SRDC ASOS DOCUMENT CONTROL SHEET

Final Report For The Winter Test of Production All-Weather Precipitation Accumulation Gauge Winter 2007-2008	**DATE: 6/17/2008**

ORIGINATOR: Gregory Whitaker

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STAGE 2: ASOS PI PM Review:	John Monte	00/00/2008		
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	Brian Rice	00/00/2008	N	
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COMMENTS:

FINAL W/OST1 REVIEW & APPROVAL:	DATE:

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FINAL REPORT FOR

WINTER TEST OF PRODUCTION
ALL-WEATHER PRECIPITATION ACCUMULATION GAUGE (AWPAG)

NOVEMBER 2007 – MAY 2008

Version 3

July 7, 2008

Prepared for

ASOS Product Improvement Program

National Weather Service W/OST1

John Monte, ASOS PI Manager
by

SAIC
From Science to Solutions

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EXECUTIVE SUMMARY

Background

The National Weather Service (NWS) ASOS Product Improvement (PI) team evaluated commercial off-the-shelf (COTS) sensors from October 2000 to March 2001, eventually awarding a contract to C.C. Lynch and Associates (CCLA) of Pass Christian, Mississippi, in partnership with OTT Hydrometry of Kempten, Germany. Approval for the limited production of twenty sensors was granted to the contractor by the NWS. A variety of Alter shields have been constructed over the testing periods to enhance precipitation catch of the AWPAGs, and many versions of firmware have been developed for AWPAG improvement. See REFERENCES section for prior Alter shield and firmware versions and their results.

A more rigid shield mounting structure that eased AWPAG maintenance and a new lamella design was established for the winter 2007-2008 test, with slightly longer ATDD shield Lamellas and slightly greater spacing in between. These improvements were made to prevent the hoop from jumping out of the slots on the support arms. Fasteners now secure the hoop in the slot. This new “version III” shield also contains support arms which are perpendicular to the hoop arc, eliminating the possibility of a flipped lamella resting on that support arm. This new shield was installed on Sensor #705 in the Johnstown test bed fairly late into the winter test. This shield remained in the test bed from February 20, 2008 until April 2, 2008 (when it was shipped to Caribou, ME for further testing). This shield was not installed for testing at Sterling, VA.

In addition to testing the new shield design, firmware Version 3.60 was evaluated. It was installed in December 2007 at Sterling. This new firmware version addresses the temperature for the orifice heater cut-off and prevents false tips without missing true precipitation.

Results

The upgrade of firmware version 3.60 worked well in Sterling, VA until false tips began to occur on all four AWPAGs. After a thorough investigation, it was determined that the new firmware was resetting the Temperature Compensation (TC) values of the AWPAGs. The problem was corrected by OTT and a new firmware version (3.61) was created, delivered, and installed on the AWPAGs. None of the data from Sterling before the date which firmware v3.61 was installed (5/2/08) was included in winter 2007-2008 testing purposes.

One of the AWPAGs (Sensor #198) in Johnstown, PA also began experiencing frequent false tips around November 11, 2007. The sensor was examined several times, but no causes of malfunction could be determined; the sensor was removed from the Johnstown test bed on April 2, 2008, and none of the data from Sensor #198 was used for winter 2007-2008 data analysis. All AWPAGs in Johnstown were configured with firmware version 3.58 throughout all 5 events analyzed in the winter test.

Five events were evaluated in Sterling during the 2007-2008 test, all of which were comprised of liquid precipitation. All but one of the AWPAGs met the event requirements **100%** of the time; the AWPAG inside the large wooden DFIR met the event requirements **80%** of the time. The AWPAGs at Sterling reported an average of 0.011 to 0.023 inches different from the manual gauges.

Slightly different results were seen in Johnstown during the 2007-2008 test, where five events were evaluated. The AWPAG with the old version II OTT 8-foot diameter outer Alter shield (Sensor #702) met the specification requirements **60%** of the time, while the AWPAG with the new version III OTT Alter Shield (Sensor #705) met the event requirements **100%** of the time. The AWPAG 8-foot diameter outer Alter shield with the ATDD lamella design (#715) met requirements in **20%** of the events. The AWPAGs at Johnstown reported an average of 0.023 to 0.057 inches different from the manual gauges.

Water content was investigated in the events from Johnstown. Changes between snow, ice, and freezing rain made it hard to analyze the true water content of the first event. The snow to water ratio for Event 1 was able to be estimated at **8:1**. The other four events were comprised mostly of snow and saw slightly clearer results. Event 2 (2/26-2/27) averaged a **40:1** snow to water ratio, Event 4 (2/29-3/1) had a **14:1** ratio, and event 5 (3/21-3/23) had a **10:1** ratio. Event 3 (2/27-2/28) had a **100:1** snow to water ratio.

High wind events were also investigated for the winter 2007-2008 test. In Johnstown, each of the events experienced windy conditions. The first and fourth events seem to have been affected the most by high winds. The first event (2/21-2/23) experienced winds ranging from 6-14 mph, with gusts up to 21 mph, while the fourth event (2/29-3/1) experienced even stronger sustained winds of 5-22 mph and gusts up to 33 mph. The majority of the AWPAGs recorded slightly more precipitation than the manual gauges.

In Sterling, two of the five events experienced relatively windy conditions, possibly lowering precipitation catch. In the first and last events, 5/8-5/9 and 5/31-6/2 respectively, several of the AWPAGs outperformed the manual gauges. The first event had winds between 7 and 20 mph, and gusts of 25 mph. The final event experienced even windier conditions. Thunderstorms brought 7-24 mph sustained winds and gusts of 17-33 mph to the area.

Conclusions

Testing during 2007-2008 has allowed for several discoveries regarding the firmware, shields, and AWPAGs themselves. The test has shown that the new version III OTT Alter shield outperformed all of the other gauges in Johnstown, as it passed specification in all 5 events. Overall, the new OTT shield shows a significant improvement in performance compared to the standard shield.

Testing in Sterling has shown that all AWPAGs equipped with firmware version 3.61 are compliant with the specification. AWPAGs equipped with firmware version 3.61 did not experience any known false tips, and passed every event with the exception of one sensor.

Overall, low water content cannot be determined to be a major issue at Johnstown or Sterling. The third event in Johnstown (2/27-2/28) was the only event in which low water content conditions may have had a substantial effect on precipitation totals. The remaining events consisted of fairly wet snow. There were no events analyzed from Sterling that contained frozen or mixed precipitation; therefore, low water content is not an issue at Sterling.

It can be concluded that the high winds that occurred in the first and fourth analyzed events at Johnstown had an impact on the AWPAG data. Two of the five gauges in Johnstown, sensors #715 and #729, failed to meet the event requirements because of over reporting in precipitation. It was also determined that winds did not have a significant impact on precipitation catch in Sterling; each AWPAG met the necessary specifications by passing between 80% and 100% of the events.

