

A User's Guide for AgDRIFT® 2.0.07:  
A Tiered Approach for the Assessment of  
Spray Drift of Pesticides

Public Use Version

Prepared by:

Milton E. Teske  
Continuum Dynamics, Inc.  
34 Lexington Avenue  
Ewing, NJ 08618

Sandra L. Bird  
U. S. Environmental Protection Agency  
960 College Station Road  
Athens, GA 30605

David M. Esterly  
Environmental Focus  
2801 Bexley Court  
Wilmington, DE 19808

Scott L. Ray  
Dow AgroSciences LLC  
9330 Zionsville Road  
Indianapolis, IN 46268

Steven G. Perry  
U. S. Environmental Protection Agency  
4930 Old Page Road  
Research Triangle Park, NC 27709

Prepared for:

David R. Johnson, Project Manager  
Spray Drift Task Force  
c/o Stewart Agricultural Research Services, Inc.  
P. O. Box 509  
Macon, Missouri 63552

February 2003

## Table of Contents

Section	Page
Table of Contents.....	i
Figure Titles .....	iii
Table Headings .....	xii
I. Overview and Background.....	1
A. Introduction .....	1
B. The Tiered Approach to Estimating Exposure from Pesticide Drift .....	1
C. AgDRIFT® as the Basis for Aerial Tiers .....	3
D. Units .....	4
II. Development of Tier I Curves.....	5
A. Aerial Assessment Methodology .....	5
B. Aerial Assumptions and Evaluation.....	5
C. Tier I Ground Sprayer Assessment Methodology.....	10
D. Tier I Orchard Airblast Sprayer Assessment Methodology .....	12
E. Using the Tier I Curves .....	13
III. Tier III Predictions .....	15
IV. Program Operation .....	16
A. General Program Operation .....	16
B. Tier I Orchard Airblast.....	33
C. Tier III Program Extensions.....	33
V. Tier I Example Assessment .....	63
VI. Interpretation of Model Predictions.....	67
A. Numerical Results from Tier Calculations .....	67
B. Plotted Results from Tier Calculations .....	68
C. Toolbox Results .....	71
VII. Model Sensitivity.....	75
VIII. Forestry Mode Operation .....	96
A. Tier I and Tier II .....	96
B. Tier III Program Extensions.....	96

IX. Summary and Future Model Update .....	111
X. Trademarks .....	112
XI. Model References.....	113
XII. References.....	115
A. Lagrangian Model History.....	120
B. Stream Assessment Model.....	121
C. Multiple Application Assessment Model .....	123
A. SAMSON Database.....	123
B. Wind Rose Generation .....	123
C. AgDRIFT® Model Runs .....	124
D. Controlled Sampling .....	124
D. Interpolation Methods.....	126
A. Root Normal.....	126
B. Rosin-Rammler .....	126
C. Log Normal .....	127
Index.....	128

## Figure Titles

Figure	Page
1. Drop categories used in the definition of the aerial assessment curves. The six drop categories (Very Fine, Fine, Medium, Coarse, Very Coarse, and Extremely Coarse) are based on the nozzle categorization scheme developed in ASAE S-572. The five curves shown here define the upper diameter boundaries of Very Fine, Fine, Medium, Coarse, and Very Coarse atomization regimes.....	6
2. Deposition as a function of distance for the five ASAE S-572 threshold categories. These curves represent the upper range of deposition as a fraction of the nominal application rate for Very Fine, Fine, Medium, Coarse, and Very Coarse atomization regimes. Simulation results assume a 20-swath field application.....	8
3. The About AgDRIFT® screen. ....	17
4. The Tier I ground input screen presenting Title, Boom Height, Drop Size Distribution, Extended Settings, and Information. ....	18
5. Application cross section. The sprayer travels into the paper, along spray lines labeled by 1, 2, 3, etc., displaced by the Swath Displacement from the Edge of the Application Area. ....	18
6. The Export screen (under File) presenting the options for Notes, Results to Export, Options (Headers), and Delimiter. ....	19
7. The Preferences screen (under Edit) presenting the options for setting the operational mode within AgDRIFT® of its Starting Mode and Tier (when the program is first entered), Units, program menu behavior, and User Library name. ....	20
8. A plot of the Tier I ground deposition for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution. The 0 ft location locates the edge of the application area. ....	21
9. A plot of the Tier I pond-integrated deposition for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution. ....	21

10. The Plot Options screen reached from the plot screen. Plot Options include additional Data, with Color and Style changes, Legend, and manipulation of the X axis (horizontal on the screen) or Y axis (vertical on the screen) with manually selecting the plot size, adding grid or logarithmic appearance, and changing character font.....	22
11. Tier I Plot Options screen presenting the Application Method (Ground or Orchard Airblast) and the selected Tier I input screen. ....	23
12. The Aquatic Assessment Calculator screen (under Toolbox) defining the type of water body to examine and calculating Distance to Water Body from Edge of Application Area, Initial Average Deposition, and Initial Average Concentration, where one of the five values is inputted by the user, and the Calc button is used to compute the other four (red indicates user input).....	24
13. Cross section of the water body size and downwind location relative to the edge of the application area.....	24
14. Toolbox Export screen, where the Results for Export are known, and Notes, Options (Headers), and Delimiter may be entered.....	25
15. The Terrestrial Assessment Calculator screen (under Toolbox) defining the type of terrestrial field to examine (point or area average) and calculating Distance to Point or Area Average from Edge of Application Area, and Initial Average Deposition, where one of the five values is inputted by the user, and the Calc button is used to compute the other four (red indicates user input). .....	26
16. Cross section of the terrestrial field size and downwind location relative to the edge of the application area. ....	26
17. The Spray Block Assessment Calculator screen (under Toolbox) presenting the entry of Deposition type (Deposition or Pond-Integrated Deposition) and Deposition Level (Fraction of Applied, g/ha, or lb/ac) and Concentration Level (in ng/L or ppt) if applicable. The calculator generates a plot of Block Width versus Buffer Distance downwind from the edge of the spray block where the desired level of deposition occurs (red indicates user input). .....	27
18. Spray Block Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution. The 0 ft location (on the vertical axis) locates the edge of the application area. ....	28

19. The Stream Assessment Calculator screen (under Toolbox) defining the necessary details needed to compute stream diffusion of spray materials applied to the surface of the stream.....	29
20. Stream Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution, with a Turn-Around Time of 30 sec. The 0 ft location locates the center of the spray block in the direction of the sprayer paths.....	30
21. The Multiple Application Assessment Calculator screen (under Toolbox) defining the details needed to assemble and compute multiple applications to the same area.....	30
22. Median temperature for Sioux City, IA from the SAMSON database. Also shown are the 25 <sup>th</sup> and 75 <sup>th</sup> percentile bounds of the meteorological data.....	31
23. Wind rose for Sioux City, IA .....	31
24. Multiple Application Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution in Tier I for Sioux City, IA. The curves are the average multiple application deposition pattern (including zero deposition effects when the wind is blowing upwind of the spray block) and the maximum deposition pattern recovered across the selected wind speed range. Ten events per year assumed.....	32
25. The Tier I orchard airblast input screen presenting Title, Combination Orchards, Extended Settings, and Information.....	33
26. The Tier III Input screen with the inputs of Aircraft (Name, Nozzles and DSD, Boom Height, and Number of Flight Lines), Swath (Swath Width, Swath Displacement, and Half Boom Effect), Spray Material, Meteorology (Wind Speed, Wind Direction, Temperature, and Relative Humidity), Advanced Settings, Transport (Flux Plane Location), and Terrain (Surface Roughness). ....	34
27. Wind directions (as viewed from above) relative to the spray block and distance downwind.....	38
28. The Advanced Settings screen from Tier III, presenting the model-specific default input (Height for Wind Speed Measurement, Maximum Computational Time, Maximum Downwind Distance, Vortex Decay	

Rate, Aircraft Drag Coefficient, Propeller Efficiency, Ambient Pressure, and Ground Reference Height) .....	38
29. The Aircraft screen from Tier III, presenting the Aircraft Type and its Properties. ....	39
30. Schematic of aircraft wing and boom details.....	40
31. The Aircraft User Library, with Name and Properties. ....	40
32. The Aircraft Library screen from Aircraft Type, presenting Filters for Aircraft Name and Type; and the Browse Filtered Entries for each selection.....	41
33. The Nozzle Configuration screen from Tier III, presenting the Nozzle Installation Properties, Nozzles, Nozzle Location, and Nozzle Drop Size Distribution.....	42
34. The Drop Size Distribution screen, with the Drop Distribution Type selected on the left side (User-defined, Basic, DropKick®, USDA ARS Nozzle Models, or Libraries) and the Drop Distribution itself presented on the right side (Average Diameter, Incremental Volume Fraction, and Cumulative Volume Fraction). ....	43
35. The Drop Size Distribution User Library, with Name and Drop Distribution.....	45
36. The Parametric Drop Size Distribution screen, permitting input of $D_{v0.5}$ and Relative Span, and calculation of the selected drop size distribution Output. ....	45
37. The DropKick® screen, presenting the entry areas of Nozzle ( $D_{v0.5}$ , Relative Span, and Effective Nozzle Diameter), Spray Material (Dynamic Surface Tension, Shear Viscosity, Elongational Viscosity, and Specific Gravity), Spray Data (Air Speed, Nozzle Orientation, Pressure, and Spray Rate), and Output. ....	46
38. The DropKick® Nozzle Library screen, presenting a Filter for Nozzle and the Browse Filtered Entries for Nozzle, Type, Manufacturer, $D_{v0.5}$ , Relative Span, Spray Angle, and Effective Nozzle Diameter. ....	48
39. The DropKick® Spray Material Library screen, presenting Filters for Component and Substance, and the Browse Filtered Entries for	

Substance, Dynamic Surface Tension, Shear Viscosity, Elongational Viscosity, Specific Gravity, and Components.....	48
40. The USDA ARS Nozzle Models screen, presenting Nozzle (Name and Orifice Size or Number), Spray Material, Spray Data (Air Speed, Nozzle Deflector or Angle, and Pressure), and Output.....	49
41. The Drop Size Distribution Library screen from Drop Size Distribution, presenting Filters for Component, Substance, Nozzle, Orientation, RPM, Pressure, and Air Speed; and the Browse Filtered Entries for Substance, Nozzle, Manufacturer, Orientation, RPM, Pressure, Air Speed, Drop Size Classification, and Components. ....	51
42. The Spray Material screen from Tier III, presenting the Spray Material Type and Properties (Specific Gravity, Evaporation Rate, Nonvolatile Rate, Active Rate, and Spray Volume Rate). .....	52
43. The Spray Material Library screen from Spray Material, presenting Filters for Component and Substance, and the Browse Filtered Entries for Substance, Evaporation Rate, Nonvolatile Fraction, Specific Gravity, and Components. ....	52
44. The Load Field Trial Data screen (under File and Plot Options in Tier III with the SDTF Library), presenting access to SDTF field trials, with Filters for Test Name, Type and Number, Aircraft, Percent < 141 $\mu\text{m}$ , Boom Height and Wind Speed, and the Browse Filtered Entries for each selection.....	54
45. An incremental plot of the ASAE S-572 Medium to Coarse drop size distribution. ....	55
46. A cumulative plot of the ASAE S-572 Medium to Coarse drop size distribution. ....	55
47. Vertical transport through a flux plane positioned at the edge of the application area for the ASAE S-572 Medium to Coarse drop size distribution and all model defaults. ....	56
48. One hour average concentration through a flux plane positioned at the edge of the application area for the same conditions as Figure 47. ....	56
49. Coefficient of Variation as a function of Swath Width. ....	57

50. Mean Deposition within the spray block as a function of Swath Width.....	57
51. Fraction Aloft for the ASAE S-572 Medium to Coarse drop size distribution and all model defaults.....	58
52. The Numerical Values screen (under View) presenting summary information on the Drop Size Distribution, Deposition, and Accountancy of Active.....	59
53. The AgDRIFT® calculation screen. The bar at the bottom of the screen illustrates the completion of the calculation by the number of drop sizes examined.....	60
54. The Batch Operations screen template. AgDRIFT® file names are entered in the upper portion of the screen; operation status is given in the lower portion.....	61
55. The Drop Distance Calculator screen (under Toolbox) presenting the entry of Drop Size and Release Height.....	61
56. The Spray Block Statistics Calculator screen (under Toolbox), calculating the Coefficient of Variation (COV), Effective Swath Width, and Mean Deposition within the spray block, where one of the three values is inputted by the user, and the Calc button is used to compute the other two (red indicates user input).....	62
57. Layout for Multiple Application Assessment in Tier III, where the dominant wind direction blows from 240° (in this example) but the sensitive area (dark square at top) is located 180° to the spray block. ....	62
58. The Tier I Ground Input screen. ....	63
59. Plot of the pond-integrated deposition for the High Boom (ULV) ground sprayer application. ....	64
60. The Aquatic Assessment Calculator screen set to 1.0 lb/ac.....	65
61. Plot of the pond-integrated deposition for the ASAE S-572 Very Fine to Fine drop size distribution aerial application. ....	66
62. Cumulative spray volume for ASAE S-572 Fine to Medium drop size distribution, plotted as a function of the average drop diameter in each size class, and the locations for $D_{v0.1}$ , $D_{v0.5}$ , $D_{v0.9}$ , and 141 $\mu\text{m}$ . ....	67

63. ASAE S-572 Medium to Coarse drop size distribution deposition curve.....	70
64. ASAE S-572 Medium to Coarse drop size distribution pond-integrated deposition curve.....	70
65. Distance profiles of active spray material deposited to a stream at four times identified on the plot.....	73
66. Time profiles of active spray material deposited to a stream at four distances identified on the plot.....	73
67. Drop categories based on the nozzle classification scheme developed by BCPC. The four curves shown here define the boundaries of the Very Fine to Fine, Fine to Medium, Medium to Coarse, and Coarse to Very Coarse atomization regimes. ....	77
68. Sensitivity of deposition to a 10% variation in Boom Height. ....	79/80
69. Sensitivity of deposition to a 10% variation in Boom Length. ....	81/82
70. Sensitivity of deposition to a 10% variation in Nonvolatile Fraction .....	83/84
71. Sensitivity of deposition to a 10% variation in Relative Humidity. ....	85/86
72. Sensitivity of deposition to a 10% variation in Relative Span. ....	87/88
73. Sensitivity of deposition to a 10% variation in Temperature.....	89/90
74. Sensitivity of deposition to a 10% variation in Volume Median Diameter $D_{v0.5}$ . ....	91/92
75. Sensitivity of deposition to a 10% variation in Wind Speed.....	93/94
76. The Tier III input screen in Forestry Mode, with the addition of canopy effects. ....	97
77. The Canopy input screen in AgDRIFT® Tier III: Story (top); Optical (bottom).....	98
78. The Tier III Aircraft screen in Forestry Mode, with the addition of Library (FS). ....	100

79. The Library (FS) screen from Aircraft, identical to its Agricultural Mode counterpart except for the number of library entries and their content.....	100
80. The Tier III Drop Size Distribution screen in Forestry Mode, with the addition of Library (FS).....	101
81. The Library (FS) screen from Drop Size Distribution, identical to its Agricultural Mode counterpart except for the number of library entries and content, and an active Nozzle RPM. The FS library contains rotary atomizer data.....	102
82. Settling velocity as a function of drop size, for the carrier and nonvolatile fraction assumed. The two curves will be different only if specific gravity is different.....	103
83. Application layout, combining the spray block deposition (Figure 84) to 630 ft upwind of the edge of the application area (at 0 ft) and the downwind deposition to 1000 ft.....	103
84. Spray block deposition pattern, measured from the edge of the application area (at 0 ft) upwind into the spray block (20 flight lines assumed in this example). .....	104
85. Spray block area coverage, indicating how much area is covered by specified levels of application rate.....	104
86. Canopy deposition profile, for an Optical Aspen canopy with a height of 3 ft and a LAI of 0.1. Aircraft boom height is 10 ft.....	105
87. Total accountancy of the released tank mix material, as a cumulative function of time after release.....	105
88. Total accountancy of the released tank mix material, for the most downwind flight line, as a cumulative function of distance.....	106
89. Total accountancy of the released tank mix material, as a cumulative function of height.....	106
90. Trajectory Details plot for a 141 $\mu\text{m}$ droplet.....	108
91. The Spray Block Details toolbox screen. ....	108
92. The Spray Block Boundary table entry screen.....	109

93. The Discrete Receptors table entry screen. Inputs are: collector type (either default flat card with a collection efficiency of 100%, flat card or ribbon, cylinder, or sphere); ( $X_s, Y_s, Z_s$ ) receptor location; ( $X_s, Y_s, Z_s$ ) outward normal; and characteristic size of the collector (width for flat card or ribbon, diameter for cylinder and sphere). Once a calculation has completed, the last column (deposition) will be filled with the predicted values. ....	109
94. The Area Coverage Boundary table entry screen.....	110
95. Spray Block Details contour results for ASAE S-572 Fine to Medium drop size distribution with zero swath displacement. Deposition is in ozf/ft <sup>2</sup> . .....	110

## Table Headings

Table	Page
1. AgDRIFT® Model Options .....	3
2. Aerial Simulation Variables.....	7
3. Partitioning of Atomization Tests According to ASAE S-572 Spray Category and Spray Volume Rate .....	9
4. Extended AgDRIFT® Tier III Model Limits .....	35
5. Typical Roughness Lengths Gathered from the Literature .....	37
6. AgDRIFT® Sensitivity Study Limits .....	76
7. AgDRIFT® Sensitivity Study Drift Fractions .....	95
8. Extended AgDRIFT® Tier III Model Limits in Forestry Mode .....	99

## I. Overview and Background

### A. Introduction

This report describes a proposed overall method for evaluating off-site deposition of pesticides applied by aerial, ground, and orchard airblast spraying means, and for evaluating the potential of buffer zones to protect sensitive aquatic and terrestrial habitats from undesired exposures. The methodology discussed here includes a “screening” or Tier I level, designed to yield conservative exposure estimates for downwind deposition values less than the assessment value, and “detailed” or Tier II and Tier III levels, requiring more knowledge of spraying conditions and information related to the specific spray material anticipated, spray system, and meteorological conditions. Tier I is designed as a preliminary screen for aerial, ground, and orchard airblast spraying; Tier II and Tier III permit increasing access to more model details for aerial spraying only.

The methodology is built into the Microsoft® Windows™-based personal computer program AgDRIFT®, and is provided to the U. S. Environmental Protection Agency's (EPA) Office of Pesticide Programs (OPP) as a product of the Cooperative Research and Development Agreement (CRADA) between the EPA's Office of Research and Development and the Spray Drift Task Force (SDTF), a coalition of pesticide registrants formed to develop a comprehensive database of off-target drift information in support of pesticide registration requirements.

The public use version of AgDRIFT® contains the Tier I screens for ground and orchard airblast spraying, and the Tier III screen for aerial spraying. The Tier I and Tier II aerial spraying screens are not available in the public use version of the model; Tier II and Tier III ground and orchard airblast spraying screens have not been developed.

The Tier I ground and orchard airblast sprayer curves are based solely on field data. Tier III aerial predictions may be used to explore detailed model comparisons with aerial data, parametric sensitivity in specific situations, or unique spraying scenarios. Contained within the program are various libraries and databases (containing information on aircraft, drop size distributions, and spray material physical properties), toolbox items (to assess the environmental consequences of the predicted scenario), and graphical output (to plot all important results of the prediction).

### B. The Tiered Approach to Estimating Exposure from Pesticide Drift

A variety of approaches can be used to estimate the environmental exposure from off-target drift during the application of agricultural pesticides. These approaches range from the excessively simplistic – i.e. use of a single number to estimate exposure for any application scenario – to the use of detailed modeling in conjunction with full-scale field trials of specific

formulations and label application methods. A sequential or tiered approach provides a lowest tier with a quick, pass-fail screening to identify products that have little probability of posing an environmental hazard when labeled for use with a standard set of “Good Application Practices.” It also permits the use, at higher tiers for aerial application, of other appropriate assessment tools for more detailed analysis of other compounds or for evaluating product labeling that does not conform to the standard label guidelines.

Specifically, a three-tiered approach is proposed to facilitate an efficient analysis centering on the use of general labeling instructions that maximize the amount of pesticide that remains on target, while allowing flexibility for evaluating those products requiring more or less restrictive application conditions. The results of each assessment tier include an estimate of off-target deposition as a function of distance from the application zone, and vertical flux profiles, air concentration, and application variability and efficiency (in Tier II and Tier III). For aerial assessment all three tiers are based on a mechanistic model, but are empirically confirmed. The ground and orchard airblast sprayer assessments are curve fits based on field data. The application types and analysis variables are summarized in Table 1.

The Tier I aerial analysis (regulatory version only) is entered via the drop size classification or atomization spectrum of the nozzle emission (the primary controlling variable for off-target drift); the Tier I ground and orchard airblast sprayer analyses depend solely on reasonable averages to field data. In Tier I the user can evaluate the level of exposure and the effect of buffer zones for the spray application examined. If the estimated environmental exposure in Tier I, coupled with the product toxicity for the organisms of concern, provides an adequate safety margin with the indicated buffer zone (if any), then no additional analysis would be required.

Tier II aerial analysis (regulatory version only) provides the mechanism to evaluate the effects on off-target drift of the most significant application and environmental variables. The specific variables that the user can evaluate in Tier II include atomization spectra, wind speed, application area, temperature, relative humidity, aircraft class and speed, boom length, nonvolatile fraction, formulation properties, and release height above the ground.

Tier III provides the analyst access to all aerial input variables and additional control of the variable limits. Generally, this tier is to be used to evaluate crop-, site-, formulation-, and equipment-specific applications. Likely uses include incident investigation, new application methods, special equipment specification, and unique site restrictions.

Table 1. AgDRIFT® Model Options

Type	Tier I	Tier II	Tier III
Aerial	Not Available in the Public Version	Not Available in the Public Version	Model-Based - All Model Variables Available for Change - Drop Size Library - DropKick® - Aircraft - Material Properties
Ground	Field Data Curve Fit - 2 Boom Heights - 2 Drop Sizes	No Model	No Model
Orchard Airblast	Field Data Curve Fit - 3 Orchard Types	No Model	No Model

Each of the three sequential assessment tiers requires increasing knowledge of application techniques and environmental factors that influence the potential for a pesticide to move off the target area. Tier I is based on a set of standard “Good Application Practices” and requires little knowledge of actual application conditions or the product's properties. These variables are preset in the model to represent the upper limits expected during an application. Tier II requires an increased knowledge of the application equipment, environment, site, and product. The user can change many of the model variables within fixed, preset limits. Tier III modeling provides the free access to all model variables and assumes the user is an application specialist with a thorough understanding of the atmospheric transport of small particles.

### C. AgDRIFT® as the Basis for Aerial Tiers

The AgDRIFT® model is used to generate the aerial deposition values. Results from the SDTF field studies were used to confirm the model results at each of the different levels of analysis. Since each aerial tier uses the same mathematical model, results are consistent among the tiers. In general, efforts to reduce the off-target deposition by moving to a higher tier will generate an increase in application restrictions for the product label or require more rigorous data about the specific product.

AgDRIFT® is a model that predicts the motion of spray material released from aircraft, including the mean position of the material and the position variance about the mean as a result of turbulent fluctuations, pointing toward a prediction of spray drift. Its predecessor computer program AGDISP (Bilanin and Teske 1984) was developed by the National Aeronautics and

Space Administration, the U. S. Department of Agriculture Forest Service, and the U. S. Army, culminating in a relatively mature aerial predictive model (Bilanin et al. 1989). AgDRIFT® enhancements to AGDISP include a significant solution speed increase, an in-memory computation of deposition and flux as the solution proceeds (eliminating the need for intermediate disk storage in data files), increased number of drop categories, deposition smoothing, improved evaporation parameterization for small droplets, and extensive validation based on 180 separate aerial treatments performed during field trials by the SDTF (Bird et al. 2002). AgDRIFT® operates efficiently and rapidly in the personal computer Microsoft® Windows™ environment through a user interface developed in Microsoft® Visual Basic™ and scientific programming in Microsoft® FORTRAN. Model history is summarized in Appendix A and detailed in Teske et al. (2002).

#### D. Units

AgDRIFT® maintains two sets of units, selected in the Preferences screen (discussed in Section IV) as either English or metric. This distinction is maintained on nearly all program screens, with several exceptions: (1) Aquatic Assessment, Terrestrial Assessment, and Spray Block Assessment toolboxes mix units to recover the commonly used units for deposition and concentration; (2) Multiple Application Assessment identifies the Maximum Wind Speed in integer values of m/sec for convenience; (3) DropKick® Spray Material properties (Dynamic Surface Tension, Shear Viscosity, and Elongational Viscosity) are given only in metric units, common for these scientific variables; (4) USDA ARS Nozzle Models gives Orifice Size in inches only, consistent with the way this variable is identified; (5) Spray Material Evaporation Rate is given only in  $\mu\text{m}^2/\text{°C/sec}$ ; and (6) plots of Vertical Flux and 1 Hour Average Concentration are given only in their metric units.

## II. Development of Tier I Curves

### A. Aerial Assessment Methodology

The drop size distribution is widely agreed to be the primary application variable in controlling off-site drift of pesticides (Bird et al. 1996). In AgDRIFT® drop regimes are classified as Very Fine, Fine, Medium, Coarse, Very Coarse, and Extremely Coarse based on ASAE S-572. Figure 1 shows the ASAE reference threshold curves with drop diameter in micrometers ( $\mu\text{m}$ ) as a function of cumulative volume fraction. These curves define the thresholds between the reference atomization regimes. Properties of these spray distributions at release, including 10<sup>th</sup> percentile drop size ( $D_{v0.1}$ ), volume median diameter ( $D_{v0.5}$ ), 90<sup>th</sup> percentile drop size ( $D_{v0.9}$ ), and fraction of driftable material (defined here as the fraction of volume containing drops less than or equal to 141  $\mu\text{m}$ ) are summarized near the bottom of Table 2. Other parameter values used in typical default aerial model simulations are also given in Table 2. These parameters are defined below, and the rationale for their selection is discussed.

### B. Aerial Assumptions and Evaluation

In SDTF study numbers A92-003 and A92-004 (Hewitt 1996, 1995), more than 3000 wind tunnel atomization trials were performed with several different nozzles, at different wind speeds, a variety of nozzle angles relative to the wind field, and a range of physical properties for material sprayed. A subset of these trials was used to evaluate the correlation between spray application rate and atomization category for aerial type applications. Table 3 shows the ASAE spray category and flow rate for a subset of these atomization trials that included airspeeds > 36 m/s (80 mph) with nozzle angles < 45° (i.e. nozzle pointing toward the back of the plane). To calculate the spray application rate (i.e. gallons per acre), the aircraft was assumed to be equipped with 42 nozzles (6-in spacing along the boom), traveling at the same airspeed as the wind tunnel test condition, and producing a 60-ft swath. Considerable variation exists on the setup of aircraft used in spray operations. A survey of aerial applicators indicates the number of nozzles used during a spray operation ranges from 20 to 60 (Kidd 1994). For the three spray volume rate groupings tabulated (1-2 gal/acre, 2-5 gal/acre, and > 5 gal/acre), the majority in each fall into the Medium spray category. A significant percentage (38%) of the atomizations in the 1-2 gal/acre spray volume rates fall into the Fine category. Conversely, only 2% of the high spray volume rates (> 5 gal/acre) fall into the Fine category.

Besides atomization spectra, many other equipment and environmental variables influence the level of off-site drift of pesticides. Additional variables used in aerial simulations are shown in Table 2. A sensitivity study using AGDISP (Teske 1992) identified wind speed and release height as the primary variables affecting off-site movement, in addition to drop size distribution. Increasing either the release height or the wind speed will increase the amount of downwind drift of spray material. This result is corroborated by analysis of the SDTF field

study results. Indeed, analysis of the SDTF field study data identified drop size distribution, release height, and wind speed as the primary parameters affecting the magnitude of off-target deposition (Bird et al. 2002). *While other factors can affect off-site drift, the heterogeneity of natural deposition processes makes quantification of these effects difficult in a field environment.*

The meteorological conditions and release height selected are based on reasonable assumptions. These assumptions are used in the generation of the deposition curves shown in Figure 2. The wind speed is assumed to be measured at 6 ft above the ground – i.e. the approximate height of a hand-held anemometer – and the application height of 8 ft is taken as the elevation of the spray boom mounted on brackets on the underside of the wing such that it is located behind and slightly below the wing (a corresponding consistent definition for application height may also be made for helicopters). It should be noted that the sensitivity analysis indicates that higher winds and higher release heights increase off-site drift. Wind direction is taken to be perpendicular to the direction of the plane during application.

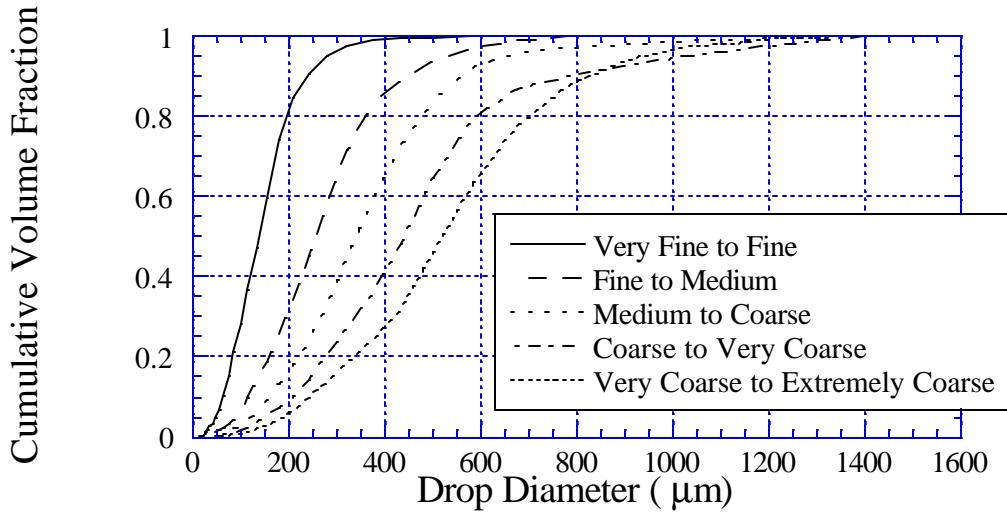


Figure 1. Drop categories used in the definition of the aerial assessment curves. The six drop categories (Very Fine, Fine, Medium, Coarse, Very Coarse, and Extremely Coarse) are based on the nozzle categorization scheme developed in ASAE S-572. The five curves shown here define the upper diameter boundaries of Very Fine, Fine, Medium, Coarse, and Very Coarse atomization regimes.

Table 2. Aerial Simulation Variables

GENERAL PARAMETERS				
Aircraft Description / Operation				
Type	Air Tractor AT-401			
Weight of Aircraft	26683 N (5998 lb)			
Wing Semispan	7.48 m (24.5 ft)			
Flight Speed	53.6 m/s (120 mph)			
Release Height	2.44 m (8 ft)			
Nozzle Setup				
Number	42			
Vertical Offset	-0.35 m (-14 in)			
Horizontal Offset	-0.25 m (-10 in)			
Boom Span	$\pm 5.7$ m ( $\pm 18.7$ ft)			
Spacing (even)	0.28 m (11 in)			
Meteorology				
Wind Speed @ 2 m (6.28 ft)	1.79 m/s (4 mph)			
Wind Direction	Perpendicular to Flight Path			
Surface Roughness	0.015 m (0.6 in)			
Stability	Neutral			
Relative Humidity	75 %			
Temperature	21.1°C (70°F)			
Test Substance / Application				
Specific Gravity	1.0			
Nominal Application Rate	100 ng/cm <sup>2</sup> (0.25 lb/ac)			
Swath Width	18.29 m (60 ft)			
Nonvolatile Fraction	0.03			
Number of Flight Lines	20			
CURVE SPECIFIC PARAMETERS				
Parameter	Very Fine to Fine	Fine to Medium	Medium to Coarse	Coarse to Very Coarse
Swath Displacement/Swath	0.6506	0.3722	0.2851	0.2191
D <sub>v0.1</sub>	62 µm	114 µm	157 µm	209 µm
VMD (D <sub>v0.5</sub> )	137 µm	255 µm	341 µm	439 µm
D <sub>v0.9</sub>	237 µm	444 µm	560 µm	786 µm
Fraction < 141 µm	0.52	0.16	0.08	0.05

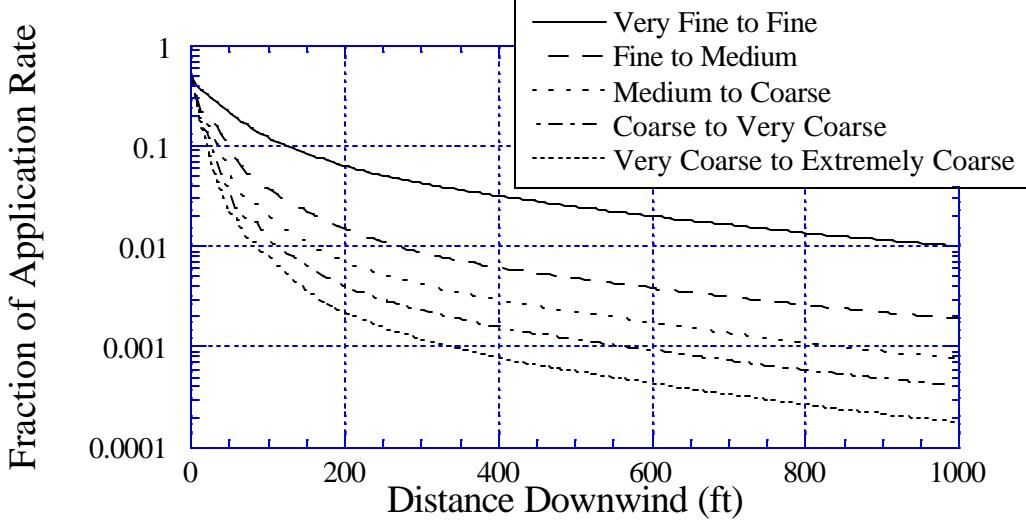


Figure 2. Deposition as a function of distance for the five ASAE S-572 threshold categories. These curves represent the upper range of deposition as a fraction of the nominal application rate for the Very Fine, Fine, Medium, Coarse, and Very Coarse atomization regimes. Simulation results assume a 20-swath field application

Meteorological parameters that have been shown to have secondary effects on off-site spray drift and deposition include air temperature, relative humidity, and atmospheric stability. Temperature and relative humidity affect the evaporation rate of spray droplets and, in effect, the drop size distribution. With high evaporation, droplets become smaller, less material deposits close to the aircraft, and downwind deposition increases. Evaporation is greatest during low humidity and high temperature conditions. A moderate evaporation scenario – i.e. 70°F and 75% relative humidity – was selected. Except for dry areas of the country, this is a typical evaporation scenario.

Atmospheric stability is basically a measure of the atmosphere's resistance to or encouragement of turbulent vertical motions. Under stable conditions, the atmosphere resists vertical motion, whereas under unstable conditions (sunny days), it enhances them. With increasing cloud cover or increasing wind speed, atmospheric stability moves toward neutral conditions (neither encouraging nor discouraging vertical movement).

Stability issues advise the applicator to avoid inversion (strongly stable) conditions and periods when the wind speed is less than 2 or 3 mph. Wind has a “neutralizing” effect on stability, thus promoting mechanical mixing that, in turn, breaks down the thermal gradients. This effect is why extreme conditions of stability (both stable and unstable) are associated with light wind or calm conditions. Avoiding near calm winds also avoids the likelihood of variable and unpredictable wind direction during spraying. AgDRIFT® is based on neutral stability.

Table 3. Partitioning of Atomization Tests According to ASAE S-572 Spray Category and Spray Volume Rate

Spray volume rate is calculated assuming an aircraft setup of 42 nozzles, a 60-ft lane separation, and flying at the wind speed used for the specific atomization test. In actual practice, considerable variation exists on the setup of aircraft used in spray operations.

Spray Volume Rate (gal/ac)	Percentage of Tests in Spray Category				Number of Tests in Flow Class
	Fine	Medium	Coarse	Very Coarse	
Nozzle angles ranging from 0 to 45° (0° indicates nozzle pointed straight back)					
1-2	38	53	9	0	159
2-5	22	57	17	4	517
> 5	2	80	18	0	100
Nozzle angle 0° only					
1-2	30	60	9	0	23
2-5	3	27	56	15	154
> 5	0	73	27	0	22

Formulation affects off-target deposition in three ways – as an impact on drop spectra, through evaporation effects based on the size of the nonvolatile fraction, and by altering the density. Effects of formulation changes on the drop spectra can be explored by accessing the atomization data base in Tier III or through use of regression equations based on the SDTF atomization data. Decreasing the nonvolatile fraction tends to slightly increase deposition downwind and decrease deposition near the aircraft. The nonvolatile fraction was calculated based on the assumption that 0.5 lb of formulated material was applied per acre. The formulation was assumed to be composed entirely of nonvolatile materials, diluted with water to obtain the prescribed spray application rate. The evaporation rate for the volatile fraction was assumed to be equal to that of pure water. This assumption was confirmed by an analysis performed for the SDTF (Teske and MacNichol 1996) demonstrating that tank mix additives do not significantly alter evaporation rates of water-based tank mixes. For each application category the lower boundary of the spray application rate was used in the calculation.

Equipment other than the nozzle itself also affects drift levels. The aircraft type, speed of operation, and placement of nozzles on the aircraft all affect off-site drift potential to some extent. Generally speaking, fixed-wing aircraft produce more drift than helicopters, while placement of nozzles near the wing tips increases off-site drift. By default, nozzles are placed out to 65% of the wing span in a typical field set-up configuration. The aircraft itself also affects off-site drift. An Air Tractor AT-401 was chosen for use in these simulations. This aircraft is

average in off-site drift levels, according to a modeling study of sensitivity of drift to aircraft type (MacNichol 1994), and is one of the most popular aircraft for use in agricultural applications.

Factors including the swath width (distance between application flight lines), number of swaths applied, and swath offset (the distance a pilot offsets application from the downwind edge of the application area to account for the wind speed) can also affect off-site deposition. Swath width is determined by aircraft type, nozzle placement, and flight height, and typically ranges from 40 to 75 ft for low flight agricultural applications. Application area (swath width multiplied by the number of flight lines) can potentially have a major impact, particularly in the far field. For consideration of the near-field effects, field size is a less sensitive variable. By default the model assumes a 60 ft distance between flight lines and a total of 20 flight lines applied to the field.

In the SDTF survey of aerial applicators (Kidd 1994), it was reported that 90% of operators account for swath offset during application. When wind speeds are in the 7 to 10 mph range, the majority of applicators offset the application approximately one swath upwind. The appropriate swath offset is a function of drop size, wind speed and application height, and, by default, is set so that one-half of the application rate is recovered at the edge of the application area.

Finally, the size and type of canopy on the field, along with the presence of canopies and barriers in the off-target areas, will affect drift movement. The SDTF field trials were performed on short grassed fields, and the aerial modeling was done assuming short grass both on and off the target field.

### C. Tier I Ground Sprayer Assessment Methodology

The Tier I ground sprayer assessment method is based solely on SDTF field data collected in two ground studies (Johnson 1995a). The collected data are most easily analyzed (Teske 2001a) by separating into two subsets: low boom and high boom. Sufficient data exist to collect the deposition patterns as produced into “Very Fine to Fine” and “Fine to Medium/Coarse” droplet size distributions. For low boom data, boundary curve development proceeded by ranking the deposition data at each downwind measurement point. Measured values that bounded 50% of the data at each point were then identified. Since four sprayer paths (separated by a swath width of 45 ft) were traversed to generate one field measurement, these data were further corrected to a single sprayer path (enabling the estimation of low boom ground deposition for other than four sprayer paths), by curve fitting to the expression

$$D(x) = \frac{c}{[1 + ax]^b}$$

where  $D(x)$  is the deposition level relative to the nominal application rate,  $x$  is the downwind distance, measured from the edge of the application area and assumed perpendicular to the ground sprayer path, and  $a$ ,  $b$  and  $c$  are curve shape parameters determined from the data. Solutions were obtained for both low-boom droplet size distributions.

As the curve-fit expression is a nonlinear function of the curve shape parameters, the downhill simplex method due to Nelder and Mead (Press et al. 1992) was used to recover the curve shape parameters by a least squares analysis. Since the first downwind data points were at 25 ft, it was determined to match two curve fits at that point: one curve fit is applicable between  $x = 0$  and  $x = 25$  ft (with  $c = 1$  to match the deposition anticipated at the edge of the application area), and a second curve fit begins at  $x = 25$  ft. The value of  $D(x)$  and its slope at  $x = 25$  ft were matched to the value and slope of both curve fits to generate a consistent representation of the low boom ground sprayer deposition pattern. These assumptions permit the determination of the coefficients  $a$ ,  $b$ , and  $c$  for a single sprayer path

<u>Low Boom</u>	$a (\text{ft}^{-1})$	$b$	$c$
Very Fine to Fine			
$0 < x < 25 \text{ ft}$	0.8082	1.5208	1.0
$x > 25 \text{ ft}$	0.9749	1.5085	1.2628
Fine to Medium/Coarse			
$0 < x < 25 \text{ ft}$	1.3742	1.4863	1.0
$x > 25 \text{ ft}$	1.6014	1.4803	1.2205

Because high boom deposition data were sparse, an implied high boom model was developed by extending the low boom deposition model with the equation

$$D(x) = \frac{c}{[1 + ax]^b} [1 + A \exp(-Bx)]$$

where the added exponential expression is used only for  $x > 25$  ft, and  $A$  and  $B$  are determined by matching the high boom data at 25 ft and assuming that high boom deposition is ten percent higher than low boom deposition at 2600 ft. These assumptions recover (for a single sprayer path)

<u>High Boom</u>	a (ft <sup>-1</sup> )	b	c	A	B (ft <sup>-1</sup> )
<b>Very Fine to Fine</b>					
0 < x < 25 ft	0.1409	1.8605	1.0		
x > 25 ft	0.9749	1.5085	1.2628	5.4877	0.001541
<b>Fine to Medium/Coarse</b>					
0 < x < 25 ft	0.7802	1.5183	1.0		
x > 25 ft	1.6014	1.4803	1.2205	1.0639	0.000910

Because of the limited extent of the field data, the default curve fits are validated by data for one sprayer path out to only 1300 ft downwind; additional sprayer paths reduce the validated downwind distance by the swath width (45 ft) for each path added (i.e., 20 sprayer paths are validated to only 445 ft downwind). However, the deposition curves are always extrapolated to 1000 ft downwind in Tier I.

Further, because the curve fit is determined functionally, an integration of D(x) from the edge of the application area ( $x = 0$ ) to a large distance downwind ( $x \rightarrow \infty$ ) recovers the amount of material that will drift. The rest of the released material may then be assumed to deposit in the spray block, generating the Application Efficiency.

#### D. Tier I Orchard Airblast Sprayer Assessment Methodology

The Tier I orchard airblast sprayer assessment method is also based solely on SDTF field data collected in several orchard studies (Johnson 1995b), identified as Grapes (Wrap-Around), Grapes, Apples, Almonds, Oranges, Grapefruit, Grapefruit (Mist Blower), Small Grapefruit, Small Grapefruit (Mist Blower), Pecans, and Dormant Apples. In all cases data were collected for two treatments: one application to the outside rows of trees (the rows or sides of trees adjacent to the open downwind edge of the orchard), and one application to the inside rows of trees (the rows or sides of trees upwind of the outside treatment further into the orchard). The collected data for each of the eleven orchard and equipment type combinations were examined by developing a curve fit for each tree row of the form

$$D(x) = \frac{c}{[1+ax]^b}$$

where D(x) is the deposition level relative to the nominal application rate, x is the downwind distance measured from the edge of the orchard, assumed perpendicular to the orchard sprayer path, and a, b, and c are curve shape parameters determined from the data. In all cases a nonzero swath displacement was assumed for each of the orchards.

Since several sprayer paths were traversed to generate one treatment and therefore one set of field measurements, the outside and inside treatment data were examined separately to determine separate single sprayer paths (Teske 2001b). These assumptions permit the determination of the coefficients a, b, and c for a single sprayer path for the outside and inside treatments. Three composite orchards, grouped by orchard characteristics into Normal [averaging the data for Grapes (Wrap-Around), Grapes, and Apples], Dense [averaging Almonds, Oranges, Grapefruit, Grapefruit (Mist Blower), Small Grapefruit (Mist Blower), and Pecans], and Sparse [averaging Small Grapefruit and Dormant Apples] give the coefficients (a is in units of ft<sup>-1</sup>)

Orchard Type	a outside	b outside	c outside	a inside	b inside	c inside
Normal	1.0291	1.9286	0.9737	1.3961	1.4996	0.1320
Dense	0.1300	2.5037	2.9451	1.6150	1.1886	0.2190
Sparse	0.0629	3.3201	5.1769	0.1582	2.7868	5.2652

Because of the limited extent of the field data, the default curve fit is validated by data for one tree row out to only 600 ft downwind; additional tree rows reduce the validated downwind distance by the spacing between tree rows. However, the deposition curves are also always extrapolated to 1000 ft downwind in Tier I.

As with the Ground Sprayer, an integration of D(x) from the edge of the application area to a large distance downwind recovers the amount of material that will drift. The rest of the released material may then be assumed to deposit in the spray block, generating the Application Efficiency.

#### E. Using the Tier I Curves

For the evaluation of hazards to sensitive plants, the user needs to know the level of concern as a fraction of the spray application rate. Given this level of concern and a specified spray application rate, the user can use the model to determine the size of the buffer zone (if any) required to protect a sensitive species.

The aquatic analysis included in AgDRIFT® (in its Aquatic Assessment calculator) is based on the estimated deposition on a pond with a downwind width of 208.7 ft and length in the direction of the flight lines of 515.8 ft (a 1 ha pond surface area). Two elements of information are required to perform the analysis: an estimated environmental concentration (ng/L) for the pesticide that presents a hazard or Level of Concern (LOC) in the water body, and a required application rate for the active ingredient in lb/ac or kg/ha. The Tier I analysis assumes that the deposited pesticide mixes through the water column, does not degrade, and is completely bioavailable.

Also included in the toolbox in Tier I are: (1) a Terrestrial Assessment calculator for recovering similar deposition estimates on land; (2) a Spray Block Assessment calculator for determining the effect of spray block width (number of flight lines, ground sprayer paths, or tree rows) on buffer distance; (3) a Stream Assessment model for determining the diffusion of spray material entering a stream downwind of the spray block; and (4) a Multiple Application Assessment model for determining the probabilistic influence of wind speed and direction changes on repeated applications to the same spray block.

A Tier I example assessment is detailed in Section V, following a general description of the menu screens in AgDRIFT®.

### III. Tier III Predictions

Tier III AgDRIFT® aerial predictions permit the user access to all model inputs, including drop size distribution, nonvolatile application rate, active application rate, spray application rate, carrier type (water or oil), wind speed, temperature and relative humidity, aircraft type (to include the Cessna Ag Husky, Air Tractor AT-502, and Wasp helicopter), boom length, boom height, number of swaths, swath width, and swath displacement. The drop size distribution may be obtained from the SDTF atomization library or by use of the DropKick® analysis, that further permits access to the SDTF nozzle and physical properties libraries. DropKick® is developed from a neural network interpretation of the SDTF atomization library, and is described in greater detail in Esterly (1998). Alternately, the USDA ARS Nozzle Models analysis may be used (Kirk 1997, 1998, 1999, 2000). Additional inputs include the SDTF spray materials evaporation library, wind direction, the SDTF aircraft library, nozzle positioning, and surface roughness. Advance settings permit access to AgDRIFT® modeling parameters that are not normally changed.

Tier III permits access to the Drop Distance Calculator for computing the travel distance of a specified drop size. Tier III also permits access to the Spray Block Statistics calculator for inferring the swath width, COV, and mean deposition within the spray block for input conditions specified to the model.

## IV. Program Operation

### A. General Program Operation

AgDRIFT® operation will now be described, beginning with Tier I. The model is installed within the Microsoft® Windows™ environment by invoking the command SETUP (with SETUP.EXE) on the distribution CD (in all that follows, it is assumed that the user is knowledgeable about the operation of applications written for the Microsoft® Windows™ environment). AgDRIFT® will run in Windows™ 9X, NT, ME, and 2000, and is a 32-bit application. If a version of AgDRIFT® exists on the computer, that version should first be removed with Add/Remove Program from the Control Panel.

Model installation will install the program and all of its auxiliary files (these files may include Windows™ files already on the computer, in which case the installation routine will skip over them). Model installation will include the Default Library, containing water-based library entries and results developed in cooperation with the USDA Forest Service. If the user has access to the SDTF Library, which contains confidential data on the field trials and specific company products, that library will supplement the Default Library and be installed from a diskette. If the libraries are not compatible with the model version installed, AgDRIFT® will generate a warning or error message, depending on the severity of the mismatch. The AgDRIFT® spray aircraft icon is double-clicked to begin program operation. The first screen to appear is the About AgDRIFT® screen, as shown in Figure 3.

AgDRIFT® always begins at Tier I ground. The appearance of this screen is shown in Figure 4. The default input parameters comprise the “default” data. Data being examined by the user in the input screens is considered “current” data; data saved previously by the user in data files is considered “saved” data. A cross-section of the field of application is given in Figure 5.

The inputs that may be changed in Tier I ground include the sprayer **Boom Height** (low boom or high boom) and **Drop Size Distribution** (classified as “Very Fine to Fine” or “Fine to Medium/Coarse” consistent with ASAE S-572). The Title information cannot be saved but becomes a part of the plot title. **Extended Settings** permits the user to access the Number of Swaths. An **Information** section provides Boom Height, Swath Width,  $D_{v0.5}$ , and Application Efficiency (based on 20 swaths) for the selections made by the user. The ground model is based solely on field data.

The menu bar options in Tier I permit the following:

## File

The user may select a **New** set of current data (set to the default data); **Open** a previously saved Tier III data file (Tier I data are not saved); **Export** deposition results into an ASCII file for import into other graphics packages or analyses after leaving AgDRIFT®; **Print Preview** potential output to an attached printer device; **Print Setup** printer characteristics; **Print** the data selected; or **Exit** the program.

