

Laboratory Evaluation of the Pressure Water Level Data Logger Manufactured by Infinities USA, Inc.—Results of Pressure and Temperature Tests

Open-File Report 2015–1049

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By Mark V. Carnley, Allegiance Consulting, Inc., contractor to the
U.S. Geological Survey

Work performed under USGS contract G14PC00006

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**U.S. Department of the Interior
U.S. Geological Survey**

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Abstract

The Pressure Water Level Data Logger manufactured by Infinities USA, Inc., was evaluated by the U.S. Geological Survey (USGS) Hydrologic Instrumentation Facility for conformance with the manufacturer's stated accuracy specifications for measuring pressure throughout the device's operating temperature range and with the USGS accuracy requirements for water-level measurements. The Pressure Water Level Data Logger (Infinities Logger) is a submersible, sealed, water-level sensing device with an operating pressure range of 0 to 11.5 feet of water over a temperature range of -18 to 49 degrees Celsius. For the pressure range tested, the manufacturer's accuracy specification of 0.1 percent of full scale pressure equals an accuracy of ± 0.138 inch of water. Three Infinities Loggers were evaluated, and the testing procedures followed and results obtained are described in this report. On the basis of the test results, the device is poorly compensated for temperature. For the three Infinities Loggers, the mean pressure differences varied from -4.04 to 5.32 inches of water and were not within the manufacturer's accuracy specification for pressure measurements made within the temperature-compensated range. The device did not meet the manufacturer's stated accuracy specifications for pressure within its temperature-compensated operating range of -18 to 49 degrees Celsius or the USGS accuracy requirements of no more than 0.12 inch of water (0.01 foot of water) or 0.10 percent of reading, whichever is larger. The USGS accuracy requirements are routinely examined and reported when instruments are evaluated at the Hydrologic Instrumentation Facility. The estimated combined measurement uncertainty for the pressure cycling test was ± 0.139 inch of water, and for temperature, the cycling test was ± 0.127 inch of water for the three Infinities Loggers.

Introduction

The U.S. Geological Survey (USGS) Hydrologic Instrumentation Facility (HIF) evaluates the performance of instruments and equipment that are used to measure hydrologic conditions. These devices are used to measure properties needed to quantify streamflow (such as river stage, water velocity, or water discharge), to monitor groundwater levels, or to measure water quality in a variety of field settings. In addition, the HIF evaluates the performance of instruments and equipment that are used to support the collection of hydrologic data. These devices include data loggers and recorders, radios for data telemetry, power supplies, solar panels, batteries, cableway and bridge measuring equipment, and water-quality sampling devices. The performance of these devices is evaluated in a variety of ways. The primary factors evaluated are

- the manufacturer's stated specifications for accuracy and resolution;
- the equipment's operation within relevant USGS accuracy requirements;
- the ability of the device to operate under a wide range of environmental conditions at remote, unmanned field stations;
- the power source and power consumption; and
- the compatibility with existing USGS field hydrologic data-collection infrastructure and equipment.

The evaluations may involve extended operation in one or more field locations or may employ the use of testing chambers designed to reproduce a range of environmental conditions, or both. Instrument and equipment evaluations are done primarily to determine if particular devices would be suitable for use by USGS personnel for hydrologic data collection.

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Purpose and Scope

This report describes the procedures followed and the results obtained from the pressure sensor evaluation testing of a commercially available, water-level measuring device—the Pressure Water Level Data Logger manufactured by Infinities USA, Inc. (hereafter referred to as Infinities Logger). The Infinities Logger has a pressure range of 5 pounds per square inch gage (psig) or 11.5 feet of water.

Description of the Infinities Pressure Water Level Data Logger

The Infinities Logger (fig. 1) includes a vented gage, submersible-pressure sensor enclosed in a 1.25-inch Schedule 40 (polyvinyl chloride) PVC housing, 25 feet of polyethylene cable, and a data logger enclosed in a 4-inch Schedule 40 PVC male adapter. The Infinities Logger is a submersible, sealed, water-level sensing device with an operating pressure range of 0 to 11.5 feet of water over a temperature range of -18 to 49 degrees Celsius ($^{\circ}\text{C}$). This pressure, measured in pounds per square inch (psi), can be converted into feet of water and can be used to continuously measure water level in a stream or well. For a detailed explanation of types of pressure measurements and sensors, see Freeman and others (2004). The data logger housing will fit inside a 4-inch well casing and contains four AA 1.5-volt direct current user-replaceable batteries, internal hardware, and a communication serial port inside a sealed compartment. The polyethylene cable includes the power and communication cables and an atmospheric vent tube for the sensor. The Infinities Logger has a tubular container filled with color-indicating desiccant attached to the data logger vent to protect the pressure sensor and electronics from moisture caused by condensation. The Infinities Loggers evaluated for this report came with a 4- to 3-inch Schedule 40 PVC reducing fitting installed for use with a 3-inch Schedule 40 PVC pipe. Selected manufacturer's specifications for the device are listed in table 1.



Figure 1. Infinities USA, Inc., submersible pressure water level data logger water-level sensor.

Table 1. Manufacturer’s specifications for the Infinities Pressure Water Level Data Logger sensing device.

[lbs, pounds; ±, plus or minus; °C, degrees Celsius]

Feature	Specification
Housing dimensions	Sensor (2.18 inches in diameter x 11.12 inches in length) Logger (4 inches in diameter x 6.34 inches in length)
Housing material	Polyvinyl chloride (PVC) plastic, Schedule 40
Weight	Sensor (1.5 lbs); Total with Logger and 25 feet cable (6.5 lbs)
Pressure sensor reading	Vented gage
Pressure sensor type	Piezoresistive, strain gage
Pressure units	Pounds per square inch vented gage (psig)
Water-level measurement units	Inches
Pressure sensor accuracy	±0.1 percent full scale
Pressure sensor resolution	0.01 inch
Pressure sensor range	0 to 11.5 feet of water (0 to 5 psig)
Pressure-compensated temperature range	-18 to 49 °C
Operating temperature range	-18 to 49 °C

Proprietary software, Infinities Data Logger Series PC Transfer Software, from the manufacturer is needed to communicate with the device using either a Windows personal computer or the optional Hewlett-Packard (HP) 48GX pocket calculator (fig. 2). A serial cable and null modem adapter are necessary to establish communications. The software (fig. 3) is used to initialize the Infinities Logger, configure it for long-term unattended data logging, and access its serial number. The serial number is not inscribed on the outside of the device. The software is also used to retrieve the data from the logger. The data can be exported as comma-separated values (fig. 4) and imported into Excel for data analysis. Figure 5 shows two field installations of the Infinities Logger in a Louisiana wetland.



Figure 2. Optional HP48GX calculator/computer.