1.0 BACKGROUND

The heated tipping bucket (HTB) was the initial precipitation accumulation gauge used when the Automated Surface Observing System (ASOS) was deployed. The sensor measures liquid accumulation, but is not specifically designed to accurately measure liquid equivalent of freezing or frozen precipitation. The accurate measurement of liquid equivalent accumulation in all types of liquid, solid, and mixed precipitation is an important part of weather observations. The National Weather Service (NWS) ASOS Product Improvement (PI) team evaluated commercial off-the-shelf (COTS) sensors from October 2000 to March 2001. The government down-selected to one vendor and a contract for design and development of ten pre-production gauges was awarded on September 25, 2001, to C.C. Lynch and Associates (CCLA) of Pass Christian, Mississippi, in partnership with OTT Hydrometry of Kempten, Germany.

Subsequent to required environmental qualification testing of six pre-production gauges, approval for limited production of twenty sensors was granted to the contractor by the NWS. Operational acceptance testing of these sensors was conducted during the winter of 2002-2003 at selected ASOS sites across the United States.

In late August 2003, firmware version 3.58 was installed to replace version 3.55 in Sterling and Johnstown. The major change to V3.58 firmware was the re-design of the internal algorithm that determines the threshold for precipitation intensity. The new algorithm calculates the precipitation intensity threshold on a minute by minute basis resulting in a more accurate threshold with lower accumulation losses. In addition, all production balance mechanisms are now characterized for temperature influence at high and low extremes to develop a temperature compensation factor that minimizes performance differences among gauges. AWPAG firmware 3.59 was installed in November 2005 to allow for a user alterable low temperature orifice heater cut-off, but was removed in February 2007 due to a heater cycle that allowed for an ice bridge to form.

Precipitation intrusion was addressed with a redesign of the orifice that increased the overlap of the bottom of the orifice and the top of the catch bucket. Orifice heating was increased slightly to account for the larger orifice mass. Production AWPAGs reflecting these changes replaced the pre-production AWPAGs in October 2003. Testing during the winter of 2003-2004 produced inconclusive results at Johnstown most likely as a result of test bed shadowing by the large Double Fence Intercomparison Reference (DFIR) windshield that produced deep snow drifts in the test bed. This issue was addressed when the large DFIR was relocated from the windward side of the test bed at Johnstown, Pennsylvania.

Winter of 2004-2005 testing demonstrated that the AWPAG met the NWS hourly requirements, but failed to meet the event requirements due to under-reporting in sustained wind driven mixed and/or frozen precipitation. Based on these results, an 8-foot diameter Alter-style wind shield surrounding a production AWPAG/Tretyakov was added. This configuration equaled or exceeded the catch of the NWS reference gauge. Upon completion of this testing, CCLA/OTT Hydrometry designed and fabricated prototype 8-foot diameter Alter-style wind shields that bolted directly to the existing Tretyakov wind shield mounts for the winter 2005-2006 test. A significant improvement in performance was shown with the AWPAG with added 8-foot Alter shield versus the standard Tretyakov shield.

A more rigid shield mounting structure that eased AWPAG maintenance and a new lamella design was established for the winter 2007-2008 test. The new ATDD shield Lamellas were slightly longer and the spacing between lamellas was slightly greater. These improvements were made to prevent the hoop from jumping out of the slots on the support arms. Fasteners now secure the hoop in the slot. Also, the new shield contains support arms which are perpendicular to the hoop arc, eliminating the possibility of a flipped lamella resting on that support arm.

In addition to testing the new shield design, firmware version 3.60 was evaluated. See Section 4.3 for more information on this new firmware.

2.0 PURPOSE

The purpose of this test was to perform a winter assessment of the production AWPAGs based on compliance with the AWPAG performance requirements in NWS specification D113-SP001. The results of these tests are intended to validate the final production AWPAG configuration.

The goals of the winter 2007 - 2008 test at Sterling and Johnstown were:

- Determine test gauge comparability to collocated reference sensors, in all types of precipitation, based on the NWS AWPAG accuracy requirements in Section 3.0

- Determine compliance with requirements for false reports of precipitation accumulation.

- Compare gauge performance between the production AWPAGs with Tretyakov shields, production AWPAGs with the 8-foot diameter Alter shields and production AWPAGs in the small and large DFIR, which are used for reference purposes only.

- Study effects on AWPAG accuracy with the addition of 8-foot diameter Alter shields in wind driven frozen precipitation.

- Install new firmware version 3.60, and study effects of improvements on precipitation catch. See Section 4.3 for additional details.

3.0 PERFORMANCE REQUIREMENTS

The following three paragraphs are the hydrometeorological performance requirements for the NWS AWPAG from Specification No. D113-SP001, Section 3.3.1.4:

The AWPAG shall be linear over the entire measurement range, with an accuracy of ±4% or ± 0.02 inch, whichever is greater, when compared to a standard National Weather Service 8-inch non-recording precipitation gauge installed at the standard height with a National Weather Service Alter shield. Comparisons will be made on hourly accumulations and event accumulations.

When compared to the standard National Weather Service 8-inch non-recording gauge described above, the AWPAG shall not false report (report accumulation in the absence of precipitation) more than 0.09 inches for a single, continuous 30-day period. The goal is that there are no false reports.

It is recognized that smoothing or filtering algorithms may be required in order to reduce false precipitation reports. If such algorithms are required, the maximum acceptable delay in reporting of precipitation due to filtering shall be five (5) minutes.

The methodology for verification of these performance requirements is detailed in Section 5.0

4.0 TEST SITES AND CONFIGURATION

4.1 Test Locations and Data Collection

Testing took place at Johnstown, Pennsylvania, and Sterling, Virginia (firmware only); the two permanent test sites operated by the NWS Sterling Field Support Center. See Appendices B & C for maps of the Sterling and Johnstown test bed layouts.

One minute data for the Sterling and Johnstown test sites was collected from all test sensors using a personal computer based data acquisition system (DAS). ASOS heated tipping bucket was also included in the AWPAG data comparison. Data from all ASOS sensors at Sterling and Johnstown is available for use in post-processing. Typical reference weather sensors include a freezing rain sensor, visibility, temperature/dew point sensor, wind speed and direction, precipitation identification, and ceilometer. Additionally, a heated sonic anemometer is installed at gauge orifice height in proximity to the precipitation gauges to assess wind-induced effects. These reference data were also used in post-processing, in verifying false precipitation reports from the test gauges, and in case study analyses.

4.2 Sensor Description

4.2.1 Production AWPAG

One 56-inch capacity production AWPAG was tested at Sterling (firmware only). Figure 1 depicts an installation of an AWPAG that is typical at an ASOS site, including mounting on a 3-inch pipe, 18 inches above grade, with a free-standing Tretyakov wind shield flush with the 59-inch orifice height.

