LARVICIDING

FEDERAL SECURITY AGENCY
U. S. PUBLIC HEALTH SERVICE
COMMUNICABLE DISEASE CENTER
Atlanta, Georgia August 1946

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INTRODUCTION

Mosquito larviciding is the practice of applying poisons to kill mosquito larvae in their breeding places. The purpose of this manual is to furnish basic information on where, when, and how to use the different larvicides available for malaria control purposes. The material included is designed to acquaint operations personnel with the several types of larvicides, which type to use for best results, the method of application best suited to different breeding places, and the kind of equipment to use.

LARVICIDES

As larvicides commonly used in mosquito control are not effective for more than a few hours, they must be applied at intervals of from seven to ten days to prevent completion of the mosquito's development. Hence, larviciding produces only temporary results and is expensive when applied year after year to the same breeding place.

Larvicides may be classed in general as contact poisons or as stomach poisons, depending on the way they kill larvae. Some larvicides may act as both a contact and a stomach poison. Diesel oil and DDT are good examples of contact larvicides; paris green is typical of stomach poisons.

The following outline classifies most of the common larvicides according to physical characteristics and method of killing:

A. Dusts - Stomach poisons applied to water surface to kill anopheline larvae.

1. Paris green (copper aceto-arsenite)
2. Phenothiazine (sometimes used in an alcohol solution)
3. DDT (contact and stomach poison)
4. Calcium and sodium arsenite
5. Pyrethrum powder
6. Paraformaldehyde.

The last three are used almost exclusively to kill anophelines for experimental purposes.

B. Oils - Contact larvicides sprayed on the water surface to kill culicine and anopheline larvae.

1. Diesel or fuel oil (No. 2)
2. Kerosene
3. Waste motor oil (generally diluted with kerosene or Diesel oil)
4. DDT dissolved in fuel oil or other solvent.

C. Emulsions (mixtures or suspensions of one liquid in another) - Contact larvicides applied by spray to breeding places.

1. Pyrethrum-oil emulsion
2. Petroleum oil-water emulsions
3. DDT emulsion
4. Phenol and cresol emulsions.

Larviciding for malaria or mosquito control should be used under the following conditions:

1. To effect quick *Anopheles* reduction during outbreak of malaria.

2. To furnish temporary protection where larviciding is less expensive and equally or more effective (temporarily) than other methods; e.g. than drainage.

3. When physical corrective measures are undesirable or impracticable; e.g. a water supply reservoir, a wildlife refuge, a recreational lake, or a river.

4. To supplement other control measures.

5. To furnish immediate protection while permanent control measures are being taken.

Choice of a larvicide is based on the following considerations:

1. Comparative effectiveness and economy against anopheline mosquitoes under local breeding conditions.

2. Availability of larvicidal materials, equipment, and transportation.

3. Local experience and practices.

Principal requirements of a larvicide are:

1. High toxicity to larvae under field conditions.

2. Economic feasibility.

3. Harmlessness to man, domestic animals, and wildlife.

4. Easy application.

In an area containing many breeding places, the preferred method of control should be selected for each principal breeding place or collection of breeding places. The discussions following under Types of Larvicides; Materials, Equipment, and Larvicidal Techniques; and Planning and Organization will aid in the selection of method and larvicide.

Anopheline Breeding Place in Stranded Flotage.

TYPES OF LARVICIDES

I. DUSTS

Paris green is the most extensively used larvicide for *Anopheles* mosquito control. It is a stomach poison; mosquito larvae must eat the particles in order to be killed. Applied to the water surface, the particles usually float for several hours, and anopheline larvae, which habitually feed at the water surface, eat them and are poisoned. While paris green is the most economical larvicide commonly used against anopheline mosquitoes, it is not ordinarily effective against culicine mosquito larvae, which feed below the water surface.

Paris green is usually diluted with a material such as hydrated lime, soapstone, talc, or road dust and applied as a dust mixture with hand or power equipment. Rarely, it is used as a spray in the form of an emulsion or suspension. As a dust mixture in malaria mosquito control, it has the advantage over other larvicides in economy; effectiveness in places overgrown with grasses, pond weeds, and other vegetation; and harmlessness to fish, waterfowl, plants, men, and domestic animals in the dosages used.

Its principal disadvantages when employed in malaria control are that it kills only larvae of *Anopheles* mosquitoes, fails to kill any pupae and most of the first-stage larvae, and requires favorable atmospheric conditions for effective application in many breeding places.

A dust containing one percent of DDT in an inert carrier such as pyrophyllite is a promising substitute for paris green dust. It is less expensive to apply than paris green and is effective against all stages of mosquito larvae. It must still be considered to be in the experimental stage, but all evidence at present is favorable.

DDT is definitely less harmful to wildlife when applied as a dust than when applied as a spray. As DDT in its pure form tends to be very lumpy and will not mix readily with dust diluents, to be used as a dust DDT must be purchased as a specially prepared 10 percent (or stronger) dust concentrate. This concentrate can be diluted with some inert diluents in the same manner as is paris green. DDT, however, is decomposed by alkalis, so it should not be mixed with any form of lime.

A number of chemicals — calcium and sodium arsenites, copper carbonate, pyrethrum, and others — have been tried as larvicidal dusts. These have had limited use because they do not meet fully the practical requirements of a good larvicide.

II. *PETROLEUM OILS (DIESEL, KEROSENE, AND CRANKCASE)

Diesel or fuel oil (No. 2) has had wide use as both an anopheline and a general mosquito

See appendix for description and specifications.

larvicide. On malaria control programs, which are concerned only with *Anopheles* mosquitoes, oil larvicides are several times more costly than paris green. Diesel oil or fuel oil, however, is effective in killing almost all kinds of mosquito larvae, and very young larvae and pupae as well. Fuel oil is used undiluted in power- or hand-operated sprayers, as an oil-water "mixture" in high pressure sprayers, or as an emulsion.

Because of its high cost kerosene is seldom used to control *Anopheles* larvae. Alone or mixed with waste motor oil, it has been used to larvicide small ponds or pools. Its effectiveness in killing larvae is generally similar to that of Diesel oil, although it has a tendency to spread farther than does Diesel oil. In other countries, under special conditions of anopheline breeding, kerosene has been used mixed with paris green and water.

Waste motor oil alone is a very poor mosquito larvicide. It has low toxicity, does not spread well, and leaves a dirty, unsightly film on the water surface and on vegetation. It has limited usefulness and is not recommended for malaria control operations.

Unlike paris green, petroleum oil kills mosquito larvae and pupae by contact. A one- to ten-minute exposure to the recommended larvicidal oil is sufficient to kill, but a much longer period may elapse before death actually occurs.

Diesel or fuel oil (No. 2) or kerosene can be used as a solvent for DDT. When so used, it is applied in such small quantities that the oil itself probably has no larvicidal properties and serves only as a carrier.

III. *EMULSIONS

Pyrethrum emulsion is used to some extent in special situations, although it has not had wide application in malaria control. Its harmlessness to fish, plants, animals, and man and its inoffensive appearance and odor make this larvicide especially suitable for control of mosquitoes in ornamental fish ponds, fish hatcheries, and the like. It is effective against all species and stages of larvae. The stock emulsion, which contains pyrethrum extract, kerosene, water, and an emulsifier (soap, sodium lauryl sulfate, etc.) is diluted 1 to 10 with water before application.

Emulsions of Diesel oil and kerosene have been developed to reduce the amount of oil necessary for effective larviciding. This is done by adding an emulsifier to Diesel oil or kerosene to prevent the dispersed oil droplets from separating out. Before it is sprayed on the breeding place, the oil mixture is diluted with water taken from the pond or pool and agitated to form a uniform emulsion. This results in a saving of both oil and transportation. Used in this form, as little as six gallons of oil will cover one acre.

