THE PRACTICAL USE OF AGDRIFT® AND OTHER DRIFT EXPOSURE MODELS FOR AERIAL, GROUND AND ORCHARD SPRAY APPLICATIONS

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ABSTRACT

The practical use of spray drift databases and models for predicting drift exposure in pesticide applications is discussed. The AgDRIFT® model, developed by government and industry scientists in the US facilitates such assessments for various application scenarios. Aerial applications can be modelled using a predictive model that considers the effects of application, tank mix, meteorological and environmental variables on off-target spray movements and deposition. Such assessments can be made at three different tier levels, each allowing access to more of the input variables than the preceding lower tier level. The lowest tier level allows specification of spray quality, while higher tiers allow access to variables such as release height, wind speed and other variables. Ground rig application scenarios are currently modelled as curve fits of field data allowing spray quality and release height to be assessed for different numbers of spray swaths. Orchard airblast applications are included at the lowest tier level for different sprayer and canopy types, with the default setting including composite orchard and vine canopies. Predictive models are being developed for higher tier level assessments for spray applications by ground rig and orchard airblast equipment. An atomization model has also been developed to predict droplet size for applications of tank mixes with user-defined or reasonable worst-case physical properties through a wide range of hydraulic nozzle types applicable to aerial applications. This model, DropKick® is included within AgDRIFT® or as a stand-alone model. Other atomization models are also available within AgDRIFT® for predicting droplet size of nozzles types that have been tested by the United States Dept. of Agriculture (USDA). These and other models are described in the present paper with a particular emphasis on drift exposure assessments.

Key words: Spray drift, deposition, pesticide, droplet size.

INTRODUCTION

An accompanying paper to the present paper explains the history and development of the AgDRIFT® model (Hewitt et al. 2001). The present paper explains the utility of drift models for assessing the movement and deposition of pesticide sprays. The purpose of this paper is not to give a detailed description of risk assessment for pesticide use, since this often requires additional information and/or models to assess toxicity and other exposure sources. Drift models such as AgDRIFT® only provide information on the drift exposure risk from user-defined scenarios, which can be useful for input to other assessment models or exercises. Environment Protection Authority (EPA) evaluates risk to non-target organisms as a two-stage process where environmental concentrations are used to estimate exposure to the contaminant and then combined with measurements of biological activity to determine risk (Anon 1983). Several drift models are discussed in the present paper, with particular emphasis on their practical use for assessing the drift exposure risk from pesticide applications.

AGDRIFT® AND AGDRIFT®/FS: DRIFT MODELS WITH EMPHASIS ON SPRAY DEPOSITION

The AgDRIFT® model represents the culmination of developments in modelling by the U.S. Forest Service, NASA, US Army, Spray Drift Task Force and others. The aerial application database against which it has been validated was described by Hewitt et al. 2001. The AgDRIFT® model was developed for studying the effects of different variables on the drift potential of sprays, primarily for developing labels for pesticides. The model has been structured as a three-tiered model, with each tier level providing access to more input variable options than lower tier levels. At the time of preparation of this manuscript, the tier structures were being modified, and only Tier III was likely to be available for public use. For an update on the current model structure and contents, please visit the following web site: www.agdrift.com. An example of the highest tier screen (Tier III) is shown on Figure 1. The model includes agricultural and forestry modes, each offering different input and output options, as appropriate for the two application types. The Tier III screen shown on Figure 1 is for the forestry mode. The agricultural mode is similar, but does not include the following sections: Stability Class; Canopy Type; Minimum and Maximum Transport Height under the Transport section; and Upslope and Sideslope Angle options under the Terrain input section. AgDRIFT® was not developed as a pre-application decision support system per se, but does offer valuable information on "what if" scenarios for drift potential (Hewitt et al. 1997). To run the model for such assessments, the user needs to define the input variables or use default values which are currently at reasonable worst-case settings. The application, meteorological, tank mix, environmental, canopy and other variables are entered from default values, libraries of data or user-defined settings. Calculations can be run from individual files or as batches of files with previously-saved input characteristics.

The model output will provide information on the amount of material that deposits on horizontal surfaces at different distances downwind of the edge of the application area ('deposition', Figure 2), as well as the amount of material airborne at distances downwind, in both droplet and vapour form (eg. vertical spray distribution, Figure 3 and distance accountancy, Figure 4). In addition to providing these and many other graphical representations of the spray distribution and deposition information (and file export options), various toolboxes are offered to more closely inspect the model predictions as follows:

Droplet size spectrum

The droplet size spectrum can be examined as an incremental or cumulative plot. Droplet size spectra can be plotted from various parts of the spray process as follows:

- Initial (the emission droplet size spectrum selected or entered by the user from a library, model or other source. The value given is a mean of all locations and nozzles on the booms)
- Downwind (the droplet size spectrum downwind of the application area, in the off-target area after evaporation and settling effects)
- Vertical Profile (the droplet size spectrum in the air averaged across the vertical flux plane)
- Spray Block (the droplet size spectrum within the spray block)
- Canopy (the droplet size spectrum depositing on the canopy being sprayed).

Deposition and fraction aloft

Plots are available showing the amounts of active ingredient airborne or depositing on terrestrial or aquatic surfaces downwind of the application area.

Vertical profile and 1-hour average concentration

These plots show the amount of active ingredient material against height above the ground at the user-defined flux plane distance downwind of the application area as amount of material per unit area (Vertical Profile) or amount of material per unit volume of air (1- Hour Average Concentration).

Application layout and spray block deposition (Forestry mode only)

These plots focus primarily on deposition for individual and overlapping flight lines within the application area.

Coefficient of variation and mean deposition (Forestry mode only)

These plots show the effective swath width that can be associated with a given coefficient of variation (cov) and deposition against effective swath width, respectively. For most applications, a cov less than or equal to 0.3 is deemed acceptable for effective lane separation.

Spray block area coverage (Forestry mode only)

This plot shows the area that is covered by specified levels of application rate.

Canopy deposition profile (Forestry mode only)

The canopy deposition profile plot shows the volume fraction of active ingredient remaining at different vertical distances for the user-defined flux plane distance.

Total accountancy (Forestry mode only)

Accountancy plots are available to show the amount of released material in each of the phases, droplets aloft, vapour and droplets deposited on the ground for different times, distances and heights in the spray operation.

Ground and orchard modules within AgDRIFT®

The AgDRIFT® model includes several options for investigating drift potential for sprays applied by hydraulic ground rigs and orchard airblast sprayers. These are described as follows:

Ground hydraulic

The SDTF conducted field studies with ground hydraulic sprayers. The studies included high boom and low boom heights of 40 and 20 inches respectively. Droplet size spectra varied from Fine to Very Coarse. When analysed statistically, the data showed that at least four categories could be specified for drift rates: high boom Fine sprays, high boom Medium to Very Coarse, low boom Fine and low boom Medium to Very Coarse (Hewitt et al. 1999a). AgDRIFT® includes curvefits from the field data for these categories, with an option for the user to specify the number of rows being sprayed.

When considering using the deposition curves from specific field studies such as those of the SDTF within AgDRIFT®, or other databases such as the German regulatory situation (Ganzelmeier et al. 1995) or other European data (eg. Nordby and Skuterud 1975), the user should carefully consider whether the conditions are representative of their geographical and application conditions. The SDTF ground rig field studies used a Melroe Spra-Coupe® hydraulic boom sprayer with an effective swath width of 45 ft (13.7 m). The boom was fitted with 27 nozzles at spacings of 20 inches (50.8 cm) for all applications. As mentioned above, the nozzle types encompassed spray quality ratings of Fine to Very Coarse. Some field trials were conducted using 8010LP low pressure flat fan nozzles with an operating pressure of 20 psi to represent high volume custom applications such as pre-plant, turf and right-of-way. Other tests were conducted using 8004LP low pressure flat fan, and 8004 flat fan nozzles to represent widespread drop size application configurations with ground sprayers. The nozzles were operated at respective pressures of 20 and 40 psi. Finally, TX-6 hollow cone nozzles were operated at a pressure of 55 psi to present finer sprays that might be used for reasonable worse case (drift potential) applications of fungicides and insecticide sprays. The meteorological conditions encompassed a wide range of the following variables: wind speeds were 5 to 20 mph (8.04 to 32.2 km/hr), air temperature ranged from 44 to 91°F (21.6 to 32.8°C), relative humidity varied from 8 to 82%. Sprayer ground speeds were 5 and 15 mph.

