Suffolk County Vector Control & Wetlands Management Long Term Plan & Environmental Impact Statement

LITERATURE REVIEW

Atmospheric Dispersion and Deposition Modeling

For the:

Suffolk County Department of Public Works
Suffolk County, New York

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Cashin Associates, PC
Cameron Engineering & Associates, LLP
RTP Environmental Associates, Inc.

SUFFOLK COUNTY VECTOR CONTROL AND WETLANDS MANAGEMENT LONG - TERM PLAN AND ENVIRONMENTAL IMPACT STATEMENT

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AERMOD	AMS/EPA Regulatory Model
AgDISP	Agricultural Dispersal
AgDRIFT	Agricultural Drift
AGL	Above Grade Level
AIMMS	Aircraft Integrated Meteorological Measurement System
AMCA	American Mosquito Control Association
ASAE	American Society of Agricultural Engineers
CALINE	California Line Source Dispersion Model
CALPUFF	California PUFF Model
CAMEO	Computer Aided Management of Emergency Operations
CDC	Centers for Disease Control
DDT	Dichloro Diphenyl Trichloroethane
EIS	Environmental Impact Statement
FEIS	Final Environmental Impact Statement
FSCBG	Forest Service Cramer-Barry-Grim
GEIS	Generic EIS
GIS	Geographic Information Systems
GPS	Global Positioning System
ISC	Industrial Source Complex Model
ISCST3	Industrial Source Complex Short Term Model, Version 3
NASA	National Aeronautical and Space Administration
OPP	Office of Pesticide Programs
SAP	Scientific Advisory Panel
SDTF	Spray Drift Task Force
ULV	Ultra Low Volume
US	United States
USDA	United States Department of Agriculture
USDA-FS	United States Department of Agriculture-Forest Service
USEPA	United States Environmental Protection Agency
VMD	Volume Median Diameter

EXECUTIVE SUMMARY

The consequences of chemical use in pest management programs for mosquito control are significantly influenced by atmospheric dispersion and deposition processes. These processes govern the fate of a pesticide when released, where it will travel, what it will impact, and the intensity and character of that impact. Knowledge of dispersion and deposition has been expanding steadily. This knowledge is based on empirical measurements, as well as mathematically driven models that allow researchers to theoretically predict the behavior of pesticides during planned applications. This literature review provides a summary of the progress that has been achieved by various groups working toward sustainable vector control management techniques. It also defines the key variables that must be analyzed before accurate and representative estimates of how and when to apply pesticides can be realized. It discusses what techniques are currently available to assist pest management programs in making application decisions. Finally, it provides some data that validates recommended techniques, as well as suggests where additional research would be helpful in improving model predictive accuracy and completeness.

Historically, researchers in this field have come from a variety of backgrounds, often solving problems unrelated to vector control. Initial efforts were by military and agricultural groups that studied atmospheric processes related to warfare and agricultural applications. These researchers, although few in number, made significant progress in developing measurement techniques for key meteorological and atmospheric variables, as well as developing measurement systems for observing ambient concentrations and dose rates. The US Department of Agriculture – Forest Service (USDA-FS) continues to work on these issues. It has been joined by the US Environmental Protection Agency (USEPA), which developed analytical models and measurement techniques for use in evaluating stationary and mobile pollutant source impacts. Industry groups like the Spray Drift Task Force (SDTF) were organized to evaluate pesticide application rates and to supply empirical data for use in evaluating various predictive models. Organizations like the American Society of Agricultural Engineers (ASAE) and the American Mosquito Control Association (AMCA) also provide forums at which researchers discuss advances being made.

The literature review has sought to delineate what is known about atmospheric dispersion and deposition, and which variables are key to predicting the behavior of pesticides released into the environment. The key variables include those related to the release point of the pesticide such as:

- nozzle type
- spray pressure
- orientation
- aircraft or vehicle type
- vehicle wake characteristics
- rate of release
- droplet size distribution
- orientation of the nozzle

Other key variables relate to the transport of the pesticide from the the release point to the target area and beyond. These variables include:

- wind speed and direction
- temperature
- humidity
- atmospheric turbulence
- time of day

These variables must be specific to the local area so that they represent conditions associated with the release. Finally, there are key variables associated with intended target areas,as well as non-target areas. These include:

- target pest of interest
- pest characteristics
- surface conditions
- topography
- geography
- critical environmental receptors

- other environmental factors that would influence the effectiveness of an application strategy

All of the above variables are influential in determining the outcome of any application. Some, such as local meteorology, can exclusively determine if a pesticide will impact the intended target.

Mosquito control program managers influenced by the outbreak of West Nile Virus have made several major demands on the research community studying atmospheric dispersion and deposition. Typical pesticide applications in agriculture use large droplet sizes to douse vegetation completely to impact plant-feeding insects. The mosquito control industry currently uses very small droplets to create a fog through which insects fly to achieve insecticidal impacts, while minimizing deposition. Because the application approaches are very different, the factors critical to predicting the behavior of the pesticide released are also different. These differences have only recently been understood sufficiently to be able to make progress in modeling mosquito control applications. The newest modeling systems, currently in limited use, are beginning to demonstrate some competence. These systems can monitor local meteorology in real-time, and then use onboard computer software to predict specific flight trajectories would deliver an effective dose onto a target area. They also have the ability to forecast pesticide plumes and to determine deposition rates. Spray patterns, aircraft speed, nozzle orientation and droplet size distributions can now be adjusted to target applications, while minimizing pesticide wastage and dispersion away from the application area.

The current state-of-the-science has been advanced so that vector control program managers can make reasonable decisions on where, when, and how to apply to achieve effective mosquito control, while at the same time minimizing the negative aspects of applying. However, more work is necessary to improve model performance, especially with regard to calibration through the measurement of flux rates in three dimensions downwind of multiple passes. Ample data in this area would allow improved confidence in model applications.

1.0 Introduction

The decision of when and where to apply pesticides to control mosquito populations must be made on a sound technical basis. Since pesticides can be hazardous to human and ecological receptors, the ability to predict the potential impact of pesticide applications is critical to the decision making process. Atmospheric dispersion and deposition processes govern the distribution and impact of pesticide releases. Thus, developing algorithms or modeling systems that can accurately predict the behavior of pesticides as they are affected by atmospheric processes is critical to decision makers.

Research into atmospheric dispersion and deposition of pesticides has been rapidly expanding over the past 30 years (Barry, 1996). Individuals have become progressively more aware of the effects of man-made chemicals on the natural environment, as well as on human health. Initially, it was acceptable to achieve effective mosquito control with little regard for the impacts on sensitive receptors. Today's society, however, demands a more thorough evaluation of the costs and benefits of a control scheme working towards sustainable integrated mosquito management (Rose, 2001). Therefore, predictive systems have evolved to assist in quantifying the variety of impacts associated with vector control management practices.