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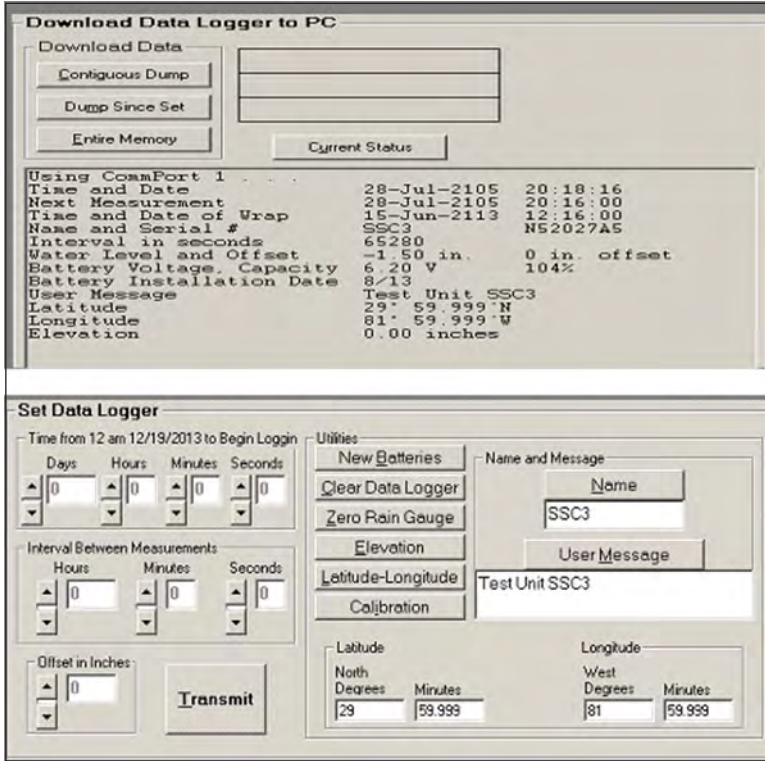


Figure 3. Infinities data logger series PC transfer software examples.

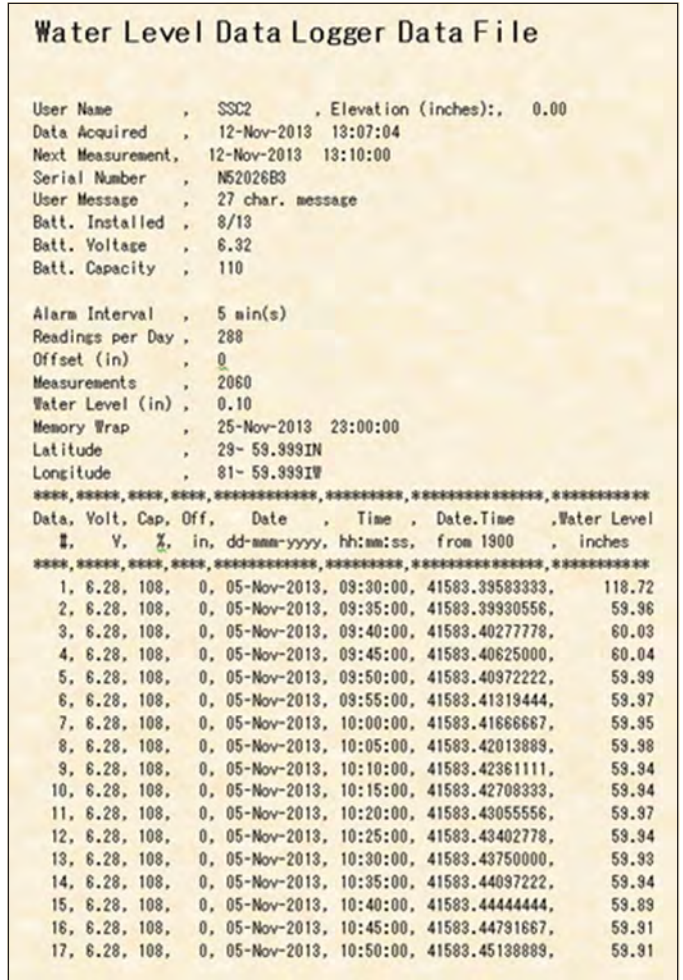


Figure 4. Infinities water level logger data file example.



Figure 5. Infinities water level logger in place.

The Infinities Logger measures and records the water level relative to an arbitrary elevation reference that is selected by the user and called a Zero-Mark by the software. The Infinities Logger will record water-level data referenced to the Zero-Mark, typically either the site elevation or sea level. For example, if the ground surface is the elevation reference Zero-Mark and the pressure sensor is 80 inches below the ground surface, the sensor reading will be negative 80 inches. The negative number denotes the sensor is below the arbitrary elevation reference, which is the ground surface.

Methods

Three Infinities Loggers with a range of 11.5 feet of water were evaluated: serial numbers N52027A5, N52026B3, and N52025D8. The Infinities Loggers were evaluated by subjecting them to varying pressures and temperatures in an environmental test chamber (ESPEC¹ ESZ-3CA, serial no. 017947). The environmental test chamber is capable of achieving and accurately maintaining temperatures from -20 to 50 °C and is capable of achieving ± 1.0 °C accuracy. The temperature chamber is calibrated biennially and verified using National Institute of Standards and Technology (NIST) traceable standards. The Infinities Loggers were installed inside the environmental test chamber and connected with pressure fittings and tubing through a chamber port to a test manifold located outside the test chamber. The test manifold was connected to a pressure controller (Ruska² Model 7250xi, serial no. 68549) that used nitrogen gas to vary the pressure monitored by the Infinities Loggers. A Paroscientific³ Model PS-2 (serial no. 49293) gage pressure sensor was also installed inside the test chamber and connected to the test manifold. The PS-2 was used to monitor the pressure fittings and tubing for gas leaks that could compromise the integrity of the test. The pressure controller supplies gage pressure and is capable of achieving 0.003 percent accuracy. The pressure controller is calibrated biennially and verified using NIST-traceable standards. Operation of the environmental chamber and pressure controller and data collection from the chamber sensors and the Infinities Loggers under test were automated using custom software (LabVIEW⁴).

Two basic evaluations were performed. In the first evaluation, referred to as pressure cycling, the Infinities Loggers were subjected to pressures above ambient atmospheric pressure ranging from 0 to 11 feet of water at temperatures ranging from -18 to 49 °C (fig. 6). This test was performed primarily to evaluate the accuracy of the Infinities Loggers at multiple points over their operating temperature range when the pressure is changing relatively rapidly. During the pressure cycling evaluation, the Infinities Loggers were equilibrated to, and held at, a constant temperature while the pressure was varied in a stepwise fashion from 0 to 11 and back to 0 feet of water. The order in which the pressures were applied was 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 10, 9, 8, 7, 6, 5, 4, 3, 2, 1 and 0 feet of water. The entire pressure cycle was completed in about 2 hours and 30 minutes. When a pressure cycle was completed, the environmental chamber temperature was changed to a new value, and all test units were allowed to equilibrate to the new temperature. The transition between two temperature settings was accomplished in about 15 hours. The next pressure cycle was initiated approximately 2 hours after the new temperature was achieved in order to allow the Infinities Loggers to equilibrate to the new temperature, a time period commonly referred to as “soak time.”