**Open** moves the user to the Tier consistent with the contents of the data file selected.

**Export:** This screen (Figure 6) presents Notes (as a record of the run), Results for Export (selecting one or more of the available model outputs of Drop Size Distribution, Deposition, Pond-Integrated Deposition, Vertical Profile, 1 Hour Average Concentration, Coefficient of Variation within the spray block, Mean Deposition within the spray block, and/or Fraction Aloft, depending on Tier), Options (whether an identifying header is added at the top of the file), and Delimiter (selecting the separator between columns of output, either tab, space, comma, user-defined other character, or fixed-width columns). An **OK** brings up the File Browser. The export file always contains an AgDRIFT® identification line. All comment lines (generated by notes, header, and/or run ID) in the export file begin with “#” in column one to separate them from data.

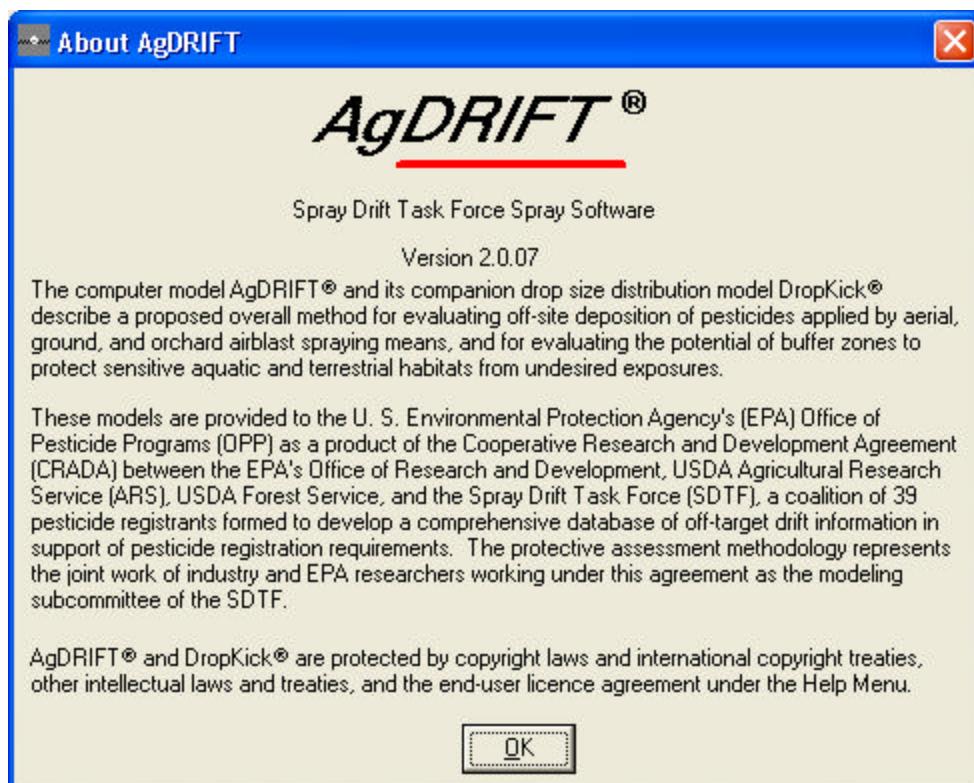


Figure 3. The About AgDRIFT® screen.

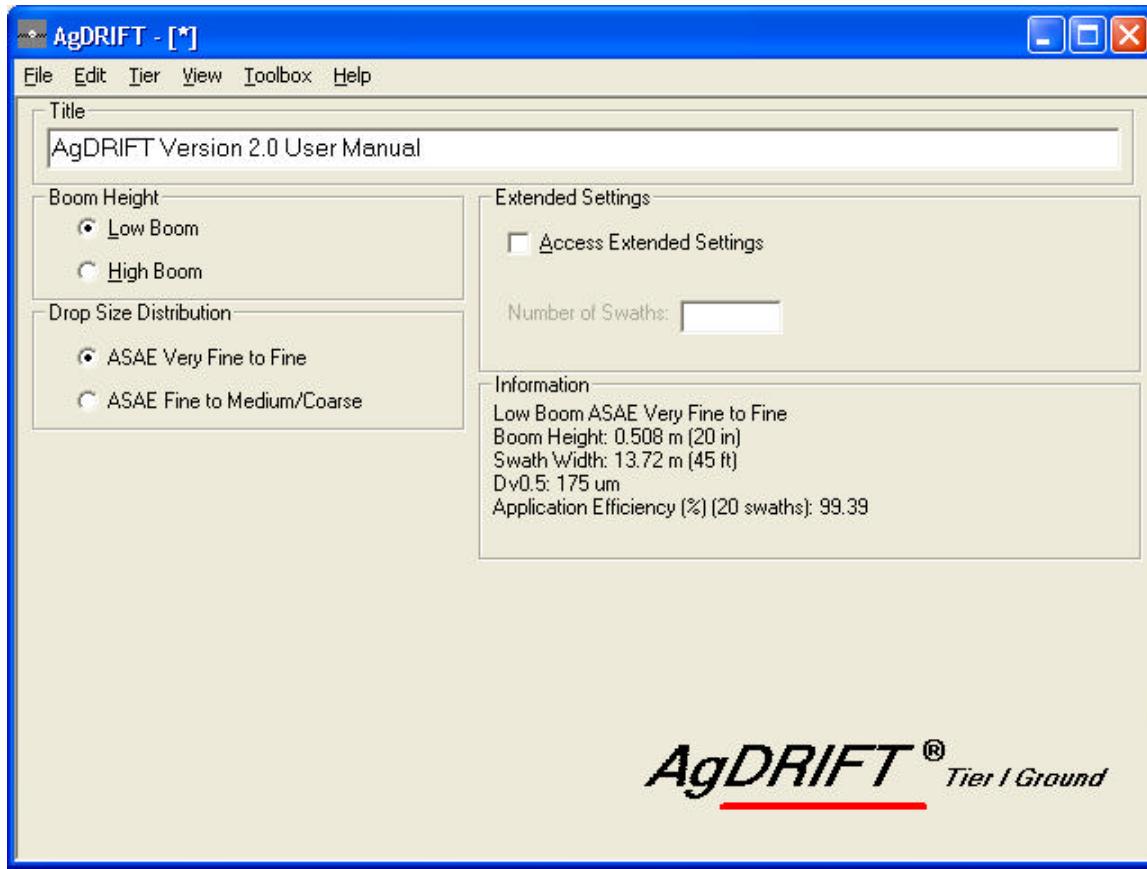


Figure 4. The Tier I ground input screen presenting Title, Boom Height, Drop Size Distribution, Extended Settings, and Information.

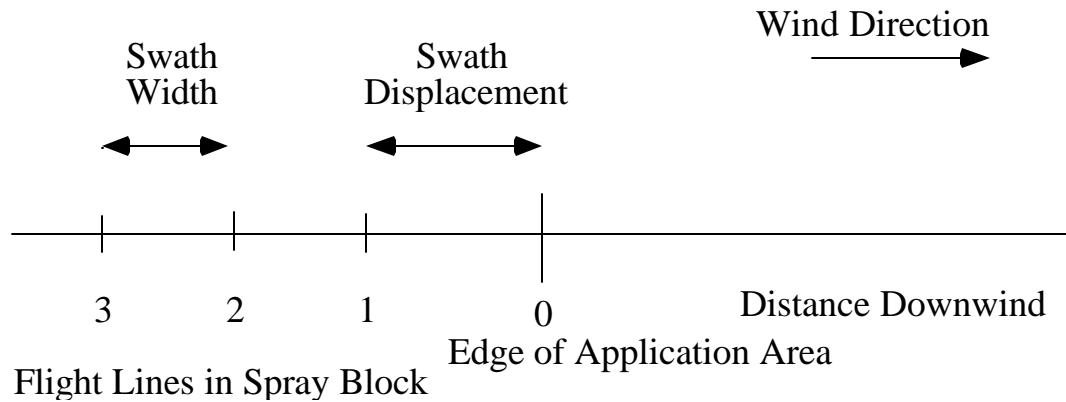


Figure 5. Application cross section. The sprayer travels into the paper, along spray lines labeled by 1, 2, 3, etc., displaced by the Swath Displacement from the Edge of the Application Area.

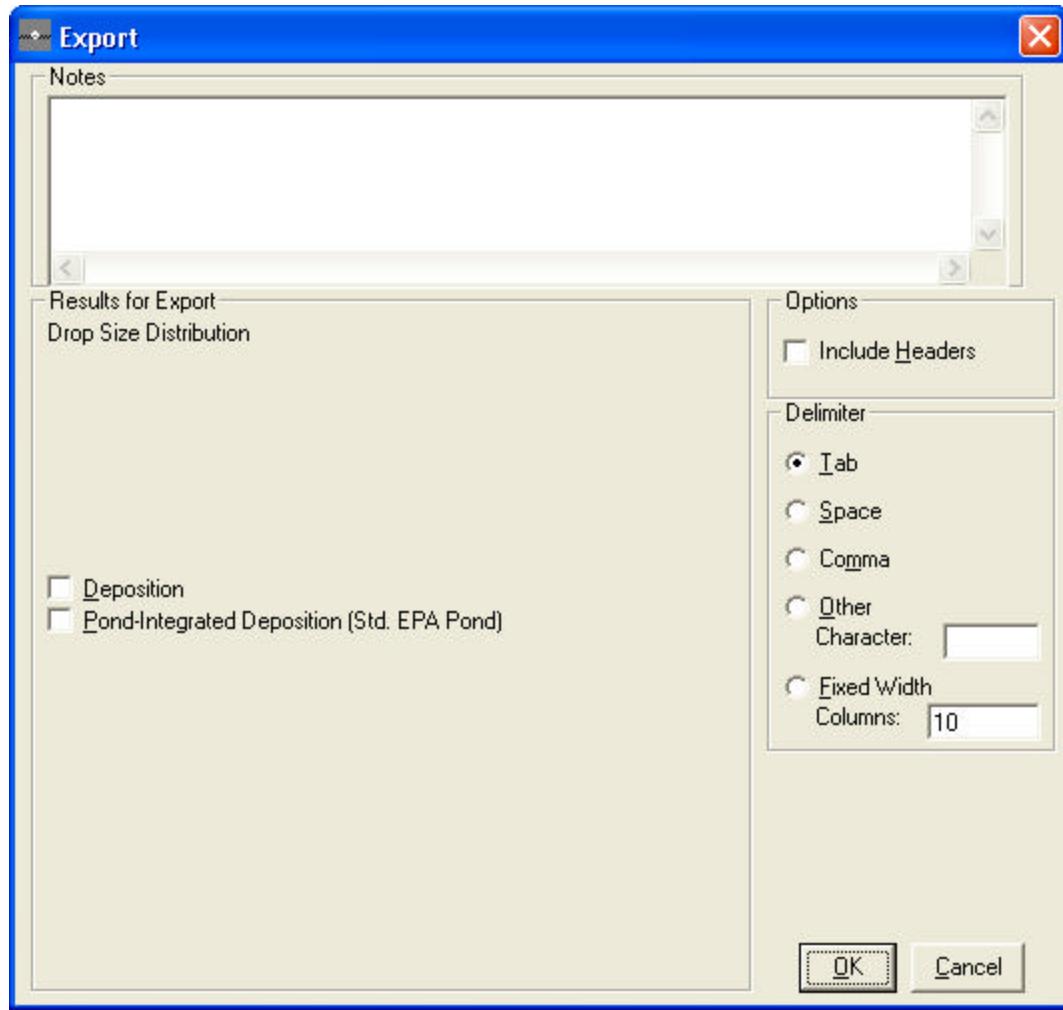


Figure 6. The Export screen (under **File**) presenting the options for Notes, Results to Export, Option (Headers), and Delimiter.

## Edit

The user may highlight certain data values within an entry box (such as the Title box), then **Cut** the highlighted information from the entry box (and store it in the Clipboard), **Copy** the highlighted information from the entry box into the Clipboard (leaving the highlighted information in place), **Paste** information from the Clipboard back to a different entry box or location, or **Clear** the highlighted information from the entry box (and not store it in the Clipboard); the user may also set various **Preferences** for computer or program operation parameters.

**Preferences:** This screen (Figure 7) presents several default settings for the model, and allows the user to change them, including the default **Starting Mode** and **Starting Tier** when the program is first entered, the default **Units** (all units in this document are in English), and check boxes to **Warn on Tier change** (a tier change may change current data), **Pause before**

**calculating** (to review inputs) and **Suppress Calculation Warnings** (to maintain program flow). The **User Library** name, defining the name of the user library containing unique aircraft and drop size distribution data, may be selected here for Tier III. Preferences are stored in the file AGDRIFT.INI, located in the same directory or folder as the AGDRIFT.EXE file.

## Tier

AgDRIFT® may operate in one of three Tiers: Tier I Ground, Tier I Orchard / Airblast, or Tier III Aerial; and one of two Modes: Agricultural or Forestry. Forestry Mode (discussed in Section VIII) includes additional computations, plotting features, and toolboxes found in predecessor USDA Forest Service models (Teske and Curbishley 2000).

## View

The user may compile **Notes** about the current AgDRIFT® run; examine an **Input Summary** of the input; or plot the ground **Deposition** (Figure 8) or the **Pond-Integrated** ground **Deposition** (Figure 9).

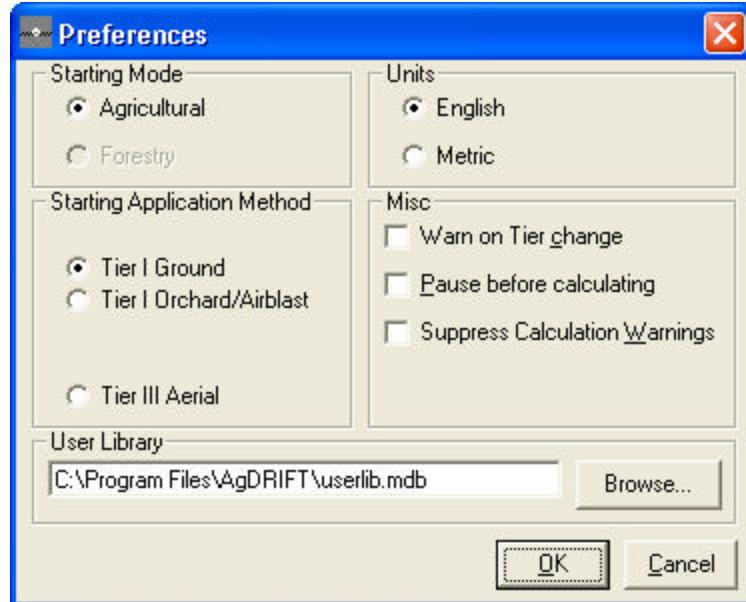


Figure 7. The Preferences screen (under **Edit**) presenting the options for setting the operational mode within AgDRIFT® of its Starting Mode and Tier (when the program is first entered), Units, program menu behavior, and User Library name.

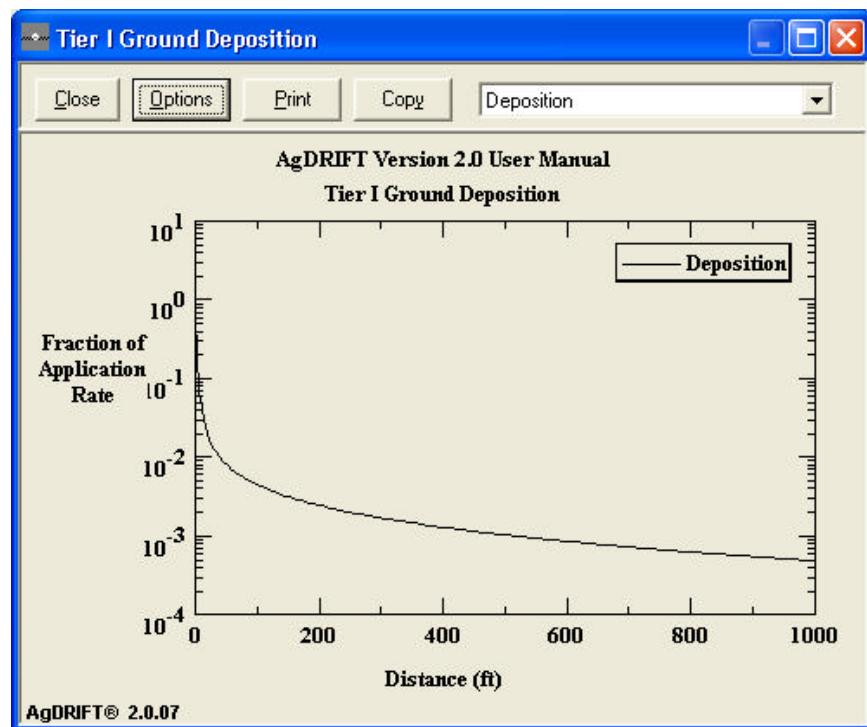


Figure 8. A plot of the Tier I ground deposition for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution. The 0 ft location locates the edge of the application area.

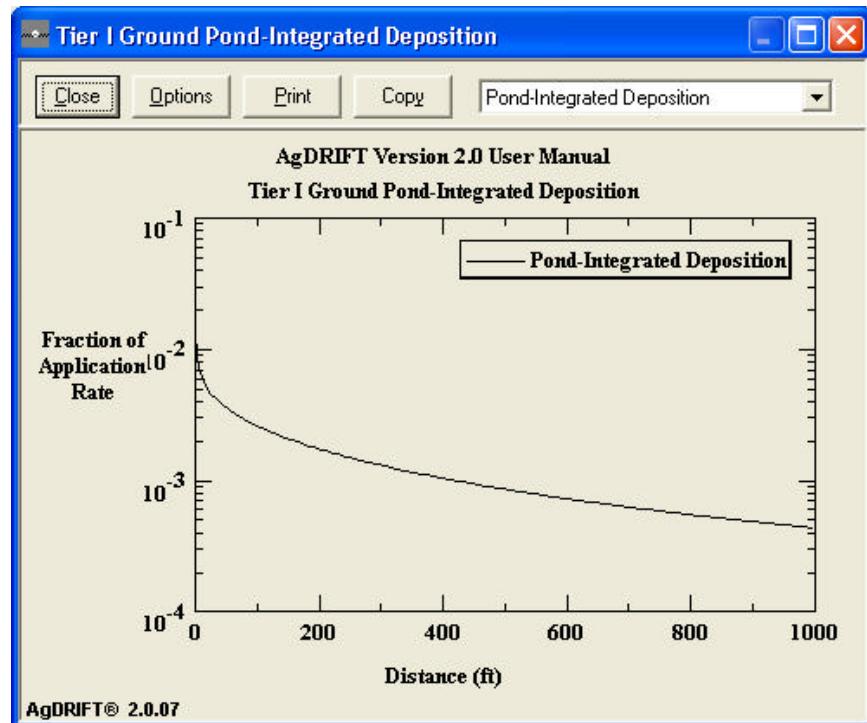


Figure 9. A plot of the Tier I pond-integrated deposition for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution.

**Plot Options:** On any plot screen the horizontal (X-axis) and vertical (Y-axis) labels, as well as the two lines of plot title, may be changed by clicking on them; within the label and title screens the font may be changed by opening the **Font** screen. A plot **Options** button at the top of the plot screen accesses an additional screen (Figure 10), which includes a Data section that allows the user to include curves for up to five sets of data on the plot simultaneously. Data Sources, which may be accessed through the pull-down menu (Tier appropriate), include: Current Data, any Tier I data (Figure 11), Saved Results from previous predictions, Library entries, SDTF field trial measurements, and corresponding SDTF field trial model predictions. Data Titles are the associated data identifiers in the Legend. This screen also allows the user to select Color and Line Style for each data set, and alter the scale for both the X-axis and Y-axis, including choosing log or linear scales and resetting minimum and maximum values for each axis. The user can **Save** plot options (in AGDRIFT.INI) or return to **Default** values by clicking on the buttons at the bottom of the screen. From the plot screen, the user can **Print** the graph with the button at the top of the screen, **Copy** the plot into the Clipboard (for pasting into other applications) or toggle between plots with the pull-down menu.

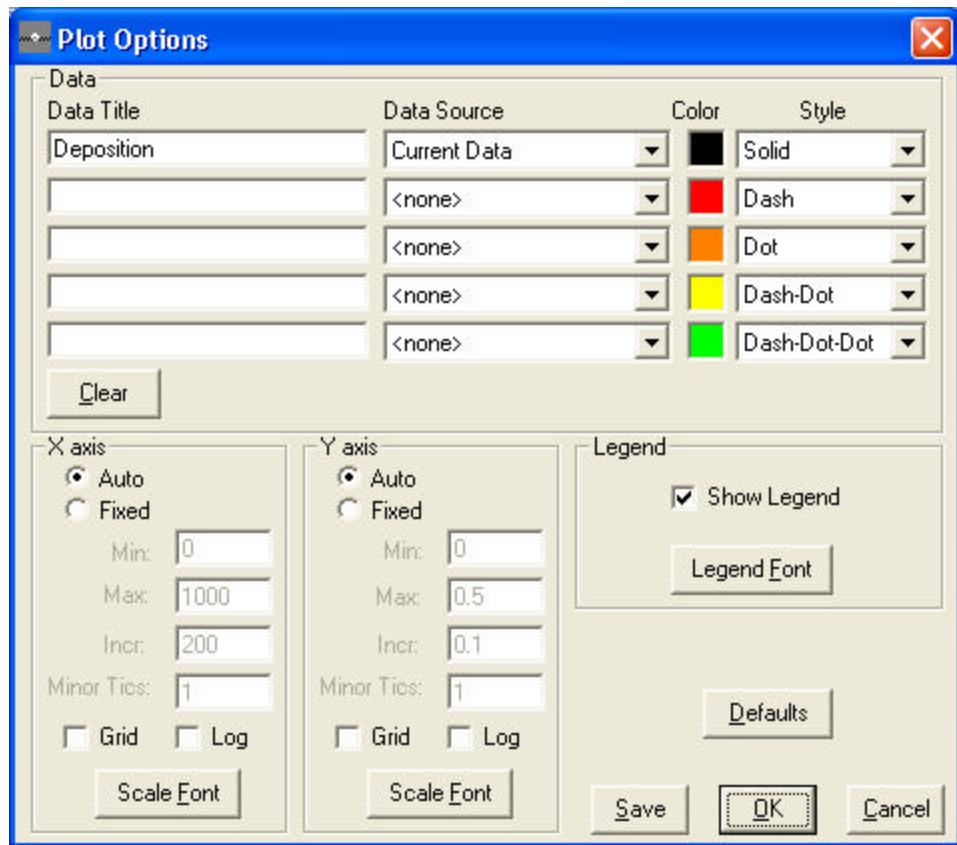


Figure 10. The Plot Options screen reached from the plot screen. Plot Options include additional Data, Color and Style changes, Legend, and manipulation of the X axis (horizontal on the screen) or Y axis (vertical on the screen) with manually selecting the plot size, adding grid or logarithmic appearance, and changing character font.

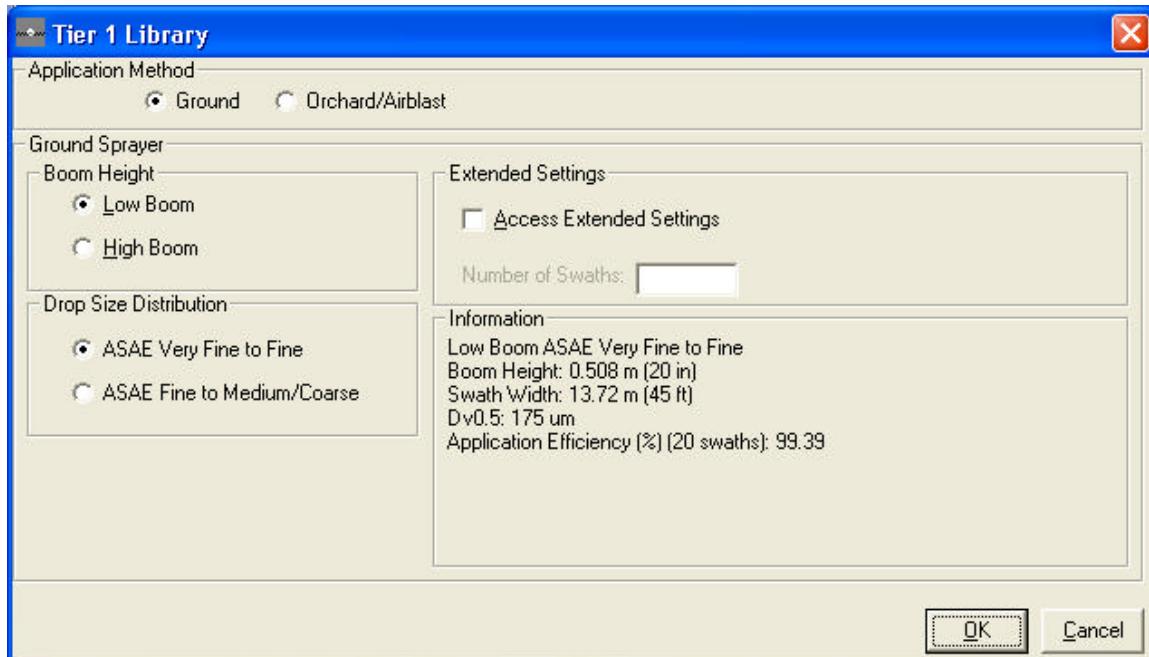


Figure 11. Tier I Plot Options screen presenting the Application Method (Ground or Orchard Airblast) and the selected Tier I input screen.

## Toolbox

The user may enter the **Aquatic Assessment** calculator, the **Terrestrial Assessment** calculator, the **Spray Block Assessment** calculator, the **Stream Assessment** calculator, or the **Multiple Application Assessment** calculator.

**Aquatic Assessment:** This calculator (Figure 12) contains three input sections, Aquatic Body Definition, Tier I Settings, and Calculations. Calculations are based on the current deposition profile. Aquatic Body Definition (in the top half of the screen, also shown schematically in Figure 13) defines the water body as either EPA Pond, EPA Wetland, or User-Defined. The downwind width of an EPA Pond is 208.7 ft and its depth is 6.56 ft; the downwind width of an EPA Wetland is 208.7 ft and its depth is 0.49 ft. The surface area of an EPA Pond or EPA Wetland is 1 ha (implying that the length of the pond or wetland is 515.8 ft). In Tier I the user may enter a value for active application rate (in lb/ac or kg/ha). In the Calculations section the user enters a value for one of the five parameters shown: Distance to the Water Body from the Edge of the Application Area (in ft or m), Initial Average Deposition (in fraction of applied, g/ha, or lbs/ac), or Initial Average Concentration (in ng/L or ppt). The **Calc** button enables a computation of the other four parameters, based on the deposition profile. The **Print** button prints the screen. If the aquatic body is User-Defined, the user will be able to **Plot** the pond-integrated deposition and **Export** it (Figure 14).

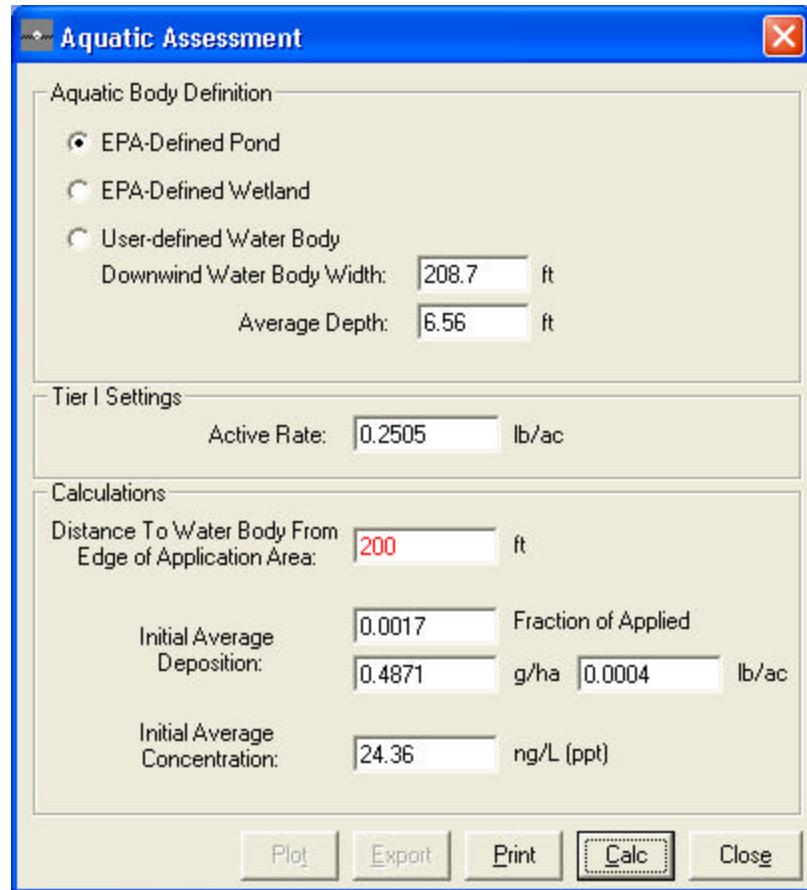


Figure 12. The Aquatic Assessment Calculator screen (under **Toolbox**) defining the type of water body to examine and calculating Distance to Water Body from Edge of Application Area, Initial Average Deposition, and Initial Average Concentration, where one of the five values is inputted by the user, and the **Calc** button is used to compute the other four (red indicates user input).

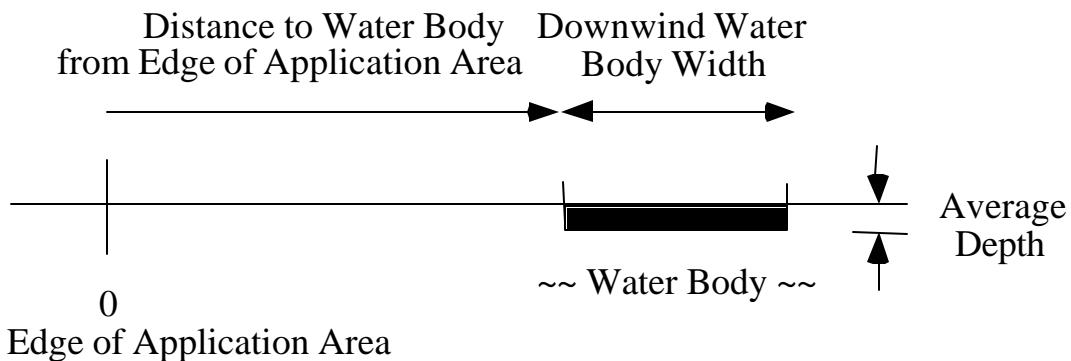


Figure 13. Cross section of the water body size and downwind location relative to the edge of the application area.

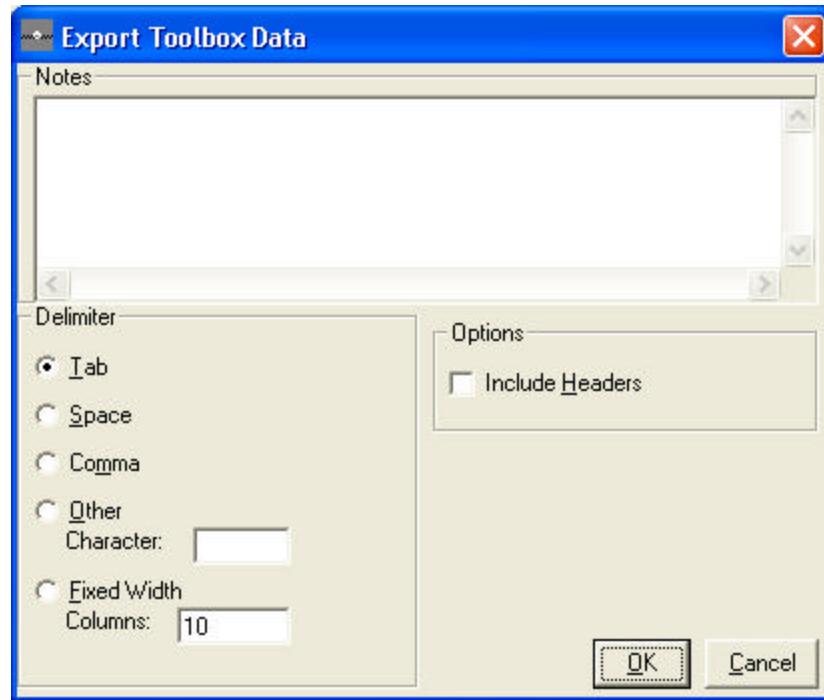


Figure 14. Toolbox Export screen, where the Results for Export are known, and Notes, Options (Headers), and Delimiter may be entered.

**Terrestrial Assessment:** This calculator (Figure 15) also contains three input sections, Terrestrial Field Definition, Tier I Settings, and Calculations. Calculations are based on the current deposition profile. Terrestrial Field Definition (in the top half of the screen, also shown schematically in Figure 16) defines the field as either point deposition or User-Defined. The default downwind width is 208.7 ft. In Tier I the user may enter a value for active application rate (in lb/ac or kg/ha). In the Calculations section the user enters a value for one of the five parameters shown: Distance to the Point or Area Average from the Edge of the Application Area (in ft or m), or Initial Average Deposition (in fraction of applied, g/ha, lb/ac, or mg/cm<sup>2</sup>). The **Calc** button enables a computation of the other four parameters, based on the deposition profile. The **Print** button prints the screen. If the field is User-Defined, the user will be able to **Plot** the equivalent average-integrated deposition and **Export** it.

**Spray Block Assessment:** This calculator (Figure 17) contains three input sections, selecting either deposition or pond-integrated deposition, then specifying the desired deposition level (in fraction of applied, g/ha, or lb/ac), or concentration level (in ng/L or ppt) if applicable. If pond-integrated deposition is chosen, the user can specify the Downwind Width of the Water Body, and its Average Depth (both in ft or m), or default to EPA Pond or Wetland. In Tier I the user may also enter a value for active application rate (in lb/ac or kg/ha). The **Calc** button enables a computation of the distance downwind from the edge of the application area to the desired deposition level, as a function of the number of spray lines; the **Plot** button plots the result (Figure 18); the **Export** button exports the result.

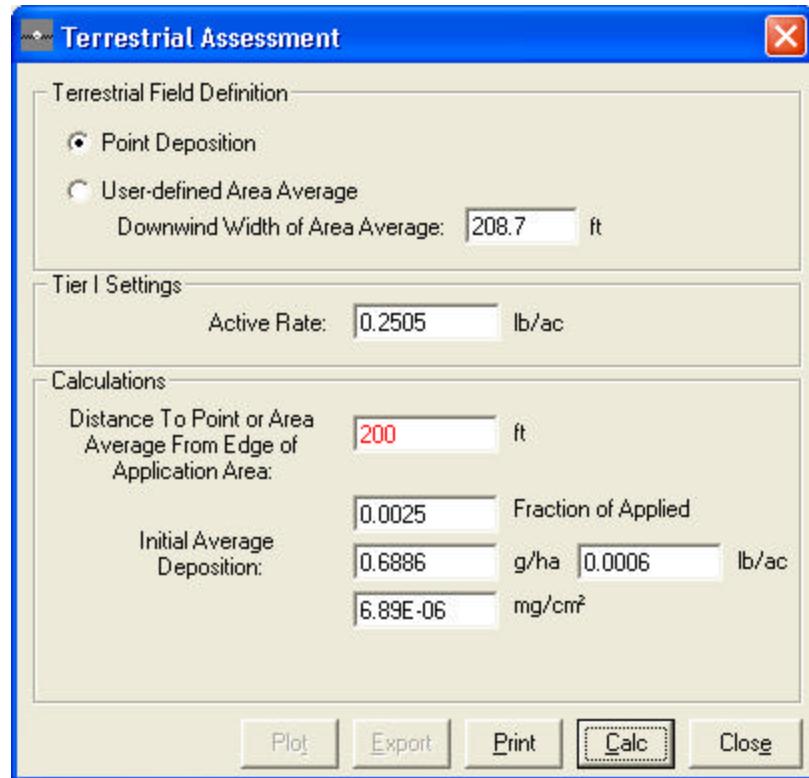


Figure 15. The Terrestrial Assessment Calculator screen (under **Toolbox**) defining the type of terrestrial field to examine (point or area average) and calculating Distance to Point or Area Average from Edge of Application Area, and Initial Average Deposition, where one of the five values is inputted by the user, and the **Calc** button is used to compute the other four (red indicates user input).

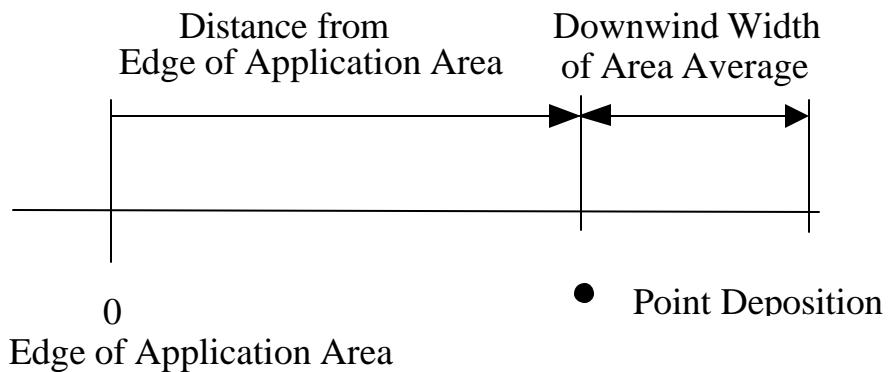


Figure 16. Cross section of the terrestrial field size and downwind location relative to the edge of the application area.

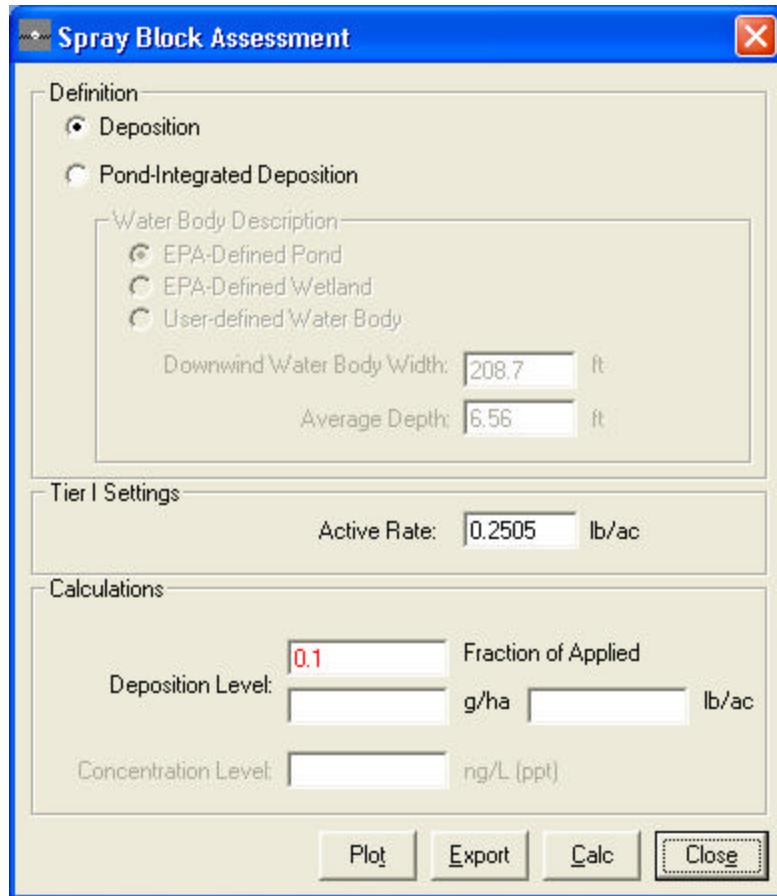


Figure 17. The Spray Block Assessment Calculator screen (under **Toolbox**) presenting the entry of Deposition type (Deposition or Pond-Integrated Deposition) and Deposition Level (Fraction of Applied, g/ha, or lb/ac) and Concentration Level (in ng/L or ppt) if applicable. The calculator generates a plot of Block Width versus Buffer Distance downwind from the edge of the spray block where the desired level of deposition occurs (red indicates user input).

**Stream Assessment:** This calculator (Figure 19) contains three input sections. The top part permits entry of all needed inputs: Spray Line Length (the length of the field in the sprayer direction, in ft or m, a direction assumed to be parallel to the stream); Turn-Around Time (the time to change from one sprayer line to the next, in sec); Stream Width (in ft or m); Stream Depth (in ft or m); Stream Flow Rate (in gal/s or  $m^3/s$ , with a computation of Stream Speed in mph or m/s); Distance from the edge of the application area to the center of the stream (in ft or m); Riparian Interception Factor (the fraction of active material removed from the air by the presence of vegetation upwind of the stream); Instream first order Chemical Decay Rate (normally defined as  $\ln(2)/DT_{50}$ , in days $^{-1}$ ); and Recharge Rate (the flow rate per distance for fresh water entering the stream, in gal/s/mi or  $m^3/s/km$ ). In Tier I the active rate may also be entered. These inputs drive the stream equation once AgDRIFT® has been run to generate the integrated deposit on the surface of the stream (the stream equation formulation is summarized in

Appendix B). Results may be recovered by either time or distance plots, choosing the distance increment and times desired, or the time increment and distances desired. The model will automatically generate appropriate time and distance values if so requested (Automatically set distance/time values), based on built-in plotting increments. The single-point answer is also available (entering Time or Distance, and recovering Distance or Time and Peak Concentration). The user may then freely change these values and rerun the calculation (with the **Calc** button), **Plot** the results, and **Export** them. The **EXAMS** button generates a file of input data for a future version of the EXAMS program (Burns 1997) if a Time increment (the third Control option) is entered. A typical result is shown in Figure 20.

**Multiple Application Assessment.** This calculator (Figure 21) contains several input sections. The Wind Rose may be: (1) developed from meteorological data available at a Library site entry, or (2) provided by the user from an ASCII file containing the necessary information (this file is constructed with a first line of two entries for the average temperature (in °C) and relative humidity (%), a second line containing the number of wind speeds, and succeeding lines beginning with an integer wind speed and 36 numbers representing the frequency of occurrence within each ten-degree increment in wind direction (from 10 to 360°, with the wind rose centered about 180° as directly downwind of the spray block), for each wind speed sequentially from 2 m/s to the maximum examined). The sum of all frequencies of occurrences across all wind speeds must equal 1.0.

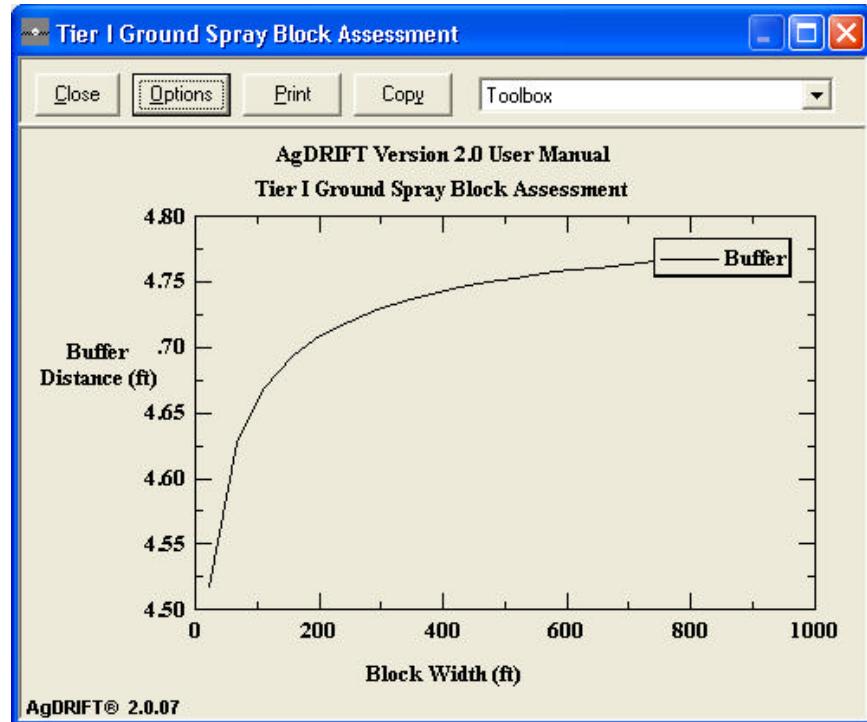


Figure 18. Spray Block Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution. The 0 ft location (on the vertical axis) locates the edge of the application area.

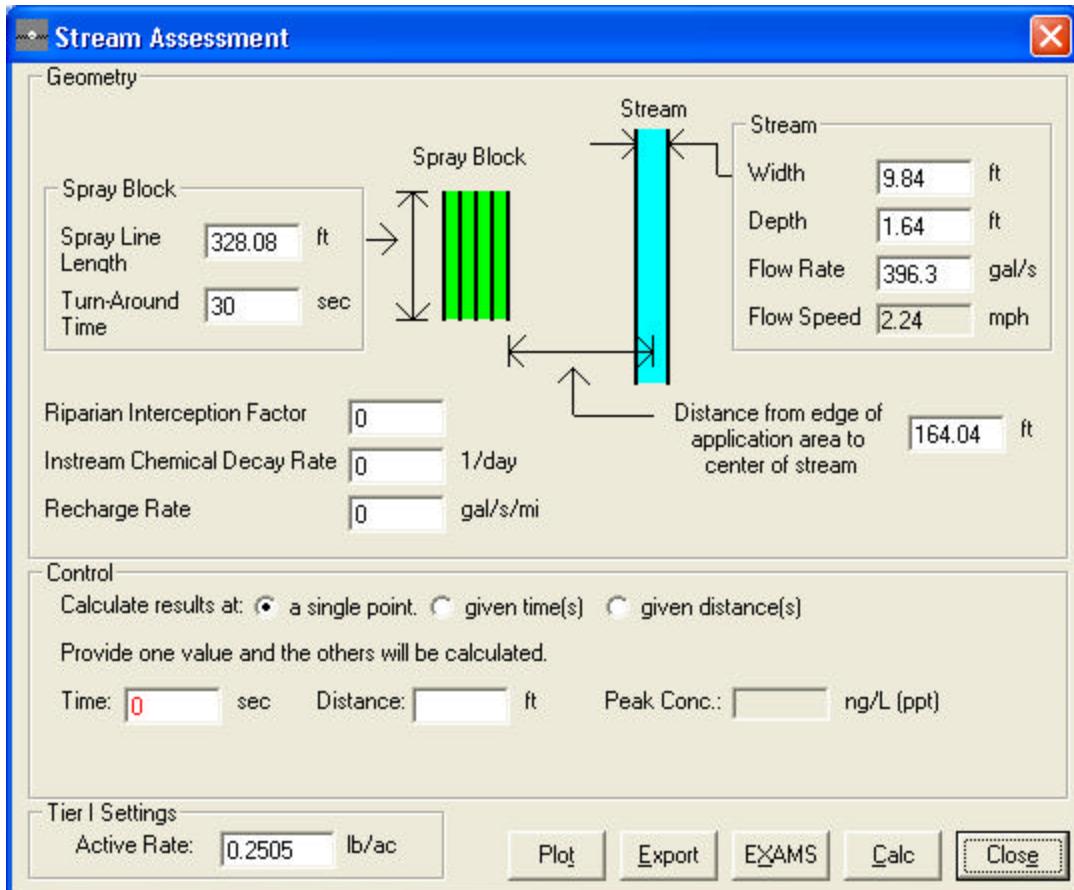


Figure 19. The Stream Assessment Calculator screen (under **Toolbox**) defining the necessary details needed to compute stream diffusion of spray materials applied to the surface of the stream.

Library entries are recovered from the NREL (National Renewable Energy Laboratory) 30-year compendium of meteorological data at 239 sites within the United States (1961-1990 National Solar Radiation Data Base, Version 1.0, Solar And Meteorological Surface Observational Network [SAMSON]) and 20 sites recovered from Canadian Climatological Surface Data. Library entries also contain median temperature, relative humidity, and wind speed, along with dominant wind direction, for the twelve months. These results may be plotted with the smaller **Plot** button (Figure 22).

Data Selection permits the user to limit the maximum wind speed examined, select the month increment for the generation of the wind rose, and set the direction from the field to the sensitive area (Tier III only). The resultant wind rose may be displayed with the **Plot Wind Rose Probability** button (Figure 23). Control enables the user to select the number of applications (events) per year and the number of years for multiple applications. Meteorology permits the user to select temperature and relative humidity values from Current data (entered previously in Tier III), Generated data (recovered from the Library), or User-Defined.

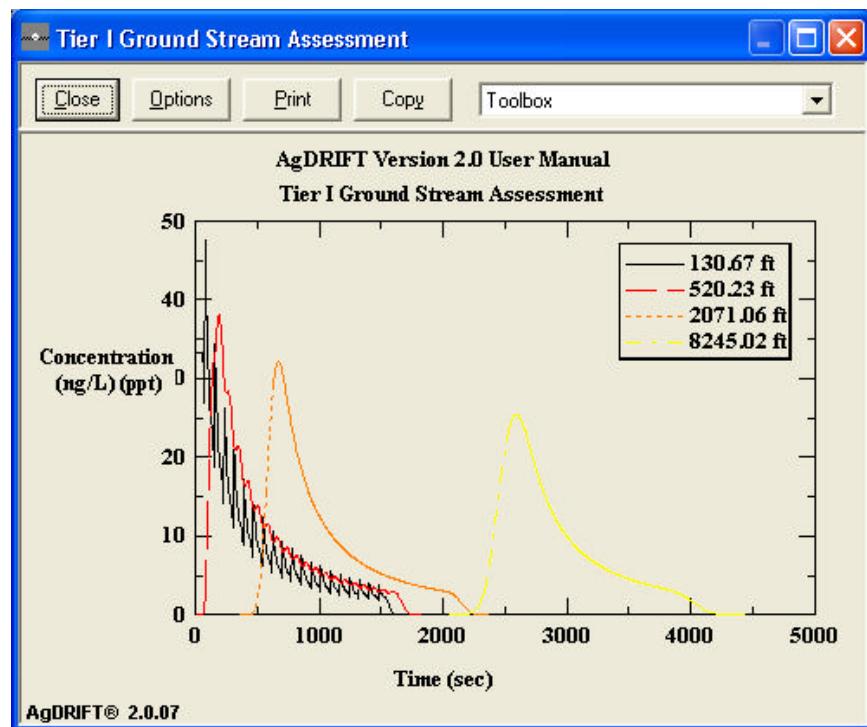


Figure 20. Stream Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution, with a Turn-Around Time of 30 sec. The 0 ft location locates the center of the spray block in the direction of the sprayer paths.

