Environmental Technology Verification

Pesticide Spray Drift Reduction Technologies for Row and Field Crops

EVALUATION OF THE VERIFICATION PROTOCOL FOR LOW AND HIGH SPEED WIND TUNNEL TESTING

Prepared by

RTI International

USDA-ARS

Alion Science & Technology

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

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Notice

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Foreword

The Environmental Technology Verification (ETV) Program, established by the U.S. Environmental Protection Agency (EPA), is designed to accelerate the development and commercialization of new or improved technologies through third-party verification and reporting of performance. The goal of the ETV Program is to verify the performance of commercially ready environmental technologies through the evaluation of objective and quality-assured data in order to provide potential purchasers and permitters an independent, credible assessment of the technology that they are buying or permitting.

EPA established a Drift Reduction Technology (DRT) project under EPA's Environmental and Sustainable Technology (ESTE) program, which itself is part of EPA's Environmental Technology Verification (ETV) Program. Before the pesticide spray DRT generic verification protocol (GVP) is used for verification testing, the draft protocol requires testing and evaluation. Results of testing will be used to revise the draft DRT GVP. This report describes the evaluation of the draft protocol for pesticide spray DRTs verification at low and high speeds.

All testing was performed in accordance with approved test/quality assurance plans that implement the requirements of the generic verification protocol at the test laboratory.

Availability of Report

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- RTI International
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Executive Summary

Pesticide spray drift is defined as the movement of spray droplets through the air at the time of application or soon thereafter from the target site to any non- or off-target site, excluding pesticide movements by erosion, migration, volatility, or windblown soil particles after application. EPA established a Drift Reduction Technology (DRT) project under EPA's Environmental and Sustainable Technology (ESTE) program, which itself is part of EPA's Environmental Technology Verification (ETV) Program. Before the pesticide spray DRT generic verification protocol (GVP) is used for verification testing, the draft protocol requires testing and evaluation. Results from testing will be used to revise the draft DRT GVP. This report describes the evaluation of the draft protocol for pesticide spray DRTs verification at low and high speeds. This report provides stakeholders the validation data in a transparent manner so they can provide U.S. EPA suggestions to revise and improve the GVP.

The goal of the DRT project is to test and verify the effectiveness of a variety of spray DRTs, and has the ultimate goal of reducing unintentional exposures during the pesticide application process. In 2007, U.S. EPA completed a draft protocol for the verification of pesticide spray DRTs for row and field crops. *Draft Generic Verification Protocol for the Verification of Pesticide Spray Drift Reduction Technologies for Row and Field Crops* (http://www.epa.gov/etv/pubs/600etv07021.pdf) was developed by U.S. EPA with input and commentary from stakeholders that included academia, industry, and other government agencies.

For the low- and high-speed tests, the validity of and applicability of the pesticide spray DRT protocol were evaluated using two test nozzles and one reference nozzle. The two candidate nozzles tested were an AI11003-VS nozzle (Teejet Technologies, Wheaton, IL) and a ULD 120-04 nozzle (Hypropumps, New York, NY). The reference nozzle used for testing was an ASABE S572 nozzle associated with the fine/medium boundary. Measurements of the droplet size distribution produced by the candidate test systems were compared to the reference spray system based on the ASABE S572 standard for droplet size. Wind tunnel and spray liquid conditions measurements were supplemental measures that established the bounds of the spray size distribution data. Additionally, spray flux and deposition measurements were collected during low-speed tests. The low-speed measurements were conducted by Alion personnel in a low-speed wind tunnel environment in EPA's Aerosol Test Facility (ATF) at Research Triangle Park, NC. High-speed tests were conducted in the high-speed wind tunnel (HSWT) at the USDA-ARS in College Station, TX.

Data quality indicator goals (DQIGs) were established in the draft DRT protocol as criteria that provide qualitative and quantitative attributes that useful for evaluating and, in some cases, controlling environmental data quality. Evaluation of the feasibility of these criteria and identifying realistic adjustment for the protocol were key goals of this testing effort.

The low-speed wind tunnel tests did not achieve all the spray size distribution, spray flux, and spray deposition DQIGs included in the draft protocol. A combination of the nozzle orientation, low wind speed, and large droplets produced by the nozzles contributed to the failure to meet numerous DQIGs. However, the data collected were adequate for revising the low-speed wind tunnel portion of the DRT GVP, the main goal of this research.

The high-speed wind tunnel tests achieved the most important DQIGs. Two DQIGs were not achieved. The spray liquid and ambient temperature difference was greater than 2 °C for some tests. Also, spray liquid flow rates were not recorded. Failure to achieve these two DQIGs did not affect overall data quality or our ability to update the high-speed wind tunnel portion of the DRT GVP.

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List of Abbreviations and Acronyms

ADQ	audit of data quality
ANSI	American National Standards Institute
ASABE	American Society of Agricultural and Biological Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	ASTM International, formerly American Society for Testing and Materials
ATF	Aerosol Test Facility
AWT	aerosol wind tunnel
°C	degrees Celsius
cfm	cubic feet per minute
cm	centimeter
cp	centipoise
CV	coefficient of variance
DQIG	data quality indicator goal
DQO	data quality objective
DRT	drift reduction technology
$D_{v0.1}$	droplet diameter (μm) at which 10% of the spray volume is contained in smaller droplets
$D_{v0.5}$	droplet diameter (μm) at which 50% of the spray volume is contained in smaller droplets
$D_{v0.9}$	droplet diameter (μm) at which 90% of the spray volume is contained in smaller droplets
dyne/cm	dynes per centimeter
EC	emulsifiable concentrates
EPA	United States Environmental Protection Agency
ESTE	Environmental and Sustainable Technology Evaluations
ETV	Environmental Technology Verification
fpm	feet per minute
ft	foot
gal/acre	gallons per acre
gpm	gallons per minute
GVP	generic verification protocol
HELOS	helium neon laser optical system
HETS	human exposure test section
HSWT	high-speed wind tunnel
Hz	hertz

in.	inches
ISO	International Standards Organization
kPa	kilopascal
L	liter
LSWT	low-speed wind tunnel
m	meters
mph	miles per hour
min	minute
mg	milligram
mL	milliliter
mm	millimeter
ms	millisecond
m/s	meters per second
NIS	nonionic surfactant
NIST	National Institute of Standards and Technology
µL	microliter
µm	microns
OPP	Office of Pesticide Programs
ORD	Office of Research and Development
PE	performance evaluation
PES	performance evaluation system
PMT	photo multiplier transistor
psi	pounds per square inch
QA	quality assurance
QC	quality control
QM	quality manager
QMP	quality management plan
QSM	quality system manual
RH	relative humidity
RTI	Research Triangle Institute
s	second
SD	standard deviation
SNR	signal to noise ratio
SOP	standard operating procedure
STS	sampler test section
TSA	technical systems audit
T/QAP	test and quality assurance plan
USDA-ARS	United States Department of Agriculture – Agricultural Research Service
v/v	volume/volume

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The authors acknowledge the support of all those who helped plan and conduct the protocol evaluation activities. In particular, we would like to thank Michael Kosusko, U.S. Environmental Protection Agency's (EPA's) project officer, Bob Wright, EPA's quality manager, both of EPA's National Risk Management Research Laboratory in Research Triangle Park, NC, and Clint Hoffman and Brad Fritz, USDA-ARS, College Station, TX, for providing access to the USDA-ARS high-speed wind tunnel.

1.0 Introduction

Pesticide spray drift is defined as the movement of spray droplets through the air at the time of application or soon thereafter from the target site to any non- or off-target site, excluding pesticide movements by erosion, migration, volatility, or windblown soil particles after application. EPA established a Drift Reduction Technology (DRT) project under EPA's Environmental and Sustainable Technology (ESTE) program, which itself is part of EPA's Environmental Technology Verification (ETV) Program. The objective of the ETV Program is to verify, with high data quality, the performance of technologies that reduce pollution. The goal of the DRT project is to test and verify the effectiveness of a variety of spray DRTs, and has the ultimate goal of reducing unintentional exposures during the pesticide application process. In 2007, U.S. EPA completed a draft protocol for the verification of pesticide spray DRTs for row and field crops. *Draft Generic Verification Protocol for the Verification of Pesticide Spray Drift Reduction Technologies for Row and Field Crops* (http://www.epa.gov/etv/pubs/600etv07021.pdf) was developed by U.S. EPA with input and commentary from stakeholders that included academia, industry, and other government agencies.

Before ETV can implement the pesticide spray DRT generic verification protocol (GVP) for verification testing, the draft protocol requires testing and evaluation. This report describes the evaluation of the draft protocol for pesticide spray DRTs verification at low- and high-speeds. EPA, RTI, vendors, test facilities, and other stakeholders will use this report to evaluate the pesticide spray DRT protocol and suggest changes that will provide improvements.

ETV testing to validate the draft DRT protocol was conducted during a series of low-speed wind tunnel tests in June 2009 by Alion Science & Technology, under contract with RTI, and high-speed wind tunnel tests conducted in March 2009 by the United States Department of Agriculture – Agricultural Research Service (USDA-ARS).

For the tests described here, the pesticide spray DRT protocol was evaluated for both low- and high-speed applications, using two test nozzles and one reference nozzle. Low-speed is defined as a speed of the air in the wind tunnel crossing the nozzle representative of ground application and high-speed is defined as speed of the air in the wind tunnel crossing the nozzle representative of aerial application. The purpose of this testing was to gather information and data for evaluating the applicability of the pesticide spray DRT protocol for successfully testing commercially ready pesticide spray DRT nozzles that will be used for aerial spraying and ground applications. Evaluation of the protocol through spray liquid formulation modifications to the viscosity, surface tension or other characteristics was not conducted.

