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DEVELOPMENT OF A HELICOPTER WATER QUALITY MONITORING/SAMPLING SYSTEM

by

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SUMMARY

USEPA-EMSL-LV has developed a helicopter borne water quality monitoring/pump-sampling system for sampling lakes and rivers. Development of this sampling system originated at the beginning of the National Eutrophication Survey (NES) in May of 1972 for use in Bell UH-1H, "Huey" helicopters (outfitted with floats), but the design concepts apply to any aircraft. Development continued intermittently, while the system was in use, for the next 5 years. This document reports the problems encountered in our original sampling effort and the design concepts applied to correct those problems.

The basic system, originally designed for ship-board use (InterOcean model 513 with pump sampler), was mechanically tailored to fit our aircraft. Components were replaced or modified as deficiencies became apparent.

Water samples of any volume can be collected to a maximum depth of 172 meters at a rate of 7 liters/minute and in-situ measurements can be made of conductivity, temperature, sampling/measuring depth, dissolved oxygen, pH, and turbidity.

From our experiences with this sampling system we have concluded that:

- -- helicopters equipped with floats are versatile, cost-effective sampling platforms;
- -- this sampling/measuring system is reliable when properly maintained;
- -- the pump-sampling concept is the desirable way to collect multiple samples from multiple depths in the water column to a depth of about 350 meters;
- -- electrical interferences and vibration problems are hazards when using water quality monitoring systems in an aircraft;
- -- dissolved oxygen and pH sensors are extremely vulnerable to mechanical damage and electrical interference, and are of questionable utility for use with an airborne system; and
- -- to ensure continued reliable operation, water quality monitoring systems require frequent calibration and maintenance.

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ABBREVIATIONS AND SYMBOLS

A	--	ampere
a.c.	--	alternating current
cm	--	centimeter
d.c.	--	direct current
DO	--	dissolved oxygen
ft	--	feet
FTU	--	formazine turbidity unit
g	--	gram
gpm	--	gallons per minute
gal	--	gallon
hp	--	horsepower
in	--	inch
IO	--	InterOcean
kg	--	kilogram
kw	--	kilowatt
l	--	liter
lpm	--	liters per minute
lb	--	pound
m	--	meter
mm	--	millimeter
psi	--	pounds/square inch
rpm	--	revolutions per minute
V	--	volt
VA	--	volt ampere

INTRODUCTION

In the spring of 1972, the U.S. Environmental Protection Agency's Environmental Monitoring Systems Laboratory at Las Vegas (EMSL-LV) initiated the National Eutrophication Survey (NES), a 4-year field investigation of the effects of nutrients on the aging process of the nation's lakes and reservoirs. The program was designed to sample each of 815 lakes, distributed nationwide, once each during spring, summer, and fall seasons (USEPA 1974, 1975). It was necessary to collect water samples for laboratory analyses that would best characterize the individual water bodies in terms of nutrient levels and their manifestations, e.g., chlorophyll a concentrations and phytoplankton composition.

To sample this large geographical area in 4 years and to visit each lake three times in the same year, aircraft were considered the only practical survey platform. After some field experience with both helicopters and fixed-wing aircraft, helicopters were chosen as the most versatile and cost-effective survey platform to accomplish our mission. No commercial water quality monitoring/sampling system designed specifically for use from an aircraft was available, nor was there time for system development before beginning the field effort. To execute the rigorous schedule of the field study, a ship-board system was procured and subsequently modified for airborne application during the survey.

This report describes the helicopter water quality sampling system developed originally for use by the NES and subsequently used in support of other water quality projects. It also describes the salient problems associated with the use of a helicopter as a sampling platform and the modifications made in the system to fulfill our needs. This system should be useful to other groups involved in sampling large numbers of water quality sites distributed over large or inaccessible areas.

CONCLUSIONS

1. Our experiences indicate that helicopters equipped with floats are versatile sampling platforms and are cost-effective when large or inaccessible geographic areas must be sampled quickly with few personnel.

2. The sampling/measuring system described here is reliable when properly maintained.

3. The pump-sampling system is desirable when multiple water samples of variable volume are to be collected from many different depths in the water column (to a maximum of about 350 meters), especially from sampling platforms with limited space.

4. Electrical interference and vibration problems are hazards when using water quality monitoring systems in aircraft.

5. Outfitting an aircraft for water sampling requires detailed planning and engineering.

6. Dissolved Oxygen and pH sensors are extremely fragile, easily fouled, and vulnerable to electrical interference and "ground-loops." These sensors and circuitry require constant attention by qualified technical personnel to ensure reliable dissolved oxygen and pH data.

7. To ensure continued, reliable operation in the field, water quality monitoring systems require frequent maintenance and calibration.

RECOMMENDATIONS

GENERAL RECOMMENDATIONS

1. Helicopters are recommended for use as water sampling platforms when large numbers of lakes or lakes located in inaccessible areas must be sampled quickly with few personnel.

2. This helicopter-borne water monitoring system is recommended when there is sufficient space in the aircraft and sufficient electrical power available.

3. When electronic water quality monitoring systems are used, a well experienced electronics technician with a high mechanical aptitude and a general chemistry background should be part of the field team.

SPECIFIC RECOMMENDATIONS

These recommendations may not be appropriate for all systems; they are based on our experiences with our system. They were implemented and tested on our system or will be implemented on the next generation system.

1. Because of their maneuverability on the water and ability to take-off and land in a limited area, helicopters are recommended over fixed-wing aircraft as water sampling platforms.

2. Static inverters are recommended where 117 V a.c. power is required (the power factor should be corrected to one).

3. Aircraft power should be used without conversion wherever possible.

4. Equipment racks should be designed to conform to the internal contours of the craft.

5. Sample storage racks should be designed, where possible, to utilize space that is otherwise unusable.

6. All equipment and storage racks should be secured to the aircraft.

7. All permanently mounted hardware should be shock-mounted. Shock mounts should conform to military specification Mil. Std. - 810. All deployable systems should have cushioned restraining cradles for on-board storage. All fragile electrodes should be individually shock mounted.

8. Hardware for in-situ measurements and sampling should be as light-weight and compact as possible.

9. Strong, light-weight, noncorrosive materials (i.e., plastics) should be used wherever possible, especially on deployable hardware.

WATER QUALITY SAMPLING PLATFORMS

SAMPLING PLATFORM REQUIREMENTS AND OPTIONS

The NES sampling program required visits to several hundred lakes scattered across the 48 conterminous United States. Even with optimal planning of the sampling schedule, distances as great as 160 km (100 miles) separated consecutive lakes. Each lake was to be sampled a minimum of three times and, generally, at more than one sampling site. In-situ measurements and water samples were to be collected from various depths in the water column for physical, chemical and biological analyses. The magnitude of the program required that the sampling platform be a) large enough to safely ferry the sampling crew and the sampling system; b) stable and easy to work from on the water; c) capable of providing sufficient electrical power to operate the sampling system; d) capable of maintaining position at the site during sampling operations in wind and water currents; e) capable of sampling an average of eight sites per day in a 100-mile radius; f) reliable; and g) cost-effective.

The options for sampling platforms considered included small boats, fixed-wing aircraft, and helicopters. To meet the time constraints, use of small boats would require a large number of independent field crews and monitoring/sampling systems. This would be an ineffective use of manpower and too expensive. Aircraft represented a much more attractive option.

The selection of the type of aircraft was based on several considerations. Although fixed-wing craft are more economical to operate and maintain than helicopters, and have a greater operational radius in terms of time and distance, they require more open water for take-off and landing, and their maneuverability on the water is minimal. Also, the doors on fixed-wing craft are too small for convenient deployment and recovery of sampling packages and the standard floats used are not configured to accommodate personnel during sampling operations. Helicopters, although less economical to operate and more limited in operational radius, can take-off and land with minimal open area and are capable of lateral as well as fore and aft maneuvers, and rotation about a central vertical axis while on the water. Floats are available that have a flat, deck-like top surface for working personnel. Some aircraft have large sliding doors convenient for the ingress and egress of sampling equipment. The more reliable helicopters are powered by jet turbines. However, the number of small airports that can supply jet fuel, particularly among those in rural or remote areas, are limited. If a turbine-powered craft is selected, fuel may have to be trucked into the sampling area, or some intermediate location to minimize the time lost in refueling.

Two Bell UH-1H "Huey" helicopters and one de Havilland U-1a "Otter" fixed-wing aircraft were borrowed from the U.S. Department of Army. All three craft were outfitted with floats and used in the field during the first month of the NES. Because it required too much open water for take-offs and could not maneuver on the water to maintain station, the "Otter" was used only for cargo and personnel transport. The "Huey" was quite maneuverable and versatile and, after the first month of sampling, was chosen to complete the survey. A third "Huey" was obtained from the Army.

HELICOPTER SAMPLING PLATFORM

The three Bell UH-1H "Huey" helicopters (Figure 1) used as sampling platforms are thirteen-passenger craft with a total payload of 1,400 kg (3,100 lbs) at sea level, and are powered by a single jet turbine delivering 820-kw (mechanical) (1,100-shaft horsepower). The total available electrical power to operate sampling equipment is approximately 200 A at 28 V d.c. or 5,600 watts. Each aircraft was fitted with floats (a standard Bell retrofit kit) to allow it to land on the lake surface (as opposed to hovering) thereby conserving fuel, reducing the risk of injury, and providing greater sampling convenience.

The helicopter's main fuel tank capacity is 635 kg (1,400 lbs), yielding about 2 hours of flying time at 100 knots (the airspeed is limited to 100 knots by the floats). After the first year of the NES, an auxillary fuel tank with a capacity of 136 kg (300 lbs) was installed in each aircraft. This increased the flying time by 1/2 hour. While performing sampling on the water surface, the turbine was idled to reduce fuel consumption (the rate at flight idle is about 1/2 the flying consumption rate) and yet retain sufficient power to maintain position on the station. The total time between refueling stops was in excess of 2-1/2 hours since each half hour of sampling consumed the equivalent of only 15 flying-minutes of fuel.

All of the seats except those of the pilot and co-pilot were removed to accommodate the auxillary fuel tank, sampling equipment and sample storage. The auxillary tank served as a bench seat for the sampling technician and any additional passengers. The arrangement of the sampling equipment and storage is shown in the floor plan of the cabin (Figure 2).

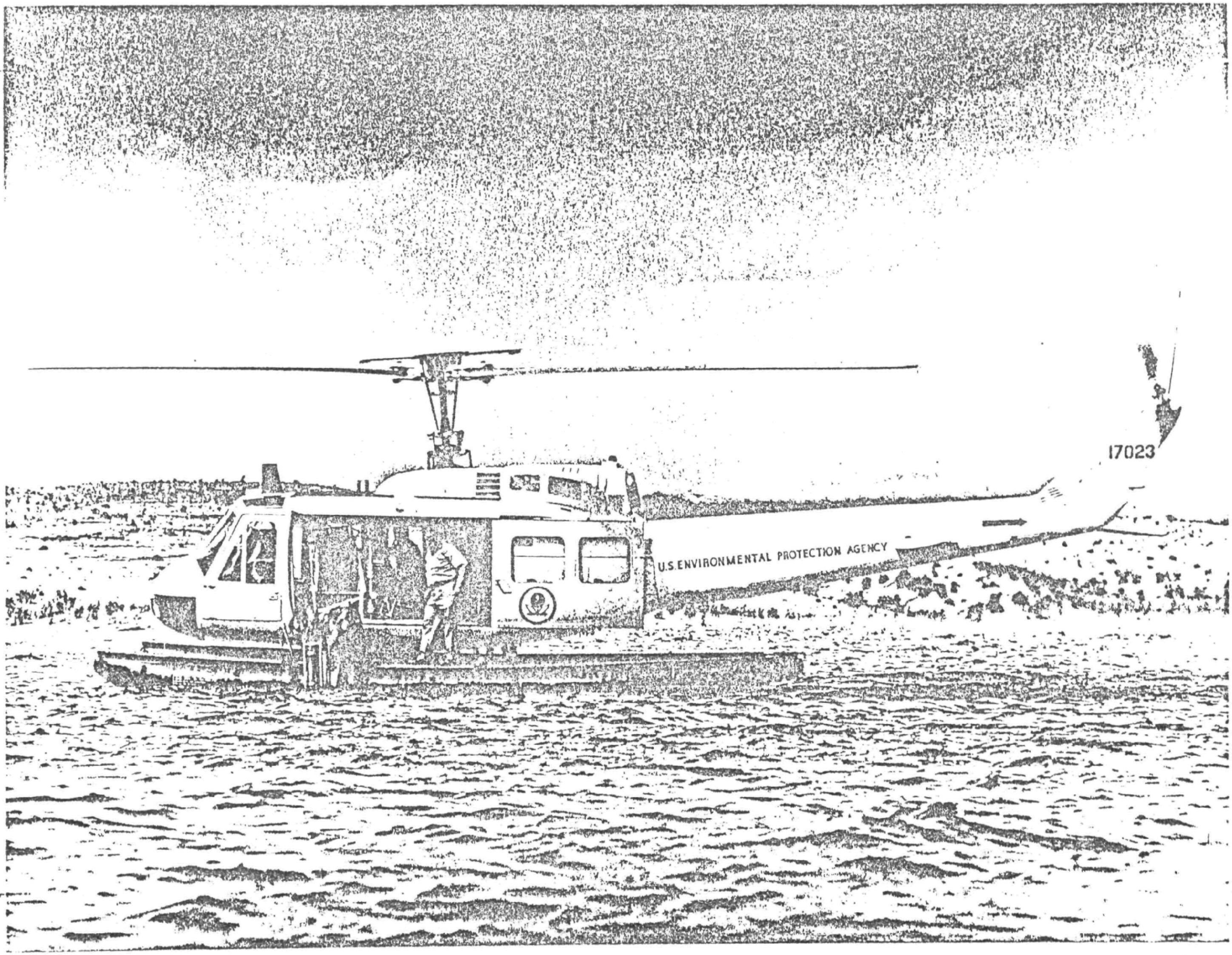


Figure 1 In-Situ Sensor/Pump Assembly Being Deployed from the "Huey" Helicopter While On Station.