Figure 1 Production AWPAG

4.2.2 Production AWPAG in DFIR

Two production AWPAGs are installed at each test site in a small and large scale Double Fence Intercomparison Reference (DFIR) wind shield. Both DFIRs were built to minimize wind-influenced measurement losses (precipitation under-catch). These gauges were used only for comparison and not qualification.

4.2.3 Production AWPAG inside OTT 8-foot Diameter Alter Shield

One production AWPAG modified with an 8-foot diameter OTT-style Alter shield (Figure 2) was also tested at each test site. The shield is 2¼ inches above the height of the production AWPAG Tretyakov shield. This configuration was proposed by NWS to further reduce wind speeds around the orifice during wind influenced frozen precipitation events to increase AWPAG catch.

Figure 2 AWPAG with 8-foot diameter Alter Shield (OTT Style)

4.2.4 Heated Tipping Bucket

The standard ASOS HTB (Figure 3) was used as a comparison sensor for this test. The HTB gauges were not used to evaluate measurement accuracy of the test gauges, but did provide data for assessing improvements to ASOS precipitation measurements as a result of AWPAG deployment. HTB data was also used as an aid to determine false reports. The HTB gauges are installed with the standard ASOS vinyl wind shields one inch above the orifice height.

Figure 3 ASOS Heated Tipping Bucket

4.2.5 NWS 8-inch Manual Gauge

Four standard NWS 8-inch non-recording gauges were used for reference measurements of all types of precipitation at each test site (Figure 4). For each test site, two of the gauges were designated as hourly references and two as event references. All manual gauges at the test sites are installed with the orifice height at 60” (5 feet). Alter style wind shields were installed one inch above the orifice height on all of the manual gauges.

Figure 4 NWS 8-inch Manual Gauge

4.2.6 Production AWPAG with ATDD-Style Alter Shield

Two production AWPAGs modified with an 8-foot diameter ATDD-style Alter shield were tested at Johnstown. One shield is the original design manufactured by the Atmospheric Turbulence Diffusion Division (ATDD), and the other is a new version of the ATDD-style manufactured by OTT (Figure 5). The shield modification corrected the two problems identified in testing of the previous OTT shield design. First, to prevent the hoop from jumping out of the slots on the support arms, there are fasteners to secure the

Figure 5 AWPAG with version III OTT Alter Shield

hoops in their slots. Second, it was found that the lamellas could be flipped by the wind and end up resting on the nearby support arms. They would remain in this position and thereby reduce the effectiveness of the shield in disrupting wind flow and thereby causing a decrease in precipitation catch.

To correct this problem, the new shield the support arms were made to be perpendicular to the hoop arc, so there was no possibility of a flipped lamella resting on that support arm. Additionally the field test showed the ATDD style shield was more effective (i.e. had greater precipitation catch) than the OTT design. The differences are that the ATDD shield Lamellas are slightly longer and the spacing between lamellas is slightly greater. As a result, it was decided that the OTT shield should use lamellas and lamella spacing identical to that of the ATDD shield.

4.3 Installation of Firmware Version 3.60

Several improvements were made in the newest firmware (version 3.60), which was installed in December 2007 at Sterling. The primary improvement in the firmware was an adjustment to the orifice heater controller. This alteration was made to prevent ice from accumulating between the outer shell's orifice and the precipitation bucket. Ice bridging has been a common problem in the AWPAG at several different sites during the winter season. The new firmware allowed the orifice heater to turn on when the temperature drops below 32°F. A manual adjustment was made so that instead of turning off at 17°F, the heater did not shut off until the temperature reached 10°F. The new heater controller firmware also allowed the operator to set the low temperature cut-off to any value below 30°F, and it eliminates the automatic 1-minute heater shut-off which occurs once every hour. This new version was meant to overcome another large obstacle by preventing false tips without missing "true" precipitation. False tips have been a problem in the recent past, due to ice bridges, large temperature fluctuations, and the impacts of surrounding wildlife. Several additional measures were taken to avoid this problem including better versatility in drastic temperature fluctuations, deleting certain "intensity rest" values, and optimizing the Temperature Compensation (TC) level. Please see Section 6.0 Results for performance results of firmware version 3.60.

4.4 Weather Observations

Detailed surface observations were made by SAIC and NOAA/NWS staff at the test sites during covered events. Observers were deployed to cover events when a significant period of wintry precipitation was forecasted to occur. For this test, event coverage decisions were made based on forecasts of snowfall of 2 inches or more, or on forecasts of freezing rain and/or ice pellets exceeding 2 hours. Once an event started, coverage continued until the precipitation ended and did not start again within approximately 15 minutes, or the hourly liquid equivalent accumulations decreased to less than 0.01 inch per hour for two hours.

The intent was two-fold at the observer's discretion: 1) to avoid stopping an event prematurely when more significant precipitation is imminent, or 2) to needlessly prolong a significant event that has gradually tapered off to very light precipitation with no additional significant precipitation expected.
Liquid events at Sterling were covered during regular workdays to ensure sufficient data are collected to evaluate the performance of the test gauges during liquid precipitation. For this test, valid events were those with reference amounts of 0.04 inches or more. Events that total less than 0.04 inches were not used in statistical analyses.

The actual time of observation was coordinated with the DAS time to ensure synchronization of data. Prior to each event, observers verified the accuracy of both the station clock and the DAS clock. During events, the observers:

- recorded precipitation onset/cessation times
- recorded type and intensity of precipitation, with a resolution of five minutes
- inspected the test gauges at least once every hour during events and took photographs of unusual occurrences (e.g., snow/ice sticking on the inside orifice)
- measured the precipitation accumulation in the standard NWS 8-inch reference gauges once per hour (at the top of the hour) and at the end of an event
- performed observer functions required for other related tests

5.0 METHODOLOGY

AWPAG data was analyzed in the following areas: accuracy (comparability) of reported hourly amounts, comparability of event totals, and false reporting. In addition, an engineering assessment was performed during the course of the test in areas related to calibration stability, reliability, maintainability, installation, and logistics requirements.

Data was analyzed on an event-by-event basis, and reference gauge data was used to validate each event prior to test gauge evaluations. To ensure uniform spatial distribution of precipitation across the test bed, the hourly and event reference gauges are located around the perimeter of the test bed and opposite from each other. Wind speed data at orifice height in each test bed are used in conjunction with the reference gauge measurements to validate results. A valid event is defined as an event in which the two event reference gauges agree within the greater of ±4% or ±0.02 inches of each other (when the total catch is 0.04 inches or more).

Data was also analyzed on an hour-by-hour basis during covered events by comparing reported test gauge accumulations to measurements obtained from two additional Alter-shielded NWS standard 8-inch gauges installed in each test bed.

