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Evaluation of the Radar Stage Sensor Manufactured by Forest Technology Systems—Results of Laboratory and Field Testing

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

Cover image. The Radar Stage Sensor by Forest Technology Systems. Photograph by Joanne C. Jones, U.S. Geological Survey.

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U.S. Geological Survey
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Conversion Factors

International System of Units to U.S. customary units

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
meter (m)	1.094	yard (yd)

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as

$$°F = (1.8 \times °C) + 32$$

Abbreviations

FTS	Forest Technology Systems
HIF	Hydrologic Instrumentation Facility
LCD	Liquid Crystal Display
OSW	Office of Surface Water
PC	Personal Computer
RSS	Radar Stage Sensor
SN	Serial Number
USGS	U.S. Geological Survey

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By Gerald A. Kunkle

Abstract

Two identical Radar Stage Sensors from Forest Technology Systems were evaluated to determine if they are suitable for U.S. Geological Survey (USGS) hydrologic data collection. The sensors were evaluated in laboratory conditions to evaluate the distance accuracy of the sensor over the manufacturer's specified operating temperatures and distance to water ranges. Laboratory results were compared to the manufacturer's accuracy specification of ±0.007 foot (ft) and the USGS Office of Surface Water (OSW) policy requirement that water-level sensors have a measurement uncertainty of no more than 0.01 ft or 0.20 percent of the indicated reading. Both of the sensors tested were within the OSW policy requirement in both laboratory tests and within the manufacturer's specification in the distance to water test over tested distances from 3 to 15 ft. In the temperature chamber test, both sensors were within the manufacturer's specification for more than 90 percent of the data points collected over a temperature range of –40 to +60 degrees Celsius at a fixed distance of 8 ft. One sensor was subjected to an SDI-12 communication test, which it passed. A field test was conducted on one sensor at a USGS field site near Landon, Mississippi, from February 5 to March 29, 2016. Water-level measurements made by the radar during the field test were in agreement with those made by the Sutron Accubar Constant Flow Bubble Gauge.

Upon the manufacturer's release of updated firmware version 1.09, additional SDI-12 and temperature testing was performed to evaluate added SDI-12 functions and verify that performance was unaffected by the update. At this time, an Axiom data logger is required to perform a firmware update on this sensor. The data confirmed the results of the original test. Based on the test results, the Radar Stage Sensor is a suitable choice for USGS hydrologic data collection.

Introduction

The U.S. Geological Survey (USGS) Hydrologic Instrumentation Facility (HIF) evaluates the performance of instruments and equipment that are used to directly measure hydrologic data. These devices may measure properties needed to quantify streamflow (such as river stage, water velocity, or water discharge), to monitor groundwater levels, or to measure water-quality parameters in a variety of field settings. 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 primary factors evaluated are

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

The evaluations may involve extended operation in one or more field locations and (or) may employ testing chambers designed to reproduce a range of environmental conditions. Instrument and equipment evaluations are done primarily to determine if particular devices would be suitable for use by USGS personnel for hydrologic data collection. Reports describing instrument evaluation results are not indicative of an endorsement by the USGS of the tested instrument.

This report describes the procedures followed and the results obtained from the evaluation of a commercially available water-level sensor, the Forest Technology Systems (FTS) Radar Stage Sensor (RSS). Initial testing was performed with firmware

version 1.05. Additional testing was later performed with firmware version 1.09. The results are applicable only to the versions of the devices tested and may or may not be representative of the results obtained with different versions of the devices.

Description of the Radar Stage Sensor

The RSS (fig. 1) is a water-level sensor that uses radar to measure the distance between the sensor and the water surface. The sensor is manufactured by FTS. A radar sensor transmits energy in the direction of the water surface, and uses the energy reflected back to the sensor to determine the distance between the radar and the water. By entering the initial water level into the device, the radar can convert this distance measurement (or air gap) into a water-level (or stage) measurement. The RSS includes a fully enclosed antenna and conforms to part 15 of Federal Communications Commission regulations. The firmware version used during initial temperature and field testing was 1.05. Additional SDI-12 and temperature testing was later performed with firmware version 1.09.

Figure 1. The Radar Stage Sensor by Forest Technology Systems. Photograph by Joanne C. Jones, U.S. Geological Survey.

Selected manufacturer specifications for this device are listed in table 1 and are available in the FTS Radar State Sensor Operating Manual (FTS, 2016). The RSS includes SDI-12 and 4–20 milliampere outputs. Only the SDI-12 output was tested. Two methods can be used to configure the RSS. The first method requires a device that supports SDI-12 transparent mode, such as a data logger or a personal computer (PC) with a serial-to-SDI-12 converter. The SDI-12 transparent mode allows a user to directly communicate with a sensor by sending individual SDI-12 commands (SDI-12 Support Group, 2016). The second method is to use the optional liquid crystal display (LCD) module that can be purchased with the RSS. Configuration options include programming the initial stage, units, and averaging period. If the LCD module is purchased, it can be used to program an "echo curve," which allows the sensor to filter out false signals that may be caused by other reflective structures between the radar and the water surface. The model tested in this evaluation did not include an LCD module.

Firmware version 1.09 was released after laboratory and field testing were completed, and this new version included additional SDI-12 extended commands and features. One of the added SDI-12 commands allows the user to set the averaging

Table 1. Selected specifications for the Forest Technology Systems Radar Stage Sensor.