Section 2 of this report documents the DRTs tested, procedures used for the tests and the conditions over which the tests were conducted. The results of the test are summarized and discussed in Section 3, Quality Assurance and protocol recommendations are discussed in Section 4, and references are presented in Section 5.

This report contains summary information and data from the tests; however, as the purpose of these tests is to verify the protocol and test plan, no verification statement is included. Complete documentation of the test results is provided in a separate data package report and an audit of data quality report. These reports include the raw test data from product testing and supplemental testing, equipment calibrations results, and quality assurance (QA) and quality control (QC) activities and results. Complete documentation of QA/QC activities and results, raw test data, and equipment calibrations results are retained in Alion and USDA files for seven years. All files and records will also be stored at U.S. EPA indefinitely. Helium neon laser optical system (HELOS) data are included in Appendices A and B of this report.

2.0 Test Description

The low-speed measurements in this report were conducted by Alion personnel in a low-speed wind tunnel (LSWT) environment in EPA's Aerosol Test Facility (ATF) in Research Triangle Park, NC. High-speed tests were conducted in the high-speed wind tunnel (HSWT) at the USDA-ARS in College Station, TX. For the low- and high-speed tests, the validity of and applicability of the pesticide spray DRT protocol were evaluated using two test nozzles and one reference nozzle. Measurements of the droplet size distribution produced by the candidate test systems were compared to the reference spray system based on the ASABE S572 standard for droplet size.

The DRTs were tested in accordance with Draft Generic Verification Protocol for the Verification of Pesticide Spray Drift Reduction Technologies for Row and Field Crops[1], Test/QA Plan for the Evaluation of the Verification Protocol for High Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops[2] and Test/QA Plan for the Evaluation of the Verification Protocol for Low Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops.[3] These documents incorporated all requirements for quality management, QA, procedures for product selection, auditing of the test laboratories, and reporting format. The draft generic verification protocol describes the overall procedures used for verification testing and defines the data quality objectives (DQOs). The test/QA plans (T/QAPs) detail how the test organizations implemented and met the requirements of the protocol.

The primary performance measure for the evaluation of the pesticide spray DRT protocol will be derived from droplet size distribution measurements. Droplet size is one of the most important factors affecting spray applications, efficacy and drift potential. All nozzles and atomizers produce a range of droplet sizes within a given spray. This droplet size spectrum (or distribution) typically may include some relatively small droplets that may be more prone to drift than are their larger counterparts. There is general agreement in the literature that droplets with diameter below less than 200µm often pose the greatest risk of spray drift in conventional applications. Therefore, minimizing the proportion of the spray volume that is contained in droplets of this size may help mitigate spray drift risk. Some nozzles are more effective than are others in producing narrower droplet size spectra with fewer small ("fine") droplets.

The basic experimental design was to measure the droplet size spectrum under targeted test conditions with the DRT operating at the specified spray pressure, air speed, and the ambient environmental conditions. Droplet size spectrum is the critical measurement for these tests. Droplet size measurements of interest are the $D_{v0.5}$, $D_{v0.1}$, and $D_{v0.9}$. $D_{v0.5}$ is the volume median diameter (µm) where 50% of the spray volume is contained in droplets of smaller diameter. Similarly, $D_{v0.1}$ and $D_{v0.9}$ describe the percentage (10% or 90%, respectively) of the droplet volume in the specified size or less. Wind tunnel and spray liquid conditions measurements are supplemental measures that establish the bounds of the spray size distribution data.

Spray flux and deposition measurements are only applicable to the low-speed wind tunnel tests. For the spray flux tests, monofilament lines approximately 2 mm in diameter were used as sample collectors. These were extended horizontally across the wind tunnel at seven heights starting at 10 cm above the synthetic turf that was on the wind tunnel floor and spaced in 10 cm increments. Droplet size was measured 2 m downwind of the spray nozzle at the same seven heights as the flux measurements

Off-site spray drift and resulting downwind deposition of pesticide can be hazardous to nearby non-target receptors. The results of testing to be conducted under this program are to be used to estimate downwind deposition. For example, the testing results from wind tunnel testing (droplet size distribution and spray flux) will be used as inputs to models that will estimate deposition downwind such as the dispersion models, AGDISP or WTDISP.

To meet the DQO, at least three replicate experiments using each nozzle were performed. As required by the DQO in the approved test plans, the product of this test design will be the measurement of a droplet size distribution consisting of 32 or more droplet size bins for the specified operating range.

2.1 Description and identification of DRTs

One reference and two candidate nozzles were tested using the pesticide spray DRT protocol in low-speed and high-speed wind tunnels. The reference nozzle used for testing was an ASAE S572 nozzle associated with the fine/medium boundary and was a 110° flat-fan nozzle operated at 300 kPa (43.5 psi) and 1.18 L/min (0.31 gpm). USDA-ARS provided the reference nozzle for the LSWT tests.

The two candidate nozzles tested were an AI11003-VS nozzle (Teejet Technologies, Wheaton, IL) and a ULD 120-04 nozzle (Hypropumps, New York, NY). These are shown in Figure 1. The AI11003-VS is an induction nozzle that produces a “very coarse” spray, as defined by ASABE S572 (1999), at the operating conditions defined in element B1 of the approved T/QAP. This nozzle is used extensively by industry and its performance characteristics have been extensively studied. The AI11003-VS flow is 1.13 L/min (0.3 gpm). The ULD 120-04 is a dual air induction nozzle also extensively used by industry. The ULD 120-04 nozzle produces a “coarse” spray at the operating conditions defined in element B1 of the T/QAP. The ULD 120-04 flow is 1.51 L/min (0.4 gpm). Both test nozzles were operated at 300 kPa (43.5 psi) for all tests.

Teejet AI11003-VS

(manufacturer photo)

Hypropumps ULD 120-04 nozzle

(manufacturer photo)

Figure 1. Nozzles under test. Used with permission.

2.2 Spray material

The material used for droplet sizing measurements was a deionized water solution containing a 0.25% volume/volume (v/v) of a 90% nonionic surfactant (R-11, Wilbur-Ellis Company, San Antonio, TX). For the flux and deposition measurements, uranine was added to the above solution to make an uranine concentration of 3.6 g/L. The solution was sprayed with a FIMCO 300 agricultural sprayer with boom (FIMCO Industries, North Sioux City, SD). Pressure at the nozzle was measured using a digital pressure gauge (Ashcroft Inc., Stratford, CT).

2.3 Procedures and methods used in testing

2.3.1 Test facilities

Low-speed testing was conducted in the aerosol wind tunnel (AWT) at the U.S. EPA ATF in Research Triangle Park, NC (Figure 2). The AWT system can produce a wide range of air velocities, particle sizes, and aerosol loadings with controlled temperature and humidity. In plan view, the AWT is rectangular in shape with outside dimensions of approximately 20 m by 14 m. Flow through the recirculating AWT during all operations is counterclockwise. The graphic of the tunnel shows two test sections: the human exposure test section (HETS) and the sampler test section (STS). The HETS was used for this series of

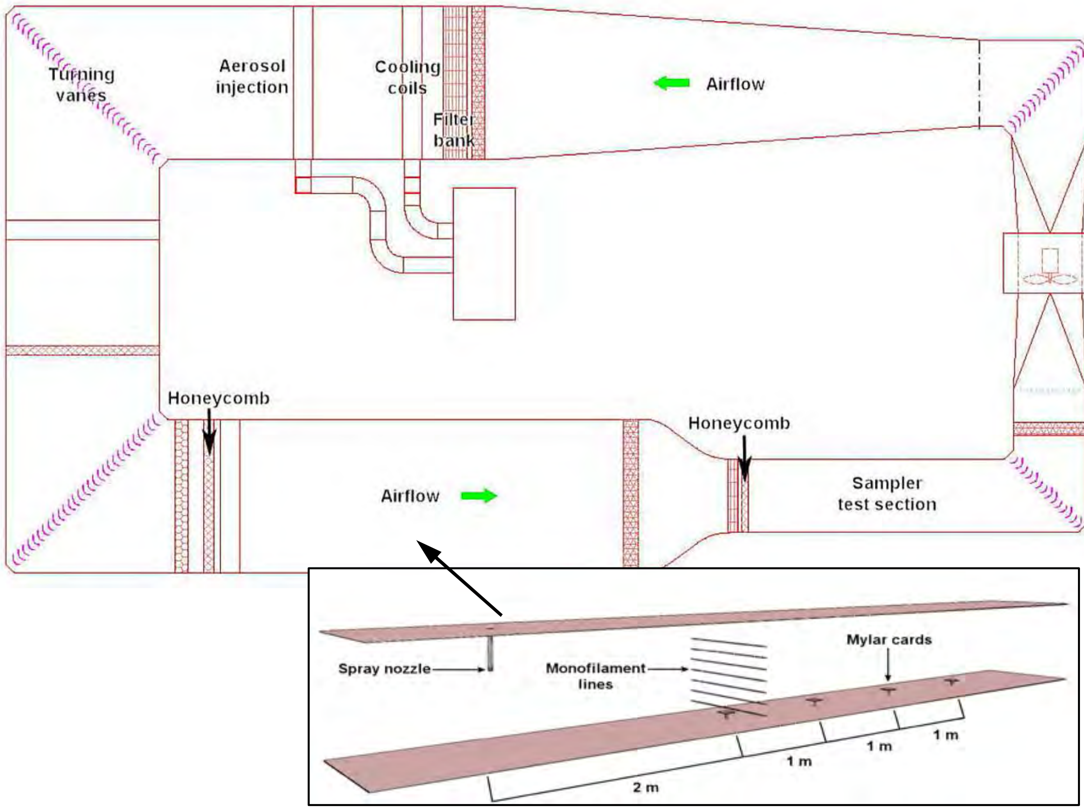

Figure 2. EPA's aerosol wind tunnel (AWT).

experiments. The HETS has a cross section 3.7 m wide, 3.0 m high, and 9.0 m long, and the STS has a cross section 1.8 m wide, 1.4 m high, and 6 m long. The wind speed in the HETS can be varied from 0.1 to 1 m/s (0.36 to 3.6 km/h) while the STS can range from 0.56 to 13.3 m/s (2 to 48 km/h). Air speed in the wind tunnel was measured with a CSAT3 sonic anemometer (Campbell Scientific). The AWT is described in more detail in the approved low-speed DRT T/QAP. Wind tunnel temperature and relative humidity were measured by a HMT 333 Probe (Vaisala, Woburn, MA). Spray solution temperature was measured using a digital thermometer (Model 14-648-12, Fisher Scientific, Pittsburgh, PA). The equipment setup for testing DRTs in the low-speed tunnel is pictured in Figure 3.