An example of a Tier I ground screen from AgDRIFT® is shown at Figure 15. It should be noted that the SDTF, EPA and U.S. Forest Service are working on developing a Tier II predictive model for ground rig applications. However, it is not known if and when such a model will be finalized.

Orchard airblast

The SDTF orchard airblast field studies included several different canopy types and typical sprayer configurations representative of typical orchard airblast spraying in the U.S. Drift rates were generally higher for dormant canopies, and wide spacings between rows and trees, with less dependence on droplet size than for aerial and ground applications. The AgDRIFT® model allows the user to specify individual canopy types or composites of similar canopies from vineyard or orchards. The model provides a description of the canopy characteristics and leaf area index as well the sprayer description and droplet size spectrum measured from atomization

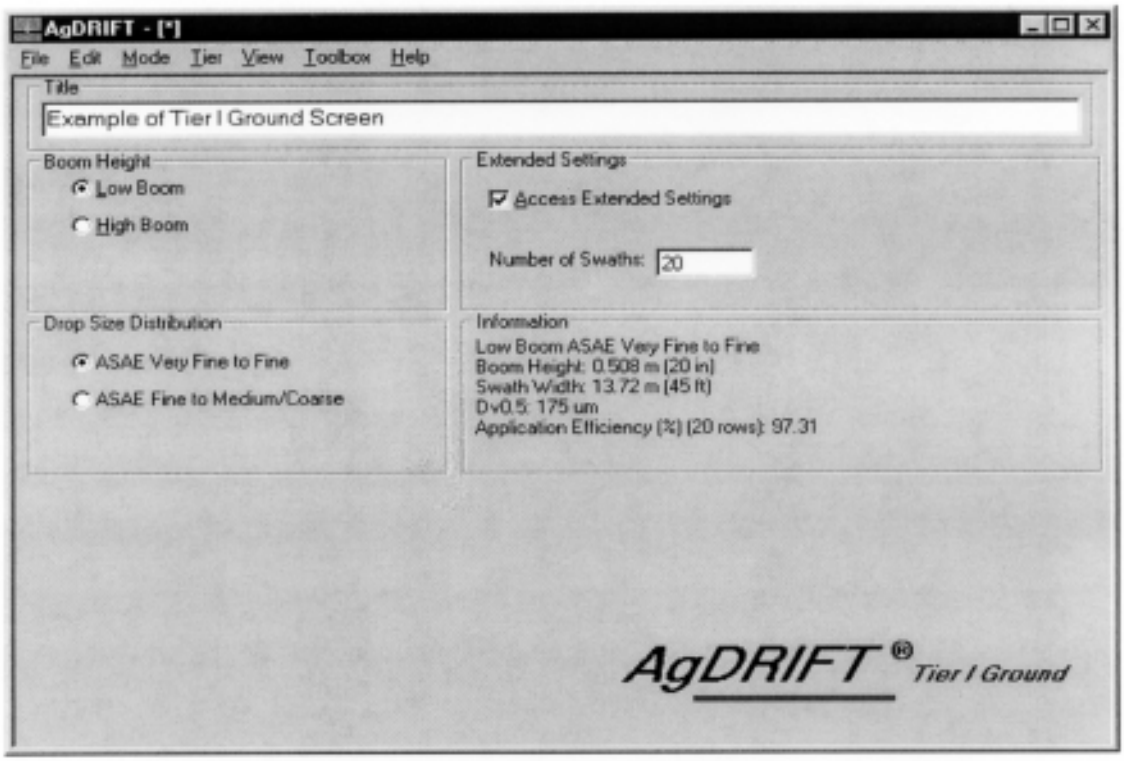

Figure 15. Example of Tier I Ground Screen With Very Fine to Fine Low Boom.

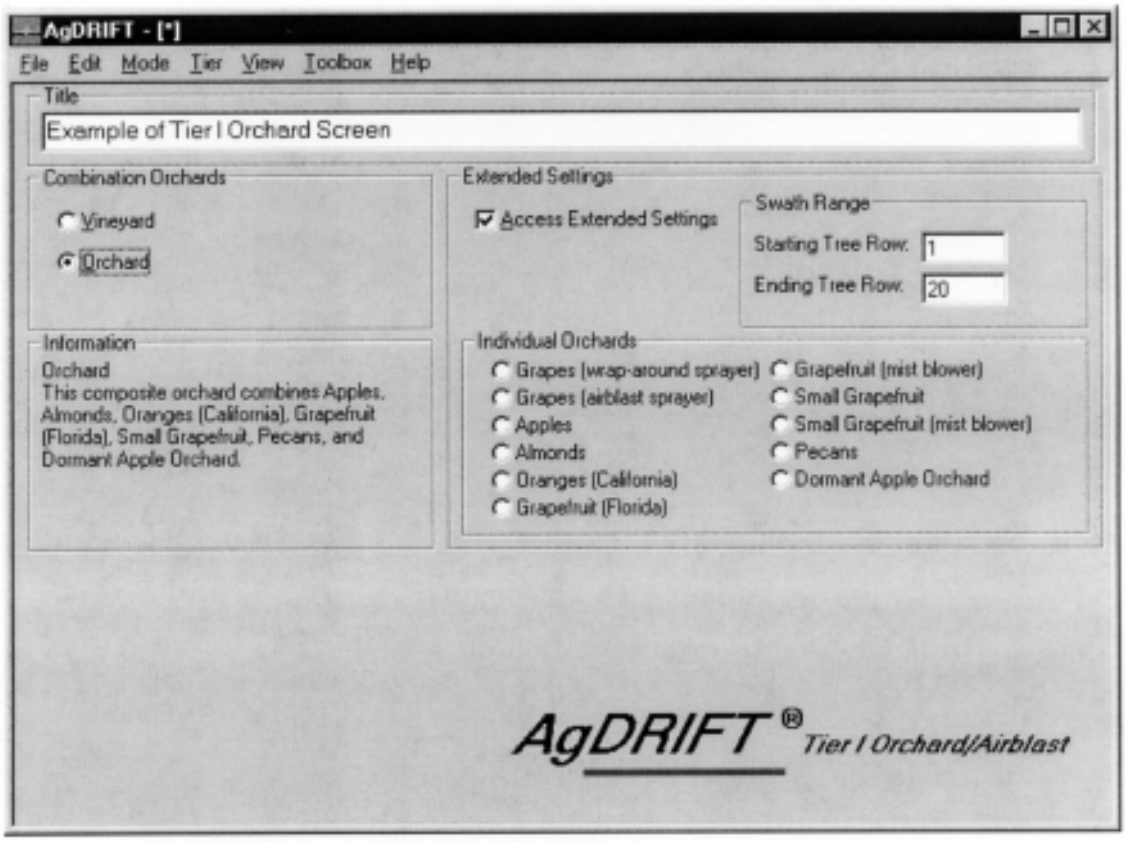

Figure 16. Example of Tier I Orchard Screen for Composite Orchard.

studies (Hewitt et al. 1999b). The user can also specify the starting and ending rows for applications, since a drift mitigation option is often not to spray the outer row(s) of trees nearest the downwind sensitive area.