[mm, millimeter; m, meter; ft, foot; °C, degrees Celsius; VDC, volts direct current; mA, milliampere; GHz, gigahertz; ±, plus or minus]

Feature	Specification
Measurement accuracy	± 2 mm (±0.007 ft)
Measurement range	0.5 m (1.64 ft) to 35 m (114.8 ft)
Recommended measuring range	up to 20 m (65.62 ft)
Operating temperature range	–40 to +60 °C
SDI-12 supply voltage	10.6–16 VDC
SDI-12 interface	Version 1.3 compliant
SDI-12 output variables	Water level, distance, quality factor, internal temperature
4-20 mA output loop voltage	12–24 VDC
Output current	3.8–20.5 mA
Measuring frequency	K-band (26 GHz)
Beam angle	± 10 degrees

duration. The averaging duration is the length of time over which samples will be averaged when a measurement is reported in response to the SDI-12 measure command. The default averaging duration is 20 seconds. Another added command provided the ability to set the radar in either high-power or low-power mode. In high-power mode, the radar continuously calculates 1-hertz average distance values. The latest averaged measurement can be obtained at any time by using the SDI-12 measure command. In low-power mode, the radar remains in a low-power state until a measurement is requested. When a measurement is requested, the radar takes 65 seconds to warm up before any measurements are initiated. The sensor will then average the number of measurements defined by the averaging duration setting at a rate of one measurement per second, and report the average of those values. When the measurement is complete, the radar returns to the low-power state.

At this time, any firmware updates for the RSS require the use of an FTS Axiom data logger (FTS, 2015) and the FTS Firmware Updater software.

Methods

Two identical RSSs were evaluated by subjecting the sensors to laboratory, SDI-12 communication, and field testing. Initial testing was performed with firmware version 1.05. Laboratory testing was conducted to evaluate the accuracy of the sensor over the manufacturer's specified operating temperature and distance to water ranges. Individual distance measurements obtained during laboratory testing were compared to the manufacturer's accuracy specification for water level and to the USGS Office of Surface Water (OSW) policy requirement that water-level sensors have a measurement uncertainty of no more than 0.01 foot (ft) or 0.20 percent of the indicated reading (USGS, 1996). Due to test equipment constraints, the maximum distance (or air gap) used during laboratory testing was limited to 15 ft. The SDI-12 communication testing was conducted to evaluate compliance with the SDI-12 communication protocol (SDI-12 Support Group, 2016). Field testing was conducted at a USGS field site near Landon, Mississippi, to evaluate performance under field conditions.

At the conclusion of the initial laboratory and field tests, the firmware on serial number 78534 was updated to version 1.09. This new version added features accessible through SDI-12. An additional temperature test was performed to verify that the radar's accuracy and performance over a range of temperatures was not affected by the new firmware. All measurements taken during initial laboratory and field testing with firmware version 1.05 were recorded with the radar in high-power mode. Testing with version 1.09 was performed with the radar in low-power mode. The averaging duration in all tests was set to 20 seconds, which is the default for the sensor.

Temperature Testing

Two identical RSSs, serial numbers 78534 and 78535, were evaluated inside a walk-in environmental test chamber. The purpose of this test was to measure how much the distance measurements varied in response to changes in environmental

temperature. The RSSs were mounted to a rack and aimed horizontally at a stationary target approximately 8 ft from the radars. An attached PC running custom software (LabVIEW[1]) was used to control the chamber temperature and log data from the sensors. The average distance in feet measured by each radar over the previous 20 seconds was logged every 5 minutes. The chamber was programmed to cycle between –40 and 55 degrees Celsius (°C). Due to technical problems with the environmental chamber at the time of the test, the chamber was only able to achieve –27 °C. Three temperature cycles were completed during the course of the test (fig. 2). The cycles consisted of "ramp" periods, during which the chamber was transitioning between temperatures, and "soak" periods, during which the temperature was held at a constant value to allow the device being tested to equilibrate to the new temperature. Soak periods occurred at 25, 55, –10, and –25 °C. During ramp periods, the rate of temperature change was 0.2 °C per minute. Soak periods lasted 180 minutes.

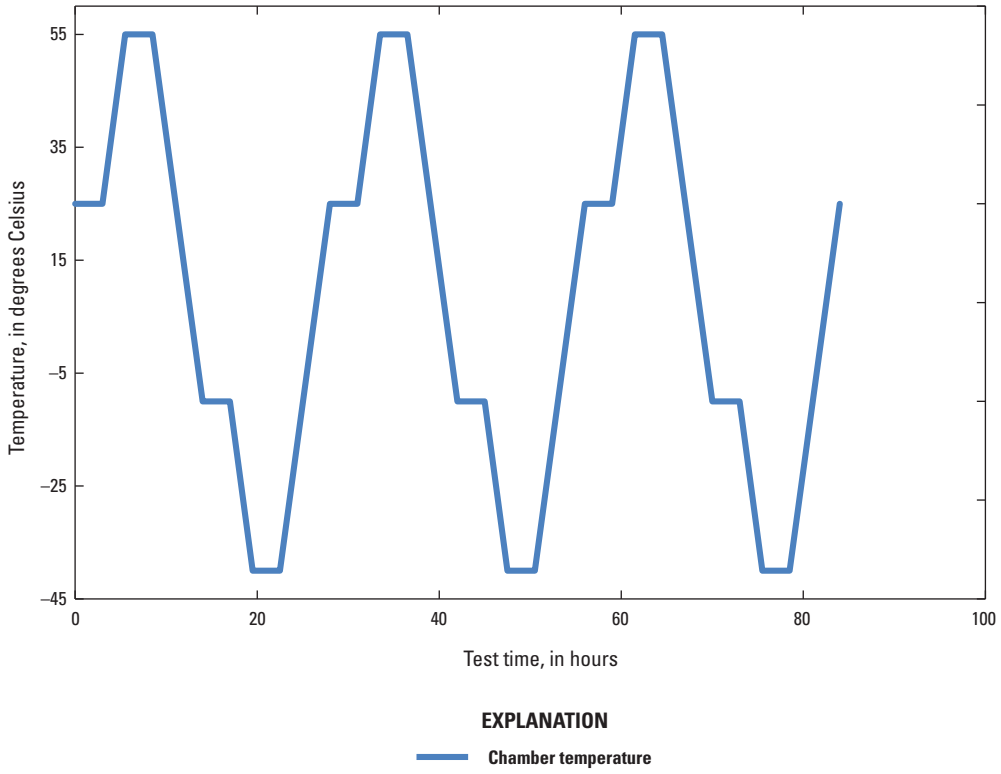

Figure 2. Walk-in environmental test chamber planned temperature profile used to test the Forest Technology Systems Radar Stage Sensor with firmware version 1.05. The chamber was programmed to cycle between a temperature range of –40 to 55 degrees Celsius. Due to problems with the chamber, however, the lowest temperature achieved was –27 degrees Celsius.