High-speed testing was conducted in the HSWT at USDA-ARS located in College Station, TX, and depicted in Figure 4. The USDA-ARS HSWT consists of a high-speed centrifugal blower powered by a 48.5 kw (65 hp) gasoline engine. The blower speed is controlled by adjusting the engine's throttle. The high-speed air generated by the blower exhausts through a 30 x 30 cm outlet. Prior to leaving the outlet, the high-speed air passes through air straighteners mounted inside the tunnel. Airspeed is measured directly at the outlet using a pitot tube attached to an airspeed indicator. A 30 cm section of aircraft boom is mounted directly at the tunnel's outlet. The boom is affixed to a pair of linear slides and a linear motor to allow it to be traversed vertically across the length of the outlet. The boom section is plumbed to a pressurized spray tank. The center of the boom has a fitting to mount the required check valves and nozzles. A pressure gauge is also plumbed to the boom to monitor pressure at the nozzle. A movable 40 x 40 cm Plexiglas tunnel is positioned in-line with the airstream flush against the tunnel's outlet. This section is moveable to allow access to the spray boom and nozzle. The Plexiglas tunnel has a pair of access holes downwind of the nozzle through which the laser diffraction instrument operates. Additional details on the USDA-ARS HSWT can be found in the approved high-speed DRT T/QAP (Reference 2).

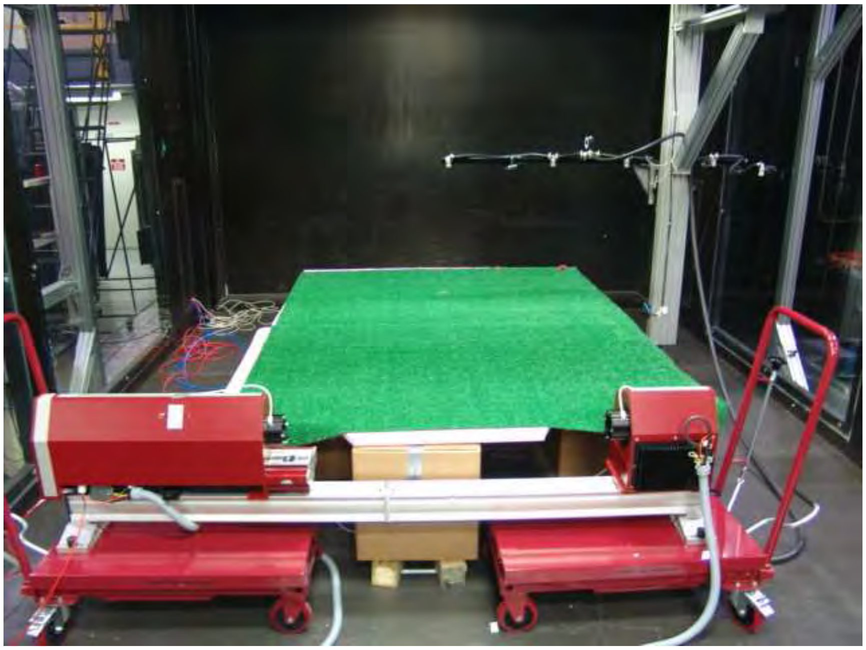

Figure 3. AWT setup for low-speed DRT tests.

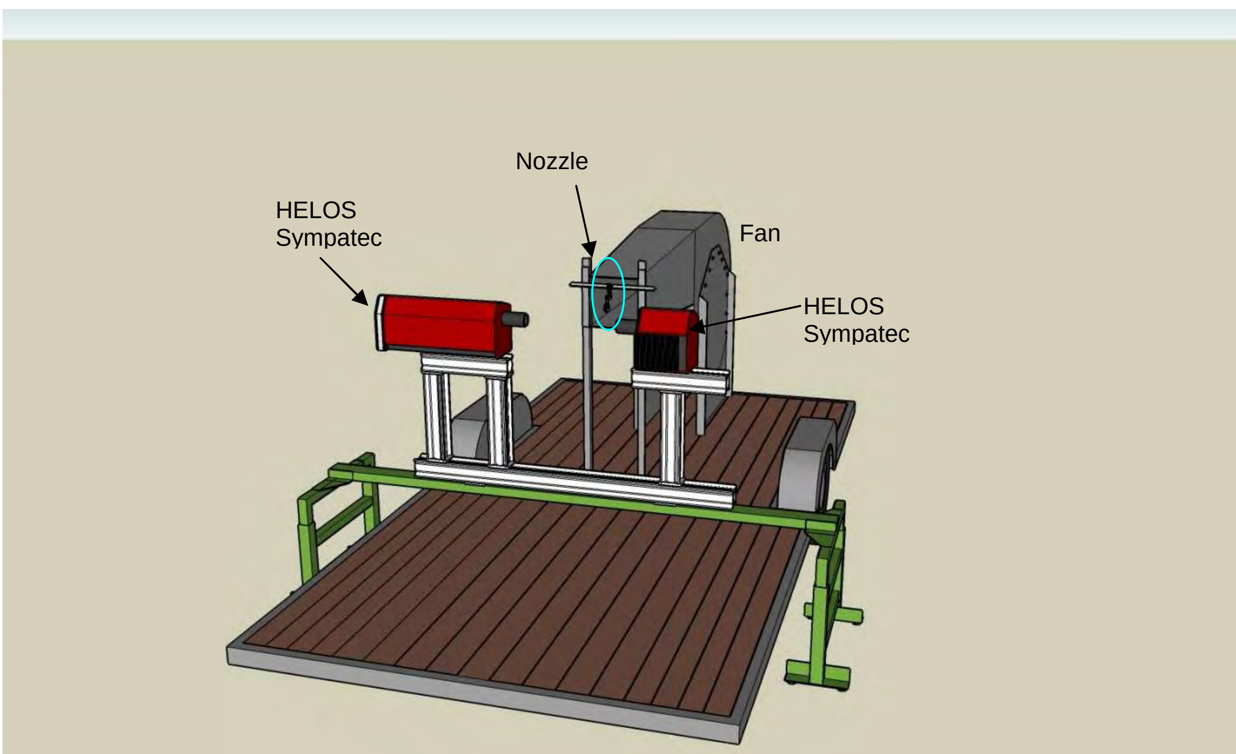

Figure 4. Overview of HSWT with enclosure removed for clarity.

2.3.2 Droplet sizing measurements

At each test location, droplet sizing measurements for this study were conducted using that facility's Sympatec HELOS-Vario laser diffraction droplet sizing system (Sympatec Inc., Clausthal, Germany), which use a 623 nm He-Ne laser. The HELOS systems were fitted with an R5 lens, which resulted in a dynamic size range of 0.5 µm to 875 µm in 32 sizing bins. Droplet sizing data measured included volume median diameter ($D_{v0.5}$) and the 10% and 90% diameters ($D_{v0.1}$ and $D_{v0.9}$). HELOS is an acronym for helium-neon laser optical system.

For low-speed tests, two types of droplet sizing measurements were made for each nozzle: spray characterization in static air and drift characterization 2 m downwind at 1 m/s wind speed. For the high-speed tests, drift characterization at a downwind distance of 60 cm at 120 mph (55.3 m/s) wind speed

(aerial application air speeds) was performed. Spray characterization measurements were not performed at USDA.

2.3.2.1 Spray characterization measurements – low-speed wind tunnel

Spray characterization measurements were performed in the low-speed wind tunnel in static air.[4] The wind tunnel was run for sufficient time to allow stabilization at the temperature and relative humidity (RH) set points described in the approved T/QAP prior to testing. The three nozzles tested were the reference, AI11003-VS and ULD 120-04 nozzle. Droplet size measurement and classifications were consistent with ASABE S572 except that all tests were conducted under the same conditions (e.g., spray material, spray pressure, nozzle settings) and following the procedures outlined in the approved test plans. The nozzle that defined the fine/medium category [flat fan 110° at 300 kPa (43.5 psi)] served as the reference nozzle for all subsequent tests (low- and high-speed).

2.3.2.2 Droplet sizing 2 m downwind – low-speed wind tunnel

For the low-speed droplet sizing measurements 2 m downwind of the nozzle, the wind tunnel was set at 1 m/s, 25 °C, and 80% RH and run for sufficient time to allow it to stabilize. The spray nozzle of interest was mounted on a sprayer boom attached to the internal wind tunnel traverse and oriented at 90° so that the spray pattern was perpendicular to the wind.

