FINAL REPORT FOR

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

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EXECUTIVE SUMMARY

Background

The heated tipping bucket (HTB) was the initial precipitation accumulation gauge used when the Automated Surface Observing System (ASOS) was deployed. The HTB measures liquid accumulation, but is not specifically designed to accurately measure freezing or frozen precipitation. The accurate measurement of liquid equivalent accumulations in all types of liquid, solid, and mixed precipitation is an important part of weather observations.

The National Weather Service (NWS) awarded a contract for design and development of an All-Weather Precipitation Accumulation Gauge (AWPAG) on September 25, 2001, to C.C. Lynch and Associates (CCLA) of Pass Christian, Mississippi, in partnership with Ott Hydrometry of Kempten, Germany. Development testing from January 2002 to October 2003 demonstrated significant improvements in gauge catch, accuracy, and increased capacity. Full production AWPAGs were delivered in October 2003 and included hardware temperature compensation and revised internal sensor algorithm logic to improve gauge sensitivity.

Since 2002, there have been several enhancements to the gauges and firmware. Since 2005, the primary focus has been the assessment of various 8-foot Alter wind shield designs to improve the catch of a standard production AWPAG with Tretyakov windshield in conditions of wind-driven, dry snow when compared to the NWS field reference gauge, an 8-inch non-recording precipitation gauge (Specification# D040) with a 4-foot diameter Alter wind shield. Early 2005-2006 winter test results indicated an 8-foot diameter Alter-style wind shield surrounding a production AWPAG/Tretyakov configuration equaled or exceeded the catch of the NWS reference gauge. Based on the preliminary results, 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. For the winter 2006-2007 test, a redesign of the 8-foot Alter shield included a more rigid structural support that improved maintenance access to the AWPAG, as well as a new lamella design.

The 2006-2007 statistical results (event and hourly) from these performance test sensor configurations at Johnstown, Pennsylvania, Sterling, Virginia and the extended ASOS field sites, are presented in full detail in the results section.

Results

Eighteen events were evaluated in Johnstown during the 2006-2007 winter test. The AWPAGs with the Ott 8-foot diameter outer Alter shield met the event requirements in **11** out of **18** events each, while the AWPAG with Tretyakov shield met the event requirements in **8** out of **18** events. The AWPAG 8-foot diameter outer Alter shield with the ATDD lamella design met requirements in **14** out of **18** events. The hourly results indicated that two AWPAGs with 8-foot diameter Alter shield were within NWS accuracy requirements with an average of **100** out of **103** hourlies and for the AWPAG with Tretyakov shield, **99** out of **103** hourlies.

The overall precipitation catch results at Johnstown with the two AWPAGs in the Ott 8-foot diameter Alter shields averaged **3.66** inches. The AWPAG catch results in the 8-foot diameter Alter shield with the ATDD lamella design was **3.83** inches. These were compared to the standard production AWPAG at **3.38** inches. The 8-foot diameter Alter shield with the ATDD lamella design comes closer to the results of the large DFIR AWPAG, which had **4.24** inches. The goal is getting as close to the truth as possible.

Twenty-one events were evaluated in Sterling during the 2006-2007 winter test. The AWPAG with the Ott 8-foot diameter outer Alter shield met the event requirements in **18** out of **21** events, while the AWPAG with Tretyakov shield met the event requirements in **19** out of **21** events. Frozen events were very few in comparison to Johnstown as it is a more favorable location for quantifiable winter results. The hourly results indicated that the AWPAG with the 8-foot diameter Alter shield were within NWS accuracy requirements for **67** out of **73** hourlies, and for the AWPAG with Tretyakov shield, met NWS accuracy requirements for **66** out of **73** hourlies.

The overall event precipitation catch results at Sterling with the AWPAG in the Ott 8-foot diameter Alter shield were **7.47** inches compared to the standard production AWPAGs **7.41** inches. The AWPAGs with the 8-foot diameter Alter shields come closer to the results of the large DFIR AWPAG, which had **7.53** inches. The goal is getting as close to the truth as possible.

Total event measurements from the eight extended ASOS field sites were acquired during frozen precipitation events only; using NWS forecast office personnel who took manual measurements from collocated 8-inch manual gauges. The summary data indicates that for all sites / all frozen / mixed events, the 8-inch reference gauges measured **23.30** inches, and the AWPAGs with the Ott 8-foot Alter shields measured **21.77** inches. For example, data from sixteen events in Caribou, Maine showed that the AWPAG in the Ott 8-foot Alter caught **3.11** inches of frozen / mixed precipitation while the 8-inch manual reference caught **3.32** inches. In Buffalo, New York, data from eighteen events show that the AWPAG in the Ott 8-foot Alter caught **4.85** inches of frozen / mixed precipitation while the 8-inch manual reference caught **4.73** inches.

Conclusions

The data from the Johnstown, Sterling and the ASOS field sites demonstrates that the new shield design will measure approximately the same as the 8-inch manual gauge in most conditions. At Johnstown, where one of the AWPAG gauges was protected by the standard Tretyakov shield, the catch was about **10**% lower than the AWPAG with added 8-foot Alter shield. This shows a significant improvement in performance with the auxiliary shield over the standard shield. Despite the significant improvement in catch, some high wind events still showed slightly lower catch than the manual gauge – not quite meeting requirements in a few cases. There was also one high wind event at Cheyenne and one high wind event at Caribou, where the AWPAG catch was significantly lower than the manual gauge.