Distance to Water Testing

After the temperature testing, both RSSs were evaluated at varying air gaps above a tank of still water in the HIF Hydraulic Laboratory. The purpose of this test was to measure how well the RSSs tracked changes in the air gap between the radar and water surface. Both radars were mounted to a plate at the end of a movable arm above the water surface (fig. 3). The water level was measured by using a float system attached to a Sutron Model 56-0540 SDI-12 shaft encoder (Sutron Corporation, 2014). The arm level was measured with a separate Sutron Model 56-0540 shaft encoder. The reference distance from the arm to the water was computed based on the arm encoder reading and the water-level encoder reading. The arm was initially set so that the radar was approximately 3 ft above the water. By using an attached motor controller, the arm was raised in 3-ft increments to a maximum air gap of 15 ft. At each 3-ft set point, both radars were given approximately 4 minutes to adjust to the new level before recording a water-level measurement. No attempt was made to set the radar to correctly read the water level. At each step, the change in the RSS water-level measurement was compared to the change in air gap to assess the accuracy of the radar. A total of five cycles from 3 to 15 ft and back to 3 ft was completed.

[1] National Instruments Corporation, Austin, Texas.

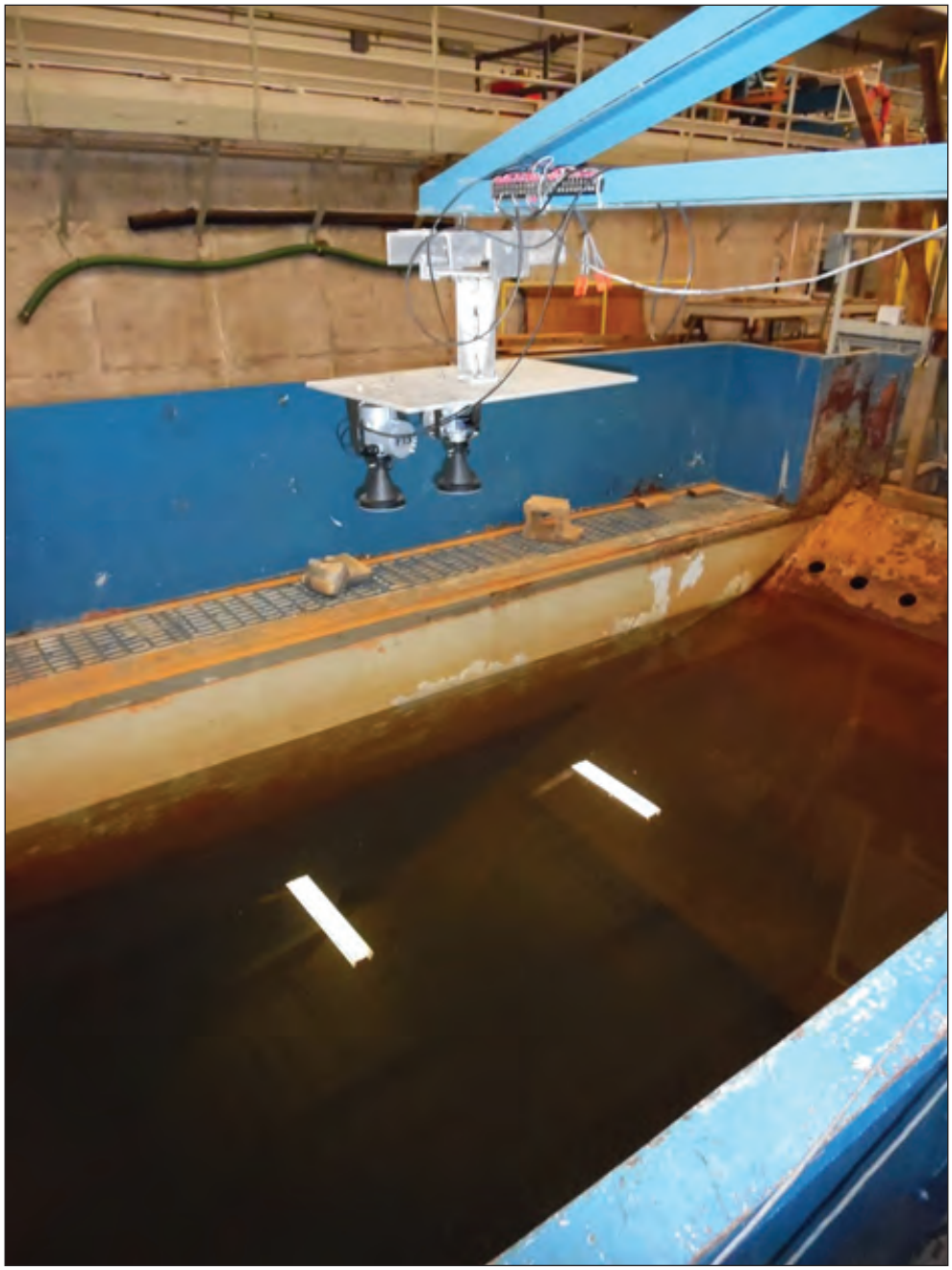

Figure 3. Forest Technology Systems Radar Stage Sensors mounted above water during distance to water testing in the U.S. Geological Survey Hydrologic Instrumentation Facility Hydraulic Laboratory.