In the second evaluation, referred to as temperature cycling, the Infinities Loggers were subjected to a series of temperatures at a constant pressure of 5 feet of water (fig. 7). This evaluation was designed to examine the stability and accuracy of the Infinities Loggers during substantial temperature variations across their entire operating temperature range. The temperatures experienced by the Infinities Loggers varied continuously between -18 and 49 °C, and three complete temperature cycles were completed over a 98-hour time period.

¹ESPEC North America, Inc.

²Ruska Instrument Corp.

³Paroscientific, Inc.

⁴System design software by National Instruments Corp.

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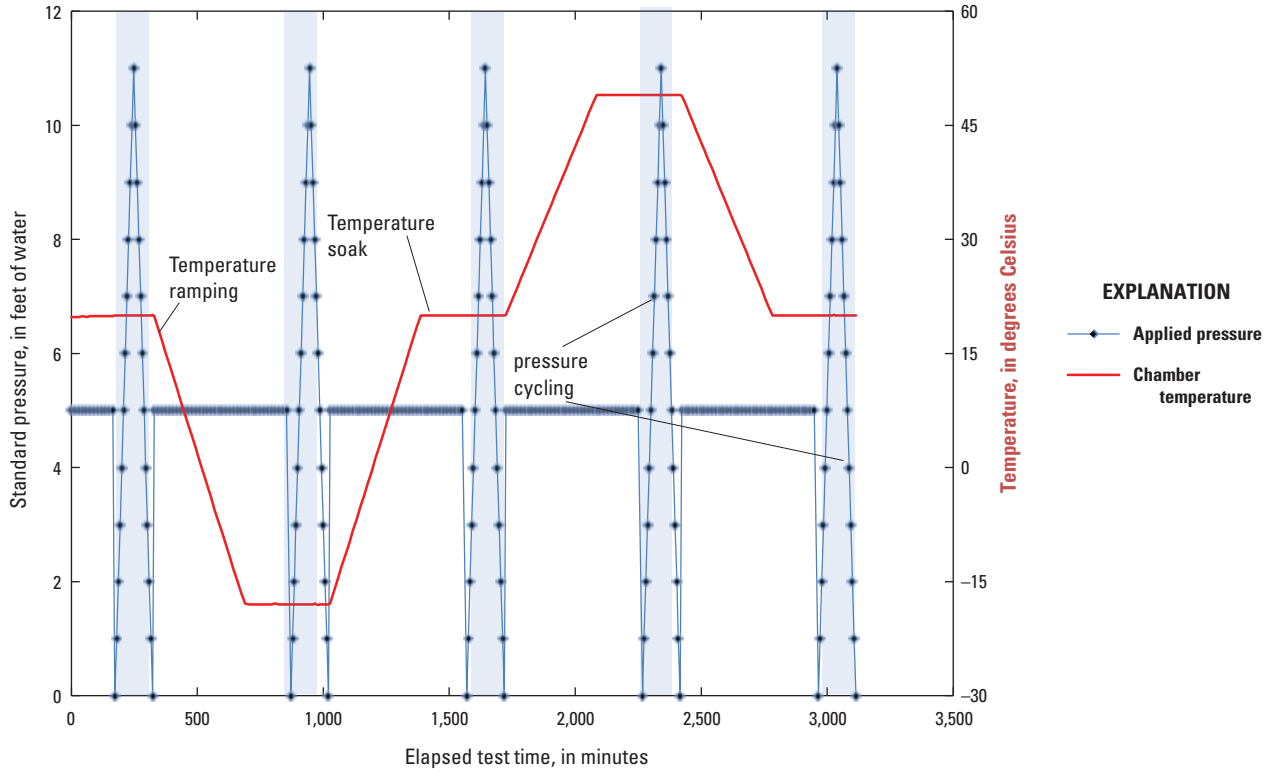


Figure 6. Pressures and soak temperatures applied during pressure cycling for the three Infinities Pressure Water Level Loggers.

