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Vibrating Wire Fall Protection Device for the USCRN Geonor Weighing-Bucket Precipita- tion Gauge

Mark E. Hall
Oak Ridge Associated Universities
NOAA/Atmospheric Turbulence and Diffusion Division
Oak Ridge, TN

Marjorie McGuirk
Consultant, NOAA/National Climatic Data Center
Asheville, NC

U.S. DEPARTMENT OF COMMERCE

Donald L. Evans, Secretary

National Oceanic and Atmospheric Administration

Vice Admiral Conrad C. Lautenbacher, Jr., U.S. Navy (Ret.), Under Secretary

National Climatic Data Center

Thomas R. Karl, Director

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Mark E. Hall, NOAA-ATDD, Oak Ridge, TN
Marjorie McGuirk, Consultant, NOAA-NCDC, Asheville, NC

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National Climatic Data Center
Asheville, NC 28801-5001

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1. Introduction

Precipitation in the USCRN network is measured using a Geonor model T-200B weighing-type gauge using three separate vibrating-wire load sensors¹. The load sensors are fitted with a collar to prevent wire breakage in any sensor from disrupting the operation of the remaining sensors. The protective collar, called a Geonor wire break fall protection device (FPD), was designed and developed by ATDD² for the USCRN program. The FPD allows the remaining sensor wires to continue operating even if one or two wires break. This results in an accurate report to continue from the remaining sensors.

A decision was made to add the FPD to all USCRN Geonors. The USCRN Configuration Change Board³ approved the FPD through Configuration Change Request (CCR) Number Six⁴ in August 2003. Justification was partly based on maintenance requirements. Without the FPD, one breaking wire can cause the other wires to break. The FPD limits damage to the remaining wires caused by stress of the breakage of one wire, thus limiting the maintenance actions. If no precipitation reports are available from a site, the required repairs must be completed within four days. If however only one sensor is not operational, (two others reporting with a FPD) the required repairs must be completed within two weeks⁵. The addition of this device thus gives more time to restore a sensor. Additions of FPDs to USCRN stations are being implemented on a site-by-site basis during annual maintenance visits or as appropriate. As these modifications occur, the appropriate metadata is recorded⁶.

This Technical Note describes the FPD and presents laboratory tests performance data. Precipitation data from USCRN sites where wires have broken are presented. Sites with and without the FPD are used to validate the operational performance of the FPD. Laboratory and field data examined in this Technical Note demonstrate that the FPD allows the continued operation of the Geonor gauge in the event of breakage of one or two wires.

2. Description of the Geonor Wire Break Fall Prevention Device (FPD)



Figure 1: Geonor catch bucket from above.



Figure 2: Geonor catch bucket from the side.

A photograph of a Geonor catch bucket taken from above (Figure 1) shows the top of the three

vibrating wire load sensors (round, black objects) spaced 120 degrees apart around the collecting bucket, and the transducers' surge suppressors (in turquoise). A side view of the bucket (Figure 2) shows the vibrating wire casing (without the FPD suspending the bucket.) The sensor arrangement allows the weight of the bucket and its contents to be equally suspended by the three wires. The balanced suspension ideally results in an identical signal at all three sensors when the bucket is level. As the suspended weight increases, a corresponding change is induced in the harmonic frequency of each the three wires. A quadratic equation converts frequency to depth measurements⁷. From depth, a corresponding measurement of precipitation contained in the bucket is obtained.

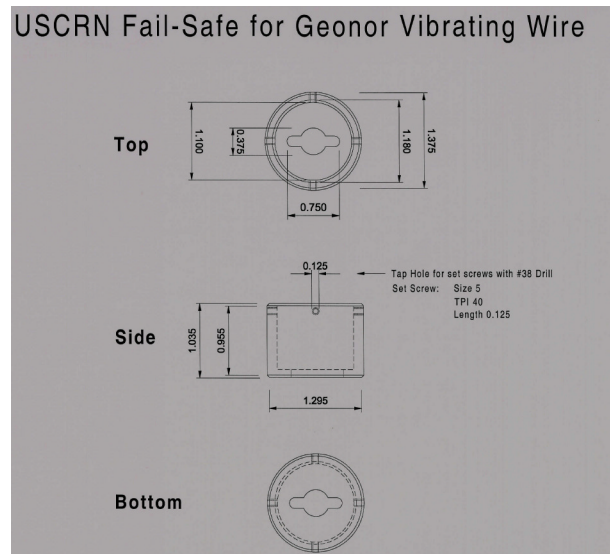


Figure 3: FPD schematic drawing (left) and FPD (right)

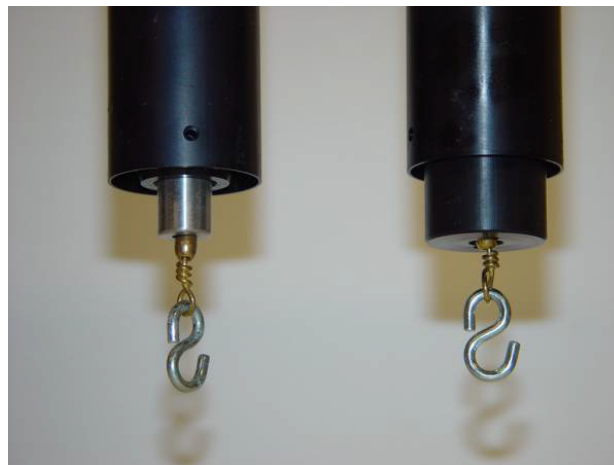


Figure 4: Vibrating wire without (left) and with (right) the FPD

A schematic drawing and a photograph of the FPD are shown in Figure 3 (left and right, respectively). It is a simple, lightweight, aluminum collar that is fitted to the vibrating wire casing. The device was fabricated⁸ at a cost of \$10 per piece. In a close-up view of the wire casing, the small silver cylinder that is attached to the end of the vibrating wire is shown without the FPD and with the FPD installed, (Figure 4, left and right, respectively).

When a Geonor sensor wire breaks without the FPD, the cylinder falls, the balance of the catch bucket becomes uneven, and the two remaining sensors fail to accurately report depth. When a Geonor sensor wire breaks with the FPD, the silver cylinder is caught by the FPD. It drops no more than 1.4mm and the bucket tilts by approximately one degree. The FPD allows the two remaining wires to continue operating even if one wire breaks. This results in an accurate report to continue from the two remaining sensors.

3. Laboratory Testing

Tests were performed by NOAA/ATDD to ascertain the error introduced into the depth measurement of the two remaining transducers in the case of one wire breaking. Results of these tests were presented in June 2003⁹. Excerpts from the presentation and the laboratory experimental notes are included in this Technical note.

