

Operational manual on larval source management

Control of *Anopheles* and *Aedes*
mosquito vectors



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Abbreviations

Bs	<i>Bacillus sphaericus</i>
Bti	<i>Bacillus thuringiensis var. israelensis</i>
CMC	community mosquito collector
CVCT	community vector control technician
DDT	dichlorodiphenyltrichloroethane
GIS	geographic information system
IGR	insect growth regulator
IRS	indoor residual spraying
ITN	insecticide-treated net
IVM	integrated vector management
LC	lethal concentration
LSM	larval source management
LV	low volume
M&E	monitoring and evaluation
PMI	U.S. President's Malaria Initiative
SOP	standard operating procedure
ULV	ultra low volume
USAID	United States Agency for International Development
WG	water-dispersible granule
WHO	World Health Organization

Glossary

The definitions given below apply to the terms as used in this document; they may have different meanings in different contexts. Some definitions listed have been taken or adapted from other World Health Organization guidance, which may be subject to amendment (1–3).

Note that the definition of larval source management has been adapted for this manual to consider both *Anopheles* and *Aedes* vectors. It differs from the definition of larval source management used in the *WHO guidelines for malaria*.

aquatic habitat	Site where immature development stages of mosquitoes (eggs, larvae and pupae) are found or that appears to be ecologically suitable for particular species Note: This preferred term is synonymous with “breeding site”, “larval site” and “immature habitat”.
biological control	One type of larval source management that involves the introduction of natural agents into specific water bodies, e.g., predatory fish, predatory invertebrates, parasites, competitors and other disease-causing organisms
container and waste management	One type of larval source management that involves elimination or alteration of containers that are not naturally occurring, e.g., by cleaning, scrubbing, covering, destroying, disposing of, recycling, emptying, inverting, moving, filling in and improving water supply
entomological surveillance	The regular, systematic collection, analysis and interpretation of entomological data for risk assessment, planning, implementation, monitoring and evaluation of vector control interventions Note: For larval source management, this may include measures of vector aquatic habitats, immature and adult bionomics and behaviours, and insecticide susceptibility.
environmental (habitat) manipulation	One type of larval source management that involves a recurrent activity to make temporary alterations to the environment that disrupt vector development, e.g., manipulating water level (stream flushing, drain clearance), increasing salinity, shading or exposing habitats to the sun
environmental (habitat) modification	One type of larval source management that involves a permanent or long-term alteration to the environment to eliminate larval habitats, e.g., surface water drainage, filling in, landscaping or land reclamation
evaluation	The episodic assessment of any change in targeted results that may be attributed to the programme, project or intervention. It aims to link a particular output or outcome directly to a programme, project or intervention after a certain period of time.
formulation	The combination of various ingredients (insecticide active ingredient, formulants, additives, emulsifiers, etc.) designed to render the product useful and effective for the purpose claimed and for the envisaged method of application
immatures	Egg, larva and pupa stages of the mosquito life cycle
insecticide resistance	Property of mosquitoes to survive exposure to a standard dose of insecticide; may be the result of physiological or behavioural adaptation

integrated vector management	<p>Rational decision-making process for the optimal use of resources for vector control</p> <p>Note: The aim is to improve the efficacy, cost-effectiveness, ecological soundness and sustainability of vector control activities against vector-borne diseases.</p>
key habitats	<p>Types of containers or water bodies that sustain the most immatures and are expected to produce the greatest number of adult vectors</p> <p>Note: This considers average adult productivity and number of habitats of the type, and usually relies on counts or estimates of late instars or pupae as a proxy. Key habitats are defined for a specific area, as proximity to human habitation is an important consideration.</p>
larval source management	<p>The management of water receptacles or water bodies that are potential or actual habitats for mosquito immatures (eggs, larvae, pupae) to prevent the production of adult mosquitoes by stopping water accumulation, preventing oviposition or egg-hatching, reducing immature densities or otherwise preventing their development into adult mosquitoes</p> <p>Note: In the context of this document, this includes source reduction (container and waste management, environmental modification, environmental manipulation) and source treatment (larviciding, biological control, other).</p>
larvicide	<p>Substance used to kill mosquito larvae</p> <p>Note: In the context of this document, this includes chemical or biological formulations developed for intentional application.</p>
larviciding	<p>One type of larval source management that involves periodic and often repeat application of biological or chemical insecticides in appropriate water bodies</p> <p>Note: The timing of larvicide application is usually based on either detection of immatures or historical or ecological information indicating a high likelihood of production of adult mosquitoes.</p>
monitoring	<p>The routine tracking of key elements of programme/project performance (usually inputs and outputs) through record keeping, regular reporting and surveillance systems</p>
source reduction	<p>Any measure that aims to prevent the proliferation of mosquitoes or alter or eliminate their aquatic habitats. This includes environmental modification, environmental manipulation and other actions for container and waste management, such as destruction, disposal, emptying, cleaning, filling, draining, modifying or otherwise preventing water accumulation in artificial or natural containers.</p> <p>Note: If such measures are long-lasting or permanent changes in land, water or vegetation, they are often referred to as environmental modification. When such measures have a temporary effect and need to be repeated, they are known as environmental manipulation.</p>
source treatment	<p>A broad category of larval source management that includes larviciding, biological control such as larvivorous fish, and other methods</p>
vector	<p>An insect that transmits a pathogen from one organism to another</p> <p>Note: In the context of this document, this term applies to arthropod insects of the genera <i>Aedes</i> and <i>Anopheles</i>.</p>

vector control	Measures of any kind against pathogen-transmitting vectors, intended to limit their ability to transmit the pathogen to humans Note: Ideally, vector control results in reduction of transmission rates by reducing the vectorial capacity to a point at which transmission is interrupted.
vector density	The number of female insects in terms of any collection unit (e.g., per hour, per trap, per house, etc.)
vectorial capacity	The number of new infections that the population of a given vector would induce per case per day at a given place and time, assuming that the human population is and remains fully susceptible to the disease

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1. Introduction

This operational manual is designed to guide the establishment, management, implementation, reporting and evaluation of safe and effective larval source management (LSM) campaigns and activities within the context of a locally adapted and sustainable vector-borne disease control programme. Earlier versions of this document focused on LSM against *Anopheles* vectors for the prevention and control of malaria (1–3). In 2025, the document was extended to include guidance on LSM for *Aedes* vectors to underscore that LSM can potentially impact multiple vector species and vector-borne diseases and to align with the *Global vector control response 2017–2030* (4). Updates were also made to reflect current World Health Organization (WHO) recommendations, standards and best practices for LSM.

Revisions were based on advice from a working group of external experts that met remotely to deliberate on required updates and to review document drafts. Deliberations were informed by an informal online opinion survey held by the WHO Global Malaria Programme (now the Department of Malaria and Neglected Tropical Diseases) in March 2024. The 80 respondents to this survey were technical experts in the field who were given access to the survey through postlists of the WHO Joint Action Group on the Global Vector Control Response and the RBM Partnership to End Malaria Vector Control Working Group. Some content for this revised version was drawn from materials provided by the United States Agency for International Development/United States President’s Malaria Initiative/Abt Associates (5). The case studies in Annex 1 were provided by the RBM Partnership Vector Control Working Group.

This is the first attempt by WHO to expand its guidance on LSM to other vectors beyond malaria, having already conducted a similar exercise for guidance on indoor residual spraying (IRS) (6). The focus on routine LSM operations as a component of national or subnational vector-borne disease control programmes in rural areas has been retained. However, guidance has been added on urban mosquito control in integrated programmes, in line with the *Global framework for the response to malaria in urban areas* (7). Updates have also been made to reflect the current disease situation, including biological threats to effective vector control, and to incorporate knowledge on new tools, technologies, strategies and approaches that have become available since the last update. It is expected that later iterations of this document will incorporate further consideration of these new options and subsequent experiences with urban mosquito control targeting both *Anopheles* and *Aedes* vectors.

This manual forms a companion document to the *WHO guidelines for malaria* (8) and draws on content from the *Manual for surveillance and control of Aedes vectors in the Pacific* (9), *Technical document for the implementation of interventions based on generic operational scenarios for Aedes aegypti control* (10) and *Vector control operations framework for Zika virus* (11). Companion documents such as this manual are made available in electronic form to enable rapid update as soon as warranted by new WHO recommendations.

This manual is divided into five key chapters. The first chapter introduces the concepts of LSM and the purpose of the manual. The second outlines the requirements for establishing and managing an LSM programme. The third details how to plan and prepare for LSM, and the fourth details the operational aspects of how to conduct LSM. The fifth highlights the importance of monitoring and evaluation (M&E) for LSM activities and its key components. Useful resources are available in the references, with case studies (Annex 1), generic forms (Annex 2) and additional tools (Annex 3) available in the annexes.

The information provided can support:

- development or refinement of national LSM strategies;
- development or update of LSM operational guidelines and procedures;
- development or update of training materials;
- assessment of the delivery and coverage of LSM operations; and
- assessment of the implementation quality and impact of LSM operations.

The key audience for this document is, therefore, vector-borne disease control programme managers and staff, and implementing and private-sector partners at the national, provincial, state and local levels, who are responsible for the design, planning, implementation, monitoring and evaluation of vector control operations.

1.1 Background on LSM

Vector control is a key intervention for the prevention of a range of vector-borne diseases (4), including those transmitted by mosquitoes of the *Anopheles* and *Aedes* genera. These include malaria, dengue, chikungunya, yellow fever and Zika virus disease.

Much of the decrease in the global malaria burden since 2000 was achieved through the scale-up of interventions against malaria vectors, particularly the use of insecticide-treated nets (ITNs) and IRS (12). However, changes in *Anopheles* malaria vectors are undermining this progress. There have been alarming increases in the prevalence and intensity of insecticide resistance and shifts in species composition to vectors that prefer biting outdoors or earlier in the evening. A further threat in Africa is posed by *Anopheles stephensi*, an efficient malaria vector with the capacity to thrive in urban settings, adapt to new habitats and invade new territories. Following its first detection in Djibouti in 2012, this species has since been reported in additional countries on the African continent (13). Such changes in malaria vector populations have precipitated a “gap” in the effective protection offered by ITNs and IRS, which have been the mainstays of malaria vector control for decades.

Aedes-borne diseases have posed a significant threat to human health in recent years. Dengue is now the most prevalent mosquito-borne disease globally, with about half of the world’s population at risk (14). Chikungunya transmission is ongoing in Africa, Asia and the Americas, with outbreaks in other regions, and Zika virus disease persists in some areas of the world. There is no specific treatment for these diseases, and the main preventive measure is vector control. One vaccine against dengue is available and licensed in some countries, but it is recommended only for those aged 6–16 years in high transmission settings. Several additional dengue vaccines are under evaluation (14). Even for vaccine-preventable yellow fever, epidemics occur in Africa and the Americas, and vector control remains an important preventive measure. However, control of *Aedes* mosquitoes can be challenging. Most known vector species bite predominantly during daylight hours when people are away from their homes or outside; consequently, IRS and ITNs are less efficient against these vectors and are not broadly recommended. Insecticide resistance is also a concern, and *Aedes* species can sustain viral transmission even when adult mosquito numbers are low.

Interventions targeting the larval stages of *Anopheles* and *Aedes* mosquitoes in their aquatic habitats have been used effectively for more than a century. Until the 1950s, LSM was the primary method of malaria control. For example, the Tennessee Valley Authority in the United States of America used environmental management to control malaria in the early 20th century (15, 16), and engineering works such as filling, draining and clearing bodies of water were used to control malaria and dengue to protect the workers constructing the Panama Canal (17). Larviciding with Paris Green¹ was the main approach used to eliminate *An. gambiae s.l.* from Brazil by 1940 following its introduction in the late 1920s (18), and from Egypt by 1945 following its introduction in the 1940s (19). The Global Malaria Eradication Programme used larval control alongside IRS using dichlorodiphenyltrichloroethane (DDT) and other residual insecticides and antimalarial medicines to successfully eliminate malaria from large parts of the world between 1955 and 1967, particularly those areas with more temperate climates and seasonal transmission (20, 21). After the introduction of IRS with DDT in the 1950s and ITNs in the 1990s, LSM became less common in Africa, and it was not applied systematically on a wide scale. However, more recent examples from Burkina Faso, Ethiopia and the United Republic of Tanzania indicate that LSM can be used to reduce vector densities and malaria (22–24). Nearly all countries that have eliminated malaria have used some form of LSM (25).

In the 1950s and 1960s, container inspections, oiling of aquatic habitats and later perifocal spraying of DDT in water containers and on nearby walls in Latin America led to elimination of *Ae. aegypti* from large parts of the region (26). Entomological surveillance and larval source reduction were effective in maintaining low dengue incidence in Singapore for over three decades (27), although outbreaks occurred later. Larviciding in water reservoirs is an essential component of most national programmes in the Americas (10). LSM has been applied against *Aedes* vectors at the local and community levels in many parts of the tropics.

There has been renewed interest in LSM, particularly for use in areas where there is resistance to the insecticides commonly used for ITNs or IRS, where outdoor or early evening biting by malaria vectors is a problem, and where container-inhabiting mosquitoes such as *An. stephensi* and *Ae. aegypti* are a major threat. However, there has been limited epidemiological evidence on the impact of LSM on malaria or *Aedes*-borne diseases transmission and burden.

