REPUBLIC OF ZAMBIA MINISTRY OF HEALTH

GUIDELINES FOR LARVAL SOURCE MANAGEMENT

2019

NATIONAL MALARIA ELIMINATION PROGRAMME WWW.NMEC.ORG.ZM

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Acronyms

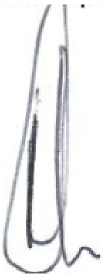
BR	Briquettes
Bs	Bacillus sphaericus
Bti	Bacillus thuringiensis israelensis
CCM	Community case management
CI	Confidence Interval
CM	Case management
EC	Emulsifiable concentrate
EIR	Entomological inoculation rate
FMDA	Focal mass drug administration
HMDA	Household Mass drug admiration
GIS	Geographical Information System
G	Gram (weight)
ICD	Infection case detection
IPTp	Intermittent preventive treatment during pregnancy
IPC	Inter Personal Communication
IRS	Indoor residual spraying
ITN	Insecticide-treated Mosquito Net
L	Litre (volume)
LLIN	Long-lasting insecticide-treated net
LSM	Larval Source Management
M	Metre (length)
MDA	Mass drug administration
MG	Microgranule
Min	Minute (time)
NMEP	National Malaria Elimination Programme
RBM	Roll Back Malaria Partnership
SC	Suspension concentrate
WG	Water-dispersible granule
WHO	World Health Organization
WP	Wettable powder

Foreword

Zambia is committed to fulfilling the goals of eliminating malaria by 2021. We continue to promote the integration of vector Management approach. In integrated approach, Larval Source Management is one of the interventions of our malaria programme in an effort to reduce the aquatic stage of vector population and thus, decrease malaria incidence.

The National Malaria Elimination Programme of Zambia has identified the need to have a standardized protocol that guides districts in implementing and assessing Larval Source Management programmes. These guidelines have been developed to meet that need. They highlight key points applicable to all the districts and facilitate monitoring and evaluating that will ensure that programmes are successful. I recommend that each district adhere to these guidelines and note that these guidelines will be revised periodically as need arise.

I hope that the users of this document will find it useful in their daily operations in a bid to reduce malaria illness and death and attain the goal of eliminating malaria from Zambia.



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Introduction

Zambia's Ministry of Health, along with its partners, through the National Malaria Elimination Programme, continues to provide quality malaria control, prevention, and treatment services in an aggressive, integrated approach to reduce malaria and malaria-related burden in the country, with an aim of eliminating the disease by 2021. The following are some of the interventions being implemented in the integrated approach:

- Long-lasting insecticide-treated nets (LLINs)
- Indoor residual spraying (IRS)
- Intermittent preventive treatment during pregnancy (IPTp)
- Case management
- Laval source management

Larval Source Management (LSM) has not been widely implemented. The World Health Organization (WHO) has recently recommended the use of LSM as a supplementary strategy to core interventions such as LLINs and IRS. However, WHO's Larval Source Management manual (WHO 2012) LSM can only be used in specific settings where malaria vector mosquitoes breed in permanent or semi-permanent breeding habitats that can be easily accessed and are few, fixed, and findable (i.e., "The Three Fs"). Thus, it is mostly suitable in urban areas as opposed to rural areas where the breeding habitats will be too numerous and unstable, especially in the wet season.[1] LSM is only recommended as a supplementary control measure and it should not be used to replace the core vector malaria interventions (LLINs and IRS).

The Zambia National Malaria Elimination Programme has adopted LSM as a supplementary vector control tool. This manual is intended for use by all vector control personnel at national, provincial, district, and community levels. It provides complete step-by-step guidance on the planning, implementation, management, and evaluation of the LSM programme.

LSM in malaria vector control

LSM refers to the targeted management of mosquito breeding sites with the objective of reducing the number of mosquito larvae and pupae.

There are four types of LSM:

- Habitat modification

  A permanent alteration to the environment, aimed at eliminating larval habitats, including: Landscaping, surface water drainage, filling and land reclamation
- Habitat manipulation

  Temporary environmental changes to disrupt vector breeding, including: Water-level manipulation, e.g. flushing, drain clearance to eliminate pooling; Shading or exposing habitats to the sun depending on the ecology of the vector
- Larviciding

  The regular application of biological or chemical insecticides to water bodies
- Biological control

  The introduction of natural enemies into larval habitats, including: Predatory fish, Predatory invertebrates, Parasites or other disease-causing organisms

Mosquito eggs, larvae, and pupae are confined to aquatic habitats. Hence, they can't escape from physical modifications or insecticides applied directly to their habitats, thereby reducing adult mosquito densities. LSM can permanently eliminate breeding habitats and reduce the entomological inoculation rate (EIR) and malaria transmission in the area.

LSM has an impressive track record that was largely gained when it was the only mainstream malaria prevention strategy before the advent of long-lasting adulticides. However, there is renewed interest in using LSM as a complimentary tool to LLINs and IRS, specifically in settings where resistance to insecticides used in the recent past for adult malaria vector control has been seen, as in Zambia. There is also renewed interest in LSM to mediate residual transmission, which is transmission occurring even after complete coverage of LLINs/IRS.

Historical background

In the early twentieth century, larviciding with Paris green and with environmental management were the main vector control interventions. These tools were implemented with great success in Africa and elsewhere. In the Zambian context, in order to prevent economic losses due to malaria in mining towns, LSM was implemented for two decades starting in the late 1920s. The package of control measures included draining of swamps, oil application to open water bodies, vegetation clearance, modification of river boundaries, and house screening. This resulted in a 97 percent reduction of annual malaria incidence from 514 per 1000 population in 1929/1930 to 16/1000 in 1949/1950. Additionally, overall mortality decreased by 88 percent from 32/1000 per year to 4/1000 per year.[2] Clearly, LSM has previously demonstrated its impact in the Zambian context; it is still being deployed by mining companies in the country. In order to maintain the momentum of reduced disease burden—as highlighted in the National Malaria Elimination Strategic Plan 2017–2021—in the country's ten provinces, supplementary tools such as LSM are urgently needed.

How effective is LSM?

When appropriately used, LSM can contribute to reducing the numbers of both indoor- and outdoor-biting mosquitoes and, in the malaria elimination phase, it can be a useful addition to programme tools to reduce the mosquito population in malaria hotspots. Where appropriate, it can also help programmes to reduce their overall dependence on insecticides thereby contributing to prevention of the emergence of insecticide resistance. As Zambia has embarked on the elimination agenda, LSM is a very useful intervention.

Purpose of the guidelines

The purpose of these guidelines is to provide a coordinated, quality assured, and standardised mode of implementing LSM activities and promoting its effective use in the country. The guidelines provide a framework within which the strategies can be managed and effectively executed.

Aim

To contribute towards malaria elimination in Zambia.

Objectives

- To provide the dual benefit of reducing the numbers of both indoor- and outdoor-biting mosquitoes.
- To contribute to mosquito reduction in malaria hotspots.
- To contribute to the prevention of the emergence of insecticide resistance.

1. Guiding principles for LSM

1.1 Applicability of larval source management (when and where)

Programme managers will need to assess whether LSM is appropriate and, if so, what strategy should be used. LSM is an approach that needs to be tailored to local environmental conditions. In general, there are four approaches to implementing LSM:

- LSM is an intervention that is part of the National Malaria Elimination Strategy, however in areas about to implement, it should start on a small scale with pilot schemes which are necessary to build the much needed capacity and this will be done in collaboration with the NMEP.
- Small communities or municipalities with few resources but significant motivation to control malaria, such as in places where LLINs and/or IRS have not yet been deployed, can conduct LSM as part of a local community effort.
- Sectors outside the health sector can contribute to LSM through careful road and building construction and infrastructure development.
- Large urban areas and private schemes—such as mining and agricultural operations with an interest in malaria control and improved quality of life through the reduction of mosquito populations—can implement LSM independent of, but in collaboration with, national malarial elimination activities using local or corporate resources.

LSM can also be deployed according to the malaria burden in an area as shown in Table 1.

Table 1: Malaria incidence and recommended corresponding interventions.

Thresholds by incidence	Interventions to be deployed
More than 150 cases/1000 population	IRS, insecticide-treated nets (ITNs), case management (CM), community case management (CCM), mass drug administration (MDA)
50-149 cases/1000 population	IRS, ITNs, CM, CCM, MDA
10-49 cases/1000 population	ICD, IRS, ITNs, CM, CCM, focal MDA (fMDA), LSM
Below 10 cases/1000 population	ICD, fIRS, fLSM, ITNs, CM, CCM, hMDA

The following factors will contribute to the success of LSM programmes in all settings:

- **Leadership and clarity of objectives:** Personnel at all levels of the organization must receive the message that LSM is an important undertaking and has the support of management.

- **Good management:** Management capacity is the key to a successful LSM programme. The ability to quickly collate and report meaningful monitoring data is important. Typically, it is the inadequate management of staff and logistics that limits the success of an LSM programme.

- **Entomologists with detailed knowledge of local vectors:** it is essential to have trained entomologists conduct detailed surveys of the ecology and behaviour of local vectors in order to establish which (if any) LSM interventions are appropriate and to monitor the impact of the programme.

- **Community engagement and support:**
    - LSM interventions must have the support of the local community in a target area so that larval habitats can be accessed and either treated with a larvicide or modified.
    - Key community members (neighbourhood health committees, traditional leaders, community health workers, and other influential leaders) must be involved from the planning stage.
    - Local needs must be taken into consideration when interventions are planned (e.g., the livelihood of the local population might depend on some of the aquatic habitats such as rice fields, irrigation channels, and wells).
    - Social and behavioural change communication should be conducted prior to the deployment of interventions and ideally community members will be directly involved in conducting LSM.
    - Strengthening community surveillance is also cardinal.

- **Collaboration between sectors:**
    - LSM requires a multisectoral approach for it to successful.
    - LSM often overlaps with the responsibilities of other sectors such as the local authorities and agricultural sector. Therefore, careful coordination can be productive and cost effective.
    - Collaboration with other sectors to ensure good practice in infrastructure development and housing is also important so that activities such as road construction, brick making, or house building do not create new larval habitats.

- **Targeting LSM in urban areas:** Larval habitats in towns and cities are largely man-made and relatively easy to identify and treat. In addition, other interventions that may be acceptable to a rural population may not be well-received in urban areas such as IRS. LSM may be one of the vector control interventions deployed in such settings.

- **Strong surveillance systems:** Continuous entomological monitoring is crucial to ensure that all larval habitats are being correctly handled and epidemiological surveillance is important to monitor the impact of the LSM programme.

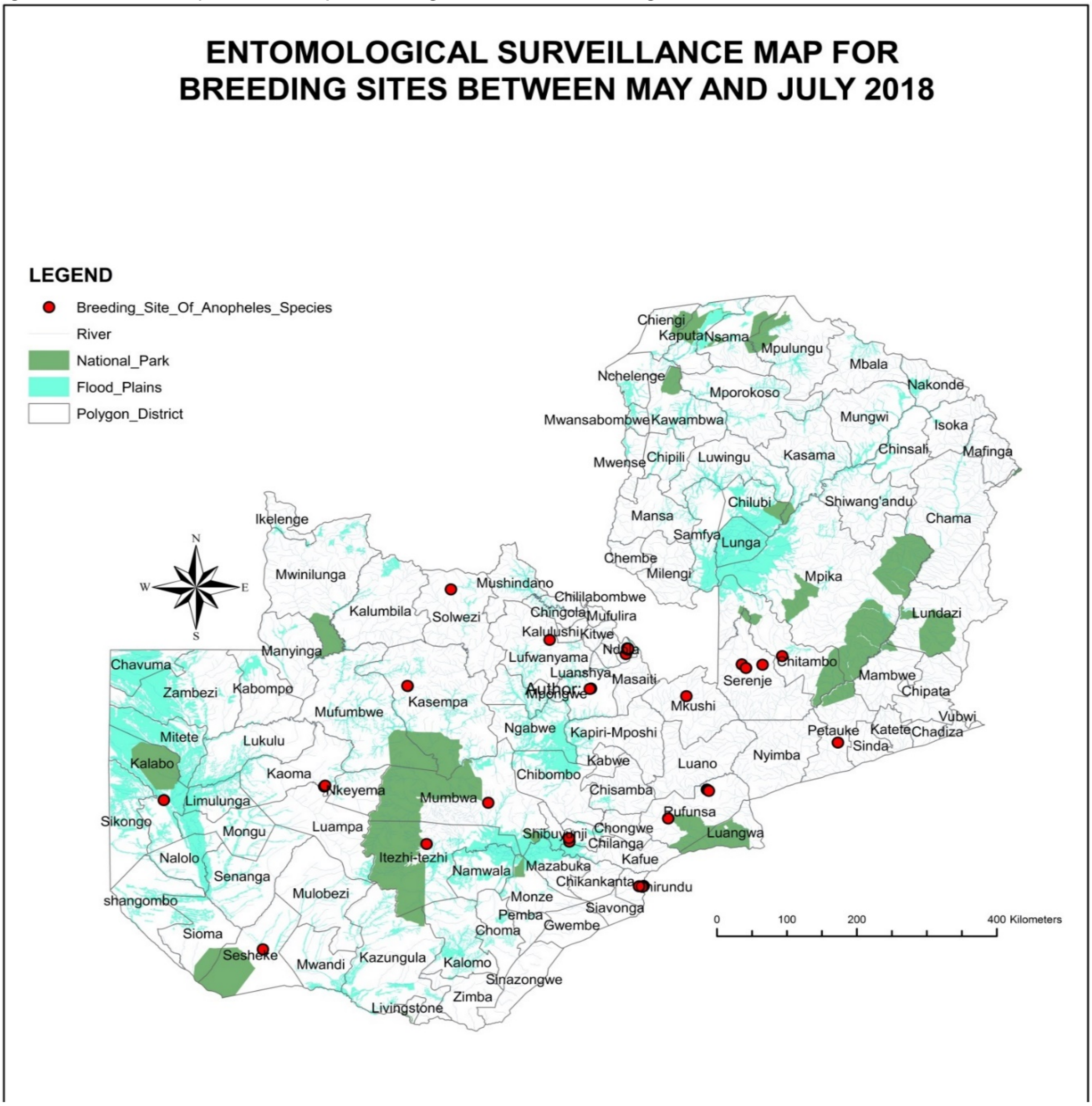
2. Strategies of larval source management

