MANUAL ON LARVAL CONTROL OPERATIONS
IN MALARIA PROGRAMMES

prepared by the
WHO Division of Malaria and Other Parasitic Diseases

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This manual is intended for planners in malaria programmes and for all who are responsible for the execution of large-scale antimalaria operations.

It provides valuable teaching material for the senior staff at malaria training centres as well as a source of reference for them and their students.

Senior operational and engineering staff in malaria programmes will find it particularly useful in the planning and execution of antilarval operations, and they will be able to develop their own operational and training manuals from it.

It is hoped that all malariologists will welcome it as a comprehensive reference work on antilarval operations in malaria programmes.
FOREWORD

The control of malaria has been attempted mainly by attacking the parasite in man by the administration of drugs, by preventing contact between the mosquito and man, or by eliminating or incapacitating the vector mosquitos through various means.

The attack on the parasite in man proved insufficient by itself to obtain the eradication of malaria; the attack on the vectors alone, without eliminating the residual reservoir of infection in humans, also failed to attain eradication. A combination of the two methods has therefore been used to advance malaria eradication. The attack on the vector mosquitos attempts to interrupt transmission through decreasing the density and longevity of the vector population, while the attack on the parasite reduces the sources of infection in man by attempting to eliminate all infective cases.

Spraying with residual insecticides to destroy the adult vector mosquitos continues to be the principal operational measure employed in malaria eradication programmes. Though directed mainly against adult Anopheles mosquitos, residual spraying may involve some control of the larval stages. Due to the complexity of larval control, it alone has seldom been the method of choice in malaria eradication programmes except where imagicidal operations failed to produce effective results or where they were very much more expensive or impracticable. The malaria eradication programme is a gigantic undertaking involving almost two-thirds of the population of the world, mainly in remote areas of developing countries where complicated, highly technical and costly technology cannot be readily used. On the other hand, malaria control programmes aiming at the reduction of infection, may find it convenient or more economical to make more extended use of antilarval measures.

Where the vectors are susceptible to residual pesticides, indoor spraying has the following advantages compared with other mosquito control measures:

Simple: No complicated techniques or equipment are needed and unskilled workers are easily trained.

Practicable: Can be performed effectively in most situations and under virtually all conditions where needed.

Effective: Complete interruption of malaria transmission can be achieved in most cases.

Low-cost: Annual and total cost is generally considerably lower than that of achieving the same goal by other methods.

When total spray coverage with an effective insecticide was completed according to plan, malaria transmission has generally been interrupted within the expected period. However, there have been increasing failures due to technical factors; for example:

(a) The mosquito vectors were not domestic, i.e. they did not feed and rest inside houses (exophagic and/or exophilic), or

(b) They have been deterred from resting upon, or have been irritated by, sprayed surfaces, or

(c) They have acquired physiological resistance to the insecticide used, or

(d) Extradomiciliary malaria transmission has been favoured by certain aspects of human behaviour and ecology such as nomadism, outdoor sleeping, human dwellings without walls, etc.
In some malarious areas of the world, difficulties of the above nature have rendered indoor spraying of available insecticides largely ineffective. The extent of such problem areas is limited but is gradually increasing, and may become much greater when large scale malaria programmes are developed in tropical Africa. The search for substitute residual insecticides is actively under way, but antilarval measures appear to offer the best potential for immediate application.

**DEFINITION OF ANTILARVAL OPERATIONS**

Antilarval operations are any measures which will prevent, reduce or eliminate the production of the aquatic stages of malaria vector species. They include:

(a) Changing the environment of a breeding place to make it unsuitable for the development of mosquito larvae;

(b) The use of biological agents such as larvivorous fish;

(c) The conservation and efficient use of water supplies as well as the proper disposal of waste water to prevent the unnecessary creation of mosquito breeding places;

(d) The use of mechanical methods to eliminate, reduce or alter mosquito breeding places;

(e) The use of chemical larvicides to kill mosquitos in their aquatic stages.

**THE PLACE OF ANTILARVAL OPERATIONS IN MALARIA PROGRAMMES**

To attain malaria eradication man must apply all effective methods available, and simultaneously pursue research for yet more effective measures.

The eleventh report of the Expert Committee on Malaria (WHO, 1964) paid special attention to the increasing need for the application of additional methods of vector control in malaria eradication programmes, especially in areas where the response to residual insecticides in adult vectors is unsatisfactory, and stated that: "The present trend indicates a greater use of larval control in the near future and therefore urgent action is required".

The Committee formally recommended: "That larval control be used more fully in special circumstances and that its further improvement should be studied especially in those areas that are refractory to residual spraying operations".

Antilarval operations should be considered:

(a) When there are few breeding places, so that a relatively small input of effort for larval control will substantially reduce the adult vector population;

(b) When house spraying is impractical, or uneconomical, as when the area to be protected is a densely populated urban area;

(c) As a preventive measure in receptive areas during the maintenance phase;

(d) Where for technical or operational reasons house spraying either alone or combined with drug administration fails to interrupt transmission or to effect adequate reduction of malaria cases or endemicity.
OBJECTIVES OF ANTILARVAL OPERATIONS

The objective of larval control operations in malaria eradication or control is to reduce either alone or in combination with other methods, the density of adult vector mosquitoes below a level set up by the programme. In malaria eradication programmes this level should be a level lower than that found to permit transmission. In malaria control programmes this level varies in accordance with the degree of control of malaria that is planned.

Since the eradication of the vector species is not usually considered to be practicable nor essential to malaria eradication or control, the objective of the larval control programme is the systematic reduction of mosquito production to decrease the vector factor, thereby proportionally increasing the effectiveness of other attack measures.

METHODS OF LARVAL CONTROL AND A CONSIDERATION OF THEIR USE IN MALARIA PROGRAMMES

Current methods for the control of mosquito larvae can be classified as follows:

- Naturalistic control, including biological control
- Source reduction
- Chemical control (larviciding)

These may be combined into a comprehensive programme of larval control. Within the concept of comprehensive control, all of the known methods are applied as appropriate in accordance with the specific problem to be met. There must be considerable flexibility at the field level in the choice of specific measures to be applied. This calls for the evaluation of individual problems by technically qualified personnel authorized to select the appropriate technology within the limits of pre-established guidelines. Preventive measures are emphasized, and may be given high priority particularly in the control of permanent or consistently recurring sources, but when the sources are of a temporary nature a major portion of the effort must frequently of necessity be directed towards the immediate elimination of developing larval populations through the application of chemicals.

Unlike residual house spraying, which is applied to every situation in a relatively uniform fashion, larval control operations and the methods and materials employed are very varied. The methods applied must be carefully matched to the specific problems. Knowledge of local conditions, the vectors and their biology, the type of water, and the extent and accessibility of larval sources must be available to plan successful programmes. Comparative studies should be made of the costs and benefits of larval control as compared with residual house spraying, or administration of antimalaria drugs, so that the relative costs and benefits can be weighed and form a basis for the programming of operations.

Naturalistic control methods

The natural factors which affect the production, distribution and longevity of vector mosquitoes are many. For example, where water is present continuously, as in a lake or reservoir, with no significant mosquito production occurring, the explanation will usually be found in the effective functioning of natural barriers to mosquito development. A delicate balance may have been achieved by nature which has prevented the transmission of malaria and other mosquito-borne diseases, but which can be easily upset by man. Where predatory aquatic insects and mosquito fish are functioning in a complementary relationship which inhibits mosquito production, a single application of pesticides for any purpose may eliminate the predator insect population, which may not recover as rapidly as the mosquitoes,
so that thereafter the fish alone cannot suppress the mosquitoes. Great care should be taken to avoid the use of pesticides wherever such natural controls provide adequate control of mosquito fauna.

Because the early aquatic stages of the mosquito may exist along with the predators, the effectiveness of this natural control must be judged by the number of mosquitoes which complete their development and emerge as adults. Moreover, as a small percentage of the larvae present frequently escape pesticide applications, there may be no gain in applying a pesticide if natural controls already provide a comparable level of control.

Natural controls frequently do not fully suppress mosquito production, but through an understanding of the natural factors which increase or decrease mosquito populations, man can often manipulate them to his advantage. Extensive and very important information on the methodology of this naturalistic control has been presented by Boyd (1949)(3) but has been largely neglected since the extraordinary efficacy and economy of residual house spraying against susceptible vector populations was demonstrated and adopted as a primary measure in malaria control and eradication.

The naturalistic techniques previously demonstrated as successful should therefore be re-examined and introduced into programmes where they can contribute substantially to a comprehensive attack on the vectors. In arid regions, naturalistic approaches may be combined with those which involve conservation and optimum use of the limited water supplies; conversely, in areas oversupplied with water, the opposite approach should be considered, with emphasis on drainage and land reclamation. But in either case, preliminary ecological reviews should be made to ensure that man is working with, rather than against, the forces of nature which tend to suppress vector populations.

Source reduction methods

Source reduction involves water control, drainage, filling, ponding, ditching for circulation, and other engineering operations.

In some instances the application of an engineering operation permits natural enemies of the mosquito larvae to provide an important service to man. A ditching system installed on a salt marsh which is open to the tides allows the water to come on to the low places at every high tide, and to drain off at low tide. The native minnows in the bays and streams will go with the water into all the low places at high tide, feed upon mosquito larvae, and return to the natural streams at low tide where the outflowing ditches continue to bring to them the larvae which escaped their incursion on to the marsh (Smith, 1904) (26).

Sometimes, freshwater swamps where mosquito control is difficult to attain may be converted to impoundments, by the construction of levees and water control structures which maintain a constant water level and depth sufficient to discourage the growth of emergent vegetation. The mosquitoes may be controlled by wave action, and/or predators, or by judicious use of pesticides to specific areas. In such instances, source reduction, naturalistic control and chemical control are all contributing to the end result: control of mosquito production.

In the execution of source reduction projects, perhaps more than in naturalistic or chemical control, there is opportunity for promoting cooperation with other projects and activities. Whether in villages, agricultural regions or urban situations, where direct benefits beyond the reduction of malaria mosquitoes will be obvious, the concept of self-help should be promoted whereby the people or communities benefitted will share the burden of construction and maintenance work. Where it can be shown that the elimination of breeding places will simultaneously improve a natural water supply, or produce additional
farm land, or eliminate pollution, odours and nuisance in an urban situation, it should be possible to obtain the public's support and cooperation.

**Chemical control methods**

Mosquito larvae may be killed by the application of liquid, dust or granular pesticides, employing very simple or highly complex mechanical dispensers, including those mounted upon aircraft. In all instances, the objective is to distribute a quantity of pesticide evenly in or on the surface of the water of mosquito breeding places and to expose all the larvae to a predetermined toxic dosage. Care should be exercised that non-target areas are not contaminated by the pesticides applied, particularly water supplies which may be used by man or domestic animals.

Most larviciding programmes in running malaria eradication and control schemes will emphasize the use of hand application equipment because of the initial lower cost as only minor modifications will be necessary to the available equipment and the familiar techniques used in residual house spraying; also, spraymen can be trained to make the conversion from house spraying to larvicide spraying although more supervision will be required.

While larvicides, if injudiciously applied, may have a negative effect upon naturalistic control or source reduction, in some instances their careful and selective use may enhance the functioning of other methods of vector control. If mosquito fish are to be introduced into a source which is already heavily populated with mosquito larvae, the number of fish available may be unable to control the larvae, then the selective application of a larvicide non-toxic to the fish might be indicated. Also, where other aquatic insects, which are ineffective as predators, provide competing food for the fish, the application of pesticides could check these other aquatic insects and induce the fish to feed on mosquito larvae.

The use of herbicides to control terrestrial and aquatic weeds can substantially lessen the cost of maintaining drainage and other water control works, and can be beneficial in suppressing plant growth which tends to inhibit the performance of predators. However, careful attention should be given to the breeding habits of the local vectors. In some cases the removal of vegetation favours rather than controls breeding.

In a comprehensive programme, maximum complementary benefits should be sought from every control procedure which is applied. It is therefore essential that the technical personnel directing larval control operations understand and consider fully the secondary effects, either beneficial or harmful, which may result from the application of biological, physical or chemical control.

The training and employment of local labour to perform the larvicide spray operations by hand contributes to local income and also serves to arouse interest in the programme, and assists in informing the local people of the purposes of the programme and of the way in which vector mosquitos are a threat to their wellbeing.

Where the operations can be performed economically and effectively by hand, hand equipment should be used. However, there should be no hesitation in employing vehicle-mounted power equipment where substantial economies in total expenditures can be achieved thereby. Important advances have been made in the techniques of aerial application of pesticides through the use of highly concentrated formulations. These can be applied at very low volumes of only 1/100 to 1/200 of the volume used in hand spraying thus greatly lowering the cost of aerial application. Also, on deep water mosquito sources or those severely obstructed by dense, tall aquatic vegetation, men on foot may not be able to apply insecticides effectively. For these reasons, information on the more sophisticated or complicated types of equipment is included.
Liquid preparations are usually the most convenient and economical to use, particularly in the form of concentrates to be diluted with water from the mosquito source. However, even though the entire volume to be used must be transported to the site, oils may be the best choice when they are available at very low cost and/or where it is desirable that the vegetation in or encroaching upon the mosquito source be checked by the phytotoxic action of the oil.

Granular formulations exhibit marked superiority in penetrating dense foliage. Dusts may be used where it is necessary to treat wide areas from one shoreline, when the wind is blowing in a favourable direction.

When larviciding programmes are initiated, pesticides of low mammalian toxicity should be used until the spray operators have gained proficiency. Oils have several advantages at this stage, because the inexperienced operators can readily see the areas already covered and they will find any contamination of their clothing or exposed skin areas unpleasant and will soon learn to spray with a minimum of personal contamination. When experience and proficiency with the safer materials of lower toxicity have been gained, the more potent and lower cost spray materials can be introduced.
# CHAPTER I - NATURALISTIC CONTROL

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CHAPTER I - NATURALISTIC CONTROL

1. DEFINITION

Naturalistic control of mosquito larvae may be defined as the destruction of mosquito larvae or the prevention of their development by the manipulation of any natural force, animate or inanimate. This is a broad term, which includes the more specific "biological control" which was defined by the WHO Expert Committee on Insecticides in 1963[1] as the "direct or indirect manipulation of the natural enemies of pest species in such a way as to increase mortality among the pest populations". Autocidal control was described as a form of biological control in which individuals of pest species are manipulated through sterilization, genetical procedures or other means to harm their own kind. Biological control therefore implies the specific destruction of one living organism by another, but naturalistic control also includes the influencing of environmental factors which inhibit the production of the target vectors.

2. PRESENT STATUS OF NATURALISTIC CONTROL

The reproductive potential of mosquitos is enormous. Only a small percentage of the eggs which are deposited manage to develop and survive the many hazards which must be overcome in order to complete a life cycle. Yet mosquito populations exist and thrive, probably because they have an extraordinary genetic capacity to adapt to unfavourable conditions and to evade threats to their existence. The tremendous range of habitats colonized, the global geographic range utilized, and the complex speciation of mosquito fauna all attest to the genetic versatility of this insect.

Among the more common natural hazards which constantly threaten and often destroy the mosquito are:

- failure of the adult to find a suitable place to deposit her eggs;
- wind and wave action which may prevent the laying of eggs and which may strand eggs or larvae on a shore where they will be destroyed by dehydration;
- percolation, evaporation or transpiration which may remove all of the water in which the larvae are developing;
- run-off which may carry away all of the water or transport the larvae to a place where they will be exposed to predation;
- predatory aquatic insects which colonize the pools in which the larvae occur; and,
- predator mosquito fish, of which Gambusia and the guppies are perhaps the best known, although there are many other species.

Adult mosquitos, too, are subject to natural losses: high temperatures and low humidity may shorten their life span by dehydration, birds may devour them in flight, and unfavourable winds may carry them to an environment in which they cannot survive and diseases and parasites take a toll.

Of all the natural hazards to mosquitos, mosquito fish are so far the most amenable to practical, reliable manipulation in a positive way. But even where there are mosquito fish, other natural influences may also exert a beneficial influence, and man may take constructive steps which together may substantially reduce the mosquito population. These are:
- Carefully evaluate the effect on the mosquito population of natural controls, by determining the numerical relationship between the number of small larvae which can be found, as compared to the numbers of full grown larvae and pupae, and the number of adults which emerge.

- Take particular care to avoid the application of pesticides to areas where predators, which may be substantially reducing the mosquito population, could be damaged.

- Estimate the numbers of mosquito fish, and if deficient, plant additional supplies.

- Improve the environment so that existing or introduced natural enemies of the mosquito can function more effectively. Operations which might be performed include at least the stabilization of water levels, ponding, clearing aquatic vegetation from waterways, dredging marshy edges and building up swampy shore lines of ponds so that the fish may function effectively close inshore.

Practical techniques for the operational use of pathogenic organisms such as bacteria, fungi, protozoa or viruses as biological control agents for mosquito control have not yet been developed. The successful use of these biotic agents calls for much more knowledge of the ecology of the mosquito than is required in the application of chemical larvicides.

Autocidal control methods such as the use of radiation, chemosterilants and other methods for inducing sterility in natural mosquito populations are not sufficiently developed to predict that they will find practical use in mosquito control, but trials indicate that there is a potential which should be studied further.

From a practical standpoint, the use of mosquito fish constitutes a most important element of the broad concept of "naturalistic control", and, within the limitations of present knowledge, can be utilized effectively as a tool to aid malaria eradication or control. This aspect of biological control is, therefore, emphasized.

3. MOSQUITO FISH

The use of mosquito fish in vector control has many advantages including the following:

- Once established in a satisfactory habitat, a population of mosquito fish tends to be self-perpetuating and may continue to provide benefits in the reduction of vector populations for a long time.

- The cost of introducing mosquito fish is very low in relation to the benefits obtained.

- Substituting the use of fish for chemical control reduces the introduction of contaminants in the environment and avoids the hazard of exposing people who may use the water for washing or for drinking purposes to such contaminants. The fish do no harm to the water.

- In waters which are colonized by bass or other game fish useful for food, the mosquito fish tend to serve as food for the larger forms; the fact that there are larger fish present also tends to make the mosquito fish more effective as predators of mosquito larvae since, in their efforts to avoid the larger fish, they are forced into the shallower areas where the larvae occur.

- Mosquito fish may be used effectively in deep water swamps or those with dense emergent vegetation where hand labour cannot function effectively, if at all, in applying chemical pesticides.
Larger fish, which may be introduced to facilitate predation by mosquito fish, may also be useful as an addition to the food supply of the local people. These include, notably, *Cyprinus carpio*, the carp, which by rooting and feeding at the bottom of the water tends to reduce the density of the aquatic vegetation; and *Tilapia mossambica*, a prolific, rapid growing warm water fish, which feeds on algae and floating organic material, thereby tending to reduce the harbourage of Anopheles larvae.

One warning must, however, be added. Before importing any species of mosquito fish into an area or embarking upon any extensive fish planting or propagating programme, a survey should be made by qualified fisheries technologists to ascertain whether there are native species which may be used to equally good advantage. The survey should also include an investigation into the possible effect of introducing a species like *Gambusia* on the local fish. Particular care should be taken in islands lest the introduced species completely eliminate any useful native fish.

There are many species of fish which prey upon mosquitos. In the temperate zone, many minnows, sticklebacks, goldfish and a number of other species feed freely on mosquito larvae. In the subtropical and tropical zones there are many more species, most of which belong to the family commonly known as the tooth carps. This family includes species which lay eggs and other which give birth to living young. Of the latter, the most commonly used are *Gambusia affinis*, the mosquito fish, and *Poecilia*, the guppy. They have flattened heads and can cruise close beneath the surface of the water, they have protrusable mouths, set forward and orientated upwards and they are small so that they can inhabit shallow waters favoured by mosquitos and can penetrate reedy areas. They are also prolific breeders and have voracious appetites with a predilection for insect larvae. All of these characteristics make them very suitable for mosquito control.

### 3.1 GAMBUSIA AFFINIS

*Gambusia affinis* is commonly known as the mosquito fish or top minnow because of its feeding habits. It is an effective species and has been distributed throughout the warmer parts of the world, Dees (1961)(8). It can adapt to wide variations in temperature as well as to considerable variations of chemical and organic content of the water. It frequents areas especially suitable for the support of mosquito larvae. It lives and multiplies in ponds stocked with predacious fish providing there is very shallow water and protective vegetation for refuge.

*Gambusia* females may reach a length of 6 cm while males seldom exceed 4 cm. They breed throughout the summer at intervals of four to six weeks with as many as six broods (rarely) during a single season. *Gambusia* are ovoviviparous and the female may expel up to several hundred young per brood. Mortality due to predators and other causes is high, and probably only 25% to 50% reach maturity. *Gambusia* are cannibalistic and will feed upon their own young when other food is scarce. The young are about 1.25 cm in length when born and immediately start feeding. The early broods of the year become sexually mature and produce young within four or five months, while the later broods do not reproduce until the following season. The rate of development is greatly affected by temperature and food supply, and only in warm climates is the maximum attained. In most climates, not more than three or four broods can be expected, and in cooler climates, only one or two.

### 3.1.1 Operational methods for the use of *Gambusia affinis*

For the best and most economical use of mosquito fish, a mosquito control programme must have adequate facilities for their rearing, holding and distribution. Rearing is
most practical under natural conditions since the young will be eaten by the older fish if adequate space and protection is not available. Ponds or reservoirs are chosen which are conveniently located and of a size and depth to facilitate the capture of the fish as needed. A portion of the shoreline must be accessible and the water clear of vegetation to permit use of minnow sieves, scoop screens or nets. A scoop screen consisting of a 76 cm diameter hoop attached to a 3 m pole and covered with aluminium window screen has proved most useful. The fish can be attracted to the point of capture by the use of artificial food. A mechanical trap to facilitate collection of the fish has been designed which saves time and labour. Regular feeding during the early spring will sometimes permit the fish to mature earlier than normal and thereby increase the number of fish available for distribution. Since Gambusia do not reproduce during the winter season, the establishment of many rearing ponds is desirable to assure a sufficient supply.

3.1.2 Transportation and distribution

Under favourable weather conditions only simple equipment is needed for transporting Gambusia. A number of small containers are preferred to a large tank. Wooden barrels or plastic containers, 20 or 40 l in size are best. Water from the rearing pond should be used for transportation but before releasing the fish, water from the new location should be added gradually to avoid the shock of a sudden change in water temperature and/or quality. For extreme differences of temperature, pollution or salt content, gradual conditioning over several days may be required. When transportation time is likely to be more than eight hours, or in hot weather, additional precautions are necessary to maintain the oxygen supply in the water. Ice may be used to prevent the temperature of the water in the tanks from increasing while in transport, and where ice is not available, considerable temperature control can be achieved through evaporation by keeping the tanks wrapped with wet cloths. The number of fish per container must be reduced and the water constantly aerated by means of a small compressor or by employing a clean compression type hand sprayer, with a valve to release a metered flow of air into the bottom of the tank. All equipment used for collecting and transporting fish must be protected from contamination by insecticides and when not in use should be stored separately from all spray equipment.

Holding tanks should be provided at each unit headquarters to ensure a convenient supply of fish for day-to-day use throughout the season. Holding tanks can be any large container that can sustain several hundred fish. Tanks should be shaded in hot weather and protected from dropping leaves. The number of fish which any tank can hold without excessive loss can be increased by directing a fine water spray on to the water surface and providing a screened overflow. Artificial feeding is also helpful.

Experience in the use of Gambusia in Iran provides some useful points. In this country, the main source of the species is on the Caspian littoral and the headquarters of the provinces in which they are used are anything from 1000 - 2000 km distant. The means of transport used is a jeep pickup equipped with an oxygen cylinder. Double-walled polythene bags of 30-40 l capacity fitted into strong wooden boxes are used for this long distance transportation. About 300 fish are placed in each bag which is half filled with water, then pumped full of oxygen and sealed. The bags are checked once every two hours during transportation and oxygen added to any which are found deflated. The fish are found to reach their destination with low mortality and can be easily introduced into already prepared ponds. If the fish are not fed for 24 hours before transportation, the mortality is found to be even lower.

After establishment and satisfactory reproduction at the provincial headquarters, the fish are further transported to the areas of operations. This does not involve more than three or four hours' travelling time so simple means of transportation can be used. Twenty-five litre PVC cylindrical churns with air-vented screw tops are used.
Four of these churns are fitted into specially constructed wooden boxes lined with plastic sponge to minimize vibration in the moving vehicle. Again the churns are half filled with water and about 300 fish can be introduced, the remaining space merely containing air. The driver changes the water every hour, using fresh water carried in a spare drum in the vehicle, until he reaches the district headquarters (Tabibzadeh et al, 1970) (27).

Mosquito fish can be transported great distances quickly and safely by means of cargo aircraft. At their destination, they can be planted directly from the aircraft without landing, by flying low over the place to be stocked, and pouring the fish out of the aircraft through an opening in the floor, or simply through an open door. Where small places are to be stocked, the fish may be preloaded into small plastic bags, containing one or two litres of water each, with a rubber band around the top to avoid spilling while in the aircraft. At the site to be stocked, the rubber band is removed and the pool "bombed" by dropping the bag into it from a height of not more than 15 m. A stone or other weight placed in the bottom of the bag will ensure that it goes to the bottom of the pond and that the fish are immediately released. Damage to the fish is minimal, whether they be dropped in plastic bags, in unconfined water dumped from ladles or buckets, or taken from the aircraft tank by a small net and dropped without protection through the air into the mosquito source. However, they may be damaged by shock if there is a great difference in temperature between the water in the tank and that in the mosquito source.

The distribution of Gambusia to garden pools, stock drinking tanks, small ponds, ditches, etc., should be encouraged throughout the year. This operation can be done quickly and without loss of time if the supply of fish and proper equipment is readily available. Eight litre minnow buckets or plain plastic buckets can hold 50 or more Gambusia which is sufficient for five or six small sources. Plastic bags which can hold about one litre of water are ideal for issuing half a dozen fish to a resident for stocking a garden pool. Small fish nets are needed for capturing the fish from the holding tank.

Large quantities of fish are not required for stocking small sources. Six Gambusia can completely control a 5-10 m² pool that is fairly free of aquatic plants and weed growth. The fish reproduce rapidly in warm weather when food is ample. It is desirable that some of the original fish stocked in a pool be gravid females, so that multiplication can begin in less than the time required for a full life cycle. The total population which a pool will sustain is limited by the fact that Gambusia will devour the young when space and protection are limited.

3.2 POECILIA (THE GUPPY)

This is a favourite in the ornamental tanks of fish hobbyists because it is small, colourful, graceful, easy to care for, and it reproduces quickly and prolifically. This species, formerly known as Lebistes reticulatus, has other characteristics which suggest its increased use as a mosquito fish. It tolerates high levels of organic pollution, it can be transferred easily, because it is small it can invade very shallow water and make its way effectively through screening vegetation, and it is a warm water species which still has considerable tolerance for colder waters. Although its value as a predator of Anopheles has not been so fully established as that of Gambusia, it should be considered for use wherever it is easily available and particularly where the importation of Gambusia may be difficult, or for use in water in which Gambusia may not survive.

3.3 ANNUAL FISH

The investigation of a group of "annual" fish (popularly known as "instant" fish) which hold unusual promise for the control of mosquitos and other aquatic invertebrates was suggested by Hildemann & Walford (1963)(14). Annual fish occupy a wide range of
temperature and tropical habitats. Where the water frequently disappears every two to
three months or at least once a year, the population survives until the next wet season in
the form of eggs buried in the soil. These eggs may be concentrated, transported and
dispersed in slightly damp peat. Ripe eggs hatch within a few hours after re-introduction
to water. The voracious young are hearty, mature rapidly, and show high fertility.

3.3.1 *Nothobranchius guentheri*

This annual fish is native to Zanzibar, Tanzania and immediately adjacent coastal
regions of East Africa. Laboratory studies and a small scale field introduction have
been reported by Haas (1965) (10). Full growth is attained in about eight to ten weeks
with males reaching a length of 8.5 cm and females 7 cm. Young fish will eat first
instar mosquito larvae within three or four days and reach sexual maturity in four weeks
or so. Spawning is on a daily basis, producing 15-20 eggs per day for periods up to 10-11
months. The eggs are laid in the mud and survive the dry period. When reflooded, ripe
eggs hatch within hours.

3.3.2 *Cynolebias bellottii*

Investigations of this annual fish to determine its usefulness under California
conditions has been reported by Bay (1965) (2). Known as the Argentine pearlfish,
*Cynolebias bellottii* is found in the grasslands of Argentina and Brazil. Since their
habits and life cycle are much like *N. guentheri* they may be useful for mosquito control
in rice fields and irrigated pastures where other fish cannot survive. Since most
species of annual fish cannot reproduce in permanent water there is apparently little
danger that their introduction would threaten conservation or sporting interests.

3.4 *APHANIAS (LEBIAS) DISPAR*

Daggy (1959) (7) reporting on malaria in the Eastern Province of Saudi Arabia, stated:
"Greater use of larvivorous fish is indicated especially in isolated wells and ponds, in
the new irrigation systems in newly developed gardens, and in isolated smaller oases. A
native cyprinodont, *Aphanias (Lebias) dispar* Rüppell, is found very commonly in local
irrigation systems both along the coast, on Bahrain Island and at Al-Hassa." He
introduced this hardy species successfully in the Al-Kharj area in the Najd in 1948.
Wherever this fish occurs, it is an efficient predator on anopheline larvae, but its
effectiveness is decreased where emergent vegetation and algal mats furnish protection to
mosquito larvae. Hence, clearance of drains, irrigation channels, and wells is important
for maximum effectiveness.

3.5 *FUNDULUS HETEROCLITUS*, *F. MAJALIS* AND *F. DIAPHANUS*

Of these *F. heteroclitus* is evidently the most numerous and important. All are
somewhat loosely called "salt marsh killifish" and together occur in very large numbers
in the streams and bays of the coastal marshes of the eastern United States, (Smith (1904) (26)
and Chadester (1916) (6)). Based upon the activity of these species, Smith proposed the
systematic ditching of the marshes so that the water of the high tides would circulate
into all of the holes or low places, bringing with it the predacious fish, and then be
drawn off again at low tide, so that larvae which ran off with the lowering tides would be
exposed to the fish in the creeks and bays. The system was adopted, and after 60 years
or more is still functioning, resulting in substantially reducing the number of mosquitos
which can complete their development.

3.6 *GASTEROSTEUS ACULEATUS* (THE THREE SPINED STICKLEBACK)

This is the most common of twelve known species of this genera. It is widely
distributed in the United States (and probably elsewhere) and was reported to be an effective species as early as 1904 by Smith (20) in a summary of east coast mosquito fish. It is found in both freshwater and brackish to salt water in coastal marshes. It is a wary species, which takes refuge in the bottom of a pond whenever it is disturbed by a shadow or a moving object within its field of vision, and does not reappear until the observer has been motionless for several minutes. The stickleback is usually seen only in small numbers, not in schools like Gambusia. Hubbs (1919) (15) studied this interesting fish in some detail, and his account can be summarized as follows:

Abundance of other food will not deter the stickleback from feeding on the mosquito (larvae and pupae); its mouth, small even for such tiny fish, will not permit it to feed on large insect larvae. It feeds at all levels of the water, from bottom to surface. Because of this fact, mosquito larvae and pupae of different habits are all picked up. The stickleback itself is largely immune to the attacks of larger fishes. This gives it a distinct advantage in many cases over other mosquito-eating fish, such as the top minnows, which would, under such circumstances, soon be devoured. It is a widely distributed fish. Several varieties are found along the seashores in the brackish waters of the bays and estuaries, and in the coastal streams. From the estuaries they can penetrate far up into the mountain canyons. At high water they spread out and are trapped in many pools from which mosquitos are thus eliminated. The stickleback lives and breeds in small pools along stream sides, and in shallow ponds and reservoirs around houses, etc. After planting, it requires no further care. The rise in temperature during the summer months does not seem to kill sticklebacks; they have been found in the hot springs of Tiajuana, near the Mexican boundary. It withstands transportation from its native streams to artificial ponds in open buckets or in cans.

3.7 PANCHAX PANCHAX

This species is a native of south-east Asian countries. It is an egg-laying carp which inhabits warm waters of many types. In India this fish was valued for mosquito control as being superior to Gambusia and Poecilia, except in wells, where Gambusia is rated as superior. In India, introduced Gambusia apparently have seriously depleted the native Panchax while Poecilia seem to live in harmony with it.

3.8 EPIPLATYS SENEGALENSIS

This species, a cyprinodontid, occurs in northern Nigeria and is a voracious feeder upon mosquito larvae. This top minnow measures about 4-5 cm and inhabits lakes, rivers and swamps, including the surrounding hoof-prints. It is a very effective mosquito fish and a remarkable absence of mosquitos has been reported in areas where it is prevalent. Epiplatys hangs on the surface of the water, waiting for its prey rather than searching for it, as Gambusia does. This suggests that it may prey upon flying insects attracted to its bright reflecting white spot on top of its head. A brief field feeding study revealed its having fed specially healthily on ants.
# CHAPTER II - SOURCE REDUCTION

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1. INTRODUCTION

Source reduction is a broad term. It covers any planned modification of the environment which physically removes from the surface of the ground or reduces the water in which mosquitoes develop, or through physical changes in the environment renders the water unsuitable for mosquito production.

Source reduction usually implies the regulation of water, the construction of water control works, or other physical changes in the environment. It may also contribute to the use of naturalistic methods by changing the environment so that naturalistic controls are enhanced, or to chemical control by concentrating water in a smaller area so that it may be more conveniently and effectively treated with pesticides.

The most obvious types of source reduction are the removal of standing water in which mosquito larvae occur by filling, grading, ditching and diking, the installation of culverts, underground drains or conduits, tidegates, pumps, drainage outlets through sand or other unstable soils, and other works designed to remove water from the soil.

Somewhat less obvious are the clearing from the banks and edges of reservoirs of the vegetation and debris which may afford shelter to mosquito larvae; the conversion of marshes or swamps to open water impoundments so that wave action along the shore line will tend to strand mosquito larvae and to discourage egg laying; the daily circulation of tide water on to and off coastal marshes; the installation of injection, or "upside down", wells by which surface water is introduced into pervious underground soil strata; the planting of willow or other water loving plants to dewater and shade wet soils, and the cleaning and straightening of waterways so that the water will flow more briskly, with no still areas to encourage the development of mosquito larvae; the installation of baffles in streams to create turbulence; the periodic flushing of streams to strand or physically destroy larvea; the diversion of water from swamps or pools or streams to the irrigation of crops or grasslands or trees; the introduction of salt water into sources where the vectors cannot tolerate salinity, and other induced changes in water quality which will render it unfit for the production of the locally prevalent species.

A most important though indirect means of achieving large scale source reduction, particularly in countries where major development projects are planned or are being constructed, involves painstaking negotiations with the promoters or developers of major flood control, irrigation or water supply projects, which result in the incorporation into these projects of safeguards that vector mosquito sources will not inadvertently be allowed to exist or be created as by-products of the project.

The physical construction of permanent or semi-permanent works is often but not always involved. The construction of a drain to remove excess irrigation water before mosquitoes can develop is source reduction, as are the planned, careful regulation of the irrigation water applied so that ponding is avoided, the dredging of the shallow, weedy edges of a pond and filling of its swampy borders, and the raising and lowering of the water level on a planned schedule so that the larvae along the edges are alternately exposed to stranding and dehydration and to predation by fish and other natural enemies.

The most acceptable forms of mosquito source reduction are those which, while eliminating or substantially reducing mosquito breeding, also reclaim unused land where water remains long enough to produce mosquitoes, but serves no useful purpose. For example, land areas, large or small, may receive destructive run-off following rains or periods of snow-melt, so that mosquito larvae develop, but the water does not remain long enough or
is not in sufficient quantity to serve a useful purpose. Water conservation and land reclamation projects in such situations have resulted in the creation of many improvements: useful impoundments which support valuable fish and which may be used as potable water or irrigation on a controlled basis, parks, building space, stock watering facilities, wildlife refuges, and productive agricultural lands. When joint use of the resultant improvements is practicable, the entire costs involved should be shared equitably, so that the malaria programme may not have to bear the entire burden of funding.

Outstanding major examples of historical interest are the extraordinary irrigation-drainage projects in the flood plain of the Nile; a recently constructed model land reclamation-irrigation-desalinification-drainage-malaria control project at a large inland oasis in Saudi Arabia; the famous Pontine Marsh reclamation project in Italy; the great TVA (Tennessee Valley Authority) regional reclamation-development programme in the United States of America; and many small, individual drainage or recirculation projects completed by cooperative effort in the irrigated agricultural areas of California.

In developing countries, the number and variety of opportunities to promote such beneficial cooperative improvements will be limited only by the imagination and the technical competence of the personnel having responsibility for source reduction.

The source reduction techniques employed should be those which yield quicker results in order to contribute most effectively to the antimalaria programme, and those which can be used most advantageously where other measures may be less effective, or more costly.

Apart from the various source reduction measures carried out in conjunction with extensive agricultural or hydroelectric development projects, measures carried out in rural or urban areas are in general simple and easily implemented, especially as they are applied mainly by manpower not skilled in the use of mechanical contrivances. In tropical regions with high annual rainfall, these measures may be of limited efficacy in respect of species depending on rainfall for breeding places (e.g. A. gambiae). Source reduction is often the control measure of choice during the dry season when there is a limited number of water holding sources.

Source reduction has a special place in malaria control where programmes are not strictly time-limited as in malaria eradication. The lower overall cost, the land reclaimed, the water conserved and the other side benefits will be specially attractive to public administrators and will facilitate the provision of funds for malaria control.

Application of source reduction measures generally produces results that are permanent, that is, they require little or no maintenance. This implies that with a fixed budget, representing a small percentage of the total malaria budget, it would be possible to produce progressively over a number of years considerable reduction in breeding areas. Hence, 10% of the annual budget being spent on source reduction would result in fewer areas to be treated with temporary measures each year, thus providing important economy in the programme's overall expenditure.

2. PLANNING OF SOURCE REDUCTION

Prerequisite to the establishment of a source reduction programme, as with other antilarval approaches, is the definition of the problem, its geographic scope, and its biological and malariogenic implications. This involves the collection of all baseline epidemiological data on malaria in the whole area. The vector species should be identified, their flight range should be determined, and their breeding places, particularly within flight range of the areas to be protected, should be delimited by careful entomological observations and mapped. The habitat preferences of the local vectors should be taken into account when designing or selecting the measures to be applied. For example,
where the vector is a sun-loving species, the shade trees which may occur along the banks of the waterways should not be removed even though the task of improving the waterway is made more difficult.

In new programmes, most of the basic engineering data should be compiled at the time of the initial geographic reconnaissance and the maps made then should also show in detail sources of vector mosquitoes, together with notes giving the opinions of the initial observers as to preventive or corrective antilarval measures which might be taken. When source reduction projects are considered for implementation in already established programmes, additional studies and maps may have to be made.

A convenient scale for detailed area maps is 1/8000. When greater detail is needed, double the scale, 1/4000, or four times the scale, 1/2000, may be used for easy reference to the basic scale. For general maps of large areas 1/64000 or 1/840000 may be convenient.

When good local maps at a different scale are already available, they may be used to good advantage. Among maps which are particularly useful in planning source reduction projects are geological survey maps which present physical features, contours, elevations and standard surveying bench marks; the coast and geodetic survey maps which emphasize coastline physical features and reference points; the political subdivision and road maps which give many landmarks to which locally made maps or surveys can be referred. Civil or military aerial maps which show physical features and vegetative cover in unexcelled detail are extremely useful in planning drainage or other projects, or as base maps from which outline maps can be prepared by simple tracing.

Useful data to be plotted on the working maps include lakes, rivers, reservoirs, canals, drain ditches, population centres, roads and landmarks, and the data resulting from engineering studies of projected developments.

Each of the sources found to be important by the entomological survey may be studied to determine the alternative methods which can be employed for its elimination or reduction. The presence of native natural enemies, or the potential for establishing imported predators should be considered, together with environmental changes which could improve their effectiveness. The study should include a comparison of the engineering feasibility and the estimated costs of the various alternatives, and should provide an assessment of the incidental benefits which may accrue to the people in the community. When the elimination of an important source also provides a direct and substantial benefit to the people living in the area, greater cooperation and assistance in the construction and/or maintenance of the improvement can be expected as for example where a vector-producing swamp is converted to an impoundment which serves as a source of food fish and which also ensures that water will be available through a dry season, or where an intermittent flood area is protected by drainage works so that it can be developed to productive agriculture. Particular efforts should be made to enlist the active cooperation of agricultural and reclamation agencies or organizations in joint purpose developments which will benefit malaria control and the local economy.

When source reduction operations are initiated it may be necessary at the outset to provide protection for the labour force engaged by means of chemical larviciding or even house spraying.

3. ENGINEERING SURVEYS AND DESIGN

Mosquito source reduction operations may involve drainage or water control projects so small and simple that the average supervisory workman, instinctively sensing the slopes of the land and observing the water levels in a swamp or ditch and the residual patterns left by the drainage of previous high waters, can excavate as necessary to obtain satisfactory
drainage, without the use of instruments. In such situations, after roughing out the
ditch, the workman will generally allow a little water to run through it, using the water
levels observed as a guide to finishing the bottom so that no pools are left. Many minor
mosquito sources have been eliminated on this basis where critical engineering was not
necessary. By contrast, major drainage or reclamation projects, which require for their
successful execution the highest levels of training, experience and technology in water
resources development, justify the employment of specialist consultants and contractors
to design and construct the project.

Most malaria vector source reduction projects lie between the two extremes of non-
technical small operations and highly technical specialized major operations. For
proper design and execution, these usually require the services of competent, technically
trained engineers or vector control specialists, employing accepted principles of design
and adequate instrumentation. Included in this category of projects are most of the
drainage, filling, diking, pumping, tidegating and ponding projects necessary to eliminate
mosquito sources.

Various useful handbooks on surveying and the design of water control structures are
available, but for those who may not have ready access to such texts, the following section,
while not intended to provide a complete text, may suffice to guide workers who are
confronted with routine surveying problems normally encountered in mosquito source reduction
in situations where accuracy of the highest order is not required. More complete
information on the theory and practice of surveying in antimalaria works is given in
"Geographical reconnaissance for malaria eradication programmes" (WHO, 1965) (36).

3.1 PLANE SURVEYING AND LAND DRAINAGE FOR MOSQUITO CONTROL (USPHS, 1954 (30))

The procedures and methods described here do not necessarily represent the only or the
most practical solutions to surveying problems. Depending upon the individual, the
results desired, and circumstances associated with the problem, other means may be applicable
which would result in a satisfactory solution with the expenditure of less effort. "Short
cut" methods may possibly be introduced by which equivalent end results may be achieved.

3.1.1 Definitions

The art of measuring and locating lines and angles on the surface of the earth is
called surveying.

When the survey is of such limited extent that the effect of the earth's curvature
may be safely neglected, the term plane surveying is used.

Geodetic surveying takes into account the effect of the earth's curvature as in the
survey of a state or country.

Surveys are made for a variety of purposes, such as the determination of areas, the
fixing of boundary lines, the plotting of maps, and for engineering construction works -
highways, railroads, bridges, buildings, irrigation and drainage systems, land levelling,
etc.
3.1.2 Measurement of lengths and direction

In surveying, all measurements of length are horizontal or else are subsequently reduced to horizontal distances. In addition to determining the length of a survey line, its direction must, in many cases, also be determined. The direction of a line is determined with reference to the direction of a magnetic needle (as of a compass) which possesses the property of pointing in a fixed direction, namely, the magnetic meridian. This direction is expressed in terms of an angle called the magnetic bearing of the line, or simply its bearing. A bearing reckoned from the geographical meridian is called the true bearing or azimuth and in general will not coincide with the magnetic bearing of the line. The angle between the magnetic meridian (the fixed direction of the magnetic needle) and the true (geographical) meridian is called the declination of the needle. For example, this declination varies from 0° to as much as 24° in various locations in the United States and may be either east or west of the true north depending on the location.

In present day surveying, the two principal instruments employed in measuring distances are the steel tape (of 10 m length) and a telescope on a transit or level which is equipped with a set of stadia hairs.

The surveyor's compass is the principal instrument used in measuring the direction of lines. Most transits and some levels are equipped with a compass. The horizontal circle of the compass is graduated to degrees and half-degrees and numbered from two opposite zero points each way to 90°. The zero points are marked with the letters N and S and the 90° points are marked E and W.

The magnetic bearing of a line is reckoned from 0° to 90°, the 0° being either at the N or the S point and the 90° either at the E or the W point. The quadrant in which a bearing falls is designated by the letters NE, SE, SW, or NW (see Figure 1 below). The magnetic bearing of the line OA in this figure is N 62° 15' E.

The true bearing of a line is usually reckoned from the south point right handed (clockwise) to 360°; i.e., a line running due west has an azimuth of 90°; a line due north has an azimuth of 180°. In Figure 1, the azimuth of the line OA is 242° 15'.

![Figure 1](attachment:image.png)
3.1.3 Measurement of angles

After the magnetic bearings of two lines have been determined by use of the surveyor's compass, the angle between the two lines can be calculated by addition or subtraction, or a combination of these simple mathematical computations. However, for more accurate results in measuring horizontal (and vertical) angles, an engineer's transit should be used.

3.1.4 Measurement of elevation

A level surface is really a curved surface which at every point is perpendicular to the direction of gravity at that point, such, for example, as the surface of still water. Any line of sight which is perpendicular to the direction of gravity at a given point is therefore tangent to the level surface at that point and is called a horizontal line.

The elevation of a point is the height of the point reckoned from some zero plane, such as mean sea level. The plane is called the datum, and its elevation is always zero. If mean sea level is not known, a datum can be arbitrarily assumed. This is particularly applicable for short or limited surveys which will not have to be "tied in" to an existing or future survey. For the sake of convenience in recording and later interpreting the survey data, the assumed datum plane, to which surface elevations are referred, should lie below the lowest point likely to be reached on the survey.

A bench mark (B.M.), or simply bench, is a permanent mark of which the elevation above the datum plane is accurately known. It may be a bolt or similar object set into the top of a solidly fixed stone or simply a mark on a stone, a tack driven into a projecting root of a tree, or the top of some concrete structure, such as a culvert headwall or similar irrigation works structure.

The instrument chiefly used for the direct determination of differences of elevation is the level in combination with the levelling rod. There are three principal types of level: namely, the Wye level, the Dumpy level and the hand level. For more accurate measurements the two former named types are used, the hand level being used only when approximate levels are desired. The engineer's transit, which has the long level attached to the telescope, is frequently used for levelling.

A commonly used levelling rod is the self-reading Philadelphia type with every hundredth of a foot (3mm approx.) marked. The graduation lines are 0.01 ft (3mm approx.) wide with the upper edges being the even numbered hundredths and the lower edges the odd numbered hundredths. The rod is graduated from 0 at the lower end to 7 ft (2.3 m approx.) or higher (by extending) at its upper end. There are also rods graduated in the metric system.

3.2 Levelling

The process of finding the difference in elevation of any two points is called differential levelling. Levelling for the purpose of determining the changes in elevation of the surface of the ground along some definite line is called profile levelling. In elementary surveying and for most ordinary surveying problems, the direct levelling method is used. Trigonometric levelling is used only in advanced surveying work and takes into account vertical angles.

The first step in beginning a survey which involves elevations (vertical distances) is to establish the first bench mark and record its elevation. The instrument (level or transit) is firmly set up at a moderate distance from the bench so that the telescope is somewhat higher than the bench and in full view of a rod held vertically upon it. The instrument is properly adjusted so that the level bubble stands in the centre of its tube.
(and the vertical circle reads zero for a transit) during an entire revolution of the telescope about the vertical axis. With the instrument so adjusted, the line of sight through the intersection of the telescope's cross-hairs is known to be horizontal. The rod is held vertically upon the bench, the line of sight of the telescope is turned upon the rod and the point on the rod intercepted by the horizontal cross-hair (reading of the rod) and is known to be level with the cross-hair. Therefore, the cross-hair is higher than the bench by the distance intercepted on the rod from its lower end. Adding this distance to the elevation of the bench gives the elevation (above the datum) of the horizontal cross-hair, or height of instrument (H.I.).

Once the height of instrument has been determined the elevation of any point lower than the cross-hair by a vertical distance not exceeding the length of the rod is easily ascertained. The rod reading subtracted from the H.I. gives the elevation of the point above the datum.

But the elevation of points on ground higher than the cross-hair or farther below it than the length of the rod cannot be determined because in either case the line of sight will not cut the rod, and hence there can be no reading. To observe such points, the instrument must be moved to a new position, higher or lower than before, as the case may require, and the new H.I. determined.

Before moving the instrument to a new position, however, a temporary bench called a turning point (T.P.) must be established and its elevation ascertained as for any other point but with more accuracy. The reading having been taken and recorded for the T.P. (to obtain its elevation), the instrument is carried forward to a new point and there properly levelled. A new rod reading is taken on the same T.P. and added to the T.P. elevation for the new height of instrument. The elevation of additional points within the vertical range previously described and within practical horizontal distances from the instrument may now be determined simply by reading the rod on the points. Readings on bench marks and turning points should be to the millimetre or fraction thereof depending upon the accuracy desired. Elevations on the surface of the ground will not usually be needed closer than to a few centimetres.

To find the height of instrument, add the reading on a point to the elevation of the point; and to find the elevation of a point, subtract the reading on it from the height of instrument (see Figure 2, page 24).

A reading taken for the purpose of finding the height of instrument is called a backsight (B.S.) and a reading taken for the purpose of finding the elevation of a turning point (or of a bench used as such) is called a foresight (F.S.). Hence backsights are always plus (+S) and foresights are always minus (-S). The terms backsight and foresight, as used here, do not refer to the directions in which the sights are taken.

