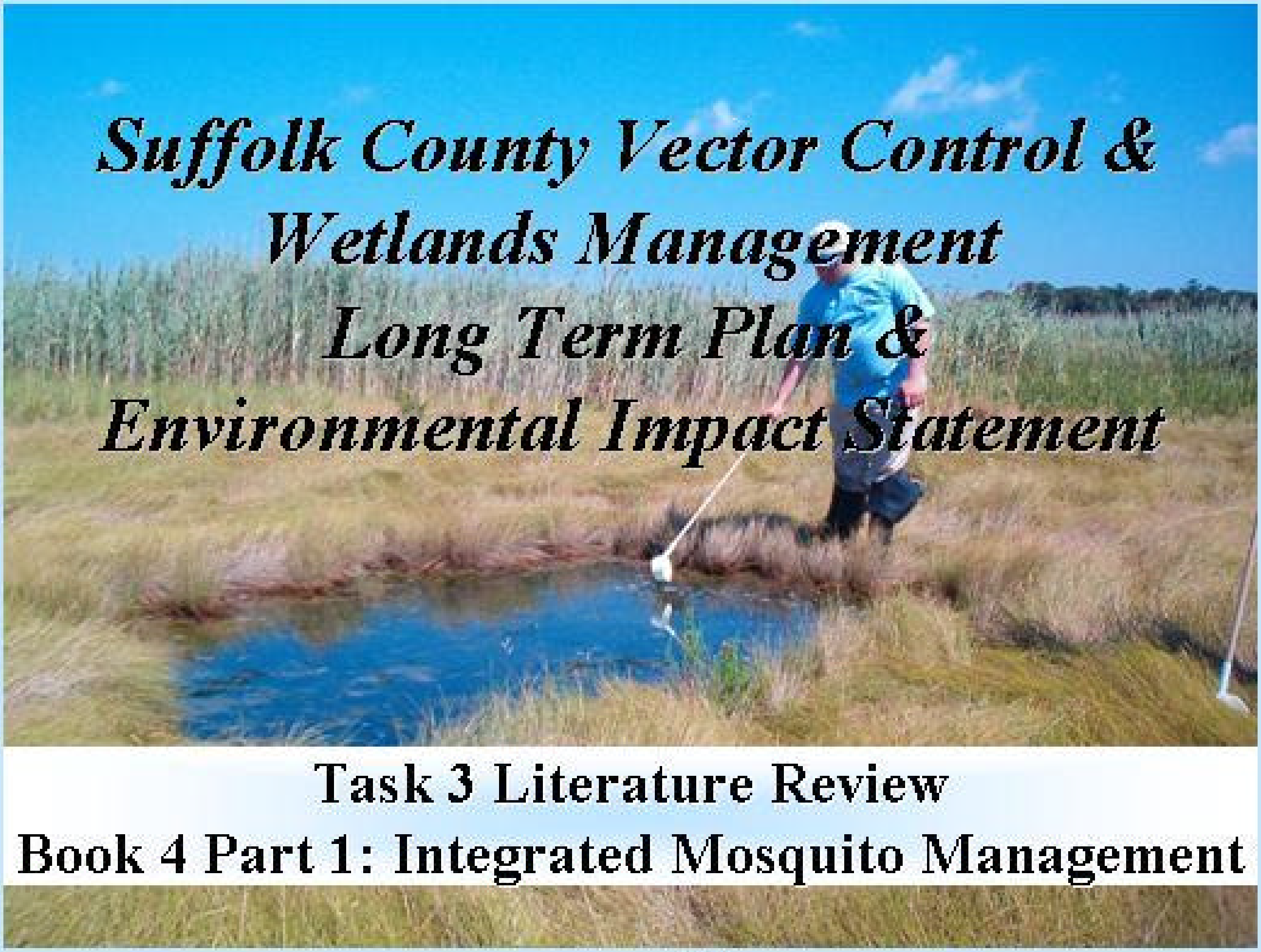

Suffolk County Vector Control & Wetlands Management Long Term Plan & Environmental Impact Statement

Task 3 Literature Review
Book 4 Part 1: Integrated Mosquito Management

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

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Ac	Acre
AI	Active Ingredient
AMCA	American Mosquito Control Association
A.L.L.	Altosid liquid larvacide
ATV	All Terrain Vehicle
Bs	*Bacillus sphaericus*
Bti	*Bacillus thuringiensis israelensis*
BTU	British Thermal Unit
CDC	Center for Disease Control & Prevention
DP	Dip
EPA	Environmental Protection Agency
F	Fahrenheit
FL	Fluid
Gal	Gallon
GPS	Global Positioning System
Hr	Hour
IMM	Integrated Mosquito Management
IPM	Integrated Pest Management
KPH	Kilometers per Hour
Lb	Pound
Mi	Miles
MPH	Miles per Hour
NYSDOH	New York State Department of Health
OMWM	Open Marsh Water Management
OP	Organophosphate Compounds
OZ	Ounce
PBO	Piperonly Butoxide
RIM	Rotational Impoundment Management
ULV	Ultra Low Volume
USEPA	United States Environmental Protection Agency

USDA	United States Department of Agriculture
WNV	West Nile Virus
Wt	Weight
Yds	Yards

Executive Summary

Mosquito control in the United States has evolved from reliance on insecticide application for control of adult mosquitoes to Integrated Pest Management (IPM) programs that include surveillance, source reduction, larvicide application, and biological control, as well as public outreach and education. IPM programs that focus on mosquito control are also known as Integrated Mosquito Management (IMM) programs.

Source reduction involves the elimination of mosquito larval habitats or management that renders the habitats unsuitable for larval development. Public education plays an important role in source reduction, as mosquitoes can breed anywhere water collects, even temporarily.

Water management is a form of source reduction that is practiced in both freshwater and saltwater environments with the intent of reducing the need for pesticide applications. This can include the maintenance of existing ditch systems to drain water from breeding habitats before immature mosquitoes can complete their life cycle, and to hold water so that insectivorous fish can prey on immature mosquitoes. Impoundments are also used in parts of the country to maintain water levels such that the *Aedes* and *Ochlerotatus* spp. mosquitoes will not deposit their eggs on marsh soils. In Suffolk County, water management accounts for approximately 70 percent of the total vector control operations.

Biological organisms can also be used to combat mosquitoes. These can include predators such as fish, birds, and insects, parasites such as nematodes, plants, and pathogens. The most commonly used biocontrol agents include the mosquito fish (*Gambusia affinis* and *G. holbrooki)*, which prey on mosquito larvae, and the bacteria strains *Bacillus thuringiensis israelensis* and *Bacillus sphaericus*, which attack the digestive system of mosquito larvae.

When surveillance programs show that larval or adult populations are above acceptable levels, control activities are considered. Well-managed source reduction and larviciding operations will reduce the need for pesticide chemicals to be applied to control adult mosquitoes.

Larviciding is a general term for the process of applying natural agents or commercial products to control mosquito larvae and pupae. Larviciding was originally implemented as a malaria control measure in the early 1900s and has become a prominent method of mosquito control. Larvicide treatments can be applied from either the ground, usually via truck-mounted equipment, or from the air, via fixed-wing or rotary-wing aircraft.

Larvicide agents utilized in IMM programs include:

1. Temephos – An organophosphate compound, used since the early 1950s, that inhibits the activity of cholinesterase enzymes at the neuromuscular junction, causing paralysis and death in insects.

2. Methoprene – An insect growth regulator (IGR) that mimics a naturally occurring insect hormone and prevents the adult mosquito from emerging.

3. *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (Bs) – Naturally occurring bacteria which, when ingested by mosquito larvae, attack the gut causing death.

4. Surface Control Agents – Monomolecular films that reduce the strength of the water surface, making it unable to support larvae and pupae, causing them to drown. They can also cause egg-laying females to drown.

Mosquito control districts routinely sample known breeding areas for the presence of mosquito larvae. While some have specific numerical triggers that will automatically initiate treatment, most do not. In Suffolk County, considerations include, but are not limited to, distance to populated area, mosquito species present, number and distribution of mosquitoes over the area, weather forecast, and larvicide agent to be used.

Treatment of adult mosquitoes is the most visible practice exercised by mosquito control operations. As with larvicides, adulticides can be applied either by ground or by air, most commonly via ultra low volume (ULV) or thermal fogging techniques. Several factors must be considered in adulticide applications including target mosquito species, droplet size, dosage rate, and environmental conditions, which all contribute to the delivery of an effective chemical dose.

Delivery systems must be calibrated and managed so as to apply the right dosage to achieve maximal mosquito control and minimal unintended impacts.

Adulticide agents utilized in IMM programs include:

1. Organophosphates – Used for mosquito control since the early 1950s, they inhibit the activity of cholinesterase enzymes at the neuromuscular junction, causing paralysis and death. Compounds include malathion, fenthion, naled, and chlorpyrifos.

2. Pyrethrins and pyrethroids – Natural pyrethrins (pyrethrum), extracted from chrysanthemum flower heads, kill adult mosquitoes by affecting sodium channel functions in the neuronal membranes. Pyrethroids are synthetic analogues of the natural pyrethrins, and include resmethrim, sumithrin, and permethrin.

There is no single set of treatment thresholds that can be universally applied to the application of mosquito control chemicals, as each district has its own unique mixture of mosquito species, habitats, human population densities, and public tolerance. As with most progressive, integrated-management mosquito control programs, Suffolk County does not have specific numerical triggers that will initiate adulticide applications. Many factors are considered, including trap counts, landing rates, citizen requests for service, and the history of a particular area. In general, as with many other programs, trap counts of 20 to 25 mosquitoes per night of human biting species, or landing rates of five or more mosquitoes per minute, indicate that consideration should be given to applying adulticide agents. However, other important factors including the species causing concern, the age of the mosquitoes, past history at particular locations, and the potential for viral transmission, which all tend to resist parameterization, weigh on any treatment determination.

1. Introduction

Integrated Mosquito Management (IMM) is the term used for a mosquito control district's Integrated Pest Management (IPM) Program. These programs employ control measures in a hierarchical manner that emphasizes prevention. Control proceeds from the more permanent, generally more "environmental friendly" measures of source reduction, and water management, through biological controls and highly specific larvicides, to the use of chemical controls such as adulticides, only after other measures prove to be insufficient or not feasible. This hierarchy has been endorsed by the US Environmental Protection Agency (USEPA), the Centers for Disease Control and Prevention (CDC), the New York State Department of Health (NYSDOH), the American Mosquito Control Association (AMCA), and most planning organizations that are involved in mosquito management issues.

This report is intended to be a general overview of IMM. With respect to the mosquito control chemicals discussed within the body of this report, the intent is to present those chemicals that could be incorporated into an IPM program, their mode of action against immature or adult mosquitoes, the commercial products in which they are distributed, and the means by which they may be applied to the mosquito habitat. The human health and environmental impacts of mosquito control chemicals are discussed elsewhere in this literature search (see Books 6 and 7). Similarly, the Literature Search has discussed salt marsh and freshwater wetlands management in more detail elsewhere (see Books 9 and 10). In addition, Part 2 of Book 4 discusses many alternative and innovative approaches to mosquito management.

2. Source Reduction

Source reduction is also known as physical or permanent control. It consists of the elimination of larval habitats or the rendering of such habitats unsuitable for larval development (Rose, 2001). This can be accomplished by properly discarding old containers that hold water, or by more complex measures such as implementing Open Marsh Water Management (OMWM) techniques, which control salt marsh mosquitoes and restore habitat as an added benefit (Meredith et al., 1985). Water management will be discussed further in Section 3 below, and is extensively discussed in Book 9 of the Literature Search.

Mosquitoes require stagnant water to breed. Stagnant water is not necessarily "polluted," which is a term used by mosquito control professionals when addressing water that has high organic matter content. In Suffolk County. most of the mosquitoes that bite humans actually need water that is clear to relatively clear. Others, however, prefer, or even need, to breed in water that has a heavy organic burden.

The scope of mosquito breeding in Suffolk County includes at least 2,077 natural breeding areas and 100,000+ artificial sites such as roadside catch basins, sumps, etc. Not included in this number are the innumerable domestic breeding sites that are created by property owners or their tenants.