This report provides a literature review of the methods available to predict atmospheric dispersion and deposition characteristics of pesticide releases. It includes a discussion of the key variables that influence the rates of dispersion and deposition. The various models that have been developed to quantify various aspects of atmospheric dispersion and deposition are reviewed and evaluated for use in the prediction of pesticide applications as envisioned in the Suffolk County Vector Control program. These discussions provide the technical basis for the use of specific models and methods of verifying and validating model predictions, including the use of available monitoring data collected by Suffolk County during pesticide application.

Most vector control programs currently rely on two platforms of applying pesticides: aerial based applications via helicopter or airplane, and ground based applications via vehicle-mounted application equipment or backpack applicators. The variables that govern the dispersion and deposition processes are not identical for these two application platforms. Consequently, each will be treated separately and the different algorithms, modeling techniques, and systems needed for each application method will be described.

Today's atmospheric diffusion and deposition models make it possible to calculate the concentrations of pesticides that are predicted to result from an application for each of three pathways critical to the evaluation of human and environmental health risk: inhalation, ingestion, and dermal exposure. The modeling systems also have the ability to predict exposure impacts at multiple locations in a target area. These modeling systems can, therefore, be used to predict an entire matrix of concentration impacts on the three exposure pathways, over the short- and long-term, and at multiple locations. Health risk assessments can be made to evaluate acute or short-term exposures and the subchronic and chronic or longer-term exposures once the atmospheric diffusion and deposition impact matrices have been developed.

The review will focus on key atmospheric modeling variables including:

- local meteorological conditions
- topography
- geography
- pesticide dynamics
- pesticide chemistry
- release characteristics
- fate and transport following pesticide release and encountering a receptor
- key interactions associated with the receptor leading to the ultimate fate of the pesticide

Researchers have developed diffusion algorithms (mathematical solutions) to analyze how particles move, how they settle out of an air flow based on the particles' density, how liquid particles evaporate, and how particle size distributions are maintained in target areas. These algorithms have been used to predict the behavior of pesticide releases, to maximize lethal-to-mosquito concentrations in target areas, and minimize impacts on adjoining areas.

Model validation or verification is also critical for the reliable use of models to predict the behavior of pesticides in the environment. This review will discuss the field monitoring data that are available to verify model predictions and, where necessary, to adjust model algorithms. As will be shown, model results have often been compared to the results from other models with little, if any, comparison to actual observed concentrations. Any disparity between predicted and measured values is most often thought to be due to a lack of appropriate meteorological data during the test event (Rafferty et al., 1996). Meteorological data must be consistent with the time frames and spatial distribution of the materials being applied, as well as the areas being sampled. Appropriate choices for time and spatial scales are extremely important for plume behavior predictions because of the variability of local conditions. In particular, vector control applications commonly occur during early evening or early morning hours when micrometeorological conditions are in transition between highly unstable, turbulent flow, and stable, laminar flow, atmospheric conditions. As such, model validation is a critical component for the selection of predictive techniques.

According to the Centers for Disease Control and Prevention (CDC) (2003), "There is no simple formula for determining how large an area to treat… or the degree of vector population suppression that must be attained." However, mosquito control managers are required to make precisely these decisions. These issues may be largely addressed by the real-time modeling systems now in use and under development. More accurate predictions of the impacts from the atmospheric release of vector control chemicals can be made by the new systems. Real-time modeling systems are capable of predicting the impact of a release as it is occurring. An applicator using the new systems is now able to adjust the spray patterns and duration of releases to maximize impacts to intended areas and minimize the collateral impacts on adjoining non-targeted areas.

This literature review is divided into the following sections. Section 2 provides a historical review of techniques that have been developed to predict the behavior of materials released into the atmosphere on a variety of scales. Section 3 addresses the aerial application of pesticides. The variables that are critical to the prediction of pesticide impacts from the release point through their trajectory and, finally, the impacts are reviewed. The advantages and disadvantages of available models that are available are also discussed. Section 4 provides similar information on ground- based pesticide applications from vehicles to handheld devices. Here, the predictive methods have not advanced as rapidly as compared to aerial applications. However, an approach is suggested that should be effective in predicting impacts from such sources. Section 5 contains a review of the validation of both deposition estimates and air concentration estimates provided by the selected modeling systems. The field studies, conducted to specifically address these issues, are discussed along with an analysis of the model's ability to predict aerial and surface-based chemical applications. Finally, Section 6 provides a summary of salient points and our conclusions on the state-of-the-art of atmospheric dispersion and deposition models as related to vector control.

2.0 Historical Perspective

A perspective on atmospheric dispersion and deposition processes can be gained with some basics of how atmospheric process are measured and estimated. This begins with an understanding of the complex atmosphere in which these processes occur. The atmosphere is comprised of a mixture of gases, liquids and solid particles. It has certain properties that can be measured such as density, temperature, and relative humidity. Measurements can also be made of the air (wind) speed, the direction from which the wind is blowing (wind direction), and eddies that are present (turbulence). These are the three most important components for evaluating atmospheric diffusion and dispersion (although diffusion and dispersion are not equivalent, for simplicity's sake they will be used interchangeably in this discussion). Most people understand wind speed and wind direction; this is not true for turbulence. Simplistically, turbulence is the chaotic motion of the atmosphere. The dancing movement of smoke from a flare on a windy, gusty day is a good example of how turbulence makes atmospheric modeling difficult. If the settings and conditions are simplified (such as an open field with no obstacles and a moderate, persistent steady wind), the smoke trajectory is somewhat predictable. However, adding even the smallest interference (putting a building near the flare, for example) makes the smoke plume behavior much more complicated, and, with it, the task of trying to predict that behavior.

Three conceptual approaches have been developed to quantify atmospheric diffusion. They are referred to as Eulerian, Lagrangian and Gaussian methods (Pasquill, 1962). The Eulerian approach attempts to take physical measurements of atmospheric variables, such as wind direction and wind speed at all points in space at one moment, and uses those to predict atmospheric behavior or how a plume may be expected to move from one point to another. Atmospheric behavior is discussed in terms of a fixed framework. The Lagrangian approach uses the velocity for individual particles, and follows the trajectory traced by a dispersing plume of particles; it discusses atmospheric behavior based on relative positions. The Lagrangian method tracks the dynamics that occur within the plume and translates these internal conditions to predict the path. The Gaussian approach is statistical in nature. It posits that the dispersion process, over a sufficiently long time, will assume a distribution similar to a classical bell-shaped curve. This plume path determination produces an output that is a probability that the plume will reach a certain point. For example, the majority of the time the puffs of smoke from a flare will be near a centerline based on the mean wind direction. At a distance laterally from the centerline, the smoke will be found less frequently. Over time, the positions that the smoke plume can assume are distributed from the centerline in terms of a bell-shaped distribution. These approaches have been incorporated into attempts to mathematically describe the turbulent motions of the atmosphere and, thereby, define atmospheric diffusion processes. The end result is a mathematical description or a computer simulation that attempts to describe how a plume might form and the concentration and deposition profiles that might be expected as the plume disperses.

