pH sensor (no spare).
12/30 to 1/22	Yes		X			Faulty dissolved-oxygen stirrer assembly and sensor.
1/22 to 2/5	Yes	X	X	X	X	Removed monitor for modification by HIF.
2/5----------			X			Replaced stirrer assembly and sensor.
3/5----------	No			X		Faulty temperature sensor (replaced).
6/9 to 7/21	No		X			Replaced sensor.
6/9 60 7/22	No			X		Replaced sensor.
7/22 to 8/6	Yes				X	Faulty sensor; spare also faulty.
7/22---------	No		X			Replaced sensor.
8/20---------	No	X				Replaced faulty sensor after cleaning.
9/14 to 9/19	Yes				X	Faulty sensor (replaced).
9/17---------	No					Replaced sensor.
Site 4						
10/1 to 11/6	Yes		X			Faulty sensor and stirrer assembly; no spare.
12/4 to 12/12	No		X			Stirrer not working; replaced.
12/18 to 12/30	No		X			Stirrer not working; replaced (human error).
1/15---------	No		X			Stirrer not working; replaced (human error).
1/22---------	No		X			Stirrer very slow; faulty motor. May have caused all card failures.
1/22 to 2/5	Yes	X	X	X	X	Removed for modification by HIF.
2/5----------	No		X			Replaced sensor and stirrer assembly.
2/5----------	No				X	Replaced faulty pH sensor.
2/5----------	No				X	Faulty sensor (replaced).
3/19---------	No		X			Dissolved-oxygen sensor had water inside (sent with wrong O-ring).
9/3----------	No		X			Replaced sensor.

Table 4.--History of equipment problems, packaged-sensor systems

Site number and date	Any data loss?	Characteristic affected: Specific conductance	Dissolved oxygen	Temperature	pH	Remarks
Site 1						
10/1 to 10/15	Yes	X	X	X	X	No data stored (instrument failure).
10/15 to 10/29	Yes		X			No data stored or sensor failure.
11/12 to 11/13	Yes	X	X	X	X	Batteries had run down.
11/22 to 11/28	Yes	X	X	X	X	Batteries had run down.
12/10 to 12/12	Yes	X	X	X	X	Batteries had run down.
12/12 to 1/7	Yes	X	X	X	X	High water took out pipe.
1/22 to 2/11	Yes	X	X		X	Only temperature was programmed in (human error).
3/14 to 3/23	Yes	X	X	X	X	No data stored (instrument failure).
4/24 to 9/30	No	X	X	X	X	Modified instruments, removed silicone membrane (4/24 to 9/30), water-bath calibration.[1]
Site 2						
10/21 to 10/23	Yes	X	X	X	X	Batteries had run down.
11/3 to 11/5	Yes	X	X	X	X	Batteries had run down.
3/14 to 3/19	Yes		X			Sensor failure.
2/20 to 9/30	No	X	X	X	X	Modified instruments, removed silicone membrane (4/24 to 9/30), water-bath calibration.[1]
Site 3						
10/22---------	Yes	X	X	X	X	Batteries had run down.
11/5-6, 18-19	Yes	X	X	X	X	Batteries had run down.
1/2 to 1/14	Yes	X	X	X	X	Instrument failed (sent in for repair).
6/10 to 6/24	Yes	X	X	X	X	Instrument failed; no data stored.
7/11 to 7/21	Yes	X	X	X	X	Instrument failed; no data stored.
4/16 to 9/30	No	X	X	X	X	Modified instruments[1] removed silicone membrane (4/24 to 9/30), water-bath calibration.[1]

Table 4.--History of equipment problems, packaged-sensor systems--Continued

Site number and date	Any data loss?	Characteristic affected: Specific conductance	Dissolved oxygen	Temperature	pH	Remarks
Site 4						
10/21 to 10/22	Yes	X	X	X	X	Batteries had run down.
11/4-5, 18-19	Yes	X	X	X	X	Batteries had run down.
11/19 to 12/3	Yes				X	Did not program in (human error).
12/3, 15-17, 29	Yes	X	X	X	X	Batteries had run down.
2/19 to 3/5	Yes	X	X	X	X	No data stored (instrument failure).
4/16 to 9/30	No	X	X	X	X	Modified instruments, removed silicone membrane (4/24 to 9/30), water-bath calibration.[1]

[1]When packaged-sensor units were first installed, excessive power consumption caused battery life to be insufficient for 2-hour data storage for the required 2-week period between site visits. After modifications by the manufacturer, data could be stored at 1-hour intervals for the required 2 weeks. Dissolved-oxygen sensors for the packaged-sensor units intially came with silicone-rubber membrane on top of standard 1-mil Teflon membranes. After the modifications mentioned above, use of only the standard membranes was recommended by the manufacturer. The dissolved-oxygen sensor was first calibrated in air; however, calibration using a circulating water bath was substituted later in the test period.

In general, there were fewer equipment problems with the packaged-sensor units near the end of the test period than at the beginning (table 4). Early in the project, short periods of record were lost because excessive power consumption resulted in drained batteries. After modifications were made to correct for excessive power consumption, only two periods of record were lost. These losses were due to one malfunctioning unit that would calibrate but not store data. The high-water event that caused loss of minimonitor sensors also removed the packaged-sensor housing, which caused loss of data and damage to the unit. Packaged-sensor data were lost only twice due to errors. In one case, temperature was the only parameter programmed into the unit. In the other case, pH was omitted during programming of the unit.

CONCLUSIONS

1. On the basis of results of this test, the packaged-sensor system is less time consuming--and therefore less expensive--to install, operate, and maintain than the minimonitor system.

2. The packaged-sensor unit's diagnostic calibration checks take the responsibility of diagnosing equipment problems out of the field person's hands. This, along with the many sensor and recorder problems the minimonitor had, was probably a significant factor that contributed to time savings.

3. The processing and editing of data from the packaged-sensor system was faster and easier than for the 16-channel paper tape generated by the minimonitor. Correction of tape-punch errors and subsequent editing of the data generally had to be done before data processing for the minimonitor was complete.

4. Installation of a packaged-sensor housing requires much less time and materials than installation of a minimonitor sensor housing and equipment shelter.

REFERENCE CITED

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☆U.S.Government Printing Office: 1988 — 549-720/62049