Precise Water Temperature Measurement at Remote Field Sites

C. CLARK, S.F. DALY AND J. RAND
U.S. Army Cold Regions Research and Engineering Laboratory
72 Lyme Road
Hanover, New Hampshire 03755-1290, U.S.A.

ABSTRACT

An instrument developed at USACRREL to precisely measure water temperature at field sites consists of a temperature probe, connecting cabling and an interface box; it is rugged, highly accurate and easily deployable. The probes contain individually calibrated thermistors, whose resistance is determined by voltage measurements of a half-bridge circuit in the interface box. A precision 10-kΩ resistor in the interface box helps assess the accuracy of the voltage measurements, and provides a means of correcting the thermistor readings. Generally, the temperature probe is connected to a Data Collection Platform (DCP) and the readings are transmitted through a Geostationary Operational Environmental Satellite (GOES) to a downlink. Such probes are installed on the St. Clair, the St. Lawrence, the Ohio, the Missouri and the Illinois rivers. They are adaptable to a variety of site conditions, and can be strapped to vertical walls or deployed horizontally through gage well connecting pipes.

INTRODUCTION

Water and air temperature measurements are required at remote sites for many reasons, including forecasting ice, monitoring environmental conditions and providing baseline data. Generally, the measurements are made by a data logger or a Data Collection Platform (DCP), which then transmits the data via a Geostationary Operational Environmental Satellite (GOES) to a centrally located downlink. To accurately and reliably measure water temperature, the water temperature measurement system must be rugged, easily adaptable to a variety of sites, easily replaceable, and self correcting for errors that may be introduced in sampling and transmitting.

The water temperature measurement system developed by USACRREL fulfills all these requirements. It uses thermistors that are protected in a rugged housing. The housing, termed a water temperature probe, can be deployed vertically, such as on dam and lock walls, or horizontally, by "snaking" it through pipes such as the inlets of water level gage stilling wells. The system contains a "precision" reference resistor, which is sampled along with the thermistors. Sampling the reference resistor allows the water temperature measurements to be corrected and also provides a means of compensating for bias, nonlinearities and random errors in the DCP or data loggers, which generally are the largest sources of error. It also allows the performance of the DCP or data logger to be monitored.

DESCRIPTION OF TEMPERATURE MEASUREMENT SYSTEM

The thermistors used for measuring water and air temperature are small electronic components made of a semiconductor material whose electrical resistance changes with change in temperature. During the manufacturing process, the properties of the thermistor can be controlled so that small changes in temperature produce relatively large changes in resistance. The relationship of the thermistor resistance and temperature is highly nonlinear but well known, and the exact response of thermistors can be determined through individual calibration.

The thermistors themselves are relatively fragile and must be protected. As mentioned before, the probes are designed for either vertical or horizontal deployment.

Vertical Deployment

The vertical water temperature measurement system consists of a water temperature probe, a probe support pipe with probe adaptor, a connecting cable and an interface box.

The vertical water temperature probe is a 3-ft (0.91-m) stainless steel tube with a 1-in. (25.4-mm) outside diameter (Fig. 1). The lower tip of the probe is nylon and contains two thermistors. A cable grip attaches the probe to the cable