Phenol (carbolic acid) and cresol (cresylic acid) larvicides have been used but little

*See appendix for description and specifications.

in malaria control and are not recommended. They are very poisonous to fish, water plants, waterfowl, animals, and men and should never be used except in special cases under expert supervision. They have been used in nuisance mosquito control work to larvicide sewage-contaminated pools, sewers, and catch basins, and to control treehole-breeding mosquitoes. They are used as emulsions or are added to petroleum oil to increase its toxicity.

IV. *DDT

Recent studies of DDT show it to have excellent larvicidal properties. Used in extremely small amounts (0.05 to 0.1 lb. per acre), it is effective and economical. As previously mentioned, it has some advantage over paris green when used as a dust. Present indications, however, are that it will find its greatest usefulness when dissolved in oil, or other solvent, and applied as a mist spray at a rate approximating one gallon per acre. In this form it may completely displace straight petroleum oils as a larvicide, and in the future it may well challenge paris green as the most extensively used anopheline larvicide.

The most serious drawback of DDT is its toxicity to many forms of aquatic wildlife. Though it can be used safely, it must be used carefully, proper precautions being taken against overdosing in areas where there are fish or other aquatic wildlife. At safe dosages it has

*See appendix for description and specifications.

shown no residual effectiveness beyond about the third day. Because it kills all stages and species of larvae, including those that hatch during the first 24 hours or so after treatment, it is possible that retreatment can safely be delayed several days longer than would be possible with most other larvicides. The use of DDT in an emulsion or suspension cannot be generally recommended for anopheline larviciding, for in these forms DDT is much more dangerous to aquatic wildlife.

The manner in which DDT kills larvae is not fully known, but it is probably both by contact and by stomach, depending upon its physical state at the time. It is effective against both anopheline and culicine larvae.

V. MISCELLANEOUS LARVICIDES

Borax has been used successfully to control mosquito breeding in cisterns, fire barrels, and other artificial containers; but it will destroy plants and fish and is not suitable for malaria control operations.

Phenothiazine in dust form or in alcohol suspension is a useful larvicide against *Aedes aegypti* and pest mosquitoes that breed in flower vases, old tire casings, drinking troughs, and similar containers. Because it is very poisonous to fish, it cannot be used widely in malaria or general mosquito control. In the dosages used it is non-toxic to man, domestic animals, and plants.

MATERIALS, EQUIPMENT, AND LARVICIDAL TECHNIQUES

I. *PARIS GREEN

Paris green is applied usually as a dust mixture. It is diluted with an inactive material such as hydrated lime, soapstone, talc, or road dust. The addition of a diluent is necessary to avoid overdosage and to distribute small amounts of paris green (usually 0.5 to 1 lb. per acre) over a large area. The ratio of paris green to diluent (by weight) varies from 1:1 for some airplane dusting to 1:99 for broadcasting by hand. For rotary hand dusters and most power equipment, dilutions of 1:9 and 1:19 are commonly used. In order to distribute one-half pound of the active larvicide over an acre of breeding surface by rotary duster, it is necessary to apply five pounds of 10 percent (by weight) paris green dust.

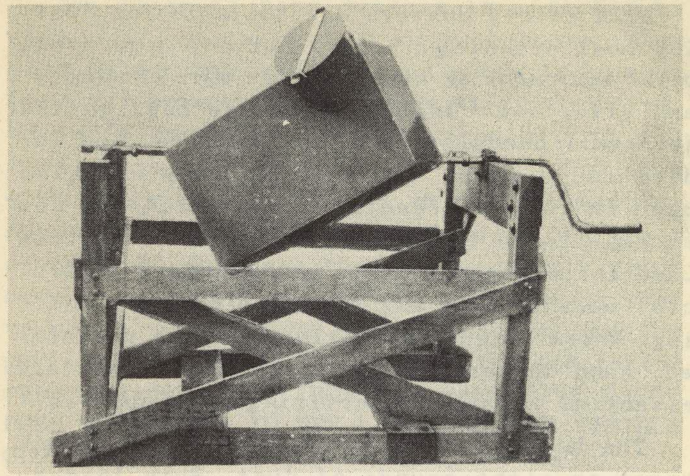
The rate of application depends principally upon density and type of vegetation to be penetrated, amount of scum and flotage on the water surface, and other practical problems of distribution. Field tests with equipment used routinely are recommended. These will help in determining the most economical, effective dosage and will improve the work generally, especially if the laborers are allowed to dip for larvae before and after the dust is applied. The initial application rate before the first inspection should be from one-half

See appendix for rules governing handling of paris green.

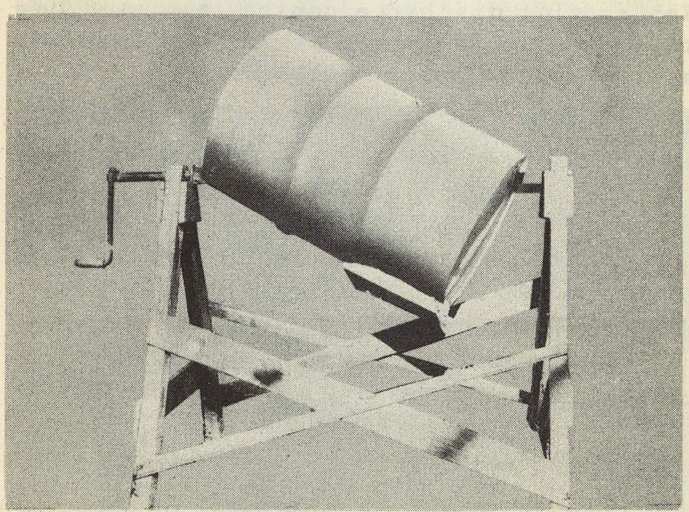
to one pound of paris green per acre, or from five to ten pounds (10 percent paris green by weight) of mixed dust per acre.

Thorough and careful mixing is important. Hand-operated mechanical mixers are most frequently used, but larger projects often employ power mixers. One common type of hand mixer consists of a metal drum or box mounted eccentrically on a horizontal shaft. The paris green and diluent are measured and placed together in the mixer, which is revolved by a crank-like handle at one end. About five minutes' cranking, clockwise and counterclockwise, is sufficient to produce a well-mixed dust.

Most power mixers used are standard commercial models. The most commonly used make is composed of a steel hopper, clutch, and electric motor (5 H.P.) or gasoline engine (6 H.P.) mounted on a flat bed plate. The hopper is equipped with a high speed vertical rotor which whips the paris green and diluent into a fluff. Mixing with most diluents is completed in less than a minute. This equipment has a nominal hopper capacity of 100 pounds. It will easily mix 50 pounds of diluent and the proportionate amount of paris green and has a maximum capacity of 2½ tons of mixed dust per eight-hour day. The mixing operation can be expedited by quick-opening inlets and outlets in the hopper and provision for the gravity discharge of mixed dust directly into bags or drums.