2.1 Baseline information for larval source management

Prior to conducting an LSM programme, the following baseline information on mosquito habitat identification, characterisation, and mapping will be critical for the operational success of larval control strategies in malaria-endemic areas of Zambia:

- Identify all potential breeding habitats of mosquitoes in an operational area and list them categorically as rivers, streams, puddles, rain pools, dams, ponds, canals, ditches, streams, and wells. These could be either permanent, non-permanent, closed, or open.
- Characterise mosquito breeding habitats based on physical presence of vegetation type, amount of shade, water turbidity, habitat size and depth.
- Map all identified mosquito breeding habitats using either sketch maps or handheld Geographical Information Systems (GIS) receivers to determine mosquito larvae species distribution and density (Anophelines and Culicines).
- Conduct an ecological assessment based on the nature of mosquito breeding habitats aimed at informing feasibility of implementing larval control strategies (i.e., larviciding, environmental modification, or manipulation in the operational settings).
- Classify habitats as active or non-active based on presence or non-presence of larvae.
- Classify habitats in terms of few, fixed, and findable (i.e., “The 3 Fs”).

Figure 1: An example of a map showing identified breeding sites.



After the baseline information on mosquito habitat identification, characterisation, and mapping is established, an LSM programme can commence. As stated earlier, there are four types of LSM:

- Habitat modification
- Habitat manipulation
- Larviciding
- Biological control

2.2 Habitat modification

Habitat modification is a permanent alteration of the environment. It includes:

- Landscaping—transformation of land and vegetation.
- Drainage of surface water.
- Land reclamation and filling.
- Coverage of large water storage containers (e.g., wells) with mosquito-proof lids and permanent slabs, or complete coverage of water surfaces with a material that is impenetrable to mosquitoes (e.g., expanded polystyrene beads).

The target areas include, but are not limited to:

- Irrigation systems
- Man-made containers
- Quarries
- Construction sites or borrow pits
- Areas with seepage from dams
- Areas with poor waste water management or broken water pipes
- Areas of urban agriculture
- Small ground pools resulting from ground depressions filled with rain
- Low water tables

In order for this approach to work effectively, integration is encouraged. Therefore, the Ministry of Health through National Malaria Elimination Program has constituted a national integrated Vector Control Technical Working Group. This group provides a foundation for policy development by coordinating policy formulation, implementation, and evaluation. It includes representatives from the National Malaria Elimination Programme and ministries of agriculture, environment and natural resources, infrastructure, housing and construction, and local government. Additionally, municipal agencies that are involved with surface water management (water utility companies) and road development, the Zambia Environmental Management Agency, and nongovernmental and private organisations are also members. Through the Vector Control Technical Working Group, principles and techniques for LSM should be adopted by all Government departments and stakeholders involved in integrated vector management efforts. A detailed operating procedure is in Annex 4

2.3 Habitat manipulation

Habitat manipulation is a form of environmental management aimed at producing temporary conditions that are unfavourable for vector breeding. Unlike habitat modification, habitat manipulation must be repeated to remain efficacious and is normally directed at one particular vector species.

The following methods of habitat manipulation are recommended:

- Controlling water levels (including intermittent irrigation)
- Stream flushing or sluicing
- Shading
- Clearing of aquatic vegetation and algal mats
- Straightening and steepening shorelines
- Changes to water salinity and water pollution. See details in Annex 4.

Controlling water levels

Fluctuations in the water level in impoundments or irrigation systems lower vector breeding by:

- Discouraging the growth of plants that provide shelter for larvae along margins.
- Removing larvae from vegetation at margins so they are more exposed to predators and water turbulence.
- Stranding larvae at margins. The interval between fluctuations must be shorter than the life of larvae (7–10 days) and the water level should vary by 30 to 40 cm.

In the tropics, floating vegetation may undermine the effectiveness of managing water levels for controlling mosquito breeding, such as the water hyacinth (*Eichhornia* sp.), water chestnut (*Trapa* sp.), water primrose (*Jussiaea* sp.), water lettuce (*Pistia* sp.), alligator weed (*Alternanthera* sp.), water milfoil (Myriophyllum sp.), and Kariba weed *Salvinea* sp. Where they are abundant, species such as these will require control, as discussed later in this section.

Intermittent irrigation

In rice-growing areas, intermittent irrigation must be practiced in order to control vector breeding. If the ground is level with good drainage, paddy fields can be completely dried for two to three days at regular intervals. Drying must occur simultaneously across a large area of farmland.

This is not possible in the three weeks after first transplanting rice seedlings and during this period other methods of larval control will be required. The length of time intervals between drying will need to be determined by an agricultural expert.

Intermittent irrigation is less successful for the control of mosquitoes such as *An. gambiae s.l.*, which rapidly re-colonise larval habitats after flooding and also flourish in small residual puddles left after drying.

The local vector needs to be assessed, however, because in some settings a continuous flow of water is conducive to the breeding of certain species.

Stream flushing or sluicing
Flushing is used for small streams with a sufficiently slow and continuous flow of water to allow mosquitoes to breed along margins. Periodic flushing with a large volume of water washes away eggs, larvae, and pupae from the banks, or pushes them to higher-level dry land where they cannot survive.

Flushing also stirs up sediment at the bottom of the stream, which can bury aquatic mosquito stages and can help slow the growth of new marginal vegetation. Despite the high initial investment required, flushing is a long-lasting method, which requires little maintenance. It has been successfully used in South-East Asia to control *An. maculatus* and *An. minimus*. It is less appropriate for species that do not prefer streams or where water is in short supply.

A small dam should be constructed to collect the water required for flushing, at a point where the stream is narrow and banks are high. A sluice gate built into the dam can be opened once a week. Flushing should begin at the start of the mosquito breeding season and end when the stream has dried up.[3]

Shading
Planting trees or shrubs along the banks of streams can control mosquitoes, which prefer to breed in partial or full sunlight

Clearing of aquatic vegetation and algal mats
Some mosquito species may be controlled by clearing water vegetation, since this removes shelter for larvae. This can be easily done using rakes in small and larger larval habitats by introducing herbivorous fish such as the grass carp. This may be impractical in some settings such as swampy areas. Driftwood should also be removed from larger water bodies such as reservoirs.[3]

Straightening and steepening shorelines
Straightening and steepening the margins of ditches, streams, and ponds removes shallow water suitable for vector breeding, and increases the water flow which washes away eggs, larvae, and pupae.

Changes to water salinity
Vectors which breed in brackish waters in coastal marshes or lagoons may be controlled by introducing seawater into their larval habitats via sluice gates, culverts or channels to increase water salinity. This may not be practical in Zambian set up.

2.4 Larviciding
Larviciding is the regular application of microbial or chemical insecticides to water bodies or water containers to kill the aquatic immature forms of the mosquito (Tusting, 2013). Larvicides are used in areas where the breeding sites are few, fixed, and findable (WHO, 2013). Mosquitoes lay their eggs in standing water and the eggs develop through a series of life stages (larvae and pupae) into adults. The type of breeding habitat chosen for oviposition by an adult female mosquito depends on the species and the habitat type can be classified as natural or man-made, and temporary or permanent (Bruce-Chwatt, 1985).

Selection and application of larvicides

The selection and application of larvicides is based on the recommendation of World Health Organization Prequalification Team (Table 2). The selection of larvicides is based on level of toxicity to humans as well as to the environment. In addition, operational costs, transportation requirements, durable equipment, and, most importantly, storage requirements and shelf life have to be considered.

Susceptibility tests of the local vectors to candidate larvicides must be conducted before selection. Laboratory assays must be conducted to determine the minimum effective dose and field studies must be conducted to determine the optimum effective dosage.

It is recommended that the insecticide class used for larviciding be different from that used for IRS in the same area.

Types of larvicides and mode of action

There are different types of larvicides used for mosquito control. These include insecticides, insect growth regulators, microbial larvicides, and oils. The larvicides have different modes of action:

- **Surface oils and films.** These are light refined oils and biodegradable alcohol-based products. For example, surface films, such as mineral oils and alcohol-based surface products, suffocate the mosquito larvae and pupae by covering the surface of a water body
- **Synthetic organic chemicals.** These are insecticide compounds that kill immature larval stages of mosquitoes by inhibiting cholinesterase and affect the central nervous system of the mosquito. Examples include organophosphates such as chlorpyrifos, fenthion, pirimiphos-methyl, and temephos.
- **Microbial larvicides.** These are bacteria such as Bacillus thuringiensis israeliensis (Bti) and Bacillus sphaericus (Bs) which produce toxins that are very effective in killing mosquito larvae after ingestion. The ingested toxins will attack the gut system of the larvae causing the mosquito larvae to stop eating and eventually die (WHO 2013).
- **Insect growth regulators.** These are chemical compounds that are highly toxic to mosquito larvae by preventing their development into adults. They interfere with insect metamorphosis and prevent adult emergence from the pupal stage. These chemical compounds include diflubenzuron, methoprene, novaluron, and pyriproxyfen.

Table 2. WHO-prequalification recommended compounds and formulations for control of mosquito larvae.

S/N	Product Name	Active Ingredient (Insecticide compounds and formulations)	Formulation	Product Type	Classification	Dosage (active ingredient)	
						General (g/Ha)	Container-breeding (mg/L)
1	VectoBac	Bacillus thuringiensis	WG	Larvicide	Bacterial larvicide	125–750[3]	12.5–75[3]
2	Actellic	Pirimiphos-methyl	EC	Larvicide	Organophosphate	50–500	1
3	Dimilin	Diflubenzuron	GR	Larvicide	Benzoylureas	25–100	0.02–0.25
4	Sumilarv	Pyriproxyfen 0.50% GR	G	Larvicide	Juvenile Hormone Mimics	10–50	0.01
5	MOZKILL	Spinosad	SC	Larvicide	Spinosyns	20–500	0.1–0.5
6	Abate	Temephos	EC	Larvicide	Organophosphate	56–112	1

DT = tablet for direct application; GR = granule; EC = emulsifiable concentration; WG = water-dispersible granule; WP = wettable powder.

Formulations

Most larvicides are available in a variety of formulations, including:

- **Emulsifiable concentrate (EC):** A solution of an insecticide in a solvent, EC is a liquid, homogeneous formulation to be applied as an emulsion after dilution in water. Application is done through pouring or spraying over water surface, most often using a portable sprayer. ECs are the most commonly used formulations for organophosphates.

- **Suspension concentrate (SC):** A formulation obtained by suspending solid water-insoluble pesticides in water to produce a flowable liquid product. It can be applied undiluted or diluted with water depending on active ingredient/formulation and application needs.

- **Water dispersible granule (WG):** A formulation consisting of granules to be applied after disintegration and dispersion in water. This formulation provides the storage stability of a dry product with the application versatility of a liquid spray (note: in some cases, WG formulations can be applied directly to artificial/natural containers for control of mosquito larvae).

- **Wettable powder (WP):** Dry powder of the insecticide formulated with a wetting (dispersing) agent, which promotes rapid mixing with water to form a suspension.

- **Granules:** A free-flowing solid formulation of a defined granule size range ready for use. Granule formulations allow for direct penetration of dense aquatic vegetation better than with liquid formulations. Application is typically made with portable blowers or by hand.

- **Pellets:** A formulation obtained by extrusion of inert materials impregnated with active ingredients. Like granules, these formulations allow for direct penetration of dense aquatic vegetation better than with liquid formulations. Typically, pellets allow for a more controlled release of the insecticide, thus extending the residual activity of the product.