For malaria, a 2022 systematic review on aquatic habitat modification and/or manipulation identified only two studies with epidemiological outcomes. These investigated the release of water from flood gates of dams or spillways (overflow channels) across streams to flush downstream areas with water, but the evidence was deemed of very low certainty (28). Additional studies with entomological outcomes for a wide range of highly heterogeneous habitat manipulation or modification interventions, many in specific ecologies, indicated that the potential impact, feasibility, acceptability and resource needs of each intervention are likely to be highly variable (28). A 2019 systematic review on larvivorous fish found no studies reporting epidemiological outcomes. While there was no clear evidence of an effect on *Anopheles* larval densities, there was some indication of reductions in the number of habitats positive for larvae due to larvivorous fish (29).

1 Paris Green is the common name for copper acetoarsenite, a highly toxic emerald green crystalline powder. It was a popular pesticide from the late 19th century and remained commonly employed on fruit in the United States of America until the 1970s. For *Anopheles* larval control, a floating dust formulation was used extensively throughout the 1940s, including in Brazil, Egypt and Sardinia, Italy. Paris Green has since been replaced by synthetic larvicides that have a greater margin of safety.

For larviciding against *Anopheles*, a 2019 systematic review found that the certainty of evidence of impact on malaria incidence or parasite prevalence was low for habitats less than 1 km² and was very low for larger habitats (30). This finding informed the development of a conditional WHO recommendation for larviciding in specific areas with ongoing malaria transmission where larval aquatic habitats are limited in number, are permanent or semi-permanent, and can be readily identified and accessed – in other words, habitats are considered “few, fixed and findable” (8). WHO further acknowledges that while larviciding may reduce vector densities, it does not have the same potential for health impact as ITNs and IRS – both of which reduce vector longevity (a key determinant of transmission intensity) and provide protection from biting vectors. As a result, larviciding should never be seen as a substitute for ITNs or IRS in areas with significant malaria risk (8). Resources should not be diverted from ITNs or IRS for larviciding in such settings, although larviciding could be added should resources permit.

Recent evidence found that combined use of ITNs and larviciding with *Bacillus thuringiensis* var. *israelensis* (Bti) significantly reduced the incidence of malaria in Côte d'Ivoire (31). In certain settings where ITNs and IRS are less effective or not practical, such as in humanitarian emergencies where shelter types are not amenable to spraying or the hanging of nets, LSM could be given special consideration as the main vector control intervention (32). Likewise, in rural settings with early- or outdoor-biting malaria vectors, LSM may be more appropriate than IRS or ITNs. Further examples are outlined in section 1.4.5 on exceptional settings or circumstances.

There is currently no formal WHO guideline in place providing recommendations on vector control for *Aedes*-borne diseases, although as of November 2025 this is being formulated. A recent systematic review and meta-analysis of entomological and dengue epidemiological outcomes found that interventions at the household level against immature *Aedes* stages performed similarly to those against both immature and adult stages, but that interventions against adults alone performed less well (33). Larval source reduction supported by community involvement was found to reduce larval and pupal indices in four of seven included studies, with no significant reduction in the three remaining studies. Aquatic predators – including *Toxorhynchites* larvae, dragonfly nymphs, larvivorous fish and copepods – were found to reduce vector populations in nine of 10 studies. Combined source reduction and larviciding with Bti led to significant reductions in *Ae. aegypti* immature populations, particularly pupae, in Myanmar (34). Chemical larviciding with pyriproxyfen alone or in combination with other interventions had positive outcomes against *Aedes* larvae in four studies, with evidence of a reduction in new dengue infections in volunteers in one of these studies (35). Wide area spraying with Bti has been used in Florida, United States of America, to suppress *Ae. aegypti* populations and avert local arboviral transmission (36, 37), with similar observations in Sarawak, Malaysia (38).

Overall, the epidemiological evidence on the impact of LSM on malaria and *Aedes*-borne diseases is not definitive. Although there are well documented accounts of successful LSM programmes, there are also examples of LSM failing to have an epidemiological impact when the intervention was applied suboptimally or applied in inappropriate ecological settings, resulting in a waste of resources. Nevertheless, a recent review concluded that the available evidence is sufficient to establish a link between LSM approaches and reduced disease transmission of mosquito-borne illnesses (25).

LSM can be a complex undertaking that requires a good understanding of vector ecology to inform the design and implementation of appropriate strategies. Well-designed community sensitization and engagement initiatives are also required to ensure that communities understand the link between mosquitoes and disease and

desire interventions, and that any concerns about ethical, health and safety aspects – such as the application of larvicides to drinking water or other domestic water sources – are addressed. Employment of the local workforce to foster ownership and leadership is also key to sustaining LSM implementation (25). Efforts to engage communities in LSM can act in concert with regulatory or legislative actions to support vector control, such as through property access for source reduction and larvicide application.

Involvement of multiple partners within and outside the health sector will also be essential to ensure an integrated approach to vector management, especially in urban areas, for the streamlined control of dengue and malaria vectors that may cohabit, such as *An. stephensi* and *Ae. aegypti*. Promising new tools against different stages of both *Anopheles* and *Aedes* vectors are on the horizon that will provide further options for control of these diseases.

Numerous countries, programmes and partners are currently implementing or planning to implement LSM and may benefit from information to improve the impact of operations. This manual therefore aims to assist programme managers in deciding where and how LSM should and should not be applied. It is designed to inform the planning and implementation of LSM programmes and activities by presenting the range of strategies, interventions and designs that may be considered at the national, community or household level. WHO will continue to work with Member States to ensure that LSM is integrated as part of a broader approach to prevent, control and eliminate malaria and *Aedes*-borne diseases.

1.2 Purpose and definition of LSM

Female *Anopheles* and *Aedes* adult mosquitoes can transmit pathogens to humans that cause malaria, dengue, chikungunya, yellow fever and Zika virus disease. The life cycle of mosquitoes has four stages: egg, larva, pupa and adult. Mosquitoes in the first three stages are called “immatures”. Eggs are laid on the water–air interface. Larvae then hatch into the water and progress through four larval instars to the pupal stage. Adult mosquitoes emerge from water and the females seek a blood meal to support egg maturation. Pathogens are transmitted during the process when the mosquito extracts blood from a human. The mosquito imbibes pathogens from an infected person and, following incubation and egg laying, it may inject the parasites or virus into another person as it seeks its next blood meal. In some *Aedes* species, the adult female can pass the virus to her eggs; the virus may remain viable as the eggs hatch and develop into infective adult mosquitoes.

LSM in the context of malaria control involves managing water bodies that are potential aquatic habitats for mosquitoes to disrupt the development of the immature stages (eggs, larvae and pupae) and thus prevent the production of adult mosquitoes, with the overall aim of preventing or controlling transmission of malaria (8). However, this definition mainly considers interventions targeting naturally occurring aquatic habitats (water bodies) and not those addressing artificial water containers and waste. In some parts of the world, a variety of receptacles found in and around homes in rural and urban settings are important habitats for malaria vectors such as *An. stephensi* and *Aedes* vectors such as *Ae. aegypti*. These include common peri-domestic containers such as flower vases, cement water tanks, discarded tires and roof gutters that accumulate rainwater. Elimination of such habitats through a variety of methods is often a first step in any campaign against container-inhabiting immature vectors.

Therefore, for the purpose of this manual, an adapted definition of LSM is adopted to include container and waste management in the types of LSM (Box 1).

Box 1. Adapted definition of LSM

The management of water receptacles or water bodies that are potential or actual habitats for mosquito immatures (eggs, larvae, pupae) to prevent the production of adult mosquitoes by:

- stopping water accumulation;
- preventing oviposition or egg hatching;
- reducing immature densities; or
- otherwise preventing the development of immatures into adult mosquitoes.

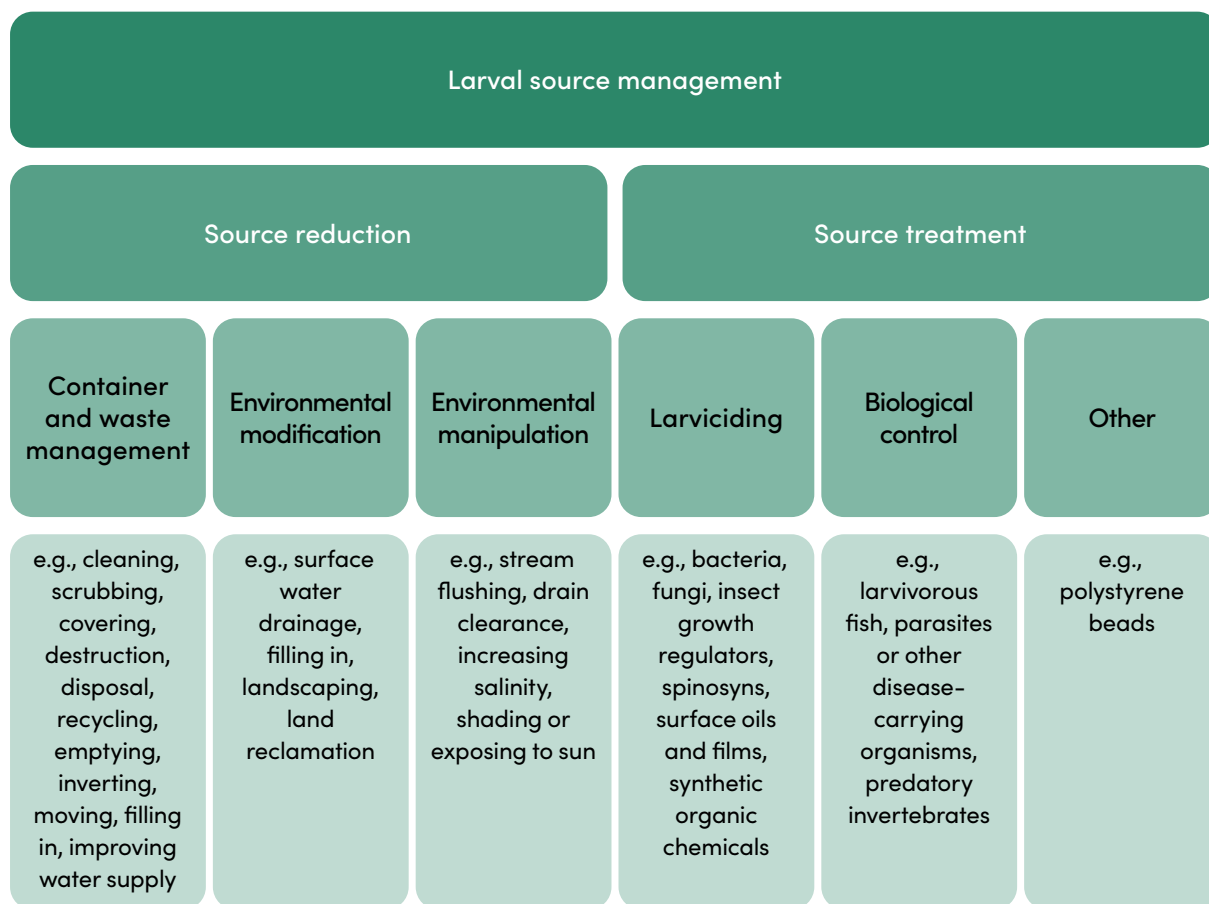
The effective elimination or treatment of all potential aquatic habitats could be expected to reduce the number of infective bites on humans and thereby prevent or reduce pathogen transmission (39). Intervention options and operational modalities are therefore critical considerations for LSM. Management of all aquatic habitats can be a cost-effective and long-term solution in certain settings (40–42). However, feasibility and effectiveness are highly variable depending on the setting. For instance, it is resource-intensive and difficult to access and treat all natural habitats of *Anopheles* vectors in rural areas using ground teams, whereas it is easier to carry out source reduction for *Aedes* vectors in urban areas where habitats are more easily accessible. New options for locating and treating habitats – such as with remote sensing potentially combined with artificial intelligence or drones – provide a substantial opportunity to improve the efficiency of LSM (43).

1.3 Types of LSM

LSM, as defined in the context of control of *Anopheles* malaria vectors, includes four broad types: habitat (environmental) modification, habitat (environmental) manipulation, larviciding and biological control (8). To incorporate the variety of methods used to control *Aedes* immature vectors, a fifth type is also relevant: container and waste management.

The five types of LSM can generally be categorized as either source reduction or source treatment (see Fig. 1). Effectiveness and feasibility will depend on the vectors targeted and the socio-ecological setting, among other factors.

Fig. 1. Schematic representing classification of different groupings, types and examples of LSM



Source reduction aims to eliminate immature habitats, prevent egg laying or hatching, or disrupt immature development through:

- container and waste management: elimination or alteration of water receptacles that are not naturally occurring;
- environmental modification: permanent or long-term alterations to the environment to eliminate aquatic habitats; and
- environmental manipulation: recurrent activity to make temporary alterations to the environment that disrupt vector development.

Source treatment aims to disrupt immature development through:

- larviciding: application of biological or chemical insecticides to water bodies;
- biological control: introduction of natural enemies of mosquito immatures into water bodies; and
- other methods, including physical or mechanical approaches that disrupt mosquito development.

Other options, such as mechanical devices to disrupt and kill immatures, have been explored, but there is limited information available on their wide-scale application in public health. The latest WHO recommendations (8) and WHO list of prequalified vector control products (44) should be referred to for any updates.

Examples of each type of LSM are provided in Table 1, with details in Chapter 4.