The precipitation catch in the reference gauges for each event was determined using a weight measurement. Each test site has a precision scale to enable the observer to weigh the catch in each reference gauge. The outside surfaces of each reference gauge retrieved from the test bed are thoroughly dried with paper towels prior to weighing. Once the measurements are completed, the inside surfaces of the hourly reference gauges were dried in preparation for the next swap in the test bed.

5.1 Weather Assessment

Precipitation types were divided into the following four categories:

- LIQUID rain (RA), drizzle (DZ)
- FREEZING freezing rain (FZRA), freezing drizzle (FZDZ)
- FROZEN snow (SN), ice pellets (PL), snow grains (SG), snow pellets (GS)
- MIXED any combination of two or more of the above three categories

These categories are used to describe the precipitation type for each hour of a covered event and entire events based on the human recorded weather observations.

5.1.1 Comparability

The comparability of each AWPAG was measured using the AWPAG accuracy requirement listed in section 3.0. This requirement states that an AWPAG must be accurate to within ±4% or ±0.02 inches (whichever is greater) of the reference value for all hourly precipitation measurements and for event totals. The upper specification (+0.02 inches) causes the AWPAG located in the 8-foot diameter Alter shields to fail in wind-driven, light snow conditions due to increased catch compared to the standard 8-inch manual gauges with the 4-foot Alter shield.

For all types of precipitation, test gauge accuracy was determined by comparing the reported accumulation from each test gauge with the measured accumulation from the collocated 8-inch manual reference gauges. A test gauge was considered compliant if accumulation differences do not exceed the greater of ±4% or ±0.02 inches of ***either*** of the two Alter-shielded reference gauge measurements. This comparison was applied to reported hourly accumulations and total event accumulations from the AWPAGs. As an additional evaluation, the AWPAGs located in the small and large DFIR, including HTB gauges, were monitored and evaluated using them only for informational purposes.

The AWPAG specification includes a requirement that is stated:

> It is recognized that smoothing or filtering algorithms may be required in order to reduce false precipitation reports. If such algorithms are required, the maximum acceptable delay in reporting of precipitation due to filtering shall be five (5) minutes.

The following ratio was calculated, first for all the events in the test, then the total population of hourly observations per event:

$$\frac{\textit{Number of AWPAG Events (Hourlies) within Specification}}{\textit{Total Number of AWPAG Events (Hourlies)}} \times 100$$

The same ratios were also computed after stratifying the data by precipitation type. Statistics derived from these comparisons were used for evaluating the test gauges by the level of compliance with the AWPAG performance requirements. Additional statistics were derived from the AWPAGs located within the small DFIR, large DFIR and heated tipping buckets, but were included only for informational comparison for the AWPAGs.

5.1.2 False Reporting

A false report is defined as a report of precipitation accumulation from the sensor in the absence of precipitation. Test gauge data was scanned on a daily basis to identify any false reports.

If false accumulations were identified, all relevant meteorological conditions were analyzed in an attempt to determine the cause. If no cause could be determined for a false report, it was listed as unknown.

The AWPAG specification allows for reports of false accumulation in the absence of precipitation of up to 0.09 inch within a discrete 30-day period. The first check was manual verification that no precipitation accumulated in standard NWS manual 8-inch gauges that are installed near the gauges under test. If a tip occurred during a period in which there was no accumulation in the 8-inch gauges, additional checks were made using radar, satellite, precipitation identifier, and in the case of Sterling, observations from Dulles International Airport. This was an attempt to attain 100% certainty that no precipitation occurred during the time period in which the tip occurred. Then a visual inspection was made to see if environmental factors beyond the control of the manufacturer are the cause. For example bird droppings, leaves, and/ or insects may have fallen into the bucket during the period and caused the tip. These were not counted as "false" for the purpose of this analysis.

5.2 Engineering Assessment

An engineering assessment was performed on all test gauges throughout the testing period and included issues related to documentation, installation, calibration, and maintenance, both periodic and corrective. Specific areas to be assessed included the 180 day maintenance cycle and serviceability. The assessment was derived in part from the experience gained in operating the gauges at the test sites during the testing period and included summaries of hardware and software failures and deficiencies. Separate logbooks at each site were used to record any maintenance, calibration, or performance issues. Recommendations were provided for any design or integration issues that could impact deployment and implementation on the ASOS.

Each test sensor underwent a field calibration check at the beginning of the test period, and then monthly until the completion of the test. The routine calibration checks were comprised of a calibration history as a function of total catch to ensure measurement linearity over the operating range (capacity) of the gauge.

The field calibration test evaluated each test gauge’s ability to respond to liquid accumulations by adding a pre-measured amount of water to the gauge. Specification No. D113-SP001 states: *“It is recognized that smoothing or filtering algorithms may be required in order to reduce false precipitation reports. If such algorithms are required, the maximum acceptable delay in reporting of precipitation due to filtering shall be five (5) minutes.”* Therefore, the temporal responses of the gauges during the field calibration tests are used to evaluate the test gauge’s accuracy and compliance with the real time reporting requirement. The results of any failed calibration test were forwarded to the Contracting Officer Technical Representative (COTR) through the test director.

6.0 RESULTS

The test of the AWPAGs located in both Sterling, VA and Johnstown, PA underwent several modifications during the 2007-2008 winter test; multiple issues were discovered while testing was already underway. After all changes, improvements, and data exclusions, there were very few events from both Johnstown and Sterling that were available for winter test analysis.

6.1 Firmware

In Sterling, an upgrade was performed on the AWPAGs to update the firmware from version 3.58 to version 3.60. This upgrade was done in an attempt to correct orifice heater control issues. The upgrade worked well until false tips began to occur on all four AWPAGs equipped with firmware v3.60. After a thorough investigation, it was determined that the new firmware was resetting the Temperature Compensation (TC) values of the AWPAGs. The problem was corrected by OTT through a new firmware version (3.61) which was created, delivered, and installed on the AWPAGs. None of the data from Sterling before the date which firmware v3.61 was installed (5/2/08) was included in winter 2007-2008 testing purposes.

The following table presents the results of event comparisons at Sterling based on the specification accuracy requirements. It includes the number of events in each category and the quantity and percentage of those events which met the requirements.

Sterling Event Comparisons

	SN 704	**SN 722**	**SN 286**	**SN 706**
	Tretyakov only	OTT vII Alter	Large DFIR	Small DFIR
# of Events Passed	5	5	4	5
Total # of Events	5	5	5	5
% Within Specification	100%	100%	80%	100%
Average Departure From Totals	0.017”	0.013”	0.023”	0.011”

Table 1

Five events were evaluated in Sterling during the 2007-2008 test, all of which were comprised of liquid precipitation. All but one of the AWPAGs met the event requirements **100%** of the time; the AWPAG installed in the large wooden DFIR met the event requirements **80%** of the time. The AWPAGs at Sterling reported an average of 0.011 to 0.023 inches different from the manual gauges.

