

THE CONTROL OF MOSQUITOES

INTRODUCTION

Mosquito control activities are important to the public health, and responsibility for carrying out these programs rests with state and local governments. The federal government assists states in emergency situations and provides training and consultation in vector and vectorborne disease problems on an ongoing basis as requested by the states. The current interests in ecology and the environmental impact of control measures, and the increasing problems that have resulted from insecticide resistance emphasize the need for "integrated" control programs. An integrated approach to mosquito control involves accurate and complete assessment of the problem and the employment of control measures that are best suited to the situation. Mosquito control measures generally used in this approach include any one or a combination of techniques aimed at: (1) eliminating mosquito-producing habitats, (2) control of mosquito larvae by chemical means or by predatory fish, and (3) chemical control of adult mosquitoes. In addition, experimental efforts aimed at new alternative means of mosquito control are under way, including use of parasites and other pathogens, predators, and sterile male and other genetic techniques. These alternative methods, however have not been used extensively in public health mosquito control.

In many situations the application of insecticides is still necessary to achieve acceptable control. Persons with responsibility for the application of pesticides are regulated by the Federal Environmental Pesticide Control Act which became law in October 1972. This act is the amended Federal Insecticide, Fungicide, and Rodenticide Act

(FIFRA) of 1947, and specifics that all pesticides must be classified for "general use" or "restricted use."

General-use chemicals are those which can be safely handled by home owners, farmers or others without special training. Restricted chemicals are those which can be handled only by trained and qualified people because they could be dangerous if carelessly applied.

The amended FIFRA requires persons who apply restricted-use pesticides to be certified as competent after passing an examination, or to work under a certified person's supervision. The certification examination is usually given by a state agency. In preparing for this examination, the U.S. Department of Agriculture and the U. S. Environmental Protection Agency have published a core manual on general standards entitled "Apply Pesticides Correctly."¹ All persons applying restricted-use pesticides will be expected to understand information in the core manual. In addition, mosquito control workers who apply pesticides must pass a competency examination covering insects of public health importance. Special manuals for mosquito control personnel have already been prepared in some states.

NATURALISTIC CONTROL

Naturalistic control, as used in this Manual, refers to all commonly employed methods of mosquito control other than chemical or biological. These "naturalistic" methods include mainly those which involve the physical or mechanical alteration of topography or the management of water. Elimination or reduction of mosquito larval habitats by these methods is often termed "source reduction." Although control of larvae by chemical or other means might also be considered "source reduction," such methods will be considered

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separately in the section on biological and chemical control.

For ecological reasons, naturalistic control methods are generally considered to be more desirable than dependence on chemical control. Further, the emergence of widespread resistance of mosquitoes to the commonly used pesticides has, in some areas, necessitated virtually full reliance on the use of source reduction methods. It should be remembered that all source reduction methods require some manipulation of the environment, and all must be examined prior to use for possible undesirable effects on the aquatic or terrestrial environment. While naturalistic control techniques are effective, for environmental, economic or other reasons they may not always be feasible.

Source reduction today often requires an environmental impact statement, a permit from the U.S. Army Corps of Engineers, and compliance with the following laws: Clean Water Act of 1972, 1977, and 1987 (sections 404 and 401), U.S. Fish and Wildlife Coordination Act, Endangered Species Act, National Historic Preservation Act of 1966, National Environment Policy Act of 1969, and Coastal Zone Management Act of 1972.

Source reduction methods commonly used include filling, deepening, draining, ditching, management of water levels, shoreline maintenance, management of aquatic and inundated vegetation, and others. Impounded reservoirs, irrigation systems, navigational dredging, and natural wetlands present special problems in the production of mosquito breeding sites, as well as opportunities for mosquito control by environmental manipulation.

Filling, a method of mosquito habitat elimination, implies placing soil and similar compactable materials into depressions, pot holes, and low lying areas.

Deepening is a method used to modify impoundments or other depressions which are intended to hold water permanently. A backhoe, dragline, or other mechanical method may be used to deepen shallow and marginal areas and to increase the slope of the shoreline. The resulting steep, clean shoreline precludes or reduces growth of emergent vegetation. These modifications are frequently made on borrow pits to reduce mosquito breeding potential.

Draining of standing water is another method of larval control. This involves open ditching, use of subsurface drains, or pumping. Each technique has a specific application, and its use depends on the size of the area to be drained, the terrain, soil type, and economic feasibility.

Open drainage ditches are used throughout the United States and are a common means of salt-marsh mosquito control. For example, in New Jersey much of the tidal marsh was ditched for mosquito control about 1910-1920, although the ditching was often improperly installed. Subsequent to research on the "high" and "low" salt marshes, new ditching concepts have emerged which are more efficient. These will be discussed in more detail below.

Water and land management, i.e., the management of surface water and contiguous land areas, plays a very important role in the control of mosquito larvae, and poor management commonly leads to severe mosquito problems (USDA, 1967). This can apply to entire watersheds or to collections of waste water, precipitation runoff, irrigation water and other impounded water. As water becomes a more highly valued resource, water management practices are being revised to conserve and recycle water.

When considering control of mosquito larvae, it is difficult to separate water management from land management. In most

cases the two elements should be considered together because the bulk of the associated larval production occurs at or near their interface. This concept was clearly shown to be true by the Tennessee Valley Authority (TVA) for malaria control. The interaction of water level management on reservoirs, along with the proper preparation of reservoirs before impoundment, proved that anopheline vector production could be greatly reduced. The valuable lessons learned from TVA malaria control are still valid and should be considered by the major water resource developers in the planning, construction, operations, and maintenance of reservoirs. Mosquito problems on TVA projects have been minimized because mosquito biology and ecology are well understood, and naturalistic control measures are integrated into reservoir operation (USPHS and TVA 1947).