Table 1. Types of LSM for *Anopheles* and *Aedes* control and examples

Type	Includes	Examples
Source reduction		
Container and waste management	Cleaning or scrubbing	Scrubbing inner surfaces of drums, tanks and other containers to remove mosquito eggs and biofilm that supports larval development
	Covering	Applying tight-fitting lids, insect-proof mesh or modified tank inlets to prevent mosquito oviposition
	Destruction, disposal or recycling	Disposing of unused containers, drilling holes in tires before recycling, and removing or repurposing containers that collect rainwater
	Emptying, inverting or moving	Turning over buckets, regularly emptying plant saucers and relocating drums under shelter to prevent rainwater accumulation
	Filling in	Filling abandoned domestic wells or pits with sand or soil to eliminate stagnant water collection
Environmental modification	Improving water supply	Installing piped water, covered tanks or closed water supply systems to reduce household reliance on open containers
	Improving surface water drainage	Constructing or rehabilitating open or closed drainage systems to remove standing water from urban or agricultural areas
	Filling in	Filling borrow pits, puddles or shallow depressions with soil or construction waste
	Landscaping	Regrading land surfaces to promote runoff, eliminating surface pooling following rainfall
Environmental manipulation	Land reclamation	Converting swamps or marshland to agriculture or development, thereby eliminating mosquito aquatic habitats
	Water-level manipulation	Using intermittent irrigation in rice fields; flushing channels, drains or streams periodically to disrupt immature development
	Shading or exposing to sun	Planting trees around containers or water bodies to reduce sunlight exposure, or cutting back vegetation to increase sunlight and reduce algal mats
	Increasing salinity	Diverting seawater into brackish lagoons or coastal ditches to increase salinity and reduce freshwater mosquito larval survival
	Clearing aquatic vegetation or algal mats ^a	Manually or mechanically removing emergent and floating vegetation that provides shelter and food for mosquito larvae
	Straightening or steepening shorelines	Modifying the gradient of pond or stream banks to reduce stagnant water edge zones that serve as mosquito habitats

Table 1. Types of LSM for *Anopheles* and *Aedes* control and examples (cont.)

Type	Includes	Examples
Source treatment		
Biological control	Larvivorous fish	Introducing <i>Poecilia reticulata</i> (guppies) or <i>Gambusia affinis</i> into domestic wells, ponds or water storage containers
	Predatory invertebrates	Using <i>Mesocyclops</i> copepods in small domestic containers or discarded items such as tires to prey on mosquito larvae
	Parasites or other organisms	Deploying <i>Toxorhynchites</i> larvae (non-biting mosquitoes that prey on other larvae), or applying entomopathogenic fungi to habitats
Larviciding	Bacteria	Applying Bti or <i>Bacillus sphaericus</i> (Bs), which produce toxins lethal to mosquito larvae
	Fungi	Applying <i>Metarhizium anisopliae</i> or <i>Beauveria bassiana</i> fungi as formulated spores to infect and kill larvae
	Insect growth regulators (IGRs)	Using pyriproxyfen, methoprene or novaluron that inhibit adult emergence from pupae
	Spinosyns	Using spinosad-based products, derived from <i>Saccharopolyspora spinosa</i> , which act on nicotinic acetylcholine receptors causing larval death
	Surface oils and monomolecular films	Using silicone-based or oil-based films that form a thin layer on water surfaces to suffocate mosquito larvae and pupae
Other	Synthetic organic chemicals	Applying organophosphates such as temephos or pirimiphos-methyl to water bodies to kill mosquito larvae through neurotoxicity
	Expanded polystyrene beads	Using small, lightweight plastic spheres that float on the water surface and act as a physical barrier to suffocate mosquito larvae and pupae

^a May also include clearing of coconut husks or management of crab holes where these are key vector aquatic habitats

1.4 LSM for mosquito control

1.4.1 Integrated vector management (IVM)

Vector-borne disease control programmes are encouraged to adopt an approach that supports effective locally adapted sustainable vector control, as articulated in the *Global vector control response 2017–2030* (4). This approach builds on the basic concept of IVM (45–47), which seeks to improve the efficacy, cost-effectiveness and sustainability of disease–vector control through:

- a rational decision-making process for the selection of vector control methods and action thresholds based on knowledge of local vector biology and disease transmission;
- active surveillance of both adult and immature stages of vector populations;

- collaboration among the health sector, other private and public sectors, and local communities;
- rational use of insecticides for resistance management, human safety and protection of ecosystems; and
- good management and well trained staff.

The Global Vector Control Response provides a renewed focus on improving human capacity at national and subnational levels, emphasizes the need to strengthen infrastructure and systems, and promotes intersectoral and interdisciplinary action. It also draws critical attention to current opportunities and challenges that must be addressed to enable effective and sustainable vector control adapted to local contexts.

A good example is the use of intermittent irrigation in China, India, Indonesia and Sri Lanka, where, in combination with other vector control measures, this approach has reduced the incidence of both malaria and Japanese encephalitis, while reducing costs for farmers due to more efficient water use (48). In India, where *An. stephensi* and *Ae. aegypti* share some common container habitats, LSM and entomological surveillance target both vector species (49). Under the Indian Urban Malaria Scheme, LSM is conducted year-round to reduce the populations of dengue, filariasis and Japanese encephalitis vectors in addition to malaria vectors (50). A synthesis of data from Latin America and the Caribbean indicated that the most effective approach for mitigating *Aedes*-borne infectious diseases was IVM employing multiple interventions, including LSM with community participation (51, 52).

LSM can contribute to the overall effectiveness of vector control and reduce vector-borne disease burden through the following:

- **Controlling outdoor-resting and -biting or daytime-biting mosquitoes:** while ITNs and IRS target indoor- and night-biting vector populations, LSM can control vectors that are not highly susceptible to these interventions, such as vectors that rest and bite outdoors or bite during the early evening when residents are not inside their homes.
- **Targeting disease “hotspots”:** in some locations, malaria may persist even with high ITN and/or IRS coverage. LSM may therefore be particularly useful for helping to remove residual foci of malaria transmission in elimination programmes.
- **Supporting rapid focal response in outbreaks:** during household-level investigations in response to a case or cases of *Aedes*-borne disease, an operational team can rapidly implement vector control measures that target multiple life stages of the mosquito at the case house and in the surrounding areas, such as focal IRS and larval source reduction and treatment. This approach capitalizes on the presence of health staff at the household level to take actions that can reduce the onward transmission of an arbovirus.
- **Managing insecticide resistance:** resistance to pyrethroid insecticides commonly used in ITNs and IRS is now widespread in *Anopheles* vectors, and resistance has also been found to additional insecticide classes used in these interventions (13). There is evidence of the emergence and spread of resistance to pyrethroids and other insecticide classes in the two common arboviral vectors *Ae. aegypti* and *Ae. albopictus* (53). The diversity of insecticidal and biological larvicides and options for environmental modification/manipulation and biological control presents an opportunity to: (i) reduce the overall dependence on insecticides; (ii) preserve the efficacy of existing insecticides; and (iii) manage the spread of insecticide resistance once it has emerged.

- **Addressing other gaps in protection:** LSM may be appropriate for wide-scale deployment in other exceptional settings and circumstances due to limitations in the coverage, effectiveness or appropriateness of interventions such as ITNs and IRS (see section 1.4.5).
- **Controlling other vector-borne diseases:** LSM can be adapted to target the vectors of multiple diseases, thereby improving cost-effectiveness.
- **Leveraging community action:** community participation in larval source reduction and treatment, for example through the deployment of biological agents such as fish or copepods, promotes awareness and has reportedly reduced entomological indices in some areas (54).

1.4.2 Approaches

LSM programme design must be appropriate to the local setting, infrastructure and resources available and should be done in conjunction with national or subnational vector-borne disease control programmes. To this end, LSM interventions should be adapted to the socio-ecological setting in which they are applied.

In general, there are four approaches to implementing LSM:

- LSM is incorporated as a component of the national or subnational vector-borne disease control programme. When introducing LSM, the aim should be to build and institutionalize capacity and experience through a staged roll-out. Strategic and long-term funding and political support will be needed so that local programmes and supporting institutions have sufficient time and resources to learn and consolidate.
- LSM is conducted as part of a local community effort, such as by municipalities with few resources but significant motivation to control vector-borne diseases, including in places where ITNs, IRS or other vector control tools are not feasible or have not yet been deployed.
- LSM is implemented independent of, but in collaboration with, national programme activities using local or corporate resources, for example in urban areas and through private schemes at mining and agricultural operations where authorities have an interest in controlling vector-borne diseases and reducing nuisance mosquito populations to improve health and quality of life.
- LSM is integrated into activities of sectors outside of health, such as infrastructural development and construction projects (especially those involving the water sector), agricultural practices (e.g., irrigation) and education initiatives. There are likely to be many situations where this is feasible, and this approach can be highly effective with encouragement and engagement by the health sector.

This operational manual provides guidance mainly on LSM applied as a component of a national or subnational vector-borne disease control programme, although some information on strategies that use community and municipality engagement is included in Chapter 2.

1.4.3 Recommended interventions for *Anopheles* malaria vector control

At the time of publication of this manual, the current recommendations on LSM can be found in the *WHO guidelines for malaria* (8). These recommendations are expected

to evolve as new evidence on LSM emerges and is reviewed by WHO. Readers are therefore encouraged to consult the online MagicApp platform for the most up-to-date version of the WHO guidelines.

1.4.4 Recommendations for *Aedes* arboviral vector control

LSM has been a mainstay of *Aedes* vector control in urban settings. The availability of a broad range of potential habitats in urban environments has given rise to an extensive range of methods to prevent those potential sources from becoming inhabited or producing adults (10). These include specific targeted measures (such as covering, turning over or washing out containers), introduction of biological interventions (such as fish, copepods or bacteria), and application of chemical or biological larvicides, as well as more comprehensive measures such as educational strategies (promotion of good practices, behaviour change) and wide-scale source reduction (clean-up campaigns) or habitat manipulation (basic sanitary engineering). In general, high coverage rates and frequent reapplication, often in combination with environmental management, are key determinants of success when targeting *Aedes* immatures (larvae and pupae). Improved strategies have also been developed for broad-scale control of mosquito larvae in container habitats that are difficult to find or access, including aerial or ground-based application of larvicides (55).

However, there are currently no formal WHO recommendations on vector control for *Aedes*-borne diseases. As of November 2025, plans to update the *Aedes*-borne disease recommendations are in place.

1.4.5 Exceptional settings and circumstances

Effective vector control faces dynamic and evolving challenges that can undermine the impact of interventions, including LSM. Insecticide resistance, which has been increasingly reported in vector populations, limits the efficacy of chemical larvicides and demands greater reliance on non-chemical approaches or alternative products. Changes in vector behaviour, such as shifts in biting times or habitat selection, can reduce the predictability of aquatic habitat distribution and complicate surveillance and intervention targeting. In addition, climate change and other environmental transformations – such as urbanization, land use changes and water management infrastructure – can create new or more persistent aquatic habitats, alter vector or disease seasonality, and alter vector species composition. These combined factors necessitate adaptive LSM strategies, supported by robust surveillance, local ecological understanding and cross-sectoral collaboration.

WHO recommendations are formulated based on available evidence. Recommendations may be subject to revision based on evolving situations or additional evidence on existing or new tools, technologies, approaches or strategies. Despite the current conditional recommendation for larviciding only, there are specific settings or circumstances in which LSM may be appropriate for wide-scale deployment. For instance:

- areas with ongoing vector-borne disease transmission, despite historical high coverage of vector control interventions such as ITNs or IRS;
- areas where the main vectors bite at times and in places when people are away from sprayed residences or are not sleeping under ITNs;
- areas where shelter structures are not suitable for hanging nets or applying IRS, such as some humanitarian emergency settings involving displaced populations, refugee camps or natural disaster zones (32);

- areas with high human population density and lower surface areas of aquatic habitats that permanently hold water year-round, such as urban and semi-urban zones inhabited by or at high risk of invasion by *Ae. aegypti* or *An. stephensi* (56);
- areas where insecticide resistance is otherwise undermining the effectiveness of ITNs and IRS;
- areas where vector-borne disease transmission has been interrupted and larviciding is more suitable than ITNs or IRS for the prevention of re-establishment of transmission; and
- areas with specific vector habitats that are particularly amenable to LSM, such as rice cultivation zones or water development projects.

Furthermore, as technologies that increase the operational efficiency of habitat detection and larvicide application are developed, assessed and become available – such as Geographic Information System (GIS), remote sensing and drone applications (potentially in combination with artificial intelligence) – the cost-effectiveness of LSM can be improved. Such developments will also challenge the existing limitation of applicability to *Anopheles* aquatic habitats that are “few, fixed and findable” and potentially expand the range of contexts suitable for LSM.

Revision of WHO guidelines may be undertaken if there is additional evidence on new tools, technologies, approaches or strategies that improve the operational feasibility of LSM.

1.4.6 Coverage targets

While there is a strong theoretical foundation for requiring high coverage of LSM interventions, there is limited knowledge of the quantitative relationship between the level of community coverage and the resulting reduction in vector-borne diseases. The impact of single or multiple LSM interventions in relation to the presence or absence of tools such as ITNs or IRS that target adult mosquitoes is also unclear. Therefore, it is not possible to stipulate a specific LSM coverage rate that will ensure adequate effectiveness across all situations and settings.