The Geonor gauge was calibrated using precision-machined stainless steel weights that self-center within the collection bucket, allowing for both calibration in the field as well as in the laboratory. Under laboratory conditions, weights were added to a Geonor gauge in 1000 g increments, where 1000 g is equal to 50 mm of rainfall. First, measurements were made while all three wires suspended the bucket normally. The depths calculated from the frequency of vibrating wires two (VW-2) and three (VW-3) were recorded as weights were added to the bucket. Next, to simulate a break in a wire, the adjusting set screw of sensor one (VW-1) was turned two turns counterclockwise, resulting in a 1.4 mm drop, and a bucket tilt of approximately one degree. After the turning of the screw, the two remaining wires suspended the bucket. Depths were again calculated from sensors two and three, taking measurements while adding weights incrementally. See Figure 5 for a view of the three wire suspension (left) and for a view of the set screw placement (right).

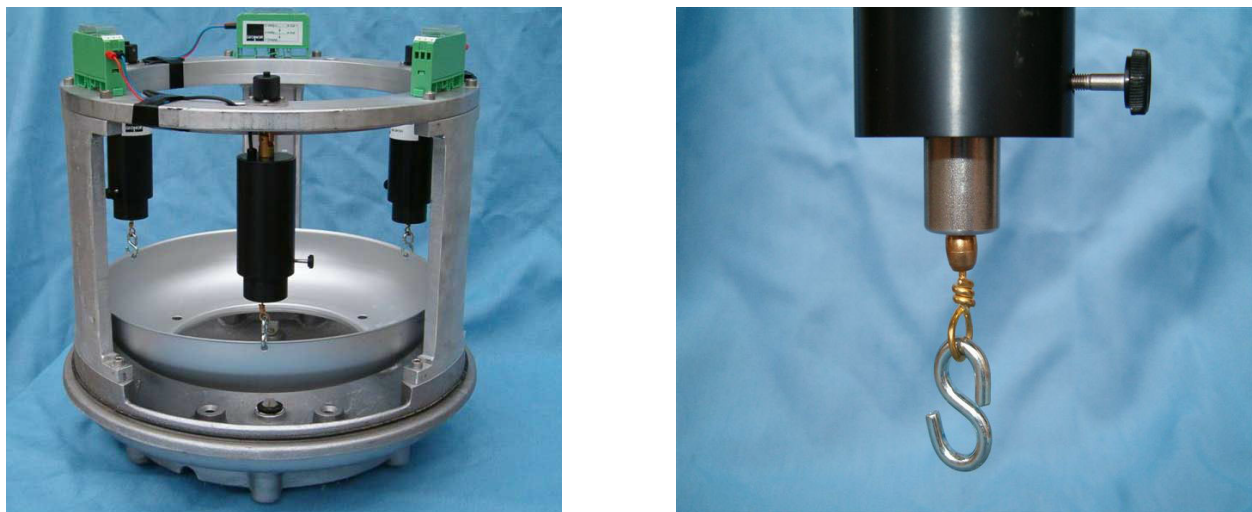


Figure 5: Three wire suspension (left) and set screw (left)

The experimental measurements made on VW-2 and VW-3 are recorded in Tables 1 and 2, respectively (next page.) The change in the calculated depths before the simulated break was compared

	Before Simulated Break					After Simulated Break					Difference	
	Frequency F	F-Fo	Depth (mm)	Rate of Change (Actual)	Percent Error	Frequency F	F-Fo	Depth (mm)	Rate of Change (Actual)	Percent Error	Before - After	Rate of Change
0	1066.3	0	0.000	0.000	0.000	1064	0	0.000	0.000	0.000	0.000	0.000
1000	1322.9	256.6	49.202	49.202	-1.597	1323.6	259.6	49.848	49.848	-0.304	-0.065	-0.647
2000	1534.2	467.9	98.767	49.565	-0.869	1534.6	470.6	99.453	49.605	-0.790	-0.069	-0.040
3000	1718.3	652	148.615	49.848	-0.304	1718.8	654.8	149.421	49.968	-0.064	-0.081	-0.120
4000	1883.2	816.9	198.532	49.917	-0.166	1883.6	819.6	199.391	49.970	-0.060	-0.086	-0.053
5000	2034.5	968.2	248.712	50.179	0.359	2034.4	970.4	249.472	50.081	0.163	-0.076	0.098
6000	2174.5	1108.2	298.877	50.165	0.330	2173.8	1109.8	299.471	49.998	-0.004	-0.059	0.167
7000	2306.3	1240	349.382	50.506	1.011	2305.6	1241.6	350.015	50.544	1.088	-0.063	-0.039
8000	2429.9	1363.6	399.635	50.253	0.506	2428.8	1364.8	400.137	50.122	0.244	-0.050	0.131
9000	2548.4	1482.1	450.440	50.805	1.611	2546.3	1482.3	450.528	50.392	0.783	-0.009	0.414
10000	2660.5	1594.2	500.868	50.428	0.855	2658.3	1594.3	500.914	50.386	0.772	-0.005	0.042
11000	2769.3	1703	552.011	51.143	2.286	2765.1	1701.1	551.100	50.185	0.371	0.091	0.958
12000	2874	1807.7	603.273	51.262	2.524	2868.4	1804.4	601.627	50.527	1.055	0.165	0.735

Weight g	Before Simulated Break					After Simulated Break					Difference	
	Frequency F	F-Fo	Depth (mm)	Depth Change (Actual)	Percent Error	Frequency F	F-Fo	Depth (mm)	Depth Change (Actual)	Percent Error	Before - After	Rate of Change
0	1061.7	0	0.000	0.000	0.000	1059.1	0	0.000	0.000	0.000	0.000	0.000
1000	1318.8	257.1	49.309	49.309	-1.382	1319.9	260.8	50.107	50.107	0.214	-0.798	-0.798
2000	1529.1	467.4	98.640	49.331	-1.338	1527.8	468.7	98.970	48.863	-2.274	-0.330	0.468
3000	1715.2	653.5	149.047	50.407	0.813	1713.0	653.9	149.162	50.192	0.383	-0.115	0.215
4000	1878.5	816.8	198.500	49.454	-1.092	1876.9	817.8	198.818	49.657	-0.687	-0.318	-0.203
5000	2028.8	967.1	248.332	49.831	-0.337	2022.9	963.8	247.193	48.375	-3.250	1.139	1.456
6000	2167.1	1105.4	297.838	49.506	-0.988	2162.0	1102.9	296.912	49.719	-0.562	0.926	-0.213
7000	2295.9	1234.2	347.093	49.255	-1.491	2293.5	1234.4	347.172	50.259	0.519	-0.079	-1.005
8000	2417.5	1355.8	396.381	49.288	-1.423	2415.0	1355.9	396.423	49.251	-1.498	-0.042	0.037
9000	2533.8	1472.1	446.054	49.673	-0.655	2532.3	1473.2	446.535	50.113	0.225	-0.482	-0.440
10000	2645.7	1584.0	496.185	50.131	0.262	2642.7	1583.6	496.001	49.466	-1.068	0.183	0.665
11000	2752.0	1690.3	545.930	49.745	-0.510	2748.7	1689.6	545.595	49.594	-0.812	0.334	0.151
12000	2854.1	1792.4	595.657	49.727	-0.545	2850.6	1791.5	595.210	49.615	-0.770	0.447	0.112

Table 1 (top): Sensor VW-2 Depth = $0.0000091535*(F-Fo)**2 + 0.0168256371(F-Fo)$

Table 2 (bottom): Sensor VW-3 Depth = $0.0000092289*(F-Fo)**2 + 0.0168701749(F-Fo)$

to the depth change after the simulated break. These values are plotted in Figures 6 and 7 for sensors VW-2 and VW-3 (next page.) The blue bars represent the values before the break, and the magenta bars represent the measurements after the break. From these graphs, it is evident that the actual change in the calculated depth was very close to the theoretical value of 50 mm. This was true for both before and after the simulated break and true for both sensor VW-2 and sensor VW-3.