Water and land management practices for mosquito control can be more easily understood and appreciated if viewed in relation to specific types of water resource developments, such as reservoirs, irrigation systems, wildlife refuges, and navigable waterways.

Reservoirs are developed for multipurpose uses such as hydro-power generation, flood control, municipal and industrial water supply, outdoor recreation, and fish and wildlife interests. All types have caused mosquito problems. If a reservoir is not to cause mosquito problems, the following requirements must be satisfied: (1) proper preimpoundment preparation of the reservoir, (2) correct management of the pool level, and (3) proper maintenance of the shoreline.

Proper preimpoundment preparation of the reservoir is the most satisfactory means of eliminating potential mosquito producing habitats. Preparation involves shoreline conditioning, brush and vegetation removal, and providing for drainage. Preimpoundment

preparations are the most desirable of available methods because any modifications attempted after filling are not easily made and are more costly.

Shoreline conditioning involves steepening the gradient in places which would otherwise be very shallow after the reservoir impoundment. Shallow vegetated areas produce mosquitoes prolifically and must be deepened wherever practicable. A shoreline gradient of 3:1 has been found to deter the establishment of emergent vegetation. Mosquito-producing habitats are commonly observed in the shallows of the upper reaches of a reservoir and in tributary embayments. Clearing of brush and vegetation within the zone of recession removes potential mosquito habitats. Much vegetation is not water tolerant and should always be cleared from the shoreline prior to impoundment and "rebrushed" during drawdown periods.

Another aspect of reservoir preparation which minimizes potential mosquito larval habitats is the installation of drains in natural depressions, borrow pits, and dikes. Water is frequently trapped in such sites within the summer fluctuation zone of a reservoir and when the pool level is drawn down, they can retain water and become serious mosquito-producing situations which must be controlled chemically.

Maintenance of the pool level and the contiguous land areas are important parts of mosquito control on reservoirs. The manipulation of the pool level through fluctuations was demonstrated by Hess and Kiker (1943) to be effective in minimizing anopheline mosquito production. The spring surcharge and subsequent drawdown serves to strand flotsam such as plant parts and accumulated debris, which, if not removed from the reservoir pool, would create prolific mosquito habitats.

Another maintenance consideration is

seepage through the dam which is frequently observed. When such seepage occurs, it should be properly drained into the main outfall below the dam, or the resultant accumulation may become a mosquito habitat.

Irrigation systems are among the largest contributors to the mosquito problem in the western United States (USDA 1967). Mosquito production has been recorded from every aspect of the irrigation system, with sources off the irrigated field being the most important and difficult to control.

An irrigation system typically begins with an impounded reservoir which stores water and releases it as needed into the main distribution canal and through a series of smaller channels or laterals until it reaches the area requiring irrigation. Ideally, the unused water or runoff will be channeled into drain collection ditches, and finally returned through a main drain to the original source of the water or to a stream. Reservoirs that are drawn down sharply during the mosquito producing season generally do not cause mosquito problems.

Irrigation distribution canals in themselves are not major sources of mosquito production. Usually the water in the canals is in constant motion and does not provide the permanence or stability needed for ideal oviposition sites or larval development. Canals are usually 6-12 feet deep and steeply banked, factors which tend to preclude mosquito production.

The important sources of mosquitoes in the distribution system are seepages emanating from unlined canals. There are several solutions to the seepage problems, and all of them are expensive to install. For large canals, the installation of a lining is probably the only practical method. Concrete linings are the usual choice because of their durability but polyethylene sheeting and other impervious materials have been used successfully. The

Bureau of Reclamation has installed laterals on certain projects in underground conduits where surface canals would be aesthetically objectionable. This is also a water conservation technique, since it has been estimated that as much as 75% of the water entering the distribution system is lost before it reaches the target because of seepage, evaporation and waste (USDA 1967).

In the past, **irrigated fields** were frequently observed to be abundant mosquito producers. Unevelled fields with surface depressions and poor drainage at the low end of the field created mosquito habitats. Currently, the Bureau of Reclamation requires that fields be levelled, conditioned, and properly prepared for efficient irrigation before water is delivered to new systems.

Close-growing crops, such as alfalfa, and wildflooded pastures produce mosquitoes abundantly, whereas a row crop, such as cotton, does not. Fields of some crops (e.g. sugar beets and fruit orchards) usually do not produce mosquitoes because over-application of water will result in damage to these crops, and irrigation is carefully managed. Corn, on the other hand, is a row crop with a deep root system which tolerates much moisture, resulting in poor irrigation management and associated mosquito production. Over-application usually occurs with runoff accumulating at the low end of the field and in roadside ditches. *Aedes*, *Culex*, *Culiseta*, and *Psorophora* larvae are commonly found in agricultural waste water.

Efficient *drainage systems* are uncommon in irrigation agriculture. Once water reaches the field, there is likely to be little or no provision for removing the excess and abundant mosquito production may occur at the low end of the field and in adjacent roadside ditches. These ditches which often receive irrigation drainage, are not designed to dispose of such drainage efficiently. Throughout its range the

larvae of *Culex tarsalis* may be abundant among the dominant species found in these poor drainage situations. This species was found in such situations in an area endemic for western equine encephalitis in west Texas (Harmston *et al.* 1956) and similar relationships have been seen in many other irrigated areas. Drainage is now being considered more carefully in the design of irrigation systems partly because it has become necessary to reclaim the waste water, and in the future more efficient design and maintenance of drainage systems in irrigation should serve to minimize mosquito production.