The HELOS system was set up inside the HETS on two hydraulic lift carts and oriented across the width of the test section (along the x-axis, also perpendicular to the wind). The two halves of the HELOS were separated as far as possible while still mounted to the rail. The distance from the transmitting to the receiving part of the instrument was 94.6 cm (as shown in Figure 5). A 2.6-m long, 1.8-m wide false floor was constructed 54.5 cm above the wind tunnel floor and was covered with artificial turf grass. The spray nozzle was positioned 60 cm above and 60 cm downwind of the leading edge of the false floor.

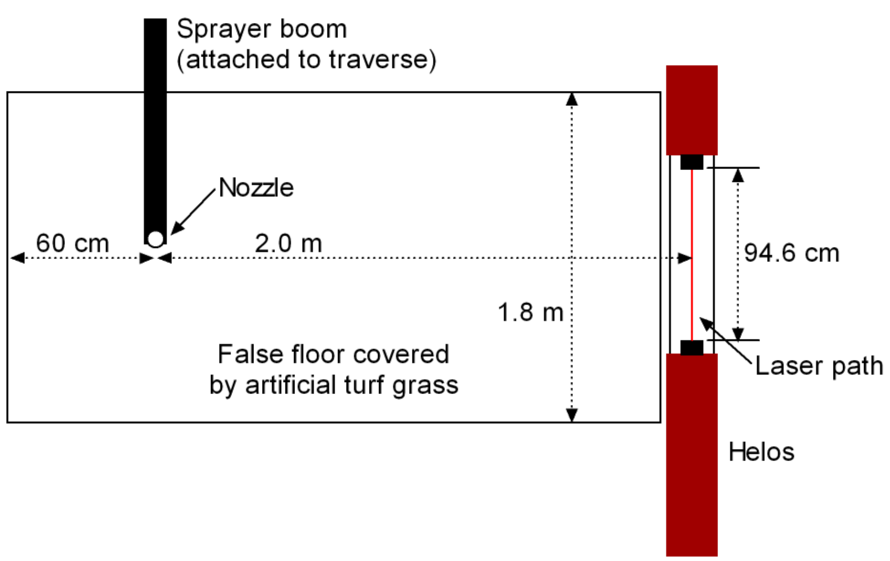

Figure 5. Schematic diagram of the set up for droplet sizing measurements 2 m downwind.

The HELOS was positioned as close as possible to the downwind edge of the false floor with the laser beam 10 cm higher than the turf grass surface. The hydraulic lift carts were used to raise and lower the HELOS unit to obtain the required measurement heights (10, 20, 30, 40, 50, 60 and 70 cm higher than the turf grass), and a level was placed on the rail connecting the two parts of the HELOS system to ensure that the system was always level. In order to minimize the number of times the HELOS was moved up and down, measurements for all of the nozzles were made at one position before moving the HELOS system up to the next position.

2.3.2.3 Droplet sizing 60 cm downwind – high-speed wind tunnel

For the high-speed droplet sizing measurements 60 cm downwind of the nozzle, the wind tunnel was set at 192 km/hr (120 mph, 53.3 m/s), ambient conditions and run for sufficient time to allow it to stabilize. The spray nozzle of interest was installed in the wind tunnel at or near the centerline and oriented at 0° so that the spray pattern was parallel to the wind. Nozzles were positioned in the center of the wind tunnel to be free from edge effects. High-speed test procedures are outlined in the approved T/QAP.

For these tests, USDA collected data from the reference nozzle, four different ULD 120-04 nozzles and three different AI11003-VS nozzles. For a separate study, USDA compared the variation between nozzles of the same type. Although comparing nozzles of the same type was not part of the T/QAP, for completeness, all collected data are presented here, however a discussion of any variation is not presented.

2.3.3 Spray flux and deposition measurements – Low-speed wind tunnel

Spray flux and deposition measurements are only applicable to the low-speed wind tunnel tests. For the spray flux tests, monofilament lines approximately 2 mm in diameter were used as sample collectors. These were extended horizontally across the wind tunnel at seven heights starting at 10 cm above the turf grass that was on the wind tunnel floor and spaced in 10 cm increments. Each end of the monofilament line was supported in enclosed boxes within the AWT to prevent contamination of the unused portion of sampling line.

Spray flux was measured 2 m downwind from the spray nozzle using monofilament line at the same seven heights as the droplet sizing measurements (see Figure 2). On one side of the test section, fishing reels with the monofilament line were secured at each height inside a specially-constructed cabinet designed to protect the unexposed monofilament line from uranine exposure. Another cabinet on the other side of the tunnel held a series of dowels covered by plastic drinking straws at each height to hold the monofilament in place. A small piece of tape was used to attach the loose end of the monofilament to the dowel. After each spray replication, the monofilament at each height was collected by hand-winding onto plastic straws (0.6 cm dia. x 19 cm long). Prior to spray exposure, the monofilament line was marked with a permanent marker at the location where it exited the cabinet holding the fishing reels. The line was then wound onto the straw until the mark was reached. The straw with the line was removed from the dowel and placed in a labeled plastic Whirl-Pak bag. The process of collecting the exposed monofilament also spooled new line from the reel into the tunnel, which was then secured onto new plastic straws on the dowels.

Spray duration for an experiment was 15 ± 0.5 s. This was an unintended deviation from the T/QAP specification of 10 ± 0.5 s that was only realized after all of the tests were completed. However, the longer spray time did not cause overloading of the monofilament lines or puddling on the Mylar cards. Immediately after an experiment, the exposed monofilament line was collected into a labeled plastic bag, and 30 mL of 0.01N NaOH was added to the bag to dissolve the uranine into solution. The bag contents were shaken for 10 s before an aliquot of the liquid was removed for fluorometric analysis.

Spray drop deposition at multiple horizontal distances from the nozzle were collected simultaneously with the spray flux volume samples. Deposition sampling onto 10 cm by 10 cm (100 cm^2) Mylar cards.

(VWR part # 95017-735, GE Healthcare Biosciences, Piscataway, NJ) was used to measure horizontal deposition within the wind tunnel. Mylar cards were placed directly downwind from the nozzle aligned with the plume centerline on metal support stands located 2, 3, 4, 5 and 6 m downwind of the nozzle. The cards were at a height of 0.1 m above the turf grass on the wind tunnel floor to avoid boundary layer effects.

Immediately after an experiment, the exposed Mylar cards were collected and placed in a labeled plastic bag. 30 mL of 0.01N NaOH were added to the bag to dissolve the uranine into solution. The bag contents were shaken for 10 s before an aliquot of the liquid was removed for fluorometric analysis.

The relative fluorescence in a 5 mL aliquot of the extract was measured using a Turner digital fluorometer (Model FM109515, Thermo Scientific, Waltham, MA) following standard operating procedures. The fluorometer used a 12 x 75 mm round cuvette. A narrow band (NB360) excitation filter and emission filter (NB460) were used. A calibration curve linking fluorescence units to mass of fluorescent material was generated for each batch of 50 samples. The curve spanned the detection range of the fluorometer and demonstrated linearity in the instrumentation response as a function of mass deposited. From this curve, fluorescent tracer measurements were converted to the fraction of spray liquid applied.

3.0 Results

3.1 Low-speed wind tunnel test results

3.1.1 Spray characterization results

The management of pesticide drift exposure may involve careful consideration of many factors such as the droplet size spectrum, spray release height, meteorological conditions, application practices, no-spray buffer zones, tank mix physical properties, liquid temperature, and target characteristics. Managing these factors can be complex, so focus is often placed on the major parameters of importance. For example, droplet size is often the most important factor, so optimization of the size range to include relatively few small droplets (by volume) can provide a major reduction in spray drift potential while maintaining product efficacy for many application scenarios.

Table 1 presents the results from the nozzle spray characterization measurements without wind. The results shown are the average of three replicate measurements. The $D_{V0.5}$ of the reference nozzle spray was 220.7 µm. Results are shown graphically in Figure 6.

Table 1. Spray characterization droplet size data (means ± standard deviations) 60 cm below the nozzle.

Nozzle	Pressure (psi)	Flow (Lpm)	Replicate	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	Statistic	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)
Reference	43.5	1.20	1	127.6	217.2	310.2	Average	112.4	220.7	329.9
			2	130.6	220.8	318.9	SD	29.1	3.5	26.9
			3	78.8	224.2	360.5	CV	0.26	0.02	0.08
AI11003-VS	43.5	1.21	1	154.6	280.3	388.9	Average	148.8	268.0	366.6
			2	155.0	280.4	388.5	SD	10.4	21.4	38.2
			3	136.8	243.3	322.5	CV	0.07	0.08	0.10
Hypro ULD 120-4	43.5	1.65	1	22.2	162.0	231.0	Average	20.0	185.1	277.5
			2	17.2	190.2	297.2	SD	2.6	21.0	40.5
			3	20.7	203.2	304.5	CV	0.13	0.11	0.15