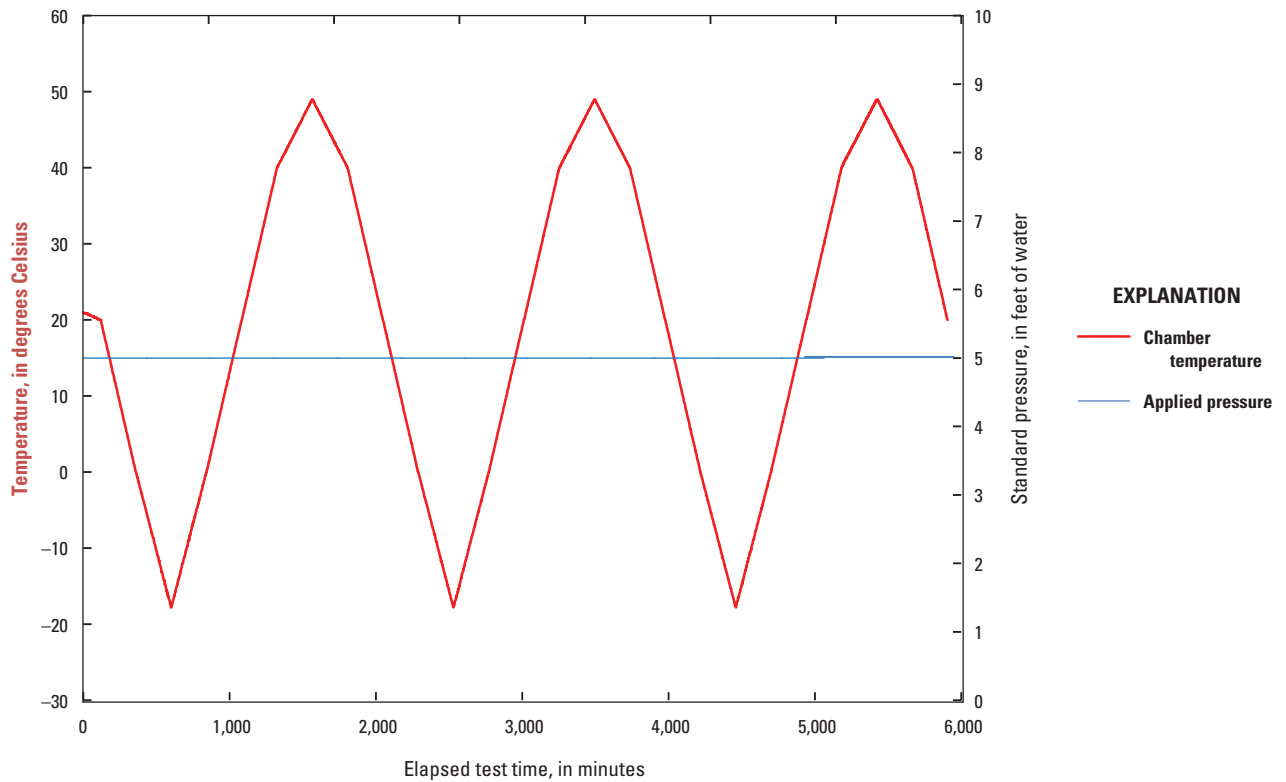


Figure 7. Temperatures and pressure applied during temperature cycling testing for the three Infinities Pressure Water Level Loggers.

Measurement Units and Conventions for Pressure

Gage and standard pressure terms are presented in this report. Pressure sensors can have the sensing element either vented or sealed to the atmosphere. The pressure sensing devices that were evaluated were vented to the atmosphere; these devices measure pressure in pounds per square inch gage. The pressure controller sensor used to vary and measure pressures was a vented sensor and supplied pressure in units of feet of water, which is termed standard pressure in this report. The Infinities Logger reports pressure only in inches of water. Standard pressure was converted to inches of water by multiplying feet of water by 12.

In the laboratory evaluation and as reported here, differences between the pressures measured by a device and standard pressures were computed as

$$P_{\text{device}} - 12 \times P_{\text{controller}} = (\text{inches of water}) \quad (1)$$

where

P_{device} is the pressure measured by the pressure sensing device in inches of water, and
 $P_{\text{controller}}$ is the standard pressure in feet of water units measured by the Ruska pressure controller.

Throughout this report, all differences between the device and standard pressure refer to values computed using this equation. The Infinities Logger manufacturer accuracy specification is ± 0.1 percent full scale (FS) and equates to ± 0.138 inches of water for the evaluated device.

Results

The performance of the three Infinities Loggers at varying temperatures and pressures were evaluated using the methods described previously. For the pressure cycling evaluation, the difference between the pressure measured by the device and the standard pressure is shown for each of the three Infinities Loggers in figures 8 through 10. Different symbols are used to denote the three temperatures (-18 , 20 , and 49 °C) at which pressures measured by the Infinities Loggers were recorded. Red horizontal dotted lines in the figures denote the specified accuracy of ± 0.138 inches of water (± 0.1 percent full scale) for each device. Black dashed lines in the figures denote USGS Office of Surface Water (OSW) Technical Memorandum No. 96.05 (Yorke, 1996) accuracy requirements. The USGS OSW accuracy requirement for “non-submersible pressure sensor instruments” is “the larger of 0.01 ft or 0.10 percent of reading” with an implied measurement resolution of 0.01 ft or ± 0.173 inches of water (0.0144 ft x 12 inches/ft). This requirement was established before the widespread use of submersible pressure sensors by the USGS and has been applied to submersible sensors as they have increased in availability and usage through time. The three Infinities Loggers evaluated in this study did not meet the manufacturer’s accuracy specification for stage measurement or the USGS OSW accuracy requirement during the pressure cycling test.

All pressure measurements made at -18 °C by all of the Infinities Loggers resulted in differences from the standard pressure that exceeded the device’s stated accuracy specification (figs. 8–10). The three Infinities Loggers performed similarly and exhibited a large increasing negative bias with increasing pressure for measurements made at -18 °C. Almost all measurements made at 49 °C exhibited a large increasing positive bias with increasing pressure, and the three Infinities Loggers performed similarly at 49 °C.

Summary statistics for the pressure differences measured during the pressure cycling test over the compensated temperature range are given in table 2. For the three Infinities Loggers, the mean pressure differences varied from -4.04 to 5.32 inches of water and were not within the manufacturer’s accuracy specification for pressure measurements made within the temperature-compensated range. Except at 20 °C, the differences increased with increasing pressure (figs. 8–10). The standard deviations of the pressure differences were similar among the Infinities Loggers and varied from 1.390 to 1.598 inches of water. All three Infinities Loggers had high measurement variability. The differences in the Infinities Loggers’ pressure reading at the same temperature and pressure at the start and end of the test (drift) was small and was the same for all Infinities Loggers, 0.020 inches of water.

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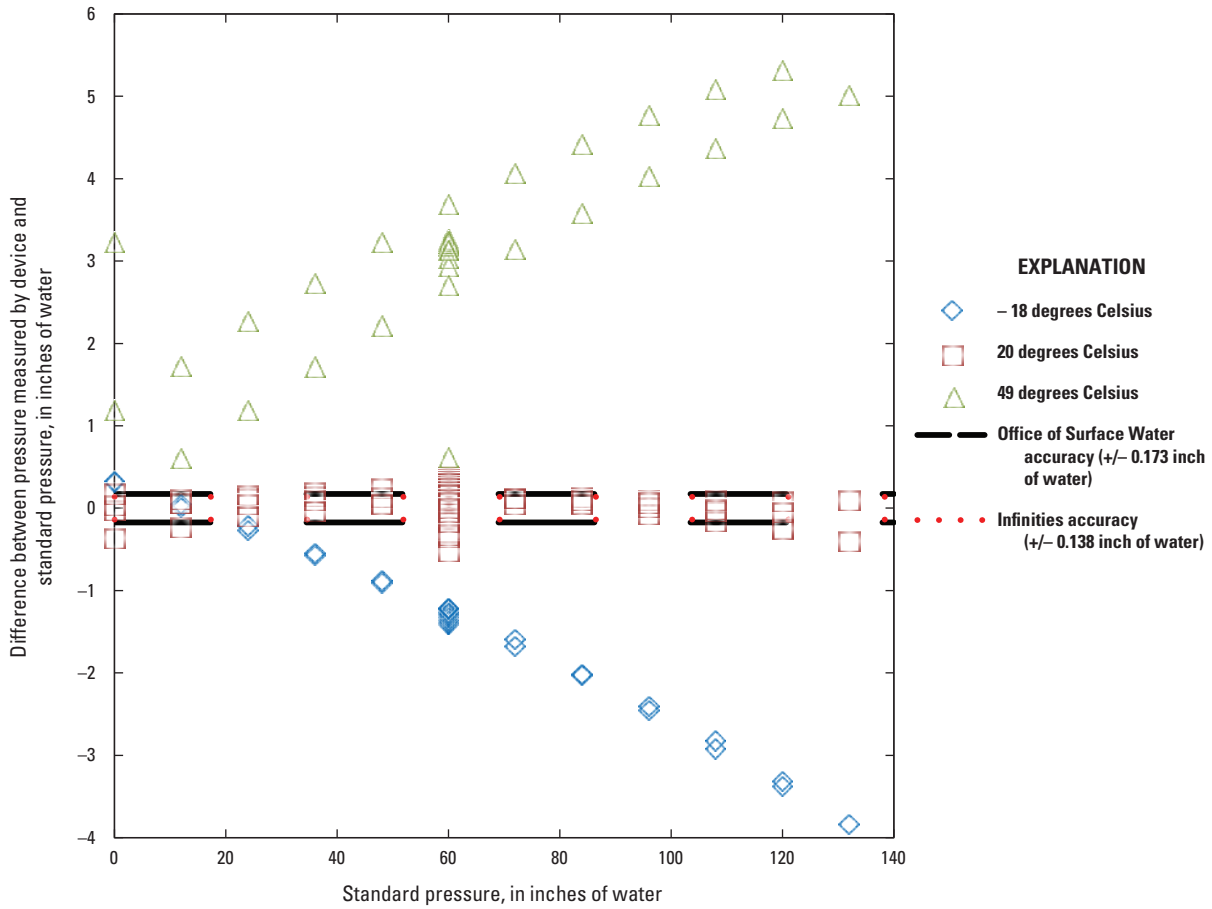