3.2.1 Profile levelling

Profile levelling is for the purpose of obtaining data which indicate the changes in elevation of the surface of the ground along some definite line, and from which a profile or vertical section may be developed showing in detail the rises and falls of the surface over which it passes. From such a profile, grade can be established and design for construction may be made. The line is first "stationed"; i.e. marked at a certain interval, usually every 30 m, by stakes upon which the station number is written. Surveys for drainage are usually begun at the lower or downstream end, unless there is some doubt as to the location of an adequate outlet in which case the survey would begin upstream and extend to the point of satisfactory outlet as determined by the levels. The instrument is set up and the H.I. determined as previously described. Foresights are then read on as many station points on the line as can be conveniently taken from the position of the
Figure 2. GRADING LAND FOR SURFACE IRRIGATION

Starting a topographic survey from a bench mark.

Moving instrument while making a topographic survey.
instrument. Intermediate sights are taken at any points where marked changes of slope occur and plus (+) stations of these intermediate points are recorded with the rod readings. The instrument is moved forward as is necessary and this general process is continued until the end of the line is reached.

The level notes may be kept in any convenient form that is easily understood by the notetaker or any others who may have to interpret them. The development of satisfactory and workable plans for a construction job depends largely upon the surveying notes and data available. Table 1 gives a form of profile levelling notes:

Table 1. PROFILE LEVEL NOTES

<table>
<thead>
<tr>
<th>STATION</th>
<th>B.S.</th>
<th>H.I.</th>
<th>F.S.</th>
<th>ROD</th>
<th>GROUND ELEV.</th>
<th>DESCRIPTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM1</td>
<td>1.460</td>
<td>101.460</td>
<td></td>
<td></td>
<td>(100.000)</td>
<td>Nail in red oak</td>
</tr>
<tr>
<td>0</td>
<td></td>
<td></td>
<td>2.955</td>
<td>98.505</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>1.550</td>
<td>99.910</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>1.495</td>
<td>99.965</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+50</td>
<td></td>
<td></td>
<td>1.830</td>
<td>99.630</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td>1.195</td>
<td>100.265</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP (BM2)</td>
<td>2.295</td>
<td>101.010</td>
<td>2.745</td>
<td>(98.715) Top Rt. D.S. wingwall hwy.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td>1.765</td>
<td>99.245</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td>2.075</td>
<td>98.935</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>2.135</td>
<td>98.875</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td></td>
<td></td>
<td>2.350</td>
<td>98.660</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td></td>
<td></td>
<td>2.500</td>
<td>98.510</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td></td>
<td></td>
<td>2.780</td>
<td>98.230</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP (BM3)</td>
<td>1.250</td>
<td>100.105</td>
<td>2.155</td>
<td>(98.855) Nail in tp. cypress stump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td></td>
<td></td>
<td>2.175</td>
<td>97.930</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td></td>
<td></td>
<td>2.325</td>
<td>97.780</td>
<td></td>
<td></td>
</tr>
<tr>
<td>+30</td>
<td></td>
<td></td>
<td>2.420</td>
<td>97.685</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.005</td>
<td></td>
<td></td>
<td>4.900</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The additions and subtractions made on each page of the notes should be proved before proceeding to the calculations of the next. When correct, the difference of the sums of the BS's and FS's on the page equals the difference of the first and last elevations on the page. Thus, in the example given in Table 1, 5.005 - 4.900 = 0.105 = 100.105 - 100.00.

In this proof, all elevations except those for T.P.'s and B.M.'s used as such, and the H.I.'s are ignored.

A line of levels should be checked by connecting with some reliable bench mark, if possible. Bench marks along the line of levels should be used as turning points, if convenient, or at least check readings should be taken on them in order to detect mistakes.

3.2.2 Establishing grades

Utilizing the level notes, the profile is plotted on profile paper printed for the purpose (see Figure 3, page 26). A horizontal scale of 1 to 1200 cm and a vertical scale
Figure 3. SAMPLE PLAN AND PROFILE SHEET

POND

N 62°32'E

BM1

BM2

P.C.

P.I. Sta.

0+00

5+00

10+00

NATURAL GROUND LINE

GRAD LINE

Δ = 21°00' Lt
T = 30.5 m
L = 60.5 m

Δ = 7°12' Rt
T = 15 m
L = 30 m

Δ = 21°45' Rt
T = 18.3 m
L = 36 m
of 1 to 120 cm is commonly used in road and drainage work. This distortion of scale magnifies the vertical measures so that slight changes in the elevation of the surface may be distinctly seen on the profile paper.

A line which is drawn on a profile to correspond to the finished surface of a road, or the flow line of a ditch or a canal, is called the grade line. Many factors must be considered in designing the grade lines for construction projects and such factors vary widely depending upon the type of project.

The gradient is the rate of change of elevation in the grade line and is usually expressed as a percentage. Thus a 1.7% gradient indicates a rise or fall of 1.7 m in a horizontal distance of 100 m. When the grade is ascending the gradient is marked plus (+) and when descending, minus (-). The word grade is frequently used instead of gradient.

In the example on pages 25 and 26 the gradient will be approximately -0.20% which represents the ratio of the difference of elevation to the distance between the first and last stations

\[
\frac{(98.505 \text{ m} - 97.685 \text{ m}) \times 100}{395.5 \text{ m}} = -0.20\
\]

3.2.3 Cross-section levelling

In practically all railroad and highway work and for large canals or ditches it is necessary to run cross-section levels. The data thus obtained is utilized in estimating the quantity of earthwork required. Cross sections for this purpose are usually taken at full station points of the line usually 30 m apart, more often if the longitudinal slope changes considerably and at right angles to the centre line of the proposed road, canal or ditch. For smaller canals and ditches, through level or flat terrain involving excavation only, cross-sections are rarely necessary. Under these conditions, earthwork quantities may be estimated fairly accurately from the profile and grade elevations. The procedure for cross-section levelling is similar to that previously described for profile levelling. Rod readings of the points right and left of the centre line are recorded along with the distances of the points from centre line.

![Figure 4. TYPICAL DITCH CROSS-SECTION](image)
3.3 LEVELLING FOR CONSTRUCTION

In earth-moving operations for highways, irrigation canals, drainage ditches and land levelling, the established grade upon the final profile of a located line is the basis to which all construction work must conform. When the desired grade line has been drawn (in the office) on the profile and its grade or gradient determined, the grade elevation at each station of the line may be computed. Before construction begins, the proposed work must be "staked out" with grade stakes at every full station (30 m apart) or more often on the centre line and at both sides with slope stakes where the finished slope intersects the surface of the ground (see Figure 4, page 27). The amount of the "cut" or "fill" ("cut" only in drainage work) is marked on these stakes for guidance in the actual construction operations.

A common practice in drainage work is to offset the grade stakes either right or left of the centre line for a minimum distance equal to at least one-half the bottom width of the proposed drainage ditch, with the stake extending about 15 cm above the surface of the ground. The grade stakes then will not be disturbed while "roughing in" the ditch to the grade. Unless there is considerable transverse slope of the land along the line, it is not always necessary to mark the cut on the slope stakes - the marking of the grade stake will suffice. Slope stakes in this case serve only to mark the point of intersection of the ditch side slope with the ground line.

For determining the cuts (and fills) in the field, the level (or transit) is set up and the H.I. is determined from some convenient B.M. in the manner previously described. The difference between the H.I. and the grade elevation at any given point (from the profile prepared in the office) is called the rod reading for grade (or simply grade rod); i.e. the rod reading which would be obtained if the lower end of the rod could be held at the given point on the flow line of the ditch, or finished surface (grade) of the road, as the case may be. Then the rod is held on top of the grade stake and a reading is taken to the nearest 3 cm. The difference between this rod reading and the rod reading for grade will give the cut (or fill) at that point as reckoned from the top of the grade stake. The cut (or fill) is marked on the grade stake which also has the station number marked on the opposite side. The first stake (station) is numbered 0 + 00, the second 1 + 00, the third 2 + 00, etc. When readings are taken at intermediate points the stakes marking these positions will be numbered according to the number of metres each lies in advance of the preceding stake, e.g. 2 + 10 m which means 70 m from the first station (30 m + 30 m + 10 m).

Table 2 illustrates one method of note keeping in levelling for grade stakes which indicates the "cut" at the centre line only of a proposed drainage ditch.

For most open drains constructed through fairly flat or level terrain, the distance from the centre line to the point of intersection of the side slope with the natural ground surface is equal to 1/2 the ditch bottom width plus the centre line cut multiplied by the slope, the slope being the inclination of the side slope expressed in terms of the ratio of the horizontal to the vertical distance from the edge of the ditch bottom. Thus a slope which rises 1 m vertically in a horizontal distance of 1 1/2 m is called "a slope of 1 1/2 to 1". Slope stakes are set right and left of each station to mark the points of intersection with the ground. Slope stakes for adjacent stations may be connected by a string line which will provide a continuous mark for the intersection of the slope with the ground line.

Depending upon whether the excavation is accomplished by hand or machine, various methods of establishing the grade during construction are utilized. For hand-dug ditches a string line, set from grade stake data, parallel to and at a given number of metres above the established grade line will be adequate in checking for the proper depth. Targets consisting of crossbars (batten boards) at a constant distance above the grade line serve to guide operators of machines in digging ditches.
Table 2. LEVEL NOTES FOR GRADE STAKES

<table>
<thead>
<tr>
<th>STATION</th>
<th>B.S.</th>
<th>H.I.</th>
<th>F.S.</th>
<th>GRADE ELEV.</th>
<th>GRADE ROD</th>
<th>ROD</th>
<th>CUT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>BM1</td>
<td>1.311</td>
<td>101.311</td>
<td></td>
<td>(100.000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>101.525</td>
<td></td>
<td>2.836</td>
<td>2.806</td>
<td>0.030</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>101.586</td>
<td></td>
<td>2.897</td>
<td>1.250</td>
<td>1.647</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>101.470</td>
<td></td>
<td>2.958</td>
<td>1.159</td>
<td>1.799</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>+50</td>
<td>101.677</td>
<td></td>
<td>2.989</td>
<td>1.586</td>
<td>1.403</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.P.</td>
<td>1.738</td>
<td>100.457</td>
<td>2.592</td>
<td>(101.281)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>101.708</td>
<td></td>
<td>2.165</td>
<td>0.579</td>
<td>1.586</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>101.769</td>
<td></td>
<td>2.226</td>
<td>1.037</td>
<td>1.189</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>101.830</td>
<td></td>
<td>2.287</td>
<td>1.372</td>
<td>1.915</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>101.891</td>
<td></td>
<td>2.348</td>
<td>1.433</td>
<td>1.915</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>T.P.</td>
<td>1.250</td>
<td>100.030</td>
<td>1.677</td>
<td>(101.220)</td>
<td></td>
<td></td>
<td></td>
<td>Top culvert</td>
</tr>
<tr>
<td>7</td>
<td>101.952</td>
<td></td>
<td>1.982</td>
<td>1.220</td>
<td>0.762</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>102.013</td>
<td></td>
<td>2.043</td>
<td>1.403</td>
<td>1.640</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>102.740</td>
<td></td>
<td>2.104</td>
<td>1.555</td>
<td>1.549</td>
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CHECK: (4.299 - 4.269) = 0.030 = 100.030 - 100.00

This procedure for setting grade stakes is also applicable to the installation of drain tile. A trench similar to that for open drains must be dug for the drain tile. However, no sloping is required and the trench is backfilled after the tiles are laid.

3.3.1 Design of open drainage ditches

The need for drainage and the type required depends to a large extent upon the climate of the area under consideration. In humid areas of considerable rainfall heavy or fine textured soils, or those with relatively impervious subsoils require drainage because the rainfall or surface water will not readily penetrate the soil and disappear through the subsoil strata. In arid or irrigated areas where much of the land has light or coarse to medium textured soils with relatively permeable subsoils, seepage, excessive irrigation and other artificial means sometimes cause an accumulation of water in the subsoil resulting in a high water table and a need for drainage. These arid soils often contain alkali salts near the surface as a result of the high water table.

Many factors must be considered in the design of open drainage ditches. The principal factors involve amounts and sources of water, slope of the land, soil texture, amount and nature of cover, adequacy of outlet and purpose of the drain - to remove surface water or to lower the water table. Drains which are to remove surface water only may be designed to run full at times of maximum run off, while those intended to lower the water table must be designed so that the water surface in the drain is always below the level of the desired water table.

The side slope of a ditch depends largely on the type of soil involved. Fine grained soils, such as clay, will stand on a much steeper slope than the coarser textured soils. Even through clay, however, in order to minimize the tendency of a ditch bank to "slide in" after becoming wet, a side slope steeper than 1 to 1 is not recommended. In the coarser textured soils a 2 to 1 slope may be advisable and very sandy soils may require slopes of 3 to 1.
Some of the factors affecting the design of open drains are known, others must be assumed. The grade or fall of the drain is to a great extent dictated by local topographic conditions and can be determined by measurements on the ground as previously described. The grades used for drainage ditches range from 0.0005 to 0.006. The desired side slopes must be decided upon. The quantity of water to be carried by the drain, however, must be estimated. This estimate must be based on the rainfall of the area or on other sources of water, such as irrigation run off and the outfall of a system of covered tile drains. An approximation of the run off from small drainage areas can be made through the rational method and is expressed by the formula

\[ Q = 0.0028 C I A \]

where

- \( Q \) = run off in cubic metres of water per second
- \( C \) = run off coefficient representing the ratio of the rate of run off to the rate of rainfall. The value of \( C \) ranges from 0.10 for flat areas and high pervious soil to 0.40 for small agricultural watersheds in rolling country to 0.95 for city pavements and roofs.
- \( I \) = rainfall intensity in millimetres per hour
- \( A \) = watershed area in hectares

The capacity or size of simple open form drains is expressed by the formula

\[ Q = AV \]

where

- \( Q \) = the discharge of water passing a given point in cubic metres per second
- \( A \) = the area of the water cross section, in square metres, at that point, and,
- \( V \) = the mean velocity of flow of the water in metres per second.

The velocity of water flowing in an open drain is expressed by Elliott's formula:

\[ V = \sqrt{\frac{A \times 2.414 S}{P}} \]

where

- \( V \) = velocity of the flow in metres per second
- \( A \) = area of the cross section of the drain in square metres
- \( P \) = wetted perimeter in metres (the bottom width plus the length of the side slopes which will be wetted). Friction becomes greater with increase of the surface in contact with the water.
- \( S \) = grade or fall in metres per kilometre.

The erosive power of water depends upon the energy of its flow which varies as the square of the velocity. If the velocity is doubled then the cutting capacity of water is increased four times. The velocity of water therefore should be kept below a safe limit. This limit ranges from 0.45 m/sec in fine sand, to 1.2 m/sec in stiff clay.

A low flow velocity tends to allow silting in the drains. The size of particles than can be moved varies as the sixth power of the velocity. If the velocity is doubled the size of particle that can be carried along the bottom is increased 64 times. On the other hand the amount of material that can be carried in suspension varies as the fifth power of the velocity.
3.3.2 Design computation

The quantity of water to be discharged "Q" must first be determined. This is sometimes difficult to determine accurately, so some quantity must be assumed, based upon the known factors. Now in relation to formula

\[ V = \sqrt{\frac{A \times 2.414 S}{P}} \]

the cross sectional area and the velocity must be determined. For this the grade of the drain should first be selected as previously explained. Then, by trial the dimensions of the cross section which with this grade will give the required area and velocity, should be obtained. For this purpose the depth of flow or the shape of cross section will have to be fixed. The trapezoid is the standard for earth channels with the bottom as narrow as possible to provide for the flow of residual water in dry weather. To maintain the shape, the bottom should be lined with concrete or other material. Side slopes should be designed so as to avoid caving or sliding. A slope of 2 to 1, or 3 to 1, will be necessary in sandy soils while in hard clay side slopes may even be vertical. Depending on the local conditions and the purpose of drainage, a trial depth of ditch is assumed and the suitable slope is adopted. Now the cross sectional area of the flow will be calculated:

\[ \frac{b_1 + b_2}{2} \times d \]

where:

- \( b_1 \) = width of top base
- \( b_2 \) = width of bottom base
- \( d \) = depth of water

Example:

Let the assumed "Q" be 0.16 cubic metres per second, the fall or slope having been determined to be 1 metre per kilometre, or 1 per 1000. The side slope selected is 1 to 1. As a trial, assume that a drain 60 cm wide on the bottom and flowing 30 cm deep will be required. Substitute these values in Elliott's formula:

\[ V = \sqrt{\frac{0.27 \times 2.414 \times 1}{1.44}} = \sqrt{\frac{0.672}{1.44}} = 0.679 \text{ m/sec} \]

Substituting this value of "v" in the formula, \( Q = A \times V \), we have \( Q = 0.27 \times 0.679 = 0.183 \text{ m}^3/\text{sec} \).

Thus, it can be seen that the capacity of a drain with a 60 cm wide bottom, 1 to 1 side slopes, and flowing 30 cm deep on a fall or grade of one metre per kilometre is 0.183 m³/sec. This is 0.023 m³/sec more than the estimated flow of 0.16 m³/sec, and such a ditch should be adequate. A "freeboard" of from 15-30 cm above the maximum surface of the water to the top of the ditch bank should be allowed in establishing the depth of the ditch. This will provide an additional safety factor with regard to capacity and will also minimize the erosion potential. If the trial gives greater or lower flow capacities, then the depth of flow can be reduced or increased to obtain a satisfactory result.

3.3.3 Simple engineering instruments

There are excellent light-weight surveying instruments available from many optical instrument companies which have the capability of yielding highly accurate results in the hands of a skilled surveyor. Some are self-levelling and therefore easily and quickly
set up and convenient to use. These better quality instruments have powerful telescopes which allow the surveyor to read a target or rod which is a long distance away so that the instrument need not be moved frequently. However, the better instruments are costly and are possibly more easily damaged or maladjusted by workers who may have only a modicum of experience.

For most source reduction projects which will be attempted routinely by malaria workers, the moderately priced "farm level", equipped with compass and stadia, is quite satisfactory. With these, the operator cannot read a level rod over distances of more than a few hundred metres (by using a target on the rod, the distance can be at least doubled), the scales are not so finely divided and vernier adjustments may be omitted, and readings cannot be made to so high a level of accuracy as with the best instruments. However, the low priced instruments suffice to the order of accuracy demanded in most mosquito control source reduction projects.

In any event, the engineers' level is essentially a device by which a person may establish a line of sight parallel to the surface of a body of water which is motionless upon the surface of land, and at a precise known distance above any selected point of reference. From this line of sight, which may be turned towards any compass direction while still being held parallel to the surface of the water, distances directly downward to any other point of reference may be measured, thereby establishing the height relationship or the "level" of the second point to the first. A resourceful workman who understands the principles of differential levelling can improvise substitutes to obtain usable though perhaps less accurate data when the highly precise tripod mounted instruments are not available to him. For preliminary study of drainage problems, a "hand level" and a pocket compass or military type "marching compass" are useful for quickly determining approximate levels and directions. When tripod mounted surveyor levels are not available the pocket level can be used for determining approximate grades by holding it level on top of a firmly fixed stake and reading a rod set on reference points as previously described. If no accurately manufactured rod is available, one which will do for less precise work can be made locally by fastening several metre scales or a section of metallic cloth surveyors tape to a straight length of 1 x 3 wood, which has been painted white and which is at least 2 m long or as much longer as may be required to span the difference between the highest and lowest points which may be determined from any one instrument setting.

Locally made rods should have the principal measurement points marked prominently so that they can be read from a greater distance. Also, there are available from some manufacturers non-stretch tapes, in various designs, which are designed to be fastened to any locally procured straight wood rod, and these are especially designed for easy and accurate reading by surveyors.

When there is not even a pocket level at hand, and levels must be determined, a long mason's or carpenter's level can be substituted and used in much the same way. It should be held on top of a firmly fixed stake of convenient height by an assistant, who can observe the bubble in the level vial, keeping it in the "on target" position while the observer reads the rod along the top surface of the level. The observer must have an assistant to keep the instrument level while the sights are made, because he cannot see the bubble while sighting over the instrument.

When no levelling tools at all are available, the experienced workman can use the surface elevation of the water in any conveniently located pool as a base line reference, by locating two stakes of convenient height (say 1\(\frac{1}{2}\) m) so that the tops of both are at precisely the same distance above the surface of the water, and so that the stakes are 1 m or more apart. By sighting over the tops of these stakes the line of sight will be parallel to the water surface, and a rod may then be sighted as before.
Figure 5. CONVENTIONAL LEVELLING FROM BENCHMARK A TO POINT C (HEIGHTS IN METRES)

Table: Notebook entry

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<tr>
<th>Station</th>
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<th>Backsight</th>
<th>Height of Instrument</th>
<th>Foresight</th>
</tr>
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<td>2.4</td>
<td>111.6</td>
<td>0.2</td>
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<tr>
<td>C</td>
<td>111.3</td>
<td></td>
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</tbody>
</table>
The same principles may be employed in building and using a "water trough level" in which a trough perhaps 1 m long x 7.5 cm wide x 15 cm deep is made of wood or metal, and half filled with water. To its ends are fastened vertically two straight lengths of wood, about 2.5 cm x 5 cm x 91 cm. These must be precisely the same length. The trough is placed upon any convenient base, and wedged up and the depth of water adjusted until it just touches the bottoms of both vertical lengths of wood. Since these are identical in length, and their bottom ends just touch the surface of the water in the trough, a line of sight over the top ends of the lengths of wood is parallel to the surface of the water in the trough, and thus to the average surface of the earth at that point. In surveying training sessions, the building and use of such a "surveying instrument" is a very useful device in helping the student to understand fully the basic principles of surveying.

3.4 PRACTICAL CONSTRUCTION HINTS

3.4.1 Ditch grades, velocity and erosion

The grade of a ditch greatly affects the velocity of the water flowing in it, and the velocity in relation to the type of soil largely determines the degree of erosion which will occur. Very soft soil or sand may erode with velocities less than 0.3 m/sec, while firm soils may tolerate velocities of 1.5 m/sec. Under average conditions, velocities of 0.3 m - 0.9 m/sec yield good results and straight ditches of regular cross section and fairly smooth banks with only minimal vegetative growth will usually develop velocities of this order when the gradient is about 0.1% - 0.3% (1 m - 3 m fall/1000 m length). In practice, it is often impracticable to obtain the desired grade.

Where less than the desired fall is available, the flow will be sluggish, silting and the growth of aquatic vegetation will usually be increased thereby requiring more maintenance, and the ditch will have to be wider to accommodate the desired volume.

Where the grade is too steep, the velocity may increase above the safe limit for the local soils so that erosion will take place, causing collapse of the banks, and increased maintenance may be necessary where the slips occur or farther downstream at places where the velocity is less and silting may occur.

Various devices may be employed to reduce velocity: rocks or other obstructions may be left in the bed of the ditch, artificial "drops" may be constructed at key locations of logs, rocks or concrete, or aquatic vegetation which is growing may be left to slow the flow. Where bends or turns occur in straight ditches of critical or near-critical velocity, there is likely to be erosion damage to the bank on the outside of the curve. This may be compensated for by gradually increasing the width of the ditch before it reaches the point where the bend must occur so as to reduce the velocity through the turn, by making a long radius gradual curve rather than a sharp bend, or by protecting the outer bank of the curve with rip-rap, or other protective surfacing material. In maintaining ditches, it is generally advisable at the curves to leave the root growth of grass or other plants which may have colonized the outside bank on the curves, since the roots tend to hold the soil in place.

In steep, rocky grades, where flows tumble down steep grades through a rocky stream bed, maintenance men normally should not remove the rocks which obstruct the flow, for the energy due to velocity of the flowing water is absorbed in the impact against the rocks; one should bear in mind that the destructive force of water in motion increases as the square of the velocity, and greatly increased ditch bank erosion can be expected at higher velocities.
3.4.2 Spoil banks

The spoil banks of a ditch should be moved back from the edge so as to leave a "berm" about as wide as the ditch is deep, so that rainfall will not cause washing of the spoil back into the ditch and so that the weight of the spoil may not cause caving of the supporting bank. Alternatively, the spoil may be spread over a wider area to reduce its height and the corresponding unit area pressure on the supporting ditch bank; in this case the wider spoil bank should be graded so that rain which may fall upon it will run off the outside rather than towards the excavation. Smoothing the top of the spoil bank while the recently excavated earth is still soft involves only a little extra labour, and may greatly facilitate any subsequent inspection or spraying of the ditch since the inspectors or spraymen can walk easily and quickly down the graded spoil bank instead of stumbling along a rough, overgrown unfinished bank.

Where ditches run across a slope rather than down the fall-line, the spoil should be placed on the down-grade side in a continuous pile, particularly where the ditch line crosses low areas, to serve as a levee at times when the normal capacity of the waterway may be exceeded by flood flows. If the spoil bank must be placed on the up-grade side, openings should be left in it at intervals so that run off from higher land will not be trapped behind the spoil.

3.4.3 Low flow conduits in high capacity ditch

Where seasonal flow varies greatly, with low flow through most of the season, but occasional demands for greatly increased capacity, maintenance may be greatly decreased by installing a "low flow" closed pipe conduit, as shown at "A" or precast invert liner, as shown at "B" (Figure 6).

Figure 6

![Diagram of low flow conduits in high capacity ditch](image-url)
Secure headwalls of concrete or masonry, well anchored into the banks, should be installed at entrance and discharge ends, to minimize the possibility of damage when maximum flow periods occur. After the bottom of the ditch is backfilled over the pipe to "high water flow line", it may be desirable to seed the bottom of the ditch with a low-growing grass, to serve as a binder for the soil during the times when the ditch is flowing at near capacity. If precast concrete inverts are used, as in "H", optional precast side plate extensions may also be installed to protect the side walls when the capacity of the invert is exceeded. These may be particularly important on the outside walls of curves, where the greatest ditchbank erosion can be expected to occur. The liners should be securely anchored by pipes or metal pins driven into the bank through holes left in the precast side plates for that purpose. Corrugated metal ditch liners and side plates are also available, which may be substituted.

3.4.4 Permanent masonry drains

Open drains lined with concrete, brick, stone, etc. should never be constructed without first making a simple earth ditch to test the required depth, grade, flow, etc. Lined drains should have a central deeper channel or "cunette" to increase the rate of flow when the water level is low and also in order to reduce the extent of the potential breeding area. Where a side channel joins the main drain, the opposite side of the drain should be strengthened and raised to prevent overflow. "Weep-holes" should be incorporated into lined drains so as to allow subsoil water from the surrounding land to find its way into the drain. Weep-holes should slope towards the bottom of the drain and should enter the drain just above the low flow level. Key walls should be constructed at right angles to the drain at intervals. These are particularly desirable where there is a curve in the course of the drain so that water from outside the drain may not tear away the earth supporting the side walls. Such key-walls should extend 15-30 cm into the ground below the bottom of the drain and it is important to provide weep-holes just up-stream of every key-wall. The side walls of wide drains can be almost vertical.

3.5 MEASUREMENT OF FLOWING WATER

Various means of measuring flowing water have been devised, ranging from highly precise devices or meters through which the entire volume of water must pass, usually with some loss, although with some devices this is ordinarily insignificant. Other methods have also been devised, including velocity meters and pitot tubes with which readings are taken at representative points across the stream, the cross section area of which is then measured as accurately as conditions will permit, and the quantity passing a given point per unit of time calculated by the formula \( Q = AV \), in which \( Q \) is the quantity in cubic measure, \( A \) is the measured or estimated cross section area of the stream, and \( V \) is the measured velocity per unit of time.

The velocity may also be measured with acceptable accuracy for many purposes by taking the time required for a chip or other object to float down a measured reach of the stream where its cross section is regular in shape and where turbulence and cross currents are at a minimum. Care must be taken that the object does not brush against the bank or against aquatic vegetation or other obstructions which would tend to retard its passage. A bottle or can partly filled with water so that it is nearly but not quite submerged makes a good float, for most of its area is exposed to the flowing water.

In the following pages the measuring of water flow in a V-notch weir and in a rectangular weir are inserted for convenience.

The flow of a small stream, i.e. a stream less than 60 cm deep and not more than 15 m wide, may be measured by means of the rectangular weir shown in Figure 7, page 37. With such a device, daily or weekly observations may be made of the flow over the year.
Figure 7. RECTANGULAR WEIR

Figure 8. CROSS SECTION DITCH FOR MOSQUITO CONTROL
NOTE: Over and under baffles, set 10 cm below top and 10 cm above floor of channel respectively, are to create stilling basins.

Rule or measuring stick may be nailed on inside of box with zero point or rule set the same distance off the channel floor as the notch in the weir plate.

A 2.5 x 7.5 cm board should be nailed over the top of the box near the weir to prevent spreading.

The box should be constructed of 2.5 cm lumber and all cracks should be made watertight. The underflow baffle could be made so that it could be adjusted in height off the floor as needed to prevent disturbance of the water surface at the weir. The weir plate should be heavy-gauge metal backed with 2.5 cm lumber.

Care should be taken to shore up the box so that the weight of the water will not cause structural failure. 5 x 10 x 10 cm timbers could be nailed to the under-side of the box with the ends extending to be used as handles.
These data may be correlated with the records of rainfall collected simultaneously. It may be difficult to set a dam across the larger stream and to prevent leakage around its edges. But, in many instances, great accuracy is not required. The following formula may be used for computing the discharge:

\[ Q = 1.838 \times b \times H^{3/2} \]

where

- \( Q \) = discharge, in cubic metres per second,
- \( b \) = length of weir, in metres, and
- \( H \) = head over crest of weir, in metres.

Approximate results may be obtained from the table on page 40 (Table 3).

For smaller streams, the flow may be measured by means of a V-notch weir of the type shown in Figures 9 and 10, pages 38 and 40, and the discharge may be obtained from the accompanying table. Daily or weekly measurements should be made over at least one year in order to gather a fair knowledge of the variations of flow in the stream.

For large rivers, it is necessary to measure at a fixed station the cross section of the stream and its mean velocity by floats or current meters in order to calculate the discharge. These measurements are beyond the scope of this work, being generally connected with large hydraulic projects.

4. PRACTICAL APPROACHES TO SOURCE REDUCTION

Source reduction operations range from extremely simple filling or ditching activities to highly complex reclamation-drainage-irrigation-water supply-land use programmes. As a malaria programme plans source reduction operations, it is logical to attempt the smaller, simpler tasks first, and as experience is gained, progress to more complicated operations.

4.1 FILLING

4.1.1 Small fills

In and near communities where malaria transmission is taking place, a high priority should be accorded to the filling of unused holes or other excavations which hold water serving as a habitat for Anopheles larvae. Included in this category are borrow pits, abandoned ditches, holes where trees have fallen, unused irrigation ditches, abandoned wells, etc. For the very small places, no particular engineering skill may be needed, only the intent to eliminate the mosquito source and the necessary input of labour and materials are required. Waste materials are often available which can be used for the bulk of the fill, but no fills should be left without being topped off with clean earth and the area then graded and left appearing as attractive as may be practicable. Where the area can serve a useful purpose after filling, a double gain will have been made.

The smallest places may be filled with no tools except hand shovels and hand barrows or wheelbarrows, but scrapers and bulldozers lessen the labour load greatly on larger areas. In places where machines are not available but beasts of burden are commonly employed, these may be substituted as motive power for small scrapers.

Fills, whether large or small, should always be graded in the direction of the general land slope so that water will run off in its natural direction and earth from higher land areas may be brought down into the low places to establish the desired grade.
Figure 10. DISCHARGE OVER A TRIANGULAR WEIR

\[ Q = \frac{1}{4} H^{5/2} \]

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<th>Depth (cm)</th>
<th>1/sec</th>
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Table 3. DISCHARGE IN L/SEC OVER A RECTANGULAR WEIR

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When fills are made where depressions extend below the ground water level so that water stands continuously before filling, the fill should be begun at the "up-slope" end, so that as the filling proceeds, the water will be pushed ahead of it towards the natural outlet.

4.1.2 Natural fills

A somewhat special case often occurs where there is frequent heavy rainfall so that ditches and streams which debouch on to low, flat areas tend to carry considerable amounts of silt. By appropriate planning, the silt may be trapped to create a "natural fill", in due course eliminating a swamp or intermittently flooded area. The process is much like that employed in hydraulic filling: the incoming silt-laden stream is diverted to discharge just above the low point of the area to be filled, and the outlet of the marsh or low area is restricted by temporary gates and levees as may be necessary to cause silt-bearing water coming on to the area to quickly flood over the low points, spreading out to form a "water dam" and immediately losing most of its initial velocity, so that the silt may settle to fill the lower portions. In such an installation, the dam at the lower end should be of a height no greater than the final elevation wanted, it should provide for overflows and it should have provision so that the normal "low-flow" of the ditch or stream can pass through continuously. The silt trap so constructed functions only at times of high flow when the water may be expected to carry more than the normal amount of silt.

The outlet gate may be made in the form of a vee, so that as the inflow increases, the outflow, though continuously restricted, gradually increases when the surface level of the settling basin increases, thereby accommodating the excess while continuously allowing the silting action to take place over the area to be filled.

The same technique may be employed when it is desired to desilt ditch or stream water which would otherwise result in unwanted settlement of silt in the waterway further downstream.

4.1.3 Large hydraulic fills

Very large areas can be filled in this way by means of hydraulic fills, by which large size specially designed centrifugal pumps (45 cm to 75 cm pipe size) on "suction dredges" suck up silt from the bottom of a waterway, carrying the silt suspended in water which moves at high velocity (usually more than 3 m/sec) through a pipeline, to finally debouch into a stilling and settling area at the outlet end of the pipe, where the fill is to be made. A hydraulic suction dredge usually moves only about 10% to 15% solids, but large size dredges move such great volumes that this may be the most economical way to obtain large fills. The smaller sizes are much less efficient, and probably no dredge smaller than the 20 cm diameter pipe size should be considered.

Projects of this kind are rarely attempted solely for malaria or mosquito control, but when such a project is implemented in connexion with the dredging of a river or harbour, arrangements may sometimes be made to have the soil deposited so as to eliminate a large source of Anopheles mosquitos. Many beneficial projects of this type have been accomplished in the industrialized countries (an outstanding example is the disposal of dredgings from the Panama Canal, which eliminated thousands of acres of difficult to control vector Anopheles breeding places).

As major land and water use projects are instituted in developing countries, elimination of malaria vector sources may be obtained if alert malaria personnel can guide the agencies carrying on the projects in the disposal of the soil.
4.2 DRAINAGE OF FRESHWATER OR UPLAND AREAS FOR MOSQUITO CONTROL

The drainage facilities for mosquito control may be much smaller and correspondingly much less expensive than for most other purposes. Urban storm water drainage facilities must have sufficient capacity to accommodate the maximum run off from roofs and paved areas, which occurs almost immediately when rain falls. Railroad and highway drainage must draw down the water table a few metres below the surface in order to stabilize the subgrade foundations, and farm drainage in wet areas must draw down the water table as much as 2 or 3 metres to remove water and salts from the root zone if some crops are to be grown successfully. By contrast, the drainage ditches for mosquito control need only remove the water from the surface of the ground within a period of a few days.

Very often the amounts of water to be removed are small. The water which remains in the bottoms of borrow pits along railroad or highway rights-of-way is not significant to the primary rail or highway operators; the few centimetres of water which remain as pools in the bottoms of unused irrigation or drainage ditches in farming areas is of no concern to the farmer; and water remaining during dry times in the street corner catch basins or siphon drains under streets is neglected by the city engineers; and temporary rain pools, seepages, springs, and swamps which occur in great variety on undeveloped lands are of little interest to anyone - yet these are in the aggregate very important sources which must concern mosquito and malaria control workers. Lakes and other large volumes of water tend usually, but not always, to be mosquito-free through naturalistic means, but smaller accumulations are those most often preferred by vector mosquitoes. Shallow margins of lakes, and large swamps, may be important exceptions and may require large areas of operations.

4.2.1 Small water accumulations

Among the more common and simple source reduction ditching operations are the drainage of temporary rain or run off pools which develop in depressions on sloping ground, or which occur below seepages or springs. Frequently these small places are drained by short ditches which carry the water downgrade to where it can spread out over a gently sloped area of pervious soil so that the water disappears underground. Alternatively, the ditch may lead to a stream or other outfall which carries the water away. If only a short ditch is needed, there may be little technical consideration of its actual capacity, its gradient, the slope of its banks, or the kind of soils through which it may pass. The size of the ditch, its location and shape may be dictated more by convenience of construction than by rigid engineering design. In many instances this may be quite acceptable, for the purpose is merely to provide an outlet for a small amount of water, and the ditch functions and may then go dry, not to function again till the next inflow occurs. The input of labour is minimal, and if the ditch should fail because of inadequate design, it can be improved with little cost when the time for maintenance comes round. Furthermore, if the capacity of the ditch is temporarily exceeded while run off is at a maximum, no great damage is done.

4.2.2 Large area drainage

Where large and long channels are to be constructed, the importance of good engineering design is increased in direct proportion to the cost of the installation. However, even in these systems, no great harm should result from exceeding the designed capacities for short periods when run off may be at a maximum, so long as the structures are not damaged.

In such situations, installations large enough to completely prevent the flooding of the swamp might have cost ten times as much, with no greater effect upon the mosquito population. The principle illustrated is that of practising economy by installing only the minimum structures which will obtain the desired results, so that the funds saved may be employed in solving other problems elsewhere.
The hydrographic data available for the area should be reviewed, and considered in the light of standard practice with respect to hydrology and flood control engineering. However for mosquito control purposes solely, more specific data will usually be available from local sources, yielding directly applicable data on the areas frequently flooded, the depth, and the length of time so that more precise calculations may be made for the drainage ditches required for mosquito control.

For depressions which customarily hold open water, the ditching system may draw water from the low point to the outlet by the most direct route. However, where there is dense swamp vegetation, or where considerable seepage or drainage comes from nearby higher land, the seepage should be picked up by interceptor or "contour" drains located along the edges of the swamp area. These may be installed after the main drain is functioning.

When ditching through wet or soft marsh soils is necessary, it is advisable to rough out the complete ditch system so that it can drain off most of the water from the area, and then delay the finishing and ditch bank grading until the soil has stabilized, perhaps several months later.

In general drainage practice, it is a rule of thumb that ditches should have a bottom width at least as great as the depth (usually greater), but in mosquito control operations it is frequently desirable to use a narrow bottom width and a vee cross section, so that when low flow periods occur, the flow will be confined to a narrow cross section, rather than developing a meandering channel in a bottom that is much wider than necessary for low flow periods. When this practice is followed, it is desirable that the side slopes be flatter than standard design to compensate for the greater opportunity for erosion which is presented when the flow is confined to a narrow cross section, and in order to increase the capacity rapidly as the depth increases with longer flows.

For very large capacity channels, where the narrow vee section cannot be used, a flat vee bottom with a narrow, subsidiary channel in the centre may be used. Where the velocity is not great when the main channel is flowing full, the narrow centre channel may be concrete lined, so that at low flow periods, the water will be free of emergent aquatic vegetation.

4.2.3 Major projects

The construction of source reduction projects involving large water accumulations and large structures may have great permanent effects on the local and downstream environment and ecology. These effects may extend far beyond the elimination of Anopheles vectors. Therefore, the planning and execution of source reduction projects on large water sources demands the application of standard hydrological and water control technology (Pickels, 1941 (23) and Boyd, 1949(3)) performed by fully qualified professional workers employing accurate specialized instrumentation. In these cases, improvisation is not sufficient, and full consideration must be given to the ultimate effects of the project upon land and water use in the area and downstream.

In planning a major project, the anticipated run off from the watershed above the project should be calculated (see page 30) taking into account seasonal variations in precipitation as well as the long range weather cycles. The results of the calculations or estimates should be compared with observed or measured inflow from higher land and the historical records of high waters in the area to be controlled. The effects of recorded flood periods upon downstream areas should also be investigated as a basis for assessing the probable effects of additional drainage.

The probable future land and water use of the area in question should be studied, for projects which permanently affect the environment should be designed so as to benefit the local economy. Most large sources can be eliminated or controlled in several ways;
analysis should be made to determine whether the particular source should be drained and reclaimed to agriculture or other productive use; whether it should be converted to a reservoir or lagoon, or whether the water should be conserved by diversion to a reservoir at a more suitable point above or below the site of the mosquito source.

Drainage of large areas

Where a decision is reached that drainage should be employed, a number of steps will be necessary:

(i) Determine the depth of the lowest point which must be dewatered; in some instances, the surface elevation of swamps may need to be lowered only a small amount to draw off from the shallow margins the water in which the vector mosquitoes breed leaving the deeper areas as open water which may be stocked with mosquito fish; conversely, in other locations raising the level by installing a low dam at the downstream end may flood the flat shallow margins so that mosquito production is eliminated by wave action and predators. Where only a small change is required, the water control works may be more economically constructed.

(ii) Determine by survey the location of a suitable outlet, at an elevation low enough to permit a drainage canal or ditch to be constructed which will have a satisfactory hydraulic gradient. The route the ditch should follow and the cuts and excavation that will be required should be determined at the same time.

(iii) Analyse the effect of the probable maximum and minimum flow on downstream water users, and on downstream vector production.

(iv) Determine what should be done with the spoil; on some large projects it can be used advantageously to fill the lowest points of the area to be drained, thereby lessening the required depth of the outlet channels; or it may be used beneficially for filling small locations which might otherwise require supplementary drains.

(v) Where deep cuts are needed, analyse the desirability of installing pipe or other conduits, or ditch liners to minimize maintenance. Also protect ditch banks where erosion may be expected to occur.

(vi) Where the ditch line will cut regularly travelled trails or roads, crossings should be provided. These should be ample to withstand anticipated maximum flow.

(vii) Where very high flood water conditions occur only occasionally, particularly if these occur only at a season when Anopheles vectors are not likely to develop, the principle of by-passing the excess flood flow through its natural route may be followed, so that the vector control drain need only accommodate the normal low flow conditions. Where such a system is installed, the low water flow structures must be separated from the flood overflow and protected by levees so that they will not be damaged by the high water flow. This is common practice in flood water areas. It can be accomplished most easily where the low flow is through enclosed conduits, but can also be provided for by open ditch systems where the low flow ditches are separated from the flood flows, and a control at the entrance limits the volume which can enter to the capacity of the waterway.

(viii) Plans must always be made for regularly scheduled maintenance of large area water control structures, for next to inadequate design, neglected maintenance is probably responsible for the failure of more drainage structures than any other cause. A little maintenance at the right time may prevent very costly maintenance if delayed until a failure has occurred.
Local manual labour versus mechanical equipment

Whenever operations can be performed as well and as economically by local manual labour as by the use of mechanical equipment, the former is to be preferred as this will have the advantage of stimulating the local economy. While the use of mechanical earth-moving equipment may prove economical on large construction jobs involving extensive earth-moving operations, in many developing countries, not only are local labour wages very low, but there is also much experience in the use of manual labour on construction jobs of considerable size and a surprising level of efficiency is attained. In all cases, the operations should be planned so as to make the maximum efficient use of local manual labour reserving mechanical equipment for use where this is technically or financially advantageous.

4.3 DITCHING OF COASTAL MARSHES

In coastal areas, the marshes which develop along the edges of bays and streams at the interface of the land and the tide water present a problem which differs greatly from the problem occurring in fresh water marshes. Coastal marshes are referred to variously as tidal marshes, tidal salt marshes, salt marshes and coastal marshes. To the casual observer they appear to be level and all more or less alike; but they are in fact very variable and the mosquito fauna also varies considerably and includes Aedes, Culex and Anopheles species, the total production of which may be extraordinarily high and result in the infestation of uplands many miles from the coast.

The marshes may be small, forming a very narrow band at the edge of the water, or very large, in some places more than 8 km wide, in the delta areas of great rivers which flow through low coastal lands and empty into shallow bays. Salt content in the water of the marshes may range from very little where fresh water rivers flow into them or where artesian wells occur, to more salt than the ocean where evaporation has concentrated the salt in the water of isolated pools.

Even the tidal effects from which the marshes take their name vary greatly. The open ocean may have a mean diurnal range between low and high waters of 1.5 m, while only a few kilometers away places at the head of long, shallow bays may have a mean range of less than 30 cm, and at other places nearby which are greatly affected by an inflowing river the range may be nearly 2 m.

The surface elevation of the marsh may also vary 30 cm or more over a distance as short as 300 m, due to accretion which is constantly occurring where the high tides bring silt-bearing water on to the marsh from a bay or stream. The marsh grasses trap the silt so that the area near the bay increases in elevation more rapidly than areas farther from the open water. At the upland interface, rainwater run off may bring silt on to the inland edge of the marsh so that it too increases in elevation. Some marshes therefore develop a saucer-like profile, and when overflowed by the higher high tides, the water is trapped in the low places long enough to mature a brood of mosquitoes. Smaller holes also develop in some areas of the marsh surface, and these may trap water brought in by normal high tides.

The vegetation of the marsh varies, from normally fresh water plants to those which can persist only in salt water. In local situations, there may be demonstrable relationships between the prevalence of certain plants and the occurrence of certain species of mosquitoes, but this phenomenon is not so firmly fixed that the plants can be used as an index upon which to predict without fail the occurrence of mosquitoes.

Generally the plants which form the salt marsh vegetation complex are deep rooted, and form a densely matted sod, mainly of organic plant material but trapping a percentage of the finely divided silt brought into the marsh by high tides. The sods when first cut in
ditching a marsh have a density (weight) greater than water, but upon drying will weigh substantially less than water so they may be carried away when a high tide floods over the marsh. Because the marsh sod is so firm, vertical walled ditches stand well with little erosion, and it is customary to build the ditches with vertical walls instead of sloped banks. This procedure also limits the growth of grass on the banks thereby lessening ditch maintenance.

4.3.1 Patterns of ditches on tidal marshes

Because marshes form by accretion of silt, which is trapped on the grass and on the surface of the marsh from high tides, and by the accumulation of detritus from decaying plants, they are in fact constantly changing, though so slowly that the changes may be inapparent. While marshes are often interlaced with an unpredictable pattern of curved streams of various sizes, there are sizeable areas between these natural waterways which have insufficient circulation or tidal drainage and it is to correct this situation that ditches are installed.

The surface of the marsh is not level; usually there is a band of higher land built up by accretion along the bays and along the main streams where more silt comes on to the marsh at high tide periods. It is therefore customary to lay out ditch patterns which will allow for drainage into the smaller waterways at the back of the marsh rather than creating outlets through the high marsh to the main streams or bays along the outer rim. Very often there will be a very low area at the edge of the upland, which calls for the construction of a "band ditch" (contour drain) at the junction of the mainland and the marsh. Emptying the dug ditches into the network of smaller waterways also tends to ensure that they will receive maximum velocity flow with the tidal prism, thereby tending to remain open, since most of the water flowing on and off the marsh must pass through them. If they are robbed of the flow by man-made ditches which by-pass the natural flow pattern, they will tend to become overgrown and silt filled. There may be considerable variation in the choice of outlets, and there are no firm rules to be followed.

The ditches on the poorly drained parts of tidal marshes are usually installed in one of two general patterns.

(i) A parallel system may be used, with the ditches spaced equally at the maximum spacing found by trial to provide good water control (usually 40-60 m apart on east coast marshes of the United States of America). These small lateral ditches are rarely less than 40 cm and may be 60 cm deep. They are often only 25 or 30 cm wide, and have vertical walls. Individual holes which do not drain well may be connected by means of short "spur" ditches, or the holes may be filled with sods taken from the main ditches.

(ii) In other cases, a primary "hole-connecting" system is used, the ditches running in random fashion from one hole to the next, finally outletting into a natural stream. Where machines are used for digging and cleaning ditches, the parallel system (with local modifications) is generally employed for convenience but where only hand work is done there would be little preference. It is customary to try to "work with" the natural pattern of water flow, instead of disregarding it.

4.3.2 Hand cut ditches

It is common practice, with special hand tools, to cut lateral ditches which are only 25 cm wide and 35-60 cm deep. The marsh grass, often 30-60 cm high, which grows on the surface of the marsh along these ditches will often fall across the ditch so as to form a mat so dense that one cannot see the ditch, although it may remain in good operating condition for many years. In one test area, such ditches were still functioning and had
a residual effective depth of 20-30 cm after 20 years without maintenance. However, normal maintenance schedules usually programme clearing of the ditches every third year, with accidental blockages removed every year. Ditches through very firm sods may last longer without cleaning, and through very soft areas, more frequent reconditioning may be necessary. Through average marsh sods, a three man team can cut 250 m x 25 cm x 50 cm ditch per day, using special spades and other tools (marsh spade, sod knife and 4-tined long handle hook).

4.3.3 Machine cut ditches

Special machines can cut similar ditches at speeds up to 450 m/h on good firm marshes, and clearing can be accomplished at even higher speeds. However, the average is much less, probably only 40%, because of the time lost in transport over and around natural streams which cannot be crossed by the machines except on bridges or barges. Main ditches on the marshes are much larger, may be cut by hand or by machines, and may last for several years or may require annual cleaning, depending upon local conditions.

4.4 SALT MARSH MOSQUITO CONTROL BY WATER CONTROL

Mosquito production on the salt marshes may be prevented or controlled by several systems.

4.4.1 Open marsh ditching to promote natural tide water circulation

Open ditches can be installed to permit the free circulation of high tides onto the low areas, and the drainage of water off the surface at low tides. This is the most used system on large open marshes, and is most effective where there is a considerable diurnal variation (60 cm or more) between mean low water (MLW) and mean high water (MHW). The system depends largely upon predation by naturally occurring or introduced organisms or mosquito fish. The pattern of the ditch system may be one of connecting low places or holes to each other and to a natural outlet, or one of installing a parallel system, with holes connected to the nearest ditch (see Figure 11, page 48). Where it is convenient to do so, soil from the ditches should be used to eliminate nearby holes by filling. This also removes the sods from the surface of the marsh so that they will not dry out and be floated away by a high tide, and possibly be deposited and block another ditch.