Late in the winter at Johnstown, it was observed that the lamellas on the new AWPAG Ott Alter shield did not swing as freely as the manual gauge Alter shield lamellas. This created concern that this lamella design was contributing to the gauges with the new shield being lower in precipitation catch compared to the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division (ATDD) that were installed with Alter shield lamellas with a design similar to the 4-foot Alter shield lamellas on the manual gauge. The AWPAG with the 8-foot Alter ATDD lamella design was catching about **5**% more than the gauges with the new Ott 8-foot Alter shield lamella design. The lamella designs differed in two ways. Ott had a concern about long term wear on the lamella hoop, and designed the lamella to have built-in "bushings" instead of just clearance holes for installing on the hoop. The lamella bushings increase friction and restrict the lamellas from swinging as freely as the lamellas without bushings on the manual Alter and ATDD lamella based shields. Second, the new AWPAG lamellas are shorter. This has an effect of reducing the wind force on the section of lamella below the hoop, thus requiring greater wind speed and gustiness to make the lamella swing. The overall effect is to restrict the lamella from swinging as freely as the lamellas that are longer and without bushings.

It is evident from our data that, while the new Ott 8-foot Alter showed improvement, it would be desirable to replace the current lamella design with the original Alter shield lamella design. The most significant benefit should be seen in high wind events (i.e. the only type of event where significant under catch was observed at Johnstown and ASOS AWPAG field sites in a few cases).

1.0 BACKGROUND

The heated tipping bucket (HTB) was the initial precipitation accumulation gauge when the Automated Surface Observing System (ASOS) was deployed nationally. The sensor measures liquid accumulation, but is not specifically designed to accurately measure 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, Virginia and Johnstown, Pennsylvania. 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. All AWPAG were retrograded back to firmware 3.58 in late January 2007 due to a flawed process in the adjustable heater cut-off in low temperatures.

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.

In the autumn of 2004, 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 events.

Early 2005-2006 winter test results indicated an 8-foot diameter Alter-style wind shield surrounding a production AWPAG/Tretyakov configuration equaled or exceeded the catch of the NWS reference gauge. Based on the preliminary results, 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 more rigid shield mounting structure that eased AWPAG maintenance and a new lamella design was established for the winter 2006-2007 test.

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 2006 - 2007 test at Sterling and Johnstown are as follows:

- 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 among 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.

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 was conducted at Johnstown, Pennsylvania, and Sterling, Virginia, the two permanent test sites operated by the NWS Sterling Test Facility. See Appendices A & B for maps of the Sterling and Johnstown test bed layouts.

In addition to the Sterling and Johnstown sites, eight operational ASOS sites were utilized by installing the 8-foot diameter Alter shield and a collocated 8-inch manual gauge with an NWS Alter shield. These sites are Aberdeen, South Dakota; Bethel, Alaska; Buffalo, New York; Caribou, Maine; Cheyenne, Wyoming; Great Falls, Montana; Kodiak, Alaska and Tulsa, Oklahoma.

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). An ASOS heated tipping bucket data was included in the AWPAG data comparison. Data from all ASOS sensors at Sterling and Johnstown was 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 used in post-processing, in verifying false precipitation reports from the test gauges, and in case study analyses.

Each recorded event from the operational ASOS sites was treated as a single event total. NWS staff at the extended ASOS sites was asked to take 8-inch gauge measurements for forecasted solid precipitation events as frequently as workload allows. Precise times of empty bucket deployment and end-of-event measurements were also recorded. The 8-inch gauge measurements and event times were sent to Sterling personnel at the end of events.

4.2 Sensor Description

4.2.1 Production AWPAG

Two 56-inch capacity production AWPAGs were tested at Johnstown, Pennsylvania and one in Sterling, Virginia. Figure 1 depicts an installation of an AWPAG that would be 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 were 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 sensors were used only for comparison and not qualification.

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

4.2.3 Production AWPAG inside Ott 8-foot Diameter Alter Shield

Two production AWPAGs modified with an 8-foot diameter Ott-style Alter shield (Figure 2) were tested at Johnstown and one at Sterling. The shield is 2 ¼ 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.

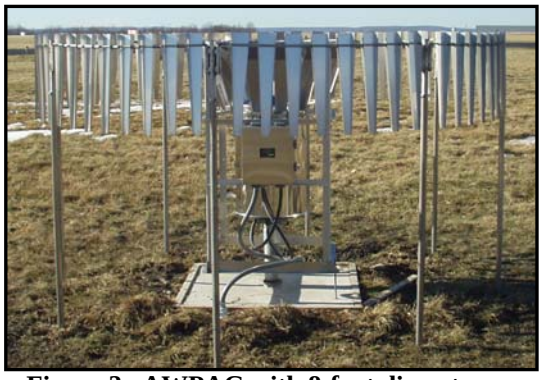


Figure 3 AWPAG with 8-foot diameter Alter Shield (ATDD Style)

4.2.4 Production AWPAG inside 8-foot Diameter Alter Shield with ATDD Lamella Design

One production AWPAG modified with an 8-foot diameter Alter shield designed by the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division (NOAA / ATDD) (Figure 3) was tested at Johnstown. The shield is 2 ¼ 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.

The primary difference between the Ott and ATDD lamella design is overall length and surface area. The ATDD lamella is 18 inches long and has a total surface area of 40.5 square inches while the Ott lamella is 15.88 inches long with a total surface area of 37 square inches.