It is important to consider that while complete control or elimination of all aquatic habitats in the control area may be ideal, benefits can be realized from alternative, more focused interventions. The identification of key aquatic habitats that considers their abundance and estimated relative productivity of adults (using immatures as a proxy) can guide prioritized control that can save precious resources without compromising impact. It is essential to define key aquatic habitats through baseline assessments, so that rapid and targeted action can be taken in situations of urgency such as an outbreak or epidemic.

Another option to promote the optimal use of resources is seasonal application at the appropriate time to avert increases in vector densities. The timing will depend on the setting and the target vector. For instance, larviciding against *Anopheles* vectors in natural habitats in rural areas prior to the onset of the rainy season may assist in reducing adult populations throughout the season. The application of larvicides in urban areas against *Aedes* vectors could coincide with the dry season, when water storage is high in areas without reliable piped water.

More information on possible scenarios for targeting LSM interventions is provided in Chapter 2.

1.4.7 Effectiveness and cost-effectiveness

The systematic reviews and meta-analyses reflected in the available WHO guidelines show that there is limited evidence for the effectiveness of LSM in reducing malaria and *Aedes*-borne disease transmission (8, 25, 28–30, 33).

LSM is often a substantial logistical and financial undertaking. Some analyses indicate that larviciding can be cost-effective for malaria control. In certain settings, the value of LSM has been comparable to that of ITNs or IRS, despite the need for repeat application (57). However, these findings are highly context-specific and depend on the intervention, deployment method and setting. Larviciding has been considered cost-effective in areas where aquatic habitats are few, fixed and findable, but much less so in areas where habitats are abundant, scattered or variable (8).

For *Aedes*-borne diseases, cost-effectiveness data are particularly scarce, and assessments have usually relied on entomological rather than epidemiological outcomes. A notable example is a multi-country non-inferiority cluster-randomized trial showing that a simplified, lower cost approach – targeting container types producing the majority of *Ae. aegypti* pupae – was as effective at reducing vector numbers as more resource-intensive strategies targeting all containers (33). The transferability of such an approach depends heavily on local vector ecology and human behaviour, such as peri-domestic water storage and waste management practices.

Further research is therefore needed to evaluate the cost-effectiveness of different LSM tools, technologies, strategies and approaches, either alone or in combination with other interventions, across diverse socio-ecological and epidemiological settings. Evidence is particularly lacking for source reduction, environmental manipulation/modification and biological control.

1.4.8 Potential harms or unintended consequences

The following potential harms or unintended consequences should also be considered when determining whether and how to implement LSM, including management and disposal of products:

- human health risks versus the anticipated benefit of the intervention;
- impact on non-target species, including interruption of natural predation;
- effect on water quality, including sources for human consumption and use;
- insecticide resistance development in target and non-target species of public health and agricultural significance;
- economic impact on communities, including on local industry or primary production; and
- public mistrust and compliance issues that may arise before, during or after implementation.

Environmental guidelines and national regulations or regulatory requirements should be examined accordingly. Appropriate mitigation measures should be undertaken, including community engagement (see Chapter 4).

1.4.9 Applicability and appropriateness in a specific setting

The practicality and appropriateness of implementing LSM in vector-borne disease control programmes should ultimately be determined locally. Programme managers will need to identify the intervention and deployment options that are potentially suitable to the setting and assess their relative utility. Resource requirements for LSM must be considered relative to the expected reduction in transmission intensity or disease incidence (if possible).

To determine the likely success of LSM in a given context, data should be compiled to answer questions that include technical, socio-ecological, logistical and financial considerations (Box 2). Further details on feasibility assessments are provided in Chapter 3. Programme managers may also contact WHO for technical assistance in determining the feasibility of LSM in specific settings.

Box 2. Example data that may be used to inform the appropriateness of LSM within a given context

- current vector-borne disease epidemiology and human demographics
- vector bionomics
- physical environment, larval ecology and hydrology
- status of vector resistance
- economics and available resources
- health system and national control programme capacity
- community willingness and previous engagement in vector control interventions

1.4.10 Key components of effective implementation

The following factors will contribute to the success of an LSM programme:

- **Strong leadership and political will:** personnel at all levels of the organization must receive the message that LSM is an important undertaking that has the support of the management.
- **Good management and resourcing:** availability and effective use of human, infrastructural and financial resources, and the ability to leverage data to inform decisions are essential. Challenges in managing staff and logistics can limit the potential of programmes in areas suitable for LSM.
- **Trained and skilled personnel:** trained technicians/entomologists who conduct detailed surveys of the ecology and biology of local vectors are essential to determine which (if any) LSM interventions are appropriate, and when and where these should be applied. Sufficient and competent operational personnel to implement, supervise, monitor and evaluate LSM activities are critical, as are staff responsible for procurement and logistics. Personnel with data analysis skills who can leverage available information to inform operations are also essential.
- **Robust baseline information and strong surveillance systems:** information on the vector species present in the control area and their behaviour, insecticide susceptibility and key immature habitats is critical for the design of appropriate LSM strategies. Continuous entomological monitoring is crucial to ensure that

all aquatic habitats are being correctly managed. Epidemiological surveillance is important to assess the impact of the LSM programme.

- **Community acceptance, support and participation:** local needs and priorities must be considered when interventions are planned. For example, even if there is a relatively high perceived risk of vector-borne diseases, the local population's livelihood might depend on some of the aquatic habitats earmarked for control (e.g., rice fields, irrigation channels, pits and wells). LSM interventions must have the support of the local community in a target area so that aquatic habitats can be accessed for modification or treatment. Education and engagement of community members in implementation will encourage community acceptance.
- **Collaboration between sectors:** LSM often overlaps with the responsibilities of other sectors beyond health, for example environmental modification by urban works or waste disposal by municipal councils. Collaboration with other sectors is also important to ensure good practice in infrastructure development, water supply and housing, so that activities such as road construction, brick making or house building do not create new aquatic habitats. Urban by-laws and enforcement may also be an important means of preventing the proliferation of aquatic habitats.
- **Conducting general mosquito abatement rather than *Anopheles* or *Aedes* control alone:** integration of mosquito control across species can enhance the benefits of disease control efforts and reduce nuisance biting. For example, community support for LSM programmes may be enhanced if there is concurrent reduction in biting by *Culex* species. This also simplifies the work of field staff, as it reduces the need to identify and separate vector and nuisance species. In urban areas of Africa, the identification of key aquatic habitats shared by *An. stephensi* and *Aedes* spp. will be an important consideration when designing targeted strategies.

Further information is provided in Chapter 3.

1.4.11 Recent and future developments

Since the publication of the previous version of this document in 2012, there have been several promising developments with the potential to address current challenges to the effectiveness and feasibility of LSM. New tools are being developed for the application of LSM, along with methods and technologies that enhance the accuracy of mapping aquatic habitats, which may improve the overall efficiency and reduce the cost of LSM operations. While these advances in the field are not necessarily subject to review and evaluation for public health value by WHO, and their potential benefit to LSM operations may not have been comprehensively reviewed, they are referenced in this document to ensure that programme managers are aware of recent technological developments and how they may lead to improved efficacy in the future. Although their inclusion in this operational manual should not be considered an endorsement, consideration of these developments may prove valuable when designing long-term LSM programmes.

Widespread use of GIS and other data management systems in health programmes has presented the opportunity to leverage information technology for more precise mapping of aquatic habitats and identification of areas for treatment. Remote (satellite) sensing, high-resolution aerial imagery from drones, hydrological terrain analysis and other environmental DNA mapping (e.g., collection of DNA fragments shed by organisms into their environment) provide precise, accurate and timely information on the location of potential habitats (43). Citizen science, which relies on the collection, reporting and analysis of data by members of the public, can provide

further data to support LSM, such as in response to the threat of *An. stephensi* in Africa (58) or for monitoring of *An. gambiae* or *Aedes* vectors (59, 60).

The rapid development of artificial intelligence that can consolidate, process and analyse large data sets can be programmed for iterative learning. This can integrate information generated through aerial surveys of rural or urban areas with ground-based surveillance and operational information to guide decision-making. New trapping technologies for adult *Anopheles* and *Aedes* vectors have also improved the accuracy of entomological surveillance information that can guide more refined and targeted LSM.

Helicopters and airplanes can also support efficient wide-scale application of larvicides, such as in rice fields or when flooding occurs. Advances in uncrewed aerial vehicles and systems – especially drone technologies – offer additional aerial application methods for larviciding and have already been used for vector habitat surveillance and larvicide delivery in some locations (61, 62). Such approaches can circumvent the need for resource-intensive ground-based searches for aquatic habitats across both rural and urban settings. Any aerial application of larvicides should be conducted in accordance with relevant local, national and regional regulations and regulatory requirements, including pesticide registration, environmental safety and airspace management.

Further information on these developments is provided in the relevant sections throughout this document.

2. Establishment and management of an LSM programme

This chapter describes the organization of an LSM programme and the main considerations for its establishment and management.

2.1 Organization of an LSM programme

LSM programme design must be appropriate to the local setting, infrastructure and resource availability. The four general approaches to implementing LSM have been outlined in Chapter 1 and include LSM deployment: (i) as a component of a national or subnational vector-borne disease control programme; (ii) as a small-scale community or corporate effort; (iii) through activities undertaken by other sectors outside of health; and (iv) as a large initiative in urban areas or through private schemes.

While this operational manual focuses on guidance for the application of LSM as part of national or subnational vector-borne disease control programmes, all relevant levels of the health system, other sectors, relevant partners and community members should be engaged to ensure that measures are appropriate for the socio-ecological settings in which they are applied, to enable continuity of protection, and to avoid any gaps or duplication of effort.

2.1.1 Programme structure and staffing

To ensure that LSM is thoroughly and correctly conducted within national and subnational programmes, a clear hierarchy will need to be established. Components of the LSM programme should fit within existing structures and take advantage of current human resources, infrastructural and institutional capacity. An LSM programme should be implemented by the local authorities according to national guidelines and in collaboration with other sectors. Specifics should be overseen or reviewed by qualified specialists, such as an entomologist.

Two possible simplified structures for an LSM programme – one urban and one rural – are shown in Figs. 2 and 3, respectively.

LSM programmes are far more complex than the structures illustrated here and will usually need to fit into existing vector-borne disease control programme structures. A well thought-out management structure that incorporates programme M&E and supports informed decision-making is essential. Ongoing monitoring of progress, such as by measuring adult and larval indices, should ideally be performed by individuals other than those responsible for implementing control activities to ensure independence of processes. In Fig. 2 below, larval surveillance and control are separate functions, with each officer responsible for a designated area or zone. However, in Fig. 3, the vector surveillance and control functions are combined, with M&E conducted separately by an independent team. Note that key functions such as administration, finance, logistics and procurement are not indicated in the structures, as these may be either programme-specific or centralized.

Fig. 2. Simplified LSM programme structure for an urban area

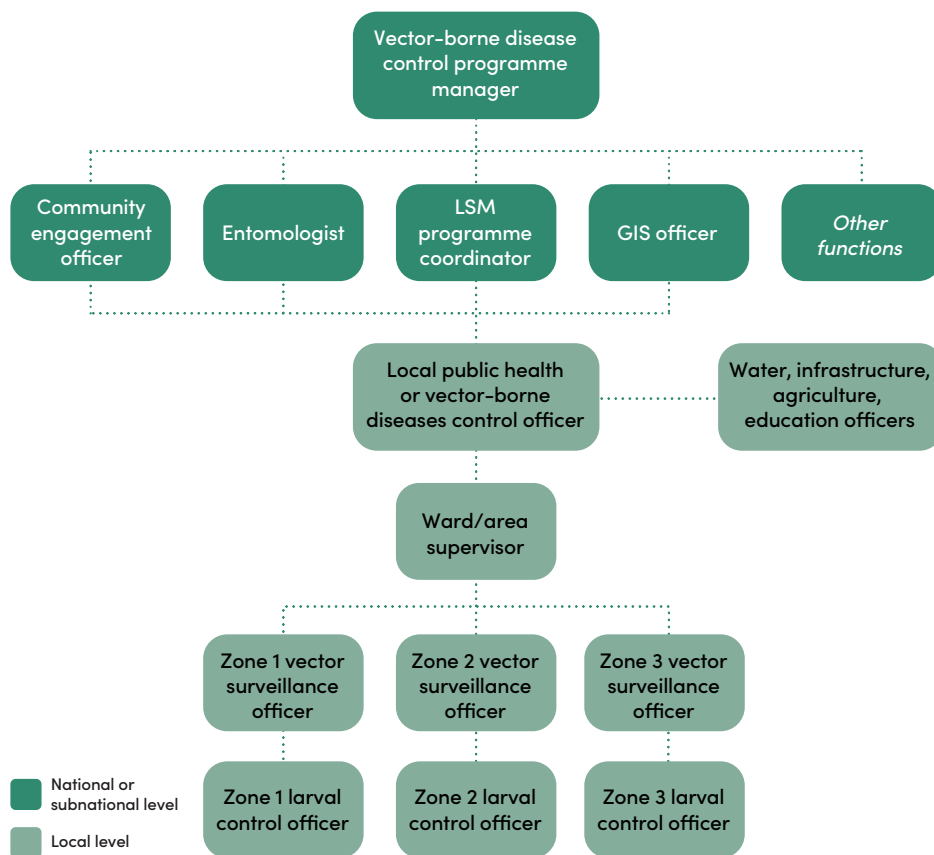
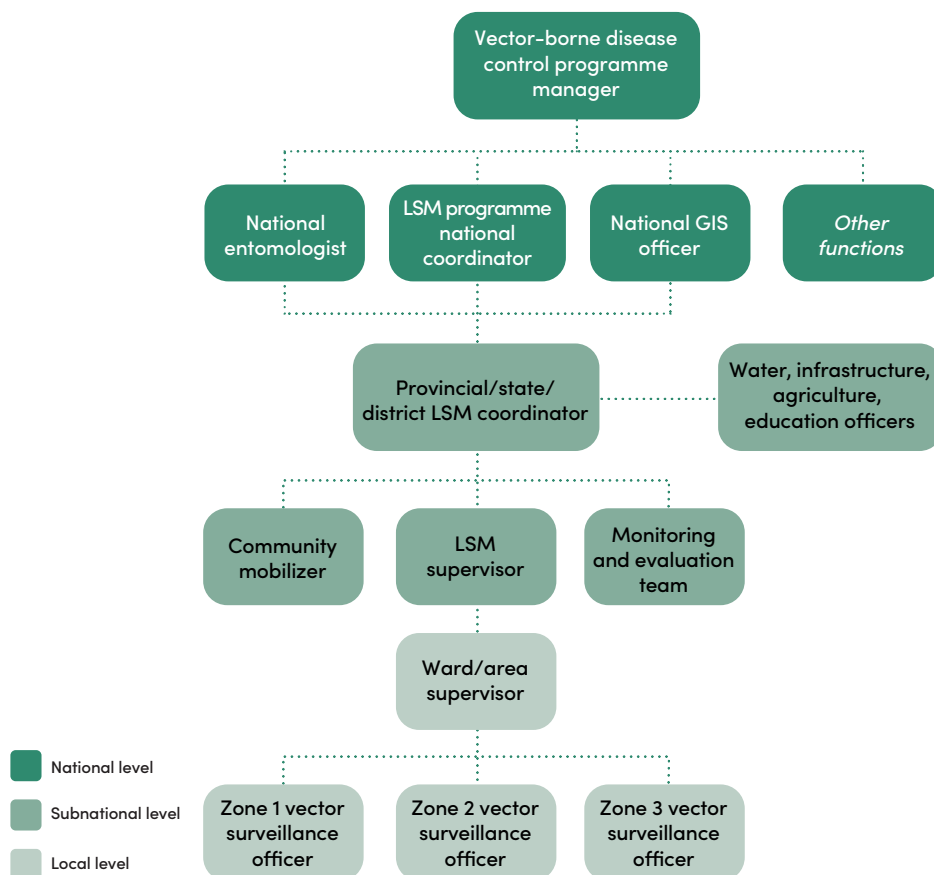