Figure 8. Differences in pressures measured by Infinities Pressure Water Level Logger (number N52026B3) for 12 standard pressures.

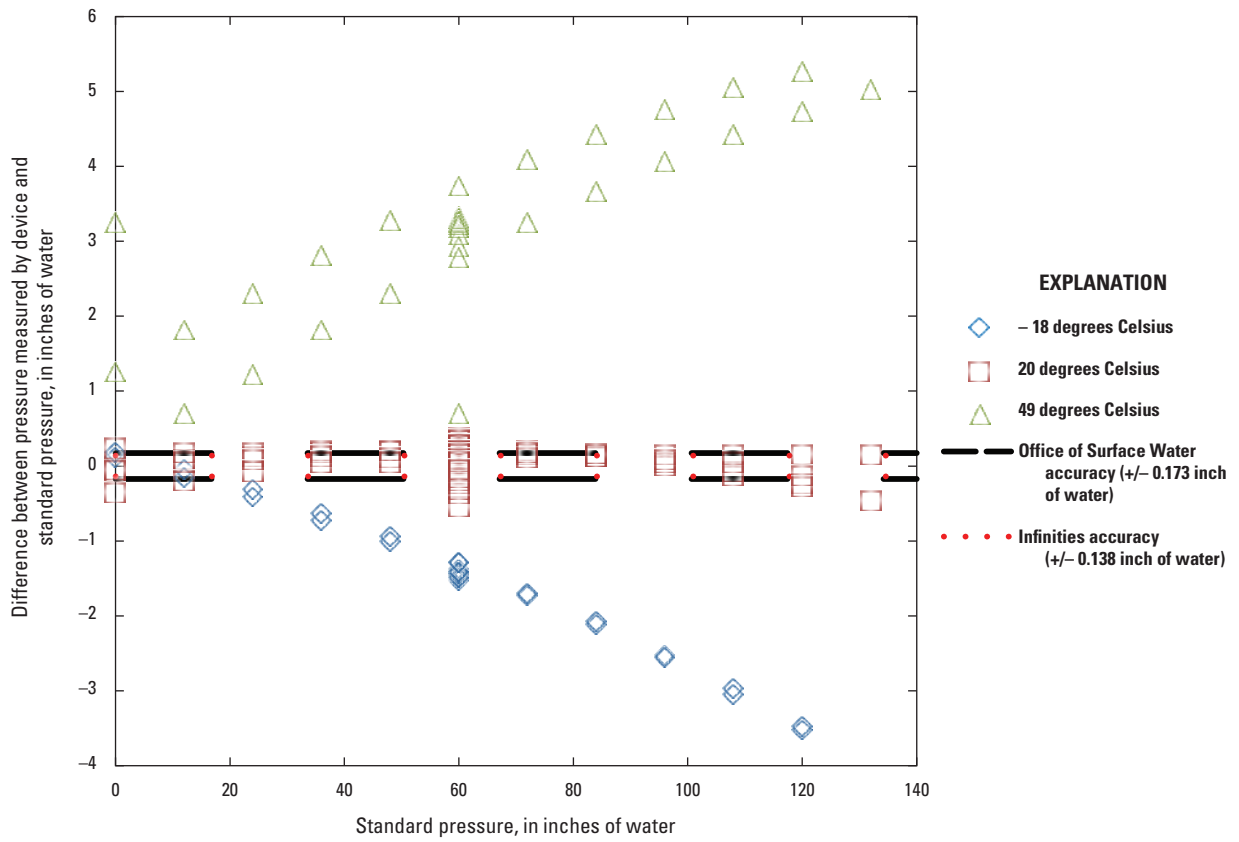


Figure 9. Differences in pressures measured by Infinities Pressure Water Level Logger (number N52025D8) for 12 standard pressures.