Next, the percent error in depth change was compared to the theoretical value of 50 mm, before and after the simulated break. This is shown in Figures 8 and 9 for VW-2 and VW-3, respectively (next page.) There was an error of less than 1% over much of the range of weights, both for wires VW-2 and VW-3. The error varied randomly with depth and was traceable to noise in the signal.

The error introduced into the depth measurement with the two remaining transducers was well within specifications.¹⁰ The FPD enabled the remaining two sensors to be as effective as the original

Depth Change Between Weights (Sensor 2)

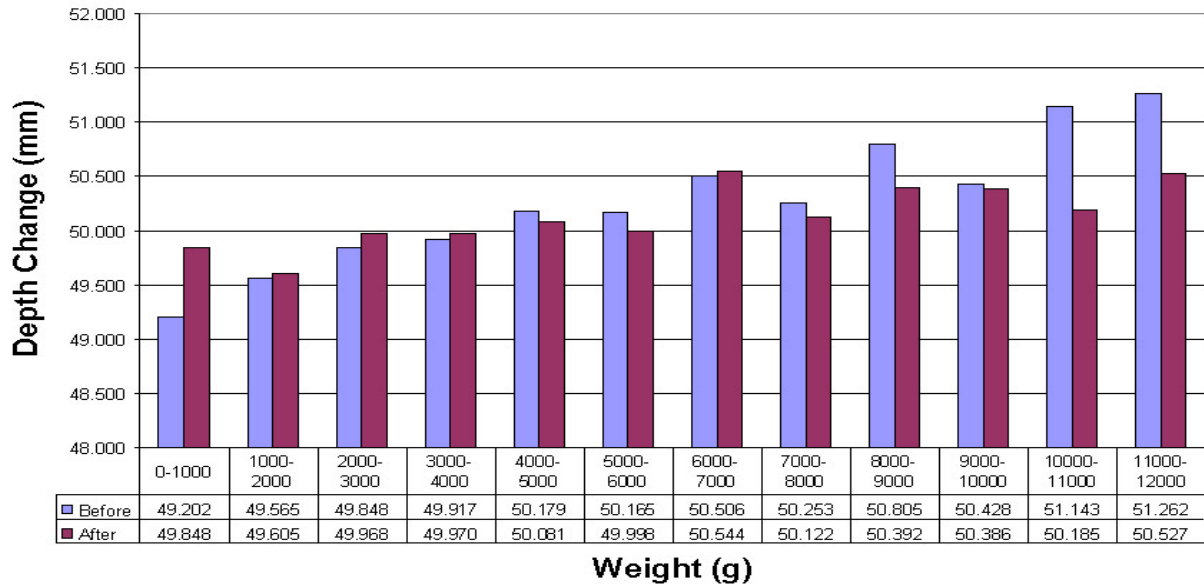


Figure 6: Sensor VW-2 change in calculated depth before and after simulated break of VW-1

Depth Change Between Weights (Sensor 3)

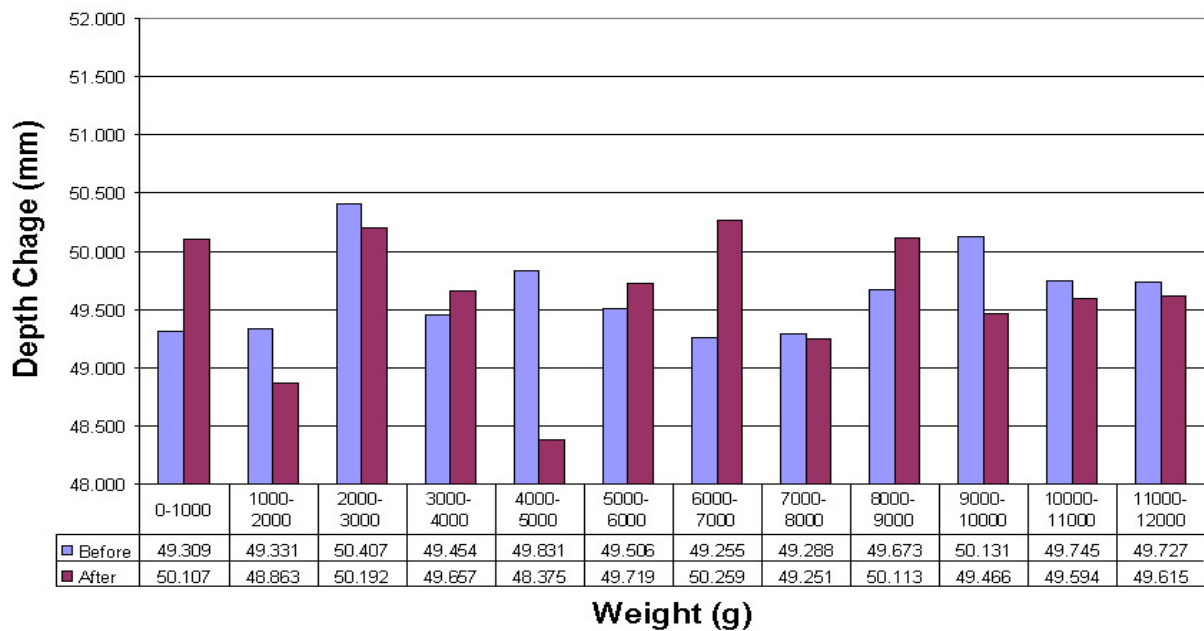


Figure 7: Sensor VW-3 change in calculated depth before and after simulated break of VW-1