Fig. 3. Simplified LSM programme structure for a rural area



Clear definition of roles and responsibilities, along with explicit clarification of how different partners will interact, is an important foundation for LSM programmes. When this step is taken early and maintained throughout implementation, programmes can:

- strengthen collaboration between staff by ensuring complementary functions;
- foster a shared sense of accountability for both achievements and challenges, which supports team cohesion; and
- promote cooperation across sectors, including with local government partners, by clarifying contributions and expectations.

In this way, well-structured role clarity not only prevents confusion and inefficiency but also builds strong partnerships, encourages cross-sectoral engagement and enhances the effectiveness of LSM programme delivery. Where possible, LSM should be fully integrated into the existing public health infrastructure with existing public health staff involvement. If a vector-borne disease control programme is well established with a team of field workers conducting other vector control activities, it may be possible for those workers to conduct LSM, provided that they are based locally and have local knowledge. This may require the field workers to receive additional training in LSM, providing them with a more expansive skill set. Financial and career-track incentives will help to retain a consistent and experienced LSM workforce. In some situations, it may be necessary to recruit new staff for the LSM programme, as existing public health staff may be overburdened and unable to take on extra responsibilities. It may be appropriate to create new field teams, depending on the work required and the resources available.

Adequate staffing for implementation, supervision and evaluation will be required if the programme involves extensive larviciding. Core personnel for LSM should be established and maintained. An engineer may be needed if large-scale environmental management operations are planned and if coordination with other sectors is envisaged. LSM functions can be integrated into other components of the vector-borne disease control programme when implementation is not as intensive. For example, larval surveys or application of larvicide can be conducted by individuals who are also responsible for IRS deployment in a particular area. However, timing is a key consideration, as optimal timing for LSM will depend on hydrological factors influencing habitat availability and productivity, whereas IRS is best completed prior to seasonal rains. Strategic planning of the different components of the control programme, coupled with a workforce that is trained in multiple areas of the field work, can help ensure that staff can be employed year-round.

2.1.2 Staff training

Table 2 lists training topics that may be considered depending on programme structures and LSM strategies.

If surveillance and control functions are to be separated, vector surveillance officers should also be trained in aspects of control, and larval control officers can be trained by accompanying surveillance teams for one month during baseline data collection.

Field workers should be trained in mapping and characterizing aquatic habitats, in searching for and identifying mosquito larvae and pupae, and in the LSM approach of choice in the area. Since mosquito control officers are usually trained outside the main transmission season when many aquatic habitats will be dry, it is important for all aquatic habitats, both new and old, to be found and treated during the wet seasons.

Standard operating procedures (SOPs) for LSM should be developed based on the aim and targets of the programme and the local situation, and all staff involved should be trained to ensure understanding and adherence.

Table 2. Potential training topics for the workforce supporting LSM

Potential training topics	Responsibility				
	Vector surveillance officer	Larval control officer	Ward or area supervisor	LSM supervisor	LSM programme coordinator
Approaching households and community members	x	x	x	x	x
Mapping and characterizing aquatic habitats, including use of digital technologies	x				
Mosquito larvae and pupae identification	x				
Community mobilization	x	x			
Source reduction techniques	x	x			
Larviciding dose calculation and application technique		x			
Environmental and physical safety, including waste and incident management		x	x	x	
Record keeping and reporting	x	x	x		x
Performance monitoring			x		x
Storehouse management, including storage and stock control				x	
Equipment management, maintenance and repair				x	
Logistics management				x	
Data entry, database management and reporting			x		x
Review and lessons learned			x	x	x

Local capacity for training is important for sustained capability. It is essential that LSM staff can access entomological advice and guidance from national or subnational staff. It would also be expected that LSM staff be trained in basic mosquito biology and ecology to aid in aquatic habitat recognition, larval identification, quantification and estimation, and selection and correct application of control options. Periodic assessment of the competency of personnel in their key responsibilities should be built into the programme design. Training-of-trainer or cascade training models and refreshers should be considered, especially if employing seasonal workers. Curricula should be reviewed with relevant stakeholders and modified as necessary. Good training materials and manuals with content on LSM that can be adapted are available from multiple sources (63–65).

2.1.3 Role of the local authorities

The local government may be responsible for vector surveillance and control including LSM, particularly in public locations such as hospitals, schools and marketplaces.

This may include systematic waste disposal during household clean-up campaigns and setting up education and awareness campaigns through schools, special meetings and local media that encourage community members to take responsibility for source reduction around their homes. The local government can also support the local enforcement of laws that aim to prevent formation of aquatic habitats and vector proliferation. At minimum, local authorities must be well informed so that those in charge can judge the cost–benefit and likely advantages and disadvantages of LSM in the local context.

The local authorities will be essential in coordinating and encouraging action across different sectors. For example, the department for transport and public works can be encouraged to build roads that do not collect standing water on either side; the department for agriculture can help modify farming practices to avoid creating aquatic habitats, such as through the introduction of intermittent irrigation; and the department of water can take action to reduce household-level storage of water through the provision of reliable piped water. Cross-sectoral action may be supported by: embedding vector expertise in relevant departments, such as through secondment; holding regular interdepartmental meetings to ensure that information flows smoothly and responsibilities are clear; and ensuring systematic monitoring and feedback loops to reinforce engagement.

2.1.4 Role of the local population

The local community should be educated and involved in LSM as much as possible for the following reasons:

- Local residents have the best knowledge of local geography.
- Workers must be allowed to enter private properties.
- Local residents can help with LSM by removing aquatic habitats inside and around the home.
- Costs may be lower and community contributions may be higher if members of the community are paid to conduct LSM.
- The public (both schoolchildren and the wider community) should be educated about vector-borne disease transmission and the LSM programme.
- The programme should target all relevant mosquito species to control malaria and *Aedes*-borne diseases and also to reduce nuisance biting where possible.
- Local customs should be considered when planning the programme.

2.1.5 Funding

Ideally, an LSM programme will be funded by the government as part of general health expenditure, municipal public works and/or infrastructure development. Costs for the ministry of health can be kept lower by involving other ministries or corporations with economic interests in healthy workers. Costs can also be reduced by recruiting volunteers or modestly paid members of the community. Schoolchildren, scouts and other service organizations can also help in LSM efforts on a few designated days each year.

Where local funding is insufficient to conduct LSM, financing from international development partners may be possible. It is important to secure long-term support for LSM programming, as establishing a functional and high-quality LSM programme requires considerable time and effort, and capacity must be maintained to ensure sustained impact.

2.1.6 Political support

Securing and maintaining political support for an LSM programme is crucial for the following reasons (Box 3):

- The government will be more likely to provide any additional funding required by the vector-borne disease control programme to implement LSM.
- Collaboration between the ministry of health and other sectors is desirable.
- New legislation for the compulsory removal of certain aquatic habitats or for preventing the creation of new aquatic habitats can be helpful.

Box 3. Community-driven LSM in Mexico and Nicaragua

The Camino Verde intervention in Mexico and Nicaragua was a large-scale, community-based programme that successfully reduced dengue risk by mobilizing households and neighbourhoods to take collective action. Communities were involved in identifying, eliminating and protecting water containers that served as aquatic habitats, rather than relying solely on chemical spraying. The programme demonstrated that participatory LSM – through container clean-up, covering and removal – was more effective, sustainable and socially acceptable than vertical, insecticide-driven strategies (66). Political support was crucial, as government commitment ensured resources, legitimacy and scale-up of the intervention, enabling community-driven larval control efforts to be integrated into national dengue control policy.

2.1.7 Multisectoral engagement

If sectors external to health are involved in LSM, the responsibilities for activities will need to be planned, coordinated and shared accordingly (see examples in Box 4).

Box 4. Multisectoral engagement for LSM in Rwanda and Thailand

In Rwanda, LSM is a critical component of the country's malaria control strategy, particularly in targeting the aquatic habitats of *Anopheles* mosquitoes. The approach includes the identification of habitats and management through environmental modification, such as draining stagnant water from swamps, ditches and water containers, as well as the application of larvicides such as Bti to control larvae in difficult-to-reach areas. Rwanda has integrated LSM with other malaria control measures, including ITNs and IRS, to create a comprehensive, multi-pronged approach to vector control. The success of LSM in Rwanda is enhanced by strong community involvement, regular surveillance and government support, although challenges such as limited resources, logistical constraints and environmental factors persist. Overall, LSM remains a vital tool in reducing malaria transmission and improving public health outcomes in the country.

Box 4. Multisectoral engagement for LSM in Rwanda and Thailand (cont.)

In Thailand, the Department of Disease Control works alongside several government sectors to manage the spread of *Ae. aegypti* mosquitoes. The health sector coordinates the surveillance of mosquito larvae and the application of biological and chemical larvicides in water storage containers, construction sites and public spaces. The municipal and urban planning sectors are involved in ensuring that urban development includes proper waste management and drainage systems to prevent the accumulation of stagnant water, which can support mosquito proliferation. The agriculture sector plays a role in controlling mosquitoes in irrigation channels and rice paddies. In addition, the education sector supports public health campaigns to raise awareness and encourage community participation in eliminating mosquito aquatic habitats. This coordinated effort across health, urban planning, agriculture and education sectors has been instrumental in controlling the mosquito population and reducing dengue transmission in Thailand.

2.1.8 Procurement and supply chain management

Timely and efficient sourcing, storage and distribution of larvicides, application equipment and other necessary resources is essential. Required resources must be locally available ahead of peak larval development periods. Insecticides must be stored correctly and used before the expiry date, and equipment should be adequately maintained and serviced. Adherence to regulatory and environmental guidelines is essential.

Additional capacity for procurement and supply chain management will be required if this is not already available through centralized functions within the broader disease control programme.

2.1.9 Environmental protection and human safety

When establishing an LSM programme, the following should be considered to ensure adequate environmental protection and human safety:

- Appropriate regulatory and environmental compliance approvals should be obtained prior to LSM implementation.
- Larvicide products should be WHO-prequalified to ensure safety, quality and efficacy (44), and larvicide application equipment should be compliant with WHO guidelines (67).
- Manufacturer and label instructions (including correct use of personal protective equipment) should be adhered to for the mixing, application and disposal of larvicide products.
- SOPs on LSM should be established and available, outlining the storage, use, disposal and waste management requirements and incident management.
- Waste management practices for all hazardous and non-hazardous materials should align with international (WHO and Food and Agriculture Organization of the United Nations) best practices and country requirements.
- Storage facilities, application equipment and personal protective equipment must be appropriate for the product to be used, and its use should be in accordance with established SOPs.

- All staff tasked with management, application or monitoring or who are otherwise exposed to larvicides should be adequately trained in relevant implementation and safety practices.
- Transportation of equipment, supplies and staff should be monitored with respect to licensing, insurance and safety standards.
- Safety and security incident reports should be routinely investigated and monitored to identify areas for improvement.
- Ecologically sensitive habitats should be identified, and interventions should be selected that minimize non-target impacts in those habitats.