6.2 Alter Shields

The AWPAGs in Johnstown, PA also underwent several changes during the winter test. One of the AWPAGs (Sensor #198) began experiencing frequent false tips around November 11, 2007.

The sensor was examined several times, but no causes of malfunction could be determined; the sensor was removed from the Johnstown test bed on April 2, 2008. It is unsure what data gathered from this sensor can or cannot be used due to variations in precipitation time, inconsistencies in false tips, etc.; therefore, none of the data from Sensor #198 was used. Unfortunately, this sensor was used as the standard production gauge in previous tests. The test results from the winter of 2007-2008 were compared to the standard 8" manual gauges, which were the reference gauges for this test. All AWPAGs were configured with firmware version 3.58 throughout all 5 events analyzed in the winter test.

Table 2 presents the results of event comparisons at Johnstown.

Johnstown Event Comparisons

	SN702	SN705	SN715	SN769	SN729
	OTT vII Alter	OTT vIII Alter	ATDD Alter	Large DFIR	Small DFIR
# of Events Passed	3	5	1	3	2
Total # of Events	5	5	5	5	5
% Within Specification	60%	100%	20%	60%	40%
Average Departure From Totals	0.031"	0.023"	0.029"	0.048"	0.057"

Table 2

Slightly different results were seen in Johnstown during the 2007-2008 test, where five events were evaluated. The AWPAG with the old version II OTT 8-foot diameter outer Alter shield (Sensor #702) met the specification requirements **60%** of the time, while the AWPAG with the new version III OTT Alter Shield (Sensor #705) met the event requirements **100%** of the time. The AWPAG 8-foot diameter outer Alter shield with the ATDD lamella design (#715) met requirements in **20%** of the events. The AWPAGs at Johnstown reported an average of 0.023 to 0.057 inches different from the manual gauges.

6.3 Low Water Content

Water content was investigated in the events from Johnstown. The first event analyzed in this study (2/21-2/23) had a variety of precipitation types. The event began as all snow, and then snow grains and ice pellets began to mix in after approximately 10 hours. Precipitation changed over to only freezing rain an hour and a half later. Light freezing rain and freezing drizzle were present throughout the remainder of the event.

The second event (2/26-2/27) began as light rain, and changed to snow after about two hours. Snow was present throughout the remainder of the event. The third and fifth events (2/27-2/28 and 3/21-3/23 respectively) were comprised of only snow. The fourth event (2/29-3/1) was comprised of mostly snow; however, ice pellets mixed in for about thirty minutes.

Low water content conditions were difficult to determine in event 1 because of the nature of the precipitation. Changes between snow, ice, and freezing rain made it hard to analyze the true water content of this storm. However, snow was noted as being very wet during the majority of its descent, and the snow to water ratio for event 1 was able to be estimated at **8:1**. The other four events were comprised mostly of snow and exhibited slightly clearer results. Event 2 (2/26-2/27) averaged a **40:1** snow to water ratio, event 4 (2/29-3/1) had a **14:1** ratio, and event 5 (3/21-3/23) had a **10:1** ratio. Event 3 (2/27-2/28) showed a **100:1** snow to water ratio. Overall, Event 3 (2/27-2/28) was the only event in which low water content conditions may have had a substantial effect on precipitation totals. However, the AWPAG with the version III OTT Alter Shield proved successful, despite these windy conditions, by passing the specifications in every event.

There were no events analyzed from Sterling that contained frozen or mixed precipitation

6.4 High Wind Events

High wind events were also investigated for the winter 2007-2008 test. In Johnstown, each of the events experienced windy conditions. The first and fourth events seem to have been affected the most by high winds. The first event (2/21-2/23) had winds ranging from 6 to 14 mph, with gusts up to 21 mph, while the fourth event (2/29-3/1) experienced even stronger sustained winds of 5 to 22 mph and gusts up to 33 mph. The majority of the AWPAGs recorded slightly more precipitation than the manual gauges.

In Sterling, two of the five events experienced relatively windy conditions, possibly lowering precipitation catch. In the first and last events, 5/8-5/9 and 5/31-6/2 respectively, several of the AWPAGs outperformed the manual gauges. The first event had winds between 7 and 15 mph during the onset of light rain. Thunderstorms moved across the area midway through the event, bringing winds near 20 mph, and gusts of 25 mph. Winds were between 6 and 17 mph throughout the remainder of the event. The final event experienced even windier conditions. Thunderstorms brought 7 to 24 mph sustained winds and gusts of 17 to 33 mph to the area. Winds subsided overnight, but then picked up again towards the end of the event, as speeds were recorded between 8 and 18 mph with gusts of 24 mph.

Yearly winter maintenance was performed on all AWPAG sensors during the winter 2007-2008 test by performing standard calibration checks and adding propylene glycol to the buckets.

6.5 Hourly Comparisons

There was not enough hourly data from Sterling or Johnstown to warrant the use of any hourly data in this analysis. Typically hourly data is compared to the overall event data. However, in this case it was determined that the amount of hourly data was insufficient to draw conclusions on the performance of the new shields and firmware versions.

7.0 CASE STUDIES

7.1 False Tips

The following case study was taken from Sterling on March 3, 2008. The purpose of this case study was to analyze the behavior of the AWPAGs at Sterling. The following figure shows the reports from the four AWPAGs and two HTBs at the Sterling test bed. At this time, the AWPAGs were configured with firmware version 3.60.