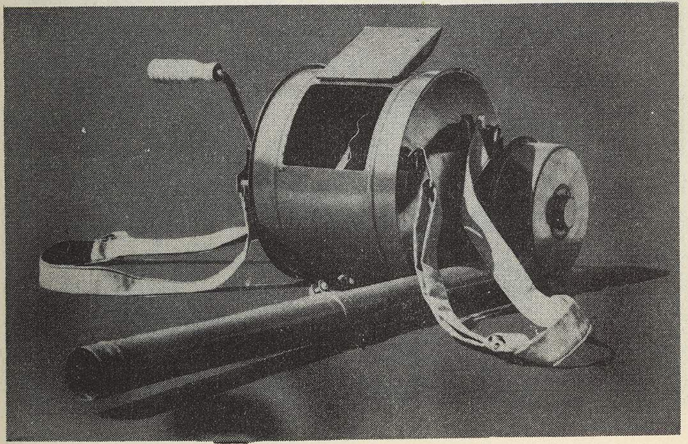
Rectangular Hand Dust Mixer



Converted Oil Drum Mixer

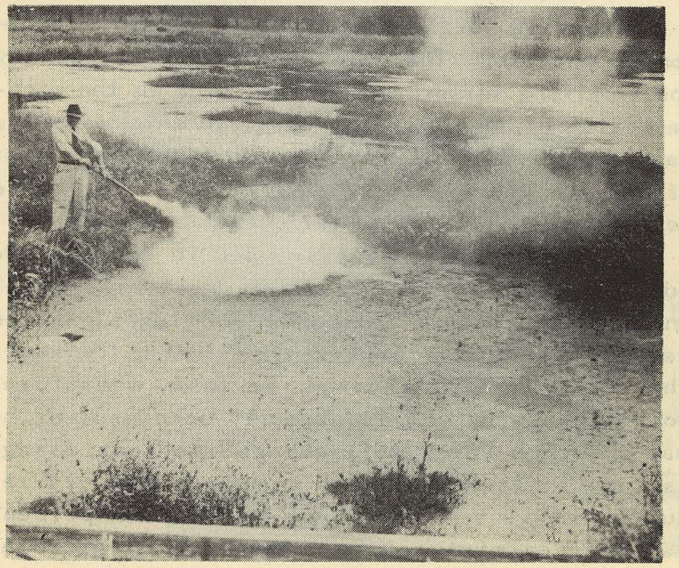
Hand rotary dusters are suitable for dusting most breeding places, but on large areas power equipment or airplanes are more economical and effective. Hand dusters are best suited for small ponds, swamps, and marshes, and for ditches, creeks, and canals. They are also used in larger breeding areas which are not accessible to trucks and boats. Hand dusters used for malaria control are standard commercial models used for crop and orchard dusting. Where extensive dusting is to be performed, hand dusters with ball-bearing cranks are essential to avoid overtiring the laborers.

The hopper of several makes holds about seven or eight pounds of dust. When loaded, the duster weighs approximately 20 pounds. The rate of discharge can be regulated between one and 10 pounds per acre by means of a valve at the hopper outlet.



Rotary Hand Duster

The range of hand dusters is affected by wind velocity and density of vegetation. When wind direction and velocity are favorable (velocity between two and five miles per hour), the effective range varies from 100 to 150 feet. Careful manipulation of the dust gun with moderately high wind velocities may increase this to 200 feet or more. Vigorous cranking to increase the initial nozzle velocity is a factor, but not so important as wind velocity. It must be noted that the heavier paris green settles from the dust cloud faster than the diluent. THUS THE EFFECTIVE RANGE DOES NOT EXTEND TO THE LIMITS OF THE VISIBLE CLOUD!



Note the Drifting Dust Cloud

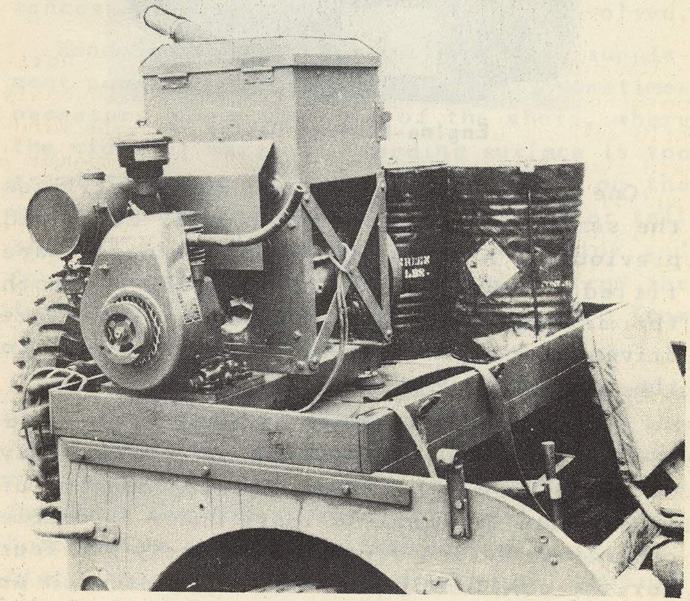
Rotary Hand Duster in Operation

The outlet nozzle is generally held in a horizontal position. The laborer cranks continuously while walking forward at a normal pace on the windward side of the breeding area. In this manner a band of breeding surface within 100 to 150 feet of his path is treated effectively, except where heavy stands of brush or tall grasses intervene.

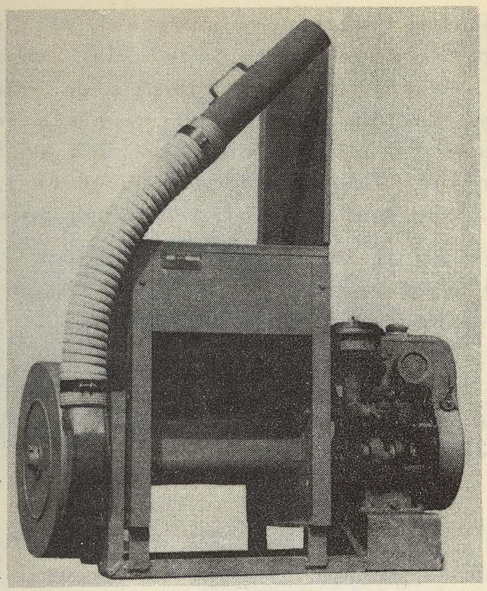
A different technique is used in dusting the edges or surfaces of canals, small creeks, or individual ditches. A laborer, walking along the banks of such places, is often directly above the surface to be treated. He must, therefore, point the spray nozzle directly downward, or he may attach a spray deflector. Since overdosage is inevitable even though cranking speed is reduced, it is better to use a 5- or 2½-percent paris green mixture when this type of breeding place is being dusted routinely.

Two types of power dusters are commonly used on trucks or boats. One is an independent unit consisting of a hopper and a motor to power a fan-blower. The other is similar, but the power is taken from the truck or inboard boat engine. The rate of discharge varies with motor speed and size of discharge opening.

One make of independent engine-powered unit having wide use is offered in three sizes, with hopper capacities of 40, 50, and 100 pounds. The fan-blowers are driven respectively by 1-3/4, 2-1/3, and 6-1/2 H.P. air-cooled, gasoline engines, with maximum speeds up to 3300 r.p.m.



Power Duster Mounted on a Jeep



Engine-Powered Duster

One make of power take-off duster utilizes the same hopper as the power mixer described previously. A blower and flexible nozzle are fitted to the base of the hopper, and both the mixing rotor and discharge blower are driven by a power take-off shaft connected to the boat or truck engine.

The effective radius of application for power dusters is determined by the capacity of the blower, wind velocity, and density of vegetation. The maximum range under favorable conditions varies from approximately 400 feet for the smallest power duster to as much as 1,000 feet for the larger type. Volume of dust

cloud rather than nozzle velocity is responsible for effective kill at the longer distances. Although initial nozzle velocities of as high as 250 feet per second are reported by manufacturers, this force is largely dissipated in the first 50 to 100 feet, and the dust cloud thereafter is carried by the air currents in which it is launched.

Under average conditions, the two smaller sizes (1-3/4 and 2-1/3 H.P.) of power dusters are best adapted for treating water surfaces from 50 to 250 feet away from the point of discharge. The two larger sizes (6-1/2 H.P. and power take-off) are indicated where distances of 250 to 500 feet are also involved.

Hand dusting is frequently used to supplement power dusting. Hand dusting is sometimes necessary along the edge of the shore, where the width of marginal breeding surface is too great to cover with the power duster on the water side, where banks of thick brush or tall grasses near the water's edge are wide and dense enough to shield the shoreline from the dust cloud, and where pools are isolated from the main body of water.

Most airplane dusting has been done with a biplane equipped with a dust hopper in the front cockpit. An agitator, generally powered by a small wooden propeller mounted on the front of the lower wing, is installed in the hopper. One type of agitator is made of heavy piano wire. The dust is discharged through an air funnel (venturi type) under the hopper. When the plane flies at low altitudes (15 to

Power Duster Mounted In Boat

50 feet above the water), the dust is distributed in swaths 50 to 200 feet wide.

For most airplane dusting, lower dilutions are usually employed than for hand and power dusting. The percentage of paris green may be as high as 25 percent or more by weight. One study has shown that a low-speed biplane may cover as much as 373 acres per hour.