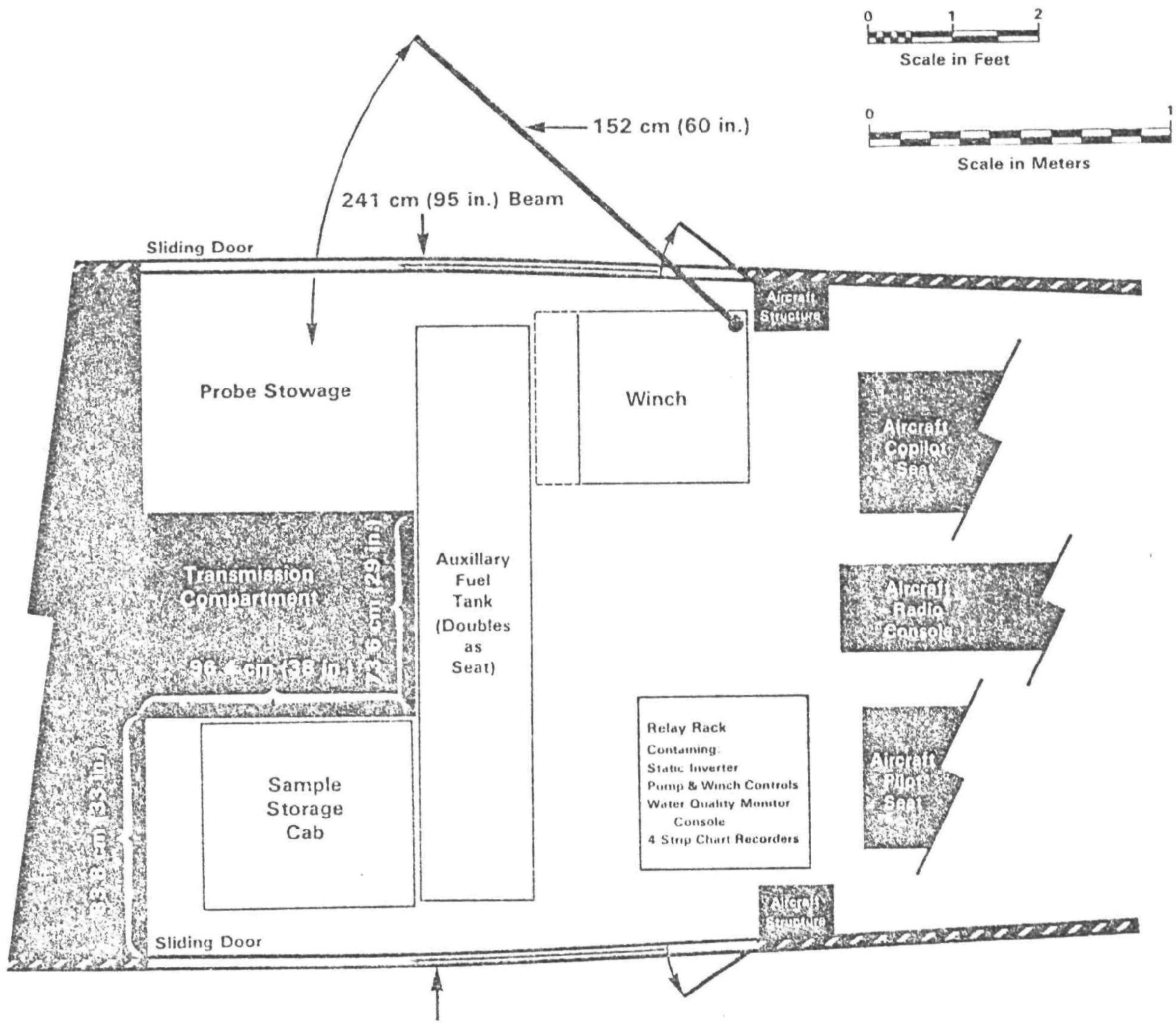


Figure 2. Floor plan of the helicopter with the monitoring/sampling system located.

HELICOPTER-BORNE WATER SAMPLING SYSTEM

Each of the three Hueys was outfitted with a sampling system. The sampling system consists of six in-situ sensors (Table 1), their associated analog electronics, and a submerged pump, mounted together on a frame; a hose/cable, boom assembly and winch; on-board electronics; a solar illuminance meter, a Secchi disk and a sediment sampler (Figure 3).

TABLE 1. THE PARAMETERS AND TYPES OF SENSORS USED ON THE INTEROCEAN IN-SITU SENSOR SYSTEM

Parameter	Type of Sensor
Conductivity	Inductive sensor
Temperature	Glass-bead thermistor
Depth	Wheatstone bridge strain gauge pressure transducer
Dissolved Oxygen	Polarographic membrane w/external temperature compensation
pH	Non-ruggedized combination pH electrode w/external temperature compensation
Turbidity	Optical transmissometer

IN-SITU SENSORS AND PUMP

Assembly

The in-situ sensor/pump sampling system was of a commercial ship-board design for use in a marine environment and manufactured by InterOcean of San Diego, California (Model 500, modified to include a pump sampling system). It

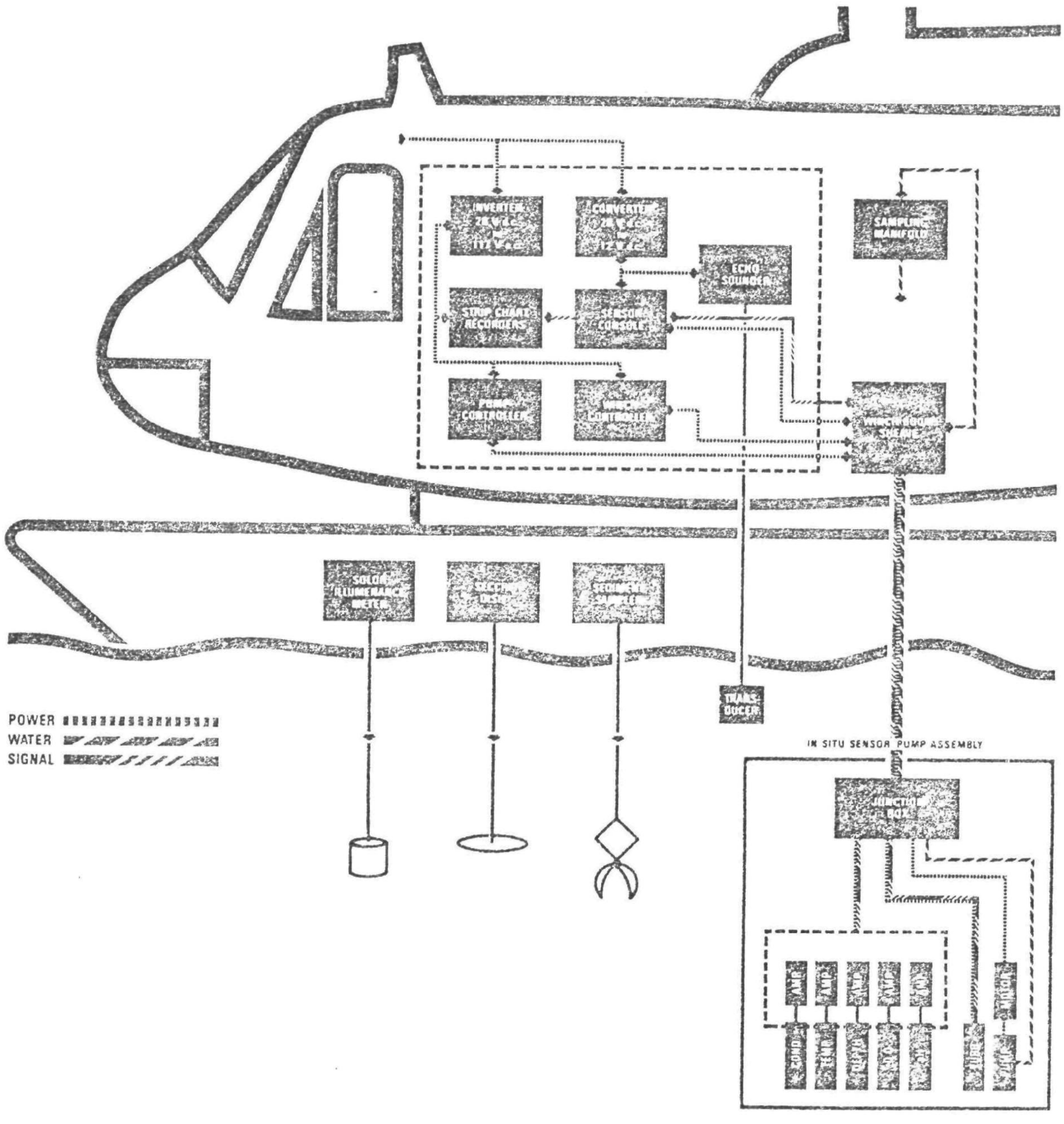


Figure 3. Block diagram of the helicopter water quality monitoring/sampling system.

was heavier and bulkier than necessary for the acquisition of data from most inland water bodies. Both mass and bulk are critical in airborne applications. The in-situ sensor assembly consists of five sensors mounted on the end of a cylindrical stainless steel pressure case (10 cm diameter, 41.3 cm length, 8.5 kg weight) and a sixth optical sensor mounted on the side of the pressure case. The case housed the analog electronics and calibration controls for the sensors. The pressure case and pump were mounted on a stainless steel frame 30 cm (12 in) in diameter and 96 cm (38 in) in length. The frame was mechanically attached to the hose/cable via a Kellem™ grip. The signal and power cables, and the hose "fanned-out" from a potted splice on the end of the hose/cable.

Handling of the sensor package during sampling operations was initially the source of some sensor damage. In particular, the dissolved oxygen sensor and the pH sensor were occasionally broken and the alignment of the transmissometer optics was disturbed. Reduction of the size and weight of the probe-assembly and relocation of the turbidity sensor in a more protected location, closer to the center of the assembly, reduced the vulnerability of the sensor to rough handling (Figure 4).

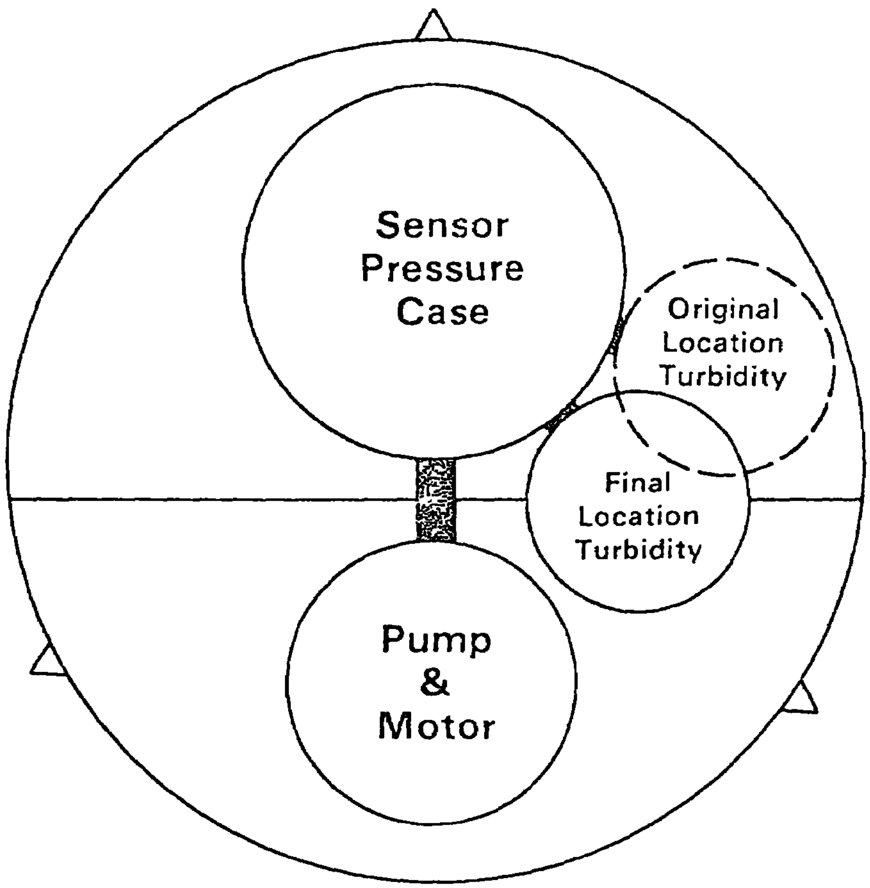


Figure 4. Plan view of the in-situ sensor/pump assembly showing relocation of the turbidity sensor.

Junction Box

Originally, there was no provision for strain relief where the pigtails to individual components on the sensor/pump assembly exited the potted splice. The constant motion of the wires at the splice caused some conductors to fail. Repair was not readily effected since the potting compound had to be cut away, the pigtails respliced to very short wires at the pot, and the splice resealed to maintain watertight integrity. InterOcean provided the solution to this problem. The multiconductor cable/hose was brought into a watertight oil-filled junction box. The box was fitted with rubber-bushed plastic stuffing-glands for cable entry and a rubber diaphragm in one side for pressure equalization. All splices are now inside the junction box and are easily repaired or modified. The box is mounted firmly to the frame so the cables can no longer move and be broken (Figure 5).

Pump

The pump originally supplied by InterOcean was a 250-watt (mechanical) (1/3 horsepower) 11-stage centrifugal well pump of cast naval bronze. It weighed 16 kg (35 lbs) and was 80 cm (32 in) in length and 9.5 cm (3 3/4 in) in diameter. The motor was manufactured by Franklin Electric Company. The pump delivered about 7.5 lpm (2 gpm) through a 100-meter length of hose/cable. The delivery rate is inversely proportional to the total length of hose; it is not affected by sampling depth. There was a protective screen over the intake that would pass nothing larger than approximately 1.6 mm (1/16 in) in diameter. The screen blocked the passage of algal masses and jeopardized quantitative estimates of chlorophyll _a_ and phytoplankton components. When the screen was removed, accumulated algae eventually clogged the pump impellers and stopped the pump. The length of the pump was the limiting factor in reducing the size of the sensor/pump assembly.

Since a smaller, lighter, positive-displacement pump would allow reduction in the size and weight of the assembly and avoid the clogging problems, such a pump, the Hypro Flexroller model B-612, which weighs only 2 pounds without the motor, was procured. It required very low start-up torque, and was designed for a maximum operating speed of 1,800 rpm. The pumping seal was maintained by four rubber rollers (Figure 6). The only sealed submersible motor available that met size, mechanical, and electrical power requirements was the motor from the original pump, which ran at 3,400 rpm. The rubber rollers in the pump were replaced with Teflon rollers, and the pump and motor combination was tested with the hose/cable.

The new pump, operating at 3,400 rpm, delivered more than 34 lpm (9 gpm) at zero meters of head. However, when 34 lpm of water was forced through 100 m (328 ft) of 9.52-mm (3/8-in) tubing, the friction head loss in the tubing was greater than 300 m (1,000 ft). In other terms, the pressure differential from one end of the hose to the other was about 30 kg/cm^2 (430 psi). This was more pressure than the hose could withstand and required more power than a 250-watt (1/3-hp) motor could deliver. The solution was to relieve the pressure and reduce the flow accordingly. A "bleed-hole" was drilled in the

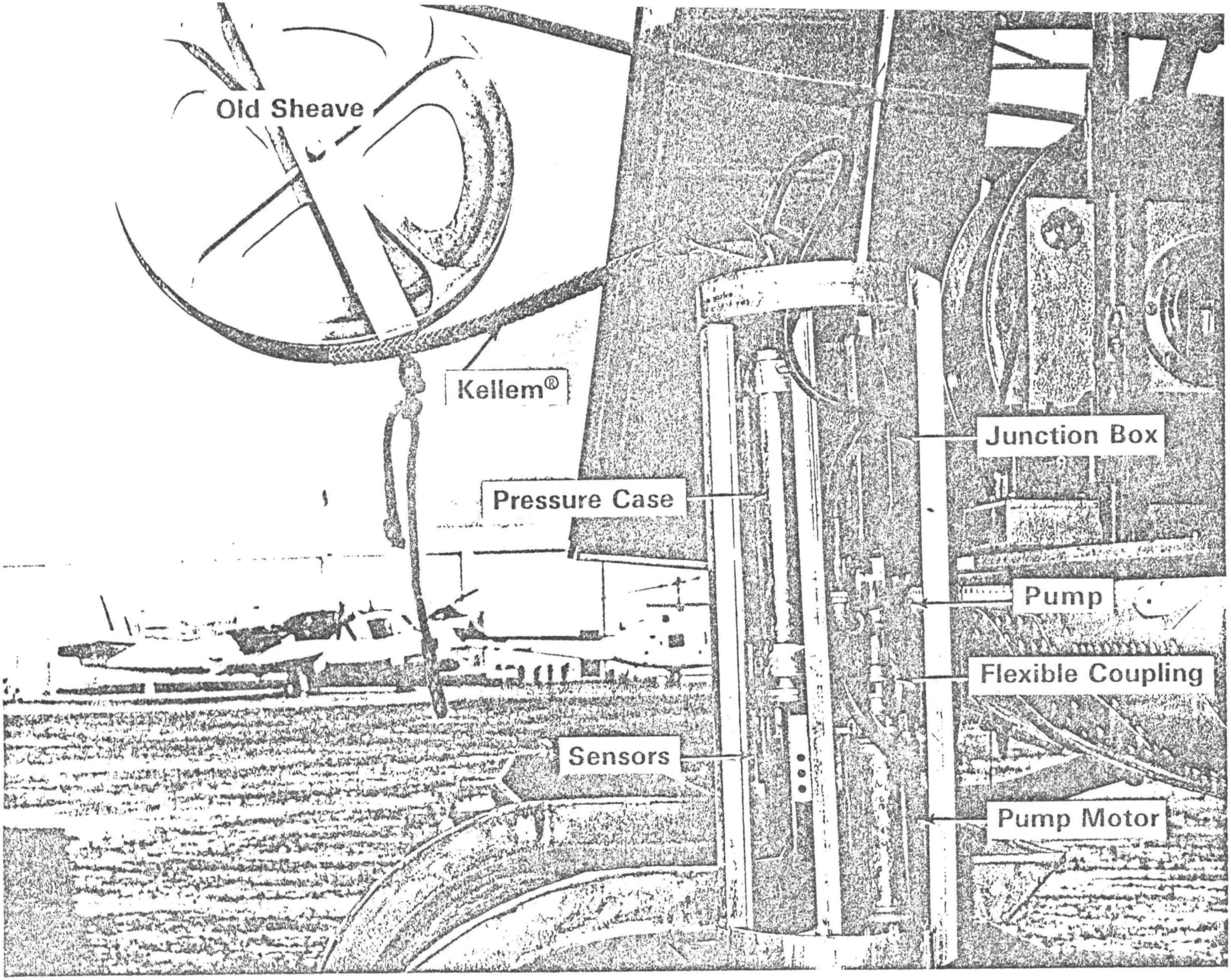


Figure 5 In-Situ Sensor/Pump Assembly with Components Identified.