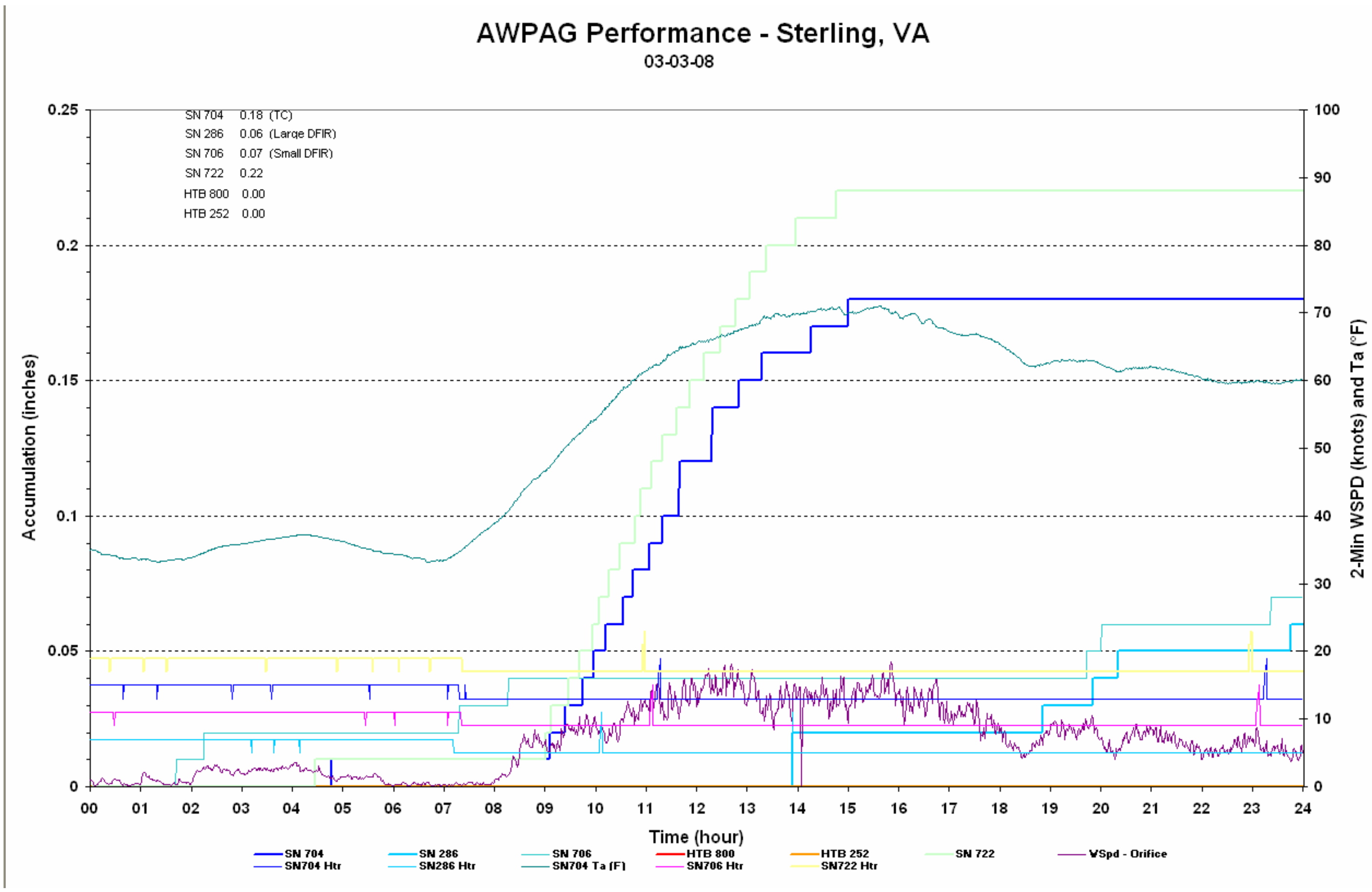

Figure 6

The figure above shows that all of the AWPAGs reported precipitation. However, after much research and investigation, it was determined that no precipitation had fallen on this date. After looking at the PX data from the AWPAGs, it became evident that the TC values of each AWPAG had reset themselves, unbeknownst to Sterling personnel. Electronics technicians reset all of the AWPAGs to their proper TC values, and the problem ceased. After relaying this information to OTT, it was determined that the firmware was responsible for the TC errors. OTT then developed a new version of firmware (v3.61) which corrected this problem.

7.2 High Wind Event

High winds were common amongst all of the events analyzed in Johnstown for the winter study. One specific event saw results that were slightly different from the other events, and wind seems to be the underlying cause. The February 21-23, 2008 event was the first to be analyzed from Johnstown, and the primary problem was that only three out of the five sensors passed the specification. The two sensors that failed this event were #715 (ATDD Shield) and #729 (Small DFIR), both of which caught more precipitation than the manual gauges. Winds were breezy initially on the 21st, with speeds of 8-15 mph throughout the evening (when precipitation began), and gusts of 21 mph. Winds decreased on the 22nd during a lull in precipitation, and picked back up during the evening of the 22nd, with gusts of up to 17 mph. The winds began to decrease again on the 23rd as precipitation dissipated.

Overall, the bulk of the precipitation fell on the 22nd. The majority of the differences in catch between sensors occurred on the 21st. As shown in Figure 7, there is a noticeable difference in precipitation catch between sensors in the later hours of the day (when the highest wind speeds were recorded).