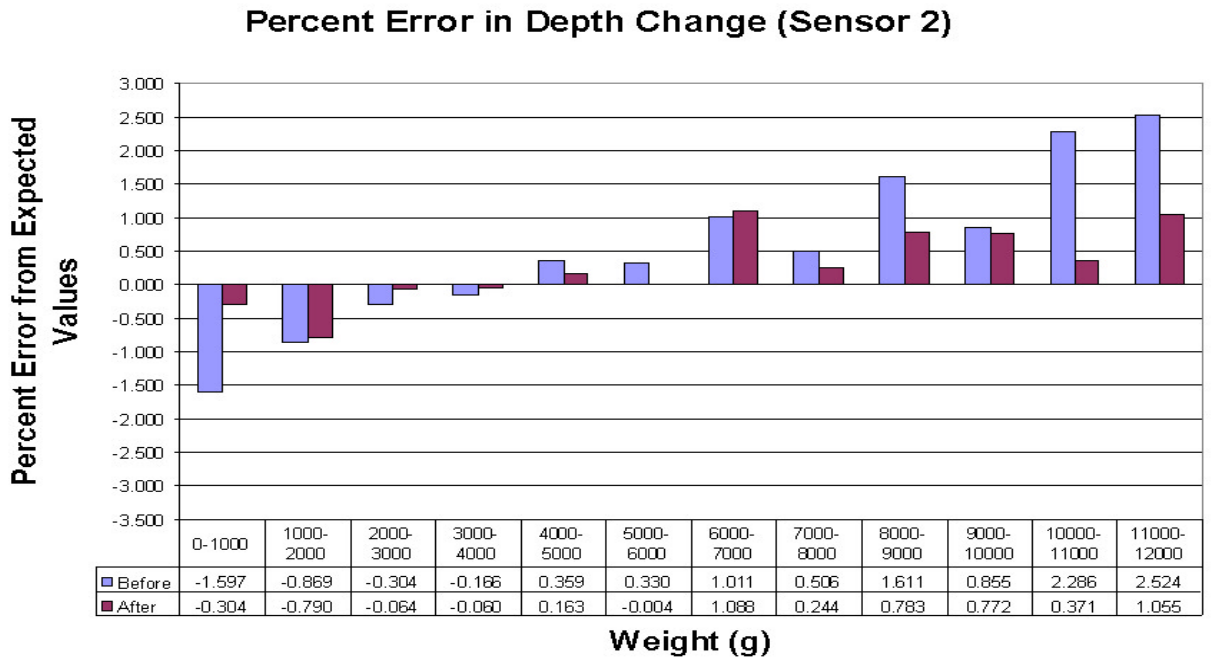


Figure 8: Percent error in depth change for sensor VW-2

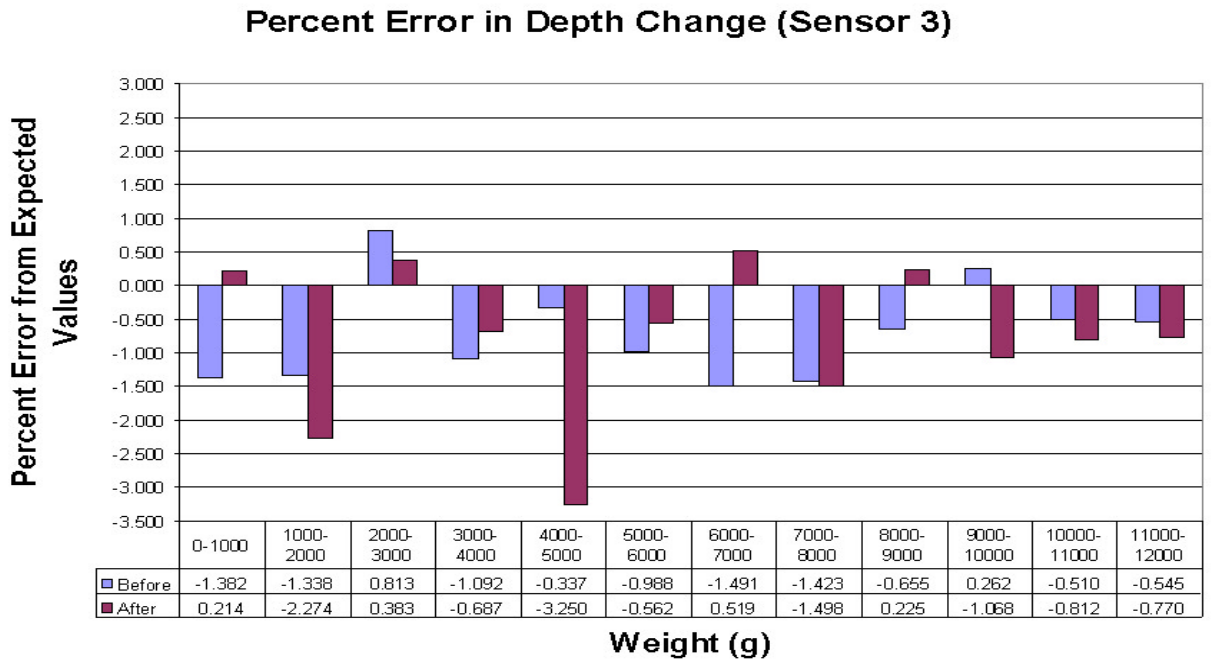


Figure 9: Percent error in depth change for sensor VW-3

three sensors. The two remaining wires continued to function and the depth measurements were not significantly affected.

4. Field Validation

Data from USCRN sites were examined to validate the operation of the FPD. Several sites had broken wires. See the chart below.

Station Name	FPD Installed	Wire Broke	Wire Replaced	Set Screw
<i>Wire broke, no FPD, set screw to mimic FPD</i>				
Redding, CA	12/22/03	11/10/03 VW-1, VW-3	12/03/03	11/19/03
Darrington, WA	12/22/03	12/15/03 VW-1, VW-2	12/22/03	12/16/03
<i>Wire broke before installation of FPD</i>				
Limestone, ME	9/16/03	8/29/03 VW-2	9/16/03	
<i>Wire broke after installation of FPD</i>				
Fairbanks, AK	9/15/03	11/01/03 VW-3	1/14/04	
Goodridge, MN	8/20/03	12/28/03 VW-3	1/12/04	
Manhattan, KS	10/1/03	12/22/03 VW-1	1/12/04	
Old Town 2W, ME	10/18/03	11/05/03 VW-3	11/24/03	
Redding, CA	12/03/03	12/23/03 VW-2	1/16/04	

The first analytical step is to examine depth data from two stations not equipped with FPDs, Redding CA and Darrington, WA. Both stations had two broken wires.

The Redding 12 WNW, CA, site had two broken wires on November 10, 2003, and was not equipped with a FPD. There were no valid precipitation data from the site at this point. The data logger transmitted null depth values (-6999) for VW-1 and VW-3. However, according to maintenance records recorded in the USCRN Anomaly Tracking System¹¹, a technician performed a temporary repair on November 19, 2003. The steel cylinder was re-inserted and the setscrews on each of the two broken wires were tightened (to hold the cylinder in place), and the bucket was leveled. At this point, the sensors were in a configuration similar to the laboratory experiment, although two broken wires had not been tested explicitly in the laboratory. (The factory configuration of the Geonor gauge is to measure with a single wire.) Following the technician's temporary repair, 500 ml of water was added to the gauge to verify that VW-2 recorded the depth changes accurately and that the sensor would record precipitation. Figure 10 (next page) shows the precipitation plot for November 29, 2003, at Redding as calculated from the depth readings of VW-2. Total daily precipitation amounted to 27.6 mm or 1.09 inches. The Redding Airport¹² measured 0.92 inches for the day. The USCRN site is located 12 miles northwest of the airport in the Whiskeytown National Recreation area and is co-located with a RAWS sites. Using ancillary data, such as radar data, it would appear that the one wire at the Redding USCRN recorded precipitation accurately. The sensors were later replaced on December 3, 2003. During this maintenance visit, it was noted that the RAWS station itself was not functioning and was repaired.