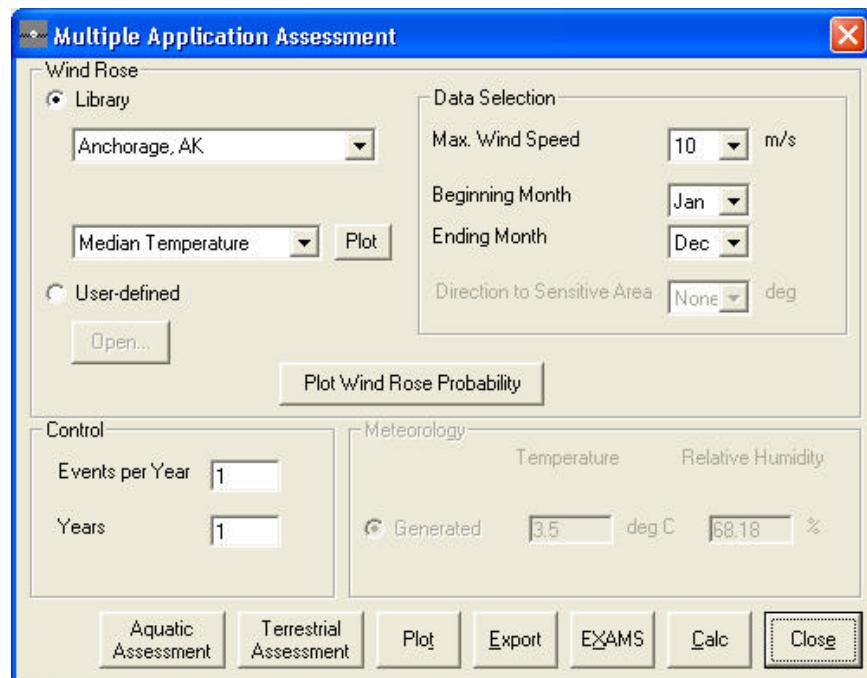


Figure 21. The Multiple Application Assessment Calculator screen (under **Toolbox**) defining the details needed to assemble and compute multiple applications to the same area.

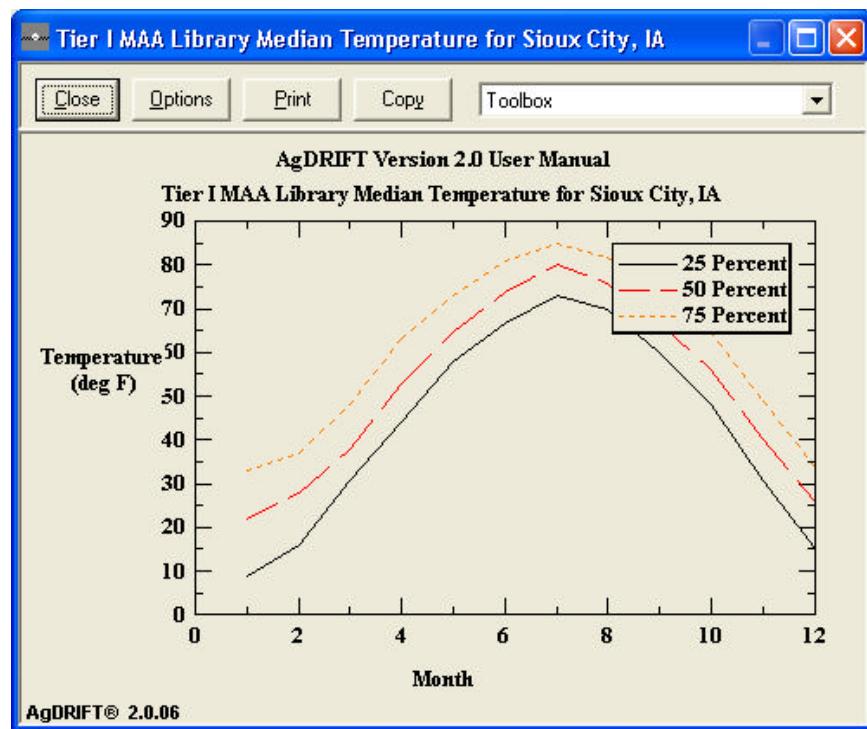


Figure 22. Median temperature for Sioux City, IA from the SAMSON database. Also shown are the 25<sup>th</sup> and 75<sup>th</sup> percentile bounds of the meteorological data.

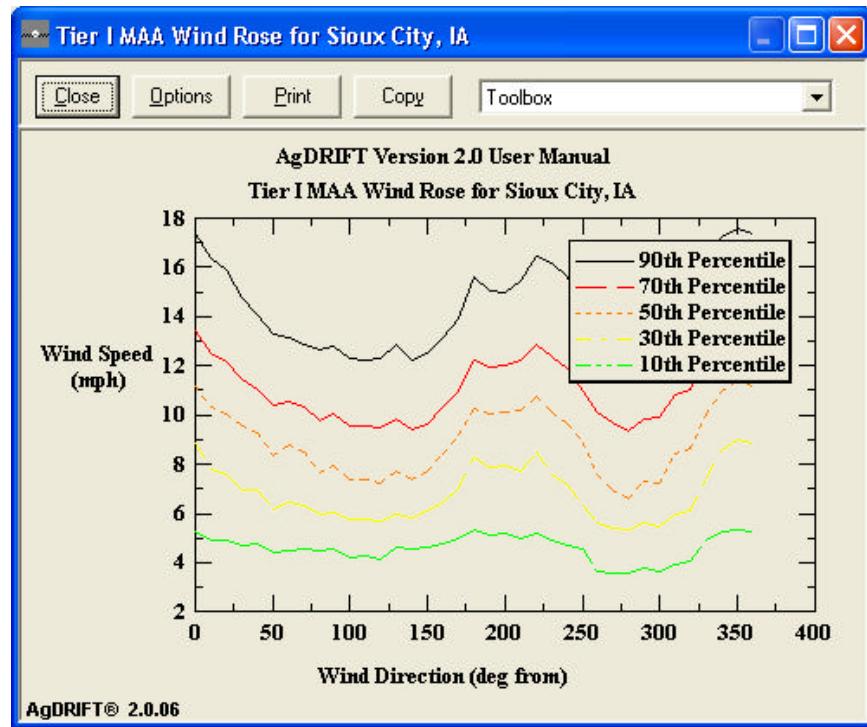


Figure 23. Wind rose for Sioux City, IA.

Calculations are performed with the **Calc** button. These calculations involve repeated AgDRIFT® runs for incrementally increasing values of wind speed, until the maximum desired wind speed is reached. The wind rose data is then accessed for controlled sampling of wind speed and wind direction, to recover the 95<sup>th</sup> percentile deposition pattern from multiple applications to the field (in Tier I controlled sampling examines only wind direction effects). A discussion of the overall approach may be found in Teske (2000c), summarized in Appendix C. The summary deposition profiles may be **Plotted** or **Exported**, and each deposition realization may also be exported (with the **EXAMS** button) to a file that will serve as input into a future version of the EXAMS program (Burns 1997). The average deposition may be further examined with **Aquatic Assessment** and **Terrestrial Assessment**. A typical result is shown in Figure 24.

## Help

The user may enter the **Help** facility at the menu bar or from any entry box or screen in the program with the F1 function key. The **Metric-English Units Conversion Table** is a reference guide for a change in units. The **End User License Agreement** and the **About AgDRIFT** screen (previously shown in Figure 3) are found here as well.

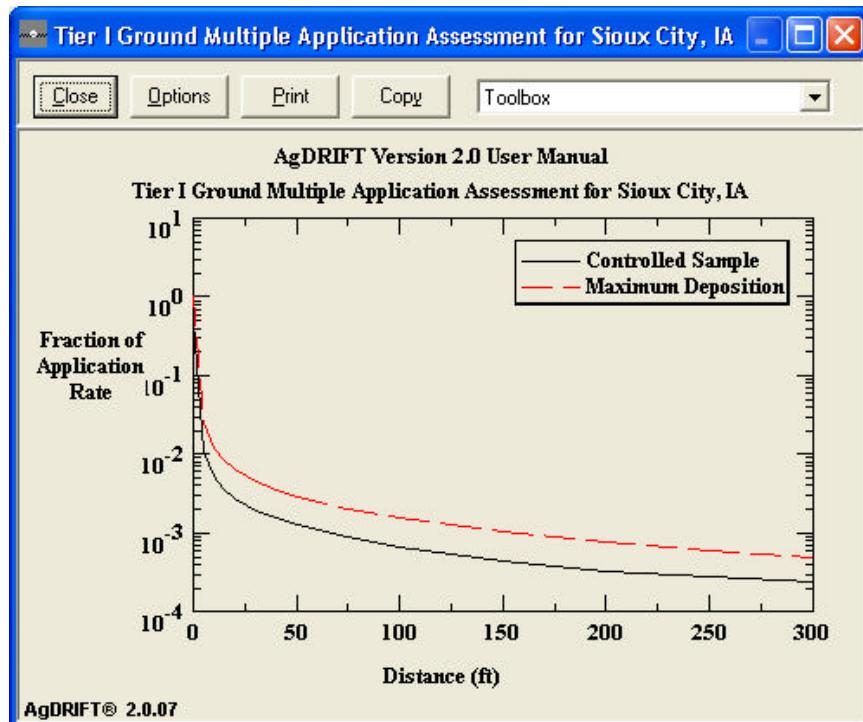


Figure 24. Multiple Application Assessment for the Low Boom ASAE S-572 Very Fine to Fine drop size distribution in Tier I for Sioux City, IA. The curves are the average multiple application deposition pattern (including zero deposition effects when the wind is blowing upwind of the spray block) and the maximum deposition pattern recovered across the selected wind speed range. Ten events per year assumed.

## B. Tier I Orchard Airblast

Tier I orchard airblast may be accessed from **Tier** on the menu bar. Its screen entries (Figure 25) include specifying the **Combination Orchard** (normal, dense, or sparse). An **Information** section provides combination details. **Extended Settings** permits the user to access the Starting Tree Row and Ending Tree Row, and the Individual Orchards [Grapes (Wrap-Around), Grapes, Apples, Almonds, Oranges, Grapefruit, Grapefruit (Mist Blower), Small Grapefruit, Small Grapefruit (Mist Blower), Pecans, and Dormant Apples] with the SDTF Confidential Library. The orchard airblast model is based solely on field data.

## C. Tier III Program Extensions

Tier III model inputs (Figure 26) include the following variables (AgDRIFT® limits for these variables are given in Table 4; inputs outside these limits will generate an Error Message when Calculations begin; if variables are inside these limits but outside a second set of more conservative limits, inputs will generate a Warning Message consistent with these limits):

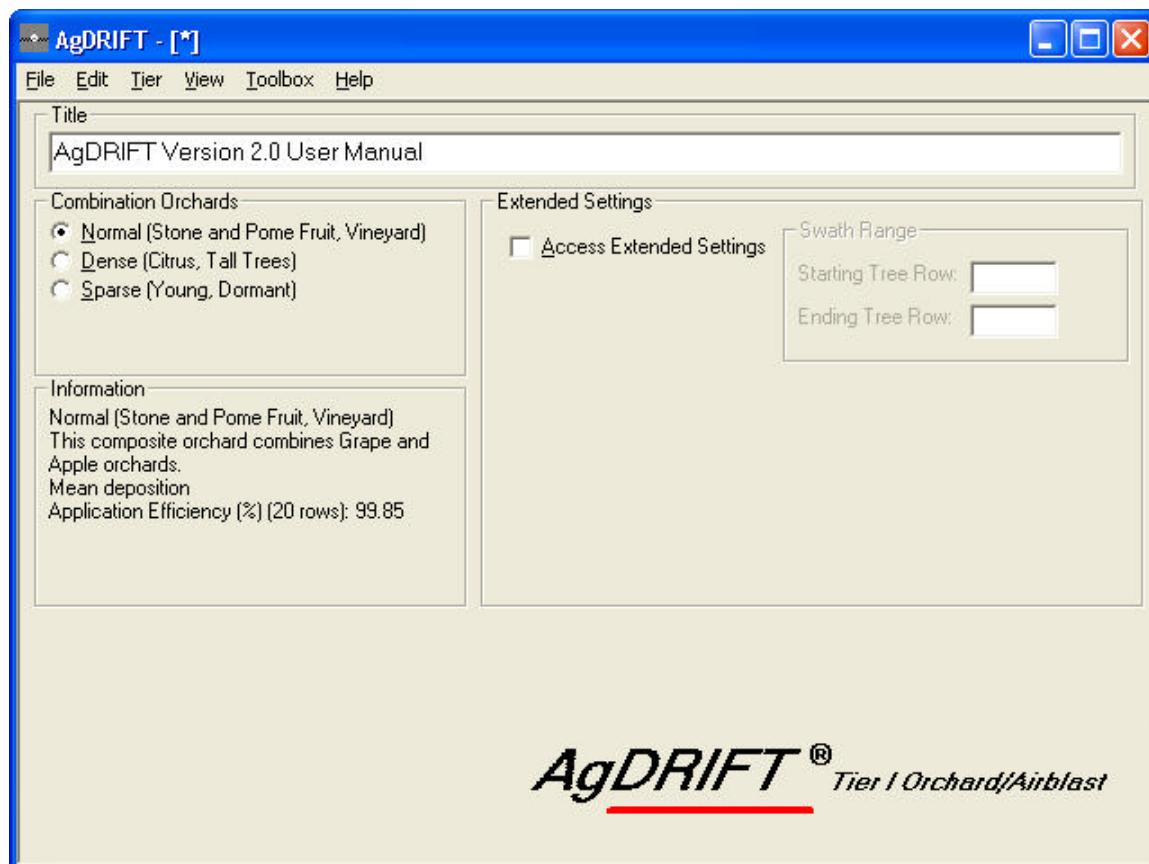


Figure 25. The Tier I orchard airblast input screen presenting Title, Combination Orchards, Extended Settings, and Information.

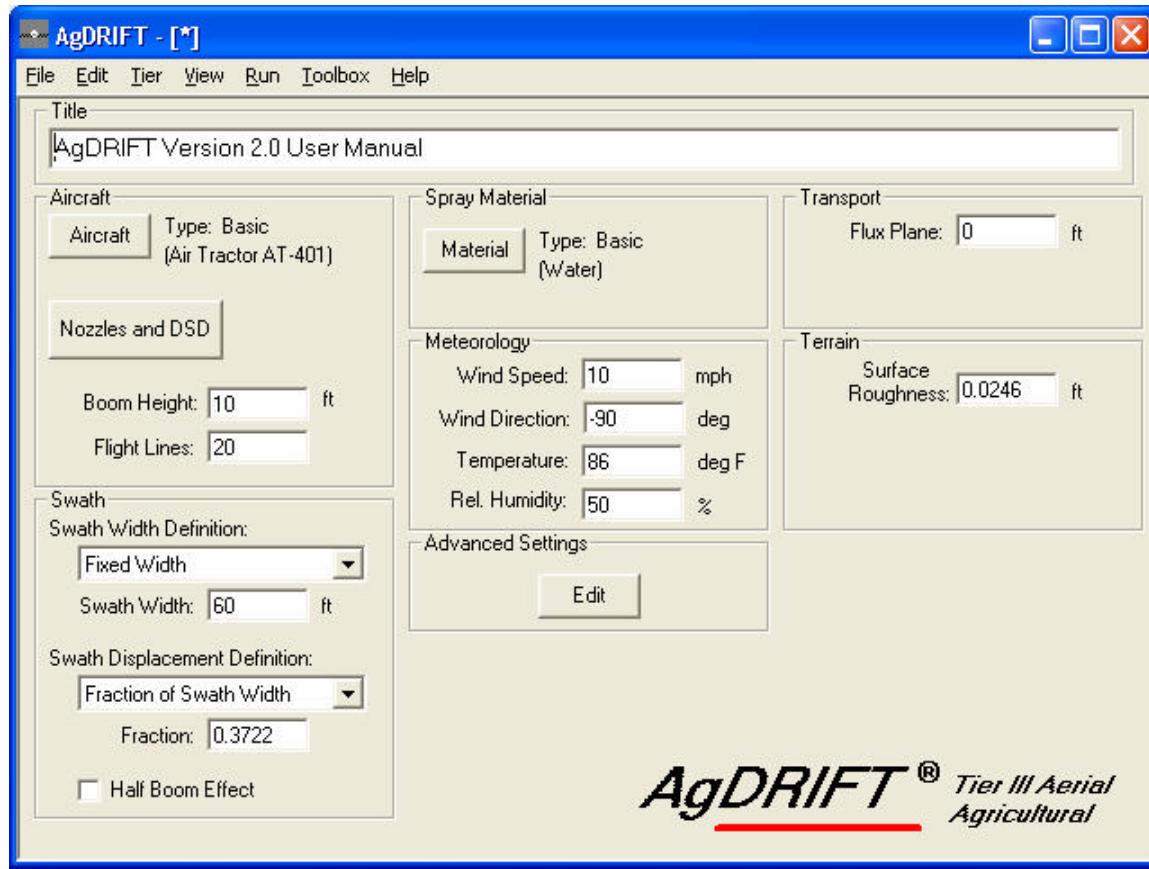


Figure 26. The Tier III Input screen with the inputs of Aircraft (Name, Nozzles and DSD, Boom Height, and Number of Flight Lines), Swath (Swath Width, Swath Displacement, and Half Boom Effect), Spray Material, Meteorology (Wind Speed, Wind Direction, Temperature, and Relative Humidity), Advanced Settings, Transport (Flux Plane Location), and Terrain (Surface Roughness).

**Boom Height:** The height of the spray boom above the ground.

**Flux Plane:** The horizontal distance downwind of the edge of the application area at which to compute the vertical transport.

**Half Boom Effect:** Normally the most downwind flight line is positioned upwind of the edge of the application area by the swath displacement, with nozzles operating on both the left and right sides of the boom. If Half Boom Effect is checked, the aircraft will be moved  $\frac{1}{2}$  swath width downwind and only the upwind nozzles will operate on the first flight line.

**Number of Flight Lines:** The number of flight lines located a swath width apart assumed in the prediction.

Table 4. Extended AgDRIFT® Tier III Model Limits

Variable Name	Lower Limit	Upper Limit
Active Rate (lb/ac)	0.001	Nonvolatile Rate
Boom Height (ft)	1.0	300.0
Boom Length (%)	0.0	125.0
Surface Roughness (ft)	0.003	3.28
Flux Plane (ft)	0.0	2600.0
Nonvolatile Rate (lb/ac)	Active Rate	Spray Rate
Number of Flight Lines	1	50
Number of Nozzles	1	60
Relative Humidity (%)	1.0	100.0
Spray Volume Rate (gal/ac)	0.05	100.0
Swath Displacement (ft)	-½ Swath	10 Swaths
Swath Width (ft)	10.0	500.0
Temperature (°F)	32.0	125.0
Wind Speed (mph)	0.5	40.0
Wind Direction (deg)	-30.0	-150.0
Flying Speed (mph)	10.0	350.0 *
Nozzle Orientation (°) **	0.0	150.0
Pressure (psig) **	2.9	360.0

\* 250 mph in DropKick®; \*\* In DropKick®

Relative Humidity: The ambient relative humidity.

Surface Roughness: The effective roughness height of the ground cover. Typical values are summarized in Table 5.

Swath Displacement: The horizontal distance along the ground from the farthest downwind flight line to the edge of the application area. All calculations assume a  $\frac{1}{2}$ -swath width displacement by default. Predictions initiated from default conditions carry over the assumed additional swath width fractions needed to recover 0.5 of the applied rate at the edge of the application area. The user may modify the swath displacement by overwriting the fraction of swath width, specifying the fraction of maximum deposition at which to set the swath displacement, entering a fixed distance downwind, or eliminating any swath displacement whatsoever by specifying that the farthest downwind flight line (aircraft centerline) coincides with the edge of the application area (swath displacement will be computed as a negative  $\frac{1}{2}$ -swath width in this case).

When Swath Displacement is specified as Fraction of Application Rate, AgDRIFT<sup>®</sup> does not know before running calculations where the edge of the application area is. Therefore, in this case two plots are not available (Vertical Profile and 1 Hour Average Concentration), and the model assumes zero added swath displacement for several other calculations (including Spray Block Deposition and Area Coverage; Downwind, Vertical Profile, and Spray Block Drop Size Distributions; Application Layout; Stream Assessment Toolbox; and Spray Block Details Toolbox). These features will be discussed as they are presented.

Swath Width: The effective lane separation (or track spacing) between adjacent flight lines.

Temperature: The ambient temperature.

Wind Direction: The direction the wind is blowing from. In the default condition the wind is blowing from left to right across the spray block, a wind direction of -90° (Figure 27).

Wind Speed: The crosswind speed 6 feet off the ground.

Model-specific inputs are changed in **Advanced Settings** (Figure 28), including the current default values for height for wind speed measurements, maximum computational time, maximum downwind distance, vortex decay rate, aircraft drag coefficient, propeller efficiency, ambient pressure, and ground reference height. Knowledge of these parameters is essential before changing them.

Table 5. Typical Roughness Lengths Gathered from the Literature

Roughness (m)	Surface
0.0001	Smooth ice
0.0001 to 0.001	Water, depending on wind speed
0.0001 to 0.02	Snow, depending on underlying surface
0.0003	Desert sand, depending on grain size and presence of dunes or ripples
0.001 to 0.01	Bare soil; higher values if plowed
0.003 to 0.01	Grass 0.02 to 0.1 m high
0.04 to 0.1	Grass 0.25 to 1 m high
0.04 to 0.2	Crops, depending on wind speed
0.02 to 0.1	Rural farmland with isolated trees and buildings
0.5 to 1.0	Orchards, seasonal variations
1.0 to 6.0	Forests, seasonal variations
0.4 to 2.0	Suburban; low buildings and trees
1.0 to 10.0	Center city; buildings 10 to 50 m high

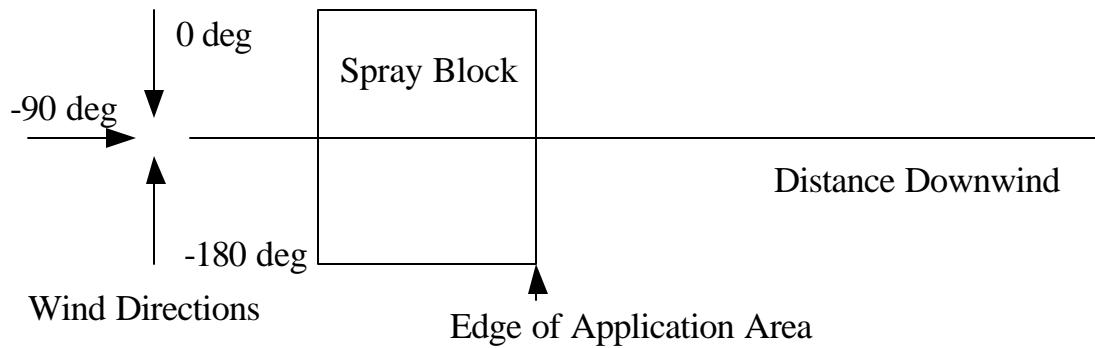


Figure 27. Wind directions (as viewed from above) relative to the spray block and distance downwind.

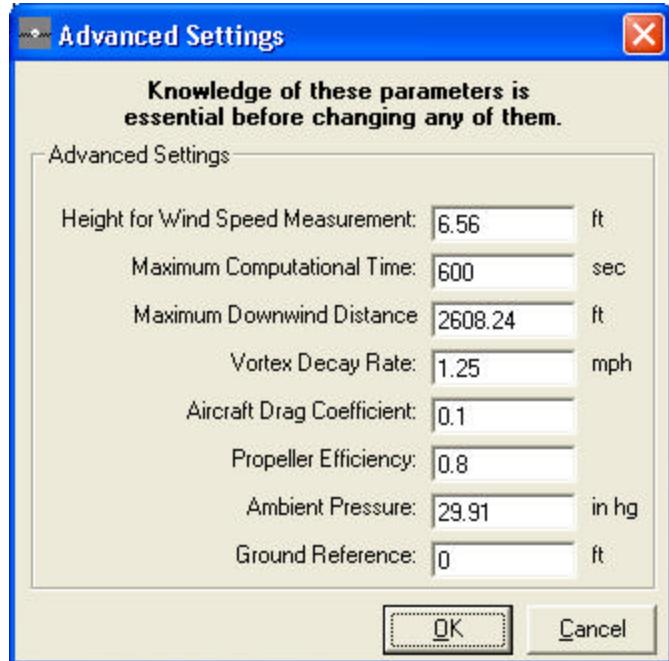


Figure 28. The Advanced Settings screen from Tier III, presenting the model-specific default input (Height for Wind Speed Measurement, Maximum Computational Time, Maximum Downwind Distance, Vortex Decay Rate, Aircraft Drag Coefficient, Propeller Efficiency, Ambient Pressure, and Ground Reference Height).

The **Aircraft** button from the Tier III screen leads to a screen (Figure 29) describing the Aircraft Type and Properties describing the aircraft: Semispan or Rotor Radius, Weight, Typical Flying Speed, Propeller or Rotor RPM, Propeller Radius, Biplane Separation, Planform Area, Number of Engines, Engine Vertical, Engine Forward, Engine Horizontal, Wing Vertical, Boom Vertical, and Boom Forward. A wing and boom schematic is shown in Figure 30. Pressing **OK** moves the selected entry into the current data. Pressing **Cancel** exits the Aircraft screen without changing any data.

The user can access the aircraft portion of the user library. **Add Current** will add the current aircraft properties to the library (making sure the Aircraft Name is unique), and **Select From/Modify** opens to a screen (Figure 31) that displays each entry in the library (from the pull-down Name menu) and permits the displayed entry to be deleted with **Delete Entry**.

The **Library (SDTF)** (Figure 32) contains descriptions for aircraft typically used in agricultural spraying. Menus within the Filter section are available to select the aircraft by name or type. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1st**, **Prev**, **Next** and **Last**. Pressing **OK** moves the selected entry from the library into the edit window of the aircraft screen. Pressing **Cancel** exits the library without changing any data.

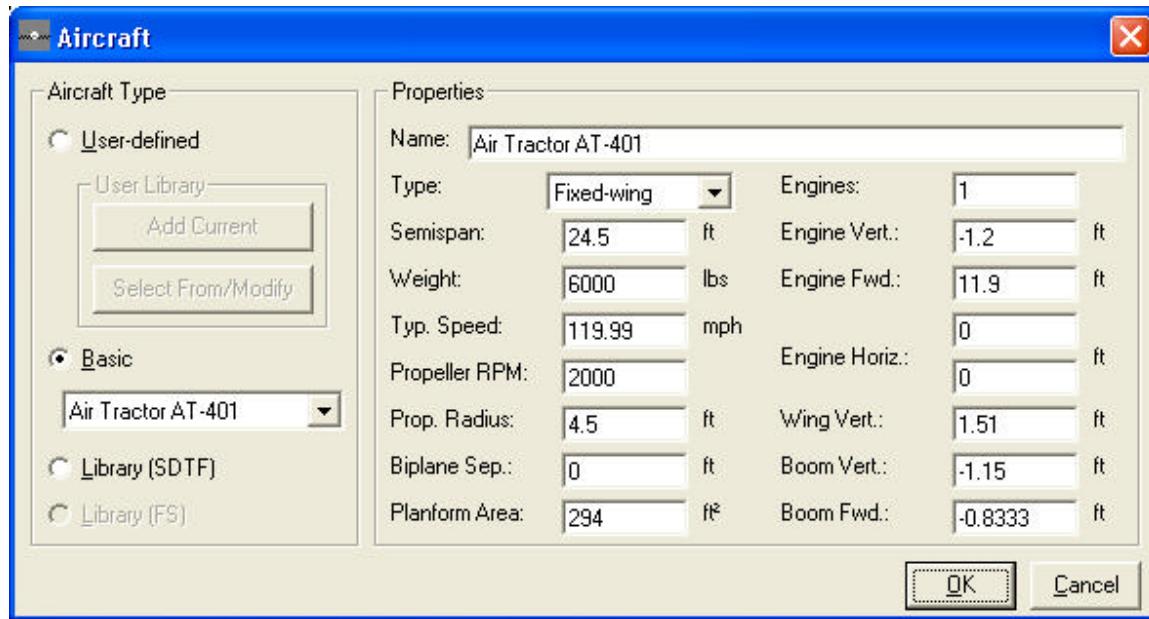


Figure 29. The Aircraft screen from Tier III, presenting the Aircraft Type and its Properties.

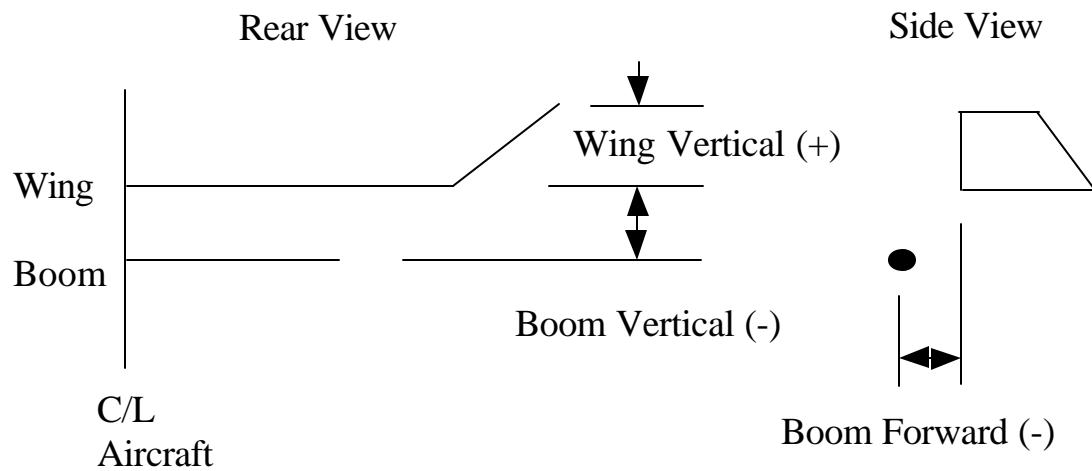


Figure 30. Schematic of aircraft wing and boom details.

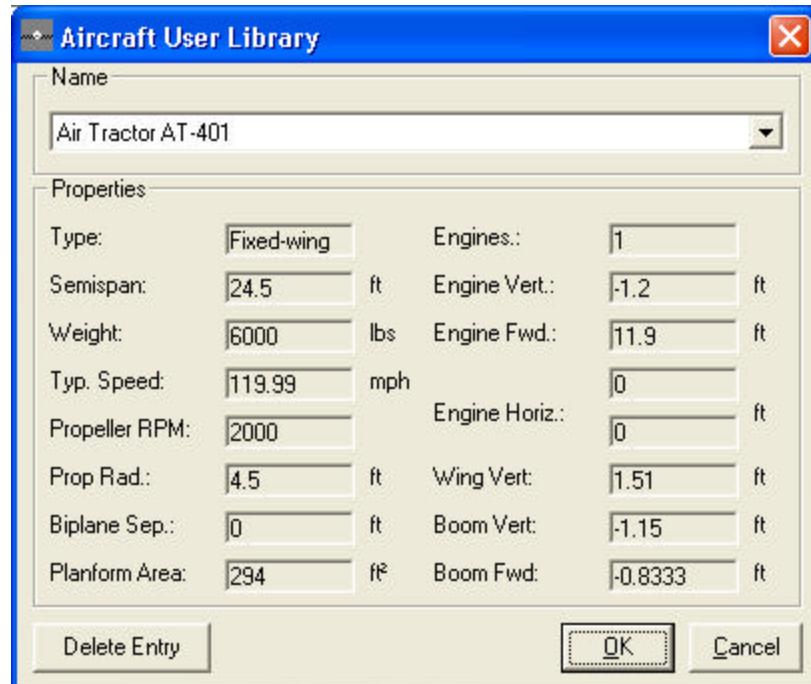


Figure 31. The Aircraft User Library, with Name and Properties.

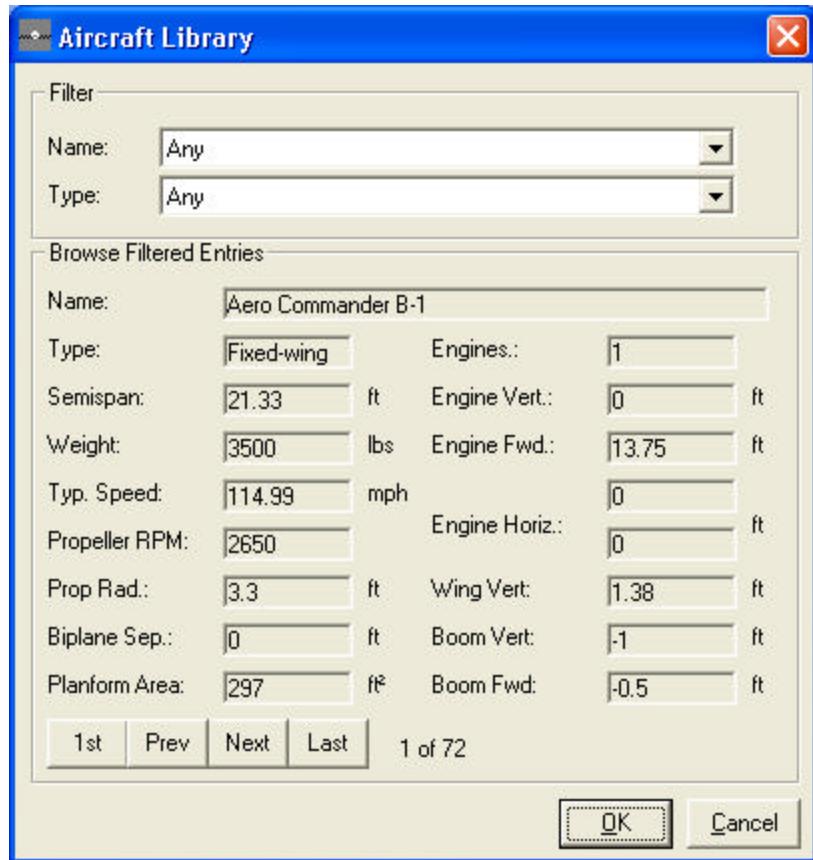


Figure 32. The Aircraft Library screen from Aircraft Type, presenting Filters for Aircraft Name and Type; and the Browse Filtered Entries for each selection.

If the user changes the aircraft type or any aircraft parameter, and exits the Aircraft screen, an information screen will appear, indicating that AgDRIFT® will automatically replace the current nozzle locations with a nozzle distribution consistent with a Boom Length of 65% and a nozzle spacing of 1 ft (for User-defined or Library aircraft), or the nozzle distribution consistent with the Basic aircraft selection. The user may decline the nozzle adjustment for User-defined or Library aircraft only.

The **Nozzles and DSD** button from the Tier III screen opens to a screen (Figure 33) which allows the user to generate any nozzle distribution desired on the spray boom, containing the additional inputs:

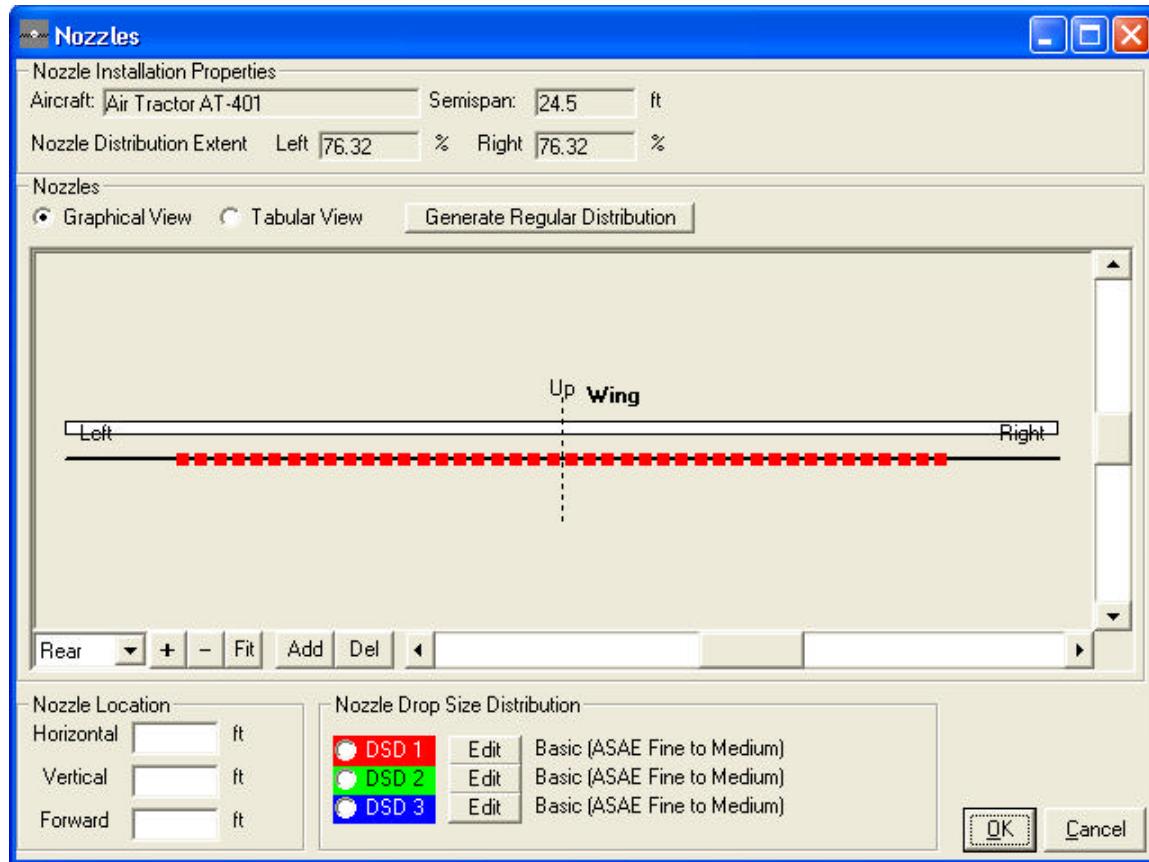


Figure 33. The Nozzle Configuration screen from Tier III, presenting the Nozzle Installation Properties, Nozzles, Nozzle Location, and Nozzle Drop Size Distribution.

**Drop Size Distribution:** The amount of volume fraction in each drop size category may be selected by clicking on one of the **DSD Edit** buttons.

Nozzles may be edited graphically or tabularly by **Adding** them to the screen or table (which will place a nozzle at the center of the aircraft) and moving them where wanted, or highlighting specific nozzles and **Deleting** them. In the Graphical View the user may switch between the **Rear** and **Top** views, come in closer (+) or move back (-), or fill the screen (**Fit**). In the Tabular View the user may **Sort** the nozzles or **Import** nozzle locations from an ASCII file. All dimensions in an import file must be in meters. Any comment line in the import file must begin with “#” in column one to separate it from the data. Nozzles may also be moved by entering their Horizontal, Vertical, and Forward Parameters. The user can modify the Boom Length of a Basic aircraft or Generate a Regular Nozzle Distribution by entering any two of the three values for “Number of Nozzles”, “Boom Length”, and nozzle spacing. Up to three drop size distributions (color-coded) may be placed on the spray boom. Boom position is generally rearward and below the trailing edge of a fixed-wing aircraft, and on the skids below the rotor blade hub of a helicopter; boom position is changed in the Aircraft screen. Pressing **OK** moves

the selected entry into the current data. Pressing **Cancel** exits the Nozzles screen without changing any data.

The drop size distribution **DSD Edit** buttons each opens to a screen (Figure 34) showing a table containing the current drop size distribution, and displaying five options:

**User-Defined:** Automatically invoked whenever the user changes any of the table values. Clicking on a table entry places an invisible cursor at the right of the number (the user then manipulates this value). **Insert** places a blank row above the current row, **Delete** removes the highlighted row, and **Clear** blanks the highlighted entries.

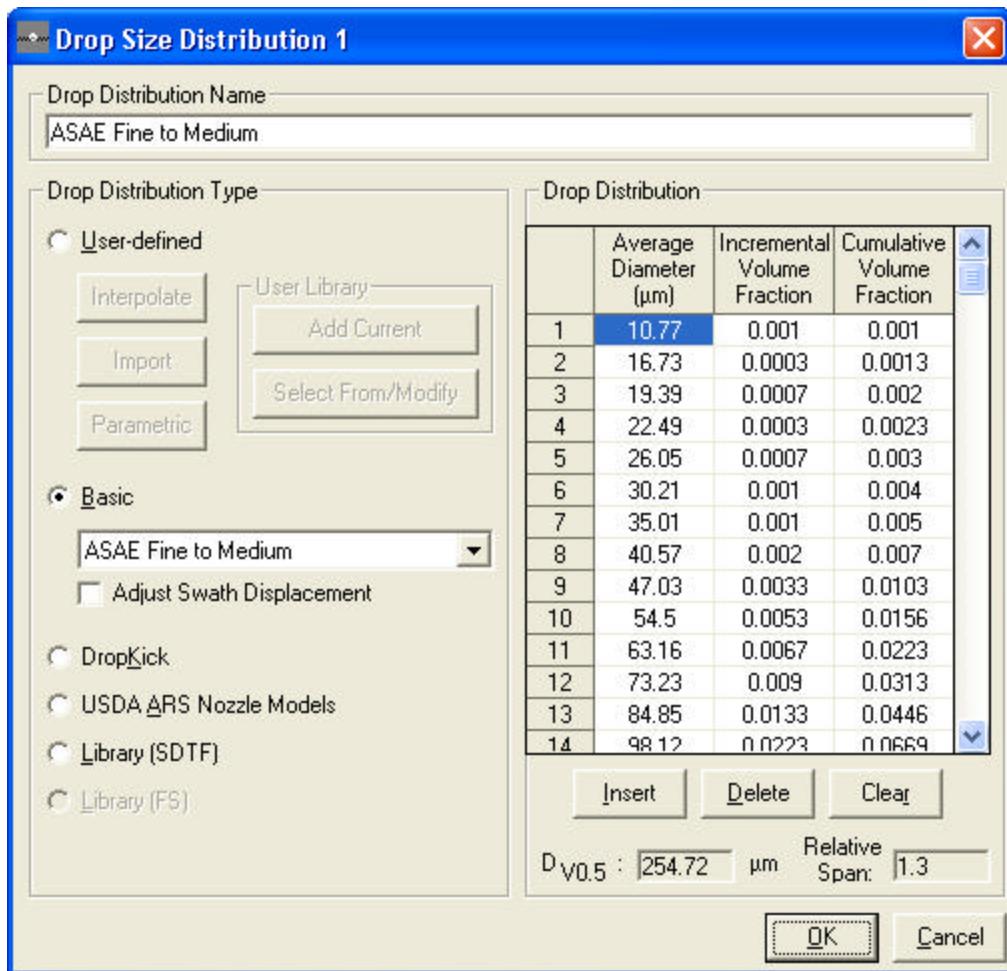


Figure 34. The Drop Size Distribution screen, with the Drop Distribution Type selected on the left side (User-defined, Basic, DropKick®, USDA ARS Nozzle Models, or Libraries) and the Drop Distribution itself presented on the right side (Average Diameter, Incremental Volume Fraction, and Cumulative Volume Fraction).

This option includes **Interpolate**, **Import**, and **Parametric**. The Interpolate button invokes a menu screen for selecting the interpolation method to be applied to the current drop size distribution, either Root Normal (Simmons 1977), Rosin-Rammler (Rosin and Rammler 1933) or Log Normal (Mugele and Evans 1951). These techniques are described in Appendix D. The Import button invokes the File Browser to enter a drop size distribution stored in an ASCII file. The Parametric button invokes a menu screen for entering the volume median diameter  $D_{v0.5}$  (in  $\mu\text{m}$ ) and Relative Span ( $D_{v0.9} - D_{v0.1}$ )/ $D_{v0.5}$ ; the Root Normal approach is then used to generate the drop size distribution.

Because table entry in AgDRIFT® is laborious, it is anticipated that ASCII file entry will be used whenever possible, and **Import** will be an important option. All drop size categories in AgDRIFT® are specified by their volume-Average Diameter (found by Herdan 1960); however, the user may enter drop size distributions by Upper Diameters as well. Typically, the ASCII data are in two columns (diameters and volume fractions). Any comment line in the import file must begin with ‘#’ in column one to separate it from the data. If the first data line of the file contains a diameter with a volume fraction of zero, AgDRIFT® will assume that this diameter is the lower diameter of the first size class, and that all subsequent diameters are upper diameters; AgDRIFT® will compute the Average Diameters from these data. In addition, by testing the maximum and sum of the volume fractions in the ASCII file, AgDRIFT® will determine whether the entries are in Incremental or Cumulative volume fractions, and whether the volume entries are fractions or percentages.

The user may also access the drop size distribution portion of the user library. **Add Current** will add the current drop size distribution to the library (making sure the Drop Distribution Name is unique), and **Select From/Modify** will open to a screen (Figure 35) that displays each entry in the library (from the pull-down Name menu) and permits the displayed entry to be deleted with **Delete Entry**.

The Parametric screen (Figure 36) permits the user to condition the output from the drop size distribution generation (this feature is available on the Drop Size Distribution screen as well, and on the DropKick® and USDA ARS Nozzle Models screens). The computed drop size distribution may be replaced by the most representative drop size classification, either one of the ASAE S-572 drop size distributions or one interpolated between each available drop size distribution. Alternately, the drop size distribution may be partitioned into categories consistent with those recovered from the SDTF wind tunnel studies (Standard). Finally, the actual drop size distribution may be partitioned into categories that just capture the total spray volume (Optimized). The user may also request that the swath displacement consistent with the Drop Size Classification selection be carried back to the main input screen by checking the Adjust Swath Displacement box.

**Basic:** A menu displays the available drop size distributions, including an Aerosol to Very Fine distribution (A. J. Hewitt, 2000, personal communication), interpolated distributions between all ASAE S-572 distributions, and the precursor BCPC distributions.

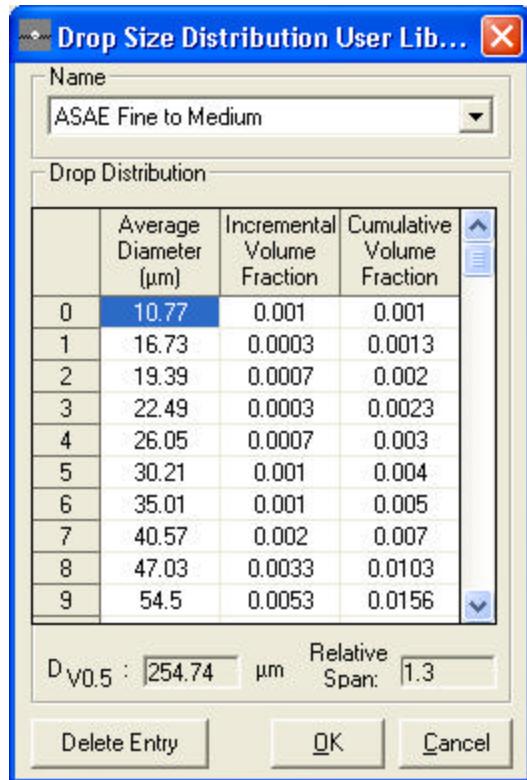


Figure 35. The Drop Size Distribution User Library, with Name and Drop Distribution.

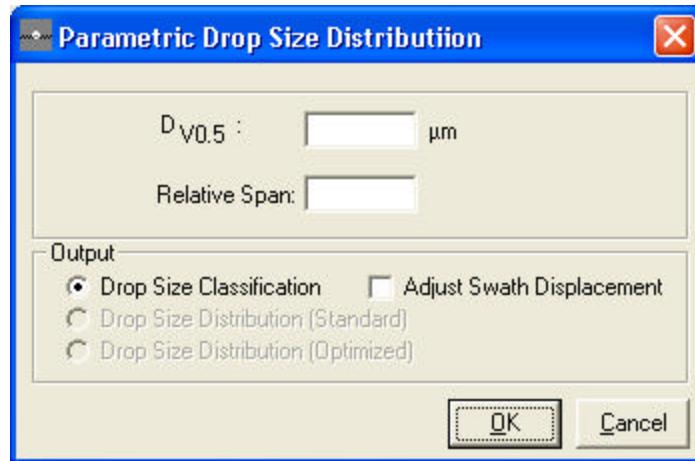


Figure 36. The Parametric Drop Size Distribution screen, permitting input of D<sub>v0.5</sub> and Relative Span, and calculation of the selected drop size distribution Output.

**DropKick<sup>®</sup>**: An additional input screen for the inputs needed to run the DropKick<sup>®</sup> model and construct a drop size distribution from them. Invoking DropKick<sup>®</sup> brings the user to another input screen (Figure 37), showing four sections – Nozzle, Spray Material, Spray Data, and Output. Invoking **OK** will, after reviewing the input data on this screen for consistency, generate the drop size distribution consistent with the entered data.

**Nozzle** permits entry of the parameters that describe nozzle type:

D<sub>v0.5</sub>: The volume median diameter (in  $\mu\text{m}$ ) for water through the nozzle in its default configuration.