Paris green dusting of open areas by hand, power, or airplane should generally be performed in the early morning, when the air is relatively still, although suitable conditions are sometimes found in the late afternoon or on cloudy days when the air is suit-

able. During other daylight hours the air becomes warm, and air currents may carry the dust up and away so that little paris green will reach the water surface on open ponds and marshes.

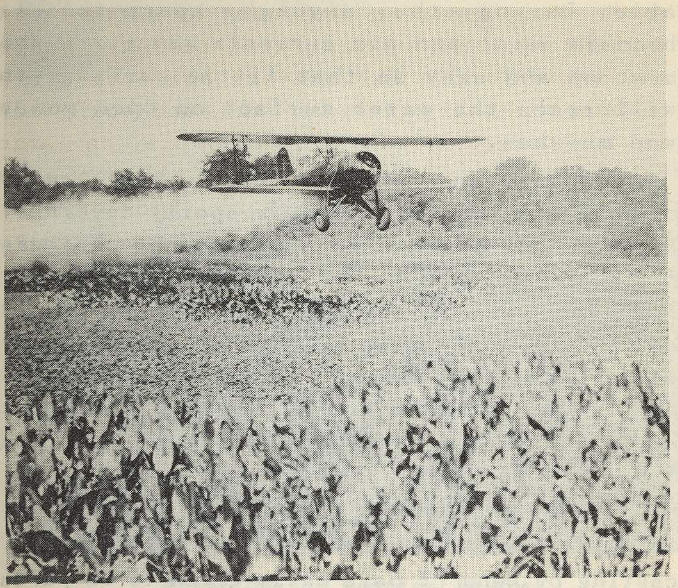
Air turbulence which is too light to carry off the dust may still cause spotty coverage. Work must be planned so that dusting of these places can be done during suitable hours. Breeding places which are protected from breezes and thermal air currents, however, may be dusted at almost any time. These include ditches and creeks where the bank serves as a windbreak, or larger breeding surfaces shielded from breezes by heavy stands of trees, brush, or tall grasses.

Paris green has also been applied by broadcasting by hand (1 part paris green to 99 parts of road dust); in an emulsion with kerosene and water; and in suspension with water. These methods are seldom used or recommended for use in this country.

II. PETROLEUM OILS

Diesel or fuel oil is usually applied undiluted but may be used in an emulsion. In general mosquito control, phenol or cresol is sometimes added to oil to increase its toxicity.* Oil mixed with water and distrib-

* The volatile properties of oils are primarily responsible for their lethal effects on larvae (inflaming the internal tissues), although mechanical suffocation (clogging the breathing tubes) may have some supplementary effect.



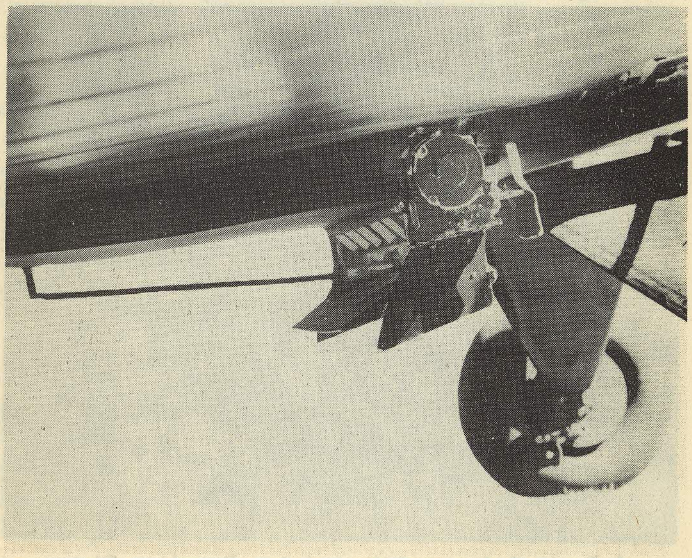
Airplane Dusting Paris Green

uted at high pressure is also used in larviciding. It serves as a dual purpose larvicide where both malaria mosquitoes and nuisance mosquitoes are present. Because spreading of the oil film is impeded by thick grasses, pond weeds, and many kinds of dense flotage, the cost of oil larviciding may be greatly increased by necessary extensive clearing. Best results are obtained in breeding places that are relatively clean and exposed.

Power spraying is more economical than hand spraying on many large areas (reservoirs, lakes, and ponds) or on numerous small roadside breeding places accessible by jeep or

truck. Hand-operated equipment is suitable on smaller places, on scattered isolated pools and ponds, or on large areas not accessible to power sprayers. Power and hand equipment are often used together. For example, on large lakes there may be adjacent small pools or bights impossible to reach by truck or boat but easily accessible with hand-operated equipment. The distance to which larvicide can be discharged from hand sprayers is limited to from 10 to 15 feet. This is greatly increased (to 100 feet or more) by the use of power equipment.

Rate of application will vary widely with type and density of vegetation and flotage,



Close-Up of Venturi

length of shoreline in relation to breeding surface, and kind of equipment used. Applied undiluted, 10 to 40 gallons of oil per acre may be needed. Used in emulsion form, as little as six gallons of oil per acre may suffice.

Four types of hand sprayers are in use for oil larviciding. One is the hand air-pressure sprayer, capacity from two to five gallons, consisting of a cylindrical steel tank equipped with an air pump, rubber discharge hose, and spray nozzle. In spraying, the operator first fills the tank about three-quarters full, then pumps in air with the hand pump to a pressure of about 35 pounds. The sprayer is carried by a shoulder strap. Its principal ad-

A Typical *A. quadrimaculatus* Breeding Place

vantages are (1) portability and (2) free use of the operator's hands in directing spray and in getting through thick brush.

Another type, not so commonly used in malaria control, is the "trombone" sprayer. It has a knapsack type tank (about five gallons capacity), the usual hose fittings, and a double-action hand pump fitted immediately behind the nozzle. It is difficult to aim accurately with this sprayer because both hands are employed in spraying and pumping.

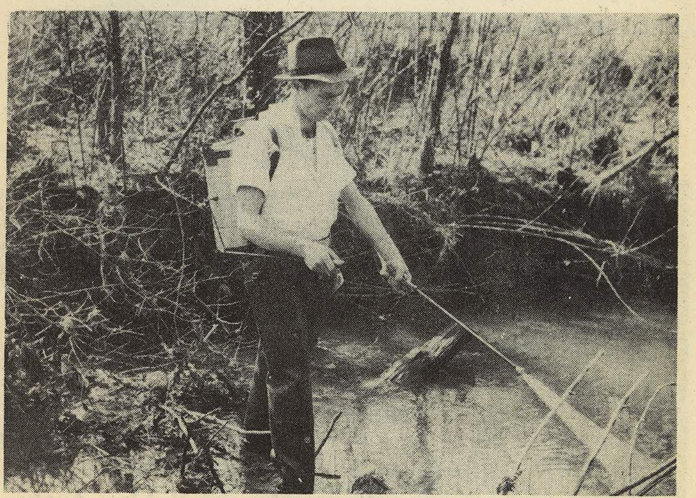
Two other types of knapsack sprayers have been commonly used in mosquito control. Both have brass piston pumps mounted inside the tank, with an air chamber and a jet agitator. One type has the pump lever located under the tank; in the other, the lever is fitted at the top of the tank. The latter has a swivel pump handle which hangs in front of the worker at elbow level. Both are convenient to carry on the back. Pumping is done with one hand while the spray is directed with the other. The top lever type is generally preferred because the pumping position is more comfortable; but the swinging handle sometimes snags in heavy brush. These sprayers hold four to five gallons of larvicide.