Further guidance on the procurement, registration, handling and application of larvicides (and other public health pesticides) is available elsewhere (68–71).

2.2 Possible LSM implementation strategies

Examples of different LSM strategies are provided below.

2.2.1 Strategy 1: Community-led household clean-up

Individuals can take responsibility for the elimination of small aquatic habitats near their home. This community ownership of LSM at an early stage will help if larviciding is to be introduced later.

Source reduction can often be achieved by educating the community about LSM and by correcting common misconceptions (Box 5). The messaging will need to be tailored depending on the target vectors. For instance, source reduction for *Ae. aegypti* could focus on clearing rubbish such as tires from the environment, whereas this would not be a focus for most *Anopheles* vectors; clearing bush or vegetation around houses does not reduce mosquito biting.

To educate the wider population, meetings with individual communities or awareness campaigns through the media should be conducted. Special lessons in schools might be introduced through collaboration with the ministry of education or by approaching schools directly.

Box 5. Communication for Behavioural Impact in Malaysia

In Malaysia, the COMBI (Communication for Behavioural Impact) approach mobilized communities through structured behaviour change communication emphasizing the elimination of *Ae. aegypti* aquatic habitats in and around homes. Local volunteers were trained to conduct house visits, educate residents on identifying and removing standing water, and promote regular weekly clean-up routines. The initiative also involved schools, religious institutions, and media campaigns to reinforce key messages. Evaluations showed increased community participation and improved knowledge and practices related to dengue prevention, highlighting COMBI's role in fostering sustained, community-driven source reduction, thereby complementing broader vector control interventions.

2.2.2 Strategy 2: Municipality-led and -enforced source reduction

It is often difficult to achieve source reduction objectives through community participation alone. Clean-up campaigns initiated and led by the municipal council in urban areas can provide an impetus for community involvement (Box 6). The involvement of public health staff or village health workers to propagate key messages can give authority to the campaign. Municipal assistance with the proper disposal of collected rubbish will also be essential.

The introduction or enforcement of by-laws may be useful.

Box 6. The Urban Malaria Scheme in India

In India, the Urban Malaria Scheme incorporates legislation and regulatory measures as part of its strategy to prevent and control mosquito breeding in urban areas. For instance, in Mumbai, the municipal council inspects properties and issues contravention notices to households where potential or actual mosquito habitats are identified. If deemed unaddressed during follow-up inspections, legal action may be taken, including fining (50). Annual surveys of government and municipal properties are also conducted, with any requests for action issued and two months allowed before non-compliance is noted and legal action initiated. For construction projects, 10-point advisories are issued, with stop-work notices for non-compliance.

2.2.3 Strategy 3: Large-scale environmental management

In some circumstances where larger scale engineering is required to achieve environmental modification or manipulation, communities or local authorities may be unable to carry out LSM alone. Therefore, collaboration with other ministries can be fruitful.

Careful design and maintenance of infrastructure is also important, so close engagement with public works departments is essential (Box 7). For example, small barriers built in roadside drains to slow the flow of water can create aquatic habitats.

Box 7. Large-scale environmental management in Sudan

In Khartoum, Sudan, large-scale environmental management was key to reducing *Anopheles* mosquito populations. The Khartoum State Water Corporation worked closely with the Federal Ministry of Health to address leaking water pipes that created stagnant water and mosquito habitats. By prioritizing repairs to these pipes and coordinating larviciding efforts in areas with persistent water pools, the Water Corporation helped to mitigate larval proliferation. This collaboration between the health sector and water infrastructure departments also demonstrated the importance of intersectoral coordination in urban malaria control.

2.2.4 Strategy 4: Larviciding of all potential aquatic habitats

Once source reduction, environmental modification and environmental manipulation have been used to eliminate as many aquatic habitats as possible, larviciding can be considered. Applying larvicides to all potential aquatic habitats is generally considered to be labour-intensive. However, wide-scale larviciding can be feasible in urban centres (Box 8) (72, 73).

In areas with extensive larval sources, such as large river flood plains and rice production areas, larviciding was previously considered impractical. However, new technologies such as drones enable broad application of larvicides through aerial means, for example for rice farms, flooded plains or difficult-to-access overhead water tanks. These technologies can improve habitat identification and treatment efficiency and support rapid treatment of vast tracts of habitats at a lower cost than previously (62, 74).

Wide-area larvicide spraying has also been used in urban and semi-urban settings with extensive small receptacles, including those that are hidden or hard-to-reach. This approach employs the use of drones, truck-mounted sprayers or other methods to apply larvicides to broad environments such as entire neighbourhoods or districts. Rapid treatment of multiple *Aedes* spp. habitats can be achieved, and this strategy has been used successfully in *Aedes*-borne disease control programmes in countries such as Brazil, India, Singapore, Thailand and the United States of America.

There must be careful consideration of the conditions under which large-scale larviciding can be undertaken, especially any potential effects on non-target organisms.

Box 8. Large-scale larviciding for *Anopheles* control in the United Republic of Tanzania

As part of the Urban Malaria Control Programme in the United Republic of Tanzania, LSM was implemented in conjunction with routine surveillance and community engagement. After mapping and characterizing aquatic habitats, all potential *Anopheles* habitats – such as drains, construction pits and other water bodies – were treated weekly with microbial larvicides (primarily Bti). Although larviciding was traditionally considered labour-intensive, the urban setting of Dar es Salaam, where aquatic habitats were relatively fixed and identifiable, made widespread application feasible. This approach led to significant reductions in larval densities and adult mosquito populations, and decreased malaria incidence in treated areas. The experience in Dar es Salaam demonstrates that, when paired with strong mapping, surveillance and operational capacity, large-scale larviciding can be an effective strategy for urban *Anopheles* control.

2.2.5 Strategy 5: Targeted control of key habitats

To reduce costs and operational constraints, LSM can target the aquatic habitats expected to produce the most adult mosquitoes (using immatures as a proxy) (34). For example, source reduction campaigns can target those habitats that are the most amenable to removal, disposal or destruction, and then larviciding can target the remaining containers that could not be eliminated but that are known to sustain a large proportion of the immature mosquito population.

Other situations in which larviciding could be used include habitats with low numbers of vectors or productive habitats with limited longevity (e.g., only the rainy season), such as in areas with brief seasonal transmission. Population suppression through larviciding in aquatic habitats may also be possible in the dry season, especially in very cool seasons in parts of southern Africa or at the beginning of the rainy season (Box 9).

Box 9. Targeting productive habitats in western Kenya

Entomological surveys in the highlands of western Kenya revealed that a small proportion of aquatic habitats – such as hoof prints, puddles and drainage ditches – were disproportionately responsible for producing most *Anopheles* larvae. Based on this information, the control strategy focused on identifying and regularly treating only the most productive habitats with microbial larvicides. Seasonal timing was also used to enhance efficiency: Larviciding was intensified during the early rainy season and in dry-season habitats where larval populations were concentrated in fewer, persistent water bodies. This targeted approach reduced adult mosquito densities and malaria transmission while minimizing operational costs, demonstrating how evidence-based habitat prioritization can support effective LSM for *Anopheles* vectors.

2.2.6 Strategy 6: Integrated mosquito control

Targeting LSM beyond *Anopheles* and *Aedes* vectors to include other mosquito genera such as *Culex* spp. is highly advisable wherever this is practical and resources allow (Box 10). This is because:

- use of one or more LSM methods can help to control malaria, dengue, lymphatic filariasis and other mosquito-borne diseases and reduce nuisance biting, particularly in urban areas;
- programmes that impact multiple species often have good community support, as they improve quality of life through a general reduction in overall mosquito biting;
- this can improve efficiency, especially considering it is the same institutional structures, systems and resources leveraged to deliver interventions against multiple vectors or diseases;
- field staff have less need to differentiate between mosquito genera when surveying and conducting LSM; and
- public engagement is simplified, as few people understand that only certain mosquito species transmit certain pathogens.

Box 10. Integrated approaches to vector control in Brazil and Sri Lanka

Brazil's approach to vector control involves municipal legislation that mandates integrated strategies targeting both *Aedes* and *Anopheles* mosquitoes. Local laws require regular surveillance, community engagement and environmental management to eliminate aquatic habitats. These legal provisions empower municipalities to implement tailored interventions, reflecting the country's commitment to decentralized and participatory vector control.

In Vavuniya District, Sri Lanka, the Anti-Malaria Campaign implements an integrated vector control programme that addresses multiple mosquito-borne diseases, including malaria, dengue, lymphatic filariasis and leishmaniasis. Entomological surveillance is carried out by district-level staff who are trained to identify and monitor various vector species, enabling efficient deployment of interventions such as LSM, space spraying and public education. The Anti-Malaria Campaign also collaborates with the district disaster management unit to coordinate vector control in response to seasonal flooding that creates new aquatic habitats. This integrated approach ensures the more efficient use of limited resources while maintaining strong community engagement and health system responsiveness (50).

2.2.7 Strategy 7: No introduction of LSM

Introducing LSM into a vector-borne disease control programme may sometimes not be the appropriate choice, particularly in wet rural areas, in areas with vast larval sources such as large river flood plains and extensive rice planting areas, in areas with a proliferation of water storage containers that are not accessible by available means, and in areas with cryptic habitats that are difficult to locate (Box 11). As with all the scenarios discussed, this option should be periodically reviewed based on current scientific information and changing local conditions. For instance, eliminating a highly productive larval source from within a village could significantly impact dry-season transmission. Such spot treatments should never be completely ruled out.

Box 11. Choosing to not implement LSM in rural United Republic of Tanzania

In rural areas of the United Republic of Tanzania, a 2021 study assessed LSM but concluded that the required infrastructure, resources and monitoring systems were inadequate to sustain effective larval control on a large scale (75). Consequently, malaria control efforts prioritized ITNs and IRS, which could be more easily scaled up and sustained.

2.3 Examples of recent LSM programmes

Summary examples are provided below, with further details of some programmes available in Annex 1.

2.3.1 Urban Malaria Scheme, India

The Urban Malaria Scheme includes 131 towns and 19 states and union territories in India with a population of over 50 000 and an annual parasite incidence of two or more. The Scheme focuses on LSM through minor engineering and mosquito-proofing activities aimed at preventing mosquito proliferation, such as through the control of larvae with the application of larvicides or distribution of larvivorous fish, with enforcement through by-laws. In addition, some focal spraying is conducted in and around positive cases during outbreak situations to kill infective mosquitoes. Activities are run by a biologist and supervised by state and central health authorities. Every target municipal area of each town is divided into wards of 25.6 km², which are further divided into sectors of 2.56 km². Each ward has one inspector and one insect collector, and each sector has one supervisor field worker and one or two field workers (depending on the quality of the drainage system). One driver and vehicle are provided per 40 sectors (76).

2.3.2 Urban Malaria Control Programme, Malindi, Kenya

The Urban Malaria Control Programme was initiated in 2008 by Malindi Municipality in collaboration with research institutions and nongovernmental organizations. The programme is divided into grid cells, each of which is 1 km² in size and manned by a cell scout or mosquito scout. These scouts are responsible for routine mosquito control and surveillance and report to the district public health offices within the Ministry of Health. The mosquito scouts working in this community-based LSM programme are responsible for creating awareness and conducting neighbourhood campaigns and house-to-house visits to educate the community about the intervention (72).

2.3.3 Anti-Malaria Campaign, Sri Lanka

Built cement wells used for domestic purposes have been identified as the key habitat for immature *An. stephensi* in Sri Lanka. The Anti-Malaria Campaign initiated a programme in Mannar, with the support of the town council, to fill unused wells with sand to ensure that they cannot retain water or serve as aquatic habitats for *An. stephensi*. The campaign also initiated a programme of introducing the larvivoracious fish *Poecilia reticulata* to the wells used for domestic purposes. This example from Sri Lanka shows that the closure of unused wells and introduction of larvivoracious fish has the potential to control *An. stephensi*, but sustainability and cost-effectiveness need to be evaluated.

2.3.4 Ethiopia Ministry of Health/Malaria and Other Vector Borne Disease Prevention and Control Desk and development partner, Ethiopia

The Malaria and Other Vector Borne Disease Prevention and Control Desk, in collaboration with a development partner, initiated enhanced *An. stephensi* surveillance in 2018, yielding positive detections at over 50 sites. Pilot implementation of LSM commenced in August 2022 targeting 87 309 residential, commercial, government and nongovernment properties across eight towns. Every two weeks, 34 community mosquito collectors and 300 community vector control technicians visit every property to find, record and implement source reduction or larviciding with Bti.

2.3.5 National Malaria Control Programme and development partner, Madagascar

In Madagascar, LSM is used in addition to ITNs and IRS in areas of high malaria burden where vectors exhibit outdoor-biting and -resting behaviour patterns. In two malarious districts, the programme, in collaboration with a development partner, supported the use of drones to map aquatic habitats and apply Bti. Drone mapping of habitats allowed for high-resolution planning of operations and significantly reduced field time compared to land-based ground truthing methods.

2.3.6 National Dengue Control Programme, Brazil

In Brazil, vector control in municipalities is guided by national policies that emphasize integrated and decentralized strategies. The Ministry of Health provides overarching guidelines and resources, while municipalities are responsible for implementing localized actions. Key components include regular surveillance of *Ae. aegypti* populations, community engagement to eliminate aquatic habitats, and the application of larvicides and adulticides as needed. Innovative approaches, such as the release of *Wolbachia*-infected mosquitoes, have been adopted in certain areas to reduce disease transmission. These efforts are coordinated across federal, state and municipal levels to ensure a comprehensive response to vector-borne diseases.