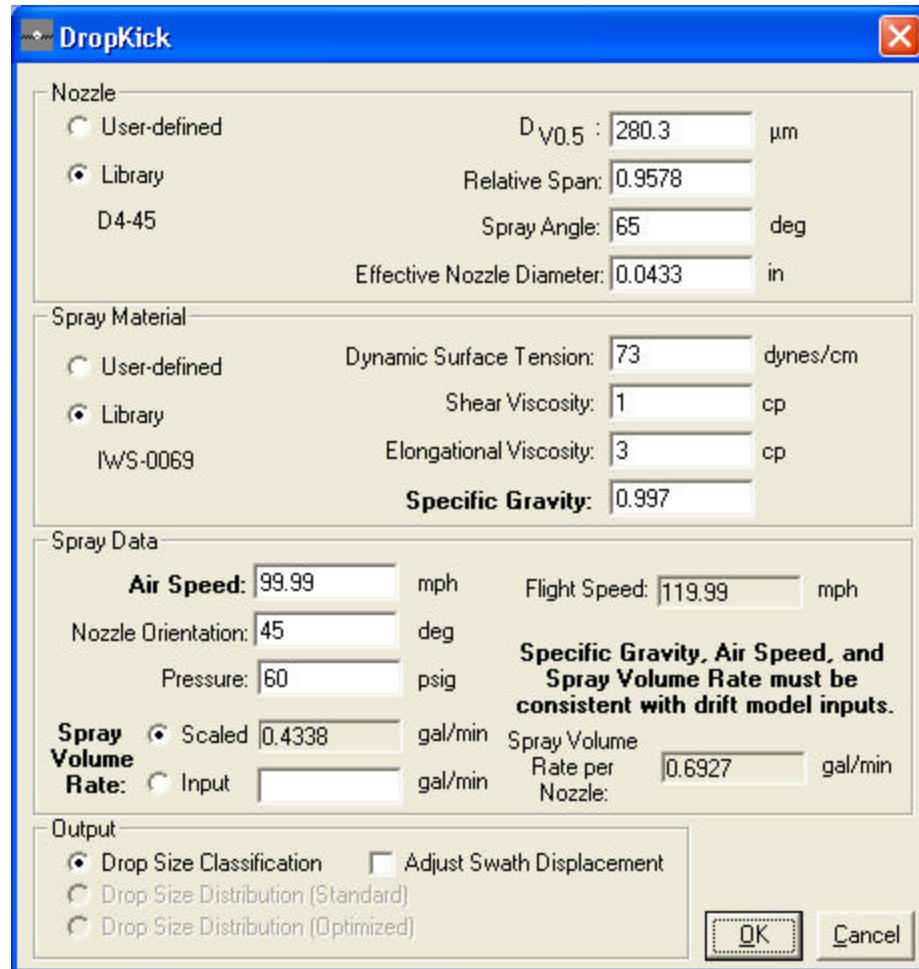


Figure 37. The DropKick<sup>®</sup> screen, presenting the entry areas of Nozzle (D<sub>v0.5</sub>, Relative Span, and Effective Nozzle Diameter), Spray Material (Dynamic Surface Tension, Shear Viscosity, Elongational Viscosity, and Specific Gravity), Spray Data (Air Speed, Nozzle Orientation, Pressure, and Spray Rate), and Output.

Relative Span: The relative span of the drop size distribution,  $(D_{v0.9} - D_{v0.1})/D_{v0.5}$ . DropKick® only works with the Root Normal interpolation method.

Effective Nozzle Diameter: The equivalent diameter of a nozzle, describing the effective flow area through the nozzle based on a circular flow area.

The **DropKick<sup>®</sup> Nozzle Library** screen (Figure 38) contains nozzles tested by the SDTF. These nozzles may be selected by the Filter, or marched through with the buttons of the Browse Filtered Entries, including **1st**, **Prev**, **Next** and **Last**. Pressing **OK** moves the selected data from the library into the DropKick® Nozzle edit window. Pressing **Cancel** exits the DropKick® Nozzle Library without changing any DropKick® input data.

**Spray Material** permits entry of the parameters that describe the material:

Dynamic Surface Tension: The force (in dynes/cm) between the air and the liquid arising from tension along their interface.

Shear Viscosity: The resistance (in cp) of a fluid to change in its shape by shear.

Elongational (or Extensional) Viscosity: The resistance of a fluid to stretching (in cp).

Specific Gravity: The ratio of the density of the spray material to the density of water.

The **DropKick<sup>®</sup> Spray Material Library** (Figure 39) contains substances tested by the SDTF. These substances may be selected by the Filter, by selecting a Component or Substance, or by marching through the database with the buttons of the Browse Filtered Entries, including **1st**, **Prev**, **Next** and **Last**. Pressing **OK** moves the selected data from the library into the DropKick® Spray Material edit window. Pressing **Cancel** exits the DropKick® Spray Material Library without changing any DropKick® input data.

**Spray Data** permits entry of the remaining inputs for DropKick®:

Air Speed: The desired speed of the wind tunnel.

Nozzle Orientation: The angle (in °) of the nozzle relative to the airstream (flight speed), where 0° is straight back (co-flowing with the airstream) and 90° is pointed straight down.

Pressure: The pressure at the nozzle tip for the single nozzle tunnel test.

Spray Volume Rate per Nozzle: With the data supplied, a Scaled value (in gal/min or L/min) can be computed. Alternatively, the user may Input any desired value.

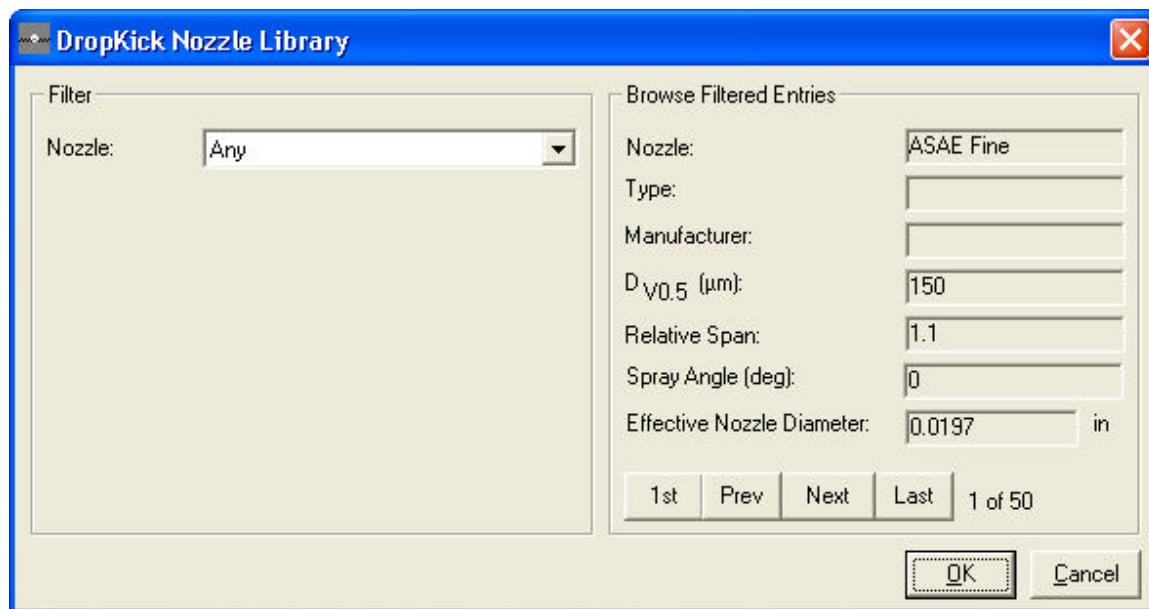


Figure 38. The DropKick® Nozzle Library screen, presenting a Filter for Nozzle and the Browse Filtered Entries for Nozzle, Type, Manufacturer,  $D_{v0.5}$ , Relative Span, Spray Angle, and Effective Nozzle Diameter.

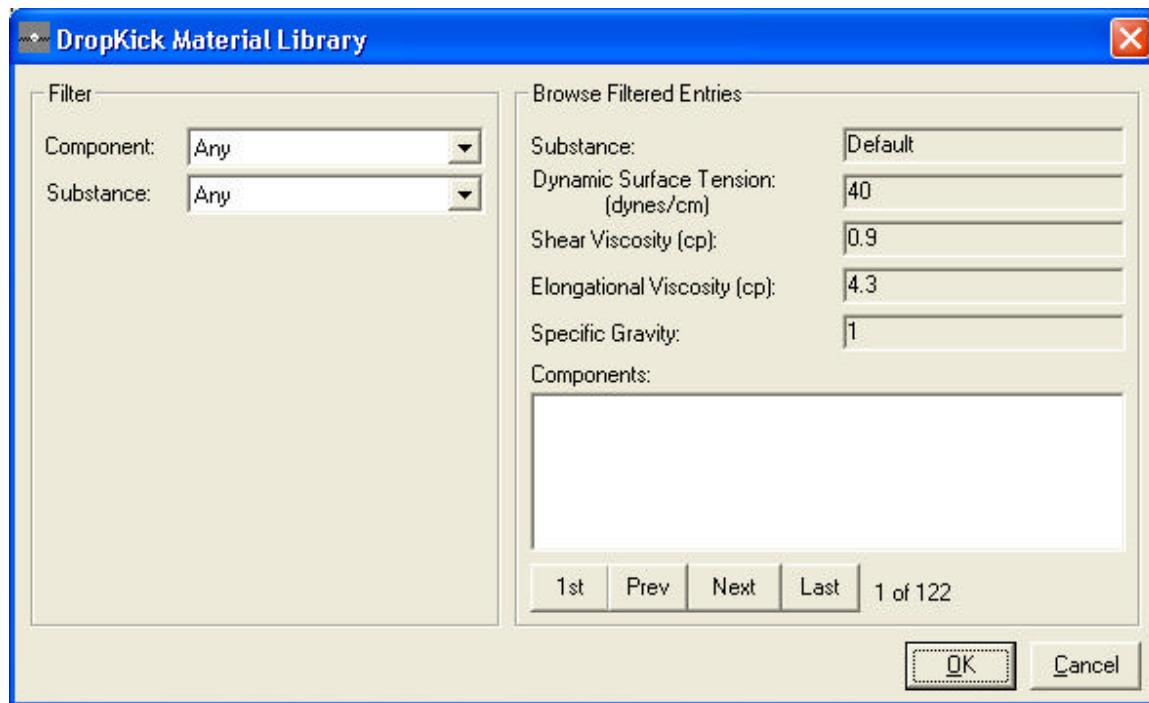


Figure 39. The DropKick® Spray Material Library screen, presenting Filters for Component and Substance, and the Browse Filtered Entries for Substance, Dynamic Surface Tension, Shear Viscosity, Elongational Viscosity, Specific Gravity, and Components.

The Flight Speed of the aircraft and the Spray Volume Rate per Nozzle are shown for information purposes from the main input screen. AgDRIFT® will provide a warning if the Specific Gravity, Flight Speed, or Spray Volume Rate per Nozzle in DropKick® exceeds  $\pm 10\%$  of the current modeled values.

Pressing **OK** enables DropKick® to compute its curve-fitting parameters, then reconstruct the drop size distribution with the Root Normal interpolation method. These results are moved into the edit window of the drop size distribution screen. Pressing **Cancel** exits the DropKick® screen without changing any current data.

**USDA ARS Nozzle Models:** An additional input screen for the inputs needed to run the available USDA ARS Nozzle Models and construct a drop size distribution from them. Invoking this option brings the user to another input screen (Figure 40), showing four sections – Nozzle, Spray Material, Spray Data, and Output. Invoking **OK** will, after reviewing the input data on this screen for consistency, generate the drop size distribution consistent with the entered data.

**Nozzle** permits entry of the Name of the nozzle and its Orifice Size or Number. There are fourteen USDA ARS nozzle models currently available.

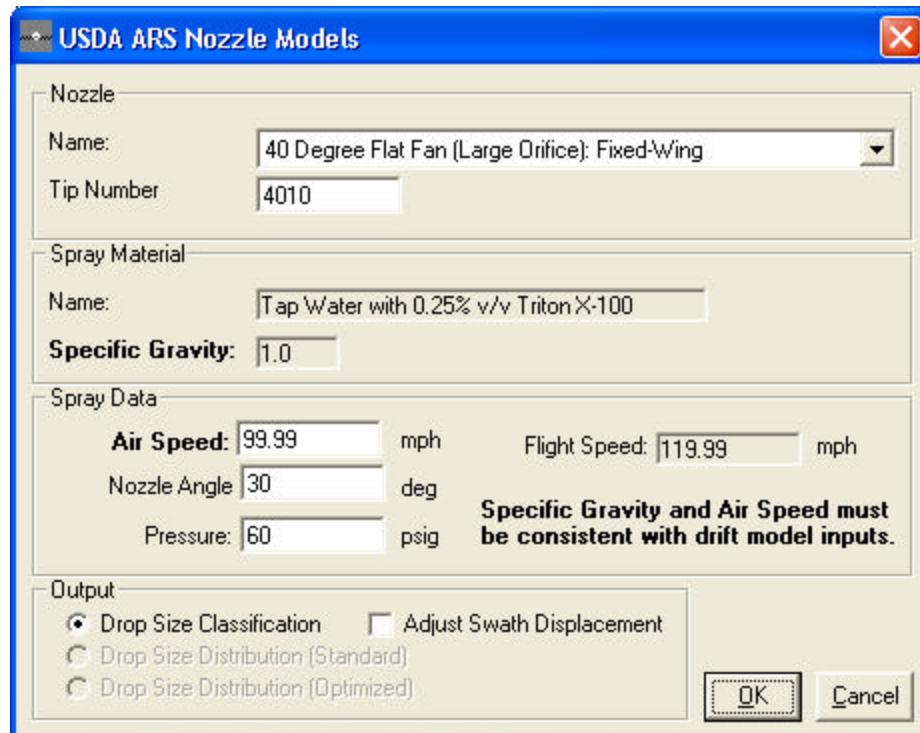


Figure 40. The USDA ARS Nozzle Models screen, presenting Nozzle (Name and Orifice Size or Number), Spray Material, Spray Data (Air Speed, Nozzle Deflector or Angle, and Pressure), and Output.

**Spray Material** is Tap Water with 0.25% v/v Triton X-100.

**Spray Data** permits entry of the remaining inputs to the nozzle model: Air Speed, Nozzle Deflector or Angle, and Pressure. The Nozzle Name selection configures the Deflector or Angle options available here. Nozzle Angle is similar to Nozzle Orientation in DropKick® entry.

The Flight Speed of the aircraft is shown for information purposes from the Tier III Input screen. AgDRIFT® will provide a warning if the Specific Gravity or Flight Speed in USDA ARS Nozzle Models exceeds ±10% of the current modeled values.

Pressing **OK** enables USDA ARS Nozzle Models to compute its curve-fitting parameters, with data based on PMS measurements, then reconstruct the drop size distribution with the Root Normal interpolation method. These results are moved into the edit window of the drop size distribution screen. Pressing **Cancel** exits the nozzle model screen without changing any current data.

**Library (SDTF):** The drop size distribution Library Browser accessing the datasets collected by the SDTF. The drop size library (Figure 41) contains drop size distributions generated from SDTF wind tunnel studies. Available data have been averaged over all replicates. These data are arranged in increasing Test Substance Number. However, the Filter may be used to narrow the field of interest. Menus within the Filter section are available to select by Component, Test Substance Number, Nozzle, Nozzle Orientation, Nozzle RPM (no entries), Nozzle Pressure and Air Speed. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1st**, **Prev**, **Next**, and **Last**. Pressing **OK** moves the selected entry from the library into the edit window of the drop size distribution screen. Pressing **Cancel** exits the drop size library without changing any current data.

Invoking the **Material** button from the Tier III screen leads to a screen (Figure 42) describing the Spray Material Type and Properties, containing the additional inputs:

Active Rate: The application rate at which the active material is sprayed.

Carrier Type: One of two carrier types may be selected: water or oil. If the selection is oil, evaporation of the spray material will be suppressed.

Evaporation Rate: The rate of evaporation of the volatile material following the diameter-squared evaporation law, corrected for low relative wind speeds (Teske et al. 1998a).

Nonvolatile Rate: The application rate at which the nonvolatile material is sprayed.

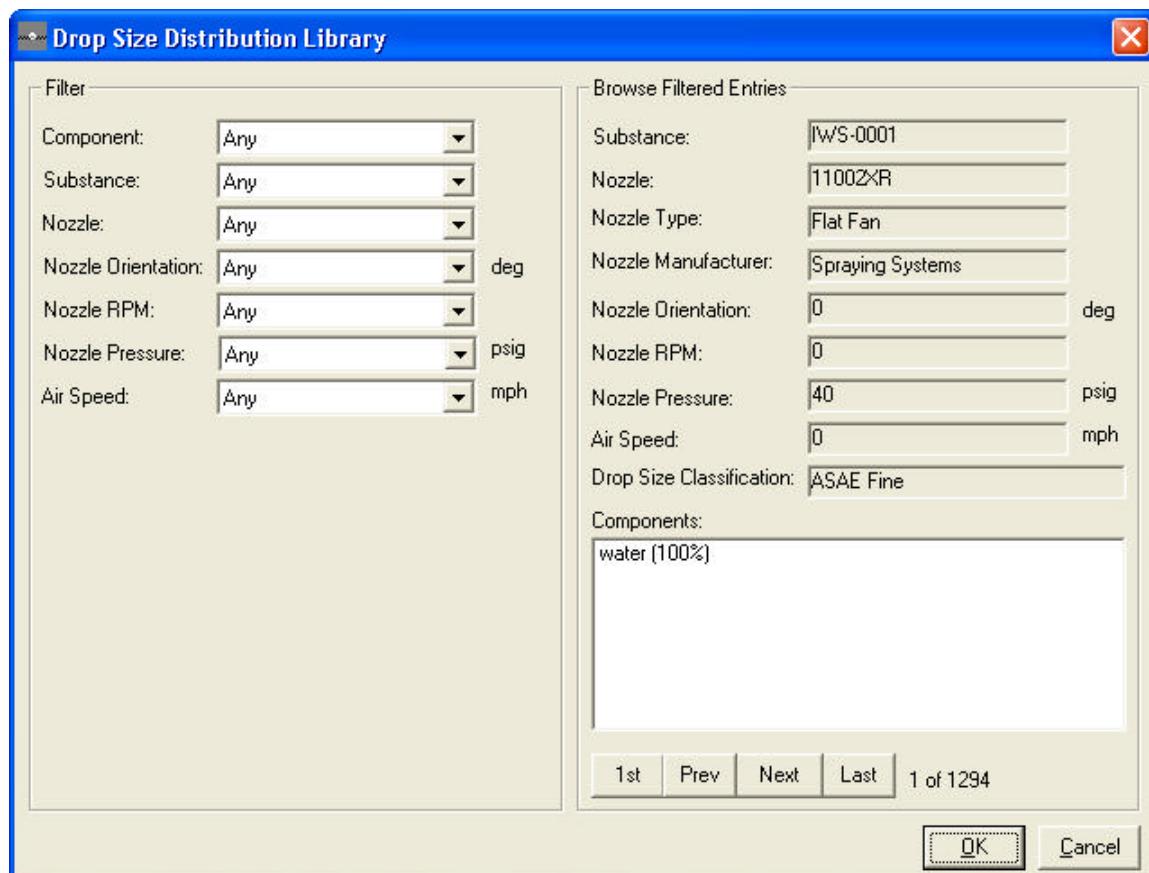


Figure 41. The Drop Size Distribution Library screen from Drop Size Distribution, presenting Filters for Component, Substance, Nozzle, Orientation, RPM, Pressure, and Air Speed; and the Browse Filtered Entries for Substance, Nozzle, Manufacturer, Orientation, RPM, Pressure, Air Speed, Droplet Spectra Classification, and Components.

**Spray Volume Rate:** The volumetric rate at which the tank mix is pumped through the spray booms and nozzles.

In addition the Specific Gravity may be specified separately for the carrier and the nonvolatile.

The **Spray Material Library** (Figure 43) contains test substances tested by the SDTF. Menus within the Filter section are available to select Component of most interest and Test Substance Number. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1st**, **Prev**, **Next** and **Last**. Pressing **OK** moves the selected entry from the library into the edit window of the Spray Material screen. Pressing **Cancel** exits the library without changing any data. Since the library contains nonvolatile fraction as an entry, the nonvolatile rate must be corrected according to the spray rate.

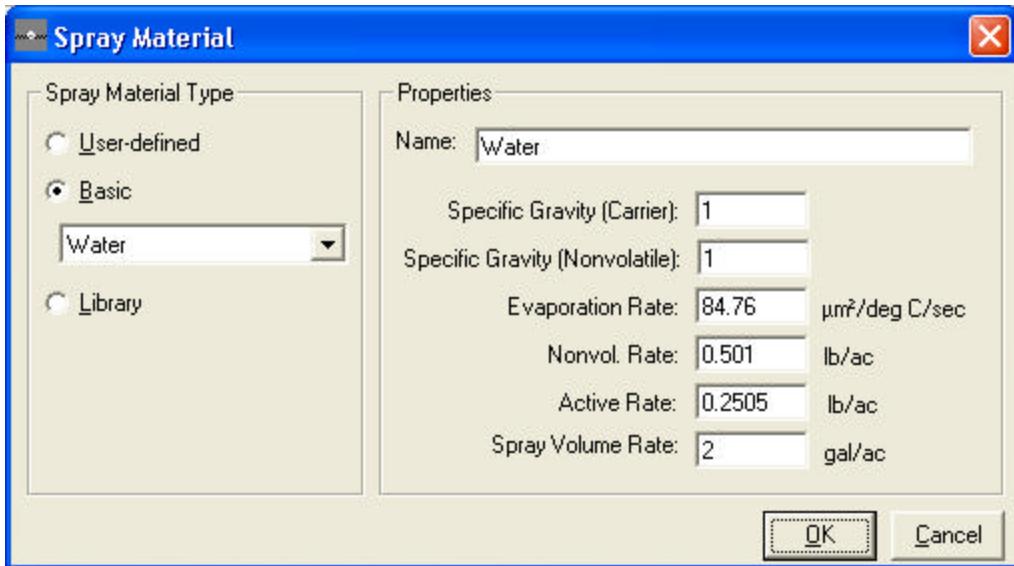


Figure 42. The Spray Material screen from Tier III, presenting the Spray Material Type and Properties (Specific Gravity, Evaporation Rate, Nonvolatile Rate, Active Rate, and Spray Volume Rate).

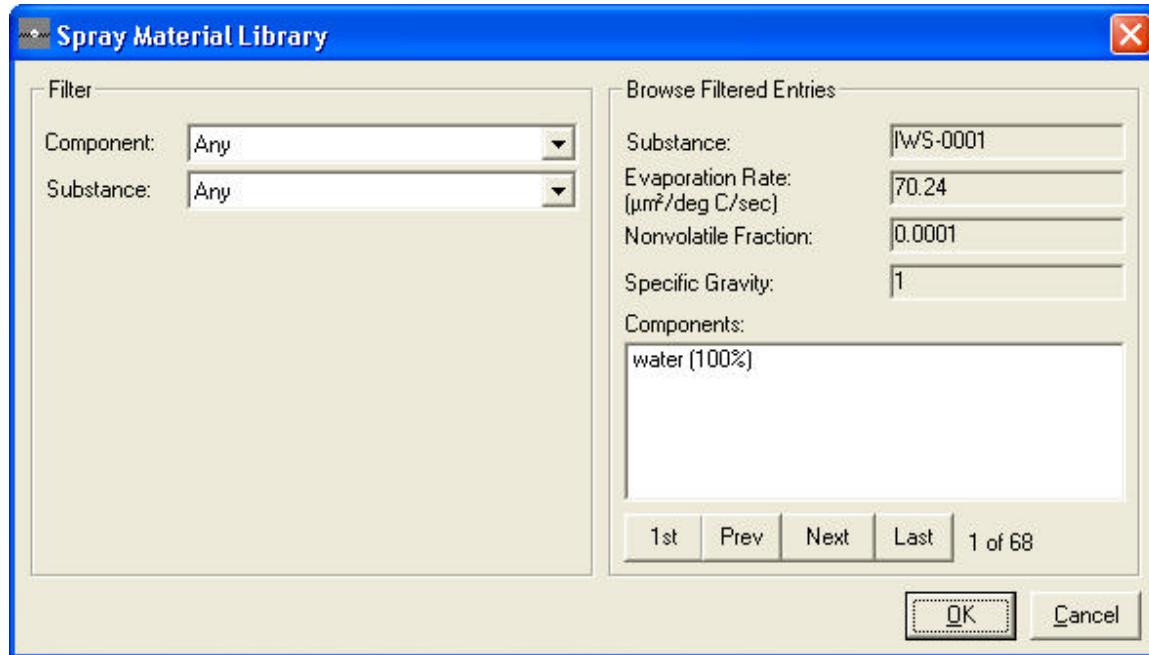


Figure 43. The Spray Material Library screen from Spray Material, presenting Filters for Component and Substance, and the Browse Filtered Entries for Substance, Evaporation Rate, Nonvolatile Fraction, Specific Gravity, and Components.

Additional Tier III menu bar options permit the following:

## File

The current Tier III data (and its calculations) may be saved into the existing data file (**Save**), or into a different (or new) data file (**Save As**). The default data file extension in AgDRIFT® is AGD; however, the user may override the default extension (not recommended) when in the File Browser.

**Load Field Trial Data** from the SDTF aerial field trials (Figure 44) contains all applicable aerial field trial data collected by the SDTF. Menus within the Filter section are available to select Field Trial Name, Test Type (Standard or Variable), Test Number (three tests were conducted: 008, 015 and 017), Aircraft involved (Ag Husky, Air Tractor AT-502 and Wasp Helicopter), Percent < 141  $\mu\text{m}$  in the released spray, Boom Height, and Wind Speed. The last three filters permit data parsing by constructing logical expressions limiting the data selected. The first databox includes Any, = (equal),  $\neq$  (not equal),  $<$  (less than),  $>$  (greater than),  $\leq$  (less than or equal), and  $\geq$  (greater than or equal). The value databox opens automatically after the first databox is selected. The third databox contains And or Or, the fourth databox, another symbol identifier, and the fifth databox, another value. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1st**, **Prev**, **Next** and **Last**. Pressing **OK** moves the selected entry from the Library into current data (or, for Plot Options, as additional data to plot). Pressing **Cancel** exits the screen without selecting any data.

The field trials will load only the drop size distribution and its deposition profile; other plots will require AgDRIFT® to recalculate. Some field trials exceed the model limits and may generate a calculation warning.

## View

The user can display **Numerical Values** from the computation, examine the **Calculation Log**, plot the **Drop Size Distribution** (by **Incremental** or **Cumulative** volume fraction, Figures 45 and 46, respectively), and the incremental and cumulative **Downwind Drop Size Distribution** (from spray material depositing between the edge of the application area and the flux plane), the incremental and cumulative **Vertical Profile Drop Size Distribution**, the **Vertical Profile** (Figure 47), the **1 Hour Average Concentration** (Figure 48) through a flux plane positioned downwind of the edge of the application area, the **Coefficient of Variation (COV)** within the spray block (Figure 49), **Mean Deposition** within the spray block (Figure 50), and **Fraction Aloft**, the fraction of released active spray material aloft as a function of distance downwind of the spray block (Figure 51).

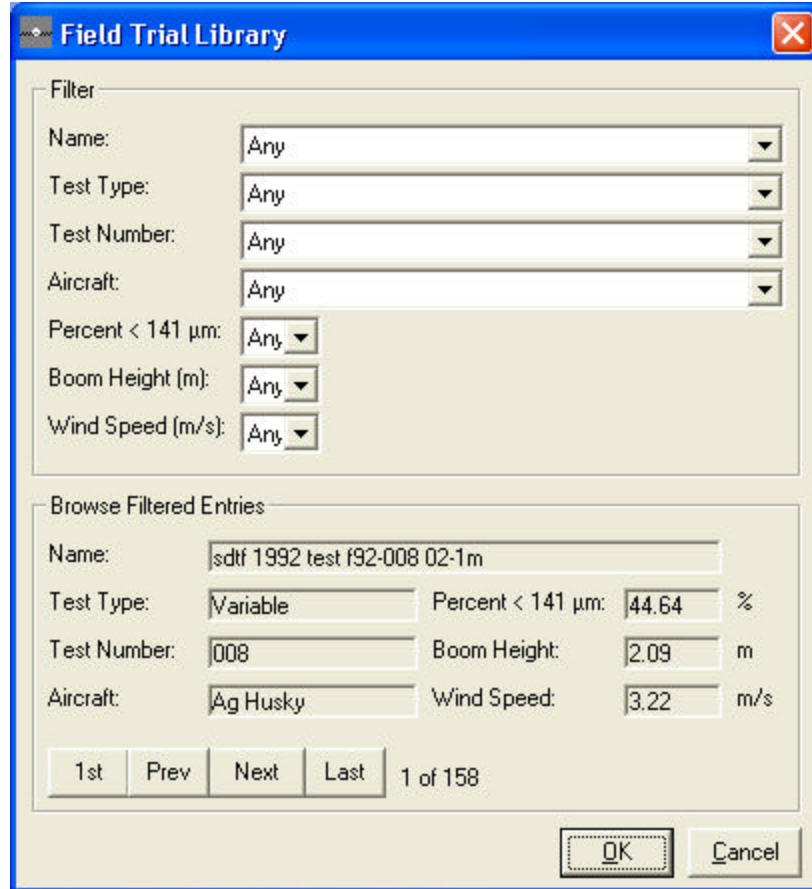


Figure 44. The Load Field Trial Data screen (under File and Plot Options in Tier III with the SDTF Library), presenting access to SDTF field trials, with Filters for Test Name, Type and Number, Aircraft, Percent < 141  $\mu\text{m}$ , Boom Height and Wind Speed, and the Browse Filtered Entries for each selection.

**Numerical Values:** This screen (Figure 52) presents the results from several sections of the calculation. The selected drop size distribution is examined to construct the  $D_{v0.1}$ ,  $D_{v0.5}$ , and the  $D_{v0.9}$  drop sizes in  $\mu\text{m}$ , the Relative Span ( $D_{v0.9} - D_{v0.1}$ )/ $D_{v0.5}$ , and the volume fraction of material < 141 mm, expressed as a percentage of the total spray volume. **Swath Displacement** is shown when a calculation is undertaken. Additional Numerical Values include **COV** and **Mean Deposition** within the spray block, **Application Efficiency** (how much of the active material lands on the spray block or target), **Downwind Deposition** (how much of the active material lands between the edge of the application area and the maximum downwind distance), **Airborne Drift** (how much of the active material remains aloft beyond the maximum downwind distance), and **Carrier Evaporated** (how much of the tank mix evaporates). A **Print** will print the Numerical Values screen on the printer. A **Save** will permit the user to save the data present on the screen to an ASCII file.

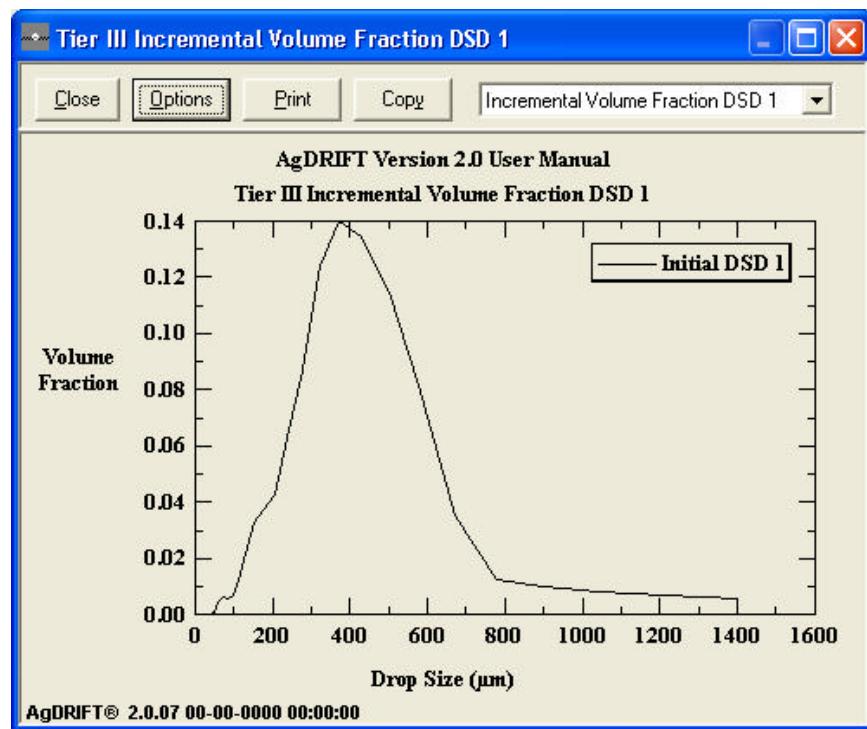


Figure 45. An incremental plot of the ASAE S-572 Medium to Coarse drop size distribution.

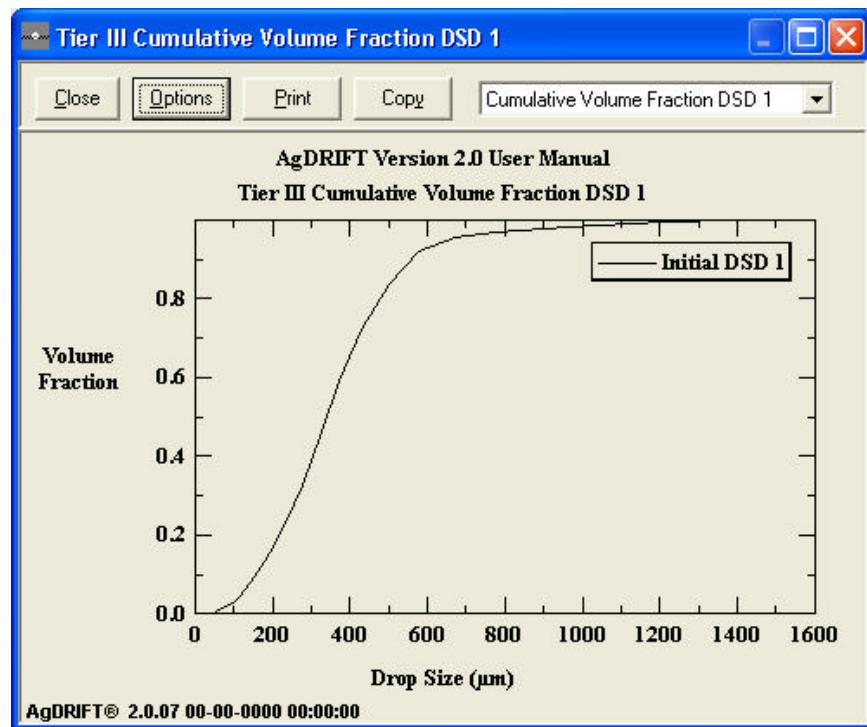


Figure 46. A cumulative plot of the ASAE S-572 Medium to Coarse drop size distribution.

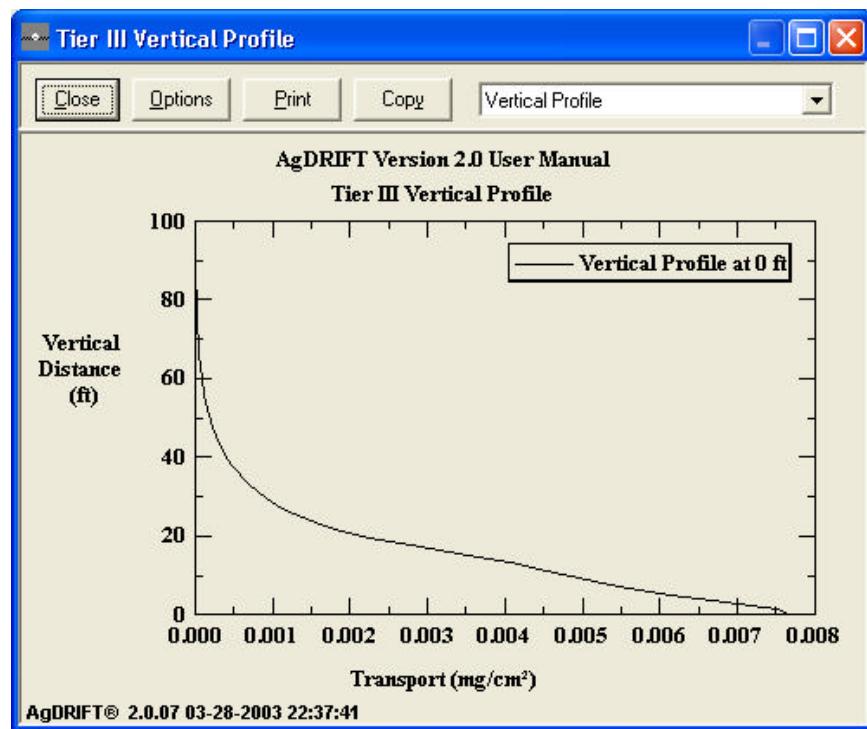


Figure 47. Vertical transport through a flux plane positioned at the edge of the application area for the ASAE S-572 Medium to Coarse drop size distribution and all model defaults.

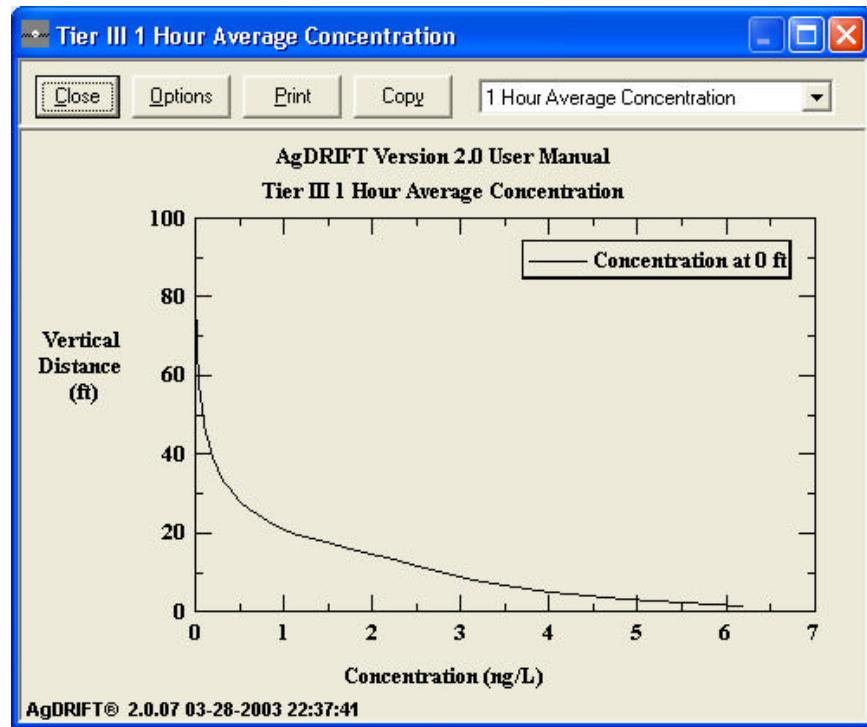


Figure 48. One hour average concentration through a flux plane positioned at the edge of the application area for the same conditions as Figure 47.

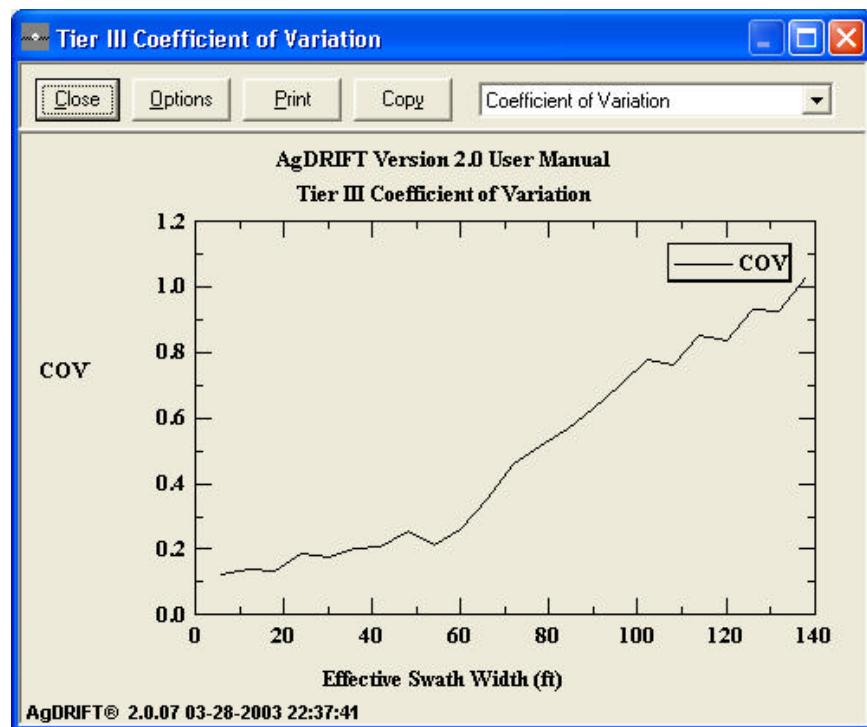


Figure 49. Coefficient of Variation as a function of Swath Width.

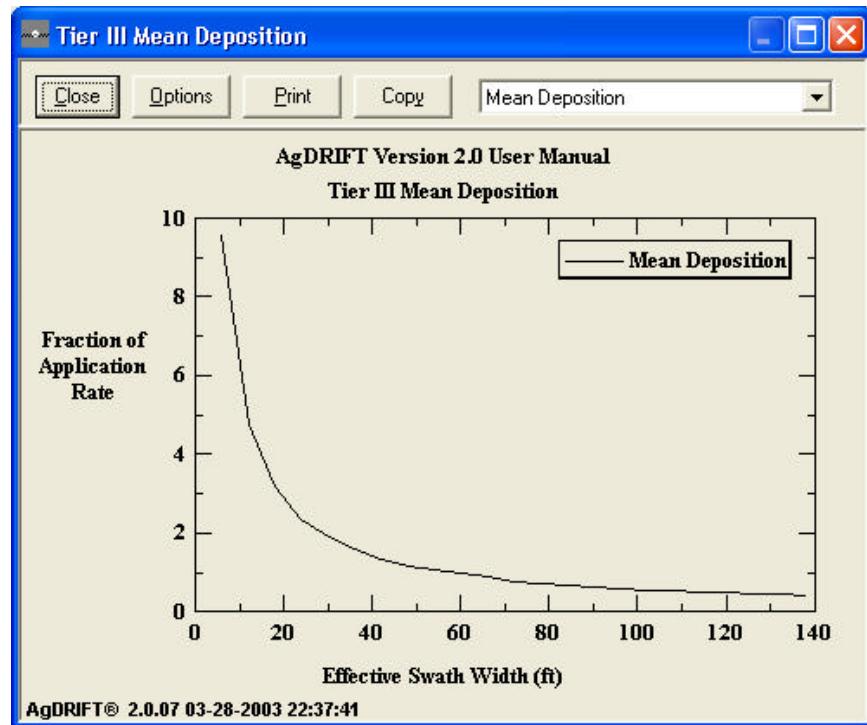


Figure 50. Mean Deposition within the spray block as a function of Swath Width.

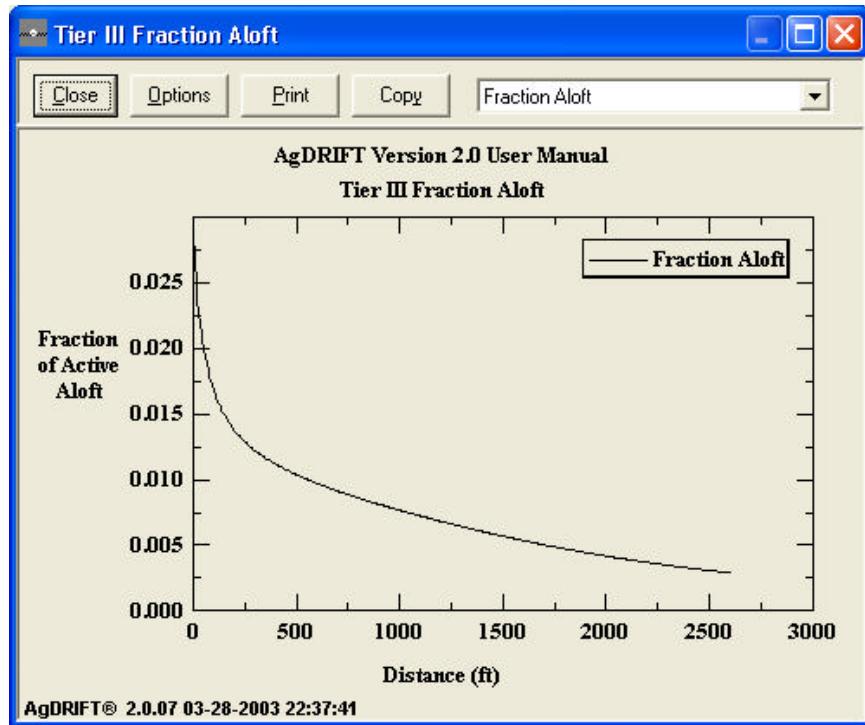


Figure 51. Fraction Aloft for the ASAE S-572 Medium to Coarse drop size distribution and all model defaults.

## Run

The user must run the model to generate results. **Run Calculations** performs this function. Alternately, the user may set up a series of input data files, then run them sequentially with the **Batch Operations** procedure. If inadvertent changes are made to inputs, the user may also recover the last calculated results (with **Revert to Last Calculations**).

A **Calculations** screen (Figure 53) appears during the computations. The Messages section of the screen summarizes the model inputs. All inputs into AgDRIFT® at Tier III must fall within the bounds specified in Table 4. Calculation **Status** is shown by a moving bar, which also displays the drop size being processed and the percentage of drop sizes completed. Calculations may be aborted with the **Stop** button.

When the drop size distribution has been generated by either DropKick® or USDA ARS Nozzle Models, input consistency checks are performed on specific gravity, speed, and spray volume rate per nozzle. If compared values are not within 10 or 20% of each other, Calculation Status will generate a warning or error message. To correct spray rate values in DropKick®, the user may have to change the pressure, select a different nozzle type, change the number of nozzles on the spray boom, or change the total spray rate.

A **Batch Operations** screen (Figure 54) appears whenever the user decides to run a series of AgDRIFT® calculations sequentially. One portion of the screen identifies the files to be accessed during the calculation (these files must have already been saved in AgDRIFT® format; filenames are added to or deleted from the list with the **Add** and **Remove** buttons, respectively), and a second portion of the screen indicates messages pertaining to the current file and the operational status of the calculation.

## Toolbox

The **Drop Distance Calculator** (Figure 55) accepts a drop size value (in  $\mu\text{m}$ ) and release height (in ft or m), then, based on the current model conditions, calculates the size of the drop at impact (in  $\mu\text{m}$ ), the downwind distance traveled by the drop (in ft or m), and the time to impact (in sec). Aircraft wake effects are not included in this calculation. The **Print** button prints the screen.

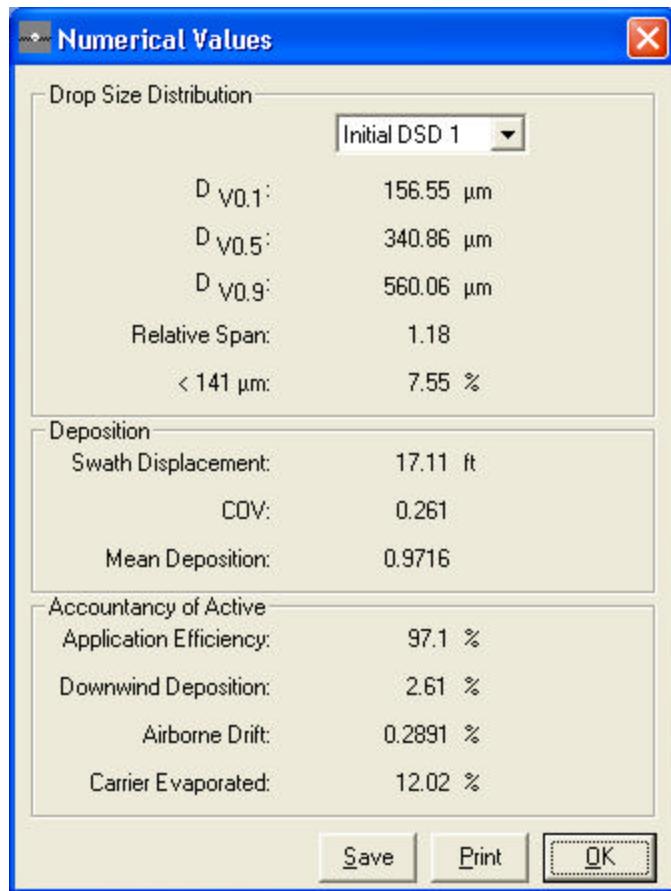


Figure 52. The Numerical Values screen (under View) presenting summary information on the Drop Size Distribution, Deposition, and Accountancy of Active.

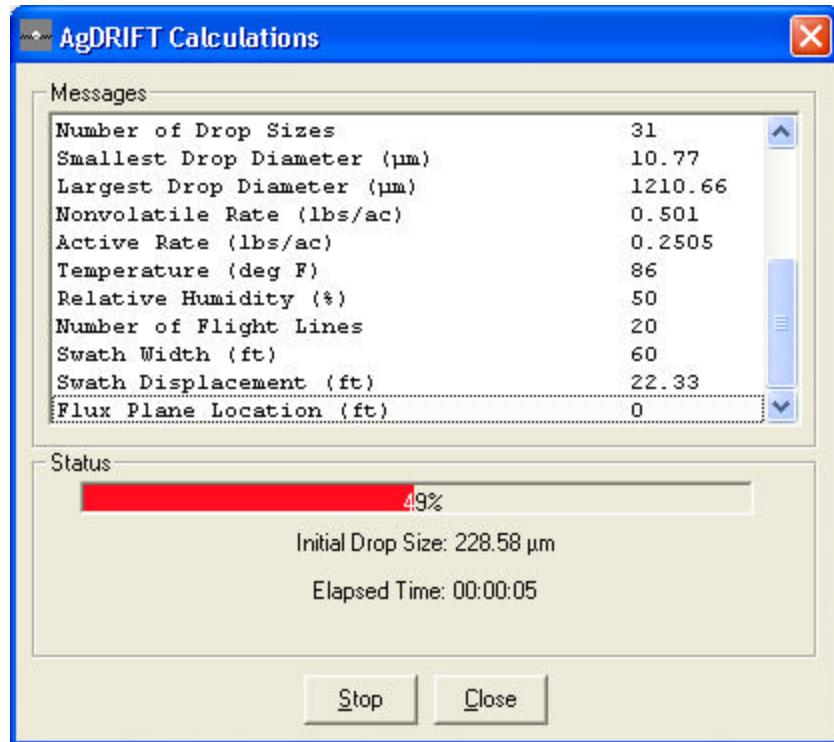


Figure 53. The AgDRIFT® Calculation screen. The bar at the bottom of the screen illustrates the completion of the calculation by the number of drop sizes examined.