The time required to fill hand sprayers is an important element of larvicidal cost. In part, this can be kept down by proper labor management — avoiding "bunching" of laborers waiting to refill spray cans. Various mechanical improvements have been developed to speed the process. Generally, the spray cans are

Air Pressure Sprayer

Trombone Sprayer

Top Lever Knapsack Sprayer



Bottom Lever Knapsack Sprayer

filled from 55-gallon steel oil drums standing upright in the truck. Several drums may be placed along the center line of the platform of a 1½-ton stake body truck, with space left for the cans and men on each side. The battery of drums is connected to a 2-inch pipe line running beneath a false floor, with projecting outlet pipes at the rear for filling the cans.

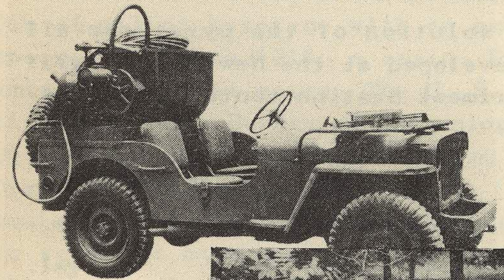
The Bordeaux nozzle is most commonly used on knapsack-type sprayers. This nozzle is adjustable from a small jet stream to a fan-shaped mist spray. It seldom clogs and can be cleaned easily. The disk nozzle is more generally used with air pressure sprayers. Most disk nozzles are equipped with screw plungers for quick adjustment of the spray. Power sprayers employ nozzles (guns) specially designed and constructed to withstand high pressures.

Power sprayers, operated under pressure as high as 300 pounds, are used to larvicide extensive breeding places that are accessible to truck or boat. These consist usually of a gasoline engine, a pump, and tank with multiple hose connections, mounted on a chassis. Tank capacity is from 50 to 500 gallons. They are usually supplied with one or two hoses, each at least 100 feet long.

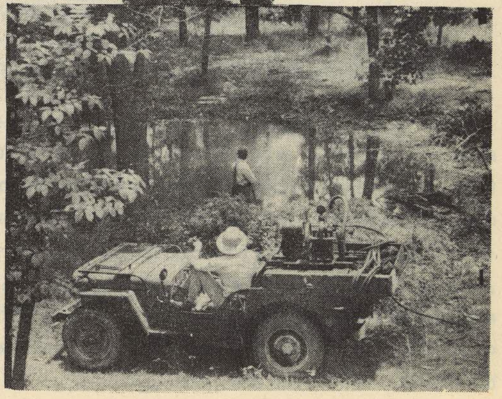
A special type of power unit used on some large reservoirs is the water-oil sprayer mounted in shallow-draft boats. One model, used extensively by the Tennessee Valley Authority, has a centrifugal pump operated by a

gasoline engine. A small fuel line connects the oil tank to the suction side of the pump, and a larger pipe through or over the side of the boat carries water to the pump intake. The boat is propelled by an outboard motor. In this way, a small amount of oil is mixed with a large volume of water and discharged under high pressure. This method is very effective for breaking up flotage, penetrating dense vegetation, and reaching inaccessible spots.

A number of miscellaneous methods, such as drip cans, submerged oil-soaked sandbags or sawdust, etc., have been used, but these are seldom suitable.



Power Spray Unit Mounted on Jeep



Small Power Unit In Operation

Water-Oil Sprayer Mounted In Shallow Draft Boat

III. EMULSIONS

The stock solution of the pyrethrum-oil emulsion as developed at the New Jersey Agricultural Experiment Station contains the following:

WATER	3 gal.
EMULSIFIER (sodium lauryl sulfate)	6 oz.
KEROSENE (or light oil)	6 gal.
PYRETHRUM EXTRACT (2% pyrethrins)	40 oz.

To prepare the emulsion, an emulsifier is added to the water and the mixture agitated thoroughly. Then the kerosene or light oil containing the pyrethrum extract is added slowly, while agitation is continued. Stability of the emulsion depends on effective agitation. A power sprayer or hand sprayer can be used to form the emulsion when small batches are to be mixed.

The stock emulsion is diluted in the ratio of 1:10 with clean water at the jobsite. To prevent clogging of spray nozzles, *always strain the dilution water.* The pyrethrum-oil larvicide can be applied with the equipment described for oil larvicide. The quantity of spray needed per acre will vary from 25 to 50 gallons (2½ to five gallons of stock emulsion), depending on the nature of the breeding area and the kind of sprayer used. By comparison with oil alone, substantial saving in weight of material hauled is realized because only the concentrate need be carried to the breeding place.

The oil-water emulsion is made by mixing Diesel oil or kerosene with an emulsifier (a sperm oil, Nopco 1216; a resin, B1956; or an amine, 230X) and water. The U. S. Department of Agriculture, Bureau of Entomology and Plant Quarantine, has developed an emulsion using Diesel or fuel oil with three or four percent emulsifier. One part of this mixture is added to seven or more parts of water to make up the spray. For fresh water breeding places, the following formula is recommended:

OIL-WATER EMULSION FORMULA

3	gallons Diesel or fuel oil
1	pint emulsifier
15-18	gallons water

First, the oil and emulsifier are mixed thoroughly. Water is then added and the mixture stirred vigorously. The resulting spray is effective when applied at a rate of about 40 gallons (six to seven gallons of oil) per acre. This larvicide has not had wide enough use to permit conclusions as to its value as an anopheline larvicide.

IV. DDT

DDT is undoubtedly the most versatile larvicide that has been developed to date. Not only is it effective against both disease-bearing and pest mosquitoes, but it can be applied by any of the general methods described for paris green and petroleum oils, as well as by newer, more efficient methods.

DUST. DDT in dust form is mixed and applied much as is paris green, with the following exceptions:

1. The dosage of DDT should be approximately one-tenth the dosage recommended for paris green. Thus, where ten percent of paris green in the finished dust is recommended, one percent of DDT can be substituted.

2. Pure DDT cannot satisfactorily be mixed with the diluent in ordinary dust mixers; therefore, a specially prepared DDT dust concentrate must be obtained from the manufacturer. Concentrates containing 10, 20, or 40 percent DDT have been made, and other concentrates can be diluted with the equipment described in the section on paris green.

3. DDT is decomposed by alkalis, so no form of lime should be used as a diluent for

DDT dusts. Pyrophyllite is considered satisfactory, as are certain other insecticide diluents such as talc or kaolin.

EMULSIONS. DDT could be dissolved in petroleum oil and applied as described under the section on petroleum oils. There would be little reason for doing so, however, for the increase in control obtained over that of a good oiling job without DDT would be insignificant. A concentrate made of DDT dissolved in a small amount of petroleum oil can be emulsified in water and used as described in the section on "Emulsions." For this purpose 0.05 lb. of DDT should be added to each gallon of Diesel or fuel oil (No. 2) or of kerosene, and the proper amount of suitable emulsifier added. This quantity of concentrate should be mixed with sufficient water to spray one acre.

This method effects considerable saving of material, for one gallon of oil is sufficient to treat one acre. It also effects savings in transportation of materials (as discussed in the section on "Emulsions"). This type of application is necessarily somewhat toxic to aquatic wildlife and should be used with caution where fish or other aquatic organisms are considered to be of value.

SUSPENSIONS. Several water-dispersible DDT powders are on the market, but to date none of them has shown much promise as a larvicide.

MIST SPRAYS. The most effective method of hand dispersal of DDT developed at present is mechanically atomizing a small volume of DDT oil solution over the area to be treated, allowing the mist to be carried by the wind. One gallon of kerosene or fuel oil, when properly dispersed in this manner, is able to cover an acre of water surface adequately, particularly if its spreading coefficient is enhanced by the use of one-half of one percent of a suitable spreading agent (such as B1956 or Emulphor AG Oil Soluble). This method permits the savings in material and transportation previously discussed under DDT emulsions. Moreover, it permits a great saving in labor over described methods of oiling, for it makes use of the wind to provide a wider swath than is possible with heavier sprays and permits the use of light-weight sprayers, with less frequent repumping of compressed air sprayers and much less refilling. The economy of this method compares favorably with that of any other method of hand larviciding known today.

A DDT oil concentrate may be purchased and diluted to produce a solution containing 0.625 percent of DDT. Where any large acreage is concerned, however, it would be more economical to purchase the ingredients and prepare the concentrate at a convenient base of operations.