- **Briquettes (BR):** Blocks of an inert material impregnated with insecticide. Depending on the inert composition, briquettes may either float or sink. Degradation of briquettes and the inert composition allows for controlled release of the insecticide. This type of formulation is typically applied by hand.

2.5 Biological control

Biological control is the introduction of natural enemies into larval habitats, including predatory fish, predatory invertebrates and parasites, or other disease-causing organisms.

Larvivorous fish

The mosquito fish or top minnow, Gambusia affinis

This species is the most widely used against mosquito larvae. Together with the guppy it belongs to the live-bearing tooth carp family, Poeciliidae. Their mouths are adapted to feeding from the surface. It originates from Central America but, because of its success in controlling mosquitos, has been introduced into many parts of the world. These fish can withstand large fluctuations in temperature as well as pollution of the water, but they are most productive in relatively clean water of moderate temperature.

Larvivorous fish are recommended and have been widely used. The following characteristics are preferable in larvivorous fish:

- Small size to allow access to all parts of the larval habitat.
- Preference for mosquito larvae above other prey at the water surface.
- High reproduction rate in small water bodies.
- Local, not exotic species.
- Tolerance to salinity, pollution, temperature fluctuations and transportation.

Species largely used for the control of mosquito larvae include:

- Tooth carp (Poeciliidae and Cyprinodontidae).
- Guppy (Poecilia reticulata).
- Top minnow or mosquito fish (Gambusia affinis).

Gambusia is more appropriate for clean water. Poecilia is more efficient for organically polluted water and in water with a higher temperature, such as in rice fields.

Advantages to using larvivorous fish include:

- If introduced into a suitable environment, natural larval predatory fish may establish themselves, thereby providing a self-perpetuating method of larval control.
- Fish are not expensive to introduce, nor is specialist equipment required to introduce them.
- Fish do not contaminate the environment and can be used in reservoirs of drinking water.

Disadvantages include:

- Natural predators are only effective if a large number become established, and may never provide comprehensive control (i.e., mosquito breeding may continue at low levels). Therefore larvicides may also be necessary.
- Natural predators may take several months to control larvae.
- Fish are less effective where there is abundant vegetation or debris and these require removal.
- Fish must be reared in special ponds.
- Transportation and stocking require particular care.
- Introduction of non-native species can disrupt ecosystems.
- Apart from larvivorous fish, the other methods of biological control have not been used on a large scale to evaluate their effectiveness.[1]

2.6 Equipment

The choice of equipment, equipment calibration, and applicator training are critical for the success of LSM operations. The choice of equipment depends on the following factors:

- Choice of larvicide formulation (liquid or granular).
- Nature and size of targeted larval habitats.
- Availability of fuel, oil, and maintenance services for power equipment.
- Local capacity to securely store equipment that may be useful for agriculture or other pursuits.
-

While hand application of granules may be sufficient for many applications, such as routine treatment of small urban sources, many LSM operations will require the use of some equipment. This will certainly be true when liquid sprays are employed and for application of granules in large areas.

Table 3. Tools and equipment for LSM implementation

S/N	Requirements
1	Handheld compression sprayers either manual or motorised
2	Vehicle mounted low volume fogger
3	Vehicle mounted ultralow volume fogger
4	Power backpack blowers
5	Vehicle mounted rotary spreader
6	Solid stream nozzles (Disk – no core)
7	Tools for environmental manipulation and modification (rakes, wheel barrows, shovels, machetes, piks, hoe, axe and many others)

Figure 2 Examples of suitable spray equipment for high volume, hand application liquid larvicides.

Figure 3 Examples of solid stream nozzle configurations.

Disk – no core Solid stream

3. Application of liquid sprays

Liquid larvicide sprays are used in a number of applications due to their efficiency and potential cost savings. High volume or low volume sprays can be selected depending on available equipment, type of habitats, and specific application objectives. The availability of clean water for the preparation of sprays can be a limiting factor in some locations. Extensive, dense, emergent vegetation in larval habitats can also limit the effectiveness of liquid sprays.

Manual application of high volume sprays is an appropriate choice for small- to medium-sized habitats that have a low density of emergent vegetation. Manual equipment requires no fuel and minimal maintenance, so it can be carried out in areas where these resources are limited. For high volume, hand application of liquid insecticides to larval habitats, compression or backpack sprayers fitted with a solid stream nozzle should be employed using the swathing spray or spot spray methods.

Figure 4: Schematic swathing spray method.

Swing spray wand back and forth to create an arc while walking through the source. Always make a full semi-circle arc (180°) and keep the wand pointed high. Spray mix will depend on effective swath, walking speed, and sprayer flow rate.

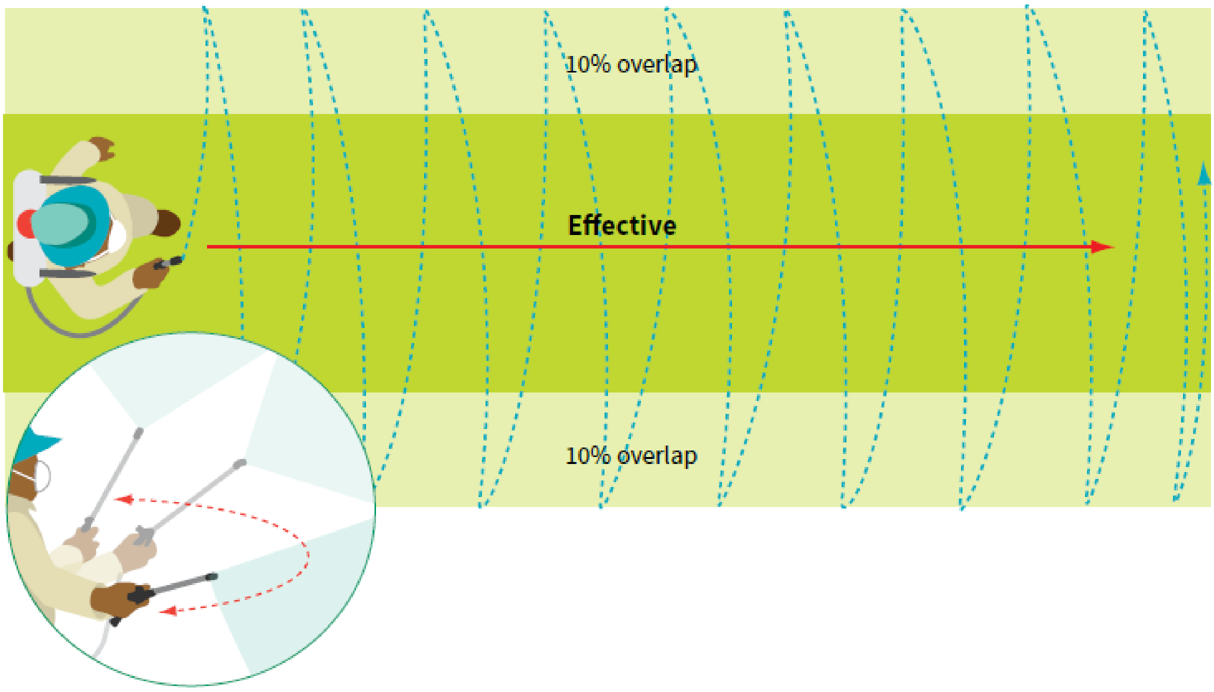


Figure 5: Application of swath spray to a large larval source.

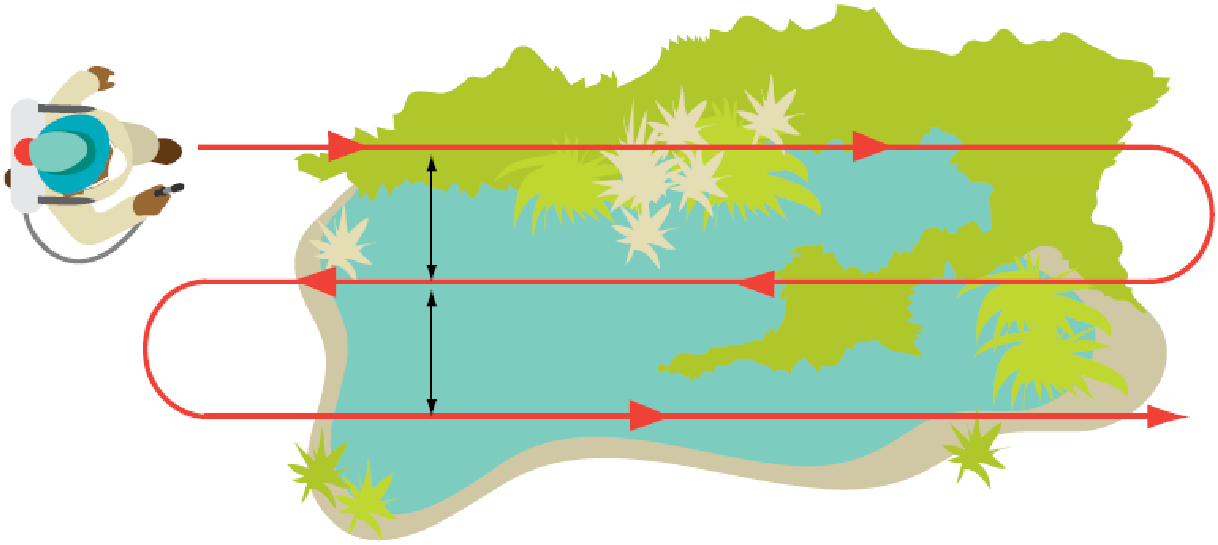
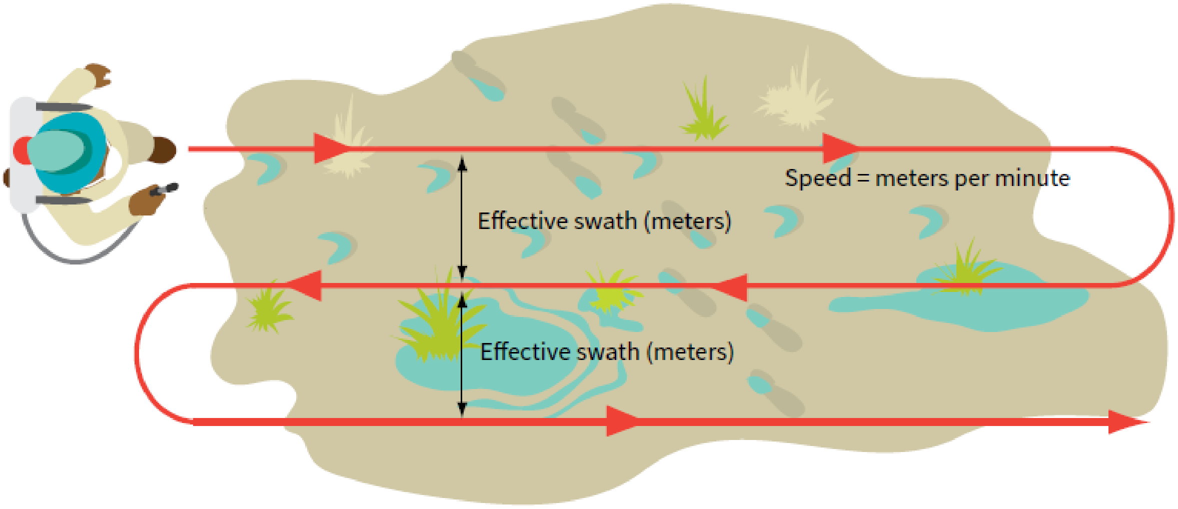


Figure 6: Application of swath spray to a concentration of numerous larval sources.



4. Social behaviour change communication

LSM uses a community-based approach to implement the activities and create demand through existing structures such as neighbourhood health committees, malaria task forces, community-based volunteers such as community health workers and community health assistants (Table 4).

Table 4. Social behaviour change communication approaches for Larval Source Management.