Figure 4 Heated Tipping Bucket

4.2.5 Heated Tipping Bucket

The standard ASOS HTB (Figure 4) was used as a comparison sensor for this test. The HTB gauges were not used to evaluate measurement accuracy of the test gauges, but provided data for assessing improvements to ASOS precipitation measurements as a result of AWPAG deployment. HTB data was used as an aid to determine false reports. The HTB gauges were installed with the standard ASOS vinyl wind shields one inch above the orifice height.

4.2.6 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 5). 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 were installed with the orifice height at five feet. Alter style wind shields were installed one inch above the orifice height on all of the manual gauges.

Figure 5 NWS 8-inch Manual Gauge

4.3 ASOS Field Sites Used in AWPAG Shield Test

4.3.1 Cheyenne, WY (KCYS)

The city of Cheyenne is located on a broad plateau between the North and South Platte Rivers in the extreme southeastern corner of Wyoming at an elevation of approximately 6,100 feet just east of the 9000 foot Laramie Mountains. Snow accompanied by high wind is common from fall through spring. Snows are dry with occasional blizzard conditions during the winter, and can be heavy and wet, again with high winds, in fall and spring. This provided an interesting variety of snow conditions for the AWPAG shield test.

The ASOS AWPAG is located on the airport and the reference 8-inch gauge was installed adjacent to the ASOS. The local Data Acquisition Program Manager, Arthur Hutcheon, took the 8-inch gauge manual measurements and provided the reference manual and AWPAG measurements for snow events.

4.3.2 Aberdeen, SD (KABR)

Aberdeen is located in the northeast quarter of South Dakota at an elevation of 1,300 feet. Low hills rim the area on the east and west. Located near the center of the North American land mass, the climate is continental with distinct seasons. The winters are cold and dry. Heavy snowfalls rarely occur during the first two-thirds of the winter season, with heaviest snowfalls developing during late February and early March as temperatures moderate. The frequent occurrence of snow with high wind made this an excellent location for a test of the modified AWPAG wind shield. The 8-inch gauge that is used for the Supplementary Climatological Data reported by the WFO was in an open area (non-collocated) nearby the airport ASOS and with similar exposure.

The comparison of AWPAG to the 8-inch gauge only required us to monitor their Supplementary Climatological Data for liquid equivalent manual gauge measurements for comparison to the AWPAG liquid equivalent measurements.

4.3.3 Tulsa, OK (KTUL)

The city of Tulsa lies along the Arkansas River at an elevation of 700 feet above sea level. The surrounding terrain is gently rolling. While snow in winter is generally light, occasional snowstorms with blizzard conditions do occur. The ASOS AWPAG is located on the airport and the comparative eight inch gauge was installed with similar exposure (non-collocated). The local Data Acquisition Program Manager, Michael Teague, took the 8-inch gauge manual measurements and provided the comparative manual vs. AWPAG measurements for snow events.

4.3.4 Great Falls, MT (KGTF)

Great Falls, Montana is located in the high plains of central Montana at an elevation of 3600 feet. Precipitation generally falls as snow during the winter, late fall and early spring and is typically accompanied by high wind. This is an ideal location to test the effectiveness of the modified AWPAG shield. The shield was installed on the ASOS AWPAG and an 8-inch manual gauge was located nearby (non-collocated). After snow events, the Data Acquisition Program Manager, Richard Prewitt, would measure the manual gauge and compare it to the ASOS AWPAG. This data was then provided to Sterling for inclusion in our analysis.

4.3.5 Caribou, ME (KCAR)

The Caribou Municipal Airport is located in Aroostook County, the largest and northernmost county in the state. The airport is at about 600 feet elevation on top of high land which is about on the same level as most of the surrounding gently rolling hills. Winters are particularly long and windy, and seasonal snowfalls averaging over 100 inches are not unusual. This is an ideal location to test the effectiveness of the modified AWPAG shield.

The 8-inch manual gauge was installed near the ASOS, but off the airport (non-collocated), so it would be accessible to WFO personnel. On days after snow events, station personnel took measurements of liquid equivalent precipitation for comparison to the ASOS AWPAG daily liquid equivalent precipitation. This data was then provided to Sterling for inclusion in our analysis.

4.3.6 Buffalo, NY (KBUF)

The airport is at an elevation of about 700 feet about 9 miles north-northeast of Lake Erie. Outbreaks of Arctic air in December and throughout the winter months produce the locally heavy snowfalls from the lake, giving Buffalo an average snowfall of nearly 90 inches per year. For this test, an 8-inch gauge was located near the Upper Air inflation shelter, which is off the airport, but quite close to the airport ASOS (non-collocated). The gauge was sited so that the exposure was similar to the ASOS AWPAG. If snow occurred during the previous day, the upper air observers were requested to bring in the 8-inch gauge for measurement at the time of the morning balloon release. The Data Acquisition Program Managers, initially Steve Francis and later Thomas Schmidt, then tabulated the comparative daily liquid equivalent precipitation measurements from the 8-inch gauge and ASOS AWPAG, and provided these summaries to Sterling for inclusion in this report.

4.3.7 Kodiak, AK (PADQ)

Kodiak Island is located on the western side of the Gulf of Alaska, 90 miles southwest of the Kenai Peninsula. The terrain is rugged, with the mountains averaging from 2,000 to 4,000 feet in height. Precipitation measurement is often difficult due to strong, gusty surface winds which frequently accompany precipitation. Drifting and blowing snow occasionally close the field for periods of up to 24 hours.