The female adult mosquito will lay her eggs in practically any wet location. Breeding sites are often classified as permanent, transient, and containers. Some specific locations used by mosquitoes include:

- Ponds
- Puddles
- Tire Ruts
- Swamps
- Marshes

- Tree stumps
- Abandoned swimming pools
- Buckets
- Cans
- Bird baths
- Dirty gutters
- Stored tires

This list has been weighted to emphasize locations over which people can take responsibility, although any place where water collects, even temporarily, is capable of supporting mosquito breeding (USEPA, 1998). The IMM approach to mosquito control concentrates on stopping the mosquito at the larval stage. This is because larval mosquito breeding sites can be readily identified and, generally, are relatively small in area. Once identified, most of these listed sites can be addressed to stop or minimize breeding. By contrast, the adult mosquito can fly many miles and cause problems over a much wider area. Thus, larvae are condensed within delineated habitats, but adults disperse widely following emergence (Rose, 2001).

The by-products of the activities of man have been a major contributor to the creation of mosquito breeding habitats. An item as small as a bottle cap or as large as the foundation of a demolished building can serve as a mosquito breeding area. Sanitation is a major part of all IMM programs, exemplified by tire removal, clearing waterways, catch basin cleaning, and container removal (USEPA, 1998).

Public education is an important component of source reduction. Many county or state mosquito control agencies have public school education programs that teach children what they and their families can do to prevent mosquito proliferation (USEPA, 2003). Suffolk County has greatly expanded its role in educating the public about the public health importance of mosquitoes. Public education includes the distribution of pamphlets, telephone contact, site visits, media exposure and presentations to citizens' groups and associations. Because WNV vectors such as *Culex pipiens* and *Ochlerotatus japonicus* often breed in artificial containers that hold water in and around the home, educating the public to eliminate or empty these is the only practical way to reduce this mosquito source (MD DOA, 2004).

Source reduction can be the most effective and economical method of providing long-term mosquito control. It can help to reduce the need for pesticide use in and adjacent to the affected habitat (FCCMC, 1998). For example, the removal of discarded tires from the environment, whether they be individually littered items or tires that have been collected into a large stockpile, is widely noted as a basic step in reducing human health risks. This is because many encephalitis-bearing mosquitoes will use the temporary breeding habitats that invariably occur in tires. Tire removal from isolated dumpsites is also credited with aesthetic improvements, and tire removal reduces fire threats when the larger stockpiles are eliminated.

3. Water Management

Water management for mosquito control is a form of source reduction that is conducted in fresh and saltwater breeding habitats. In many mosquito control operations, water management is the primary control method and, generally, the best way to reduce the need for pesticide applications.

3.1. Freshwater Habitats

Source reduction for mosquito control in freshwater habitats typically involves the construction and maintenance of channels, ditches, to reduce mosquito production in areas such as flood plains, swamps, and marshes. The principle that directs source reduction work entails manipulating water levels in low-lying areas to eliminate or reduce the need for pesticide spraying applications (Lesser and Shisler, 1979).

Generally, three different mosquito control strategies are considered when performing freshwater source reduction. The first strategy involves reducing the amount of standing water or reducing the length of time that water can remain in low-lying areas following significant rainfall events. This type of strategy involves constructing channels or ditches with control elevations low enough to allow for a certain amount of water to leave an area before immature mosquitoes can complete their life cycle.

The second strategy involves constructing a main central ditch with smaller lateral ditches at the lowest elevations of intermittent wet areas to serve as an insectivorous fish reservoir. As rainfall increases, the fish move outward to adjacent areas to prey on immature mosquitoes, and as water levels decrease, the fish retreat to water in the ditches. Weirs are constructed in the main ditches to decrease water flow, decrease emergent aquatic weeds, prevent depletion of the water table, and allow insectivorous fish year-round refuge (FCCMC, 1998).

From a historical perspective, the construction of most source reduction drainage projects in the country occurred between the 1930s through the mid-1960s (Bruder, 1980). Currently, very few, if any, mosquito control districts are involved in the construction of new ditching projects because of environmental restrictions associated with obtaining permits. In addition, because of recognition that wetlands represent resources rather than problems, conducting water management that minimizes change to these systems has been emphasized. Nonetheless, many districts with existing drainage systems perform maintenance to prevent the systems themselves from becoming mosquito-breeding areas. This maintenance includes the cutting, mowing or clearing of overgrown vegetation as well as the excavation of built up spoil material.

The third source reduction technique used in fresh water environments is to continuously flood areas through dams or other impoundments. This serves to prevent desiccation-resistant mosquito eggs from undergoing necessary drying. Impoundments are discussed in more detail in Section 3.4, and their use is restricted to areas where desiccation-resistant mosquitoes are the primary mosquitoes of concern, as flooding could encourage breeding of desiccation-intolerant mosquitoes.

In New York State, there are restrictions on water management in freshwater environments. Any freshwater wetland that is regulated by the New York State Department of Environmental Conservation (NYSDEC) (see the Task 2, Part 1 report on Legal Factors impacting vector control activities) is off-limits for water management. Areas that were previously ditched or otherwise manipulated can be maintained, however.

3.2. Saltwater Habitats

Similar to freshwater habitats, the primary historical method to minimize mosquito populations in saltwater habitats has been through the construction and maintenance of a system of channels, ditches, that drain off tidal surface water or allow access to breeding sites by predatory fish. Control of the aquatic stage of mosquitoes that are produced in tidal wetlands requires a complete understanding of tidal marsh ecology (Gilmore et al., 1982).

Another strategy employed in saltwater habitats is the use of impoundments, which consist of earthen dikes that maintain water on high salt marshes that would otherwise alternately flood and dry down. Impoundments are, generally, artificially flooded for mosquito control purposes from May through August or September, eliminating sites for salt-marsh mosquitoes to deposit their eggs. Salt marsh mosquitoes require their eggs to dry out to complete maturation, and so cannot breed where water levels are maintained. In addition, most mosquitoes cannot successfully breed in water that is more than three feet deep, as most larvae need to reach the bottom of the water body as they grow and develop. Finally, permanent water bodies are also fairly effective at supporting insectivorous fish. For all of these reasons, impoundments have been widely used for mosquito control (Carlson and Carroll, 1985).

3.3. Ditching

Ditching can be used in both salt marsh and freshwater locations to control mosquitoes by either enhancing drainage, thus, eliminating mosquito breeding sites, or by allowing insectivorous fish access to mosquito breeding locations during the periods when they are temporarily inundated by floodwater. This aspect can be enhanced through the creation of permanent water bodies that act as predatory fish reservoirs. Over the past twenty years, rotary ditching as part of an Open Marsh Water Management (OMWM) system has been implemented on both the east and west coasts of the United States. Rotary ditching involves the construction of shallow ditches, usually four feet wide and two to three feet deep, using high-speed rotary equipment, which broadcasts spoil evenly over the marsh surface (FCCMC, 1998).

A ditching network frequently connects shallow ditches to permanent water habitats, such as ponds or canals. Where it is impossible or impractical to connect to major waterways, a permanent pond can be constructed deep enough to hold water throughout the year to harbor fish, with radial ditches connecting the mosquito breeding sites to the pond (Meredith et al., 1985).

Rotary ditching is generally considered more environmentally acceptable than deep ditching because spoil material from these shallow ditches is evenly distributed in a very thin layer over the marsh surface. Consequently, the problem of the accumulation of overburden, with the subsequent invasion of vegetation, is eliminated. Impacts to vegetation are usually limited due to the low ground pressure of the tracking units, so that plants spring back following the end of construction. The even deposition of spoils across the marsh seems to affect existing vegetation as a top-dressing of dirt might affect a lawn. Experience has demonstrated that a properly designed rotary ditching system can greatly decrease the need for larvicide application on the affected marsh (FCCMC, 1998). The latest generation of rotary ditchers also has the ability to swivel on its arm and, therefore, cut ditches that meander. New Jersey, which uses these devices in its water management, constructs OMWM projects with rotary ditchers that cleverly mimic natural systems.

Grid ditching (which was the most common form of ditching used on the east coast of the US, where 90 percent of the salt marshes were ditched in the 1930s) is perceived of as having environmental impacts such as alterations in vegetation communities and loss of avian habitat through elimination of surface water bodies. OMWM, originally referred to as "quality ditching", is generally perceived as having fewer environmental impacts than grid ditching. These topics are discussed in much more detail in Book 9 of the Literature Search.

3.4. Impoundments

Impounding has been used in some parts of the country for mosquito control, especially on the east coast from Delaware and south. The principle is simple: keeping a sheet of water across a salt marsh substrate prevents *Aedes* and *Ochlerotatus spp.* mosquitoes from depositing their eggs on these otherwise attractive soils. Aedine species with desiccation-resistant eggs require a period of dry conditions in order for the eggs to mature. On an impounded marsh, mosquito control is effectively achieved with a minimum of pesticide use (Carlson, 1988).

Based on research conducted during the 1980s and 1990s, Rotational Impoundment Management (RIM) is considered to be a favorable, and versatile, management technique that provides a great public benefit (FCCMC, 1998). RIM accomplishes mosquito control while still allowing the marsh to function in a close to natural condition for much of the year (O'Bryan et al., 1990). RIM is implemented by installing culverts with water control structures through the impoundment dikes to allow a seasonal connection between the marsh and the estuary. Also, installation of a pump or pumps allows summer flooding of the marsh surface that would otherwise be dry. The culverts serve as pathways for nutrient and organism movement. In areas where impoundments are used, sampling has shown that fish use the culverts as ingress and egress points to the impounded marsh, which serve as habitat for juvenile fish and macrocrustaceans (Meredith et al., 1983).

In Suffolk County, water management is the primary control method, accounting for much of the total operations budget, and is considered the best way to reduce the need for pesticide applications. Over 95 percent of the County's salt marshes have been ditched. The Division of Vector Control conducts ditch maintenance in each of the County's ten towns, with work performed on a priority, as needed basis. The highest priority is assigned to wetlands where infestations have the greatest potential for negative impact (Suffolk County, 2004).

The County has worked with other local organizations, particularly Ducks Unlimited, the US Fish and Wildlife Service (USFWS), and NYSDEC, to implement changes in water management as part of overall marsh restoration efforts, known as the Long Island Wetlands Initiative. In addition, over the past 20 years a handful of ditched salt marshes have been the focus of ditch-plugging efforts, which is a form of OMWM. Suffolk County Department of Health Services Office of Ecology has also secured grant monies to implement some demonstration OMWM projects. However, NYSDEC has expressed strong reservations regarding the potential impact of OMWM, and generally has not issued the necessary permits to allow these kinds of projects to proceed. A permit was received from NYSDEC in January 2005 for a large-scale OMWM demonstration project at Wertheim National Wildlife Refuge, proposed by USFWS and funded by the Long-Term Plan. Results from this demonstration project will guide the direction or many future OMWM projects in Suffolk County.

4. Biocontrols

The use of biological organisms or their byproducts to combat pest insects, such as mosquitoes, is termed biological control, or biocontrol. Biocontrol is defined as the study and utilization of parasites, predators, and pathogens to regulate pest populations (USEPA, 2002a). Generally, this definition includes natural and genetically modified organisms and means that the agent must be alive and able to attack the mosquito. Biocontrol agents that attack mosquitoes naturally are grown in the lab and then released into the environment, usually in far greater numbers than they normally occur, and often in habitats that previously were devoid of them, so as to control targeted mosquito species (FCCMC, 1998).

When combined with conventional chemicals and physical control procedures, biocontrol agents can provide short and, occasionally, long-term control. Biocontrol, as a conventional control method, should aim at the weakest link of the life cycle of the mosquito. In most cases, this is the larval stage (Schreiber and Jones, 2000).

4.1. Advantages/Disadvantages of Biocontrol

One advantage of biocontrol agents is host specificity, which implies minimal impacts to non-target species and to the environment. A good example of host specificity is where an introduced organism parasitizes only the target organism, as certain wasp species do with particular crop pests. Such a biocontrol would have limited to no impact on non-target species. However, specificity also tends to limit the market for any one biocontrol, as many situations, especially in agriculture, have a number of potential pest species, each one of which would require a specific biocontrol. This specificity and the occasionally large start-up costs deter commercialization and application of biocontrol agents. In addition, other problems include the generally narrow pest control market and, for the user, increased outlays of capital and the associated training required for personnel (FCCMC, 1998).