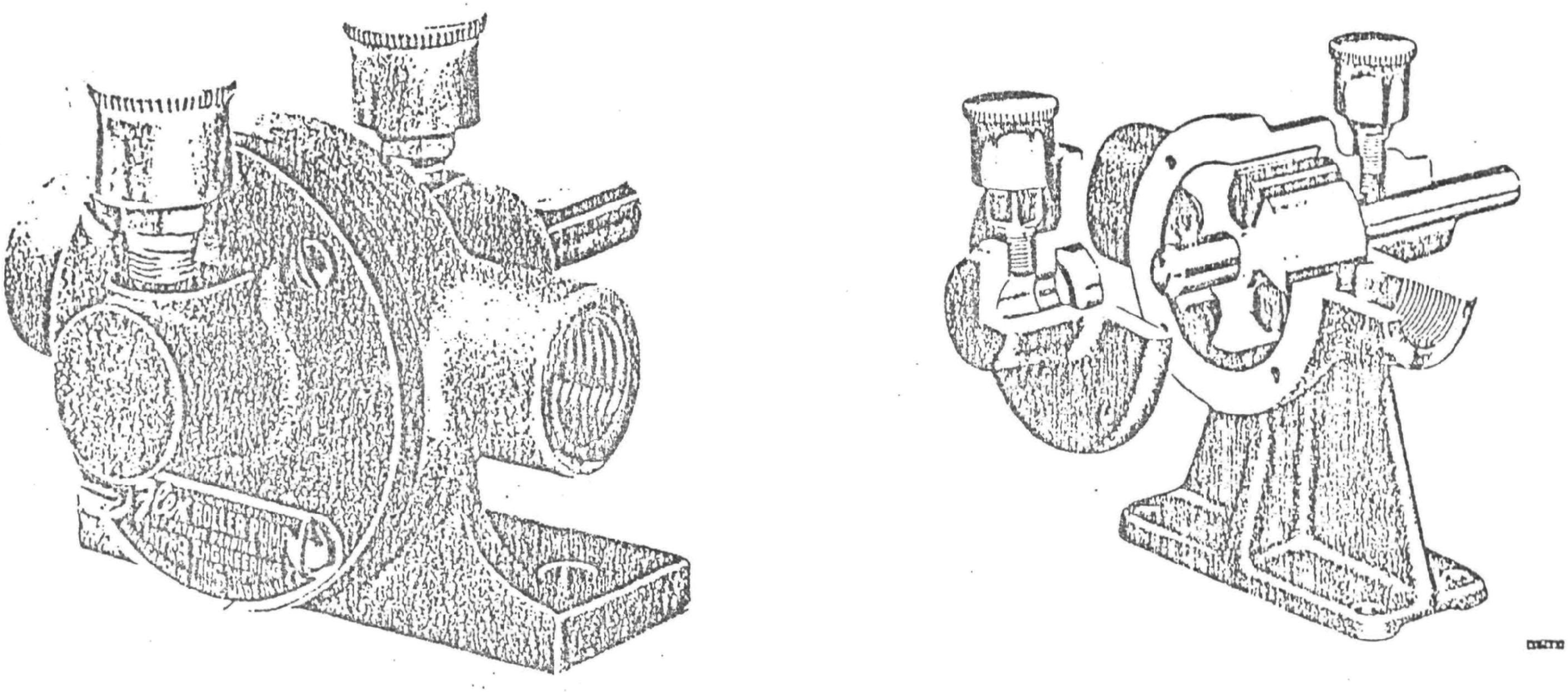


Figure 6. Hypro model B-612 positive displacement pump shown on the left is identical internally to the model B-634 shown in cut-away on the right.

output of the pump and was enlarged until the pressure at the pump was reduced to 7 kg/cm² (100 psi). This diverted 3/4 of the pumped water back to the lake and yielded a flow rate of about 7.5 liters (2 gal) per minute which was acceptable for sampling. A better solution might have been a slower motor (1,800 rpm) or a gear reducer between the motor and the pump. Neither was readily available in a compact watertight assembly and the method used represented a simple, cost-effective solution to the problem.

After modification the smaller, lighter pump assembly (Figure 5) weighed 8.6 kg (19 lbs) and was 46 cm (18 in) long vs. the 16 kg (35 lbs) and 81 cm (32 in) of the original assembly (both weights include motor). Thus a new, smaller frame assembly, 30 cm (12 in) in diameter by 81 cm (32 in) in length, was fabricated from aluminum (Figure 5), which provided a significant reduction in weight and bulk. The frame could have been made smaller but these dimensions provided some sensor protection and facilitated handling during deployment and retrieval.

Sensor and Analog Electronics

Conductivity--

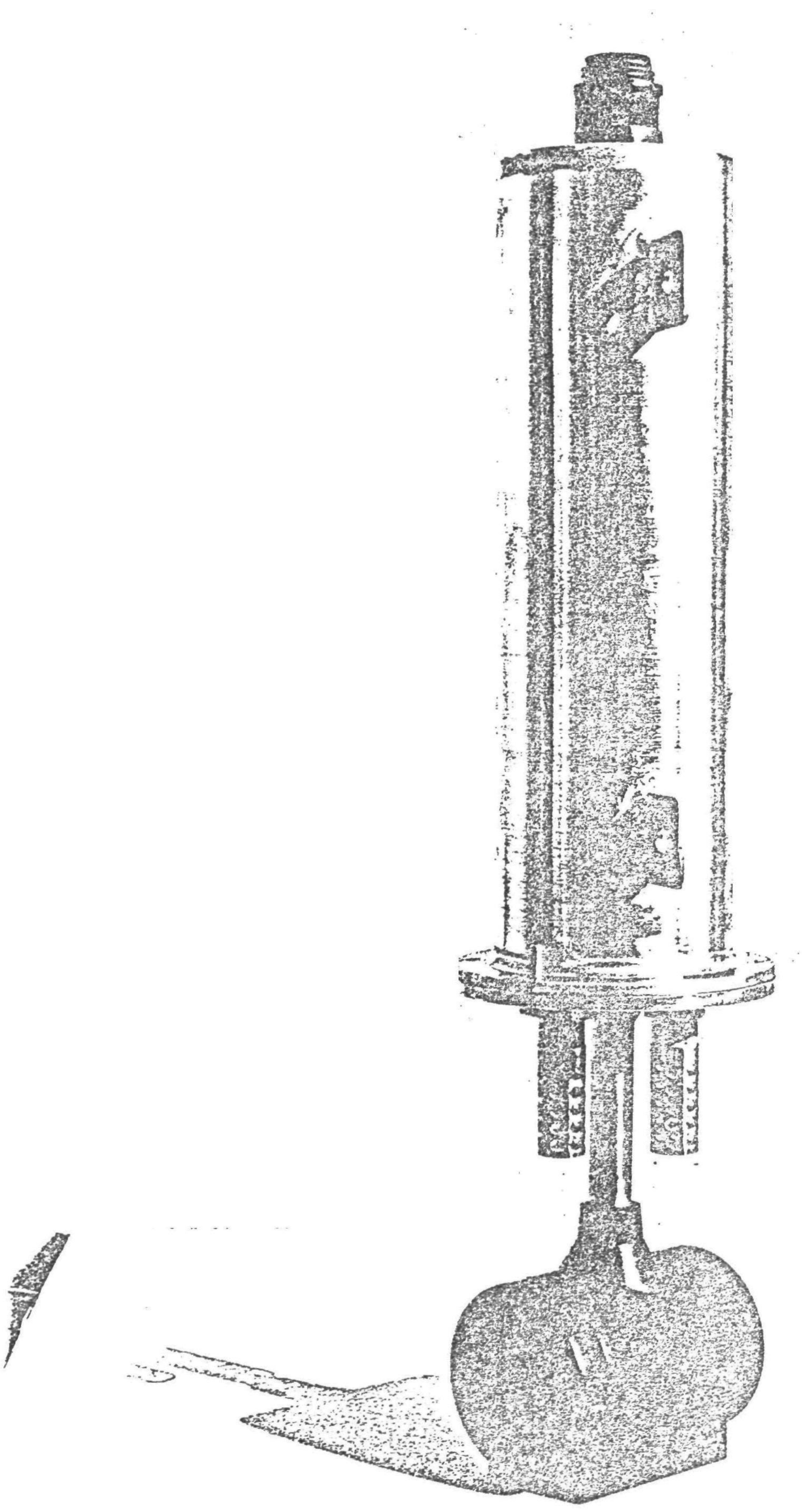
The conductivity sensor used is an inductive type, designed and fabricated by InterOcean that consists of two torroidal coils molded together in a donut shape (Figure 7). The pair of coils acts as a transformer. The electromagnetic coupling between the coils is a function of the conductivity of the water column that passes through the "donut." One coil is driven with a "saw tooth signal" generated by an oscillator; the amplitude of the signal in the second (sensor) coil is processed to yield a d.c. voltage analog of conductivity. This type of sensor is not susceptible to electrode contamination. Only one problem was experienced with this conductivity-measuring device; the driver oscillator frequently would not initiate oscillation at temperatures below 0°C. The value of the resistor that provided the forward bias to the oscillator transistors was changed to move the operating region to a more reliable range on the "characteristic curve" of the transistors.

Temperature--

The response time of the InterOcean glass bead-thermistor temperature sensor was too long to allow rapid profiling of the water column. The thermistor and its electronics were replaced by a platinum resistance thermometer (originally manufactured by Rosemount and adapted by InterOcean) and appropriate analog electronics (InterOcean retrofit). The time constant for the thermometer is 60 milliseconds, more than a factor of 50 faster than the thermistor, and thereby allowed much more rapid temperature profiling. The platinum resistance thermometer sensor cost $485.00 each vs. $4.00 for the thermistor at the time of purchase in 1972.

Depth--

The depth sensor is a bonded strain-gauge pressure transducer; the measuring element is a resistive Wheatstone bridge. Some units were temperature sensitive, and changed calibration with a temperature change. Some sensors exhibited as much as 1/2 foot per degree Celsius drift. Those sensors with extreme drift were replaced by the manufacturer. As a backup



igure 7. InterOcean [illegible] conductivity [illegible]

means of obtaining measurements of the depth of sampling, the hose/cable was marked at 5-foot intervals with color-coded tape. Visual interpolation was employed when the depth value was located between the markings.

Dissolved Oxygen (DO)--

The response times of the dissolved oxygen sensor (Beckman 39552) and associated temperature-compensation thermistor were too long (in excess of 5 seconds) to allow rapid profiling. The change in the sensor and circuitry for temperature allowed and improved dissolved oxygen sensor response time. By utilizing the analog output voltage of the temperature circuitry rather than the thermistors to provide temperature compensation information for the oxygen circuitry, the response time of the dissolved oxygen information was reduced to about 4 seconds (Appendix A). The oxygen sensor provided by InterOcean had two advantages over other sensor designs: 1) the low volume and low thermal mass yielded quicker responses to temperature and oxygen changes than other oxygen sensors, and 2) the low oxygen-consumption rate eliminated the need for a stirring mechanism. However, the sensor was very fragile and developed internal electrolyte leaks that yielded inflated oxygen readings. We were forced to change to a more rugged sensor, manufactured by Yellow Springs Instrument Company, which had a slower thermal response. The oxygen sensor provided by Yellow Springs (YSI) is model YSI 5419, a pressure compensated sensor that YSI installed in a stainless steel fitting provided by EPA (Figure 8). The sensor has a body of PVC and acrylic, and silver and gold electrodes; it is a clark-type polarographic electrode. InterOcean has since gone to yet another supplier for DO sensors.

There are still inherent problems with the new DO sensor. The sensor membrane is easily torn and subject to fouling by algae and sediment. The DO circuitry is vulnerable to electrical interference and "ground-loops;" the polarizing potential applied to the sensor can, at the same time, interfere with the pH signal. Both sensor and circuitry require frequent attention by the technician. For these reasons, we found this sensor to have limited utility in the helicopter application.

pH--

The combination electrode for pH was the most fragile of all the sensors. InterOcean redesigned the sensor mounting to improve its resistance to shock, but the electrode still failed mechanically in our application. Failures were attributable to both extreme shock (such as dropping the sensor package) and to aircraft vibration.

The circuitry provided by InterOcean for the pH analog was quite vulnerable to electrical interferences and ground loops from other sensors and the aircraft. We redesigned this circuit utilizing a differential amplifier (Appendix B), and separate Beckman Lazaran reference and glass measuring process-type electrodes (Figure 9) that resulted in a much more rugged sensor assembly and more stable, interference-free electronics. InterOcean now uses a similar differential amplifier circuit to reduce interference.