Kodiak was one of the stations that was already taking 8-inch gauge measurements for the official precipitation records due to concern with the under catch by the Kodiak airport ASOS AWPAG precipitation measurements. It was thus possible to obtain their official 8-inch gauge measurement from the National Climatic Data Center (NCDC). Also available from NCDC was the hourly ASOS precipitation accumulation measurements which could be summed daily for comparison to the official 8-inch gauge. While the 8-inch gauge was somewhat sheltered from wind by nearby buildings, we felt it would be useful to compare the two measurements to see how great the differences were.

4.3.8 Bethel, AK (PABE)

The two main topographical features affecting the climate of Bethel are the Bering Sea, which is about 100 miles to the west and southwest, and the Kilbuck Range of mountains located about 40 miles to the east and southeast of the station. This range, averaging about 4,000 feet in height, extends, roughly, in a north-south direction in that portion nearest to Bethel. Some 160 miles southeast of the Kilbuck Range are the Aleutians, extending in a northeast-southwest direction, provide an additional natural barrier to many of the storms originating on the outward end of the Aleutian Chain and moving out through the Gulf of Alaska. Both ranges tend to direct some of the storms northeastward into the Bering Sea, and thus directly affect the Bethel area. During invasions of such storms, it is not uncommon for wind velocities to exceed 50 mph. Maximum speeds usually accompany northeast winds in the winter. Around the latter part of December and early January, cold, clear continental air becomes quite dominant, and the climate of Bethel becomes quite similar to other areas located farther inland. Average temperatures through the entire winter season, however, are considerably higher than those experienced in the Alaskan interior.

Bethel was one of the stations that was already taking 8-inch gauge measurements for the official precipitation records due to concern with the under catch by the Bethel airport precipitation measurements. It was thus possible to obtain their official 8-inch gauge measurement from the National Climatic Data Center (NCDC), Also available from NCDC was the hourly ASOS precipitation accumulation measurements which could be summed daily for comparison to the official 8-inch gauge.

4.4 Weather Observations

Detailed surface observations were made by SAIC and NOAA/NWS observers at the test sites during covered events. Observers were deployed to cover events when a significant period of wintry precipitation was forecast 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 decrease to less than 0.01 inch per hour for two hours.

The intent is 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 was collected to evaluate the performance of the test gauges during liquid precipitation.
Selected liquid events accompanied by winds in excess of about 10 knots at Johnstown were covered to add to the database. 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 take 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, calibration checks were performed during the course of the test to verify calibration stability

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 was 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 were 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 were 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. The 8-foot diameter Alter style AWPAGs technically fail the specification requirement by over-reporting compared to the standard NWS manual reference gauge, but actually are closer to the ground truth measurements of the DFIR in wind driven, dry snow events. For this reason, comparisons to the reference were performed both with and without the +.02 inch specification.

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 did 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 are 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. Statistics derived from the AWPAG located within the small and large DFIR and heated tipping bucket gauges were included as an informational comparison for the AWPAGs.

5.2 Engineering Assessment

Each test sensor will undergo a field calibration check at the beginning of the test period, and then monthly until the completion of the test. The routine calibration checks will comprise 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 will evaluate 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."*

6.0 Final AWPAG Winter Results

Tables 1-4 summarize winter event and hourly results at Johnstown, Pennsylvania showing an improvement of the production AWPAGs with the 8-foot diameter Ott Alter shield (AWPAG #702, #705) and AWPAG #715 with the 8-foot diameter Alter shield ATDD lamella design. This is compared to the standard production AWPAG with Tretyakov shield (AWPAG #198), and the standard production AWPAG located within the small and large DFIR (AWPAG #729, #769). The AWPAGs in the small and large DFIR were used only for comparison purposes, not qualification.

Eighteen events were evaluated in Johnstown during the 2006-2007 winter test. The AWPAGs with the Ott 8-foot diameter outer Alter shield met the event requirements in **11** out of **18** events each, while the AWPAG with Tretyakov shield met the event requirements in **8** out of **18** events. The AWPAG with the 8-foot diameter outer Alter shield ATDD lamella design met requirements in **14** out of **18** events. AWPAG #702 and AWPAG #198 met the specification for the same amount of events. AWPAG #702 failed one event due to over catch. This means that an AWPAG with the 8-foot diameter Alter exceeded the allowable catch (±0.02 inches or 4%, whichever is greater) when compared to the 8-inch manual reference gauges, but in all cases the catch was less than the DFIR shielded gauges.

Johnstown Event Comparisons										
	Total		**Liquid**		**Freezing**		**Frozen**		**Mixed**	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG #702 (Ott 8' Alter)	18	11	1	1	--	--	12	5	5	5
AWPAG #705 (Ott 8'Alter)	18	11	1	1	--	--	12	7	5	3
AWPAG #715 (ATDD 8'Alter)	18	14	1	1	--	--	12	8	5	5
AWPAG #198 (Tretyakov)	18	8	1	1	--	--	12	5	5	2

Table 1 – Johnstown, Pennsylvania Winter Event Summary

The 8-foot diameter Alter style AWPAGs still report less than the AWPAGs installed in the international reference wind shields in wind-driven, dry snow events. This is to be expected without an application of a transfer function. The event precipitation catch results with the AWPAGs in the Ott 8-foot diameter Alter shields in frozen events averaged **1.30** inches. The AWPAG located in the 8-foot diameter Alter with the ATDD lamella design caught **1.42** inches. These were compared to the standard production AWPAGs catch of **1.13** inches. The AWPAGs with the 8-foot diameter Alter shields come closer to the results of the DFIR AWPAGs. The goal is getting as close to the truth as possible.