3. Planning and preparation for LSM

Integrating LSM into a vector-borne disease control programme is a stepwise, information-based process. These steps should be followed systematically to reach a sound decision about (i) the feasibility of LSM in the local setting and (ii) which LSM interventions are appropriate.

The scale of LSM will vary for different target vectors and in different settings, with extensive LSM in some settings and minimal LSM in others. For instance, in urban and semi-arid areas, research has demonstrated the potential for achieving high levels of vector suppression with LSM (8, 77–79). In other settings, LSM may be less appropriate or inappropriate. In all cases, good decisions cannot be made without a systematic approach and a thorough understanding of the local vector and transmission ecology (Box 12).

Information on the following factors is required to make an informed decision about whether LSM is appropriate:

- **malaria or Aedes-borne disease epidemiology**, including incidence of confirmed malaria or dengue cases and determination of place of infection (e.g., malaria infections detected by urban health centres may have been acquired in rural areas or dengue infections may have been acquired at daytime locations such as schools or marketplaces rather than in the domicile);
- **existing disease prevention and control interventions** (e.g., ITN coverage, IRS coverage, access to diagnostic testing and treatment);
- primary and secondary **vector species**;
- **vector bionomics**, including oviposition site preference, larval development times, and adult mosquito biting and resting habits (e.g., indoor or outdoor biting and resting; daytime, early- or late-evening biting);
- **vector resistance** (e.g., reduced susceptibility to temephos if it is in use or planned for use);
- **physical environment** (e.g., rural, urban, peri-urban, semi-arid), larval ecology and hydrology (e.g., type and stability of habitats);
- **economics** (e.g., predicted cost per person protected by LSM per year, potential sources of funding for LSM);
- **community commitment** to initiate or engage in community-based LSM; and
- **health system** and national vector-borne disease control programme capacity and commitment.

Box 12. Important considerations during baseline data collection

Throughout the duration of baseline data collection, it is important to remember that the **primary LSM interventions should focus on source reduction**. Where possible, containers should be eliminated or altered and waste managed. Opportunities for environmental modification or manipulation should also be sought for the long term.

Where larval sources cannot be reduced by applying these strategies (or where sites have been identified but are not yet under management), sources can be treated by **larviciding** or **biological** control to disrupt immature development and reduce mosquito production.

3.1 Compiling data

Before introducing LSM, it is important to ensure that WHO-recommended vector control interventions (such as ITNs and/or IRS) that are appropriate for the setting are deployed at high coverage and are being used for maximum benefit. Routine health system and survey or programmatic data capturing interventions and their use may be used as a baseline. Vector susceptibility to insecticides, as well as resting and biting behaviour, should also be factored into the assessment of maximum benefit. Community acceptance of existing interventions and LSM should also be considered.

LSM is considered a supplemental intervention to ITNs or IRS for the control of malaria. However, in certain circumstances and settings (such as those outlined in [56]), LSM may be the most viable option to address ongoing transmission. It is essential to collect data to support the initial and continued use of LSM over more commonly deployed interventions.

3.1.1 Current vector-borne disease epidemiology and human demographics

To identify the areas where LSM may add benefit, the population(s) at risk for the relevant vector-borne disease(s) should be mapped (Box 13). If possible, the proximity of households to aquatic habitats should be determined for *Anopheles*, as people living close to such habitats are at a greater risk for malaria (80). For dengue, it is important to consider social factors such as proximity to low-income urban and peri-urban centres, which is associated with greater risk, particularly for those with good transport connections (81). Population movements, such as an influx of new individuals into endemic areas due to civil disturbances, should also be considered.

Health management information system data can be used to identify the highest burden districts. In areas of moderate to high transmission, the total number of cases, inpatients and deaths recorded at health facilities per month can be used to assess the geographical distribution of diseases. In low endemic areas, geographical clustering of cases or foci of transmission should be defined and mapped because these are ideal targets for LSM.

Routine health facility data are less costly than survey data and help to build capacity. However, in some situations, cross-sectional surveys to determine parasite prevalence or virus serostatus may be required if health facility data are not sufficiently complete

or testing capacity is limited. Care must be taken to select a representative and sufficiently large sample of the target population.

Box 13. Questions to be addressed by surveys and health information system data

Surveys and analysis of health information system data should aim to address the following questions:

What is the prevalence and/or incidence of confirmed malaria or *Aedes*-borne disease(s)?

Are there clear hotspots or clusters of malaria or *Aedes*-borne disease transmission?

Which households or areas have the greatest risk of malaria or *Aedes*-borne disease infection, and is the risk greater close to certain aquatic habitats?

Which age, sex or employment groups have a higher risk, and is this risk associated with a particular location or activity?

This information should be used to identify areas or municipalities **where LSM should first be considered**, which may be characterized by:

- the highest relative infection rates or disease burden, historically or currently;
- an emerging or re-emerging malaria or *Aedes*-borne disease problem;
- a high population density (e.g., urban and peri-urban areas) or a low population density (e.g., rural villages) with clearly defined, limited and accessible aquatic habitats;
- high-risk locations, such as in and around hospitals with patients or schools with sick students; and
- elevated risk of other vector-borne diseases.

Vector bionomics

Once potential target areas for LSM have been identified using data on vector-borne disease transmission and intervention coverage, the local vector biology needs to be well understood to decide which, if any, LSM interventions are suitable and when these should be implemented. More details on the types of aquatic habitats suited to LSM are provided later in this section.

Search of historical data

At the outset, it is important to clearly define the target vector populations and understand as much as possible about their ecology. The first step in this process is to search historical data on both adult and larval populations within the specific area targeted for protection or within similar ecotypes. This information should then be combined with data from ongoing surveys of both adult and larval populations. Much of this information already exists for many operational settings, which gives a good starting point for local data collection.

Adult mosquito surveys

The purpose of adult population surveys for LSM is to confirm the presence and behaviour of vector species and determine when and where these populations are concentrated. This will help focus the larval survey on more likely targets. These surveys also provide a baseline against which to gauge the success of LSM interventions. It is important to remember that the measure of success for a larval control operation is the impact on the **adult** vector population; larval surveys alone are not sufficient.

Larval mosquito surveys

With the aid of historical information about vector populations and current information from ongoing adult surveys, it is possible to design and carry out a programme of larval surveillance and habitat identification. The information from larval surveys is of general use in other areas of a vector-borne disease control programme, not only for LSM. For example, it can help to delineate disease risk areas, forecast the need for adult mosquito control, assess the effectiveness of adult control measures, help interpret adult mosquito surveillance data and serve as a source of specimens for insecticide resistance monitoring (82). Larval surveys are useful where adult densities are low or where adults are difficult to locate due to hidden resting sites.

3.1.2 Physical environment, larval ecology and hydrology

The natural environment can provide numerous sources of mosquito vectors (e.g., swamps and river flood plains) that fluctuate in size depending on local rainfall. Aquatic habitats are also often created by human activity or development projects. The target area should therefore be checked for specific features that are favourable to mosquitoes. This can include irrigation systems, quarries, construction sites or borrow pits that may be used for brick making or plastering, seepage from dams, and urban agriculture. Other types of aquatic habitats might be small ground pools resulting from ground depressions filled with rain or a high water table.

The hydrological setting of water bodies is a fundamental consideration in planning and implementing LSM. Understanding how water accumulates, flows and persists in an environment determines both the availability and productivity of mosquitoes from aquatic habitats. Factors such as rainfall patterns, drainage systems, tidal influences and groundwater dynamics affect the formation, size and duration of aquatic habitats, and influence the success of interventions such as source reduction, larviciding and habitat modification. Without accounting for these hydrological characteristics, control efforts risk being inefficient or unsustainable, as new *Anopheles* or *Aedes* aquatic habitats may quickly form after rainfall or flooding, and treated sites may be re-inhabited. Incorporating hydrological mapping and analysis into LSM ensures that interventions target the most persistent and productive habitats while optimizing resource use and long-term vector control impact.

For instance, in both urban and rural settings, unreliable or interrupted water supply can lead to increased water storage in the domestic environment. Broken water pipes or poor wastewater management can support the formation of aquatic habitats. Other sites for vectors such as *An. stephensi* and *Ae. aegypti* can include wells, tanks, drums and barrels for storing water, discarded plastic waste such as bottles, pools or ornamental ponds, unused tires or boats, plastic sheeting and house gutters. Potential sites vary greatly depending on the setting and vector species.

Ideally, the aquatic habitats that produce the most adult mosquitoes should be identified so that they can be targeted for LSM. These are called “key habitats” and are determined by examining the abundance of the container type and its expected productivity of adults (using late instar larvae or pupae as a proxy, if needed) (Box 14). Where quantitative information is not available, habitat positivity (proportion with larvae) versus habitat negativity (proportion without larvae) for the target vector can be determined for the different habitats present. Numerous studies have been conducted in different ecosystems to assess mosquito productivity in different aquatic habitats and identify key containers for both *Anopheles* and *Aedes* vectors. Similar assessments in each setting can be used to determine the feasibility of LSM and determine how to target interventions.

Box 14. Determining key habitats

Key habitats are types of containers or water bodies that are expected to produce the greatest number of adult vectors in a given setting.

This is determined for a target vector species as:

$$\text{abundance of habitat type} \times \text{average estimated adult productivity}$$

The estimated or actual number of late instars or pupae can be used as a proxy for determining adult productivity.

Irrigation systems

Irrigation can create aquatic habitats for mosquito vectors, contributing to increased vector densities and, in some cases, higher disease transmission (Box 15). This has been observed for *Anopheles* species in countries such as Burundi, Ethiopia and Kenya, and for *Aedes* species in Brazil, India, Mexico, Sri Lanka and Thailand (83, 84). Poor canal water management, raised water tables, vegetation growth in irrigation channels, and soil or water salinity changes can all contribute to the creation of aquatic habitats. In Ethiopia, inadequate canal management has been linked to intensified malaria transmission near irrigation schemes (84). However, in some settings, people living near irrigated zones experience similar or even lower disease burdens than those in non-irrigated areas, possibly due to better socioeconomic status, housing and access to tools such as ITNs (83). In some areas, irrigation may change vector composition. For example, *An. funestus* has been displaced in some locations by the less efficient vector *An. arabiensis*.

When assessing the potential impact of irrigation systems on vector populations, several key factors should be considered. Irrigation may raise the local water table or lead to the formation of standing water around infrastructure, creating ideal aquatic habitats. It can also alter soil or water salinity, potentially influencing the suitability of habitats for different mosquito species. Vegetation growth within irrigation channels can slow water flow and cause pooling, whereas its removal may restore fast-flowing conditions that deter vector development. The presence or absence of vegetation may either promote or suppress vector proliferation, depending on the species involved. In addition, irrigation can influence the composition and density of larval and adult mosquito populations.

Surveillance and control strategies in irrigated agricultural systems – especially rice-growing regions – should be timed to coincide with practices such as crop transplanting and fertilization, when mosquito populations often peak. Irrigation systems can also affect the relative abundance and overall density of immature and adult vectors. Effective control measures may include modifying irrigation practices through scheduled drying of canals, regular flushing or clearing of vegetation (Box 16). Involving rice growers and other local stakeholders in these efforts can enhance the success of IVM initiatives.

Box 15. Contribution of irrigation to the creation of aquatic habitats in Spain

In an urban area of Catalonia, Spain, continuous private water irrigation and the presence of vegetation created humid, shaded conditions that provided ample larval and adult habitats for *Ae. albopictus*. These conditions may also have increased vector longevity and potentially vector competence for arboviruses (85).

Box 16. Control measures targeting irrigation systems in Sudan

In Khartoum, Sudan, regular drying of irrigated fields was compulsory across government and private irrigation schemes to manage vector habitats. This initiative was supported by the farmers' union and the Ministry of Agriculture, and 98.2% of irrigation schemes were dried for at least 24 hours during 2011 (83). Leakages from irrigation canals are also repaired, with vegetation around canals cleared in cooperation with the Ministries of Irrigation and Agriculture (86).

Dams

Over the past half century, an estimated 40 000 large dams and 800 000 small dams have been built worldwide (87, 88). Such construction can reduce vector production but can in fact create additional aquatic habitats through seepage, irrigation canals and associated man-made or natural water pools, which may lead to a rise in vector-borne disease incidence if there are human settlements close by. Environmental management can mitigate these effects by addressing standing water and involving communities in vector control measures (Box 17). It will be important to determine how the aquatic habitats have been created, what hydrological factors affect their availability and vector productivity, and which environmental management strategies may be appropriate for the local conditions.

Box 17. Addressing aquatic habitats caused by a microdam in Ethiopia

In Tigray, Ethiopia, a microdam was associated with the creation of aquatic habitats through seepage at the dam base (28% of habitats), leaking irrigation canals (16%), pools that formed along the bed of streams from the dam (13%) and man-made pools (12%). Consequently, in the village close to the dam, the number of *An. arabiensis* adults were 5.9–7.2 times higher than in a control village 3–4 km away, and there was a 3.1% higher prevalence of splenomegaly in children under 10 years of age (89). The local community in Deba village was engaged in environmental management activities such as filling, draining and shading aquatic habitats. These actions led to a 49% reduction in *An. arabiensis* adults.