At present, the only orchard airblast information contained in AgDRIFT® is the generic deposition curves at Tier I (Figure 16). It is possible that a Tier II predictive model may be developed at a future time to facilitate analyses with user-defined inputs characterizing the canopy (structure, porosity, etc), sprayer (air velocity/ volume profile, emission droplet size spectra, etc), meteorology (within and outside the canopy) and other parameters.

ISC: long-range transport model

The Industrial Source Complex (ISC, US EPA, 1995) model is a steady-state Gaussian plume model that can be used to estimate pollutant concentrations and/or deposition from point, area, and volume sources. Line sources can be modelled as either volume or area sources. The model can process multiple sources and multiple receptors at once. For far-field analysis (beyond aerodynamic wake effects), an aerial application of a pesticide can be represented as a line source. Schnelle and Dey (2000) suggested that if a release lasts from 10 to 30 minutes, it could be described as a small continuous release, thereby allowing use of the Gaussian plume representation in an analysis.

DropKick® and USDA atomisation models

The main factor affecting both the on-target performance and off-target drift potential of most sprays is the droplet size spectrum produced at the time of application. Obtaining reliable droplet size data for input to drift models is therefore essential if the models are to provide accurate predictions of the transport and deposition of a given spray. The AgDRIFT® model allows the user to input droplet size in one of several ways as follows.

BCPC/ASAE Spray Quality - The British Crop Protection Council (BCPC) developed a classification system for droplet size spectra from agricultural flat fan nozzles in the 1980's (Doble et al. 1985). The BCPC system was centred around the most common spray quality applied for arable farming in the UK, referred to as a "Medium" spray quality. Other spray quality categories included Very Fine, Fine, Coarse and Very Coarse. The BCPC system has been adapted with the addition of an Extra Coarse category to develop the ASAE standard S-572, "Spray Nozzle Classification by Droplet Spectra" (Anon, 1999), and extended in Europe to consider drift potential factors (Southcombe et al. 1997).

The original BCPC system included a definition of aerosols based on a $D_{v0.5}$ below 50 µm. A possible reference spray has been proposed by the senior author of the present paper, based on it producing a possible boundary curve for this definition. This has been included in the AgDRIFT/FS model. Spray quality provides a convenient way to address droplet size spectrum requirements on labels (Hewitt 2000).

Measured Droplet Size Spectrum – The user can use a wind tunnel measurement of the emission droplet size spectrum for input to the AgDRIFT® model. Ideally, this needs to be in compliance with the other droplet size spectra within the model with respect to measurement system. The SDTF used a laser diffraction technique to measure droplet size spectra for its sprays (Hewitt et al. 1996, 1999). If the measurement system is substantially different from that of the SDTF, the data could be input either as a spray quality classification or converted to Malvern-equivalent data. The former requires the user to measure the spray quality boundary curves for his test system using the ASAE reference nozzles and standard (Anon, 1999). A conversion between PMS and Malvern data was provided by Teske et al. 2000. Theoretical and practical measurements of rotary atomizer sprays were explained by Teske et al. (2001).

DropKick® Prediction – The SDTF developed an empirical model, DropKick® (Esterly 1998) that can estimate the droplet size spectrum that would be produced for a user-defined spray. The model is only appropriate for certain aerially-applied sprays through selected nozzle types. The user needs to provide information on the nozzle being used (such as effective orifice diameter and ground application reference droplet size spectra), the tank mix and application conditions (flight speed, nozzle angle and spray pressure). A library of nozzle types and tank mixes are included from the SDTF database. The model will provide a droplet size spectrum prediction as an entire droplet size distribution or spray quality category. The DropKick® model is based on the main liquid physical properties that affect the aerial atomisation of agricultural tank mixes. These include shear and extensional viscosity and dynamic surface tension (Hewitt and Hermansky 1997). Other variables related to emulsions may also be important for the atomisation of ground sprays (Butler-Ellis et al. 1999, Dexter 2001).

USDA Models – The United States Dept of Agriculture Agricultural Research Station (USDA-ARS) has provided several empirical models for estimating droplet size spectra for the most common nozzles that are used for aerial spray applications in the US. The current models include CP nozzles (Kirk 1997, 1998) and several straight stream nozzle types. Data are being collected for other nozzle types to allow additional nozzles to be modelled in the future (I W Kirk, USDA-ARS, personal communication).

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The author wishes to acknowledge all of the individuals and organizations who were involved with the development of the AgDRIFT®/ FS model. These include personnel from the SDTF, EPA, USDA-FS, USDA-ARS, PMRA Canada, NCASI and many others who have been involved with this model or its predecessors.

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Aquatic toolbox

This toolbox (Figure 5) provides information on the deposition of active ingredient onto standard EPA-defined ponds or wetlands, or user-defined water bodies. The deposition is integrated across the water body based on the distance from the spray source. Dilution, based on the depth and width of the water body, allows the result to be expressed as concentration of active ingredient in the water body. By knowing the toxicity of the active ingredient to specific sensitive areas (eg. aquatic species), the integrated drift deposition provided by this toolbox can be interpreted for establishing safety factors such as buffers or appropriate application conditions for protecting the sensitive area.

Terrestrial toolbox

The terrestrial assessment toolbox (Figure 6) is similar to the aquatic assessment toolbox, but provides analyses of deposition rates versus distance for terrestrial surfaces based on point deposition at a fixed distance from the edge of the spray block area or integrated over a distance range for considering populations of sensitive areas rather than individual entities.

Spray block assessment

At the request of Canadian interests in drift assessments, a toolbox has been included to show the effect of increasing number of flight lines on buffer zone size (Figure 7).

Stream assessment

A toolbox has been included in the model for determining the amount of active ingredient within streams at fixed distances from the application area (Figure 8). The user must define the stream dimensions, water flow rate, recharge and discharge rates. The application is defined by the distance from the stream, length of flight lines and turn-around time. This screen allows removal of airborne droplets by vegetation around the stream to be considered. The user can enter a riparian interception factor from 0 (no interception) to 1 (100% interception). A typical value used by PMRA in Canada for risk assessments of ponds surrounded by riparian vegetation is 0.5. The breakdown of the active ingredient in the stream can be accounted for through specifying an instream chemical decay rate. Once the inputs have been provided for the stream assessment screen, the user must specify whether to inspect the results as a single point or at different times for user-defined distances or different distances for user-defined times. An example of the latter is shown on Figure 9.

Multiple application assessment

The multiple application assessment toolbox provides a probabilistic mode for investigating the effects of multiple spray applications within a season or year (Figure 10). The probability of combinations of wind speeds and directions are accounted for by user-defined or library specifications of wind rose data. The model includes meteorological data from the Solar And Meteorological Surface Observational Network (SAMSON). The user can specify the number of spray events per year and the number of years, as well as the meteorological conditions and any restrictions on wind speed (for example maximum wind speeds allowed for applications on the pesticide label). The calculation recovers the 95th percentile deposition pattern from multiple applications to the field (Figure 11).

Trajectory details (Forestry mode only)

The Lagrangian trajectory of different droplet sizes released from each nozzle on the aircraft boom can be inspected using the 'Trajectory Details' screen. Figure 12 shows an example for 100 µm diameter droplets, as viewed from the rear of the aircraft. Other views include the top and right side of the aircraft boom. A push button activates the terrain co-ordinate transformation.

Spray block details (Forestry mode only)

Another key feature of the FSCBG model that has been included in AgDRIFT®/FS is the ability of the user to specify an application area (spray block) and recover contours of deposition rates for active ingredient rate or droplets per cm^2 from the current flight pattern (Figure 13).

The user may also scribe an area within the deposition pattern and recover statistics on the predicted deposition (Area Coverage). The user may also specify discrete receptor locations within the spray block to view predicted deposition rates. The inputs are entered as follows:

The user can define the position (X and Y co-ordinates) of the corners of the polygon-shaped spray block. The location, type and orientation of discrete receptors within and around the spray block can also be defined. If the user is interested in looking at the deposition within a specific area, he can define that part of the spray block, or region downwind of the spray block, referred to as 'Area Coverage Boundary' prior to running the assessment. These entries are all defined through co-ordinate tables. If the user defines an area coverage boundary, the results for area coverage are displayed on the input screen, including the size of the area and the average deposition level within the defined area.