The modified circuit of the extremely high-input-impedence amplifier required by pH sensors ($>10^{12}$ ohms) is less vulnerable to "ground-loops" and electrical interference. Very clean water (specific conductance <200

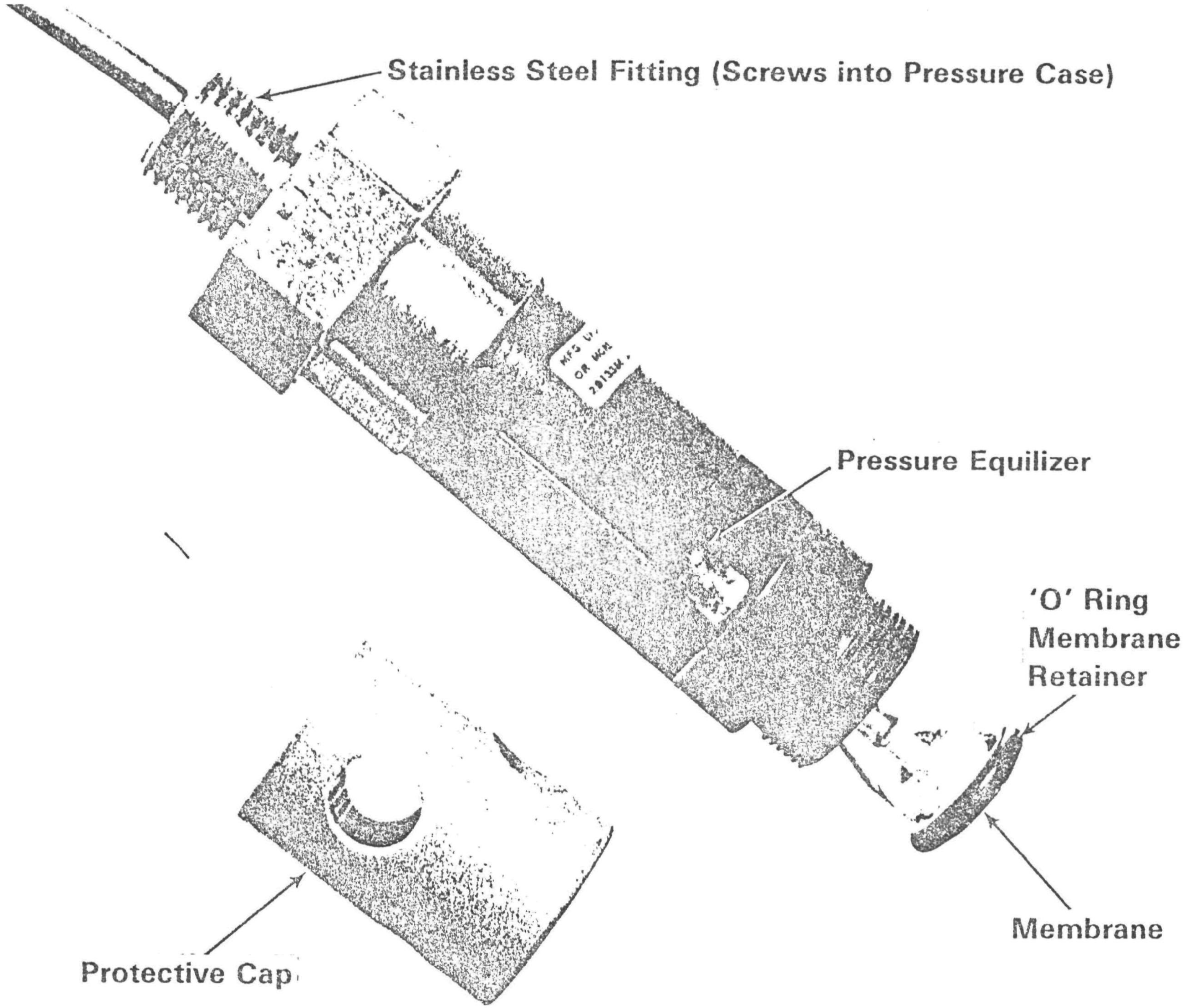


Figure.8 Dissolved [redacted]ellow Springs Instruments).

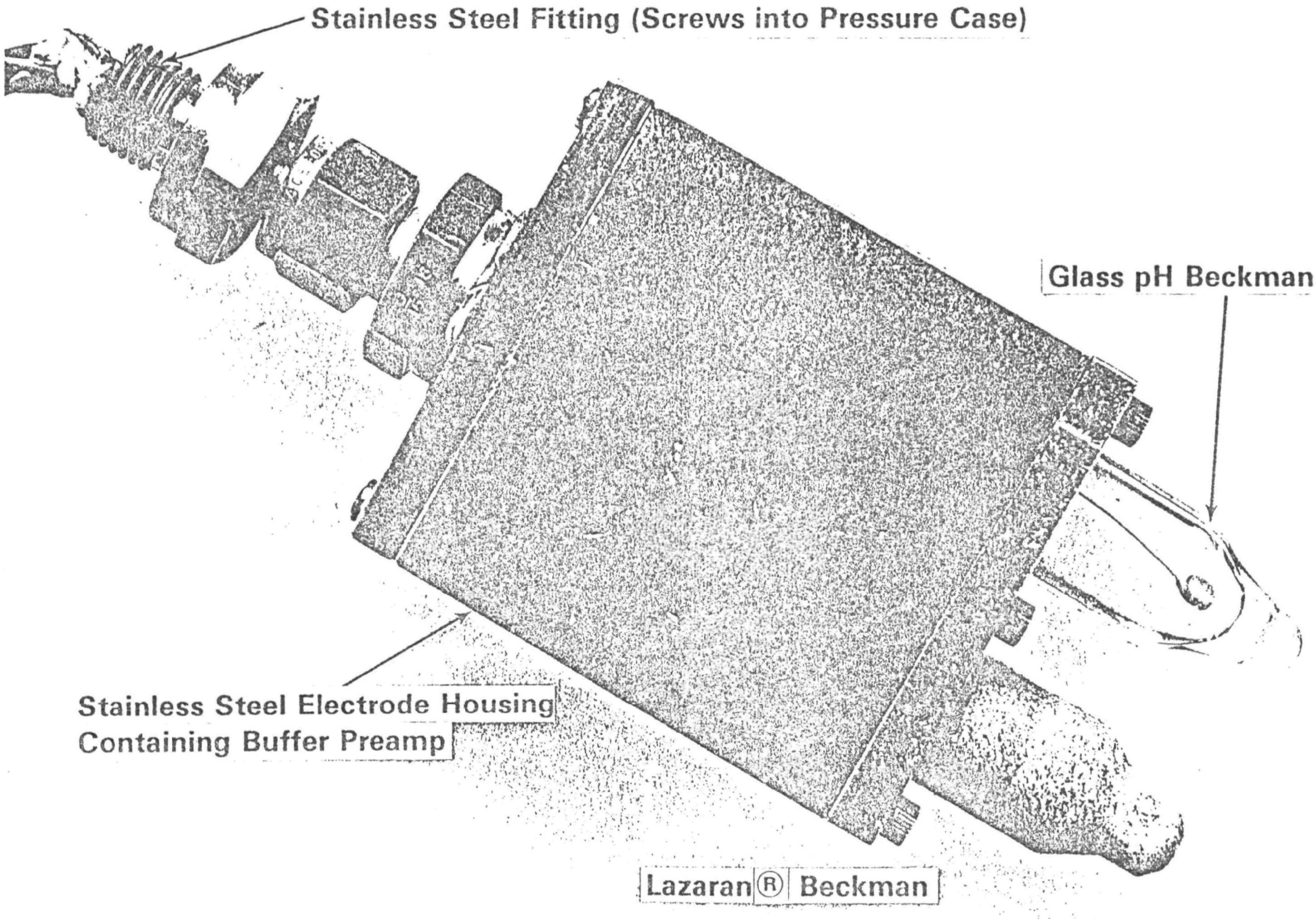


Figure 9. Process La[illegible]

μmhos/cm) does not ionize sufficiently for the pH sensor to be effective. When the sensor package is not in the water, a protective cover filled with water should be placed over the glass measuring electrode to keep the electrode wet. If dry, the sensor may have to be soaked for 2 to 3 hours before consistent pH values can be obtained on calibration.

Turbidity--

The turbidity sensor used, is a simple transmissometer consisting of a light bulb, a photo cell, and associated optical system. The output signal is an analog of the percentage of light transmitted along a fixed 10-cm path length through the water. This is displayed on the digital display. The analog meter is labeled in formazine turbidity units (FTU), however, the FTU values do not correlate with Jackson Turbidity Units (JTU) in all cases. The only problems with this sensor were those of mechanical misalignment of the optics caused by rough handling and its relative lack of precision.

HOSE/CABLE, BOOM, SHEAVE AND WINCH

The in-situ package mechanical delivery/recovery system that consisted of a hose/cable, boom, sheave and winch from InterOcean provided the means to recover water samples from discrete depths, supply electrical power for the sensors and pump, and transmit the analog signals (Figure 3).

Hose/Cable

The hose/cable, a concentric structure, was constructed with a 10 mm (3/8 in) i.d. nylon sample delivery hose at the center. Twenty conductors of 20 gauge stranded, Teflon insulated wire were wound around the hose at about one turn per 60 cm (2 ft), and the voids between the conductors were filled with a gelatinous substance to minimize water movement in this layer if the cable inner jacket were damaged. These power and signal transfer conductors were covered with a single, concentric vinyl jacket, and a galvanized steel wire strain member was braided over the jacket to support the mechanical load of the in-situ sensor/sampler system. The voids in the braid were not filled, and the braid was covered with a second vinyl outer jacket about 0.305 mm (0.012 in) in thickness.

In use, this thin vinyl outer jacket was easily damaged and the braid exposed. Water from the outside then moved along the strain-member layer. The natural working of the braid strands against each other wore away the galvanized coating, which allowed the steel braid to rust and ultimately led to strain-member failure. Fortunately, the conductors and the hose were capable of supporting the relatively light load of the sensor package. When the cable-design oversight was detected, we specified and procured new cable with a stainless steel braid instead of the original galvanized steel and a much thicker (2.4-mm) outer jacket. We also specified a smaller bend radius (20.3 cm (8 in) vs. 35.5 cm (14 in)) than that of the original cable, in order to reduce the diameter of the sheave on the boom to 40.6 cm (16 in). The original hose/cables were each 100 meters (328 ft) long. The new cables were 100 and 200 meters long to fill the new winches.

Boom

The original boom was mounted on a pivoting mast that attached to existing fittings in the deck and the overhead in the craft. After the first year, a new hinged-boom system was designed which attached to three existing attachment points in the "overhead" and used a fourth point for bracing in the extended mode (Figure 10). This configuration allowed relocation of the winch a few centimeters forward and outboard of its original position, which in turn, made available the necessary room to add an auxillary fuel tank.

Sheave

The sheave provided on the original procurement was a massive aluminum casting more appropriate for marine applications. For our relatively short cable and cramped quarters onboard the aircraft, a smaller, lighter sheave was needed. This need was satisfied by casting polyurethane in the modified rim of a heavily constructed 40.6-cm (16-in) bicycle wheel and then machining a groove in the urethane that fit the cable radius (Figure 11).

Winch

The winch provided the mechanical recovery and hose/cable spooling functions, and provided for continuous signal and power transfer through slip rings. A rotary union permitted continuous water sample transfer when the winch was in motion.

The original winch provided by InterOcean was powered by a variable speed, direct current control motor through a planetary gear speed reducer and a chain drive to the drum. The winch controller converted alternating current from the inverter to variable direct current for speed control of the drum. The hose/cable was secured to the drum with a Kellem grip, and the hose member was attached to a rotary union in one end of the winch drum. A 20-conductor slip ring assembly extended outside the winch. The conductors of the cable were hard-spliced to the slip rings inside the winch drum. Changing slip rings in this configuration was a major task. In general, the winch was too large to work around conveniently and was inadequately braced. It also had no provision for manual operation in the event of an electrical power failure, a serious safety consideration.

Between the first and second field years a new winch was designed, and three copies were fabricated (Figure 12) that overcame the operational shortcomings of the original winch. Two of the new winches had 100-meter capacity drums and one had a 200-meter drum. The slip rings were recessed into the winch drum and a connector was added between the rings and cable; this connector was accessed through a service port in the side of the drum. This winch was powered by a control motor similar to the original winch, but a worm gear speed-reducer was used. A manual crank (Figure 12) was included to retrieve the cable in the event of a power failure and a manual brake was added to the drum to prevent free-wheeling in the event of a broken drive chain. A slipclutch was incorporated in the drive assembly to prevent damage to the air frame at the boom attachment points if the sensor/sampler were