SDI-12 Communication Testing

One RSS, serial number 78534, was tested for compliance with SDI-12 Specification, version 1.3 (SDI-12 Support Group, 2016). The SDI-12 communication test was performed by using a PC and an SDI-12 Verifier[2] in sensor test mode. The internal verifier software used in the test was version 2.32, and the PC software was version 6.0.15.0. The SDI-12 Verifier comprehensive sensor test is an automated procedure that simulates an SDI-12 device requesting data from the sensor. As SDI-12 communication is taking place, the verifier monitors the data and signal timing to verify that the device complies with the requirements described in the SDI-12 standard. It should be noted that while the verifier is capable of analyzing digital communication

[2] NR Systems Incorporated, River Heights, Utah.

taking place on the SDI-12 bus, it is not able to check the full range of electrical conditions that the sensor may experience when deployed with other SDI-12 devices in the field.

Field Testing

One RSS, serial number 78534, was evaluated at a USGS field site. Deployment testing was performed over the Wolf River near Landon, Mississippi, over a period of 6 weeks, from February 5 to March 29, 2016, to evaluate the RSS in a real-world environment. The RSS was mounted near the center of the upstream side of a bridge, inside an enclosure, and aimed down through an opening toward the water surface (fig. 4). A Sutron Accubar Constant Flow Bubble Gauge (Sutron Corporation, 2014) was used as a reference instrument during the test, with its orifice line positioned near the left bank of the river. The water was approximately 33 ft below the RSS (fig. 5), and the RSS was 20 ft horizontally from the end of the Accubar orifice line. The mean water level measured at the site over a 1-year period was 6.1 ft. Data from both sensors were logged every 15 minutes by using a Campbell Scientific, Inc., CR1000 data logger (Campbell Scientific, Inc., 2015). The difference between the data from the RSS and the bubbler was used to assess the performance of the RSS during the test.

Figure 4. Bridge view of field test site for Forest Technology Systems Radar Stage Sensor (RSS) serial number 78534 on the Wolf River near Landon, Mississippi (U.S. Geological Survey site number 2481510). The RSS was mounted on the upstream side of the bridge, inside an enclosure, pointing down through an opening toward the water surface.

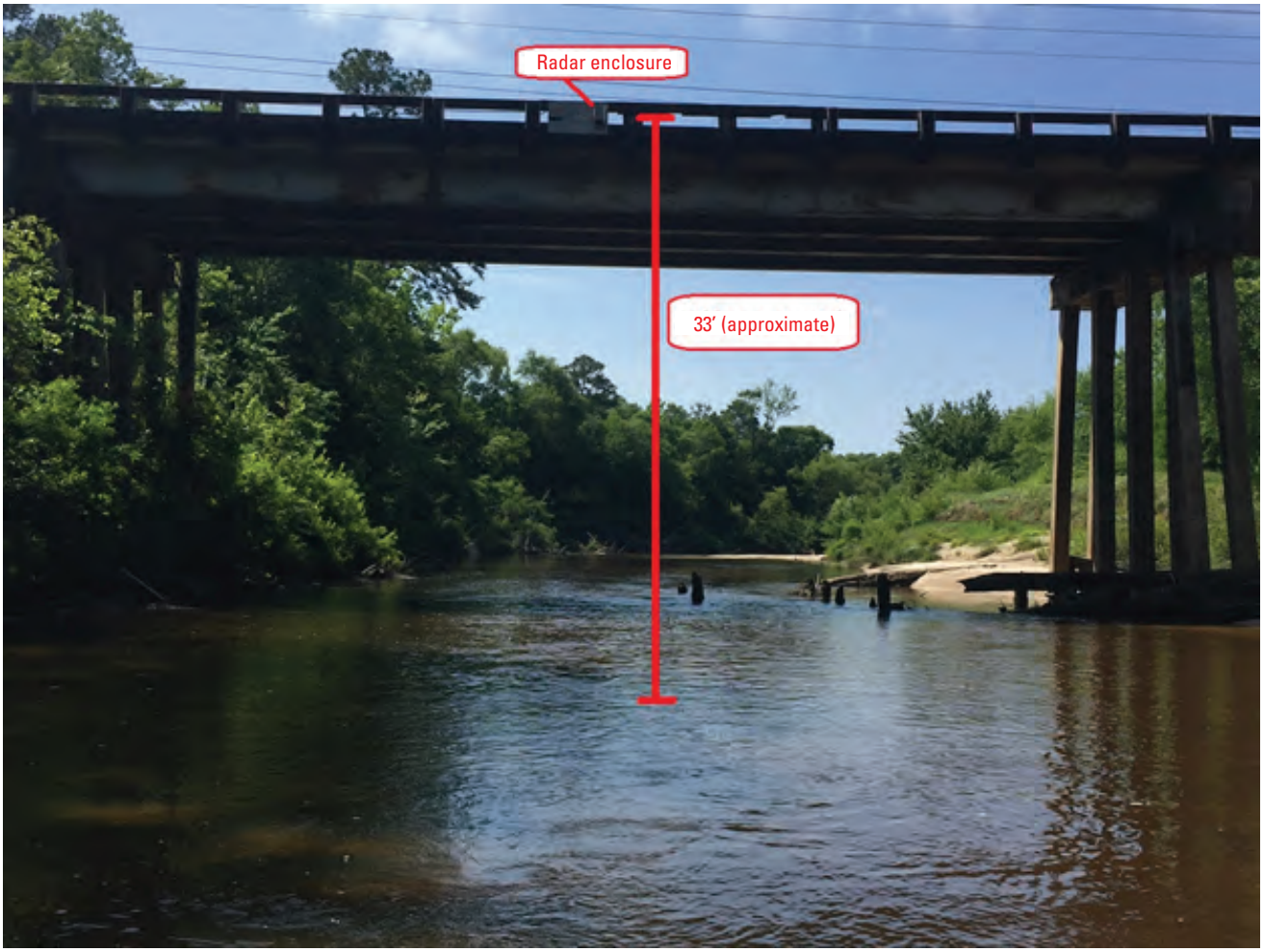

Figure 5. River view of field test site for Forest Technology Systems Radar Stage Sensor (RSS) serial number 78534 on the Wolf River near Landon, Mississippi (U.S. Geological Survey site number 2481510). The RSS was mounted on the upstream side of the bridge, inside an enclosure, pointing down through an opening toward the water surface. The approximate vertical distance from the RSS to the water surface was 33 feet. Photograph by Scott A. Kimball, U.S. Geological Survey.