SD = standard deviation, CV = coefficient of variation

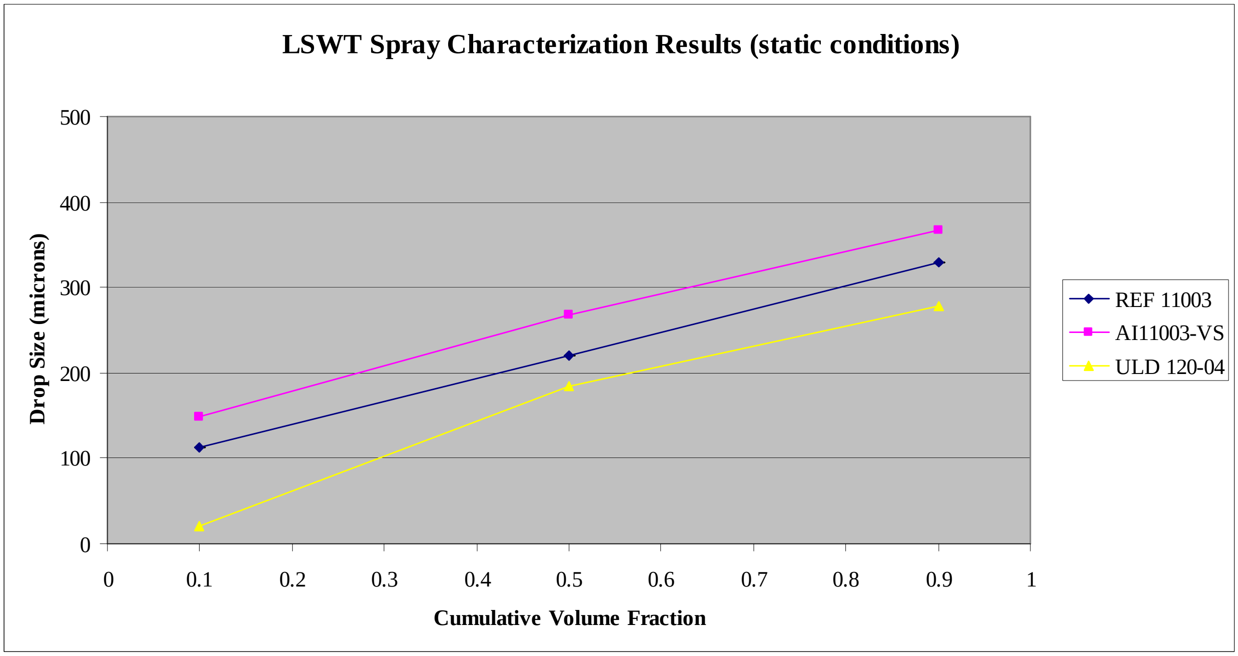

Figure 6. LSWT spray characterization results under static wind conditions.

3.1.2 Droplet sizing 2 m downwind results

The measured droplet sizes for all three nozzles at the seven heights are shown in Table 2. For example, spray characterization at a height of 20 cm is shown in Figure 7. The decrease in the size distribution at heights lower than 30 cm (Hypro) or 40 cm (Teejet) identified the point where all DQIGs were achieved. The very large droplet sizes measured at the higher positions resulted from extremely low optical concentrations. No data were reported for the Hypro ULD 120-4 nozzle at 30 and 50 cm heights because the optical concentration was so low that the HELOS could not detect and thus not report any data. All size distribution data at 2 m were impacted by failure to achieve HELOS data collection data quality indicator goals (DQIGs). The HELOS was operating normally and without operator error. The low wind speed (1 m/s) and extremely large droplets generated by all nozzles caused HELOS minimum obscuration to be less than 2% for 83% of measurements and percentage of drop volume in largest and smallest bins to be > 1% in approximately 65% of measurements (See Table 10).

Wind speed, temperature, and relative humidity averages and standard deviations measured for each nozzle over the three replicate droplet sizing measurements at 2 m downwind are given in Table 3.

Table 2. Droplet size data (means ± standard deviations) 2 m downwind of nozzle at 1 m/s wind speed.

Nozzle	Height (cm)	Replicate	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)	Statistic	$D_{V0.1}$ (μm)	$D_{V0.5}$ (μm)	$D_{V0.9}$ (μm)
Reference	70	1	550.2	660.0	720.0	Average	567.3	662.3	720.5
		2	592.3	666.1	721.2	SD	22.2	3.4	0.7
		3	559.4	661.2	720.2	CV	0.04	0.01	0.00
	60	1	490.9	647.8	717.6	Average	517.7	652.8	718.6
		2	541.2	657.5	719.5	SD	25.3	4.9	1.0
		3	520.9	653.1	718.6	CV	0.05	0.01	0.00
	50	1	20.2	39.9	60.6	Average	19.6	38.4	61.5
		2	19.1	38.0	61.6	SD	0.6	1.4	0.9
		3	19.4	37.3	62.4	CV	0.03	0.04	0.02
	40	1	14.8	43.1	74.4	Average	18.9	45.0	77.5
		2	19.7	45.8	77.9	SD	3.7	1.7	2.9
		3	22.2	46.1	80.1	CV	0.20	0.04	0.04
	30	1	19.9	48.1	85.3	Average	19.5	46.6	84.1
		2	20.4	47.3	85.1	SD	1.2	1.8	1.9
		3	18.2	44.6	81.9	CV	0.06	0.04	0.02
	20	1	23.7	56.9	133.5	Average	25.3	55.3	125.0
		2	23.9	54.5	119.2	SD	2.5	1.4	7.6
		3	28.2	54.4	122.1	CV	0.1	0.03	0.06
	10	1	27.3	52.0	86.0	Average	27.8	52.5	86.7
		2	28.4	52.9	86.8	SD	0.5	0.4	0.7
		3	27.8	52.7	87.4	CV	0.02	0.01	0.01
AI11003-VS	70	1	540.9	652.9	718.6	Average	541.0	652.5	718.5
		2	541.3	652.9	718.6	SD	0.9	0.8	0.2
		3	541.8	652.8	718.6	CV	0.00	0.00	0.00
	60	1	455.6	618.8	711.8	Average	458.2	618.4	711.7
		2	452.8	609.1	710..1	SD	7.1	8.7	1.6
		3	466.2	626.4	713.3	CV	0.02	0.01	0.00

Nozzle	Height (cm)	Replicate	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)	Statistic	$D_{V0.1}$ (µm)	$D_{V0.5}$ (µm)	$D_{V0.9}$ (µm)
	50	1	1.0	2.9	61.1	Average	1.0	2.9	59.1
		2	1.0	2.9	58.8	SD	0.0	0.0	1.9
		3	1.0	2.9	57.4	CV	0.01	0.01	0.03
	40	1	479.4	644.0	716.8	Average	465.9	641.5	716.3
		2	464.1	646.3	717.3	SD	12.7	6.5	1.3
		3	454.2	634.1	714.8	CV	0.03	0.01	0.00
	30	1	12.4	55.2	87.2	Average	11.8	55.0	87.0
		2	11.9	54.7	86.7	SD	0.8	0.3	0.3
		3	10.9	54.9	87.1	CV	0.06	0.01	0.00
	20	1	45.0	75.6	111.9	Average	44.9	75.8	112.2
		2	45.5	76.1	111.2	SD	0.6	0.2	1.1
		3	44.3	75.8	113.4	CV	0.01	0.00	0.01
	10	1	47.3	83.9	119.5	Average	46.8	83.3	119.3
		2	46.2	83.0	119.8	SD	0.6	0.5	0.6
		3	46.8	83.1	118.6	CV	0.01	0.01	0.01
Hypro ULD 120-4	70	1	535.5	648.4	717.7	Average	534.6	647.4	717.5
		2	534.4	647.3	717.5	SD	0.8	0.9	0.2
		3	533.9	646.6	717.3	CV	0.00	0.00	0.00
	60	1	474.0	636.6	715.3	Average	478.3	633.5	714.7
		2	481.0	634.1	714.8	SD	3.8	3.5	0.7
		3	480.0	629.7	713.9	CV	0.01	0.01	0.00
	50	1	-	-	-	Average	-	-	-
		2	-	-	-	SD	-	-	-
		3	-	-	-	CV	-	-	-
	40	1	551.6	657.6	719.5	Average	557.7	658.5	719.7
		2	563.4	661.0	720.2	SD	5.9	2.2	0.4
		3	558.2	656.9	719.4	CV	0.01	0.00	0.00
	30	1	-	-	-	Average	-	-	-
		2	-	-	-	SD	-	-	-
		3	-	-	-	CV	-	-	-
	20	1	40.9	67.0	98.3	Average	41.3	68.0	100.3
		2	41.3	67.8	99.8	SD	0.4	1.1	2.3
		3	41.8	69.2	102.7	CV	0.01	0.02	0.02
	10	1	43.6	73.9	101.2	Average	43.1	73.6	102.6
		2	43.1	73.4	102.2	SD	0.5	0.3	1.5
		3	42.7	73.6	104.3	CV	0.01	0.00	0.02

SD = standard deviation, CV = coefficient of variation

Table 3. Nozzle pressure, wind speed, air temperature, relative humidity, and spray solution temperature for droplet sizing measurements (means ± standard deviations) at 2 m downwind.