Other recent developments in irrigation include the development and refinement of sprinkler irrigation systems, which will probably reduce mosquito production in irrigated areas. Sprinklers apply water uniformly and more conservatively than other surface irrigation methods, but mosquito problems have been found where the land was improperly prepared, application was poorly managed, and water was allowed to accumulate: Center-pivot irrigation systems are being widely accepted by farmers in the United States, and are extending irrigation in the arid western United States (Splinter 1976).

Recent studies have shown that there is a strong correlation between good irrigation practices, high crop yield, and low mosquito production; and conversely, poor water and land management practices, low crop yield, and high mosquito production indices are also strongly associated. Because of the economic benefits that can be demonstrated, it is less difficult to encourage practices which will also diminish the production of vector mosquitoes.

The use of sewage effluent for irrigation is becoming an accepted practice, and the high nitrogen content of this waste makes it valuable in agricultural and horticultural pursuits. Where such effluent has been used for irrigation, pronounced changes

may occur in the larval mosquito populations, including species composition, relative densities, and the introduction of new vector species. The association of *Culex* mosquitoes with waste water of high organic content is well known, a fact which has been demonstrated in these situations.

Because of **diked dredged spoils areas**, a serious mosquito control problem exists along some of the navigable waterways of the United States. The problem is due to production of *Aedes sollicitans*, a salt-marsh mosquito, in spoil material dredged from the waterways in the course of their maintenance. Among the states experiencing mosquito production with diked dredged spoils are Louisiana, Texas, California, and the Atlantic Coastal states on the inland waterway.

Spoil material from the dredge is a liquified substance consisting of silt, sand, and a large percentage of water for conveyance purposes. The normal practice has been to deposit some of this material in a designated site and allow it to dry. Once dry, the material may be bulldozed into a dike so that a large basin is created, into which more spoil material will be pumped. Spoil material does not spread uniformly but produces a "waffle" effect of high and low portions. The lower ones tend to hold precipitation, become vegetated quickly and provide excellent oviposition and development sites for *Aedes sollicitans*. As the spoil dries, it often becomes cracked due to shrinkage. The cracks collect precipitation, and may become productive *Aedes sollicitans* habitats. Spoils sites range in size from a few to more than 1,000 acres.

Various methods have been used to reduce mosquito production associated with these spoils areas, including plowing, harrowing, scraping, and other mechanical means of altering the topography. Research is needed to determine other naturalistic methods of control of mosquitoes in diked dredged spoils deposits.

Naturalistic control of mosquitoes on wetlands, along the Atlantic seaboard and in California, has been the subject of much work and research since the early 1900's. For many years, the wetlands were thought of as wastelands because their role in the ecosystem and their economic contributions were not well understood. Recent studies have shown that in addition to the production of salt grass hay, the salt marshes are valuable nursery areas for several species of fish and crustaceans. Intensive studies have been accomplished in California, Utah, New Jersey, Delaware, and Florida, for the control of saltmarsh *Aedes* and for the enhancement and protection of the environment. In all instances, consideration has been given to mosquito control, fish and wildlife interests, and agriculture. The original approach for mosquito control on salt marshes was drainage and miles of ditches were dug for this purpose. As knowledge of marsh-plant-mosquito production developed, it was seen that there was a high-marsh area which was subjected to intermittent tidal flooding, and this section of the marsh produced mosquitoes abundantly. The low-marsh portion received frequent flooding, making it unfavorable for oviposition for salt-marsh *Aedes*. Thus, the low-marsh was not the source of the problem, but had been indiscriminately ditched for mosquito control purposes (Provost 1974).

Two basic methods of marsh management for mosquito control are being used: water level management and management of the open tidal marsh. Both of the foregoing depend on the knowledge of the biology and ecology of *Aedes sollicitans* and *Ae. taeniorhynchus*. These saltmarsh mosquitoes lay their eggs on soil or plants, never on the water surface.

Water level management has been used successfully on salt marshes in Utah, New Jersey, and Florida. The areas under control

were located near human population centers and were intermittently flooded, producing large numbers of mosquitoes. To correct this situation, the problem areas were diked appropriately to maintain the desired level of flooding. A pump may be required to fill the area or to add water when indicated. With a constant water level, optimum oviposition sites for salt-marsh mosquitoes are eliminated.

Other marsh areas indicate a need for open management techniques. Canal systems are developed to connect any section of isolated marsh with tidal waters. The important concept in this method is to bring circulation or tidewater into isolated marsh areas, which may hold floodwater or rainfall, within 1-2 days following the flooding. Minnows predaceous on mosquito larvae are provided access to all regions of the marsh as well (Provost 1974).

The Open Marsh Water Management (OMWM) concept (Ferrigino *et al.* 1975) is an important source reduction approach. OMWM is employed in marsh areas which are situated either slightly above the spring tide line, or slightly below it. Three basic modifications can be made, and they can be used separately or in conjunction. They are tidal ditches, ponds, and pond radials (short ditches). In some areas, a series of depressions are arranged in a linear distribution. Such depressions could be connected with a ditch to the nearest source of tidal flow in order to provide circulation. Some depressions could be linked to others by short lateral lines which would eventually connect to the main ditch. In other areas, several depressions might be arranged in a roughly circular fashion. In this case, a pond would be constructed by connecting all the depressions together and deepening them in the process. Smaller depressions, near the pond, could be tied into the pond by means of radials. All of these modifications serve to reduce the potential for

salt-marsh mosquito breeding, with a minimum effect on the natural environment.