4.4.2 Induced tide water circulation

Circulation may be induced by installing one-way inlet tide gates of relatively small cross section at the inlet ends of open ditches, and one-way outlet gates of full ditch capacity at the outlet end. No levees are involved. When extra high tides flood over the entire marsh, the installations are completely submerged, hence they must be adequately protected by sheet piling, etc. This system may be indicated where ditches must be very long or where the diurnal mean tide range is small.

4.4.3 Shallow flooding of diked or leveed low marshes to a constant level

This is accomplished by means of one-way inlet gates installed in tandem with manual gates so that the system may function automatically when the manual gates are open, but may be cut off when so desired by closing the manual gates. The inlet installation allows replenishment of the water on the marsh whenever tides are high enough. The water on the marsh must be stocked with mosquito fish, which may occur naturally as the area is flooded, but must be provided by man if not by nature.

At the outlets, usually on the far side of the marsh, automatic outlet tide gates discharge excess water from rain, seepage, or any other source. A vertically adjustable gate or flashboards, in tandem with the automatic outlet gate, can be set to prevent
Figure 11. PATTERNS OF SALT MARSH DITCHING

Parallel system, hole connecting system and combined system. Also illustrating intercepting band ditch at junction of marsh and upland.
drainage below any predetermined elevation. This system can be used only where the marsh is low enough so that the high tides frequently reach a greater elevation than the desired water level on the marsh. It has been advantageously used on joint mosquito control - wildfowl refuge projects.

4.4.4 Impoundment or deep flooding to a constant level

The levees or dikes must be high enough so that they will not be topped by storm tides, and both strong enough and tight enough to prevent excess leakage or seepage while holding the water level a few metres above mean high tide elevation. Polyethylene or rubber sheets may be used in the levees to cut off leakage if good material for levees is not available. There must be a source of water which will allow the maintenance of a constant surface elevation a few metres above that of local MHW. This may be from a stream which comes on to the marsh from a higher level, or by the use of wind driven or other powered pumps. It is desirable that the levees be wide enough and gravel topped to carry maintenance vehicles or construction equipment. An adjustable spillway or gate must be provided so that excess water is discharged automatically to keep the surface elevation constant. Impounds of this sort are very effective for the control of Aedes mosquitos and for joint use as wildfowl preserves.

4.4.5 Reclamation for agriculture or for industrial and housing developments

This system demands that the marsh be enclosed by very secure levees that will not be breached by the most severe storms which could be expected to occur in the area, since the losses would be very high if the area were to be flooded. The tide gates, or pumps, required for dewatering the area must also be of sufficient capacity to prevent flooding of the area during storms or by run off which may come from higher land nearby. For agriculture, there must be an ample low cost supply of water for leaching and flushing. This may be rain, or fresh water from artesian wells, pumped wells, or a stream at a higher level.

When a tidal salt marsh is reclaimed in this fashion, by dewatering, it may be expected that the material composing the marsh aggregate will shrink and the surface elevation will be lowered. Where marshes of this kind have been reclaimed for many years, the elevation of the surface may be 3-4.5 m or more below local MHW, and if a levee is breached, the flooded marsh will become a veritable lake. As the marsh shrinkage takes place, it becomes more difficult to keep it dewatered, and the maintenance of the levees and other water control works become much more expensive than at first. If the reclaimed marsh is to be used for industrial or housing development, it is desirable that a deep layer of good quality fill be placed on the marsh as a foundation for the developments which are planned. Projects of this kind should not ordinarily be attempted solely for malaria but as a comprehensive approach towards vector control or agricultural or industrial development.

4.4.6 Differential flooding at high tide

Experienced marsh workers learn to recognize the lower areas by plant associations, and by observing the differential flooding which occurs when tidal elevations are at a maximum. This pattern is most evident if observed from a low-flying aircraft, but can also be clearly recognized on small areas when seen from the marsh surface. The small lateral ditches are almost always installed by eye and judgement, although instrumentation may be employed in locating the grades for large main ditches. Instruments should always be employed in establishing the lowest practicable grades for water controls such as tide gates, sluices, and pumps, in order to take advantage of the lowest tides which can be expected to occur. It is also essential to locate carefully the top elevation of dikes or levees, so that they may not be overflowed by extraordinarily high or storm tides. Usually the topographic and
predicted tide data are available from coast and geodetic survey agencies, related to permanent bench marks distributed along the coast.

4.4.7 Diked marshes

Where the daily tidal fluctuation is not sufficient to give good circulation, or where the marsh is to be utilized for other purposes, it is frequently cut off from the tides by dikes and the water drained off at low tide periods by tide gates (Herms & Gray, 1944(13)). This usually results in considerable change in the character of the marsh, its plants, and the wildlife. Shrinkage of the marsh surface also occurs as it is dewatered, and then it becomes more difficult to drain the water off, so pumps must be installed. Accordingly, dewatering projects should not be implemented without thorough study and recognition of all the implications.

4.5 BLASTING DITCHES WITH DYNAMITE

Blasting is a quick and economical method of construction of an open ditch in some soils. The method and equipment used are simple and can be easily adapted to conditions in malaria programmes. For soft, muddy soils underlaid by a firm strata or through heavily wooded swamps it is frequently economical. When blasting through wooded swamps, it is necessary to cut the trees which are in the line of the ditch, so that there will not be overhanging branches directly above the line. Extra dynamite sticks should be loaded under the tree stumps to shatter them. Also, a considerable cross wind must be blowing when the charges are detonated, for in still air, a considerable amount of the blasted material may fall back into the ditch. It is effective when ground conditions will not support vehicles or is too boggy to be shovelled. Where the surface of a marsh is characterized by having a tough, resilient sod, underlaid by nearly fluid, soft mud, blasting may not be satisfactory.

4.5.1 Dimensions of ditch

The dimensions of the ditch can vary from a depth of 75 cm to 3.5 m and a top width 1-12 m. Under favourable conditions 0.5 kg of dynamite will excavate about 1 m³ of material. Blasting of ditches has the following advantages:
- rapid completion of the job
- minimum equipment required
- simplicity
- minimum of spoil left along ditch
- low cost.

Caution: Only well-trained workers should be employed for blasting!

4.5.2 Two common methods of ditch blasting

There are two principal methods of blasting ditches:

(a) The propagation method can only be used in wet soils and is recommended because it permits shooting long sections of ditch and is economical of materials and labour. When the soil can be moulded in the hands so that it sticks together in a ball, it usually contains enough moisture for this method. Only one hole is primed and fired, and the shock or concussion detonates the next stick, and so on progressively down the line of charges, so rapidly that the explosions appear to be simultaneous. This method can be employed even when the marsh is covered with half a metre of water. The greater the amount of moisture, the greater will be the allowable distance between sticks of dynamite.
Under good conditions, single sticks of 50% straight dynamite may propagate well when spread 30-35 cm apart. However, propagation blasting should be preceded by test shots to determine the optimum distance for the particular soil and water condition.

(b) The electric method of blasting ditches is required in ground that is too dry for the successful use of the propagation method. An electric blasting cap must be inserted in every charge and exploded simultaneously by means of a blasting machine.

The dimensions of the desired ditch determine the spacing to be used in placing the dynamite. Four arrangements are commonly used:

- single line method
- cross section method
- post hole method
- relief method.

Except for the post hole method the dynamite cartridges are loaded one above the other in holes made with a suitable punch bar. In the post hole method the cartridges are placed in a bundle at the bottom of the hole.

Caution: Never use a metal tool to tamp the dynamite into the hole, use only wood.

Dynamite specially designed for ditch blasting is 50% straight nitroglycerin. It is packed in cartridges 3 cm x 20 cm with 104 cartridges to a 25 kg case. The cost is about US$ 30-40 per 50 kg.

4.6 FLUSHING SYSTEMS

The periodic, sudden discharge of a head of water sufficient to raise the surface elevation of the stream several centimetres as the "flush" passes by has been shown to be effective in controlling some vector species which characteristically occur in small streams (A. maculatus, A. minimus, A. fluviatilis, A. superpictus, A. culicifacies, etc.) The larvae as well as a large proportion of eggs, are stranded, damaged or killed by the buffeting of the rushing, turbulent wall of water, or sometimes merely carried beyond the limits of the protected zone.

In many cases the simple act of transporting the larvae by the flush beyond the protected area suffices for local disease control, even if the larvae are not killed. If simple transportation of larvae outside a protected zone is all that is necessary, the volume of the flush need not be great provided it gives sufficient variation in the stream flow to flush out all pools and eddies. The variation in flow above the flushing structure also appears to have a marked effect in reducing mosquito breeding.

An installation for flushing requires a reservoir which will accumulate a considerable volume of water, preferably at a place where there is considerable slope in the stream bed so that a high velocity will be attained quickly when the flush is released, and a device, either manual or automatic, to release the water quickly at the proper time. A large volume of water on a stream bed which has considerable slope will yield results for a long distance downstream. The efficacy of the system is reduced with smaller volumes and flatter grades, but may still be employed beneficially.

4.6.1 Flushing devices

Automatic devices are advantageous because they function as frequently as the
predetermined head of water is accumulated, but they are more difficult to construct and do require periodic maintenance. Good descriptions of these devices have been given by Boyd (1949) (3) and by Herms & Gray (1944) (13). Two types of automatic devices are described. The first employs a counter-weighted gate made in the form of a tilting bucket, which tilts and discharges when the weight of water accumulated overbalances the effect of the counterweight. The gate is kept open by the dynamic force of water flowing across it until the supply of water for the flush is exhausted; then the counterweight tilts the gate back to its "set" position, ready to begin accumulating water for the next flush. (See Figures 15 and 16).

The second type employs the self-priming siphon principle, and functions automatically when the reservoir fills. A siphon discharging 21.5 m³/min through a dam about 1 m high, with a reservoir capacity of 13.5 m³ is sufficient to flush a stream bed 60 cm wide, with a very flat grade, for a distance of 0.8-1.2 km. Other workers reported that the velocity in the stream bed should be at least 0.5 m/sec, and have given tables of the discharge areas of siphons necessary to control 1.6 km of streams of various widths and slopes.

The quantity and rate of flush should be regulated so as not to cause property damage along the stream or channel. Signs should be posted to warn persons passing along the stream.

The quantity stored above the dam, and the rate of discharge, should also be so regulated on streams or channels in alluvial or other erodible soils that the flush does not exceed the quantity carried by the stream under normal flood conditions. The purpose here is to avoid excessive erosion of stream banks.

If an automatic flushing device is used, it is desirable to place in the dam a manually operated sluice gate, which may be used to flush out silt and gravel accumulations above the dam; to pass at least a part of the excess flow during floods; and to discharge water at times of very low flows when insufficient water accumulates to operate the automatic devices on a sufficiently frequent schedule.

If the dam is of permanent construction an overflow spillway should be designed and constructed to prevent excessive erosion at the toe of the dam, which might cause its destruction.

Automatic flushing devices cannot be depended upon to operate continuously and effectively unless they are inspected at reasonably frequent intervals to see that the priming and sealing vents are clear, that debris is kept away from the inlet opening, and that the equipment is not tampered with by curious or malicious persons.

4.6.2 Design and operation of automatic siphon

Various types of automatic siphons have been constructed and used for flushing streams. Of these, the one of Legwen & Howard (1942) (16) can be considered as representative as it includes desirable features which were worked out with supporting data. It is of the inverted U-type. Its design features are shown in Figure 14 and its operation in the sealing, intermediate and discharge stages are shown in Figure 15. To start the siphon's operation it is essential that the sealing basin is completely filled as well as the priming vent up to the water surface in the basin. The full flow usually takes place in less than one minute from the release of air in the priming vent, and the siphon then effectively seals and resets itself in readiness for the next cycle.

The capacity of a siphon can be increased simply by increasing the width of the siphon's mouth or throat or by increasing the head. The table given in Figure 16 shows various
Figure 12. A wooden tilting bucket, counterweighted, for automatic flushing of small streams. Bucket in raised position, accumulating flush water behind dam.

Figure 13. A wooden tilting bucket, counterweighted, for automatic flushing of small streams. Bucket in lowered position, discharging flush water.
Figure 14. COMPARISON OF MACDONALD AND LEGWEN-HOWARD AUTOMATIC SIPHONS

Figure 15. DIAGRAMMATIC REPRESENTATION OF OPERATION OF LEGWEN-HOWARD AUTOMATIC SIPHON
Figure 16. MEASUREMENTS FOR SEVERAL SIZES OF LEGWEN-HOWARD AUTOMATIC SIPHONS

Figure 17. METHODS OF INSTALLING LEGWEN-HOWARD AUTOMATIC SIPHONS IN EXISTING DAMS OR WEIRS

<table>
<thead>
<tr>
<th>Min. head (cm)</th>
<th>Max. head (cm)</th>
<th>Fluct. head (cm)</th>
<th>Height head (cm)</th>
<th>V. Section</th>
<th>D. Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.16</td>
<td>49.53</td>
<td>39.37</td>
<td>97.79</td>
<td>34.29</td>
<td>7.62</td>
</tr>
<tr>
<td>30.48</td>
<td>70.48</td>
<td>40.00</td>
<td>118.74</td>
<td>55.24</td>
<td>27.94</td>
</tr>
<tr>
<td>60.96</td>
<td>101.60</td>
<td>40.64</td>
<td>149.86</td>
<td>86.36</td>
<td>58.42</td>
</tr>
<tr>
<td>91.44</td>
<td>132.71</td>
<td>41.27</td>
<td>180.97</td>
<td>117.47</td>
<td>88.90</td>
</tr>
<tr>
<td>121.92</td>
<td>163.83</td>
<td>41.91</td>
<td>212.09</td>
<td>148.59</td>
<td>119.38</td>
</tr>
</tbody>
</table>
siphon dimensions meeting different stream conditions. The capacity of discharge may be increased by installing more than one unit.

The construction may be precast concrete or poured in place on the stream or on the existing dams (see Figure 17, page 55) where it can be used for regular water fluctuation behind the dam.

4.6.3 Calculation of the amount and rate of flush in the stream

The following is the equation worked out by Worth & Subrahmanyam (1940) (43) estimating the amount and rate of flush required for a stream bed.

Let $Q = \text{rate of flushing in stream bed in cubic metres per second}$

$W = \text{width of stream bed in metres}$

$D = \text{depth of flow (average) in metres}$

$V = \text{velocity of flow, in metres per second, required to control mosquito breeding}$

$C = \text{average rate of discharge of one siphon in cubic metres per second}$

$M = \text{number of siphons}$

$K = \text{available quantity, in cubic metres of water stored in reservoir above the dam}$

$T = \text{total time of flush}$

Then $Q = WDV$

$Q = CM$

$T = \frac{K}{Q} = \frac{K}{CM}$

The velocity of flow, $V$, in the stream bed will depend on the average longitudinal slope (grade) of the stream bed and its roughness as primary factors, and also upon the quantity of flush and the shape of the cross section of the stream bed. In general, Ramsey & Anderson (1940) (24) found a velocity of 1.6 km/hr or 0.44 m/sec to be the minimum effective rate of flush; higher velocities will probably be found to be more effective.

For computing the velocities of flow in a stream bed channel, the simpler Manning formula may be used:

$$V = \frac{1}{M} R^{2/3} S^{1/2}$$

Where:

$V = \text{velocity in metres per second}$

$R = \text{hydraulic radius which is the cross-sectional area of flow (A) in square metres divided by the wetted perimeter (P) in metres of the cross-sectional area of flow (or the length of the perimeter of the cross section of the channel in contact with the water)}$

$S = \text{hydraulic gradient or the longitudinal slope of the stream bed (drop in elevation, in metres, divided by the length in metres)}$

$N = \text{a coefficient of roughness, which is calculated by experiments and for natural streams will range from about 0.030 for straight reaches with smooth sides and bottom, through about 0.055 for stony and gravelly bottoms, to as much as 0.150 for shallow streams with irregular bottoms and sides badly overgrown with brush and vegetation.}$
Improved streamlining of the interior, and the use of a 7 mm diameter sealing vent instead of the regular 21 mm one, has been tested and proved to increase the discharge by up to 60%.

Legwen has also modified his siphon to work on a minimum head of as little as 2.5 cm, by replacing the regular priming vent with another at a higher elevation connected through the cover of the siphon into the throat. In this manner very small flows can be used to actuate the siphon without leakage or flow-through (see Figure 18, page 58).

4.7 PUMPING FOR DEWATERING OR FLOODING

High capacity low-head pumps (see Annex 5) are used to dewater areas which are either below the low water level or where the grade is too flat to permit the drainage ditch system to function. A sump or collecting basin is dug deep enough to permit drainage. The size of the sump is governed by the flow, the capacity of the pump or pumps, and the desired frequency and time the pumps are to operate. Permanent installations of this type are used for:

- salt marsh reclamation projects
- extensive fresh water marshes
- flood control projects
- recirculation of agriculture irrigation water.

Portable pumps can be used for dewatering low areas filled only by winter or spring rains or flooded basements, vaults, etc., within the community. Non-clog pumps used by contractors for dewatering construction excavations are most suitable and are available in many capacities for various heads against which the water is to be pumped. Small, lightweight centrifugal pumps are also useful but their suction inlet must be protected by an adequate strainer to prevent clogging.

Portable pumps are usually driven by ordinary internal combustion engines and can be mounted on skids or trailers. Pumps mounted on vehicles can be driven by power take-off.

4.8 REGULATION OF WATER RESOURCES, USAGE AND DISPOSAL

A very large proportion of the sources of vector mosquitoes and pest mosquitoes also are created by the procurement, distribution and use of water for man's domestic and agricultural needs and probably most importantly by the method of disposal of the waste water. The prevention of breeding sources depends on how these facilities are constructed, maintained and operated. Since other agencies and individuals have the primary responsibility for these facilities, the source reduction programme will depend on their support. Information must be presented on how to avoid the creation of malaria vector habitats by the more efficient use of water resources. Plans must be developed with the assistance of conservation, water supply, sanitation, public works and agricultural agencies. The most difficult part of the source reduction programme is to secure the cooperation of the land and water users in the construction and operation of the proposed development.

4.8.1 Regulation at the source of supply

Regulation or control at the source of supply may avoid the creation of a mosquito source at some other location. Springs or flowing wells could be walled up to increase the head and to provide regulation of the flow to the amount needed (see Figures 19 and 20, page 59).
Figure 18. LEGWEN-HOWARD SIPHON MODIFIED
TO ACTUATE ON A SMALL FLOW
Springs can offer an economical and safe source of water. A thorough search should be made for signs of ground-water outcropping. Springs that can be piped to the user by gravity offer an excellent solution. Rainfall variation may influence the yield, so dry-weather flow should be checked.
4.8.2 Regulating irrigation water delivered to land

The use of water for the irrigation of crops requires proper land preparation and careful control over the quantity of water applied. Except for such specialized crops as rice, water which stands on fields for more than 24 hours after irrigation is of no benefit to crops. Irrigation practices which are optimum for crops (except rice) are also desirable for the control of mosquito production. Irrigated fields should be carefully graded, with a continuous slope (commonly 0.2% to 0.5%). The prevention of low spots is important, especially on soils that do not take water readily. It is practically impossible to apply only the optimum amount of water in irrigating a crop by the strip check method (see 4.8.3 below), and a drainage ditch at the low end of the field is required to remove excess water to a drainage ditch or to a sump where it can be collected and pumped back to the irrigation system for re-application until all of the water applied has gone into the ground.

4.8.3 Recirculation of waste water

The use of a return-flow system is a practical and economical method of conserving irrigation water and at the same time preventing water from collecting at the low end of the field or at some other location. The system consists of a sump at the low end of the field where the water is collected, a low-lift pump and a pipeline which delivers the water back to the irrigation system. The capacity of the sump depends on the size of the agricultural operations. It can be an open excavation, an enclosed sump lined with timber or large diameter concrete pipe or sections sunk in the ground. Pump capacities depend on the size of the sump and whether or not they are automatically operated. Electrically operated pumps can be started and stopped by a float operated switch and therefore operated in accordance with the water inflow. Internal combustion engine driven pumps must be manually operated and are usually larger in capacity to reduce dewatering time.

Large holding reservoirs have been successfully used for accumulating barn wash water on dairy farms. Reservoirs up to several hectares in area and 2 m deep have been constructed to hold from a few weeks to several months of waste water discharge. The manure-rich water is pumped to selected fields as desired for irrigation needs. The size of the return line varies with the distance to the nearest irrigation stand and the capacity of the pump. For a 40 hectare farm it is usually 5 cm in diameter.

4.8.4 Rotational spreading of waste irrigation water

If waste water can be spread on the surface of the ground in such a manner that it will evaporate, percolate into the soil or be taken up by transpiration within three days, no breeding will occur. This method applies where there is no irrigation facility to use the water or when the water is not suitable for the irrigation of crops.

4.8.5 Alternate check method

Small checks (rectangles) or plots of ground are enclosed by earth dikes to confine the water to a small area called a strip check. When the check is full the next check is used, permitting the first check to dry out. The quantity of water which each check can handle will depend on the climate and the porosity of the soil. With an adequate number of checks, none need be re-irrigated until it is dry. The water is distributed to the checks by a header ditch, a gravity pipe line, or by a small pressure line. The prevention of excessive weed growth is essential and can be accomplished by ploughing or discing when the checks are dry.
4.8.6 Furrow method

The same principle can be applied to a system of furrows constructed several hundred metres long and separated to prevent cross seepage. This system has been successfully used for the disposal of large quantities of sugar refinery liquid wastes (up to 5 million litres per day over a two month period).

4.8.7 Lagooning and oxidation basins

Large quantities of community or industrial waste water can be collected in properly prepared and maintained lagoons or basins to permit stabilization and clarification prior to being used for irrigation or disposal to a stream bed. The following construction and maintenance factors should be considered:

- minimum water depth of 100 cm
- steep embankments
- vehicle access road around basins
- width of basins limited to 30 m to permit spray applications for mosquito and weed control as needed
- complete suppression of weed growth on embankments and within ponds
- establishment of mosquito fish when waste water is sufficiently stabilized.

4.9 ENVIRONMENT MODIFICATION

Any change which may be induced in the ecological conditions favourable to the development of a target mosquito species which will discourage or eliminate that species is referred to as an environment modification. A change in the character of the water of the mosquito source or a change in the immediate surroundings may bring about the desired results. Examples of the environment modifications used in the control of malaria were summarized by Hackett et al (1938)(11). The following types have been successfully used:

- changing salinity content
- fluctuation of water level
- movement of the water surface
- flushing small streams
- additions of pollution
- providing or removing shade
- removal of marginal vegetation
- drying by planting trees

5. MAINTENANCE

Mosquito sources that have been eliminated by methods other than filling will require maintenance. The success of a source reduction project will depend on the adequacy of this maintenance. Features which commonly require maintenance or different types of surface water management are:

5.1 FRESH WATER MARSH DRAINAGE

- erosion of banks
- growth of vegetation
- artificial obstructions
- silting at low flow and on flat grades
- silting at ditch outlets

5.2 FREE FLOWING DRAINS AND DITCHES
- erosion of banks and bottom by flood flows
- silting after flood flows
- low flow ditch within large drain channels
- growth of vegetation
- artificial obstructions and debris

5.3 SALT WATER MARSHES

Open drainage type:
- drain ditches
- main drains

Reclamation type:
- dikes
- outlet structure
- tide gates
- drainage system
- ground cracking
- shrinkage

5.4 LAKES, PONDS AND SUMPS
- growth of weeds and vegetation at shoreline
- growth of floating aquatic plants
- water level management
- embankments
- floating debris
- mosquito fish

6. EQUIPMENT FOR SOURCE REDUCTION

For survey and planning of source reduction operations a surveyors' or marching compass will be required together with one of the three following sets of simple survey equipment:

- Farm level with compass and stadia, tripod, rod, steel surveyors' tape 30 m, or
- Plane table, tripod, alidade, rod, steel surveyors' tape 30 m, or
- Surveyors' hand level, metallic cloth surveyors' tape 30 m
6.1 SMALL DRAINS AND DITCHING EQUIPMENT

- *Square point spade, long handle (LH) for sod and firm soils
- *Square point shovel, LH
- *Round point shovel, LH for sand, gravel, soft soil
- *Round point shovel, short D handle (D) for sand, gravel, soft soil
- *Special heavy ditching spade, T handle, for salt marsh ditching only

(* = Step welded on top of blade to prevent cutting of boots or shoes. It may be of about 0.5 cm x 2 cm steel angle, or 2 cm iron pipe slotted one side, and welded over top of blade).

- Flat files 25 cm for sharpening shovels and spades
- Marsh knife, extended handle, for cutting sides of salt marsh ditches with deep sod only (e.g. Weymouth hay knife with extension welded in handle).
- Pick, for rocky soils
- Pick-mattock for rocky, root filled soils
- Bush hook
- Machete
- 4-tined LH hook for sod removal (e.g. potato hook, heavy)
- Chain saw, 60 cm blade, motor driven, for brushing and felling trees
- Small slip scraper for use with draft animals
- Small ditching plough for use with draft animals
- Large ditching plough for use with tractors
- Large scraper for use with tractor, which must be matched to scraper
- Small tractor, crawler type (e.g. Caterpillar D2 or equal).

(Note: some of the above items are optional, to be included only if usage is justified. This category includes the ploughs, tractors, scrapers and the salt marsh tools).

6.2 EXCAVATORS FOR PROJECTS TOO LARGE FOR ECONOMICAL ACCOMPLISHMENT BY HAND LABOUR

Crawler mounted excavators, capable of traversing soft soils, are generally used for drainage operations on medium and large source reduction projects. The highly adaptable crane type excavators are preferred, and may be equipped with any of several front-end tools, as follows:

- Back hoe firmly attached to an articulated boom; bucket is pulled toward base of machine by cable while loading
- Dragline with bucket attached to boom by cable; it is pulled towards base of machine while loading
- Dragline cableway with gravity return or tail-haul return is a special form of dragline, where the regular dragline digging bucket or a special bottomless "crescent" bucket is returned to the start of the digging cycle by means of a trolley cable or pull-back cable fastened to a fixed or movable anchor.
- Clamshell crane with distinctive excavating bucket attached to tip of boom by two supporting and operating cables
- Orange peel crane, similar to clamshell except for shape of bucket
- Shovel crane with digging bucket firmly attached to articulated boom, digs with bucket going away from base of machine while being loaded opposite to back hoe; particularly useful for loading trucks.

The back hoe works fastest on new ditches at regular sections but has limited reach or range, works well in firm soils as well as in soft soils. Generally preferred for small to medium sized ditches.

The dragline has a greater range than the back hoe, and is a very versatile tool in the hands of an expert operator. Much used in maintaining drainage works.

The dragline cableway has the greatest working range of any of the mobile crawler mounted cranes, but at long range has less precise control than the other tools. It is particularly useful for clearing swampy margins of ponds, where the excavator can work from a firm bank on the shoreward side with the anchor in the pond or on the far shore.

The clamshell crane and orange peel crane are useful for digging far below the level on which they are standing, and make vertical-walled excavations. The orange peel bucket is particularly well adapted to handling soft, wet soils, as when excavating from much below the water level.

The efficiency of the machines increases with size, but weight, cost, and the difficulty of moving to and from the job and over soft marshes also increases greatly with size, so most of the excavators regularly employed by mosquito control agencies are of the 0.3 - 0.5 m³ capacity, and these operate at 2-3 cycles per minute.

Crawler mounted continuous chain and bucket excavators work rapidly on excavating new ditches with vertical walls as for the installation of pipe drains. They are less versatile than the crane type excavators and are therefore less used in open ditch drainage.

For very large ditches, where the excavation can be kept dry and the width of the ditch is to be as great or greater than the width of the machine, crawler tractors with bulldozer blades and carry-all scrapers are highly efficient tools, and they allow the spoil to be transported quickly to some nearby place where it can be used for fill or grading. Size and power is important for efficiency and the equipment should be matched to the job. For average mosquito source reduction jobs, most agencies use machines equivalent to the D4 Caterpillar size or larger.

Tractor-drawn ploughs are also available, in many types and sizes, but these are useful mainly for smaller ditches, which they cut rapidly at great savings of labour. They are of little use in very soft, wet soils because in such situations they may have insufficient traction, or may bog down.

For salt marshes, special light weight machines have been designed or adapted, with larger than normal tracks or treads, which can operate on soils that support a loading of only 0.2 kg/cm². These have been of the plough type or the continuous bucket and chain type. At least one salt marsh ditching machine is commercially available, known as the scavel. It is a plough, for cutting new ditches in soft marshes or cleaning old ditches very rapidly up to a width of 45 cm, even under difficult conditions where the soils are so soft that there is no satisfactory way to do the work with hand tools.
# CHAPTER III - CHEMICAL CONTROL OF MOSQUITO LARVAE

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CHAPTER III - CHEMICAL CONTROL OF MOSQUITO LARVAE

1. INTRODUCTION

1.1 OBJECTIVES

The objective in malaria programmes is to suppress quickly or reduce to insignificant numbers the production of vector mosquitoes in areas within flight range of the human population to be protected. In malaria eradication it may complement drug administration and residual house spraying while in malaria control it may be the major programme element.

1.2 NEED

When a decision has been made to attack the vector mosquitoes at the source, it is essential that there be a method available which will permit the immediate destruction of the developing larvae, until more permanent measures take over complete control.

In malaria eradication larviciding is needed in areas where residual insecticides alone or together with the administration of drugs cannot yield adequate control. It may also have substantial uses in urban situations or in arid areas.

In malaria control, however, larviciding offers excellent possibilities of reducing malaria with limited means. It can be used as the sole measure or combined with the administration of drugs and judicious residual spraying when need be.

1.3 ADVANTAGES AND DISADVANTAGES

The advantages of chemical larviciding are that:

- mosquitoes developing in an aquatic habitat can be destroyed before they emerge and disperse into the areas inhabited by man
- operations can be programmed and executed within a very short time after the presence of the developing larvae has been discovered by inspection
- operations can be carried out effectively by hand labour, by machine, or by aircraft if very large areas must be treated quickly. By using the most modern technology, aircraft applications may be performed at very low cost by either fixed-wing small aircraft or small helicopters
- there is a large choice of pesticides, some of which may be locally available
- for hand application, equipment already available in malaria eradication programmes can be easily adapted, and the spraymen can be trained in the techniques of larviciding.

The disadvantages of chemical larviciding are that:

- the results are of a temporary nature, and a continuing programme could be costly in areas where there are a great many or very large sources
- all insecticides are toxicants, some exhibiting greater hazards than others, so field personnel must be trained in the special safety techniques required for the particular technology and materials employed.
2. MOSQUITO LARVICIDES

2.1 DEFINITION

A mosquito larvicide is a chemical used as an agent to destroy the larvae of mosquitoes. Similarly, insecticides lethal to the egg may be called "ovicides", those lethal to the pupae may be called "pupicides", and those effective against the adults or imagos are called "adulticides" or "imagicides". Some "larvicides" are also effective against the adults and pupae, but very few destroy the eggs.

There are larvicides, e.g. Flit MLO, that may kill mosquitoes coming to lay eggs on the surface of water. Also in space application some larvicides may also have a direct effect on adult populations.

2.2 DESIRABLE CHARACTERISTICS OF MOSQUITO LARVICIDES

Many chemicals can be used to kill mosquito larvae, but each is subject to limitations. The larvicide should be chosen for efficacy, economy, and safety to personnel and to non-target organisms. Desirable characteristics of a larvicide, not all of which are likely to occur in any one insecticide, are:

- high toxicity to mosquito larvae
- rapid and persistent action
- good dispersal qualities in the spray tank and in the water of the mosquito source
- readily obtainable locally at low cost
- safe and convenient to handle, transport and apply
- effective under the weather conditions anticipated
- effective primarily against larvae, and possibly against eggs, pupae, and adults
- effective in various kinds of water where larvae occur (brackish, polluted, acidic, alkaline, etc.)
- not toxic to non-target forms of life (man, food, fibre and ornamental plants, poultry, domestic animals, food fish and larvicidal fish, aquatic insect predators of mosquito larvae)
- good penetration of emergent aquatic vegetation and of debris on water surface
- effective when applied at low dosage rates; exhibiting the following characteristics: no intolerable residues in crops; no toxicity to wildlife and/or beneficial arthropods; no persistent pollution of water or environment; low operational cost.

2.3 CLASSIFICATION OF MOSQUITO LARVICIDES

Mosquito larvicides currently in use fall into three groups of chemical compounds, viz inorganic, natural organic and synthetic organic. A common method of classifying insecticides is based on the way in which the chemical enters the body of the insect. Thus, stomach poisons are ingested and absorbed through the alimentary system; contact poisons penetrate the body wall; and respiratory poisons (fumigants and volatile chemicals) enter the insect through the spiracles or breathing pores.

Figure 21, page 71 is an example of this classification system. Stomach poisons in present use are inorganic compounds while contact poisons are inorganic and organic compounds of natural or synthetic origin. Contact poisons such as the petroleum group
Figure 21. THE CHEMICAL CONTROL OF INSECTS

INSECTICIDES

STOMACH POISONS
Mode of action: must be ingested by insect; are absorbed through digestive system
Use: used as special-purpose pesticides, but no longer used as larvicides

FUMIGANTS
Mode of action: enter body of insect and are transported to target site via respiratory system, but are not necessarily respiratory poisons
Use: widely used as special-purpose pesticides; not used as larvicides

CONTACT POISONS
Mode of action: pass through body wall of insect

SYNTHETIC
ORGANOCHLORINE COMPOUNDS
Mode of action: neuro-muscular poisons; most act as both stomach and contact poisons, some also as fumigants
Use: formerly used widely as general insecticides; now greatly restricted, and not used as larvicides, owing to persistence in the environment and accumulation in food-chain organisms (see pages 73 and 107)

ORGANOPHOSPHORUS COMPOUNDS
Mode of action: inhibit cholinesterase, blocking transmission of nerve impulses
Use: widely used against adult insects; as larvicides.

CARBAMATES
Mode of action: similar to that of organophosphorus compounds
Use: widely used against adult insects; with a few exceptions, not effective as larvicides

PYRETHROIDS
Mode of action: neuromuscular poisons
Use: used for special purposes against adult insects; not used as larvicides owing to higher cost of the materials

ORGANIC

PETROLEUM PRODUCTS
Mode of action: are both toxic and suffocating
Use: widely used as larvicides

PYRETHRUM
Mode of action: neuromuscular poison
Use: has good larvicidal action but is expensive

ALKALOIDS
Mode of action: neuromuscular poisons
Use: a few are used as special-purpose pesticides, but they are not used as larvicides
as well as the various solvents for the chlorinated hydrocarbons and the organophosphorus compounds are volatile chemicals which may also act as respiratory poisons against the mosquito larvae. Also shown are some of the repellents, attractants, impregnants, and auxiliary chemicals used for insect control and in the formulation of insecticides.

2.3.1 Stomach poisons

The arsenical compound, Paris green, is an old and well-known anopheline larvicide. It is a stomach poison and was widely used until largely supplanted by DDT. Paris green is a general protoplasmic poison that is absorbed primarily in the mid-gut of the larva and therefore must be ingested to be effective.

2.3.2 Contact poisons

(a) Natural organic larvicides

(i) Botanical group

Pyrethrum and rotenone are natural organic larvicides derived from plant materials. They kill on contact. Pyrethrum is perhaps the oldest known and the safest insecticide commercially available. Volatile solvents are used to extract pyrethrum from the ground flower heads of several plant species of the genus Chrysanthemum. The usual commercial concentrate contains 2.5% pyrethrins. Insect sprays in deodorized kerosine contain only 0.1%. A highly refined and concentrated form used for aerosol formulations contains 20% pyrethrins. The addition of a synergist, such as piperonyl butoxide increases the efficacy of pyrethrins.

Allethrin is a synthetic insecticide similar to an important ingredient of pyrethrum and can be produced in much higher concentrations. It is considered to be one of the safer insecticides.

Rotenone is extracted from the roots of certain legumes and acts both as a stomach poison and as a contact poison. Although of low mammalian toxicity, it is highly toxic to fish.

(ii) Petroleum group

Petroleum oils are complex mixtures of natural organic chemicals which are classed as contact poisons when used as larvicides. The toxic effect on mosquito larvae and pupae is believed to result from penetration of the trachea by the more volatile toxic fractions, and by the more stable fractions interfering with air intake by the mosquito larvae.

Before synthetic organic larvicides were available, fuel oils and kerosine were applied at rates up to 500 l/ha to obtain fully satisfactory larval control. More recently the use of spreading agents has decreased the effective rate to less than 100 l/ha. The addition of new synthetic toxicants has further reduced the minimum rate to only 20 l/ha of fuel oil, applied by ground equipment. For spraying from aircraft using high concentrations of insecticide and low volume rates of application, diluents other than fuel oil are preferred.

Petroleum oils are frequently used as solvents or diluents for other insecticides. The physical properties of some organic solvents are presented in table 9 on page 80. When used in mosquito control the following chemical and physical properties of petroleum oils are important: viscosity; flash point; density; surface tension; odour intensity; and, sulfonation.
(b) Synthetic organic larvicides

(i) Chlorinated hydrocarbons

This group of compounds, of which DDT is the best known and most widely used, are so called because they all contain chlorine in combination with hydrogen and carbon. They vary widely in chemical structure and activity. Some are stable and long lasting, which accounts for their effectiveness as residual insecticides. Their ability to accumulate in the fatty tissues of humans, animals, fish and other living organisms makes their use as mosquito larvicides undesirable except under certain conditions. The ability of mosquitos as well as other insects to develop resistance to these effective and economical insecticides has also reduced their usefulness in many areas. These insecticides act as a central nervous system poison but the basic mode of action is not known. The toxicity of some selected chlorinated hydrocarbon insecticides to female laboratory rats are presented in Table 4.

Table 4. TABLE OF TOXICITY OF SOME SELECTED CHLORINATED HYDROCARBON INSECTICIDES TO FEMALE LABORATORY RATS

<table>
<thead>
<tr>
<th>Insecticide **</th>
<th>Acute dermal LD₅₀ (mg/kg)</th>
<th>Acute oral LD₅₀ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DDT SERIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DDT</td>
<td>2510</td>
<td>118</td>
</tr>
<tr>
<td>TDE</td>
<td>slightly irritating</td>
<td>2500</td>
</tr>
<tr>
<td>Methoxychlor</td>
<td>-</td>
<td>6000</td>
</tr>
<tr>
<td><strong>HEXACHLOROCYCLOHEXANE SERIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lindane (not less than 99% HCH)</td>
<td>900</td>
<td>91</td>
</tr>
<tr>
<td><strong>CHLORDANE SERIES</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlordane</td>
<td>530</td>
<td>430</td>
</tr>
<tr>
<td>Heptachlor</td>
<td>250</td>
<td>162</td>
</tr>
<tr>
<td>Aldrin</td>
<td>98</td>
<td>60</td>
</tr>
<tr>
<td>Dieldrin (not less than 85% HEOD)</td>
<td>60</td>
<td>46</td>
</tr>
<tr>
<td>Endrin</td>
<td>15</td>
<td>7.5</td>
</tr>
</tbody>
</table>

* Data largely from Gaines (1960)¹⁹

** See 4.1.3, page 93

(ii) Organophosphorus compounds

The insecticides of this group all inhibit the enzyme cholinesterase. This ability to interfere with the normal mechanism of nerve impulse transmission makes them toxic to man and animals. Most organophosphorus compounds are unstable when used as larvicides as they quickly hydrolyze in water. The more recently developed OP compounds are much less toxic to man, animals and fish and some are quite selective as insecticides. Toxicity ratings of selected OP insecticides as tested against female laboratory rats are presented by Table 5, page 74.
Table 5. ACUTE ORAL AND DERMAL LD $_{50}$ VALUES FOR FEMALE WHITE RATS OF 15 ORGANOPHOSPHORUS PESTICIDES

<table>
<thead>
<tr>
<th>Compound</th>
<th>Type $a$</th>
<th>Oral LD$_{50}$ (mg/kg)</th>
<th>Dermal LD$_{50}$ (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbaryl</td>
<td>C</td>
<td>500</td>
<td>&gt;4000</td>
</tr>
<tr>
<td>chlorpyrifos</td>
<td>OP</td>
<td>82</td>
<td>-</td>
</tr>
<tr>
<td>diazinon</td>
<td>OP</td>
<td>285</td>
<td>455</td>
</tr>
<tr>
<td>dichlorvos</td>
<td>OP</td>
<td>56</td>
<td>75</td>
</tr>
<tr>
<td>dimethoate</td>
<td>OP</td>
<td>245</td>
<td>610</td>
</tr>
<tr>
<td>fenchlorphos</td>
<td>OP</td>
<td>2630</td>
<td>&gt;5000</td>
</tr>
<tr>
<td>fenitrothion</td>
<td>OP</td>
<td>570</td>
<td>350</td>
</tr>
<tr>
<td>fenthion</td>
<td>OP</td>
<td>245</td>
<td>330</td>
</tr>
<tr>
<td>malathion</td>
<td>OP</td>
<td>1000</td>
<td>&gt;4444</td>
</tr>
<tr>
<td>naled</td>
<td>OP</td>
<td>250 $b$</td>
<td>800 $b$</td>
</tr>
<tr>
<td>parathion</td>
<td>OP</td>
<td>3.0</td>
<td>6.8</td>
</tr>
<tr>
<td>parathion-methyl</td>
<td>OP</td>
<td>24</td>
<td>87</td>
</tr>
<tr>
<td>temephos</td>
<td>OP</td>
<td>13000</td>
<td>&gt;4000</td>
</tr>
<tr>
<td>tetrachlorvinphos</td>
<td>OP</td>
<td>1125</td>
<td>&gt;4000</td>
</tr>
<tr>
<td>trichlorfon</td>
<td>OP</td>
<td>560</td>
<td>&gt;2000</td>
</tr>
</tbody>
</table>

* From the seventeenth report of the WHO Expert Committee on Insecticides (WHO, 1970 (40))

$a$ C = carbamate; OP = organophosphorus compound

$b$ For male rats

(iii) Organic thiocyanates

The insecticides of this group are not widely used in mosquito control although they are efficient contact insecticides which produce rapid knockdown. In solution in kerosene or fuel oils they may be used as larvicides, or applied by fog or mist machines for adult mosquito control. They are suitable for use in thermal fog generators as they are comparatively heat stable. The organic thiocyanates have a low toxicity to warm-blooded animals. Lethane and thanite are insecticides of this group.

(iv) Dinitro derivatives of phenol

Although toxic to mosquitoes these insecticides are not generally used in mosquito control because they possess objectionable characteristics. These compounds give a quick knockdown and death to certain insects. Action is reported to be caused by the increase of both carbohydrate and fat metabolism and the rate of respiration.

(v) Carbamates

The carbamates are generally poor larvicides. However, carbaryl is an effective larvicide at dosages in excess of 100 g/ha, and is therefore expensive for most applications. The mode of action is believed to be similar to that of the organophosphorus insecticides. The acute oral LD$_{50}$ for carbaryl is 850 mg/kg.
(vi) Phenothiazine

Phenothiazine has been used for larviciding in restricted places. It is effective when added to water stored in barrels used for fire protection. Recent trials have shown that phenothiazine 18.5% formulated with Tween 80 emulsifier is effective against Aedes larvae resistant to OP compounds at dosages of 0.5-1 kg/ha.

2.3.3 Respiratory poisons (fumigants)

There are no larvicides in use that act solely on the respiratory tract of mosquito larvae. The vapour of oils and solvents used as larvicides or as carriers for contact larvicides may have a toxic effect on the larvae, although the primary killing action is considered to be by penetration through the body wall.

Dichlorvos is an effective fumigant against adult mosquitoes and is used instead of larviciding in small confined mosquito sources, such as catch basins, water cisterns, etc. Liquid preparations have also been used experimentally as larvicides but are not available for practical field use.

2.4 SELECTION OF A LARVICIDE

A list of pesticides useful as larvicides is presented in Table 6 on page 76. Each of these may be considered in relation to its peculiar capabilities and limitations, as compared against the criteria previously cited as "desirable characteristics of mosquito larvicides".

Seven of these compounds have been used extensively in mosquito control, and are compared in Table 7 on page 77, with respect to dosage and costs. This table should be used with caution as it is based upon average availability, costs, and usage, and there may be wide local variations from the values cited.

It should be noted that the use of chlorinated hydrocarbons and other pesticides used in residual spraying is not recommended for larviciding in malaria programmes. All insecticides are in fact toxicants, and the use of each involves some element of risk or hazard, ranging from insignificant to high, and appropriate safeguards should be adopted in each case. Where people, domestic animals and wildlife, and plants are likely to be exposed in the treated area, the potential hazards should be considered in the selection. Generally it is desirable to use the material of lowest inherent toxicity where it is practical to do so. However, the manner of use greatly affects the hazard, and a selected material may have high inherent toxicity as a technical concentrate, but relatively low hazard as employed in an operational programme.

2.5 TOXICITY AND HAZARD

In the United States of America, currently millions of hectares of mosquito breeding areas are being treated safely with pesticides of high mammalian toxicity. The observance of proper techniques, the employment of trained personnel and the organization of effective and adequate supervision have been the principal factors for the safe use of these compounds. Although the toxicity of the technical material of most of these compounds is great, the hazard of using the dilute spray in a carefully executed programme is low, though in the mixing process strict precautions have to be taken. Exposure to the chemicals of personnel engaged in larviciding is markedly lower than in the indoor residual spraying of houses thus hazards are also lower. However, the operator applying larvicides must be taught how to take advantage of the air currents for ventilation of the immediate area in which he is applying pesticides, and must be aware that he may be using compounds of higher toxicity than those used for indoor residual spraying. Operational personnel
### Table 6. SOME CHEMICALS USEFUL AS MOSQUITO LARVICIDES

<table>
<thead>
<tr>
<th>By Name</th>
<th>OMS No.</th>
<th>By OMS No.</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>allethrin</td>
<td>468</td>
<td>1</td>
<td>malathion</td>
</tr>
<tr>
<td>bromophos</td>
<td>658</td>
<td>2</td>
<td>fenithion</td>
</tr>
<tr>
<td>bromophos-ethyl</td>
<td>659</td>
<td>14</td>
<td>dichlorvos</td>
</tr>
<tr>
<td>carbaryl</td>
<td>29</td>
<td>17</td>
<td>lindane (99% gamma-HCH)</td>
</tr>
<tr>
<td>chlorpyrifos</td>
<td>971</td>
<td>19</td>
<td>*parathion</td>
</tr>
<tr>
<td>chlorpyrifos, dimethyl</td>
<td>1155</td>
<td>75</td>
<td>naled</td>
</tr>
<tr>
<td>homologue</td>
<td></td>
<td>123</td>
<td>fenchlorphos</td>
</tr>
<tr>
<td>chlorthion</td>
<td>217</td>
<td>187</td>
<td>dimethrin</td>
</tr>
<tr>
<td>diazinon</td>
<td>469</td>
<td>193</td>
<td>heptachlor</td>
</tr>
<tr>
<td>dichlorvos</td>
<td>14</td>
<td>213</td>
<td>*parathion-methyl</td>
</tr>
<tr>
<td>dimethrin</td>
<td>187</td>
<td>217</td>
<td>chlorpyrifos</td>
</tr>
<tr>
<td>EPN</td>
<td>219</td>
<td>219</td>
<td>EPN</td>
</tr>
<tr>
<td>fenchlorphos</td>
<td>123</td>
<td>223,43</td>
<td>fenitrothion</td>
</tr>
<tr>
<td>fenitrothion</td>
<td>223,43</td>
<td>466</td>
<td>methoxychlor</td>
</tr>
<tr>
<td>fenthion</td>
<td>2</td>
<td>468</td>
<td>allethrin</td>
</tr>
<tr>
<td>HCH, gamma- (see lindane)</td>
<td>193</td>
<td>469</td>
<td>diazinon</td>
</tr>
<tr>
<td>heptachlor</td>
<td>193</td>
<td>658</td>
<td>bromophos</td>
</tr>
<tr>
<td>lindane (99% gamma-HCH)</td>
<td>17</td>
<td>659</td>
<td>bromophos-ethyl</td>
</tr>
<tr>
<td>malathion</td>
<td>1</td>
<td>786</td>
<td>temephos</td>
</tr>
<tr>
<td>methoxychlor</td>
<td>466</td>
<td>971</td>
<td>chlorpyrifos</td>
</tr>
<tr>
<td>naled</td>
<td>75</td>
<td>1075</td>
<td>phenthoate</td>
</tr>
<tr>
<td>oils (various)</td>
<td></td>
<td>1155</td>
<td>dimethyl homologue of</td>
</tr>
<tr>
<td>Paris green</td>
<td></td>
<td></td>
<td>chlorpyrifos</td>
</tr>
<tr>
<td>*parathion</td>
<td>19</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*parathion-methyl</td>
<td>213</td>
<td></td>
<td></td>
</tr>
<tr>
<td>phenthoate</td>
<td>1075</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pyrethrum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>temephos</td>
<td>786</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* The general use of these compounds is not recommended at present in antimalaria programmes (see pages 103 and 104)
Table 7. COST COMPARISON OF SEVEN COMMONLY USED LARVICIDES* BASED ON WEEKLY APPLICATION (EXCLUDING OPERATIONAL COST)

<table>
<thead>
<tr>
<th>Larvicides</th>
<th>Formulation</th>
<th>Approximate cost US$/1 or kg ex-factory</th>
<th>Recommended dosage 1 or kg/ha (active ingredient)</th>
<th>Approximate cost US$/ha treated</th>
<th>Approximate cost ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Oil (diesel oil) + 0.5% spreader (Triton x-100)</td>
<td>-</td>
<td>0.0441/1</td>
<td>80 1</td>
<td>3.5</td>
<td>0.2 3.7 16.3</td>
</tr>
<tr>
<td>2. Flit MLO</td>
<td>-</td>
<td>0.16/1 (USA)</td>
<td>18.7 1</td>
<td>3.0</td>
<td>13.2</td>
</tr>
<tr>
<td>3. Paris green</td>
<td>50% powder</td>
<td>0.75 kg (France)</td>
<td>1.5</td>
<td>6.6</td>
<td></td>
</tr>
<tr>
<td>4. Temephos (&quot;Abate 500-E&quot;)</td>
<td>EC 50%</td>
<td>6.5/1 (USA)</td>
<td>0.111 kg</td>
<td>1.44</td>
<td>6.3</td>
</tr>
<tr>
<td></td>
<td>SG 1%</td>
<td>0.4/kg</td>
<td>0.111 kg</td>
<td>4.4</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>CG 1%</td>
<td>0.57/kg</td>
<td>0.111 kg</td>
<td>5.7</td>
<td>25</td>
</tr>
<tr>
<td>5. Fenthion (special mosquitocide)</td>
<td>EC 50%</td>
<td>3/1 (Federal Republic of Germany)</td>
<td>0.111 kg</td>
<td>0.66</td>
<td>3</td>
</tr>
<tr>
<td>6. Chlorpyrifos</td>
<td>EC 48%</td>
<td>10/1 (USA and Europe)</td>
<td>0.056 kg</td>
<td>1.166</td>
<td>5</td>
</tr>
<tr>
<td>7. Parathion</td>
<td>EC 48%</td>
<td>12/1 (USA)</td>
<td>0.111 kg</td>
<td>0.227</td>
<td>1</td>
</tr>
</tbody>
</table>

* For any use information refer to "Field manual on antilarval operations" (WHO, 1969) (39)
1 Price in Jordan
2 USA market prices, include taxes and agent's commission
3 Sand granule
4 Celatom granule
5 This insecticide has not been recommended for use in antimalaria operations due to high mammalian toxicity
should fully understand the extent of the hazards, and how to avoid them. They may then proceed with confidence to use these effective materials so long as the precautionary measures are observed at all times. Nevertheless, highly toxic larvicides should not be applied in malaria programmes as long as other safer and effective larvicides are available.