Audiences	Barriers/ facilitator	Behavioural communicat ion	Communication objective	Key messages	Channels
Every household	People do not bury or drain pools of water and abandoned wells in their surroundings	Increase the number of household occupants that bury or drain pools of water and abandoned wells around their surroundings	To increase the percentage of households who know how mosquitoes breeds by 100%	If you clean your surroundings by way of burying stagnant water pools, clearing drainages ditches, getting rid of empty tins and tires, and removing piles of rubbish you will reduce the breeding of mosquitoes and thereby prevent your family and your neighbours from suffering from malaria	Mass media PA System Meetings Focus group discussions
			To increase the percentage of households strictly adhering to the guidelines and procedures in the provision of domestic water supply	If you bury abandoned wells to destroy mosquito larvae, you will reduce the mosquito population and thus reduce the chances of transmitting malaria and reduce malaria incidence in your community	IPC Flyers PA system Road show Billboards
Every household	Illegal canalisation around households for	Discourage canalisation in urban areas	To increase the percentage of household members adhering	By keeping your surroundings clean by clearing vegetation and	IPC Flyers Brochures PA system

	agricultural purposes (residential areas)		to Public Health ACT and regulations	stagnant water around your homes, you will prevent mosquitoes from having a conducive environment to proliferate	Drama Road show Mobile video
Construction industries (sand quarrying, stone crushing industries, road construction)	Construction industries/brick-making sites leave quarries, which allow for the collection of stagnant water	Increase number of construction industries treating and burying stagnant water quarries	To increase the percentage of inspections by regulatory authorities on road/building construction companies and some residential areas	By treating water collection pools/wells/dams and quarry sites to destroy mosquito larvae, you will reduce the mosquito population and thus reduce the chances of transmitting malaria and reduce malaria incidence in your community	Meetings Billboards
Community	Some peasant cattle ranchers sink dams to provide water for their animals, thus creating potential breeding sites for mosquitoes	Increase the number of communities who treat dams Increase number of farmers doing habitant manipulation	To increase the percentage larvicided /manipulated dams by local authorities in conjunction with the Ministry of Health	By treating water collection dams to destroy mosquito larvae, you will reduce the mosquito population and thus reduce the chances of transmitting malaria and reduce malaria incidence in your community.	Village meetings

5. Monitoring and evaluation

Monitoring and evaluation is integral to an operational vector control programme. It is key to documenting progress towards the achievement of goals and for data-driven decision-making at all levels of the programme. If the LSM programme is based on larviciding, it is necessary to monitor whether:

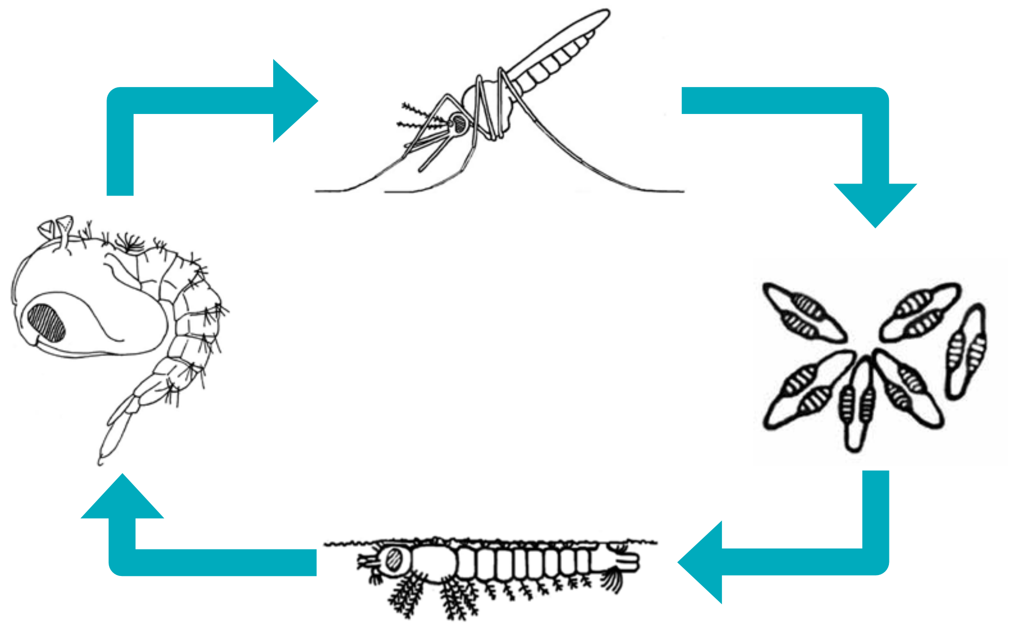
- The larvicide works.
- Larval control personnel are in the field applying larvicide according to their schedule.
- Adult vector densities are significantly reduced compared to baseline and are kept at a low level throughout the year.

Annex 1: Biological information
In accordance to WHO's Larval Source Management manual, this annex provides important biological information on mosquito bionomics and malaria transmission, an understanding of which is essential to assessing whether LSM is appropriate, and for running a successful LSM programme and I quote

Mosquito bionomics
Malaria is transmitted by females of the *Anopheles* genus (anophelines). Other genera of medical importance are *Aedes* in the subgenus *Stegomyia* (which transmit yellow fever, dengue fever, and filarial worms), *Culex* (filarial worms, Japanese encephalitis), and *Mansonia* (filarial worms). Mosquitoes of these three genera belong to the *culicine* subfamily. This annex outlines the life cycle of anopheline larvae and describes how anopheline mosquitoes can be morphologically distinguished from culicines.

Life cycle and morphological features of target larvae
The life cycle of the mosquito has four stages: egg, larva, pupa, and adult (Figure A1). The first three stages (egg, larva, and pupa) are aquatic and generally last 5–14 days, depending on the ambient temperature and species. Adults can survive for up to one month but generally live for one to two weeks.

Figure A1: Anopheline mosquito life cycle. Source: C. Whitehorn.



Eggs

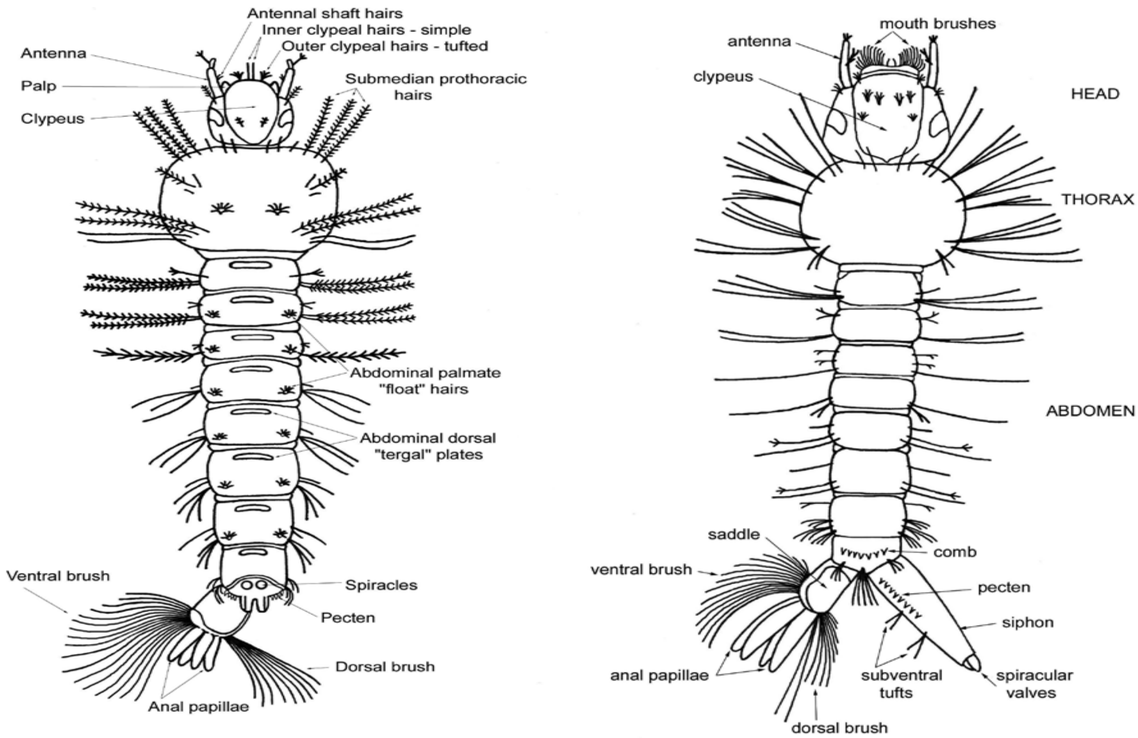
The adult female lays on average 50–200 eggs per oviposition, singly onto water. Eggs are characterised by their lateral floats (Figure A2) and attach by surface tension to the water surface or objects in the water. If eggs dry out the mosquito will not develop. Eggs typically hatch within two to three days. However, hatching may take two to three weeks in colder regions.

Figure A2. Anopheles eggs. Note these are laid singly. Source: C. Whitehorn.

Larvae

Larvae emerge using an egg tooth located on the head. They then develop through four stages or instars which are increasingly large, before metamorphosing into pupae after five to ten days. Before moving to the next stage, larvae moult and shed their exoskeleton (skin) to allow growth. Instar larvae are very small at first and this means they are often overlooked. Larvae have a head with mouth brushes for feeding, a thorax, and a segmented abdomen. Anopheline larvae do not have a respiratory siphon, which means that unlike culicine larvae, which hang perpendicular to the water surface (Figure A3, right), they must position themselves parallel to the water surface to breathe via spiracles on their abdomen (Figure A3, left). Larvae swim backwards near the water surface until contact is made with a solid object, which they then lie against. They dive below the surface when disturbed. They feed on microorganisms in the surface microlayer such as algae and bacteria.

Figure A3: Anopheles larva (left). note absence of siphon and subventral tufts that characterise Culicine larvae (right). Source: C. Whitehorn.



Pupae

When viewed from the side, the pupa is shaped like a comma. Pupae must visit the water surface to breathe via a pair of respiratory trumpets on the cephalothorax (merged head and thorax). Pupae are very active and dive below the water surface at the slightest disturbance of the water. The pupal stage lasts from a few hours to a few days, then the surface of the cephalothorax splits and the adult mosquito emerges.

Adults

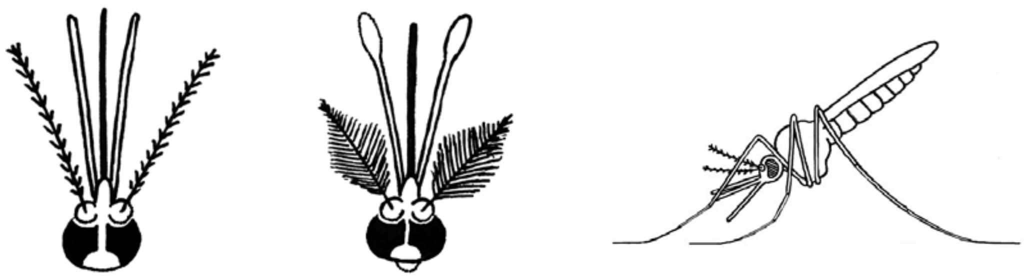
Adult *Anopheles* mosquitoes have three body sections: the head, thorax, and abdomen. Attached to the thorax are three pairs of legs and one pair of wings.

Anophelines can be distinguished from other mosquitoes by:

- Resting position, with their abdomens (rear ends) pointing upwards rather than held parallel to the ground (Figure A4).
- Palps, which are the same length as the proboscis (Figure A5).
- Wings, which have discrete blocks of black and white scales (Figure A5).

Female anophelines can be distinguished from males by their antennae, which are less hairy than male antennae (Figure A4).

Figure A4. *Anopheles* adult female head (left), *Anopheles* adult male head (centre), *Anopheles* adult (right). Note the typical adult resting position, with abdomen pointing upwards (right). Source: C. Whitehorn.



The time it takes for adult mosquitoes to mate after emerging from pupae varies from a few hours to several days. Males live for approximately one week and feed on nectar and other sources of sugar. Although females feed on sugar, they require a blood meal for their eggs to mature. After acquiring a full blood meal, females usually rest for two to three days in tropical conditions while their eggs mature, then eggs are laid and the female resumes host-seeking. The cycle of feeding, resting and ovipositing is then repeated until the female dies. The longevity of the female depends on temperature, humidity, and success in obtaining blood meals.

Larval habitats

Anopheline larvae are found in a wide range of habitats worldwide (e.g., rice fields, ditches, puddles, the edges of streams and rivers, fresh and brackish marshes, and mangrove swamps) but generally tend to avoid highly polluted water. Table A1 summarises the habitats and habitat characteristics of the major malaria vectors of Africa.[4]

The abundance of adult mosquitoes depends on the number, type, and size of potential larval habitats; their distance from blood meal sources; the density of larvae in the larval habitats; temperature; rainfall; and soil type. Larval habitats may be stable or dynamic, appearing briefly after rainfall.

Figure A5. Morphological differences between Anopheline and Culicine mosquitoes. Source: C. Whitehorn.