Land management practices which were discussed under "reservoirs" apply equally to **small ponds and impoundments**. Shorelines with a 3:1 gradient and without emergent vegetation are desirable. Farm ponds are usually constructed with one portion gently sloping and shallow so that livestock can have easy access to the water. Mosquito production has been observed on many farm ponds in the United States and the important breeding sites were commonly shallow, vegetated portions of the impoundment.

Sewage lagoons and stabilization ponds have produced abundant populations of *Culex tarsalis* and *Culex pipiens quinquefasciatus* mosquitoes. *Culex pipiens quinquefasciatus* prefers water with high organic content for oviposition, and *Cx. tarsalis* will tolerate this source as well. It has been found that mosquito production could be lessened by keeping lagoons free of aquatic vegetation, and by keeping the banks free of emergent vegetation. A minimum operating depth of three feet has been recommended to preclude mosquito production. Breeding has been observed in partially filled, vegetated lagoons; in such cases, rapid filling with sewage effluent would serve as a control measure.

BIOLOGICAL CONTROL

Biological control implies the destruction of larvae by predators or pathogens. Control of mosquito larvae by various biologic means has been the subject of considerable research and has shown much promise, but in practice, mosquito fish are used most often in control programs today. The pathologic agents under study have shown varying degrees of success in field trials, but as yet none are practical or have been licensed for mosquito control.

Larvivorous fish offer the greatest opportunity in biological control at this time,

and a number of mosquito abatement districts propagate and distribute the mosquito fish (*Gambusia affinis*) and the guppy (*Poecilia reticulata*) for control of larvae in cisterns, garden pools, ponds, and livestock watering tanks.

In New Orleans, Marten (1990) reported elimination of *Aedes albopictus* larvae from tire piles by introducing the copepod *Macrocylops albidus*. Some workers have reported varying degrees of success in controlling larvae of *Aedes aegypti*, *Ae. albopictus*, and *Ae. triseriatus* with the large predatory larvae of *Toxorhynchites*.

CHEMICAL CONTROL

Larval Control

If areas cannot be drained or filled at reasonable cost, and mosquito control by predator fish, impounding, or other naturalistic methods is not possible, larviciding may be required. Larvicidal control is of primary importance in areas where control of disease-carrying mosquitoes is necessary, particularly in situations with extensive flooding following natural disasters such as hurricanes or prolonged rainy seasons. Where chemicals are used for larviciding, it is recommended that the larvicide be with a different chemical from that used for adult control. For example, it may be desirable to use temephos (Abate) as a larvicide and malathion as an adulticide. The degree of control with larvicides differs with the various species of mosquitoes, degree of pH and pollution of the water, and type and amount of vegetation present. Table 2 lists insecticides and dosage rates currently being used to control mosquito larvae.

Types of Formulations

The synthetic organic insecticides can be applied as dusts, pellets, granular formulations, suspensions of wettable powders, solutions or emulsions. Dusts have been used

as mosquito larvicides, but they are light in weight and subject to drifting in air currents causing spotty application, and they may not penetrate vegetation to reach the water. Pellets and granular formulations have larger particle size, so they slip through leaves or dense vegetation to reach the water surface to kill the mosquito larvae. Wettable powders are frequently used in pre-hatch treatment of areas for the control of mosquito larvae. Wettable powders can be applied to snow, ice, or earth in dried-up mosquito-breeding areas seeded with eggs of temporary pool mosquitoes. Oil solutions can be sprayed on water surfaces to kill both anopheline and culicine larvae and pupae, particularly in waters with high organic content. Water emulsions have been employed extensively to treat irrigated waters, as in rice fields, since oil solutions are toxic to cultivated plants. The water in the emulsion serves as a carrier for the insecticide.

Larvicidal Chemicals

Organic Phosphorus Insecticides (OP compounds): These chemicals came into general use after World War II, particularly

after the emergence of the problems of resistance of mosquitoes to the chlorinated hydrocarbons and of environmental contamination. Soon after application, most organophosphates combine with water and break down into compounds which do not contaminate the environment.

At the present time, chlorpyrifos (Dursban(R)) and temephos (Abate(R)); are among the most widely used organophosphate larvicides. Malathion has also been used effectively. The degree of control varies widely with the species of mosquito, degree of pollution of the water, and type and amount of vegetation present (CDC 1973). Temephos is a safe and effective larvicide against most species of mosquito larvae. At recommended dosage rates, it usually does not kill predators (including fish) of mosquito larvae. It has been used to control mosquito larvae in rain barrels holding potable drinking water, in bird baths, and in animal watering devices. Chlorpyrifos (Dursban(R)) has given control of *Culex* larvae in polluted water, such as dairy drains and industrial waste water accumulations (Mulhern 1974).

TABLE 2-INSECTICIDES CURRENTLY USED IN MOSQUITO LARVICIDING

(These recommendations are guidelines only. There are many formulations available. The following are a few in current use. User must ensure that pesticides are applied in strict compliance with label and local, state, and federal regulations).

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
Organophosphates chlorpyrifos (Dursban)	0.4-1.6 oz/acre in water or oil	Dilute with water or oil for use in hand and power sprayers, mist applicators, and aerial spray equipment. Use 0.4 to 0.8 oz/acre for light (or no) to medium vegetation and 0.8 to 1.6 oz/acre for medium to heavy vegetation cover.