The United States Environmental Protection Agency (USEPA) and the United States Department of Agriculture Forest Service (USDA-FS) have been the two primary government agencies involved in developing simulation models for predicting atmospheric dispersion and deposition. USEPA has been involved from two different perspectives, stationary sources and mobile sources, while USDA-FS has concentrated on pesticide application. Specific instances of recent pesticide modeling were the efforts made in association with New York City and Westchester County assessments of the impacts of pesticides to address West Nile Virus related applications in their areas (NYCDOH, 2001; WCBOH, 2001). Another notable effort resulted because the USEPA Office of Pesticide Programs (OPP) required manufacturers to provide labeling data on pesticide use, including conditions and situations that are permissible for the pesticide to be used. In a response to these requirements, a manufacturers' task force was formed to address OPP concerns, largely through monitoring and modeling (USEPA, 1997). The results of these efforts by USEPA, USDA-FS, the Spray Drift Task Force (SDTF), and other researchers are summarized below.

2.1 USEPA and Other Applications

The need to predict the behavior of agents or pollutants released into the air was the primary impetus for the development of atmospheric dispersion models. Since World War I, the understanding of the diffusion of germ and gas agents released into the air has been in the national interest (Richardson and Proctor, 1925). USDA-FS was also involved in early attempts at predicting the trajectory and behavior of pesticides released in various agricultural applications. Furthermore, the establishment of the USEPA in the late 1960s brought renewed interest to calculating air pollutant emissions and diffusion rates, as USEPA was charged with determining the potential impact of the air pollutants. This work focused on determining if air pollutant concentrations exceeded the newly established air quality standards. Several groups, working both independently and in concert, developed a series of models that could be used to predict the dispersion and deposition of agents released into the air. USEPA initially used Gaussian type models and Eulerian based measurements to calculate atmospheric dispersion. Recently, USEPA has also introduced sophisticated numerical schemes like those used by the USDA-FS, based more on Lagrangian methods, to predict atmospheric behavior.

Some of the original work on using aircraft to control insects was discussed by Nellie and Hauser (1922) in their paper "Fighting insects with airplanes." King and Bradley (1926) also discussed the utility of aircraft in controlling malaria-carrying mosquitoes. USDA-FS recognized the role of aircraft in pest management practices and the utility of numerical mathematical methods, especially when determining the behavior of agricultural chemicals released from aircraft. Model developers have also realized that a single approach cannot address all of the variables. As such, modelers have subdivided the processes into a series of components or subroutines to address each aspect of air dispersion and deposition.

Pesticides have been used extensively in agricultural-forest service applications, with the application platform of choice for broad areas being aircrafts (Barry, 1996). The critical aspects of atmospheric dispersion processes from an aircraft include:

- dispersion of the initial plume release
- dispersion of the plume beyond the influence of the aircraft wake
- the final trajectory and deposition processes

Separate algorithms were developed to determine the size and spatial distribution of droplets leaving the spray nozzle at the aircraft. Variables such as aircraft type, wing span, speed, spray boom length, spray boom position, wing location, etc. were all analyzed and placed into a set of mathematical algorithms (subroutines) that reasonably described the potential influence of aircraft characteristics on the initial release of any agent or pesticide (Teske and Curbishley, 2003).

Separate algorithms have also evolved that describe the initial dispersion of the released material in the turbulent wake of the aircraft (Thistle et al., 1998). Aircraft generated turbulence is very intense near an aircraft because of the speeds and forces involved; these effects are evident to pilots of small planes that cross the turbulent wake left by a larger aircraft. The rate at which turbulence dissipates is a key factor in the dispersion process; however, it is difficult to measure.

Once the agent has been mixed and spread out by the aircraft wake, the agent plume enters a transition zone where wind speed, wind direction, and atmospheric turbulence begin to dominate the dispersion process. Typical aerial applications from aircraft treating agricultural areas focused on low flying trajectories within a few meters of the surface. This forced the majority of the released agents to be intensely mixed within the vegetative canopy. Application patterns on crops were positioned so that spray passes were fairly close to adjoining passes or swaths. Little attention was given to the small amount of fine droplets that quickly disappeared from view (USEPA, 1997).

The algorithms developed by various researchers in these areas to address specific variables influencing the release and dispersion process were incorporated into the AgDISP (for Agricultural Dispersion) model. The model initially quantified and described the behavior of a plume released from an aircraft and a short distance downwind (Teske et al., 2003). The AgDISP model has been continuously improved and is now being used by the vector control industry for aerial agricultural applications to specify how much material is to be applied, and in what fashion, to achieve maximum effectiveness.

In the late 1960s, USEPA was concerned with the impact of air pollutants emitted from point, area, or line sources. During the early days of USEPA, tall power plant stacks were known to release large quantities of air pollutants, and initial USEPA modeling efforts focused on these sources. The problem involved smoke stacks with vertically directed hot exhaust gases that carried air pollutants aloft. The heights of the stacks in question could vary from a few feet to those in excess of 1,000 feet. Algorithms, like the Industrial Source Complex (ISC) Model, were initially developed to mathematically describe the plume trajectory and the initial dispersion of the plume. Initial turbulence in the plume was complex because of both thermal and mechanical buoyancy, making the prediction of how high a plume might rise above the stack top under various meteorological conditions challenging. Additional complications were introduced because of the continuous operation of the sources, and the mathematics associated with plume rise under a variety of wind speed, wind direction, temperature, turbulence and daytime versus nighttime atmospheric stability conditions. Atmospheric stability, actually, is in itself a complex amalgam of mechanically and thermally generated air turbulence and vertical temperature differences. Once the stack plume lost its "near field" characteristics, those dominated by the source, it is said to transition to the "far field." The transition point is where the plume temperature approaches ambient temperature, and plume turbulence levels have dissipated so that ambient air turbulence predominates. USEPA developed improved algorithms to describe the dispersion of the plume into the far field. This required the incorporation of environmental and topographic features over a variety of time frames on which air quality standards and guidelines were based.