Nozzle	Pressure (psi)	Wind speed (m/s)	Air Temperature (°C)	Relative Humidity (%)	Solution Temperature (°C)
Reference	43.3 ± 0.12	1.03 ± 0.06	24.9 ± 0.05	80.0 ± 0.62	23.7 ± 0.82
AI11003-VS	43.4 ± 0.26	1.02 ± 0.05	24.9 ± 0.05	79.9 ± 0.73	23.7 ± 0.80
Hypro ULD 120-4	43.4 ± 0.15	1.03 ± 0.05	25.0 ± 0.05	79.8 ± 0.76	23.7 ± 0.83

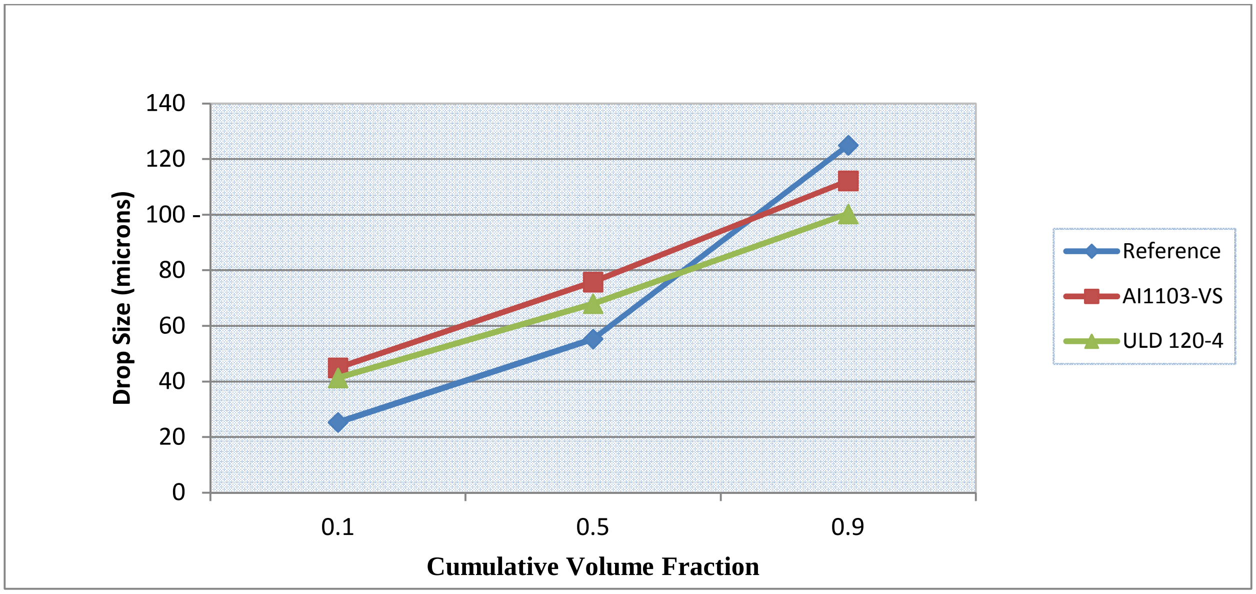

Figure 7. Example of LSWT spray characterization at the 2-meter flux plane and 20 cm height.

3.1.3 Spray flux and deposition results

Results of flux measurements from monofilament line are given in Table 4 as the average ± standard deviation of three replicate measurements expressed as ten-thousandths of total applied spray volume [(mass uranine recovered / total mass uranine sprayed) × 10^4]. Spray flux versus height at the 2-meter flux plane is shown graphically for the three spray nozzles in Figure 8. Spray flux decreased with increasing height, as expected. Spray flux was greatest for the reference nozzle and least for the Hypro ULD 120-4 nozzle.

Results of deposition measurements from Mylar cards calculated in the same manner are given in Table 5. Spray deposition was decreased with distance from the source, as expected. At each distance, the largest amount of deposition resulted from the reference nozzle, with the smallest amount from the Hypro ULD 120-4 nozzle.

Table 4. Results from flux measurements as ten-thousandths of applied (fraction × 10^4) at 2 m downwind.

		Reference		AI11003-VS		Hypro ULD 120-4	
Height (cm)	**Replicate**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**
70	1	0.46	0.40	0.19	0.26	0.14	0.09
	2	0.49	0.12	0.18	0.13	0.07	0.05
	3	0.26	0.31	0.42	0.51	0.06	0.54
60	1	invalid	0.59	0.19	0.19	0.23	0.13
	2	0.60	0.01	0.15	0.04	0.07	0.09
	3	0.59	0.02	0.23	0.22	0.07	0.74
50	1	0.83	0.91	0.22	0.20	0.20	0.11
	2	1.05	0.12	0.17	0.03	0.08	0.07
	3	0.84	0.14	0.23	0.16	0.07	0.64
40	1	3.86	3.05	0.29	0.24	0.32	0.18
	2	2.68	0.70	0.24	0.05	0.15	0.13
	3	2.61	0.23	0.18	0.22	0.07	0.53

		Reference		AI11003-VS		Hypro ULD 120-4	
Height (cm)	**Replicate**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**
30	1	14.64	19.01	1.53	1.55	0.41	0.25
	2	22.40	3.97	1.55	0.02	0.16	0.13
	3	19.98	0.21	1.57	0.01	0.20	0.53
20	1	30.12	30.65	20.26	21.33	4.86	5.23
	2	32.16	1.33	23.81	2.16	4.66	0.82
	3	29.67	0.04	19.91	0.10	6.16	0.16
10	1	61.08	91.47	64.06	75.66	18.68	19.31
	2	103.02	26.57	82.70	10.12	19.39	0.60
	3	110.32	0.29	80.22	0.13	19.87	0.03

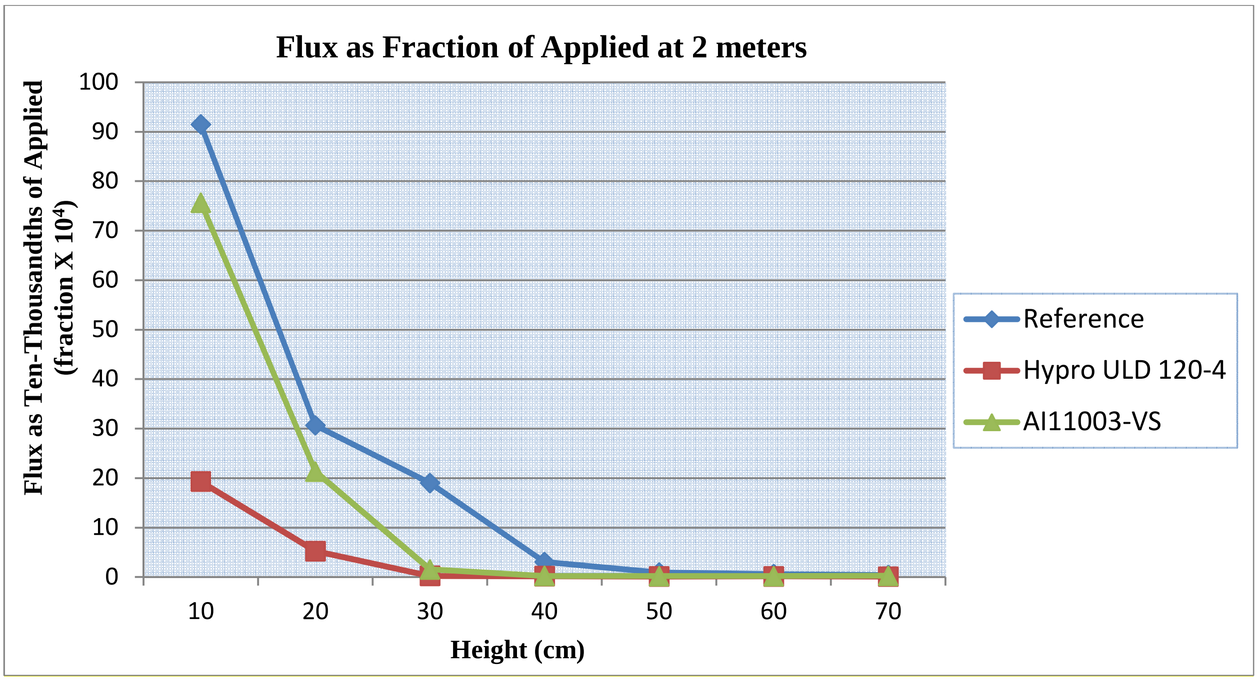

Figure 8. LSWT spray flux 2 meters from the nozzle (flux vs. height for three nozzles).

Wind speed, temperature, and relative humidity averages and standard deviations measured for each nozzle over the three replications measuring flux and deposition are given in Table 6. All of these parameters were controlled to well within the requirements stated in the T/QAP.

Table 5. Results from deposition measurements as ten-thousandths of applied.

		Reference		AI11003-VS		Hypro ULD 120-4	
Distance (m)	**Replicate**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**
2	1	32.22	26.83	20.28	19.15	0.74	1.44
	2	25.30	4.81	22.97	4.49	1.65	0.62
	3	22.97	0.18	14.20	0.23	1.93	0.43

		Reference		AI11003-VS		Hypro ULD 120-4	
Distance (m)	**Replicate**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**	**Flux**	**Average SD CV**
3	1	37.69	22.50	5.71	5.92	0.22	0.21
	2	15.05	13.16	9.05	3.03	0.20	0.01
	3	14.76	0.58	2.99	0.51	0.22	0.06
4	1	12.43	8.89	2.72	3.03	0.19	0.33
	2	7.66	3.11	4.48	1.32	0.14	0.28
	3	6.57	0.35	1.9	0.43	0.65	0.87
5	1	7.25	4.41	1.54	1.62	0.12	0.13
	2	2.43	2.52	1.45	0.23	0.17	0.04
	3	3.55	0.57	1.88	0.14	0.10	0.30
6	1	4.45	2.67	0.78	1.09	0.11	0.13
	2	1.68	1.55	0.76	0.59	0.16	0.03
	3	1.87	0.58	1.74	0.51	0.12	0.21

SD = standard deviation, CV = coefficient of variation

Table 6. Nozzle pressure, wind speed, air temperature, relative humidity, and spray solution temperature for flux and deposition measurements.