TABLE 2 (continued)

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
Malathion 57% EC	Up to 13 oz/acre	Mix 2.5 oz of malathion 57% with water to make 1 gallon. Apply up to 5 gal./acre depending on flottage and vegetation. (intermittently flooded areas, stagnant water, temporary rainpools).
Temephos (Abate)	0.05-0.1 lb/acre	Apply 5-10 lb. of 1% Abate sand and celatom granular per acre. Apply 2.5-5 lb. of 2% Abate sand and celatom granular per acre. Apply 1-2 lb. of 5% Abate sand and celatom granular per acre.
Temephos (Abate)	0.1-0.5 lb/acre	In some tidal water, marshes, and water with high organic or pollution content apply up to 25 lb. of 2% Abate sand and celatom granular, or up to 10 lb. of 5% Abate sand and celatom granular.
Temephos (Abate)	0.016-0.948 lb/acre	Mix 0.5--1.5 oz. of Abate 4E per gal of water. Apply at 1 gal./acre.
<u>Proprietary Compounds</u> Arosurf	0.2-1 gallon/acre	Apply as single layer monomolecular film to cover water surface.
Golden Bear Oil 1356	3-5 gallons/acre	Apply from air or ground to cover water surface.
<u>Insect Growth Regulators</u> Methoprene (Altosid SR 10 Altosid G Altosid Briquet Altosid Pellets)	3-4 oz. Altosid SR10 per acre 8-10 lbs. Altosid G per acre 1 Altosid briquet per 100 square feet	Mix 3-4 gallons of 10% Altosid in ½ to 5 gallons of water and apply to 1 acre. Use 8-10 lbs. of Altosid G per acre. Use Altosid Briquet 1/100 square feet. Kills 2nd, 3rd, and 4th stage larvae, not pupae or adults.
Diflubenzuron (Dimilin)	0.02-0.04 lb/acre	Interferes with formation of larval cuticle, inability to moult successfully.

TABLE 2 (continued)

INSECTICIDE	RATE OF APPLICATION (Active Insecticide/Acre)	REMARKS
<p><u>Larvicidal Bacteria</u></p> <p><i>Bacillus thuringiensis israeliensis</i></p> <p>Many formulations of Bactimos, Teknar, et al.</p>	<p>Follow label directions.</p>	<p>Many formulations, follow label directions. After ingestion, toxins released by the bacteria cause paralysis of midgut and death within a day.</p>
<p><u>Pyrethrins and synergist</u></p> <p>Tossits</p>	<p>Follow label directions</p>	<p>For small watered areas one tossit per 100 square feet.</p>

Proprietary Compounds: Special proprietary compounds such as AROSURF MSF and Golden Bear GB-1111 and GB-1356 are registered for mosquito control. These larvicides have given good control at application rates of 1-5 gallons per acre. They have low toxicity to plants and to non-target aquatic organisms. They act to suffocate larvae and pupae and thus eliminate the problem of resistance to organophosphate insecticides.

Insect Growth Regulators: Insect growth regulators have been studied intensively in recent years. Some of them have been called insect developmental inhibitors, or juvenile hormone-like materials. Some like methoprene (Altosid) cause mortality in the pupal stage, Others like diflubenzuron (Dimilin) prevent molting. Altosid is available as emulsion, granules, briquets, and pellets. These do not kill eggs, first stage larvae, pupae, or adults, but they do kill second, third, and fourth stage

larvae and prevent development of pupae. Dimilin is available as a powder which prevents hardening of the cuticle and molting. None of the insect growth regulators produce the quick kill associated with many other larvicides.

Larvicidal Bacteria: *Bacillus thuringiensis israeliensis* is a bacterial compound used to control mosquito larvae. It is sold commercially under many trademarks as Bactimos, Teknar, and Vectobac in various formulations as liquids, granules, flowables, and briquets. After ingestion by the larvae, the bacteria liberate toxins that cause paralysis of the midgut to occur within a few hours and death in about a day. The microorganisms released into the environment do not self-perpetuate, so re-application is required. This larvicide does not harm the environment -- fish and other aquatic organisms, plants, wildlife,

pets, and humans.

Pyrethrins: Larvicides containing pyrethrins are sometimes used to control mosquito larvae in lily ponds, and other situations with valuable vegetation. Tossits are gelatinous capsules containing 1% pyrethrins which can be tossed into small bodies of water such as stagnant pools, small ditches, catch basins, cisterns, and small marshy areas. The application rate is approximately one tossit per 100 square feet, per six inches of depth.

ADULT CONTROL

Control of adult mosquitoes by space spraying of any kind is only temporary since mosquitoes from nonsprayed areas can move rapidly into the sprayed area following spray applications. Also, aquatic stages are usually not affected by space spraying and new adults will continue to emerge.

Spraying operations are conducted during the late afternoon and early evening, at night or in the early morning when the air is cool and wind velocity does not exceed 6 miles an hour. If air movement is excessive, the small droplets used in space spraying are dispersed so swiftly that effectiveness is reduced or prevented. Similarly, during the middle of a hot day the droplets are dispersed by rising currents of warm air known as thermals. At night there may be an inversion of air temperatures so that small droplets are held close to the ground, usually producing excellent control of mosquitoes.

Outdoor space treatments with ground or aerial applications have been carried out effectively against many species. Susceptible populations of mosquitoes can be reduced

effectively by space application of insecticides listed in Tables 3 and 4.