Some of the organophosphorus larvicides have relatively high dermal toxicity (LD₅₀ for fenthion in rats and rabbits 330 mg/kg). In the commercial concentrate usually purchased for mosquito control (emulsifiable concentrate) the technical material is incorporated in solvents which might facilitate its entry through the skin. Therefore, any direct contact with the concentrate represents a serious hazard which should be avoided by carefully designed safety procedures, and only specially trained and protected responsible personnel should be permitted to handle or work with the concentrates.

Apart from the handling of the concentrate, the greatest hazard in normal operations is that of inadvertently allowing some fault in routine procedures to occur which may result in continual or frequent low-grade exposures, so that the damaging effects of the toxicant can accumulate over a long period of time. To detect such occurrences before serious harm can take place, all personnel who routinely handle OP pesticides should be subjected to periodic blood cholinesterase level determinations, and any individuals known to have had direct exposures should be given an immediate medical examination.

All personnel using any of the OP compounds must be thoroughly trained in their proper handling and application and in the emergency safety procedures which should be followed whenever exposures are known or suspected to have taken place. It is also important that routine safety procedures be established for the storage and transportation of these compounds.

In malaria programmes, it is only when field personnel have become fully conversant with the use of larvicides of low toxicity and have been further trained in the routine and habitual adherence to the safety protocols for the safe use of any OP compound, that consideration may be given to the use of larvicides of higher mammalian toxicity. Each programme should elaborate its own set of safety rules and procedural guides for the use of pesticides following the recommendations to be found in "Toxic hazards of pesticides to Man" (WHO, 1962)(31) "Safe use of pesticides in public health" (WHO, 1967)(38) and the Report of the Informal Group on the safe use of pesticides in public health programmes (WHO, 1967)(37). Reference should also be made to Annex 4 which gives a sample "Procedural guide and instructions for safe handling and use of pesticides", and to "Safe use of pesticides" (WHO, 1973)(42).

3. FORMULATIONS

The toxicants employed in mosquito larviciding are seldom applied in their original state but are mixed or dissolved in other materials or made into suspensions or emulsions.

The formulation of insecticides is necessary for ease of application, control of quantity, increased effectiveness and safety.

In formulating toxicants for use in larviciding, the following factors must be taken into consideration:
- rate, method and mode of application
- physical and chemical properties and toxicity of the pesticide
- conditions of breeding places and local mosquitos and environment
- cost
- solvent or carriers.
3.1 TYPES OF FORMULATIONS

The available insecticidal formulations can be divided into two categories:
- liquid formulations
- dry formulations.

3.1.1 Liquid formulations

The liquid formulations for mosquito larviciding are of three categories: solutions (toxicant + solvent + spreading agent); emulsions (toxicant + solvent + emulsifier); water-dispersible powders (toxicant + surfactant + inert matter).

(a) Solvents

A variety of solvents are used in solution or emulsion formulations. A spreading agent may be added to the solution to obtain better dispersal of the formulation on the water when used for mosquito larviciding. The choice of a solvent depends upon: phytoxicity; flash point; solvency of the toxicant; availability; cost; type and concentration of formulation desired.

In emulsions, the solvent and emulsifier must be compatible.

Solvents can be classified as follows:

(i) The aliphatics: diesel oil, fuel oils, mineral oils and kerosine (specific gravity 0.75-0.80) (see also page 89).

(ii) The xylene range aromatics: xylene, SoCal # 2, Toxicol B and Espesol # 5 (specific gravity 0.84-0.87)

(iii) The heavy aromatics: Panasol An-2 and Velsicol AV-55 (specific gravity 0.86-0.99).

The aromatics and heavy aromatics are most commonly used for formulating insecticides. Aliphatics are not good solvents for some insecticides and emulsifiers.

(b) Spreading agents

Spreading agents are oil-soluble organic compounds that are either unsaturated or have polar groups of molecules with strong affinity for water. They include some of the emulsifier compounds, such as Triton X-100 which is an effective spreading agent for oil at 0.5%.

Vegetable oils increase the spreading power of petroleum oils. The addition of 1% castor oil increases the spreading power of kerosine 25 times. The addition of excessive amounts of spreading agents reduces the spread. This point is of practical importance in formulating and using oil larvicides.

The natural spreading pressure of oils is due to small quantities of impurities such as sulphonation products. Resins are also known to increase the stability of oil films and the spreading pressure of oils.

The spreading pressure of some mineral and vegetable oils are shown in Table 8, page 80.
Table 8. THE SPREADING PRESSURE OF SOME MINERAL AND VEGETABLE OILS

<table>
<thead>
<tr>
<th>Mineral oils</th>
<th>(dyne/cm)</th>
<th>Vegetable oils</th>
<th>(dyne/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kerosine (refined) (b.p. 168° - 234°C)</td>
<td>7.5-13</td>
<td>Ground nut</td>
<td>18-21</td>
</tr>
<tr>
<td>Gas oil (b.p. 151° - 284°C)</td>
<td>13-18</td>
<td>Coconut</td>
<td>21-25</td>
</tr>
<tr>
<td>Diesel</td>
<td>18-21</td>
<td>Sesame</td>
<td>25-30</td>
</tr>
<tr>
<td>Malariaol (Shell)</td>
<td>18-21</td>
<td>Red palm</td>
<td>30-36</td>
</tr>
<tr>
<td>Malariaol + resin 0.5%</td>
<td>21-25</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Measurement of the spreading pressure of oils (WHO, 1973(41)) is performed with the help of a standard set of liquids with measured spreading pressure. Turpentine oil in medicinal paraffin (0.1-10%) is commonly used for this purpose.

The spreading power of an oil is indicated by the area of clean water which a unit quantity of the oil would cover if left to spread freely. This can be measured easily. In most oils the covering power is directly related to spreading pressure and inversely to the thickness of the oil film formed on the surface of the water. This is shown in Table 9.

Table 9. COVERING POWER AND SPREADING PRESSURE OF DIFFERENT OILS ON CLEAN TAP WATER*

<table>
<thead>
<tr>
<th>Oil</th>
<th>Approximate covering power, m² of water surface/1 cc of oil</th>
<th>Approximate thickness of film in microns</th>
<th>Spreading pressure (dynes/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diesel</td>
<td>25</td>
<td>0.04</td>
<td>21-25</td>
</tr>
<tr>
<td>Gasoline</td>
<td>35</td>
<td>0.30</td>
<td>13-18</td>
</tr>
<tr>
<td>Kerosine</td>
<td>35</td>
<td>0.30</td>
<td>13-18</td>
</tr>
<tr>
<td>Malariaol H.S.</td>
<td>15</td>
<td>0.07</td>
<td>30-36</td>
</tr>
<tr>
<td>Diesel 1 part, gasoline 10 parts</td>
<td>6</td>
<td>0.14</td>
<td>18-21</td>
</tr>
</tbody>
</table>

* Strength of the surface film on the water, 7.5-13 dynes/cm

The spreading pressure and the covering power of oils are affected by the degree of purity and organic content of the water. Highly polluted waters require oils with higher spreading pressure and covering power values.

(c) Emulsifiers or surfactants

Emulsifiers are compounds which reduce the interfacial tension between oil droplets and water, and also reduce the surface tension of water. This ability comes from the composition of these compounds which have a large oil-soluble group and a
water-soluble group in the same molecule. The oil-soluble group associates with the oil and the hydrophilic part of the emulsifier extends into the water causing dispersion of the oil in the water.

The classes of emulsifiers and surface-active agents commonly used in mosquito larvicides include non-ionic type esters, alcohol and esters of polyhydric alcohols and long chain fatty acids (Lewallen, 1952(17)). These can be classified as follows:

(i) Non-ionic emulsifiers. These present some difficulty in getting the toxicant into the water. The dispersion of the insecticide solvent is very slow. The formulation is stable and once the toxicant is in the water, it remains for a long time. This group of emulsifiers has the following features:
- improved emulsification in hard water
- improved emulsion stability at high use concentration
- improved performance in warm water
- improved ageing stability of the concentrate.

The stability of an emulsion and its relationship to the killing ability of a formulation has not been adequately classified. There has been very little or no experimental evidence to show that a stable emulsion gives higher mortality of larvae than a fast breaking one. With organophosphorus compounds which are generally unstable and which kill within the first few hours, stability of emulsion plays a rather unimportant role. But stability is an important factor in formulating stable insecticides where a residual action is sought.

Non-ionic emulsifiers include:
- Triton X-100
- Emcol H-500X
- Agrimul 70A

(ii) Anionic emulsifiers. These emulsifiers yield rapid bloom in water and quickly emulsify insecticidal solutions. The stability of the formulation, however, is very low and the emulsifier breaks rapidly. They have the following distinctive characteristics:
- improved action in soft water
- improved emulsion stability at low use concentration
- improved performance in cold water
- improved spontaneity

Emcol H-300X is an anionic emulsifier.

(iii) Cationic emulsifiers. These emulsifiers are usually phytotoxic. Their use for formulating mosquito larvicides is accordingly contra-indicated.

(iv) Anionic, non-ionic combinations. The features of anionic and non-ionic groups of emulsifiers described above suggest that a combination of the two groups should give the most suitable formulations for a variety of situations (Lewallen, 1952(17)).

Examples of such combined emulsifiers are:
- Agrimul N4R
Antarat 9184
Triton X-15

Table 10. EXAMPLES OF EMULSIFIERS USED WITH SPECIFIC INSECTICIDES

<table>
<thead>
<tr>
<th>Parathion Mixture</th>
<th>Malathion</th>
<th>Thiophosphates</th>
<th>Chlorinated hydrocarbons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triton X-155</td>
<td>Emcol H-141</td>
<td>Agrimul N4R</td>
<td>Emcol H-300 X</td>
</tr>
<tr>
<td>Triton B-1956</td>
<td>Toximul MP</td>
<td>Agrimul N4S</td>
<td>Agrimul A-100</td>
</tr>
<tr>
<td>Emcol H-500K</td>
<td>Agrimul WL</td>
<td>Atlok 3387</td>
<td>Igepal Co-430</td>
</tr>
<tr>
<td>Antarate 9184</td>
<td>Trilan X-155</td>
<td>Atlok 3335</td>
<td>Trigon X-100</td>
</tr>
<tr>
<td>Igepal Co-630</td>
<td>Atlok 3387</td>
<td>Mal 20A</td>
<td></td>
</tr>
</tbody>
</table>

(d) Emulsion

An emulsion is a suspension of droplets of one fluid in another with which it cannot normally mix. This is brought about with the help of emulsifier compounds. In addition, sometimes a proportion of light oil, such as mineral turpentine, is added to the formulation to keep the concentrate lighter than water so that it will form a film on the water surface and later sink to the bottom of breeding places.

An emulsion for mosquito larviciding should have the following qualities:

- lighter than water
- good spreading pressure
- good covering power (solvent)
- low volatility (solvent). Most toxicants are more toxic in solution form
- limited stability; extreme is undesirable; formulation should break to some extent when applied on water.

Compared with solutions, emulsions are less bulky and need less solvents; therefore they are cheaper and present less transportation and application difficulties. They are slightly more effective than similar solution formulations. They are much more effective than similar water dispersible powder (wdp) formulations (Lewallen, 1952 (17)).

3.1.2 Dry formulation

The solid formulation larvicides are usually a combination or mixture of insecticides with an inert carrier in the form of dusts, briquettes or granules. Other materials such as adhesives or surfactants may be added for better distribution or penetration.

Sometimes a liquid formulation is incorporated into or on to a carrier or vehicle of inert material to form granules.

"Microencapsulation" is a technique in which the droplets of insecticide are covered with a thin layer of water soluble polymer. This layer can be varied to regulate the release time.
(a) Dust formulations

Dust formulations are subject to drift which increases the loss of the material and the hazards of use. They have low penetrating ability and much of the material may rest on the vegetation without getting on to the water surface. In addition to the potential hazards to the environment from drift, the application of toxic dusts may also involve hazards to the operators.

(b) Granular formulations

Granular formulations are free from most of the defects of dust formulations and can be custom-made to specifications. They are gaining importance as the need for safer and more efficient formulations increases and as improved materials become available. They are therefore dealt with here in considerable detail.

Earlier granular formulations had a release rate of up to 20% only. This rate has been greatly improved. There are new formulations available which release up to 80-100% of the toxicant within 24-48 hours of application.

(i) Advantages

Granular formulations have the following advantages in mosquito larviciding as compared with liquid and dust formulations:

- better penetration through vegetation
- better distribution and more accurate coverage
- minimum residue problem on food and forage crops
- relatively safer for operations
- highly effective as pre-hatch treatments
- less weight/acre, which is particularly important in application from aircraft
- doubles operators' work rate.

(ii) Disadvantages

The principal disadvantage is high cost. Dry formulations of toxicants are generally 4-10 times more expensive than liquid larvicides (Mulla & Axelrod, 1961(22)). The cost has been reduced with new low-volume high-concentration formulations.

The cost of parathion in granular formulation is almost twice that of liquid formulations. Similar price differences occur with malathion, fenthion, DDT and dieldrin.

The cost of using parathion granular formulations is partly offset by:

- increased speed of application
- reduced weight/acre
- pre-hatch treatment
- simplicity
- inexpensive equipment.
(iii) Types of granular formulations

There are two distinct types of granular formulation available for different use and application (Mulla & Axelrod, 1961(22)).
- coated sand core granules
- the sorptive or impregnated type.

The coated sand core granules are heavier, safer to handle and produce a better distribution pattern. They also penetrate easily through vegetation. They sink rapidly and for Anopheline control should not be used in deep waters as they may fail to produce a satisfactory dispersion pattern.

The sorptive or impregnated types (Bentonite and Attapulgite) are lighter and give better dispersion. They are also suitable for low-volume, high-concentrate formulations. They are inferior to sand-coated granules in penetration and distribution properties due to their light weight.

(iv) Composition

Granular formulations usually consist of: a carrier; a solvent; a toxicant; a sticker or adhesive material; and, a surfactant or wetting agent.

The procedure for mixing is simple. The carrier is first introduced into a cement mixer or similar mixer. The sticker and wetting agent are then sprayed over the carrier while the mixer is in rotation. The liquid toxicant is added and the formulation is then dried for bagging and use.

(v) Solvents for granular formulations

The solvents used in making toxicant solutions for granular formulations have an important role in the release ability of such formulations. It is important to obtain quick kill so that the larvae cannot reach the pupal stage. It is essential that the major portion of the toxicant be released within a 24-hour period. This can be achieved and regulated by selecting an appropriate solvent for impregnation.

In petroleum solvents the speed of release of parathion increases with the decrease in flash point, initial boiling point, end point and distillation point of the solvent.

The following formula is used for determining the relative efficiency index (REI):

\[
\text{REI} = \frac{FP \times IBP (EB - IBP)}{10^5}
\]

where:
- \( FP \) = flash point
- \( IBP \) = initial boiling point
- \( EP \) = end point

Rapid release is obtained with \( \text{REI} = 1-20 \), slower release with \( \text{REI} = 20-70 \), and very slow release with \( \text{REI} = 70 \) and above.

Solvents with \( \text{REI} \) less than one are extremely volatile and involve fire hazards. For Panasol solvents, with known evaporation rates, the magnitude of release is inversely related to evaporation time. The above formula cannot be applied to chemically pure solvents, nor to solvents having flash points below 0°F.
### Table 11. PHYSICAL PROPERTIES OF SOME COMMON SOLVENTS*

<table>
<thead>
<tr>
<th>Solvent</th>
<th>Density (g/cm³)</th>
<th>Flash point (°C)</th>
<th>Solubility of DDT (g/l of solvent)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ORGANIC COMPOUNDS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetone</td>
<td>0.78</td>
<td>-10</td>
<td>572</td>
</tr>
<tr>
<td>Benzene</td>
<td>0.83</td>
<td>less than -6</td>
<td>774</td>
</tr>
<tr>
<td>Cyclohexanone</td>
<td>0.94</td>
<td>50</td>
<td>1156</td>
</tr>
<tr>
<td>ortho-Dichlorobenzene</td>
<td>1.28</td>
<td>75</td>
<td>584</td>
</tr>
<tr>
<td>Xylene (10 degree)</td>
<td>0.85</td>
<td>26 - 29</td>
<td>524</td>
</tr>
<tr>
<td><strong>Petroleum oils:</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fuel oil No. 1</td>
<td>0.82</td>
<td>less than 54</td>
<td>83 - 107</td>
</tr>
<tr>
<td>Fuel oil No. 2</td>
<td>0.85</td>
<td>54</td>
<td>71 - 95</td>
</tr>
<tr>
<td>Kerosine, crude</td>
<td>0.81</td>
<td>65</td>
<td>83 - 95</td>
</tr>
<tr>
<td>Kerosine, odourless</td>
<td>0.81</td>
<td>51</td>
<td>35</td>
</tr>
<tr>
<td>Stoddard solvent</td>
<td>more than 37</td>
<td></td>
<td>95</td>
</tr>
<tr>
<td><strong>OTHER HYDROCARBON SOLVENTS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bronoco Hi Sol No. 100</td>
<td>0.98</td>
<td>more than 121</td>
<td>345</td>
</tr>
<tr>
<td>Savacide 544-B</td>
<td>0.98</td>
<td>135</td>
<td>453</td>
</tr>
<tr>
<td>544-C</td>
<td>0.94</td>
<td>118</td>
<td>381</td>
</tr>
<tr>
<td>544-F</td>
<td>0.93</td>
<td>121</td>
<td>274</td>
</tr>
<tr>
<td>Umex 4060</td>
<td>0.93</td>
<td>98</td>
<td>274</td>
</tr>
<tr>
<td>Velsicol AR-50</td>
<td>0.96</td>
<td>110</td>
<td>548</td>
</tr>
<tr>
<td>AR-60</td>
<td>0.97</td>
<td>104</td>
<td>548</td>
</tr>
<tr>
<td>NR-70</td>
<td>1.04</td>
<td>148</td>
<td>512</td>
</tr>
<tr>
<td>NR-70</td>
<td>0.98</td>
<td>93</td>
<td>524</td>
</tr>
<tr>
<td>Water (for comparison)</td>
<td>0.99</td>
<td>none</td>
<td>trace</td>
</tr>
</tbody>
</table>

* United States Public Health Service (1962)\(^{28}\)
(vi) **Effects of storage on release**

Granular formulations prepared with highly volatile solvents have a slower speed of release of the insecticide (parathion) after storage of 10-21 weeks. Formulations prepared with solvents of low volatility show an increase in the speed of release while those prepared with intermediate range solvents show no marked difference.

The above phenomenon is considered to be the result of the distribution, retention and movement of toxicant molecules in the granular particles stimulated by evaporation of the solvent.

(vii) **Carriers**

The role of the carrier in the release of toxicants from granular formulations are generally known, though the role of various physico-chemical properties of carriers have not been fully studied. Physical properties such as formulation of colloidal suspension and the binding and absorptive forces of particles may greatly influence the release of toxicants.

Dieldrin on attapulgite and bentonite granules show markedly better control with the former carrier. Results with other toxicants on the same carriers are inconsistent. These studies show that different toxicants are likely to behave differently when formulated on various carriers. The following factors are considered important when selecting carriers for granular formulations (Mulla & Axelrod, 1961(22)).

**Degradation and deactivation of toxicant by the carrier.** Deactivators stay or slow down the decomposition of certain formulations during storage.

**Particle size.** An inverse relation exists between the particle size and the magnitude of release of parathion. The desirable range is 15-30 mesh materials. Smaller particle sizes, although more efficient, give poor distribution, toxic residue and drift problems.

**Sorptive capacity.** Highly sorptive materials (more than 30%) are necessary for high-concentrate formulations. Attapulgite, vermiculite, Pikes Peak, clay (montmorillonite), sercite and celite are suitable carriers in this group and may be used for low-volume high-concentration larvicides. Arrowhead Bentonite and Volclay KWK (both montmorillonite), calcium carbonate, Emtal, Frianite, Pynax, corncob and alfalfa granules have low to moderate (less than 20%) sorptive capacity and are suitable for ordinary mosquito larviciding.

**Shape and density.** Attapulgite, montmorillonite, celite and Frianite have roundish or ellipsoidal particles and suitable density to meet many of the physical requirements of granulation. Materials with flaky, angular and chippy surfaces are not suitable.

Calcination (drying at elevated temperature). Calcinated materials are usually firmer than ordinarily dried ones and withstand better handling and shipping.

3.2 **PERSISTENCE OF MOSQUITO LARVICIDES**

The persistence of larvicides and larvicidal formulations is an important factor to be considered when scheduling operations. Some larvicides exhibit long residual effect. While these formulations may be advantageous in remote areas where prolonged control of mosquitoes is intended, they are usually less desirable in ordinary mosquito larviciding where long persistence may increase the chance of toxicity to humans, wildlife and fish. They
may also cause persistent water contamination. Most of the organophosphorus larvicides and some carbamates disappear quickly from water. At the dosages applied in mosquito larviciding most of these materials lose over two-thirds of their initial concentration in the water in 72 hours. It is not known what part of the lost portion of the toxicants is stored in the soil and whether they are released subsequently.

Water contamination with larvicides is generally of a temporary nature. The major portion of these chemicals disappear from the water within 24 hours.

Parathion-methyl applied at 1 µg/l while highly effective against larvae, loses half its toxicity in less than two days after application (Mulla, 1963(21)).

The breakdown of toxicants in water is related to:
- light intensity
- wind action
- percolation rate of water through the ground
- micro-organisms
- organic matter
- numerous edaphic factors
- absorption in the soil colloids
- solvent emulsifiant
- temperature and pH of water

Carbophenothon at 55 g/ha gives maximum persistence in water at 10°C and 8.8 pH.

Chlorinated hydrocarbon insecticides, unlike organophosphorus compounds and carbamates have long residual effect and may cause persistent toxic hazards, water contamination, and environmental pollution. The residue problem is especially serious in areas where these insecticides have been used repeatedly in the past.

Residue determinations in treated lakes have shown that after three applications of TDE, plankton contained 17 ppm and the fat of certain fish up to 2500 ppm TDE.

Camphechlor applied in a lake at 0.2 ppm created residues of 92 ppm in plankton and up to 1700 ppm in the fat of a pelican within three weeks of the application. One year later the lake was safely restocked with trout. After another year, analysis showed 4 ppm camphechlor in the fillet of trout, evidently picked up by the fish from plankton.

DDT applied in rice fields at 165-330 g/ha for rice insect control resulted in residues of up to 2900 ppm in the fat and 400 ppm in the eggs of pheasants taken in the rice fields.

3.3 COMMERCIAL FORMULATIONS OF LARVICIDES

Most insecticides in use today are available in different types of formulations and each may be supplied in a variety of concentrations, usually stated as a percentage, or as a given weight per volume. (Example: DDT 5% dust; chlorpyrifos 400 g/l emulsifiable concentrate). The following types for formulation are commonly available:

(a) Technical concentrate. The greatest concentration of the active principle which can be made, stored, shipped and incorporated in other more dilute formulations on a chemically practicable basis,
(b) **Solution concentrate.** A liquid in which a known amount of the technical insecticide is dissolved. It can be diluted with suitable solvents such as kerosine, oil, etc. to form spray solutions of any desired strength.

(c) **Emulsion concentrate.** A solution concentrate to which emulsifiers in various combinations have been added to permit dilution with water to form spray emulsions of any desired strength.

(d) **Dust.** A finely ground form of the technical insecticide mixed with various proportions of any fine mesh dust such as talc or pyrophyllite.

(e) **Water dispersible powder.** A dust that has been treated with a wetting agent to permit quick mixing with water to form a water suspension.

(f) **Granules.** An inert carrier impregnated or coated with an insecticide which is released when applied to water. The carrier is usually a sorptive material like attapulgite, but may be grains of sand or other suitable mineral or non-mineral material.

Various uniform sizes of the finished granules are available but the 15-30 mesh screen size is usually used for larviciding. (The 15-30 mesh size granules are too large to pass through a screen having 30 wires per 2.5 cm, and small enough to pass through a screen having 15 wires per 2.5 cm, using wire of 30 I.S.W.G.)

4. **INFORMATION ON SPECIFIC LARVICIDES**

Specific information is presented in this section on selected insecticides. The characteristics of the active ingredient are summarized and some commercially available formulations are listed as examples. Names of manufacturers and approximate costs are given only for identification of the particular formulations described. Typical dosages and methods of application are presented to indicate the type of formulation which is best suited for a particular use. Toxicity and safety precautions are summarized.

4.1 **OILS AND ADDITIVES**

Petroleum oils were first recommended as mosquito larvicides (and as pupicides) by Dr L. O. Howard in 1892 and 1901. Since then, the use of oil larvicides has spread throughout the world, and a great variety of oils has been utilized. Some are highly effective, others have little value. Extensive research has been done, various specifications have been developed, and some specialized larvicides have been compounded. Other studies have shown how additives can be used to enhance toxicity or to improve their physical characteristics. They may be applied by hand equipment, vehicle-mounted power equipment and by aircraft. The toxicity of oils to mosquito larvae varies greatly, and some are effective at application rates as low as 9-18 l/ha. Some others must be used at rates of 450 l/ha or more. The usual application rate for effective oils is 45-90 l/ha, or where vegetation is dense, the amounts may be increased to 90-180 l/ha. Some oil larvicides are also effective herbicides, others have very low phytotoxicity.

The specifications of most petroleum oils intended for automotive use do not necessarily give a good indication of their larvicidal capacity; for example, "diesel oil 2" is widely used for larvicidal purposes, and some oils supplied within this grade are highly effective, others much less so. It is therefore important to evaluate the larvicidal effectiveness of the specific oil which is supplied and to adjust the application rate as necessary.
Oils kill by specific toxicity, and also by suffocation. The oil is drawn into the tracheal system of the larvae as it takes in air, and toxic oils kill very quickly. Larvae can live for a long time under a film of non-toxic oil, allowing increased opportunity for emergence of the mosquito should the oil film be broken or blown away by the wind. Some oil films remain intact and effective for several days, hence they may be said to have a residual effect. Others evaporate, break into globules, collect upon the edge of the pool or upon emergent vegetation and debris, or are blown by the wind to one side of the pool, and so may be considered non-residual. The more volatile oils tend to be more toxic but less residual. Hence, selection of a larvicidal oil is generally a matter of compromise between the factors of high toxicity and long residual effectiveness.

A mosquito oil must kill larvae and pupae within a short time after application. It must spread rapidly on the water surface in order to penetrate all the hiding places of the larvae and pupae. It must produce a uniform, unbroken film on the surface so that no wriggler can escape it. It must remain on the water for a comparatively long time in order to kill the newly hatched larvae and to prevent the adult mosquito from laying eggs.

Through efforts to improve larvicidal oils, substantial progress has been made in obtaining economies by reducing the minimum effective application rates: in 1935, it was common to apply fuel oil at a rate of 450 1/ha, but by 1965 equally good results could be obtained with 45-90 1/ha. Now specially compounded oils are effective at application rates of 9-27 1/ha, without the addition of dangerous toxicants. The lowered application rate also allows economies to be made in transport and application costs.

The oils most widely used are diesel oils, light distillate furnace and fuel oils, kerosine, and various fractions of crude oils. The physical characteristics of the various products vary widely, depending on the geographical origin of the crude petroleum from which they are obtained and the degree of refining to which they are subjected. Specifications for these products also vary widely, depending on the purpose for which they are to be used and the conditions (including season of the year) in which they are to be applied. Some of the most common oil derivates can be described as follows:

Gasoline, Naphta (boiling range 70°-150°C)

Kerosine (boiling range about 150°-300°C, specific gravity about 0.8) is derived from the light distillates obtained by the fractional distillation of crude petroleum.

Gas oil, fuel oils and diesel oil (boiling range about 250°-350°C, specific gravity 0.9) are some of the intermediate distillates.

Some partially refined fractions contain residual impurities which render them effective as herbicides, and these have been found to be also effective larvicides.

Many mixtures may be used to enhance toxicity, spreading persistence of the oil film, or other desirable features. Considerable success has been attained, particularly where local supplies of oil spread poorly, do not maintain an unbroken film, or are of a consistency which is difficult to spray. Some mixtures, with their dosage and application rates, which have been reported to give good results are as follows:
- Crude oil (heavy fuel oil) 70%, diesel 30%. Add 2% creosote as toxicant and 0.1% Triton X45* surfactant as spreader. Apply 50-100 l/ha.

- Crude oil 70%, diesel 30%. Add 2% creosote toxicant and 0.5% Triton X-100* surfactant as spreader. Apply 50-200 l/ha.

- Crude oil 50%, diesel 50%. Add 2% creosote as toxicant and 0.1% Triton X45* surfactant as spreader. Apply 50-200 l/ha.

- Diesel + 0.5% linseed oil. Apply 100-400 l/ha.

* Emulsifier-spreadder: Triton X-100 and Triton B 1956 have been widely used as spreaders for petroleum oils, usually at 0.5%. It is reported that Triton X45 and Triton X207 are better and can be used in smaller quantities. If used in too great volume, all will cause oil to emulsify with water in mosquito source. Many other emulsifier spreaders can be employed.

The physical properties of an oil considerably affects its capability as a larvicide and as an adulticide. These phenomena have been studied by many investigators. It would appear (Hagstrum & Mulla, 1968 [12]) that:

(a) The activity of petroleum oils as mosquito larvicides or pupicides varies with their aromatic and paraffin content and with their boiling range. (Viscosity appears to be a function of boiling point).

(b) Aromatic vapours are toxic and paraffin vapours are generally inert.

(c) The more effective larvicides are found in the fraction produced in the 232-316°C boiling range with a 1:1 mixture of aromatic and paraffin oils.

(d) The more volatile fractions have greater toxicity than the less volatile, high boiling range fractions.

(e) Increasing the amount of oil lengthens the period that it is active as a larvicide.

(f) Film life is long with paraffin oils, intermediate with intermediate fractions, and short with aromatics.

(g) Paraffins spread well and films persist until destroyed by evaporation; aromatics form lenses shortly after application.

(h) Loss of activity seems to be more closely correlated with the reduction of the area covered by the oil film than with the evaporation of the more volatile fractions.

4.1.1 Larvicidal oils

While training and experience in larviciding is accumulating, and while the more sophisticated materials are being field tested under circumstances common in malaria programmes, primary use should be made of oils, with spreaders and toxicants added for greater efficiency. Oils are not necessarily the lowest cost materials that could be applied, nor are the suggested application rates the lowest that will kill larvae under good conditions, but the material accounts for only a part of the total cost of the operation, and dependable results can probably be obtained more easily with oils in moderate quantities than with some of the low-volume materials, during the period when experience in larviciding is being acquired. As proficiency in larviciding is increased,
and as developmental studies demonstrate the ways in which the newer products can best be used safely in malaria programmes, these materials should be incorporated where they will produce better efficiency and greater economies.

There are several reasons for suggesting the use and development of oil larviciding: oils are readily available in some countries at relatively low prices, oil larvicides can be applied in most situations with the "Hudson" hand compression sprayers already available, with only slight modification. They are relatively non-toxic and easy to use since the areas treated are easily visible so that the operator and his supervisor can easily appraise the distribution pattern; they have some inherent residual value, which can be enhanced by fortifying the oils with toxicants and spreaders; and they are applied on the surface of the water where the Anopheles larvae spend most of the time.

(a) Specifications

Specifications for petroleum larvicidal oils vary greatly, and must be written in terms applicable in the petroleum industry, which do not necessarily represent precisely their effectiveness in killing mosquito larvae. As a result, the biological effectiveness of several oils may vary, even though each conforms to the best specifications which can be developed. Furthermore, the biological effectiveness of oils meeting the specifications may vary depending upon the area or even the well from which the crudes were obtained. Accordingly, the efficacy of each new lot of oil obtained should be evaluated in the field, under the local application conditions and procedures.

(i) Larvicidal oils without added toxicants

Specifications for larvicidal oils have been developed by WHO and are quoted in part as follows:

"Larvicidal oils without insecticide,. Specification WHO/SIP/23

"Material. The material shall consist of a mineral oil in the form of a homogenous mobile liquid, free from dirt, water, and other extraneous impurities. It may, if so specified, have additives incorporated to improve its physical performance. At the rates ordinarily used, it must not be toxic to fish, domestic animals, man, or plant life. Any additives used in the manufacture of the larvicidal oil shall comply with the requirements of the current approved specifications, where such specifications exist.

"Chemical, physical, and biological requirements. The material, sampled from any part of the consignment, shall comply with the following requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific gravity at 30°C/30°C</td>
<td></td>
<td>0.940</td>
</tr>
<tr>
<td>Distillation, volume distilling at 200°C</td>
<td></td>
<td>5%</td>
</tr>
<tr>
<td>Flash point</td>
<td></td>
<td>63.6°C</td>
</tr>
<tr>
<td>Kinematic viscosity at 21.1°C</td>
<td></td>
<td>10 centistokes</td>
</tr>
</tbody>
</table>

1 A sampling procedure is described in Method WHO/4/1 (WHO, 1973). However, this does not preclude the purchaser from sampling in any way considered desirable.
Spreading pressure

<table>
<thead>
<tr>
<th>Grade</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>46 dynes/cm</td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>25 dynes/cm</td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>18 dynes/cm</td>
<td></td>
</tr>
</tbody>
</table>

Stability of film

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 hours</td>
<td></td>
</tr>
</tbody>
</table>

Material soluble in water and oil layers

% by volume

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>2.5</td>
</tr>
</tbody>
</table>

Toxicity to mosquito larvae

Anopheles stephensi kill at 25°C
75% 

Aedes aegypti kill at 25°C
90% 

(ii) Larvicidal oils with other toxicants added

Additional specifications have been prepared by WHO for larvicidal oils with other toxicants added. These are also quoted in part, for although designed primarily to accommodate chlorinated hydrocarbon insecticides, they may also be used with pyrethrum or other toxicants.

"Larvicidal oils with added insecticide. WHO/SIF/24

"Material. The material shall consist essentially of a solution of a specified insecticide in a mineral oil, in the form of a homogeneous mobile liquid, free from dirt, water, and other extraneous impurities. It may, if so specified, have additives incorporated to improve its physical performance. At the rates ordinarily used, it must not be toxic to fish, domestic animals, man, or plant life. The technical insecticide and any additives used in the manufacture of the larvicidal oil shall comply with the requirements of the current approved specifications, where such specifications exist.

"Chemical, physical, and biological requirements. The material, sampled from any part of the consignment, shall comply with the following requirements:

<table>
<thead>
<tr>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.940</td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>65.6°C</td>
<td></td>
</tr>
<tr>
<td>10 centistokes</td>
<td></td>
</tr>
</tbody>
</table>

Specific gravity at 30°C/30°C
Distillation: volume distilling at 200°C
Flash point
Kinematic viscosity at 21.1°C
Spreading pressure:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grade 1</td>
<td>46 dynes/cm</td>
<td></td>
</tr>
<tr>
<td>Grade 2</td>
<td>25 dynes/cm</td>
<td></td>
</tr>
<tr>
<td>Grade 3</td>
<td>18 dynes/cm</td>
<td></td>
</tr>
</tbody>
</table>

Stability of film

2 hours

1 The nature and content of the insecticide shall be agreed between the purchaser and manufacturer at the time of placing the order.
2 A sampling procedure is described in Method WHO/M/1 (WHO, 1973 (41)). However, this does not preclude the purchaser from sampling in any way considered desirable.
Material soluble in water and oil layers
% by volume

Toxicity to mosquito larvae:

<table>
<thead>
<tr>
<th>Species</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anopheles stephensi kill at 25°C</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>Aedes aegypti kill at 25°C</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Insecticide content (w/w basis). The content of the insecticide shall not differ from the nominal content by more than ± 5%. The average content of all samples taken shall not be lower than the nominal content.

4.1.2 Toxicity of larvicidal oils

Most larvicidal oils cause skin irritation, the severity of which varies with the duration of exposure and the type of oil used. It may vary from mild reddening of the skin to the appearance of blisters, etc. On the other hand, the oils facilitate the absorption of toxicant additives through the skin and therefore measures should be used to protect the exposed areas of the skin when using oil larvicides.

4.1.3 Special petroleum larvicides

Most oils used in larviciding are fuel or diesel oils designed and primarily intended for other uses, but which have been found to have good larvicidal properties. However, some petroleum products have been modified and some have been especially compounded for use as mosquito larvicides. Several of these are described in this section, but this is not intended to constitute a specific endorsement. Other manufacturers may be able to supply products equally good or better. Prospective users should canvas suppliers who serve the area where the materials are to be used, and test samples of products which are offered.

(a) Analos II (a product of Associated Oil Company, United States of America). This is similar to diesel oil but not so highly refined, and contains residual components which are toxic to plants and to mosquito larvae. It is sometimes used as a herbicide, and yields both larvicidal and herbicidal benefits when sprayed in grass-grown ditches. It should be used at the same rates as diesel oil, but should of course not be used where there are valuable plants which might be damaged. The cost is 20-30% less than for high grade diesel oil.

(b) Richfield larvicide oil (a product of Richfield Oil Company). This is a dark, somewhat acrid oil, with a spreader added. It is quite phytotoxic and contains principles toxic to mosquito larvae. On clear open water it can be used at lesser dosages than diesel oil, and is somewhat toxic to plants and therefore a good product to use on grassy ditches which must be larvicided. It should not be used where there are valuable plants which might be damaged. Cost is about 20% lower than diesel oil. In general, it is used at about the same rates as diesel oil, with the exception noted.

(c) Flit MLO (a product of Humble Oil Refining Company). This is a light coloured, clear petroleum product compounded especially for mosquito control. It is non-toxic to warm blooded animals and possesses exceptional freedom from phytotoxicity. It can be used safely where agricultural plants or ornamental plants are grown. It has been used successfully at 9 l/ha on susceptible larvae in some areas, but under more difficult conditions (irrigated pastures) and on O.P. resistant larvae in California 18-19 l/ha or more was required for reliable control when applied operationally.
by aircraft. The cost is relatively high. It has been found satisfactory for use in
ditches and other sources in residential areas where its freedom from toxicity and
objectionable staining justifies the use of a premium material. In close systems such
as catch basins and lined street gutters, it exhibits residual benefits over a period
of several weeks.

(d) Low cost oils. In some oil producing countries, various crude oils may be
available at very low costs to the malaria programme. Without additives,
these may not spread well so that excessive quantities may have to be used, and the
gain in original low cost may be offset by extra transport or application costs.
However, this disadvantage may be largely overcome by mixing the crude oils with other
oils of lower viscosity and adding a spreading agent. Trials have been reported with
several combinations, as shown in Table 12 below. 70% heavy furnace oil (crude)
mixed with 30% light diesel oil, plus 0.5% Triton X-100 emulsifier gave the best results
with virtually complete control of Anopheles larvae under field conditions: the amount
of oil needed was successfully reduced from about 180-190 1/ha to about 37.5 1/ha, the
costs were reduced by about 75% for the oil alone, and further savings in labour and
transport were also made.

<table>
<thead>
<tr>
<th>Mixture of oils</th>
<th>Triton X-100</th>
<th>No detergent added</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12 h</td>
<td>24 h</td>
</tr>
<tr>
<td>80% F</td>
<td>83%</td>
<td>80%</td>
</tr>
<tr>
<td>20% D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>70% F</td>
<td>90%</td>
<td>88%</td>
</tr>
<tr>
<td>30% D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>60% F</td>
<td>85%</td>
<td>86%</td>
</tr>
<tr>
<td>40% D</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50% F</td>
<td>78%</td>
<td>80%</td>
</tr>
<tr>
<td>50% D</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

F = heavy furnace oil  D = diesel oil

4.2 PARIS GREEN

Technical grade Paris green is supplied as a finely ground green powder, containing
90% (aceto)trimetaarsenitodicopper ("copper acetoarsenite"). It is practically insoluble
in water, but floats well on the surface. Copper II arsenite ("Scheele's green") is
currently used by some manufacturers in granule formulations.

Paris green is a stomach poison and to be effective must be ingested by the larvae.
The surface feeding habits of the Anopheles larvae allow them to ingest the dust particles
floating on the surface film of the water. Bottom feeding larvae are also killed by
ingesting Paris green applied as a special granular formulation.
4.2.1 Toxicity

Although Paris green has LD₅₀ ratings of 100 mg/kg oral and 2400 mg/kg dermal to white rats, it has a long standing record of safety for fish, wildlife, domestic animals and man, probably because of the way in which it is used. Granular formulations are practically free from dust and therefore minimise the slight practical dust hazard to the spray operator.

4.2.2 Formulations

(a) Dust: 50% Paris green mosquito larvicide (cost $1.10/kg)

(b) Granule: 10%, 30 mesh vermiculite, with Paris green or Scheele's green

(c) Paris green - kerosine - water mixture

(d) Experimental suspensions: described as a dispersed Paris green and as a deflocculated Paris green

(e) Custom made formulations: Two formulations are recommended, both suitable for aircraft. Lightweight No. 1 weighs about 300 kg/m³, while Heavy No. 2 weighs about 34% more, viz. 413 kg/m³. A large percentage of the particles in the heavy formula sink to the bottom when applied to water, then rise to the surface again. The lightweight formula has some weight advantage for ground application by field men. The basic formulae are as follows:

**Formula No. 1 - Lightweight**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermiculite</td>
<td>35 kg</td>
</tr>
<tr>
<td>Emulsifiable oil</td>
<td>45 kg</td>
</tr>
<tr>
<td>Powder</td>
<td>20 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100 kg</td>
</tr>
</tbody>
</table>

**Formula No. 2 - Heavy**

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vermiculite</td>
<td>23 kg</td>
</tr>
<tr>
<td>Emulsifiable oil</td>
<td>42 kg</td>
</tr>
<tr>
<td>Powder</td>
<td>35 kg</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>100 kg</td>
</tr>
</tbody>
</table>

Vermiculite: 16-40 mesh size (US), approximately

Emulsifiable oil: Horticultural-type spray oil with 3% Triton

Powder: A combination of commercial grade Paris green and a heavy inert dust, like calcium carbonate of similar particle size and weight. Marble dust, a by-product of the marble industry, is a satisfactory diluent.

The proportion of Paris green used in this combination for either formula may be varied to adjust the strength of the finished granule. The formulating procedure is as follows:
(i) Mix by volume 97% oil and 3% Triton N-101 in the required amounts.

(ii) Place the required amount of vermiculite in a rotating drum and with the drum in motion spray on the corresponding amount of oil-Triton mixture. Agitate the oil-Triton mixture being sprayed to ensure that the Triton cannot separate and settle.

(iii) Add the marble dust and mix well.

(iv) Finally, add the required amount of Paris green powder.

(v) Allow to mix until uniform colour is attained (usually three to five minutes), then bag. No drying is required.

Note that the marble dust and Paris green are added separately, the Paris green being added last, and that the full amount of each powder should be added at one time, instead of in smaller quantities. It is not necessary to blend the marble dust and Paris green before putting these powders into the mixer. For example in making 100 kg of heavy 5% granular Paris green granules, the following steps should be taken in order: first the emulsifiable oil is sprayed on the vermiculite; then 29.3 kg of marble dust is added and allowed to mix well; then 5.7 kg of 90% Paris green is added separately and blended well.

To make a formulation containing more than 5% Paris green, simply increase the proportion of 90% Paris green per 100 kg batch to give the desired strength in the finished product, and reduce the quantity of marble dust proportionally so that the total amount of powder used in each 100 kg remains the same as shown in the basic formula.

4.2.3 Use directions

Dosage and method of application: A dosage rate of 1 kg/ha actual Paris green is normally used to control Anopheline larvae. Dust application may be by hand casting, by hand or power operated ground equipment or by aircraft. The application rate depends on the equipment used, and the percentage of Paris green must be varied accordingly. For aircraft application, a 25% dust at 4.5 kg/ha has been used. Water dispersible powders are not suitable for use on sources with dense vegetation because of the high percentage of loss on foliage. For fairly open water, a 5% wpd applied at 17 kg/ha is recommended. The use of 5% granules at 17 kg/ha applied by aircraft is recommended for penetration of dense vegetation for the control of Aedes taeniorhynchus. The effectiveness of Paris green granules on Anopheles larvae has not been confirmed in the field.

4.3 TEMEPHOS

Technical grade temephos is a brown, viscous liquid which is stable indefinitely at room temperature and moderately stable to hydrolysis in contact with aqueous alkali. It is soluble in aliphatic petroleum solvents to only 1-3%, but it exhibits good solubility in petroleum solvents which have an aromatic content of at least 85%. It is therefore suggested that one part of temephos be mixed with two parts 85% aromatic solvent as a co-solvent, and that this mixture then be diluted with kerosine or light fuel oil to the final concentration desired. Temephos larvicides have given good results in field applications in South and Central America.

1 O,O’-(thiodi-p-phenylene)-O,O’,O’-tetramethyl phosphorothioate (OMS-786)
   (temephos - ISO proposed name for Abate)
4.3.1 Toxicity

Temephos is an organophosphorus compound characterized by its very low toxicity to warm blooded animals. It has LD$_{50}$ values to female white rats of 1300 mg/kg oral, and more than 4000 mg/kg dermal. Its low toxicity to fish, birds, mammals and other non-target organisms, combined with an effective dosage rate of only 55-110 g/ha against susceptible larvae, make it an acceptable larvicide for use in a great variety of situations. It is suitable for the treatment of potable water, thus providing a means of treating mosquito larvae in drinking water supplies at a dosage rate not greater than 1 ppm. Field studies indicate no effect on rainbow trout, Gambusia or other common aquatic organisms at dosage rates used for mosquito control.

4.3.2 Formulations

Various standardized preparations are available commercially. Custom made formulations can also be compounded on special order. The standardized products include:

(a) Emulsifiable concentrates: Temephos insecticide 500E, containing 50% (w/v) emulsifiable concentrate (cost $6.5/litre); Temephos insecticide 200E, containing 20% (w/v) emulsifiable concentrate.

(b) Dilute solutions: Temephos 200 oil solution (cost $2/litre)

(c) Dusts: Temephos 50% water dispersible powder, containing 50% temephos.

(d) Granules: Temephos 1-SG sand core granules, containing 1% temephos; temephos 1-CG celatom granules, containing 1% temephos.

4.3.3 Use directions

Temephos may be applied as a larvicide by injection (drip system devices), by hand or power sprayers, or by normal volume or low volume aircraft devices. The application rates and dilutions should be adjusted to give final dosage rates of 55 g/ha of the active ingredient on relatively clean open water, to 110 g/ha where there is dense aquatic vegetation. Granular applications are more effective than liquid sprays over densely vegetated sources. On highly polluted water accumulations, dosages up to 550 g/ha may be necessary.

Temephos is less effective as an adulticide, but can be combined with malathion when both larvicidal and adulticidal effects are needed from the same application.

Temephos has been successfully tried and used in antimalaria programmes. Its large margin of safety and the low dosage applied makes this compound the larvicide of choice for Anopheles control. It permits the treatment of any water and reduces logistic, organizational and operational requirements and costs. At the usual dosages of 0.5-1 ppm (50-100 g/ha) it has been very effective against A. stephensi and A. claviger in wells and cisterns in India and Syria, against A. pulcherrimus in rice fields in Afghanistan and and Iran, and against A. sergenti and A. superpictus in the Jordan river and its tributaries in Jordan.
4.4 FENTHION

Fenthion is a brown coloured liquid with a specific gravity of 1.245 and a boiling point of 105°C. It is soluble in most organic solvents but insoluble in water. It is stable under normal use conditions but subject to hydrolysis. It is compatible with most insecticides and fungicides, except alkaline materials. Fenthion kills larvae on contact, by penetration through the body wall.