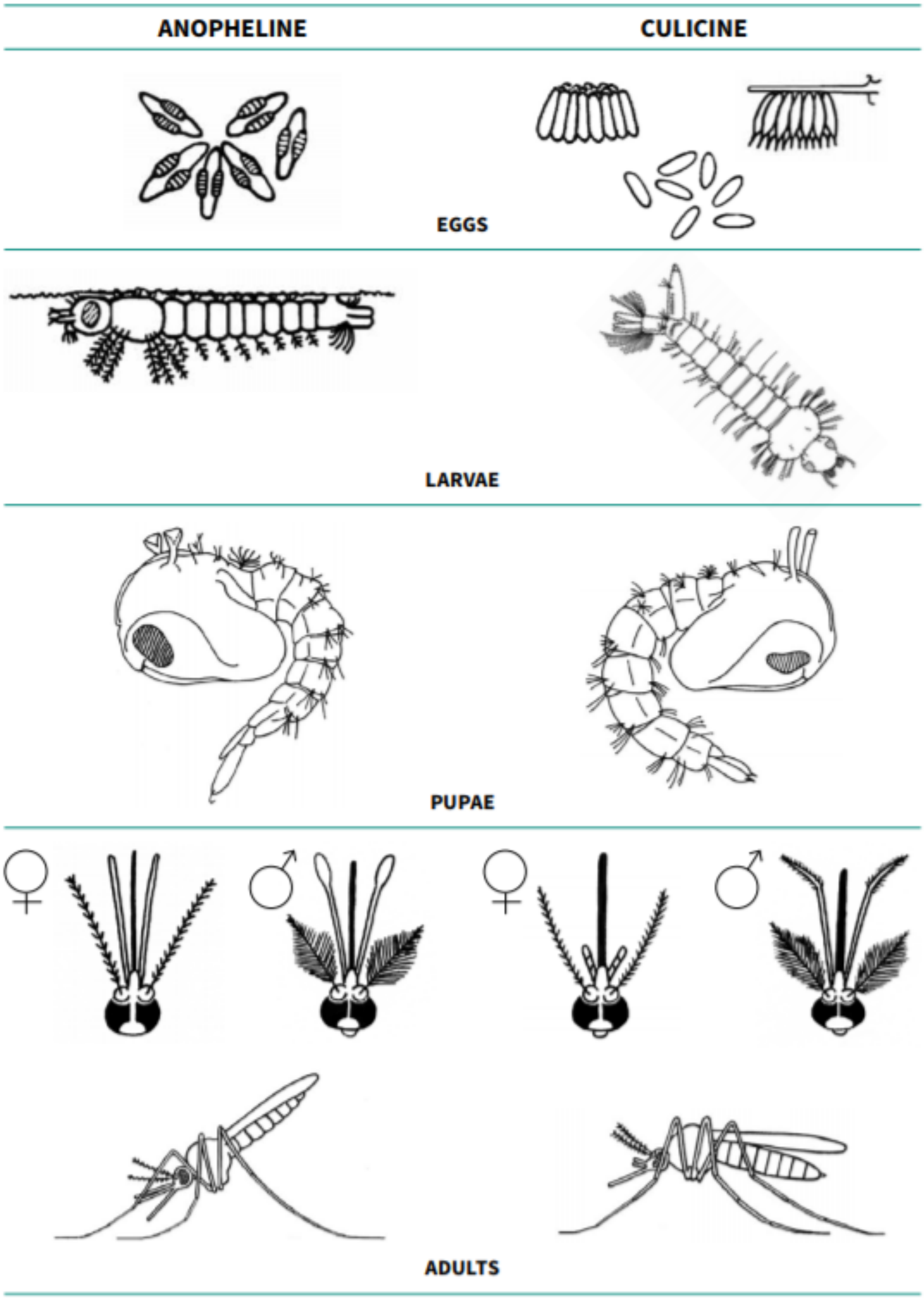


Table A1.Typical larval habitats and larval habitat characteristics of major malaria vectors.

Species	Typical larval habitats				Larval site characteristics
	Large natural water bodies	Large man-made water bodies	Small natural water bodies	Small man-made water bodies	
An. funestus	Edges of dykes, marshes, slow flowing rivers	Rice fields, fish ponds, irrigation channels	Small streams, seepage springs, pools, wells	Overflow water, irrigation ditches	Sunlit, shaded fresh
An. arabiensis, An. gambiae s.s.	Edges of lakes, marshes	Borrow pits, rice fields, fish ponds, irrigation channels	Small streams, seepage springs, pools, wells	Overflow water, irrigation ditches, borrow pits, wheel ruts, hoof prints, rice field puddles	Sunlit, fresh, and polluted
An. melas	Lagoons	–	Pools	–	Sunlit/shaded, brackish
An. merus	Lagoons	–	Pools	–	Sunlit/shaded, brackish
An. moucheti	Lakes, slow flowing rivers	Rice fields, fish ponds	Small streams, pools	–	Sunlit, fresh
An. nili s.l.	Slow flowing rivers	Rice fields, irrigation channels	Small streams	Irrigation ditches	Shaded, fresh

Adult mosquito habitats and behaviour

Mosquitoes typically disperse over several kilometres from their breeding sites. Adult male mosquitoes are weaker fliers than females. Therefore a high density of adult male mosquitoes indicates that their breeding place is relatively close.

Mosquitoes have very different biting and resting habits that need to be understood when making decisions about malaria vector control. Mosquitoes that feed and rest indoors are known as endophagic and those that feed and rest outdoors are exophagic. Feeding patterns vary with species, but biting generally tends to occur between dusk and dawn (and especially during the early hours of the morning, when the air is most humid) in species that are associated with open terrain or sunlit habitat. This is true of *An. gambiae s.l.* and *An. funestus* whose peak biting occurs an hour before dawn.[5]

Endophagic mosquitoes may rest indoors after feeding for a few hours, before either returning outdoors to rest or remaining indoors to digest their bloodmeal and produce eggs. Once eggs have developed, the gravid mosquitoes leave their resting sites and look for a suitable larval habitat.[3]

House design can influence mosquito house entry (e.g., in The Gambia where *An. gambiae* enters houses through open eaves, features such as closed eaves, concrete walls, or house screening make entry more difficult [6,7]). Even where species are predominantly endophilic, there will still be an outdoor resting population composed of males, newly emerged females, gravid females, and females that have just oviposited. When a species is predominantly exophilic, the proportion of the outdoor population that is recently blood-fed is higher. Outdoor resting places are typically sheltered, shaded, or humid and preferences vary between species, as does the preferred type of vegetation for resting on.

Anopheline species differ in the extent to which they prefer to feed on humans and animals. Species with a greater preference for humans are known as anthropophilic (and are more efficient vectors) and those with a lesser preference for humans are known as zoophilic.

Table A2. Biological information related to the vectorial efficiency of the major malaria vectors of Africa.

Species	Feeding preferences		Perdominant biting habit		Pre-feeding resting habit		Post-feeding resting habit	
	Anthropo-philic	Zoophilic	Exophagic	Endophagic	Exophilic	Endophilic	Exophilic	Endophilic
An. arabiensis	Yes	Yes	Yes			Yes	Yes	Yes
An. funestus	Yes			Yes	Yes	Yes		Yes
An. gambiae s.s.	Yes			Yes		Yes	Yes	Yes
An. melas	Yes	Yes	Yes		Yes	Yes	Yes	Yes
An. merus	Yes	Yes	Yes		Yes	Yes	Yes	Yes
An. moucheti	Yes			Yes	Yes	Yes	Yes	Yes
An. nili s.l.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Malaria transmission

Malaria is transmitted when an adult female anopheline mosquito takes a blood meal from an infected human. The parasite gametocytes are ingested by the mosquito and reproduce in the gut, forming sporozoites that migrate to the salivary glands. When the mosquito takes a second blood meal, the sporozoites are injected into the human. These enter the liver, undergo further development, and subsequently enter the bloodstream and infect red blood cells. The infected red cells later burst, releasing parasites which infect other blood cells and produce the symptoms of malaria.

LSM reduces the overall density of adult vectors, reducing the human biting rate. It therefore can have an additive benefit in reducing malaria transmission when integrated with LLINs and/or IRS in certain settings.[8–10]

Annex 2: Larval mosquito surveys

With the aid of existing historical information about adult populations and current information from ongoing adult surveys, it is possible to design and carry out a programme of larval surveillance and larval source identification.

The information from larval surveys is of general use to a malaria control programme, not only for LSM. For example, it can help forecast the need for adult mosquito control, assess the effectiveness of adult control measures, help interpret adult mosquito surveillance data and detect insecticide resistance.

A thorough survey will, over time, provide a clear picture of where, when, and under what conditions larval development occurs. It will therefore be necessary to track rainfall, and in some situations, such as southern Africa during winter, temperature data during larval surveys. Other important data, depending on the situation, will include irrigation practices, river levels, and tides that may impact larval sources. Human activities such as construction, brick manufacturing, and well digging will also play a role. Soil type will determine how long areas remain flooded after rainfall or if surface water will develop from elevated water tables. As each local situation will be unique, the possibility of other sources should always be considered. Importantly, all accessible water bodies need to be searched for mosquitoes to ensure that all larval habitats are identified and can be treated.

To identify larval habitats, it is essential to check all possible sites, even those that are difficult to reach. Potential larval habitats include:

- Small rain pools, hoof prints, drains, and ditches, where the entire surface of the water should be examined.
- Streams, which should be searched at the edges where there is vegetation and where water moves more slowly.
- Ponds, lakes, swamps, and marshes where larvae usually occur in vegetation around the edges, but can sometimes be found far from the shore amongst floating vegetation.
- Special sites, such as wells, abandoned swimming pools and water containers made of cement, where the entire surface of the water should be examined.
- Drains in urban and peri-urban areas and alongside roads.

A larval survey. Source: S. Lindsay; University of Florida

Surveys of larval populations need to be conducted in a systematic manner so that all larval sources may be logged and categorised. Larval sources within a prescribed radius of the protected area also need to be characterised in terms of ecological triggers that support larval development. These data need to be organised collectively in an accessible format such as a computer database. If available, a geographic information system (GIS) should be used for this purpose since it allows the visualisation of the data and integration with databases from other entomological and epidemiological surveys.

Modern GIS techniques are very useful for data retrieval and information tracking, but are not essential to programme development. However, detailed maps and a clearly delineated system of numbering and logging larval data are very important. These data will be essential to making decisions about the feasibility of LSM in a particular setting and in planning and carrying out operations.

Knowledge of the ecology of the local vector species will aid in identifying larval sources. A brief description of selected larval habitats of malaria vectors is provided in Annex 1. This summary of information implies that general trends exist, but local conditions may be different and there is no substitute for a thorough local survey.

Dippers for larval surveys. Source: S. Lindsay; University of Florida

Larval sampling methods

Mosquito larvae can be sampled using various methods, but the most practical is the use of dippers.[11] Mosquito dippers of various shapes and sizes may be employed. A 'standard dipper' consists of a white plastic, metal, or porcelain cup attached to the end of a stick (see image at right). The cup usually has a capacity of 350 to 400 ml and has a drain spout for transferring the sample to collection vessels to return to the laboratory.

Staff employed in a larval survey using dippers should be trained in their proper use. An effort should be made to standardise their methods to keep data consistent. A standard number of dips should be taken per unit area. Often it is best to work in transects, taking one dip for a given number of steps. Potential larval habitats should be approached slowly and carefully and facing the sun, to avoid heavy footsteps or casting a shadow over or disturbing the water which may cause larvae to dive to the bottom. Larvae are generally found at the surface close to vegetation or floating debris and at the edges of larger and deeper water bodies. Dipping should be conducted close to floating debris and vegetation, on the windward siideof the habitat where larvae and pupae will be concentrated, and not during rainfall. Water bodies often constitute a variety of microhabitats (e.g., open water, under floating vegetation) containing different mosquito species. These should all be sampled to obtain an accurate picture of the species composition of the area.[12]

Source: Vincent Robert; Malaria Journal 2002

Anopheles larvae are generally best collected using the 'shallow skim' approach. The dipper is tilted by 45 degrees and its leading edge submerged two centimetres below the water surface. The dipper is moved quickly but gently in a straight line until the dipper is full but not overflowing.[12]

Nets are also useful for collecting *Anopheles spp.* larvae and have been shown to be more efficient (see image at right), especially for collecting pupae.[13] However, for durability in routine operational use, dippers are generally preferred. Personnel will need basic training in recognition of mosquito genera in the larval stage. Most important is the ability to distinguish between *Anopheles*, *Culex*, and *Aedes* mosquitoes. More information on the differences between species is given in Annex 1.

Data on both habitat occupancy and larval density should be collected:

- Habitat occupancy: The presence or absence of larvae in a breeding site is determined by visual observation. If a habitat is positive (i.e., larvae are present), the next step is to determine larval density.
- Larval density: A number of dips should be taken from the habitat and the number of larvae collected should be counted. All the larvae present should be counted. The number of dips to be taken will depend on the size of the breeding site. A footprint or hoofprint is considered as one dip. For larger breeding sites such as borrow pits, it is recommended that one dip is taken per square metre of surface, up to a maximum of 30 dips.

  Other information collected should include: GPS coordinates of larval source, a site designator (number), habitat type, size of habitat, depth and vegetation type and density, and numbers of each larval instar collected per dip. A sample form for data recording is shown in Figure A6.

Figure A6: Example of larval inspection form

LARVAL INSPECTION FORM															
INSPECTOR NAME			HABITAT DETAILS				SAMPLING RESULTS								% VEGETATION COVER & TYPE
DATE							LARVAL STAGES PRESENT (YES/NO)					DIP COUNT (add # pupae)			
ZONE															
TIME	SOURCE NUMBER	LOCATION DESCRIPTION	LAT	LON	HABITAT TYPE	SQUARE METERS	L1	L2	L3	L4	PUPAE	# DIPS	# An	# Cx	
							An	Cx	An	Cx	An	Cx	An	Cx	

Annex 3: Larval surveillance forms and supervisor spot check forms

From *Larval source management – a supplementary measure for malaria vector control: An operational manual*.