Johnstown Event Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG #702 (Ott 8'Alter)	18	3.68	1	1.00	--	--	12	1.29	5	1.39
AWPAG #705 (Ott 8'Alter)	18	3.64	1	1.00	--	--	12	1.31	5	1.33
AWPAG #715 (ATDD 8'Alter)	18	3.83	1	1.00	--	--	12	1.42	5	1.41
AWPAG #198 (Tretyakov)	18	3.38	1	1.00	--	--	12	1.13	5	1.25
8" Manual North	18	3.89	1	0.99	--	--	12	1.46	5	1.44
8" Manual South	18	4.01	1	0.98	--	--	12	1.58	5	1.45
AWPAG #292 Large DFIR	18	4.24	1	0.98	--	--	12	1.83	5	1.43
AWPAG #729 Small DFIR	18	4.13	1	0.99	--	--	12	1.72	5	1.42

Table 2 – Johnstown, Pennsylvania Winter Precipitation Summary

The hourly results (Table 3) indicated that AWPAGs with Ott 8-foot diameter Alter shield were within NWS accuracy requirements with an average of **100** out of **103** hourlies and for the AWPAG with Tretyakov shield, **99** out of **103** hourlies.

Johnstown Hourly Comparisons										
	Total		**Liquid**		**Freezing**		**Frozen**		**Mixed**	
Test Gauge	# of Hours	# in Spec.	# of Hours	# in Spec.	# of Hours	# in Spec.	# of Hours	# in Spec.	# of Hours	# in Spec.
AWPAG #702 (Ott 8' Alter)	103	99	2	2	--	--	80	76	21	21
AWPAG #705 (Ott 8'Alter)	103	100	2	2	--	--	80	77	21	21
AWPAG #715 (ATDD 8'Alter)	103	101	2	2	--	--	80	78	21	21
AWPAG #198 (Tretyakov)	103	99	2	2	--	--	80	76	21	21

Table 3 – Johnstown, Pennsylvania Winter Hourly Summary

The overall hourly precipitation catch results (Table 4) indicate that the AWPAG 8-foot diameter Alter shield with the ATDD lamella design comes close to the results of the large DFIR at **3.63** inches while the large DFIR had an amount of **4.08** inches.

Johnstown Hourly Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG #702 (Ott 8'Alter)	103	3.51	2	1.00	--	--	80	1.79	21	0.72
AWPAG #705 (Ott 8'Alter)	103	3.50	2	1.00	--	--	80	1.83	21	0.67
AWPAG #715 (ATDD 8'Alter)	103	3.63	2	1.00	--	--	80	1.90	21	0.73
AWPAG #198 (Tretyakov)	103	3.33	2	1.00	--	--	80	1.63	21	0.70
8" Manual North	103	3.86	2	0.99	--	--	80	2.09	21	0.78
8" Manual South	103	3.92	2	0.99	--	--	80	2.13	21	0.80
AWPAG #292 Large DFIR	103	4.08	2	0.98	--	--	80	2.36	21	0.74
AWPAG #729 Small DFIR	103	3.94	2	0.99	--	--	80	2.23	21	0.72

Table 4 – Johnstown, Pennsylvania Hourly Winter Precipitation Catch Summary

Tables 5-8 summarize winter event and hourly results at Sterling, Virginia showing an improvement of the production AWPAG with the 8-foot diameter Ott Alter shield (AWPAG #722). This is compared to the standard production AWPAG with Tretyakov shield (AWPAG #704) and the standard production AWPAGs located within the small and large DFIR (AWPAG #286, #706). The AWPAGs in the small and large DFIR were used only for comparison purposes, not qualification.

Twenty-one events were evaluated in Sterling during the 2006-2007 winter test. The AWPAG with the Ott 8-foot diameter outer Alter shield met the event requirements in **18** out of **21** events each, while the AWPAG with Tretyakov shield met the event requirements in **19** out of **21** events. Frozen events were very few in comparison to Johnstown as it is a more favorable location for quantifiable winter results.

Sterling Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG #722 (Ott 8'Alter)	21	18	14	13	--	--	2	1	5	4
AWPAG #704 (Tretyakov)	21	19	14	14	--	--	2	1	5	4

Table 5 – Sterling, Virginia Winter Event Summary
*AWPAG 722 with the Ott 8' Alter shield was installed on 12/18/07

The overall event precipitation catch results with the AWPAG in the 8-foot diameter Alter shield were **7.47** inches compared to the standard production AWPAGs **7.41** inches. The AWPAGs with the 8-foot diameter Alter shields come closer to the results of the DFIR AWPAGs at **7.54** inches. The goal is getting as close to the truth as possible.

Sterling Event Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG #722 (Ott 8' Alter)	21	7.47	14	4.77	--	--	2	0.16	5	2.54
AWPAG #704 (Tretyakov)	21	7.41	14	4.72	--	--	2	0.18	5	2.51
8" Manual North	21	7.58	14	4.65	--	--	2	0.22	5	2.71
8" Manual South	21	7.59	14	4.66	--	--	2	0.22	5	2.71
AWPAG #286 (Large DFIR)	21	7.53	14	4.73	--	--	2	0.20	5	2.60
AWPAG #706 (Small DFIR)	21	7.55	14	4.71	--	--	2	0.19	5	2.65

Table 6 – Sterling, Virginia Winter Precipitation Summary
*AWPAG 722 with the Ott 8' Alter shield was installed on 12/18/07

The hourly results (Table 7) indicated that the AWPAG with the 8-foot diameter Alter shield were within NWS accuracy requirements **67** out of **73** hourlies and for the AWPAG with Tretyakov shield, **66** out of **73** hourlies.