There was no tipping bucket gauge reporting at this site at this time.

The Darrington 21 NNE, WA, site had two broken wires on the morning of December 15, 2003, and was not equipped with a FPD. The depth values on the broken wires went from 155 mm to null (-6999). Later that same day, according to ATS maintenance records, a technician performed a temporary fix, just as was done at Redding. It was further recorded in ATS that the remaining wire (VW-3) was sensing precipitation in a nominal fashion, based on the displayed Seattle radar data. Figure 11 shows light precipitation at Darrington 21 NNE, WA recorded the following day, December 16, by VW-3. 2003. The sensors were later repaired on December 22, 2003.

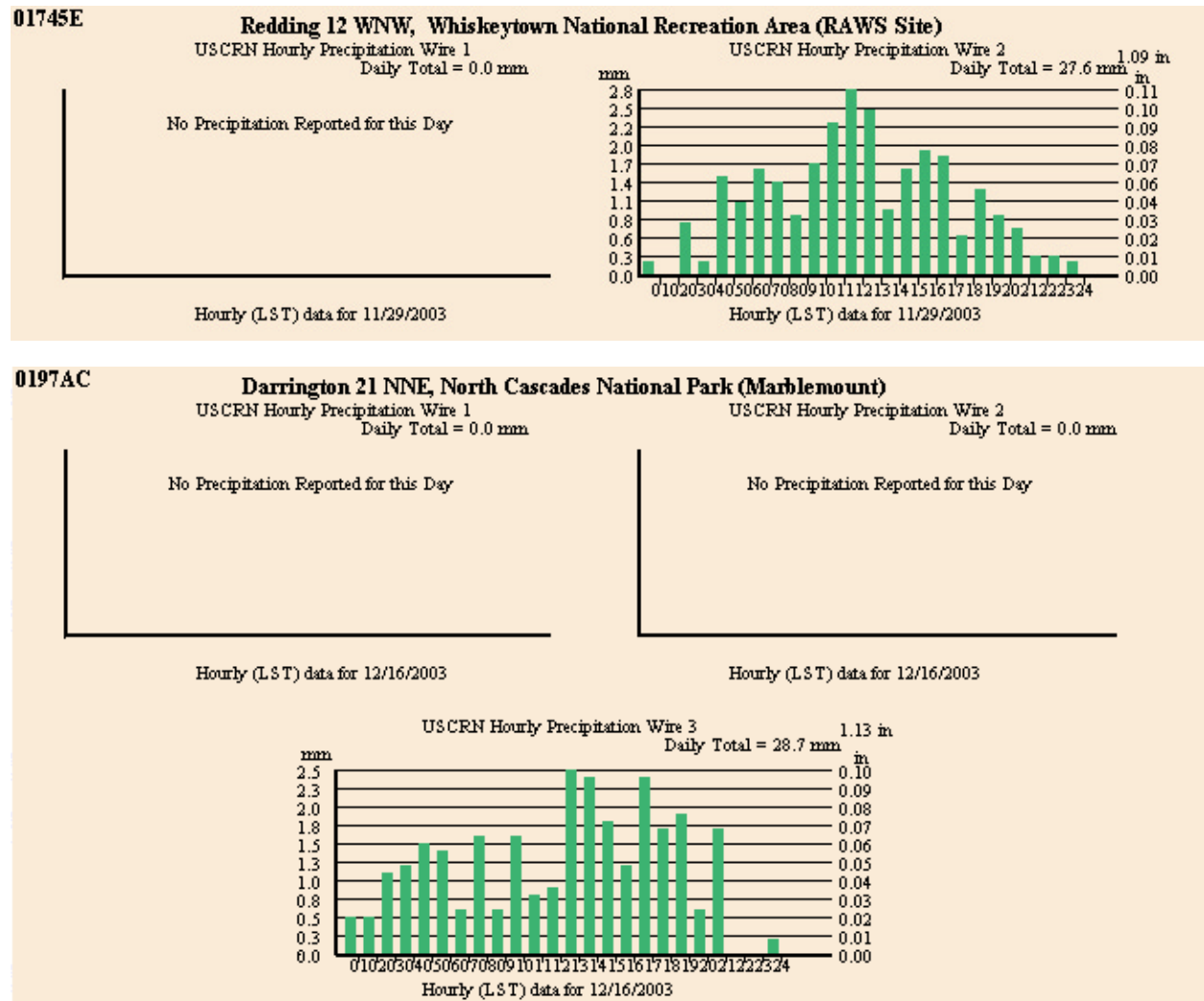


Figure 10: Precipitation plot for Redding 12 WNW, CA, on Nov. 29, 2003 (top)

Figure 11: Precipitation plot for Darrington 21 NNE, WA, on Dec. 16, 2003 (bottom)

The second analytical step is to examine depth data from two stations having one broken wire, but one station is equipped with the FPD. Depth values reported from each of the three wires at both stations are shown in Figure 12 on the following page. The depth values reported from stations with and without FPDs during a wire breakage are compared. At Limestone, ME, VW-2 broke on August 29, 2003, well before the installation of a FPD. The broken wire reported null values after the break. The depth values from the two remaining wires diverged, reporting erroneous precipitation values as

the bucket tilted out of balance. At Old Town, ME, VW-3 broke on November 5, 2003. The FPD had been previously installed October 18, 2003. The depth values reported from the broken wire decreased rapidly and then leveled off to a constant negative value. The depth values from the two remaining sensors were steady.