Additional Testing with Firmware Version 1.09

The firmware on RSS serial number 78534 was updated to version 1.09, and the RSS was again subjected to SDI-12 and temperature testing to verify that the radar's performance was not affected by the update. The SDI-12 verifier test was repeated by using the same settings that were used during the test of firmware version 1.05.

Temperature testing was repeated by using a shortened temperature profile that ranged from –40 to 60 °C (fig. 6). Soak periods occurred at 25, 60, –10, and –40 °C and lasted 180 minutes. For the duration of this test, the power mode was changed from high to low.

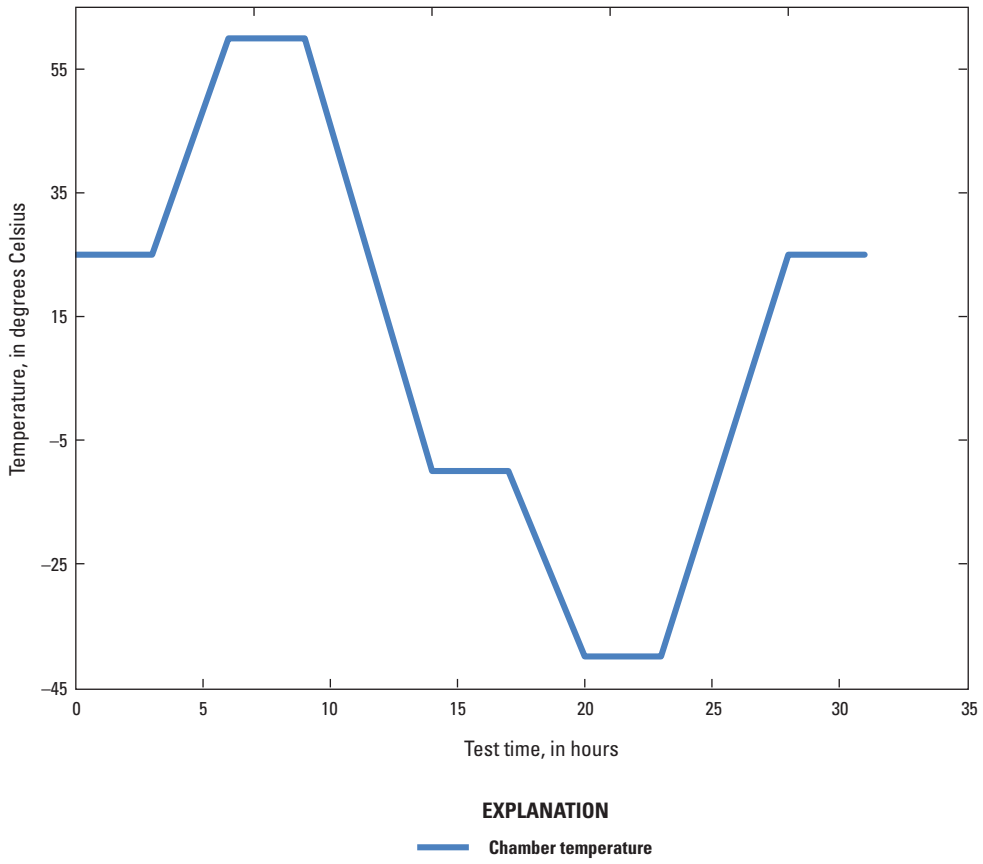

Figure 6. Walk-in environmental test chamber temperature profile used to test Forest Technology Systems Radar Stage Sensor serial number 78534 with firmware version 1.09.

Results

The results from temperature, distance to water, and field testing are presented in figures 7–10 and tables 2 and 3. Data from the testing of the RSSs were compared to manufacturer specifications, OSW requirements, and reference instruments to determine whether the sensor was suitable for USGS data collection. Additional data related to the testing of the RSSs can be found in Kunkle (2018).

Temperature Testing

Temperature chamber testing was performed on November 8, 2015 (fig. 7). Both sensors met OSW requirements for water-level measurement throughout the tested temperature range. Of the 1,039 data points collected during the test, 946 (91.0 percent) from serial number 78534 and 1,022 (98.4 percent) from serial number 78535 were within the manufacturer's specification of 0.007 ft. All measurements by both sensors were within 0.009 ft, and well within OSW requirements for water-level measurement.

Distance to Water Testing

Distance to water testing was performed on December 21, 2015 (fig. 8). Both sensors met OSW accuracy requirements and the manufacturer's accuracy specification over the tested range of air gaps. Summary statistics for each sensor are listed in table 2.

Because distance to water testing was performed over a flat, stationary water surface, it should be noted that these test results will not include errors that may occur when measuring a water surface with certain wave patterns and frequencies.