Based on the need to define atmospheric diffusion in the near and far field from a variety of sources, an entire suite of atmospheric dispersion models emerged, generated by USEPA and its contractors. Examples include ISCST3, CALPUFF, AERMOD, CAMEO, and CALINE. These models are general enough that they should be capable of assessing the pesticide behavior after its release. However, pesticide issues have been addressed using other techniques.

The vector control industry is very demanding from a modeling perspective because the nature of the chemicals used with rapid degradation and evaporation rates, result in much more complex fate algorithms. Furthermore, the models used in managing chemical application methods differ sharply, with agricultural pesticides delivered near ground surface and insecticides for mosquito control applied at elevation. Modeling the dispersion and deposition of ultra low volume (ULV) vector control insecticides requires a more complete approach such as the AgDISP model, a more versatile version of an earlier AgDRIFT model. Predicting the dispersion and deposition of vector control insecticides from ground-based platforms, such as truck mounted sprayers or handheld applicators, requires yet another modeling approach.

2.2 Recent Modeling Experience in Vector Control

The introduction of West Nile Virus into the indigenous mosquito population of areas throughout the United States has resulted in the need for public policy decisions on where, how, and when to apply control agents. The Westchester County and New York City Health Departments both commissioned Environmental Impact Statements (EISs) as part of their West Nile Virus control program (WCBOH, 2001; NYCDOH, 2001). The documents discuss the potential environmental and health impacts of the various products used in their respective vector control programs and include a discussion of the various models that can be used to simulate the dispersion and deposition of pesticides. A brief sensitivity analysis is in the New York City Final EIS (FEIS), while the Westchester Generic EIS (GEIS) includes a more complete sensitivity evaluation. The documents also briefly address model verification and validity issues. Each study also selected a model to provide a predicted impact for use in a risk assessment that was used to evaluate the impacts of the programs.

The EISs document the air concentration and deposition impacts associated with various pesticides. The approach in both was to generate a maximum concentration and deposition rate; which were then utilized in the health risk assessment as inputs for specific routes and levels of exposure.

Both evaluations are limited. For example, the Westchester GEIS provides a sensitivity analysis between two different modeling systems used to make impact predictions, but did not include an analysis for each model variable. Therefore, the sensitivity analysis is of very limited use. The GEIS made a comparison between the selected model's predictions for a receptor 25 feet from an application vehicle's path with one set of field data. The results showed a three-fold overprediction of concentrations from the model. This comparison to one set of results at one location was cited as sufficient justification for use of the model as a conservative tool for estimating impacts for all conditions and source receptor locations.

For New York City, because direct measurements of active ingredient concentrations for every adulticide following application were not available, the analysis relied on a generated range of estimates provided by air dispersion and deposition modeling (NYCDOH, 2001). Again, as in the Westchester case, a single potential receptor 25 feet downwind of the vehicle was selected as the maximum acute exposure value. This meant the modeling effort was unnecessary, as the maximum value was based on a single measured result. Furthermore, the analysis did not determine the relative differences between the worst-case impacted individual versus the average impacted individual, which is often done to add perspective to the study results.

Both studies also provided an analysis of subchronic and chronic exposure to pesticide applications from ground and aerial applications. The analysis relied on the USEPA ISCST3 model to calculate the highest average deposition rate within a 300-foot swath, over a series of meteorological conditions, for both ground and aerial application means. The deposition value was then factored to provide deposition rates for each potential pesticide and each exposure point, and worst-case values were used. No analyses were presented to determine the relative differences between the worst-case individual and the average individual. In addition, a single point was used to determine the associated risk at all locations. Both studies concluded, based on the worst-case modeling scenarios, that there would be no or minimal health impacts associated with the pesticide applications. Based on these findings, aerial application and truck-based applications were approved for both areas.

In the 1990s, a group of pesticide registrants formed a task force, the SDTF, to develop a database from which a generic approach to registering and re-registering pesticides could be designed (USEPA, 1997). This effort was directed to fulfill OPP requirements to support the registration of hundreds of pesticide products and their use. Performing separate field studies on each formulation and use was deemed impractical. In 1992 and 1993, the SDTF conducted a series of field studies to measure off-target aerial application deposition. This information allowed OPP, working in concert with the SDTF, to produce the AgDRIFT model, which was superior to earlier models for the prediction of downwind drift. A Scientific Advisory Panel (SAP) review of the data found that the chemical composition of the insecticides had little effect on off-target drift (USEPA, 1997). The dominant factors were the application fluid's physical properties, equipment factors, and meteorological conditions. The SAP review also acknowledged that wind direction under light wind speed conditions was difficult to quantify. Following this peer review, the SDTF addressed several questions and comments made by the advisory panel, and shortly thereafter disbanded, leaving behind a fairly well refined model for predicting the behavior of aerial application events that was deemed adequate to fulfill the OPP requirements.

It should be noted that Ultra Low Volume (ULV) applications were not evaluated in the SDTF studies. In addition, only unstable atmospheric conditions were tested by the SDTF, leaving a large gap in data on applications during stable air and temperature inversion conditions at low altitudes. This is unfortunate in terms of mosquito control modeling scenarios as most, if not all, applications are conducted at night when stable, low lying inversion conditions are most likely, especially when wind speeds are light or non-existent. The two key variables influencing modeling results appear to be droplet size and meteorological conditions for determining atmospheric dispersion and deposition, and atmospheric stability and the height of any pynchnocline are very important to characterizing meteorology.

Thus, there have been three major modeling groups in the U.S. focused on simulation models, which can be used for pesticide applications:

- USEPA

  The USEPA efforts focused on stationary and mobile sources of common industrial pollutants. Extensive progress was made in determining the processes that influenced atmospheric dispersion and deposition. The models that resulted provide reasonable estimates of impacts.
- USDA-FS

  The USDA-FS efforts focused on agricultural applications for both ground based and aerial platforms. The models that emerged were fairly good at predicting the behavior of various pesticides released from various platforms. The models have had several limitations and one must always determine whether the selected approach will provide an accurate prediction of impacts.
- SDTF

  The SDTF was specifically organized to develop a database to provide the necessary relationships for predicting pesticide application and off target drift under a broad range of application scenarios. There were several shortcomings to the database, especially as it relates to mosquito control.

In combination, these efforts have resulted in modeling systems that can be used to predict the dispersion and deposition of pesticides under certain, limited conditions. Accurate simulations for ULV applications under relevant weather conditions at altitudes, commonly used for mosquito control aerial applications, require adjustments to these modeling approaches.

Despite these limitations, modeling was used in the NYC and Westchester EISs to establish maximal doses at specific points. These results were used to extrapolate potential risks for exposed populations.