The user needs to provide information on the flight and wind directions relative to the defined spray block geometry. This is facilitated through a diagram with a series of arrows for directions. Since the output of the screen is a series of deposition contours (Figure 14), the user can either specify preferred contour levels or allow the model to determine appropriate ranges. Several different units are offered for selection of the contour ranges. The user can also specify whether to plot the active, non-volatile or unevaporated component of the spray.

The user must also specify which features of the assessment will be plotted on the resultant plot. One or more of the following choices are available:

- spray block boundary (eg. edges of the forest area being sprayed)
- flight lines (initially, these are uniformly spaced at single swath width separations, displaced from the downwind edge of the field by the swath displacement entered on the main model input screen)
- receptor grid (generated by the program with a minimum spacing of one swath width)
- deposition contours (in units specified under Deposition)
- area coverage boundary

The previous sections have described the various toolboxes that are available in the Forestry Model of AgDRIFT®/ FS. The model also provides several graphical representations of other aspects of the spray application scenario that has been modelled. These are discussed in the following sections.

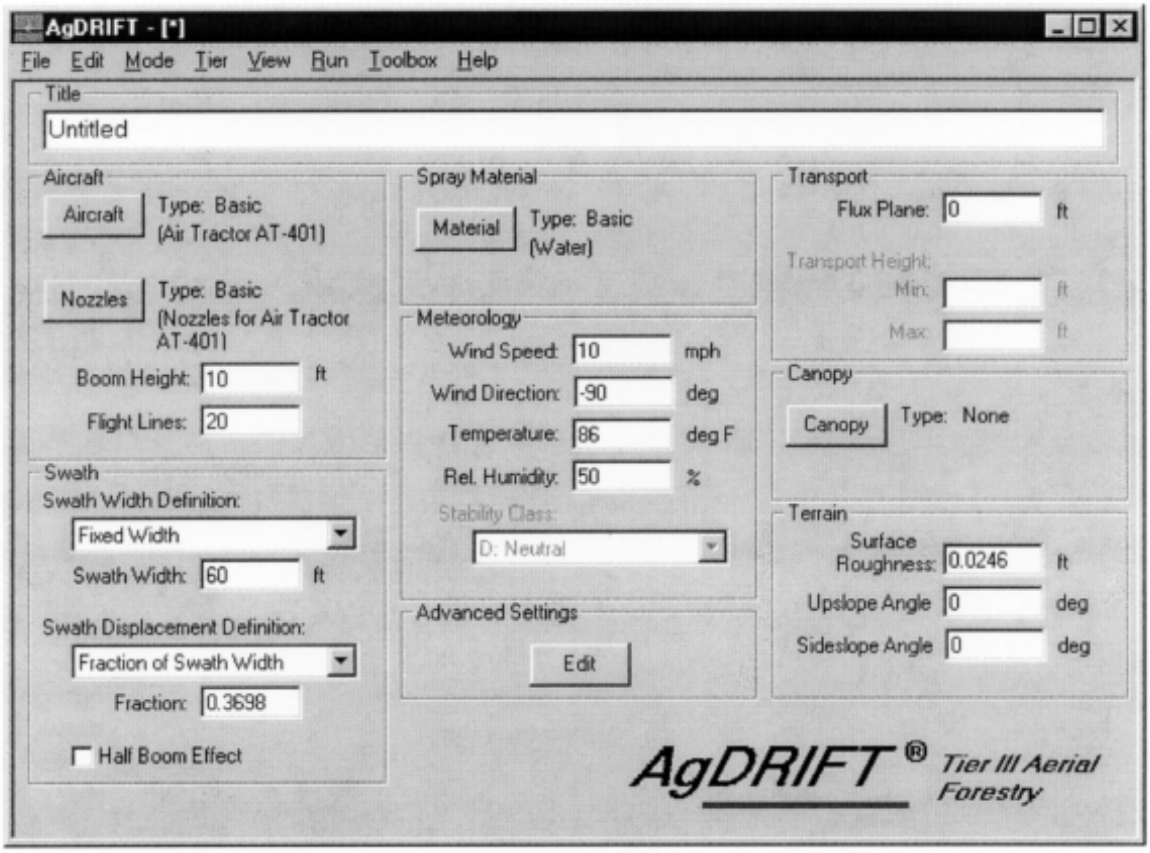

Figure 1. Tier III Screen Showing All Input Variable Sections in Forestry Mode.

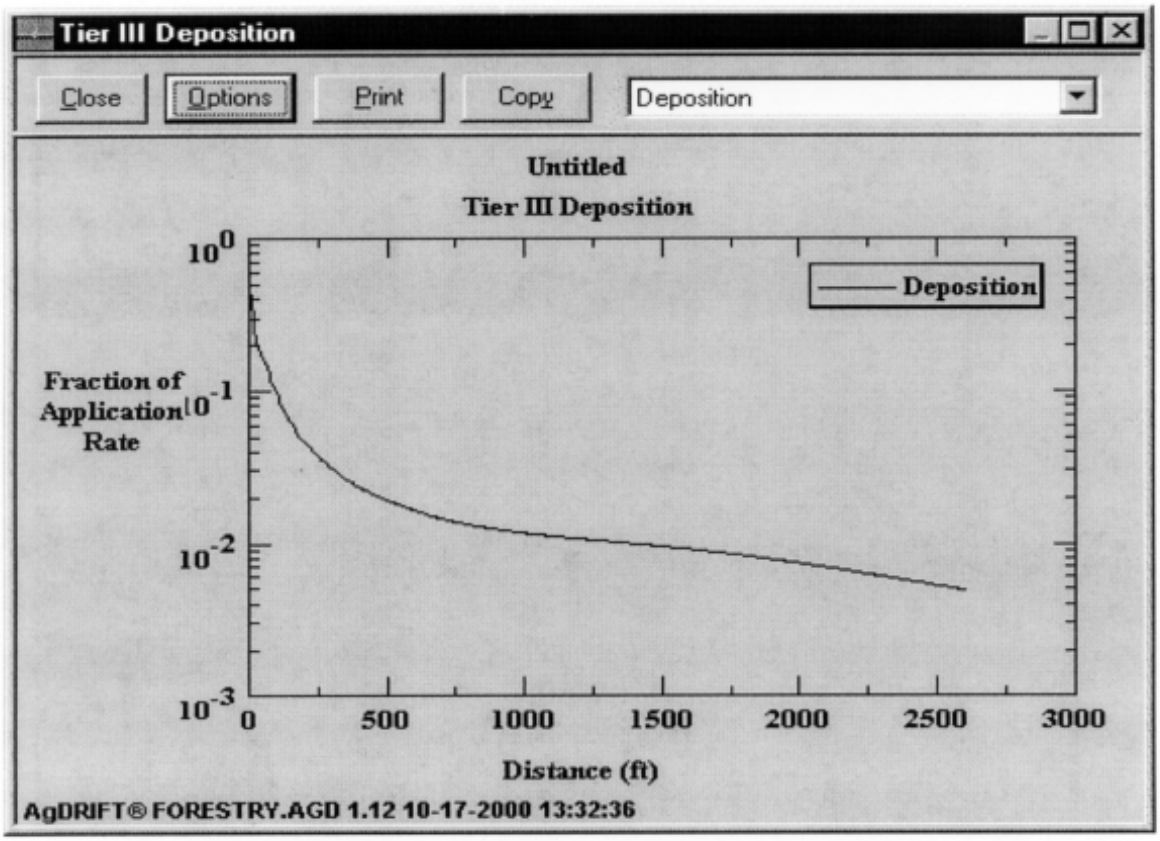

Figure 2. Deposition Against Distance Downwind from Edge of Application Area.