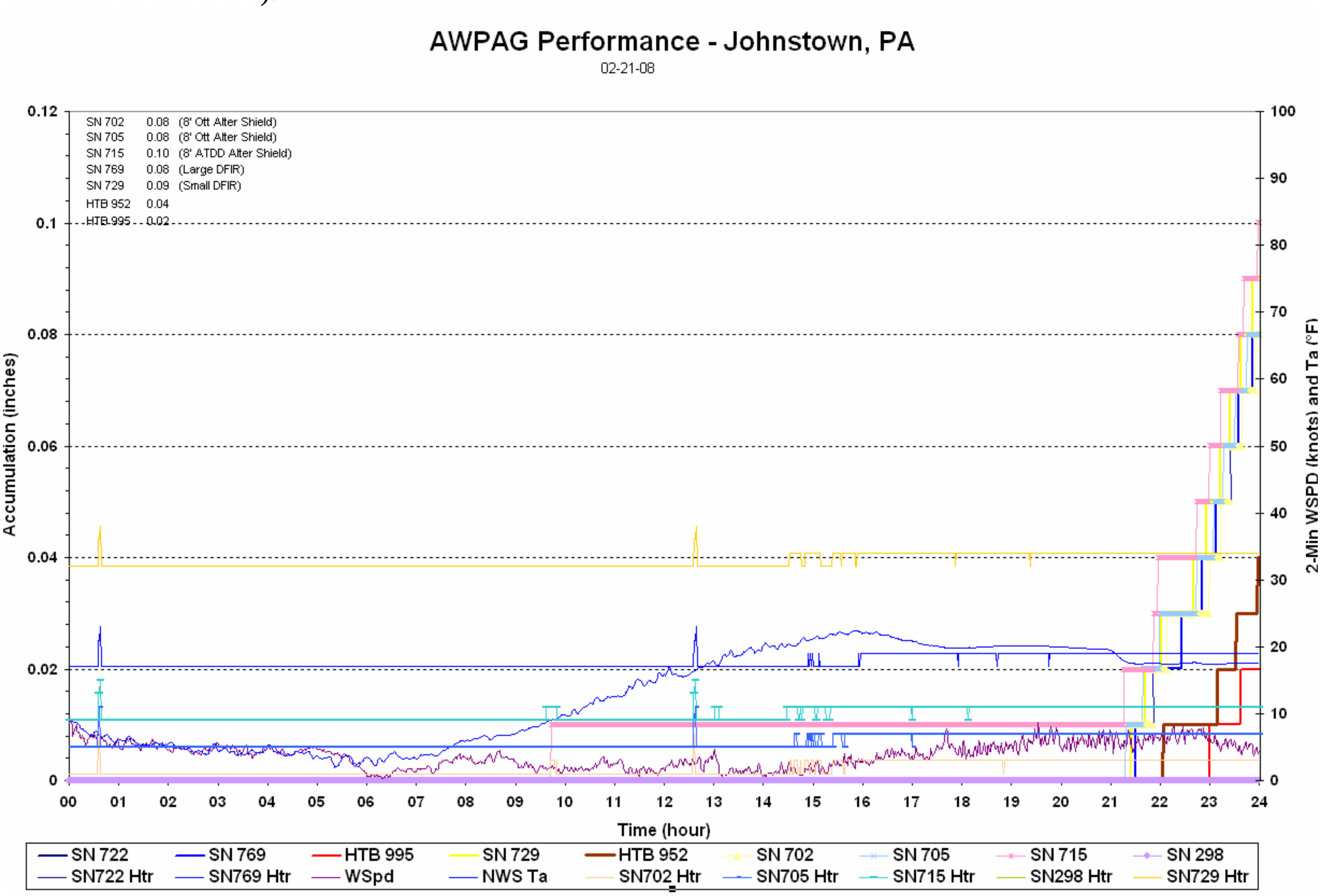

Figure 7

Figure 8 shows more similarities across the course of the day, when wind speeds were lower and precipitation fell more gradually.

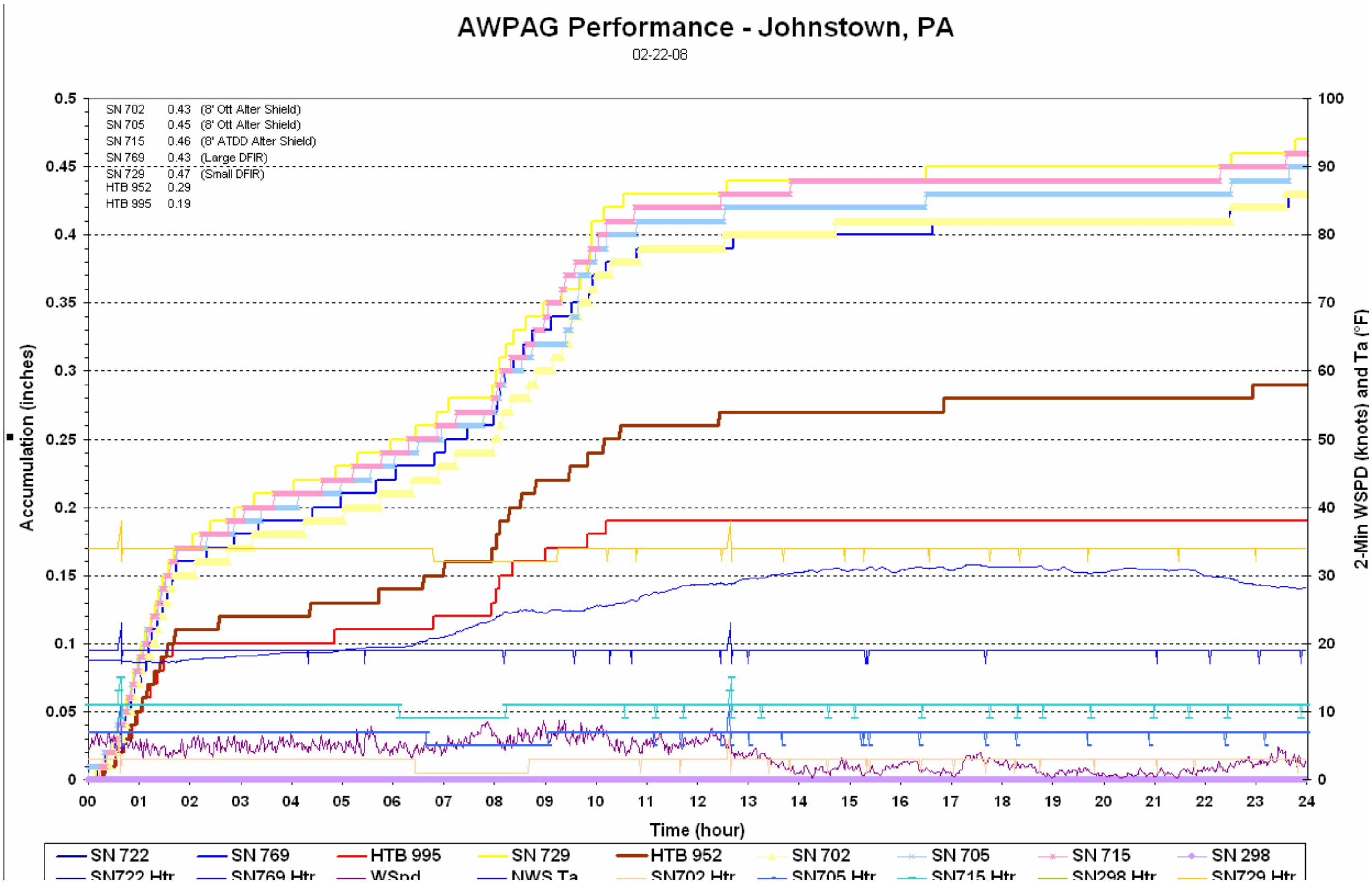

Figure 8

Overall, winds affected the entire event, but the higher winds that occurred in the early stages of the precipitation event were the likely cause in the disparity in precipitation amounts. Additionally, there was a 0.03 inch difference between the North and South manual gauges. The over catch by sensors #715 and #729 can likely be attributed to high winds.

8.0 CONCLUSIONS

Testing during 2007-2008 has allowed for several discoveries regarding the firmware, shields, and AWPAGs themselves. The test has shown that the new version III OTT Alter shield outperformed all of the other gauges in Johnstown, as it passed specification in all 5 events. The old version II OTT shield did pass the overall specification by passing 3 out of the 5 events, but was outperformed by its predecessor. Although the AWPAG surrounded by the ATDD shield only passed spec in one event, it did not fail by much each time, because its overall departure from the manual gauges was relatively small.

The data from the Johnstown site demonstrates that the new version III OTT shield design will measure approximately the same as the 8-inch manual gauge. At Johnstown, the AWPAG gauge protected by the new version III OTT Alter shield caught about **12**% more precipitation than the AWPAG with the old OTT Alter shield, and about **2%** more precipitation than the AWPAG with the ATDD shield. Overall, the new OTT shield shows a significant improvement in performance compared to the standard shield.

Testing in Sterling has shown that all AWPAGs equipped with firmware version 3.61 are compliant with the specification. Once firmware version 3.61 was installed, the AWPAGs did not experience any known false tips, and passed every event with the exception of one sensor. Sensor #286, installed in the large wooden DFIR, passed **4** out of **5** events, with the one failed event coming due to over-catch. The AWPAGs with firmware v3.61 reported an average of 0.011 to 0.023 inches different from the manual gauges, which is much lower compared to the average difference of the old firmware (0.038 to 0.056 inches).