4.4.1 Toxicity

Fenthion is an organophosphorus compound which inhibits cholinesterase and repeated over-exposure, however small it may be, may cause a dangerous degree of cholinesterase depression. It has a relatively high dermal toxicity to rats (313 mg/kg body weight). The oral LD₅₀ for male white rats is 215 mg/kg. It is appreciably more toxic to avians than to mammals. The acute oral LD₅₀ values are 15 mg/kg and 30 mg/kg to ducks and chicken respectively. It is also highly toxic to bees exposed to direct treatment or to residues on crops. On the other hand, mosquito fish (Gambusia affinis) are not affected by the normal dosage level for larval control. Tests on rainbow trout (Lewallen & Wilder, 1962(18)) indicated no apparent effect.

4.4.2 Formulations

Fenthion is commercially available in the following formulations:

(a) Solutions: 81% fenthion + 19% aromatic petroleum distillate (cost $7.7/kg). "Baytex 8 concentrate insecticide", for dilution only with oil carriers (No. 2 fuel oil, kerosine, etc.). An antisludge agent must be added if spray solution is to be held in storage longer than a few hours. By adding a sufficient quantity of suitable emulsifier, water can be used as a carrier.

(b) Emulsion concentrates:

(i) 46% fenthion + 46% aromatic petroleum distillate + 8% inert material (cost $11.5/kg) "Baytex spray concentrate insecticide", can be diluted with light petroleum fuel for surface application, or with polypropylene glycol for low volume aircraft application.

(ii) 84.5% fenthion + 8.2% aromatic petroleum distillate + 7.3% inert ingredient (cost $10/kg in USA) "M.A.D. special mosquitocide".

(c) Dusts: 3% dust for the control of pests in ornamental water collections; not extensively used as a larvicide.

(d) Wettable powder: Not available as a standard commercial item. Can be custom formulated on order.

(e) Granules

(i) 1% fenthion 15-30 mesh coated sand core (cost $28/kg). These granules weigh about 1385 kg/m³.

(ii) 1% fenthion 15-30 mesh "bouyant" coated sand core (cost $30/kg); weight 1385 kg/m³. Granules with an extra ingredient which promotes uniform distribution of the toxicant throughout the water when applied to mosquito sources.

---

1 0,0-dimethyl O-[4-(methylthio)-m-tolyl] phosphorothioate (OMS-2)
(iii) 2% fenthion 15-30 mesh sorptive type; weight 1130 kg/m³. These granules are heavier than many sorptive granules.

(f) Other formulations: low volume airspray formulations custom made by mixing equal parts of 84.5% fenthion and P400 polypropylene glycol. Apply dosage rate of approximately 110 g/ha.

Emulsifiable concentrate sprays, oil-miscible concentrate sprays, dusts, and granules may be used as larvicides; emulsifiable concentrate sprays, oil-miscible concentrate sprays and aerosols may also be used as adulticides in swamps, flood water areas, all non-crop areas, pastures, and residential areas.

4.4.3 Use directions

Fenthion is applied at a normal uniform dosage rate of not more than 110 g/ha. On non-crop water areas, under special circumstances of water more than 15 cm deep and of high organic content, sufficient dust, granular formulation, or emulsifiable concentrate may be applied to result in a final larvicidal concentration not to exceed 0.1 ppm.

Spray dilutions or aerosol may be made with necessary amounts of suitable diluent and may be applied by aircraft or ground equipment in normal or low volume formulations.

Emulsifiable concentrate may be mixed with necessary amounts of water and applied directly, or by means of a metering mechanism, to water of high organic content.

Spot treatment formulations may be made by mixing emulsifiable concentrates with water at rates of up to 15 ml per litre of water, which may be applied at not more than 70 ml/m².

Granular or dust formulations may be used at application rates adjusted to avoid exceeding the stated dosage rates.

Small areas, narrow streams and ditches can be satisfactorily treated by using man-carried mechanical spreaders, seeders, or shaker cans or by hand casting. The compressed-air granule gun is effective for applying granules from a moving vehicle on drainage channels alongside roads. Aerial application is required for efficient application on large areas with dense vegetation which are difficult of access on the ground. A 2% Volclay granules formulation (manufactured by Durham Chemical Company) is specifically designed for aerial application at the rate of 5.5 kg/ha.

An oil solution containing 6 g/l and an appropriate spreader is effective for small confined areas of polluted water as found in street drainage systems, industrial waste water and faulty domestic sewage disposal systems. Oil solutions are effective in killing pupae as well as larvae, but emulsions usually do not kill pupae.

Water emulsions containing 0.6%, applied at a rate of 19 l/ha by hand sprayer are effective for accessible small or large bodies of water and slow moving streams which have minimum vegetation and aquatic growth. When spray is applied by a power sprayer from a moving vehicle or through an extension hose from a vehicle, use an application rate of 46 l/ha obtained by diluting concentrate to 2.5 g/l. Mist blower applications of 46 l/ha are effective in reaching areas up to 30 m from the moving vehicle.

Granular formulations are favoured for treating areas containing dense floating debris or aquatic growth or dense growths of grass, tules, brush and trees. The 1% sand core granules applied at 11 kg/ha are effective for shallow water and slow moving streams less than 30 cm deep. For areas with deeper water, the buoyant type granules are required.
The 2% sorptive type granules applied at 5.5 kg/ha are preferred because they disperse before settling to the bottom. They are lighter in weight than the sand core type and do not as readily penetrate dense vegetation when applied by ground equipment. The "swinging horn granule applicator" is useful for treating larger areas which are accessible by foot.

4.4.4 Limitations and safety precautions

While fenthion is an effective larvicide against susceptible mosquito populations when applied at the dosage recommended, resistance has been acquired by some species in frequently sprayed areas.

As this compound is of relatively high oral and dermal toxicity to mammals, solution concentrates and emulsion concentrates are classified as hazardous insecticides and should only be handled by specially trained personnel. Personnel using dilute sprays should be trained to avoid all unnecessary contact with the spray and to use the standard safety techniques while applying larvicides containing fenthion. Provision should be made for thorough washing of hands immediately when contamination occurs, and routinely before eating. When the day's work is done.

Granules are much less hazardous to handle than the liquid, but the operator should avoid breathing the dust when transferring granules from a sack to other containers. A scoop should be used to fill equipment hoppers so as to minimise contact with the hands. Clothing used by spray operators should be designed to prevent granules from entering and collecting around the belt line or in socks and shoes. Horn seeder bags should be made of non-porous material to prevent contamination at the point where the bag rests against the operator's body. When granules are broadcast by hand, protective gloves should be worn.

Use particular care to avoid damage whenever spraying over areas containing fish or wildlife. Very low volume applications of fenthion at listed dosage rates have caused bird mortality. Shrimps, crayfish and crabs may be killed at these dosage rates.

Metering mechanisms must be protected by adequate safeguards so as to prevent exposure of animals or people to concentrated insecticides.

Fenthion should not be used inside dairy barns, poultry houses, or buildings where food is processed.

Low volume or very low volume applications may damage some painted automotive surfaces.

For usages other than as specified herein, follow directions on the label.

4.5 MALATHION

Malathion, technical grade, is a clear, colourless to light amber liquid, containing at least 95% active principle, free from extraneous impurities or added modifying agents, and should comply with all other requirements of specification WHO/SIT/10.R2.

Technical malathion possesses physical characteristics which make it particularly suitable for very low volume aerial application, i.e. very low vapour pressure so that evaporation is minimal; high specific gravity (1.25) which somewhat increases the settling rate of spray droplets in air; and relatively high viscosity, which reduces the number of extremely small droplets produced by conventional spray nozzles on aircraft or power machines, which droplets by reason of their extremely small size would tend to be carried out of the target area by vagrant air currents.

1 $S-\{1,2\text{-bis(ethoxycarbonyl)ethyl}\}_0.0\text{-dimethyl phosphorodithioate (OMS-1)}$
4.5.1 Toxicity

It is an organophosphorus compound which inhibits cholinesterase and is poisonous if swallowed. Due care must therefore be exercised in handling the concentrates. However, it is one of the safer organophosphorus compounds, having LD$_{50}$ values to rats of about 1000 mg/kg oral, and over 4444 mg/kg dermal. It has been widely used in mosquito control and mosquito-borne disease control programmes, often as the material of choice where exposure of persons and domestic animals would occur in the treated area. At usual dosage and application rates of 220-550 g/ha it is safe when applied in and around densely populated residential areas. As a very low volume (90-180 g/ha) aerial-applied spray (ULV), it has been the material of choice for large scale adulticiding to prevent or to interrupt mosquito-borne encephalitis epidemics or dengue haemorrhagic fever and these operations have been carried out with no serious complaints of irritation or damage. These have been comprehensive treatments, over large blocks of land of 200,000 ha to 1,200,000 ha including urban residential and industrial, agricultural and recreational areas as well as fish ponds, wildlife areas and forests. The treatments have been primarily for the control of adult mosquitoes but have also exhibited considerable reductions of larvae in mosquito sources situated in the treated areas.

4.5.2 Formulations

(a) Technical malathion concentrate: minimum 95% active principle, weight 1.25 kg/l. Technical malathion may be used as a base for making dilute sprays, or may be applied directly as a very low volume application (ULV) by man-carried mist blowers, vehicle-mounted mist blowers, or aircraft. It can be mixed in oils for surface application as a larvicide, or for adulticidal use by aircraft or in thermal aerosol or mist machines; up to 5% or more malathion may be added to No. 2 fuel oil or diesel oil without the use of a co-solvent, but the addition of 0.1-0.5% Thiosperse is recommended to prevent the formation of sediment which might clog valves or strainers. High aromatic co-solvents may be used with fuel oils when more than 5% malathion is to be added to oil. For thermal aerosol or mist blower applied aerosol adulticides, quicker response and greater efficacy may result from the addition of 2-(2-butoxyethoxy) ethyl thiocyanate (Lethane 384), in a formula consisting of 95% malathion - 3%, Lethane 384 - 3%, No. 2 fuel oil or diesel oil = 94%. Against susceptible mosquito populations, it has been an excellent larvicide when applied in either liquid or dry formulations, at dosage rates of 400-550 g/ha.

(b) 57% malathion emulsifiable concentrate (0.4 kg/ha) is a standardized commercially available product widely used in mosquito control, agricultural, and other uses where applications are made by professional workers. This product may be diluted to any desired working strength with water or with light fuel oil to suit the equipment to be used in larviciding. The oil mixed material may also be used in adulticiding with thermal aerosol machines or aircraft, and the water mixed sprays may be used for adulticiding with mist blowers or aircraft.

(c) Dust formulations: 3% - 5% dust formulations are commonly supplied by various formulators, principally for agricultural purposes. These are finely ground dusts of low density, which could be used for larviciding with applications made by ground equipment or aircraft. Custom-made dusts having much greater weight (density) could be formulated for aerial application as larvicides, but the total costs of such applications are not competitive with the low costs of ULV liquid applications.

(d) Granular formulations: Granular formulations on sand core or clay granules are manufactured by various formulators, to contain 1% - 5% actual malathion. These should be selected to suit the equipment employed in making the applications, so as to discharge an evenly distributed dosage of approximately 550 g/ha, actual malathion.
Usual rates are: hand application, swinging horn granule dispenser - 5.5 kg/ha; jeep-mounted dual rotary granule dispenser - 3.3-5.5 kg/ha; aircraft 2.2-5.5 kg/ha.

4.5.3 Use directions

A great many variations in application technology have given satisfactory results in larviciding and adulticiding with malathion. The following suggestions may therefore be considered primarily as guide lines, and variations may be made in accordance with the performance characteristic of the equipment used, so long as the nominal dosage rates of approximately 440-550 g/ha for larviciding and 220-550 g/ha for adulticiding are applied.

With hand-operated equipment, liquid larvicide sprays should be applied at 19-95 l/ha, dusts at 5.5-22 kg/ha, and granules at 2.2-11 kg/ha.

With vehicle-mounted power equipment, liquid sprays should be applied at 48-95 l/ha with hydraulic sprayers, 9-28 l/ha with mist blowers, and 440-1200 ml/ha with low volume devices. Dusts should be applied at 5.5-11 kg/ha, and granules at 2.2-11 kg/ha.

With "standard" airspray equipment, apply liquid sprays at 4.5-28 l/ha, dusts at 5.5-11 kg/ha, and granules at 2.2-5.5 kg/ha. With low volume airspray equipment, apply concentrates at 220-440 ml/ha.

4.5.4 Limitations

Although malathion is an excellent larvicide against susceptible mosquito populations, there is grave concern that its use as a larvicide in malaria programmes may tend to enhance or accelerate the development of resistance in vector populations, thereby negating its use thereafter as a residual indoor adulticide. It is therefore suggested that it should not be used for larviciding in any area where a future need for it as a house spray can be foreseen.

4.6 CHLORPYRIFOS

Technical grade chlorpyrifos is a white granular crystal-like substance that is readily soluble in many of the organic solvents such as acetone and xylene. It is insoluble in water. Most formulations are stable indefinitely under normal storage conditions. It is very resistant to leaching or movement by soil water and decomposes very slowly in warm moist soils. It is volatile and exhibits a short residual life on plant foliage. When applied to turf, soil and surfaces such as wood and concrete it is effective for several weeks. As a larvicide in sewage-charged or other organically loaded waters it also exhibits residual characteristics.

4.6.1 Toxicity

It is an organophosphorus compound which inhibits blood cholinesterase and repeated exposure, however small it may be, may cause a dangerous degree of cholinesterase depression. It has LD50 values to female white rats of 135 mg/kg oral and 2000 mg/kg dermal, the relatively low dermal toxicity making it one of the safer OP compounds to use. The concentrates should be handled only by persons trained in the safe use of OP compounds. Chlorpyrifos is highly toxic to bees and to fish. It affects insects by contact, by ingestion, and by vapour action. There is very little systemic activity in plants or in animals.

1 0,0-diethyl O-(3,5,6-trichloro-2-pyridyl) phosphorothioate (OMS-971)
4.6.2 Formulations

(a) **Technical chlorpyrifos**, minimum 98% purity, is available only from the manufacturer for testing purposes.

(b) **Emulsion concentrates**: Chlorpyrifos 2E insecticide, 240 g/l active principle plus emulsifier, is a solution in polypropylene glycol. This formulation has low volatility and is particularly useful for low volume (ULV) aerial spraying. Chlorpyrifos 4E emulsifiable insecticide contains 480 g/l active principle. Chlorpyrifos M emulsifiable insecticide contains 480 g/l active principle. Chlorpyrifos 6 insecticide containing 660 g/l active principle, does not contain added emulsifier, and is intended for manufacturing use.

(c) **Dusts and water dispersible powders**: An experimental water dispersible powder containing 25% of the active ingredient is available commercially.

(d) **Granules**: Custom-made granules, either sand coated or clay, can be had on order from several formulators.

4.6.3 Use directions

Chlorpyrifos may be applied by hand, by power machine or by aircraft at dosage rates from 140 g/ha against highly susceptible larvae in clean water, up to 550 g/ha under more difficult conditions or against less susceptible larvae. Considerable residual value has been shown in contaminated water having a high organic content, as catch basins, sewage oxidation ponds, and in log ponds, where residual effects were found to be 18 days for an application of 55 g/ha and 23 days for an application of 110 g/ha.

The emulsifiable concentrates may be diluted with water to obtain dosage rates up to 550 g/ha at the following application rates: hand equipment - 0.9-9.3 l/ha; power machines - 19-93 l/ha; aircraft - 4.5-18.5 l/ha.

**Note**: For low volume (ULV) aerial application, chlorpyrifos 2E may be used at up to 280 ml/ha without dilution, or at up to 440 ml/ha when diluted with an equal volume of P400 polypropylene glycol.

An experimental water dispersible powder containing 25% of the active ingredient may be mixed with water for application at dosage rates not to exceed 550 g/ha.

Custom-made granular formulations on sand core or clay granules are available from formulators on order, at 1% to 5% concentrations.

4.6.4 Limitations

Chlorpyrifos should never by applied so as to contaminate drinking water, milk or other foods, or over water containing fish or wildlife, or over bees.

4.7 PARATHION

The technical form of parathion, in accordance with specification WHO/SIT/11.R2, is a dark liquid, free from extraneous impurities and added modifying agents and shall contain at least 90% of the active principle.

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1. O,O-diethyl O-(p-nitrophenyl) phosphorothioate (OMS-19)
4.7.1 Toxicity

It is an organophosphorus compound which inhibits blood cholinesterase and repeated exposure, however small, can cause a dangerous degree of cholinesterase depression. Technical parathion is highly toxic to warm-blooded animals, having LD$_{50}$ values in white rats of 3.6 mg/kg oral, and 6.8 mg/kg dermal. Rigid safety measures should be observed in working with the technical concentrate.

Although its extensive use as a larvicide in a highly industrialized country was without any reported adverse effect on non-target organisms including man, if the safety measures are not fully observed, it may cause severe poisoning among operators and others accidentally exposed.

As is seen from the relevant sections of this manual the safety measures which must be observed in the use of this compound are very strict and call for close supervision. As it does not yet seem feasible to ensure this under the conditions in malaria programmes, the use of parathion is not at present recommended.

The use of parathion larvicide has been discontinued in some areas because of the development of a tolerance to it by the local mosquito fauna.

4.8 PARATHION-METHYL

The technical form of parathion in accordance with specification WHO/SIT/14, is a dark liquid, free from extraneous impurities and added modifying agents.

4.8.1 Toxicity

It is an organophosphorus compound which inhibits blood cholinesterase and repeated exposure, however small, may cause a dangerous degree of cholinesterase depression. It is somewhat less toxic to warm-blooded animals than parathion, having LD$_{50}$ values to white rats of 25 mg/kg oral, and 67 mg/kg dermal. As with parathion, rigid safety measures should be adhered to in working with the technical form. Parathion-methyl is used as a mosquito larvicide in the same ways and at the same rates as parathion and dosage rates should normally not exceed 110 g/ha. On isolated bodies of heavily polluted water, as in sewage or industrial waste disposal ponds, it may be necessary to double the normal dosage.

Parathion-methyl is not recommended for use in larviciding in malaria programmes due to its high toxicity and great hazards involved in its handling and application.

4.9 PYRETHRUM

Pyrethrum is perhaps the oldest effective insecticide known to man. It has been used for several centuries and was known to the traders and nomads of the Middle East, and was an item of early world-wide commerce. The active principle occurs in the flower heads and stems of the plant Chrysanthemum cinerariaefolium which may be dried and ground to a fine powder and used without extraction. In modern usage, the active principle, pyrethrins, is extracted and concentrated, and marketed as a precisely controlled product of known strength. Pyrethrins is the collective name for the four insecticidal constituents of pyrethrum. The method of analysis to be employed is "The Pyrethrum Board of Kenya Extract Method, September 1954". Pyrethrum is a contact poison, to which many susceptible insects exhibit an immediate response. They are first irritated, and then quickly immobilized. No resistance to pyrethrum in insects of public health importance has, as yet, been reported.

1 Q,O-dimethyl O-(p-nitrophenyl) phosphorothioate (OMS-213)
4.9.1 Toxicity

Its safety for use is unparallelled though some persons exhibit an allergic reaction to it as an aerosol or dust.

The Clinical Handbook on Economic Poisons (United States Public Health Service, 1963) refers to pyrethrum toxicity as follows: "Pyrethrum may be absorbed from the gastrointestinal tract and by the respiratory route, ... not absorbed to a significant degree through the skin, ... Injury to man from pyrethrum has most frequently resulted from the allergenic properties of the material".

Under practical conditions pyrethrum and allethrin are probably the least toxic to mammals of all the insecticides currently in use. Pyrethrum has been used orally as an antihelminthic in some areas for many years with no apparent ill effects. The approximate oral LD$_{50}$ to white rats of pyrethrum is 200 mg/kg of weight.

Pyrethrum has also been introduced in public water mains for disinfection against Acellus aquaticus in Amsterdam at the rate of 0.1-0.0001 ppm. The treatment was maintained for a period of four days.

4.9.2 Formulations

Pyrethrum may be formulated as a solution, an emulsion, a dust or as granules. It has been extensively used for more than 30 years, but because the growing and manufacturing costs are high, the final product is necessarily expensive and lower cost products are frequently substituted. It may be synergized with piperonyl butoxide, allowing a lower dosage to be applied, thereby somewhat reducing the cost.

There are numerous pyrethrum formulations, commercially available, including dusts, solutions, emulsions and aerosols, and custom formulators can supply special formulations on order. It is very useful as a household spray.

(a) Dust: Pyrethrum dust (insecticide powder) is milled from pyrethrum flowers and stems and has pyrethrins content of 1.3% (Pyrethrum Board of Kenya), stabilized by a special antioxidant. It is normally used as an insecticide dust for the control of crawling insects, or may be incorporated in mosquito coils which burn slowly, releasing the toxicant in the smoke. It could be diluted with inert dust for application as a mosquito larvicide.

(b) Solution concentrate: Liquid pyrethrum insecticide concentrate, standardized to 25% pyrethrins (weight/weight) by the addition of odourless kerosine is produced in Kenya in three qualities.

(i) Oleo-resin (OR) extract: This is a crude material containing a proportion of waxes. Its supply is restricted to manufacturers of horticultural and agricultural sprays and dust, veterinary preparations, grain protectants and mosquito coils.

(ii) Partially dewaxed (PD) extract: This has had all but a small fraction of the waxes and insolubles removed and is suitable for use in aerosols and for many other insecticidal purposes.

(iii) Pale extract: This is a dewaxed and decolourized material which is particularly suitable for use in aerosols. It is purchased by manufacturers who wish to offer a non-staining product.
4.9.3 Use directions

Pyrethrum solutions may be used alone, or for greater economy may be synergized by the addition of piperonyl butoxide (example: 25% pyrethrum extract - 8 parts, piperonyl butoxide technical - 8 parts, oil - 84 parts). Pyrethrum extract, alone or in combination with piperonyl butoxide, is often combined with other toxicants. These formulations may be used to fortify oil larvicides, thus allowing a reduction to be made in the amount of oil applied.

For fortifying larvicidal oils, as the rate of oil applied is decreased, the amount of pyrethrum should be correspondingly increased, for a minimum of 11-110 g/h (25% active extract, $24/kg, Kenya).

(a) Emulsion concentrates: Emulsions of pyrethrum, alone or in combination with other materials, may be used as mosquito larvicides, as adulticides, and as outdoor space repellent. The amounts of active toxicants should approximate the amount used in solutions. Many formulations have been employed. A formula developed in 1930 (New Jersey Larvicide) is still used where fish and plants must not be damaged. It includes: kerosine - 66%, pyrethrins - 0.07%, water - 33.5%, sodium monodecyl sulfate - 0.5%.

This formula can be used as a larvicide at a rate of 46.5 l/ha with sufficient water added to suit the spray equipment employed, up to a maximum of 465 l/ha. The same formulation was useful in temporarily clearing adult mosquitoes from limited outdoor areas when applied as a fine mist. Lower cost materials have largely displaced these formulae; nevertheless, these or more modern formulations may have application in some areas.

(b) Water soluble pyrethrum

A formulation which yields a solution in water has been devised, which has the formula: pyrethrum extract (25% pyrethrins) - 8%, piperonyl butoxide (technical) - 8%, non-ionic emulsifier - 3%, water - 81%. No operational data are available relative to the field use of this larvicide.

4.9.4 Limitations

Due to its very low mammalian toxicity pyrethrum has a very wide application in mosquito control. The only limitation it has is its high cost.

4.10 DICHLORVOS

Technical grade dichlorvos is a pale amber coloured liquid, free from extraneous impurities or added modifying agents, which contains at least 93% active principle, as required to comply with specification WHO/SIT/16.

4.10.1 Toxicity

Dichlorvos is an organophosphorus compound which inhibits blood cholinesterase and repeated exposure, however small, may cause a dangerous degree of cholinesterase depression. It has LD₅₀ values to female white rats of 56 mg/kg oral, and 75 mg/kg dermal. It is poisonous if swallowed or inhaled and it can be absorbed through the skin. It must be handled and used with due care in the observance of safety precautions. It is highly toxic to bees exposed directly or to residues on crops.

1 2,2-dichlorovinyl dimethyl phosphate (OMS-14)
4.10.2 Formulations

Dichlorvos is formulated principally in resin strips as an adulticide useful in killing insects indoors for prolonged periods of time.

It may also be formulated and used as an emulsifiable concentrate mixed with water or as an oil-miscible concentrate diluted with an appropriate carrier, for application as a space adulticide, but in existing formulations it has limited application as a larvicide.

4.10.3 Use directions

At an application rate of 1 strip hung from the ceiling to each $30^3$ m$^3$ of space, control of mosquitos for a period of 2-4 months has been reported. In buildings where air circulation is greater than normal, the effective period is probably substantially less.

As a larvicide, the strips may be suspended above the water surface of catch basins, where the effective period may be several months if excessive flushing does not occur.

4.11 CHLORINATED HYDROCARBONS

As stated before, this group of chemicals is not recommended for larviciding because of residue problems, pollution of the environment, and particularly in malaria control or eradication because of risks of an acceleration of resistance in vector mosquitos. The contra-indication is aimed at maintaining the effectiveness of these compounds as long as possible for residual spraying programmes where their replacement would create enormous financial and operational problems. As such, a description of these compounds has not been included in this manual.

5. APPLICATION METHODS AND TECHNIQUES

In applying a pesticide to a mosquito source in order to kill the mosquito larvae (sometimes also the pupae), the technical objective is to distribute the toxicant evenly so that all of the larvae will receive a toxic dose. Since liquid formulations are employed for most larviciding, a discussion of the problems relating to the even distribution of liquid preparations is presented. Similar technical problems are encountered in applying the dry dust, water dispersible powder, and granular formulations.

It is to be noted that most liquid or mist larvicidal applications made by power machines and aircraft also destroy adult mosquitos which may be in the area treated. Larvicides may also be applied in granular form by hand, by power machine, or by aircraft. These are most useful in areas where there is dense emergent vegetation in the mosquito sources which can be penetrated only with difficulty if at all by liquid larvicides. Granular applications do not kill adult mosquitos.

Thermal space aerosols and/or "cold fogs" may kill highly susceptible larvae, particularly when the aerosol machines are adjusted to yield larger than normal fog droplets, but this method is generally not used where the primary objective is that of killing larvae.

When low levels of resistance to the chemical in use have been acquired by the larvae, aerosols will usually be unsatisfactory, even though mist-blowers or hydraulic sprayers may still yield acceptable control. The space aerosol machines, although primarily adulticiding devices, are mentioned here because some may be adjusted to give primarily larvicidal spray droplet spectra, and these have a limited capability for larviciding.
Insecticidal dusts, applied by hand, ground power or aircraft devices were formerly used extensively in larval control, but the development of effective dust formulations has not kept pace with the evolution of liquid formulations and devices. Hence, dusts are now rarely used as larvicides, although they could be useful in appropriate situations. Very finely ground, low density, lightweight dusts can be air-carried for long distances and could be used for hand application while coarser, heavier larviciding dusts of much higher density can be applied by aircraft with little drift outside the target area. However, suitable larvicidal dusts are not commercially available, except as custom-ground products.

The methods and technique of application selected for each compound should be closely linked with the recommended safety requirements. It is possible that with slight modification in the formulation of the larvicide or in the technique of application or the equipment to be used, greater safety of the operator, the inhabitants and the environment could be ensured (see also paragraph 8, page 139).

5.1 DISPERSAL OF LIQUID LARVICIDES

Whether liquid larvicides are distributed by hand equipment or knapsack sprayer, by ground vehicle mounted hydraulic sprayer, mist-blower, or aerosol fogger, or by aircraft, certain principles are involved in the dispersal of the toxicant so as to effectively reach the target insect. The total problem of dispersal may be considered as having five components:

- dispersal of the toxicant in concentrated solutions or emulsions
- dispersal of the toxicant in the working dilution
- dispersal of the spray-mix by the nozzle
- dispersal of the droplets while in the air between the nozzle and the target
- dispersal of the spray droplets on or in the water of the target mosquito source.

Dispersal in each of these phases must be satisfactory if the potential value of the toxicant to kill the mosquito is not to be lost or impaired, and if undue economic losses are to be avoided. There are a great many devices which can be used in the application of larvicides and their efficiency in obtaining optimum application of the toxicant to the target insect may vary greatly.

Losses are frequently substantial. With aircraft application of pesticides, recovery studies have shown that in many applications, only 40-60% of the spray which was released could be recovered from the target area and in some extreme cases only 10-15% was recovered. With ground spray equipment, losses from the target zone are generally less, but if considerable volumes fall upon the ground and do not reach the target insect, then these amounts are also to be considered lost or wasted. There is also the grave concern that amounts which cannot be accounted for in the target zone may have served only to pollute the environment.

5.1.1 Concentrates

In order to reduce the cost of packaging, storing and shipping, most modern, highly potent pesticides are manufactured in concentrated forms containing a high percentage of the actual toxicant to be diluted to the desired strength when placed in the insecticide supply tank of the spray machine.

The concentrates may occupy only 1/100 of the space that will be needed for the dilute spray which is to be applied: generally the diluent is water, which may frequently be taken from the breeding place to be sprayed. Oil is less frequently used as the diluent, but
it may sometimes be procured locally without shipping long distances. The components of the concentrate must be compatible with each other and with the material of the container so that the chemical and physical properties remain stable for a long shelf-life. The concentrate should also be stable in low-temperature and high-temperature storage. The packages should not be so large as to be unduly heavy or awkward to handle. They should, on the other hand, be made of durable material to resist rough handling, wear and tear and to protect the toxicant against adverse shipping, storage and field conditions. Any limitations of storage or use (see Annex 4) should be prominently spelled out on the label which should also give the identification and date of manufacture and/or expiry.

The advantages of concentrates are considerable, but there are also distinct disadvantages which must be taken into account. A concentrated, highly-potent insecticide is hazardous to handle: proper equipment must be provided, and the handler must be fully trained in correct safety procedures (see Annex 4). Usually, mosquito control services allow only a few specially trained employees to work with the concentrates, which in bulk are kept in securely locked storage to which only qualified individuals are admitted. The dilute mixtures are considerably less toxic than the concentrate.

The concentrates of some organophosphorus compounds have been used safely in hand spraying and several of them are cleared for use by aircraft at low-volume application rates. It is always emphasized, however, that any insecticide concentrate should be respected for its potential hazard, and should be handled with care, and only by qualified people who have been trained to use it safely and with proper equipment.

5.1.2 Working dilution (tank mix, finished spray, diluted formulation etc.)

When diluted in the spray tank, with water in the case of emulsifiable concentrates and water-dispersible powders or with oil in the case of oil solution concentrates, the tank mix must remain homogeneous during discharge with little or no stratification of the active principle from the carrier liquid. If there is any tendency to separate or to stratify, agitation must be provided within the insecticide supply tank. The water which is used to mix emulsifiable concentrates may have a considerable effect: hard waters may not make good tank mixes etc. Also some water-mixed sprays which are satisfactory when used promptly after mixing may break down after standing in the insecticide supply tank and may require agitation before use. The tank mix may also affect the materials used in the sprayer parts damaging both the insecticide and the equipment. It is therefore important to select appropriate materials and equipment and to check frequently the performance of the entire system.

5.1.3 Nozzles

Many types of nozzles are available, and they are made of many materials. Whether used on a hand-sprayer, a powered hydraulic sprayer or mist blower, or on aircraft, its function is to cause the stream of liquid emerging from the orifice to take the desired pattern which may be a straight stream, a cone of droplets, or a fan of droplets, and to regulate the size and velocity of emission. It is also to regulate the discharge rate and ensure the application of the correct dosage of the mixture. Both the pattern and droplet size as well as the discharge rate of a nozzle vary with the liquid velocity. Usually, the higher the velocity the greater the discharge, and the finer the droplet sizes will be. Some of the commonly used nozzles, such as the flat fan, are used variously on hand-spray equipment, mist-blowers, and aircraft doing somewhat the same task on greatly different machines. For application of larvicides by hand equipment, adjustable nozzles which permit varying the pattern and discharge rate are most suitable, because the operator can adjust the pattern while spraying, to suit the breeding sites.
Adjustable cone nozzles with fingertip adjustment can produce a variety of patterns from solid jet to fine mist cone, and are specially suitable for this purpose. There has been a great deal of developmental work done with nozzles, and much evaluation of the results. It has not been practicable to secure nozzles which will eliminate all unwanted, very small droplets, nor to regulate the sizes of droplets as accurately as might be desirable. The discharge rate also varies when pressure varies or when the passage of erosive formulation increases the size of the orifice. However, workable compromises have been arrived at, and by careful selection, effective spraying can be done. For technical and economic reasons, it is important to calibrate nozzles frequently, to observe and measure the spray patterns and the discharge rate produced and to make the necessary adjustment.

5.1.4 Aerial phase

What happens to the spectrum of spray droplets as they pass through the air-filled space between the nozzle and the target, or as they are lost to non-target places, has been the subject of more intensive study than any other aspect of the dispersal problem. The literature on this subject is voluminous, but although the theoretical considerations are well understood, in practice it is not possible to produce spray droplet spectra that will permit all of the insecticide to be applied to the target area in the desired pattern, and some of the insecticide is always lost to non-target places. With aircraft spraying, the loss is frequently as great as 50% of the amount applied; even with residual house-spraying of water-dispersible powders where the objective is to cause the spray material to impinge upon the walls, many of the smaller spray droplets are diverted and become suspended in the air in the room and are carried about by such vagrant air currents as may exist.

The dispersal of sprays applied as larvicides is greatly affected by the size of the spray droplets, their velocity as they leave the nozzle, the air currents that may be created by design or by accident by the spray machine and the vehicle upon which it is carried, the wind or other air currents at and above the target mosquito source, and the obstructions which may exist between the nozzle and the water of the mosquito source (plants, floating debris, etc.). Although larviciding can be done by a technique similar to that employed in residual house spraying, which resembles that of spray painting, most larviciding is done by a considerably different procedure. Usually the objective is to discharge the liquid spray so that the spray droplets will be evenly distributed immediately above the water to be larvicided and then assisted by their initial velocity and localized air currents, to settle by gravity on to the surface of the water.

While small spray droplets are highly effective in killing adult mosquitoes and in obtaining increased dispersal of space adulticides because the small droplets stay suspended longer in the air, they have no particular advantage in larviciding. Small spray droplets are more affected by air currents and evaporate more readily because of their greater surface area in relation to volume. Hence the losses of spray from the target area may increase as the droplet size is decreased, and there is more risk of down-wind areas being contaminated. In larviciding, the first objective is to get the spray droplets on to the surface of the water of the mosquito source, but it is still necessary to obtain even dispersal of the sprayed material. In practical operations, a compromise should be sought, so as to obtain the maximum practicable amount of evenly dispersed spray on the surface of the water in which the larvae occur.

The operator must learn to observe the behaviour of the sprayed material in response to air currents and to take advantage of the air movement. He should also learn that of any spray particle spectrum, the smaller droplets are most affected by horizontal air currents and most likely to be carried out of the target area; also, the smaller droplets may involve a very small portion of the sprayed material, but because they have the effect of scattering the light which falls upon them, it often appears that a disproportionate amount of the sprayed material is being carried away when in fact it may be an insignificant fraction. An indication of the actual loss can be obtained by placing spray-sensitive cards on the ground in the area sprayed, by bio-assay, or by any of the commonly used spray pattern assessment techniques.
The system most commonly employed in larvicide spraying with hand equipment and with power sprayers in ground vehicles makes use of the fact that a thin solid jet stream, discharged through a fine orifice at high velocity, with the nozzle directed slightly above horizontal, will assume a slightly curved trajectory and the outer one third to one half of the thin solid jet will break up into droplets, of varying sizes, quite evenly distributed. If the nozzles are moved from side to side in a horizontal pattern, a band of evenly distributed droplets will settle to the ground. This technique may be known as the "swinging wand" or "swinging lance" technique of spraying. It is much used with compression sprayers in larviciding sheet water standing in over-irrigated pastures where the operator can walk through the shallow water or on the small levees which separate the narrow strips of pasture land, swinging the lance from side to side through an arc of about 180 degrees and thereby treating a strip about 10-15 m wide as he walks along the centre line of the swath at a brisk pace of about 5 km/h. Slight modifications of the lance movement allow him to treat narrower areas, or even to walk along one bank of a deep pool, or one bank of a fairly wide canal, treating the entire width at a comfortable walking speed. It has been estimated that the average production in spraying flooded pastures with this method is 1-1.5 ha/h. For treating small pools or narrow ditches the advantage is less; for very narrow ditches, production is limited by the speed at which a man can walk, so there may be no advantage over using a flat fan or cone spray nozzle with the spray directed downward to the target surface, much as the walls are sprayed in residual spraying except that the target is in a horizontal position instead of vertical. Very small pools can similarly be treated efficiently and economically. In the swinging wand system, the nozzle tip is constantly in motion as with a paint spray gun - to stop even momentarily will result in overdosing. With a little instruction and practice, operators of average intelligence soon develop a high order of proficiency in using this technique. Timing is usually accomplished by walking at a uniform cadence (usually above 5 km/h on reasonably smooth ground), and swinging the lance in cadence with the steps, to the left when taking a step with the left foot and to the right when stepping with the right foot. To avoid overdosing narrow strips to be treated, the trigger (cut-off valve) may be depressed only during every second or fourth step, depending upon how much the dosage should be reduced. The technique for using the "granule dispenser, swinging horn type" is very similar, and operators can interchange these two tools with considerable facility.

By applying the firm principles and laws of physics, chemistry, engineering and biology in an imaginative combination, there has been evolved the technique of aerial larviciding which takes full advantage of the aerial phase of dispersal. The system is known variously as very low volume spraying, concentrate spray application, ULV, etc. This method depends for success primarily upon the manipulation and exploitation of natural and induced air currents to achieve an even distribution of a small volume of potent insecticide, in a formulation which has low volatility so that the small volume of insecticide released can be divided into small droplets which will not evaporate before settling on to the target area. Great economy is possible in the rapid coverage of extremely large areas, with small or large aircraft or with helicopters. The method is now well developed, and has provided public health workers a new tool with which to combat epidemics of vector-borne disease. Operational details are included elsewhere in this manual, and safety measures to be observed are given in Annex 4.

5.1.5 Aquatic phase

Dispersal of the insecticide on the surface in the case of oils, or through the volume of water in the case of emulsions or water-dispersible powders, is greatly affected by the character of the water and the obstructions which may be in it. Spreading is inhibited to some extent by dust and other floatage, aquatic plants, algae, sewage or organic matter, salt or other dissolved solids, etc., or by air or water motion. For this reason, oil solutions should have sufficient spreader, and emulsions should have sufficient
emulsifier, to overcome the resistance to dispersal which may occur in the most unsatisfactory situations commonly encountered.

It may appear illogical to discuss applications of emulsifiable larvicides to mosquito sources in terms of dosage and application rates per unit area since the emulsifiable applications are in fact volumetric in nature and the resultant dilution can, strictly speaking, affect the efficacy of the application. However, most mosquito sources average about 10 cm in depth, and the rates are chosen accordingly because it is relatively easy to train the operators to apply "standard" rates on a surface area basis - but extremely difficult and confusing to train them to regulate the application accurately on a calculated volumetric basis. In applying emulsions to mosquito sources which are substantially deeper than the average, the operators appear to understand easily that a double or even triple application is necessary and that this can be obtained by re-treating the same place at the same speed or by cutting their rate of walking correspondingly. For oil larvicides, where the rate of application is constant for any depth, the surface measurement alone is the criterion.

Whatever the type of larvicide formulation, whether solution, emulsion, suspension or even dust or granules it would be unrealistic to expect a uniform application of the desired dosage, similar or even near to that in residual spraying. For a variety of reasons including difficult terrain, uneven walking speed, greatly varied distances to spraying sites and other environmental factors, a great deal of variation inevitably occurs in the actual applied dosages of larvicides.

Various kinds of mosquito sources will require correspondingly varied larvicides and larviciding techniques, requiring considerable flexibility in the programme at field level.

5.2 FACTORS AFFECTING THE APPLICATION OF LARVICIDES

Basic requirements for a successful safe mosquito larviciding programme are to employ trained operators who can apply the type and formulation of larvicide that will be most effective and to supply the type of equipment that will permit him to apply the larvicide at the prescribed dosage and with the required precautions and safety.

Contrary to current residual house spraying practice, a larviciding programme can seldom depend on a single insecticide applied at a prescribed spray strength and rate. The characteristics of the breeding place influence the type and formulation of the larvicide, the type of equipment, and the volume and weight to be applied. Some of these characteristics are as follows:

- chemical characteristics of the water
- organic pollution in the water
- depth of water
- area or volume of the breeding place
- shape of the breeding place
- type of breeding place
- aquatic growth in or floating on the water
- weed growth and vegetation within and around the banks of the breeding place
- use made of the water.
5.2.1 Kinds of formulations

The larvicide may be in the form of solids or liquids; such as dust, granules, wettable powder suspensions, water emulsions or oil solutions. These may be formulated at the desired concentration for direct application in the field (dusts, granules, oils) or may be supplied in more concentrated form to be diluted in the field to any desired concentration.

5.2.2 Equipment

The larvicide can be applied by many types of spraying equipment either hand or power operated as described in the following section. Mobile power equipment can be used for access to mosquito sources to speed up the larviciding operations and also to convey and drive the power equipment.

5.2.3 Types of breeding places

Sources may be of many classifications, including drinking water supplies for man or animals, natural streams, swamps, marshes, ponds supporting fish and other aquatic life, drainage and irrigation channels, rice fields, industrial waste water, community sewage, waste water or storm water run off from community streets and highways, and many more.

5.2.4 Rate of application

For effective application of larvicide, the spray operator must apply a given amount of dust, granules or liquid solution uniformly over a known area. The amount of formulation applied per unit of area is called the application rate, usually represented as kg/ha or l/ha. Dusts and granules are usually applied at rates of 0.5-2 kg/ha. Diesel oil solutions containing a toxicant and a spreading agent at 19-93 l/ha; water emulsions at 18.5-47 l/ha when applied by standard compression sprayer or 28-93 l/ha when applied by hydraulic pressure sprayer or by mist blower. Normal application by aircraft varies from 4.5-18.5 l/ha, and recently developed high concentrate low volume sprays are applied at 220-600 ml/ha.

5.2.5 Dosage rates

The larvicide dosage required to kill the larvae of the target mosquito is previously determined by bio-assays. The spray problem is to apply the prescribed dosage uniformly over each hectare of the breeding area. The dosage rate is the amount of actual insecticide applied per unit area. The concentration of the spray solution in the spray machine must be adjusted in accordance with the application rate. To obtain a dosage rate of 110 g/ha with fenthion as a water emulsion by means of a compression sprayer which has an application rate of 18.5 l/ha, each litre of spray solution must contain 6 g of fenthion. To obtain a similar dosage rate using a power sprayer or a mist blower at an application rate of 46 l/ha, each litre must contain only 2.4 g of fenthion. Sand core granules for ground application are usually formulated to contain 1% fenthion by weight or 100 g of fenthion per kg of granules. Consequently, 1.1 kg of granules are required per hectare to give the desired dosage rate of 110 g/ha.

5.3 TECHNIQUE FOR APPLYING LIQUID LARVICIDES

Since the application of the larvicide at a prescribed dosage rate depends on the spray operator's ability to apply a fixed quantity of spray solution over a fixed area, it is desirable to select a standard rate of application for normal operations using compression sprayers and another fixed rate for the average power sprayer or mist blower operations. Any prescribed decrease or increase in the dosage rate can be accomplished by adjusting the strength of the spray solution.
For some sources, such as long narrow ditches parallel to roadways, the standard rate of application will not be suitable, and one or more of the factors affecting the dosage rate and rate of application must be varied to suit the condition. These variables are:
- concentration of spray mixture
- nozzle discharge rate
- rate of travel
- swath width of the spray pattern.

Standard rates recommended for teaching spray operators the spraying techniques for basic types of liquid spray equipment are given in the table below.

<table>
<thead>
<tr>
<th>Variable factors</th>
<th>Hand Compression</th>
<th>Power sprayer</th>
<th>Mist blower</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Compression</td>
<td>Stationary</td>
<td>Moving</td>
</tr>
<tr>
<td>Rate of travel, km/h</td>
<td>3.2**</td>
<td>3.2**</td>
<td>8*</td>
</tr>
<tr>
<td></td>
<td>m/min</td>
<td>54**</td>
<td>133*</td>
</tr>
<tr>
<td>Swath width, metres</td>
<td>7.5</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Nozzle discharge, l/min</td>
<td>0.76</td>
<td>3.8</td>
<td>3.8</td>
</tr>
<tr>
<td>Rate of application, l/ha</td>
<td>18.5</td>
<td>46.5</td>
<td>46.5</td>
</tr>
<tr>
<td>Spray strength, % v/w</td>
<td>0.6</td>
<td>0.24</td>
<td>0.24</td>
</tr>
<tr>
<td>Dosage rate, g/ha</td>
<td>110</td>
<td>110</td>
<td>110</td>
</tr>
<tr>
<td>Rate of coverage, ha/min</td>
<td>0.04</td>
<td>0.08</td>
<td>0.08</td>
</tr>
</tbody>
</table>

* Speed of vehicle  
** Speed of operator walking

The three techniques for the application of liquid larvicides are:
- by compression sprayer  
- by power sprayer and long extension hose  
- by power sprayer or mist blower on moving vehicle.

Spray operators should be taught these techniques by practising under the conditions described in the following sections. When the spray operator has developed the ability to "feel" the rate of each application for each technique, he will be able to apply the larvicide at the standard rate under almost any conditions encountered in the field. The theoretical conditions described are seldom encountered where larvicides are applied by ground equipment. The success of a larviciding programme, both in economy and in larvae kills, may depend on the spray operator's ability to maintain a consistent rate of coverage for any size or shape of area.
5.3.1 Application by compression sprayer

To apply a spray solution at the rate of 18.5 l/ha the nozzle discharge rate must be 0.76 l/min, the sprayer operator must walk at the rate of 54 m/min, and the spray must be distributed evenly over a 7.5 m wide swath.

(a) Flat fan nozzles

The nozzle discharge rate can be obtained by using a nozzle No. 1/4 T 8002 (Spraying Systems Company) and maintaining an average pressure of 2.8 kg/cm² similar to the procedure used in the residual house spraying programme.

The walking speed of 58 m/min is equivalent to 35 paces per minute (each pace is two short steps averaging not more than about 1.5 m, or just over 3.2 km/h. This walking speed permits the operator to observe the spray pattern while walking in shallow water or on uneven ground surfaces that are relatively accessible.

(b) Solid stream nozzles

In this case, the operator effects the distribution of the spray pattern over a 7.5 m wide swath (assuming no air movement) by swinging the lance from side to side in cadence with his steps, keeping the direction of spray elevated slightly above horizontal. With air movements of 8 km/h or more, the distribution of the spray over the swath width is accomplished by adjusting the height and direction of the nozzle by visual observation of the resulting spray pattern. Application rates as low as 18.5 l/ha cannot be achieved if the nozzle is directed toward the water surface. The spray from the moving nozzle must be directed into the air so that the spray droplets will fall evenly over the 7.5 m swath width.

The area will be sprayed at the rate of 400 m²/min and it will take 25 minutes to cover one hectare. Since the nozzle discharge rate is 1.8 l/min, the rate of application is 18.5 l/ha, the dosage rate will be 110 g/ha if a 55 g/l spray solution is being used.

5.3.2 Application by power sprayers

The use of power sprayers increases the rate of coverage or the area sprayed per minute. Where it takes ten minutes to spray 18.5 l/ha with a compression sprayer, a power sprayer can apply 47 l/ha in five minutes.

The spray solution or emulsion is applied by hydraulic pressure provided by a mechanically driven pump drawing from the spray supply tank. Two methods of applying the spray are commonly used:

(a) Spray operator moves throughout the breeding area and the power unit remains stationary, usually mounted on a vehicle, trailer, wheel-barrow or a manually portable platform.

(b) Spray operator and the power unit are transported by the vehicle and move together through or parallel to the breeding area. The vehicle may be a boat, an amphibious tracked vehicle or a conventional truck.

To apply a spray solution at the rate of 47 l/ha the nozzle discharge rate must be 3.8 l/min and a 6 m swath must be laid down at a speed of 8 km/h. For this operation, a GunJet (Spray Gun) Series No. 14 (Spraying Systems Company) can be used with the proper nozzle orifice and setting to give a solid stream spray at 3.8 l/min with a maximum throw of about 11.5 m.
(a) In the first method the operator makes a series of passes moving the spray wand
in such a way that the spray pattern laid down at the end of the throw moves at a
speed of 8 km/h and covers the required swath width of 6 m. The operator must then
move to a new position and repeat the operation. Hose lengths of up to several
hundred metres can be used in fairly open areas but are very difficult to handle
where there is any appreciable amount of vegetation. This method permits penetration
into areas which cannot be reached from the roadway or which are inaccessible to
available vehicles.

(b) In the second method the operator rides in the moving vehicle and continuously
applies the spray in a similar manner as with the compression sprayer. For a road­
side drainage ditch 7 m wide and the vehicle travelling 8 km/h, the rate of
application will be 46.5 l/ha if the nozzle discharge is 3.8 l/min. For wider
ditches the speed of the vehicle must be reduced in direct proportion to the increase
of the swath width or the discharge rate must be increased proportionately. For
narrower drainage ditches either the discharge rate or the strength of the spray
mix must be reduced proportionately as the speed of 8 km/h is considered maximum for
thorough coverage of the breeding sources.