ULTRA-LOW VOLUME APPLICATION WITH GROUND EQUIPMENT

Ultra-low volume (ULV) application with ground equipment is becoming the most frequently used method of adult mosquito control in the United States and can be very effective in vector control. Ultra-low volume treatment is defined as the application of less than 2 quarts of insecticide per acre, usually 0.5 to 3.0 ounces per acre. Beginning in 1970, great advances were made in the development of ultra-low volume equipment and a number of ULV ground application models are now sold commercially. Ultra-low volume equipment utilizes insecticide concentrate without a diluent or carrier resulting in savings in fuel, loading time, and cost of the fuel oil required in thermal foggers. Other advantages of ULV aerosols are that they do not produce the dense fogs--as do thermal fogs -- which constitute a traffic hazard by reducing visibility. The ground ULV machine is relatively small. Its insecticide tank commonly holds 5 to 10 gallons and it is usually mounted on a small vehicle, such as a 1/2 ton pickup truck.

TABLE 3--INSECTICIDES CURRENTLY USED FOR CONTROL OF ADULT MOSQUITOES WITH ULTRA-LOW-VOLUME GROUND EQUIPMENT.
 Modified from Rathburn and Boike (1975) and Evans (1992)

(These recommendations are guidelines only. User must ensure that insecticides are applied in strict compliance with label and local, state and federal regulations).

INSECTICIDES	FORMULATION/ LABEL	REMARKS/APPLICATION
chlorpyrifos (Dursban)	Dursban Dow Mosquito Fogging Concentrate	At vehicle speed of 10 mph, 2/3 to 1 1/3 fl. oz./min. Maximum flow rate 0.3 to 0.62 gal./hour.
malathion	Cythion ULV Concentrate	At vehicle speed of 5 mph, 1-2 fl. oz./min. Maximum flow rate of 1 gal./hour. At vehicle speed of 10 mph, 2-4 fl. oz./min. Maximum flow rate of 2 gal./hour.
naled* (Dibrom)	10% Dibrom 14 in HAN 1% Dibrom 14 in fuel oil with 1% Ortho additive	At vehicle speed of 10 mph, 6-12 fl. oz./min. Maximum flow rate of 6 gal./hour. At this rate persons may have serious irritation of eyes and respiratory tract. At vehicle speed of 10 mph, 40 fl. oz./min. Maximum flow rate of 20 gal./hour.
pyrethrum	5% pyrethrins -- 25% piperonyl butoxide	At vehicle speed of 5 mph, 2--2.25 fl. oz./min. Maximum flow rate of about 1 gal./hour. At vehicle speed of 10 mph, 4--4.5 fl. oz./min. Maximum flow rate of about 2 gal./hour.
resmethrin	(Scourge) 2-4% (3.3 lb/gal.)	At vehicle speed of 5 mph, 9 fl./oz./min. of 2% finished formulation.

Note mph - miles per hour fl. oz. - fluid ounce; HAN - Heavy Aromatic Naphtha.
 *With naled, tank pressure should not be greater than 1.5 lbs. psi because of overatomization and poor mosquito control.
 **Lower concentrations of this product should become available in the near future.

TABLE 4. INSECTICIDES CURRENTLY USED FOR ADULT MOSQUITO CONTROL WITH GROUND FOGGERS, MISTERS, AND DUSTERS.

(These are guidelines only. User must ensure that insecticides are applied in strict compliance with the label and local, State and Federal regulations).

INSECTICIDE	DOSAGE (Active Insecticide/Acre)	REMARKS
carbaryl (Sevin)	0.2-1.0 lb/acre	Dosage based on swath width of 300 feet. Apply as mist or fog between dusk and dawn. Mists are usually dispersed at rates of 7 to 25 gallons per mile at a vehicle speed of 5 mph. Fogs are applied at a rate of 40 gal./hr. dispersed from a vehicle moving at 5 mph; occasionally 80 gal./hr. and 10 mph. Finished formulations for thermal foggers contain from 0.5 to 8 oz. per gallon actual insecticide in oil. For nonthermal foggers or misters, water emulsions can be used. Dusts can also be applied with ground equipment.
chlorpyrifos (Dursban)	0.025-0.05 lb/acre	
fenthion (Baytex)	0.01-0.1 lb/acre	
malathion	0.075-0.2 lb/acre	
naled (Dibrom)	0.02-0.1 lb/acre	
propoxur (Baygon)	0.05-0.07 lb/acre	
pyrethrins (synergized)	0.002-0.0025 lb/acre	
remethrin (Scourge)	0.0035 lb/acre	

Performance requirements for ground ULV equipment have been published as follows (American Cyanamid Co. 1972):

(1) The ULV cold aerosol nozzle for dispersal of malathion to control adult mosquitoes must have the minimum capability of producing droplets in the 5 to 27 micron range. Large droplets may permanently damage automobile paint. The average diameter should not exceed 17 microns. Determination of droplet size should be made by depositing a sample of the aerosol on a silicone-coated glass slide and measuring the droplets under a microscope with an ocular micrometer.

- (2) Tank pressure should not be less than 2 to 3.5 pounds nor greater than 6 pounds per square inch (psi).
- (3) Flow rate must be regulated by an accurate flow meter. Flow meter data such as that in Table 3 should be recorded at the end of each day's operation.
- (4) The nozzle should be in the rear of the truck and pointed upward at an angle of 45° or more.
- (5) Vehicle speed should not be greater than 10 miles per hour. Some agencies have obtained special local need (24.C) authority to treat at 20 mph.

Five insecticides have EPA label approval for application as ULV aerosols by ground equipment; chlorpyrifos, malathion, naled, pyrethrum, and resmethrin. These insecticides are listed in Table 3 (Rathburn and Boike 1975).