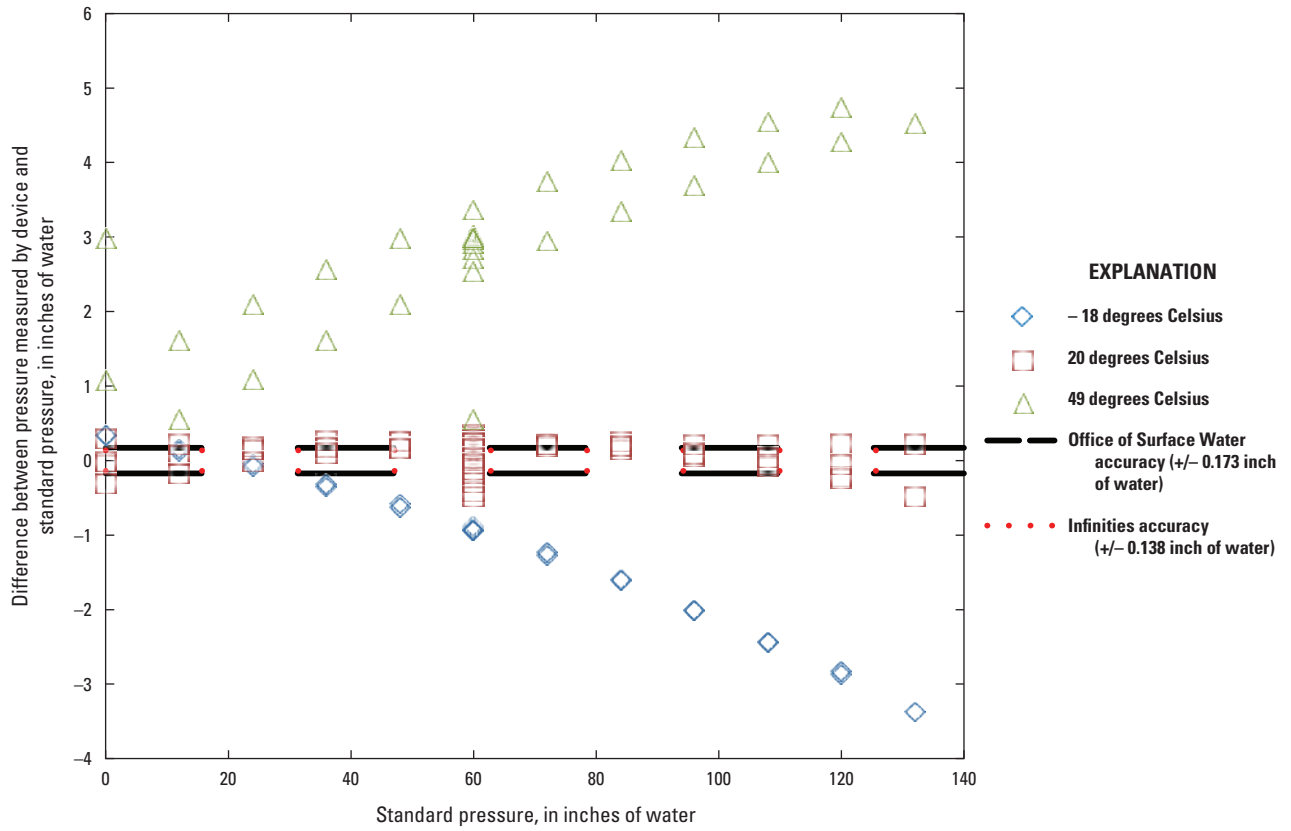


Figure 10. Differences in pressures measured by Infinities Pressure Water Level Logger (number N52027A5) for 12 standard pressures.

Table 2. Statistics for pressure differences for a pressure cycling test of three Infinities Pressure Water Level Data Logger devices for compensated temperatures of -18 , 20 , and 49 degrees Celsius.

[Values are reported in inches of water; \pm , plus or minus]

Statistic	Serial number of evaluated device			All devices
	N52026B3	N52025D8	N52027A5	
Number of measurements	270	270	270	810
Maximum	5.320	5.270	4.740	5.110
Minimum	-3.840	-4.040	-3.370	-3.370
Mean	0.4065	0.415	0.463	0.463
Standard deviation	1.572	1.598	1.3903	1.520
Drift	0.020	0.020	0.020	0.020
Average Uncertainty	± 0.146	± 0.151	± 0.119	± 0.139

The average combined uncertainty for the three Infinities Loggers' measurements for the pressure cycling test, U_p , was computed using a simplified uncertainty analysis based on International Organization for Standardization (ISO) methods (International Organization for Standardization, 2008). Systematic (mean pressure difference) and random (standard deviation of the pressure differences) uncertainties (or errors) were grouped into the average combined uncertainty for the pressure cycling test, using the following equation:

$$U_p = \left[\left(\frac{\sum x_p}{3} \right)^2 + \left(\frac{\sum s_p}{3} \right)^2 \right]^{1/2} \quad (2)$$

where x_p is the mean pressure difference for the p th device, s_p is the standard deviation of the pressure differences for the p th device, and the number 3 indicates the three devices evaluated. The average combined uncertainty for the pressure cycling test was ± 0.139 inches of water for the three devices.

Results obtained from the temperature cycling evaluation of the three Infinities Loggers are displayed in figures 11–13. The calculated differences between the pressure measured by the device and the standard pressure are plotted in each figure as a function of chamber temperature. Red horizontal dotted lines in the figures denote the evaluated device's specified accuracy of ± 0.138 inches of water ($+0.1$ percent full scale), and the black dashed lines denote the USGS OSW accuracy requirement of ± 0.173 inches of water.

As with the pressure cycling evaluation, the differences between pressures measured by the Infinities Loggers and the standard pressures for the temperature cycling evaluation were not within the manufacturer's or USGS OSW stated accuracy limits. Measurements made between temperatures of 19.1 to 22.6 °C were within the manufacturer's and USGS OSW accuracy limits. When the sensors were subjected to temperatures below 19.1 °C, and above 22.6 °C, the pressure differences increased with increasingly colder and hotter temperatures and exceeded the manufacturer's stated accuracy limits. The "looping" of the data in figures 11, 12, and 13 is an indication of the Infinities Loggers' temperature hysteresis. Temperature hysteresis is the dependence of the sensor's pressure measurement on its previous temperature. Ideally, the sensor's measurement should not be affected by its previous temperature and should depend only on current conditions. Summary statistics for the pressure differences measured during the temperature cycling test are given in table 3. Measured pressure differences ranged from -1.820 to 3.000 inches of water for the three Infinities Loggers. The standard deviations of the pressure differences for the three Infinities Loggers varied from 1.366 to 1.563 inches of water. All three Infinities Loggers exhibited high measurement variability for the temperature cycling test. The difference between the device pressure reading at the same temperature and pressure at the start and end (drift) of the test for the three Infinities Loggers was small, between -0.13 and -0.16 inches of water.