Nozzle	Pressure (psi) (Avg ± SD)	Wind speed (m/s) (Avg ± SD)	Air Temp (°C) (Avg ± SD)	% RH (Avg ± SD)	Solution Temp (°C) (Avg ± SD)
Reference	43.4 ± 0.06	1.00 ± 0.01	25.0 ± 0.06	80.4 ± 0.21	21.6 ± 0.47
AI11003-VS	43.5 ± 0.10	1.00 ± 0.05	25.0 ± 0.06	80.0 ± 0.17	21.9 ± 0.10
Hypro ULD 120-4	43.6 ± 0.26	1.00 ± 0.01	24.5 ± 0.31	80.0 ± 0.53	22.0 ± 0.00

3.2 High-speed wind tunnel test results

The measured droplet sizes for all three nozzles used in the high-speed tests are shown in Table 7. For a separate study, USDA compared the variation between nozzles of the same type. Although comparing nozzles of the same type was not part of the T/QAP, for completeness, all collected data are presented here.

Wind speed, temperature, and relative humidity averages and standard deviations measured for each nozzle over during the high-speed wind tunnel tests are given in Table 8. All of these parameters were controlled within the requirements stated in the T/QAP. Liquid flow rate data were not collected.

Table 7. Droplet size data 60 cm downwind of nozzle at specified wind speed.

Nozzle	Pressure (psi)	Speed (m/s)	Angle (°)	Rep	$D_{v0.1}$ (µm)	$D_{v0.5}$ (µm)	$D_{v0.9}$ (µm)	Statistic	$D_{v0.1}$ (µm)	$D_{v0.5}$ (µm)	$D_{v0.9}$ (µm)
Ref 11003[a]	43	0	0	1	79.5	177.8	362.4	Average	79.7	179.6	372.4
				2	80.1	182.1	374.8	SD	0.4	2.2	9.1
				3	79.4	179.0	380.1	CV	0.00	0.01	0.02
REF 11003	43	53.3	0	1	96.91	210.86	333.52	Average	96.68	210.72	335.55
				2	96.21	209.86	332.57	SD	0.40	0.80	4.36
				3	96.91	211.45	340.55	CV	0.00	0.00	0.01

ULD 120-04X	40	53.3	0	1	130.03	275.78	427.4	Average	129.76	275.69	425.30
				2	130.11	275.77	426.61	SD	0.53	0.15	2.97
				3	129.15	275.51	421.9	CV	0.00	0.00	0.01
ULD 120-04Y	40	53.3	0	1	139.25	296.87	484.13	Average	139.96	297.60	483.88
				2	140.95	298.54	483.75	SD	0.88	0.85	0.22
				3	139.69	297.4	483.76	CV	0.01	0.00	0.00
ULD 120-04Y2	40	53.3	0	1	130.21	278.41	423.44	Average	132.47	282.39	426.27
				2	132.37	283.93	429.4	SD	2.31	3.48	2.99
				3	134.82	284.84	425.98	CV	0.02	0.01	0.01
ULD 120-04Z	40	53.3	0	1	133.08	283.53	430.64	Average	133.53	284.70	443.89
				2	137.37	293.7	479.78	SD	3.63	8.48	31.43
				3	130.15	276.86	421.25	CV	0.03	0.03	0.07
AI11003-X	40	53.3	0	1	128.38	278.97	440.39	Average	127.13	275.24	425.16
				2	125.49	272.81	417.84	SD	1.48	3.28	13.19
				3	127.52	273.94	417.25	CV	0.01	0.01	0.03
AI11003-Y	40	53.3	0	1	122.92	263.74	396.66	Average	123.60	266.50	406.05
				2	123.67	268.28	411.33	SD	0.65	2.43	8.15
				3	124.22	267.49	410.16	CV	0.01	0.01	0.02
AI11003-Z	40	53.3	0	1	120.69	263.9	408.04	Average	121.07	264.05	408.12
				2	121.84	264.1	407.46	SD	0.67	0.13	0.70
				3	120.67	264.14	408.86	CV	0.01	0.00	0.00

[a]These data were not collected during the HSWT tests. Data collected in February 2009 are reported. See Section 4.2.
SD = standard deviation, CV = coefficient of variation

Table 8. Nozzle pressure, wind speed, air temperature, relative humidity, and spray solution temperature for droplet sizing measurements (means ± standard deviations) at 60 cm downwind.

Nozzle	Pressure (psi)	Wind speed (m/s)	Air Temperature (°C)	Relative Humidity (%)	Solution Temperature (°C)
Reference	43 ± 0.0	53.3 ± 0.0	21.7 ± 0.0	66.3% ± 0.0	20.3 ± 0.0
AI11003-VS	40 ± 0.0	53.3 ± 0.0	24.6 ± 0.0	55.5% ± 0.0	23.9 ± 0.0
Hypro ULD 120-4	40 ± 0.0	53.3 ± 0.0	24.6 ± 0.0	55.5% ± 0.0	23.9 ± 0.0

4.0 Verification of Performance

4.1 Quality assurance

The primary performance measures for the evaluation of the pesticide spray DRT protocol is derived from the droplet size distribution measurements and flux at the 2-meter plane. The basic experimental design was to measure the droplet size spectrum or flux under targeted test conditions with the DRTs operating at specified spray pressures, air speeds, and the ambient environmental conditions. Wind tunnel and spray liquid conditions measurements are supplemental measures that established the bounds of the spray size distribution data. EPA, RTI, vendors, test facilities, and other stakeholders will use this report to evaluate the pesticide spray DRT protocol and suggest changes that will provide improvements.

Data on calibration certificates for the flow meters, flow transducers, weights, low- and high-resolution balances, thermometer, and humidity logger are maintained at Alion and USDA in a separate data package.

To meet the DQO, at least three replicate experiments using each nozzle were performed. As required by the DQOs in the approved test plans, the product of this test design was the measurement of a droplet size distribution consisting of 32 or more droplet size bins for the specified operating range. Adherence to the DQOs, as expressed through the achieving the Data Quality Indicator Goals (DQIGs), for the high- and low-speed tests are presented in Tables 9 and 10, respectively.

As part of the GVP evaluation, an Audit of Data Quality (ADQ) was performed. Alion Science & Technology audited their data from low-speed wind tunnel testing.[5] RTI QA staff reviewed and approved the low-speed wind tunnel testing ADQ. RTI QA personnel audited the high-speed wind tunnel data collected at USDA.[6] The EPA quality manager performed a Technical Systems Audit (TSA) of the low-speed wind tunnel testing.[7]

Both Alion and RTI QA staff have reviewed the results of these tests and have found that the results did not meet the overall data quality objective (DQO) as stated in each T/QAP. Failure to achieve the DQIGs listed in Table 9 (high-speed wind tunnel) and Table 10 (low-speed wind tunnel) were the cause.

The failure to meet all high-speed and low-speed wind tunnel DQIGs did not have a significant impact on the evaluation of the protocol. In fact, the difficulty meeting those DQIGs indicated the acceptance criteria might be too stringent for those metrics. RTI suggests EPA ask the stakeholder panel if the acceptance criteria for the DQIGs in question should be relaxed to keep the verification test cost reasonable. If so, the stakeholders should propose new acceptance criteria for the DQIGs that were achieved. Another possibility for the low-speed wind tunnel DQIGs is to obtain stakeholder input on revising the GVP to include procedures for balancing wind tunnel air speed and expected spray size distribution from a particular nozzle to insure sufficient spray material is transported to all heights at the 2-meter flux plane to achieve the existing DQIGs.

Table 9. Data quality indicator goals for high-speed wind tunnel tests

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
Nozzle spray angle	Variation within ± 5% during test	✓		
Spray liquid pressure (nozzle operating pressure)	± 3.4 kPa of values specified in the ASABE standard for reference and evaluation nozzles.	✓		

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
Spray liquid temperature	Measured within 0.1 ℃	✓		
Spray liquid flow rate	± 0.04 L/min of values specified in the ASABE standard for reference and evaluation nozzles.		✓	Data not submitted by USDA
Dynamic surface tension of spray liquid	52 ± 4 dynes/cm at surface lifetime age of 10 to 20 ms for test fluids with adjuvants. 70 ± 4 dynes/cm for water, if used as test fluid	✓		
Viscosity of spray liquid	1.1 ± 0.1 cP at 20 ℃	✓		
DROPLET SIZE DISTRIBUTION DQIGs				
Spray volume in largest and smallest droplet size class bands in laser diffraction measurements	< 1% of total volume in each case (i.e., < 2% total of the spray volume) – to be achieved through selection of appropriate lens and instrument configuration for the dynamic size range of the spray being sampled	✓		Spray volumes in smallest droplet size class band met criterion. 80% of the spray volumes in largest droplet size class band were greater than 1%.
Number of size class bands for reported data	≥ 32	✓		
Standard deviation around mean $D_{v0.5}$ for three replicate droplet size measurements	Vary by less than ± 3% for replicate measurements with the same nozzle	✓		
Measured $D_{v0.5}$ (volume median diameter) , $D_{v0.1}$ and $D_{v0.9}$ (i.e., the droplet diameter bounding the upper and lower 10% fractions of the spray)	Vary by less than ± 7% for replicate measurements with the same nozzle	✓		Standard deviation of $D_{v0.9}$ for Hypro ULD 120-04 replicate is 7.1%
Obscuration for spray measurements across a spray diameter (for laser diffraction systems)	< 60% unless corrected for multiple scattering, whereupon the report shall include the measured obscuration, the algorithm used to correct for multiple scattering, and the manufacturer-stated limits of applicability for that algorithm.	✓		
Minimum obscuration for sampling to achieve cross-section average spray (e.g., start and end trigger using traverse with laser diffraction systems)	2%	✓		
Sample size per replicate measurement	> 10,000 droplets for particle counting instruments or > 5 s for laser diffraction instruments	✓		
Diode suppression (laser diffraction systems)	Diodes may not be suppressed (no channels may be killed)	✓		