Advantages of biocontrols are generally listed as:

- Reductions in chemical inputs to the environment

- Little or no effect on beneficial and non-target organisms
- Organisms may naturally be a part of the ecosystem, and only require augmentation to reduce pest populations to the desired level
- Possible recycling or establishment of biologicals to permanently reduce mosquito populations

Disadvantages of Biocontrols:

- Host specific – effective against only one or a few species
- Mass production is difficult
- Generally more expensive initially than conventional methods
- Require trained personnel to assess conditions under which they can be used effectively
- Generally, more difficult to use effectively than conventional pesticides

Most mosquito biocontrols are not species specific. They tend to target all mosquitoes, although they may be more effective on some species as compared to others. In addition, due to the boom-bust nature of most mosquito hatchings, many biocontrols cannot subsist entirely on mosquitoes. This means they do have non-target impacts. However, augmenting naturally occurring species is perceived as having a less damaging impact to natural systems than many other means of potential control.

4.2. Biocontrol Application

Biocontrols are introduced into the mosquito habitat through two basic procedures: inoculation and inundation. Inoculations introduce organisms in relatively small numbers that reproduce and maintain themselves in the habitat. Population levels may eventually reach equilibrium with the pest population and, thus, provide some long-term control.

Inundation involves the release of large numbers of the biocontrol organism, which is usually a parasite or invertebrate predator, with the aim of immediate reduction of the pest population. Because it is not anticipated that the biocontrol will establish itself in the environment, several inundative releases may be necessary to control the target mosquitoes. The sequence must be repeated if a new brood appears.

In many cases, inundative releases are used with other control practices, such as source reduction and conventional chemicals, as part of an IMM program (Schreiber and Jones, 2000).

4.3. Biocontrol Methods

Biological control methods fall into six categories:

1) Vertebrate predators (fish, birds)
2) Invertebrate predators (insects, flatworms)
3) Pathogens (bacteria, protozoa, fungi, viruses)
4) Parasites (nematodes)
5) Autocidal (genetic)
6) Botanicals (plants)

Biological control includes the use of many predators, such as dragonfly nymphs and other indigenous aquatic invertebrate predators, including *Toxorhychites spp.*, a predaceous mosquito that eats mosquito larvae and pupae. The most commonly used biological control adjuncts are mosquito fish, *Gambusia affinis* and *G. holbrooki.* Naturally occurring *Fundulus spp.*, and possibly *Rivulus spp.*, killifish, also play an important role in mosquito control in open marsh water management and rotational impoundment management in salt marshes (Gilmore et al., 1982). Differences of opinion exist on the utility and actual control benefits derived from *Gambusia* implementation in an IMM program; reports range from excellent control to no control at all. Recently, concerns have been raised over placing *Gambusia* in habitats where other fish species may, thus, become threatened. Care must be taken in placing this species in areas where endemic fish species are sensitive to further environmental perturbation (FCCMC, 1998).

In some aquatic habitats, fish function as an excellent control tool. These typically are permanent water bodies where *Culex* and *Anopheles* are the primary mosquito residents and where the mosquito densities are not excessive. In habitats such as salt marshes, however, fish are often unable to control the sudden explosion of larvae produced by rainfall or rising tides. Here, the mosquito population exceeds what the fish can consume during the brief immature mosquito developmental period. In salt marshes, fish must rely on things other than mosquito larvae for their nutritional needs most of the time because there may be long delays between hatches of larvae. Mosquito larvae present an abundant food source, but only for a few days during their rapid development (Service, 1983).

Birds and bats are often promoted as potential biocontrol agents for mosquito control. While both have been reported to eat adult mosquitoes, they do not do so in sufficient amounts to impact the mosquito populations. Mosquitoes provide such a small amount of nutrition that birds or bats expend more energy pursuing and eating mosquitoes than they derive from them, and so cannot be a primary food source. Additionally, with mosquito flight behavior being crepuscular, they are not active during the feeding periods of most birds (Crans, 1996). While bats are active during the same time periods as mosquitoes, they cannot reduce the massive numbers of adult mosquitoes available (Corrigan, 1999).

Two strains of bacteria, *Bacillus sphaericus (Bs),* and *Bacillus Thuringiensis israelensis (Bti)* have proven to be effective in controlling mosquito larvae (USEPA, 2002a). *Bti*, once ingested by the mosquito larvae, releases toxins that destroy the gut wall leading to paralysis and death of the larvae. *Bs* acts similarly to *Bti* by releasing endotoxins to the mosquito larvae, which destroy its digestive system (NTPN, 2000a, b). Both *Bs* and *Bti* will be discussed more fully in Section 5, Larvicides, below.

The yeast-like fungus *Lagenidium giganteum*, has been used for mosquito control in still water environments. It attaches to and penetrates the mosquito larvae, then grows inward, eventually filling the body cavity, causing death. It is then released, where it can form more zoospores that can infect other larvae (Rose, 2001).

The parasitic nematode *Romanomermis culicivorax*, the pathogenic protozoan *Nosema algerae*, and some non-digestible algae have been examined as biocontrol agents by university, government (USDA), and by mosquito control organizations, with mixed results (Rose, 2001).

Another group of biocontrol agents with promise for mosquito control is predaceous copepods. Copepods are easy to rear and to deliver to the target sites in the field, and they generally perform well when used with pesticides. However, they have not been shown to provide the degree of control that comes with other biocontrols such as fish. Copepods must multiply to effectively attack mosquito larvae populations, leading to a lag time between inoculation and effective control (FCCMC, 1998).

Autocidal control calls for the inundative release of genetically altered insects designed to mate with normal individuals, the offspring of which will not survive. There are two types of autocidal control: sterile male release and genetic manipulation. In most cases, sterilized individuals from laboratory strains are released into the environment. This is generally called the "sterile-male technique". The other approach is to treat the natural population in the field (Schreiber and Jones, 2000).

Sterilization is done with radioactive isotopes (radiosterilization) or, more commonly, with chemicals (chemosterilization). Concern with chemosterilants is over their effects on non-target organisms and on the workers who handle them. The success of the sterile-male technique depends on a variety of factors:

- Females must mate only once, or if they mate with more than one male, only the sperm of the first male is used
- Sterile males must compete successfully with wild males
- Sterile males must stay in the habitat over the life-span of the target species

- Sterility must be permanent

Chemosterilization techniques are still being determined. The sterile-male technique has had very limited success (Schreiber and Jones, 2000).

Genetic manipulation through inoculative or inundative releases of altered strains of mosquitoes, which mate with wild strains, can result in decreased reproduction or viability of surviving mosquitoes. Some techniques include conditional lethal genes, chromosomal translocations, and vector capacity-reduction genes. None of these has proven successful, and they remain largely theoretical in nature (Schreiber and Jones, 2000).

Rotenone and pyrethrum are plant products that have a long history in pest control. Substances released from bladderwort (*Utricularia*), stonewart (*Chara*), and duckweed (*Lemna*), are known to be toxic to mosquito larvae. Extracts from an alga (*Elodea nuttallii*) and a sage brush (*Artemisia cana*) are highly toxic to immature mosquitoes (Sherif and Hall, 1984, 1985). Data have not been collected as yet regarding their efficacy on different mosquito species and selected non-targets. The mode of action for most of these toxicants remains unknown.

5. Larvicides

Larviciding is a general term for killing mosquitoes by applying natural agents or commercial pesticides to control the larval and pupal stages. Since both of these life stages live in aquatic environments, larvicides are always applied to water (USEPA, 1998). Larvicide treatments can be applied from either the ground or air. Larviciding, originally implemented as a malaria control procedure in the early 1900s, has become a mainstay of mosquito control over the years (Harrison, 1978). Responsible mosquito control incorporates a larviciding component into the overall plan to reduce mosquito breeding in their district.

Safely altering the aquatic environments, even temporarily, for the purpose of controlling mosquitoes, requires a good working knowledge of both the target species and larvicides. The once widely used practice of smothering everything with waste oil is no longer acceptable, and mosquito control is rapidly approaching an age of prescription applications, where a competent operator will apply one or a combination of larvicides in an environmentally sound manner under a given set of conditions (FCCMC, 1998).

One of the following signal words will appear on each pesticide label: (NYSDEC, 2003)

- CAUTION -- This word signals that the product is slightly toxic. An ounce to more than a pint taken by mouth could kill the average-size adult. Any product that is slightly toxic orally, dermally, or through inhalation, or causes slight eye and skin irritation.

- WARNING -- This word signals that the product is moderately toxic. As little as a teaspoonful to a tablespoonful by mouth could kill the average-size adult. Any product that is moderately toxic orally, dermally, or through inhalation, or causes moderate eye and skin irritation.

- DANGER --This word signals that the pesticide is highly toxic. A taste to a teaspoonful taken by mouth could kill an average-size adult. Any product that is highly toxic orally, dermally, or through inhalation, or causes severe eye and skin burning.

5.1. Contact Pesticides

This group of compounds, as the name implies, kills mosquito larvae or pupae on contact. Chemicals are absorbed through the insects outer "skin" or cuticle, and may be incidentally ingested, or enter the body through other routes. Contact agents act either as toxins that target the nervous system or affect the endocrine system (FCCMC, 1998).

5.1.1. Temephos

Organophosphate compounds (OPs) have been used for mosquito control since the early 1950s. OPs work by inhibiting the activity of cholinesterase enzymes at the neuromuscular junction, ultimately causing paralysis and death (Chambers and Levi, 1992). Temephos was registered by USEPA in 1965 to control mosquito larvae, and is classified by USEPA as a General Use Pesticide. The product labels carry the signal word "WARNING" (EXTOXNET, 1996a).

Temephos is used in areas of standing water, shallow ponds, swamps, marshes, and intertidal zones. It is generally used along with other mosquito control measures in an IMM program. Temephos is applied most commonly by helicopter, but can be applied by backpack sprayers, fixed-wing aircraft, and right-of-way sprayers in either liquid or granular form (Ware and Whitacre, 2004).

Temephos is generally applied to water, at rates of less than one ounce of active ingredient per acre for the liquid and eight ounces per acre for the granular formulations. Temephos breaks down within a few days in water, and post-application exposure is minimal (EXTOXNET, 1996a).

Because temephos is applied directly to water, it has limited direct impact on terrestrial animals or birds. Although temephos presents relatively low risk to birds and terrestrial species, available information suggests that it is more toxic to aquatic invertebrates than alternative larvicides. For this reason, USEPA is limiting temephos use to areas where less hazardous alternatives would not be effective, specifying intervals between applications, and limiting the use of high application rates (FCCMC, 1998).

Commercially available temephos formulations include:

- Abate 1-SG® contains one percent (wt./wt.) temephos attached to a silica (sand) granule. Rates of application vary from five to 20 lbs (0.05 to 0.50 lb. Active Ingredient [AI]) per acre, increasing with the organic content of the receiving waters.

- Abate 2-CG® contains two percent (wt./wt.) temephos attached to celatom (diatomaceous earth) grit. Rates of application vary from 2.5 to 25 lbs (0.05 to 0.50 lb. AI) per acre, increasing with the degree of pollution in the receiving waters.

- Abate 4-E® contains 44.6 percent (wt./wt.) AI (four lbs./gal.), combined with a petroleum distillate and three different emulsifiers, to be diluted with water to produce a uniform spray. Rates of application vary from 0.5 to 1.5 fluid oz. per ac. (0.016 to 0.048 lb. AI/ac.), increasing with the organic content of the receiving waters.

- Clarke five percent Skeeter Abate® contains five percent (wt./wt.) active ingredient imbedded in an extruded gypsum pellet. Use rates vary from four to 10 lbs (0.16 to 0.40 lb. AI) per acre, increasing with the degree of pollution in the receiving waters Operationally, this is considered a slow-release product with a sustained activity of three or more weeks.

- Clarke Abate 5 percent Tire Treatment Insecticide® contains five percent (wt./wt.) temephos attached to a corncob granule. It is specifically designed to control container-breeding mosquitoes. The rate of application is one pound per 100 square feet of tire-pile surface area (equivalent to 21.8 lbs. AI/ac.) every 30 days during the mosquito-breeding season.

5.1.2. Methoprene

Methoprene was first registered by USEPA in 1975. It mimics the action of a naturally occurring insect hormone called juvenile hormone (JH). This hormone is found during aquatic life stages of the mosquito and in other insects, but is most prevalent during the early instars. As mosquito larvae mature, the level of juvenile hormone steadily declines. The fourth instar larva molts when JH levels are very low. This is an extremely sensitive period because the physical features of the adult are beginning to develop at an accelerated rate. Methoprene in the aquatic habitat can be absorbed on contact and the insect's hormone system becomes imbalanced. When this happens, the imbalance interferes with fourth instar larval development and interferes with the production of adult characteristics.

One effect is to prevent adults from emerging. Since pupae do not eat, they eventually deplete body stores of essential nutrients and starve to death. For these reasons, methoprene is considered an insect growth regulator (IGR) (Ware and Whitacre, 2004).