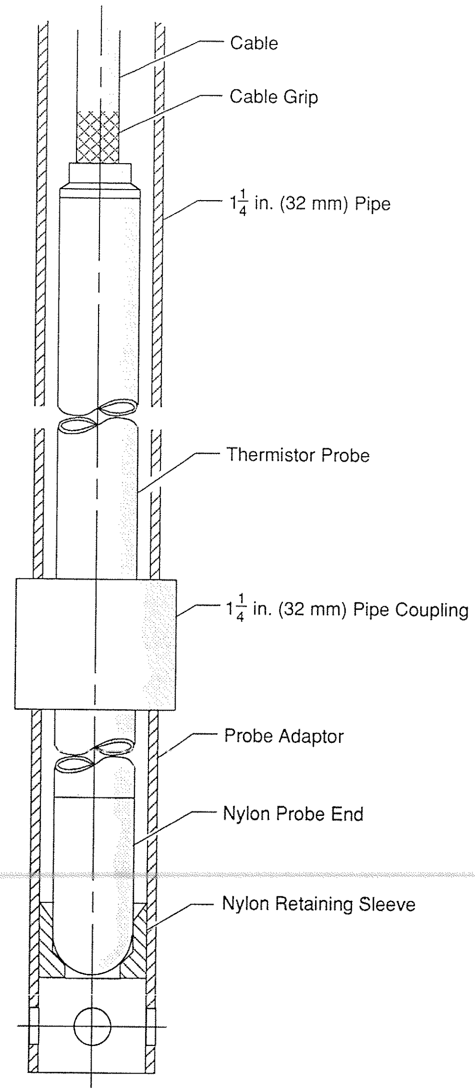

Figure 1. Vertical water temperature probe.

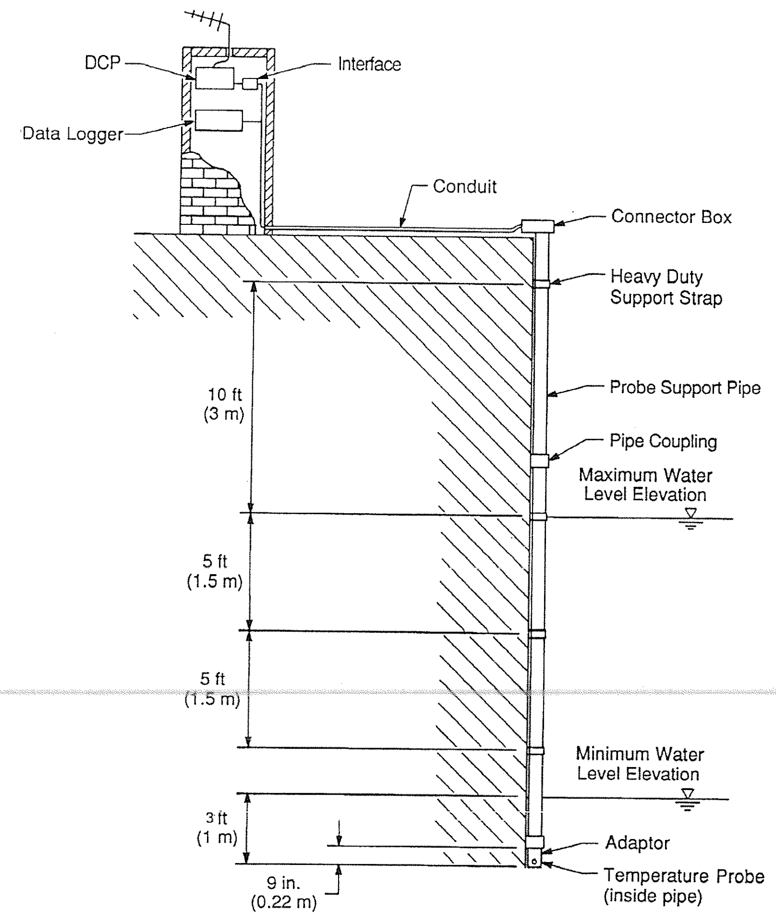

Figure 2. Measurement system.

at its upper end. The probe is deployed by being dropped down the probe support pipe so that it seats in the probe adapter (Fig. 2). The probe is designed to protect the thermistors from being hit by debris, while allowing them to directly contact the water, and to be conveniently removable for repair or replacement. The cable attached to the probe has two purposes: it provides the electrical connection to the thermistor and it is used to place or remove the probe.

The probe support pipe protects the probe and cable from debris or ice, holds it, and provides an easy way for it to be installed and removed. At the lower end of the probe support pipe is the probe adaptor, which has one Teflon or nylon ring that cradles the probe and holds it in position. The probe support pipe is 1.25-in. (32 mm) schedule 80 galvanized steel pipe with couplings.