Larval surveillance forms

The Urban Malaria Control Program, Dar es Salaam

Ward level mosquito larval habitat survey - Open habitats

Serial number of this form ______________________

Serial number on the map form ______________________

Ten cell unit identifier ______________________

Municipality:______________ Ward:______________ Mtaa/area:______________ 10-cell unit:______________ 10-cell leader:______________

Habitat codes:

1: Puddles&tire tracks
2: Swampy areas
3: Mangrove Swamp / Saltwater marsh
4: Drain/Ditch
5: Construction pits/foundations/man-made holes
6: Water storage container
7: Rice paddy
8: Matuta
9: Other agriculture
10: Stream/river bed
11: Pond
12: Other (describe below)

Plot ID	Habitat ID	Habitat type	Same habitat type from last visit? 1=Yes 2=No 3=First visit	Previous habitat type	Habitat description	House number	Wet?		Habitat perimeter			Plants				Water depth		Larval stage						Pupae		Comments
																		Anoph.			Culex					
							dry	Contains water	< 10 m	10-100 m	> 100 m	None	Short vegetation	Tall vegetation	Floating plants	< 0.5 m	> 0.5 m	Absent	Early	Late	Absent	Early	Late	Absent	Present	

CORP's signature:______________ ______ Date:____/____/____ Supervisor's signature:______________ Date of check :____/____/____

Ward level mosquito larval habitat survey - Closed habitats

Serial number of this form ____________________

Serial number on the map form ____________________

Ten cell unit identifier ____________________

Municipality:__________________ Ward:____________________ Mtaa/area:____________________ 10-cell unit:__________________ 10-cell leader:____________________

Habitat codes: 1 - Pit Latrine 2 - Soakage Pit 3 - Septic Tank 4 - Other__________________

Plot ID	House number	Habitat ID	Habitat type	Habitat description	Wet?		Condition of the latrine			Habitat perimeter			Water depth		Larval stage			Pupae		Comments
					dry	contains water	Good	Bad	Full	< 10 m	10-100 m	> 100 m	< 0.5 m	> 0.5 m	None	Early	Late	Present	Absent	

CORP's signature:________________ ________ Date:_______/_______/_________ Supervisor's signature:____________________ Date of check : _______/_______/_________

Municipal mosquito larval habitat spot check - Open habitats

Serial number of this form ____________________
Serial number on the map form ____________________
Ten cell unit identifier ____________________

Municipality:__________ Ward:__________ Mtaa/area:__________ 10-cell unit:__________ 10-cell leader:__________
GPS(UTM/WGS84): Northing__________ Easting__________ Date of CORP's data sheet:_____/_____/_____
Serial number on the map form__________

	Yes	No
Is there a map?		
Is the map accurate?		
Does map match city copy?		

Habitat codes:
1: Puddles/tire tracks
2: Swampy areas
3: Mangrove Swamp
4: Drain/Ditch
5: Construction pits/foundations/man-made holes
6: Water storage & any other man-made container
7: Rice paddy
8: Matuta
9: Other agriculture
10: Stream/river bed
11: Pond
12: Others (describe below)

Plot ID	House No.	Habitat ID	Habitat type	Is habitat type correct?	Correct habitat type	Habitat found by the CORPs? 1=Yes 2=No	Habitat Description	Wet?		Habitat perimeter			Plants				Water depth		Larval stage						Pupae		Comments
																			Anoph.			Culex					
								dry	contains water	< 10 m	10-100 m	> 100 m	None	Short vegetation	Tall vegetation	Floating plants	< 0.5 m	> 0.5 m	Absent	Early	Late	Absent	Early	Late	Absent	Present	

Inspector's signature:____________________ Date of check: _____/_____/_____
Municipal Coordinator's signature:____________________ Date of check: _____/_____/_____

Municipal mosquito larval habitat spot check - Closed habitats

Serial number of this form ____________________

Serial number on the map form ____________________

Ten cell unit identifier ____________________

Municipality:__________ Ward:__________ Mtaa/area:__________ 10-cell unit:__________ 10-cell leader:__________
GPS(UTM/WGS84): Northing __________ Easting__________

	Yes	No
Is there a map?		
Is the map accurate?		
Does map match city copy?		

Serial number on the map form__________

Habitat codes: 1 - Pit Latrine 2 - Soakage Pit 3 - Septic Tank 4 - Other__________

Plot ID	House No.	Habitat ID	Is habitat type correct?	Correct habitat type	Habitat found by the CORPs? 1=Yes 2=No	Habitat Description	Wet?		Condition of the latrine			Habitat perimeter			Water depth		Culicine stage			Pupae		Comments
							dry	contains water	Good	Bad	Full	< 10 m	10-100 m	> 10 m	< 0.5 m	> 0.5 m	None	Early	Late	Absent	Present	

Inspector's signature:__________ Date of check : ___/___/___ Municipal Coordinator's signature:__________ Date of check : ___/___/___

Annex 4: Habitat modification and manipulation

This annex addresses habitat modification methods for application to: impoundments, irrigation systems, and natural streams; land filling and grading; drainage; and the covering or screening of larval habitats.

For a full list of WHO references relevant to habitat modification and manipulation, case studies are available at http://www.who.int/heli/risks/vectors/vectordirectory/en/index1.html..

Habitat modification

Impoundments

Impoundments are water reservoirs stored behind dams; they are used for irrigation, drinking water, or hydroelectric power.

The construction of a dam will generally reduce mosquito breeding since small larval habitats become amalgamated into one large, deep reservoir which is generally not conducive to breeding, except where water is shallow at the margins or where there is floating vegetation that shields larvae.

A number of design features of dams and reservoirs can reduce the risk of malaria. Dams and reservoirs should ideally be sited away from human habitations. Reservoirs should be sited only where they will not contain a large area of shallow water, since shallow water will be associated with high evaporation rates and drying of the reservoir, potentially leaving behind shallow water conducive to larval habitats.

If possible, shallow bays should be deepened. If this is not feasible, then large shallow bays may be isolated using dikes and the land reclaimed through drainage. Small pools at reservoir margins must be drained and vegetation cleared from the sides. Reservoir margins should be as straight as possible to restrict their length. Seepage from the base of the dam should be addressed since this provides larval habitats and wastes water. Off-takes of greater size than normal from the reservoir can be used to rapidly reduce the water level, stranding larvae around its banks. The run-off from this can then be used to flush irrigation channels. Water level fluctuation and stream flushing are covered in the section on habitat manipulation.

Irrigation systems

Irrigation is the application of water to the ground to maintain soil moisture at levels required for crop production. Poor design of irrigation systems is often associated with larval habitats for malaria vectors, which can be avoided by good design.[3,5]

In general, the types of irrigation design least likely to facilitate vector breeding are localised sprinkler (trickle or drip) irrigation, sub-irrigation, and mechanised sprinkler irrigation. Furrow irrigation is generally preferable to flood irrigation.[5]

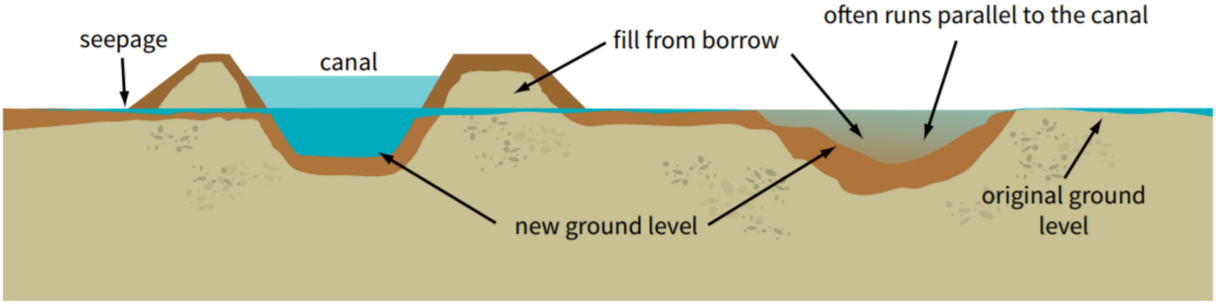
Open earth canals are often used to convey water but may be associated with problems such as seepage and vegetation growth. In addition, if water flow is too sluggish, this will encourage mosquito breeding, while water flowing too quickly will create turbulence, which erodes the canal, leading to silting downstream. Such problems can be avoided by lining irrigation canals with concrete, plastic, membranes (e.g., asphalt), or compressed earth. Lining canals has the following advantages:[5]

- Reduces seepage, which saves water and reduces the amount of standing water for mosquito breeding.
- Increases water flow, flushing aquatic stages away.
- Deters the growth of plants which provide shelter for some vectors.

The provision of stepping stones or bridges may encourage people and domestic cattle not to cross drainage channels or canals and produce hoof or foot prints which may become larval habitats.

To ensure that canals have a sufficiently high elevation to convey water to adjacent canals, their banks are sometimes built up using soil from borrow pits (Figure A7). This has the double disadvantage of encouraging seepage out of the canal, causing standing water to collect, and borrow pits may fill with water and become larval habitats. To avoid this, earth can be borrowed by stripping nearby land that lies at a relatively high elevation.[5]

Figure A7: Cross section of a typical conveyance canal.[5]



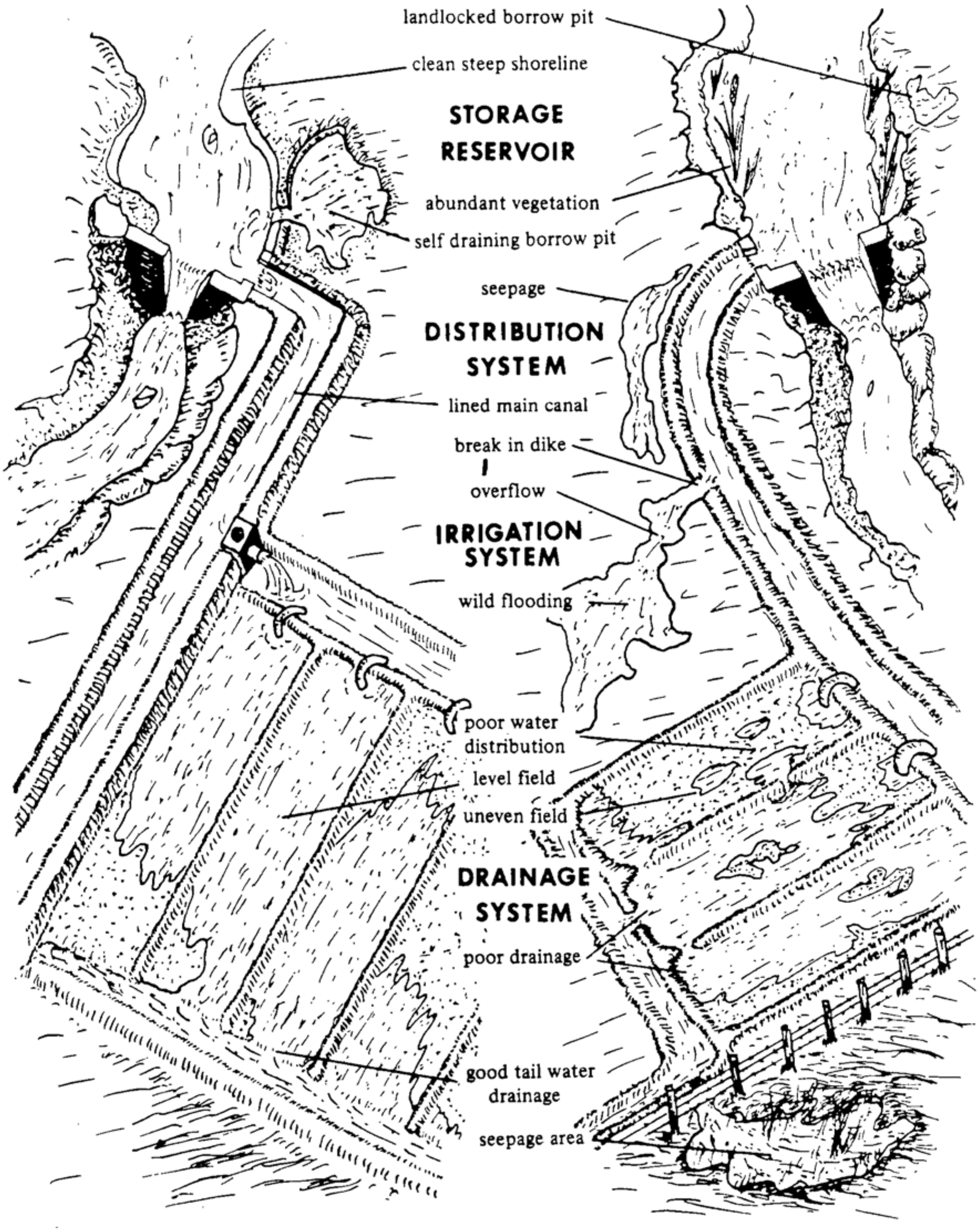
Underground pipes can replace open channels that are not accessible to adult mosquitoes, and have the added advantages of not being restricted by topography and not occupying arable land. A filter system may be required to prevent silt being carried into pipes.[5]
Irrigation based on land flooding is associated with a high risk of mosquito breeding. Two precautions can help address this (however they are not possible for uncontrolled, 'wild' flooding). Each flood period should not exceed the life of larvae (seven to ten days) and the area should be dried for at least one day afterwards. Also, the border strip should be frequently levelled to ensure there are there are no land depressions, which could fill with water.[5]

Summary of features that can make irrigation systems less conducive to vector breeding (Figure A8):

- Use of safer irrigation methods such as mechanised or localised sprinkler irrigation.
- Use of closed underground pipes rather than open canals to convey water.
- Canal lining.
- Good canal maintenance (e.g. clearance of vegetation so that water flows, or growing bushes over canals to provide shade).
- Intermittent irrigation and periodical drying.
- Canal flushing.
- Grading and levelling of the land to be irrigated.
- Good irrigation practice to prevent over-watering and water accumulating in pools.