Altosid is the name of the methoprene product used in mosquito control and is applied as briquets (similar in form to charcoal briquets), pellets, sand granules, and liquids. The liquid and pelletized formulations can be applied by helicopter and fixed-wing aircraft (FCCMC, 1998).

Altosid remains effective for the prescribed period and degrades into simpler compounds. Its mode of action allows mosquito larvae to accomplish their ecological assignments and then remain present in the water for an extended time as natural food for the ecosystem's predators (EXTOXNET, 1996b).

Commercially available methoprene formulations include:

- Altosid Liquid Larvicide® (A.L.L.) and A.L.L. Concentrate®**:** These two flowable formulations have identical components except for the difference in the concentration of active ingredients. A.L.L. contains five percent (wt./wt.) s-methoprene while A.L.L. Concentrate® contains 20 percent (wt./wt.) s-methoprene. The balance consists of inert ingredients that encapsulate the s-methoprene, causing its slow release and retarding its ultraviolet light degradation. Use rates are three to four oz. of A.L.L. 5 percent and 0.75 to one ounce of A.L.L. Concentrate® (both equivalent to 0.01008 to 0.01344 lb. AI) per ac., mixed in water as a carrier and dispensed by spraying with conventional ground and aerial equipment. Liquid formulations are designed to control fresh and saline floodwater mosquitoes with synchronous development patterns.

- Altosid Briquets®**:** The Altosid Briquet® was the first solid methoprene product marketed for mosquito control beginning in 1978. It is made of plaster (calcium sulfate), 3.85 percent (wt./wt.) r-methoprene, 3.85 percent s-methoprene (0.000458 lb. AI/briquet) and charcoal to retard ultraviolet light degradation. Altosid Briquets® release methoprene for about 30 days under normal weather conditions. Application should be made at the beginning of the mosquito season and under normal weather conditions repeat treatments should be carried out at 30-day intervals. The recommended application rate is one briquet per 100 square feet in non-flowing or low-flowing water up to two feet deep. Floodwater *Aedes* and *Psorophora* plus permanent water *Anopheles*, *Culex,* and *Culiseta* larvae are likely targets. Typical treatment sites include storm drains, catch basins, roadside ditches, ornamental ponds and fountains, abandoned swimming pools, construction sites, and other artificial depressions.

- Altosid XR Briquets®**:** The XR Briquet® was approved for use in September 1988. It is made of hard dental plaster (calcium sulfate), 1.8 percent (wt./wt.) s-methoprene (0.00145 lb. AI/briquet) and charcoal to retard ultraviolet light degradation. Despite containing only three times the AI as the "30-day briquet," the comparatively harder plaster and larger size of the XR Briquet® change the erosion rate allowing sustained s-methoprene release up to 150 days in normal weather. XR Briquets® should be applied one or two per 200 square feet in the lowest part of shallow depressions in no-flow or low-flow water conditions, depending on the target mosquito species. Targets and treatment sites are the same as for the smaller briquet. New Jersey has determined that the risk of resistance from these long-release briquets exceeds benefits that might be gained from their use, and no longer includes the product as an approved means of mosquito control there.

- Altosid Pellets®: Altosid Pellets® were approved for use in April of 1990. They contain four percent (wt./wt.) s-methoprene (0.04 lb. AI/lb.), dental plaster (calcium sulfate), and charcoal. As with the briquets discussed above, Altosid Pellets® are designed to slowly release s-methoprene as they erode. Under normal weather conditions, control can be achieved for up to 30 days. Label application rates range from 2.5 lbs. to 10.0 lbs. per ac.

(0.1 to 0.4 lb. AI/ac.), depending on the target species and/or habitat. The species and listed target sites are the same as listed for the briquet formulations.

5.2. Stomach Toxins

Mosquito control agencies utilize two stomach toxins whose active ingredients are produced by bacteria. These control agents are often designated as bacterial larvicides or biopesticides. Their mode of action requires that they be ingested to be effective, which can make them more difficult to use than the contact toxins and surface control agents (discussed in the next section) (Ware and Whitacre, 2004).

Bacteria are single-celled parasitic or saprophytic microorganisms that exhibit both plant and animal properties and range from harmless and beneficial to intensely virulent and lethal (Ray, 1991). A beneficial form, *Bacillus thuringiensis (Bt),* is the most widely used agricultural microbial pesticide in the world. It was originally isolated from natural Lepidopteran (butterflies and moths) die-offs in Germany and Japan. In 1976, a subspecies was isolated from a stagnant riverbed pool in Israel that had excellent mosquito larvicide activities. It was named *Bacilus thuringiensis israelensis* (*Bti*) (FCCMC, 1998). Another species of bacteria, *Bacillus sphaericus* (*Bs*), also exhibits mosquito larvicide properties (USEPA, 2002a).

5.2.1. *Bacillus thuringiensis israelensis* (*Bti*)

If the environmental conditions are favorable, each *Bti* organism may produce five different microscopic protein pro-toxins packaged inside one larger protein container, or crystal. The crystal is commonly referred to as delta (*d*-) endotoxin. If the *d*-endotoxin is ingested, these five proteins are released in the alkaline environment of an insect larva's gut. The five proteins are then converted into five different toxins by specific enzymes present in the gut. Once converted, these toxins work alone, or in combination, to destroy the gut wall, which leads to paralysis and death of the larvae (USEPA, 2002a).

Bti is grown commercially in large fermentation vats using sophisticated techniques to control environmental variables such as temperature, moisture, oxygen, pH, and nutrients. The process is similar to the production of beer, except that *Bti* bacteria are grown on high-protein substrates such as fish meal or soy flour, and the spore and delta endotoxin are the end products. At the end of the fermentation process, *Bti* bacteria exhaust the nutrients in the fermentation machine, producing spores before they lyse and break apart. Coincidental with sporulation, the d-endotoxin is produced. The spores and d-endotoxins are then concentrated via centrifugation and microfiltration of the slurry. The product can then be either dried for processing and packaging as a solid formulation(s) or further processed as a liquid formulation(s). Since some fermentation medium (e.g., fishmeal) is always present in liquid formulations, these generally have a distinct odor (Ware and Whitacre, 2004).

There are five basic *Bti* formulations available for use: liquids, powders, granules, pellets, and briquets. Liquids, produced directly from concentrated fermentation slurry, tend to have uniformly small (two to 10 micron) particle sizes, which are suitable for ingestion by mosquito larvae (Ware and Whitacre, 2004). Powders, in contrast to liquids, may not always have a uniformly small particle size. Clumping, which results in larger sizes and heavier weights, can cause particles to settle out of the feeding zone of some target mosquito larvae, preventing their ingestion by the typical filter feeding process used by these insects. Powders must be tank-mixed before application to an inert carrier or to the larval habitat. They must be mixed thoroughly to achieve a uniformly small consistency (USDA and USEPA, 1992). *Bti* granules, pellets, and briquets are formulated from *Bti* primary powders and an inert carrier. *Bti* labels contain the signal word "CAUTION" (NPTN, 2000a, b). The toxicology of *Bti* is discussed further in Books 6 and 7 of the Literature Search.

- *Bti* Liquids: Available commercial brands include: Aquabac XT®, Teknar HP-D®, and Vectobac 12AS®. Labels for all three products recommend using four to 16 liquid oz. per ac. in unpolluted, low-organic water with low populations of early instar larvae (clean water situations). The Aquabac XT® and Vectobac 12AS® (but not Teknar HP-D®) labels also recommend increasing the range from 16 to 32 liquid oz. per ac. when late third or early fourth instar larvae predominate, larval populations are high, water is heavily polluted, or algae are abundant. The recommendation to increase dosages in dirty water situations is also seen in various combinations on the labels for all other *Bti* formulations discussed below.

- *Bti* Powders: Aquabac Primary Powder®, Vectobac TP® and Bactimos WP® brands of *Bti* powders are available. The Vectobac TP® label recommends using a calculated 3.2 to 6.4 oz. (by weight) per ac. in clean water, and up to 12.8 oz. per ac. in dirty water situations. The Bactimos WP® label correspondingly recommends using two to six oz. per ac. and up to 12 oz. per ac.

- *Bti* Sand Granules: Until the latter part of 1996, commercial formulations of *Bti* sand granules were not available. However, labeling was available for both Vectobac® and Bactimos *Bti*® powders to guide end users in making their own "On-Site Sand Granules." Sand formulations require coating the particles with an oil, such as GB-1111 or Bonide Mosquito Larvicide®, and then applying dry *Bti* powder which will stick to the oil. It is desirable to stick the powder to the sand carrier in a way that *Bti* is released upon contact with the water and thus "puts the food on the table" for the larvae.

- *Bti* Corncob Granules: Granular formulations use a carrier that is dense enough to penetrate heavy vegetation. There are currently two popular corncob granule sizes used in commercial formulations. Aquabac 200G®, Bactimos G®, and Vectobac G® are made with 5/8 mesh size grit-crushed cob, while Aquabac 200 CG® (Custom Granules) and Vectobac CG® are made with 10/14 mesh size grit cob. Aquabac 200 CG ®is available by special request. The 5/8 mesh size grit is much larger and contains fewer granules per pound. The current labels of all *Bti* granules recommend using 2.5 to 10 lbs. per ac. in clean water and 10 to 20 lbs. per ac. in dirty water situations.

- *Bti* Pellets: Bactimos Pellets® are an extruded *Bti* product. They are manufactured using a larval food as the *Bti* carrier, which helps attract feeding larvae. Bactimos Pellets® contain twice the amount of toxic units as Bactimos Granules® (corncob), and the label correspondingly recommends using only half as much by weight in both clean water and dirty water situations.

- *Bti* Briquets: *Bti* briquets (donuts) are a mixture of *Bti*, additives, and cork. They are designed to float and slowly release *Bti* particles to the water body for extended periods of time. They apparently are attractive to raccoons and, possibly, other wildlife, because of their odor, and may sometimes be disturbed or carried off. Donuts may be staked in place to prevent wind from moving them from a site's littoral zone into open water. The use rate is one donut per 100 square feet in clean water and up to four donuts per 100 square feet in dirty water.

Bti controls all larval instars but is not effective against late 4th instar larvae that have stopped feeding in preparation for pupation. The product is very effective and can be used in almost any aquatic habitat with no restrictions. *Bti* is fast acting and its efficacy can be evaluated almost immediately. It usually kills larvae within one hour after ingestion, and since each instar must eat in order for the larva to grow, that means *Bti* usually kills mosquito larvae within 24 hours of application (Ware and Whitacre, 2004). *Bti* leaves no residues, and is quickly biodegraded. Resistance is unlikely to develop simultaneously to the five different toxins derived from the *Bti* delta-endotoxin since they have five different modes of action. This suggests that this mosquito larvicide will continue to be effective for many years (EXTOXNET, 1996c).

The timing of *Bti* application is extremely important. Optimal benefits are obtained when treating second or third instar larvae. Treatments at other developmental stages may provide less than desired results. A disadvantage of using *Bti*, therefore, is the limited treatment window available for its use (Tietze et al., 1993).

5.2.2. Bacillus sphaericus (Bs)

Bacillus sphaericus is a commonly occurring spore-forming bacterium found throughout the world in soil and aquatic environments (Schreiber and Jones, 2000). Some strains produce a protein endotoxin at the time of sporulation. *Bs* can be grown in fermentation vats and formulated for end use with processes similar to that of *Bti* (Ware and Whitacre, 2004). The endotoxin destroys the insect's gut similarly to *Bti* and has been shown to have activity against larvae of many mosquito genera such as *Aedes, Culex, Culiseta,* and *Psorophora* (Lacey, 1990). The toxin is active only against the feeding larval stages and must be partially digested before it becomes activated. At present, the molecular action of *Bs* is unknown (Schreiber and Jones, 2000).

VectoLex-CG® is the trade name for a granular formulation of *Bs* (strain 2362). The product is formulated on a 10/14 mesh size ground corncob carrier. The VectoLex-CG® label carries the "WARNING" hazard classification (NYSDEC, 2003).

Bacillus sphaericus is designed to be applied by ground (by hand or truck-mounted blower) or aerially at rates of five to 10 lbs. per ac. Best results are obtained when applications are made to larvae in the first to third instars. Use of the highest rate is recommended for dense larval populations. Larval mortality may be observed as soon as a few hours after ingestion but typically takes as long as two to three days, depending upon dosage and ambient temperature. *Culex* species are the most sensitive to *Bs*, followed by *Anopheles* and some *Aedes* species. *Ae. aegypti* and *Ae. albopictus*, have shown little or no susceptibility, and salt-marsh *Aedes/Ochlerotatus* species are not susceptible (FCCMC, 1998).