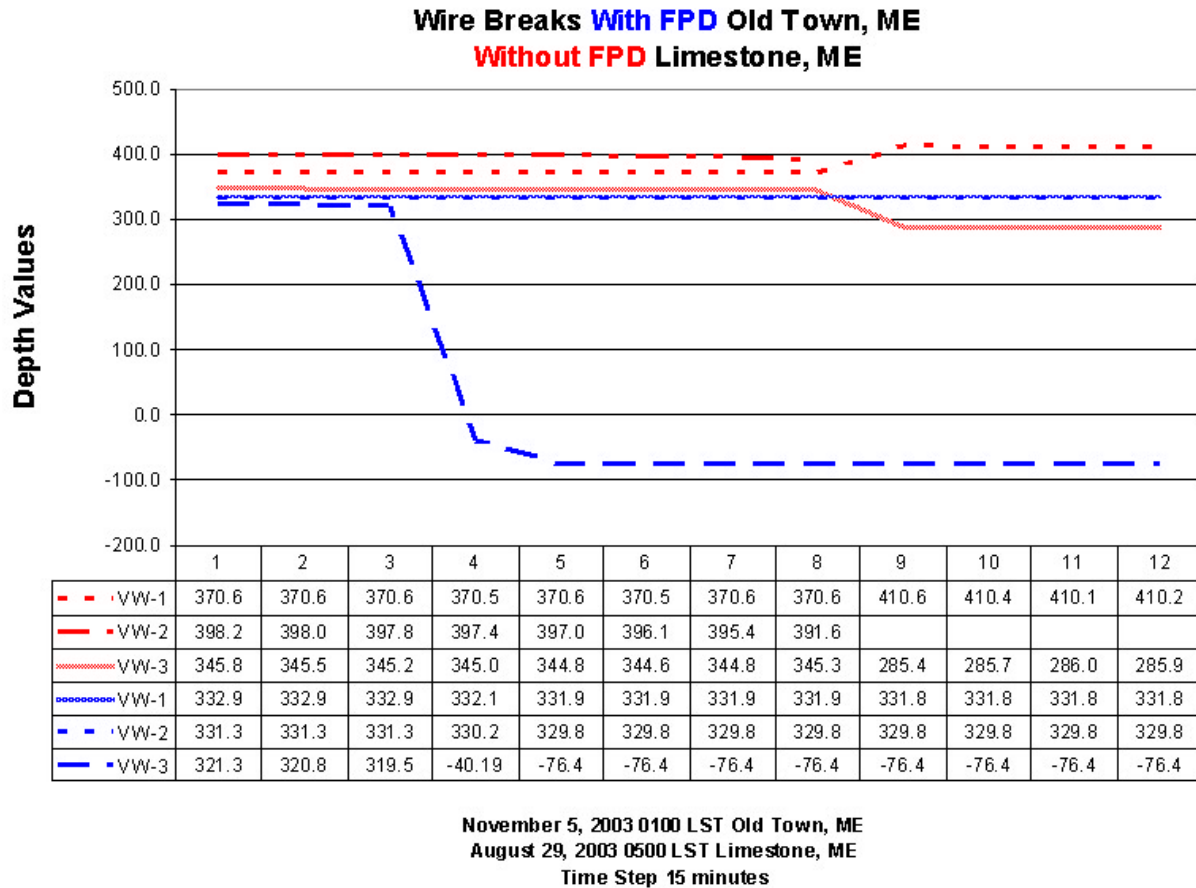


Figure 12: Depth values from Limestone and Old Town, ME

The next step is to examine precipitation measurements from stations equipped with a FPD and with one broken wire. Results show that precipitation was recorded accurately from the two remaining wires at these sites, though the number of precipitation events between the break and the repair was limited. A detailed examination of the precipitation values measured at two of these sites is presented.

A zoom view of the depth values at the time of the break at Old Town is shown in Figure 13 (next page.) The values for VW-3 were not plotted after the break in order to keep the graph to scale. Note the rise in the depth curves for the remaining two wires. Light precipitation at Old Town on November 5, 2003, was verified. The values of the VW-1 and VW-2 depths and resulting precipitation are plotted in Figure 14 (left and right, page 11.) The plots appear to be identical. A few days later, on November 20, 2003, heavier amounts of precipitation occurred. Precipitation plots from the remaining two wires at Old Town are shown in Figure 15 (page 11.) The precipitation values derived from the depth measurements from VW-1 and VW-2 show good agreement.