3.0 Aerial Applications of Pesticides in Vector Control

3.1 Background

With the sudden outbreak of the West Nile Virus in the New York Metropolitan area during the summer of 1999, local government officials were forced to establish emergency vector control management plans which relied on the use of pesticides in residential communities. One commonly used application method was the aerial release of ULV pesticide formulations from a fixed wing aircraft or helicopter. The vector control industry has adopted techniques developed by USDA-FS to estimate how to deliver precise and effective insecticide applications over large areas. For example, Suffolk County Vector Control sometimes applies pesticides by helicopter in the dusk to early evening hours, or in the predawn hours. The application pattern typically covers several square miles using a multiple pass technique. Applications are restricted to a limited set of acceptable meteorological conditions, to minimize releases to non-target areas. Typically, due to topography and geography of the area, the flight elevation is 100 to 200 feet above the surface.

To accurately model such applications, there are critical variables that are instrumental in defining the trajectory and fate of the pesticides. The following discusses these variables and models available for use.

3.2 Critical Components of Aerial Application Modeling

A review of the literature suggests that there are three critical components for aerial application modeling. The first component, the release, is defined as the immediate departure of material from the aircraft application equipment. The second component is the trajectory of the material in the atmosphere. The trajectory is associated with exactly where, when, and how the material will disperse after its release. The third component of aerial application modeling is pesticide impact. The impact is associated with where and when particles and vapors will collide with the ground, tree canopies, buildings, and other obstacles, such as human and mosquito receptors. Understanding the dynamics of these three components simultaneously has lead to the development of aerial application drift models.

3.2.1. Release Issues

The variables that describe an aerial release of pesticide are commonly summarized in three subcategories. The first release variable issue is associated with the physical and chemical properties of the applied material that govern its behavior once released. Material properties include:

- tank mix fractions (active fractions and non-volatile fractions)

- carrier substance (oil or water)
- specific gravity
- reaction rates
- evaporation rates

The second material release issue concerns the application equipment variables that dictate the initial physical movement upon release. Variables include:

- spray nozzle type (which determines the droplet size distribution)
- nozzle orientation
- boom length
- nozzle pressure

Application rate is also included as an equipment variable that must be closely monitored. The third release issue concerns aircraft variables including:

- aircraft type (fixed wing or helicopter)
- aircraft weight
- flight speed
- release height
- the number and placement of flight lines (swaths)

(Teske, 1996)

3.2.2. Trajectory Issues

Once the release variables are defined, the next critical component is the trajectory of the released material. Unlike the release variables, where most of the information is known before the release or can be obtained during the time of release, determining the trajectory requires estimating a series of variables at the time of release and directly thereafter. Computer algorithms have been developed to define the movement of ULV particles released into the air.

Defining the behavior of particles released via aircraft requires knowledge of the turbulent effects of a moving aircraft and the movement of the ambient atmosphere from the time of release until particle impact

(Thistle, 1996). The period from when particles are released until they impact is often very short, on the order of a few minutes or less. Monitoring atmospheric turbulence over such a short time period can be very difficult. Ambient atmospheric turbulence can be measured with meteorological monitoring equipment. The turbulence associated with the aircraft wake, however, is typically estimated through modeling simulations, such as using Lagrangian methodology to calculate the turbulence generated, and then predict dissipation of the wake-associated turbulence.

3.2.3. Impact Issues

The third critical component of aerial application modeling is an understanding of when and where particles released to the air will impact the ground, tree canopies, buildings, and, most importantly, target pests, and human and wildlife populations. Modeling software has been developed which incorporates trajectory estimation with impact prediction. When determining the health risks from an aerial application, it is critical to define where impacts will occur and the amount of chemical delivered at specific points. In order to calibrate the equations used to drive the impact portion of the model, air deposition and concentration data should be collected.

3.3. Aerial Application Modeling

The development of sophisticated aerial application dispersion models began in the 1960s. Before this, there was no quality control for application programs in USDA-FS. The real change came about because of the ban of dichloro diphenyl trichloroethane (DDT) in 1964 and the introduction of less persistent substitutes, which meant that pesticide applications now needed to hit the intended target to be effective (Barry, 1996). By the late 1960s, the US Army was applying 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 were developed to describe the penetration of droplets into tree and brush canopies as well as droplet evaporation. These model development efforts were a combination of USDA-FS and the Army. The result was a computer code (dispersion model) called the FSCBG model (for Forest Service Cramer-Barry-Grim, after its developers). The FSCBG model description and model capabilities were documented by Teske et al. (1993).

In 1979, Continuum Dynamics, Inc. began developing a Lagrangian model for the dispersal of application material utilizing the equations for particle motion first suggested by Reed (1954) and culminating in a National Aeronautical and Space Administration (NASA) model known as AgDISP (Bilanin and Teske, 1984). The approach included models for aircraft wake effects (vortices, propellers, and jet engines) and evaporation (Bilanin et al., 1989). This model was linked to FSCBG as a near-wake model to improve the FSCBG model performance. The AgDISP modeling technology has now become the computational engine of choice in making most active, near-wake estimates in the US, Canada, and New Zealand.

AgDISP also continues to undergo further development, including algorithms to estimate far-field dispersion. It is now in Version 8.08, and is considered state-of-the-art in predicting aerial application deposition and drift. Although originally developed for agricultural applications, AgDISP has also been used by the mosquito control industry over the past five to 10 years for estimating impacts from aerial applications. In particular, AgDISP was incorporated into an interactive real-time aerial application and modeling system, designed by Continuum Dynamics and Adapco, Inc. (Teske et al., 2003).

3.4 Interactive Application and Modeling Systems

A technologically advanced and interactive aerial application and modeling system has recently been developed by Adapco, Inc. (Adapco, 2003). It is an aerial precision guidance and recording system that:

- receives real-time, multi-level meteorological information
- incorporates the AgDISP application fate modeling system
- displays the optimization results to the pilot in real-time

This system has a US patent as the Wingman™ GX. The system provides a pilot the ability to impact target areas with an effective dose of pesticide using current data to properly position the aircraft and determine the duration of applications.