ULTRA-LOW VOLUME AERIAL APPLICATIONS

Aircraft have been used for many years to apply insecticide dusts, pellets, sprays, and aerosols. Since 1964, aerial ULV has been used many times for controlling mosquitoes in disaster areas and for controlling epidemics of mosquito-borne disease. The ULV method was used in 1966 to kill infected *Culex pipiens quinquefasciatus* during the Dallas, Texas, epidemic of St. Louis encephalitis; in 1967, to kill species of *Aedes*, *Psorophora*, *Culex*, and *Anopheles* in a 3-million acre flooded area in Texas; in 1969, in Ohio to kill *Aedes* vectors of LaCrosse encephalitis during an epidemic; in 1972 and 1974 in New England to kill species of *Aedes*, *Coquilleltidia* and *Culiseta* during an outbreak of eastern equine encephalitis; in 1975, in North Dakota and Minnesota to kill infected *Culex tarsalis* during an outbreak of western equine encephalitis; and in 1975 in Guam and Puerto Rico to control the vectors of dengue.

The aerial ULV technique uses the application of 0.5 to 3.0 ounces of highly concentrated insecticide per acre for the control of adult mosquitoes. These insecticides are currently approved for adult mosquito control by the ULV method of application from airplanes: malathion at 3.0 fluid ounces per acre, naled at 0.5-1.0 fluid ounce per acre, and resmethrin at 3 fluid ounces per acre. On occasion, car paint spotting and bee kills have occurred as a result of ULV aerial applications.

Special aircraft equipment for the ULV involves special tanks, electrically-driven

pumps, spray booms, and 8001 to 8008 Tee-Jet nozzles or other specialized delivery and nozzle systems. In general, airplane ULV applications should be made only under the following conditions (Kilpatrick 1967):

- (1) when temperatures are below 80°F (usually early morning).
- (2) with droplet size of not more than 50 to 60 microns MMD (Mass Median Diameter); no more than 10% of the droplets should exceed 100 microns. In some areas damage to car paint has occurred when larger droplets were dispersed or more than 10% of the droplets exceeded 100 microns. Effectiveness against adult mosquitoes requires 10 or more drops per square inch. Determination of droplet size should be made by depositing a sample of the aerosol on a silicone-/or Teflon-coated glass slide and measuring the droplets under a microscope with an ocular micrometer. Other droplet measuring systems are available.
- (3) by multi-engine aircraft flying at a height of 100-150 feet, at speeds of about 150 miles per hour or more, with swath widths of 300-1000 feet with pump pressures and nozzle sizes and positions adjusted to provide the proper droplet size. Single-engine fixed wing and rotary wing aircraft are undesirable for this technique because of their slower air speed and resulting problems with droplet breakup. There are additional safety factors with single-engine aircraft and with their limited "pay load" which need to be considered when used in urban areas.

THERMAL FOG AND DUST APPLICATIONS

Thermal fog applications have been used successfully for adult mosquito control for

many years. Thermal fogs require the addition of a fuel oil carrier and depend on a high temperature system to produce the fog droplets. Tests have shown ULV and thermal fogs to be similar in effectiveness. Disadvantages of thermal fogs include the hazard of the dense fog produced and the expense of carrying and using the fuel oil carrier.

In past years there has been much interest in the use of dusts for adult mosquito control, and they can be effective. Tests with ground-dispersed dusts (19% and 7.5%) of carbaryl have produced 99% reduction of adult salt-marsh mosquitoes at dosages of 0.2 and 0.3 pounds of carbaryl per acre.

OTHER METHODS OF ADULT MOSQUITO CONTROL

Residual treatment outdoors for mosquito control does not always produce good results. However, limited relief from biting mosquitoes can, at times, be obtained in small city parks, playgrounds, picnic areas, patios and yards. Water suspensions or emulsions with a low percent of insecticide (rather than oil solutions) are used in order not to "burn" vegetation. These applications can be made with power sprayers or with hand sprayers, using nozzles which provide a broad fan or cone and a coarse spray, such as the Tee-Jet 8004. The insecticides used for such outdoor applications include Punt (containing pyrethrin).

Residual spraying is a primary method of controlling mosquitoes that breed in catch basins. In many large cities with thousands of catch basins along the edges of the streets, surveys indicate that often one catch basin in every ten holds enough water to produce broods of mosquitoes of the *Culex pipiens* complex. The application of petroleum oils or granular insecticides to these catch basins is not the complete solution to this type of

mosquito control because a single rain shower produces enough runoff to flush the larvicide into the storm sewer. Therefore, a special nozzle has been developed which produces a radial spray pattern and coats the walls of the catch basin with insecticide. Some of the insecticides used are not readily soluble in water and the residual insecticide may remain on the walls of the catch basin for weeks or months. It kills the adult mosquitoes as they rest on the walls after they emerge from their pupal cases, while their wings and body harden sufficiently for flight.

The organophosphate insecticide, dichlorvos, is formulated into resin strips which release an insecticide vapor. Usually one resin strip per 1000 cubic feet (10'x10'x10') provides good control of mosquitoes for 3 to 4 months. Results of tests with such strips for control of adult mosquitoes in catch basins, cisterns, etc. have been variable. Studies in Savannah, GA and elsewhere have shown good control as tested with caged *Culex pipiens quinquefasciatus* for 11-18 weeks when one resin strip was wired to the grating of a catch basin (CDC 1973).

ENVIRONMENTAL ASPECTS

Assistance should be sought from competent conservationists, fish and game specialists, and others in planning control measures in areas where delicate ecosystems could be disrupted by mosquito control practices. In mosquito control only those pesticides approved by the EPA for the planned use should be considered.