Sterling Hourly Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG #722 (Ott 8'Alter)	73	67	23	23	2	2	19	18	29	24
AWPAG #704 (Tretyakov)	73	66	23	23	2	2	19	18	29	23
AWPAG #286 (Large DFIR)	73	68	23	23	2	2	19	18	29	25
AWPAG #706 (Small DFIR)	73	69	23	23	2	2	19	19	29	25

Table 7 – Sterling, Virginia Winter Hourly Summary
*AWPAG 722 with the Ott 8' Alter shield was installed on 12/18/07

The overall hourly precipitation catch results (Table 8) indicate that the AWPAG with the Ott 8-foot diameter Alter shield come close to the results of the large DFIR at **4.25** inches while the large DFIR had an amount of **4.35** inches.

Sterling Hourly Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG #722 (Ott 8' Alter)	73	4.25	23	1.17	2	0.04	19	0.83	29	2.21
AWPAG #704 (Tretyakov)	73	4.22	23	1.18	2	0.05	19	0.84	29	2.15
8" Manual North	73	4.67	23	1.21	2	0.04	19	0.94	29	2.48
8" Manual South	73	4.63	23	1.20	2	0.04	19	0.96	29	2.43
AWPAG #286 (Large DFIR)	73	4.35	23	1.17	2	0.04	19	0.87	29	2.27
AWPAG #706 (Small DFIR)	73	4.38	23	1.16	2	0.04	19	0.88	29	2.30

Table 8 – Sterling, Virginia Hourly Winter Precipitation Catch Summary
*AWPAG 722 with the Ott 8' Alter shield was installed on 12/18/07

Tables 9-24 summarize winter events at various ASOS field sites showing an improvement of the production AWPAGs with the 8-foot diameter Ott Alter shield. This is compared to the NWS standard 8-inch manual reference gauge. Despite the significant improvement in catch, some high wind events still showed slightly lower catch than the manual gauge – not quite meeting requirements in a few cases. There was also one high wind event at Cheyenne and one high wind event at Caribou, where the AWPAG catch was significantly lower than the manual gauge.

Cheyenne, Wyoming Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	8	5	--	--	--	--	8	5	--	--

Table 9 – Cheyenne, Wyoming Winter Event Comparisons

Cheyenne, Wyoming Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	8	0.7	--	--	--	--	8	0.7	--	--
8" Manual Gauge	8	0.72	--	--	--	--	8	0.72	--	--

Table 10 – Cheyenne, Wyoming Winter Precipitation Summary

Aberdeen, South Dakota Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	14	12	--	--	--	--	14	12	--	--

Table 11 – Aberdeen, South Dakota Winter Event Comparisons

Aberdeen, South Dakota Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	14	2.21	--	--	--	--	14	2.21	--	--
8" Manual Gauge	14	2.27	--	--	--	--	14	2.27	--	--

Table 12 – Aberdeen, South Dakota Winter Precipitation Summary

Tulsa, Oklahoma Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	2	2	--	--	--	--	--	--	2	2
8" Manual Gauge	2	2	--	--	--	--	--	--	2	2

Table 13 – Tulsa, Oklahoma Winter Event Comparisons

Tulsa, Oklahoma Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	2	1.75	--	--	--	--	--	--	2	1.75
8" Manual Gauge	2	1.78	--	--	--	--	--	--	2	1.78

Table 14 – Tulsa, Oklahoma Winter Precipitation Summary

Great Falls, Montana Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	12	10	--	--	--	--	12	10	--	--

Table 15 – Great Falls, Montana Winter Event Comparisons

Great Falls, Montana Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	12	1.80	--	--	--	--	12	1.80	--	--
8" Manual Gauge	12	1.89	--	--	--	--	12	1.89	--	--

Table 16 – Great Falls, Montana Winter Precipitation Summary

Caribou, Maine Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	16	13	--	--	--	--	13	10	3	3

Table 17 – Caribou, Maine Winter Event Comparisons

Caribou, Maine Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	16	3.11	--	--	--	--	13	2.80	3	0.31
8" Manual Gauge	16	3.32	--	--	--	--	13	3.01	3	0.31

Table 18 – Caribou, Maine Winter Precipitation Summary

Buffalo, New York Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	18	11	--	--	--	--	12	9	6	2

Table 19 – Buffalo, New York Winter Event Comparisons

Buffalo, New York Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	18	4.85	--	--	--	--	12	1.94	6	2.91
8" Manual Gauge	18	4.73	--	--	--	--	12	1.92	6	2.81

Table 20 – Buffalo, New York Winter Precipitation Summary

Kodiak, Alaska Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	36	23	12	8	--	--	11	6	13	9

Table 21 – Kodiak, Alaska Winter Event Comparisons

Kodiak, Alaska Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	36	12.20	12	6.46	--	--	11	1.54	13	4.20
8" Manual Gauge	36	14.42	12	7.28	--	--	11	2.26	13	4.88

Table 22 – Kodiak, Alaska Winter Precipitation Summary

Bethel, Alaska Event Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.	# of Events	# in Spec.
AWPAG (Ott 8'Alter)	26	25	1	1	--	--	23	22	2	2