AWPAG #198 is currently being tested at the Sterling Test Facility, in an attempt to diagnose the problems it continues to experience. The new version of firmware (v3.61), which was developed after discovering the issues with versions 3.58 and 3.60, has performed well thus far at Sterling. After obtaining favorable initial results, firmware version 3.61 was installed on the AWPAGs in Johnstown on May 14, 2008. This new firmware could help increase sensor precipitation catch to be within the specification, especially during events with frozen precipitation. Monitoring of the new firmware will continue at both Sterling and Johnstown.

Overall, low water content cannot be determined to be a major issue at Johnstown or Sterling. The third event in Johnstown (2/27-2/28) was the only event in which low water content conditions may have had a substantial effect on precipitation totals. The remaining events had fairly wet snow. There were no events analyzed from Sterling that contained frozen or mixed precipitation; therefore, low water content is not an issue at Sterling.

It can be concluded that the high winds that occurred in the first and fourth analyzed events at Johnstown had an impact on the AWPAG data. Two of the five gauges failed to meet the event requirements because of over reporting; sensors #715 (ATDD Alter) and #729 (small DFIR) were the gauges that failed to meet the specification. It can also be determined that winds did not have a significant impact on precipitation catch in Sterling; each AWPAG met the necessary specifications by passing between 80% and 100% of the events. Additionally, none of the events at Sterling consisted of frozen precipitation, meaning high winds had a very minimal impact in terms of precipitation catch.

Unfortunately, none of the events analyzed in Sterling contained freezing precipitation. Future events will be analyzed with the intention of gaining further insight into the performance of the new firmware and shield in weather throughout the year. Despite a slow year in terms of winter precipitation, and several changes needed in the middle of testing, the outlook is promising for continuing to test the new versions of firmware and Alter shield.

Further testing will be needed for correction of the AWPAG catch efficiency in frozen, wind-driven precipitation with the addition of an improved, applied transfer function under the current additional shielding configuration.

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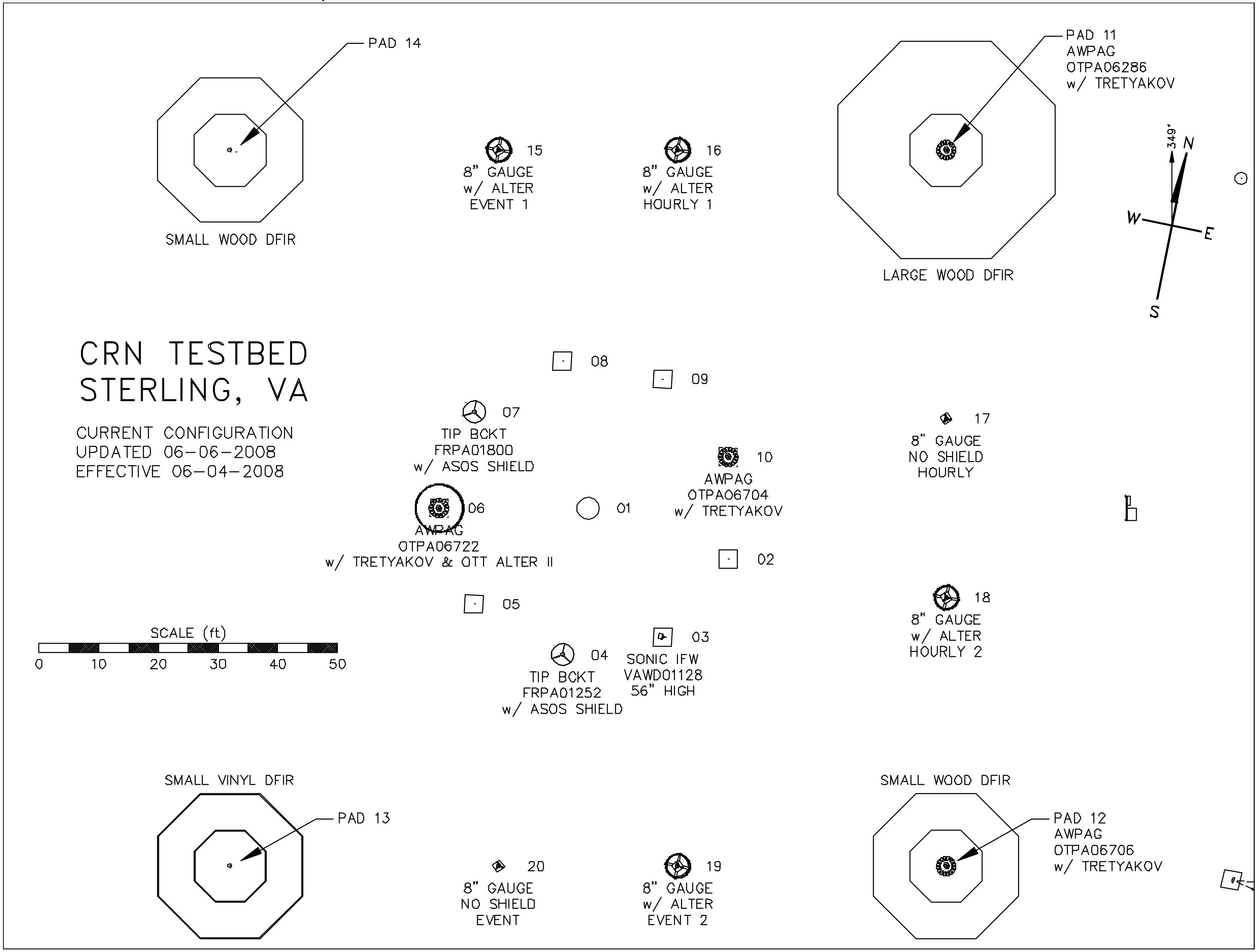
APPENDIX A - FIRMWARE VERSION DESCRIPTION

Firmware Version	Test Dates Sterling, Virginia	Test Dates Johnstown, Pennsylvania	Comments
3.55	4/29/03 - 8/26/03	5/8/03 - 8/27/03	under-catch correction
3.58	8/26/03 – 11/18/05	8/27/03 – 11/18/05, & 2/1/07 – 5/14/08	temperature compensation / precipitation threshold improvements
3.59	11/17/05 – 1/29/07	11/18/05 – 2/1/07	user alterable low temperature orifice heater cut-off
3.60	2/25/08 – 5/2/08	N/A	orifice heater controller improvements
3.61	5/2/08 - present	5/14/08 - present	fix for TC value errors

APPENDIX B STERLING, VIRGINIA TEST BED



APPENDIX C JOHNSTOWN, PENNSYLVANIA TEST BED