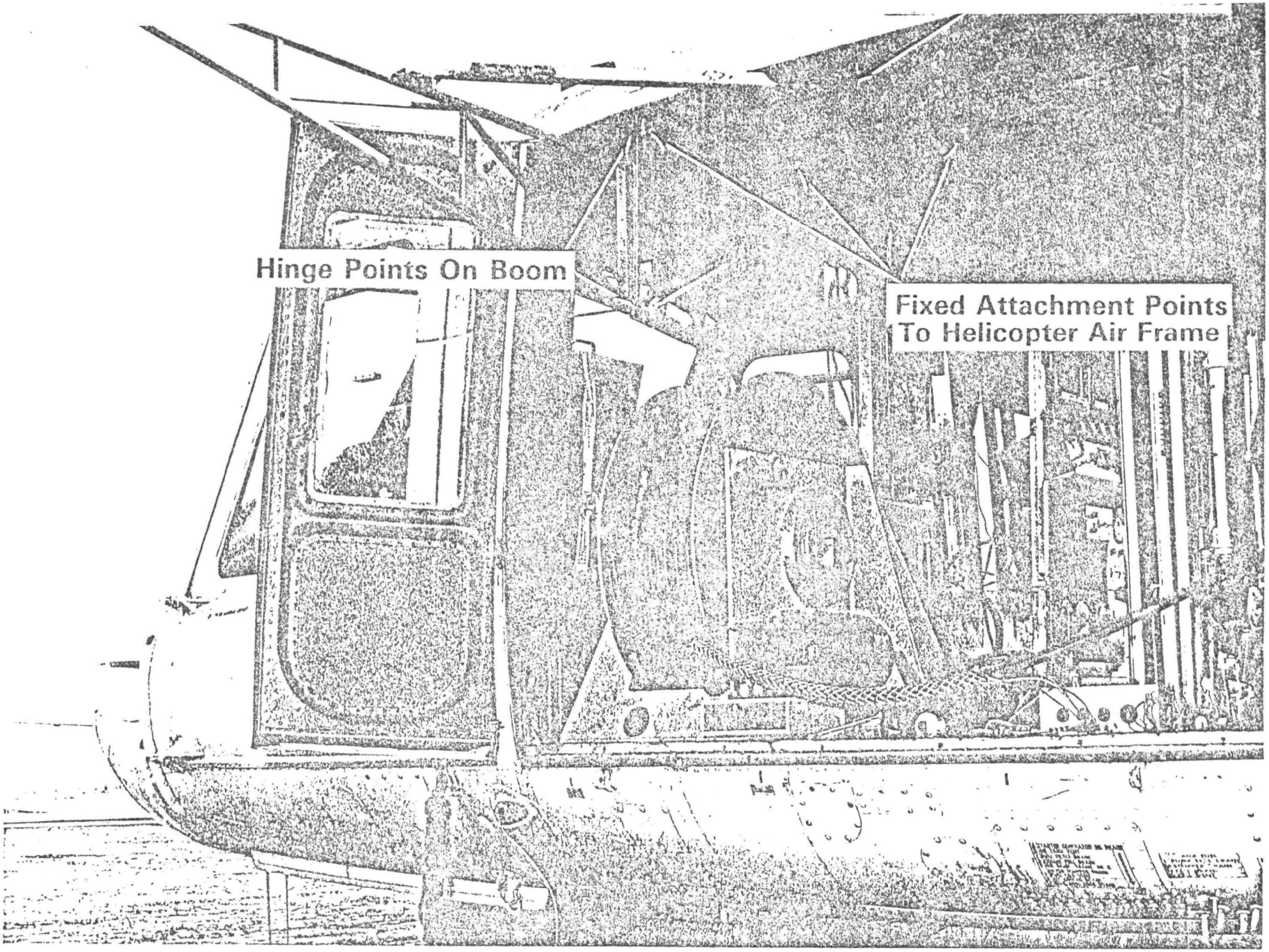


Figure 10 Hinged Boom Mounted in the Helicopter

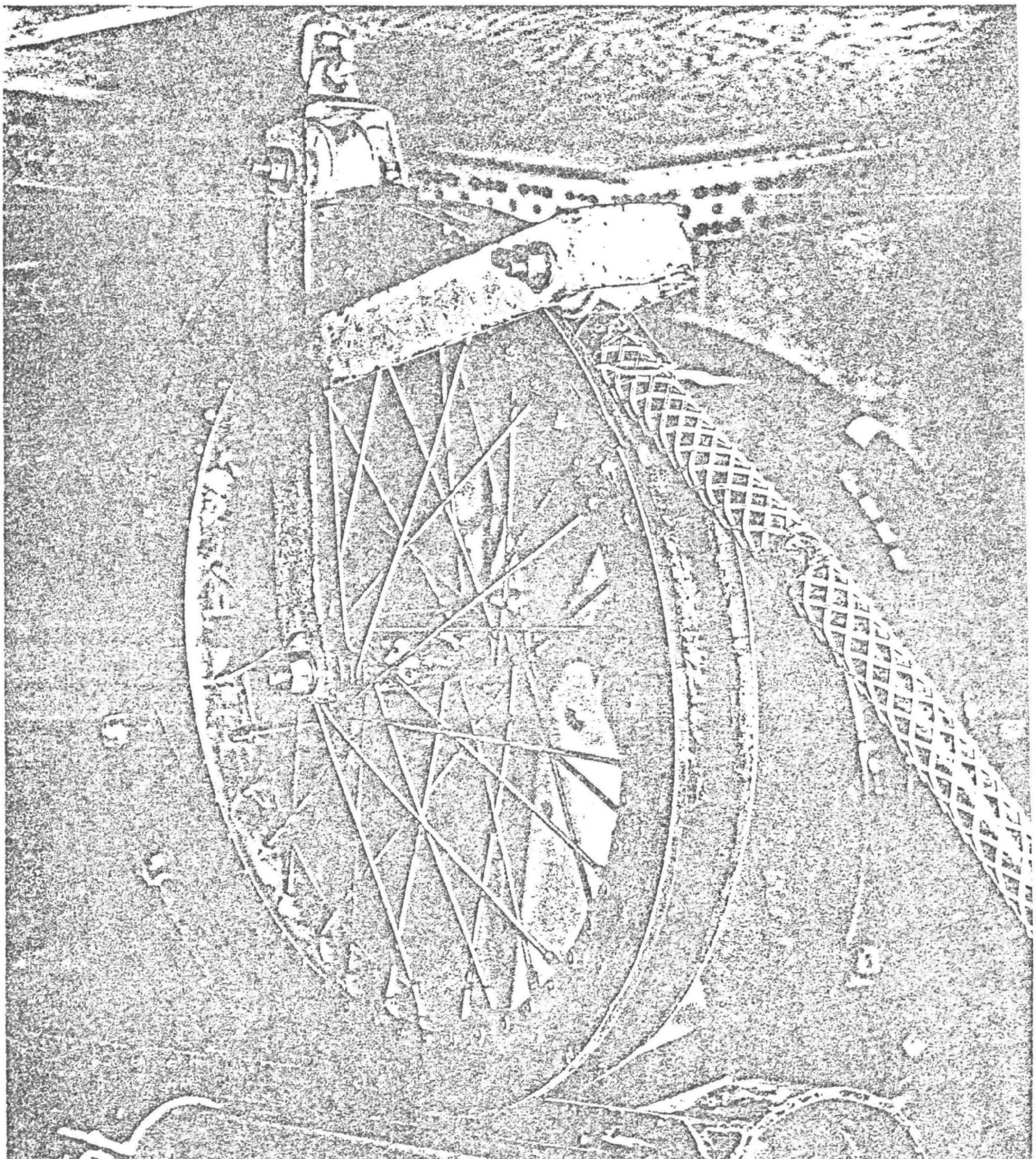


Figure 11 Lightweight [illegible] hose/cable.

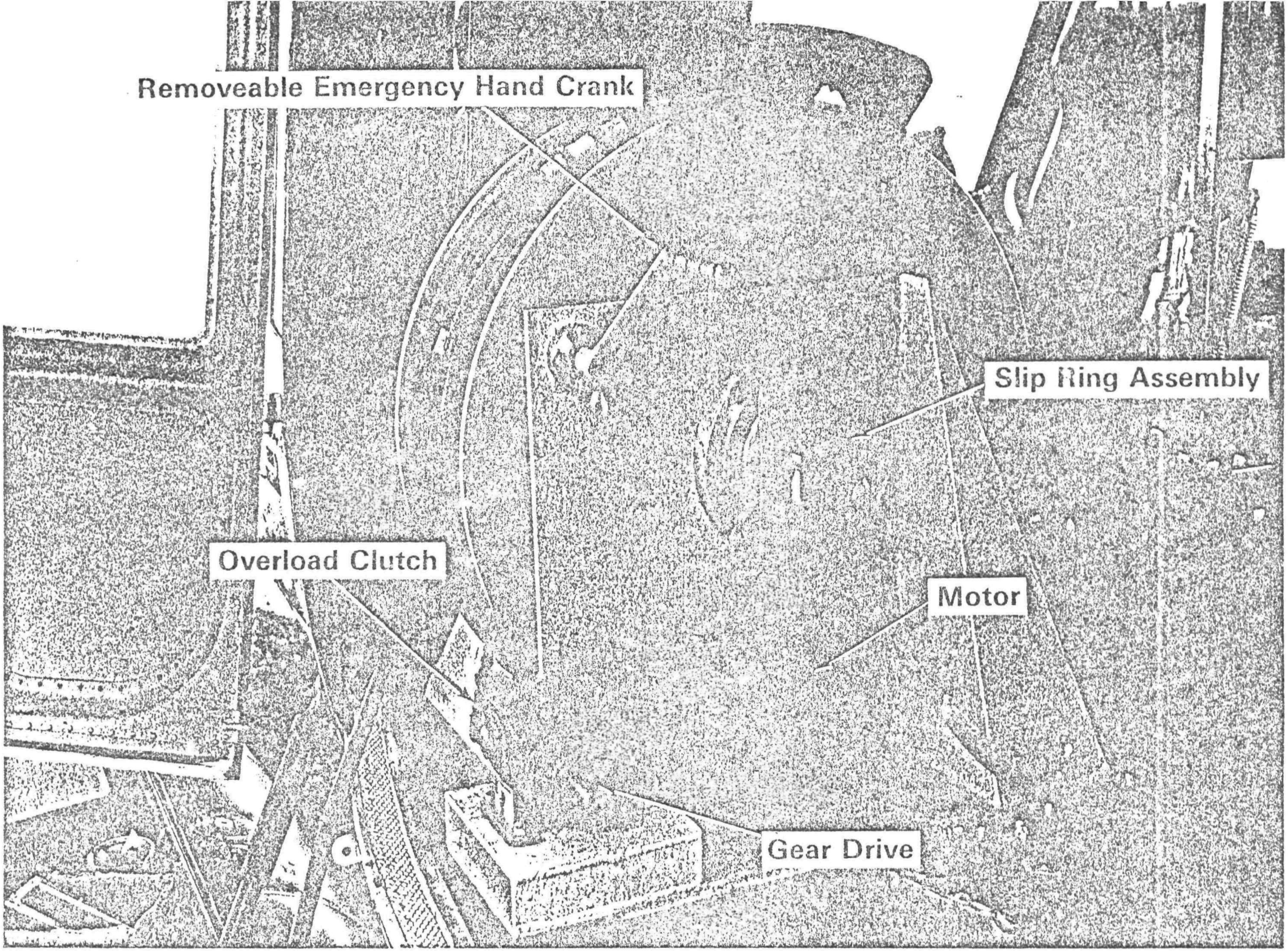


Figure 12 New 100-meter Winch Mounted in the Helicopter

accidentally snagged on some submerged object. The chief advantages gained from the redesign of the boom and winch assembly were in operational safety and size reduction. The latter allowed relocation in the aircraft; the gain in working space made it possible to replace the rear seat with an auxillary fuel tank mounted athwart ship. The tank doubled as a seat and extended the operational radius of the helicopter.

ONBOARD ELECTRONICS

The onboard electronics included the console for the in-situ sensor subsystem, the pump and winch controls, the graphical displays, the echo sounder display and the power supplies (Figure 13).

Mounting Rack

An open-frame 19-inch relay rack was fabricated from aluminum angle-stock. The base was 20.5 inches (52 cm) square and was mounted on shock mounts specially designed for helicopter use. The overall height of the rack and mounts was 52 inches (132 cm). The back of the rack was shaped to fit the contours of the helicopter cabin, and the rack was bolted to the deck of the helicopter. The onboard electronics systems were installed with the static inverter, the heaviest component (82 kg, 180 lbs), at the bottom; then the pump and winch controllers and the in-situ sensor console; and finally the four graphical recorders at the top (Figure 13). The echo sounder display was mounted on the side of the "relay rack."

Console

The console and digital-display module for the InterOcean model 514A was provided in a box for portability. This was remounted in the relay rack to consolidate the onboard electronic systems. The console operates on 12-volts d.c. power and provides the power to the analog circuitry for the sensors. It also contains the analog to digital conversion circuitry, analog panel meters, and a switchable digital display for greater resolution of the measurements. This was the single most trouble-free component in the entire system. The only change made in this component was a new front panel provided by InterOcean to fit a 19-inch relay rack.

Graphical Displays

The original graphical recorder was a x,y,y', y" flatbed recorder with a plotting area 27.9 cm (11 in) by 43 cm (17 in). Neither the electronics nor the mechanical pencarriage assembly could withstand rotary-winged aircraft vibration. Four separate strip chart recorders, Hewlett-Packard model 680A, were substituted. An event marker feature was used to key regular depth intervals to correlate the values noted to specific depths. Electric-writing recorders were selected to avoid the inevitable untidiness of filling ink reservoirs in an aircraft.

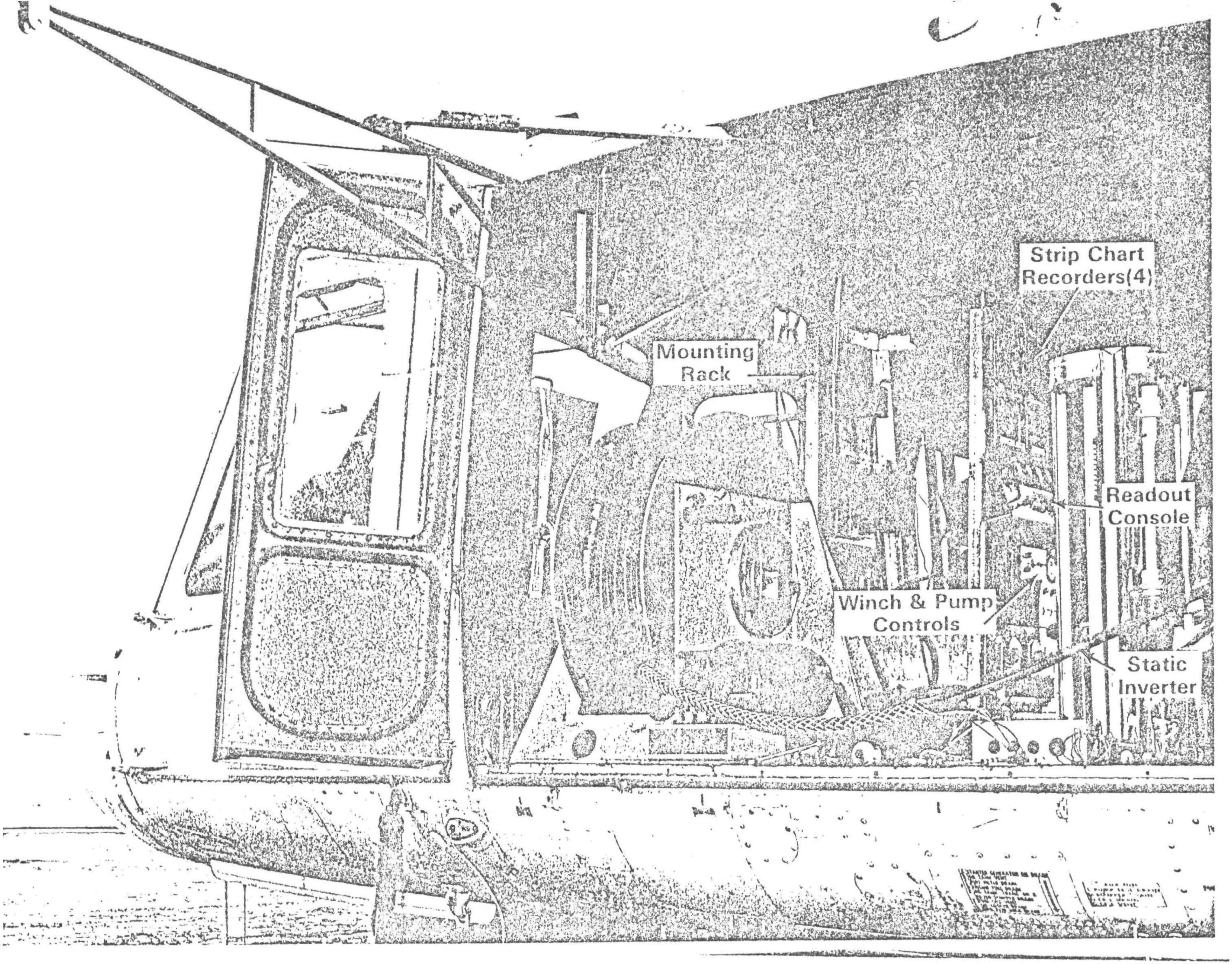


Figure 13 Onboard Electronics Subsystems Mounted in the Helicopter

Winch Controller

The winch controller, Browning model M, was modified mechanically to mount behind a relay-rack panel. The controller is powered by 117-volt alternating current and provides a variable d.c. voltage to the winch motor for speed and direction control.

Pump Controller

The pump controller includes the main power switch for the pump, the "power factor" correction capacitor, a step-up transformer (117 V a.c. to 230 V a.c.) to power the motor from a 117-V a.c. source, the starting-winding capacitor, and starting-winding disconnect relay. The transformer and correction capacitor are mounted on a panel on the rear side of the rack. The remaining components comprise the standard "1/3 horse power" Berkley pump controller and are mounted on the same panel as the winch controller.

Power Supplies

The power available on the aircraft is 28 V d.c. with maximum of 200 amperes available. Most of the sampling and measuring equipment requires 117 V a.c. power. During the first year of the NES, a 1,000-VA rotary inverter, Leland Model MGE 37-400, was used to convert the 28 V d.c. to 117 V a.c. 60 Hertz. Rotary inverters function better than static inverters when used with inductive loads, e.g., the pump motor; however, they are inefficient when little current is being drawn from them. One thousand volt-amperes was just sufficient to operate the winch and pump simultaneously. When the pump clogged, the motor would draw more current than the inverter could deliver. This repeated overloading of the inverter caused numerous inverter failures. Larger capacity rotary inverters were not available. After the first year of NES, the rotary inverter was replaced with a 2,000-VA static inverter, Unitron model PS 67-324-1. The inductive load of the pump motor was corrected to a power factor of about one by adding an appropriately sized capacitor in parallel with the load. The winch motor required no correction since the power supplied to the inductive load by the winch controller was d.c. The static inverter is much more efficient than the rotary inverter, especially during low load conditions. However, it weighs 54 kg (120 lbs) more than the rotary inverter.