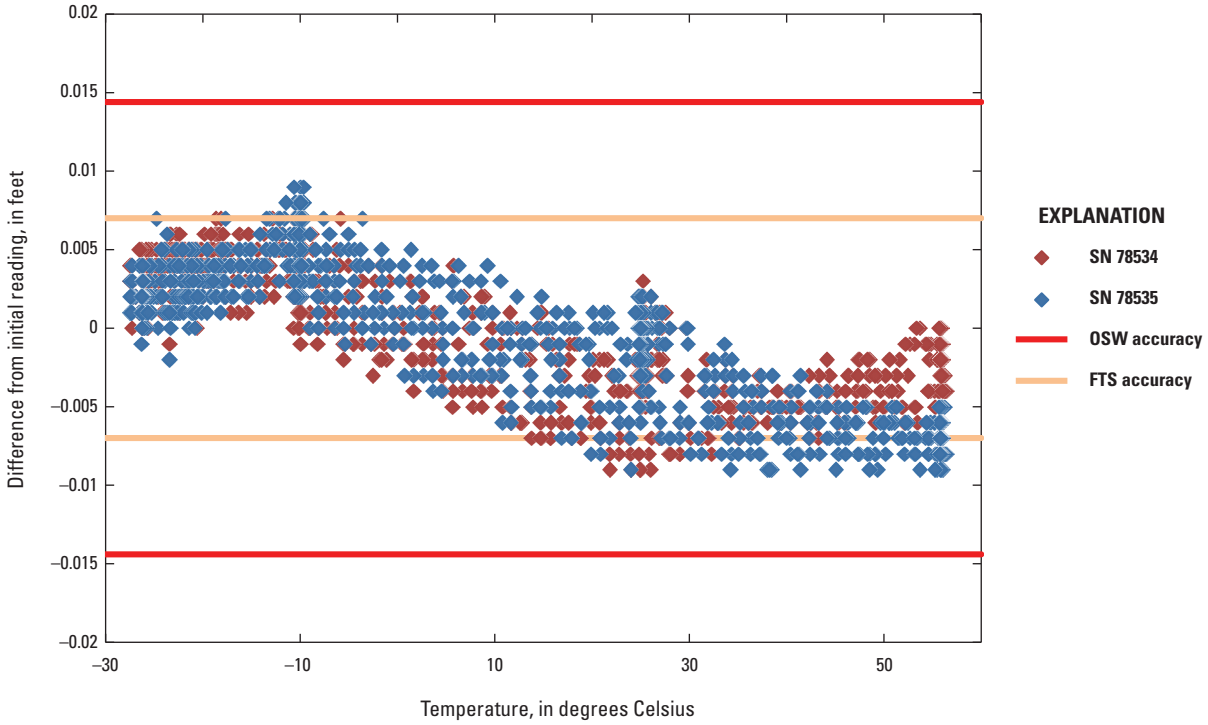

Figure 7. Summary of test results from walk-in temperature chamber testing of the Forest Technology Systems (FTS) Radar Stage Sensor with firmware version 1.05. Two sensors were tested, serial numbers (SN) 78534 and 78535. The U.S. Geological Survey (USGS) limit is plotted as ±0.01444 foot based on the implied resolution of the stated USGS Office of Surface Water (OSW) accuracy requirement of ±0.01 foot.

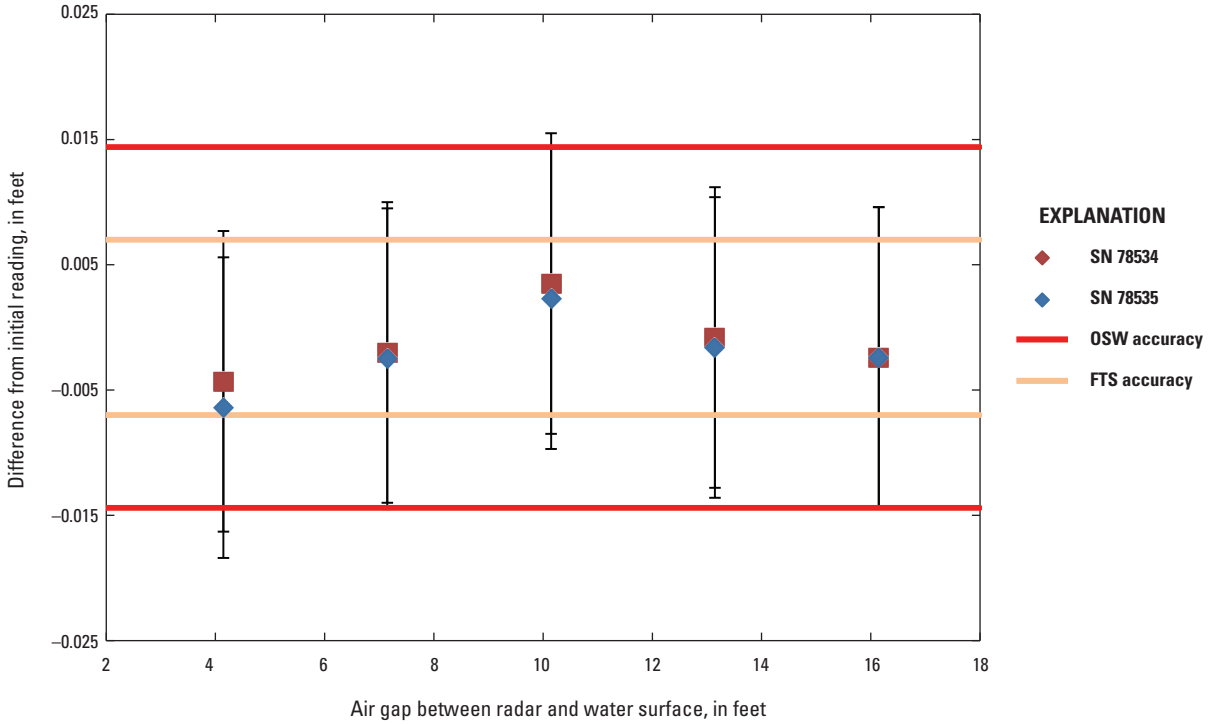

Figure 8. Summary of test results from distance to water testing of the Forest Technology Systems (FTS) Radar Stage Sensor. Two sensors were tested, serial numbers (SN) 78534 and 78535. The U.S. Geological Survey (USGS) limit is plotted as ±0.01444 foot based on the implied resolution of the stated USGS Office of Surface Water (OSW) accuracy requirement of 0.01 foot. Vertical error bars are plotted at ±0.012 foot, reflecting the uncertainty of the reference instruments, which were a pair of Sutron Model 56-0540 shaft encoders.

Table 2. Summary statistics for the difference between the Forest Technology Systems Radar Stage Sensor measurement and the reference measurement during distance to water testing with firmware version 1.05.