Bacillus sphaericus has the unique property of being able to control mosquito larvae in highly organic (polluted) aquatic environments (USEPA, 2003). After a single application at labeled rates, extensive field evaluations show VectoLex-CG® can persist for two to four weeks (FCCMC, 1998).

Bacillus sphaericus will not regenerate (recycle from mosquito corpses) in salt water, rendering its use impractical for control of saltwater mosquitoes (Lacey, 1990). Recycling is limited to permanent freshwater bodies, and if organics are very high, recycling may be minimal.

5.3. Surface Control Agents

Larvicides in this category include oils and ethoxylated isostearyl alcohols. Commonly used larviciding oils kill larvae and pupae when inhaled into the tracheae along with air when the insects are breathing at the water's surface (USEPA, 2002a). With low dosages (one gal. per ac.), they can work very slowly; taking four to seven days to give a complete kill. Higher dosage rates are usually used (up to five gal. per ac.) to lower the kill time (Ware and Whitacre, 2004).

The ethoxlate of isostearyl alcohols produce a thin (monomolecular) film on the water surface which lowers the surface tension of the water and subsequently kills mosquito larvae by inhibiting proper orientation at the "on-water" surface, or by wetting trachael structures and causing anoxia. Larvae normally use surface tension to suspend for long periods when breathing or resting. Emerging and egg-laying adults cannot be supported on the water surface when these materials are present and often drown (USEPA, 2002a).

Commercially available formulations include:

- Golden Bear 1111®: This product is a petroleum-based napthenic oil, commonly referred to as GB-1111. Its label contains the signal word "CAUTION." GB-1111 contains 99 percent (wt./wt.) oil and one percent (wt./wt.) inert ingredients including an emulsifier. The nominal dosage rate is three gal. per ac. or less. Under special circumstances, such as when treating areas with high organic content, up to five gal. per ac. may be used. GB-1111 is effective on a wide range of mosquito species. Applied to breeding areas, GB-1111 is an effective material against all mosquito larvae and pupae obtaining atmospheric oxygen at the water surface. The product can even be effective in treating adult mosquitoes as they emerge. GB-1111 is a material with good spreading characteristics. The product offers the advantage of acting as both a pupacide and a larvicide, which may result in better efficiencies and a wider time range for effective application.

- BVA Larvicide 2®: This product contains 97 percent distilled petroleum oil and three percent inert ingredients. It is formulated with a structurally modified mineral oil to produce a water-clear product designed to work fast and effectively as both a larvicide and a pupacide in mosquito-breeding areas. Application rates call for three to five gal. per ac. Where vegetation is not a factor, three gal. per ac. should be sufficient. If vegetation is dense, the higher application rate will be necessary. BVA Larvicide 2® is designed to be effective against a variety of mosquito species. This product has good spreading characteristics, and the water-clearing characteristic makes it less aesthetically objectionable than other surface films. This is an advantage because of public perceptions that water that appears to be fouled is polluted.

- Bonide Mosquito Larvicide®: This product is a petroleum-based mineral oil containing 98 percent (wt./wt.) mineral oil and two percent inert ingredients, including surfactants.

The treatment objective is to apply a thin film over the surface of breeding areas. For ground applications, the dosage rate is one to five gal. per ac., depending on water surface conditions and vegetative density. The label rate for aerial applications is two to four gal. per ac., also adjusted for water conditions and vegetation. The product is designed for surface application to intermittently flooded areas and temporary rain pools. Instructions for treating salt marshes, swamps, drainage ditches, catch basins, stagnant pools, and open sewage basins are included on the label. Both larvae and pupae are targets of this product. Bonide Mosquito Larvicide® has good spreading characteristics and acts as both a pupacide and a larvicide.

All of the above products produce a thin oil slick on the water surface when applied. When viewed under some lighting conditions, the resulting unnatural appearance may be objectionable, precluding widespread use of the oil in some areas (FCCMC, 1998).

- Agnique MMF ®: This product is 100 percent (wt./wt.) ethoxylate of isostearyl alcohol. It belongs to a group of surfactants that have been routinely used in detergents and cosmetics for over 20 years. It is a biodegradable, non-ionic, surface control material that spontaneously and rapidly spreads over the surface of the water to form an ultra-thin film that is about one molecule in thickness.

  Monomolecular surface films do not kill by toxic action but exert a physical impact on mosquito populations that cause larvae, pupae, and emerging adults to drown (USEPA, 2002a). They act by slightly reducing the strength of the water surface film. They affect only species that depend on the air-water interface, such as mosquitoes. The weakened tension of the water's surface fails to support larvae and pupae and allows water to wet their breathing apparatus so they drown. No mixing is required. It may be applied directly from its container using hand or power sprayers (Ware and Whitacre, 2004).

  Application rates for this mosquito larvicide and pupacide generally range from 0.2 to 0.5 gal. per surface ac. of water. It is effective against most species. Agnique MMF may be used safely in potable waters, waters holding fish and other aquatic organisms, and in runoff waters that enter fish-bearing waters. Because the method of action is physical rather than toxic or biochemical, mosquitoes cannot easily develop resistance. This kind of control is especially useful against chemically resistant species. The chemical decomposes into harmless elements and has a broad range of activity. It kills all stages and can entrap and drown egg-laying females or surface-resting males (Rutgers, 2004).

5.4. Application Techniques

5.4.1. Ground Application

Many mosquito control districts use four-wheel-drive equipment as a primary larvicide vehicle. In most cases, an open-bed pickup truck is equipped with a chemical container, a high-pressure, low-volume pump, and a spray nozzle. A switch and extension hose allows the driver to operate the equipment and apply the larvicide from the truck's cab. Some agencies have the sprayer mounted on the front bumper of the truck and install a mechanical control that allows the driver to direct the spray while remaining in the cab. Roadside ditches, swales, retention ponds, treatment ponds, and other, similar bodies of water can be treated this way. Ultra Low Volume (ULV) rigs can also be mounted in the bed of the truck to apply larvicides over a larger area (Rutgers, 2004). ULV dispersal, as defined by the USEPA, is a method of dispensing liquid insecticides at the rate of one half gallon or less per acre. Insecticide is applied as an aerosol consisting of particles ranging in diameter from 0.1 to 50 microns. Droplet parameters within the aerosol range are further specified for each insecticide labeled for ULV dispersal (Mount, 1998).

Additionally, all-terrain-vehicles (ATVs) are commonly used for vector control purposes, as these allow operators to reach breeding areas that are inaccessible by truck, yet still can carry a reasonable payload. As with a truck, a chemical container is mounted on the ATV, a 12-volt electric pump supplies a high-pressure, low-volume flow, and a hose and spray tip allow for application while steering the ATV with one hand. ATVs are ideal for treating areas such as salt-marshes and other off-road sites (MD DOA, 2004).

Additional equipment used in ground applications includes hand-held sprayers and backpack blowers. Hand-held sprayers, handguns, are standard one- or two-gallon, garden style pump-up sprayers, used to treat small isolated areas. A backpack sprayer consists of a gas-powered blower with a chemical tank and calibrated proportioning slot. Generally, a pellet or small granular material is applied with a backpack sprayer. They are extremely useful for treating tire piles (FCCMC, 1998).

There are several advantages to using ground application equipment, both on foot and from vehicles. Ground larviciding allows the control agents to be applied to the treatment area only, that is, those habitats where larvae are actually present. This reduces both the unnecessary pesticide load on the environment and the associated financial costs (DE DNR, 2004). Both the initial and maintenance costs of ground equipment are generally less than those for aerial equipment. Ground larviciding applications are also less likely to be interrupted by weather conditions than are aerial applications (Rutgers, 2004).

One of the main disadvantages of ground application is the reliance on human estimates of the size of treatment areas and equipment output with a greater chance of overdosing or under-dosing (Delaplane, 1996). Rutgers University has, therefore, created a short-course for applicators to sharpen their ability to estimate acreage and apply appropriate dosages. Ground larviciding is impractical for large or densely wooded areas. Also, there is a greater risk of chemical exposure to applicators during ground applications than during aerial larviciding operations. Trees and buildings will interfere with the spread of the pesticide from the application point. Unequal loading may also occur, as the chemical is sent up and away from the application site, as opposed to being carried downward by diffusive forces in an aerial application (FCCMC, 1998).

5.4.2. Aerial Application

Aerial larviciding is accomplished via fixed wing or rotary aircraft. Both types of aircraft can apply solids and liquids. A variety of nozzles and metering systems can be used, depending upon target configuration and size (Mount, 1998). Flying services can be contracted to perform the actual application for a fee, removing the expense of aircraft purchase, maintenance, and having a pilot on staff. Depending upon target conditions, liquid or granular applications are used. Granular applications can either be sand, pellets, or corncob granules supplied by a manufacturer. Most granular formulations are applied at six to 15 lbs. per ac. (Ware and

Whitacre, 2004). While granules have less drift and can penetrate vegetative cover, they are generally bulky (*e.g.*, corncob), heavy (*e.g.*, sand), and expensive, especially for premixed materials (Rose, 2001).

With liquid applications, using small droplets or ULV allows the same payload to cover considerably more acreage and, thus, be more economical, however, the amount of material actually reaching the target may be reduced. Wind, temperature, evaporation, and droplet movement can result in reductions in ULV application efficiency. Using large droplets eliminates some of the drift problems of ULV applications, but greatly reduces the payload (Mount, 1998).

For successful control of many mosquito species, getting complete coverage of the breeding area is critical. Missing just a tiny fraction of the target area can result in the emergence of very large numbers of biting adults. While many pilots claim that they can apply accurate swaths based on flying skill alone, experience has shown that this rarely happens. For that reason, some type of guidance system is suggested when conducting aerial larviciding over large areas (FCCMC, 1998).

Global Positioning Systems (GPS) uses a series of satellites orbiting the earth in known positions. A GPS receiver picks up the radio signal from several satellites and computes that information into a location, where the error is usually on the order of several feet. Computer programs can take the mission parameters (*e.g.*, treatment area, coordinates of treatment area, swath width, etc.), and accurately track the aircraft flight relative to the target flight, thus providing the pilot with almost instantaneous necessary course corrections. In addition to improving treatment accuracy, these systems can download the flight information into a map or display, generating accurate records of treatments (MD DOA, 2004).

There are several advantages to using both fixed and rotary-wing aerial larvicide application equipment. The approach is more economical for large application areas, where the entire site has breeding activity. Equipment calibration and applicator briefing are facilitated because the target area is generally mapped and the material is weighed or measured when loading. It is also more practical for remote or inaccessible areas, such as islands and salt marshes, than ground larviciding (FCCMC, 1998).

6. Adulticide

When source control measures and larvicide applications cannot provide adequate control of mosquito populations, or if there is a threat of mosquito-borne diseases, it may be necessary to resort to adulticide usage (USEPA, 2002b).

Treatment of adult mosquitoes with adulticide is the most visible practice exercised by mosquito control operations. Most mosquito control districts adulticide to some extent, using aerial and/or ground application methods. The most common forms of adulticiding are ULV and thermal fogging (Rose, 2001). The small droplet sizes utilized allow less of the pesticide to be spread over a larger target area (see Section 6.3 below).

The efficiency of adulticiding is dependent upon a number of integrated factors. First, the mosquito species to be treated must be susceptible to the insecticide applied. Some mosquitoes are resistant or more tolerant to some adulticides, thus affecting the pesticide selection. Pesticide applications must be made during periods of adult mosquito activity, which is variable with species. Adulticiding should be timed when the mosquitoes are flying and exposed to the aerosol mist. It is necessary for the pesticide to contact the adult mosquito in order for the chemical to be effective (Rose, 2001, USEPA, 2002c).

As with all pesticides, mosquito adulticides have restrictions regarding dosages to the environment. In order to ensure that proper application rates are being followed, equipment must be calibrated for the proposed use. The need to completely predetermine usage patterns has been obviated by linking computer controllers to applicators. However, it is still important to determine that the applicator actually produces the right droplet size and mixes and releases chemicals at the appropriate rate. Failure in any aspect of this process can lead to inefficient pesticide applications that do not affect the targeted mosquito populations, or result in unnecessary potential risks to non-target organisms due to overapplication of the pesticide.