Portable power spray units may also be mounted on a small boat or on an
amphibious tracked vehicle for access to lake shores or swamps. The rate of
application is made in the same manner with swath widths, nozzle discharge rate,
speed of travel and strength of spray solution calculated to give the required dosage
rate.

5.3.3 Application by mist blowers mounted on moving vehicles

The use of mist blowers again increases the rate of coverage of the area sprayed
per minute. In comparison with a power sprayer with an average rate of coverage of
46.5 l/ha in 12.5 minutes (nozzle discharge rate of 3.8 l/min) a small size mist blower
with a nozzle discharge of 7.6 l/min and an effective swath width of 12 m can apply
46.5 l/ha in half the time or 6.25 minutes. For larger mist blowers with higher
nozzle discharge and airflow capacities, the swath width can be extended to 30 m with a
resulting rate of coverage of one hectare in 2.5 minutes at the standard application rate
of 19 l/min.

5.4 TECHNIQUE FOR APPLYING GRANULAR LARVICIDES

Granular larvicides are considered simple and safe for most types of breeding sources.
They are light in weight and can be accurately applied by hand, power or aircraft
equipment. The technique of applying granules is very similar to that for liquid
larvicides. Granules for ground application are usually formulated to contain 1% or 2% by
weight of insecticide. For dosage rates of 110 g/ha, 4.5 kg of 1% or 2.3 kg of 2% granules
would be applied. Since granules cannot be diluted like liquid larvicides, variations in
the dosage rate of each granule formulation is dependent on the rate of application. The
variable factors are limited therefore to the nozzle discharge rate, the swath width and
the forward speed of the operator. By adopting a standard swath width and forward speed,
the rate of application is then dependent solely on the nozzle discharge rate.

Granules are available in different sizes, such as 15-30 mesh, 20-40 mesh and 30-60
mesh. They also come in different gross weights per cubic metre depending on the type
of carrier used in formulation. Sand core granules weigh about 1390 kg/m² while the
sorptive type carriers used for air applications weigh only 12 kg/m³ or less. The
discharge nozzle for each type of granule spray equipment must be calibrated for each mesh
size and weight of granule. Consequently, it is desirable to standardize on one or two
types of granule.
The application of granules in very small quantities is sometimes very convenient for the treatment of artificial containers, e.g. ornamental pools or fountains and similar type sources found within a community. "Spooning" the granules or the use of small shaker cans is an effective method of treatment.

The number of individual particles which make up a kilogram of granules may be used to determine the average number of particles which should fall on one square metre at various rates of application. Table 14 presents information on two types of granule formulated by a company.

### Table 14. NUMBER OF PARTICLES PER SQUARE METRE AT VARIOUS RATES OF APPLICATION

<table>
<thead>
<tr>
<th>Type of carrier</th>
<th>Volclay</th>
<th>Sand core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesh size</td>
<td>15-30</td>
<td>15-30</td>
</tr>
<tr>
<td>kg/m³</td>
<td>4.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Particles per kg</td>
<td>762 000</td>
<td>2 249 280</td>
</tr>
<tr>
<td>Particles/m² at 1 kg/ha</td>
<td>362.7</td>
<td>213.9</td>
</tr>
<tr>
<td>&quot;             &quot; at 5.5 kg/ha</td>
<td>1813.5</td>
<td>1069.5</td>
</tr>
<tr>
<td>&quot;             &quot; at 11 kg/ha</td>
<td>3727.0</td>
<td>2139.0</td>
</tr>
</tbody>
</table>

5.4.1 Application by hand-operated horn seeder

Granules are applied by swinging the horn or nozzle from side to side with sufficient velocity to distribute the granules evenly over a 9 m swath width. One swing or swath pass is made for each step. The walking speed is regulated to 70 steps per minute. The forward speed is 58 m/min, the standardized walking speed for applying liquid larvicides with the compression sprayer. At this speed it will take a little over nineteen minutes to cover an area 9 m wide by 1111 m long, which is one hectare. Since it requires 1340 steps to walk the 1111 m, the operator will make the same number of swath passes. With this procedure standardized, the rate of application in kilograms of granules per hectare will depend only on the nozzle discharge rate. The adjustable gate or opening at the base of the horn must be calibrated for the particular granule being used and for each rate of application desired. For 5.5 kg/ha, each swath pass must deliver 4.1 g of granules (1340 passes x 4.1 g = 5.5 kg). For 11 kg/ha the nozzle must be calibrated to discharge 8.2 g of granules per swath pass. The dosage rate per hectare then depends on the strength of the granules. For 1% fenthion granules 11 kg must be applied per hectare to give the required dosage of 110 g/ha.

In actual field operations where a uniform swath width cannot be maintained because of obstructions, size, inaccessibility or irregularity of the breeding place, the "feel" of the standard method of application and the calibrated settings of the nozzle gate enable the trained operator to apply the granules quite accurately. The knowledge of the discharge rate per swath pass is also helpful, e.g. 60 passes with the nozzle gate set for 11 kg/ha will discharge 492 g of granules. A small area of about 400 m², for example, may be inaccessible or may contain vegetation that interferes with the swing of the horn seeder. The operator may be able to treat this area by making a total of 60 swath passes from one or more points around the area to give desired application rate of 11 kg/ha. By increasing the velocity of the swing the operator can project the granules much further. The addition of the plastic tube extension 0.9 m long further increases the velocity of the granules and swath widths up to 20 m are possible. For special inaccessible sources it may be desirable to also increase the rate of discharge. The maximum for the horn seeder
in current use with the nozzle gate wide open is about 22.5 g/min for 15-30 mesh sand granules. Fourty-four swath passes will distribute one kilogram of granules.

5.4.2 Application by hand-operated mechanical seeder

The simplicity, ease of operation and effectiveness of the horn seeder has limited the use of mechanical seeders to small or special type breeding sources. The plastic "Whirlybird" spreader is very useful for long narrow sources. Its 1.5 kg capacity (Annex 5) is sufficient to treat over 1 km of drainage ditch 1 m wide or above 450 m of 3 m wide ditch with larvicide granules at the rate of 11 kg/ha. The conventional mechanical spreader with a capacity of 11 kg is limited to a swath width of 3.5 m and is primarily designed for the application of granular weed killer at rates between 110 kg and 880 kg/ha.

5.4.3 Application by compressed-air granule gun

Granules can be ejected up to 12 m at rates up to 1.3 kg/min by the use of the compressed air granule gun. The technique of applying a desired dosage of granules to a breeding source is similar to that used in applying liquid sprays from a power operated sprayer. Eight kilometres of drainage ditch 9 m wide can be treated at the rate of 11 kg/ha in one hour. This rate is equivalent to treating one hectare in 7.5 minutes. The air gun can also be used for treating areas away from the road by dragging the air hose and carrying a supply of granules. This method is similar to the application of liquids but is more convenient because the lightweight air hose is much easier to handle in the field than the high pressure liquid spray hose. Eleven kilograms of granules, sufficient for one hectare are carried with the operator. The horn seeder bag, without the horn, provides a convenient and comfortable container. The short section hose from the gun is inserted through the open end of the bag which normally accommodates the horn section.

5.5 FREQUENCY AND TIMING OF APPLICATION

Generally the period of development from the egg stage to the emergence of the adult mosquito determines the frequency of the larvicidal application. In the case of stomach poisons the frequency will be the period of development from egg to the pupal stage. Although many factors may effect the period of development, the seasonal changes are most critical. The increasing number of daylight hours and increasing temperatures of the water decrease the number of days of the mosquito's aquatic stages. From eight to fourteen days is considered about the average. Repetitive larviciding is required for control of mosquitoes which lay their eggs on existing water. The frequency of application varies throughout the season. Treatment may be required only every three weeks at the beginning and towards the end of the season. Treatment every seven days is normally required during the main part of the breeding season. The success and efficiency of a mosquito larviciding programme depends on a thorough understanding of the ecology of each species and the employment of entomological principles in the timing of the larviciding application.

5.5.1 Eggs laid on water

For those mosquitos which lay eggs on the surface of water the timing is determined by routine inspection of a significant number of representative sources. Some sources may have to be treated more frequently than others. Sources similar in breeding characteristics can be grouped together and treated in sequence. The treatment of one group is referred to as a "treatment cycle". The number of days between treatment cycles is determined by the speed of development of the mosquito for that time of year. During the mosquito season it is usually necessary to complete a treatment cycle for each group every seven days.
Water emulsions or granules made or currently available as larvicides will not kill mosquito pupae and the treatment cycle must be completed before that stage. It is desirable to time the larviciding while the larvae are in their earlier stages, if at all possible. Some larvicides will incite 4th instar larvae to change into pupae and escape the effects of the larvicide. The use of fortified oil solutions are necessary to kill pupae and can be used for one treatment cycle that has fallen behind schedule. Oil solutions are also used for individual sources that were missed during the last treatment cycle or for new sources that contain all stages.

5.5.2 Eggs laid prior to flooding (Pre-flood larviciding)

Certain species of Anopheline mosquitos may possibly lay their eggs on wet surfaces, especially when water is not readily available. Once these eggs are covered by water the timing of larvicide application is the same as above. The timing for these species therefore depends on the knowledge of when these eggs will be flooded. Alternatively, pre-flood larviciding may be applied. Granules have been used successfully for this purpose.

5.6 RESIDUAL LARVICIDING

Residual larviciding is not ordinarily employed within organized larviciding programmes. Its use is restricted to small or large bodies of static or slow moving water containing varying degrees of vegetation growth where fish and wildlife are not involved. Water suspensions and granular formulations of DDT and other chlorinated hydrocarbons have been used at dosages from 1-11 kg/ha. Treatments are usually required every two or three months.

5.7 TREATMENT OF DOMESTIC WATER SUPPLIES

Tests at Savannah, Georgia (Brooks et al, 1966(4)) for residual effectiveness of five formulations of temephos against Aedes aegypti in 180 l water storage drums indicated that 1% sand granules was the compound of choice for field applications to water stored in containers for domestic use. Selection was based on the following advantages over the other formulations tested:

- it does not affect appearance and taste of the water
- granules can be seen on bottom to verify treatment
- ease of handling
- little loss of strength during storage
- effective 14 weeks at 1 ppm dosage.

Temephos has been used extensively in India for the control of A. stephensi in wells and in domestic water containers with good results. It has also been used in wells in Syria for the control of A. claviger. In Jordan and Cyprus large scale use has been made of this compound for Anopheles control in water that was consumed for drinking.
6. EQUIPMENT USED FOR APPLYING LARVICIDES

Larvicidal compounds can be applied by hand, by hand-operated equipment, power equipment or by aircraft. The choice of equipment and the mode of application much depends on the following:

- type of formulation (liquid, dust, granules, etc.)
- the extent and condition of breeding places
- road and communication facilities
- cost and availability.

Mosquito larviciding by plane has been proved efficient and economical where planes and pilots are readily available. In certain areas (Silveira, 1963) it has proved to be 12 times cheaper than by ground power equipment and 15 times cheaper than by hand equipment. The extent of breeding places have to be considerable to offset the initial cost and high operating expenditure of aerial larviciding. Where planes and pilots are not readily available or good, and adequate roads are not present, hand-operated equipment would probably be the choice, as also in areas where the cost of labour is low.

6.1 TYPE OF EQUIPMENT

Equipment for the application of mosquito larvicides can be divided into the following categories:

- hand-operated equipment
- ground power equipment
- aircraft equipment.

6.1.1 Hand-operated equipment

This is equipment which, as indicated by its name, is operated by the operator without the use of any power sources. There are two types of equipment in this category depending upon the types of formulation used.

(a) Equipment for application of liquid formulation:

- paint brush
- shaker bottle
- trombone sprayer
- hand sprayer
- knapsack sprayer
- stirrup pump
- double-acting force pump
- compression sprayer
- aerosol dispenser

This equipment has been sufficiently described in "Equipment for vector control" (WHO, 1964) (35). The choice of each of the above devices for any programme should be governed by local conditions and possibilities. In view of the wide use of compression sprayers in malaria programmes the advantages of any other equipment should be
carefully weighed before making changes. Compression sprayers are greatly improved in performance and durability standards. Furthermore, local operators are familiar with their operation, care and maintenance. It is possible to use them in most larviciding situations with certain minor adjustments or replacements.

(b) Equipment for application of solid formulation:

(i) Dusters
- puff duster
- hand duster - plunger type
- bellows
- knapsack duster
- rotary knapsack duster
- barrow duster

(ii) Granule applicators
- horn seeder
- knapsack or front-carried

(iii) Pellet applicators
- knapsack or front-carried

Of the above, only the horn seeder (see page 129) has not been described in "Equipment for Vector Control" (WHO, 1964). This is specially suitable for the application of granular formulations. It consists of a "horn" (a metal pipe with a gauge which can regulate the flow or granules), a reservoir made of plastic or leather with a capacity of 13.5 kg and a carrying strap. The output is normally set at 2.2-5.5 kg/ha and the coverage will thus be at least 2.5 ha/charge. The device is very simple and durable. It needs practically no maintenance or repairs.

6.1.2 Ground power equipment

Power equipment items for application of larvicides are basically the same as hand equipment except that they are operated by a power source. Depending upon weight of the unit, they may be hand carried, barrowed, mounted, trailed or driven.

The use of larger models is usually limited to areas where good roads exist or the ground is suitable for their operation. Their output is normally higher than hand-operated equipment and therefore their use is specially indicated in areas where large and extensive breeding areas exist. In such areas, their use may be more economical than hand-operated equipment. The power is supplied usually by electrical or internal combustion engines or sometimes by the power take-off of the vehicle.

(a) Power equipment for application of liquid formulations can be divided into the following categories depending upon types of energy employed:
- hydraulic energy (power sprayers)
- gaseous energy (mist blowers)
- centrifugal energy
Power sprayers usually consist of a source of power for the sprayer's operation, a tank, a pump and the discharge system. A second type of hydraulic sprayer is that which is provided with an air-carried system. This is provided in addition to the above parts, with an air-blower delivering up to 850 m$^3$/min with a tank capacity of 350-3000 l. The air delivery velocity varies from 120-320 km/h.

The gaseous energy equipment or mist blowers are different from the hydraulic air-carried sprayers in nozzle construction and performance. The nozzle may be operated under the hydraulic system or by pressure and suction exerted by a blower system. These may deliver up to 8.5 m$^3$/min for the hand carried and up to 1700 m$^3$/min for larger multiple nozzle vehicle mounted machines. The air delivery velocity varies from 145-385 km/h.

In centrifugal energy equipment the spray is produced by spinning discs, cups, wire cages, etc. which are rotated at various speeds and are fed centrally with liquid formulations.

Of the foregoing, the jeep-mounted, air-carried hydraulic type power sprayers are more commonly used in mosquito larviciding ground operations. In malaria programmes, however, the knapsack or lighter portable types are more likely to be used.

(b) Ground power equipment for application of solid formulations includes power dusters and power ground applicators.

(i) Power dusters consist of a power unit, dust reservoir, an agitating mechanism, a feeding and metering unit, a fan or blower and a discharge outlet. They are available in many forms and sizes, powered by electric or internal combustion engine or by the vehicle power take-off. The knapsack and stretcher 2-pole carried types may be more suitable for malaria programmes in rural areas while wheel barrow, vehicle mounted or trailer types may be more suitable for use in urban areas or where road and communication facilities are good.

Granule applicators have the same type of components as power dusters, except for the agitating mechanism which may not be present in some models. The granules are spread by sieve plates, wire meshes or worm feeds. They are available in knapsack, front-carried, vehicle mounted or trailed by a tractor or a vehicle. The present equipment for application of granules requires much improvement in connexion with uniformity of coverage and dosage which is connected with variation in size, shape and density of granules.

(ii) Compressed air gun. This is a standard sand blast gun which has been adapted to suck the granules from a simple container and to eject them at a desired uniform rate. The device comprises a granule gun, a reservoir, an automatic compressed air supply, and a vehicle. For each type and size of granule, the discharge rate is determined by the following factors: air pressure; gun air jet diameter; nozzle diameter; length of the suction hose. For maximum throw a minimum of 0.165 m$^3$/min of air at 4.7 kg/cm$^2$ is required. The actual discharge rate is 0.25-0.9 kg/min. The maximum effective throw is about 12 m for 15 mesh sand core granules. The reservoir has a capacity of about 9 kg of granules. The device has been successful for larviciding in drainage channels.
6.2 EQUIPMENT USED FOR LIQUID FORMULATION

There is a wide choice of commercially available liquid spray equipment which can be used as it is or adapted to the particular needs of a mosquito larviciding programme. The selection of the type of equipment depends on the size of the control programme and on the types of breeding places to be controlled. The size, shape, accessibility and degree of vegetation growth of each breeding place type influence the selection of the equipment best suited to do the job. Large programmes may require several types. The selection of power sprayers is subject to the justification for a higher rate of coverage than can be accomplished by hand operated equipment. Table 15 presents a comparison of the number of hectares that can be larvicided per hour by several types of liquid spray equipment at specified application rates.

Table 15. RATES OF COVERAGE IN HECTARES PER HOUR FOR TYPES OF LIQUID SPRAY EQUIPMENT USED FOR AREA APPLICATION OF MOSQUITO LARVICIDES

(Based on average conditions and application rates)

<table>
<thead>
<tr>
<th>Spray Equipment</th>
<th>Nozzle discharge (l/min)</th>
<th>Nozzle pressure (kg/cm²)</th>
<th>Swath width (m)</th>
<th>Spray pattern speed (km/h)</th>
<th>Application rate (l/ha)</th>
<th>Rate of coverage (ha/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression</td>
<td>0.76</td>
<td>2.7</td>
<td>7.6</td>
<td>3.2</td>
<td>18.5</td>
<td>2.4</td>
</tr>
<tr>
<td>Low volume - low pressure</td>
<td>0.76</td>
<td>2.7</td>
<td>8</td>
<td>3.2</td>
<td>18.5</td>
<td>2.4</td>
</tr>
<tr>
<td>*Low volume - high pressure</td>
<td>3.8</td>
<td>6.8</td>
<td>6.7</td>
<td>8</td>
<td>46.5</td>
<td>4.85</td>
</tr>
<tr>
<td>Mist blower - small</td>
<td>7.6</td>
<td>6.8</td>
<td>12</td>
<td>8</td>
<td>46.5</td>
<td>9.6</td>
</tr>
<tr>
<td>Mist blower - large</td>
<td>15.2</td>
<td>6.8</td>
<td>30</td>
<td>8</td>
<td>46.5</td>
<td>24</td>
</tr>
</tbody>
</table>

* Using spray hose extension from stationary power pump

6.2.1 Compression sprayers

The standard 11.5 l compression sprayer is well known and widely used. It is adequately described by WHO specification WHO/EWP/1.82. Because it is a portable, self-contained unit, it is an indispensible piece of equipment for small or large mosquito larviciding programmes. It is best suited for spot spraying of small contained sources or for area spraying of accessible open sources of one or two hectares in size. Its main limitation is the rate of coverage. The minimum application rate of 18.5 l/ha requires ten minutes of continuous spraying with a nozzle discharge rate of 0.76 l/min. Additional time is required for filling, pumping and walking between swath patterns. Under average conditions, the rate of coverage is limited to about 2.5 ha/h. For higher application rates the area could be covered.

6.2.2 Low volume - low pressure pumps

These pumps are used to do the same type of work as accomplished by compression sprayers but at a faster rate. The time required for filling and pumping the sprayer is eliminated since the operator is furnished with a steady supply of spray at the
desired uniform pressure. For area spraying an extension hose must be dragged into the field. These pumps are very adaptable for spraying from a moving vehicle the narrow road-side ditches, street gutters, storm water inlets and other similar small sources found in and around a community.

Low volume - low pressure pumps are of the centrifugal or rotary type and are very small and light in weight. Capacities of five or ten litres per minute at 27 kilograms pressure are best suited for this type of larviciding. Lightweight portable units driven by 1 hp internal combustion engines can be carried into the field, or placed on trucks or boats. For permanent mounting on vehicles they can be best driven from the power take-off or from the fan belt pulley.

6.2.3 Low volume - high pressure pumps

These pumps are selected for special situations where access is difficult and where the target cannot be reached by low pressure sprayers. Wide drainage channels, deep ravines or inaccessible industrial waste sources are examples. Pump capacities up to 38 l/min at 34 kg/cm² pressure can be used. Pressure and discharge rates are reduced to specific requirements by an adjustable pressure control valve and by using appropriate nozzles. With "orchard" type spray guns, jet streams of several litres per minute or more can be projected up to 12 m.

6.2.4 Compressed air system

For operations applying liquid larvicides under pressure from pumping equipment mounted on a vehicle, the compressed air system has many advantages. The system is simple, consisting of an automatic air compressor (air brake type) and a pressure tank of desired capacity. The compressor, mounted on the engine block and driven off the fan belt pulley, maintains a constant pressure, usually 6.25 kg/cm², on the larvicide in the tank. The desired nozzle pressure is set by a hydraulic regulator. The system eliminates the noise and maintenance problems of pumps driven by internal combustion engines and the loss of pressure from pumps driven by the power take-off when the vehicle slows or stops. Only a very small air compressor is required, 0.06 m³/min or 0.08 m³ since the air demand is limited by the discharge rate of the larvicide. The main disadvantages are the weight and cost of the pressure tank as compared to non-pressurized spray tanks. If the application of granular formulations by a compressed air granule gun is anticipated, the air compressor should have a 0.35 m³/min nominal air delivery rating.

The pressure tank should meet the requirements for a 57 kg working pressure (ASME Code) and should be hot dip galvanized after fabrication. Tanks of this design have been in continuous service (annual cleaning only) using emulsions, diesel oil solutions and weed oils with no corrosion problems. The tank serves a dual purpose by providing storage space for the liquid larvicide (oil or emulsion) as well as for the compressed air used by the granule gun. Excessive oil and water vapours are removed by a filter so that the air gun receives dry air. A pressure regulator with a gauge is also installed at this point so that the operator can set the pressure required for the desired granule discharge rate.

6.2.5 Mist blowers

The application of liquid sprays by means of a high velocity air stream is an effective and efficient method of larviciding large breeding areas by ground equipment. The effectiveness of a mist blower depends largely on its ability to distribute the spray droplets uniformly over a specific swath width. The spray pattern is obtained by a proper balance of the volume and velocity of the discharged air with the volume and method of injecting the liquid spray into the air stream. The efficiency of the blower itself
depends largely on its design and on its proper operating speed. The choice of mist blower will depend largely on the method of transportation. Portable mist blowers such as the Solo "Junior" or M70 B model can be carried on the back of the operator or operated from a small boat. The rate of coverage is limited by the low air volume discharge and by the size of the spray material tank. Small mist blowers such as the Potts P.24 or the "California Mist Blower" are compact, lightweight units which can be mounted on a trailer or small vehicle with 190-380 litre spray tanks. Large mist blowers with spray capacities of 15 l or more per minute are usually self contained units mounted on special trailers or trucks and are designed primarily for agricultural spraying of fruit or ornamental trees.

The characteristics of several related mist blowers are presented in the following table.

**Table 16. CHARACTERISTICS OF SOME MIST BLOWERS**

<table>
<thead>
<tr>
<th>Name of Mist blower</th>
<th>Weight without spray tank (kg)</th>
<th>Drive (hp)</th>
<th>Outlet diameter (cm)</th>
<th>Air velocity (km/h)</th>
<th>Air volume (m³/min)</th>
<th>Spray capacity (l/min)</th>
<th>Swath width (m)</th>
<th>Approx. cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solo &quot;Junior&quot; portable</td>
<td>6.8</td>
<td>2.5</td>
<td>5</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>6-7.5</td>
<td>300</td>
</tr>
<tr>
<td>Solo &quot;M70B&quot; portable</td>
<td>12.3</td>
<td>5</td>
<td>7.5</td>
<td>400</td>
<td>-</td>
<td>-</td>
<td>9-12</td>
<td>-</td>
</tr>
<tr>
<td>Potts-P.24²</td>
<td>107</td>
<td>7</td>
<td>12.5</td>
<td>80-320</td>
<td>68</td>
<td>11.5-38</td>
<td>9-18</td>
<td>900</td>
</tr>
<tr>
<td>&quot;California design&quot;³,⁴</td>
<td>-</td>
<td>-</td>
<td>27.5</td>
<td>128</td>
<td>131.5</td>
<td>3.8-7.5</td>
<td>24</td>
<td>-</td>
</tr>
</tbody>
</table>

1 Solo Kleinmotoren GMBH, 7034 Maichingen, Near Stuttgart, Germany
or: Solo Industries Inc., P.O. Box 128, Woodside, New York 11377, USA

2 S. Frederick Potts, P.O. Box 51, Crawford, Mississippi, USA

3 Mulhern et al (1961)²⁰

4 Akesson (1961)¹¹

**6.2.6 Spray guns and nozzles**

Spray guns and nozzles of proper design and good quality should be selected. The effectiveness of the larviciding programme depends on the spray operator's ability to apply the spray efficiently and effectively with a minimum of hazard and discomfort. Spray guns should be leakproof and designed for easy replacement of stuffing glands, washers or needle valves when excessive wear results in leakage and contamination to the hands. Since the spray operator spends the greater part of each day applying larvicide, the spray gun should be well balanced and the valve lever should require a minimum of pressure at the open position. Two types of spray gun are needed, one for low pressure and one for high pressure. For each gun a set of nozzles and tips should be selected to provide the operator with a choice of spray patterns best suited for the particular breeding source to be larvicided. Adjustable nozzles which vary the spray pattern from a cone spray to a straight stream are the nozzles of choice for experienced spray operators. The following...
spray guns and nozzles are examples of the type of equipment suitable for mosquito larviciding operations.

(a) **Spray gun and nozzle for low pressure spraying**

* SS Co. Trigger Tee-Jet shut-off valve with:

(i) **Adjustable Cone-Jettip No. 5500-X8**

- Cone spray - 490 ml/min at 74° angle at 2.7 kg/cm²
- Straight stream - 1.80 l/min and 11 m maximum throw

(ii) **1/4 T Tee-Jetspray nozzle with orifice tip No. 8002**

- Flat spray pattern - 0.757 l/min at 80° angle at 2.7 kg/cm²

(b) **Spray gun and nozzles for high pressure spraying**

* SS Co. Gun-Jetspray gun model No. 14 with:

(i) **Orifice disc No. D-4**

- Cone spray - 3.5 l/min at 26° angle at 6.25 kg/cm²
- Straight stream - 3.5 l/min and 11 m maximum throw

(ii) **Orifice disc No. D-6**

- Cone spray - 0.72 l/min at 41° angle at 6.25 kg/cm²
- Straight stream - 7.6 l/min and 13.5 m maximum throw

### 6.2.7 Drip application equipment

This equipment is used for applying liquid larvicide or herbicide formulations. They are economical and nearly labour-free. They can be installed on irrigation systems for constant feeding, and are especially useful for larviciding in rice fields. The dosage can be regulated with the flow in order to get proper dilution rates. Different flow rates can be obtained by using different jet orifices (see Table 17). The installation, however, needs to be theft-proof and protected against manipulation by the public and especially children.

Various devices for drip application have been used. The most appropriate are those with metering devices and those that give constant flow.

The construction is simple and the example given on page 128 can be constructed with about $5 worth of pipes, ells and tees. The metering device is attached to the 2 cm bung of a 19 litre drum. The drum should not be punctured, but filled with the liquid formulation from its opening at the top where the bushing will be installed. It will deliver a constant, even flow, until the drum is empty. The same device may also be used with a 114 litre drum.

* Manufactured by the Spraying Systems Company, North Avenue at Schmale Road, Wheaton, Illinois 60187, USA,
Table 17. **FLOW RATES FOR VARIOUS TEEJET\(^1\) ORIFICES**

<table>
<thead>
<tr>
<th>TeeJet orifice</th>
<th>ml/min(^2)</th>
<th>kg/h</th>
<th>Approximate time (hours) for 1 litre</th>
<th>5 litres</th>
</tr>
</thead>
<tbody>
<tr>
<td>.014</td>
<td>7.04</td>
<td>0.30</td>
<td>2.36</td>
<td>11.80</td>
</tr>
<tr>
<td>.015</td>
<td>7.90</td>
<td>0.34</td>
<td>2.10</td>
<td>10.50</td>
</tr>
<tr>
<td>.016</td>
<td>8.87</td>
<td>0.38</td>
<td>1.87</td>
<td>9.35</td>
</tr>
<tr>
<td>.018</td>
<td>12.57</td>
<td>0.54</td>
<td>1.30</td>
<td>6.50</td>
</tr>
<tr>
<td>.020</td>
<td>15.67</td>
<td>0.67</td>
<td>1.06</td>
<td>5.30</td>
</tr>
<tr>
<td>.022</td>
<td>20.70</td>
<td>0.90</td>
<td>0.79</td>
<td>3.95</td>
</tr>
<tr>
<td>.024</td>
<td>24.40</td>
<td>1.21</td>
<td>0.68</td>
<td>3.40</td>
</tr>
<tr>
<td>.026</td>
<td>32.53</td>
<td>1.35</td>
<td>0.53</td>
<td>2.65</td>
</tr>
<tr>
<td>.028</td>
<td>37.55</td>
<td>1.62</td>
<td>0.42</td>
<td>2.10</td>
</tr>
<tr>
<td>.030</td>
<td>41.40</td>
<td>1.75</td>
<td>0.39</td>
<td>1.95</td>
</tr>
<tr>
<td>.032</td>
<td>44.35</td>
<td>1.89</td>
<td>0.36</td>
<td>1.80</td>
</tr>
<tr>
<td>.034</td>
<td>50.27</td>
<td>2.16</td>
<td>0.31</td>
<td>1.55</td>
</tr>
<tr>
<td>.035</td>
<td>54.70</td>
<td>2.34</td>
<td>0.30</td>
<td>1.50</td>
</tr>
<tr>
<td>.037</td>
<td>65.05</td>
<td>2.79</td>
<td>0.25</td>
<td>1.25</td>
</tr>
<tr>
<td>.039</td>
<td>75.40</td>
<td>3.20</td>
<td>0.22</td>
<td>1.10</td>
</tr>
<tr>
<td>.041</td>
<td>85.75</td>
<td>3.65</td>
<td>0.19</td>
<td>0.95</td>
</tr>
<tr>
<td>.043</td>
<td>94.62</td>
<td>4.03</td>
<td>0.17</td>
<td>0.85</td>
</tr>
<tr>
<td>.045</td>
<td>104.97</td>
<td>4.47</td>
<td>0.15</td>
<td>0.75</td>
</tr>
<tr>
<td>.047</td>
<td>115.32</td>
<td>4.91</td>
<td>0.14</td>
<td>0.70</td>
</tr>
<tr>
<td>.049</td>
<td>125.67</td>
<td>5.35</td>
<td>0.13</td>
<td>0.65</td>
</tr>
<tr>
<td>.051</td>
<td>133.06</td>
<td>5.67</td>
<td>0.12</td>
<td>0.60</td>
</tr>
<tr>
<td>.053</td>
<td>143.41</td>
<td>6.12</td>
<td>0.11</td>
<td>0.55</td>
</tr>
<tr>
<td>.054</td>
<td>147.85</td>
<td>6.30</td>
<td>0.11</td>
<td>0.55</td>
</tr>
<tr>
<td>.055</td>
<td>158.20</td>
<td>6.74</td>
<td>0.10</td>
<td>0.50</td>
</tr>
<tr>
<td>.057</td>
<td>167.07</td>
<td>7.16</td>
<td>0.09</td>
<td>0.45</td>
</tr>
<tr>
<td>.059</td>
<td>184.81</td>
<td>7.87</td>
<td>0.08</td>
<td>0.40</td>
</tr>
<tr>
<td>.061</td>
<td>190.73</td>
<td>8.12</td>
<td>0.08</td>
<td>0.40</td>
</tr>
<tr>
<td>.063</td>
<td>199.60</td>
<td>8.50</td>
<td>0.08</td>
<td>0.40</td>
</tr>
<tr>
<td>.065</td>
<td>211.43</td>
<td>9.00</td>
<td>0.07</td>
<td>0.35</td>
</tr>
<tr>
<td>.067</td>
<td>223.25</td>
<td>9.51</td>
<td>0.07</td>
<td>0.35</td>
</tr>
<tr>
<td>.070</td>
<td>239.52</td>
<td>10.20</td>
<td>0.06</td>
<td>0.30</td>
</tr>
</tbody>
</table>

1 Spraying Systems Co.

2 Figures were taken at 15°C and are approximate. Be sure occasionally to measure flow in the field, to make certain you have the correct orifice and because rates vary with temperature.

Note: The drip application is especially useful for larviciding in rice fields.
Figure 22. CONSTRUCTION OF DRIP APPLICATION EQUIPMENT

20 litre drum

- 19-12.5 mm bushing
- 12.5-51 mm nipple
- 12.5 mm streit ell
- 12.5-152 mm bushing
- 12.5 mm streit ell
- 12.5 x 51 mm nipple
- 12.5 x 152 mm nipple
- 12.5 x 6 mm bell reducer
- Spraying systems orifice holder with 200 mesh screen
6.3 EQUIPMENT USED FOR GRANULAR FORMULATIONS

6.3.1 Swinging horn granule dispenser (horn seeder)

The application of granular formulations by this simple, inexpensive equipment is efficient and effective. As originally described "the only moving part is the operator". The rate of coverage is at least twice that of compression sprayers using liquid sprays. The weight carried by the operator is only 11 kg/ha for 1% granules and 5.5 kg/ha for 2% granules as compared to 17.5 kg/ha for liquid sprays at 18.5 l/ha. Since the horn seeder has a capacity of 9 kg the operator can treat one hectare without stopping to refill and no pumping is required as with the conventional spray can.

The horn seeder consists of three parts, the bag, the shoulder carrying strap and the horn. For mosquito control operations the bag is made of an impervious material, nylon or plastic, and the top opening is equipped with a zipper to prevent spillage on the operator. The impervious material prevents the insecticide from contacting the operator's body. The bottom opening of the bag is tapered horizontally to a snout-type opening and secured to the metal base or nozzle section of the horn. This base section contains an adjustable opening or gate which can be set at different positions to meter out the rate of discharge of the granules. The remainder of the horn, consisting of two telescoping, tapered metal sections, is attached to the base and swung from side to side to broadcast the granules.

At the present time there is no commercial source of supply for ready-made bags made of impervious material so they are custom made. Figure 23 shows the horn seeder and the dimensions of the bag which can be made in many places at a cost less than $10.

The three parts of the metal horn are commercially available (e.g. from Cyclone Seeder Co. Inc., Urbana, Illinois, USA) at a total cost of $1.50 per set. Canvas bags, without zippers as used for broadcasting grain and alfalfa seed are also available from this company at a very nominal price.

Figure 23. HORN SEEDER
6.3.2 Mechanical granule spreader

The use of the horn seeder has generally replaced the use of mechanical spreaders for the application of granular insecticides used for mosquito larviciding. Commercially available granule spreaders are primarily designed for the application of weed killers at high rates of application, 111-880 kg/ha. These spreaders can be adapted to meet mosquito control requirements. A hand operated mechanical spreader with a capacity of 11.7 kg of granules, designed for weed killers is available commercially. A model made of plastic sells for about $12.

A very small spreader made of plastic and holding only 1.5 kg of granules is commercially available. It is designed for home use for the application of lawn seeds and granular fertilizers. The discharge rate is controlled by a selector knob with four settings, the maximum producing 220 kg/ha at the normal working speed. A uniform swath width of 2.7-4 m can be applied. (A 1.5 kg capacity spreader costs $3).

6.3.3 Compressed air granule gun

Granular larvicides can be shot from this gun at discharge rates up to 1.5 kg/min and distances up to 13 m. It is a standard sand blasting gun and requires 0.35 m³/min of free air at 4.75 kg/cm² when operating at maximum capacity. The air pressure, size of air jet, nozzle size and length of suction hose determines the rate of discharge and the throw, or distance the granules are projected.

The vacuum created by the air jet within the body of the nozzle draws the granules through a short section hose 1-4 m long, and the high velocity jet stream ejects the granules through the nozzle orifice.

The granule gun can be operated from a moving vehicle in the same manner as liquid spray. By dragging a light air hose and carrying a supply of granules in a horn seeder bag, the operator can treat breeding places a few hundred metres from the vehicle. Applications can be made from a small boat using a portable air compressor as the source of supply.

The parts of the granule gun assembly are all standard equipment, for example:

- Kelco sandblast gun model G790C, with 1.5 mm and 1 mm jets and No. 3 and No. 4 nozzles, total cost $50, Kelco Sales and Engineering Co., 11936 Front Street Norwalk, California, USA
- *7 mm ID Duraprene air hose, single braid, 15 mm OD and 88 kg working pressure, weight - 6.75 kg per 50 m
- *1 cm ID "Signal call hose" (for suction hose), part No. 260, 1 cm OD, weight - 6 kg per 50 m

* Acme Rubber Manufacturing Company, Trenton, New Jersey
6.4 SPECIAL EQUIPMENT FOR LARVICIDING

6.4.1 All-purpose spray vehicle

Many special breeding area conditions and control problems can be overcome with the use of power equipment. For new programmes depending mainly on hand operated spray equipment the availability of one or more vehicles completely equipped with compact, lightweight power equipment, could be a decisive factor in the success of the larviciding programme. The cost of an all-purpose spray vehicle equipped as summarized below is estimated at $5000 (including the vehicle) in the United States.

(a) Vehicle: four wheel drive pick-up truck equipped with maximum floatation tyres.

(b) Compressed air system:
- 12 CFF air-brake type compressor mounted under the hood and driven off the vehicle engine
- 228 litre pressure tank for storage of larvicide and/or air under 6.8 kg/cm²
- adjustable hydraulic pressure regulator for larvicide supply to spray gun and mist blower
- combination air filter and pressure regulator for air supply to granule gun.

(c) Hydraulic spray gun: Orchard type spray gun similar to Spraying Systems Gun-Jet Model No. 14 with 7.5 1/min capacity at 6.8 kg/cm² and equipped with 30-60 m of 1 cm one braid, weed-spray type hose (Hycar) Beua-N.

(d) Mist blower: High volume type similar to the "California Mist Blower" driven by a separate internal combustion engine and permanently located at the rear of the truck to permit discharge direction to be varied from left to right through an arc of about 260°. Equipped with two separate sets of nozzles to permit either larviciding or space adulticiding. All mist blower controls to be mounted in the cab of the truck for operation from the driver's seat.

(e) Compressed air granule gun: The gun should be equipped with proper jet and nozzle sizes to permit granule discharge rates from 0.2-1.35 kg/min at air pressures from 1.3-3.2 kg/cm² and with several hundred metres of 7 mm inside diameter lightweight air hose.

(f) Miscellaneous equipment: Hand operated equipment, consisting of two compression sprayers and two horn seeders should also be included. A small fresh water storage tank 19-38 l permanently installed with a faucet extending outside the body of the truck is recommended for hand washing purposes. The cargo body of the truck should be of sufficient size, and the power equipment should be so installed as to permit extra space for storage of one day's supply of spray concentrate and/or granules.

6.4.2 Air-thrust powered boat

Lightweight boats of wood or metal with a flat bottom, propelled by an air-thrust power unit (instead of the conventional underwater propellers) have proved very practical for access to many breeding areas. Shore lines of lakes or lagoons with heavy growth of vegetation can be conveniently larvicided from the boat. Swamps or reservoirs with submerged or floating aquatic growth which foul conventional underwater propellers can be navigated by the air boat. Boats of this type draw only 7.5-15 cm depending on the cargo weight, thus permitting access to very shallow water. Liquid sprays can be applied by a compression sprayer or by a low pressure portable pump unit. Granules can be applied by
the horn seeder or by the granule gun using a portable air compressor. The following air-thrust unit and boat have proved satisfactory for the above operation, carrying the equipment and a two man crew.

(a) 60 cm air thrust portable power unit (cost $240): Two bladed 60 cm prop develops 10 kg of thrust, driven by a 2.5 hp Clinton two-stroke engine equipped with ratchet type impulse starter. Fibre glass duct confines air stream. Aluminium mounting clamp for boat transoms up to 5 cm thick and 20° pitch. Total weight is 11 kg. Other portable units include 45 cm for 7.3 kg thrust and 88 cm for 39 kg thrust.

(b) Wards 3.6 m Sea King aluminium boat (cost $119): 117 cm beam, 35 cm midships depth and 110 cm top width of transom. Bottom, sides and three seats made of 0.5 gauge aluminium. Total weight - 36.3 kg. Similar boats from 2.4-4.8 m long are available.

6.4.3 Amphibious tracked swamp vehicle

This type of vehicle is designed for mobility in marshes, swamps, deep water or on rough land. The all-purpose spray equipment consisting of compressed air system, mist blower, hydraulic spray gun and compressed air spray gun for granules can be readily installed. Breeding sources which are not accessible by foot, boat or motor vehicle can be larvicided with a minimum of manpower. Where breeding sources are not adaptable to air spray operations or where aircraft are not available, swamp vehicles can be used to good advantage.

A model has been successfully used for mosquito control in the United States for several years. It travels on land up to 55 km/h and in the water at 7 km/h. Fuel consumption varies from 30-60 l/100 km. The turning radius is 3 m and it can climb a 60% earth slope. The vehicle weighs 1450 kg empty and has a track area of 1.7 m² and a ground bearing pressure of 0.05 kg/cm². In addition to two passengers, the cargo capacity is 455 kg and the cargo area is 185 x 175 cm. (Price is about $8000). A tilt type trailer is recommended for hauling between jobs.

7. LOW VOLUME AND ULTRA-LOW VOLUME - HIGH CONCENTRATE APPLICATION OF INSECTICIDES BY AIRCRAFT

Aircraft have been used extensively in the application of insecticides as mosquito larvicides and as space adulticides. Various chemicals are employed, the formulations and volumes being varied to suit the individual problems and the local conditions. Liquid sprays are used most, but granular and dust formulations are also applied in appropriate situations.

7.1 CATEGORIES OF INSECTICIDE APPLICATION BY AIRCRAFT

There is no unanimously accepted descriptive designation for volumes of insecticide applied by air per unit area treated. For convenience, the following designations are used herein for aerial insecticide application in mosquito control:
Table 18. APPLICATION RATES

<table>
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<tr>
<th>Designation</th>
<th>Liquid formulations</th>
<th>Granular or dust formulations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high volume</td>
<td>More than 140 l/ha</td>
<td>More than 27.5 kg/ha</td>
</tr>
<tr>
<td>High volume</td>
<td>28-140 l/ha</td>
<td>16.5-27.5 kg/ha</td>
</tr>
<tr>
<td>Standard volume</td>
<td>4.6-28 l/ha</td>
<td>5.5-16.5 kg/ha</td>
</tr>
<tr>
<td>Low volume</td>
<td>1.1-9.3 l/ha</td>
<td>3.3-515 kg/ha</td>
</tr>
<tr>
<td>Ultra-low volume</td>
<td>74 ml/ha - 1.1 l/ha</td>
<td>1.1-3.3 kg/ha</td>
</tr>
</tbody>
</table>

The cost of application by some techniques may be greater than the cost of the insecticide, and is related to the volume applied per unit area. Hence there has been a continuing interest in the development of procedures that will provide dependable mosquito control with decreased volumes of spray material, thereby resulting in greater economy.

7.2 APPLICATION OF LIQUID FORMULATIONS

It is common practice in mosquito control to apply the emulsible larvicide at low volumes, usually from 4.6-18.5 l/ha. At 9.5 l/ha, it has been possible to attain application costs as low as $0.60 to 0.85 per hectare, exclusive of the insecticide costs. The emulsible formulations of the organophosphorus toxicants may contain only 1.2 ml/l of actual toxicant, the balance of the formulation being mostly water, with a little emulsifier added. Thus the cost of the actual toxicant, such as parathion, to cover one hectare would be about $0.25. When some or all of the water is eliminated, the volume of liquid applied being reduced accordingly, the aircraft can treat with each load a correspondingly greater area before returning to its supply point, thus increasing its productive capacity and lowering the unit costs. It frequently happens that on a particular operation, at a rate of 9.5 l/ha about 20 minutes is required to discharge a load of 380 l, and another 20 minute period will be required to ferry back to the base, reload the plane, and return to the field to be sprayed.

7.2.1 Advantages of low volume applications

It is apparent that if the volume per unit area is halved, the frequency of loading will be halved, and very important spray time, at the most desirable time of day can be utilized in spraying instead of in loading and ferrying. If the application rate could be still further reduced to the point where the plane could operate continuously on spraying for a period limited only to the capacity of the fuel tank (usually about two hours), then the plane could treat six times as much area with one load, with no increase in size or power, thus eliminating five of the loading periods. Continuing the projection a little farther, if a plane carrying 380 l were to start flying at 5 a.m., applying only 1.5 l/ha and averaging 40 ha in 20 minutes, by 7 a.m. it would have treated 240 ha. After a 20 minute loading period, it could be back in the air spraying by 7:20 a.m. and by 9:20 a.m. it would have treated for the morning a total of 480 ha. This compares with a theoretical maximum of 240 ha that could be treated in the same time period at the 9.5 l/ha rate.

In operational field experience, one small helicopter with a 320 kg payload capacity loading from a truck alongside the fields to be sprayed, has larvicided 800 ha in a single morning, applying 445 ml/ha on fields of varying size from 2 ha to 64 ha (Tulare Mosquito Abatement District).
While it would be in the interests of economy to continue to spray later into the
day, experience has shown that the water mixed emulsible sprays cannot be depended upon to
give consistently reliable results, probably because evaporation causes a shrinkage of the
droplets to a size so small that they can drift out of the target area before settling to
the ground. There is good evidence to indicate that non-evaporative sprays of relatively
large droplet sizes may allow spraying to be done much later in the day and under more
windy conditions, as well as allowing the successful use of lower volumes. Motor oil
has been used as a viscosity and evaporation control additive in earlier work with DDT oil
solutions, but it was not considered a suitable additive to apply over agricultural crops
or in residential areas. Polypropylene glycol P400 has proved to be a good carrier for
chlorpyrifos and fenthion and would probably be equally good with other toxicants in low
volume formulations.

7.2.2 Insecticide formulations

Technical malathion, without dilution, at ultra-low volume rates of 150-600 ml/ha has
given good results as an adulticide, against Culex vectors of encephalitis and salt marsh
and fresh water pasture Aedes species and, in Haiti, against Anopheles. With emulsifier
added, malathion at ultra-low volume rates of 500-800 ml/ha has effectively controlled
pasture Aedes and Culex larvae. Fenthion emulsible formulations with the addition of
"Golden Bear" DMN oil, but with no water added to the spray tank, has given effective results
as a larvicide and as an adulticide against pasture Aedes and Culex, and against rice field
Anopheles and Culex. Formulations of other toxicants should be equally effective, so long
as the physical properties of the formulations are similar, with low volatility, relatively
high viscosity, and high specific gravity. Technical malathion happens to fit these
criteria very well. Other insecticides may require the use of diluents of low viscosity:
polypropylene glycol or suitable oils.

7.2.3 Technique of low volume application of insecticides

Emulsible formulations have been successfully employed in operational larviciding
programmes at a low volume rate of 4.5 l/ha by using fewer nozzles to reduce the amount
delivered, but not reducing the orifice size of the nozzles, so as to retain the same
droplet size. When smaller nozzle orifices are used, the droplets produced are smaller
and settle so slowly that much of the spray material may be lost by evaporation or drift
out of the target area. With these water mixed sprays, the plane must be flown very low,
1.5-3 m.

With concentrate sprays of low volatility and higher viscosity than water mixed sprays,
small orifice nozzles operated at low pressures tend to produce satisfactorily large droplet
sizes for larviciding. These droplets fall more rapidly and thus are not so subject to
drifting out of the target area. Furthermore, being of low volatility, the droplets do not
shrink due to evaporation so the rate of fall tends to be constant, allowing the plane to be
flown at a greater altitude 6-30 m. Theoretically, if nozzles could be used which would
deliver an ultra-low volume rate of say 0.9 l/ha with all of the droplets having a diameter
of 200 microns, they would fall 30 m in 0.7 minutes. If these droplets were evenly
distributed when they reached the surface of the mosquito producing waters, there would be
about 2.2 droplets per cm² of surface; allowing for even moderately good dispersal of the
insecticide in the water of the mosquito source, it is evident that the mosquito larvae
would be exposed. Experience has proved that this is so, and volumes as low as 450 ml/ha
and 225 ml/ha under very favourable conditions have given satisfactory results.

For adulticiding, smaller droplets are desirable. However, drift must be considered,
and droplets of the 200 micron size could drift 75 m with a wind of only 6.4km/h in the
0.7 minutes required to fall from a release point 30 m above the ground.
Down-wind transport of spray droplets

Figure 24 presents a graphic theoretical representation of the movement of non-volatile spray droplets released from an aircraft, flying 30 m above the ground, into a mass of air assumed to be moving horizontally across the track of the aircraft at a right angle to it, without turbulence at speeds of 3.2, 6.4 and 9.6 km/h. The chart also disregards the turbulence created by the aircraft because this factor could not be adequately represented although it is well known that it greatly affects the distribution pattern of sprays, particularly when released from a low flying aircraft. In practice, even under the best spraying conditions, considerable turbulence is present and does affect the distribution of the spray. Furthermore, it is not possible to develop droplet spectra of only the wanted drop sizes; nevertheless, field programmes can be successful when predicted upon approximations of the type presented here.