Some of the system's primary features include:

- Real-time tracking of aircraft position and application system variables
- Real-time monitoring, displaying and recording of multi-level meteorological conditions

- Real-time alarming of meteorological condition changes
- Use of AgDISP for maximum/minimum offsite drift predictions
- Use of Global Positioning System (GPS) and Geographic Information Systems (GIS) for tracking and mapping
- Touch screen color map display

The Wingman™ GX provides basic flight guidance, flight recording, and obstacle awareness through GPS technology and GIS software. The system also records flow rates, application totals, and acres treated. The system is capable of receiving, processing and displaying real-time, multi-level meteorology from either an Aircraft Integrated Meteorological Measurement System (AIMMS-20), a Kitoon (a balloon carrying meteorological equipment), or a meteorology tower station, together with ground-level meteorological measurements. The Wingman™ GX system instantaneously resolves the proper offset and altitude of the aircraft, flight path, to define droplet density and optimize droplet size through or onto the targeted area, while minimizing off-target drift. As the application is being made, the pilot watches a computer-generated image of the drifting spray cloud, generating confidence that the applied material is being delivered through or to the intended target. This is achieved by integrating real-time meteorology with the AgDISP model (Adapco, 2004).

To date, however, only one extensive field effort has been conducted to verify the model results. This test used the Wingman™ GX system with appropriate meteorology, as well as eight deposition-monitoring sites to measure actual deposition and transport flux values. The test was performed on July 18, 2002 in Manatee County, Florida, using a helicopter at 150 feet above ground level (AGL), and a high-pressure atomizer with a 23-micron volume median diameter (VMD) (Latham, unpublished). Initial appraisals of the data suggest the AgDISP model results were similar to measured deposition and transport flux values, although the specific results have not yet been peer reviewed.

Other systems have also been developed to improve awareness of local meteorology and, thus, refine aerial applications. For example, Ag-NAV2 is a navigation system developed by Ag-NAV, Inc., that allows the pilot to precisely define swath locations and flight paths. AGS-IV, developed by UTJ Navigation Systems, AgGPS Trim Flight 3, developed by Eastern Avionics, and SatLocSLX$_g$3 developed by SatLoc, LLC, also provide similar guidance systems for precisely defining where a material is being applied. None of these systems incorporate a dispersion model to predict the trajectory of the pesticide and its dispersion and deposition, as the Wingman^{TM} GX system does.

The US is not the only area where model development and advances have occurred. For example, the SpraySafe Manager 2 (SSM2) system has been developed by New Zealand researchers in conjunction with USDA-FS. The major SSM2 innovation is the integration of the deposition and biological response calculations in a GIS environment. This allows users to see the data superimposed on a map of the application area (Schou et al., 2004). Other approaches are being developed in Europe.

It must be understood that the aerial application of near surface agricultural pesticides differs in many ways from applications of insecticides for mosquito control. The most notable differences in variables between traditional USDA-FS agricultural aerial applications and aerial mosquito control program include those detailed in Table 1.

Table 1 – Differences between Agricultural and Mosquito Control Aerial Pesticide Applications

Agricultural Applications	**Mosquito Control Applications**
Large droplets	Small droplets
Low elevation release	High elevation release
Water carrier	Oil carrier at ULV
Neutral to moderately unstable atmosphere (daytime)	Stable atmosphere (nighttime)
Wind speed and direction at application release (surface)	Wind speed/direction at application release (elevated)

Because of these differences, mapping the dispersion and deposition of ULV insecticides used for mosquito control cannot be done by simply applying AgDRIFT or AgDISP modeling approaches, or by plotting the position of the aircraft as pesticides are being released. However, the latter approach is the basis for regulating aerial pesticide applications.

In summary, the field of modeling aerial applications has matured over the past ten years. A variety of models and aircraft guidance systems exists for use by the vector control industry. To date, the most advanced system from the perspective of mosquito control using aerial platforms appears to be the Adapco Wingman^{TM} GX system.

4.0 Ground Based Applications of Pesticides in Vector Control

4.1 Background

Ground-based application techniques are the most common means for pesticide applications in the vector control industry. Initially, ground-based applicators were rarely concerned with off target application drift. It was assumed that the applications were so precisely directed at target areas that little drift could occur beyond the target zone. This was largely true when applicators were using handheld sprayers to treat local problem areas. However, control programs expanded and became responsible for broader geographic scales, treating persistent problems. The banning of DDT by USEPA in 1972, prompted by health and environmental concerns, marked a dramatic change in the management approach to controlling mosquitoes. The emergence of West Nile Virus as a nationwide health threat caused a more aggressive response to mosquito control, and, as applications increased, health and environmental concerns were reenergized.

The studies evaluating the impacts of ground-based applications of pesticides are extensive for agricultural programs. Studies by agricultural researchers provide data on measured impacts, especially for certain water-based pesticides (USEPA, 1997). In these efforts, agricultural tractor-drawn sprayers were studied to improve coverage within crop canopies, where there is a minimal distance between the application apparatus and the target vegetation or area.

Few studies of ground-based mosquito control adulticide applications provide the kind of data required to make accurate predictions of impacts for mosquito control applications. The applicability of available research is further compromised by the droplet size, volume median diameter (VMD), of pesticides used for effective mosquito control. Mosquito-control droplet VMDs are far smaller than droplet VMDs studied in agricultural research. For example, in mosquito control pesticide applications, ULV sprays with VMDs of 20 to 40 microns are used. These 20 to 40 micron droplets have relatively slow settling velocities. Smaller droplets drift further, with the resultant potential impacts on non-target areas. In addition, work that measured ULV applications during evening or predawn time frames has not been found. Typically, mosquito control applications occur under conditions of low wind speed and low-lying inversion, in complex topographic settings. These are extremely difficult environments to measure impacts and variables of interest to support model verifications. In addition, the mosquito control chemicals are fairly unstable, and rapidly degrade, making detection of their presence difficult. All of these factors mean few advances in the impact prediction of ground based pesticide application have been made.

4.2 Ground Based Application Modeling

It is important to predict the behavior of adulticides applied by ground-based systems. It may in fact be more important than accurately modeling aerial applications, since more applications in Suffolk County are ground-based than aerial. There have been several recent studies where attempts were made to measure the amount of adulticides deposited in areas downwind of surface applications (Knepper et al., 2001). In addition, the impact data collected by the SDTF in 1992 and 1993 (USEPA, 1997) was later compared to a similar AgDISP Lagrangian modeling approach, but with little success (Teske et al., 2001). A major problem is that none of the studies collected sufficient data for any specific event, so that a computer-based model could be calibrated.

Most of the variables associated with aerial applications are important for ground applications. There are important differences in the release characteristics and trajectory. The release characteristics for ground-based applications include:

- the physical and chemical properties of the applied materials
- the application equipment variables
- the vehicle variables

The physical and chemical properties of the application include:

- the tank mix fractions
- carriers
- specific gravity
- reaction rates
- evaporation rates

Application equipment variables that determine the initial dispersion of the plume include:

- nozzle type

- nozzle orientation and position
- nozzle pressure

The vehicle variables include:

- vehicle size
- vehicle speed
- release height
- trajectory

Near field dispersion and deposition processes can be determined once the values of these variables are known. In this case, the near field extends along the entire vehicle trajectory and only a few vehicle widths downwind, since the turbulence generated by the vehicle movement dissipates more readily than turbulence generated by aircraft.