The static inverter provided 117 V a.c. power to operate the pump, the winch, and four strip chart recorders. The echo sounder and the console for the in-situ sensors required 12-volt d.c. power. A Narco 28' to 12-V d.c. power converter was used to power these components. The converter was mounted on the back panel of the rack next to the pump step-up transformer.

Echo Sounder

A number of different pleasure-boat echo sounders of the revolving-disk/flashing-light type have been installed on the helicopter since 1972. Some of the manufacturers and models are as follows:

Columbian Hydrosonics	Model CB-324	Ray Jefferson	Model 520
Heath Company	Model MI-1031		

However, none was found to be rugged enough to endure constant use and helicopter vibration. The bearings supporting the revolving disk and motor armature typically failed after a few months of field use and replacement parts were not readily available.

The indicator unit was mounted on the front of the winch/pump controller panel. The transducer is addressed in "Other Underwater Components."

SAMPLING MANIFOLD AND SAMPLE STORAGE

Sample water delivered from the rotary-union on the winch was transferred to a cylindrical clear-acrylic manifold for sample delivery. The manifold was 51 mm (2 in) diameter, 305 mm (12 in) long and was oriented horizontally. Three sample ports on the bottom were fitted with plastic valves for sample withdrawal. The supply hose from the winch was introduced at one end and an overflow hose was attached to the other end. A small stainless steel sink 102 mm (4 in) by 205 mm (12 in) was mounted below the manifold. The sink drain and manifold-overflow hoses drained outside of the helicopter. Both the manifold and the sink were mounted on the side of a specially fabricated aluminum sample-storage cabinet.

Samples were collected in 125-ml (4-oz) polyethylene bottles (Nalge #2003-0004) which were carried in plastic coated wire bottle racks, 48 bottles per rack (Cole Parmer #6049-10). The sample-storage cabinet was constructed such that three racks of bottles fit on each of four shelves. A large space at the bottom of the cabinet was reserved for tools, spare system parts etc.

OTHER UNDERWATER COMPONENTS

Solar Illuminance Meter and Secchi Disk

At the outset of NES, secchi disk measurements represented the sole basis for estimating photic zone depth. Beginning in the second year, a solar illuminance meter was used in addition to the secchi disk. A Montadero-Whitney model LMT-8a was chosen. It functioned well during the remaining years of NES and on other later applications. This instrument was deployed independently of the sensor/pump system. A possible improvement would be to integrate it with the sensor/pump assembly. This would have required that only one system be put in the water and would have expedited the on-site operation. Both the secchi disk and the solar illuminance meter readings, when taken from the helicopter, were shallower than when taken from a boat at the same site. This is, in part, attributed to reflections and refractions at the water surface from the rotor-wash turbulence. In the case of the secchi disk, the demonstrated shading effect of the rotor blades also contributes to the shallower readings. Generally, the 1-percent light level, as measured from the helicopter float with the light meter, was about 2.2 times the secchi disk depth measured from the same position.

Sediment Sampler

Bottom sediments were collected for nutrient and heavy-metals analyses. The original sampler was a Phleger corer. The intent was to describe the stratification of the nutrient accumulation in the sediments. The corer resembles a bomb, with a core tube and cutter on its anterior. This assembly is dropped into the water and rapidly decends to penetrate the bottom. When it is extracted it recovers a 35-mm (1.375-in) diameter cylinder of sediment, essentially undisturbed.

The corer was too heavy to recover by hand and interferred with the primary mission of collecting water samples. Recovery after complete penetration into the sediments sometimes resulted in failure to the boom system. The concept of collecting intact cores was waived for expediency and a small, light-weight clam-shell dredge, which could be deployed and recovered by hand with a 3-mm (1/8-in) nylon line, was used for the remainder of the study.

Echo Sounder Transducer

The echo-sounder transducer was mounted on a fixed bracket on the left helicopter float. The transducer was positioned such that when the aircraft was on the ground the transducer was about 20 cm (8 in) above the ground and when the aircraft was on the water the transducer was submerged about 5 cm (2 in).

When different manufacturers' echo sounders were used, the transducer was also changed to ensure compatibility.

SAMPLING OPERATIONS

As a safety precaution, sampling should never be conducted with fewer than three persons. The pilot, riding in the right-hand front seat, is constrained to remain seated and to maintain control of the aircraft at all times, in the air, on the water, and on land, as long as the main rotor is in motion. If someone sampling has an accident or falls overboard, the pilot is not at liberty to leave his place to lend assistance. The limnologist rides in the left front seat and identifies the sampling sites. The sampling technician rides in the rear of the aircraft. The limnologist records observations concerning the site location, general water appearance, and any other observations pertinent to the mission on a field data sheet. After the sampling site is reached and the aircraft has landed on the water, the technician debarks to the right float and deploys a station reference buoy for the pilot. While on the water with the helicopter at flight idle for sampling, the pilot maintains position on the site against wind and/or currents.

The limnologist, meanwhile, debarks to the left float and deploys the in-situ sensor/sampler package. The limnologist then occupies the technician's seat at the system console to operate the winch and pump during the "cast" (Figure 3). The technician takes secchi disk observations and bucket-dipped surface-water samples. The limnologist lowers the sensor/pump package slowly through the water column until it contacts the bottom (or the cable end is approached). During this process, the four analog strip-chart recorders are activated to generate analog profiles of conductivity, temperature, dissolved oxygen and turbidity. The sensor/pump is then raised free of the bottom before the pump is activated, to avoid damage to the pump from sediments entering the intake. Water samples are collected and preserved as necessary by the technician. Samples are collected from a manifold inside the aircraft. Sufficient time must elapse after starting the pump for the hose/cable to be purged of water from the previous sampling (purge times were routinely measured for each system). Sampling depths for the collection of other water samples are chosen by the limnologist after inspection of the analog profiles of the four parameters. The digital display on the console is read and recorded on the field data sheets for all of the parameters at each sampling depth. Upon completion of sampling near the bottom, the sensor is raised to the next level, digital values are recorded, the hose is purged and water samples are pumped. This process is repeated at each depth selected for collection of water samples at a given site.

Integrated samples for some analyses are collected by continuing to pump while raising or lowering the sensor package. Water collection is timed to provide a uniform mixture of water over the integration depth range.

Samples are collected in polyethylene bottles for all required types of analyses, both chemical and biological, are preserved as necessary, and stored in racks in the sample storage cabinet or in an ice-chest as sample requirements dictate.

When sampling in rivers with noticeable current, as was sometimes the case in both NES and the Atchafalaya Study, the sensor/pump package is not lowered through the water column, but rather is used for surface samples and measurements only.

At the conclusion of sampling, the limnologist retrieves the sensor/sampler from the water, secures it in the aircraft and returns to the left front seat before take-off. The technician recovers the buoy and returns to his seat for take-off. Because of the high noise levels, headsets connected to the helicopter's intercom system are used for communications while sampling as well as during flight.

CALIBRATION AND MAINTENANCE

The sensor analog electronics proved to be quite stable; however, the wet/dry cycling of the sensors and the physical abuse from deployment/recovery and sensor contamination necessitate daily calibration. During routine operations the system is typically calibrated to standards and buffers in the evening (Table 2) and checked against these standards the following morning before flight. Differences between the system and standards for the morning check are recorded and added/subtracted from the observations made that day. The operational checks (Table 3) are performed both evening and morning concurrent with calibration and calibration check.

Before beginning the day's operation the sampling technician reviews a check-list for the presence of sampling supplies: bottles, reagents, ice and other preservatives; removable sampling gear (sampling bucket, secchi disk, sediment sampler and tool kit); and spare parts (pump, pump rollers and pump motor).

Maintenance that was accomplished outside of this daily schedule was in response to catastrophic failures. In order to ensure reliable calibrations and timely maintenance, it is necessary to keep a calibration/maintenance person available to the system daily while the system is in use. This calibration/maintenance person should be a qualified electronics technician with an understanding of water chemistry and water quality sensors.

A portable artificial water column for calibration of the echo-sounder was devised and is illustrated in Appendix C.

A buffer-board was designed to be added to the console to simplify calibration. This modification was never fully tested or implemented; it is illustrated in Appendix D.

TABLE 2. DAILY CALIBRATION PROCEDURE FOR HELICOPTER BORNE WATER QUALITY MONITORING PACKAGE

Parameter or Circuit	Procedure
Bipolar regulated power supply	Using a 4 1/2-digit digital volt meter, the positive and negative outputs of regulator are calibrated to 8.000 V d.c. ± 0.001 V d.c.
Ground current regulator	Using a 4 1/2-digit digital volt meter, the voltage between the two white test points is checked. The voltage should be 0.000 V d.c. for proper function.
Temperature Analog zero	Using an ice water bath on the temperature sensor with constant stirring and monitored by laboratory thermometer, the zero pot is adjusted to yield an electrical analog (0.100 V d.c. = 1.0°C) of the thermometer indication.
gain	An ambient temperature water bath monitored by a laboratory thermometer is applied to the temperature sensor. The gain pot is adjusted to yield an electrical analog (0.100 V d.c. = 1.0°C) of the thermometer indication.
Conductivity Analog zero	With the conductivity sensor clean and dry, the zero pot is adjusted to yield an electrical analog of zero for conductivity 1.000 V d.c. = 1,000 μmhos.
gain	With the buffer box provided by the manufacturer set to 2,400 μmho position and the wire looped through the sensor, the gain pot is adjusted to yield 2,400 μmho analog or 2.400 V d.c.
Depth Analog zero	With the sensor connected, but not in water, the zero pot is set to yield 0.000 V d.c. output.
gain	With shunt points shorted on depth board the gain pot is adjusted to yield the shunt value for that serial number transducer from calibration sheet.
Turbidity	The windows are cleaned, the lamp current set to 60.00 and the full scale air calibration is set to 96.00%; then, with the optical system occluded with a card, the zero is checked.

(continued)

TABLE 2. (Continued)

Parameter or Circuit	Procedure
Dissolved oxygen	
zero	The sensor is bathed in a stream of dry nitrogen or dry helium and the zero pot is set to yield a zero analog on the sensor console.
gain	In ambient air, the gain pot is set to the O_2 saturation value at ambient temperature on the sensor console.
pH	
zero	With the sensor in a pH 7 buffer, the zero pot is adjusted to yield 7.00.
gain	Then with the sensor pH in a 10 buffer, the gain pot is adjusted to yield a pH 10.00 on the console display. With the sensor in pH 4 buffer, the gain adjustment is checked for pH 4 on the display.
Echo sounder	With the sensor in a 10'x4" water column (Appendix C) the speed of the motor is adjusted to yield blips at exactly 10 foot intervals after the motor is lubricated. The oscillator and electronics alignment are checked by seeing at least 10 blips at 10-foot intervals or to 100 ft in a 10 ft pipe.

TABLE 3. DAILY OPERATIONAL CHECKS OF THE IN-SITU SENSOR/SAMPLING PACKAGE

Equipment	Procedure
Strip chart recorders (4 ea)	With the input shorted, the zero control is set to position the pens to zero on the paper, for each recorder.
Static Inverter (output)	The inverter is turned-on, the winch brake is set, and the winch started slowly while the output voltage, frequency and current are monitored via the meters on the inverter. The inverter should deliver 10 amps to the winch without a voltage or frequency change.
Winch	After the inverter check, the winch drive is then checked in both the deploy and recovery directions. The winch drum slip clutch tension is checked.
Pump	The sampling pump is checked for worn rollers and impeller, worn motor and pump bearings and hard starting of the pump motor (This is only accomplished at the evening check, except for the ease of starting).

SAMPLING CAPABILITIES

The airborne sampling system is totally integrated; the equipment has been custom-tailored to fit the interior contours of a UH-1H model "Huey" helicopter; thus the helicopter platform has become part of the system.

The helicopter has an operational period of about 2 hours at 100 knots (airspeed limited by floats), without auxiliary tanks. An accessory auxiliary tank can extend that period to about 3 hours.

It should be noted that 3 hours times 100 knots air speed does not necessarily equal 300 nautical miles of ground track, because of head winds or tail winds. Fuel consumption is cut in half when the aircraft is at flight idle during sampling. Travel time from the operations base to the first sampling site and the distance (or time) between sampling sites strongly influence the number of sites that can be covered between refuelings. Factors of lesser influence include the type of sampling, the number of samples per site and the depth of water at each site. Thus it is difficult to make any meaningful statement about the number of sites that can be sampled in any given time period. However, during the NES, the sampling extremes ranged from one site per refueling (far away from the base) to nine sites per refueling when the sites were close to one another, and to the operations base and the sites were shallow (less than 10 meters).

The crew required for normal sampling operations consists of a pilot and two sampling personnel. The aircraft can accommodate two additional sampling personnel or observers. The three sampling systems are identical except for the sizes of the winches and the maximum sampling-depth capabilities. Two systems can sample to a maximum depth of 80 meters (263 ft) and the third system can sample to a maximum depth of 172 meters (565 ft).

The system is capable of in-situ measurements of: temperature, conductivity, dissolved oxygen, pH and turbidity (Table 4).

The water-sample cabinet can hold 576 125-ml (4-oz) samples in storage racks. Additional samples may be stored in other locations within the air craft, as necessary. Water samples of any volume can be collected at a rate of 7 lpm from any depth up to the maximum. The sampling pump can be operated while the winch is retrieving the sampling assembly, in order to collect a depth-integrated sample of the water column. The total number of samples that can be collected is limited by the storage space in the aircraft. The water samples collected may be used for a variety of water quality analyses from water chemistry to phytoplankton analyses. If the pump and hose/cable

TABLE 4. SPECIFICATIONS OF THE IN-SITU WATER QUALITY MONITORING PACKAGE

Parameter	Range	Precision*
Conductivity	0 to 65,000 µmhos	± 10 µmhos
Temperature	-5 to 45°C	± 0.02°C
Depth	0 to 100 m	± 0.3 m
DO	0 to 20 mg/l	± 0.2 mg/l
pH	2 to 12 pH	± 0.05 pH
Turbidity	0 to 100% transmission	± 2% transmission

* From the manufacturer's specifications.

were replaced with a Teflon pump housing and Teflon hose in the hose/cable, the system would be satisfactory to sample water for pesticides.

The system has most commonly been used to sample in lakes and other non-flowing waters. However, it has also been used to collect surface data and water samples in rapidly flowing streams, e.g., some Atchafalaya study sites. In this case, the in-situ package was not lowered through the water column, because difficulties in maintaining orientation of the helicopter in flowing waters enhance the hazard of snagging the sensor package or fouling the pump system.

Bottom sediment samples can be collected with a small, hand-operated, clamshell-type dredge. More sophisticated sediment samplers have been used from this sampling platform, e.g., cores using a Pflegar Corer, but there is not sufficient room in the cabin to do this type of sampling without removal of the water quality sampling hardware. As we used it, the Pflegar Corer also required a cut-out in the floor of the craft and removal of the athwart-ship auxiliary fuel tank.

DISCUSSION

Originally, three identical, off-the-shelf, in-situ water-quality monitoring/sampling systems were procured. Throughout the 4 field years of NES, for an additional 2 field years on Atchafalaya Basin Water Management Study, and during other subsequent studies, the systems were constantly being modified to better fulfill our requirements.