Horizontal Deployment

The horizontal water temperature measurement system consists of a horizontal water temperature probe, a connecting cable and an interface box. The water temperature probe (Fig. 3) is designed to be "snaked" through horizontal pipes or conduits, such as those providing an inlet to stilling wells in which water level measurements are made, where it will extend slightly beyond the end of the inlet pipe. The probe is an aluminum cylinder, 5 in. (127 mm) long and $^{3}/_{4}$ in. (19.05 mm) in diameter. The probe generally houses two thermistors. The cable is gel-filled, direct-burial, two-pair 22 AWG, with a copper "gopher shield." The cable is relatively stiff and can be easily fed through horizontal pipes.

Interface Boxes

As DCPs typically measure only voltages as analog signals, a voltage divider circuit is necessary to serve as an interface between the thermistors and the DCP (Fig. 4). The nominal switched 12-V dc available from the DCP is used to power the voltage divider circuitry. This voltage is first passed through a 10-kΩ resistor to supply approximately 1.2 mA to a diode. The diode is conducting, and the voltage difference across its junction is the excitation voltage

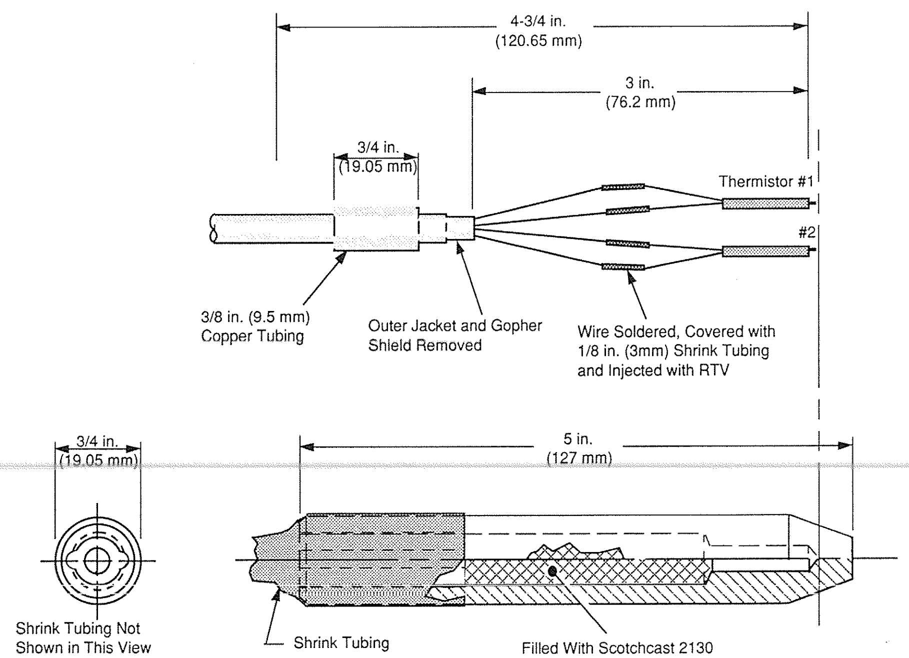

Figure 3. Horizontal water temperature probe.