Table 23 – Bethel, Alaska Winter Event Comparisons

Bethel, Alaska Precipitation Catch Comparisons										
	Total		Liquid		Freezing		Frozen		Mixed	
Test Gauge	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)	# of Events	Total Catch (inches)
AWPAG (Ott 8'Alter)	26	1.25	1	0.16	--	--	23	1.03	2	0.06
8" Manual Gauge	26	1.32	1	0.16	--	--	23	1.10	2	0.06

Table 24 – Bethel, Alaska Winter Precipitation Summary

7.0 ENVIRONMENTAL ISSUES AND CONCERNS

Previously, some precipitation gauges have required a solution of antifreeze to melt solid precipitation and a lighter-than-water (usually oil) compound on the surface of the catch area to reduce evaporation losses. The addition of oil to the collection containers is not allowed in the AWPAG specification. At the start of the test, all AWPAGs were charged with 1.5 gallons of propylene glycol antifreeze. Previous testing has indicated that pure propylene glycol exhibits hygroscopic properties, absorbing moisture from the atmosphere that can lead to false positive reports of accumulation. For this reason, all initial antifreeze charges were diluted at 6:1 ratio of antifreeze to water, which minimizes the hygroscopic tendencies.

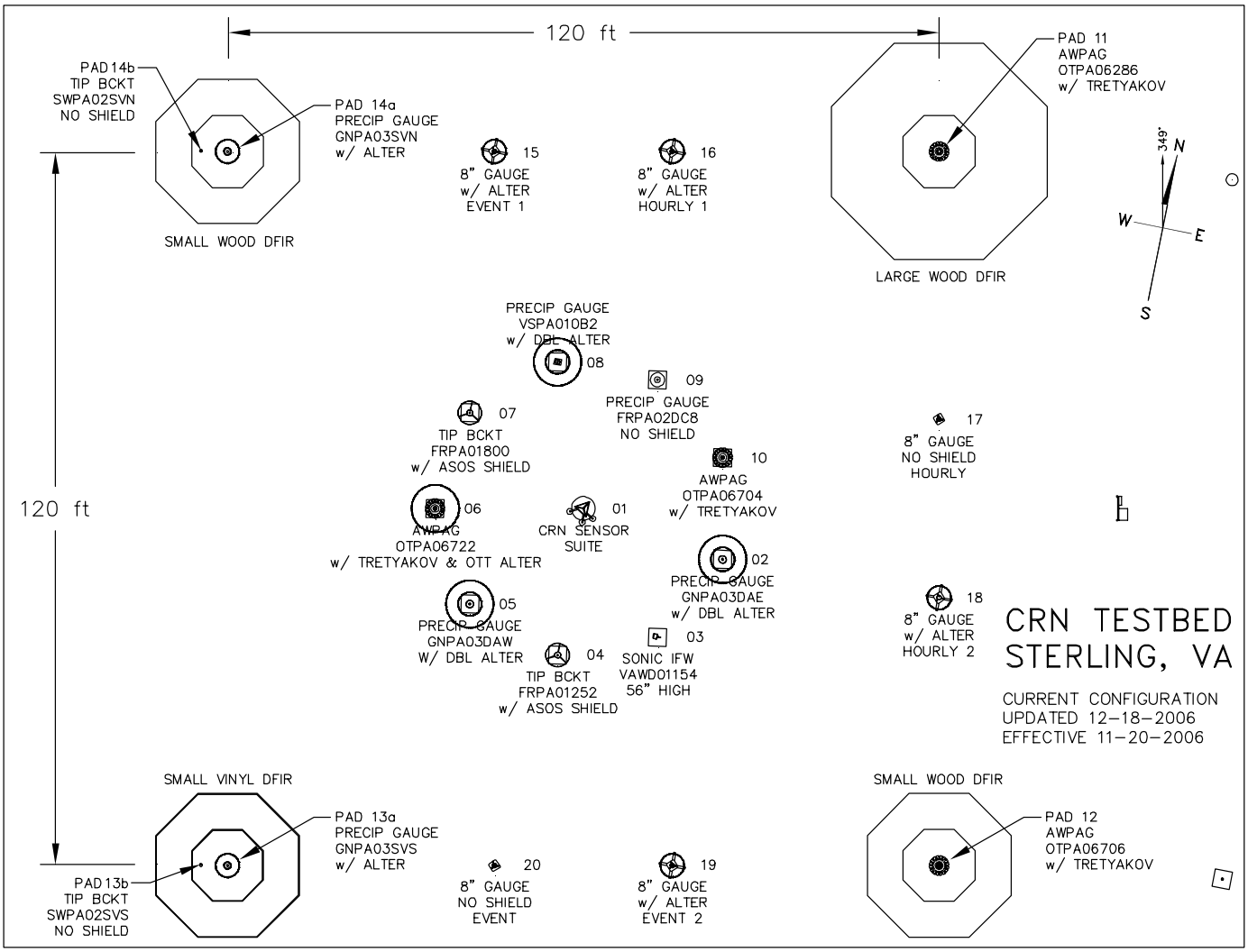
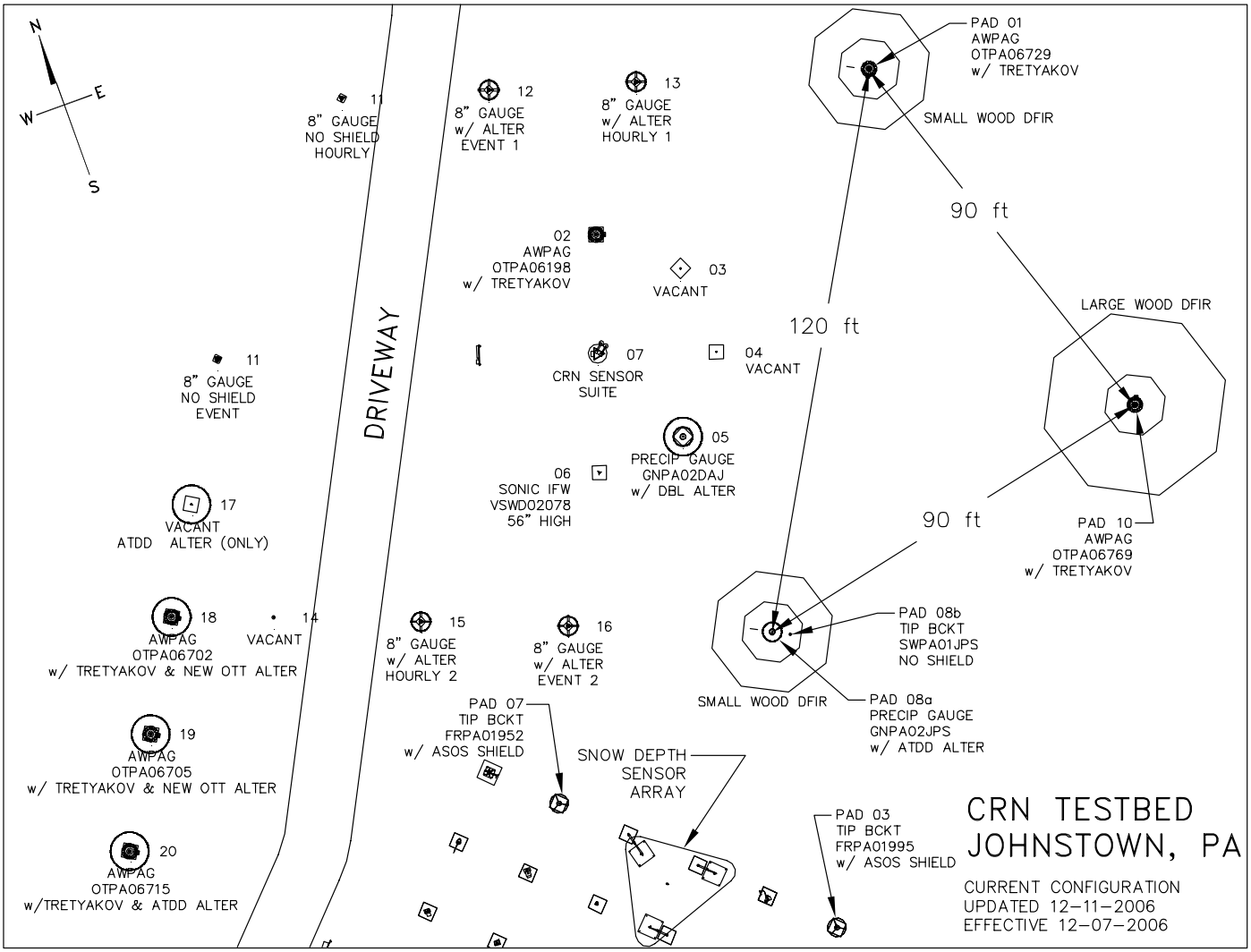
8.0 CONCLUSIONS