Broken Wire Example Old Town, ME

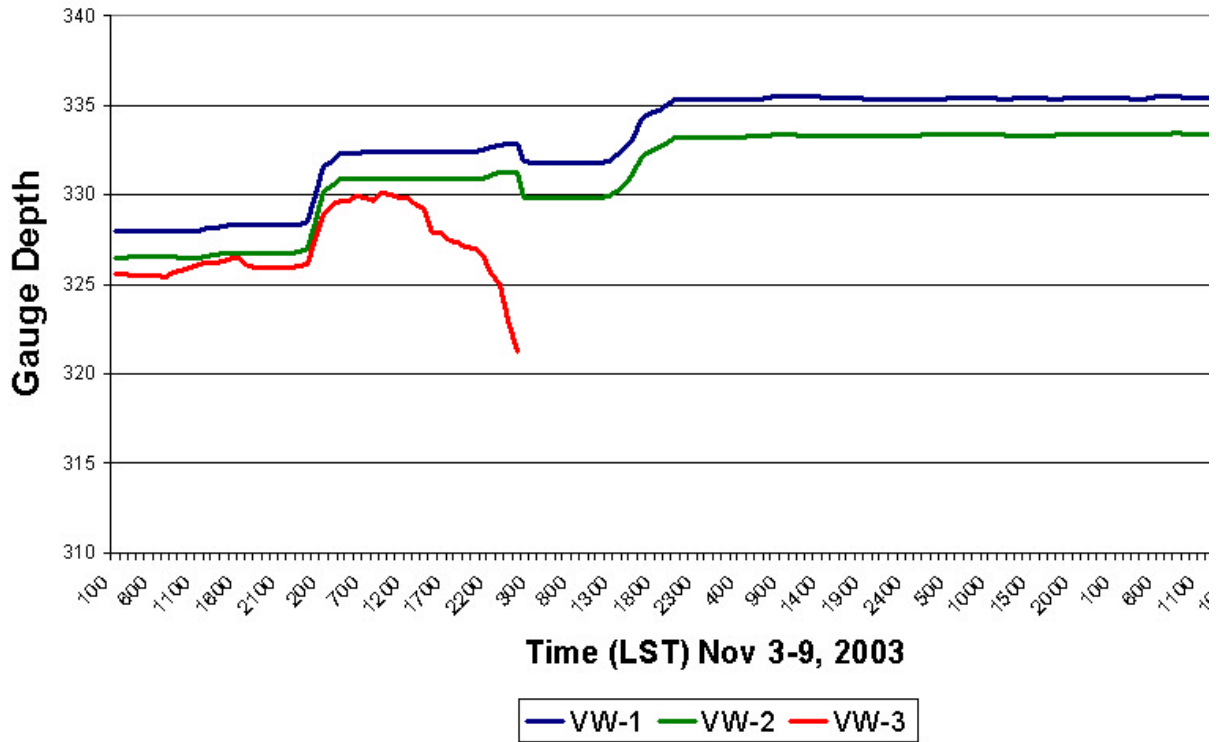


Figure 13: Depth values at the time of the break at Old Town, ME

Broken Wire Example Old Town, ME

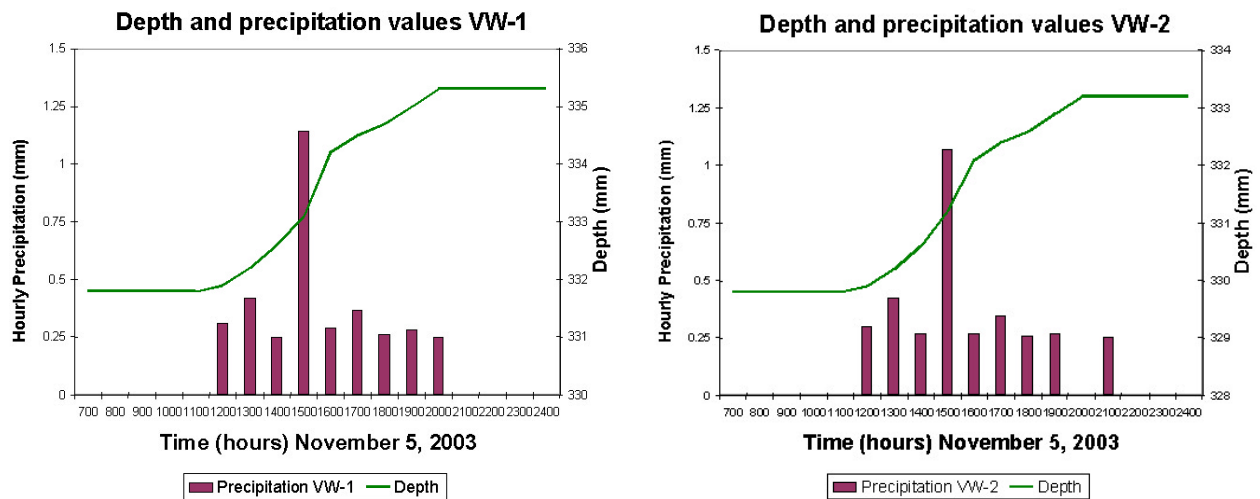


Figure 14: VW-1 (left) and VW-2 (right) depths and resulting precipitation.

Old Town, ME, Precipitation Measurements with FPD, One Broken Wire

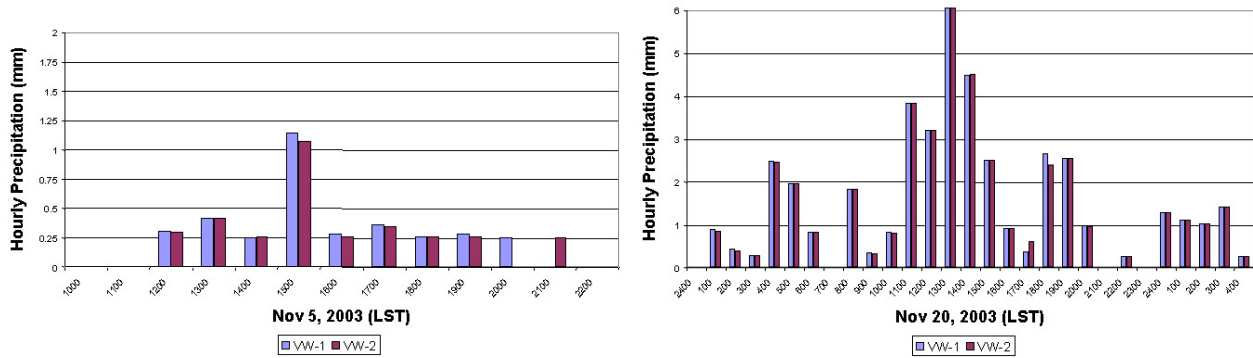


Figure 15: Precipitation values for Old Town sensors VW-1 and VW-2 on Nov. 5, 2003 (left), and Nov. 20, 2003 (right.)

To statistically compare the values of the VW-1 and VW-2, a Student T test was performed on both the light and heavier precipitation events at Old Town. For this test, the 15-minute precipitation values of precipitation were used in order to increase the number of samples (and degrees of freedom). Results in Table 3 (below) show that the measurements differences between VW-1 and VW-2 were insignificant in each of the events. No Tipping Bucket gauge was installed at Old Town, ME.

Location	Event Date and Times (LST)	Sample Size	Probability	T-Value
Old Town, ME	2000-2400 Nov. 5, 2003	32	0.096	1.7
Old Town, ME	2400 Nov. 19 – 0400 Nov. 21, 2003	116	0.941	0.073
Redding, CA	0800 Dec. 23 – 0800 Dec. 24, 2003	100	0.509	0.662
Redding, CA	0100 – 1800 Jan. 8, 2004	72	0.744	0.327

The sensors at Redding 12 WNW, CA, had been fitted with FPDs on December 3, 2003. After this, VW-2 broke during a precipitation event on December 23, 2003. According to ATS records, repairs to that sensor did not occur until January 16, 2004. Two precipitation events between that single wire break and the repair were examined, moderate precipitation on December 23, 2003 (see Figure 16, next page) and light precipitation on January 8, 2004 (see Figure 17, next page.) A student T test was performed on the 15 minute values of precipitation of both events (see Table 3.) The differences between VW-1 and VW-3 were insignificant. Total precipitation in the time period was measured at 85.8 VW-1 and 85.3mm VW-3. The Tipping Bucket Gauge installed at Redding measured 81.8 mm for the same time period.

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Redding 12 WNW, Whiskeytown National Recreation Area (RAWS Site)

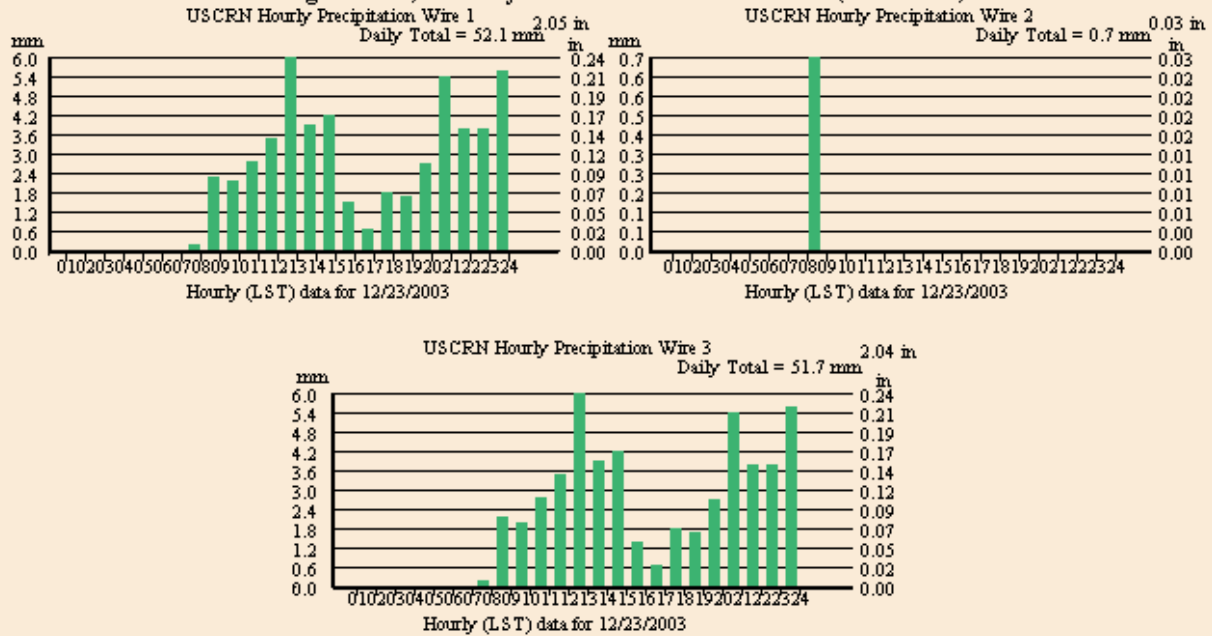


Figure 16: Redding 12 WNW, CA, hourly precipitation for VW-1, VW-2, and VW-3 (clockwise from top left) on Dec. 23, 2003.