Calibration frequency is determined by the kind of equipment used, including its age, its sensitivity to upset, and the conditions of its use. If the equipment is sturdy and is permanently mounted on a particular vehicle, it will not need to be adjusted as often as a finely-tuned instrument that is brought out of storage and mounted when needed.

Each kind of chemical application has its own set of conditions that determine success or failure. The application must be at a dosage rate that is lethal to the target insect and applied with the correct droplet size. Whether the treatment is ground or aerially applied, it must distribute sufficient insecticide to cover the prescribed area with an effective dose. Typically, with ground applications, vegetated habitats may require up to three times the dosage rates that open areas require. This is purely a function of wind movement and its ability to sufficiently carry droplets to penetrate foliage (Mount, 1998).

Environmental conditions may affect the results of adulticiding. Wind is a critical factor in adulticiding operations as it determines how the ULV droplets will be moved from the output into the treatment area. Conditions of no wind will result in the material not moving from the application point. High wind, a condition that inhibits mosquito activity, will quickly disperse the insecticide too widely to maintain effective concentrations. Light wind conditions (less than 10 mph) are the most desirable because they effectively move the material through the treatment area and also are favorable for mosquitoes to be active. Thermal fogs perform best under very light wind conditions (USDA and USEPA, 1992).

ULV application should be avoided during hot daylight hours. Thermal currents can cause the small droplets to quickly rise, moving them away from mosquito habitats. Generally, applications are made between sunset and sunrise, depending upon mosquito species activity. Some mosquitoes (*Culex* and *Anopheles*) are most active several hours after sunset, while others (*Ae. aegypti* and *Ae. albopictus*) are more active during the daytime. Applications should be made during the period of highest activity for the target species, provided that meteorological conditions are suitable for application (USDA and USEPA, 1992). It should be noted that periods of peak activity change as the season progresses. Crepuscular feeders change their biting habits from evening to late afternoon as night temperatures decline, meaning that fall evening airsprays will have less effect on their populations. Similarly, early morning applications late in the year will not have positive effects, as most species stop flying due to colder temperatures (Crans and Sprenger, 1996).

Because adulticiding is primarily carried out where people live, such as urban and suburban areas, and in heavily-used parks, people, domestic animals, and wildlife are exposed to drifting and deposited insecticide droplets (Delaplane, 1996). Since adulticides are usually applied during the night or twilight hours, nocturnal and crepuscular animals may have greater potential risks because of greater exposures. It must be realized that droplet size is of greatest consequence to deposition rates and, ultimately, the degree of exposure to non-target organisms. Many droplet sizes form "indefinite suspensions" in that they tend not to be affected by gravity. Calibration of equipment can ensure that these size ranges are the dominant distribution of droplets, so that there is a greater chance of flying mosquitoes encountering the pesticide. On the other hand, most modern adulticides are short-lived in the environment, degrading rapidly from the original compound when exposed to sunlight, water, or soil microbes (Rose, 2001).

A major consideration inherent to mosquito adulticiding is predicting and controlling the distribution of the pesticide spray during and after applications. This is because adulticides are applied by atomizing solution into micron size droplets that are intended to drift across target areas. Deposition of these droplets can occur within and beyond the target area as dictated by droplet mass and prevailing meteorological conditions. Adequate drift of small droplets through the target area is essential for efficacious mosquito control, yet 10 micron droplets may be calculated to drift 500 meters (0.3 miles) when applied by ground equipment with a wind speed of four km/h (Tietze et al., 1994). Under the same conditions, a one micron droplet is expected to drift about 2000 m (1.2 miles). These drift characteristics distribute the insecticide across a wide area, which may lead to incidental deposition into wetlands and other sensitive habitats (Delaplane, 1996). In addition to droplet size and meteorological conditions, the amount deposited depends upon application strategy (*i.e.*, ground or aerial treatments), type of equipment used, method of calibration, and flow rate (FCCMC, 1998).

One notable exception to treatments made when mosquitoes are active and flying is a residual barrier treatment application. Barrier treatments are based on the natural history and behavioral characteristics of the mosquito species causing the problem. Barrier applications use a residual material, generally applied with a powered backpack sprayer to preferred resting areas and migratory stops, in order to intercept adult mosquitoes hunting for blood meals. These barriers are generally intended to act as repellents, keeping the mosquitoes from entering the protected area, but mostly not reducing mosquito numbers. Barrier treatments are often applied during daylight hours as a large-droplet liquid application and are designed to prevent a rapid re-infestation of specific areas, such as recreational areas, parks, special-event areas, and private residences. Barrier applications can help provide control an infestation of mosquitoes for up to one week or longer (Rose, 2001).

6.1. Organophosphates

Organophosphates have been used for mosquito control since the early 1950s. Generally, they are least expensive to use. Organophosphate toxicity is due to the inhibition of cholinesterase activity. This inhibition interferes with the neuromuscular junction that ultimately causes paralysis of the insect (Ware and Whitacre, 2004).

6.1.1. Malathion

Malathion, a general-use pesticide, is one of the most widely used adulticides in the country, primarily because of its lower cost compared with other approved adulticides. The label for malathion contains a "CAUTION" warning indicating that it is only a slightly toxic material (USEPA, 2002d). Malathion is generally used against all mosquito species of concern. Malathion is most commonly applied as a ground ULV spray; thus no mixing or dilution is needed (EXTOXNET, 1996d). Dosages ranging from 0.0255 to 0.0548 lb. AI/ac. are used. Thus, at the greatest dose rate, a million square feet can be treated with slightly more than a pound of active ingredient. Another comparison is that less than a shot glass-full of pesticide treats a football field-sized area. Less common are the thermal fog applications where malathion is diluted six to eight oz./gal. with a suitable oil carrier, and applied at up to 40 gal./hr. with a vehicle speed of 5 mi./hr., or multiple thereof. The aerial application rate is 0.20 to 0.23 lb. AI/ac. (Rutgers, 2004)

The benefits of malathion usage include its relatively low cost in comparison to other adulticides, and its ease of use. Malathion's greatest disadvantage is its inefficiency in controlling some adult mosquitoes at labeled rates. In addition, malathion also has a strong odor, a propensity to cause paint damage, and a slow knockdown (NPTN, 2001a, b).

Commercially available products include Fyfanon®, Atrapa®, and Microflo®.

6.1.2. Fenthion

Fenthion is applied with both ground and aerial equipment. Its label contains a "WARNING" for this restricted-use pesticide (EXTOXNET, 1996e). Liquid concentrate (9.67 lbs. AI/gal.) is applied as ULV from the ground with a maximum dosage rate of 0.03 lb. AI/ac. Aerial applications may either be ULV at a rate ranging from 0.05-0.10 lb. AI/ac., or thermal fogging at a rate of 0.03 lb. AI/ac. mixed with 0.2-0.8 quarts of oil.

Fenthion is an effective adulticide that provides good control benefits, although it is more expensive than some of the other available adulticides (Ware and Whitacre, 2004).

6.1.3. Naled

This product is applied with both ground and aerial equipment. Product labels contain the signal word "DANGER." From the ground, naled is applied up to a rate of 0.02 lb. AI/ac., and from the air it is applied up to a rate of 0.15 lb. AI/ac. (USEPA, 2002e)

Naled is a fast-acting insecticide that degrades rapidly under typical environmental conditions and exhibits little residual activity. Difficulties associated with naled include its corrosive nature and its irritation to humans. Special application, storage, and handling equipment must be used because of its highly corrosive characteristics. Under certain environmental conditions, naled may be very irritating to humans, either from inhaling the droplet mist at close range from the output of ground ULV equipment or from getting the ULV droplets in the eyes (EXTOXNET, 1996f). The probability of irritation can be lessened by using an elevated output point or by mechanical introduction of air by turbine or fan to dilute the ULV output. Aerial applications of naled diminish the irritating nature of this material considerably (USEPA, 2000e).

Commercially available naled products include Dibrom®, and Trumpet®.

6.1.4. Chlorpyrifos

This product is a general-use pesticide, which can be applied by ground or aerial equipment, although it is most commonly applied by ground ULV equipment (NPTN, 1999a, b). Product labels contain the signal word "CAUTION" (EXTOXNET, 1996g). It is generally available in 1.0 and 1.5 lbs. AI/gal. formulations. Chlorpyrifos is relatively low-cost, low-odor, non-corrosive and has a relatively quick knockdown (EXTOXNET, 1996f). One drawback of chlorpyrifos is that it has larvicidal as well as adulticidal characteristics. Unintentional larval habitat treatment with chlorpyrifos could potentially lead to future resistance of mosquitoes to that product or group of products (FCCMC, 1998).

Commercially available chlorpyrifos products include Dursban® and Lorsban®.

6.2. Pyrethrins and Pyrethroids

Natural pyrethrins (pyrethrum) are extracted from chrysanthemum flower heads, mainly *Chrysanthemum cinerarnaefolium*, grown commercially in parts of Africa and Asia. The six pyrethrins are esters of three cyclopentenolone alcohols: pyrethrolone, cinerolone, and jasmolone with either chrysanthemic acid or pyrethric acid. Synthetic analogues, referred to as pyrethroids, of the natural pyrethrins were first marketed in the 1950s. These first generation compounds included allethrin, bioallethrin, phenothrin and tetramethrin. As with the natural pyrethrins, they are relatively unstable in light. During the 1960s and 1970s, great progress was made in synthetic light-stable pyrethroids, such as permethrin and cypermethrin. These photostable pyrethroids represent the second generation of these compounds (Ware and Whitacre, 2004).

Pyrethroids exhibit rapid knockdown and kill of adult mosquitoes, characteristics that are considered a major benefit of their use. The mode of action of these compounds relates to their ability to affect sodium-channel function in the neuronal membranes, and so they do not affect cholinterase (EXTOXNET, 1994).

Synthetic pyrethroids are non-corrosive, and so will not damage painted surfaces. They are less irritating than other mosquito adulticides and have a less offensive odor. In comparison to other adulticides, pyrethroids may be effectively applied at much lower rates of AI per ac. (Leahey, 1985).

6.2.1. Natural Pyrethrins

Natural pyrethrins are compounds that are not photostable (NPTN, 1998). Product labels contain the signal word "CAUTION" (EXTOXNET, 1994). Formulations generally contain five percent pyrethrin with piperonly butoxide (PBO) at a one to five ratio. They are applied as a ULV spray with a dosage of 0.0025 lb./ac. (PBO at 0.0125 lb./ac.) (Rutgers, 2004). Pyrethrin treatments result in the rapid kill of adults, but they are expensive to use (NPTN, 1998).

Commercially available products include Pyrocide®, and Pyrenone®.

6.2.2. Sumithrin

Sumithrin is a first-generation synthetic pyrethroid with wide use throughout the country. As with permethrin and resmethrin (discussed below), it is commonly mixed with PBO as a synergist (NPTN, 1998). Sumithrin is a general-use insecticide with more than 30 years of use. It biodegrades rapidly and has a label that contains the signal word "CAUTION" (EXTOXNET, 1994).

Sumithrin's maximum recommended dosage is 0.007 lb. AI/ac., and it is generally applied with ULV equipment. It is used against all mosquito species and has the favorable characteristics of rapid knockdown, odorlessness, and non-corrosiveness (NPTN, 1998).

Commercially available sumithrin products include Anvil®.

6.2.3. Resmithrin

Resmethrin is another first-generation synthetic pyrethroid. Resmethrin is a photolabile pyrethroid compound formulated as the active ingredient in mosquito control products (NPTN, 1998). Resmethrin is similar to the other pyrethroids in providing rapid knockdown and quick kill of adult mosquitoes. It degrades very rapidly in sunlight, and provides little or no residual activity (EXTOXNET, 1996h).

Resmithrin products are available in several concentrations that range from 1.5 to 40 percent and may or may not contain PBO. Products containing PBO have a maximum rate of application of

0.007 lb. AI per ac. (Rutgers, 2004). Product labels contain the signal word "CAUTION" (EXTOXNET, 1994).

Commercially available resmethrin products include Scourge®.

6.2.4. Permethrin

Permethrin, a second-generation pyrethroid, is a photostable pyrethroid compound (Ware and Whitacre, 2004). Permethrin is similar to other pyrethroids in providing rapid knockdown and quick kill of adult mosquitoes. However, permethrin also provides some residual activity when applied directly to surfaces (NPTN, 1997). Permethrin is a general-use pesticide with labels that may contain either the signal word "WARNING" or "CAUTION," depending on the particular product (EXTOXNET, 1996g).