PERSONAL PROTECTION FROM MOSQUITOES

People can protect themselves from mosquitoes by using proper window screens, protective clothing and repellents. The ordinary window screen with 16x16 or 14x18

meshes to the inch will keep out most mosquito species. Frequently, mosquitoes follow people into buildings or enter on the human host. For this reason, screen doors should open outward and have automatic closing devices. Residual insecticide applications on and around screen doors give added protection.

Long-sleeved clothing of tightly woven material offers considerable protection against mosquito bites. Sleeves and collars can be kept buttoned and trousers tucked in socks when mosquitoes are biting. This type of protection may be necessary for people who must work in areas where infected vector mosquitoes are particularly abundant. The use of mosquito netting to protect infants in their cribs may also be indicated in high risk circumstances.

Relief from mosquito attack may usually be obtained by applying insect repellents to the skin and clothing. A number of these have given adequate protection against mosquitoes. Effective protection may be obtained through the use of diethyl toluamide (Deet, Off). Use repellents with 25% to 30% (or lower) concentration of diethyl toluamide. Adverse affects have been reported in infants or sensitive adults treated with high concentrations of diethyl toluamide. Repellents are available as liquids in bottles, pressurized spray cans, and in stick form.

When applied to the neck, face, hands and arms, liquid repellents will prevent mosquito bites for 2 hours or more, depending on the person, species of mosquito attacking, and abundances of mosquitoes. These repellents can also be sprayed on clothes to make them repellent. Many repellents are solvents of paints and varnishes, plastics, such as watch crystals, rayon fabrics and fountain pens. Diethyl toluamide will not affect nylon. Care should be taken not to apply repellents to the eyes, to the lips, or to mucous membranes. Clothing can be treated with aerosols of

permethrin (Permanone) and allowed to dry for 2-4 hours before its worn to repel or kill mosquitoes.

Pressurized aerosol insecticide dispensers can be used in the home to kill adult mosquitoes. Most of these contain pyrethrum or allethrin because these insecticides have low human toxicity and cause a quick knockdown of mosquitoes. These aerosol dispensers may also contain a synergist such as piperonyl butoxide and another insecticide such as diazinon to kill the insects. Release of the aerosol for a few seconds usually kills most insects in an ordinary-sized room, tent, or trailer. These aerosols are not hazardous if used as directed on the container, except in rare cases where persons are allergic to pyrethrum or the synergist.

METHODS FOR ASSESSING CHEMICAL CONTROL OF MOSQUITOES

Evaluating the results of the treatments applied as larvicides and adulticides is important to any control effort. Resistance to the insecticide being used may become a problem, or improper application techniques may reduce the effectiveness of the method, or possibly increase the risk of killing nontarget species.

The basic approach used in evaluating larviciding or adulticiding applications is comparison of the number of specimens per collection made before and after the application. For this purpose collections should be made on each of several days before and after the application and as many sampling sites as possible should be included.

Another useful method is that of bioassay tests with caged specimens. A bioassay test for space sprays may be done by using the following technique:

Treatments may be applied by fog, dust, mist, or, ULV machine mounted on a vehicle

and moving at 5 or 10 mph at the recommended label dosage. Field-collected, caged specimens (100-150/cage) are hung 6 ft above the ground at stations 150-300 ft from the point of discharge of the machine along each of three streets (270-300 ft apart). Ten to 15 minutes after exposure the cages are removed and the insects are transferred to holding cages, given food and held for a 24-hour female mortality count. Seventy percent or better kill is expected. If the kill at either 150- or 300-ft station is less than 70%, then the equipment and timing of application of insecticide should first be examined, and adjusted. If, after these adjustments have been made, the kills are still unsatisfactory, then a change of insecticide should be recommended.

Bioassay tests for larvicides are of less value than sampling of natural larval habitats for larvae before and after an application is made. A useful technique to improve reproducibility of larval sampling is that of

placing numbered stakes at various sites and then taking a prescribed number of dips at the site each time it is sampled. A 70% or greater reduction in the number of larvae per dip is expected.

For years larval and adult mosquitoes have been tested for resistance to insecticides with kits purchased from the World Health Organization. These tests required large numbers of specimens, were usually conducted in the laboratory, and were subject to procedural variables such as temperature and humidity or age of the chemicals or test papers. Therefore, Brogdon and coworkers (1987, 1989) proposed the development of Nonspecific Esterase (NSE) Microplate Assay tests which permit: tests conducted in the field; analysis of single insects; up to thirty assays from a single insect; and fast and accurate methods which can be read in the field with the naked eye, at considerably lower costs than the WHO Bioassay kits.

PUBLIC RELATIONS

To be of maximum effectiveness, mosquito control must be understood and supported by the people for whom protection is provided. People who are informed about mosquito biology and control are more likely to mosquito-proof their homes, and to control mosquito breeding places on their own property. In reaching the public it is helpful to work through officials of established organizations and agencies, such as the schools, PTA's, Agricultural Extension Service, the Grange, and civic groups. If newspapers and local radio and television stations are approached and the program is explained to them, they may be willing to devote a portion of their activities to a discussion of mosquito control, frequently as a free public service. In some areas school

children have taken home "check lists" to "check off" on their own property such typical mosquito-breeding places as tin cans or bottles, old automobile tires, stopped-up gutters, low ditches or a farm pond. Exhibits at local, county or state fairs are used by some mosquito abatement districts and attract particular attention if they include live mosquito eggs, larvae, pupae and adults--one way to teach large groups about the life history of these insects. Some mosquito control organizations buy a page of a local newspaper once a year and print their annual report, with well-selected photographs to illustrate typical activities, in a mass medium read by thousands rather than the more expensive annual report sent to a select few who may file it away with or without reading it.