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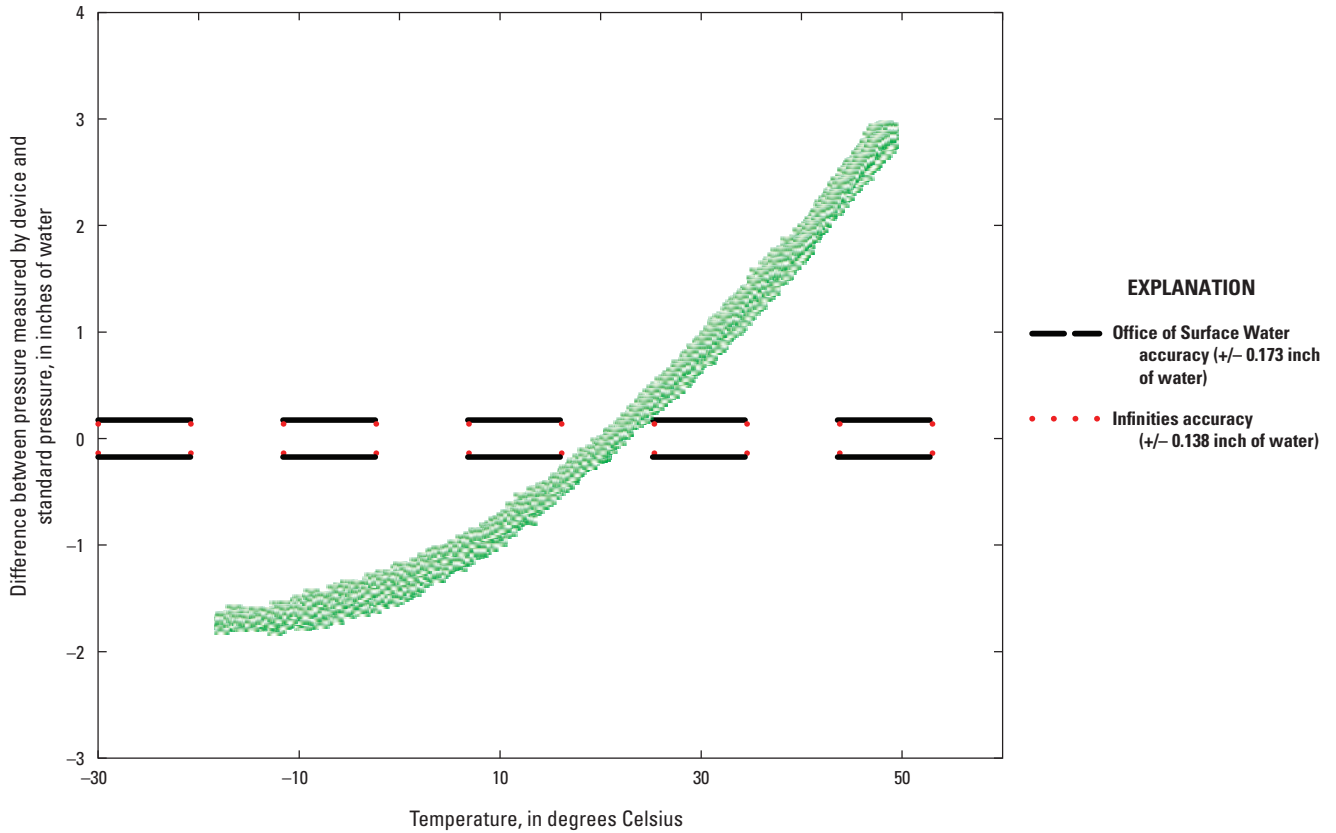


Figure 11. Differences in pressure measured by Infinities Pressure Water Level Logger (number N52026B3) for a single standard pressure (5 feet of water) over a temperature range of -18 to 49 degrees Celsius.

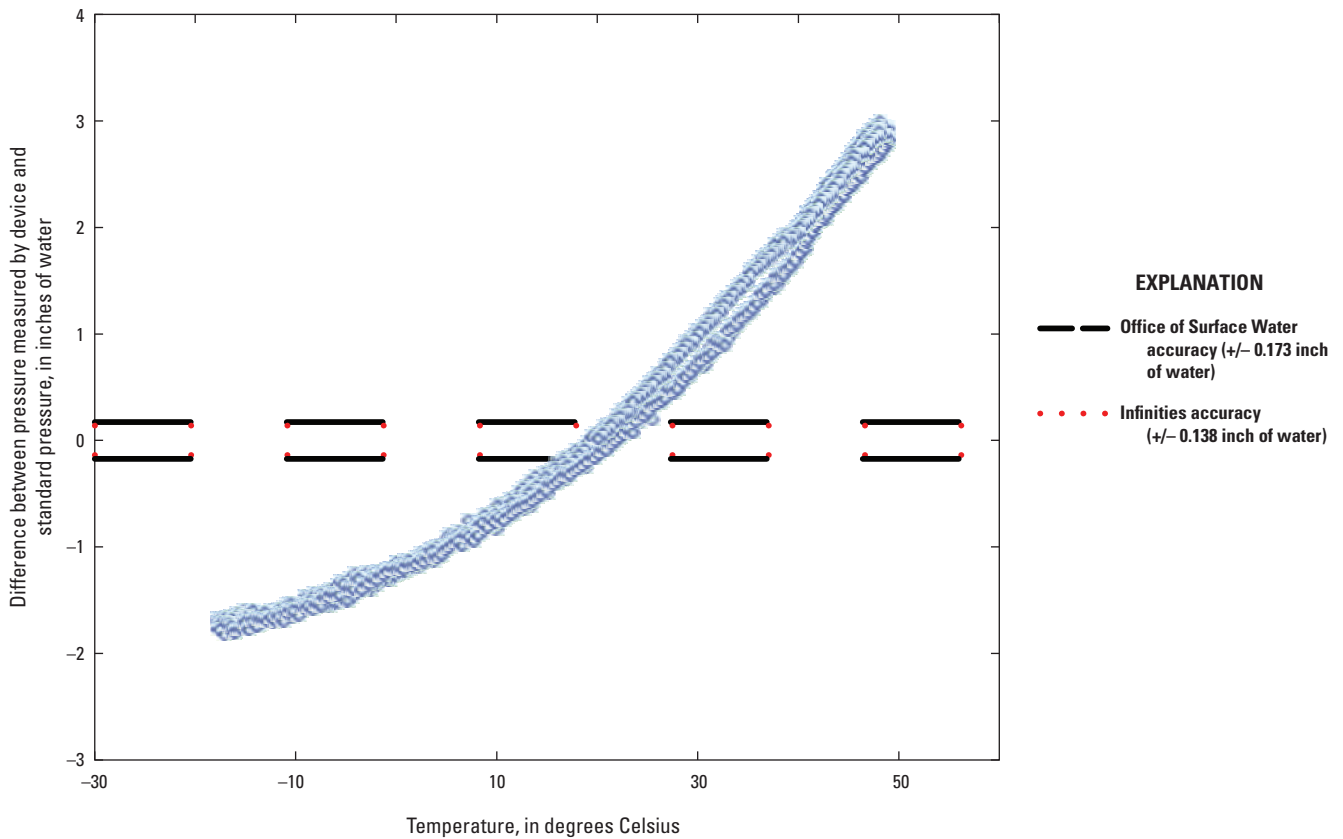


Figure 12. Differences in pressure measured by Infinities Pressure Water Level Logger (number N520265D8) for a single standard pressure (5 feet of water) over a temperature range of -18 to 49 degrees Celsius.