Helicopters are unique and versatile sampling platforms, however, they do have certain limitations. Space and weight capacity for samples and equipment, and electrical power for sampling hardware are usually limited aboard a helicopter. Mechanical vibration is usually quite severe. Light-weight, compact sampling and measuring hardware helps to reduce the hardware load and maximize available working space for sampling personnel. Sample-storage containers that are designed to optimize otherwise unusable space are a considerable advantage. Safety considerations of personnel, sampling hardware and the craft itself are best fulfilled by securing all equipment and sample-storage containers during flight. Small, light-weight, overboard sensors and samplers increase the speed of sampling operations. During the first year the system was in use, when frequent clogging of the original pump impaired our sampling efforts, we considered changing to a "bottle type" water sampler. At that time we concluded that there was neither the space to carry five or six bottle samplers in the aircraft nor time to make the multiple casts at a single station required to sample from several different depths with a single bottle sampler. When sampling from a helicopter to maximum depths of about 170 meters, the pump-sampling system is the desirable technique. It is believed that the maximum depth that would be practical to sample with a pump-sampling system in a Huey is probably about 350 meters. Sampling from greater depths with a pumping system would require a larger winch than would be practical in this aircraft.

Electrical power is limited on helicopters and is usually 12 or 24 volts d.c. It is more efficient to operate the sampling hardware directly from the aircraft power, whenever possible, to minimize the amount of power transformed to other voltages. The exception to this is when a large amount of power is required remote from the craft, e.g., a submerged electric pump. The power dissipated in the wires becomes significant when the wires are long and small, or when the currents are high (greater than 1A). In this case the power should be converted to a.c. and transformed to some higher voltage. The remote equipment should be selected for high voltage, low current requirements. Certain types of equipment require 117 V a.c. power (e.g., drive motors in some strip chart recorders). With such equipment, an inverter must be used to convert aircraft power to 117 V a.c. 60 hertz. Some inverters have poor or non-existent filtering in the input circuit which results in the reflection of electrical noise back into the aircraft power bus. This powerline noise and other electrical noises indigenous to aircraft can mask the data signals in the measuring equipment and possibly lead to generation of erroneous data. Dissolved oxygen and pH sensors and circuitry are particularly susceptible to electrical noise interferences and ground loops. If multiple pieces of equipment are to be used in the water simultaneously, they may also exhibit some interaction with one another.

Vibration levels in aircraft, particularly rotor-winged craft, are high and potentially damaging to electronic hardware and water quality sensors, especially the very fragile pH electrodes. Shock-mounting of all stationary components and cushioned restraining cradles for on-board storage of all deployable systems will reduce vibration damage.

The sensor/sampling systems on the whole functioned quite well; however, they do require constant attention in terms of calibration and maintenance. The dissolved oxygen and pH sensors are those most vulnerable to damage and drift from abuse.

One problem, quite unique to helicopter water-sampling platforms was discovered. The downwash from the rotor blades of the helicopter physically disturbs the water's surface layers. A brief dye experiment conducted at Lake Mead (Figure 14) indicated the disturbance extended to at least 1 meter depth directly below the craft. The upper 20 to 50 centimeters move outward radially from the landing site and that water is replaced by upwelling water from below. While the full extent of this effect is not known, it is apparent that all structure in the upper meter of the water column is destroyed.

The helicopter has been demonstrated as a cost-effective sampling platform when many sites must be sampled and the travel time between sites is excessive in relation to the time required for actual sampling.

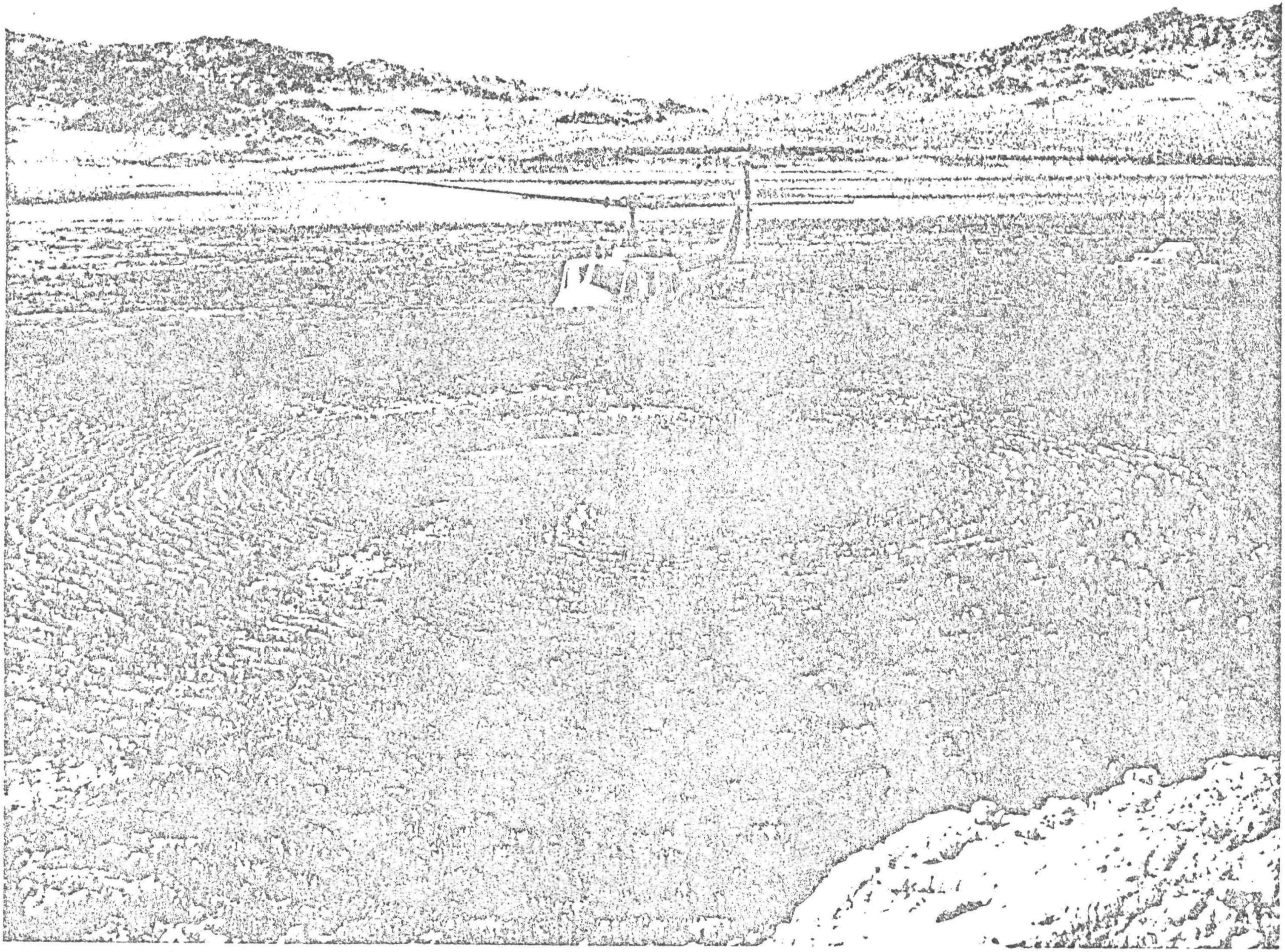


Figure 14 Dye Study of Helicopter Rotorwash-Turbulence Effects on Lake Mead.

APPENDIX A

THE DISSOLVED OXYGEN CIRCUIT

The dissolved oxygen sensor produced by Yellow Springs Instrument Company functions as a variable-current source when polarized with a 0.7 V d.c. potential; the current is directly proportional to both the partial pressure of the oxygen and the temperature of the membrane and the sensor assembly. The sensor current is converted to an analog voltage by the operational amplifier (op-amp) (AD 523 L) and the feed-back resistor network (560 K and 250 K trimpot). The sensor current and the output of the "current to voltage" transducer are zero in a zero mg/l oxygen environment. The op-amp output voltage, Vo, is calculated by Vo = -I x Rf.

The analog multiplier (AD 532 S) has differential inputs for both "X" and "Y" and its output voltage is $Vo = (X_1 - X_2)(Y_1 - Y_2)/10$. The output of the op-amp, a positive voltage, is connected to the negative "X" input of the multiplier. The positive "X" input is grounded. The temperature analog output (T), from the temperature board is connected to the positive "Y" input. The negative "Y" input is connected to a constant +3.25 V d.c. This voltage is developed by the adjustable voltage divider connected to pin 10 (-"Y" input). The voltage-temperature relationship is 0.1 V d.c. = 1.0°C. The algebraic representation of the complete circuit is DO (0.1 V = 1.0 mg/l) = -I x 0.67 (T - 3.25)/10. This is a linear approximation of the second degree polynomial $DO = 0.7945\ I/(0.0104\ T^2 + 0.2045\ T + 3.7879)$ that approximates the sensor performance between 0° and 25°C. The linear approximation was adjusted to minimize differences (±2%) from the polynomial in the temperature range of 6°C to 19°C.

The MC 1568 C is a voltage regulator circuit providing bipolar (+ & -) 15 V d.c. required for the multiplier. Other modules in the sensor package operate on the original bipolar (+ & -) regulated 8 V d.c. The voltage divider from the negative supply, the 33/K and 1.6/K resistors to ground, provides the polarizing voltage for the sensor.

Before calibrating the oxygen circuit, the temperature calibration should be assured. To calibrate the circuit and sensor combination, the following items capabilities are required:

> A 3½-digit digital voltmeter, a source of dry nitrogen or helium gas, water in the 10°C to 15°C range that is nearly saturated with oxygen, and the capacity for a Winkler titration for oxygen determination. The sensor is first bathed in a stream of the gas to exclude oxygen from the membrane. While this zero oxygen environment is maintained at the membrane, the 10 K trimpot

connected to pins 1, 4 and 5 of the op-amp (AD 523 L) is adjusted to yield 0.000 V d.c. at tp-1. Next the 20 K trimpot connected to pins 2, 5 and 9 of the multiplier (AD 523 S) is adjusted to yield 0.000 V d.c. at tp-2. At this time the sensor is removed from the zero oxygen environment. The 10 K trimpot connected to pin 10 of the multiplier is adjusted to yield +3.250 V d.c. at tp-3. A sample of the water to be used for the instrument calibration is then evaluated for oxygen concentration using a Winkler titration; the temperature and oxygen sensors are placed in the remaining water. The water is gently stirred while the temperature and oxygen sensors are allowed 2 minutes to reach equilibrium with the water. Once equilibrium is achieved, the 250-K trimpot in the "feedback" circuit of the op-amp (pins 2 and 6 of AD 523 L) is adjusted to yield an analog of the dissolved oxygen concentration, found from the Winkler titration, at tp-2 (+0.1 V d.c. per 1 mg/l of oxygen). This process may be repeated to verify stability.

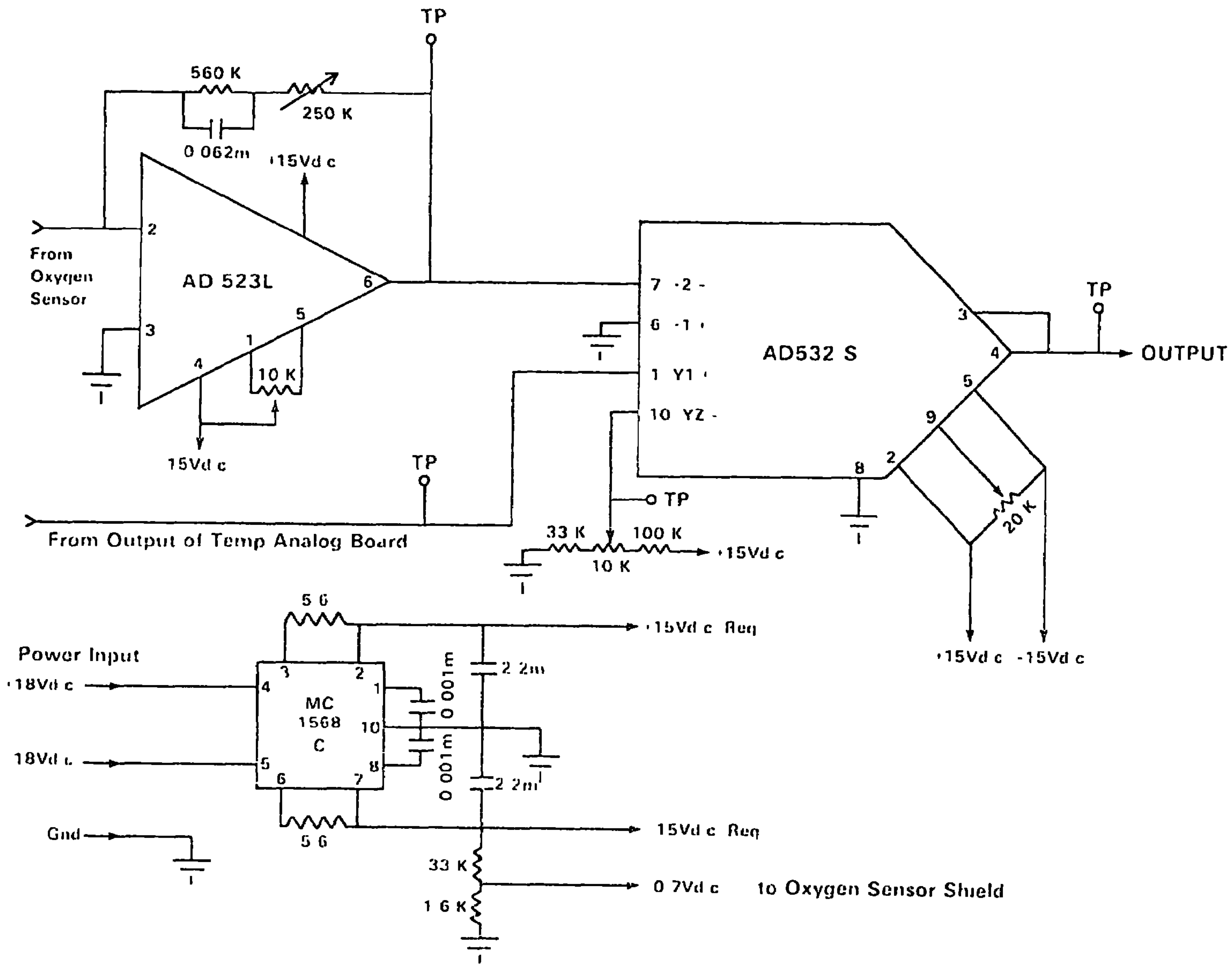


Figure A-1. The dissolved oxygen circuit.

APPENDIX B

THE DIFFERENTIAL-INPUT pH-MEASURING CIRCUIT

The glass pH-measuring electrode and the Lazaran reference electrode function as a variable voltage source with an extremely high internal impedance (10^{+6} to 10^{+8} ohms). The output potential of the pair is zero at pH 7.68; the voltage analog from the electrode pair is 59.2 millivolts per pH unit. The temperature factor is 0.77 millivolts per degree to be subtracted above 25°C and added below 25°C.

The high impedance of the sensor pair requires the use of an amplifier with a high-input-impedance. To minimize system susceptibility to electrical noise and "ground loops," a high-input-impedance differential-buffer-amplifier (HA2005) was placed in the sensor mounting block. The input leads from the electrodes to the amplifier were about 1 cm long. The buffer amplifier has an input impedance of 10^{12} ohms and unity voltage gain. The 100 K trimpot connected to terminals 1 and 5 is the balance control and is adjusted for zero output in a pH 7.00 buffer. The differential output of the buffer drives the differential input of the instrumentation amplifier (AD 520 K). The gain of the device is controlled by the ratio of the 100 K resistor (pins 9 and 11) and the 47 K resistor and 10 K trimpot (pins 5 and 7). This gain function raises the analog from 59.2 millivolts per pH unit to 100 millivolts per pH unit. The offset terminal (pin 12) is utilized to shift the sensor zero output voltage corresponding to a pH 7, to -0.7 volts or the 100 millivolt per pH unit analog. The negative output is inverted by the following stage.