Figure A8. Desirable features of irrigation systems.[5]

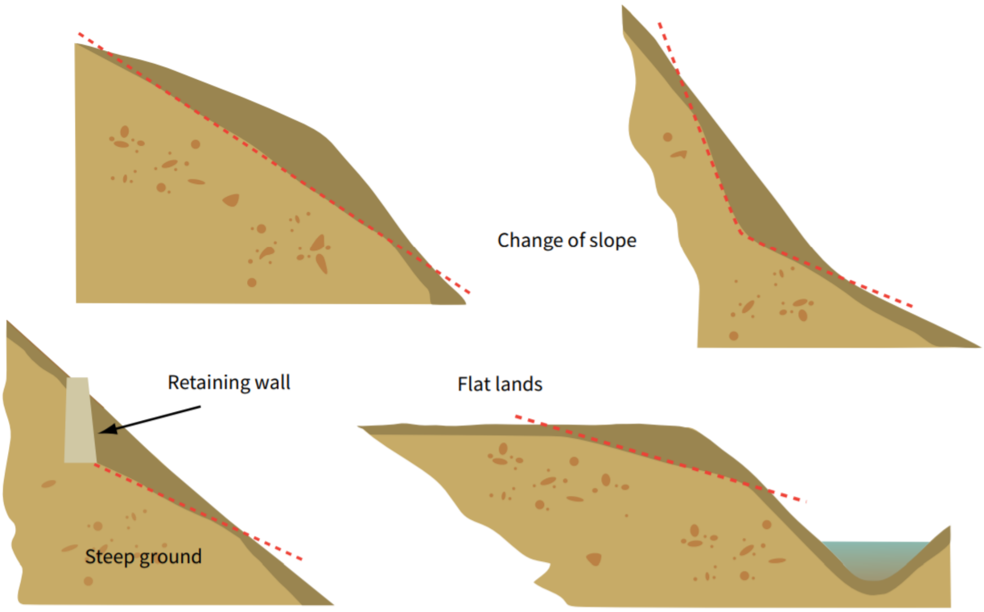
GOOD **BAD**



Natural streams
Backwater pools and isolated seepage pools associated with natural streams are often good larval habitats, in addition to the streams themselves if water flow is sufficiently slow. Channels can be straightened to increase water flow and to reduce bank erosion, floodway channels can be built to relieve natural streams from floodwater, or the central channel can be deepened. The sides of channels can also be strengthened, ideally with gabions (galvanised steel wire mesh cases filled with stones or rocks), which are most robust and flexible, or with solid revetments or retaining walls.[5]

Land filling and grading
Mosquito larval habitats such as abandoned ditches, ponds, or borrow pits can be permanently removed through filling with soil, rubble, stones, ash, or rubbish. No specialist expertise or equipment is required for small-scale works, which communities can conduct themselves. For large-scale works, tractors or diggers may be required. Caution must be taken to avoid creating new larval habitats when collecting filling material (Figure A7). Rubbish can be obtained through collaboration with industrial or public works ministries to save costs. If rubbish is used, it should be compacted and covered with earth to prevent fly breeding. Large areas can be also filled using environmentally safe waste from mining, harbour dredging, or demolitions.[3] Grading to smooth the topography and improve natural drainage is an alternative where the cost of filling is prohibitive or where there is insufficient filling material (Figure A9).

Figure A9: Obtaining soil for filling without creating larval habitats.[5]

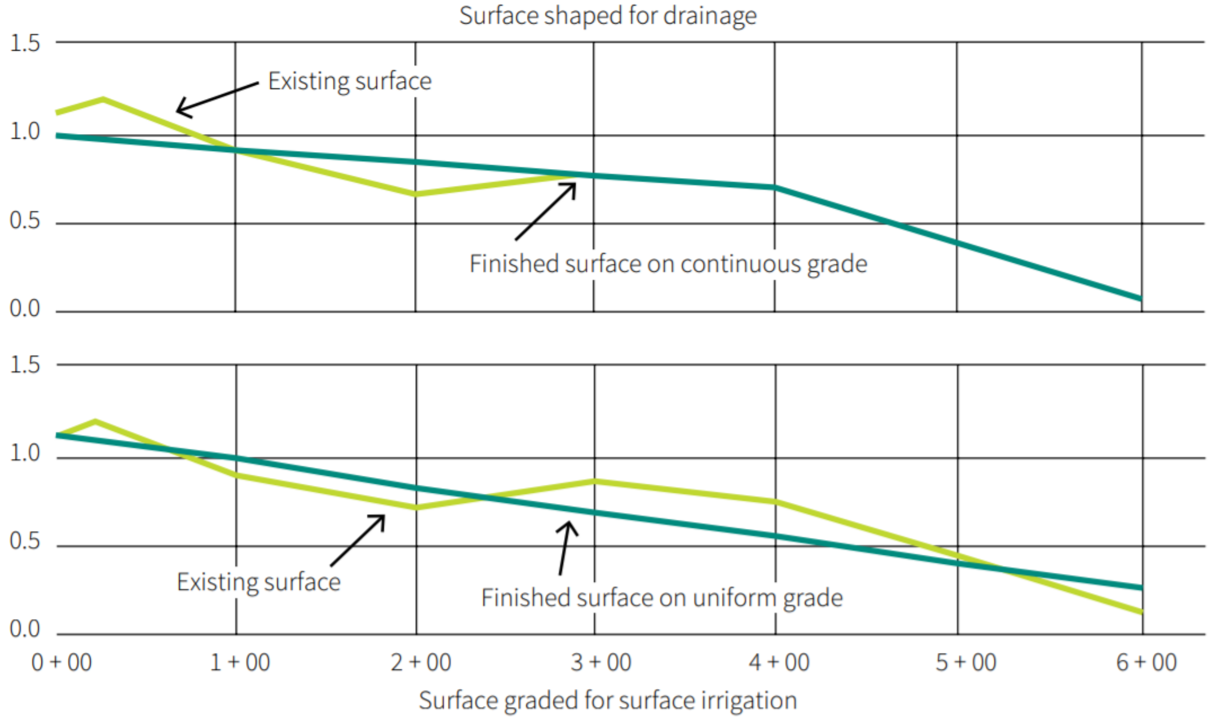


Drainage
Drainage is the removal of unwanted water on the surface or in the upper layers of soil (Figure A10). Good drainage will remove standing water and can be achieved by constructing open ditches with tidal gates, subsoil drainage and pumping.[3] However, if poorly designed and maintained, the drainage systems used to remove waste water in cities or for agriculture may be important sources of mosquitoes, especially if characterised by leaking, obstructions, or small pools of residual standing water.

Summary of features that make drainage systems less conducive to vector breeding:[5]

- Use of subsoil drains rather than open ditches.
- Lining of ditches.
- Good alignment of ditches and avoidance of curves.
- Ditch flushing and maintenance (see section on habitat manipulation).

Figure A10: Grading land for drainage and irrigation.[5]



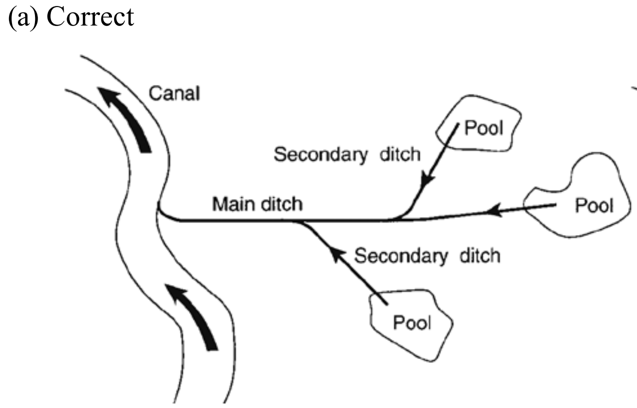
Not only can existing drainage systems be adapted to reduce vector breeding, but in certain settings close to human habitation it may be appropriate to construct new drainage systems specifically for mosquito control. In Zambia, drainage, filling, grading, and planting of eucalyptus trees (which dry the soil) was successfully used to control vectors in a public park.[15]

The design of drainage systems is complex and should be determined by topography, soil type, precipitation, height of the water table, seepage and salinity among other factors. Engineers may be required to help design large-scale drainage systems. However, smaller-scale systems can be constructed by non-specialists with simple equipment,[3,16] as described below.

Open ditches

Open earth ditches are simple to construct. They prevent excess rainwater accumulating on the ground, and drain pools, marshes, or borrow pits. Ditches have a similar structure to irrigation canals despite serving the opposite purpose. They should follow the natural water flow along the land surface to prevent pooling, and lead to a lower-lying outlet (e.g., river, pond, main ditch, or soakaway pit).[3] Ditches should be short and straight, avoiding sharp bends, to prevent erosion of their banks (Figure A11). Where lateral ditches enter the main ditch, the two water flows should meet at an angle of 30° to prevent erosion of the main ditch bank. The fewer the junctions between ditches the better, since these often become blocked, allowing mosquitoes to breed.[3]

Figure A11: Correct (a) and incorrect (b) drainage of pools.[3]



The layout of surface drainage systems is largely determined by the local topography and features such as roads or canals. Typical patterns of drainage systems are shown in Figure A12. Comb, grid-iron, and herringbone patterns are the most common layouts for flat, irrigated land.[5]

A gradient of 1–5 cm per 10 m should give the water enough velocity. Too high a gradient and velocity will lead to erosion of the ditch. The optimal cross-sectional shape of the ditch depends on the soil texture (e.g., vertical sides are appropriate for stiff clay, while sandy soils require ditch sides with a slope of 40 cm horizontally per 10 cm vertically). For most soil, a slope of 10 cm:10 cm or 20 cm:10 cm is acceptable.[3] The depth of the ditch should be at least 15 cm lower than the bottom of the water body being drained. Ditch excavation should begin at the downstream end and proceed uphill. Excavated earth can be used to fill in depressions in the ground. It should not be left too close to the ditch where it can be washed into the water, but should be set a little way back, creating a ‘spoil bank’. The spoil bank must be perforated to allow water to drain through (Figure A13).[3]

Lining ditches with concrete, brick, or stone will increase costs but will increase the water flow, reduce plant growth and the build-up of silt, and will be durable and therefore reduce maintenance costs. Lining of earth ditches is essential where rainfall is heavy. Stabilisation of banks may be required where the water flow is turbulent, especially where ditches meet. Ditches can be lined using flat stones with cement in between, or using a 4–5 cm thick layer of concrete strengthened with wire mesh. Pre-cast concrete slabs (Figure A14) can also be used with turf or concrete side-slabs laid above (Figure A15). Banks should always be kept clear of vegetation.[3]

Where the ditch narrows under a road or embankment via a culvert or pipe, a large gradient is required to prevent debris from accumulating (Figure A16). Culverts can be constructed from wood or concrete or, preferably, plastic or corrugated iron. Pipes can be made by cutting the bases off oil drums.[3]

Figure A12: Typical drainage system layouts.[5]