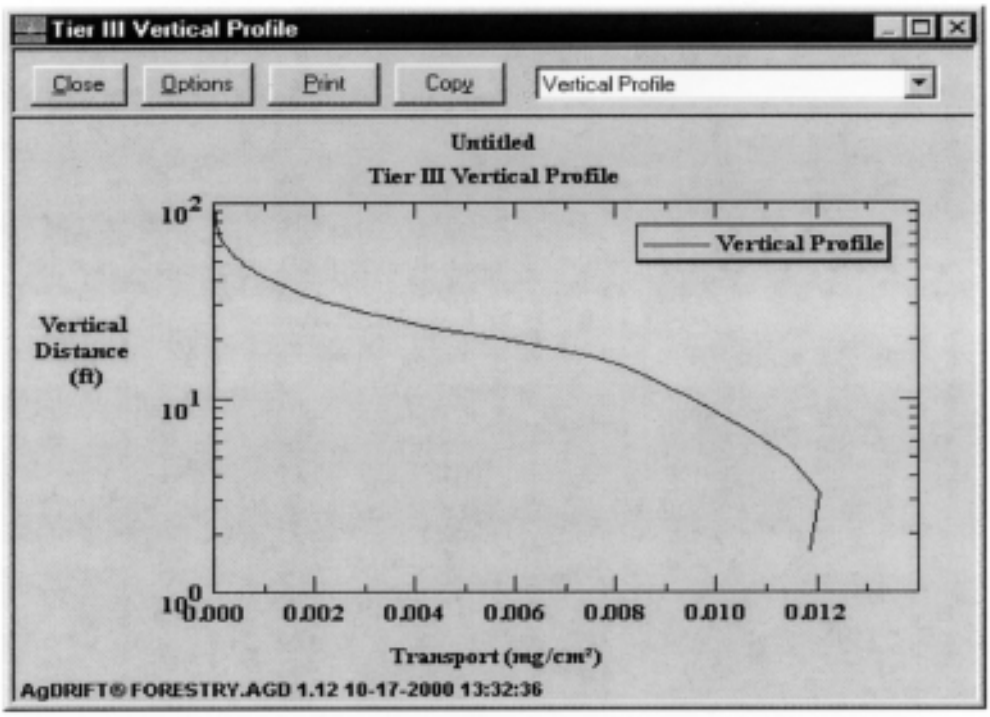

Figure 3. Vertical Spray Distribution at Flux Plane.

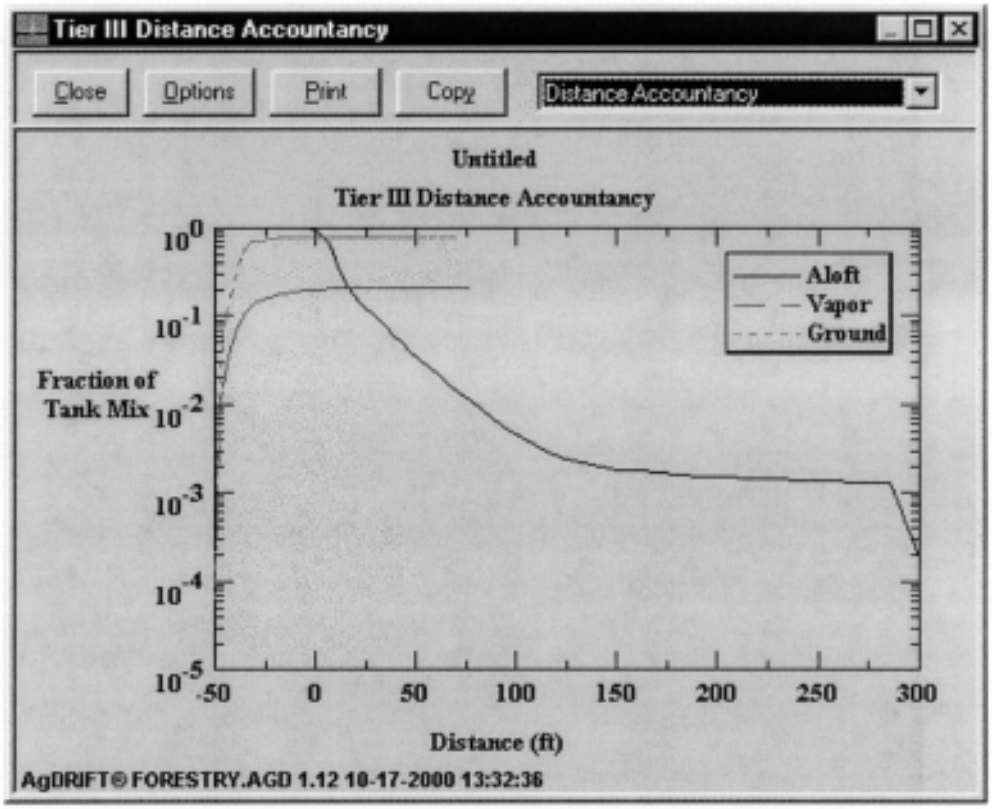

Figure 4. Distance Accountancy of Spray (Similar Plots Available for Time and Height Accountancy).

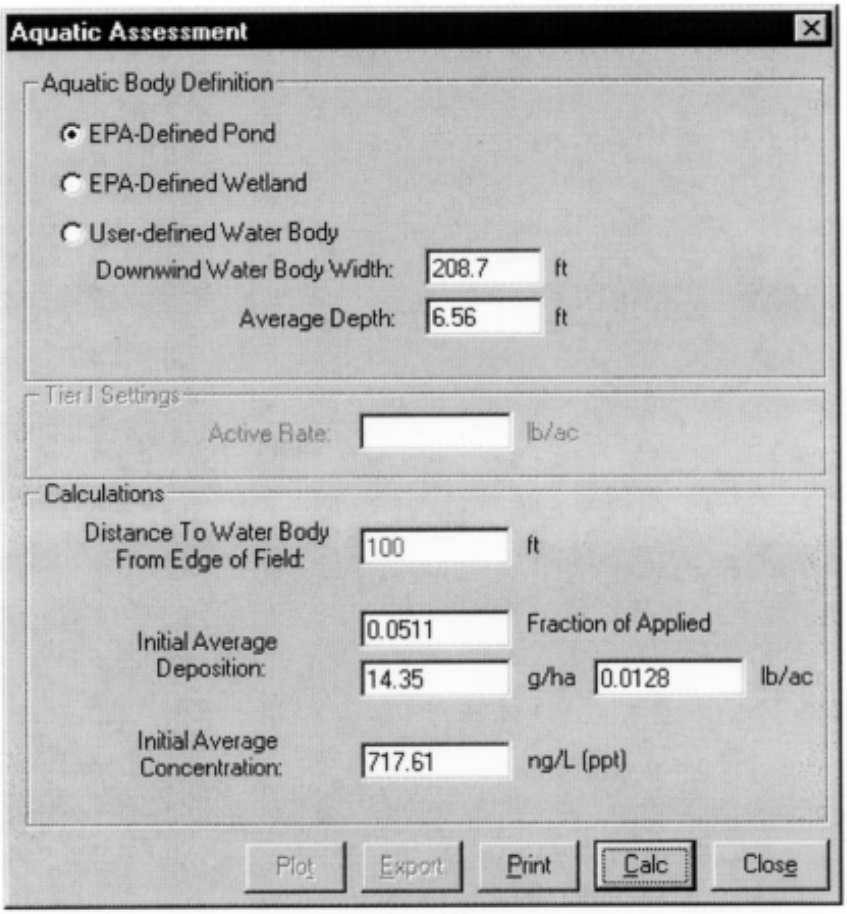

Figure 5. Aquatic Assessment Toolbox.