Any of the technical grades of DDT now on the market are satisfactory. Kerosene or any clear Diesel or fuel oil (No. 2) that is used

for larviciding can be employed. The oil must be clean in order to prevent clogging the fine nozzles used. For the same reason any batch of DDT which bears very much insoluble matter should be avoided. One-twentieth of a pound of DDT is added to each gallon of oil, or two and one-half pounds to the ordinary 55-gallon drum of oil. Under practical conditions it is sufficiently accurate to measure the dry DDT by volume, two quarts of the average technical product being the proper quantity for a drum of oil. At the same time one quart of the spreading agent can be added to the 55 gallons of oil.

The DDT is dissolved by rolling the drum or tipping it end-over-end at frequent intervals over a period of 24 hours or more. The drum should be left in direct sunlight. To insure complete dissolution of the DDT, it is wise to make up the solution at least a week before it is to be used.

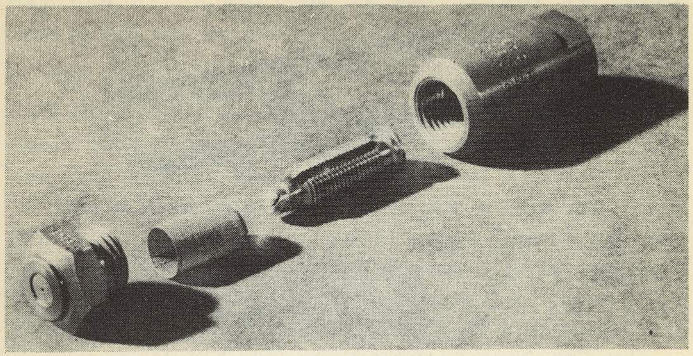
Compressed air sprayers have been found most satisfactory for application of mist sprays, the two and one-half gallon size being very convenient and having sufficient capacity to larvicide an acre or more without refilling. An air pressure of between 30 and 50 pounds per square inch is essential to proper atomization of the spray. A pressure release valve in the head or on the side of the sprayer avoids harming the rubber gaskets and is the safest way to release the pressure preparatory to opening the sprayer for refilling.

Barrel Type Hand Mixer

The key to proper atomization and low volume application is the nozzle,* which must meet certain specifications. It should deliver about 2.5 to 3 gallons of oil per hour at 40 psi pressure. This permits the operator to walk about 75 ft. per minute (a convenient pace when wading through swamps), drifting the spray to cover a 30-foot swath.

The nozzle should be held high under conditions of calm air to be sure that the spray carries 30 feet, and should be held low when the breeze is strong to insure a deposit near the operator and to prevent loss. Such nozzles operate best when the sieve screens are cleaned about twice per working day.

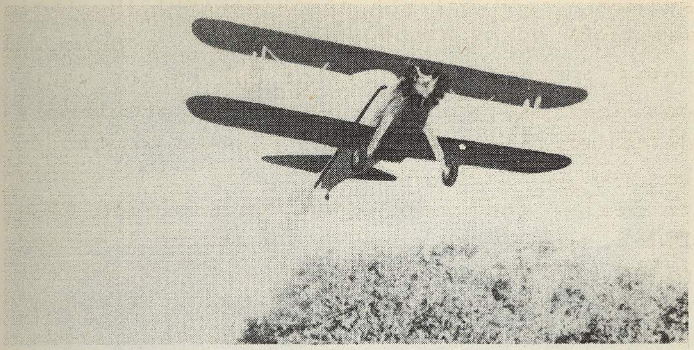
*Nozzles such as Marley 1H41 (Marley Co., Kansas City, Kansas), Spraying Systems ¼ LN (Spraying Systems, Inc., Chicago, Ill.), and Monarch 5-PLP-F80 with #9 whirlplate (Monarch Mfg. Co., Philadelphia, Pa.) are very satisfactory.



Parts of the 1/4 LN Spray Nozzle
Cap — Sieve Screen — Strainer Body — Nozzle Body

An intelligent operator can soon learn to judge wind directions and velocities so as to make this method of larviciding very efficient. Very little, if any, clearing or removal of aquatic vegetation is necessary in most cases, for the minute particles of spray will penetrate a considerable amount of vegetative cover. The pathways for the operator can thus be thirty feet apart. Under good weather conditions the swath can be widened by using a slower pace, thus enabling rather wide ponds to be treated. **UNDER NO CONDITIONS SHOULD THIS METHOD BE ATTEMPTED WHEN THE WIND VELOCITY IS OVER TEN MILES PER HOUR.**

AIRPLANE APPLICATION. Several systems of applying atomized sprays by airplane have been developed. These are of two general types: the so-called "thermal aerosol," in which the DDT solution is discharged through a venturi on the engine exhaust; and "sprays," in



Airplane Spraying Thermal Aerosol

which the atomization is obtained by discharging the solution through fine nozzles or against a breaker bar. The latter method produces somewhat larger droplets, which settle faster and therefore give a narrower swath. The spray is nearly invisible from most angles, in contrast to the "smoke" from the "thermal aerosol," which can be used to judge roughly the distribution being obtained.

With either type of apparatus, the best practice at present is to use approximately 20 percent of technical DDT in methylated naphthalene. The rate of discharge is adjusted to be about 0.1 pound of DDT per acre, though doubtless only a small fraction of this amount reaches the water surface within the limits of the swath being covered. With a small biplane flying at 85 m.p.h. at about 30 feet elevation, a swath 100 to 200 feet wide can be treated. With an average swath width of 110 feet a plane can be expected to treat about 17 acres per minute (exclusive of turns). A

payload of 30 gallons is sufficient to treat about 500 acres without reloading.

POWER SPRAYING. The use of DDT in the various power sprayers, such as the previously described water-oil sprayer mounted on a boat, has not as yet been investigated sufficiently to permit recommendation. An emulsion of a DDT-oil solution in water could well be applied by power sprayers but would be subject to the same objections that were raised against hand application of DDT emulsions. Specific recommendations cannot be made as yet, since the technique has not been thoroughly investigated.

V. CHLORINATED HYDROCARBONS

Experiments are being made to determine the insecticidal properties of several chlorinated hydrocarbon compounds. "1068," the compound on which the most definite data are available, can be used as an oil solution, an oil emulsion, a dust, or a dispersible liquid.

Nearly any type of suitable oil carrier (e.g., kerosene, deobase) may be used in making "1068" oil solutions. "1068" may be emulsified in water by the addition of an oil-soluble emulsifier, such as Triton X-100 or Duponol OS; or by the addition of a smaller quantity of emulsifier to an oil solution of "1068." Dusts containing five percent or less of active ingredient can be prepared by impregnating non-alkaline carriers with "1068."

Results of applying "1068" in various forms show no significant difference in the insecticidal properties of this compound and of DDT.

COST AND PERFORMANCE RATES

Larviciding costs vary widely, both among individual breeding places and among different area-wide projects. Important factors are size and character of breeding places, accessibility to larvicidal crews (hand and power), type and condition of equipment, efficiency of labor and supervisory personnel, and quality of work performed. The significance of these elements is more or less obvious. By quality of work performed is meant not only thoroughness, as reflected in effectiveness of kill and absence of places missed, but selectivity of operations. On projects otherwise similar, indiscriminate larviciding may show lower costs per acre than one on which selective treatment of known malaria mosquito breeding is practiced. Such a practice, however, results in excessive total cost of project operation.

The comparative cost of different larvicides varies greatly. While paris green dusting is never more expensive than oil larviciding, the direct cost of oiling may vary from about 25 percent greater for small ditches to as much as 10 times greater for some ponds. In most "acreage" breeding surfaces the greater effective radius of application for dusts or mist sprays is an outstanding advantage. Precise comparison of costs between these two larvicides is difficult because of indirect costs, which are against oil. These include weight of materials to be hauled, amount of

clearing required, and time spent in filling the spraying equipment.