The **Spray Block Statistics** calculator (Figure 56) allows the user to enter a value for one of the three parameters: Coefficient of Variation (COV) within the spray block, Effective Swath Width (in ft or m), or Mean Deposition within the spray block (in fraction of applied). The **Calc** button enables a computation of the other two parameters, based on the current deposition profile. The **Print** button prints the screen. A minimum COV of 0.3 is suggested by the work of Parkin and Wyatt (1982) and Quantick (1985).

In **Multiple Application Assessment** the user may enter the Direction to the Sensitive Area. In Tier I the wind rose is always positioned so that the maximum weighted wind direction blows directly downwind of the spray block over the sensitive area (Figure 57). In Tier III the “from” direction to the sensitive area can be adjusted.

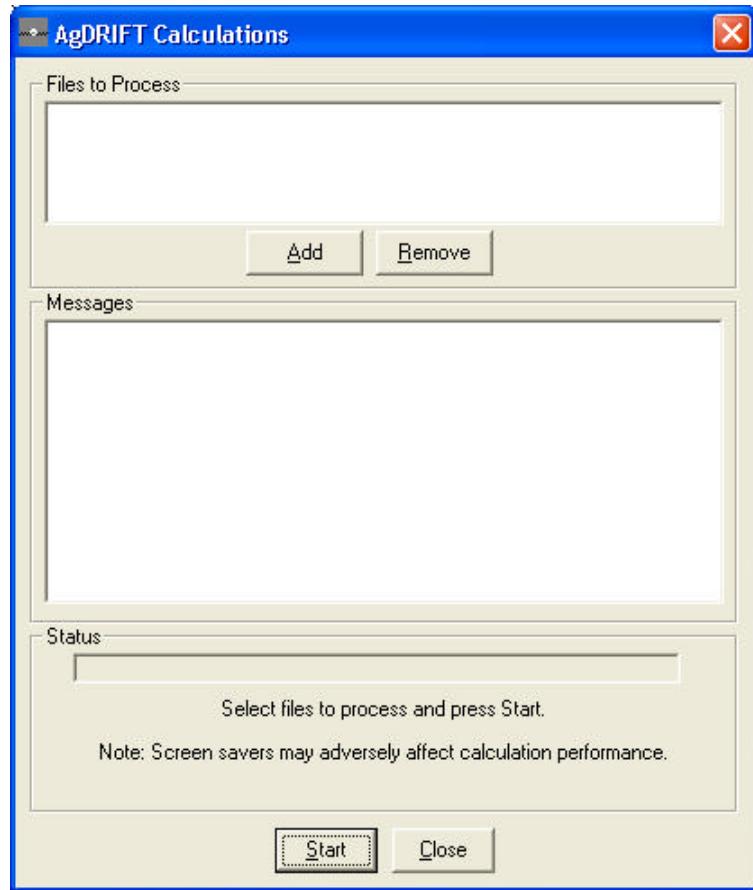


Figure 54. The Batch Operations screen template. AgDRIFT® file names are entered in the upper portion of the screen; operation status is given in the lower portion.

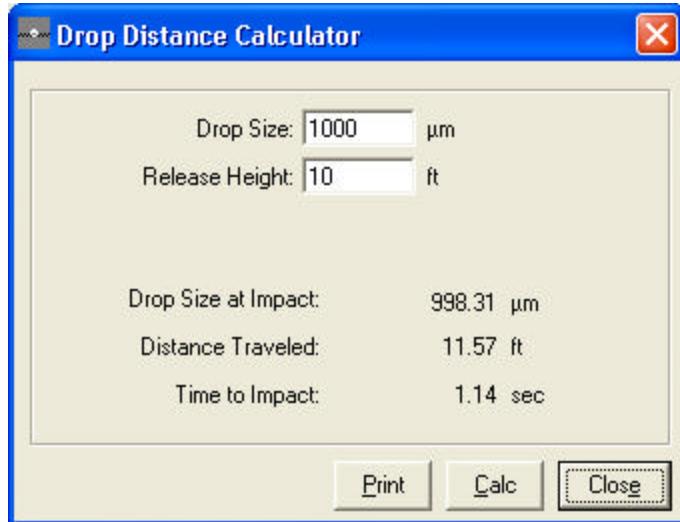


Figure 55. The Drop Distance Calculator screen (under **Toolbox**) presenting the entry of Drop Size and Release Height.

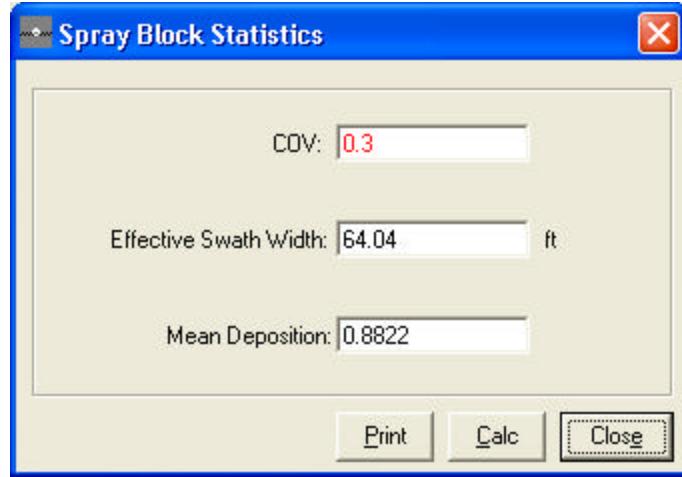


Figure 56. The Spray Block Statistics Calculator screen (under **Toolbox**), calculating the Coefficient of Variation (COV), Effective Swath Width, and Mean Deposition within the spray block, where one of the three values is inputted by the user, and the **Calc** button is used to compute the other two values (red indicates user input).

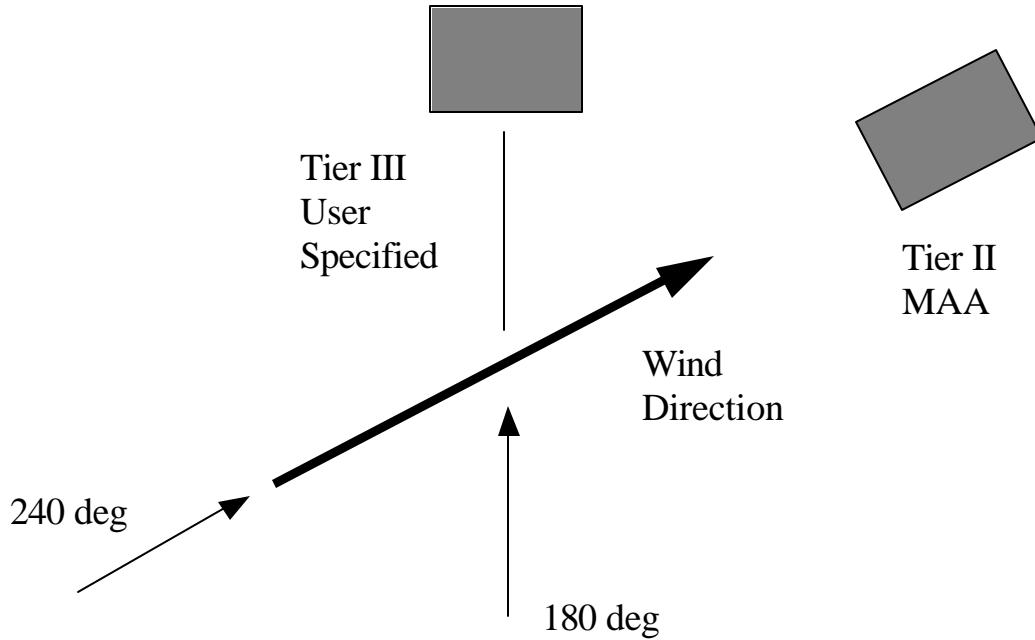


Figure 57. Layout for Multiple Application Assessment in Tier III, where the dominant wind direction blows from  $240^\circ$  (in this example) but the sensitive area (dark square at top) is located  $180^\circ$  to the spray block.

## V. Tier I Example Assessment

To illustrate the use of AgDRIFT® in an assessment, the following problem is posed:

Compound XYZ is recommended to have an application rate of 0.25 lb/ac to vegetable crops and a rate of 1.0 lb/ac for cotton. The proposed label includes either an aerial or ground sprayer application for both crops. A level of concern for aquatic organisms exists given an initial concentration of 5000 ng/L. Assuming the aquatic loadings are negligible due to runoff, do any of these applications raise potential concerns for the use of this product? The interpretation follows:

AgDRIFT® can be used for initial screening of these impacts. To evaluate the potential of drift problems from ground spray to either cotton or vegetables, start the AgDRIFT® program by double clicking on the AgDRIFT® icon and moving to the Tier I Ground screen, as shown in Figure 58.

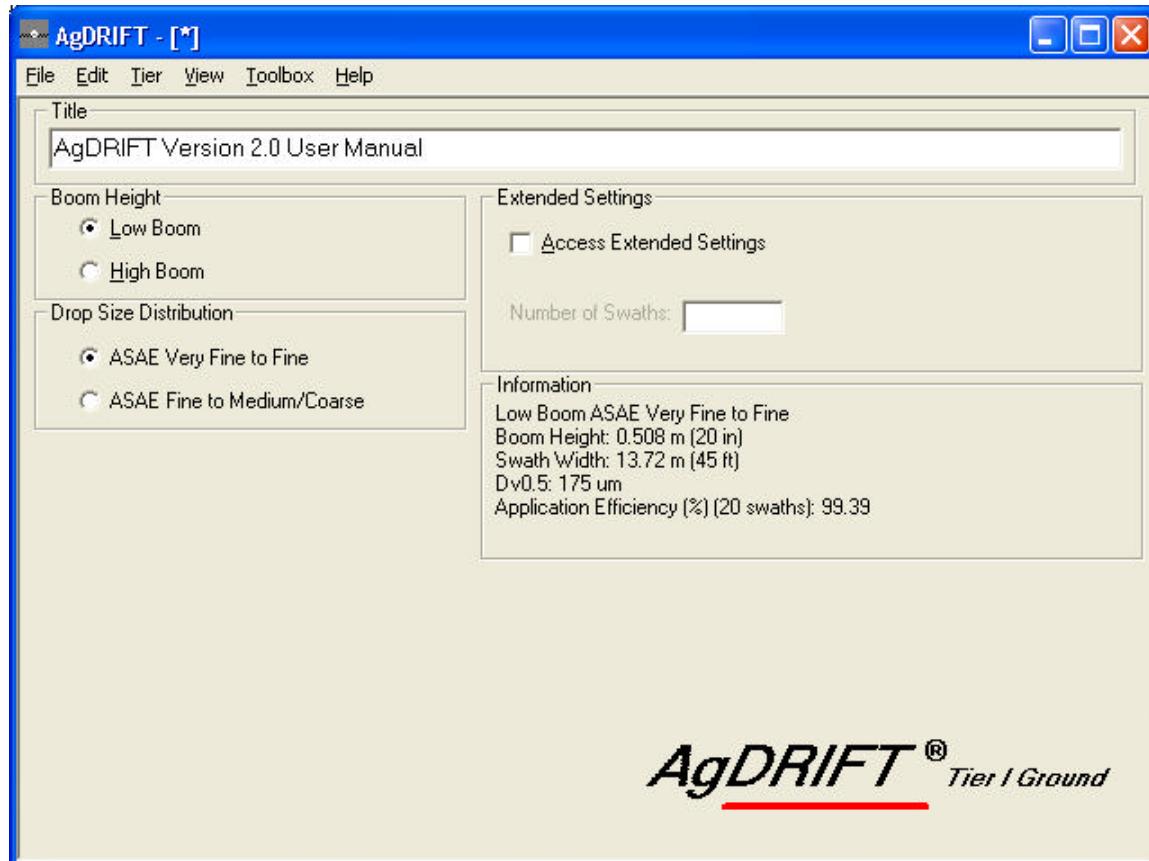


Figure 58. The Tier I Ground input screen.

Click the radio button for the High Boom ground spray application (the default number of swaths at 20). The exposure calculations and graphs in Tier I are based on the off-site deposition from a series of ground sprayer application field trials. Click **View** on the menu bar and then select Pond-Integrated Deposition to see a plot of average deposition based on the standard EPA-OPP pond as a function of the distance between the field and the nearest edge of the pond (as shown in Figure 59). The deposition is reported as a fraction of the nominal application rate – i.e. the observed deposition is normalized by the target application rate. In the case of the 1.0 lb/ac cotton application, the fraction of applied of 0.005 represents an average deposition on the pond of 0.005 lb/ac. In the case of the 0.25 lb/ac vegetable crop application, the fraction of applied of 0.005 represents an average deposition on the pond of 0.00125 lb/ac (0.25 lb/ac multiplied by 0.005).

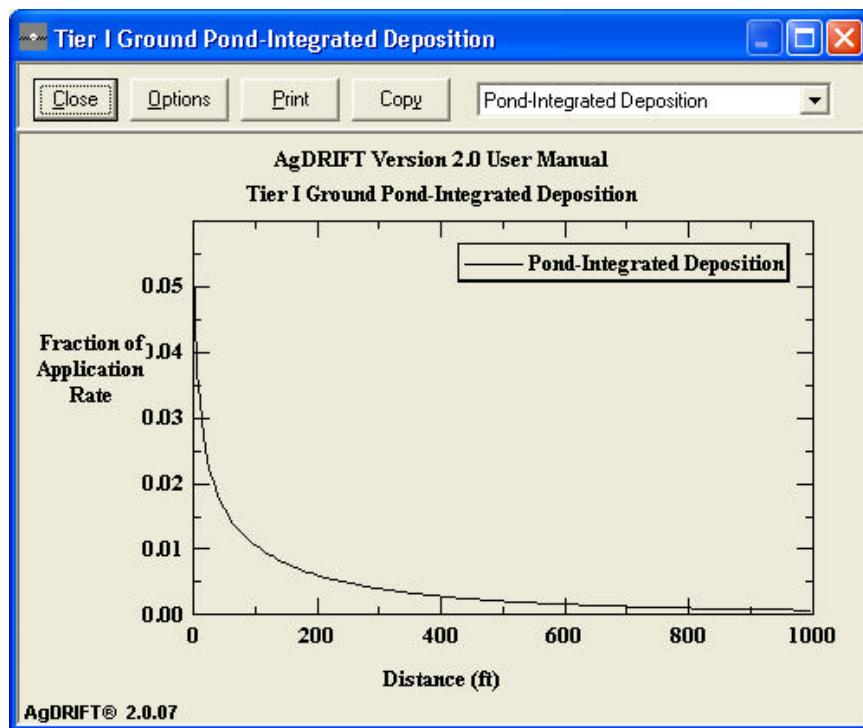


Figure 59. Plot of the pond-integrated deposition for the High Boom (ULV) ground sprayer application.

In order to calculate an aquatic concentration in the standard EPA-OPP pond, click on the Toolbox feature on the menu bar and select Aquatic Assessment from the drop down menu. The upper half of the aquatic assessment screen allows the user to define the water body and application rate (as shown in Figure 60). Click the radio button by the EPA-Defined Pond and enter the application rate – 1.0 lb/ac for cotton. On this screen, the downwind distance indicates the pond dimension perpendicular to the field and in this analysis is assumed to be directly downwind of the application area. Initially, a value of zero is used as the distance

between the edge of the pond nearest the field and the application area. The average deposition on the pond as a fraction of applied or g/ha is presented in the bottom or “Calculations” section of the screen, along with the concentration in the pond (assuming complete mixing through the depth). For 1.0 lb/ac the pond concentration is 3104.17 ng/L – below the assumed level of concern value of 5000 ng/L. For the vegetable crop application (0.25 lbs/ac), the pond concentration drops to 776.04 ng/L. From this analysis, spray drift loading alone from a ground sprayer application does not appear to present an aquatic hazard.

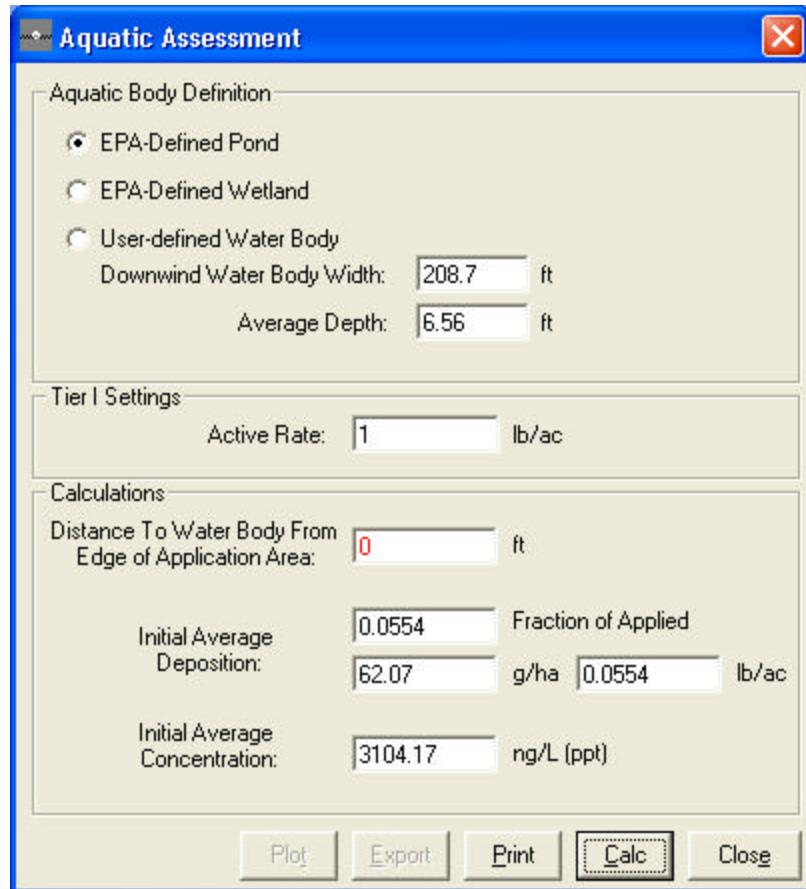


Figure 60. The Aquatic Assessment Calculator screen set at 1.0 lb/ac.

To evaluate aerial drift, change to the Tier III Aerial screen, enter the Nozzles and DSD screen, enter the DSD Edit screen, and set the Basic drop size distribution to Very Fine to Fine (adjusting the swath displacement) consistent with the Tier I ground application. We must also enter the Material screen and set the Active Rate to 0.25 lb/ac and the Nonvolatile Rate to 1.0 lb/ac. Run the calculation. As we did with the ground sprayer, we can click on View on the menu bar and then on Pond-Integrated Deposition to look at the deposition curve (as shown in Figure 61). Only a brief glance at this curve is needed to realize that deposition potential is

much higher for the aerial application case than for the ground sprayer case. Once again we invoke the Aquatic Assessment screen via the Toolbox menu. For 0.25 lb/ac, the pond concentration is 3638.9 ng/L, still well below the level of concern. However, if we enter the Material screen and set the Active rate to 1.0 lb/ac, then rerun the calculation, the pond concentration is 14555.5 ng/L – above the 5000 ng/L level of concern. If a 350 ft buffer zone were placed between the pond and the field (enter 350.0 in the box entitled “Distance to Water Body from Edge of Field”), the loading in the pond drops to 4816.6 ng/L.

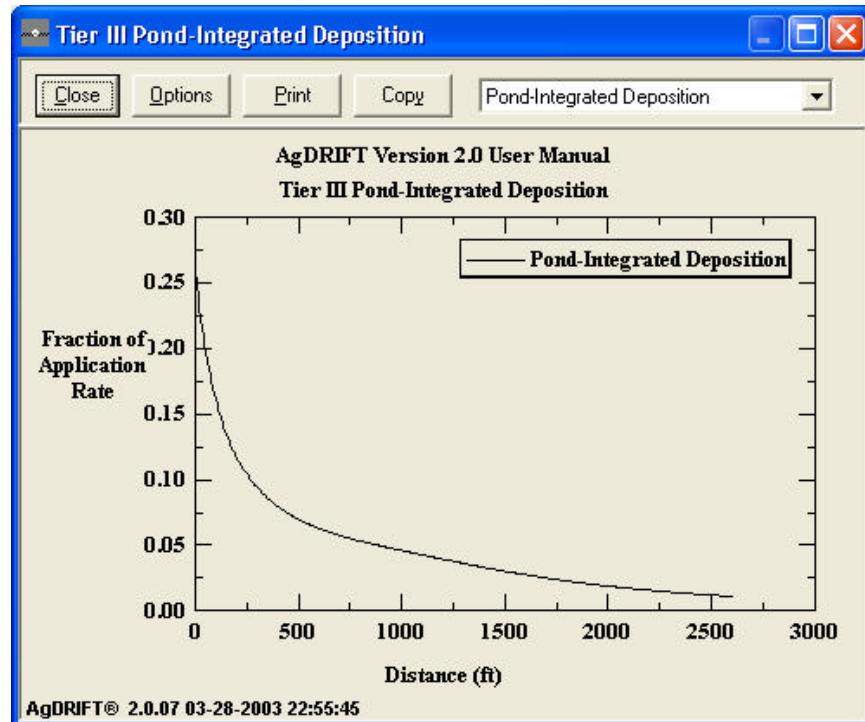


Figure 61. Plot of the pond-integrated deposition for the ASAE S-572 Very Fine to Fine drop size distribution aerial application.

If establishment of a 350 ft buffer zone is not an option, requiring a coarser drop size distribution might be considered. Selection of a Medium to Coarse drop size distribution illustrates the effect of this change. Using the same drop size scenario and once again entering the Aquatic Assessment screen at a 1.0 lb/ac application rate, the concentration reduces to below the assumed level of concern to 4555.3 ng/L with only a 5 ft buffer zone. Entry into Tier III allows the user to explore additional options to lower downwind deposition even further.

## VI. Interpretation of Model Predictions

AgDRIFT® produces a number of outputs that are presented to the user in either plot or tabular form (plot data may also be exported for further analysis or plotting). This section of the User Manual seeks to bring a deeper understanding to what is plotted or what is shown by the model, beyond the summary information provided in previous sections when the screens were first displayed.

### A. Numerical Results from Tier Calculations

Under **View** on the Main Menu Bar, the user can recover, depending on the Tier level, various numerical values, including:

**Drop Size Distribution** displays five parameters that are typically used to summarize the character of the distribution: the drop size at ten percent of the cumulative spray volume ( $D_{v0.1}$ ), the drop size at fifty percent of the cumulative spray volume ( $D_{v0.5}$ , alternately known as the volume median diameter), the drop size at ninety percent of the cumulative spray volume ( $D_{v0.9}$ ), the Relative Span ( $D_{v0.9} - D_{v0.1}$ )/ $D_{v0.5}$ , and the cumulative spray volume of spray material below 141  $\mu\text{m}$ . Figure 62 illustrates how these values are recovered (in this case, for the ASAE S-572 Fine to Medium drop size distribution curve): 0.1, 0.5, and 0.9 volume fractions (on the vertical scale) intercept at 113.71, 254.72, and 443.58  $\mu\text{m}$  on the horizontal scale, and 141  $\mu\text{m}$  on the horizontal scale intercepts at 0.1587 volume fraction on the vertical. Relative Span equals 1.295.

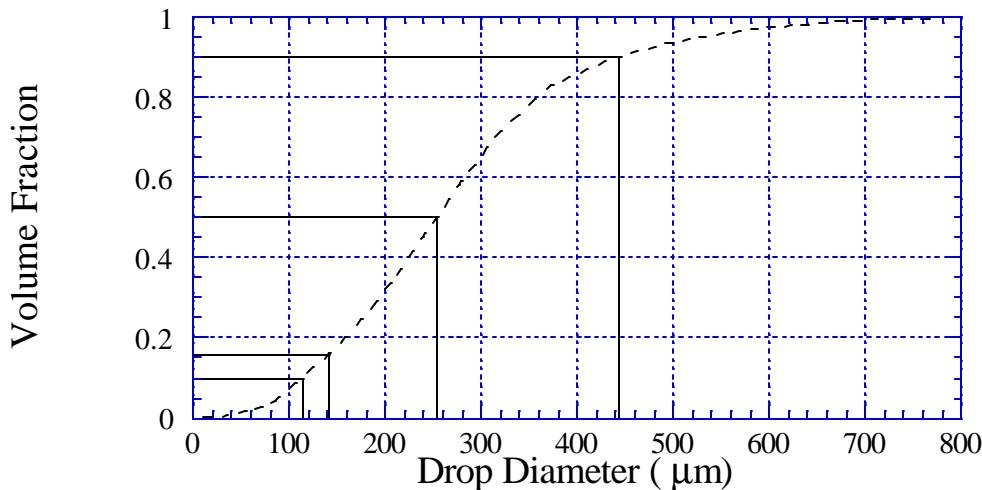


Figure 62. Cumulative spray volume for the ASAE S-572 Fine to Medium drop size distribution, plotted as a function of the average drop diameter in each size class, and the locations for  $D_{v0.1}$ ,  $D_{v0.5}$ ,  $D_{v0.9}$ , and 141  $\mu\text{m}$ .

**Deposition** shows the Swath Displacement, the offset of the center of the aircraft upwind of the edge of the application area (an additional  $\frac{1}{2}$  swath width is built into the model), and COV and Mean Deposition within the spray block. These results are not available in Tier I. In most applications Swath Displacement is directly transferred from data input by the user; however, in the option of Fraction of Application Rate, the computed Swath Displacement will be presented here.

**Accountancy of Active** summarizes where all of the released spray material goes, by computing four values: Application Efficiency, Downwind Deposition, Airborne Drift and Carrier Evaporated. Application Efficiency gives the percentage of active spray material released that landed in the spray block; Downwind Deposition gives the percentage that landed between the edge of the application area and the downwind end of the computation grid (2600 ft in Tier III is the default); Airborne Drift indicates the percentage aloft over the downwind end of the computation grid. These three numbers will always add up to 100 percent, recovering total accountancy of active spray material released. Application Efficiency multiplied by Active Rate yields the effective application rate applied to the spray block. The total active spray material applied to the spray block may be obtained by multiplying the Application Efficiency by the Active Rate by the swath width by the number of swaths by the length of the flight lines. This value must be conserved in the calculation.

Also included in this section is Carrier Evaporated, the percentage of total released carrier (volatile material, as opposed to the nonvolatile material that includes the active material) that evaporated from the point of release at the aircraft to deposit within the spray block, downwind of the spray block, or aloft at the downwind end of the computation grid.

## B. Plotted Results from Tier Calculations

Under **View** the user can recover, depending on the Tier level, one or more of the following plots:

**Drop Size Distribution** plots the volume fraction of spray material contained in each drop size category, either incrementally (with the fraction of material assigned to that category) or cumulatively (with the sum of the fraction of material assigned to that category and to all smaller drop size categories). The total cumulative volume fraction must equal one. AgDRIFT<sup>®</sup> contains an algorithm that interpolates within these drop size categories to create additional representative drop sizes such that no category contains more than two percent of the volume fraction. The behavior of these drop sizes is then traced through the wake of the aircraft with the Lagrangian solution technique.

Drop Size Distribution plots are also available for the spray material that deposits between the edge of the application area and the flux plane (Downwind) and the spray material that transports through the flux plane (Vertical Profile).

**Deposition** plots the deposit of active spray material downwind of the edge of the application area (the zero distance on the horizontal scale). The distance between the edge of the application area and the centerline of the spray aircraft is the swath offset, and is automatically included in the deposition calculation. To account for the swath displacement, an additional correction is applied to the flight path, such that at the edge of the application area the deposition is 0.5 of the applied rate. The deposition curve represents the deposit to the ground, or to a pond defined within the distance over which the deposition is generated.

**Pond-Integrated Deposition** plots the average deposit of active spray material over an EPA-defined (or user-defined) pond, defined downwind of the edge of the application area (the zero distance on the horizontal scale). The edge of the application area depends on the swath displacement. The EPA-defined pond begins at the distance shown on the horizontal scale and extends for 208.7 ft downwind. For the ASAE S-572 Medium to Coarse drop size distribution, the pond-integrated deposition at the edge of the application area is 0.0535 fraction of applied (as shown in Figure 64). The pond-integrated value is obtained by integrating over the deposition curve.

**Vertical Profile** plots the vertical transport ( $\text{mg/cm}^2$ ) through a Flux Plane positioned downwind of the edge of the spray block. The Flux Plane accounts for all of the active spray material aloft at the location specified; the plot is from the ground to a height where no appreciable transport exists.

**1 Hour Average Concentration** plots similar to Vertical Profile, but presents the cloud concentration ( $\text{ng/L}$ ). The calculation for Average Concentration requires a division by the ambient wind speed, which at the surface is 0 ft/s. For this reason Average Concentration is not computed at the surface.

**Coefficient of Variation** plots the behavior of the Effective Swath Width as a function of the relative standard deviation (COV) of the multiple flight line deposition pattern within the spray block. Within AgDRIFT<sup>®</sup> the single flight line prediction is overlapped with itself at fixed intervals across the spray block; statistics are then generated to determine how uniform the deposition pattern is (that statistic is COV). It is generally agreed that  $\text{COV} = 0.3$  is a minimum acceptable value to achieve adequate coverage and control.

**Mean Deposition** plots the Mean Deposition as a function of the Effective Swath Width of the multiple flight line deposition pattern within the spray block. The ideal value is approximately 1.0.

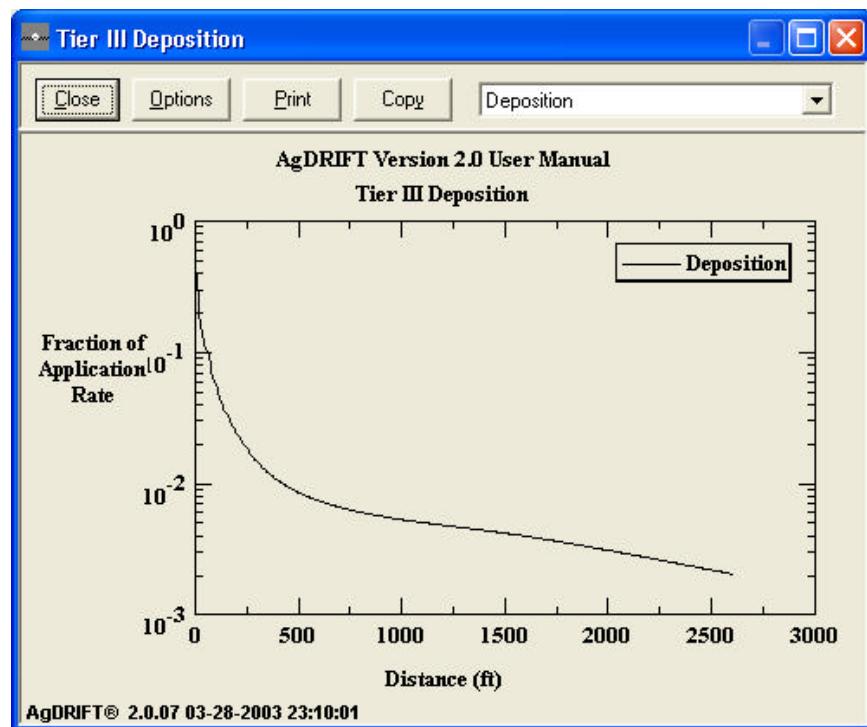


Figure 63. ASAE S-572 Medium to Coarse drop size distribution deposition curve.

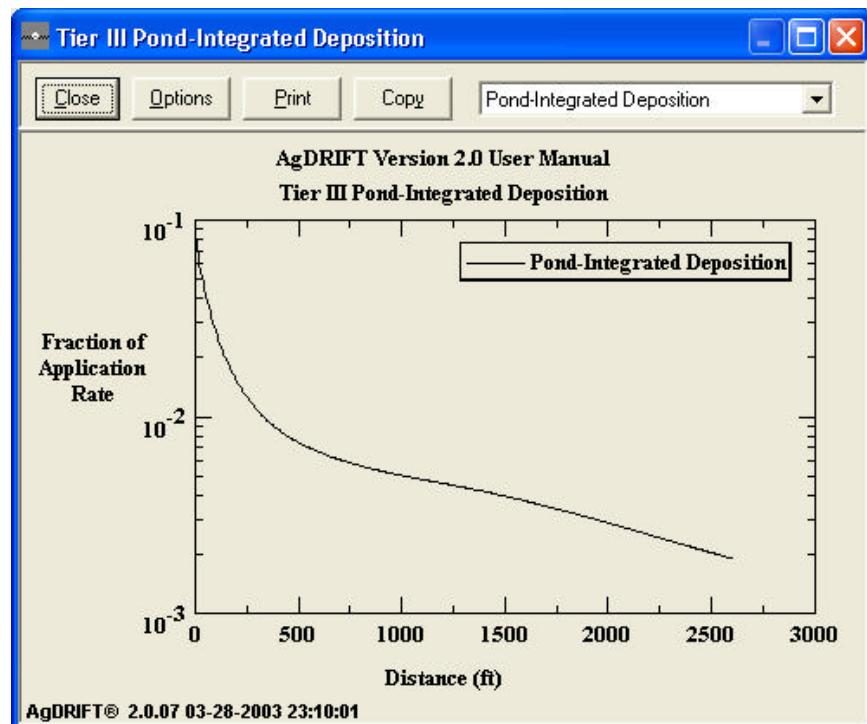


Figure 64. ASAE S-572 Medium to Coarse drop size distribution pond-integrated deposition curve.

**Fraction Aloft** plots the fraction of released active spray material aloft as a function of distance downwind of the edge of the application area. At the edge of the application area the Fraction Aloft will equal the sum of the Numerical Values for Downwind Deposition and Airborne Drift; at the downwind edge of the computation, the fraction aloft will equal the Airborne Drift.

### C. Toolbox Results

Under **View** the user can select Toolbox and, depending on the Tier level, enter one or more of the following screens:

**Aquatic Assessment** permits the definition of an aquatic water body (stationary) and calculations pertaining to the loading to that water body by the current calculations. An EPA-defined pond is 208.7 ft in downwind width and 6.56 ft deep; an EPA-defined wetland is 208.7 ft in width and 0.49 ft deep. The pond-integrated deposition curve (or the deposition curve if user-defined water body is selected) is analyzed to recover results when one of five inputs is specified: Distance to Water Body from Edge of Field; Initial Average Deposition across the width of the water body, in either fraction of applied, g/ha, or lb/ac; and Initial Average Concentration within the water body, in ng/L or ppt.

**Terrestrial Assessment** permits the definition of a terrestrial field point or area average and calculations pertaining to the loading to that field by the current calculations. The deposition curve is analyzed to recover results when one of five inputs is specified: Distance to Point or Area Average from Edge of Field; and Initial Average Deposition across the width of the field, in either fraction of applied, g/ha, lb/ac, or mg/cm<sup>2</sup>.

**Drop Distance Calculator** accepts the inputs of drop size and release height, and computes with the Lagrangian solver (with all other variables the same as in the Tier, but with the aircraft missing) the drop size when the drop hits the ground (evaporation effects), the distance traveled (wind speed effects), and the time to impact.

**Spray Block Statistics** accepts the input of either COV, Effective Swath Width, or Mean Deposition within the spray block, and recovers the other two parameters from the appropriate Coefficient of Variation curves.

**Spray Block Assessment** permits an analysis of buffer distance as a function of spray block width. The assessment may be made in one of two modes, examining either the deposition pattern or the pond-integrated deposition pattern. In deposition mode the user may specify either the fraction of applied (of active spray material) and recover the deposition level in g/ha or lb/ac, or the other way around. This deposition level will generate a curve of spray block width (on the horizontal) and buffer distance to the specified deposition level (on the vertical). The buffer distance is measured from the edge of the application area, and is the distance to the desired deposition level, as a function of the width of the spray block. The curve will always flatten as the spray block width increases, because the far downwind deposition profile always

shows less deposit for increased distances, and the effect of adding more spray lines deep within the spray block is diminished. In pond-integrated deposition mode the user may alternately specify the concentration in the stationary water body; any one of the four inputs will generate the other three. The desired pond-integrated deposition level will generate a curve of spray block width (on the horizontal) and buffer distance to the specified deposition level (on the vertical).

**Stream Assessment** permits an analysis of the deposition to a stream located downwind of the spray block, and the decay of the initial concentration to the stream as a function of time and distance downstream. The Geometry section of the screen is where the characteristics of the stream and the application to the field are specified. The important, special stream parameters are the Riparian Interception Factor (the fraction of material about to deposit in the stream, but captured by vegetation just upwind of the stream), the Instream Chemical Decay Rate (the time constant for the active ingredients to decay in water to one-half their effectiveness), and Recharge Rate (the amount of fresh water entering the stream downstream of the spray block).

In Single Point mode the Stream Assessment Toolbox will return values at the point specified (in either time or distance). In Distance range or Time range mode, multiple curves will be generated. These curves represent the concentration profile in the stream, at the times and distances selected, and are an additive function of each of the flight lines depositing active spray material within the spray block. The plots become more disperse (spread out) as time or distance increase. Figures 67 and 68 plot the predictions for the ASAE S-572 Fine to Medium drop size distribution default conditions, with a distance range of 10 to 10000 ft, and a time range of 10 to 10000 sec, respectively. The distance of zero represents the center of the spray block in the flight line direction; the time of zero occurs when the active spray material first enters the stream from the most downwind flight line (the one assumed to be sprayed first).

The EXAMS button will generate a file of initial conditions for the Time range option; these initial conditions may be used in a future version of EXAMS.

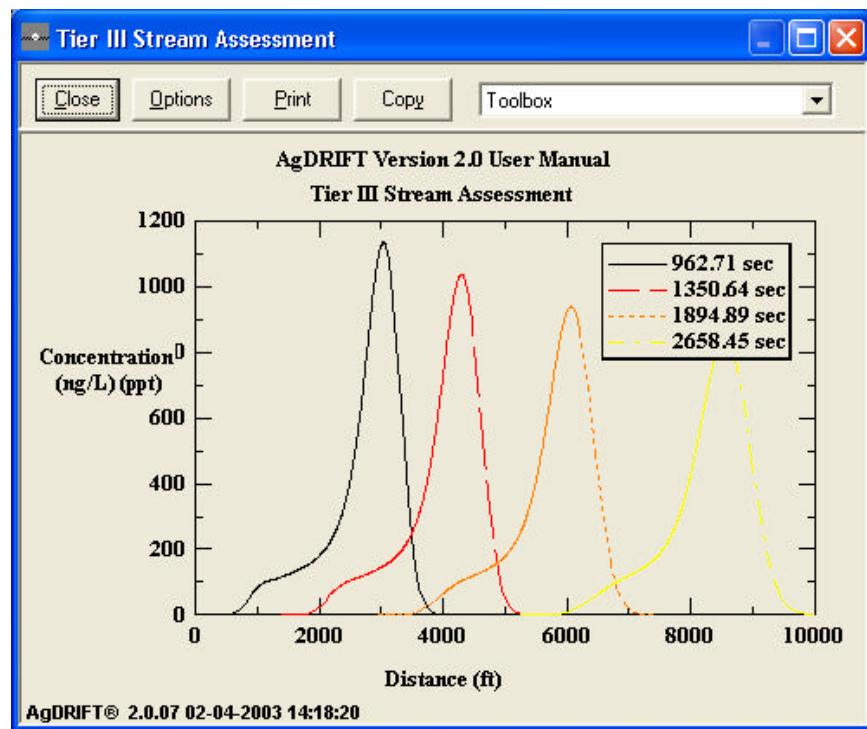


Figure 65. Distance profiles of active spray material deposited to a stream at four times identified on the plot.

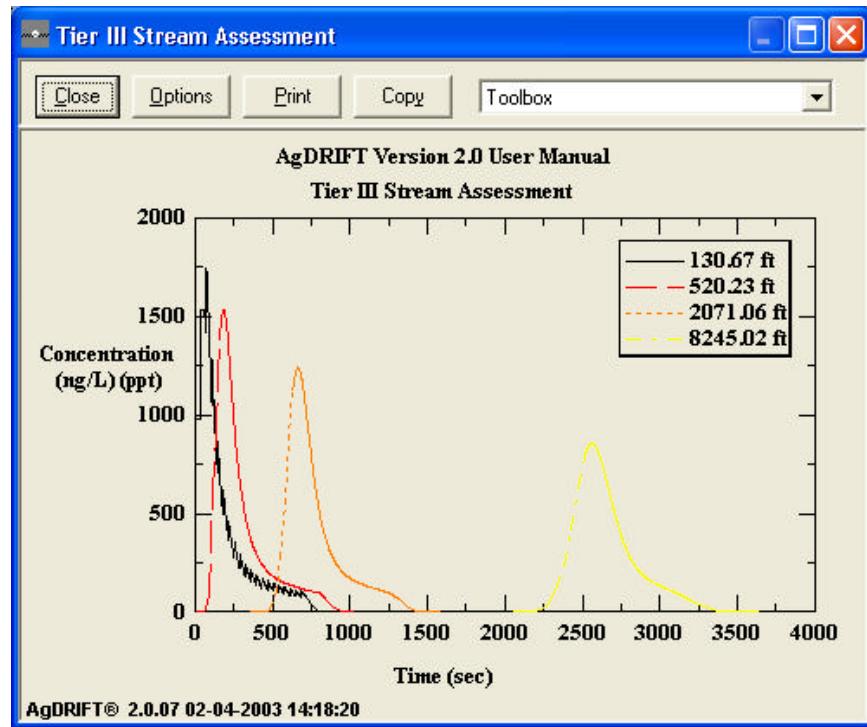


Figure 66. Time profiles of active spray material deposited to a stream at four distances identified on the plot.

**Multiple Application Assessment** (MAA) permits an analysis of multiple depositions resulting from more than one event. MAA modifies the crosswind speed to analyze variations in wind speed and direction for multiple events per year and/or multiple years. The Wind Rose section of the screen develops the statistical profile for the wind speed and wind direction. The user can restrict the maximum wind speed and the months when applications are made. Temperature and relative humidity are displayed for the selected period. The user may adjust the input temperature and relative humidity values for MAA analysis. AgDRIFT® first generates the incremental wind speed deposition profiles needed for MAA analysis, then uses the controlled sampling technique to recover the specified wind speeds and wind directions. Summary deposition patterns may be plotted or the curve fits to the individual realizations may be exported to a file for later use by a future version of EXAMS. The resulting deposition pattern may be further analyzed within Aquatic or Terrestrial Assessment.

## VII. Model Sensitivity

One of the areas in which predictive models can have great impact is in revealing trends in effects due to changes in input parameters. This is especially true in the case of complex problems, such as the aerial application of pesticides, where the wake formed by the aircraft creates a flow field superimposed over the ambient meteorological background, and into which spray material is released. The effects of different nozzles ejecting spray material, ambient wind speed, release height, evaporation, and any other parameter affecting this problem, have the possibility of significantly altering the downwind deposition pattern created by the typical spraying scenario.

Over the years practical experience has led to the observation that drop size distribution, release height, and wind speed are the most important factors in assessing deposition and drift from aerial applications (Teske and Barry 1993; Bird et al. 1996). Quantifying these effects would require a careful field study, or the use of a validated simulation model such as AgDRIFT®. This section of the user manual summarizes a sensitivity study of the inputs into the model, in an effort to illustrate the influence these parameters may have on the deposition pattern.

Previous sensitivity studies began with a set of default values, then varied each input parameter with all other parameters held constant (Teske and Barry 1993; Teske 1996; Teske et al. 1998b; Teske and Thistle 1999). In our application the AgDRIFT® input parameters were varied by ten percent around their default values; these values, and the limits tested for each parameter, are summarized in Table 6. Four drop size distributions (Figure 67) were used (taken from Doble et al. 1985, Southcombe 1988, and Parkin et al. 1994). Results are plotted in Figures 68 to 75. A summary of the computed Drift Fractions (the total amount of active spray material crossing the edge of the application area) is given in Table 7.

Observations include the following:

1. The largest variations occur in those variables controlling the shape and content of the drop size distribution: the relative span and volume median diameter  $D_{v0.5}$ .
2. The next largest variation occurs in boom height, with greater variation for BCPC Medium to Coarse and Coarse to Very Coarse drop size distributions.
3. Boom length displays significant variation below 200 ft, which suggests that changes in boom length will affect buffer zone selection.
4. Temperature and relative humidity show small variation beyond 200 ft, where differences in ambient conditions will most likely affect evaporation rates.

**Table 6. AgDRIFT® Sensitivity Study Limits**

Sensitivity includes all four BCPC drop size distributions (Very Fine to Fine, Fine to Medium, Medium to Coarse, and Coarse to Very Coarse) as shown in relative span and  $D_{v0.5}$

Variable	Lower Value	Default Value	Upper Value
Boom Height (ft)	9.0	10.0	11.0
Boom Length (%)	68.7	76.3	83.9
Nonvolatile Fraction	0.027	0.03	0.033
Number of Flight Lines	18	20	22
Relative Humidity (%)	45.0	50.0	55.0
Relative Span			
Very Fine to Fine	1.125	1.250	1.375
Fine to Medium	1.236	1.374	1.511
Medium to Coarse	1.223	1.359	1.494
Coarse to Very Coarse	1.090	1.211	1.332
Swath Width (ft)	54.0	60.0	66.0
Temperature (°F)	77.4	86.0	94.6
$D_{v0.5}$ ( $\mu\text{m}$ )			
Very Fine to Fine	107.31	119.23	131.15
Fine to Medium	194.81	216.45	238.10
Medium to Coarse	317.68	352.98	388.28
Coarse to Very Coarse	417.15	463.50	509.85
Wind Speed (mph)	9.0	10.0	11.0

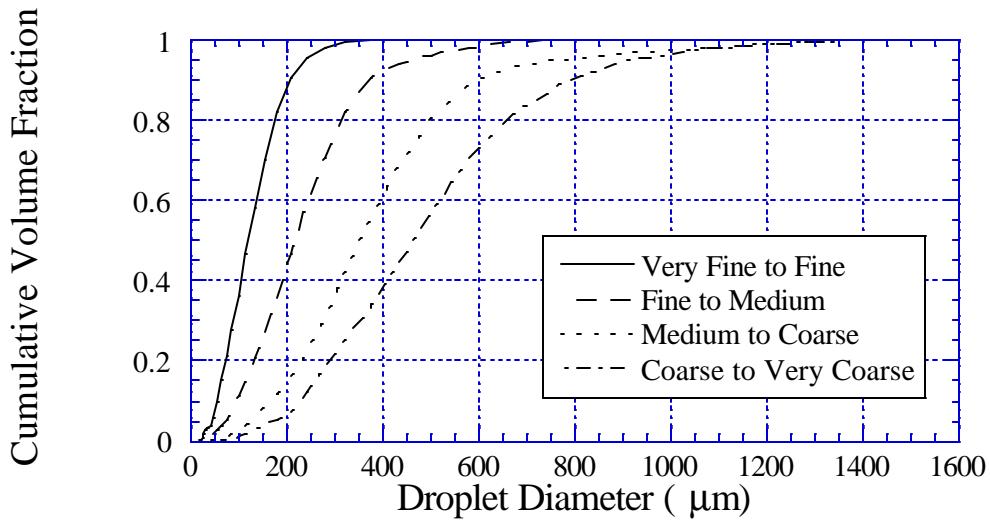


Figure 67. Drop categories based on the nozzle categorization scheme developed by BCPC. The four curves shown here define the boundaries of the Very Fine to Fine, Fine to Medium, Medium to Coarse, and Coarse to Very Coarse atomization regimes.

5. Number of flight lines, swath width, and wind speed show little variation, indicating that the major contribution to drift is from the first few flight lines.
6. Nonvolatile fraction is unchanged.

These findings are somewhat consistent with previous sensitivity studies, except for the ineffectiveness of the wind speed. Nonvolatile fraction should show some effect, but presumably only if the variation were larger.

A ranking of drift fractions (Table 7) across the four drop size distributions produces the following order:

1. Volume Median Diameter
2. Relative Span
3. Boom Height
4. Wind Speed
5. Boom Length

6. Relative Humidity

7. Temperature

8. Nonvolatile Fraction

Drift increases with an increase in boom height, boom length, relative span, temperature, and wind speed, and increases with a decrease in nonvolatile fraction, relative humidity, and volume median diameter. Increasing relative span forces more drop sizes below the volume median diameter, which increases drift. The lower than expected effect of wind speed is attributed to the study design. Wind speed increases the swath offset and swath width, masking the true effect of wind speed. Other sensitivity studies (Teske 1996; Teske et al. 1998b; Teske and Thistle 1999) demonstrate that wind speed is a significant contributor to the total drift loading.

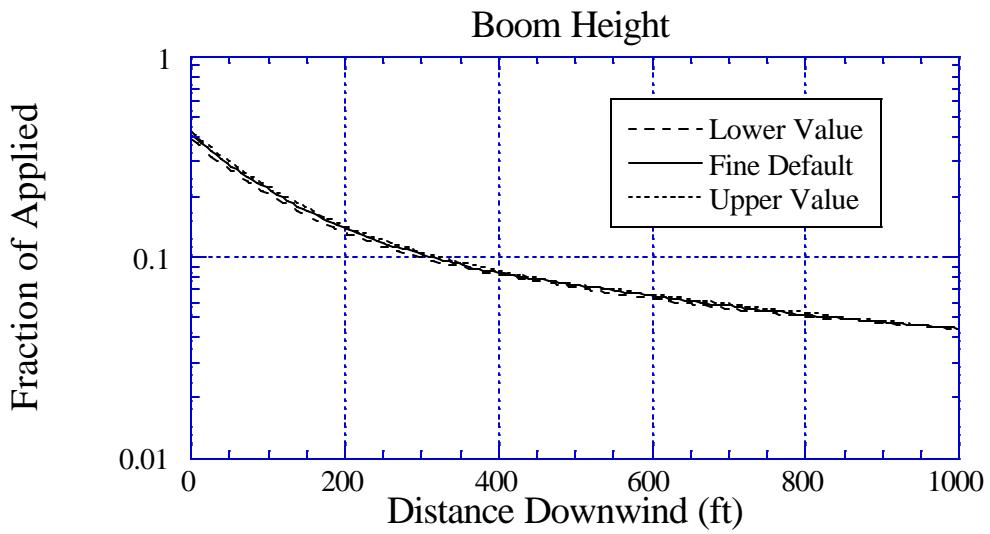


Figure 68a. Sensitivity of deposition to a 10% variation in Boom Height: the solid curve is for the default value of 10 ft; the long-dashed curve is for a lower value of 9 ft; and the dotted curve is for an upper value of 11 ft. BCPC Very Fine to Fine drop size distribution.