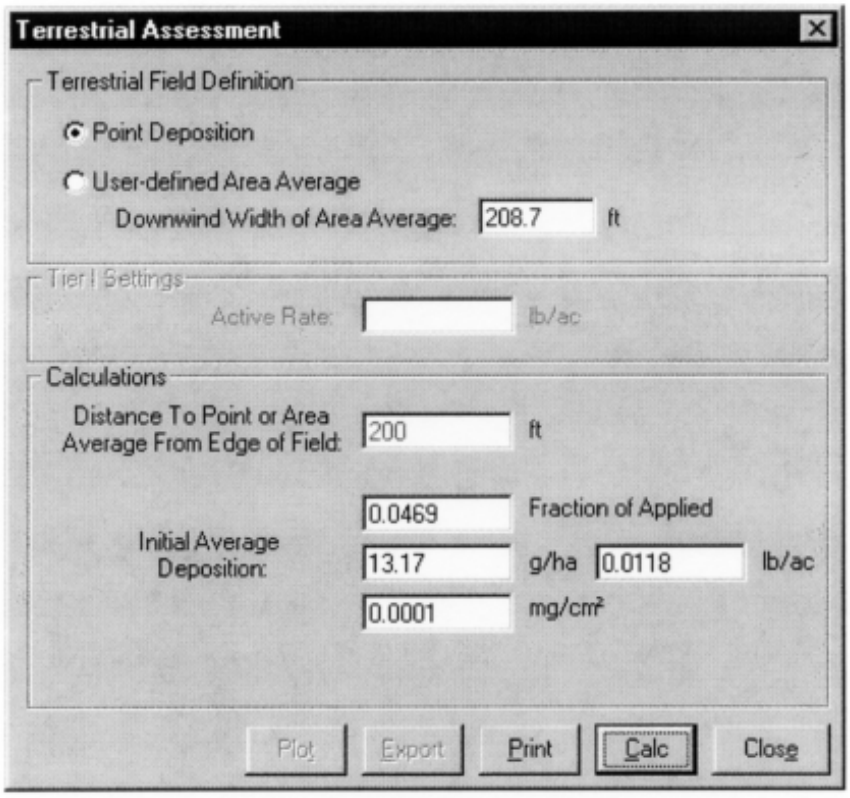

Figure 6. Terrestrial Assessment Toolbox.

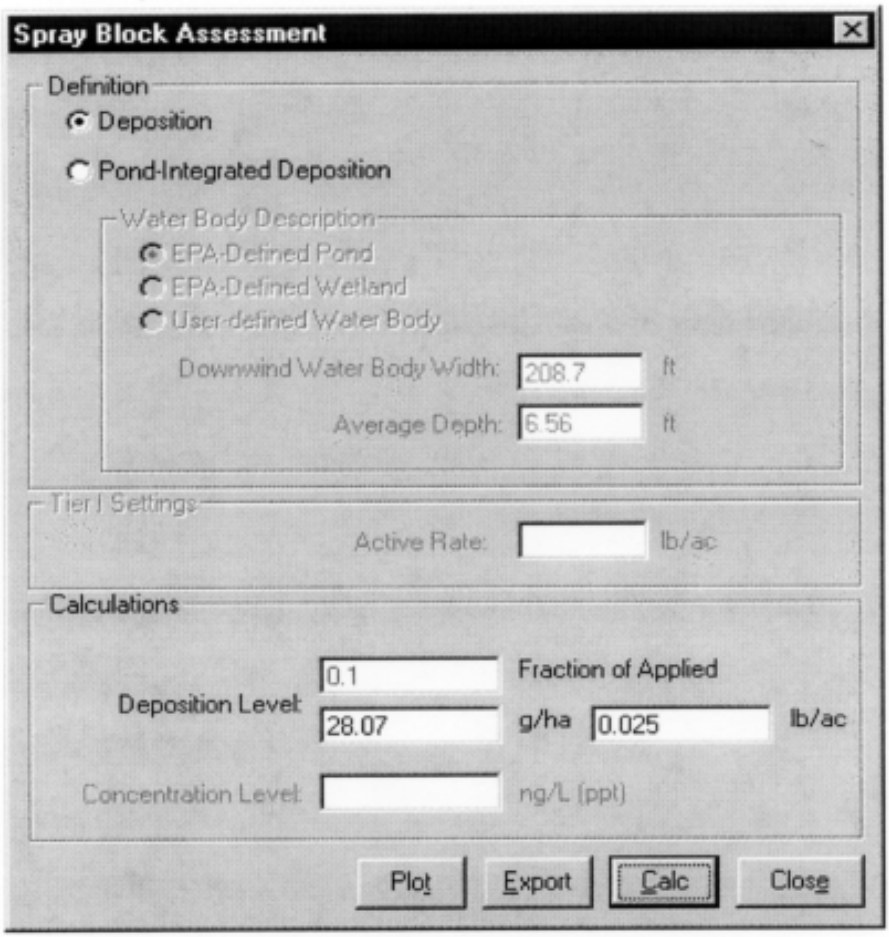

Figure 7. Spray Block Assessment Toolbox.

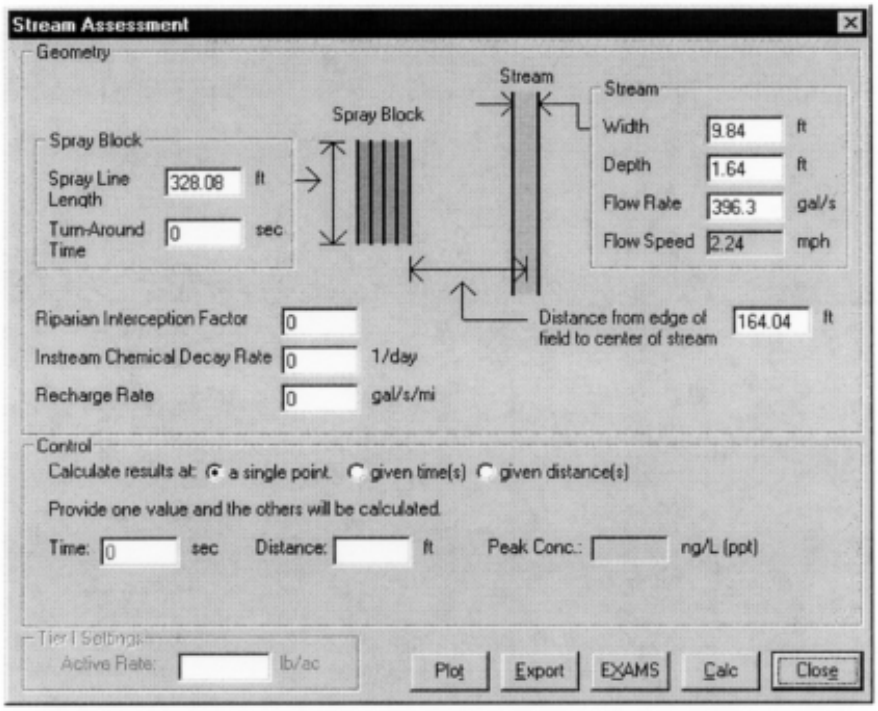

Figure 8. Stream Assessment Toolbox Input Screen.