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
HSWT OPERATION DQIGs				
Air speed inside wind tunnel	Between 50 mph (22 m/s) and 180 mph (80 m/s), and measured to an accuracy within 5 mph (2 m/s), close to nozzle location (with nozzle absent). Acceptance criteria between measurements ± 5%.	✓		
Wind tunnel cross section diameter	Cross-section at least three diameters larger than spray plume diameter (at size distribution measurement location).	✓		
Wind tunnel ambient air temperature	Measured within 0.1 ℃	✓		
Wind tunnel wet bulb/dew point temperature or percent relative humidity	Measured within ± 0.1 ℃ or ± 1%	✓		
Relative spray material and air temperatures	Spray material temperature must be within 2 ℃ of the air temperature to avoid atomization anomalies.		✓	Difference between spray and air temperature was 2.5 ℃ for certain runs

Table 10. Data quality indicator goals for low-speed wind tunnel tests

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
DROPLET SIZE DISTRIBUTION MEASUREMENT DQIGs				
Spray volume in largest and smallest droplet size class bands in laser diffraction measurements	< 1% of total volume in each case (i.e., < 2% total of the spray volume) to be achieved through selection of appropriate lens and instrument configuration for the dynamic size range of the spray being sampled		✓	39% of values were greater than 1%.
Number of size class bands for reported data	≥ 32	✓		
Standard deviation around mean $D_{v0.5}$ for three replicate droplet size measurements	Vary by less than ± 3% for replicate measurements with the same nozzle		✓	66% of all measured values were above 3%
Measured $D_{v0.5}$ (volume median diameter), $D_{v0.1}$ and $D_{v0.9}$ (i.e., the droplet diameter bounding the upper and lower 10% fractions of the spray)	Vary by less than ± 7% for replicate measurements with the same nozzle		✓	100% of all measured values were above 7%.

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
Obscuration for spray measurements across a spray diameter (for laser diffraction systems)	< 60% unless corrected for multiple scattering, whereupon the report shall include the measured obscuration, the algorithm used to correct for multiple scattering, and the manufacturer-stated limits of applicability for that algorithm.	✓		
Minimum obscuration for sampling to achieve cross-section average spray (e.g., start and end trigger using traverse with laser diffraction systems)	2%		✓	59% of optical concentration values were below 2%
Sample size per replicate measurement	> 10,000 droplets for particle counting instruments or > 5 s for laser diffraction instruments	✓		
Diode suppression (laser diffraction systems)	Diodes may not be suppressed (no channels may be killed)	✓		
Spray nozzle height measurement	Within 5 mm (without airflow)	✓		
Nozzle spray angle	Variation within ± 5% during test	✓		
Spray liquid pressure (nozzle operating pressure)	± 0.5 psi of values specified in the ASABE standard for reference and evaluation nozzles.	✓		
Spray liquid temperature	Measured within 0.1 ℃	✓		
Spray liquid flow rate	± 0.04 L/min of values specified in the ASABE standard for reference and evaluation nozzles.	✓		
Dynamic surface tension of spray liquid	52 ± 4 dynes/cm at surface lifetime age of 10 to 20 ms for test fluids with adjuvants. 70 ± 4 dynes/cm for water, if used as test fluid	✓		
Viscosity of spray liquid	1.1 ± 0.1 cP at 20 ℃	✓		
Wind tunnel ambient air temperature	Measured within 0.1 ℃	✓		
Wind tunnel wet bulb/dew point temperature or percent relative humidity	Measured within ± 0.1 ℃ or ± 1%, respectively	✓		
Percent relative humidity (low-speed wind tunnel)	80% ± 5%	✓		

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
Relative spray material and air temperatures	Spray material temperature must be within 2 ℃ of the air temperature to avoid atomization anomalies.	✓		
Air speed inside wind tunnel	1 m/s measured accuracy within 0.1 m/s, close to nozzle location (with nozzle absent).	✓		
Sampling rate for air speed	Sampling should occur over a measuring period of 30 s	✓		
DRIFT POTENTIAL MEASUREMENT DQIGs				
Spray duration for replicate measurements	Minimum spray time of 5 s for each replicate measurement. Replicate measurements for a nozzle type should be within ± 5% of mean time duration for a given setup.	✓		
Spray duration for similar nozzle types	Similar nozzle types from different vendors/ manufacturers should be tested for similar time duration, within ± 5%.	✓		
Solvent volume for extraction of tracer, if using collectors	Within 5% of volume required for analytical recovery and assessments	✓		
Air speed inside wind tunnel	1 m/s measured accuracy within 0.1 m/s, close to nozzle location (with nozzle absent).	✓		
Sampling rate for air speed	Sampling should occur over a measuring period of 10 s	✓		
Wind speed consistency in wind tunnel working section	< 5%	✓		Local wind velocity variability was not measured according to ISO 22856
Wind tunnel working section width	Minimum to avoid boundary layer and blockage effects	✓		
Wind tunnel turbulence	< 8%	✓		Wind velocity variability was not measured according to ISO 22856
Wind tunnel ambient air temperature	Measured within 0.1 °C	✓		
Wind tunnel wet bulb/dew point temperature or percent relative humidity	Measured within ± 0.1 ℃ or ± 1%, respectively	✓		
Percent relative humidity (low-speed wind tunnel)	80% ± 5%	✓		

Parameter	Acceptance Criteria	Met DQIG? Y	N	Comments
Relative spray material and air temperatures	Spray material temperature must be within 2 ℃ of the air temperature to avoid atomization anomalies.	✓		

4.1.1 Deviations

Except as noted below, the verification tests were conducted in accordance with the approved T/QAPs.[2, 3] The TSA found that the low-speed wind tunnel was properly equipped and data were collected as specified in the T/QAP. RTI determined the high-speed wind tunnel had the proper equipment to collect data as specified in the T/QAP. Deviations from the test plans and impact on data quality are described below.

Low-Speed Wind Tunnel Test Deviations

- Low-speed spray test duration of 15 ± 0.5 s instead of 10 ± 0.5 s.
  - The increased spray time did not overload the monofilament line or cause puddling on the Mylar cards. Therefore, the change did not affect data quality.

- Duplicate spray deposition samples at were not collected as a quality control check.
  - Horizontal spray deposition measurements are not an input to the AGDISP or WTDISP models that will be used to evaluate spray drift approximately 100 m downwind of spraying and cannot be used to confirm the quality of flux and droplet size distribution measurements at the 2-meter flux plane. Taking these measurements during evaluation testing highlighted their cost (an increase of 30% for each test). Given that they do not contribute to the long-range drift calculation and are expensive, they will not be included in the revised protocol for future testing using a LSWT, making further evaluation during this test irrelevant.

- The first test of low-speed flux measurements at 60 cm with the reference nozzle was invalid because the monofilament line was accidentally shaken during collection.
  - The shaking of the line dislodged collected spray droplets. In a real verification, the test may need repeated. However, EPA will not use the flux data to verify AGDISP or WTDISP model results. Therefore, the lost datum was not critical to the objectives of GVP evaluation. Note that the invalid sample does highlight the purpose of the GVP evaluation: to identify experimental procedures specified in the GVP that may increase the cost of verification.

High-speed Wind Tunnel Test Deviations

- USDA did not collect spray characterization with the reference nozzle.
  - USDA high-speed wind tunnel availability was limited during GVP evaluation. Time constraints prohibited collection of the data. Instead, historical data collected 1 month earlier were used to characterize the spray size distribution from the reference nozzle. USDA routinely collects spray characterization data with the reference nozzles. A history of size distributions is available. The historical data are suitable for GVP validation.

- USDA did not collect spray liquid flow rate data.
  - The fluid pressure in the system controlled the fluid flow at the test nozzle. Therefore, a consistent volumetric flow of fluid was achieved throughout the test. The missing flow data do not affect overall data quality.

- Pictures of the nozzles were not obtained by either laboratory, and USDA did not take pictures of their HSWT test setup.
  - This oversight did not affect data quality and the results of the GVP evaluation.

5.0 References

1. RTI International. Draft Generic Verification Protocol for the Verification of Pesticide Spray Drift Reduction Technologies for Row and Field Crops, RTI International, Research Triangle Park, NC, February 2007. Available at http://www.epa.gov/nrmrl/std/etv/pubs/600etv07021.pdf.

2. RTI International. Test/QA Plan for the Evaluation of the Verification Protocol for High Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops. RTI International, Research Triangle Park, NC, March 2008. http://www.epa.gov/nrmrl/std/etv/pubs/600etv11008.pdf.

3. RTI International. Test/QA Plan for the Evaluation of the Verification Protocol for Low Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops. RTI International, Research Triangle Park, NC, May 2009. http://www.epa.gov/nrmrl/std/etv/pubs/600etv11007.pdf.

4. ASABE S572. *Spray Nozzle Classification by Droplet Spectra*. American Society of Agricultural and Biological Engineers. St. Joseph, MI, August 1999.

5. Alion Science & Technology. *Quality Assurance Data Review Report: Evaluation of the Verification Protocol for Low Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops.* Alion Science & Technology, Research Triangle Park, NC, July 2009.

6. RTI International. *Quality Assurance Data Review Report: Evaluation of the Verification Protocol for High Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops.* RTI International, Research Triangle Park, NC, September 2009.

7. U.S. EPA. *Findings from the Assessment of Quality and Technical Systems for EPA ESTE Project, "Evaluation of the Verification Protocol for Low Speed Pesticide Spray Drift Reduction Technologies for Row and Field Crops"* U.S. EPA, Research Triangle Park, NC, July 2009.