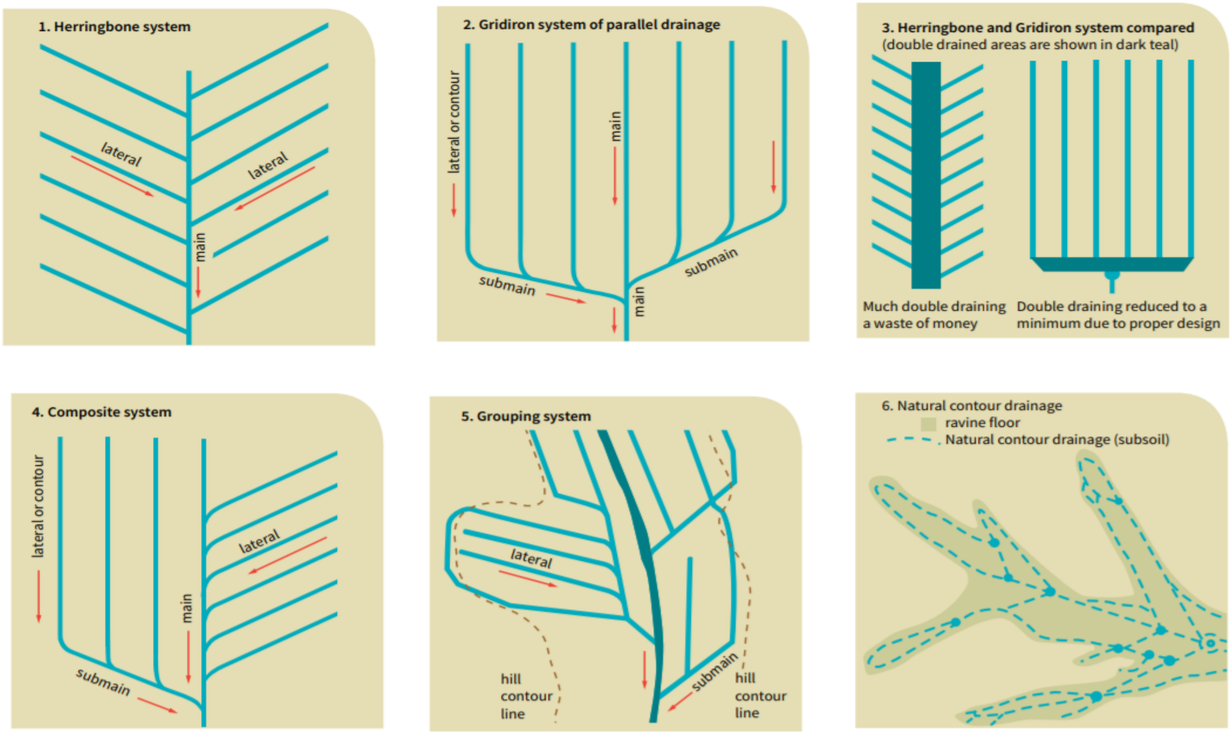


Figure A13: Location and design of spoil banks.[3]

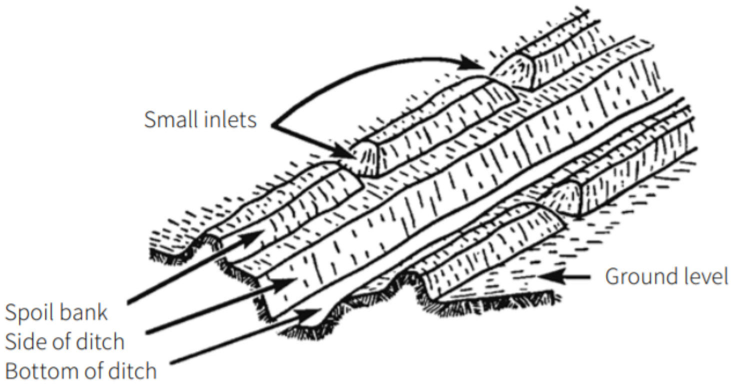


Figure A14: Pre-cast concrete slab for lining ditch.[3]

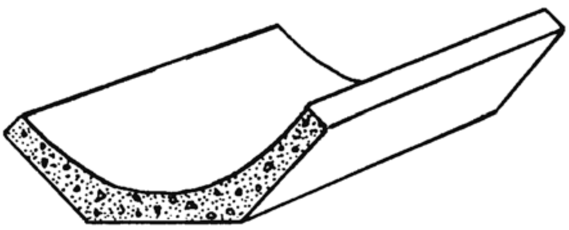


Figure A15: Ditch lined with pre-case concrete slabs and turf side slabs.[3]

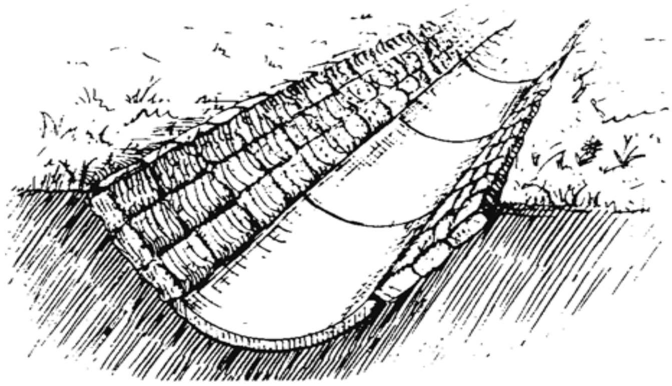
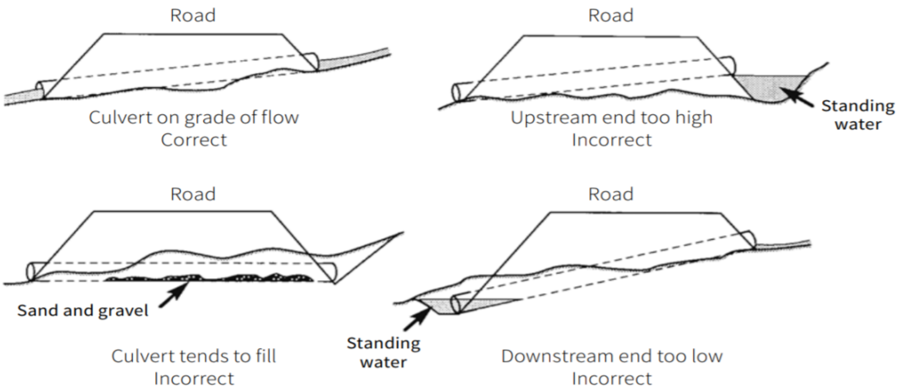


Figure A16: Culvert design.[3]

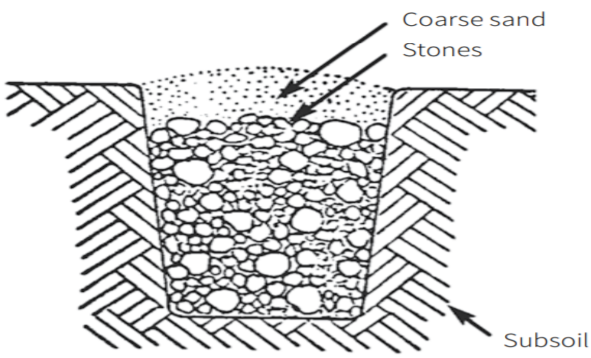


Subsoil drainage

Subsoil drainage is used where the land surface cannot be broken up by ditches or where earth is too unstable for open ditch construction. Expense limits its use in vector control. However, its advantages are that refuse or vegetation will not block the water flow, and the addition of larvicides or oils to prevent mosquito breeding is not necessary. Subsoil drainage is often used in irrigated areas and can also be used to lower the groundwater table to prevent collection of surface water.[3]

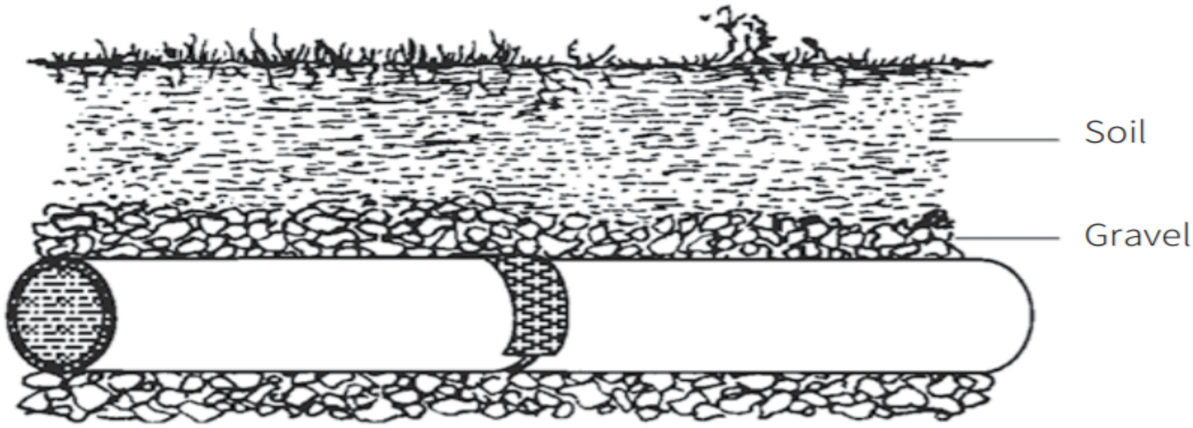
Subsoil drains can be most simply constructed by filling an open ditch with large stones which do not obstruct the water flow, and covering these with leaves, pine needles, or sand to prevent silt or clay accumulating at the bottom of the drain (Figure A17).[3]

Figure A17: Simple subsoil (French) drain.[7]



A more sophisticated subsoil drain can be constructed from ceramic tile pipes laid at the base of a ditch 0.5–2 m deep, in an exactly straight line (Figure A18). The joins between pipes are not sealed, allowing water to enter. Silting is reduced by covering the upper surface joins with rubbish, leaves or roofing paper. The ideal gradient is 1:200 to 1:400. Pipes will need to be protected if close to the surface, using small bridges.[3]

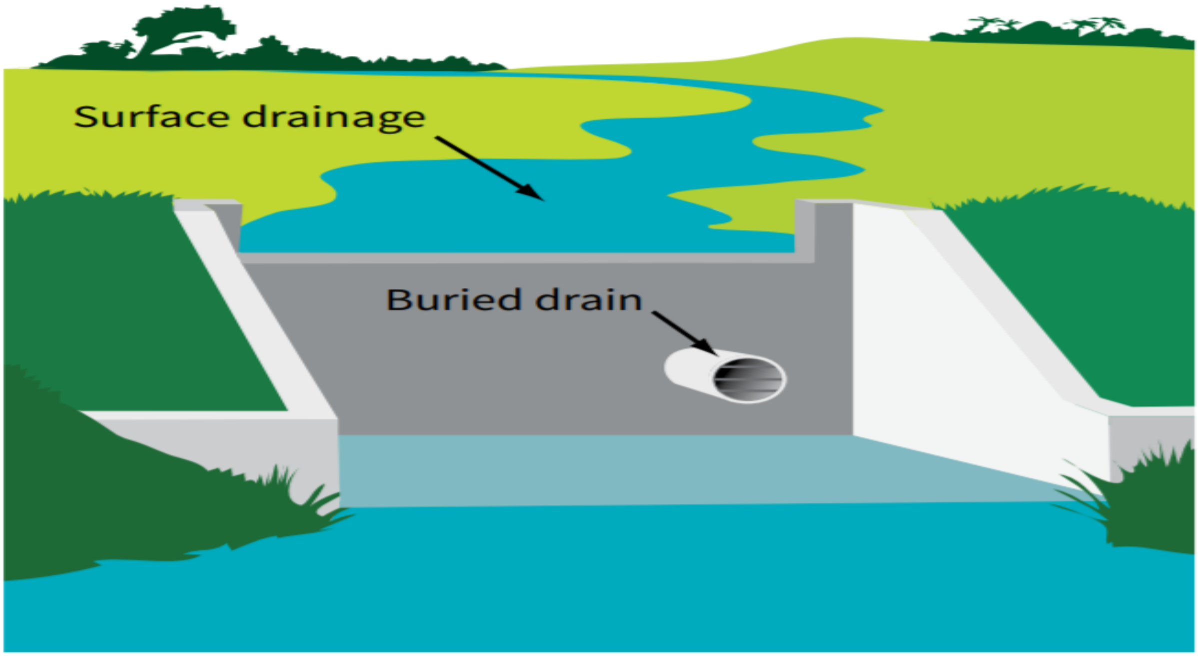
Figure A18: Subsoil (buried conduit) drain constructed from ceramic tile pipes.[3]



Mole drains can be constructed in cohesive soils, by drawing a bullet-shaped steel former welded to a sharp vertical blade through the soil using a tractor. Mole drains are not permanent and need frequent reforming, however they are effective, and easy and cheap to produce.[3]

If necessary, both subsoil and surface drainage can be combined (Figure A19). Pump drainage may also be used in some settings, for example where soil has high hydraulic conductivity and water is easily collected in wells these can be emptied by pumping. Alternatively, pumping may be necessary to dispose of water where the topography is not conducive to drainage to the point of disposal.[5]

Figure A19: Drop structure for surface drainage and outlet for subsoil drain.[5]



Vertical drainage
Where land is too flat to allow water to flow, and in silt or clay areas liable to flood, shafts can be constructed through impermeable strata if there are permeable bedrock strata below, to allow water to drain through. Shafts will remain effective for longer if protected by casing or filled with stones, gravel, and coarse sand.[5]

The 'Lido system'
Where drainage is difficult due to an abundance of vegetation, deepening the water body can prevent plant growth. Banks can be steepened and larvivorous fish introduced to control the larval population.[16]

Eucalyptus trees
Marshy areas and land with a high water table can be drained by planting eucalyptus trees, the leaves of which allow water to evaporate rapidly.

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