[SN, serial number; all values are in feet]

Summary statistic	SN 78535	SN 78534
Minimum	–0.011	–0.010
Maximum	0.009	0.010
Average	–0.002	–0.001
Standard deviation	0.004	0.004

SDI-12 Communication Testing

The RSS, serial number 78535, passed the NR Systems SDI-12 Verifier test. The results indicate that the sensor meets the timing and command requirements of version 1.3 of the SDI-12 standard.

Field Testing

Field testing was performed on an RSS (serial number 78534) from February 5 to March 29, 2016. Taking only the accuracy specification of each sensor into account, the combined uncertainty of the RSS and Sutron Accubar Constant Flow Bubble Gauge measurements is 0.017 ft. The RSS enclosure was installed at approximately the same level as the check bar on the bubbler's wire weight gage, which had a height of 37.87 ft. Based on this level, the approximate range of air gaps measured during the field test was 19.6 to 32.2 ft.

Over the course of the test, 5,009 measurements were collected from each device, with the measured water levels ranging from 5.709 to 18.330 ft (fig. 9; table 3). On February 17, a logging error occurred with the reference bubbler that resulted in 72 consecutive missed data points. Data from the radar and bubbler from this period were removed from the dataset before any analysis was performed. The cause of the logging error is unknown.

The difference between the average RSS and bubbler water-level measurements was 0.004 ft. As has been the case with previous comparisons between water-level radars and bubblers (Fulford and Davies, 2005), the RSS measured a higher maximum and lower minimum than the bubbler. Overall, the data show good agreement between the RSS and bubbler measurements.

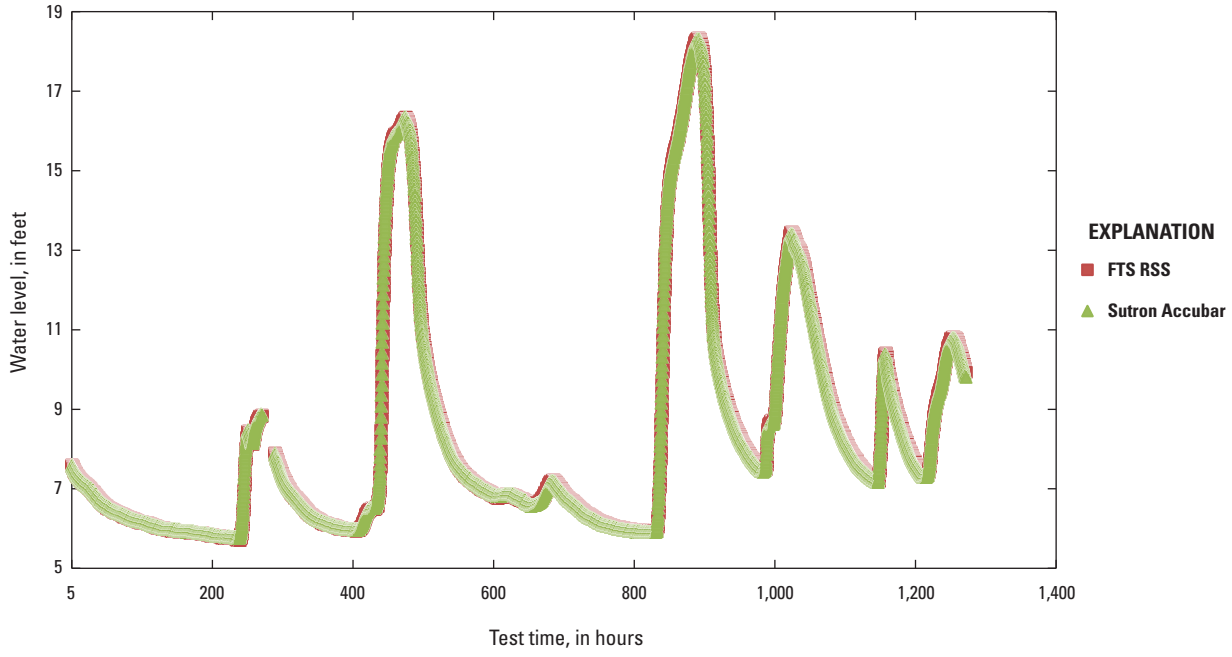

Figure 9. Water-level measurements recorded by Forest Technology Systems (FTS) Radar Stage Sensor (RSS) serial number 78534 and the Sutron Accubar Constant Flow Bubbler. A logging error occurred with the bubbler on February 17, approximately 270 hours into the test, which resulted in 72 missing data points. The cause of the error is unknown.

Table 3. Summary statistics for the Forest Technology Systems Radar Stage Sensor (RSS) measurement and the reference measurement during field testing with firmware version 1.05.

[SN, serial number]

Summary Statistic	RSS SN 78534	Accubar Bubbler
Number of measurements	5,085	5,085
Minimum (in feet)	5.709	5.771
Maximum (in feet)	18.330	18.311
Average (in feet)	8.319	8.315
Standard deviation (in feet)	2.973	2.960

Results from Testing with Firmware Version 1.09

The RSS serial number 78534 with firmware version 1.09 passed the NR Systems SDI-12 Verifier test. The results indicate that the new firmware meets the timing and command requirements of version 1.3 of the SDI-12 standard.

Temperature chamber testing with firmware version 1.09 was performed on June 24, 2016. Unlike during the first test, the chamber was able to successfully reach –40 °C. The results are similar to the results of the original test (figs. 7 and 10). Firmware versions 1.05 and 1.09 had no substantial accuracy difference; no substantial accuracy difference was measured between high-power mode and low-power mode.