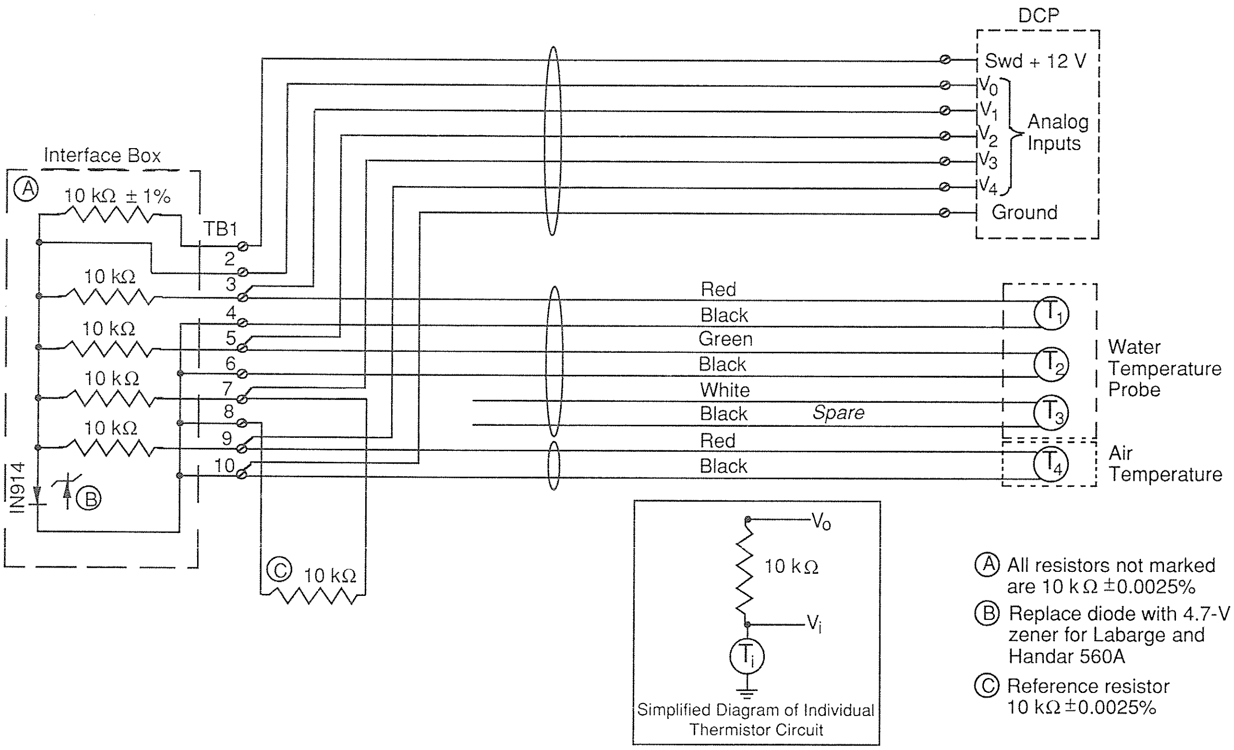

Figure 4. Interface box schematic.

applied to the thermistor circuit V_0. Each thermistor circuit consists of a "dropping" resistor and a thermistor in series. The dropping resistor is a precision, wire-wound 10-kΩ resistor with a nominal accuracy of ±0.0025% and a resistance stability of 0.0005% between –55 and 12.5°C. The voltages measured by the DCP are the excitation voltage V_0 and the voltage across each thermistor V_t. The thermistor resistance R_t is calculated by

$$R_t = R_0 \left[\frac{V_t}{V_0 - V_t} \right] \tag{1}$$

where R_0 is the resistance of the dropping resistor. The resistance of the thermistor is then entered into the Steinhart–Hart equation to calculate the thermistor temperature. The reference resistors used at all sites were identical to the dropping resistors described above. Reference resistors occupy the same position in the voltage divider circuit as a thermistor, and the resistance of the reference resistor is also calculated using eq 1.

ACCURACY

The accuracy of the water-temperature measurement system was assessed by monitoring the reference resistor measurements at 12 sites during January 1988. A complete description of the monitoring program is available elsewhere (Daly et al. 1989). This monitoring showed that a large bias existed in some of the DCPs. This bias was traced to leakage currents from the DCP sampling circuitry.

Given the existence of this leakage current, the transmitted measurements can be corrected by including a reference resistor in each interface. The resistance of each thermistor can be calculated (assuming the same offset current on each channel) by the formula

$$R_t = (10{,}000)\,(V_t)/(2V_r - V_t) \tag{2}$$

where R_t is the true resistance of the thermistor, V_t is the voltage measured across the thermistor, and V_r is the voltage measured across the reference resistor. The true thermistor resistance is then a function of the voltages across the thermistor and the reference resistor.

FIELD EXPERIENCE

The experience that we have gained at the 26 sites where the system has been installed (Table 1) has shown us that the problems with the water temperature measurements are largely a result of faulty DCP performance. Problems can also arise because of thermistor drift and difficulties with the water temperature probe support system.

Table 1. Water temperature stations.