Some figures by which to determine costs of larviciding under various conditions and with different kinds of equipment are shown on the next four pages. To avoid distortion due to abnormally high or low wage rate, figures are given in man-hours per unit of breeding surface treated. Also given are theoretical performance rates of some larvicidal equipment when operated continuously at maximum output and at recommended application rates. Actual performance rates are, of course, only a small fraction of the theoretical rates.

The amount of oiling or dusting one worker can do per day obviously depends on such things as density and type of vegetation encountered, accessibility of breeding place, distribution factors concerned with spreading qualities of oil, and skill of the operator. Experience has shown that, on area-wide operations and under good conditions, one man using hand equipment can oil from two to three acres per day. This area can be doubled under optimum conditions but is reduced under unfavorable conditions.

At least three times the area can be treated (under similar conditions) when paris green dust is used because of the greater radius of application possible with dusting equipment. DDT oil mists have not yet been used extensively enough to permit giving definite figures, but evidence indicates that one man

TYPE OF ACTIVITY	MANHOUR* ACCOMPLISHMENT	LARVICIDE PER UNIT SURFACE TREATED
OIL LARVICIDING (No. 2 Diesel Oil)		
Hand Application		
Small ditches	0.75 MH/1,000 ft.	7 gal./1,000 ft.
Ponds and large ditches	3 - 6 MH/acre	15 - 30 gal./acre
Power Application		
Small ditches, from trucks	0.10 MH/1,000 ft.	5 - 10 gal./1,000 ft.
Ponds and large ditches, from boats	0.50 MH/acre	20 - 30 gal./acre
DDT OIL MIST	1 - 1.5 MH/acre	1 gal./acre
THERMAL AEROSOLS AND SPRAYS	0.10 MH/acre	3 gal./50 acres

PARIS GREEN LARVICIDING (10% Paris Green by Weight)		
Hand Application		
Small ditches	0.40 MH/1,000 ft.	3 - 6 lbs./1,000 ft.
Ponds and large ditches	1 - 2 MH/acre	10 - 20 lbs./acre
Power Application		
Small ditches, from trucks	0.10 MH/1,000 ft.	3 - 6 lbs./1,000 ft.
Ponds and large ditches, from trucks	0.3 - 0.5 MH/acre	10 - 20 lbs./acre
Ponds and large ditches, from boats	C.3 MH/acre	10 - 20 lbs./acre
Airplane Application		
Large ponds and other breeding areas	Properly equipped biplane can dust from 21 - 30 acres per minute, using mixture 25% paris green by weight.	

**Does not include supervision above foreman.*

THEORETICAL PERFORMANCE RATES FOR SOME TYPES OF LARVICIDAL EQUIPMENT

TYPE OF EQUIPMENT	RATE OF DISCHARGE
DUSTERS	
Root Model 2 - hand	0.6 lb./minute
Root Model Y - power	8.0 lbs./minute
SPRAYERS	
Meyers - knapsack, Bordeaux nozzle	0.5 gal./minute (fine spray)
Dobbins - " , disk nozzle	0.13 gal./minute
Compressed air, ¼ LN nozzle	2.55 gal./hour
Hardie Power Sprayer	
Hardie gun with No. 5 nozzle plate, 150 psi pressure	1.0 gal./minute
Hardie Power Sprayer	
150 psi pressure - Hardie spray gun rebored with 1/8" plate hole	3.04 gal./minute
John Bean Sprayer	
500 psi pressure - Hardie gun rebored with 1/8" nozzle plate hole.	6.13 gal./minute

could treat an even greater area by this method because of the lighter equipment and greater ease of operations.

The use of power equipment greatly reduces labor costs and is more effective in terms of mosquito reduction on large breeding areas accessible to truck- or boat-mounted units. Often as much as 70 percent in over-all costs may be saved with power equipment.

Regardless of costs, there are often extensive breeding places of the malaria vector that cannot be controlled except by airplane application. On the other hand, there are places where airplane larviciding is the most economical as well as the most effective method. The low-speed biplane commonly used can treat from 15 to 25 acres of breeding area per minute. The cost per acre-treatment for contract airplane larviciding varies from 0.35 to $1.00 per acre. This does not include ground services for loading planes, entomological checking, etc.

Filling Spray Cans Efficiently

SELECTION OF LARVICIDE AND APPLICATION METHOD

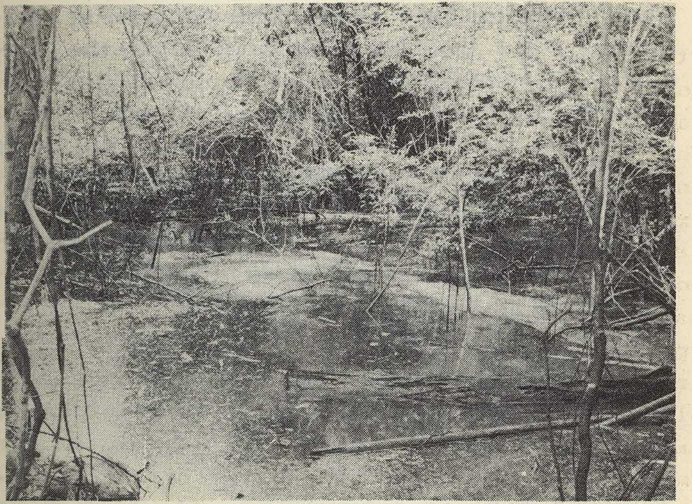
An understanding and awareness of the factors discussed below are necessary in making an intelligent approach to selection of application method and type of larvicide for anopheline species sanitation.

Effectiveness of larvicides and of the method of application selected are determined directly by the character and extent of vegetation in breeding places. Malaria mosquitoes require some form of vegetation for protection and food. Breeding may occasionally occur in temporary pools, where microscopic forms of plant and animal life are present to furnish food to the larvae. Usually, however, some visible plant life is present, offering food to the aquatic form of the mosquito. Such vegetation may be partially submerged, with leaves breaking the surface at many points. It may be horizontal — lying flat or floating on the water; or emergent — extending above the surface and standing upright. Any of these three types of vegetation is a major factor in determining the effectiveness of the larvicide and the larvicidal method.

Oil is sprayed horizontally and is deposited in small droplets on the water. To be effective, these small drops must spread to form a continuous film on the breeding surface. Growths of submerged or floating vegetation, which break the water surface, impede the spread of oil. Within limits, this reduced spread may be overcome by increasing the spreading properties of the oil (using an oil emulsion; adding a spreader such as B-1956).

Collections of flotage composed of dead or decaying particles (non-vital flotage) prevent effective spreading of oil. The high pressure spray of the water-oil spraying unit can be used successfully to break up such flotage mats and to increase the spread of the oil. This power unit also permits a considerable increase in the radius of application for oil larviciding.

Oil is less affected by emergent vegetation, although such growths may often aggravate the flotage problem by serving as an anchorage



Breeding Place with Flotage

for mats of limbs and debris of all sorts. The stems of emergent plants obstruct and deflect the oil spread to some extent where growth is heavy. More important, dense emergent vegetation obstructs the path of the spray and may make breeding places difficult to reach.

Since larvicidal dust drops vertically into position instead of spreading horizontally across the water's surface, its effectiveness is not directly hindered by floating or submerged vegetation. Emergent vegetation, however, may reduce the application radius, particularly of hand and power equipment. The distribution of dust dropped vertically from an airplane is less affected by trees or dense growth than is that of dust dispersed by hand or power dusters.

Under extreme conditions, where emergent vegetation is so dense as to still air currents completely, the effective application radius of hand and power dusters is limited to the distance that the spray can travel as a result of the initial nozzle velocity. In the worst situations experienced by the authors, this was about 25 feet for hand dusters and 50 feet for small power dusters. In each case this distance is materially greater than for hand and power oil sprayers. Fortunately, conditions of this type are rare since such thick emergent growth usually creates dense shade which inhibits production of the malaria vector found in this country. In general, DDT oil mist sprays are affected by the same factors and to about the same extent as are dusts.