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Redding 12 WNW, Whiskeytown National Recreation Area (RAWS Site)

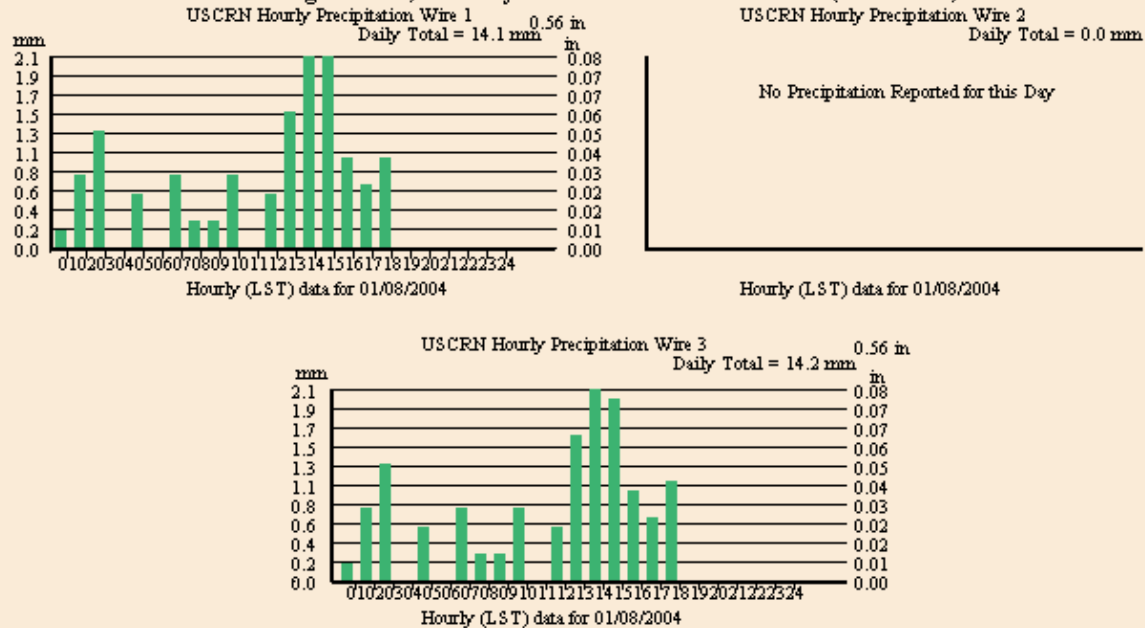


Figure 17: Redding 12 WNW, CA, hourly precipitation for VW-1, VW-2, and VW-3 (clockwise from top left) on Jan. 8, 2004.

5. Conclusion

The FPD was described and a diagram and photos were provided. Laboratory tests were presented, and validating field site data were presented. Both light and heavy precipitation events, which occurred between the time of wire breakage and repair, were examined. It was demonstrated that the device allowed accurate precipitation records to be derived from the depth measurements of the remaining sensors. Additionally, it appears that even with two broken wires, the single remaining wire records depth values accurately, although the samples of precipitation events were limited in number. Analysis in the field agreed with the experimental results.

6. Disclaimer

Mention of a commercial company or product is for information purposes only, and does not constitute an endorsement by NOAA. Use for publicity or advertising purposes of information from this publication concerning proprietary products or the tests of such products is not authorized.

7. Endnotes

1. For USCRN hardware configuration information see - Meyers, Tilden P, M. E. Hall, et. al, 2004, January 12-16: Current configuration of US Climate Reference Network stations, Proceedings: Eighth Symposium on Integrated Observing and Assimilation Systems for Atmosphere, Oceans, and Land, American Meteorological Society, Seattle, WA, Session 5.5.
2. Original design by Mark E. Hall, Oak Ridge Associated Universities, assigned to NOAA/Atmospheric Turbulence and Diffusion Division (ATDD), Oak Ridge, TN.
3. Described in USCRN Configuration Management Plan, NOAA/NESDIS Series X 033, NOAA-CRN/OSD-20020005R0UD0, (December 2002), 21 pp.
4. USCRN Document Number CCR 2003-06: Geonor Wire Failure Prevention Device 7/9/03
5. USCRN Field site Maintenance Plan, NOAA/NESDIS Series X041, NOAA-CRN/OSD-2003-00010R0UD0, (November 19, 2003), 39 pp., Section 4.4.1, Table 3, page 6 Corrective Maintenance/Time to Restore Requirements.
6. USCRN CRNSITES Metadata Database accessible through website at: <http://www.ncdc.noaa.gov/oa/climate/uscrn/>
7. For algorithms and manufacture's details on the Geonor precipitation gauge, see USCRN Web site at: <http://www.ncdc.noaa.gov/oa/climate/uscrn/in-dex.html> under headings "Instruments - Site Hardware"
8. Fabricated by Tennessee Tool and Engineering, of Oak Ridge TN from ATDD specifications

9. Presentation by William Stochaviak, Student Intern at the Atmospheric Turbulence and Diffusion Division, June 2003, Laboratory test conducted under direction of Mark E. Hall and Tilden P. Meyers

10. USCRN USCRN Functional Requirements Document. NOAA/NESDIS CRN Series X040, NOAA-CRN-20030009R0UD0 (June 27, 2003), 13 pp, Section 3.2.5 page 6 Accuracy of the precipitation measurements, the greater of 0.25mm or 2% of the reported value. Therefore the required accuracy of the depth change at 1000g (the lowest level of the test) is 2.5 mm. At 12000g (the highest weight load of the test) the accuracy of the depth change is 12mm. See Figures 6 and 7.

11. Anomaly Tracking System described in US Climate Reference Network (USCRN), Handbook for Manual Quality Monitoring June 11, 2003.

12. Preliminary Local Climatological Data (Form F-6), Redding Airport, latitude 30 30N, Longitude 122 18 W referenced from URL: <http://www.wrh.noaa.gov/sacramento/html/RDDLCDNOV.html>