Permethrin products are available in various concentrations, from 1.5 to 57 percent, and may or may not be synergized with PBO. Synergized permethrin products may contain PBO in various ratios by weight, but the maximum rate of application is 0.007 lb. AI/ac. Permethrin products, if labeled for this use, may be applied at a maximum of 0.1 lb. AI/ac. for a "barrier" effect (Rutgers, 2004).

Benefits of using permethrin include a rapid adult mosquito knockdown, odorlessness, and non-corrosiveness (EXTOXNET, 1996g). Permethrin is available in ready-to-use formulations.

The relatively high cost of some permethrin formulations compared to other adulticides can be a disadvantage of this material. Another risk of this synthetic material is the potential of some insects to more quickly develop resistance to it compared to organophosphates (FCCMC, 1998).

Commercially available permethrin products include Permanone®, and Aqua Reslin®.

6.3. Ground Adulticiding

Ground adulticiding is the most commonly used method of controlling mosquitoes in the country today (Rutgers, 2004). Ground adulticiding consists of dispersing an insecticide as a space spray into the air column, which then drifts through the habitat where adult mosquitoes are flying.

There are two techniques of mosquito control insecticidal space spraying in use at this time: thermal fogging and ULV cold aerosol. The only other form of ground treatment for adult mosquitoes in use today is a residual barrier application to foliage (Rose, 2001).

Any mosquito adulticiding activity that does not follow reasonable guidelines, including timing of applications, avoidance of sensitive areas, and strict adherence to the pesticide label, risks affecting non-target insect species (USDA and USEPA, 1992). Ground adulticiding, however, can be a very economically effective technique for controlling most mosquito species in residential areas. Preferable air currents for ground applications are two to seven mph and not in excess of 10 mph. Excessive wind and updrafts reduce control, but light wind is necessary for drifting spray droplets (Mount, 1998).

6.3.1. Thermal Fog

Thermal fogging is a space treatment against adult mosquitoes. Thermal foggers were developed largely from smoke generators, built principally for concealing military maneuvers. The insecticide is mixed into a carrier oil, usually number 2 diesel or a light petroleum distillate, which is injected into a heated, often double-walled nozzle. The mixture is vaporized by the heat, which may be in excess of 1000^{o} F. A source of forced air drives this vapor out of the nozzle where the outside cooler air condenses it into a visible fog with droplets ranging from 0.5 to 1.5 microns (FCCMC, 1998).

If the insecticide flow does not overwhelm the vaporization capacity of the machinery, all the droplets will be in this near submicron range, often referred to as a dry fog. If the insecticide flow is increased or the heat reduced some of the material will not be completely vaporized and larger droplets will be produced. The insecticide's contact time with the high temperature is so short that little, if any, degradation takes place (Mount, 1998).

A benefit of thermal fogging is its ability to atomize more insecticide with much less energy (BTUs) input than air blast ULV-delivery techniques. The technique produces a very uniform droplet spectrum of very small droplets if a dry fog is maintained. The small droplets do not settle quickly and may penetrate foliage better than the larger cold aerosol droplets (Dukes et al., 1990).

The risk associated with a dense enveloping fog is that it may create a traffic hazard. Additional concerns include the amount of non-insecticidal petroleum distillates that function only as a carrier and their potential effects on the environment. Although the total volume of thermal fogs is greater than the ULV technique, the amount of insecticide is often one half to one third of the ULV rate. This is due to the efficiency of the small droplets in penetrating and covering a targeted area (FCCMC, 1998).

6.3.2. Ultra Low Volume (ULV)

Cold fogging is also used as a space treatment against adult mosquitoes. Cold aerosol generators, or cold foggers, were developed to eliminate the need for great quantities of petroleum oil diluents necessary for thermal fogging. These units originally were constructed by mounting a modified nozzle on a thermal fogger's forced air blower (Russel, 2001). The insecticide is applied full strength, or in moderately high concentrations, as is common with the pyrethroids. This translates into very small quantities applied per acre and is, therefore, referred to as ULV. Mosquito control ground adulticiding operations rarely exceed one oz./acre. The optimum size droplet for mosquito control with cold aerosols applied at ground level has been determined to be in the range of five to 15 microns (Rutgers, 2004).

The sprayers utilized today use several techniques to meet these requirements. Air blast sprayers are almost universal. They use either high volume and low pressure vortical nozzles or high pressure airshear nozzles to break the liquid into very small droplets. Rotary atomizers, ultrasonic, and electrostatic nozzles are other forms of atomization equipment. Centrifugal energy nozzles, rotary atomizers, form droplets when the liquid is thrown from the surface of a high-speed spinning porous sleeve or disc. Ultrasonic equipment vibrates and throws the droplets off. Electrostatic systems repel the droplets (USDA and USEPA, 1992).

A benefit of ULV aerosols is that they do not require large amounts of dilutents for application and are, therefore, much cheaper and may be environmentally safer. The spray plume is nearly invisible and does not create the potential for a traffic problem. Because it is difficult to sense, people generally may not perceive the insecticide application as a problem to the same degree that occurs with thermal fogs (FCCMC, 1998). The machinery to generate cold aerosols can be much simpler in design and operation than that of thermal foggers, but requires sophisticated nozzles and, with pneumatic equipment, a great deal of energy input (horse power) to atomize even a small flow of insecticide (Mount, 1998).

Risks associated with ULV aerosols include the problems related to applying any undiluted pesticide; the material is being handled and transported in a concentrated form. The droplet spectrum is rather wide (from submicron to greater than 40 microns), can be difficult to change and may settle into non-target areas more readily than a dry thermal aerosol (Mount, 1998).

6.4. Aerial Adulticiding

Aerial adulticiding can be a very effective means of controlling adult mosquito populations, particularly in inaccessible areas. If areas are bordered by extensive mosquito production sites or are small, narrow, or inaccessible, and lack a network of roads, aerial applications may be the only reliable means of obtaining effective control. Aerial adulticiding may be the only means of covering a very large area quickly in case of a major emergence or vector borne disease outbreak (FCCMC, 1998).

Aerial applications are expensive, considering the pesticide costs per acre, and the high cost of owning and maintaining or leasing aircraft. Pesticide labels permit as much as five times the amount of toxicant to be applied by air as by ground, meaning greater quantities may also be applied (USDA and USEPA, 1992). Flying also is dependent on good weather conditions. Due to the commitments associated with aerial applications, treatment decisions are given much thought and are commonly scheduled when adult population levels have peaked (Rutgers, 2004).

Three basic aerial adulticiding techniques have been used historically for mosquito control: low volume spraying, thermal fogging, and ULV aerosols. Low volume (about a quart/acre) sprays were commonly applied with the pesticide diluted in light petroleum oils and applied as a rather wet spray. Their effectiveness was negated by problems of spotting cars or anything else left outside. The relatively large size of the droplets reduced drift, thus limiting swath widths, and was not ideal for impinging on mosquitoes. The technique has not been favored for some time, but is compatible with equipment commonly used for aerial liquid larviciding, which does not require the generation of small droplet sizes (Russel, 2001).

Thermal aerosol applications normally use the exhaust heat of the aircraft's engines, including the helicopter's turbine, to atomize a very dilute mixture of petroleum oil and insecticide. It is also an efficient means of producing a very small droplets and tight droplet spectrum. The small droplets will remain airborne much longer than larger ones. The large quantities of carrier oil require larger, heavy-lift aircraft and limit the area that can be covered economically to about one tenth that of ULV applications (FCCMC, 1998).

The most common aerial adulticiding technique is ULV. Lighter aircraft, including helicopters, can be used because the insecticide load is a fraction of the other techniques. If the aircraft are capable of speeds greater than 120 knots, the fine droplets can be created by the high-speed airstream impacting the flow from hydraulic nozzles. Slower aircraft and most helicopters typically use some variety of rotary atomizer to create the required droplet spectrum (Mount, 1998).

Most operations occur at night, typically after twilight, or early in the morning, before dawn, depending on the mosquito species being targeted. The intent is to catch adult mosquitoes at peak activity (Morris, 1991). The aircraft, typically, are flown between 200 to 300 feet altitude, with swath widths varying from 400 to 1,200 feet (Rutgers, 2004). Typically, aerial applications produce spray droplets of 30 to 50 microns measured as mass median diameter, with less than 2.5 percent of the droplets exceeding 100 microns (Mount, 1998).

Both fixed-wing and rotor aircraft are utilized for aerial adulticiding. Helicopters are becoming more widely used nationwide. Many programs that operate them for larviciding duties will change the spray equipment and adulticide with them. Additionally, programs will use them for adulticiding smaller areas that have obstructions or non-linear boundaries. They are more maneuverable than fixed-wing aircraft and can be serviced at field sites, thus, reducing ferry times (FCCMC, 1998).

7. Control Rationales and Triggers

There is no single set of treatment thresholds that can be universally applied to the application of mosquito control chemicals. The mixture of mosquito species, habitats, human population densities, and public tolerance of treatments affect decisions regarding treatment. Many larval and adult treatment thresholds are species-specific and based on knowledge of flight ranges, nuisance and vector potential, mosquito population densities, and proximity to human habitation (CT DEP, 2004). Thus, it is clear that a reliance on a wide-ranging surveillance program is key to optimizing treatments, to both maximize mosquito control and minimize chemical usage.

7.1. Larvicide Applications

Mosquito Control Districts routinely sample known breeding areas for the presence of mosquito larvae. Sampling techniques and equipment are discussed in Book 3 of the Literature Review.

Many inspectors are trained to be able to differentiate between nuisance and non-nuisance species. In general, the basic criteria used to make a determination for treatment are the number of larvae per sample dip, and the specific species present (DE DNR, 2004). For some mosquito control agencies, the sole criterion for applying larvicide agents is finding more than one larvae per sample dip in a particular area. Other agencies have developed more specific guidelines with respect to larval treatment. An example of a sophisticated approach to larval source treatment guidelines and larvicide use criteria is presented in Tables 7-1 to 7-3. These guidelines are employed by the Contra Costa Mosquito and Vector Control District in northern California. The levels noted to in the table titles refer to the following:

- Level 1: No virus detected in the Region
- Level 2: Virus detected in the Region
- Level 3: Virus detected in the County

The Region includes the Mosquito and Vector Control Association of California Coastal Region Districts (Alameda, Contra Costa, Marin-Sonoma, Napa, Northern Salinas Valley, San Mateo, Santa Clara, Santa Cruz, and Solano), plus San Joaquin, Sacramento-Yolo and Lake Counties.

Note that the mosquitoes that are of concern to the Contra Costa Mosquito and Vector Control District in northern California are not those that are of concern on Long Island.

Although these tables present specific reference numbers, they are presented as guidelines to determine if larvicide treatment is applicable. Most mosquito control agencies, in general, do not employ specific trigger thresholds that will automatically initiate treatment. In Suffolk County, considerations include, but are not limited to, distance to populated area, mosquito species present, number and distribution of mosquitoes over the area, weather forecast, and larvicide agent to be used. The Contra Costa example emphasizes the need to identify mosquito larvae to species level, and to maintain and refer to records to determine the importance of surveillance data.

Table 7-1 - Larval Source Treatment Guidelines* (Level 1)

Problem Mosquito Species Involved	Distance to Populated Area (1)	Total Larval Density, Other Factors
Oc. Nigromaculis *Oc. melanimon* *Oc. squamiger* *Oc. washinoi* *Oc. dorsalis*	0 - 10 yards 100 - 500 yards 500 yards - 2 miles 2 miles - 10 miles	0.1 per dip 0.1 per dip 0.1 per dip and source of 1/4 acre or more 3 + per dip and cource of 1 acre or more
Oc. sierrensis	0 - 500 yards greater than 500 yards	1 per slurp with turkey baster no treatment
Cx. tarsalis *An. freeborni*	0 - 500 yards greater than 500 yards	1 per slurp with turkey baster no treatment
Cx. stigmatasoma *Cx. pipiens* *Cx. erythrothorax* *Cx. apicalis*	0 - 100 yards 100 - 500 yards 500 yards - 1 mile 1 mile - 2 miles	0.1 per dip 0.1 per dip 0.1 per dip 5 + per dip and source of 1/4 acre or more
Cs. incidens *Cs. inornata* *Cs. particeps*	0 - 100 yards 100 - 500 yards 500 yards - 1 mile 1 mile - 2 miles	0.1 per dip 10 - 25 per dip 25 - 100 per dip and source over 1/2 acre no treatment
An. franciscanus *An. punctipennis* *An. occidentalis*	0 - 100 yards 100 - 500 yards 500 yards - 1 mile 1 mile - 2 miles	0.1 per dip 10 - 25 per dip 25 + per dip no treatment

* Also consider environmental conditions (e.g. probable duration of flooding, presence of natural predators, past history of source) before making a treatment decision. Consult material choice guidelines in Operations manual for choice of treatment methods. Sources with higher disease potential (e.g. *Culex* species) may be assigned higher priority if multiple sites require treatment.