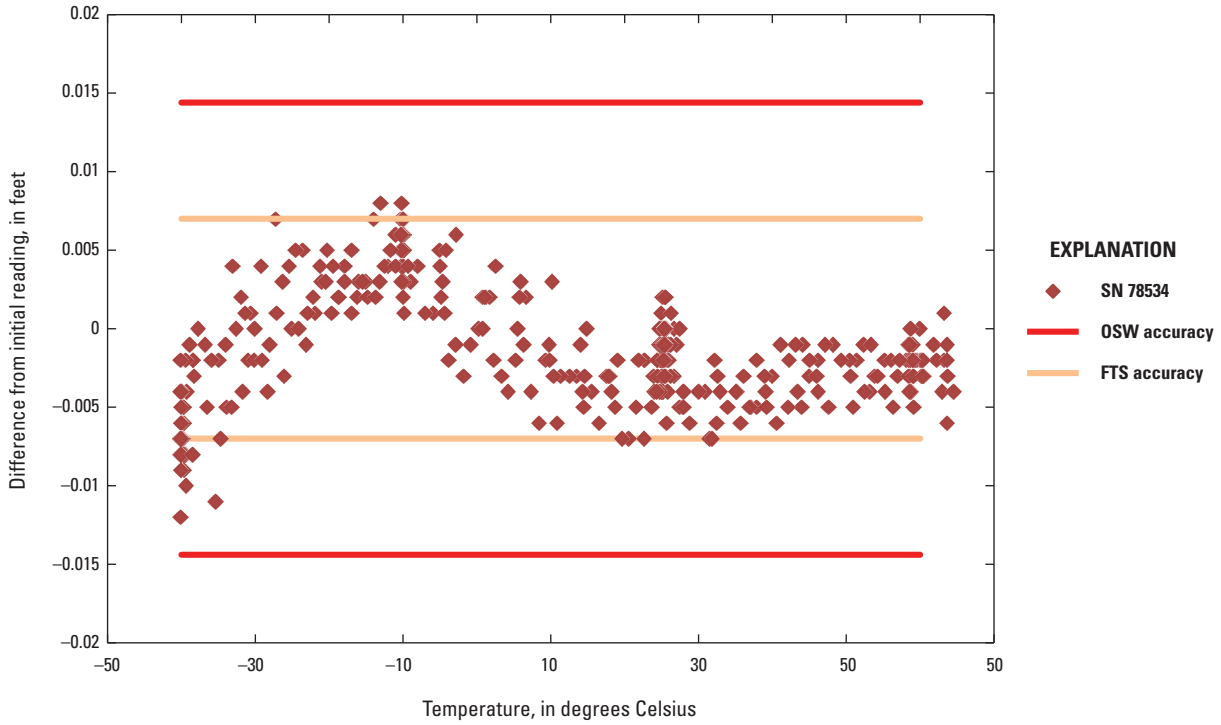

Figure 10. Summary of test results from temperature chamber testing of Forest Technology Systems (FTS) Radar Stage Sensor serial number 78534 with firmware version 1.09. The U.S. Geological Survey (USGS) limit is plotted as ±0.01444 foot based on the implied resolution of the stated USGS Office of Surface Water (OSW) accuracy requirement of 0.01 foot.

Conclusions

The FTS RSS was evaluated by using laboratory and field tests. Two sensors were tested in laboratory conditions to evaluate the accuracy of the sensor over the manufacturer's specified operating temperature and distance to water ranges. Laboratory testing was performed with air gaps ranging from 3 to 15 ft, and results were compared to the manufacturer's accuracy specification of ±0.007 ft and the USGS OSW policy requirement that water-level sensors have a measurement uncertainty of no more than 0.01 ft or 0.2 percent of the indicated reading. Both of the sensors tested were within the OSW policy requirement in both laboratory tests and within the manufacturer's specification in the distance to water test. In the walk-in environmental test chamber, both sensors were within the manufacturer's specification for more than 90 percent of the data points collected over a temperature range of –40 to +60 °C. One tested sensor passed an SDI-12 communication test. A field test was conducted on one sensor from February 5 to March 29, 2016, with a range of air gaps from approximately 19.6 to 32.2 ft. Water-level measurements made by the RSS agreed with those made by the Sutron Accubar Constant Flow Bubble Gauge. After updating the firmware on RSS serial number 78534 to version 1.09, which required the use of an Axiom data logger, the SDI-12 and temperature tests were repeated. The results of these tests confirmed the original test results. The results of these laboratory and field tests indicate the FTS RSS is a suitable choice for water-level measurement by USGS personnel at field sites.

References Cited

Campbell Scientific, Inc., 2015, CR1000 datalogger operator's manual, accessed May 23, 2016, at https://s.campbellsci.com/documents/us/manuals/cr1000.pdf.

Forest Technology Systems [FTS], 2015, Axiom operator's manual, accessed June 30, 2016, at https://s3.amazonaws.com/Product_Datalogger/700-Axiom-Man.pdf.

Forest Technology Systems [FTS], 2016, Radar Stage Sensor continuous level measurement operating manual, accessed May 23, 2016, at https://s3.amazonaws.com/Product_Sensors/700-RSS-Man.pdf.

Fulford, J.M., and Davies, W.J., 2005, Radar stage uncertainty, *in* World Water and Environmental Resources Congress, Anchorage, Alaska, May 15–19, 2005, Proceedings: p. 1–11, accessed May 18, 2017, at http://ascelibrary.org/doi/10.1061/40792%28173%29434.

Kunkle, G.A., 2018, Evaluation of the Radar Stage Sensor manufactured by Forest Technology Systems, Incorporated—Results of laboratory and field testing: U.S. Geological Survey data release, https://doi.org/10.5066/F71C1VSR.

SDI-12 Support Group, 2016, SDI-12, A serial-digital interface standard for microprocessor-based sensors, version 1.3: River Heights, Utah [variously paged], accessed May 23, 2016, at http://www.sdi-12.org/current%20specification/SDI-12_version1_3%20January%2028,%202016.pdf.

Sutron Corporation, 2014, SDI-12 shaft encoder, model 56-0540, operations & maintenance manual, Revision B, accessed November 18, 2016, at http://www.sutron.com/documents/56-0540-om-manual.pdf.

U.S. Geological Survey [USGS], 1996, Policy concerning accuracy of stage data: U.S. Geological Survey Office of Surface Water Technical Memorandum 96.05, accessed May 9, 2016, at http://water.usgs.gov/admin/memo/SW/sw96.05.html.

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