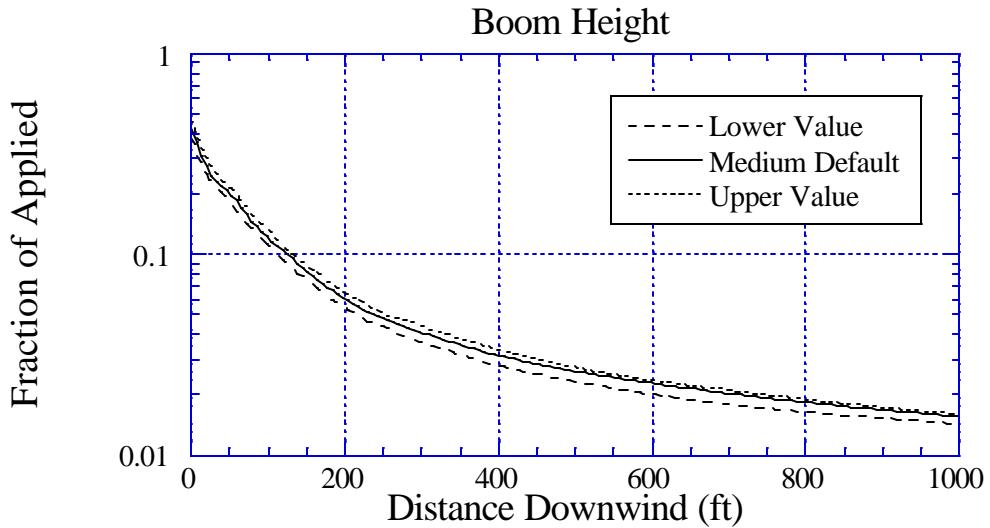


Figure 68b. Sensitivity of deposition to a 10% variation in Boom Height: the solid curve is for the default value of 10 ft; the long-dashed curve is for a lower value of 9 ft; and the dotted curve is for an upper value of 11 ft. BCPC Fine to Medium drop size distribution.

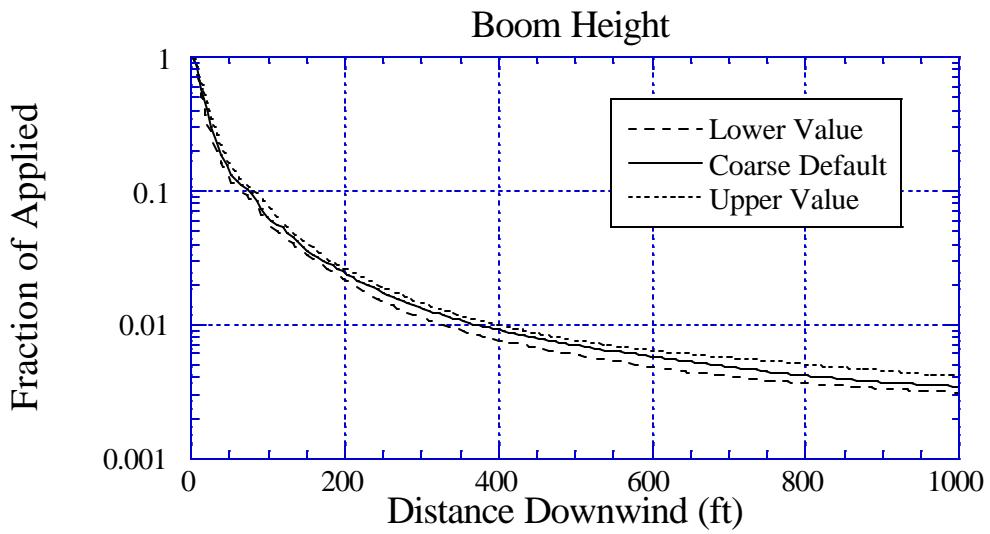


Figure 68c. Sensitivity of deposition to a 10% variation in Boom Height: the solid curve is for the default value of 10 ft; the long-dashed curve is for a lower value of 9 ft; and the dotted curve is for an upper value of 11 ft. BCPC Medium to Coarse drop size distribution.

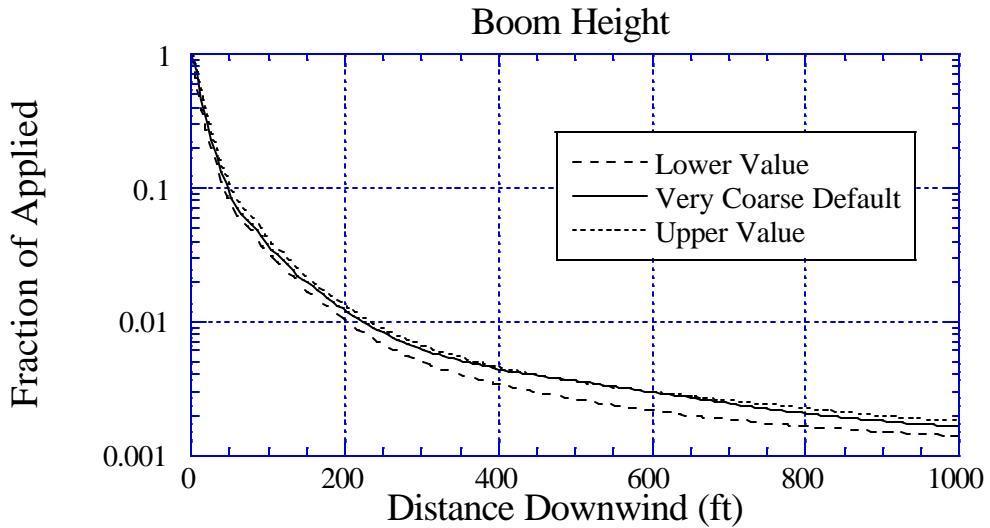


Figure 68d. Sensitivity of deposition to a 10% variation in Boom Height: the solid curve is for the default value of 10 ft; the long-dashed curve is for a lower value of 9 ft; and the dotted curve is for an upper value of 11 ft. BCPC Coarse to Very Coarse drop size distribution.

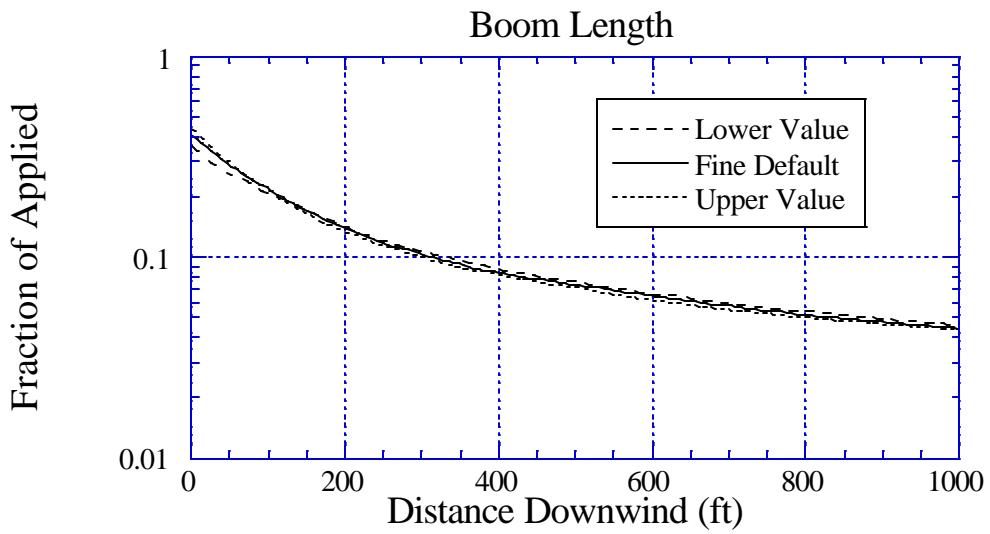


Figure 69a. Sensitivity of deposition to a 10% variation in Boom Length: the solid curve is for the default value of 76.3%; the long-dashed curve is for a lower value of 68.7%; and the dotted curve is for an upper value of 83.9%. BCPC Very Fine to Fine drop size distribution.

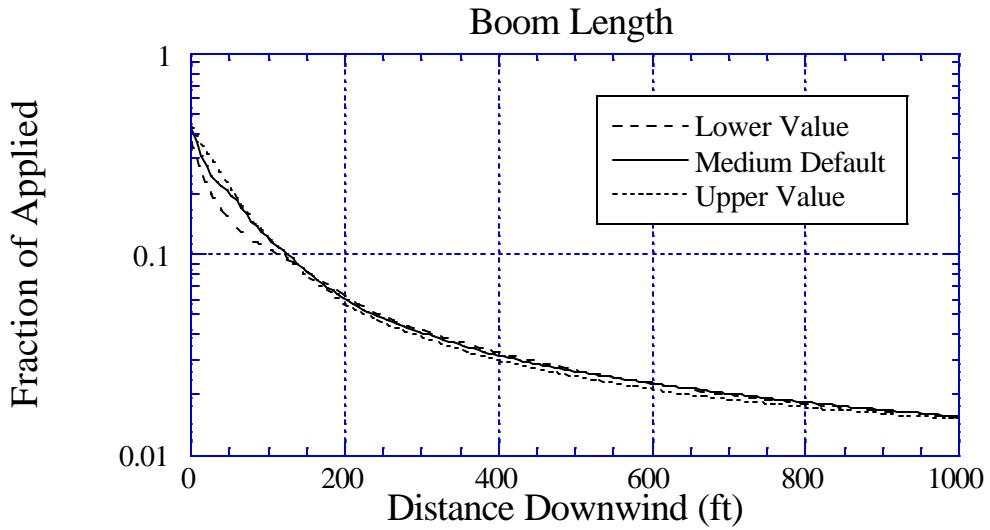


Figure 69b. Sensitivity of deposition to a 10% variation in Boom Length: the solid curve is for the default value of 76.3%; the long-dashed curve is for a lower value of 68.7% and the dotted curve is for an upper value of 83.9%. BCPC Fine to Medium drop size distribution.

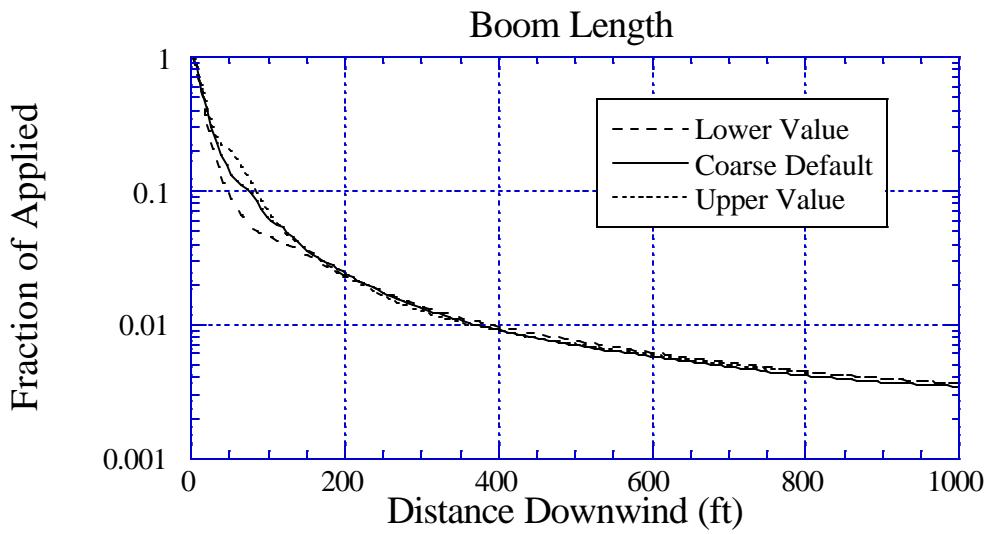


Figure 69c. Sensitivity of deposition to a 10% variation in Boom Length: the solid curve is for the default value of 76.3%; the long-dashed curve is for a lower value of 68.7%; and the dotted curve is for an upper value of 83.9%. BCPC Medium to Coarse drop size distribution.

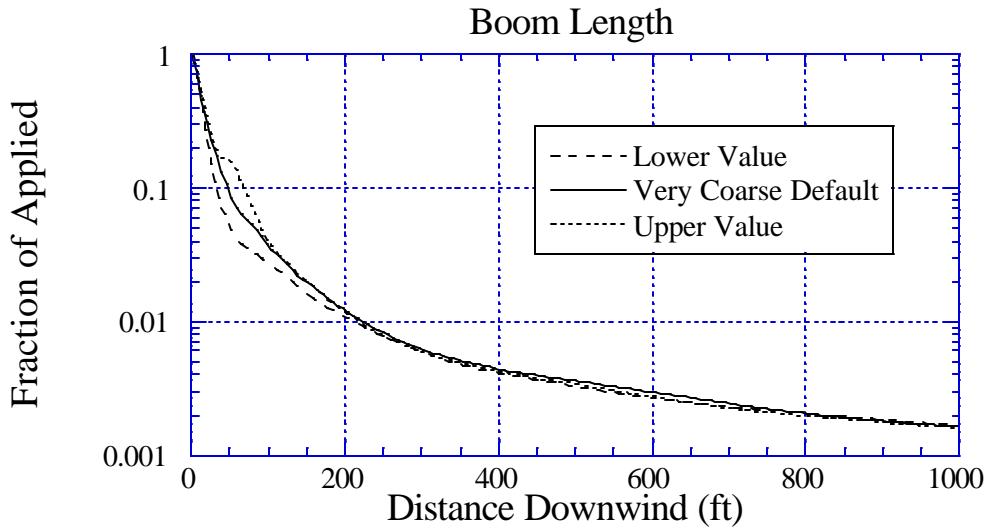


Figure 69d. Sensitivity of deposition to a 10% variation in Boom Length: the solid curve is for the default value of 76.3%; the long-dashed curve is for a lower value of 68.7%; and the dotted curve is for an upper value of 83.9%. BCPC Coarse to Very Coarse drop size distribution.

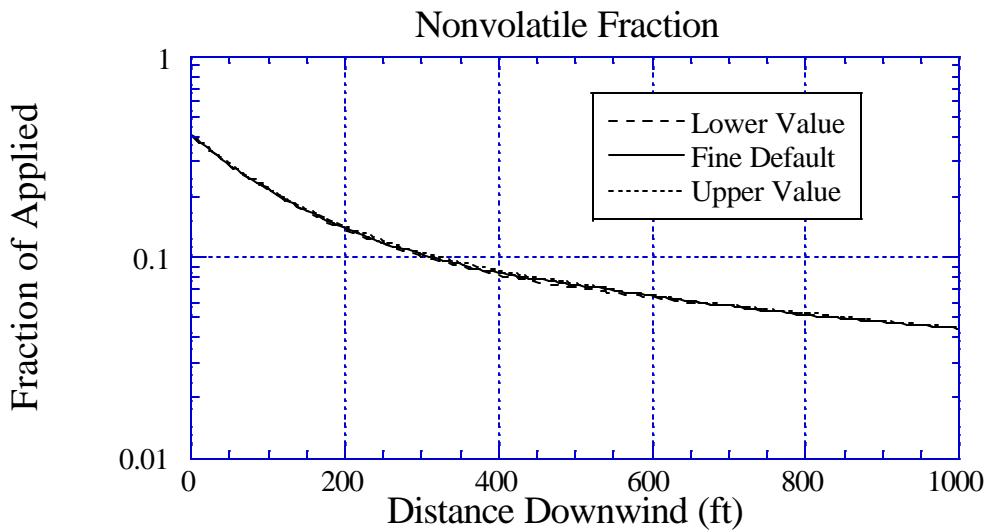


Figure 70a. Sensitivity of deposition to a 10% variation in Nonvolatile Fraction: the solid curve is for the default value of 0.03; the long-dashed curve is for a lower value of 0.027; and the dotted curve is for an upper value of 0.033. BCPC Very Fine to Fine drop size distribution.

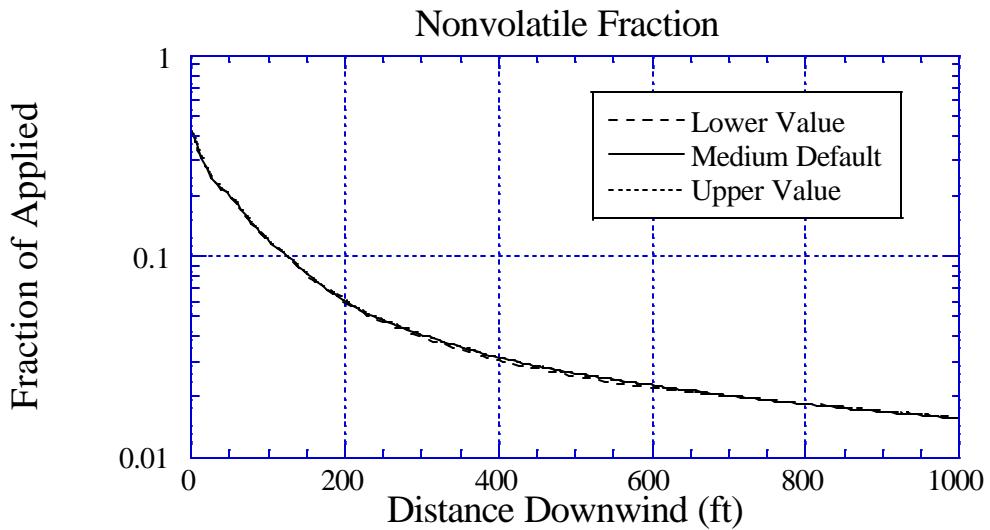


Figure 70b. Sensitivity of deposition to a 10% variation in Nonvolatile Fraction: the solid curve is for the default value of 0.03; the long-dashed curve is for a lower value of 0.027; and the dotted curve is for an upper value of 0.033. BCPC Fine to Medium drop size distribution.

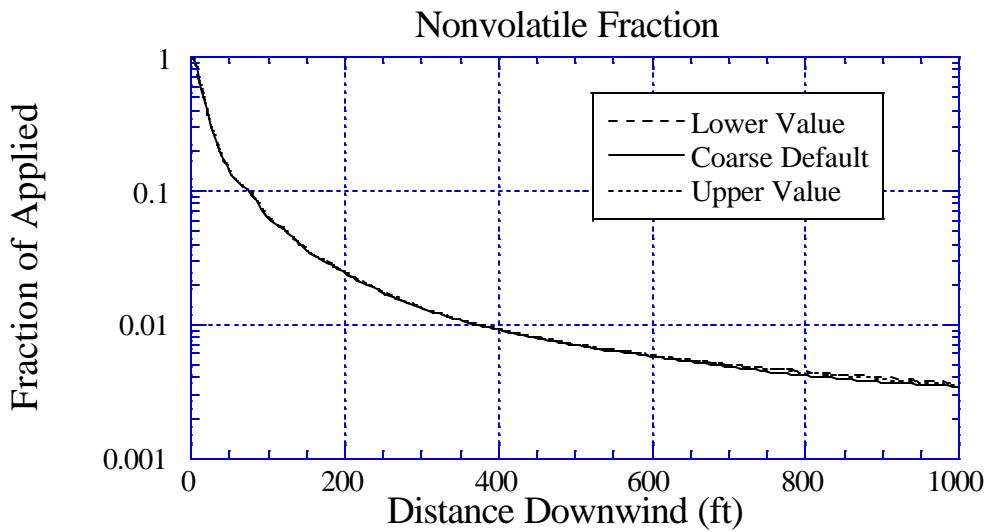


Figure 70c. Sensitivity of deposition to a 10% variation in Nonvolatile Fraction: the solid curve is for the default value of 0.03; the long-dashed curve is for a lower value of 0.027; and the dotted curve is for an upper value of 0.033. BCPC Medium to Coarse drop size distribution.

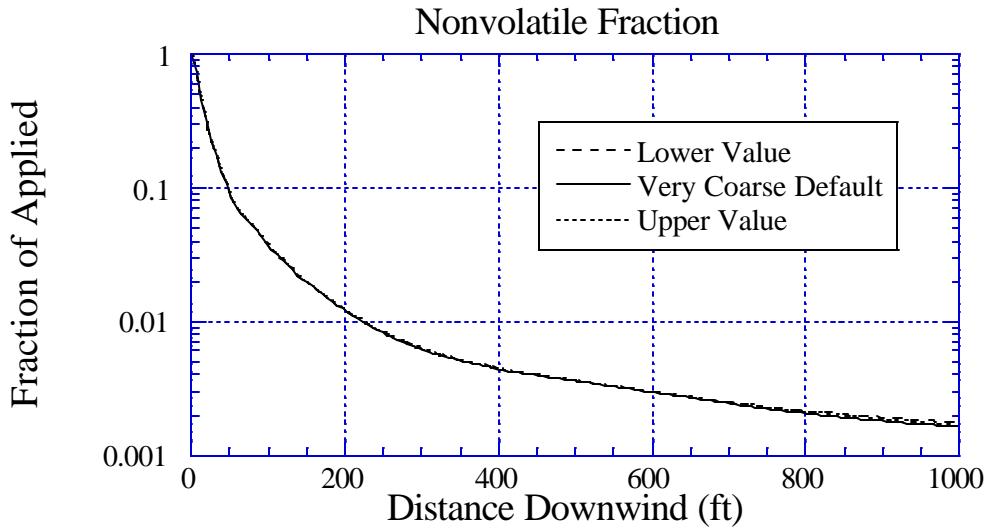


Figure 70d. Sensitivity of deposition to a 10% variation in Nonvolatile Fraction: the solid curve is for the default value of 0.03; the long-dashed curve is for a lower value of 0.027; and the dotted curve is for an upper value of 0.033. BCPC Coarse to Very Coarse drop size distribution.

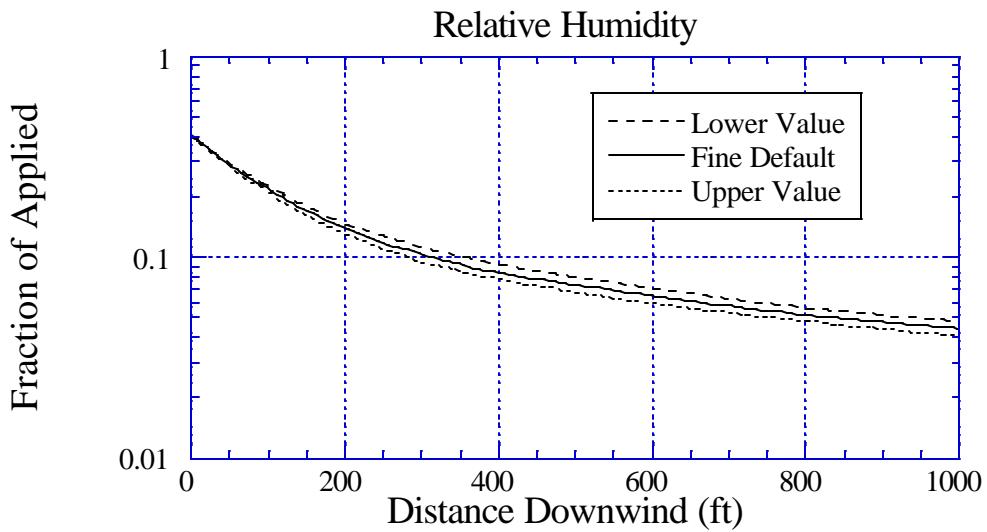


Figure 71a. Sensitivity of deposition to a 10% variation in Relative Humidity: the solid curve is for the default value of 50%; the long-dashed curve is for a lower value of 45%; and the dotted curve is for an upper value of 55%. BCPC Very Fine to Fine drop size distribution.

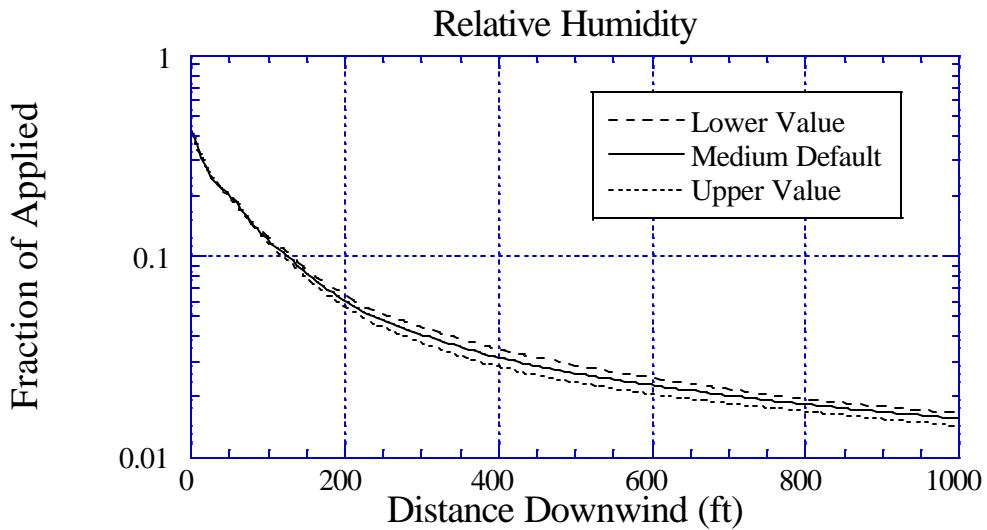


Figure 71b. Sensitivity of deposition to a 10% variation in Relative Humidity: the solid curve is for the default value of 50%; the long-dashed curve is for a lower value of 45%; and the dotted curve is for an upper value of 55%. BCPC Fine to Medium drop size distribution.

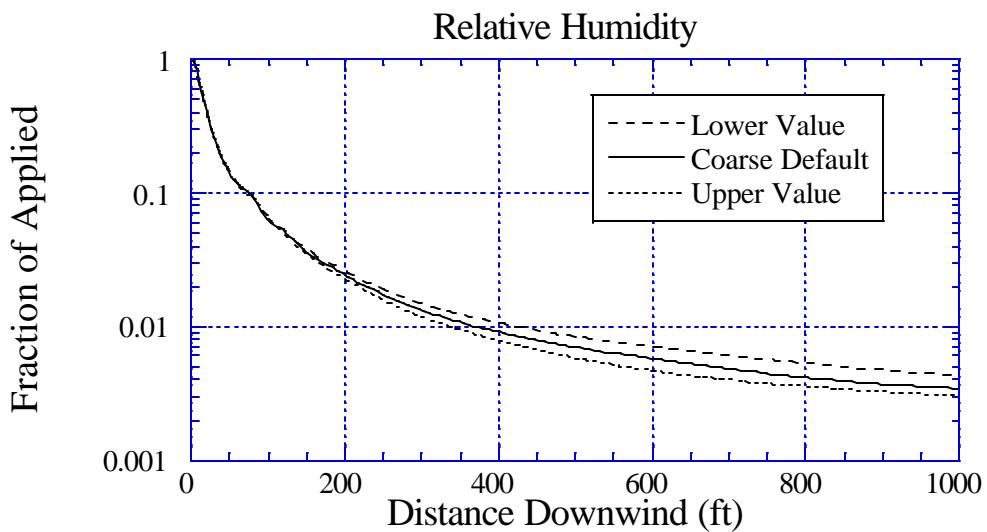


Figure 71c. Sensitivity of deposition to a 10% variation in Relative Humidity: the solid curve is for the default value of 50%; the long-dashed curve is for a lower value of 45%; and the dotted curve is for an upper value of 55%. BCPC Medium to Coarse drop size distribution.

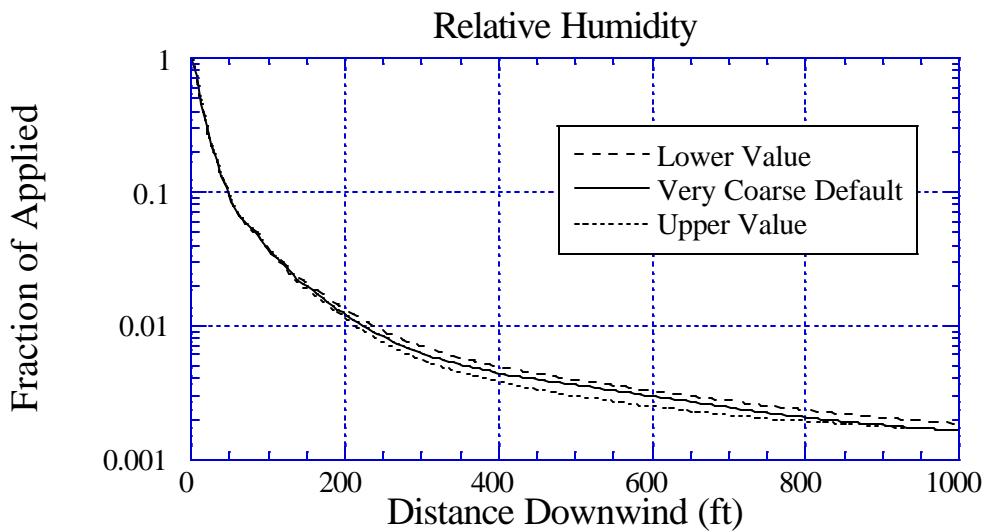


Figure 71d. Sensitivity of deposition to a 10% variation in Relative Humidity: the solid curve is for the default value of 50%; the long-dashed curve is for a lower value of 45%; and the dotted curve is for an upper value of 55%. BCPC Coarse to Very Coarse drop size distribution.

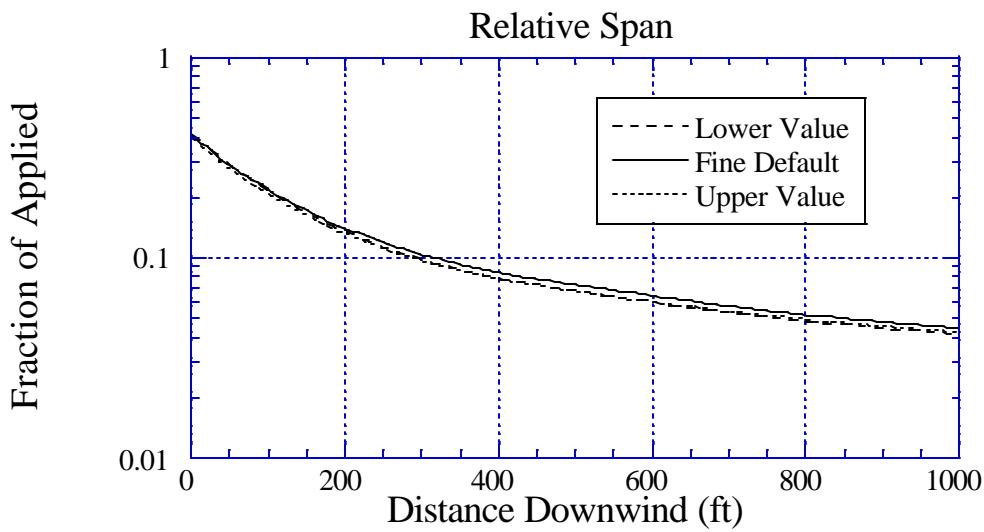


Figure 72a. Sensitivity of deposition to a 10% variation in Relative Span: the solid curve is for the default value of 1.250; the long-dashed curve is for a lower value of 1.125; and the dotted curve is for an upper value of 1.375. BCPC Very Fine to Fine drop size distribution.

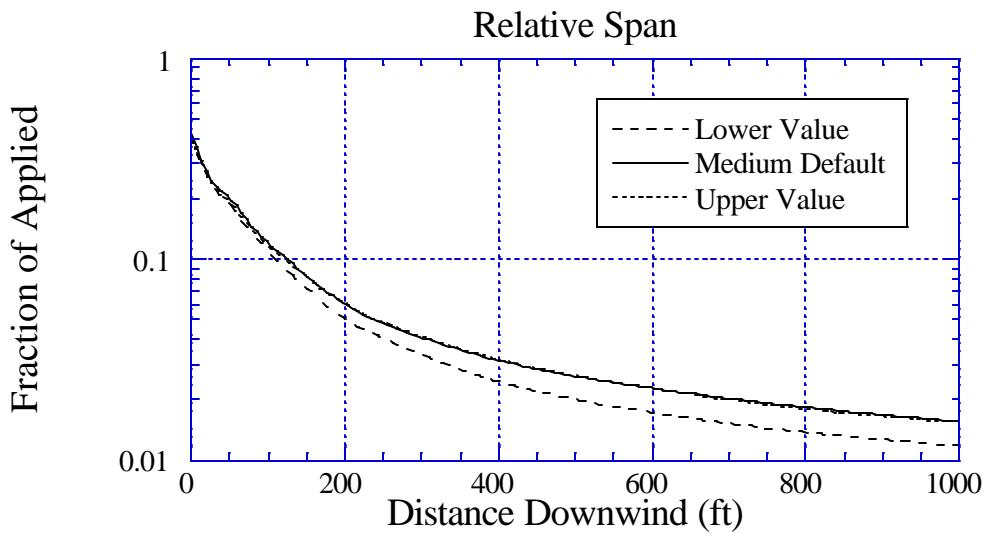


Figure 72b. Sensitivity of deposition to a 10% variation in Relative Span: the solid curve is for the default value of 1.374; the long-dashed curve is for a lower value of 1.236; and the dotted curve is for an upper value of 1.511. BCPC Fine to Medium drop size distribution.

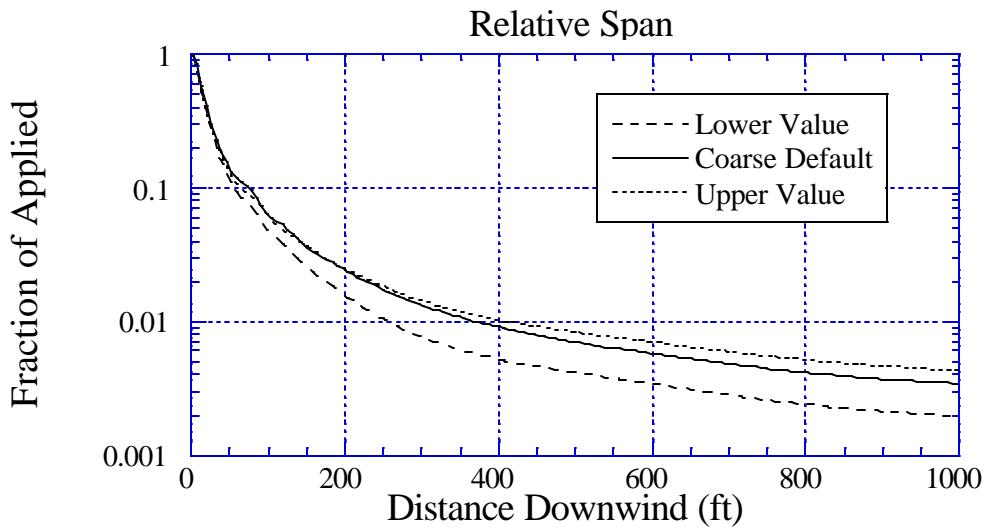


Figure 72c. Sensitivity of deposition to a 10% variation in Relative Span: the solid curve is for the default value of 1.359; the long-dashed curve is for a lower value of 1.223; and the dotted curve is for an upper value of 1.494. BCPC Medium to Coarse drop size distribution.

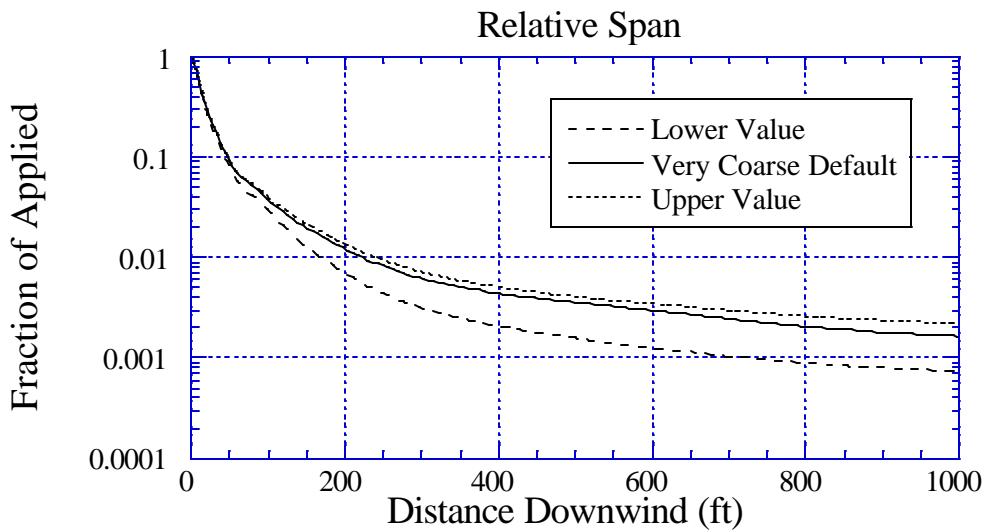


Figure 72d. Sensitivity of deposition to a 10% variation in Relative Span: the solid curve is for the default value of 1.211; the long-dashed curve is for a lower value of 1.090; and the dotted curve is for an upper value of 1.332. BCPC Coarse to Very Coarse drop size distribution.

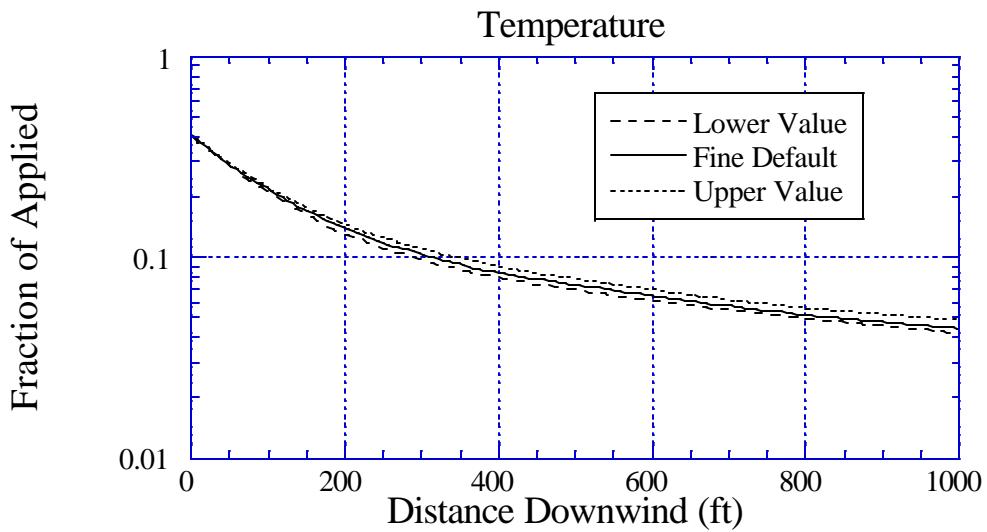


Figure 73a. Sensitivity of deposition to a 10% variation in Temperature: the solid curve is for the default value of 86.0°F; the long-dashed curve is for a lower value of 77.4°F; and the dotted curve is for an upper value of 94.6°F. BCPC Very Fine to Fine drop size distribution.

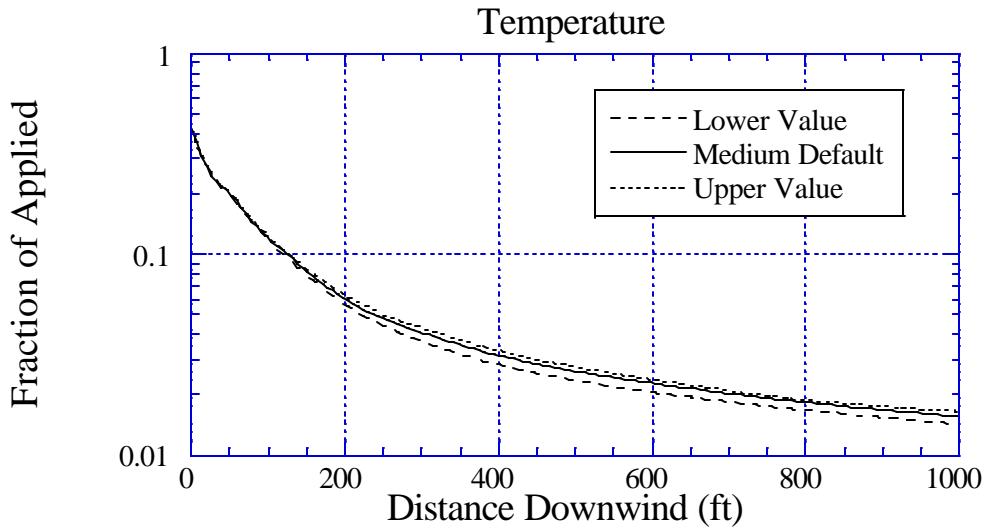


Figure 73b. Sensitivity of deposition to a 10% variation in Temperature: the solid curve is for the default value of 86.0°F; the long-dashed curve is for a lower value of 77.4°F; and the dotted curve is for an upper value of 94.6°F. BCPC Fine to Medium drop size distribution.

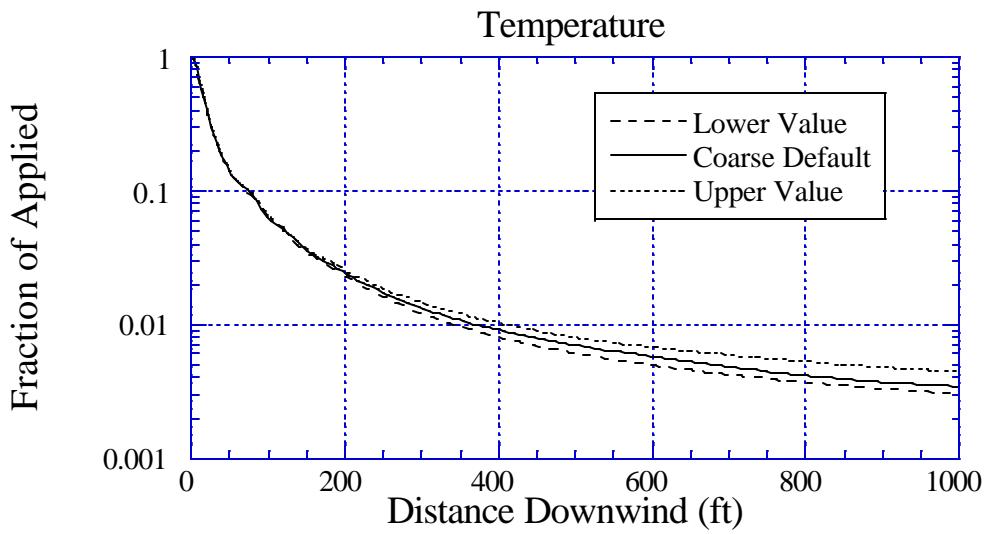


Figure 73c. Sensitivity of deposition to a 10% variation in Temperature: the solid curve is for the default value of 86.0°F; the long-dashed curve is for a lower value of 77.4°F; and the dotted curve is for an upper value of 94.6°F. BCPC Medium to Coarse drop size distribution.

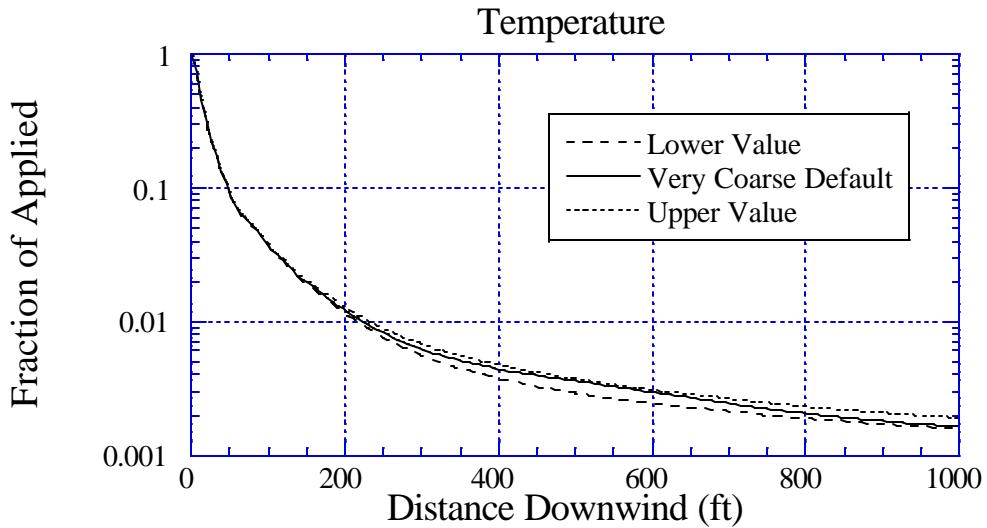


Figure 73d. Sensitivity of deposition to a 10% variation in Temperature: the solid curve is for the default value of 86.0°F; the long-dashed curve is for a lower value of 77.4°F; and the dotted curve is for an upper value of 94.6°F. BCPC Coarse to Very Coarse drop size distribution.

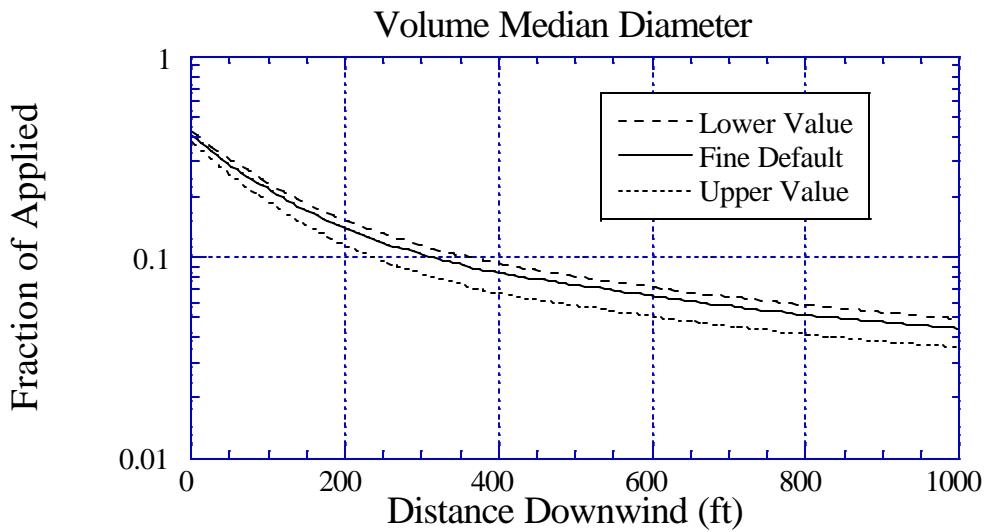


Figure 74a. Sensitivity of deposition to a 10% variation in Volume Median Diameter  $D_{v0.5}$ : the solid curve is for the default value of 119.23  $\mu\text{m}$ ; the long-dashed curve is for a lower value of 107.31  $\mu\text{m}$ ; and the dotted curve is for an upper value of 131.15  $\mu\text{m}$ . BCPC Very Fine to Fine drop size distribution.

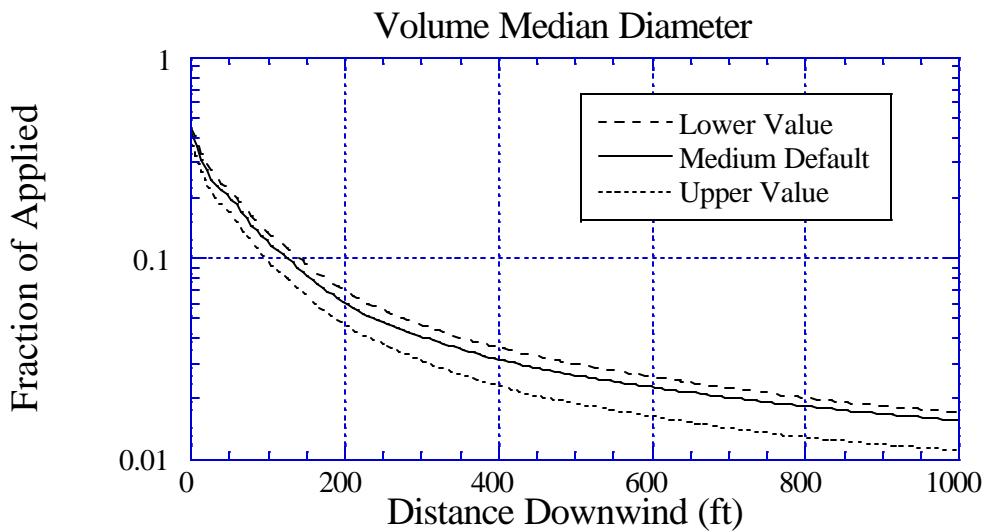


Figure 74b. Sensitivity of deposition to a 10% variation in Volume Median Diameter  $D_{v0.5}$ : the solid curve is for the default value of 216.45  $\mu\text{m}$ ; the long-dashed curve is for a lower value of 194.81  $\mu\text{m}$ ; and the dotted curve is for an upper value of 238.10  $\mu\text{m}$ . BCPC Fine to Medium drop size distribution.

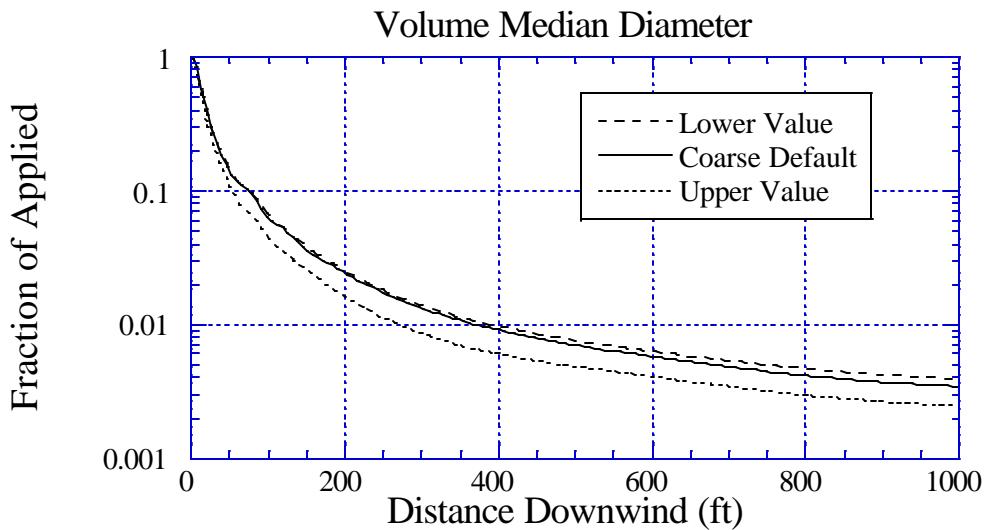


Figure 74c. Sensitivity of deposition to a 10% variation in Volume Median Diameter  $D_{v0.5}$ : the solid curve is for the default value of 352.98  $\mu\text{m}$ ; the long-dashed curve is for a lower value of 317.68  $\mu\text{m}$ ; and the dotted curve is for an upper value of 388.28  $\mu\text{m}$ . BCPC Medium to Coarse drop size distribution.