Droplet size

A given volume of spray material theoretically could be divided into relatively few large droplets of uniform size, which would have only a small surface area exposed to the air, and therefore would evaporate slowly, while falling rapidly. The same volume of spray material divided into very small droplets would yield a vastly increased number, which would have a proportionally greater total surface area and would thus evaporate far more rapidly while falling so slowly as to drift (practically) wherever the air current went. These relationships (approximations) are set forth for droplets of selected sizes in Table 19, and may be of assistance in appreciating that while very small droplets are wanted for aerial adulticiding where it is important to have a dense cloud of spray droplets suspended in the air for a considerable period of time, for larviciding fewer and larger droplets are required so that they may be expected to reach the target area more quickly and therefore more surely and with less loss to vagrant air currents.

7.2.4 Booms and nozzles

The standard booms and nozzles employed for agricultural air spraying on "Pawnee", "Call-Air", and "Stearman" spray planes (and others) may be used with emulsible water mixed formulations for the 4.5 l/ha low volume spray rate, by reducing the number of nozzles to 10 or 12 on a 10 m boom and selecting nozzle tips and pressures that will give the desired delivery rate (D4, D5 or D6 hollow cone nozzles or 8004 or 8006 flat fan spray tips). By directing the nozzles backward and downward at a 45° angle, the shattering of droplets by the airstream may be reduced. It is undesirable to attempt to reduce the delivery rate by using smaller nozzles, since this tends to produce finer droplets and more loss due to drift and evaporation.

7.2.5 Special pump and booms for low volume spraying

For ultra-low volume applications of non-evaporative formulations at rates of 600 ml or less per hectare, the standard booms and pumps on agricultural spray planes may be used by making minor modifications. However, this equipment has so great a capacity that it is not well matched to the application of ultra-low volumes. For example, if a spray boom system retains 13.5 l of spray material in the boom system when the pump "runs dry", at 0.75 l/ha there would be enough spray material left in the boom to treat 14 hectares. For this reason, some installations have employed special small diameter booms and low capacity pumps driven by 12 volt electric motors. Such booms may be clamped to the standard booms, allowing easy conversion back to the standard higher volume application rates when necessary.

Special rotary nozzles ("Minispin") driven by small air propellers have been developed for dispensing ultra low volumes of concentrates in small droplets, but for larviciding these have shown little advantage over the more conventional cone spray and flat fan spray nozzles.
Figure 24. THEORETICAL PATHS OF SPRAY DROPLETS OF SELECTED SIZES IN STABLE AIR CURRENTS OF VELOCITIES 3.2, 6.4, AND 9.6 KM/H

Chart assumes that air movement is horizontal only, uniform in direction and velocity, with no turbulence or ascending or descending currents. These conditions rarely if ever occur in nature, and allowance must be made for field conditions when applications are made.

Theoretical paths of droplets less than 50 microns diameter are not shown since droplets of that size range settle so slowly that they tend to be carried wherever the air currents go.
Table 19. A THEORETICAL APPROXIMATION OF THE NUMBER OF SPRAY DROPLETS OF VARIOUS SELECTED SIZES IN UNITS OF VOLUME AND SURFACE AREA

<table>
<thead>
<tr>
<th>Droplet sizes (Diameter microns)</th>
<th>Average number of droplets</th>
<th>Cross-sectional area of droplets for each m²</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>In the spray liquid</td>
<td>At 110 ml/ha</td>
</tr>
<tr>
<td>In each ml</td>
<td>in each 110 ml</td>
<td>Per m²</td>
</tr>
<tr>
<td>1</td>
<td>1 910 000 000</td>
<td>210 000 000</td>
</tr>
<tr>
<td>5</td>
<td>15 280 000</td>
<td>1 650 000 000</td>
</tr>
<tr>
<td>10</td>
<td>1 910 000</td>
<td>210 000 000</td>
</tr>
<tr>
<td>20</td>
<td>250 000</td>
<td>27 000 000</td>
</tr>
<tr>
<td>50</td>
<td>16 000</td>
<td>1 760 000</td>
</tr>
<tr>
<td>100</td>
<td>2 000</td>
<td>220 000</td>
</tr>
<tr>
<td>200</td>
<td>250</td>
<td>27 500</td>
</tr>
<tr>
<td>300</td>
<td>74</td>
<td>8 140</td>
</tr>
<tr>
<td>500</td>
<td>16</td>
<td>1 760</td>
</tr>
</tbody>
</table>
7.2.6 Typical boom installation

A typical spray boom arrangement on a "Pawnee" 235 plane applying water mixed emulsions at 4.5 l/ha might have ten D5 cone spray nozzles distributed along a 10 m boom, with one or two extra D6 cone spray nozzles located on the right side boom, about 1 m from the edge of the fuselage, to compensate for the spray material which is drawn from right to left by the spiral slip stream generated by the propeller of the plane.

For ultra-low volume dispersal of 0.75-0.90 l/ha of the more viscous non-volatile concentrates, the same aircraft might be equipped with four No. 8002 flat fan spray nozzles on the left wing boom, and five on the right wing boom, or for 0.5 l/ha only four or five No. 8002 nozzles would be needed.

Many other nozzle combinations may prove to be even more satisfactory. It is emphasized that each arrangement should be carefully calibrated and spray pattern determinations should be made before operational use of the system. Various means are available for evaluating swath patterns, including physical simple dye-tracer methods (Brown, 1951(5)) and biological bio-assay methods.

Current developments of aircraft and helicopter equipment and procedures for the utilization of ultra-low volume sprays are proceeding rapidly and operators preparing to make low volume treatments should investigate the latest variations in equipment before making installations.

7.2.7 Multi-purpose utilization of aircraft in disease control

There are many situations in malaria programmes where aircraft, particularly helicopters, could be used with advantage - for inspection purposes, for the movement of supervisory and other personnel, for the transportation of equipment and supplies, and for actual larviciding operations. However, there are to date few instances where the use of this sophisticated type of equipment has been considered possible due mainly to the expense and the difficulty of ensuring adequate maintenance in the kind of areas where it would be most useful. Experience of the multipurpose utilization of helicopters in other disease control programmes is, therefore, of interest.

In executing an emergency preventive field programme designed to avert a potential encephalitis epidemic in California, small helicopters were employed for inspection to determine the locations which should be sprayed, and the same machines were then used as necessary to apply low volume formulations at 450 ml/ha using chlorpyrifos at a dosage rate of 55 g/ha and fenthion at 110 g/ha, both diluted for application with polypropylene glycol P400. Highly qualified vector control specialists were assigned as inspectors, and it was estimated the helicopter transport permitted each to inspect more than ten times as much area (50 km2/h) over irrigated farm land, as would have been possible with ground transport, while having the spray equipment and spray material already on the aircraft allowed immediate treatment of sources when necessary. Both the inspection and spraying were adjudged highly satisfactory, except in one area where the mosquitos were found to be highly resistant to all available organophosphorus larvicides.

The strategy employed in meeting the emergency placed the greatest emphasis upon prevention, by destroying the developing vector mosquito populations while they were still in the aquatic larval stage. By using this approach the area treated was kept to only a fraction of the area which would have been treated had adulticiding been the primary method employed. Furthermore, by emphasizing the antilarval approach, all of the larviciding operations performed within the normal programmes of the local agencies contributed directly to the total effort.
8. PREPARATION, MIXING AND HANDLING OF LARVICIDES

Mixing and preparation of larvicide formulations to the desired strength, whether solid or liquid, deserves emphasis and attention. The organophosphorus larvicides currently in wide use are highly toxic and safeguards are indispensible for the protection of labourers mixing the concentrates.

These are expensive compounds and correct mixing and accurate formulation is essential for economy. This is best accomplished by carrying out the mixing operations in certain centres by specialists using mixing equipment minimizing the handling of insecticides and greatly reducing the chances of human intoxication.

Such centralization is more practicable where the programme employs ground power or aerial equipment which facilitates the transportation of finished formulations. For larviciding in remote areas with emulsion or suspension formulations, the mixing will have to take place in the field. In this case, the training of operators in correct and appropriate mixing and handling procedures is essential. They should be provided with protective clothing and equipment, mainly rubber gloves, measuring cups, soap and detailed instructions.

With less toxic and less costly materials, mixing in the field has been practised in the past. Paris green or some of the chlorinated hydrocarbons have been mixed with road dusts or other similar carriers in the field. In some malaria programmes fenthion concentrate is carried by the operator and is mixed with water in the field. The rate of application being very low, a small quantity of the concentrate is sufficient for a few days' work and thus it is a very time-saving practice.

Many highly toxic larvicides have been widely used without accident. Accidents should not occur if instructions for the handling and use are followed and precautions taken. However, safety requirements are not always observed and measures for their reinforcement must be employed.

The following hazards should be considered when using a toxic material in mosquito larviciding:
- toxicity to plants
- toxicity to operators
- toxicity to consumer of crops
- toxicity to inhabitants
- toxicity to domestic animals and wildlife
- residual toxicity and environmental pollution

Extracts from "Guide and recommendations for the use of insecticides in California mosquito control" (1956) are given in Annex 4.
# CHAPTER IV. PLANNING AND ORGANIZATION OF ANTILARVAL OPERATIONS IN MALARIA PROGRAMMES

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CHAPTER IV. PLANNING AND ORGANIZATION OF ANTILARVAL OPERATIONS IN MALARIA PROGRAMMES

1. PLANNING ANTILARVAL OPERATIONS

Antilarval operations are receiving more attention in malaria eradication and control programmes. In malaria eradication, they have usually been resorted to as a supplement to the traditional programme elements of residual house-spraying and drug administration, but there are cases where antilarval operations have been used as the principal attack measure. In malaria control, they can be applied wherever their use may be preferable to other control methods on grounds of efficacy, practicability, cost or other programme considerations, but here also they can be combined with other control measures where appropriate and feasible under local conditions.

Practicability and cost are often the main guiding factors in the choice of a method of mosquito control. Where breeding places are few and the number of dwellings are numerous it is more economical and practical to adopt antilarval measures than anti-adult measures, e.g. many urban areas.

The needs of the particular situation tend to dictate the basis upon which planning will be carried out (Boyd, 1949 (3)). There may be considerable differences in planning when antilarval operations are initiated at the inception of a programme, as compared to the planning for antilarval operations to be introduced into a programme that is already well established.

1.1 PRINCIPLES INVOLVED

The principles involved in planning antilarval operations are similar whether the problem occurs in a developing, remote area, or whether it occurs where modern urbanization has resulted in the construction of complex water resource developments. In either case, the objective should be to conserve the natural water supplies and to avoid waste, and planned improvements should be made to ensure that vector mosquitos do not occur in natural sources or those created by man's use of the water.

Chemicals should be applied with discretion and only where other methods are not applicable and where the environment will not be degraded by their use.

Naturally occurring water untouched by man may frequently be important sources of malaria vectors, and their control will depend mainly upon the application of sufficient effort and resources within the framework of accepted technology.

Where modern urbanization has resulted in imperfect development of water supplies for domestic, industrial and agricultural irrigation purposes, the practical application of the technology of mosquito control may be greatly complicated or hampered, and the errors made in the original design or construction may be costly to rectify. Mosquito control of a badly designed or poorly maintained reservoir, canal, irrigation ditch or sewage disposal facility may be very difficult to accomplish, and the use of water for the irrigation of crops is notable for the inadvertent production of vector mosquitos where the initial construction of the irrigation facilities did not take into account the disposal of waste and surplus water.

The understanding and cooperation of all persons concerned with the development of land or water resources should be solicited and at the same time their special interests must be given full consideration within a coordinated mosquito control programme. The planning of antilarval operations in malaria programmes should be guided by the following principles:
Epidemiological, including entomological, techniques must be used to determine the vector sources, the species involved, their habits and characteristics and the necessity for control operations, whether combating disease, or nuisance and discomfort. If larviciding measures are indicated, the timing and the frequency of treatment as well as the area to be covered needs to be indicated. Finally, the effectiveness of control operations must be evaluated by epidemiological, including entomological, techniques.

The control programme must be accepted and supported by the people of the community. A continuous educational programme is needed to inform officials, community leaders and residents of the way in which antilarval operations contribute to the control or eradication of malaria, and what each individual can do to control or help prevent the development of mosquito breeding.

The elimination of mosquito production by progressive reduction of mosquito sources, using primary methods of abatement, such as naturalistic control, drainage, water management, etc. should be carried out in preference to the employment of chemical larviciding measures.

Larviciding measures should be used to treat sources which cannot be eliminated practically or within reasonable cost limits, or as interim supplementary measures in areas which are under progressive reduction schedules.

1.2 CHOICE OF METHODS, MATERIAL AND EQUIPMENT

In most instances, a combination of available methods may be most effective and economical. Naturalistic control, mechanical control, use of fish, water conservation and management are all techniques which can be used in varying degrees depending on the size and characteristics of the vector mosquito sources and the availability of funds, personnel, equipment and material. Major source reduction projects cannot be considered if the time required for planning and construction is longer than the time scheduled for the malaria suppression programme. The cost of projects should be less than that for other available methods. Maintenance should be minimal, especially for projects located in remote areas. Sources can often be eliminated by simple methods using locally available skills and equipment. A significant reduction in mosquito production can generally be accomplished by using maintenance methods such as removing weeds and brush, clearing stream beds and digging small drain ditches by hand. These measures are equally useful in natural, agricultural, and urban areas where poor drainage practices or irrigation cause comparatively small but important breeding sources.

The control method to be applied should preferably be selected for each source by individual appraisal. An inventory of all sources within the control area is necessary and should be included in the geographical reconnaissance survey. The sources may be classified as "temporary or permanent" within the following categories.

- extensive water collections (lakes, reservoirs, swamps, marshes, etc.)
- small water collections (rainpools, ponds, cisterns, etc.)
- running water (ditches, streams, rivers, etc.)

Additional information relative to each source may include size and area, use made of the water, physical and chemical characteristics of the water, and the mosquito species found. A sample mosquito source survey record form is presented as in Table 20, page 144, and this may be modified to suit local conditions.
Table 20. SAMPLE MOSQUITO SOURCE SURVEY RECORD

<table>
<thead>
<tr>
<th>Map identification no.</th>
<th>Large water collections (swamps, marshes, lakes, reservoirs, etc.)</th>
<th>Small water collections (rainpools, ponds, cisterns, etc.)</th>
<th>Running water (ditches, streams, rivers, etc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length and width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mosquito larvae*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shade</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vegetation (marginal)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic vegetation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drinking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Rice field</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waste</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Physical condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turbid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polluted</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fresh</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brackish</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salty (sea)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chemical condition</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hardness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Organic content</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acidity</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* C = Culex, Ae = Aedes, A = Anopheles
1.2.1 Large water collections

Lakes and reservoirs may require the cleaning and shaping of their margins, and the control of the water levels. Swamps and marshes may require drainage or reclamation. The method employed to solve the individual problem should be determined by cost-benefit studies based upon epidemiological evaluation and engineering studies. Where possible, the cooperation of other agencies should be obtained. Large projects may require considerable time for construction, and, if larviciding measures are necessary in the interim, consideration should be given to the safety of fish, wildlife and environment and to humans if the water is used for domestic purposes.

Access by ground equipment to large marshes and swamps presents a difficult problem. Small air-thrust powered boats are adaptable to shallow, open water. A 3.5 metre boat can carry two men and lightweight power spray equipment for liquids, dust or granules. The amphibious swamp vehicle permits access to many types of swamp situations and has sufficient cargo capacity to mount a mist blower, high pressure spray unit or power applicator for granules. Aircraft may be used for the efficient application of chemical larvicides in large areas. If such facilities are not available, alternative measures, products or facilities will have to be proposed.

The number of units required to control a swamp by larviciding will depend on its size, the performance rate of the spray unit and the required larviciding frequency. A typical amphibious swamp vehicle can cover about 10 ha/hr using a mist blower operating at an application rate of about 19 l/min. Using the granule gun at an application rate of about 11 kg/ha the swamp vehicle can only cover about 7 ha/hr. In a five hour effective spray day, only about 40 hectares can be larvicided with this unit. Its capability can be increased by lengthening the work day during critical periods.

Aircraft should be considered for larviciding extensive breeding areas. Coverage is 30 or 40 times greater than with power applicators on ground equipment. Average coverage with small aircraft is about 400 hectares per day, depending on the ferry distance to landing fields, and the required flying time per load. However, in practice, there are many interruptions due to unfavourable weather, service and adjustment requirements, etc. so that not more than about 160 hectares per day should be programmed. A small helicopter or fixed-wing aircraft employing the low volume spray technique and operating from a nearby base can treat up to 800 ha/day.

1.2.2 Small water collections

The use of fish, Gambusia affinis or other effective species, should be adopted as early in the programme as possible. If a local source is not available, a small supply should be imported and stocked in small lakes or irrigation reservoirs which have been selected for rearing the fish. Since these fish multiply rapidly they can be transferred to other sources as needed. Gambusia affinis can provide a high degree of control in the following types of small sources:

- small pools
- ornamental pools or small lakes in public parks
- drinking water troughs or tanks for livestock
- irrigation reservoirs
- cisterns or tanks
- streams or drain channels with a continuous minimum flow
- water-filled depressions which last two or three months or longer
- lagoons or basins holding industrial wastes or domestic sewage effluent

In planning operations for the control of mosquito sources by fish, provision should be made for the mechanical removal of weeds and vegetation too dense to permit access by the fish. Larviciding may be required during the first month or two after stocking, until the numbers of fish can increase sufficiently to suppress the larvae. Pyrethrum and fenthion emulsion sprays or granules have been successfully used under these conditions to destroy larvae without affecting the fish.

Cisterns and wells which are a drinking water supply require special planning. Insecticides which impart a taste or colour to the water are not acceptable because of public reaction. Non-toxic sprays such as pyrethrum have been used but treatments every seven days are required. Insecticides which are persistent for a longer time without hazard to health are desired. A sand granule containing 1% temephos has been found to be effective for 14 weeks against Aedes aegypti when applied to 190 litre water drums at a dose of 1 ppm.

Miscellaneous small water collections which are not used for domestic or agricultural purposes and which cannot be filled, drained or stocked with fish must be programmed for regular larviciding treatments. It is usual for these sources to be grouped by numbers so that the spray operator proceeds from one to another in a specified order requiring seven days to complete a round. During the first and last part of the breeding season when the frequency of treatment may be reduced to 14 or 21 days, the spray operator is employed in cutting paths, removing weeds and vegetation, clearing and digging ditches, transferring fish and in other functions to reduce breeding source areas or to make the application of larvicides easier and more effective. For suburban areas with many sources of this type, the use of a light-weight vehicle equipped with an air compression system greatly increases the rate of coverage. For those areas which cannot be reached from the vehicle the hand-can or horn-seeder is used.

1.2.3 Irrigated agricultural areas

Mechanical source reduction methods should be used where sources are created by the use of irrigation water and by the disposal of industrial or community waste water. Sub-standard practices which waste water and create unnecessary mosquito sources should be corrected. Malaria programme personnel may exert leadership by providing information and by encouraging the cooperation and assistance of specialists from agricultural and other agencies that can contribute to the development of water management.

The execution of larviciding operations in irrigated agricultural areas must provide for adequate surveillance, since the frequency and extent of the irrigations govern the timing of larvicide applications. Low areas which will hold water long enough for mosquitos to develop must be located and treated before emergence takes place. On small farms emulsion spray can be applied by compression sprayers, or granules by the horn-seeder. Granules are preferred in alfalfa and pasture because they leave little or no residue on the foliage. Mist blowers or power sprayers mounted on jeeps with floatation type tyres or on amphibious tracked vehicles increase the capability of the available labour force. For extensive agricultural areas, aircraft are most effective and economical.

Excess water which remains on the surface of irrigated fields or on nearby unused land must be treated on a regular basis, usually following every irrigation - as often as every seven days during warm weather on some irrigated pastures. Agricultural operations may require two spray cycles, one geared to each irrigation cycle and one geared to the more or less permanent sources receiving excess irrigation and other drainage water.
Industrial wastes and community sewage effluents should be confined in lagoons or oxidation basins and the effluent disposed of by spreading on the ground through a system of checks or furrows. Since nuisance mosquito production usually occurs in polluted waste water the removal and control of weeds and vegetation growth is of importance. Weed killing oil fortified with a spreader and/or an appropriate insecticide, applied by high pressure sprayer is required where such waste water has accumulated in low overgrown areas. When confined in weedfree basins or checks exposed to the sun and wind, mosquito breeding may be prevented and where it does occur is usually confined to the edges which can be quickly sprayed with hand equipment.

1.2.4 Running water

The degree of source reduction work that can be accomplished by hand labour in rivers, streams, and drainage ditches is dependent on their size and the quantity of flow during the breeding season. Removal of debris, artificial obstructions and weed growth should be done where possible. Confining the water to the centre of the stream bed by digging a small pilot channel will eliminate breeding areas created by meanders. Where a stream is fairly wide, larvae usually occur along the protected edges and in shallow overflow areas. Water emulsions applied by hand sprayers are frequently preferred because a full day’s supply of emulsion concentrate can be carried by the operator in small bottles. Granules are effective for drainage ditches and channels supporting aquatic vegetation where the water velocity is low and treatment of the entire stream-bed is required.

1.3 EVALUATION OF ANTILARVAL OPERATIONS

This subject is discussed in detail in Annex 3 and in the Manual for Entomological Activities in Malaria Eradication (WHO, 1963[33]).

1.4 COORDINATION OF ANTILARVAL OPERATIONS

The degree of reduction of mosquito production resulting from an antilarval operation may depend on the coordination of the methods chosen for the particular location and conditions. Antilarval operations will usually be restricted to malarious cities, towns or villages. Many of the sources may result from the use of the water for agricultural, industrial and community purposes. Although a satisfactory programme of weed control and larviciding can be carried out in naturally occurring sources, it may not be successful where sources are created by the use and disposal of water unless the responsible party is concerned and cooperates with the mosquito control programme. The planning of antilarval operations in malaria programmes must coordinate the following elements:

- Community education on the need, benefits and methods of malaria vector control including demonstration of increased water and land becoming available to the communities for agriculture or domestic uses.
- Rearing and distribution of mosquito fish.
- Elimination or reduction of vector mosquito sources by simple drainage systems.
- Control of weeds, aquatic growth and debris in sources to be larvicided.
- Repetitive larviciding at frequency determined by entomological findings.
- Requirement that public agencies, industry and agriculture restrict water usage to actual needs and confine waste water to weed free areas for disposal.
Supply of technical information and guidance for the improvement of water production, transportation, storage, use and disposal facilities.
- Encouragement of planning and financing of long term cooperative source reduction programme for extensive mosquito breeding areas.

1.5 SAFETY AND PRECAUTIONARY MEASURES

The planning of antilarval operations should include safety and precautionary measures for the staff as well as for the public and the environment. These measures should cover the following:

- storage and handling of insecticide concentrates
- mixing of spray solutions
- application of insecticides
- selection of larvicides for application to drinking water supplies, agricultural crops and for the safety of fish, wildlife and environment
- use of power equipment
- use of motor vehicles

1.6 SELECTION AND TRAINING OF STAFF

All members of the staff should receive basic instruction on the objectives of the programme and on the various methods which are to be employed. Personnel, depending on individual responsibilities, should receive training in all, or in appropriate skills as follows:

- geographical reconnaissance
- inventorying mosquito sources and compiling work load assignments
- source reduction methods
- analysing sources for potential source reduction opportunities, such as drainage, weed control and the use of mosquito fish
- production, transfer and use of mosquito fish
- principles and methods of weed control
- construction of small drainage ditches
- conveyance of information to the general public
- irrigation methods used in agricultural operations
- mixing of larvicides
- techniques of applying larvicides by hand and power equipment
- inspection of sources for the presence of larvae
- safety and precautionary measures
2. ORGANIZATION OF ANTILARVAL OPERATIONS IN A MALARIA PROGRAMME

The organization of antilarval operations in a malaria programme should follow a carefully prepared plan, drawn up on the basis of needs and the existing conditions of the services and their available facilities and authorities. The plan should take note and include provision for the future development of the malaria programme and the malaria service.

2.1 THE ORGANIZATION AND STAFFING

If the malaria programme is a long established one and if other control activities are already in operation by a field operation division, the antilarval organization should be set up within this division, preferably on an integrated basis. In this way the existing organization of field operations could take over the implementation and evaluation of antilarval operations. It would be necessary to undertake the training of the staff in the new field and its requirements and possibly to provide some additional staff and labour. Such an integrated approach guarantees continuity, eliminates the need for extensive complicated organizational structures and results in considerable savings.

In programmes where a division of field operations does not exist, one may be created depending on the methods and extent of operations and the degree of control expected from antilarval measures.

The pattern of organization may be that of a field operation division in a malaria programme, re-adjusted to meet the local needs and conditions. If the programme intends to use extensive larviciding, provision for an adequate supervisory and evaluating staff is essential. The services of an engineer may be required at the headquarters if large source reduction operations are envisaged or if the programme plans to extend assistance to, and coordinate activities with, water supply or agricultural development projects.

In the field or in areas where antilarval work is to be carried out, field and sub-officers should be engaged for the implementation and supervision of operations and for the establishment of logistic facilities.

The sector chiefs should be responsible for all field operations carried out within their respective sectors, including antilarval work. Further integration of field operations below this level is frequently desirable, and should be arranged wherever practicable. The extent to which this should be done depends on the timing of various operations (spraying, surveillance, antilarval, etc.), the phasing of the programme and the local conditions and possibilities.

As has already been suggested, operations should be integrated to the extent practicable. For example, when reconnaissance surveys are being made, the collection of data should be extended to include the information required for organizing antilarval activities. When initial surveys are made at a time of year when sources are not at a maximum, this should be noted in the report for the guidance of the planners who may review the data, and who may then schedule additional survey activities at a more opportune time.

When residual house spraying teams or surveillance agents are in an area, larval inspections may be made and treatments applied if necessary by members who have been trained to perform antilarval operations.

The personnel for antilarval operations should be drawn from other elements of the programme, especially within the supervisory echelon. This may be possible by the adjustment of the timing of various operations, and by the careful selection of methods.
and techniques of operation. Additional personnel may be employed only as necessary to accomplish the added work load which will occur as antilarval operations are implemented, or to supply any special technical guidance that may be necessary.

The entomological evaluation of antilarval operations frequently requires additional entomological staff. The added personnel should augment the existing entomological staff for integrated entomological functions. At the headquarters, it may be desirable to assign an entomologist to the entomological unit to be specifically responsible for evaluation of the antilarval operations. He should work closely with the operations unit in planning and technical supervision of antilarval operations. The routine checking of larviciding operations is carried out by the supervisory staff of field operations.

2.2 FIELD ORGANIZATION

The field organization must be quite different when the primary approach is by routine frequent chemical larviciding from when it is by the use of naturalistic control or source reduction which require only a one-time operation with occasional maintenance at intervals spaced many months or even years apart. Naturalistic control and source reduction operations fit in more easily with the normal pattern of malaria programme operations, but the chemical larviciding approach demands that operations be organized to function with sufficient freedom to accommodate to the changing patterns of source area and mosquito development. The particular project must be organized with reference to the facilities available. Where the approach is that of naturalistic control or source reduction, the operations can probably be accomplished best by the working team system which is employed in residual house spraying. Where the work load represented by chemical larviciding does not justify the assignment of a permanent separate team, it may be necessary to decentralize the operation, perhaps by delegating the routine application of control measures to whatever general local health organization or other responsible government organization may exist, with the malaria programme providing training, periodic supervision and evaluation.

2.2.1 Manpower and logistics

When compression sprayers are used for the application of larvicides, operational areas should be divided into a number of units each to be of a size which can be served by one squad of larviciders within each application cycle (normally one week) during the portion of the season when breeding places are at a maximum. The size of the operational units depends on the nature, extent and distribution of waters to be treated, the work load capability of the squads, the accessibility of the areas to be treated, and the availability of transportation. The units can be divided into sub-units each to be covered by one larvicider during the cycle, or into sub-units each to be covered by the squad during each working day of the cycle. In the latter case the larviciders will work in close proximity so that supervision by the squad chief will be facilitated. In either case each larvicider should be assigned a clearly defined area to cover each working day of the cycle so that application defects can be traced back to the operator who is at fault.

2.2.2 Operational unit area

In delimiting the operational unit areas, attention should be given to the existing network of roads so as to facilitate the transportation of personnel and supplies and the supervision of the squads in the field. Each four to six larviciders can be formed into a squad. With larvicides other than oils, it may not be possible to check the coverage obtained since the applied larvicides may not be visually detectable on the surface of the water as with oils. Supervision at the higher level could be entrusted to the sector and the sub-sector chiefs, who supervise the other field activities of the malaria programme.
2.2.3 Integrating manual and power equipment units

Programmes which employ ground power equipment will probably also require some complementar larviciding by hand compression sprayers. In such instances, a few larviciders should be attached to the ground power spray squads. The operational areas of these squads should be delimited on the basis of the work load assigned to the respective groups, taking into account the limiting factors of capability, accessibility and supervision. It may be practicable for one ground power spray squad to operate in several sectors and sub-sectors, treating the larger breeding places where the greater capacity of the power unit is advantageous. The work assignments and supervision may therefore have to originate at zone level, although field supervision may be at the sector and sub-sector levels. The number of personnel in the power spray squad will depend upon the labour requirements of the specific type of spray machine and the work assigned to it. A similar pattern can be considered when planning a programme to utilize aircraft spray equipment.

2.2.4 Inspection

For every three to five larviciding squads one inspector should be assigned to inspect the breeding places prior to and after treatment and to report the results to the sector chief. The inspection is done by dipping a representative sample of the breeding places. A chief inspector should be assigned to supervise every four to six inspectors working in a section. If the number is less, the sector chief should supervise the work of the inspectors. A light transport vehicle should be assigned to chief inspectors to transport the inspectors and to provide the chief inspector maximum mobility for personally inspecting breeding places.

(a) Standardization of treatment inspection

It is desirable that pre-treatment inspections precede the larviciding by not more than 12 to 18 hours and preferably on the same day. It is highly desirable that the post-treatment inspection be made the following day, 20 to 28 hours after spraying. The dipping should be done selectively, in those parts of the breeding places which appear to have the greatest larval populations. Larval development may vary with time and changes in rainfall, temperature or other climatic factors and the selection of dipping sites should therefore be left to the discretion of the inspectors within specified guidelines and limitations.

(b) Permanent indicator stations

When permanent known breeding sites exist, a number of indicator locations may be selected where pre- and post-treatment inspections will be made regularly. The purpose of inspecting breeding places is mainly to evaluate the performance of the operators and the coverage obtained. Accordingly this portion of the inspection service should be planned and organized separately from the routine random operational inspections. The dipping should be done in undisturbed water areas, with not too many dips in one place, e.g. two to three dips/m². The dippers should be of standard diameter and volume and a uniform technique of dipping for larvae should be followed. The number of specimens collected should be recorded by larval stages together with the number of dips made in each breeding place. The pre- and post-treatment inspection procedures in the areas treated by power equipment or by aircraft should be essentially the same.
(c) Larval control evaluated

In interpreting the results of larviciding, attention should be given to the type of larvicide and its effect upon the larval populations. If the application of larvicide is done in accordance with the methods prescribed, using larvicides proved effective under the prevailing conditions, it is expected that a significant reduction in the density of larvae should be indicated by the inspection results. If significant reductions are not obtained, the failures may be traced to:

(i) improper application or deficient coverage (operator, equipment, formulation, quality of water, or other factors);

(ii) unexpected ecological changes;

(iii) possible tolerance of the vectors to the insecticide or dosage applied.

Prompt remedial action should be taken after consultation with the entomological section.

2.2.5 Supervision

Supervisors should calibrate the delivery rates from all spray equipment in use at regular intervals. When hand spray operations are being performed, it is also important to calibrate the combination of man and sprayer, since there are so many variations in the techniques employed to satisfy the various needs that the operating habits and patterns of the various men tend to differ considerably even when efforts are made by training to secure uniform performance. Hence some adjustments to the individuals are necessary.

Unlike house-spraying operations, where operators are working collectively in neighbouring houses, larviciding operators are scattered in the field and cannot be kept under continuous observation. Supervision is correspondingly difficult. Availability of detailed working maps and a carefully programmed time-table of operations is essential for effective supervision.

Where the routine larvicidal spraying may be delegated to the local general health service, special arrangements for periodic general supervision should be made, to be performed perhaps by the surveillance personnel at the time the regular rounds are being made.

The supervision of larviciding should be mostly in the form of guiding the operator and correcting errors in methods of application. The operators should be made aware that their work is continually scrutinized. With most larvicides, it is extremely difficult to assess the precision of application attained, although the efficacy of application can be determined by post-treatment inspection. It is therefore important that the supervisor observes the operator through regular and surprise visits during the application operation.

Schedules should be worked out for the visits of various supervisory staff to field units so as to regulate and ensure adequate supervision.

2.2.6 Reporting

Larviciding reports should be collected and analysed expeditiously to permit necessary
corrective measures to be applied in time to be effective. Unlike spraying operations, cycles of larviciding are very short, requiring only a few days. The inspection report and the application reports should be sent to field offices promptly for immediate analysis and action. The analysis for operational programmes can be done at the sector or zone level. To determine the effectiveness of the antilarval operations in controlling the vector population in the area, an assessment should be made concurrently by the entomological unit. Duplicate copies of the entomological and operational reports should therefore be sent simultaneously to the entomological section.

Entomological and supervisory personnel should also be required periodically to file special reports in the form of answers to a questionnaire asking:

(a) Are there other aquatic insects and/or mosquito fish in the areas larvicided? If so, are they damaged by the larvicide applications? By what materials?

(b) Can you suggest ways in which these sources can be eliminated or reduced in size? If so, which sources and how?

(c) Can you suggest ways in which to improve the present antilarval programme?

2.2.7 Training

The training of personnel employed in antilarval operations will necessarily vary considerably, depending upon the type of operations in which the individuals are to be involved. However, at some intermediate supervisory level, personnel should be trained in all three categories of antilarval operations: naturalistic control, source reduction, and chemical control. The supervisors of this class should logically be expected to train their subordinates, who would in turn be mainly responsible for the training of the workers in the field. At the ultimate field level, it is desirable that "on the job" training be emphasized, with supervisory personnel demonstrating in actual work situations how to do the job. The principal entomologists and engineers for the region should provide leadership in assuring that the training is complete and adequate to meet the needs.

For the planning and execution of antilarval operations, much reliance will have to be placed on the men in the field. Conditions differ so greatly from area to area, and possibilities of success or failure vary so greatly from place to place that only the man in the field will be in a position to make a correct decision as to precisely what control technique should be used in the particular instance. Therefore, staff members should be trained thoroughly and correctly to enable them to make appropriate judgements in the field. intensive elementary initial training and subsequent refresher or supplementary training in the course of operations is necessary. It is considered that the minimum training period should include one full week on initial training followed by at least two to three weeks of supervised field training.

The supervisory staff members should also receive special training in larviciding according to their duties. At the end of each season, a two to three-week refresher course should be organized for the supervisors. At the beginning of the season, field operators should receive a few days of refresher training. The theoretical training should include surveying and map reading, a knowledge of the vectors of the area and their breeding places; and the larviciding and other methods that can be used for their control or elimination. The operators should also be taught how to use, care for and maintain the equipment to be employed. The training should include the rudiments of the ways and means of promoting health education. Operators should be made fully aware
of the inspection methods to be used and of their reliability in detecting areas not properly larvicided. Supervisors should be taught appropriate, effective and correct supervision, the guidance and direction of operators and subordinates, and the principles and procedures of administration employed in the programme. Operators and supervisors should be made fully aware of the potential toxicity of the larvicides to plants, animals and humans, and the first-aid techniques to be employed in cases of human intoxication. The training should include safe handling of equipment and materials. The precautions necessary to avoid damage due to toxic chemicals should be emphasized in the training of all field personnel. All personnel should also be made aware of the simple sanitation methods of eliminating breeding places.

2.3 ESTIMATION OF REQUIREMENTS

Major items which must be provided for include:

- personnel (permanent or temporary)
- chemicals and formulations
- equipment
- transport
- materials and supplies

Unlike the residual spraying operation where estimation of requirements is based on easily determinable work loads, in antilarval operations requirements may vary greatly depending upon the type of equipment and the methods employed. For example, the use of power equipment will substantially reduce the need for field personnel, transport and other services. Similarly, a considerable number of ground units can be replaced by one aircraft.

2.3.1 Personnel

Major factors which determine personnel needs are:

- the area to be treated (taking into account the maximum seasonal demand);
- the average output of a larviciding unit (can be an operator with a hand sprayer, a power unit or an aircraft). When hand-carried compression sprayers are used, the number of operators can be estimated by dividing the area to be treated by the output of one operator;
- the number of personnel of various categories in each unit.

2.3.2 Choice of larvicides

During the initial years, preference should be given to less toxic compounds, i.e. to larvicides that can be used safely, without elaborate precautionary measures. Use should be made of locally available effective larvicides to minimize supply problems. Thus, oil larvicides should be used in oil-producing countries where practical and economical. Where oils are not produced locally, Paris green or pyrethrum may be a good choice.

Several synthetic organophosphorus compounds have been extensively used in general mosquito control operations. Some of these appear to have characteristics desirable for use in malaria programme larviciding, notably temephos, fenitrothion, etc. Preparations should be made to introduce these materials where they may be appropriate.
Chlorinated hydrocarbons generally should not be employed as larvicides in malaria programmes as the repeated exposure of the larvae may accelerate the development of resistance, especially where the same compounds are used in residual house spraying. For the same reasons these compounds have not been included in the list of larvicides for operational use. The residual toxicity of the chlorinated hydrocarbons also makes their use as larvicides generally undesirable. Steps should be taken to ascertain what insecticides are being used on agricultural crops in the area, since their application may have subjected the mosquito larvae to exposure which could affect the development of resistance.

Mosquitos which are subjected to frequently repeated applications of chemicals have shown an extraordinary genetic capability of acquiring a tolerance to many of the synthetic chemicals, notably the chlorinated hydrocarbons and organophosphorus compounds. It is thus necessary that tests for resistance be made a part of the evaluation procedure. Preliminary base-line tests should be made when operations are first begun, with subsequent tests being made at representative locations after every 10th to 20th round of spraying.

Due consideration should be given to possible damage to operators, plants, livestock, people or environment which might result from the use of insecticides.

2.3.3 Quantity of larvicides and selection of formulation

The quantity of larvicides required may be estimated on the basis of the surface area or the volume of water to be treated. For practical purposes, an arbitrary depth of 10 cm has been adopted for calculating the dosage of toxicant per unit of surface area (g/m² or kg/ha). The choice of formulation may depend upon the condition of the breeding places, their accessibility, and the kind of equipment available in the programme. When dense vegetation exists, the breeding places should preferably be treated with granular formulations from commercial sources or manufactured locally. Dust formulations are not generally used since they are subject to wind action and drift and the application rate is difficult to regulate. However, they may be useful in some situations. Liquid formulations are generally preferred, and of these the emulsifiable formulations are most convenient since only a small volume of the concentrate need be carried into the field, where it can be mixed with water from the breeding places before application. Water dispersible powders are used less frequently. Oil solutions to be applied by hand equipment may involve transportation problems since the bulk which must be brought to the place where it will be used is much greater than the amount of emulsion concentrate required to treat a mosquito source of equal size.

2.3.4 Equipment

As stated before, in malaria eradication and control programmes using compression sprayers for residual spraying, preference should be given to the use of these sprayers for larviciding. Power equipment, however, is desirable and sometimes necessary in large larviciding programmes but their provision should follow careful study of local conditions and an analysis of the benefits as compared to hand carried sprayers. The type of power equipment to be provided and its operational capacity needs also to be determined on the basis of the expected work load and the type of terrain. For this equipment, the programme should assign specially trained operators who could also attend to maintenance.

Use of aircraft in malaria programmes, at least in the initial stages, should be made through contracts with specialized firms.

The selection of equipment is also closely related to the type of formulation to be used, though some equipment can be used to apply several formulations. When planning larviciding and before selection of the formulation, the consequences of its application and
the kind of equipment that it may require should be taken into full account.

Upkeep of equipment and spare parts required should be considered when calculating requirements.

(a) **Simple equipment**

Compression sprayers will need but little modification - only the substitution of larviciding nozzles and adjustable angle head lances and the addition of a second carrying strap for more comfort - but the operators must learn a distinctly different technique if larviciding is to be performed quickly and easily: this is known as the "swinging wand" technique, whereby the operator can treat a strip or swath about 9 - 12m wide as fast as he can easily walk, when the conditions are such that he can walk down the centreline of the strip being treated, swinging his lance in cadence with his steps as he walks. However, experience has shown that this new technique can be learned easily by capable spraymen.

When granular materials must be applied, another simple device is available, which is used in much the same way as the swinging wand sprayer. It will be new to the spraymen, but they will probably become proficient in its use very quickly. It is known as the "swinging horn granule dispenser" (see page 129), or more commonly as the "horn seeder", taking its name from the fact that it was originally designed for distributing plant seeds, which are released from it through a tube or "horn" which the operator swings from side to side as he walks. These simple devices are low in cost and can be manufactured locally. They consist of a dust proof bag carried over the shoulder of the operator, carrying up to 13.5 kg of granules or enough to treat 4-6 hectares of mosquito sources, and the light metal horn, about 1 metre long, in which there is a simple valve device.

Dusts are rarely used as larvicides, but if necessary, they can be distributed by a hand-cranked rotary duster, supported by a strap around the back of the operator's neck.

(b) **Mechanized equipment**

Although simple hand tools are suggested for use when larviciding programmes are first begun, there should be no hesitation about adopting mechanized insecticide applicators for use in places where hand work is impracticable for technical reasons or because of excessive cost. The mechanized distributors are of many kinds, some relatively simple, others quite sophisticated, but the use of all of these should be within the capability of good operators who have had adequate training. With this equipment, also, emphasis should be on the smaller units, which are usually skid mounted so that they can easily be shifted from one vehicle to another, small enough to go into a jeep but large enough to do good production work. As needs are demonstrated in large scale operations, larger spray machines should be introduced into the programmes when it is economical to do so. When that stage of development is reached, studies should be performed to determine whether aircraft or helicopters can be employed more effectively and at lower costs than the hand operations.

(c) **Aircraft**

Where very large, difficult to spray situations are encountered, aircraft, employing low volume larviciding, may be much more efficient than hand work, and may be able to get the treatment on in time when it would be impracticable to do so with hand labour. A single small helicopter applying liquid larvicide at a rate of 4.7 l/ha
treated up to 800 hectares per day on an operational basis. It has been shown that aircraft water mixed sprays of fenthion cost 95 cents/ha at 110 g/ha.

It should be practicable for malaria eradication programmes to engage effectively in larvicidal operations using simple tools at first, gradually adopting the more sophisticated and more efficient mechanized means when the need has been demonstrated.

2.3.5 Transport

Transport should be dealt with as part of the general requirements of the programme. Vehicles of the type used in house-spray operations should normally be adequate to meet the needs of antilarval operations. It may be necessary to increase the number of vehicles in the transport fleet because of the increased work load in the operational areas. The lighter type four-wheel-drive pick-up trucks should be used for transportation of personnel and supplies and for supervision, but where conditions permit, two-wheel-drive vehicles can be used for the purpose, and are to be preferred because of their lower initial and running cost. Repair and maintenance of the transport should follow the procedures established in the malaria programme. Some antilarval programmes may also require transport of some units by boat and these should be of shallow draught.

2.3.6 Miscellaneous materials and supplies

These may include equipment for mixing, production equipment for operators, entomological supplies and laboratory supplies and equipment. The requirements can be estimated when the needs of each activity are assessed during planning.
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# Annex 1: Metric and English Equivalents

for Units Commonly Used in Mosquito Larviciding Operations

(U.S. gallons and short tons)

## Insecticide Dosage Rate - Weight per area

| Units                  | Equivalent
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 oz/ac</td>
<td>71 g/ha</td>
</tr>
<tr>
<td>0.10 lb/ac</td>
<td>112 g/ha</td>
</tr>
<tr>
<td>1.0 lb/ac</td>
<td>1.12 kg/ha</td>
</tr>
</tbody>
</table>

## Spray Dilutions - Volume per volume

| Units                  | Equivalent
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 fl.oz/gal</td>
<td>7.5 ml/l</td>
</tr>
<tr>
<td>1.0 pt/100 gal</td>
<td>125 ml/100 l</td>
</tr>
<tr>
<td>1.0 gal/100 gal</td>
<td>1.0 l/100 l</td>
</tr>
<tr>
<td>10 ml/l</td>
<td>1.3 fl.oz/gal</td>
</tr>
</tbody>
</table>

## Spray Application Rate - Volume per area

### Liquids

| Units                  | Equivalent
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 pt/ac</td>
<td>1.22 l/ha</td>
</tr>
<tr>
<td>1.0 qt/ac</td>
<td>2.44 l/ha</td>
</tr>
<tr>
<td>1.0 gal/ac</td>
<td>9.36 l/ha</td>
</tr>
<tr>
<td>1.0 l/ha</td>
<td>0.80 pt/ac</td>
</tr>
<tr>
<td>10.0 l/ha</td>
<td>1.05 gal/ac</td>
</tr>
</tbody>
</table>

### Dusts and Granules

| Units                  | Equivalent
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0 lb/ac</td>
<td>1.12 kg/ha</td>
</tr>
<tr>
<td>5.0 lb/ac</td>
<td>5.5 kg/ha</td>
</tr>
<tr>
<td>10.0 lb/ac</td>
<td>11.2 kg/ha</td>
</tr>
<tr>
<td>10.0 kg/ha</td>
<td>9.0 lb/ac</td>
</tr>
</tbody>
</table>

## Spray Discharge Rate - Volume per time

| Units                  | Equivalent
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1 gal/min or 6.0 gal/h</td>
<td>380 ml/min or 22.8 l/h</td>
</tr>
<tr>
<td>0.2 gal/min or 12.0 gal/h</td>
<td>760 ml/min or 45.6 l/h</td>
</tr>
<tr>
<td>1.0 gal/min or 60 gal/h</td>
<td>3.8 l/min or 228 l/h</td>
</tr>
<tr>
<td>5.0 gal/min or 300 gal/h</td>
<td>19 l/min or 1140 l/h</td>
</tr>
<tr>
<td>1.0 l/min</td>
<td>0.26 gal/min</td>
</tr>
<tr>
<td>5.0 l/min</td>
<td>1.30 gal/min</td>
</tr>
<tr>
<td>20 l/min</td>
<td>5.20 gal/min</td>
</tr>
</tbody>
</table>
VELOCITY OR SPEED OF TRAVEL - Length per time

1.0 ft/min = 0.31 m/min
1.0 mile/h or 88 ft/min = 1.61 km/hr
35 paces/min (5 ft pace) or 175 ft/min = 54.6 m/min
175 ft/min or 2 miles/h = 3.2 km/m
5 miles/h or 440 ft/min = 8 km/h or 136 m/min
1.0 m/min = 3.28 ft/min
1.0 km/h or 16.6 m/min = 0.63 miles/h or 55 ft/min
5.0 km/h or 83 m/min = 3.13 miles/hr or 275 ft/min

WEIGHT

1 oz = 28.35 g
1 lb or 16 oz = 453.6 g
1 ton or 2000 lbs = 907 kg
1 g or 1000 mg = 0.0352 oz
1 kg or 1000 g = 2.2 lbs or 35.27 oz
1 metric ton or 1000 kg = 1.1 ton or 2200 lbs

LIQUID CAPACITY

1 fluid oz = 29.57 ml
1 pt or 16 fluid oz = 473 ml
1 qt or 2 pt = 0.95 l
1 gal or 4 qt = 3.79 l
1 ml = 0.033 fluid oz
1 l or 1000 ml = 0.26 gal or 1.06 qt

LENGTH

1 inch = 25.4 mm or 2.54 cm
1 ft or 12 in = 30.48 cm or 0.3048 m
1 yard or 3 ft or 36 in = 91.4 cm or 0.91 m
1 mile or 1760 yd or 5280 ft = 1600 m or 1.6 km
1 micron or 0.001 mm = 0.000039 in
1 mm or 1000 micron = 0.04 in
1 cm or 10 mm = 0.39 in
1 m or 100 cm = 3.28 ft or 39.4 in or 1.09 yd
1 km or 1000 m = 0.625 mile or 1100 yd or 3300 ft

AREA

1 in² = 6.45 cm²
1 ft² or 144 in² = 0.093 m² or 930 cm²
1 yd² or 9 ft² or 1296 in² = 0.84 m²
1 acre or 4840 yd² or 43 560 ft² = 0.405 ha
1 mile² or 640 acres = 259 ha
1 cm² or 100 mm² = 0.155 in²
1 m² or 10 000 cm² = 0.12 yd² or 10.76 ft²
1 ha or .01 km² or 10 000 m² = 2.47 acres
1 km² or 100 ha = 0.39 miles² or 247 acres
### VOLUME

<table>
<thead>
<tr>
<th>Unit</th>
<th>Equivalent in</th>
<th>Equivalent in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 in³</td>
<td>16.39 cm³</td>
<td></td>
</tr>
<tr>
<td>1 ft³ or 1728 in³ or 0.37 yd³</td>
<td>28.32 l</td>
<td>0.77 m³</td>
</tr>
<tr>
<td>1 yd³ or 27 ft³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 cm³</td>
<td>0.061 in³</td>
<td></td>
</tr>
<tr>
<td>1 l or 1000 cm³</td>
<td>0.035 ft³</td>
<td></td>
</tr>
<tr>
<td>1 m³ or 1000 l</td>
<td>1.307 yd³ or 35.32 ft³</td>
<td></td>
</tr>
</tbody>
</table>

### WEIGHT - VOLUME EQUIVALENTS OF WATER

<table>
<thead>
<tr>
<th>Unit</th>
<th>Equivalent in</th>
<th>Equivalent in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 gal</td>
<td>8.34 lb</td>
<td>3.79 kg</td>
</tr>
<tr>
<td>1 ft³</td>
<td>7.48 gal</td>
<td>28.32 l</td>
</tr>
<tr>
<td>1 ft³</td>
<td>62.4 lb</td>
<td>28.32 kg</td>
</tr>
</tbody>
</table>

### MISCELLANEOUS UNITS

<table>
<thead>
<tr>
<th>Unit</th>
<th>Equivalent in</th>
<th>Approximate Equivalent in</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 acre-foot</td>
<td>325 829 gal</td>
<td>1 234 892 litres</td>
</tr>
<tr>
<td>1 ft³/sec</td>
<td>450 gal/min</td>
<td>119 l/min (approx)</td>
</tr>
<tr>
<td>1 part/million</td>
<td>8.34 lb/million gal</td>
<td>1 mg/l</td>
</tr>
</tbody>
</table>
## ANNEX 2. PROPRIETARY AND ISO NAMES OF SOME PESTICIDES

<table>
<thead>
<tr>
<th>Proprietary or other name</th>
<th>ISO name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abate</td>
<td>temephos(^1)</td>
</tr>
<tr>
<td>arprocarb</td>
<td>propoxur</td>
</tr>
<tr>
<td>Baygon</td>
<td>propoxur</td>
</tr>
<tr>
<td>Baytex</td>
<td>fenthion</td>
</tr>
<tr>
<td>Cidial</td>
<td>phenthoate</td>
</tr>
<tr>
<td>Cythion</td>
<td>malathion</td>
</tr>
<tr>
<td>DDD</td>
<td>TDE</td>
</tr>
<tr>
<td>DDVP</td>
<td>dichlorvos</td>
</tr>
<tr>
<td>Dibrom</td>
<td>naled</td>
</tr>
<tr>
<td>Dipterex</td>
<td>trichlorfon</td>
</tr>
<tr>
<td>Dursban</td>
<td>chlorpyrifos</td>
</tr>
<tr>
<td>Dursban-methyl</td>
<td>dimethyl homologue of chlorpyrifos(^1)</td>
</tr>
<tr>
<td>Entex</td>
<td>fenthion</td>
</tr>
<tr>
<td>Folithion</td>
<td>fenitrothion</td>
</tr>
<tr>
<td>Guthion</td>
<td>azinphosphos-methyl</td>
</tr>
<tr>
<td>Lebaycid</td>
<td>fenthion</td>
</tr>
<tr>
<td>Phosdrin</td>
<td>mevinphos</td>
</tr>
<tr>
<td>Rhothane</td>
<td>TDE</td>
</tr>
<tr>
<td>Ronnel</td>
<td>fenchlorphos</td>
</tr>
<tr>
<td>Sevin</td>
<td>carbaryl</td>
</tr>
<tr>
<td>Sumithion</td>
<td>fenitrothrin</td>
</tr>
<tr>
<td>Thimet</td>
<td>phorate</td>
</tr>
<tr>
<td>Toxaphene</td>
<td>camphechlo</td>
</tr>
<tr>
<td>Trithion</td>
<td>carbophenothenothion</td>
</tr>
<tr>
<td>Vapona</td>
<td>dichlorvos</td>
</tr>
</tbody>
</table>

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ANNEX 3. ENTOMOLOGICAL PROCEDURES AND TECHNIQUES FOR THE PLANNING AND EVALUATION OF ANTLARVAL OPERATIONS

The entomological component is one of the essential elements for planning and evaluating antilarval operations. It comprises several activities, the aim of which is to contribute to the assessment of the efficiency of the antilarval operations. The entomological findings together with those of parasitological observations will determine the effectiveness of the operation and its impact on malaria transmission. Each entomological activity should have well defined objectives on the basis of which the selection of the appropriate techniques, timing and duration of the observations can be planned. The scope and scale of the entomological activities and the procedures to be followed are outlined below.