The output inverter stage (AD 741 K op-amp) accomplishes the temperature correction of the sensor. The temperature correction is a linear additive correction. The 0.77 mv/1°C at the sensor is the equivilant of 0.013 pH units per degree. The zero point on the temperature correction curve is 25°C, and 0.013 pH units is added per degree celsius below 25°C. The 1 K and two 76.8 K resistors at the inverting input of the op-amp comprise a three-input adder.

The 1,000-ohm "feedback" resistor from the output to the inverting input provides unity gain when the temperature is 25°C. The 100 K trimpot is set to -2.5 V d.c., corresponding to -25°C, which is added through 76.8 K resistors to the positive temperature analog. As the temperature analog falls below 25°C (+2.5 V d.c.), the analog temperature difference from 25°C is added to the pH analog at the rate of 1,000/76.8 K per degree celsius (0.013 pH/1°C).

This circuit is powered by the original regulated 8-volt supply.

Before calibrating pH, the temperature calibration should be assured. To calibrate the circuit, the following items and capabilities are required: two celsius thermometers with 0.2 degree or finer graduations which include 25°C in their range, a 3 1/2-digit digital voltmeter, pH 7 and 10 buffer solutions, a 100-ml beaker, a 250-ml beaker, a 500-ml beaker, and a source of 25°C water for temperature control.

The pH 7 buffer is put in the 250-ml beaker which, in turn is put in a water bath in the 500-ml beaker at 25°C. When the buffer is 25°C, the pH electrode assembly is immersed in the buffer and the 100 K balance trimpot is adjusted to yield 0.000 V d.c. between TP-1 and TP-2. All following voltage measurements are made referenced to TP-7 (ground). The 10 K offset trimpot is adjusted to yield +0.700 V d.c. at TP-3 and the 500-ohm zero trimpot is adjusted to yield 0.700 V d.c. at TP-4. The 100 K temp-cal-comp trimpot is adjusted to yield -2.5 V d.c. at TP-5. With 25°C water on the temperature sensor, the 10 K zero trimpot is adjusted to yield +0.700 V d.c. at TP-6. The pH electrodes are thoroughly rinsed and immersed in pH 10.18 buffer at 25°C, and the 10 K gain trimpot is adjusted to yield +1.018 V d.c. at TP-6.

The process should be repeated to verify linearity. If the expected pH to be measured is below pH 7 the pH 10 buffer should be replaced with pH 4 buffer and the gain trimpot adjusted to yield +0.400 V d.c. at TP-6.

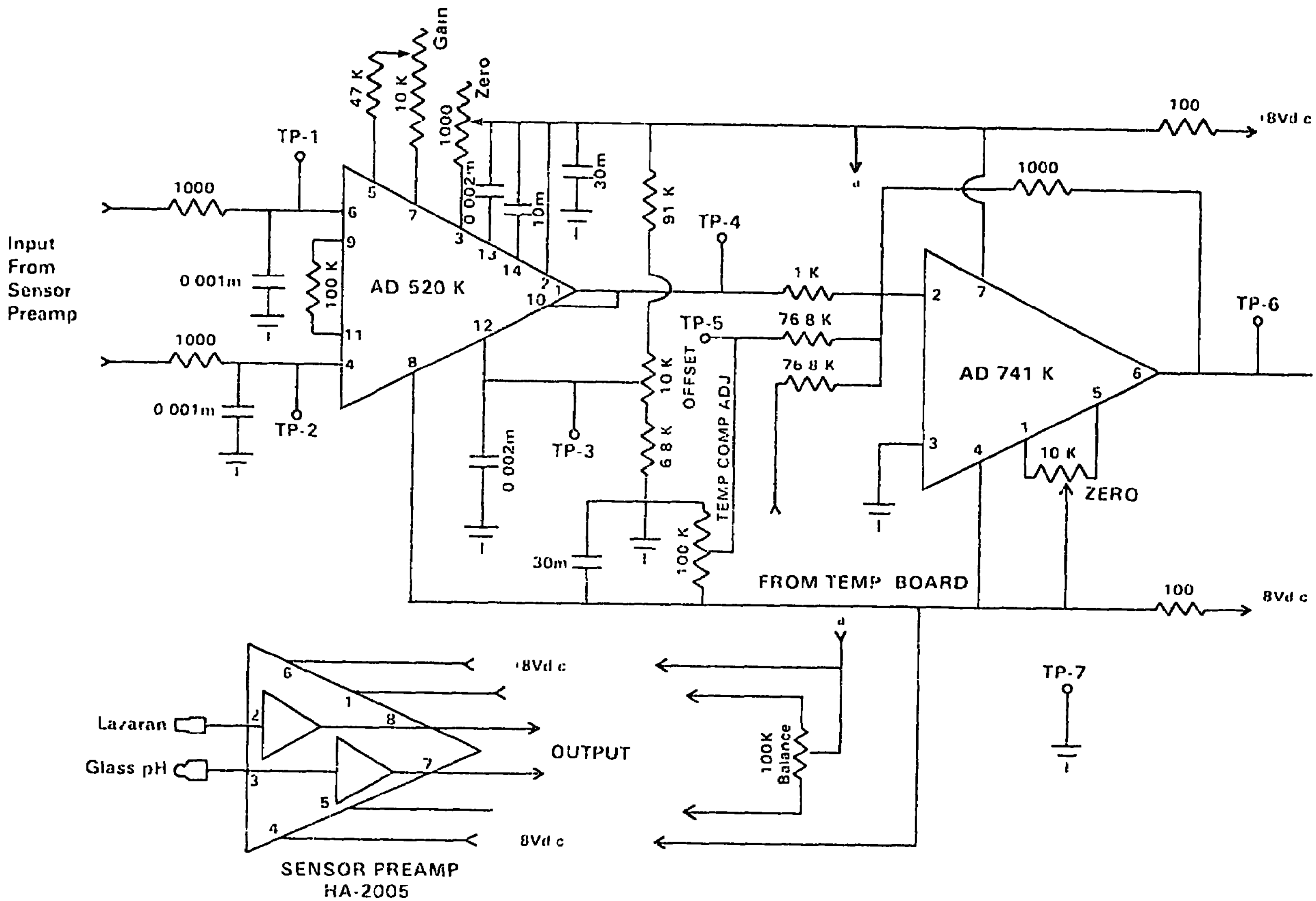


Figure B-1. The differential-input and pH-measuring circuit.

APPENDIX C

WATER COLUMN FOR CALIBRATION OF ECHO SOUNDER

The calibration of the echo sounder posed a special problem. A water column was necessary for depth calibration and for electronic alignment of the driver and receiver circuitry. An artificial water column was fabricated from a length of 4" ABS sewer pipe, a pipe cap and a plastic trash can. A piece of 1/2-inch thick plastic was mounted at a 45° angle in the trash can as a reflector. The 4-inch ABS pipe was cut to a length such that the path length from the transducer to the 45° reflector and down the pipe to the pipe cap was exactly 10 feet. The trash can/pipe assembly is placed under the transducer with the pipe lying on the ground. The pipe and trash can are filled with water to cover the transducer. Electronic alignment of the circuitry is accomplished by adjusting for the greatest number of reflections, or with an oscilloscope. Calibration is accomplished by adjusting the speed of the revolving disk.

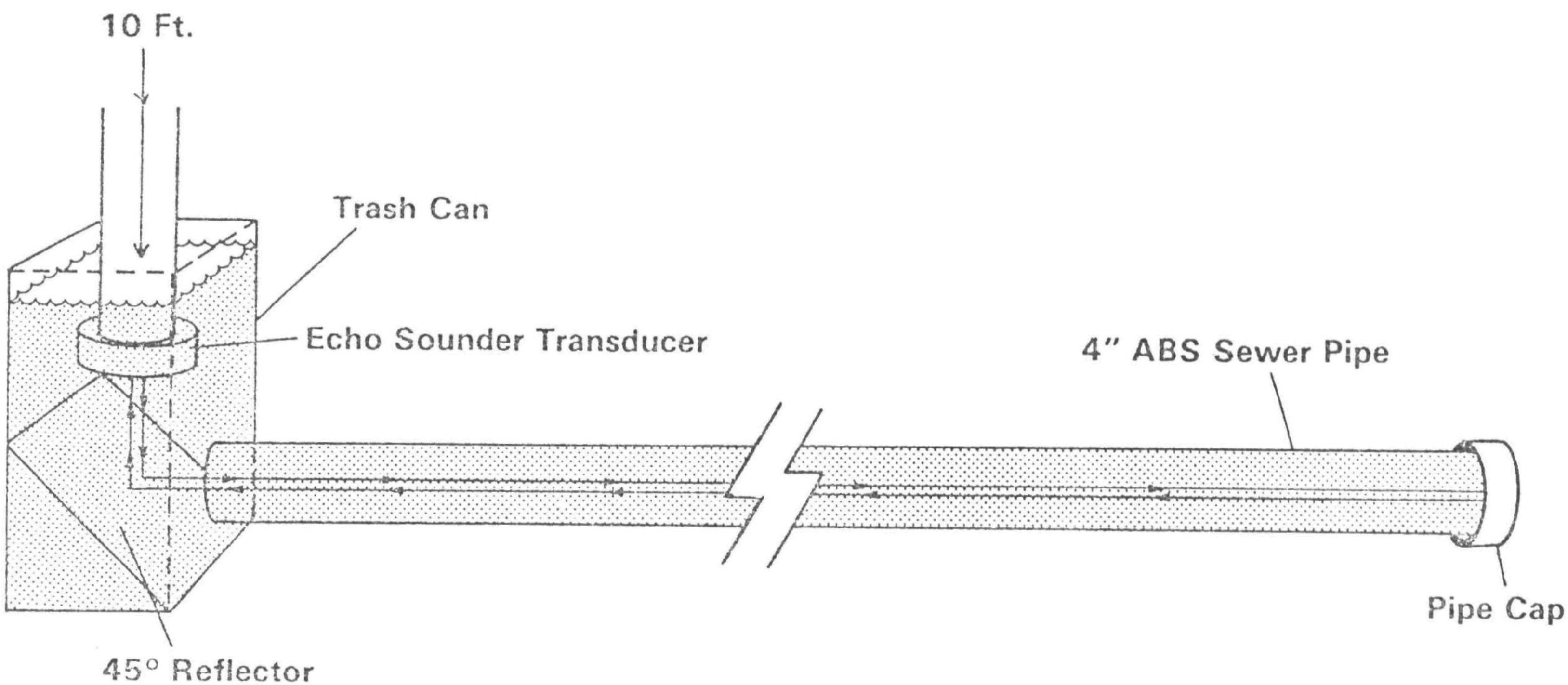


Figure C-1. Ten-foot water column for calibration of the echo sounder on the helicopter but out of the water.

APPENDIX D

CALIBRATION BUFFER BOARD

Calibration of the original sensor package required disassembly of the pressure case to access the calibration controls. A five-channel analog buffer was designed and installed on one system to evaluate the performance of the circuit. Evaluation was never completed. The circuit of a single buffer amplifier is shown. The concept is to be able to offset the zero point ±0.5 volts and to vary the gain from 0.6 to 1.5. The five-channel buffer board was mounted on the read-out console with the screwdriver-settable zero and gain controls accessible from the front of the console. Power for the buffers was taken from the read-out console. This circuit should reduce the need to open the pressure case for calibration to a rate of only one calibration in four.

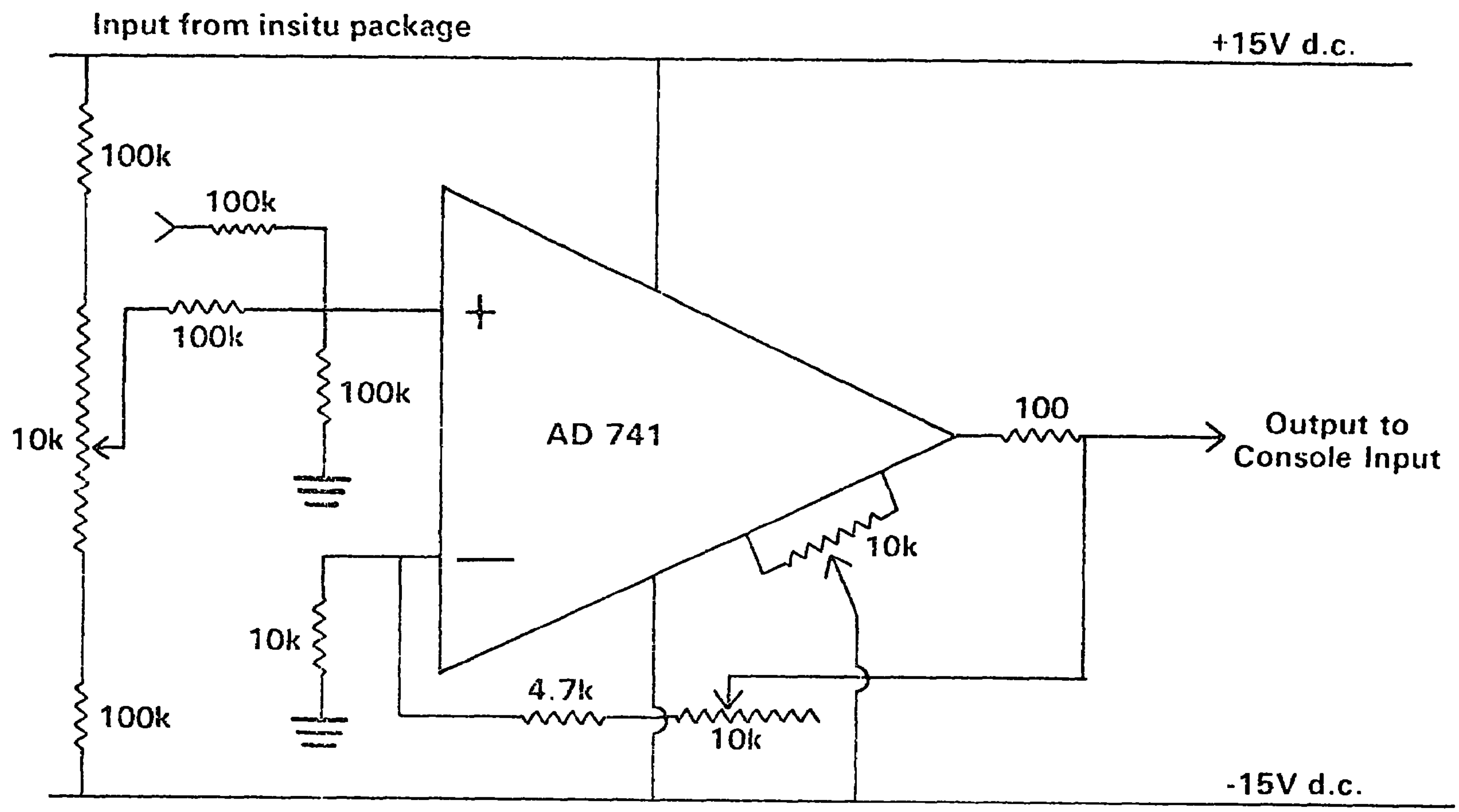


Figure D-1. Schematic of one channel of calibration buffer amplifier.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report describes the helicopter water quality sampling system developed for use by the National Eutrophication Survey and subsequently used in support of other water quality projects. It also describes the salient problems associated with the use of a helicopter as a sampling platform and the modifications made in the system to fulfill our needs. This system is useful to other groups involved in sampling large numbers of water quality sites distributed over large or inaccessible areas.

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