	Name	*DCP type*	*River*	*Date installed*
(01)	Allegheny no.4 L&D	Handar 560	Allegheny	26 Sept 88
(02)	Monongahela no.4 L&D	Handar 560	Monongahela	28 Sept 88
(03)	Emsworth L&D	Handar 560	Ohio	26 Sept 88
(04)	Montgomery L&D	Handar 560	Ohio	27 Sept 88
(05)	New Cumberland L&D	Handar 570	Ohio	27 Sept 88
(06)	Hannibal L&D	Handar 570	Ohio	29 Sept 88
(07)	Racine L&D	Handar 570	Ohio	2 Oct 88
(08)	Meldahl L&D	Handar 570	Ohio	2 Oct 88
(09)	Markland L&D	Handar 560	Ohio	22 Aug 89
(10)	McAlpine L&D	Handar 560	Ohio	10 Mar 88
(11)	Cannelton L&D	Handar 560	Ohio	14 Jan 87
(12)	Starved Rock L&D	Sutron	Illinois	31 July 89
(13)	Eisenhower Lock	Synergetics	St. Lawrence	25 Sept 89
(14)	Ogdensburg, N.Y.	Synergetics	St. Lawrence	26 Sept 89
(15)	Alexandria Bay, N.Y.	Synergetics	St. Lawrence	28 Sept 89
(16)	Cape Vincent, N.Y.	Synergetics	St. Lawrence	27 Sept 89
(17)	Dunn Paper, Mich.	Synergetics	St. Clair	30 Mar 89
(18)	Algonac, Mich.	Handar 560	St. Clair	25 Sept 90
(19)	Gavins Point Dam	Sutron	Missouri	Sept 90
(20)	Ponca, Neb.	Sutron	Missouri	Sept 90
(21)	Sioux City, Iowa	Sutron	Missouri	18 Sept 90
(22)	Omaha, Neb.	Sutron	Missouri	20 Dec 89
(23)	Nebraska City, Neb.	Sutron	Missouri	29 Nov 90
(24)	Rouseville, Pa.	Handar	Oil Creek	18 Mar 91
(25)	Pierre, S.D.	HP Datalogger	Missouri	15 Nov 86
(26)	Salmon, Idaho (3)	HP Datalogger	Salmon	2 Dec 90

As mentioned previously, DCPs can often show a bias in their sampling results. We can account for this by sampling a known reference resistor as described above. DCP performance reliability, as indicated by operational time, cannot be easily measured. Generally, new model DCPs, when properly maintained and regularly visited, will have a high degree of reliability. The DCP must also have sufficient resolution to provide an accurate reading. As a minimum, the DCP should have a 12-bit resolution.

The electrical insulation around the thermistors, and the wire connections of the thermistors, can degrade with time if improper techniques are used. This will manifest itself by a slow "drift" of thermistor readings. To counter this, we now totally encapsulate the thermistors in the water-temperature probe, i.e., the thermistors are "potted" in the probes. This provides long-lasting protection for the thermistors, but it is not possible to remove and reuse them after they have been placed in the probes.

Placing the thermistors in the probes reduces their response time, but does not affect their accuracy. As a typical sampling rate is once an hour, the reduced response time does not noticeably affect the water temperature measurement.

Several probes have been damaged by floating debris. At two sites on the Ohio River the probe support pipes were sheared off. On the St. Clair River, the probe support pipe was bent by ice, but it was still possible to remove the probe and reuse it. Generally, if the probe support pipe is carefully placed and supported so that it is relatively well protected from debris, the life of the probe will be indefinite. However, measurement in flowing water provides the most representative results, so there always exists a conflict between protecting the probe and obtaining the best measurement.

CONCLUSION

The USACRREL remote water temperature measurement system provides accurate information if the transmitted data are carefully assessed and systematic errors are corrected. This system is currently operating at 26 remote sites. We are continuously looking for ways to improve the system's performance.

ACKNOWLEDGMENTS

The authors acknowledge the assistance they have received from Tim Pangburn, who aided us in the application of DCPs, James Morse, who was instrumental in the startup of the measurement system, Francis "Butch" Doyle, who aided in finding and correcting field problems, and the many people who assisted in field installation.

REFERENCE

Daly, C.F., C.H. Clark and T. Pangburn (1989) Accuracy and precision of GOES data collection platforms for temperature measurements. USA Cold Regions Research and Engineering Laboratory, Special Report 89-37.