1. COLLECTION OF BASE-LINE ENTOMOLOGICAL DATA

The preliminary survey should be carried out during the seasons of vector(s) prevalence. It should be undertaken on a sampling basis and consist of spot surveys. Depending on the extent of the area and the availability of staff and facilities, the preliminary survey may be completed in 1 - 3 months.

The main aim is to provide background information which is a pre-requisite for planning of subsequent entomological activities, and for the initial planning of antilarval operations.

1.1 PROCEDURES

The first step is to collect from any existing documents, reports and literature, the relevant information on:

(a) the environmental conditions including seasonal meteorological changes;
(b) the anopheline fauna with special reference to recognized malaria vectors and suspected vectors;
(c) the ecology of malaria vectors, including their breeding habits, duration of the period of the immature stages, range of flight, etc;
(d) the season of malaria transmission.

The second step is to carry out adult and larval surveys:

(a) to check on the anopheline fauna with special reference to vectors and suspected vectors recorded in the area;
(b) to identify the preferential breeding places for vectors, their nature and their approximate extent, and to classify them into different types according to the physical conditions and the presence of salinity and pollution;
(c) to collect information on the suitability of some larval sites and adult day-time resting shelters as future fixed capture stations.

2. BASE-LINE TREND OBSERVATIONS

Regular observations on adults of vectors can be started shortly after the completion of the preliminary survey. They should continue for one whole year before commencing the antilarval operations.

The aim is to establish base-line data for densities of larvae and adults and the susceptibility levels to insecticides of malaria vectors and suspected vectors throughout
the different seasons; and to study the influence of environmental conditions on larval and adult output.

During this period of observations a small scale trial should be organized to determine the dosage and frequency of application of the larvicide to be used. In this trial regular observations on larvae should be conducted as described in section 7. The results of trend observations and the trial will assist in adjusting the plan of anti-larval operations.

2.1 PROCEDURES

The trend observations should be carried out on both larval and adult populations in fixed indicator areas to be selected to represent each ecological substratum in the area targeted for antilarval operations.

2.1.1 Observations on larvae of vectors

From the information gathered during the preliminary surveys a number of indicator areas each representing certain ecological substrata should be selected. In each a number of breeding places, representing the preferential breeding places of malaria vectors should be selected on the basis of high larval density. These selected breeding places should be established as fixed capture stations for regular larval checking. In each fixed capture station a standardized number of dips should be made at 7 to 10 day intervals or longer depending on the life span of the aquatic stages in different seasons.

2.1.2 Observations on adult vectors

(a) House-resting density

In each indicator area, adult capture stations having high vector density should be selected in the vicinity of larval capture stations. For this at least 10 premises should be selected. Collection of adults should preferably be carried out by hand/spray capture every two weeks.

(b) Vector/man contact

In a selected number of adult capture stations, bait capture on man indoors and outdoors should be carried out at fortnightly intervals in order to establish the base-line for vector biting density and its seasonal trends.

(c) Light traps

These devices can provide an additional tool for studying the changes in the vector density. The advantage of operating the light traps during the pre-treatment period is the experience to be gained on the best location and operation of this type of mechanical device. The optimum frequency of light trap captures should be determined by initial trials.

(d) Establishing base-line data for the susceptibility level of vectors

Susceptibility tests must be carried out in periods representing different seasons, on larvae of malaria vectors using the insecticide to be used in larviciding and other insecticides available in the WHO larval test kit. If impregnated papers are available for the same insecticide, adult susceptibility tests should also be carried out.
3. ENTOMOLOGICAL EVALUATION OF ANTLARVAL OPERATIONS

The general objective is to assess the efficiency of the antilarval operations in reducing vector density. The entomological parameters together with the parasitological findings will assess the impact of the operation on malaria transmission.

3.1 TREND OBSERVATIONS

When the antilarval operations commence, the trend observations should continue at the same fixed capture stations, in the same indicator areas selected prior to treatment. The larval and adult checking should continue in the first year of operations regularly throughout the operational season and may need to be continued at longer intervals during the off-season. Trend observations may extend to the second year to confirm the findings of the first year. Thereafter, they can be maintained in a limited number of localities and in areas where unfavourable response was encountered to assess the efficacy of remedial measures. Naturally they should be reactivated as soon as the larvicide is replaced.

3.1.1 Observations on larvae of vectors

The specific aim here is to maintain a continuous check on the efficacy of the designed dosage and frequency of application on the density of the vector population under different ecological conditions. For this, the trend observations should be continued at the same fixed larval capture stations, using the same standardized techniques of sampling. Having this specific aim in mind, those fixed larval stations and the area they represent should receive the optimum treatment. There is a tendency of larviciding teams to overdose the fixed capture stations. It is, therefore, necessary that these capture stations and other breeding places and indicator areas be larvicided under close supervision to ensure that the optimum dosage is applied at the appropriate time. Otherwise, the results of the trend observations may suffer from the variability of application. Hence the results for assessing the effectiveness of the larvicide would be confused because of the factor of operational deficiencies. The timing of the larval checking should coincide with the last day of the larviciding interval which was determined by the initial trial (section 7). The presence of third and fourth instar larvae of vector anophelines, and their pupae when found, should be recorded and the reasons of such failure be investigated.

3.1.2 Observations on adult vectors

The specific objective is to determine the effect of antilarval measures on adult densities of vectors. Larviciding essentially operates on the larval density, thereby reducing the adult output. The trend observations to be carried out on the adult vector population in the indicator areas should reveal whether the larvicide as applied under optimum conditions of adequate dosage, frequency and coverage has succeeded in reducing the adult density to an epidemiologically insignificant level.

(a) House-resting density

House searches should be continued at the same fixed capture stations from which the base-line data was collected, using the same technique.

(b) Man/vector contact

Bait capture should continue in the same capture stations using the same number of baits. Both house-resting and bait capture should be maintained at fortnightly intervals.
(c) **Light traps**

A number of light traps should be operated in each indicator area, also at fortnightly intervals if this is found to be suitable for sampling.

### 3.2 SPOT CHECKS

Spot checks should commence simultaneously with trend observations as soon as the antilarval operations have started. As mentioned earlier, trend observations should continue for the first year and may extend to the second year of the antilarval control programme. Thereafter, the number of indicator areas should be reduced to a minimum which would allow density trends to be verified. The time saved by reducing trend observations should be directed to spot checks, an activity which should continue as long as the larval control operation is kept going.

As has already been mentioned, the trend observations at fixed indicator areas would reflect the effectiveness of the larvicide as adequately applied at the designed dosage and frequency of application. Spot checks, on the other hand, should aim at detection of operational deficiencies which may occur in the large part of the treated area, hence timely remedial measures can be implemented. In addition, spot checks should aim at revealing any possible failure of the larvicide to cope with abnormal physical and environmental changes which may occur in certain areas in certain seasons.

#### 3.2.1 Procedures

In spot checks, besides inspection of breeding places, adult searches should be undertaken. Adult searches should be made by hand/spray capture in at least 10 premises in each area selected for spot checking. Light traps may be tried as an additional method. In larval searches the standardised units of 10 dips should be adopted at each breeding place selected for inspection. However, there may be a need to increase the units of dips two fold or more when a breeding place is suspected, for example, on account of finding a few early stage larvae.

Ideally, all breeding places should be inspected by spot checks but this would not be feasible in a large-scale larval control programme. Therefore, spot checks can be implemented on a sampling basis. For example, if the area of operation is divided into four sections inspection of 10 - 12% of the breeding places of each section each week on a rotational basis by the entomology teams would permit an assessment of the quality of larviciding in about 40 - 50% of the breeding places in the whole operational area once every month. Besides which there should be larval inspection which is to be undertaken by the operational supervisors in the course of their duty. Both types of inspection should be coordinated so that they cover as many of the breeding places as possible in each of the operational units of each larvicider. In the selection of areas for spot checks priority should be given to those which are known to have high transmission potential and searches should there be intensified. The entomological teams carrying out spot checks should be provided with copies of the schedules of application of the larvicide in each operational unit. Adult searches should be made around all breeding places that have been found positive.
4. RECORDING, SUMMARIZATION AND INTERPRETATION OF DATA

4.1 INFORMATION TO BE RECORDED

4.1.1 Preliminary surveys

The following information needs to be collected:

(a) **Description of the area**, dividing it tentatively into ecological substrata, to be elaborated later when geographical reconnaissance of breeding places is undertaken.

(b) **Meteorological conditions**

Meteorological records to be obtained from the existing meteorological stations for the whole area for the past ten years if possible. Specific information on conditions affecting the breeding places at the time of the survey should be collected.

(c) **Description of the breeding place and physical conditions**

(i) type, and whether water is permanent or transient;
(ii) an approximate estimation of the surface area and the depth of the water in each type of breeding place;
(iii) the presence and types of vegetation and algae, etc., and degree of their growth;
(iv) the presence of current and shade;
(v) the presence of salinity or pollution.

(d) **The number of units** (a minimum of 10 dips or multiples of 10). Since in this initial survey, the number of units of dips at each breeding place cannot be standardized, the exact number of units of 10 dips and the number of positive units of 10 dips should be recorded. A note should be made on the breeding places that can be suitable as fixed capture stations.

(e) **Description of the different types of day-time shelters** surveyed for adult vectors. A note should be made on those found suitable as fixed capture stations.

4.1.2 Trend observations

At fixed capture stations the above information (a) and (c) should be collected during the initial observations. Subsequently, only the important changes in the condition of the breeding places should be recorded. The number of units of 10 dips should be standardized at each fixed capture station selected for trend observations and maintained as such throughout the period of observations. Similarly a description of day-time resting shelters selected as fixed capture stations should be initially made. Meteorological data should be collected regularly.

4.1.3 Spot checks

Since this is a rapid survey to detect whether the breeding place is positive or negative for larvae, records of the type of each breeding place and its environmental conditions should be made when found positive. The dates of application of the larvicide are equally important and, as mentioned above, they are to be obtained from the larviciding operational schedules before the spot checks are carried out.

4.2 SUMMARIZATION OF DATA (Data of trend observations and spot checks should be summarized separately).
4.2.1 Larval density indices of vectors

(a) Samples should be classified into:
- the group of 1st and 2nd instar larvae
- the group of 3rd and 4th instar larvae for each vector species collected
- other anopheline larvae (pooled)
- anopheline pupae

(b) The index of larval density of 3rd-4th instar larvae should be calculated to give the average number per unit of 10 dips:
- for positive capture stations of each type of breeding place inspected
- for positive capture stations of all breeding places inspected
- for all capture stations of each type of breeding place inspected
- for all capture stations of all breeding places inspected.

In addition to the above it would be useful for presentation of results and assessment of effectiveness of operations, to establish the frequency distribution of the breeding places according to their larval density (using appropriate class intervals for the larval density).

Larval indices should be worked out separately for samples obtained by different devices, for example (vide section 6 - Techniques):
- index for ladle collections
- net-dipper in surface waters
- net-dipper in wells.

4.2.2 Adult density indices of vectors

The average number of females of vectors per room in day-time searches and average bites of vectors per man per night in bait capture should be worked out.

4.3 INTERPRETATION OF RESULTS

It is essential that the interpretation of the results obtained from the above-mentioned activities during the post-treatment period be made progressively in order that timely remedial action can be implemented.

For progressive assessment, the entomological parameters should be presented graphically, together with the parasitological and meteorological data as soon as the data each week (for larvae) and every fortnight (for adults) is collected.

Providing that no operational defects existed, the larval indices obtained from the fixed capture stations consistently showing the presence of advanced instar larvae as well as pupae of anopheline vectors at the end of the interval of application would indicate that the larvicide under the optimum field dosage and frequency is not effective, or the susceptibility level of the *Anopheles* vectors involved has deteriorated. This will call for close observations involving also the prevailing environmental conditions of the affected breeding places where temporary physical changes may have occurred. In the light
of the results of such investigation and the results of adult captures as well as the results of spot checks, a revision of the rate and frequency of application may need to be made in areas affected or in the whole area of operations.

The adult house-resting densities obtained from the indicator areas would reflect the impact of the larviciding applied in those areas, if the species rests mainly indoors. On the other hand, the biting indices would help to determine the net impact on the man/vector contact and whether it is still of epidemiological significance, particularly when the species involved has exophilic tendencies. In such a case, due to the difficulty of knowing the proportions that rest indoors and outdoors, the reduction in density of the outside resting population becomes difficult to estimate.

A knowledge of the critical density of the vector in relation to man would be an asset, facilitating the interpretation of levels of biting densities. For this reason a close liaison between the entomologist and the malariologist is a pre-requisite for determining, by joint entomological/parasitological analysis of data, the level of critical density, if not readily available in the existing information.

The light traps may reveal the presence of the vector, when the other methods fail to do so.

However, the adult parameters obtained from regularly observed indicator areas may also reflect operational deficiencies occurring in the surrounding area. To eliminate this possibility, the surrounding areas should be subjected to spot checks.

In spot checks the presence of advanced instar larvae and pupae of anopheline species in the breeding places inspected should immediately be investigated in order to establish whether this was due to negligence on the part of the larvicider or to the inefficiency of the larvicide to cope with a particular environmental situation. Timely remedial action can then be applied as appropriate.

5. STAFFING, TRANSPORT, SUPPLIES AND EQUIPMENT

5.1 STAFFING REQUIREMENTS

The staff required for carrying out the entomological activities in a larviciding programme will depend on the following:

(a) the size of the area of operations;

(b) the number of breeding places, their surface area and accessibility for sampling; and

(c) the distribution of the breeding places with respect to the distance to be travelled by the insect collector.

For this, experience of the preliminary surveys will permit the estimation of:

(a) the average number of breeding places that can be examined by a collector per day in each section of the operational area; and

(b) the number of collectors needed to carry out larval checks and adult mosquito captures.
The following example may illustrate the staffing needs in an area having breeding places reasonably distributed, where water is accessible and the larval density is moderate.

One collector would be able to cover 12 - 18 larval capture stations per six hour day, assuming that about half of that time would be spent walking.

If, in an area there were 100 - 150 larval capture stations to be observed at weekly intervals, and four fixed localities to be checked for adult vectors with bait and spray capture every two weeks, a team of eight insect collectors would be able to undertake the following weekly schedule:

(a) cover the larval capture stations in one day; and

(b) carry out two night observations in two of the four localities (alternating with the other two localities every second week).

It is more convenient to carry out spray capture for adult mosquitoes in the morning following night capture.

To such a team one supervisor and one technician should be assigned. Both will conduct the periodical susceptibility testing, operate the light traps and summarize the reports of the collectors. The insect collector should be trained to identify larvae and adults under the supervision of the technician and the supervisor.

After the treatment has started, additional personnel would be needed to carry out spot checks. If the above area had about 1000 - 1500 breeding places a team of four insect collectors would be able to inspect about 20 - 25% of the breeding places each week. This team would need one supervisor. A senior technician should be assigned for the overall supervision and direction of the entomological activities.

5.2 TRANSPORT

Adequate transport of the appropriate type for the teams and the supervisors.

5.3 SUPPLIES AND EQUIPMENT

(a) kit for collecting larvae

(b) kit for collecting adults

(c) WHO standard susceptibility test kit for larvae

(d) WHO standard susceptibility test kit for adults

(e) laboratory equipment and supplies for examination of larvae and adults.

6. TECHNIQUES FOR LARVAL SAMPLING

6.1 SAMPLING DEVICES

Some devices are quite elaborate and are only suitable for research studies for estimating the entire larval densities as may be found in literature. An excellent review
of quantitative methods for sampling larval density was made by Knight (1964). More recently Service (1971) attempted to estimate the size of the larval populations of Anopheles gambiae complex and Mouchet (1972) has reviewed methods for the study of larval densities of culicine mosquitoes.

The conventional devices which are commonly used for estimating the relative density of larval populations by dipping are the ladle, metal utensils and net dippers. The last device, with certain modifications, can be used in wells. Each of these devices has advantages and limitations.

6.1.1 The ladle

This device is suitable for small shallow collections of water such as puddles and hoofprints. It is also useful in experimental work involving small plots. Due to the small surface area sampled by this device, it is not suitable for the inspection of larger breeding places, as it would be time-consuming to make the large number of dips necessary in order to sample adequately the large water surface.

6.1.2 Kitchen utensils

Containers such as pans, dishes and bowls are used. They should be white in colour in order to have a contrasting background against which larvae can be seen. Such devices are suitable for dipping in breeding places of limited size, small swamps, irrigation canals, ditches, streams, ricefields, etc.

Although a larger surface area of water can be sampled with these devices, they can only be used at a short distance from the water margin. When wading, one has to come close to the preferential site and this causes disturbance to the larvae. (In areas where schistosomiasis is endemic, operators, when wading, should wear protective thigh boots).

6.1.3 The metal dipper

The best metal dipper is one which has a wire screen window on one side, to allow water to be drained off without losing any larvae which may have been caught. It has a short hollow handle into which a cane of up to two metres in length can be fitted as an extension handle to permit reaching the site of collection from a distance. This type is not usually available in local markets and has to be imported or made to order by local tinsmiths.

6.1.4 The net dipper

This is made of cloth shaped in the form of a bag and mounted on an iron ring or a triangle. Although bolting silk is the most suitable material, any other porous textile, which will allow water to strain through and retain the larvae, can be used. A cane about 1.20 m long can be fitted on the ring to serve as a handle for reaching the breeding site from a distance. The best position of the cane is to form a wide angle with the plane of the ring. After skimming through the water, the bag should be held outside the breeding place in order that the water strains through and then inverted and the contents washed out in a white enamel plate with some water. Light stirring of the water on the plates should be made in order to release the larvae from debris and algae.

The net dipper is suitable for sampling from larger bodies of water covering a large surface in a relatively short time. It has the disadvantage that it cannot easily be used when very dense vegetation occurs in the breeding place.

6.1.5 Net dippers for wells

The same net dipper described above can be used in shallow wells, for example,
those having water at a depth of about 1.5 m. Wells with water at a greater depth can be sampled with the same net after removing the cane and fitting a tripod of string to the iron frame of the net.

A roll of string should be used for lowering the net to reach the surface of the water. To keep the bag stretched when skimming through the water surface, a pebble or a small stone should be placed in it. The net should be manoeuvred to skim the surface of the water and then lifted and rinsed with water in a plate as mentioned above.

As buckets may not be available at wells, the collector should include an empty tin in his equipment for drawing water from the well to rinse the net.

As mentioned above, each sampling device has a certain scope in sampling of larvae. The best approach is to use a combination of these devices. The net dipper and the ladle have generally been found to be a satisfactory combination. Records obtained from dipping with each should be kept separately.

6.2 LARVAL SAMPLING PROCEDURES

Reliable quantitative sampling of larval density is difficult to achieve due to the following factors:

(a) larvae are not distributed at random in the breeding places. They are often crowded in concentrated sites. It is, therefore, difficult to extrapolate the finding of larvae in the site sampled to the whole surface area of each type of breeding place;

(b) breeding places vary in size and shape and their surface area is apt to fluctuate with seasonal environmental changes, making it difficult to fix a standard surface area for each type of breeding place;

(c) the behaviour of larvae in the breeding habitats varies with the species, and this calls for careful training of the collectors. On the other hand, the amount of aquatic vegetation may vary and add further difficulty in the sound sampling of larval density;

(d) with the available devices, sampling is rendered far from accurate, particularly in situations as described in (b) and (c).

Sampling of larval density should, therefore, aim at roughly estimating the relative density for qualitative evaluation. The relative abundance of larvae of the species at different times of the year and in different places can be determined provided that the methods of sampling are standardized as far as possible.

For the purpose of evaluating larval control measures, the following procedures would give reasonably standardized samples:

(a) the larval sampling should be directed to larval concentration sites in the breeding places. This can be ascertained after a wide larval search. Those sites having high density should serve as fixed capture stations;

(b) depending on the local conditions, sampling should be made with a ladle for small water collections and with a net dipper for larger water collection.

From experience gained the number of dips should be standardized as units of 10 dips or multiples of 10 (i.e. 20, 30, etc.) per capture station depending on the density of the larvae. This standard should be maintained in all larval capture stations of different
types of breeding places.

A net dipper as described above, having a diameter of 17 cm, when its front edge is submerged and skimmed through the surface of the water for a distance of about three times its diameter, would roughly cover 0.1 m² of surface area. This forms one dip after which the edge of the net should be slightly lifted above the surface of the water. Ten such dips should be made to cover as far as possible the different aspects of each capture station.

As mentioned earlier, multiples of 10 dips may need to be made in each capture station if the density is low. This can be determined by experience during the preliminary surveys and a standardized unit of 10 dips or multiples of 10 can be maintained at each capture station for regular or spot check observations.

7. ENTOMOLOGICAL EVALUATION OF TRIALS WITH CHEMICAL LARVICIDES

An essential element in planning a larviciding programme particularly when new larvicides are intended for use, is that information on the appropriate type of formulation, dosage and frequency of application should be obtained locally from a small scale trial on the following aspects:

(a) selecting the suitable formulation for prevailing types of breeding places;
(b) determining the dosage and frequency of application throughout the different seasons.

The trial should be carried out soon after the decision has been made to apply larviciding measures. It may be carried out in the preparatory year while collecting all the necessary base-line data and other information required for planning. However, it must be carried out during the favourable breeding season of vectors and should satisfy the investigator of the adequacy of the information on the formulation, dosage and frequency of application. A period of three months should be sufficient.

7.1 PROCEDURES

Checking of the adult density cannot be considered reliable in a limited size trial because of the infiltration of mosquitoes from the surrounding untreated area. Therefore the evaluation will rely on larval checking.

7.1.1 Pre-treatment larval survey

In the area chosen for undertaking the trial, a number of breeding places should be selected as fixed larval capture stations in which larval checking should be maintained using a standardized number of dips (see section 6). Larval sampling should be made in order to establish base-line data for at least a month before the application of the larvicide during the favourable season. An area having similar types of breeding places should be selected to serve as a comparison area in which a similar number of standardized dips are to be made in fixed capture stations.

7.1.2 Post-treatment observations

After the application of the larvicide the same standardized number of dips should be made in each of the fixed larval capture stations. The post-treatment observations should be made as follows:

(a) one day after treatment in a section of each type of breeding place. This will
provide information on the immediate effect of the larvicide;

(b) on the last day of the interval between applications as indicated from available information on larval life span and residual effectiveness of the larvicide, in another section of the breeding places;

(c) the same observations should be maintained in the comparison area.

7.2 RECORDING, SUMMARIZATION AND INTERPRETATION OF DATA

(Vide Section 4 of the text.)

REFERENCES

1 Knight, K. L. (1964) Quantitative methods for mosquito larval surveys. J. med. Ent., 1,109


# ANNEX 4. SAMPLE PROCEDURAL GUIDE AND INSTRUCTIONS FOR THE SAFE HANDLING AND USE OF PESTICIDES

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The sample procedural guide given below is taken directly from "A guide and recommendations for the use of insecticides in California mosquito control" in which it was published by the California Mosquito Control Association in 1956. Minor changes and/or deletions have been made where items obviously would not apply in malaria programmes. Several statements with the prefix I were added in their entirety. It is not intended that this guide be adopted by malaria programmes as presented, but that it be used as a model or a pattern upon which an appropriately modified guide can be developed to meet the needs of individual programmes.

1. GENERAL

The practical handling and application of chemicals used in public health programmes presents certain dangers which must be kept constantly in mind. The factors to be considered are (1) the chemicals may injure plants, (2) the chemicals may injure the applicator, (3) the chemicals may injure the consumer of crops, (4) the applications may result in exceeding residue tolerances, (5) children and other persons may be accidentally exposed, (6) domestic animals and wildlife may be exposed to excessive residues on food and forage crops.

Potential hazards as well as obvious benefits to public health accrue from the manufacture and use of agricultural chemicals. Accidents should not occur if instructions for the proper use of the chemicals are followed and prescribed precautions are taken.

For many years pesticides of a very high level of toxicity have been used routinely for insect control. Historically, injuries are almost invariably due to accidents or carelessness in handling. Never assume you know the procedure in handling any pesticide. Familiarize yourself thoroughly with the material you are using and ALWAYS READ THE LABEL.

2. GUIDES FOR HANDLING, STORING OR APPLYING INSECTICIDES OF MEDIUM TOXICITY, SUCH AS DDT, HCH, LINDANE, CAMPECHLOR, CHLORDANE, MALATHION* (see page 107)

(1) Store the insecticide out of reach of children, unauthorized persons and domestic animals, and preferably in an enclosed and locked location.

(2) Storage areas should be isolated from workmen and others.

(3) Post on storage and mixing areas signs, such as: "DANGER - CHEMICALS - KEEP AWAY"

(4) Always keep spray equipment clean and in good repair, preventing leakage and accidental contamination of skin and clothing.

(5) Avoid prolonged contact with spray materials; provide soap and water at all times so that materials can be washed from hands and body. I Wash hands immediately after handling the concentrates or when wet with dilute spray.

* The listing of chlorinated hydrocarbons is now outdated, since these materials were eliminated as larvicides in California by 1960, when high levels of resistance to the various chlorinated hydrocarbon sprays had been acquired by the more prevalent species of mosquitoes. More recently most chlorinated hydrocarbon insecticides have been removed from the list of acceptable pesticides, owing to their persistent residual characteristics, and the consequent potential for long lived contamination of non-target areas or animals.
(6) Avoid undue applications directly to fruit, vegetables, domestic animals, forage crops or other edible products.

(7) Avoid, where possible, applications to drying clothes, automobiles, freshly painted surfaces and plate glass.

(8) Exercise care in applying insecticidal materials wherever drinking water for man or animals may be contaminated.

(9) Take special precautions to avoid contamination of foods or forage for livestock, particularly where there are dairy cattle.

(10) Use all pesticides in strict conformance with the precautions, warnings and directions on the label.

(11) Always store chemicals in their original, properly labelled containers.

(12) If repackaging is necessary from the original container (drums or bags) use appropriate warning labels. Never use beverage bottles or other food containers.

(13) If a flagman is used in aircraft spraying operations, instruct him to get out of the plane's run or swath to avoid contamination by the spray material.

(14) Dispose of empty containers safely. Burn empty bags and stay out of the smoke. For non-returnable liquid containers, wash inside and outside thoroughly, immediately after use. Dispose of wash water so as to avoid contaminating local water supplies.

(15) Use only proper equipment, in good repair, for field applications; which will avoid routine contamination and minimize occasional or accidental contamination of operators, inhabitants, domestic animals and wild life.

3. ADDITIONAL PRECAUTIONS FOR USE WITH THE MORE HIGHLY TOXIC INSECTICIDES SUCH AS PARATHION, EPN, ALDRIN, DIELDRIN, HEPTACHLOR, FENTHION, CHLORPYRIFOS

While extremely effective as insecticides, these materials are highly poisonous to human beings and other animals if inhaled, absorbed through the skin, or swallowed. Repeated inhalation or skin contact, even in small amounts, may progressively increase susceptibility to poisoning, without giving rise to symptoms. Extreme care must therefore be exercised at all times in handling these products. Experience has shown that they can be used safely and effectively if proper precautions are rigidly and constantly followed.

(1) Make certain one or more physicians in the district are informed of the use of these chemicals and the symptoms, antidotes or other factors regarding their use. There should be available to physicians specific literature on diagnosis and treatment of insecticide poisoning.

(2) Each season prior to handling, spraying, or otherwise using any of the highly toxic organophosphorus insecticides, have a minimum of two pre-exposure cholinesterase tests made of all personnel. This establishes a reference basis for comparison should accidental contamination occur. Consult your doctor regarding this test.

(3) Call a physician at once in all cases of suspected poisoning or gross contamination.

(4) Keep all unauthorized persons away from the area where the organophosphorus insecticides are stored or mixed.
(5) Post appropriate signs of warning at storage areas.

(6) Keep all highly toxic organophosphorus insecticide concentrates in a specially designed area and under lock. If storage or packaging area is not in a building, have the area enclosed by a fence.

(7) DO NOT USE HIGHLY TOXIC INSECTICIDES IN THE FOLLOWING CASES:
- on warm blooded animals, including humans
- in households
- in mills, warehouses, etc.
- in aerosols or in equipment that will not provide reasonably uniform deposits; I without excessive atomization
- in urban areas.

(8) Burn, bury or destroy parathion containers, never re-use. Sweep up all spillage and bury. Clean up spillage area with strong lye solution. Burial should be in a specific location and in such a manner that it will not be re-exposed.

(9) Protective clothing and respirators should be provided and used when steam cleaning spray equipment. Approved respirators for use with organophosphorus insecticides are:
- American Optical Company respirator No. 5561, equipped with filter cartridge combination R-561. (American Optical Company, Southbridge, Massachusetts, USA)

(10) Authorize only a limited number of trained personnel to make up single charge units of highly toxic concentrates.

(11) Supply boxes, preferably with locks, on each vehicle for carrying supplies of highly toxic insecticides.

(12) Calibrate equipment carefully and at regular and frequent intervals.

(13) Provide facilities for personal decontamination in cases of accidental exposure.

(14) Instruct spray operators to shower at least once daily.

3.1 HANDLING OF CONCENTRATE AND LOADING OF SPRAY TANK

The material will be measured out in single tank charges in individual bottles, and each operator will be supplied with a partitioned box in which to keep them. Under no circumstances will anyone, except those specifically authorized, fill these bottles or measure this material into any container.

The material furnished for loading the spray tanks is a concentrated preparation. Great care and the strictest adherence to the prescribed safety precautions should be
observed in handling this material. It is with this concentrate that the greatest danger of an accident exists.

Spray tanks will be completely emptied before refilling, and a full tank will always be prepared. (Some districts refill partially full tanks, however, very accurate measurement must be made to ensure proper dosage rates; exact concentrations are of utmost importance.)

A special box with a lock will be furnished to each operator, and bottles whether empty or full, will be kept at all times in this box. Under no circumstances are they to be carried loose in the jeep or in any other container.

Protective devices such as rubber gloves, respirators, soap and towels will be supplied by the district. Ask your foreman about them. (Polyethylene bottles are supplied by many mosquito control organizations to minimize the hazard of breakage.)

In filling the spray tank, the following procedure should be followed, step by step:

(1) Open box containing bottles of parathion concentrate.

(2) Put on rubber gloves.

(3) Open tank.

(4) Remove bottle of concentrate from box and empty it into the tank, taking care not to spill concentrate on outside of tank or to contaminate outside of bottle.

(5) Replace cap on bottle while it is still over the tank opening and replace bottle in box.

(6) Wash the gloves while still on the hands, with soap and water.

(7) Remove gloves, put them away, and wash hands.

(8) Close and lock box.

3.2 OTHER PRECAUTIONS

(1) Cleanliness is the greatest essential in protection from any poisonous material. Hands should be washed thoroughly before smoking or eating, and hands and face should be washed after spraying. Clothes should be changed frequently and daily if spraying is heavy.

(2) Equipment should be kept free from leaking lines. When leaks develop they should be repaired immediately. If it is necessary to spray using a leaky nozzle, rubber gloves should be worn.

(3) In steam cleaning, a respirator will be provided and must be worn. The respirator should be cleaned and disinfected and returned to its proper place after use. Hands and face should be thoroughly washed with soap and water.

(4) Do not recirculate the material in your tank with the spray gun. If mixing is necessary, do it by operating the pump with the by-pass open.
(5) Keep soap in your vehicle at all times and use it freely.

(6) Keep outside of the box clean. Steam cleaning of wooden boxes is not recommended.

(7) Keep bottles in box provided; never in any other container or loose in your jeep.

(8) Never overdose any water. This is essential. If pupae are present, use oil or other suitable pupacides.

(9) Keep rubber gloves in a protected place and in good repair. If they become damaged or worn, get a new pair. These gloves are your primary protection.

(10) Protect your eyes from contamination.

(11) The bottles are not to be used for any other purpose.

(12) The bottles or any part of them are not to be disposed of outside of the district yard, or by anyone not authorized to do so.

3.3 IN CASE OF CONTAMINATION

(1) Stop operations immediately. Remove any clothing which is contaminated and wash any material from your skin with plenty of soap and water. If a bottle is accidentally broken, pick up the broken glass, wearing rubber gloves, and taking care not to cut the hands or gloves, put it somewhere in the jeep, not in the box. The jeep can be cleaned. If the concentrate is spilled on the ground, and the operator is contaminated, he should cover the spillage quickly with dirt, and immediately notify the office. It is essential that in case of contamination with the concentrate the material be washed from the body immediately with plenty of soap and water. If the eyes are affected, flush with running water for two to 15 minutes then report to the office. Experience has shown that in cases of heavy contamination with parathion, no injurious effects could be found if it was immediately washed off with soap and water.

(2) Notify the office immediately. You will be directed to a doctor for a blood test, treatment and instructions.

3.4 IN CASE OF ANY INDICATION OF CHRONIC POISONING

Report to the office immediately. You will be taken to a doctor for examination and treatment if necessary.

ANYONE NOT FOLLOWING THESE INSTRUCTIONS WILL BE SUBJECT TO IMMEDIATE DISCHARGE

4. FIRST AID TREATMENT OF CASES OF POISONING

The following instructions are for your protection and safety and should be followed in all cases of poisoning. The label warnings are as follows:

Internal

Give a tablespoon of salt in a glass of warm water and repeat until vomit fluid is clear. Have victim lie down and keep quiet. Atropine tablets of 1/100 grain are kept at the office in case you need one. These are only to be used in extreme emergency until the doctor arrives. Issuing of atropine tablets to district personnel should be at the discretion of the physician responsible for the district.
External

Skin: Immediately remove all contaminated clothing and wash skin thoroughly with soap and water.

Eyes: Flush with water for 15 minutes.

Note to attending physician

Repeated therapeutic doses of atropine may be effective. DO NOT USE MORPHINE. Therapeutic doses of atropine for poisoning by organophosphorus compounds may run as high as 1/10 grain every 10 to 15 minutes.

5. LABELLING OF PESTICIDE CONTAINERS

"DANGER - Extremely hazardous if swallowed, inhaled or absorbed through skin or eyes. Personnel showing symptoms of shortness of breath, headaches, tightness of chest or blurred vision should be removed from the area and immediately given medical attention"

Important - Keep animals and unprotected persons away during use and while there is danger from drift or residues.
Annex 5. SOME EXAMPLES OF EQUIPMENT USED FOR APPLICATION OF PESTICIDES

The mention of manufacturing companies or of their proprietary products does not imply that they are recommended or endorsed by the World Health Organization.

PUMPS - High pressure, low head, engine-driven pumps, for use in raising water not exceeding 7.5 m

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Cat.No., type and designation</th>
<th>Capacity max. (1/min)</th>
<th>Engine (hp)</th>
<th>Head (m)</th>
<th>Weight (kg)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>F.E. Myers &amp; Co., ASHLAND, Ohio USA</td>
<td>V 912 E</td>
<td>34</td>
<td>3/4</td>
<td>46</td>
<td>130</td>
<td>175</td>
</tr>
<tr>
<td></td>
<td>V 913 E</td>
<td>64</td>
<td>1</td>
<td>35</td>
<td>213</td>
<td>275</td>
</tr>
<tr>
<td></td>
<td>V 914 E</td>
<td>106</td>
<td>2</td>
<td>43</td>
<td>332</td>
<td>385</td>
</tr>
<tr>
<td></td>
<td>V 915 E</td>
<td>167</td>
<td>3</td>
<td>35</td>
<td>390</td>
<td>445</td>
</tr>
<tr>
<td>F.E. Myers &amp; Co., ASHLAND, Ohio USA</td>
<td>V 931 M</td>
<td>15.5</td>
<td>1/2-1 Ph</td>
<td>70</td>
<td>111</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td>V 932 M</td>
<td>36.7</td>
<td>2-1 Ph</td>
<td>122</td>
<td>147</td>
<td>320</td>
</tr>
<tr>
<td></td>
<td>V 933 M</td>
<td>60.6</td>
<td>5-3 Ph</td>
<td>177</td>
<td>345</td>
<td>480</td>
</tr>
<tr>
<td></td>
<td>V 934 M</td>
<td>110.7</td>
<td>7 1/2-3 Ph</td>
<td>168</td>
<td>560</td>
<td>675</td>
</tr>
<tr>
<td>Thuron Sprayer Manuf. Co. 12200 Denton Drive DALLAS 34, Texas USA</td>
<td>Eagle 20</td>
<td>32</td>
<td>-</td>
<td>18-12.5</td>
<td>-</td>
<td>30</td>
</tr>
</tbody>
</table>

LIQUID APPLICATION

(a) Compression sprayers

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Tank Capacity (l)</th>
<th>Pressure Range (kg/cm³)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hudson Manuf. Co. 1625 I Street N.W. WASHINGTON D.C. 20006 USA</td>
<td>12-16</td>
<td>1.7-4</td>
<td>30-35</td>
</tr>
<tr>
<td>Myers &amp; Co. ASHLAND, Ohio USA</td>
<td>10</td>
<td>1.7-4</td>
<td>approx. 30-35</td>
</tr>
</tbody>
</table>

(b) Power sprayers

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Cat.No.</th>
<th>Tank Capacity (l)</th>
<th>Pressure Range (kg/m²)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thuron Sprayer Manuf. Co. 12200 Denton Drive DALLAS 34, Texas USA</td>
<td>20-T-TH</td>
<td>1514</td>
<td>56</td>
<td>2160</td>
</tr>
<tr>
<td></td>
<td>20-T-AG</td>
<td>1135</td>
<td>35</td>
<td>1675</td>
</tr>
<tr>
<td></td>
<td>10 T</td>
<td>267</td>
<td>35</td>
<td>855</td>
</tr>
<tr>
<td></td>
<td>5 T</td>
<td>378</td>
<td>35</td>
<td>695</td>
</tr>
<tr>
<td></td>
<td>10-TA</td>
<td>378</td>
<td>35</td>
<td>925</td>
</tr>
<tr>
<td></td>
<td>20-TA-TH</td>
<td>1134</td>
<td>56</td>
<td>2295</td>
</tr>
</tbody>
</table>
(b) Power sprayers (continued)

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Cat.No.</th>
<th>Tank Capacity (l)</th>
<th>Pressure Range (kg/m²)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. Bean &amp; Co. LANSING Michigan USA</td>
<td>6-30TR</td>
<td>1135</td>
<td>56</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>N-6-30TR</td>
<td>1892</td>
<td>56</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>B-6-30MT</td>
<td>3784</td>
<td>49</td>
<td>-</td>
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</table>

(c) Mist blowers

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Type</th>
<th>Tank Capacity (l)</th>
<th>Engine (hp)</th>
<th>Air Velocity (km/h)</th>
<th>Reach (m)</th>
<th>Weight (kg)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>J. Bean &amp; Co. LANSING Michigan USA</td>
<td>Trailer mounted Rotomist 303T</td>
<td>1140</td>
<td>144</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S. Frederick Potts P.O. Box 51 CRAWFORD Mississippi USA</td>
<td>P24</td>
<td>125</td>
<td>7</td>
<td>80-320</td>
<td>150</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Buffalo Turbine Agric.Equip.Co. GOWANDA, N.Y. USA</td>
<td>CS Mity Mite</td>
<td>190</td>
<td>36</td>
<td>26</td>
<td>high</td>
<td>100</td>
<td>500</td>
</tr>
</tbody>
</table>

(Back packs; small mist blowers)

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Type</th>
<th>Tank Capacity (l)</th>
<th>Engine (hp)</th>
<th>Air Velocity (km/h)</th>
<th>Reach (m)</th>
<th>Weight (kg)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solo Industries P.O. Box 128 37-41 57th St., WOODSIDE, N.Y. USA</td>
<td>M70B Junior</td>
<td>10</td>
<td>400</td>
<td>9-12</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffalo Turbine Agric.Equip.Co. GOWANDA, N.Y. USA</td>
<td>Mity Moe</td>
<td>1.2</td>
<td>1.06</td>
<td>150</td>
<td>24</td>
<td>6.5</td>
<td>120</td>
</tr>
<tr>
<td>Hudson Manuf.Co. 1625 I St., N.W. WASHINGTON D.C. 20006 USA</td>
<td>Bak-Pak</td>
<td>2.3</td>
<td>3.5</td>
<td>120</td>
<td>14</td>
<td></td>
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</tbody>
</table>
## GRANULE APPLICATORS

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Tank capacity (kg)</th>
<th>Swath width (m)</th>
<th>Weight (kg)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo Turbine Agric.Equip.Co. GOWANDA, N.Y., USA (Jeep-mounted model GA)</td>
<td>90</td>
<td>7-27</td>
<td>455</td>
<td></td>
</tr>
<tr>
<td>Whirlybird Spreader Chevron Chem.Co. 200 Bush Street SAN FRANCISCO, USA (hand granule applicator)</td>
<td>1.5</td>
<td>2.5-3.5</td>
<td>1 approx.</td>
<td>a few</td>
</tr>
<tr>
<td>Cyclone Seeder Co. URBANA, Illinois USA (Swinging horn granule dispenser - horn seeder)</td>
<td>9</td>
<td>9</td>
<td>1</td>
<td>about 10 metal parts 1.5</td>
</tr>
</tbody>
</table>

## DUSTERS

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Tank capacity (kg)</th>
<th>Air velocity (km/h)</th>
<th>Weight (kg)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffalo Turbine Agric.Equip.Co. GOWANDA, N.Y., USA (MODEL D)</td>
<td>68</td>
<td>145-160</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Marunaka Sprayer &amp; Duster Manuf.Ltd. 11 Mukaidamshimach Kissham Minamiku KYOTO, Japan</td>
<td>4</td>
<td>415</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Kyoritsu Noki Co. 379 Shimorenjaku Mitaka, TOKYO Japan</td>
<td>3</td>
<td></td>
<td>4</td>
<td>15</td>
</tr>
</tbody>
</table>

See also Buffalo Mist Blowers
### GRANULE GUN

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Type</th>
<th>Nozzle</th>
<th>Maximum throw (15 mesh sand granule)</th>
<th>Discharge rate (2.5 kg/cm²)</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kelco Engineering Co.</td>
<td>Model G790C sandblast gun</td>
<td>Tungsten carbide</td>
<td>12 m</td>
<td>0.25 - 0.6 kg/min (3.5 m suction tube) 0.6 - 0.8 kg/min (0.9 m suction tube)</td>
<td>100</td>
</tr>
<tr>
<td>11936 Front Street NORWALK</td>
<td></td>
<td></td>
<td></td>
<td>(excluding compressor*)</td>
<td></td>
</tr>
<tr>
<td>California 90652 USA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Compressor TU-FLO-500, water-cooled, Bendix-Westinghouse, USA

### NOZZLES

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Type</th>
<th>Discharge rates (2.8 kg/cm²)</th>
<th>Maximum throw (m)</th>
<th>Spray Angle</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spraying Systems Co. WHEATON,</td>
<td>SS 8002 E</td>
<td>756 ml/min</td>
<td>80°</td>
<td>0.75 - 1</td>
<td></td>
</tr>
<tr>
<td>Illinois, 60187, USA (flat jets)</td>
<td>SS 8003 E</td>
<td>1134 ml/min</td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SS 8004 E</td>
<td>1512 ml/min</td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>(cone jets)</td>
<td>1/4 TL x 1.5</td>
<td>95 ml/min</td>
<td>84°</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/4 TL x 2.5</td>
<td>158 ml/min</td>
<td>83°</td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>(solid stream jets)</td>
<td>1/4 T000021</td>
<td>76 ml/min</td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1/4 T000050</td>
<td>200 ml/min</td>
<td></td>
<td>&quot;</td>
<td></td>
</tr>
<tr>
<td>(adjustable nozzle)</td>
<td>5500 x 3</td>
<td>90-740 ml/min</td>
<td>0.6 - 9</td>
<td>72°</td>
<td>1.20</td>
</tr>
</tbody>
</table>
### VEHICLES, BOATS and AIRCRAFT

<table>
<thead>
<tr>
<th>Manufacturer's name and address</th>
<th>Description</th>
<th>Estimated price ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ARRCO Industries</strong>&lt;br&gt;1859 S 8th West&lt;br&gt;SALT LAKE CITY&lt;br&gt;USA</td>
<td>Trailer (Trailmaster) 2.4 x 0.7 x 4.6 m</td>
<td></td>
</tr>
<tr>
<td><strong>Thiskol Chem.Corp.</strong>&lt;br&gt;LOGAN, Utah, USA</td>
<td>Swamp Spryte (amphibious vehicle) 450 kg cargo capacity, 1.8 x 1.7 m cargo area, 56 km/h on land, 15 km/h on water, 1.7-3.4 l/km consumption</td>
<td>7700</td>
</tr>
<tr>
<td><strong>Controlled Air</strong>&lt;br&gt;Streams Co.&lt;br&gt;1734 W.El Segundo Blvd&lt;br&gt;GARDENA, California&lt;br&gt;USA</td>
<td>Airthrust portable power unit:&lt;br&gt;0.5 m, 2.5 hp, 19.5 kg&lt;br&gt;0.6 m, 2.5 hp, 22 kg&lt;br&gt;0.9 m, 10 hp&lt;br&gt;Two-bladed propellers</td>
<td>190&lt;br&gt;240&lt;br&gt;500</td>
</tr>
<tr>
<td><strong>IMCO Inc</strong>&lt;br&gt;P.O. Box 547&lt;br&gt;AFTON, Wyoming&lt;br&gt;USA</td>
<td>CallAir A.9, Lycoming engine, 235 hp, cruising speed 190 km/h, maximum load 612 kg&lt;br&gt;CallAir B.1, Lycoming engine, 400 hp, cruising speed 190 km/h</td>
<td></td>
</tr>
<tr>
<td><strong>Bell Helicopter Co.</strong>&lt;br&gt;P.O. Box 482&lt;br&gt;PORT WORTH, Texas, USA</td>
<td>47G-5, Lycoming engine, 265 hp, cruising speed - 136 km/h, load - 590 kg, to be equipped with Agmaster spray equipment</td>
<td></td>
</tr>
</tbody>
</table>