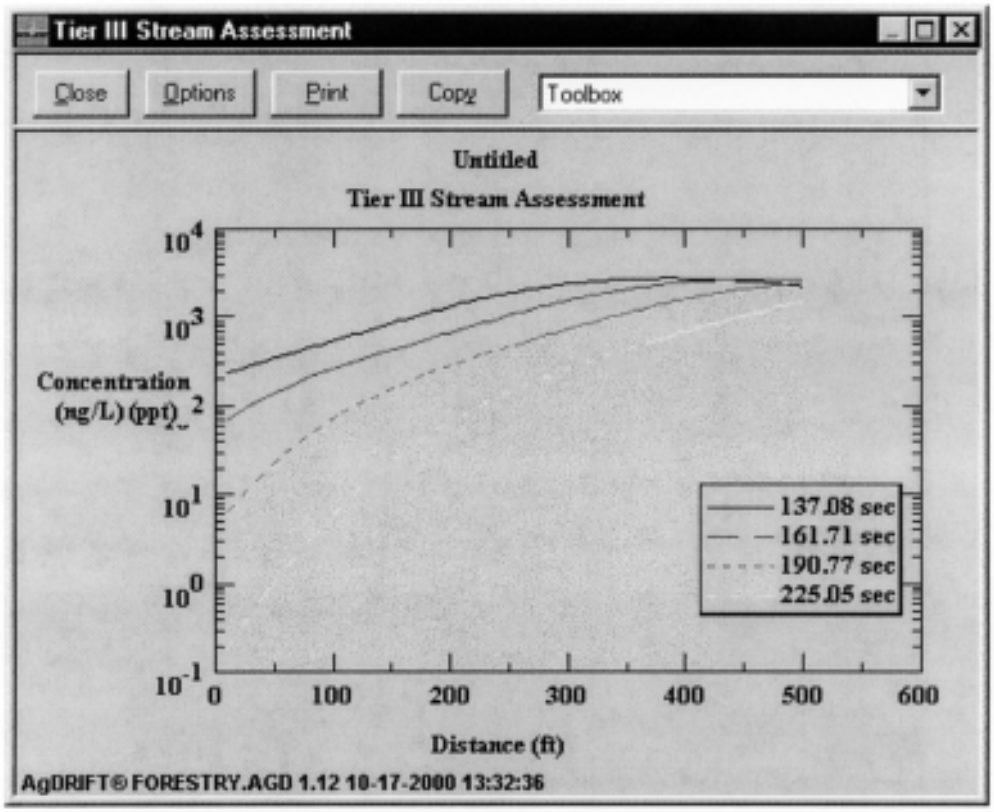

Figure 9. Stream Assessment Plot.

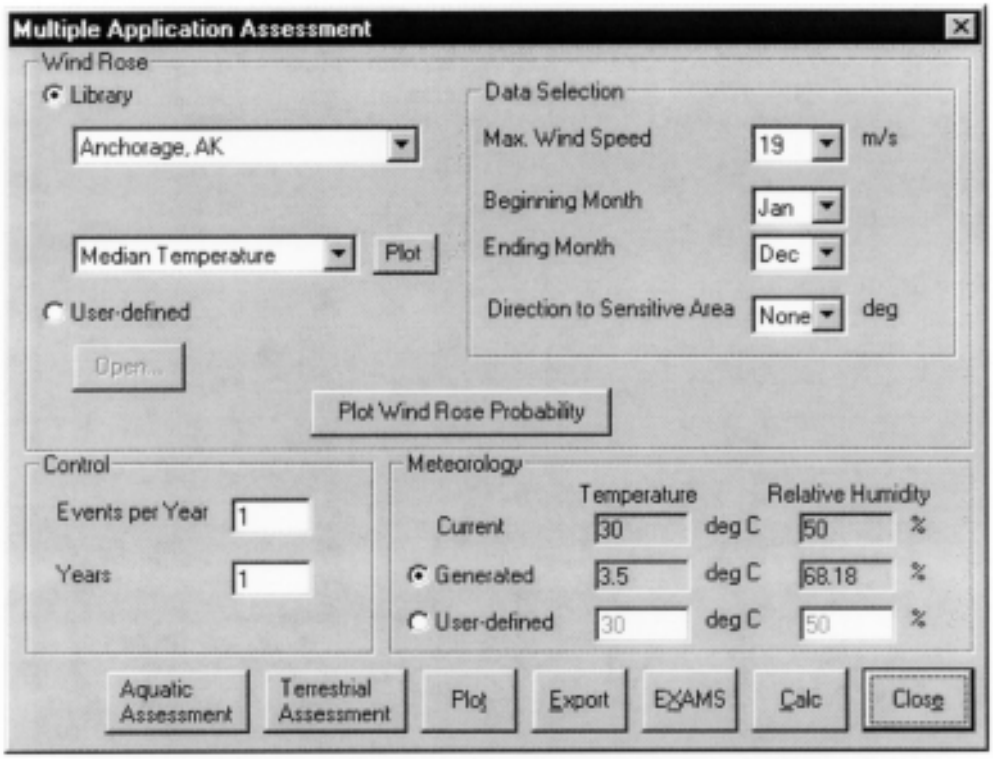

Figure 10. Multiple Application Assessment Input Screen.

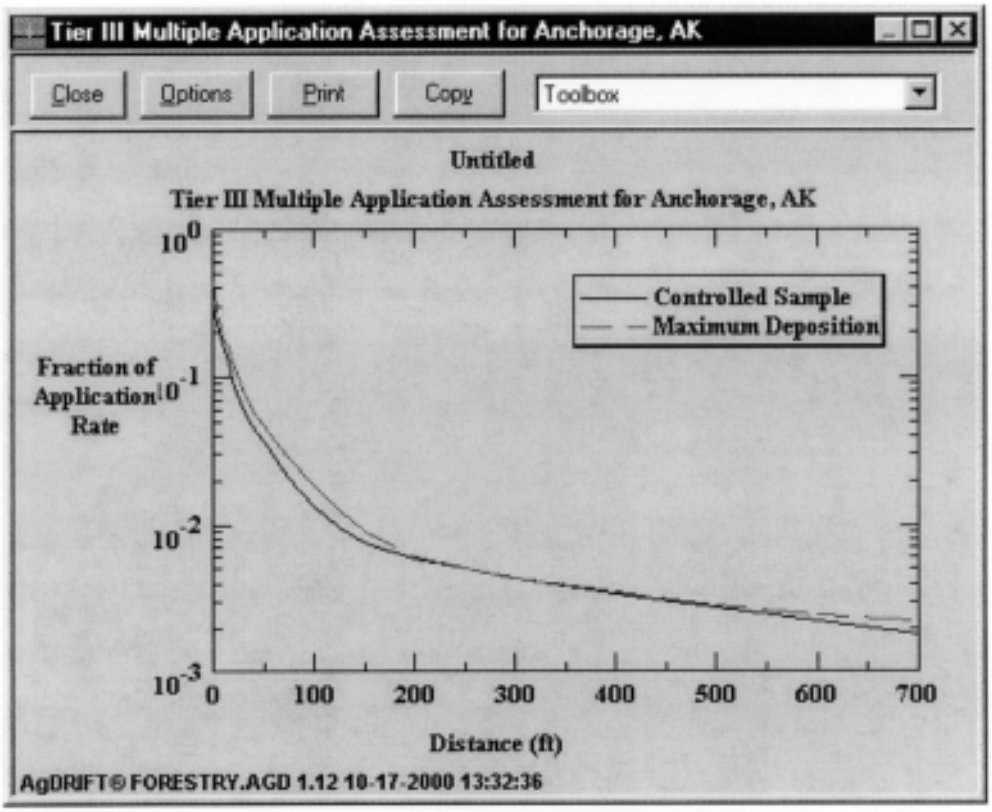

Figure 11. Multiple Application Assessment Plot.