PLANNING AND ORGANIZATION

On most projects breeding places are numerous, sometimes widely separated, often extensive. Careful planning to coordinate and conserve resources in personnel, materials, and equipment is a prerequisite for economical and effective control. Organization of larvicidal crews, division of areas into zones and districts, and selection of larvicide and application method must be based on entomological and engineering evaluation of individual projects.

In general, larvicidal operations follow routine schedules, but planning and organization must include the following considerations:

1. Location, character, and extent of breeding places of the malaria mosquito with respect to other factors in malaria transmission. (Also applicable to selection of method and larvicide.)
2. Seasonal incidence of the vector species and seasonal variations in the breeding cycle.
3. The desirability of maintaining key larviciding personnel by providing employment during the off-season on minor drainage, clearing, and maintenance activities.
4. The necessity for flexible management to meet emergencies due to unfavorable weather, equipment breakdown, and seasonal variations (Item 2, above) in mosquito densities.

On projects it is the practice to divide an area into zones, which may be sub-divided into districts. Each zone or district (depending on size) is covered by a larvicidal crew. The crew should generally be small — three to eight men. Large crews are difficult to supervise and may cause wastage of larvicide and man-hours because of excessive overlapping of crew sections. A good plan is to have a three- or four-man crew, with one of the men designated as a working foreman or sub-foreman.

Larvicidal crews should be carefully selected. Physical fitness, dependability, and intelligence are important points to consider in hiring personnel. The effectiveness of any larvicidal program depends more directly on the efficiency of the crew than on any other single factor.

Normally, crews follow routine weekly schedules. But it must be remembered that this kind of plan ignores the tactical utilization of adult *Anopheline* "A" station counts (i.e., counts made at stations in the zone immediately surrounding the protected area). Therefore, some flexibility in crew direction is necessary so that routine work may be dropped in order to concentrate the attack in locations where "A" station mosquito counts remain high. In other words, control procedures must be coordinated at all times with inspection findings.

Frequently, considerable advantage may result in provision for changing from hand to power equipment and vice versa. During dry months extensive breeding places suitable to power larviciding often develop into small, scattered places more amenable to hand operations.

During operations crews will often find important maintenance work that should be done immediately, thereby improving the efficiency of larviciding and preventing or reducing future problems. This may involve such work as removing obstructions from ditches and culverts, clearing access trails, and miscellaneous equipment maintenance. As the key man, it is the crew foreman's responsibility to keep his supervisor currently informed in regard to equipment and material needs of special problems encountered in the field, and to offer suggestions to improve the efficiency of the work. In turn, it is the area supervisor's duty and responsibility to train his foremen adequately.

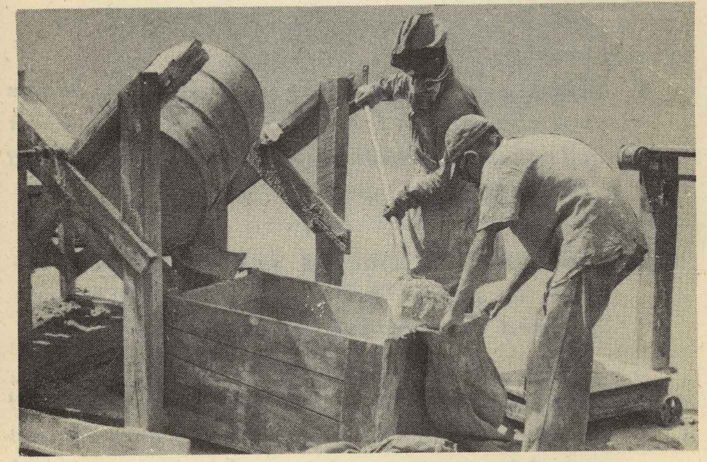
Entomological inspection has been referred to as "the essential bookkeeping of the business." It is that — and more. The inspector has pre- and post-operational responsibilities aside from observations directly related to larvicidal activities. Unfortunately, mosquito breeding places are created throughout the season, so that the inspector must locate and evaluate new breeding places as well as check on the effectiveness of current larviciding. For more detail on this phase of larviciding, refer to the "Entomological Field Handbook."

APPENDIX

RULES GOVERNING HANDLING OF PARIS GREEN

Paris green is poisonous to man, animals, insects, and other life; but if handled with reasonable caution it is not dangerous. Paris green has been used successfully for years to control insect pests in cranberry bogs and potato fields. Another arsenic compound, also poisonous to man and animals, has been used for many years in the fight against the boll weevil, without harmful effects to man.

In routine handling of, and dusting with, paris green for mosquito control, it is practically impossible for a worker to receive a fatal dose of the chemical. Some individuals who handle paris green daily (this is also true of hydrated lime, one of the diluents



Wearing Dust Masks at Mixing Station

used) may develop a skin rash which usually disappears quickly when properly treated.

Observance of the following rules will prevent paris green poisoning:

1. In mixing or applying paris green dust, *avoid undue exposure. Do not allow the dust to accumulate on skin surfaces, in the eyes or nose, or in folds of the skin where chafing may occur.*

2. *Use dust mask to avoid inhaling the dust*, especially when mixing indoors.

3. In dusting, *the operator should stand with his back to windward*, thus protecting himself from the dust and using the air currents to distribute the larvicide.

4. Handlers of paris green should *bathe at the end of each day's work. Work clothes should be changed and washed frequently.*

5. *Individuals showing signs of sensitivity to paris green should not be employed on dusting or mixing.*

6. *Persons who develop skin rash should receive immediate treatment and should avoid exposure to paris green until cured.*

RULES FOR HANDLING DDT

DDT in large quantities is toxic to human beings. With proper precautions, however, the dilutions of DDT used in larvicidal work are not harmful to man.

It should be remembered that DDT in oil solution can be absorbed through the skin; for this reason DDT, particularly in oil solution, should never be allowed to remain on the skin. It should also be pointed out that many of the solvents used in preparing DDT sprays are irritating to the skin if they are not removed immediately.

These rules should be observed in handling DDT:

1. Never allow DDT to remain on the skin. If oil solutions or concentrates are spilled on clothes, fresh clothing should be put on immediately.

2. If DDT is swallowed drink mustard water immediately (to cause vomiting), and call a physician.

3. If a great deal of spraying is to be done, wear gloves, goggles, and a respirator. Inhalation of, and contact with, DDT and its solvents is to be avoided as much as possible.

SPECIFICATIONS FOR PARIS GREEN USED IN MOSQUITO CONTROL

HAND AND POWER DUSTING

The paris green shall contain a minimum of 50 percent arsenious oxide — no more than 2½ percent being water-soluble. At least 95 percent shall pass a 325-mesh sieve, water being used as the wetting medium and the material being gently brushed on the screen surface with a camel's hair brush.

A two-hour exposure of 2nd-, 3rd-, and 4th-stage anopheline larvae to a 1:9 mixture of paris green and diluent (hydrated lime or soapstone) applied at the rate of one to 1.5 pounds of paris green per acre shall give a complete kill within 24 hours.

AIRPLANE DUSTING

The paris green must be of such fineness that at least 95 percent can pass a 200-mesh screen and at least 85 percent can pass a 325-mesh screen. At least 75 percent must consist of particles 20 microns or more in diameter. It must contain approximately 50 percent arsenious oxide, with no more than 3½ percent being soluble in water (all percentages by weight).

SPECIFICATIONS FOR OIL USED IN MOSQUITO CONTROL

Type of oil: light distillate fuel or Diesel oil.

Gravity (A.P.I.): 27 - 33

Flash point: 130°F or higher

Viscosity S.U. (a) 100°F : 35 - 40

Spreading coefficient: 16 dynes/cm or higher

Distillation:	10% :	430° - 450°F
	50% :	510° - 550°F
	90% :	630° or higher

SPECIFICATIONS FOR DDT OIL MISTS

DDT: Technical grade, meeting specifications of Army Quartermaster Corps

Diesel oil: See oil specifications above

Spreading agent: Standard Triton B 1956 or Emulphor A G Oil Soluble

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