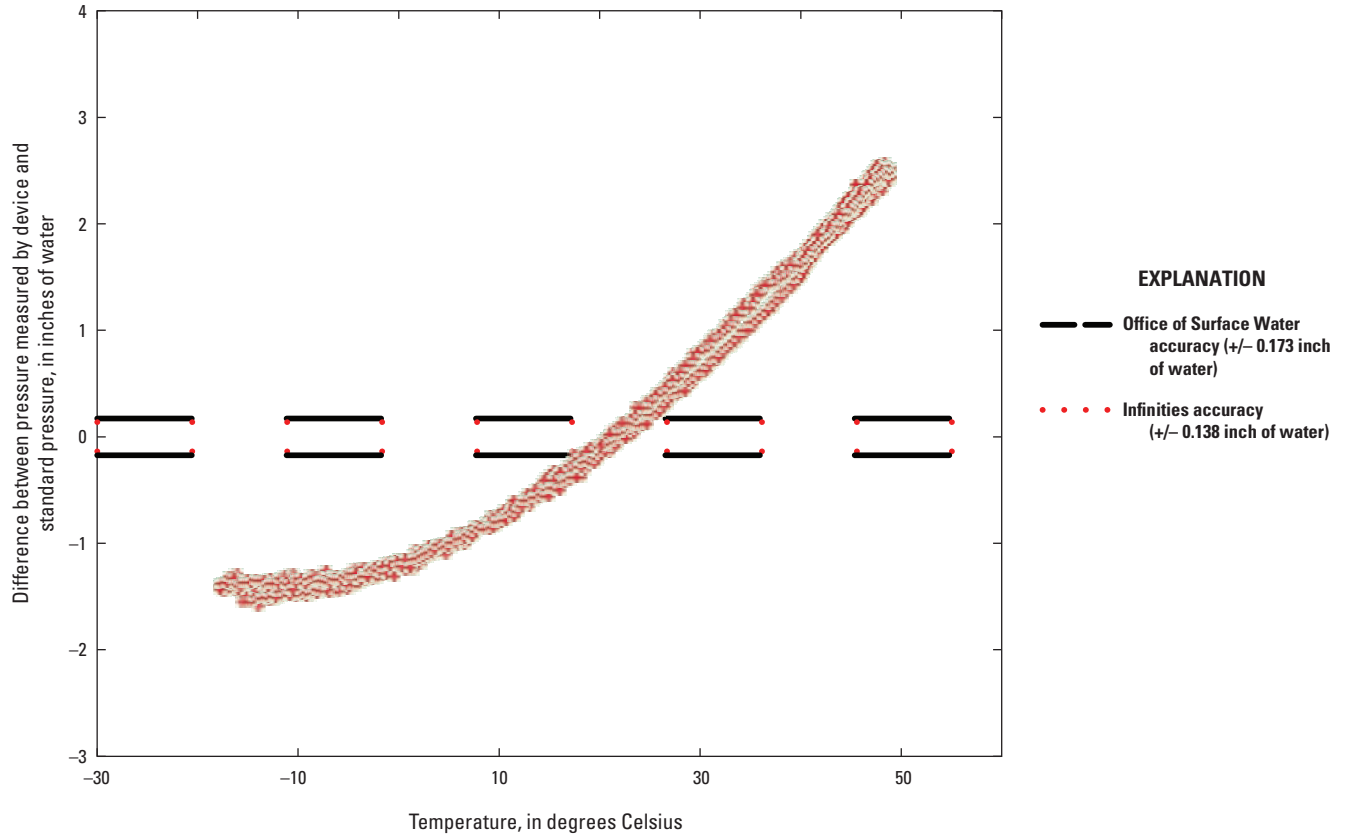


Figure 13. Differences in pressure measured by Infinities Pressure Water Level Logger (number N52027A5) for a single standard pressure (5 feet of water) over a temperature range of -18 to 49 degrees Celsius.

Table 3. Statistics for pressure differences for a temperature cycling test of three Infinities Pressure Water Level Data Logger devices for compensated temperatures of -18, 20, and 49 degrees Celsius.

[Values are reported in inches of water]

Statistic	Serial number of evaluated device			All devices
	N52026B3	N52025D8	N52027A5	
Number of measurements	3,772	3,772	3,772	11,316
Maximum	2.930	3.000	2.580	2.836
Minimum	-1.790	-1.820	-1.590	-1.733
Mean	0.203	0.270	0.176	0.216
Standard deviation	1.563	1.547	1.366	1.492
Drift over test	-0.160	-0.130	-0.160	-0.150
Average Uncertainty	±0.138	±0.137	±0.106	±0.127

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The average combined uncertainty of the three Infinities Loggers' measurements for the temperature cycling test, U_t , was computed using a simplified uncertainty analysis based on ISO methods (International Organization for Standardization, 2008) and the following equation:

$$U_t = \left[\left(\frac{\sum X_t}{3} \right)^2 + \left(\frac{\sum S_t}{3} \right)^2 \right]^{1/2} \quad (3)$$

where X_t is the mean pressure difference for the t th device, S_t is the standard deviation of the pressure differences for the t th device, and the number 3 indicates the three devices evaluated. The average combined uncertainty was 1.508 inches of water for the three Infinities Loggers.

It is important to note that the Infinities Loggers evaluated are intended to measure pressures while submerged in liquid water. At low temperatures (-18 to 0 °C) it is not possible for the devices to provide meaningful water-level data because all of the water in the vicinity of the device would be in the form of ice. But communication systems (electronic and power) are installed above the water surface and could be exposed to temperatures ranging from -18 to 0 °C. The Infinities Loggers evaluated in this study did not meet the manufacturer accuracy specification of ± 0.1 percent FS or USGS accuracy requirements for stage measurement during the pressure cycling and temperature cycling tests. Both the pressure cycling and temperature cycling test results show that the Infinities Loggers are poorly compensated for temperature effects. Most of the pressure measurements made by the Infinities Loggers (figs. 8–10) during the pressure cycling test at temperatures of -18 °C differed from the standard value by 0.3 to -4.0 inches of water and at temperatures of 49 °C differed from the standard value by 0.5 to 5.5 inches of water. The pressure measurements made by the Infinities Loggers (figs. 11–13) during the temperature cycling test at temperatures of -18 °C differed from the standard value by -1.8 to -1.5 inches of water and at temperatures of 49 °C differed from the standard value by 2.8 to 3.0 inches of water.

Summary

Three Infinities Pressure Water Level Data Logger submersible, sealed, water-level sensors with an operating pressure range equivalent to 0 to 11.5 feet of water were evaluated to determine if they met the manufacturer's stated accuracy specifications and if they were suitable for use in U.S. Geological Survey (USGS) hydrologic data-collection activities. The evaluations involved subjecting the Infinities Loggers to a range of pressures from 0 to 11.0 feet of water and a range of temperatures from -18 to 49 degrees Celsius. The three Infinities Loggers did not meet the manufacturer's stated accuracy specifications within the temperature-compensated operating range of -18 to 49 °C. On the basis of the test results, the device is poorly compensated for temperature. The estimated combined measurement uncertainty for the pressure cycling test was ± 0.139 inch of water and for the temperature cycling test was ± 0.127 inch of water for the three Infinities Loggers. The devices evaluated did not meet USGS requirements for accuracy of stage measurements at USGS continuous record streamflow-gaging stations.

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