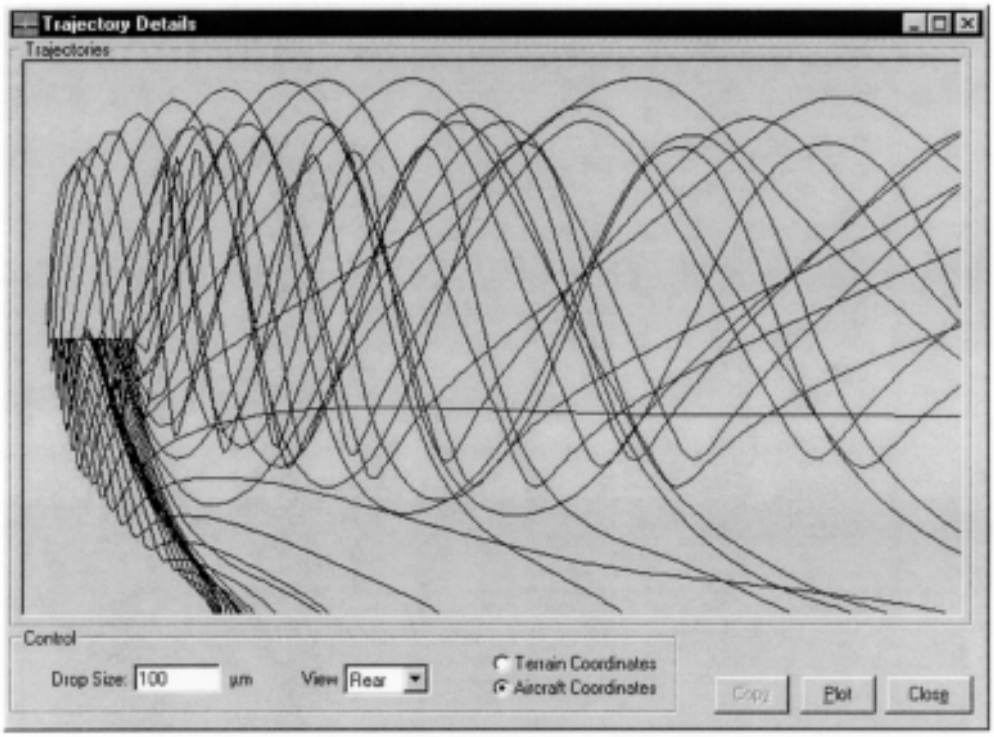

Figure 12. Trajectory Screen for 100 µm Droplets With Rear View.

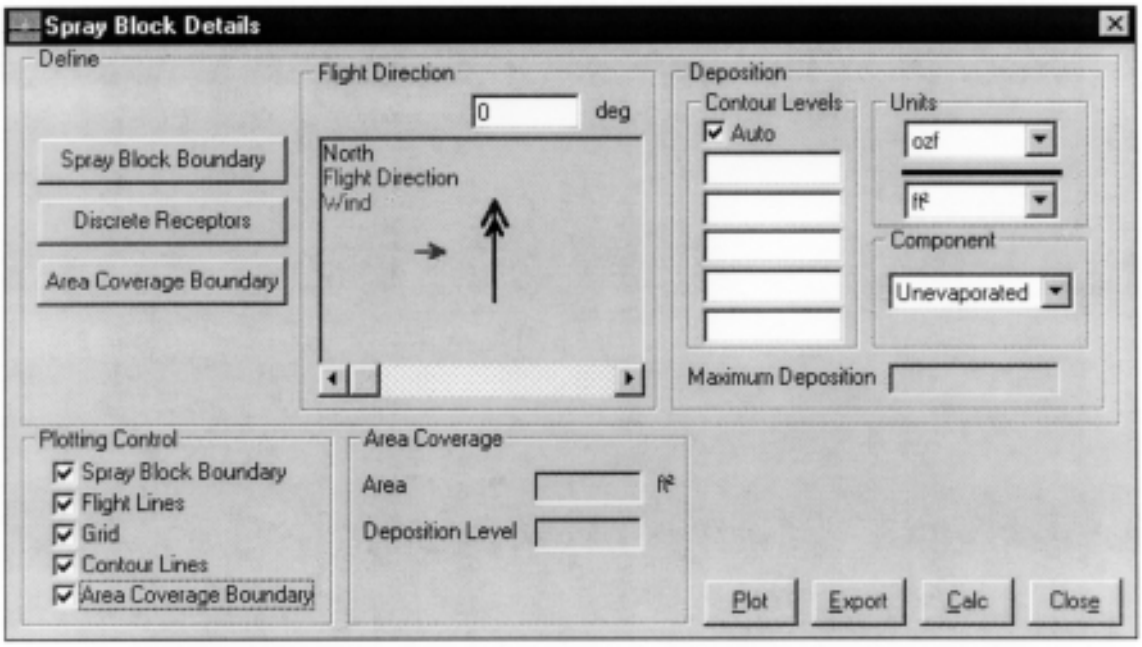

Figure 13. Spray Block Details Screen.

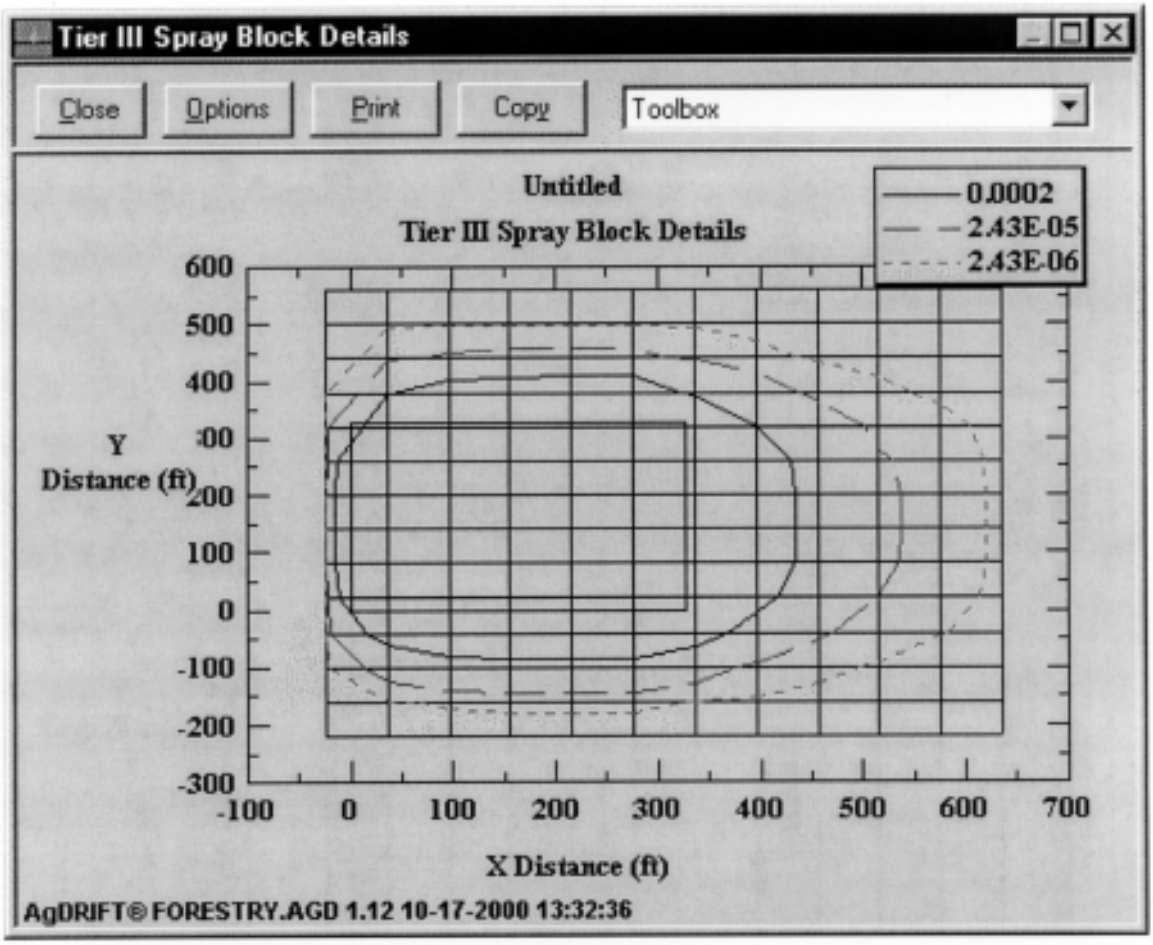

Figure 14. Example of Spray Block Details Plot.