In the case of handheld application systems, the variables of interest become even more microscale than for vehicle platforms. They are controlled by application equipment and operator dynamics. The effects of hand-held applications appear to be limited to very specific areas, and, therefore, do not appear to need the same level of modeling as ground-based or aerial based systems. Therefore, the impacts of handheld systems can be approximated by the models used for ground-based vehicle applications.

Trajectory issues for ground-based applications are typically on a smaller scale than those associated with aerial applications. For aerial applications, the overall pesticide plume is much broader, and more uniform in concentration. Ground application plumes are more compact, and disperse to an ineffective concentration more quickly. The trajectory of surface application is also greatly influenced by obstacles in the path of the plume. This is because air movement is governed by the path of least resistance. Trees and shrubs have a tendency to reduce large turbulence eddies rapidly. The speed at which a plume crosses an area is also strongly affected by semi-porous objects such as trees and shrubs. As wind speeds and turbulence decrease, the settling rate per unit of distance increases. This increases the deposition rate in the mean flow. Specific algorithms for defining settling and deposition rates are similar to those in aerial application models discussed earlier.

Effect issues include the dispersion of the plume, along with the deposition of droplets on the ground or other available surfaces. The primary forces involved are gravitational settling and inertial energy. The droplets under semi-quiescent conditions will begin settling, once removed from the turbulent wake of the application vehicle. Where wind velocities, which translate the droplets from the truck path, are low, settling will have a significant effect, keeping the plume within a few meters of the ground as it moves across the target area. Deposition rates on the ground will depend on the exact speed of translation, as well as scavenging by local vegetation and other obstacles. Since most suburban application areas are vegetated, and urban settings have some foliage, even small droplets in the order of 10 microns will begin to settle and deposit in the resulting slower moving air stream.

4.3 Interactive and Other Ground-Based Modeling Systems

Adapco is currently developing a ground-based version of its Wingman™ GX system (W. Reynolds, Adapco, personal communication, 2004). In essence, the system will be able to provide a real-time interactive system for use by vehicle operators. The system will help the operator determine that the plume from the vehicle is impacting the intended target area, and to minimize off target impacts.

This will be a substantial improvement over the current system in which an operator follows a premapped set of roadways, and, by using GPS maintains a record of when and where the vehicle-based application was released. While well intended, such approaches are not analytical. For example, the mean wind direction and speed at the instant the pesticide cloud is released from the vehicle will determine its likely trajectory and points of impact. Since the vehicle cannot always travel perpendicular to the mean wind, the plume may not reach its intended target. Defining the local meteorology in a populated area is extremely difficult, because of the effects caused by various obstacles. Calculated wind directions and speed components in a populated area suggest plume trajectories are very complex. As the plume size becomes smaller, the scale of the forces affecting the plume also decreases, and the more complex predicting trajectories becomes.

Other non-interactive models can be used to predict the dispersion and deposition of ground-based releases. These were developed by the USEPA as either stationary or mobile source models. They can provide rates of dispersion and deposition that can be expected from various applications. It is prudent to determine that the selected model has been validated for the intended use in the specified application.

5.0 Monitoring Data for Model Verification

5.1 Background

Model validation continues to be a critical aspect of this enterprise. Most reports include references to researchers using measured concentration or deposition values to compare with model predicted impacts. In fact, until a massive data gathering exercise by SDTF was undertaken, there was little in the way of sufficient quality assured data against which model predictions could be compared (USEPA, 1997). Since most models do not apply rigorous mathematical solutions of equations, but rather use approximation techniques to which more than one valid solution is possible, it is imperative that field observations be used to verify, and adjust where necessary, the estimates provided by modeling systems (Teske, 2004).

Model validation is intended to provide confidence that models are accurately predicting the processes being analyzed. Without ground-truth data against which predicted impacts can be compared, the accuracy of the prediction can always be questioned.

For model validation to be effective, it should address all application scenarios under consideration. For example, it is not sufficient to have a model predict the behavior of a plume during daytime conditions, and then assume that the model will work just as effectively for nighttime conditions, especially if key variables change substantially from daytime to nighttime. The challenge is determining when there is sufficient model validation data to conclude that a system has been adequately verified.

Measured impacts can also provide the means to adjust model predicted impacts. Caution must be used in model verification because the data being used to verify or validate a model may have limited applicability. The data sets must be consonant with the modeled scenario.

5.2 Model Verification Results

Well-managed mosquito control programs intend to have effective control with minimized off target impacts, including negative environmental and health effects. Most programs rely on ground-based applications of ULV, using rapidly degrading compounds. These minimize the impacts on the environment and human health, while the droplet size distributions and chemicals used are specifically designed to maximize mosquito control effectiveness. In general, aerial applications are used when the infestation reaches broad areas, or when threats associated with disease affect a wide area. A higher density of droplets, giving more complete area coverage, is preferred because more mosquitoes will be killed in target areas. Most programs use multiple swaths to improve coverage, yet still minimizing impacts to non-target areas. Airplanes or helicopters, at approximately 200-foot flight elevations at speeds exceeding 70 mph, are commonly used. These conditions, therefore, limit the amount of available data for model verification as most research has been conducted for agricultural applications during daytime conditions, using large-diameter droplet sprays, with aircraft at low flight elevations, or by ground-based sprayers.

Only a few aerial application trials have been completed that correspond to the conditions described above. One trial that attempted to simulate actual application conditions was reported by Adapco (2004). The field work was performed in Manatee County, Florida on July 18, 2002, at 11:40 PM. A set of samplers was positioned at eight individual sites ranging from 500 feet to 3,300 feet downwind of a single application. Each site contained:

- two filter deposit papers
- one fuzzy yarn array
- one spinning Teflon slide
- one spinning glass slide
- one container of non-target grass shrimp

The application platform was a helicopter flying at 105 mph at an altitude of 150 feet. The VMD was 23 microns. The mean wind speed was 9 mph from 175 degrees and the flight line was nearly perpendicular to the straight-line sampling array.