The data from the Johnstown, Sterling and the ASOS field sites demonstrates that the new shield design will measure approximately the same as the 8-inch manual gauge in most conditions. At Johnstown, where one of the AWPAG gauges was protected by the standard Tretyakov shield, the catch was about **10**% lower than the AWPAG with added 8-foot Alter shield. This shows a significant improvement in performance with the auxiliary shield over the standard shield. Despite the significant improvement in catch, some high wind events still showed slightly lower catch than the manual gauge – not quite meeting requirements in a few cases. There was also one high wind event at Cheyenne and one high wind event at Caribou, where the AWPAG catch was significantly lower than the manual gauge.

Late in the winter at Johnstown, it was observed that the lamellas on the new AWPAG Ott Alter shield did not swing as freely as the manual gauge Alter shield lamellas. This created concern that this lamella design was contributing to the gauges with the new shield being lower in precipitation catch compared to the National Oceanic and Atmospheric Administration's Atmospheric Turbulence and Diffusion Division (ATDD) that were installed with Alter shield lamellas with a design similar to the 4-foot Alter shield lamellas on the manual gauge. The AWPAG with the 8-foot Alter ATDD lamella design was catching about **5**% more than the gauges with the new Ott 8-foot Alter shield lamella design. The lamella designs differed in two ways. Ott had a concern about long term wear on the lamella hoop, and designed the lamella to have built-in "bushings" instead of just clearance holes for installing on the hoop. The lamella bushings increase friction and restrict the lamellas from swinging as freely as the lamellas without bushings on the manual Alter and ATDD lamella based shields. Second, the new AWPAG lamellas are shorter. This has an effect of reducing the wind force on the section of lamella below the hoop, thus requiring greater wind speed and gustiness to make the lamella swing. The overall effect is to restrict the lamella from swinging as freely as the lamellas that are longer and without bushings.

It is evident from our data that, while the new Ott 8-foot Alter showed improvement, it would be desirable to replace the current lamella design with the original Alter shield lamella design. The most significant benefit should be seen in high wind events (i.e. the only type of event where significant under catch was observed at Johnstown and ASOS AWPAG field sites in a few cases).

APPENDIX A STERLING, VIRGINIA TEST BED



APPENDIX B JOHNSTOWN, PENNSYLVANIA TEST BED