(1) Populated area refers mainly to residential areas but could also include picnic areas in parks, marinas and other recreational areas where exposure to mosquitoes may be high.

Note: Collect larval sample prior to each treatment. Please preserve sample in alcohol and submit to the lab on the same day of collection.

Table 7-2 - Enhanced Larval Treatment Guidelines*Level 2/Level 3

Problem Mosquito Species Involved	Distance to Populated Area(1)	Total Larval Density, Other Factors
Ochlerotatus/Aedes (except sierrensis)	0 - 500 yards 500 yards - 1 mile 1 - 3 miles 3 - 5 miles	1 per 10 dips 1 per 5 dips 1 per dip 10 per dip
Oc. sierrensis	0 - 500 yards greater than 500 yards	1 per slurp with turkey baster no treatment
Culex, Anopheles	0 - 500 yards 500 yards - 1 mile 1 - 3 miles 3 - 5 miles	greater than zero 1 per 10 dips 1 per dip 5 per dip
Culiseta	0 - 500 yards 500 yards - 1 mile greater than 1 mile	3 per dip 5 per dip no treatment

* Also consider environmental conditions (e.g. probable duration of flooding, presence of natural predators, past history of source before making a treatment decision. Consult material choice guidelines in Operations manual for choice of treatment methods. Sources with higher disease potential (e.g. *Culex* species) may be assigned higher priority if multiple sites require treatment.

(1) Populated area refers mainly to residential areas but could also include picnic areas in parks, marinas and other recreational areas where exposure to mosquitoes may be high.

Note: Collect larval sample prior to each treatment. Please preserve sample in alcohol and submit to the lab on the same day of collection.

Table 7-3 - Larvicide Use Criteria

CONDITION	LIQUIDS				GRANULES/PELLETS				FISH
	AGNIQUE	ALTOSID	BTI	DUPLEX	OIL	ALTOSID	BTI	BS	
Water Temperature Below 65			X		X		X	X	***
Water Temperature above 65				*					
Larval Instar 1	****	X			X				
Larval Instar 2,3	****				X				
Larval Instar 4	****		X				X		
Pupae	****	X	X	X		X	X	X	
Creek	*****	*****		*****	*****	*****	*****	*****	
Brackish Water	X		****		****		****	****	
Low Organic Load				*					
High Organic Load	X		X		****		X		
Low Vegetation									
High Vegetation		X	X	X	****				
Endangered Species Present					X				X***
Hazardous Terrain		X	X	X			X		X***
Acres Breeding Less Than 10						**			
Acres Breeding Between 10 - 50	X*	X*		X*	X*	X*	X*	X*	X***

* Consult your Supervisor
** Site must have two mosquito species breeding, back to back, after flooding
*** Consult Fish Biologist
**** Use higher rate
***** Pooled water only
X = Do Not Use

7.2. Adulticide Applications

For most mosquito control agencies, there is not one criterion that will trigger the application of adulticide agents. The specific species present, location of human population, and presence of disease are just a few of the factors used to evaluate whether adulticiding will be conducted. Surveillance is clearly a necessary component to these decisions. A well-placed light trap network will return relative mosquito densities and help determine the host-seeking species that are present. CDC traps will allow for collection of mosquitoes for virus testing, while dead bird collection and veterinarian monitoring programs have demonstrated usefulness in tracking virus presence.

The state of Delaware generally considers two forms of evidence that adult mosquito populations are unacceptably high (DDNREC, 2004):

Physical Evidence

A professional analysis of adult mosquito light-trap data or landing rate counts yielding results of 25 mosquitoes per trap night, or 3 mosquitoes landing per minute indicates a nuisance condition, substantially lowering the quality of life as well as an enhanced possibility for mosquito-borne disease transmission.

Public Complaints

Complaints will indicate that a nuisance condition exists. These are field investigated wherever practicable.

In Delaware, with the exception of a declared public health emergency by appropriate state-level officials, local municipal officials, who have to weigh several factors in making their decisions, determine the decision to adulticide for mosquito control purposes. They have to consider the impacts of intolerably high mosquito populations on quality of life factors and local economies, along with the possibility of mosquito-borne disease transmission, weighed against the risks to human health or the environment of pesticides (DDNREC, 2004). However, pesticide risks are generally thought to be low when using USEPA registered adulticides in a manner prescribed by USEPA.

The state of Maryland uses threshold guidelines, based on physical evidence, to determine the potential need for adulticide applications. For ground applications in urban areas, trap counts of ten mosquitoes per night or landing rates of one mosquito per minute demonstrate a need for spraying. In rural areas, trap counts of 20 mosquitoes per night or landing rates of two mosquitoes per two minutes are required. For aerial applications of adulticides, trap counts of 100 mosquitoes per night or landing rates of 12 mosquitoes per minute are required. The state prefers that both criteria be used; but either the trap count or the landing rates can determine the need for adulticide application. It should be noted that identifying the species of mosquito in the traps is extremely important, as not all species attracted to the traps are human biting species (MDDOA, 2002).

The state of Florida has specific treatment threshold values stated in the Florida Administrative Code, which is based on the authority of the Florida State Statutes. It states that mosquito control programs will insure that the application of pesticides are made only when necessary by determining a need in accordance with specific criteria:

- a potential for a mosquito-borne disease outbreak
- numbers of disease vector mosquitoes sufficient for disease transmission
- defined levels of, or a quantifiable increase in numbers of, pestiferous mosquitoes.

To determine the need for applications of adulticides, at least one of the following criteria must be met and documented by records (Florida Administrative Code, 1995).

1. When a large population of adult mosquitoes is demonstrated, by either a quantifiable increase in, or a sustained elevated, mosquito population level as detected by standard surveillance methods, including citizen complaints.
2. Where adult mosquito populations build to levels exceeding 25 mosquitoes per trap night or five mosquitoes per trap hour during crepuscular periods.
3. When service requests for control from the public have been confirmed by one or more recognized surveillance methods.

Connecticut, unlike most other states that consider nuisance mosquitoes as potential vectors that affect the quality of life of their citizens, takes a very conservative approach to the use of adulticides and will only advocate their use in the face of a public health emergency (CT DEP, 2004). It is outlined in their West Nile Virus Response Plan that member agencies of the Mosquito Management Program will consider the use of adulticides if the risk of West Nile Virus, or other mosquito-borne virus, is high and is projected to remain high as to pose a public health epidemic.

Suffolk County, like most mosquito control agencies, does not have specific numerical triggers that will initiate adulticide applications. Many factors are considered, including trap counts, landing rates, citizen's requests for service and the history of a particular area. In general, as with many other programs, trap counts of 20 to 25 mosquitoes per night of human biting species, or landing rates of five mosquitoes per minute or more, indicate that consideration should be given to applying adulticide agents.

With respect to West Nile Virus, all surveillance indicators are considered including dead bird sightings, positive test results in birds, virus isolations in mosquitoes, and mosquito species composition and numbers.

Tables 7-4 to 7-6 present the adulticide criteria employed by the Contra Costa Mosquito and Vector Control District in northern California. As with the larval treatment guidelines discussed earlier, the levels noted in the table titles refer to the following:

- Level 1: No virus detected in the Region
- Level 2: Virus detected in the Region
- Level 3: Virus detected in the County

The Region includes the Mosquito and Vector Control Association of California Coastal Region Districts (Alameda, Contra Costa, Marin-Sonoma, Napa, Northern Salinas Valley, San Mateo, Santa Clara, Santa Cruz, and Solano), plus San Joaquin, Sacramento-Yolo and Lake Counties.

Table 7-4 - No Virus Detected in Region (Level 1)

Culex		Ochlerotatus/Culiseta	
Landing count greater than 20/min **OR** EVS count greater Than 20/night **OR** NJLT count greater Than 20/night **IN RURAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold	Landing count greater than 50/min **OR** EVS count greater than 500/night **OR** NJLT count greater than 10/night **IN RURAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 10/min **OR** EVS count greater Than 100/night **OR** NJLT count greater Than 10/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold	Landing count greater than 100/min **OR** EVS count greater than 500/night **OR** NJLT count greater than 10/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 5/min **OR** EVS count greater Than 50/night **OR** NJLT count greater Than 5/night **IN RESIDENTIAL AREA**	No adulticiding Set EVS traps to determine species Refer to larval sample database Attempt to locate and treat sources; doortag if backyard	Landing count greater than 5/min **OR** EVS count greater than 50/night **OR** NJLT count greater than 5/night **IN RESIDENTIAL AREA**	No adulticiding Set EVS traps to determine species Refer to la rval sample database Attempt to locate and treat sources; doortag if backyard

NJLT = New Jersey Light Trap EVS = Encephalitis Vector Survey Trap

From: Contra Costa Mosquito and Vector Control District in northern California

Region includes MVCAC Coastal Region districts, plus San Joaquin, Sacramento-Yolo and Lake Counties

Rural Area excludes remote areas like marshes, industrial areas that are not inhabited and out of normal flight range from populated areas. These will be considered on a case-by-case basis.

Table 7-5 - Virus Detected in Region (Level 2)

Culex		Ochlerotatus/Culiseta	
Landing count greater than 10/min **OR** EVS count greater than 100/night **OR** NJLT count greater than 10/night **IN RURAL AREA**	Treat; set EVS traps in area after each treatment Submit pools for testing if possible Continue until count below threshold	Landing count greater than 20/min **OR** EVS count greater than 200/night **OR** NJLT count greater than 20/night **IN RURAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 5/min **OR** EVS count greater than 50/night **OR** NJLT count greater than 5/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Submit pools for testing if possible Continue until count below threshold	Landing count greater than 10/min **OR** EVS count greater than 100/night **OR** NJLT count greater than 10/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 2/min **OR** EVS count greater than 20/night **OR** NJLT count greater than 2/night **IN RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Submit pools for testing if possible Continue until count below threshold	Landing count greater than 5/min **OR** EVS count greater than 50/night **OR** NJLT count greater than 5/night **IN RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold

NJLT = New Jersey Light Trap EVS = Encephalitis Vector Survey Trap

From: Contra Costa Mosquito and Vector Control District in northern California

Region includes MVCAC Coastal Region districts, plus San Joaquin, Sacramento-Yolo and Lake Counties

Rural Area excludes remote areas like marshes, industrial areas that are not inhabited and out of normal flight range from populated areas. These will be considered on a case-by-case basis.

Table 7-6 - Virus Detected in County (Level 3)

Culex		Ochlerotatus/Culiseta	
Landing count greater than 5/min **OR** EVS count greater than 50/night **OR** NJLT count greater than 5/night **IN RURAL AREA**	Treat; set EVS traps (2 or more) in area of positive human or animal case, sentinel or pool Submit pools for testing if possible Continue until count below threshold	Landing count greater than 20/min **OR** EVS count greater than 200/night **OR** NJLT count greater than 20/night **IN RURAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 2/min **OR** EVS count greater than 20/night **OR** NJLT count greater than 2/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps (2 or more) in area of positive human or animal case, sentinel or pool Submit pools for testing if possible Continue until count below threshold	Landing count greater than 10/min **OR** EVS count greater than 100/night **OR** NJLT count greater than 10/night **WITHIN 2 MILES OF RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold
Landing count greater than 1/min **OR** EVS count greater than 10/night **OR** NJLT count greater than 1/night **IN RESIDENTIAL AREA**	Treat; set EVS traps (2 or more) in area of positive human or animal case, sentinel or pool Submit pools for testing if possible Continue until count below threshold	Landing count greater than 5/min **OR** EVS count greater than 50/night **OR** NJLT count greater than 5/night **IN RESIDENTIAL AREA**	Treat; set EVS traps in area after each treatment Continue until count below threshold

NJLT = New Jersey Light Trap EVS = Encephalitis Vector Survey Trap

From: Contra Costa Mosquito and Vector Control District in northern California

Region includes MVCAC Coastal Region districts, plus San Joaquin, Sacramento-Yolo and Lake Counties

Rural Area excludes remote areas like marshes, industrial areas that are not inhabited and out of normal flight range from populated areas. These will be considered on a case-by-case basis.

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