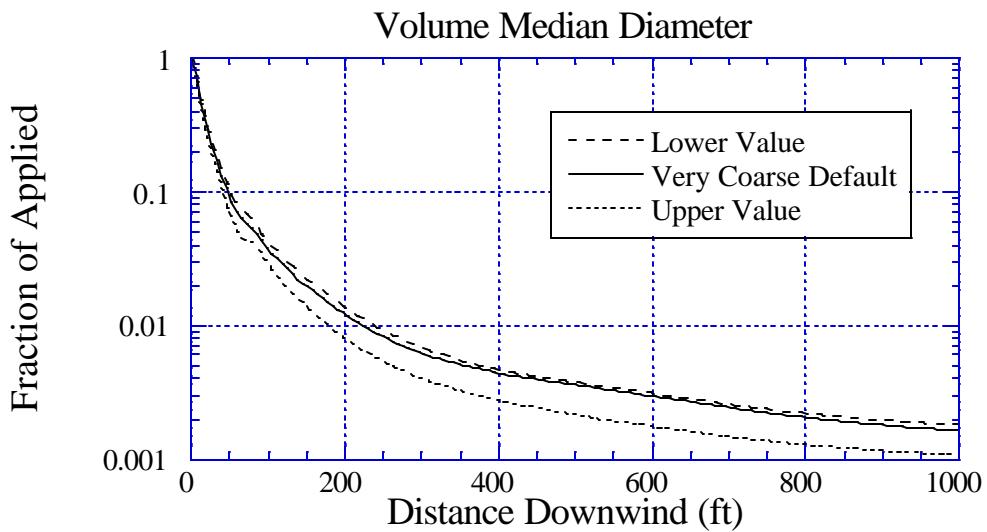


Figure 74d. Sensitivity of deposition to a 10% variation in Volume Median Diameter  $D_{v0.5}$ : the solid curve is for the default value of 463.50  $\mu\text{m}$ ; the long-dashed curve is for a lower value of 417.15  $\mu\text{m}$ ; and the dotted curve is for an upper value of 509.85  $\mu\text{m}$ . BCPC Coarse to Very Coarse drop size distribution.

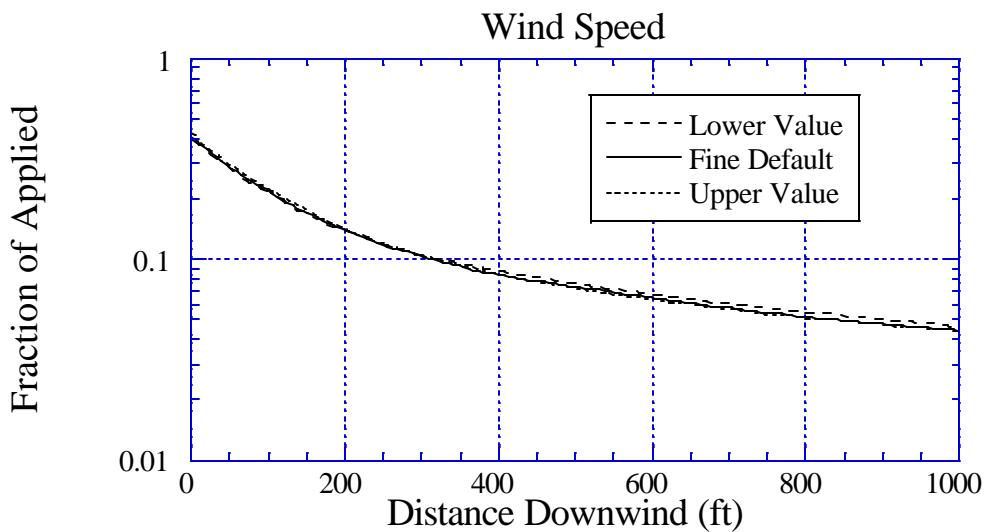


Figure 75a. Sensitivity of deposition to a 10% variation in Wind Speed: the solid curve is for the default value of 10 mph; the long-dashed curve is for a lower value of 9 mph; and the dotted curve is for an upper value of 11 mph. BCPC Very Fine to Fine drop size distribution.

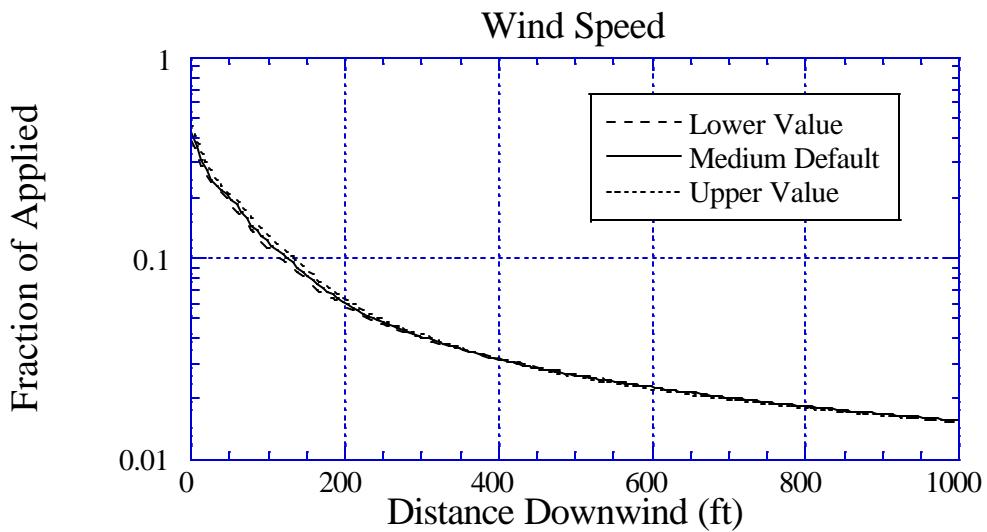


Figure 75b. Sensitivity of deposition to a 10% variation in Wind Speed: the solid curve is for the default value of 10 mph; the long-dashed curve is for a lower value of 9 mph; and the dotted curve is for an upper value of 11 mph. BCPC Fine to Medium drop size distribution.

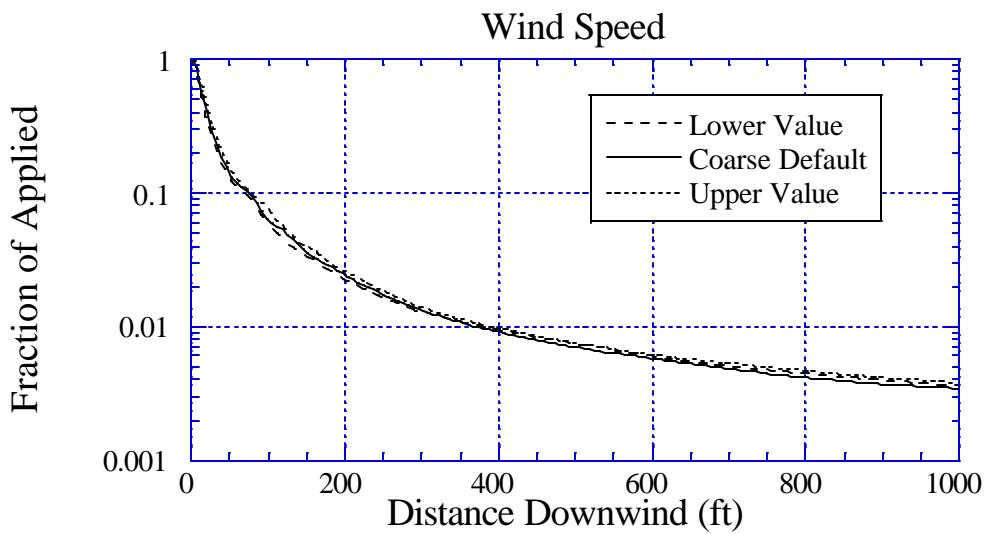


Figure 75c. Sensitivity of deposition to a 10% variation in Wind Speed: the solid curve is for the default value of 10 mph; the long-dashed curve is for a lower value of 9 mph; and the dotted curve is for an upper value of 11 mph. BCPC Medium to Coarse drop size distribution.

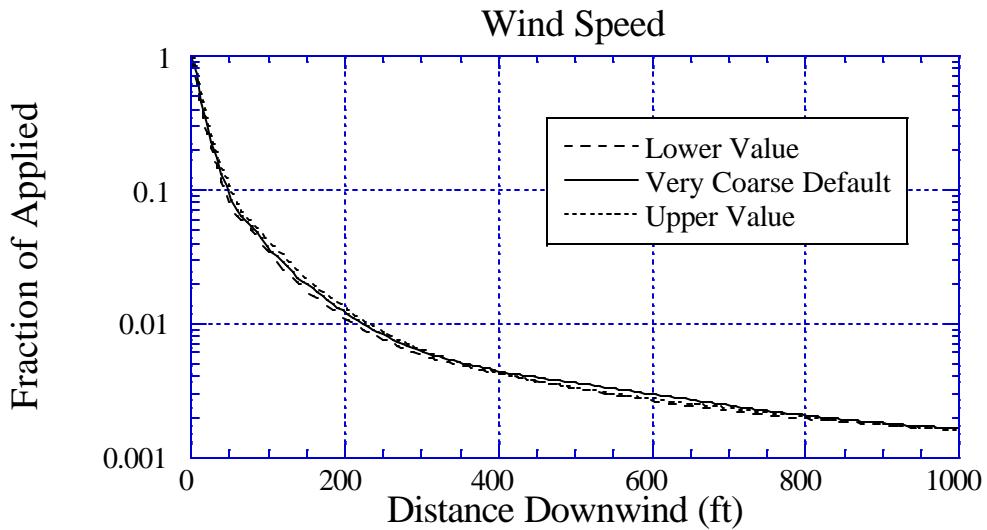


Figure 75d. Sensitivity of deposition to a 10% variation in Wind Speed: the solid curve is for the default value of 10 mph; the long-dashed curve is for a lower value of 9 mph; and the dotted curve is for an upper value of 11 mph. BCPC Coarse to Very Coarse drop size distribution.

Table 7. AgDRIFT® Sensitivity Study Drift Fractions

Sensitivity includes all four BCPC drop size distributions (Very Fine to Fine, Fine to Medium, Medium to Coarse, and Coarse to Very Coarse) for Lower and Upper Values of the variables (defaults given in Table 6); Drift Fractions given in fraction of active spray material passing the edge of the application area

Variable		Fine	Medium	Coarse	Very Coarse
DEFAULT VALUES		0.2213	0.0809	0.0376	0.0240
Boom Height (ft)	Lower	0.1928	0.0683	0.0326	0.0203
	Upper	0.2472	0.0924	0.0432	0.0271
Boom Length (%)	Lower	0.2097	0.0736	0.0338	0.0209
	Upper	0.2260	0.0833	0.0406	0.0268
Nonvolatile Fraction	Lower	0.2268	0.0826	0.0381	0.0242
	Upper	0.2167	0.0793	0.0374	0.0239
Relative Humidity (%)	Lower	0.2295	0.0840	0.0388	0.0243
	Upper	0.2127	0.0769	0.0362	0.0234
Swath Width (ft)	Lower	0.2328	0.0870	0.0421	0.0276
	Upper	0.2111	0.0759	0.0336	0.0208
Temperature (°F)	Lower	0.2138	0.0769	0.0364	0.0234
	Upper	0.2281	0.0826	0.0385	0.0241
D <sub>v0.5</sub> (μm)	Lower	0.2436	0.0941	0.0415	0.0275
	Upper	0.1684	0.0635	0.0310	0.0207
Wind Speed (mph)	Lower	0.2063	0.0734	0.0340	0.0212
	Upper	0.2343	0.0866	0.0412	0.0260

## VIII. Forestry Mode Operation

### A. Tier I and Tier II

Tier I and Tier II options are not available in Forestry Mode.

### B. Tier III Program Extensions

The Tier III main screen (Figure 76) includes the additional inputs:

**Upslope Terrain Angle:** The surface may be represented by a simple up or down slope, where an upslope angle (positive) means that the level aircraft is flying uphill, and a downslope angle (negative) means the level aircraft is flying downhill. An angle input specifies the slope in the flight direction.

**Sideslope Terrain Angle:** The surface may be represented by a simple sideslope, where a positive sideslope means that the right wing tip of the aircraft is closer to the ground than the left wing tip, and a negative sideslope means that the left wing tip is closer to the ground than the right wing tip. An angle input specifies the slope relative to horizontal.

**Canopy:** This button leads to the **Canopy** screen (Figure 77), which permits the user to specify details on the structure of the canopy. In Tier III Forestry Mode, calculations may be carried through the canopy to the ground.

Canopy options are determined at the top of the screen: None, Basic, Story, or Optical. In the Basic option the user enters only the Canopy Height, the height of the canopy cover above the ground. In this option calculations will stop when the canopy height is reached by the spray material. Since boom height is measured from the ground, the aircraft must be positioned above the canopy for a calculation to proceed. The Canopy option may be turned off by setting Canopy Height to zero or selecting the None button.

For Story and Optical canopies the user enters the Element Size of the collector, along with the Temperature and Relative Humidity within the canopy. On the Story screen the user enters the Stand Density (the number of trees per area) and the Tree Height, Tree Diameter, and Probability of Penetration. On the Optical screen the user selects either a library entry (from Witcosky et al. 1999 and Yang et al. 1999) or enters the Tree Height and Cumulative Leaf Area Index. With a library entry selected, the user also enters the Canopy Height and the Canopy LAI (library default values are provided), to scale library results to the specific problem of interest.

If a nonzero canopy height is selected, the Surface Roughness entry on the main screen is dimmed, and replaced by Canopy Roughness and Canopy Displacement. These values

overwrite whatever entries are present for these inputs, consistent with 0.14 and 0.7 times the height of the canopy entered on the Canopy screen, respectively. The Wind Speed above the canopy is adjusted to a height which is twice the Boom Height, at a value consistent with the Height to Wind Speed Measurement (found in Advanced Settings) and the Surface Roughness (when there is no canopy). Limits on model input variables have been relaxed from the Tier III Agricultural Mode (Table 8).

Nonvolatile Rate and Active Rate have been replaced by Nonvolatile Fraction and Active Fraction on the Material screen. Two additional libraries are available in Tier III: Aircraft Library (FS) and Drop Size Distribution Library (FS).

The Aircraft Library (FS) is accessed through a push button on the Aircraft screen (Figure 78), which leads to a new screen (Figure 79). This screen accesses the additional data collected by Hardy (1987), but not verified independently by the SDTF. Menus within the Filter section are available to select the aircraft by name or type. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1<sup>st</sup>**, **Prev**, **Next**, and **Last**. Pressing **OK** moves the selected entry from the library into the edit window of the aircraft screen. Pressing **Cancel** exits the library without changing any current data.

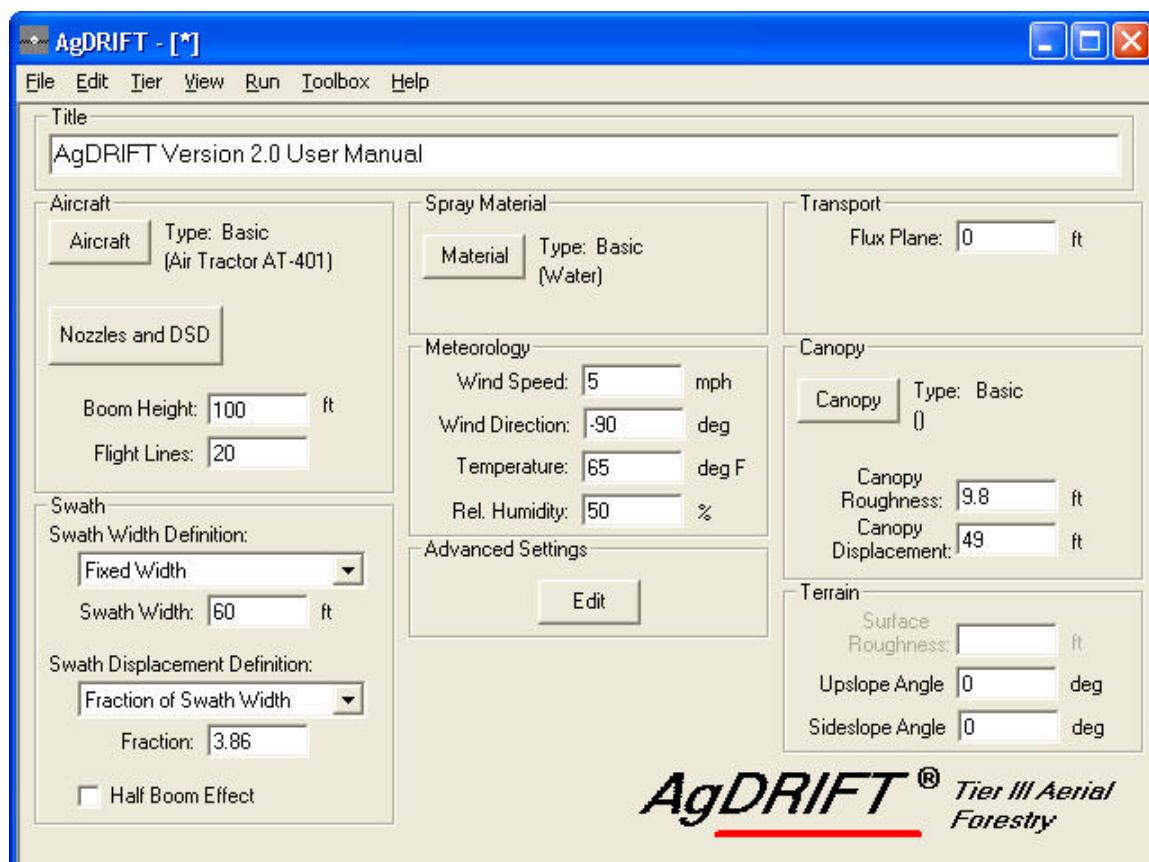


Figure 76. The Tier III input screen in Forestry Mode, with the addition of canopy effects.

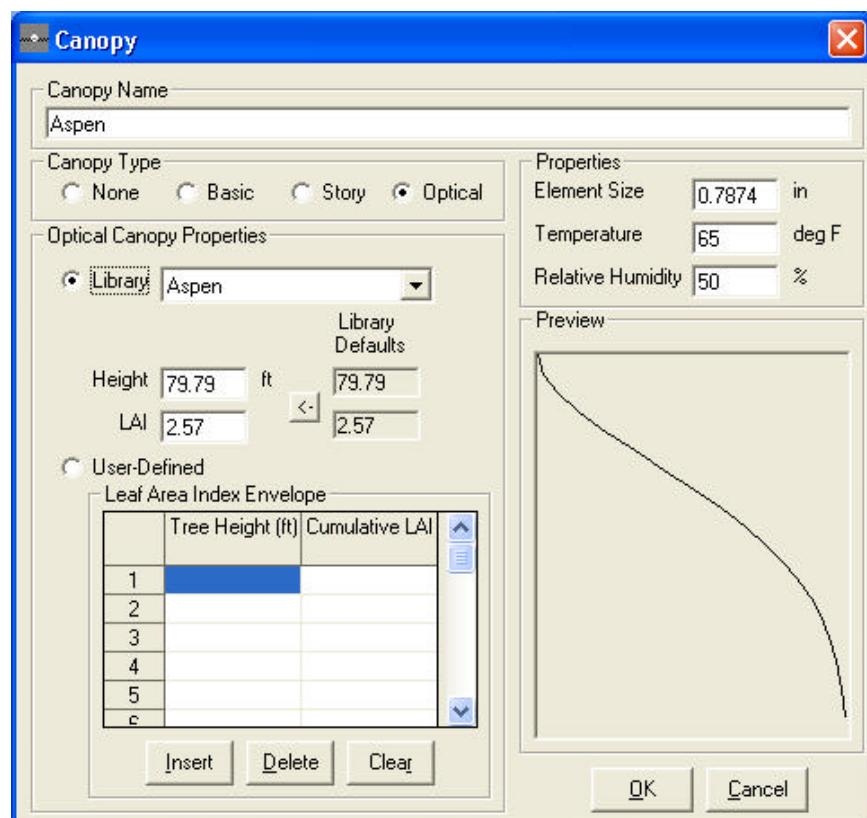
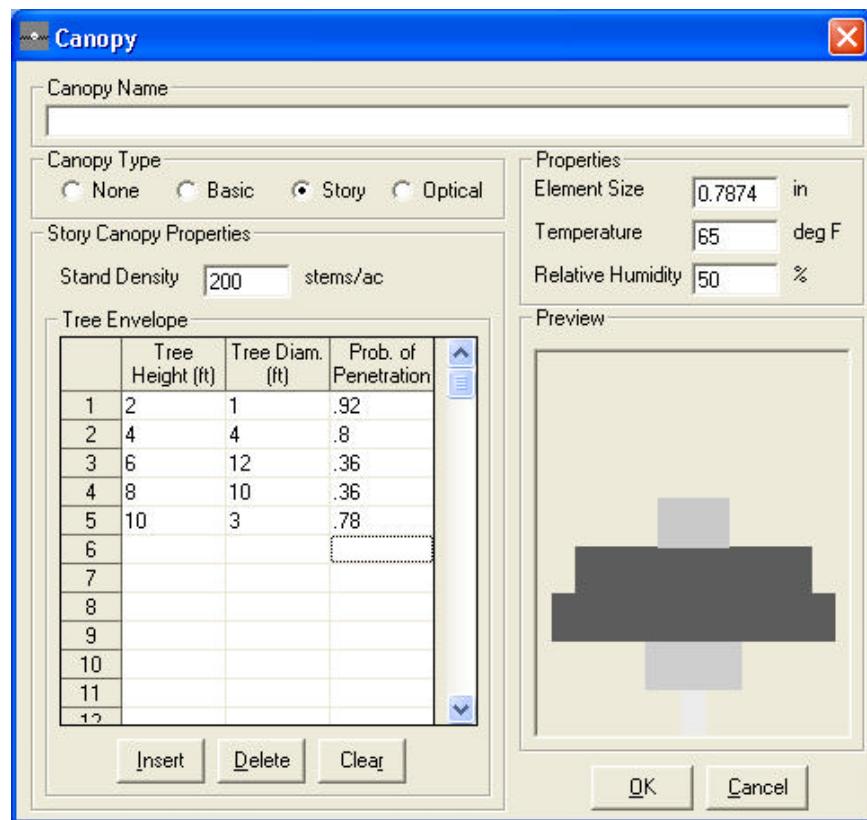


Figure 77. The Canopy input screen in AgDRIFT® Tier III: Story (top); Optical (bottom).

Table 8. Extended AgDRIFT® Tier III Model Limits in Forestry Mode

Variable Name	Lower Limit	Upper Limit
Active Fraction	0.001	Nonvolatile Fraction
Boom Height (ft)	1.0	300.0
Boom Length (%)	0.0	125.0
Surface Roughness (ft)	0.003	3.28
Flux Plane (ft)	0.0	2600.0
Nonvolatile Fraction	Active Fraction	1.0
Number of Flight Lines	1	50
Number of Nozzles	1	60
Relative Humidity (%)	1.0	100.0
Spray Volume Rate (gal/ac)	1.0	100.0
Swath Displacement (ft)	-½ Swath	10 Swaths
Swath Width (ft)	10.0	500.0
Temperature (°F)	32.0	125.0
Wind Speed (mph)	0.5	40.0
Wind Direction (°)	-10.0	-170.0

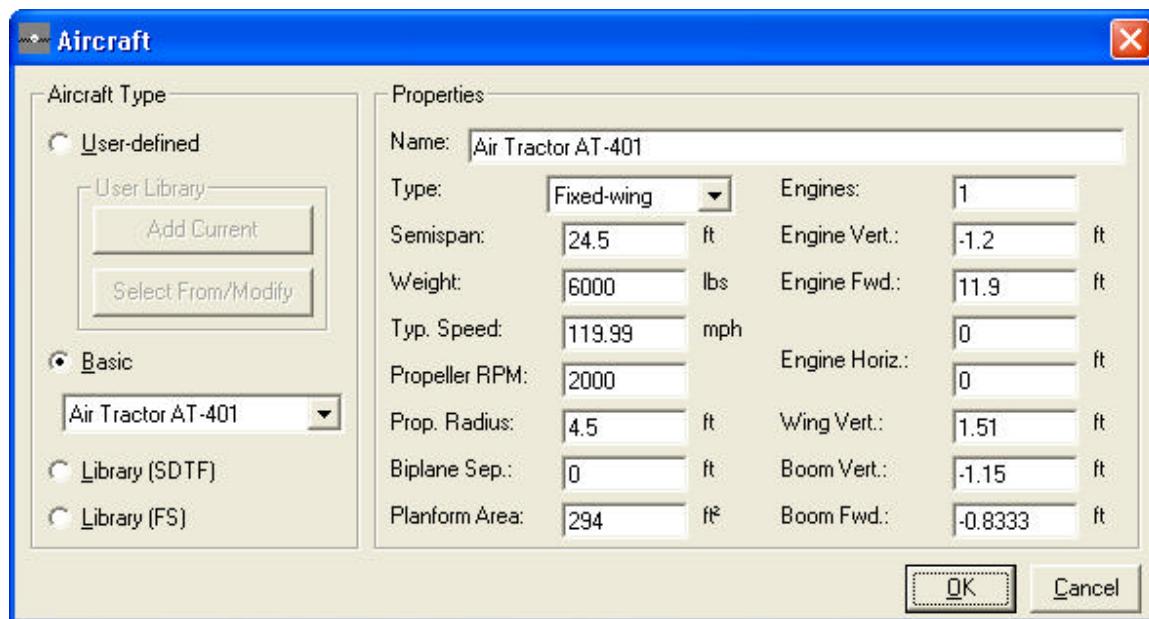


Figure 78. The Tier III Aircraft screen in Forestry Mode, with the addition of Library (FS).

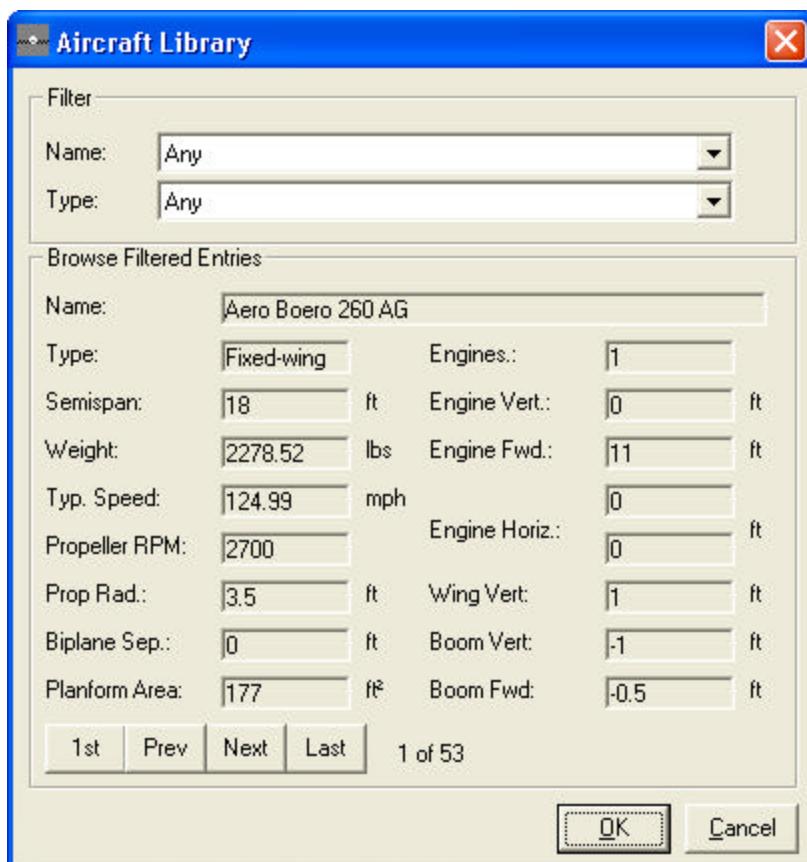


Figure 79. The Library (FS) screen from Aircraft, identical to its Agricultural Mode counterpart except for the number of library entries and their content.

The Drop Size Distribution Library (FS) is accessed through a push button on the Drop Size Distribution screen (Figure 80). The new screen (Figure 81) accesses the data collected by Skyler and Barry (1991). These data were measured with the PMS instrument and have been converted to Malvern instrument equivalent distributions by a Root-Normal technique. The Filter may be used to narrow the field of interest and reduce the number of applicable library entries. Menus within the Filter section are available to select Test Substance, Nozzle, Nozzle Orientation, Nozzle RPM, Nozzle Pressure, and Air Speed. The applicable entries may be examined in the Browse Filtered Entries section, with buttons for **1<sup>st</sup>**, **Prev**, **Next**, and **Last**. Pressing **OK** moves the selected entry from the library into the edit window of the drop size distribution screen. Pressing **Cancel** exits the library without changing any current data.

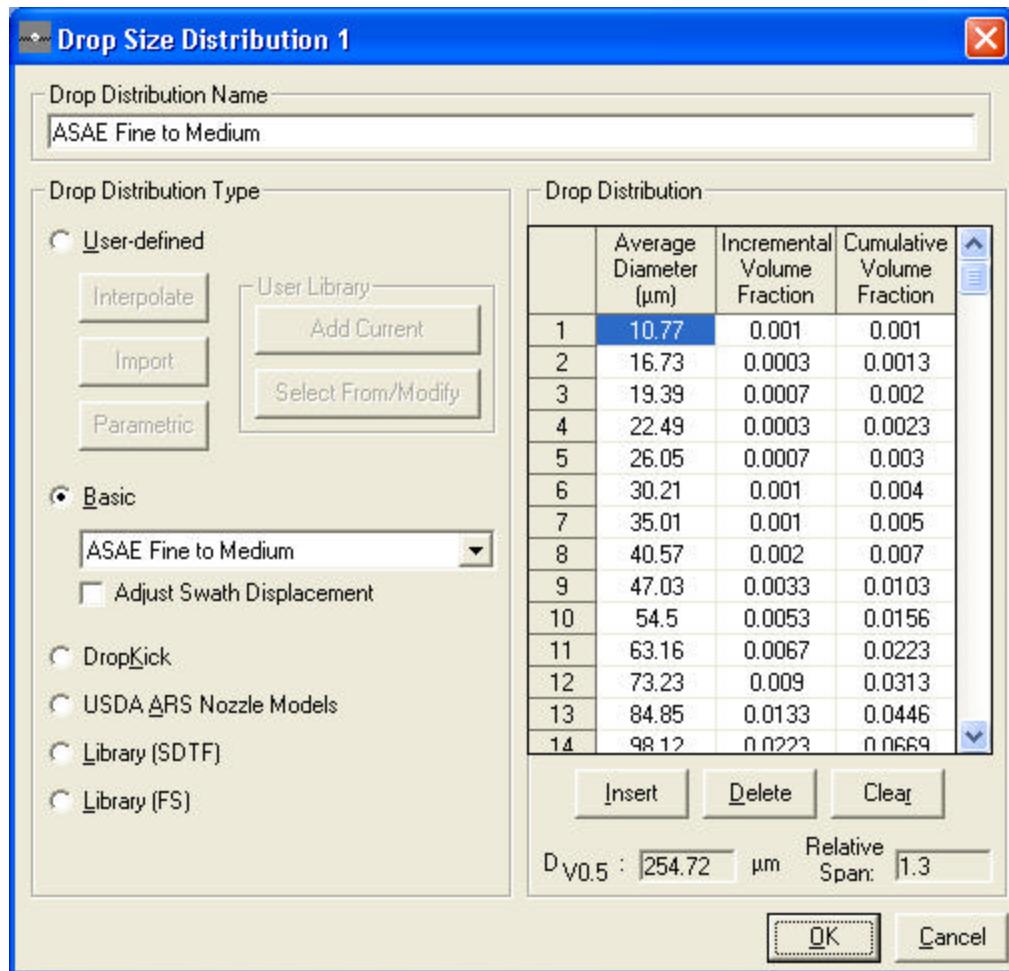


Figure 80. The Tier III Drop Size Distribution screen in Forestry Mode, with the addition of Library (FS).

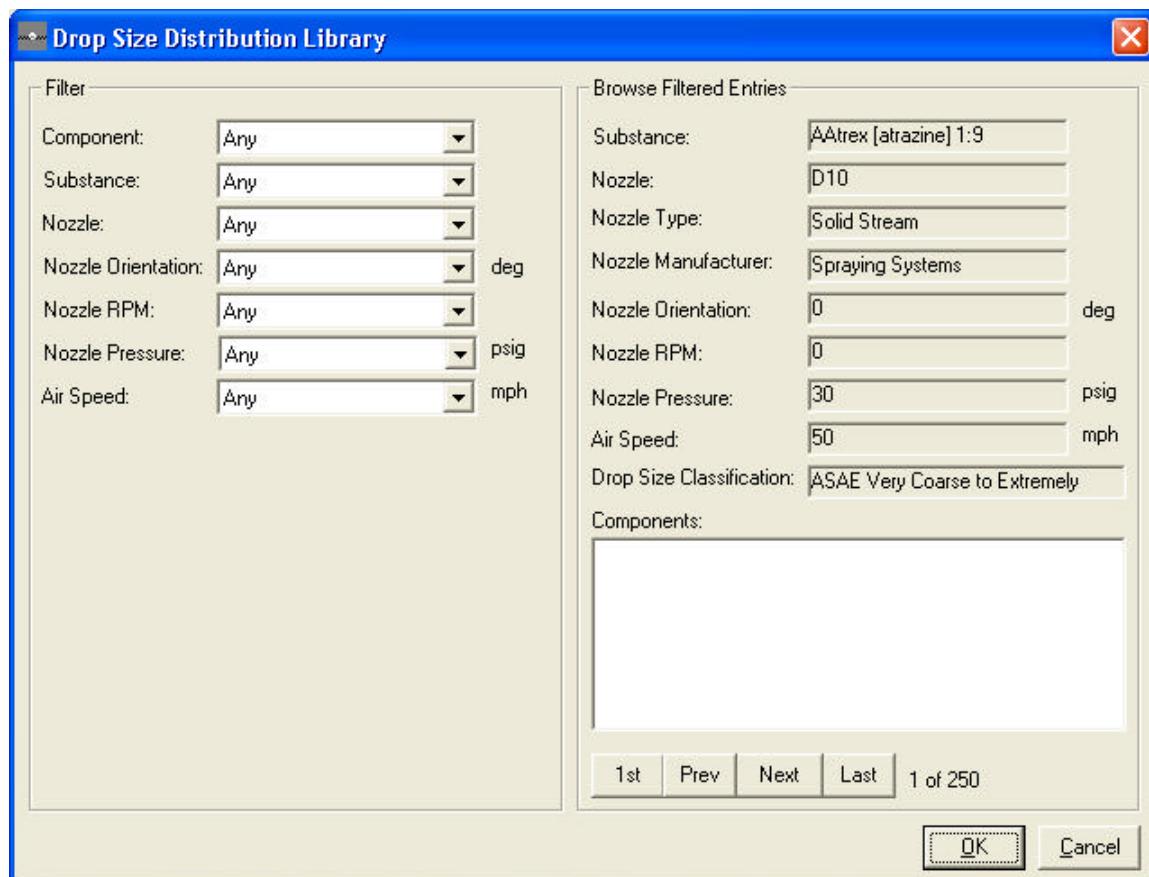


Figure 81. The Library (FS) screen from Drop Size Distribution, identical to its Agricultural Mode counterpart except for the number of library entries and their content, and an active Nozzle RPM. The FS library contains rotary atomizer data.

Under **View**, Tier III menu bar options also permit the plotting of **Settling Velocity** (Figure 82), **Spray Block Drop Size Distribution**, **Canopy Drop Size Distribution**, **Application Layout** (Figure 83), **Spray Block Deposition** (Figure 84), **Spray Block Area Coverage** (Figure 85), **Canopy Deposition** (Figure 86), **Time Accountancy** (Figure 87), **Distance Accountancy** (Figure 88), **Height Accountancy** (Figure 89), and a bar chart of **Total Accountancy**.

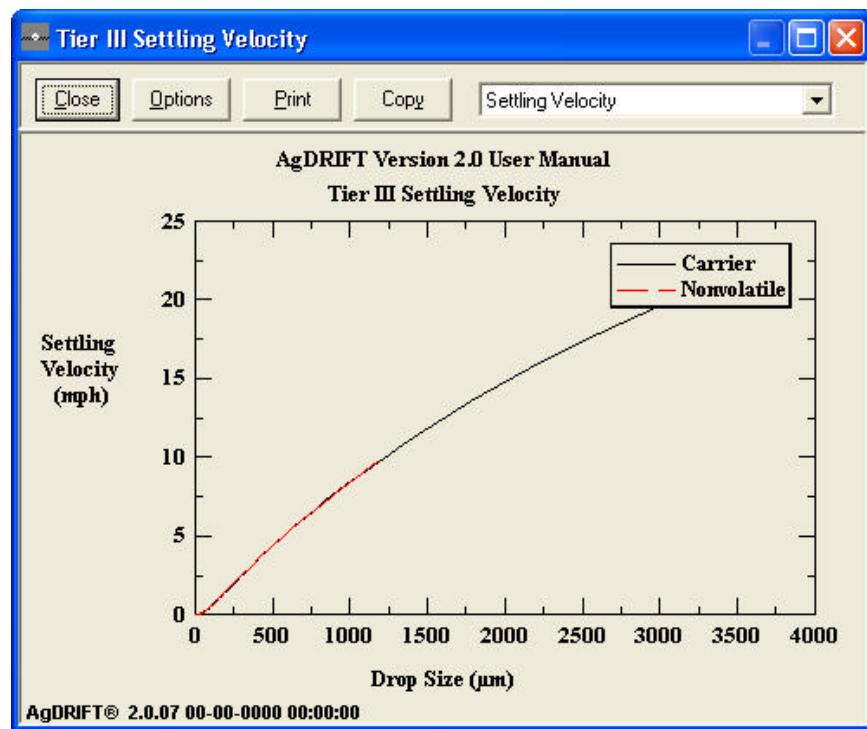


Figure 82. Settling velocity as a function of drop size, for the carrier and nonvolatile fraction assumed. The two curves will be different only if specific gravity is different.

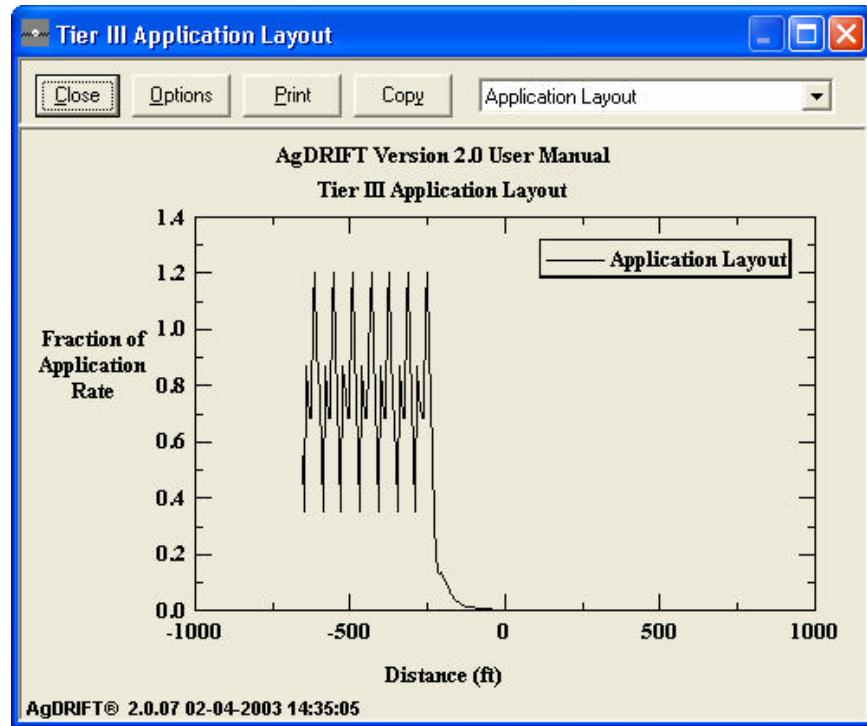


Figure 83. Application layout, combining the spray block deposition (Figure 84) to 630 ft upwind of the edge of the application area (at 0 ft) and the downwind deposition to 1000 ft.

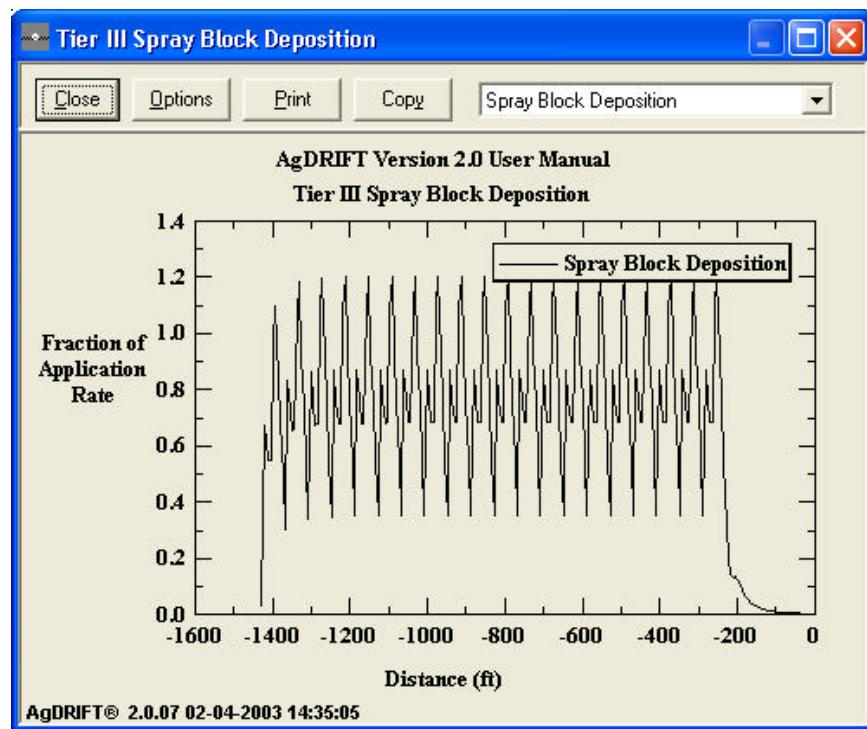


Figure 84. Spray block deposition pattern, measured from the edge of the application area (at 0 ft) upwind into the spray block (20 flight lines assumed in this example).

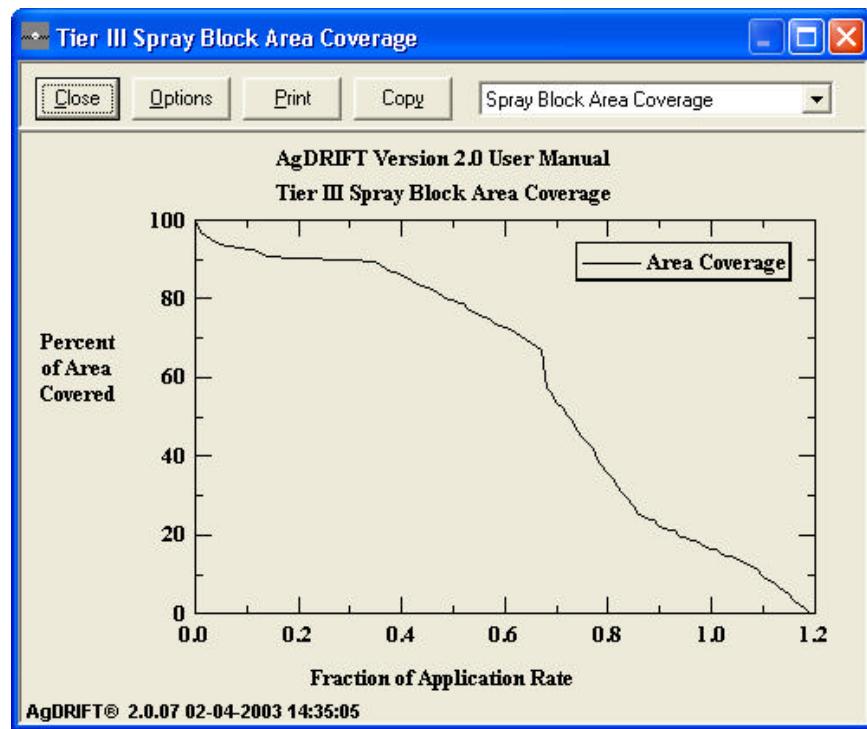


Figure 85. Spray block area coverage, indicating how much area is covered by specified levels of application rate.

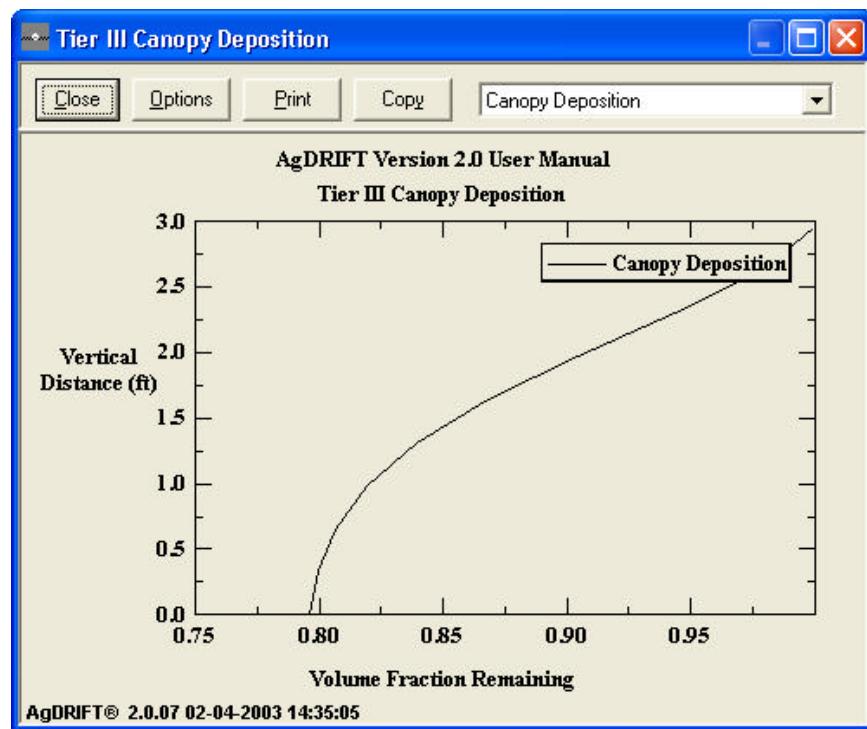


Figure 86. Canopy deposition profile, for an Optical Aspen canopy with a height of 3 ft and a LAI of 0.1. Aircraft boom height is 10 ft.

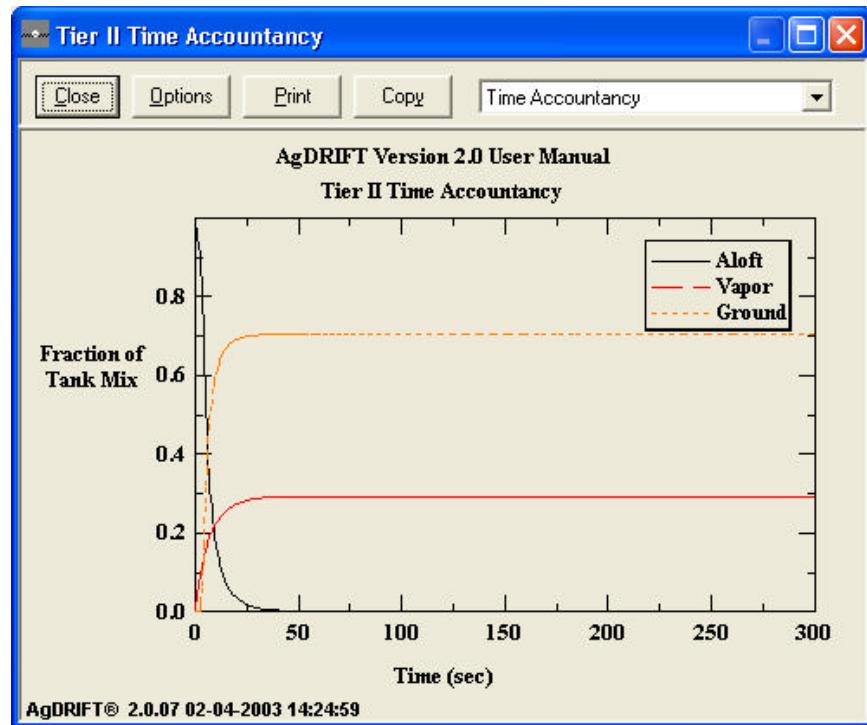


Figure 87. Total accountancy of the released tank mix material, as a cumulative function of time after release.