Observed flux and deposition rates were compared to the AgDISP and FSCBG model predicted rates. The results for deposition indicate that the FSCBG and AgDISP models predict similar values at most locations with a larger discrepancy at the 1,700 foot distance. At this location, the FSCBG model overpredicted AdDISP by approximately four-fold. The observed deposition rates were within two to three factors of the AgDISP results. For the flux of material reaching beyond a set point, the model predicted values similar to observed values. In general, both models overpredicted impacts. AgDISP appeared to have a better predictive accuracy, as it generally varied from measured amounts by factors of two to five. Latham (unpublished) notes that although it is difficult to model the real world exactly, detailed models are necessary to give any validity to predictions. However, localized meteorology is difficult to define, and accurate field measurements are difficult to obtain. Given these difficulties, the models performed reasonably accurately and he concluded they can, and should, be used to improve operations. The Adapco system is reasonably predictive of the pesticide dose, and helps to confine the pesticide delivery to the intended target area while limiting its drift over non-target areas. However, there is recent unpublished data that suggests the AgDISP model and aerial application techniques may need further refinement (W. Hoffmann, Agricultural Research Service, Area-wide Pest Management Unit, UDSA, personal communication, 2004).

5.3 Local Model Verification Data Collection

Due to the paucity of data to verify model predictions for the mosquito control applications, the Long-Term Plan project has collected data that can be used to verify model predictions, and to provide calibrated selected models. These data will be for both aerial and surface based application platform algorithms.

Data to verify aerial model results were collected in conjunction with a resmithrin application in the Mastic-Shirley area. Deposition data were collected in settings ranging from the edge of a salt marsh to locations in and among the trees in residential neighborhoods. Air samples were also collected.

Similarly, ground-based application verification data were collected in an open field in Cathedral Pines County Park, with deposition samplers arrayed from the center of the field to under the tree canopy. Air samples were also collected for this event.

6.0 Literature Analysis

6.1 Current Status of Models for Estimating Impacts

This review described the development of atmospheric dispersion and deposition simulation techniques by various governmental and private organizations, and the integration of these techniques into the systems currently used by the vector control industry. The majority of predictive techniques were not originally designed for use by the mosquito control industry. The techniques have had to be modified to allow simulation of impacts associated with the diffusion and dispersion of pesticides intended for the control of mosquito populations in a variety of topographic and geographic settings for both aerial and ground based systems. Improvements in these modeling techniques are continuing.

Few systems provide an applicator with estimates of how much pesticide reaches target and non-target areas. A modeling system designed by Adapco, Inc., has the capability to address many of the variables expected in the Suffolk County application. The system processes the meteorological conditions during the application and provides instructions on proper flight evaluation, flight trajectory, air speed, droplet size, application rate, and extent of the application zone per swath. These data are provided by an on-board computer system that continually receives meteorological information and provides minute-by-minute instructions to the applicator. The system tracks released material, provides a current and historical view of areas being treated, and predicts the rate of impact. The SpraySafe Manager 2 system developed in New Zealand is a competing technology that also has similar features, but includes GIS technology.

Models can be very effective at calculating the release area under persistent, steady state flow conditions. In these cases, the model assumes the same meteorological condition will exist for the ten minutes or so following the release. Knowing the target area and the rate of dispersion that will occur, the model can calculate the flight trajectory from an effective dose applied over the intended target area. Thus, an Adapco-type system can provide effective guidance when meteorological conditions exist that can be used to estimate site variables over a period of ten minutes or so after a release.
The Adapco and SSM2 systems may have limitations associated with certain meteorological conditions and application strategies proposed by Suffolk County during nighttime conditions. The primary limitation may be an inability to predict the trajectory of an application swath under light and variable wind conditions at

night when temperature inversions are present. Under these conditions, it may not be possible for the model to predict the precise trajectory of an application swath even with appropriate meteorological measurements. Conditions are likely to change too rapidly for the model to calculate where a swath should be directed during the release. Because of the uncertainty in the direction and extent of the drift trajectory, application during variable wind nighttime conditions may need to be reviewed more closely.

Releases under strong inversion conditions have not been researched sufficiently to provide guidance on how effective an Adapco-type system is for this condition. It is anticipated that the system could be adjusted to consider surface meteorology as the primary variable for the trajectory analysis. Elevated meteorology is typically isolated by the inversion, but supplemental data could be used in calculating the expected trajectory of a release that, for example, is driven onto the surface by the downdraft forces associated with helicopter rotors. The use of helicopters may sufficiently disturb the inversion to allow effective application to occur even under adverse conditions.

For ground-based application methods, Adapco-type models are under development. Additional schemes would also be needed to predict the behavior of a plume under low wind speed and variable wind directions. Fortunately, surface based applications are not as prone to off-target drift because of several factors. Plume dimensions are limited vertically. The transport flux decreases rapidly with distance from the spray swath due to the ground serving as a closed surface. Localized turbulence minimizes dispersion, and increases deposition within the target area. Knowledge of low-level local meteorology can result in fairly precise estimates of the general direction of the spray drift cloud, and using estimates of local vegetative scavenging can allow the manager to estimate the general droplet concentration profile downwind of the application swath without undertaking extensive modeling efforts.

6.2 Summary of Findings

Aerial applications of ULV adulticides are part of modern mosquito control arsenals. Due to photoreactivity of some adulticides and the need for applications to coincide with periods when mosquitoes are active, nighttime applications are recommended. The optimal meteorological conditions at night are just after dusk, when the forecast wind direction is constant and at speeds in the range of three to ten mph at 30 feet above the surface. Applying during these conditions avoids surface-based inversions that could significantly limit targeting areas with effective doses of pesticide. Lighter wind conditions are too variable for accurate predictions of drift trajectories. Stronger wind speeds cause the drift cloud to pass too rapidly for a lethal dose to be encountered by mosquitoes. While stronger winds will tend to reduce deposition rates on surfaces, they will increase the potential for off target drift.

For ground-based applications, night is preferred due to the photoreactivity of some adulticides, while early evening and early morning periods coincide with times when mosquitoes are active. Conditions when nocturnal inversions exist may or may not be appropriate, depending on the target area. If the inversion is surface-based and extends only a few meters vertically, special applications may be necessary to effectively treat the target area, because inversions tend to limit dispersion and may prevent the treatment of low lying vegetation. Wind speed and direction should be persistent, with the 30-foot speeds ranging from two to eight mph. Slower speeds tend to coincide with variable wind directions, making the prediction of the plume trajectory less certain. Higher speeds will cause the cloud to pass too quickly over the target area to provide the exposure required for acceptable control levels.

Finally, monitoring and utilizing meteorological information during an application will greatly assist in positioning the spray platform along paths that maximize application effectiveness, while minimizing off target impacts. Current integrated systems have the capability to use meteorological data to provide guidance to an aerial applicator on a real-time basis. Using this information will provide the best chance to disperse pesticides effectively with minimal environmental and human health impacts.

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