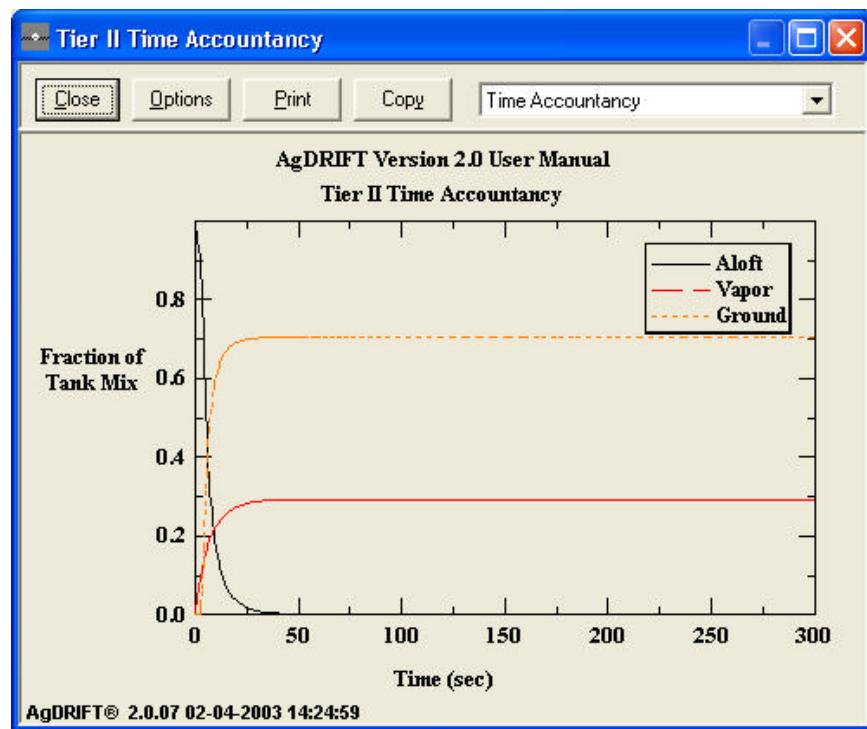


Figure 88. Total accountancy of the released tank mix material, for the most downwind flight line, as a cumulative function of distance.

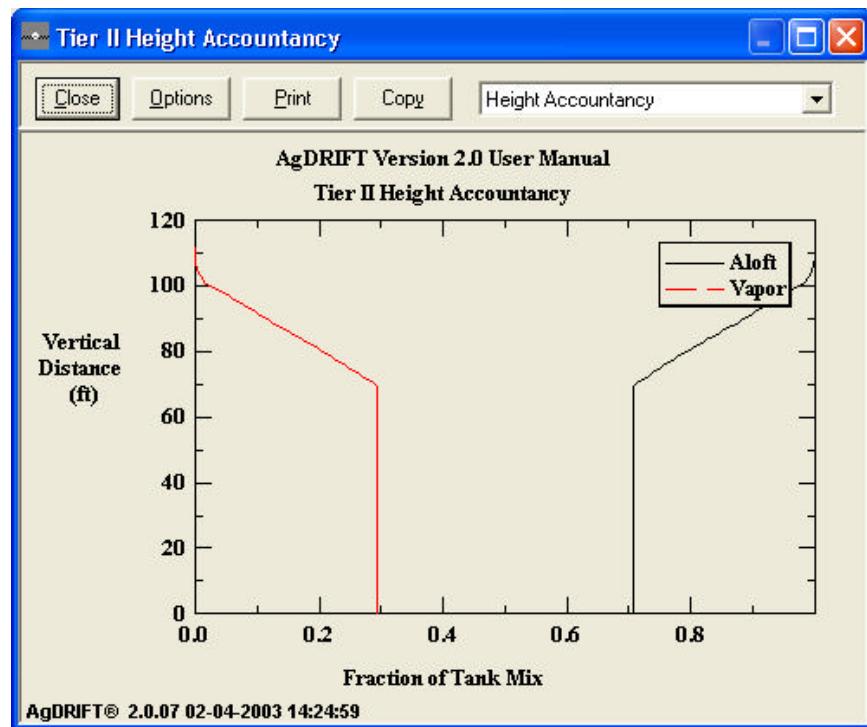


Figure 89. Total accountancy of the released tank mix material, as a cumulative function of height.

Under **Toolbox**, Tier III menu bar options also permit access to **Trajectory Details** and **Spray Block Details**.

The **Trajectory Details** screen (Figure 90) permits the user to enter an initial drop size, then plot either of the three cardinal views of the Lagrangian trajectories developed by the model (from the Rear of the aircraft, from Above the aircraft, or from the Right side of the aircraft looking back). A push button activates the terrain coordinate transformation.

**Spray Block Details** (Figure 91) permits the user to specify the spray block (as a polygon) and recover a contour deposition plot generated by the flight line pattern. Contour deposition may be in specified units, including drops/cm<sup>2</sup>. The user may scribe an area within the deposition pattern and recover statistics on the deposition predicted there (Area Coverage), and specify discrete receptor locations within the spray block and recover a record of the deposition predicted at these locations for the selected type of collector (Discrete Receptors). These inputs are collected in five input/display sections:

**Define** in Spray Block Details (Figure 91) contains three input options. “Spray Block Boundary” opens to a new screen (Figure 92) that displays the X<sub>s</sub> (horizontal coordinates) and Y<sub>s</sub> (vertical coordinates) corners of the polygon-shaped spray block. Import will read an ASCII file for this information (all dimensions must be in meters). Any comment line in the import file must begin with “#” in column one to separate it from the data. The use of Export will save this information in an ASCII file for future reference. It is assumed that the last entered point will be connected to the first entered point. “Discrete Receptors” opens to a new screen (Figure 93) that enables the user to describe the location, type, and orientation of receptors placed in and around the spray block. “Area Coverage Boundary” (Figure 94) enables the user to identify a portion of the spray block, or downwind of the spray block, within which to recover deposition information.

**Flight Direction.** In the main input screen the user specified the wind direction relative to the flight direction. Here the user specifies the wind/flight directions relative to the spray block geometry defined. The sliding scale moves the arrow pointers through a full 360 degree turn.

**Deposition.** The user specifies the contour levels to plot on the spray block (or checks Auto to have them determined by the program), the specific units to view the results, and sets the component type to plot (either the active, nonvolatile, or unevaporated portion of the released spray). When Auto is invoked, the program will generate three deposition contours, at 0.1, 0.01, and 0.001 fraction of the maximum deposition predicted within the spray block.

**Plotting Control.** Check boxes are used to turn on/off the display of selected features such as the spray block boundary, the flight lines, the receptor grid, the deposition contours, and the area coverage boundary.

**Area Coverage.** The results of the calculation for area coverage are displayed (if an area coverage boundary is defined by the user), including the size of the area and the average deposition level within the defined area. A typical result is shown in Figure 95.

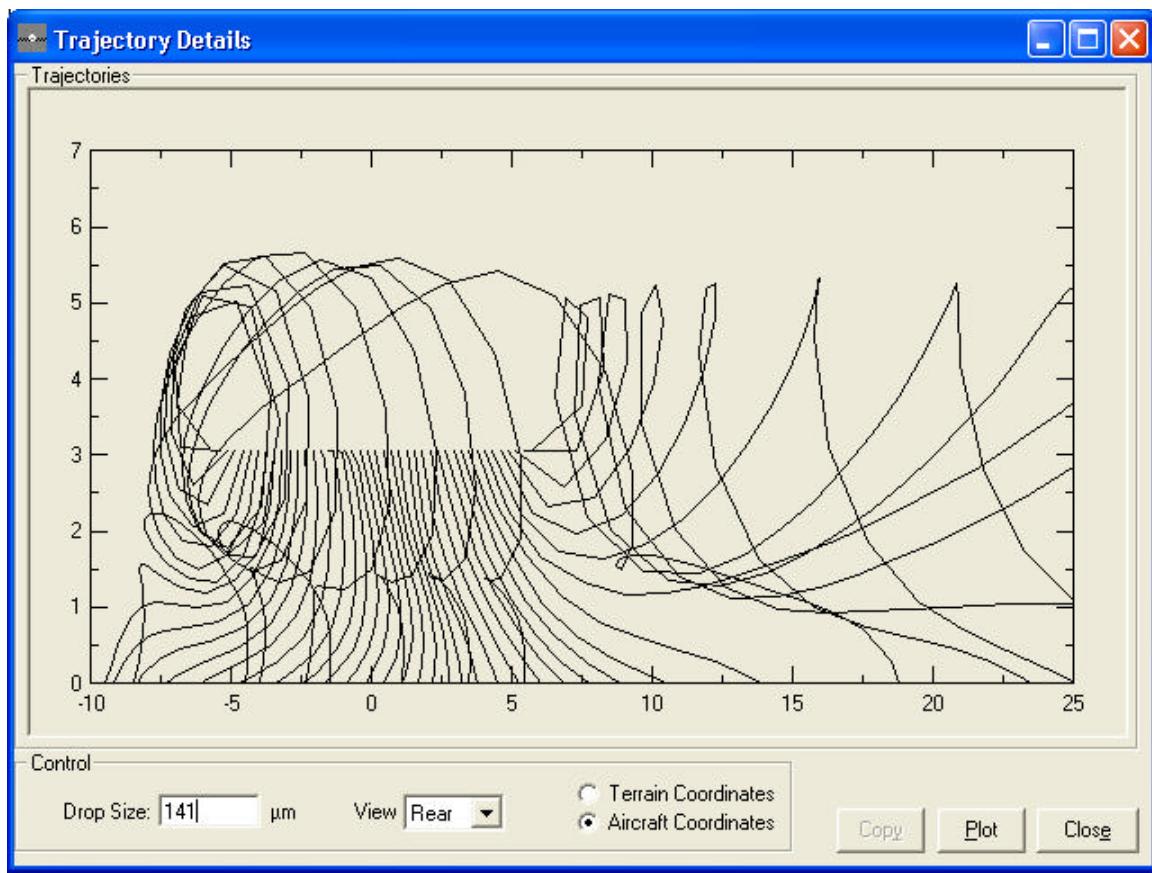


Figure 90. Trajectory Details plot for a 141  $\mu\text{m}$  droplet.

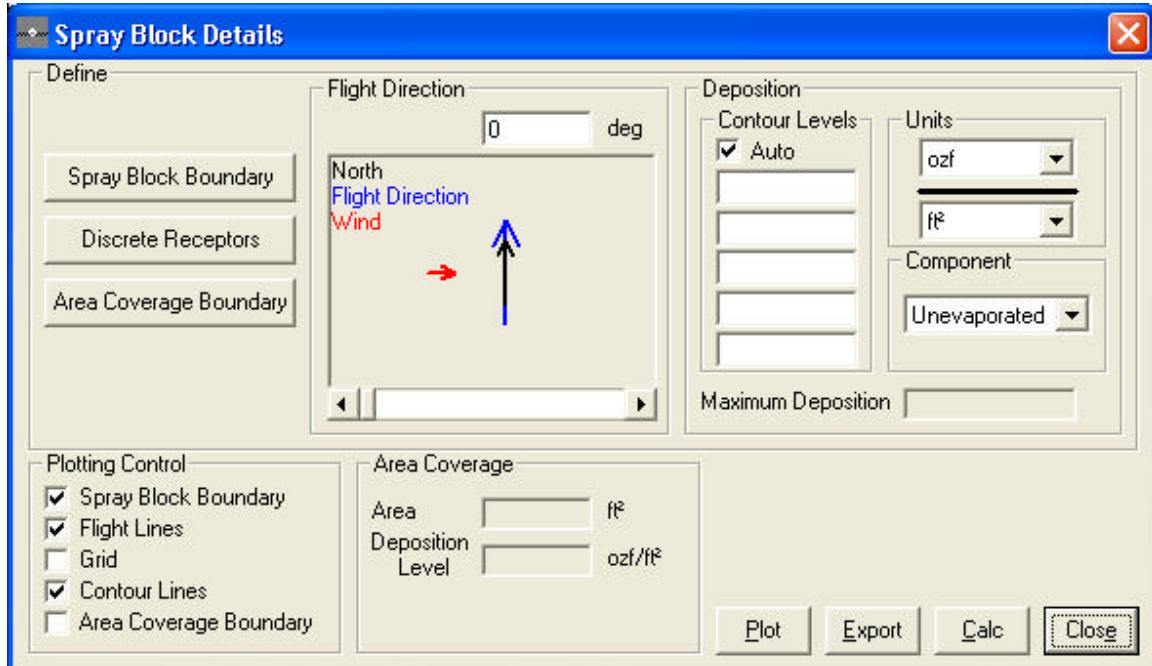


Figure 91. The Spray Block Details toolbox screen.

**Spray Block Boundary**

	Corner X (ft)	Corner Y (ft)
1	0	0
2	328.08	0
3	328.08	328.08
4	0	328.08
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Insert Delete Clear  
Import Export OK Cancel

Figure 92. The Spray Block Boundary table entry screen.

**Discrete Receptors**

	Type	X Location (ft)	Y Location (ft)	Z Location (ft)	X Normal	Y Normal	Z Normal	Size (in)	Deposition (ozf/ft <sup>2</sup> )
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									

Insert Delete Clear Import Export OK Cancel

Figure 93. The Discrete Receptors table entry screen. Inputs are: collector type (either default flat card with a collection efficiency of 100%, flat card or ribbon, cylinder, or sphere); ( $X_s, Y_s, Z_s$ ) receptor location; ( $X_s, Y_s, Z_s$ ) outward normal; and characteristic size of the collector (width for flat card or ribbon, diameter for cylinder and sphere). Once a calculation has completed, the last column (deposition) will be filled with the predicted values.

**Area Coverage Boundary**

	Corner X (ft)	Corner Y (ft)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		

Figure 94. The Area Coverage Boundary table entry screen.

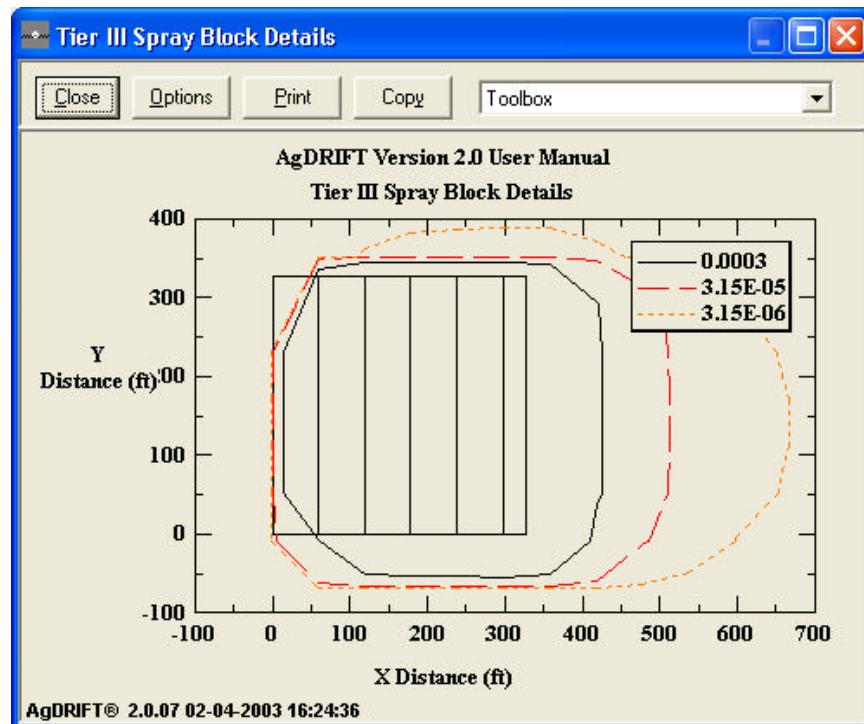


Figure 95. Spray Block Details contour results for ASAE S-572 Fine to Medium drop size distribution with zero swath displacement. Deposition is in ozf/ft<sup>2</sup>.

## IX. Summary and Future Model Update

The proposed tiered assessment method presents the user with three levels of increasing input complexity with which to determine buffer zones upwind of sensitive habitats or evaluate mitigation options. The primary utility of Tier I is to provide a rapid estimate of possible hazards and the potential for buffer zones to protect downwind sensitive habitats – both terrestrial and aquatic – based on proposed application rates and product-specific toxicity. Tier III aerial analyses are available to refine use patterns, define labeling alternatives, and/or predict whether a specific product possesses characteristics that would indicate less drift potential.

AgDRIFT® is an on-going project supported by the USDA Forest Service, USDA Agricultural Research Service, US Environmental Protection Agency, and the Spray Drift Task Force. Comments and suggestions for improvements and additional features are welcome.

## X. Trademarks

Microsoft® is a registered trademark, and Windows™ and Visual Basic™ are trademarks of Microsoft Corporation in the USA and other countries. AgDRIFT® is a computer model developed by the USDA Forest Service, USDA Agricultural Research Service, US Environmental Protection Agency, and the Spray Drift Task Force under a Cooperative Research and Development Agreement. AgDRIFT® and DropKick® are registered trademarks of the Spray Drift Task Force. The Color, File Browser, Font, Help, and Print screens are application products available with Visual Basic™.

## XI. Model References

The following peer-reviewed references are cited as background and supporting documentation for the development of the AgDRI<sup>TM</sup> and DropKick<sup>TM</sup> models:

- Anderson, D. E., D. R. Miller, Y. Wang, W. G. Yendol, K. Mierzejewski and M. L. McManus. 1992. Deposition of Aerially Applied Bt in an Oak Forest and its Prediction with the FSCBG Model. *Journal of Applied Meteorology* 31:1457-1466.
- Barry, J. W., P. J. Skyler, M. E. Teske, J. E. Rafferty and B. S. Grim. 1993. Predicting and Measuring Drift of *Bacillus thuringiensis* Sprays. *Environmental Toxicology and Chemistry* 12:1977-1989.
- Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation. *Transactions of the ASAE* 32(1):327-334.
- Quackenbush, T. R., M. E. Teske and C. E. Polymeropoulos. 1994. A Microcomputer Model for Assessing Fuel Jettisoning Effects. *Atmospheric Environment* 28:2751-2759.
- Rafferty, J. E. and J. F. Bowers. 1993. Comparison of FSCBG Spray Model Predictions with Field Measurements. *Environmental Toxicology and Chemistry* 12:465-480.
- Teske, M. E. and J. W. Barry. 1993. Parametric Sensitivity in Aerial Application. *Transactions of the ASAE* 36(1):27-33.
- Teske, M. E., J. W. Barry and H. W. Thistle. 1995. Environmental Fate and Accountancy. Biorational Pest Control Agents: Formulation and Delivery. F. R. Hall and J. W. Barry (eds). American Chemical Society Symposium Series No. 595. 95-107.
- Teske, M. E., J. W. Barry and H. W. Thistle. 1996. FSCBG Predictions Coupled to GPS/GIS Aircraft Tracking. Pesticide Formulations and Application Systems: 15<sup>th</sup> Volume. ASTM STP 1268. H. M. Collins, F. R. Hall and M. J. Hopkinson (eds). American Society for Testing and Materials: Philadelphia, PA. 15-28.
- Teske, M. E., J. W. Barry and H. W. Thistle. 1996. FSCBG Predictions of Biological Dose Response Coupled to Decision Support. Pesticide Formulations and Application Systems: 16<sup>th</sup> Volume. ASTM STP 1312. M. J. Hopkinson, H. M. Collins and G. R. Gross (eds). American Society for Testing Materials: Philadelphia, PA. 93-103.
- Teske, M. E., K. P. Bentson, R. E. Sandquist, J. W. Barry and R. B. Ekblad. 1991. Comparison of FSCBG Model Predictions with Heather Seed Orchard Deposition Data. *Journal of Applied Meteorology* 30(9):1366-1375.

Teske, M. E. and A. J. Bilanin. 1994. Drop Size Scaling Analysis of Non-Newtonian Fluids. *Atomization and Sprays* 4(4):473-483.

Teske, M. E., A. J. Bilanin and J. W. Barry. 1993. Decay of Aircraft Vortices Near the Ground. *AIAA Journal* 31(8):1531-1533.

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. 1993. FSCBG: An Aerial Spray Dispersion Model for Predicting the Fate of Released Material Behind Aircraft. *Environmental Toxicology and Chemistry* 12(3):453-464.

Teske, M. E., C. G. Hermansky and C. M. Riley. 1998. Evaporation Rates of Agricultural Spray Material at Low Relative Wind Speeds. *Atomization and Sprays* 8(4):471-478.

Teske, M. E., A. E. Kaufman, C. W. George and G. M. Johnson. 1997. Field Measurements of Helicopter Rotor Wash in Hover and Forward Flight. *Journal of Aircraft* 34(6):813-814.

Teske, M. E. and H. W. Thistle. 1999. A Simulation of Release Height and Wind Speed Effects for Drift Minimization. *Transactions of the ASAE* 42(3):583-591.

Teske, M. E. and H. W. Thistle. 2000. Droplet Size Scaling of Agricultural Spray Material by Dimensional Analysis. *Atomization and Sprays* 10:147-158.

Teske, M. E., H. W. Thistle, J. W. Barry and B. Eav. 1998. A Simulation of Boom Length Effects for Drift Minimization. *Transactions of the ASAE* 41(3):545-551.

Teske, M. E., H. W. Thistle and B. Eav. 1998. New Ways to Predict Aerial Spray Deposition and Drift. *Journal of Forestry* 96(6):25-31.

Teske, M. E., H. W. Thistle and R. E. Mickle. 2000. Modeling Finer Droplet Aerial Spray Drift and Deposition. *Applied Engineering in Agriculture* 16(4):351-357.

## XII. References

- Bilanin, A. J. and M. E. Teske. 1984. Numerical Studies of the Deposition of Material Released from Fixed and Rotary Wing Aircraft. NASA CR 3779: Langley, VA.
- Bilanin, A. J., M. E. Teske, J. W. Barry and R. B. Ekblad. 1989. AGDISP: The Aircraft Spray Dispersion Model, Code Development and Experimental Validation. *Transactions of the ASAE* 32(1):327-334.
- Bird, S. L., D. M. Esterly and S. G. Perry. 1996. Off-Target Deposition of Pesticides from Agricultural Aerial Spray Applications. *Journal of Environmental Quality* 25(5):1095-1104.
- Bird, S. L., S. G. Perry, S. L. Ray and M. E. Teske. 2002. Evaluation of the AGDISP Aerial Spray Algorithms in the AgDRIFT® Model. *Environmental Toxicology and Chemistry* 21(3):672-681.
- Burns, L. A. 1997. Exposure Analysis Modeling System (EXAMS II): User's Guide for Version 2.97.5. EPA/600/R-97/047.
- Calder, K. L. 1977. Multiple-Source Plume Models of Urban Air Pollution – Their General Structure. *Atmospheric Environment* 11:403-414.
- Carslaw, H. S. and J. C. Jaeger. 1959. Conduction of Heat in Solids. Oxford University Press.
- Cramer, H. E., J. R. Bjorklund, F. A. Record, R. K. Dumbauld, R. N. Swanson, J. E. Faulkner and A. G. Tingle. 1972. Development of Dosage Models and Concepts. Report No. DTC-TR-72-609-I. U. S. Army Dugway Proving Ground: Dugway, UT.
- Doble, S. J., G. A. Matthews, I. Rutherford and E. S. E. Southcombe. 1985. A System for Classifying Hydraulic Nozzles and Other Atomisers into Categories of Spray Quality. Proceedings of the British Crop Protection Conference 3:1125-1133. Weeds, England.
- Dumbauld, R. K., J. E. Rafferty and J. R. Bjorklund. 1977. Prediction of Spray Behavior Above and Within a Forest Canopy. Report No. TR-77-308-01. USDA Forest Service: Portland, OR.
- Dumbauld, R. K., J. R. Bjorklund and S. F. Saterlie. 1980. Computer Model for Predicting Aircraft Spray Dispersion and Deposition Above and Within Forest Canopies: Users Manual for the FSCBG Computer Program. Report No. 80-11. USDA Forest Service: Davis, CA.
- Esterly, D. M. 1998. Neural Network Analysis of Spray Drift Task Force Atomization DropKick® II. Paper No. 981014. ASAE Annual Meeting: Orlando, FL.

Fischer, H. B., E. J. List, R. C. Y. Koh, J. Imberger and N. H. Brooks. 1979. Mixing in Inland and Coastal Waters. Academic Press.

Gaidos, R. E., M. R. Patel and D. L. Valcore. 1992. Model for Prediction of Spray Drift Deposition from Aerial Applications of Pesticides. DowElanco Report No. DECO-NCM-3604.

Herdan, G. 1960. Small Particle Statistics. Butterworths, London. p. 33.

Hardy, C. E. 1987. Aerial Application Equipment. Report No. 8734-2804 MEDC. USDA Forest Service Equipment Development Center, Missoula, MT.

Hewitt, A. J. 1995. Spray Drift Task Force Atomization Drop Size Spectra for Selected Active Ingredients. Study No. A92-004. EPA MRID No. 43766502.

Hewitt, A. J. 1996. Spray Drift Task Force Atomization Drop Size Spectra for Nozzle and Physical Property Parameter Characterization. Study No. A92-003. EPA MRID No. 44100901.

Johnson, D. R. 1995a. Drift from Applications with Ground Hydraulic Sprayers: Integration and Summary of 1992 and 1993 Field Studies. Study No. I94-001. EPA MRID No. 43508001.

Johnson, D. R. 1995b. Drift from Orchard Airblast Applications: Integration and Summary of 1993 and 1994 Field Studies. Study No. I95-004. EPA MRID No. 43925701.

Kidd, F. A. 1994. 1992 Spray Drift Task Force Survey of Aerial Applicators.

Kirk, I. W. 1997. Application Parameters for CP Nozzles. Paper No. AA97-006. 1997 ASAE/NAAA Joint Technical Session: Las Vegas, NV.

Kirk, I. W. 1998. Spray Quality from CP Straight Stream Nozzles. Paper No. AA98-002. 1998 ASAE/NAAA Joint Technical Session: Reno, NV.

Kirk, I. W. 1999. Spray Quality Options with Aerial Straight Stream Nozzles. Paper No. AA99-006. 1999 ASAE/NAAA Joint Technical Session: Reno, NV.

Kirk, I. W. 2000. Spray Quality for Helicopter Spray Nozzles. Paper No. AA00-006. 2000 ASAE/NAAA Joint Technical Session: Reno, NV.

Koch, R. C. and S. D. Thayer. 1972. Sensitivity Analysis of the Multiple-Source Gaussian Plume Urban Diffusion Model. Proceedings of the Conference on Urban Environment and Second Conference on Biometeorology. American Meteorological Society: Boston, MA. 68-76.

Koch, R. C. and S. D. Thayer. 1974. Validity of the Multiple-Source Gaussian Plume Diffusion Model Using Hourly Estimates of Input. Proceedings of the Fifth Meeting of the Expert Panel on Air Pollution Modeling. NATO Committee on the Challenges of Modern Society: Ruskilde, Denmark.

MacNichol, A. Z. 1994. Spray Drift Task Force Aircraft Sensitivity Study. Technical Note No. 93-20. Continuum Dynamics, Inc.: Ewing, NJ.

Mugele, R. and H. D. Evans. 1951. Drop Size Distributions in Sprays. *Industrial and Engineering Chemistry* 43:1317-1324.

Parkin, C. S. and J. C. Wyatt. 1982. The Determination of Flight-Line Separations for the Aerial Application of Herbicides. *Crop Protection* 1(3):309-321.

Parkin, C. S., A. J. Gilbert, E. S. E. Southcombe and C. J. Marshall. 1994. British Crop Protection Council Scheme for the Classification of Pesticide Application Equipment by Hazard. *Crop Protection* 13(4):281-285.

Press, W. H., S. A. Teukolsky, W. T. Vetterling and B. P. Flannery. 1992. Numerical Recipes in FORTRAN – The Art of Scientific Computing. Cambridge University Press. pp. 402-406.

Quantick, H. R. 1985. Aviation in Crop Protection, Pollution and Insect Control. Collins, London. pp. 256-270.

Reed, W. H. 1953. An Analytical Study of the Effect of Airplane Wake on the Lateral Dispersion of Aerial Sprays. NACA TN 3032.

Richardson, B., J. W. Barry, M. E. Teske and J. W. Ray. 1996. SpraySafe Manager: An Aerial Application Decision Support System that Integrates Predictions of Deposition and Drift with Biological Response and Economic Models. Paper No. 961057. ASAE Annual Meeting: Phoenix, AZ.

Rosin, P. and E. Rammler. 1933. The Laws Governing the Fineness of Powdered Coal. *Journal of the Institute of Fuel* 7(31):29-36.

Skyler, P. J. and J. W. Barry. 1991. Final Report – Compendium of Drop Size Spectra Compiled from Wind Tunnel Tests. Report No. FPM 90-9. USDA Forest Service Forest Pest Management, Davis, CA.

Simmons, H. C. 1977. The Correlation of Drop-Size Distributions in Fuel Nozzle Sprays. *Transactions of the ASME Journal of Engineering for Power* 99:309-314.

Southcombe, E. S. E. 1988. The Coding and Selection of Agricultural Spraying Nozzles. Proceedings of the U. S. Agricultural Research Institute Workshop on Improving On-Target Placement of Pesticides: Reston, VA.

Tate, R. W. and W. R. Marshall. 1953. Atomization by Centrifugal Pressure Nozzles. *Chemical Engineering Progress* 49:226-234.

Teske, M. E. 1992. Spray Drift Task Force Sensitivity Analysis. Technical Note No. 91-04. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E. and J. W. Barry. 1993. Parametric Sensitivity in Aerial Application. *Transactions of the ASAE* 36(1):27-33.

Teske, M. E. and A. J. Bilanin. 1993. Drop Size Scaling Analysis of Non-Newtonian Fluids. Report No. FPM 93-11. USDA Forest Service: Davis, CA.

Teske, M. E., J. F. Bowers, J. E. Rafferty and J. W. Barry. 1993. FSCBG: An Aerial Spray Dispersion Model for Predicting the Fate of Released Material Behind Aircraft. *Environmental Toxicology and Chemistry* 12(3):453-464.

Teske, M. E. 1996. Evaluation of the FSCBG Aerial Spray Model's Near-Wake Sensitivity to Selected Input Parameters. Report No. FHTET 96-30. USDA Forest Service: Davis, CA.

Teske, M. E. and A. Z. MacNichol. 1996. An Interpretation of the RPC Evaporation Data. Technical Note No. 94-05. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E. and T. B. Curbishley. 1998a. Implementing a Verified Near-Wake Model into Spray Advisor. Technical Note No. 98-12. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E., C. G. Hermansky and C. M. Riley. 1998a. Evaporation Rates of Agricultural Spray Material at Low Relative Wind Speeds. *Atomization and Sprays* 8(4):471-478.

Teske, M. E., H. W. Thistle, J. W. Barry and B. Eav. 1998b. A Simulation of Boom Length Effects for Drift Minimization. *Transactions of the ASAE* 41(3):545-551.

Teske, M. E., H. W. Thistle and B. Eav. 1998c. New Ways to Predict Aerial Spray Deposition and Drift. *Journal of Forestry* 96(6):25-31.

Teske, M. E. 1999. Stream Modeling Assessment with AgDRIFT<sup>®</sup>: An Update. Technical Bulletin. Research Triangle Park, N.C.: National Council of the Paper Industry for Air and Stream Improvement, Inc.

Teske, M. E. and H. W. Thistle. 1999. A Simulation of Release Height and Wind Speed Effects for Drift Minimization. *Transactions of the ASAE* 42(3):583-591.

Teske, M. E. 2000a. Implementation of the Spray Drift Task Force Ground Sprayer Data in AgDRIFT® 2.0. Technical Note No. 98-07. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E. 2000b. Implementation of the Spray Drift Task Force Orchard Airblast Sprayer Data in AgDRIFT® 2.0. Technical Note No. 98-08. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E. 2000c. Multiple Application Assessment in AgDRIFT® 2.0. Technical Note No. 00-02. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E. 2000d. Stream Modeling Assessment with AgDRIFT®. Technical Bulletin No. 808. Research Triangle Park, N.C.: National Council of the Paper Industry for Air and Stream Improvement, Inc.

Teske, M. E. and T. B. Curbishley. 2000. The Inclusion of the USDA Forest Service Aerial Application Model into AgDRIFT® 2.0. Report No. 99-05. Continuum Dynamics, Inc.: Ewing, NJ.

Teske, M. E., S. L. Bird, D. M. Esterly, T. B. Curbishley, S. L. Ray and S. G. Perry. 2002. AgDRIFT®: A Model for Estimating Near-Field Spray Drift from Aerial Applications. *Environmental Toxicology and Chemistry* 21(3):659-671.

Teske, M. E. and G. G. Ice. 2002. A One-Dimensional Model for Aerial Spray Assessment in Forest Streams. *Journal of Forestry* 100(3):40-45.

Weeks, J. A., H. R. Blacksten and S. D. Coffey. 1982. Recommended Development Plan for an Aerial Spray Planning and Analysis System (ASPAS). Report No. FPM 82-2. USDA Forest Service: Davis, CA.

Witcosky, J. J., X. H. Yang and D. R. Miller. 1999. The Vertical Canopy Structure of Hardwood Forests in the Eastern United States. Report No. FHTET-97-08. USDA Forest Service: Morgantown, WV.

Yang, X. H., J. J. Witcosky and D. R. Miller. 1999. Vertical Overstory Canopy Architecture of Temperate Deciduous Hardwood Forests in the Eastern United States. *Forest Science* 45(3):1-10.

## APPENDIX A: Lagrangian Model History

To predict aerial spray deposition and drift, we must first approximate the background atmospheric and aircraft wake behavior, then determine the effects of the atmosphere and aircraft wake on the released spray material. The approaches considered when aerial spray models were first developed included both Gaussian and Lagrangian formulations.

By the late 1960s provision had been made in the U. S. Army's Gaussian modeling techniques to account for the loss of material by gravitational settling of droplets from elevated spray clouds, and to predict the resulting surface deposition patterns. Additional algorithms considered the penetration of droplets into canopies, simple expressions for wake effects of spray aircraft, and droplet evaporation. This work was largely a collaboration by the USDA Forest Service and the U. S. Army with H. E. Cramer and his associates (Cramer et al. 1972; Dumbauld et al. 1977, 1980). The computer code that resulted was called FSCBG (for Forest Service Cramer-Barry-Grim after its developers), detailed in Teske et al. (1993).

In 1979 Continuum Dynamics, Inc. began developing a Lagrangian model for the dispersal of spray material, utilizing the equations for particle motion first suggested by Reed (1953), and culminating in a model for NASA (Bilanin and Teske 1984) known as AGDISP (for AGricultural DISPersal). This approach included models for aircraft wake effects (vortices, propellers, and jet engines) and evaporation, and subsequently became the near-wake model for FSCBG. The AGDISP technology has become the computational engine of choice in all active near-wake models in the United States, Canada, and New Zealand. Further development and refinement led to AgDRIFT®, as well as SpraySafe Manager (Richardson et al. 1996) and GypsES Spray Advisor (Teske and Curbishley 1998a).

Both FSCBG and AGDISP (as well as all subsequent models) trace their origins to 1981, when the USDA Forest Service contracted with Ketron, Inc. to review the potential for developing and implementing a consistent and inclusive aerial spray model, using as a basis the first released version of FSCBG (Dumbauld et al. 1980). The final report (Weeks et al. 1982) is most impressive for the future vision included in its recommendations. Those familiar with the model at that time were perhaps unaware of its potential in the areas suggested, especially as a predictive platform for the development of decision support. Subsequent tasking implemented many of the report's suggestions, and brought model development to its present operational level.

Concurrent with model development has been an emphasis on model validation. A summary of such activities from the perspective of the USDA Forest Service may be found in Teske et al. (1998c). A companion analysis of SDTF field studies may be found in Bird et al. (2002), along with the current development status of the model (Teske et al. 2002; Teske and Curbishley 2000).

## APPENDIX B: Stream Assessment Model

The stream assessment solution in AgDRIFT® is obtained from the solution to a one-dimensional, unsteady advection-diffusion equation of the form

$$\frac{\partial C}{\partial t} + U \frac{\partial C}{\partial x} = D \frac{\partial^2 C}{\partial x^2} - nC$$

where  $C$  is concentration,  $t$  is time,  $U$  is the average stream flow speed,  $x$  is distance downstream,  $D$  is the diffusion coefficient, and  $n$  is the fractional rate of diffused material removed from the stream by means other than diffusion. The diffusion coefficient (Fischer et al. 1979) may be interpreted as

$$D = \frac{0.11Uw^2}{d}$$

where  $w$  is the average stream width and  $d$  is the average stream depth. The stream is assumed to flow parallel to the flight lines of the aircraft (for the initial loading of the stream only), and be located at a distance  $Y$  downwind of the most downwind flight line. Infinite diffusion rate is assumed to occur across the assumed rectangular cross-section of the stream when recovering the initial concentration.

The solution begins with an initial “top hat” concentration from the aerial spray (whose length is the length of the flight lines) on a flight line by flight line basis, and is integrated across the time and distance specified by the user until the concentration reaches a low value. The solution for each flight line is the product of the exact solution to the diffusion equation (Carslaw and Jaeger 1959, page 54) and an exponential term representing the nondiffusive decay, and is of the form

$$C = \frac{C_i}{2} \left[ \operatorname{erf}\left(\frac{a-y}{2\sqrt{Dt}}\right) + \operatorname{erf}\left(\frac{a+y}{2\sqrt{Dt}}\right) \right] \exp(-nt)$$

where  $C_i$  is initial concentration,  $a$  is one-half the length of the spray block ( $x = 0$  is at the direct downwind center of the spray block),  $y = x - Ut$  corrects downstream distance for convection,  $\operatorname{erf}$  is the error function, and  $\exp$  is the exponential function. The most downwind flight line is assumed to deposit to the stream at  $t = 0$ . Each upwind flight line deposits to the stream at uniformly increasing increments in time

$$\Delta t = m \left[ t_{turn} + \frac{2a}{U_\infty} + \frac{s}{U_{ws} \cos(\theta)} \right]$$

where  $m$  is the flight line counter ( $m = 1$  is the first flight line upwind of the most downwind flight line),  $t_{\text{turn}}$  is the aircraft turning time from one flight line to the next,  $s$  is swath width,  $U_{ws}$  is wind speed, and  $\theta$  is the angle of the wind from direct crosswind. The location of the center of the flight line deposit to the stream occurs at increasing distances from the center of the spray block

$$\Delta x = (Y + ms) \tan(\theta)$$

where  $m = 0$  recovers the most downwind flight line deposit location when  $\theta \neq 0$  (otherwise  $\Delta x = 0$ ). The initial concentration to the stream will change with each flight line because of the increasing swath width offset. Superposition generates the complete deposit pattern.

Details of the model, and comparisons with available data, may be found in Teske (1999, 2000d) and Teske and Ice (2002).

## Appendix C: Multiple Application Assessment Model

Multiple Application Assessment is based on repeated implementation of the single-event predictions, but with wind speed and wind direction for each application selected from a climatological wind rose appropriate for the user's selected spray site. The wind rose is created from representative near-surface data considering wind speed ranges and months of application selected by the user. Controlled sampling techniques (Koch and Thayer 1972, 1974; Calder 1977) are then applied to extract 100 sets of N wind speeds and wind directions (where N is the number of applications in a year). The single-event AgDRIFT® computes the spray deposition patterns for a range of wind speeds and perpendicular wind direction, and then adjusts the deposition patterns for each of the 100 times N sets of wind speeds and wind directions. The MAA tool selects the set of N spray depositions providing the 95<sup>th</sup> percentile highest weighted and summed depositions in the dominant downwind direction (the direction in which sensitive area receptors are assumed to exist). This set of N deposition curves is then output in a form desirable to the EXAMS model. The controlled sampling process is then repeated for each year of multiple application that the user desires to provide to EXAMS.

### A. SAMSON Database

NREL (National Renewable Energy Laboratory) recently published a 30-year compendium of meteorological data at 239 sites within the United States (1961-1990 National Solar Radiation Data Base, Version 1.0). This database (Solar And Meteorological Surface Observational Network, or SAMSON) enables the recovery of wind speed, wind direction, temperature, and relative humidity hourly statistics at any of the recorded sites (the entire database has been downloaded and configured into Library entries in AgDRIFT®, along with 20 sites in Canada).

### B. Wind Rose Generation

From the database we first extract all of the data for wind speed (m/s) and wind direction (from North in increments of 10°) at the selected site (temperature and relative humidity are also extracted to recover monthly averages). Because we are interested in data only when it is reasonable to expect aerial application spray projects to occur, we limit the data by: (1) retaining only daylight hours (sunrise to sunset, including the hours they occur in), by using an algorithm that determines these times based on latitude, longitude, time zone, and Julian day; (2) removing all null data; and (3) correcting wind speed to a height of 2 m (from an assumed tower height of 10 m) and discarding all wind speeds below and including 1 m/s as light and variable. The resulting data comprise a site entry in the AgDRIFT® Library.

The user then selects the month interval over which spraying occurs, and the maximum wind speed to consider. With this information the applicable data are then used to determine the dominant wind direction across the months and wind speeds selected. To do so, the entries

in each wind direction ( $10, 20, \dots, 360^\circ$ ) are summed for all wind speeds and months selected. A direction-weighting function is then applied

$$TF(A) = F(A) + F(A \pm 10) \cos(10) + \dots + F(A \pm 60) \cos(60)$$

where  $TF$  is the total frequency of occurrence and  $F$  is the frequency at each angle  $A$  in deg. The dominant wind direction is taken as the angle with the largest  $TF$  value, and used to center the wind rose. The total of all frequencies in the wind rose sums to unity.

### C. AgDRIFT® Model Runs

AgDRIFT® calculations are then made for all integer wind speeds from 1 m/s to the maximum wind speed considered, for the application conditions desired by the user (aircraft type, boom height, spray material, etc.). Wind direction is assumed to be normal to the flight lines and directly downwind.

### D. Controlled Sampling

In all cases we assume that 100 replications will be computed to generate one controlled sample (this step makes it easy to find the 95<sup>th</sup> percentile of the predictions). The user enters the number of applications per year (up to a maximum of 30) and the number of years to examine (up to a maximum of 60). A random seed (set at 0.42) begins the analysis.

Controlled sampling is a way of extracting representative wind speeds across incremental wind directions from 0 to  $360^\circ$ . Because of the way it is developed, controlled sampling will always produce some wind directions that blow away from the direction of sensitive receptors, and hence produce no ground deposition in some probabilistic realizations. That is, not all of the  $N$  applications will necessarily contribute to the multiple application impact. This is the effect we are looking for.

For each sample for each year, the process: (1) generates a cumulative sum over all wind speeds for each wind direction; (2) randomly selects a cumulative frequency (between 0 and 1), which determines a wind direction, with uniform cumulative frequency intervals equal to the number of applications per year, to generate the number of applications needed and recover their wind directions (although the cumulative frequency intervals are uniform – and wrap-around – the recovered wind directions are not uniformly incremented); (3) locates these wind directions within the  $10^\circ$  wind direction intervals; and (4) for each selected wind direction recovers its wind speed frequency and randomizes the wind speeds to randomize the wind speed frequency array, then makes a random selection of frequency to recover the selected wind speed. This process essentially selects representative wind speeds and wind directions from the cumulative sum of all wind speeds and wind directions found in the database and the cumulative wind rose.

If, for example, ten applications were made per year to a specified field ( $N = 10$ ), one controlled sampling would recover ten wind speeds and wind directions. Overall, controlled sampling develops 100 sets of ten such combinations of wind speeds and wind directions. Because the flight lines are assumed to be infinitely long, a wind direction not normal to the flight lines will multiply the wind speed by the cosine of the angle difference, to give an effective crosswind speed (all wind direction differences greater than  $60^\circ$  are assumed to be blowing upwind and generate zero deposition downwind). The effective crosswind speed is interpolated across the AgDRIFT® deposition profiles to recover the deposition at all downwind distances for one combination of wind speed and wind direction. This process is repeated for all wind speed and wind direction combinations.

The wind speed and wind direction combinations are then ranked so as to extract the 95<sup>th</sup> percentile set. The assumption is made that every part of the deposition profile is important; therefore, the ten deposition profiles (one for each combination of wind speed and wind direction – ten combinations are assumed in this example) are scaled by their distance-appropriate means and standard deviations, referenced to the overall mean and standard deviation of the ten profiles (zero deposition entries are not included in this portion of the analysis). The formula for correcting each deposition value is

$$D_{\text{new}} = M_e + (D - M_y) \sigma_e / \sigma_y$$

where  $D_{\text{new}}$  is the corrected deposition value at any distance and for any wind speed and wind direction combination;  $M_e$  is the mean value across all ten deposition profiles;  $D$  is the original AgDRIFT® deposition value at the distance considered;  $M_y$  is the mean value across all ten profiles at the distance considered;  $\sigma_e$  is the average relative standard deviation across all ten profiles; and  $\sigma_y$  is the relative standard deviation across all ten profiles at the distance considered (standard deviation is normalized by  $M_y$  to recover relative standard deviation). The ten applications (in this example) are then added together at all distances to produce a single effective deposition value that is ranked, and from which the 95<sup>th</sup> percentile set is extracted. The ten combinations of wind speed and wind direction that make up the 95<sup>th</sup> percentile are recovered, and generate ten deposition profiles that represent the multiple applications to the field.

## APPENDIX D: Interpolation Methods

Three techniques are available in AgDRIFT® to interpolate minimal information about the drop size distribution, and curvefit to recover a representation of the complete distribution. This Appendix summarizes these techniques.

### A. Root Normal

In this technique (Simmons 1977, from an idea he attributed to Tate and Marshall 1953) the cumulative volume fraction (CVF) is plotted on a normal probability distribution scale Pr as a function of the square root of the drop diameter D. If drop diameters are further normalized by VMD, a least squares fit through the drop size distribution plotted in these coordinates yields a straight line

$$\sqrt{\frac{D}{VMD}} = a \text{Pr(CVF)}$$

At its midpoint CVF = 0.5, Pr(0.5) = 0, and drop diameter D equals VMD. The VMD and slope of the straight line s become the curve-fitting parameters. Evaluation of these two parameters determines the entire drop size distribution (making use of the inverse of the normal probability distribution function).

It may be noticed (Teske and Bilanin 1993) that slope is related to the Relative Span (RS) of the distribution

$$s = 0.195 \text{ RS}$$

### B. Rosin-Rammler

The most widely-used expression for drop size distribution is the Rosin-Rammler logarithmic normal representation (Rosin and Rammler 1933)

$$1 - \text{CVF} = \exp[-(D/X)^b]$$

where X and b are the curve-fitting parameters. If a logarithm is taken of this expression, then multiplying both sides of the equation by -1, and then a second logarithm is taken, there results

$$\log[-\log(1 - \text{CVF})] = b \log(D/X)$$

which represents the equation for a straight line in logarithmic space, of slope b and intercept (-b log X). Evaluation of these two parameters by least squares analysis determines the entire drop size distribution.

### C. Log Normal

In some cases neither the Root Normal nor the Rosin-Rammler technique adequately represents the lower end of the drop size distribution. The upper limit log normal function (Mugele and Evans 1951) and its extension to bounded log normal (Gaidos et al. 1992) seek to overcome this difficulty. The functional form assumed is

$$CVF = \frac{1}{2}[1 + \text{erf}(\frac{dy}{\sqrt{2}})]$$

with

$$y = \log \left[ A \frac{D - D_{\min}}{D_{\max} - D} \right]$$

where  $D_{\min}$  is the minimum drop size,  $D_{\max}$  is the maximum drop size, and d and A are additional parameters (besides  $D_{\min}$  and  $D_{\max}$ ) to be determined. In the bounded log normal application, four parameters must be determined. In a simpler application the user may take  $D_{\min} = 0$  and  $D_{\max}$  equal to the maximum drop size determined by the instrument used in the wind tunnel studies. Then, after solution for d and A, either the minimum or maximum value can be relaxed to see whether a better curve-fit results. For completeness it may be noticed that

$$VMD = \frac{D_{\max} + AD_{\min}}{1 + A}$$

## Index

- 1 Hour Average Concentration, 69  
Accountancy of Active, 68  
Active Rate, 50  
Advanced Settings, 36, 38  
Aircraft, 39, 100  
Aircraft Library, 39, 42, 97, 100  
Aircraft User Library, 39, 40  
Air Speed, 47  
Aquatic Assessment, 23, 24, 71  
Basic Drop Size Distribution, 44  
Batch Operations, 59, 61  
Boom Height, 34  
Canopy, 96, 98  
Carrier Type, 50  
Coefficient of Variation, 69  
Deposition, 68, 69  
Drop Distance Calculator, 59, 61, 761  
DropKick®, 46  
DropKick® Nozzle Library, 47, 48  
DropKick® Spray Material Library, 47, 48  
Drop Size Distribution, 43, 67, 68, 101  
Drop Size Distribution Library, 50, 51,  
    101, 102  
Drop Size Distribution User Library, 44, 45  
 $D_{v0.5}$ , 46  
Dynamic Surface Tension, 47  
Edit menu, 19  
Effective Nozzle Diameter, 47  
Elongational Viscosity, 47  
Evaporation Rate, 50  
Export, 17, 19  
File menu, 17, 53  
Flux Plane, 34  
Fraction Aloft, 71  
Half Boom Effect, 34  
Help menu, 32  
Load Field Trial Data, 53, 54  
Mean Deposition, 69  
Multiple Application Assessment, 28, 30,  
    60, 74  
Nonvolatile Rate, 50  
Nozzle Orientation, 47  
Nozzles, 41, 42  
Number of Flight Lines, 34  
Numerical Values, 54, 59  
Parametric Drop Size Distribution, 44, 45  
Plot Options, 22  
Pond-Integrated Deposition, 69  
Preferences, 19, 20  
Pressure, 47  
Relative Humidity, 36  
Relative Span, 47  
Run menu, 58  
Shear Viscosity, 47  
Sideslope Terrain Angle, 96  
Specific Gravity, 47  
Spray Block Assessment, 25, 27, 71  
Spray Block Details, 107, 108  
Spray Block Statistics, 60, 62, 71  
Spray Material, 47, 52  
Spray Material Library, 51, 52  
Spray Volume Rate, 47, 51  
Stream Assessment, 27, 29, 72  
Surface Roughness, 36, 37  
Swath Displacement, 36  
Swath Width, 36  
Temperature, 36  
Terrestrial Assessment, 25, 26, 71  
Tier I Ground Input, 10, 16, 18  
Tier III Aerial Input, 33, 35, 96, 97, 99  
Tier I Orchard Airblast Input, 12, 33  
Tier menu, 20  
Toolbox menu, 23, 59  
Trajectory Details, 107, 108  
Upslope Terrain Angle, 96  
USDA ARS Nozzle Models, 49  
Vertical Profile, 69  
View menu, 20, 53  
Wind Direction, 36  
Wind Speed, 436