Large and stable natural water bodies

Natural habitats such as vegetated swamps are often sources of *An. funestus* and tend to be stable but fluctuate in size depending on local rainfall. Large river flood plains (i.e., in the Gambia) are often very dynamic and not discrete. While large-scale treatment in the rainy season will call for advanced surveillance systems and aerial application of larvicides, survey and treatment in the dry season may be simple. For instance, efforts could target smaller streams usually associated with flood plains in the wet season.

In general, LSM is best implemented in the dry season just prior to the onset of the rainy season, during which peak mosquito populations are sustained. However, this timing will vary based on ecological and climatic conditions. Therefore, local conditions and other programmatic activities should inform decisions on the appropriate timing of LSM deployment.

Urban dwellings

Urban dwellings significantly contribute to the proliferation of *Aedes* mosquitoes, particularly *Ae. aegypti* and *An. stephensi*. These mosquitoes thrive in domestic

environments, where they find abundant containers that collect rainwater, discarded tires, flower vases, water storage tanks and even uncovered drains that are amenable to oviposition and can serve as aquatic habitats. Plastic waste and other trash that catch and hold water provide further habitats. Urbanization increases the availability of these potential habitats, particularly in areas with poor waste management, inconsistent water supply and inadequate drainage systems. Studies in Brazil, Mexico and Sri Lanka have shown that *Aedes* populations are higher in urban areas compared to rural ones, partly due to the concentration of water-holding containers and human activity (Box 18).

Basic water management and sanitation are fundamental to any LSM programme for container mosquitoes. Water storage containers can be made mosquito-proof, but this is rarely done or maintained. Reliable municipal water supply is the answer. If that is not economically feasible, regular application of larvicides may be necessary in urban environments.

Box 18. The challenge of urban aquatic habitats in Sri Lanka

In Sri Lanka, water storage practices in urban settings and the presence of small artificial containers have been shown to sustain large *Aedes* populations. Furthermore, urban heat islands – where cities tend to be hotter than surrounding rural areas – can also extend the peak mosquito season, as warmer temperatures accelerate mosquito development and increase vector survival rates. Consequently, urban areas with inadequate water management and sanitation infrastructure are particularly vulnerable to *Aedes*-borne disease outbreaks. Effective vector control in urban settings requires tackling both the elimination or alteration of aquatic habitats and the improvement of urban infrastructure.

Urban infrastructure

For *Aedes*, unreliable water supply is known to influence water storage and larval indices at the household level (90). Storm drains have been identified as larval development and adult resting sites for *Ae. aegypti* and *Ae. albopictus* in Salvador, Brazil (91). Similarly, following drain clearance in Dar es Salaam, United Republic of Tanzania, there was a lower probability of malaria infection in the local population compared to the pre-intervention period (92). Through immature surveys, programmes should determine if broken water pipes, drains or cisterns provide aquatic habitats and, if so, how best to manage those habitats, such as through repair, removal, covering or treatment.

Road construction can create aquatic habitats both in the borrow pits used to obtain soil during construction and in the drainage channels alongside completed roads, where debris often collects. Vectors also breed in concrete water storage containers used to provide water for construction projects. Poor wastewater management and drainage in urban areas can create aquatic habitats. Programmes should determine if vectors are proliferating in other man-made infrastructure (Boxes 19 and 20).

There is a need for sectors outside of health care, such as municipal public works departments, to take responsibility for careful construction projects and good design and maintenance of roads and drains.

Box 19. The impact of construction projects on aquatic habitats

In Dar es Salaam, United Republic of Tanzania, over 70% of *Anopheles* and *Culex* aquatic habitats were man-made, of which many were drains (93). In Ethiopia, the unprecedented construction boom since 2018 is thought to have been instrumental in the establishment, persistence and propagation of *An. stephensi* via the year-round availability of perennial aquatic habitats associated with construction (94). Construction sites were also found to be an important driver of the sustained transmission of dengue in the 2013–2014 dengue outbreak in Singapore, with higher *Aedes* larval populations also noted than in other locations (95).

Box 20. Man-made aquatic habitats in Kenya

In Malindi, Kenya, more than 90% of all *Anopheles* aquatic habitats are man-made, of which many are unused swimming pools, drains and wells. The unused swimming pools are normally located in up-market residential and tourist areas and quickly fill with water during the rains, allowing vectors to breed (96). These swimming pools could be filled in, covered or treated with larvicide.

Urban agriculture

The methods used for cultivating crops, including the water applied, can influence the availability of aquatic habitats. Growing vegetables and crops in urban areas may create mosquito aquatic habitats close to human habitation, as demonstrated in Accra, Ghana (97), and Dar es Salaam, United Republic of Tanzania (98), with a consequent increase in malaria, as seen in Ghana (73) and Côte d'Ivoire (99). Small water impoundments constructed for irrigation or soil furrows may become aquatic habitats. Garden pots in apartments in urban and peri-urban areas can also sustain mosquito populations, especially for *Aedes* vectors.

Programmes should determine if and how urban agriculture is creating aquatic habitats in order to identify mitigating measures. However, urban agriculture provides food and commerce for local citizens, and it may be difficult to introduce changes.

There may be other opportunities to alter farming practices to incorporate LSM or to draw on existing expertise from agriculture. Drip-line irrigation may be of some benefit (Box 21). Farmers may already be trained to identify and control pests such as the diamondback moth larvae that are pests of cruciferous vegetable crops. Farmers may also be trained to recognize and eliminate *Anopheles* larvae in dug wells or rain-filled furrows – an approach recently explored in Kumasi, Ghana (100). Youth or women from farming villages can be engaged in certain LSM activities.

Box 21. Addressing agricultural practices in Uganda

In Kampala, Uganda, flooding of sweet yams was practiced, creating ideal aquatic habitats for local vectors, even though the yield of sweet yams is lower in saturated soils. In this case, a discussion with farmers about best agricultural practices would be helpful to improve yield and reduce vector-borne disease transmission. In general, drip-line irrigation prevents aquatic habitat development and is more water-efficient.

3.1.3 Status of vector resistance

LSM may be a useful component of insecticide resistance management in settings where vectors develop resistance to the insecticides used in common vector control tools, such as ITNs or IRS. For instance, where local vectors are resistant to pyrethroids but are susceptible to non-pyrethroid insecticides, non-pyrethroid chemical larvicides can be used. Several non-pyrethroid larvicides (e.g., bacterial larvicides, benzoylureas, juvenile hormone mimics, organophosphates, spinosyns) and a monomolecular film-producing product have been prequalified by WHO (44). Together, these offer a choice of products that belong to unrelated alternative chemical and microbial classes or that act as a physical barrier, and that have different residual action in aquatic environments. These include products for application in storage containers for non-potable water and drinking water.

The insecticide susceptibility status of the local vector populations should be monitored periodically as part of every vector control operation. If the vector intervention under consideration targets larval stages (e.g., chemical larviciding), insecticide resistance testing should ideally be conducted using larvae (82). Data should be used to inform resistance management strategies. WHO susceptibility test procedures for larvae have not been further validated or updated since they were established in 1981 (101), so these procedures are less standardized than for adult tests. Larval susceptibility guidance is available from other sources (102, 103).

3.1.4 Economics

The costs of LSM must be carefully considered. Recent studies indicate that costs vary significantly depending on the context and method, including the intervention selected (e.g., container habitat management, larviciding, fish), application method (e.g., drone-based versus ground-based) and implementation strategy (community-led versus centralized). While technological advancements, such as drone-based larviciding, offer precision and scalability, community-driven and traditional methods may be more practical in resource-limited areas, especially in rural and low-income settings (Box 22).

Box 22. Examples of cost-effective implementation of LSM

- Burkina Faso: routine Bti-based larviciding against *Anopheles* in a rural district was logistically feasible and relatively low cost, with high local acceptability and integration into health systems (104).
- Cambodia: annual targeted larviciding against *Ae. aegypti* significantly reduced dengue cases and was cost-effective, especially when integrated into existing health programmes (105).
- Malawi: community-led LSM and house improvement targeting *Anopheles* in rural areas were low-cost but required strong local engagement for sustainability (106).
- United Republic of Tanzania:
 - In Zanzibar, drone- and smartphone-based larviciding operations targeting *Anopheles* showed high operational costs but were operationally feasible with high-quality outcomes (62).
 - Larviciding against *Anopheles* was cost-effective, particularly in high-transmission malaria settings, while the cost of rural implementation was higher per person protected (107).
 - Urban larviciding against *Anopheles* using microbial larvicides in Dar es Salaam was found to be cost-effective in reducing malaria incidence, particularly when targeting high-risk areas (108).

Estimating the cost of a planned LSM programme

The cost per person in the target area per year for a planned LSM programme can be estimated using the “ingredients approach”:

- Identify the different activities to be costed.
- Quantify the “financial” (direct) and “economic” (indirect) costs of conducting these activities.
- Summarize economic and financial costs in a table.
- Estimate the size of the target population for protection.
- Calculate costs per person in the target area per year.

Financial costs are direct, out-of-pocket expenditures involved in running the LSM programme. They are costs that are explicitly incurred and recorded in financial statements or budgets. Economic costs include broader societal costs associated with running the programme, including indirect costs and benefits that may not be reflected in the budget but impact overall well-being. By separating the financial and economic costs, decision-makers gain a comprehensive understanding of the total impact of an LSM programme – not only the immediate expenditures but also its broader implications for health, the environment and the economy. Table 3 provides a summary of possible costs associated with LSM.

Table 3. Possible financial and economic costs associated with LSM

Financial costs	Economic costs
<ul style="list-style-type: none"> • Commodities (e.g., larvicide) • Other costs for interventions (e.g., fish production) • Labour (e.g., for implementation, monitoring, data entry) • Training (e.g., for spray or application personnel) • Equipment (e.g., sprayers, drones, boats, trucks for application) and its maintenance • Transport (e.g., fuel, team vehicles, maintenance) • Disposal (e.g., of containers, chemicals, or other waste generated by the programme) • M&E (e.g., mosquito surveillance, environmental assessment) • Administration (e.g., planning, coordination, logistics) 	<ul style="list-style-type: none"> • Opportunity costs (e.g., resources that could have been used elsewhere, such as personnel or funding diverted from other initiatives) • Health costs (e.g., reduction in health spending due to fewer vector-borne disease cases) • Environmental impact costs (e.g., potential effects on non-target organisms, changes in biodiversity) • Social costs (e.g., public perception, social acceptability of the intervention, potential conflicts or controversy) • Long-term economic benefits (e.g., improved productivity, lower health care costs) • Impact on local economy (e.g., local business support, local employment, boost to public health infrastructure)

If the programme runs in multiple cycles (e.g., biannual applications), adjust the costs and frequency of protection accordingly. Major cost drivers often include personnel, transport and community engagement. For more complex or urban environments, additional costs (e.g., mapping, drone use, higher personnel costs) should be incorporated. Start-up costs

(e.g., initial training, equipment purchase) can be annualized over several years to reflect their useful life.

Decision-makers may also want to consider the effectiveness of the larviciding programme in terms of reduced vector populations or disease incidence, which could further refine the assessment of cost-effectiveness. Guidelines on estimating the cost and cost-effectiveness of vector control are available (109). Resources may be secured locally, from national authorities, or externally.

The cost per person protected by LSM per year is determined using the following calculation:

$$\frac{\text{total cost of LSM programme}}{\text{total number of people protected by the programme}}$$

3.1.5 Health system and national control programme capacity

As with the deployment of ITNs and IRS, LSM is a major financial and technical undertaking for which full political and community support is essential. Therefore, it is important to assess whether the national health system and the national or subnational vector-borne disease control programmes have the capacity to support LSM, and whether different sectors can work together (particularly health, agriculture, education, food and water). Moreover, programmes should assess whether they have the necessary personnel and time to implement LSM. Integral to the success of LSM will be a critical mass of trained field staff and public health officers supported by entomologists with detailed knowledge of local transmission ecology and vector control.

Even more important than entomological capacity is management capacity, particularly the ability to collate, synthesize and report monitoring data accurately, appropriately and rapidly. Large-scale programme management of logistics and human resources is often the most limiting capacity. A variety of GIS-based software packages are available to automate these tasks.

In particular, the following questions should be asked:

- What funding is available for LSM?
- Will funding LSM divert resources away from other proven and effective methods of vector control?
- How is the health system organized at district, regional and national levels and does it have the capacity to support or implement LSM?
- Are health system and control programme managers in favour of LSM?
- Is there enough staff, particularly trained entomologists, technicians and field workers?
- Is there capable and competent management for LSM?
- Is there sufficient logistical support?
- Are there outside funding sources that may provide initial entomological, management and logistical support while building capacity at the local level?
- Could existing M&E activities be adapted or streamlined to include LSM?

3.2 Analysing information

When as much baseline information has been collected as possible, it should be analysed to answer specific questions, as outlined in Table 4.

Table 4. Summary of information to be collected

Topic	Key questions
Disease epidemiology	<p>What is the malaria or <i>Aedes</i>-borne disease incidence and prevalence?</p> <p>Are there transmission foci?</p>
Human demography	<p>What are the geographical distribution and characteristics of the population, and how do these relate to transmission? Are there particular groups at higher risk?</p>
Other interventions	<p>What other interventions are ongoing in the area?</p> <p>If coverage of other vector control interventions, such as IRS and/or ITNs, is not high, why is this?</p> <p>Are the other interventions delivering sufficient suppression of disease transmission?</p> <p>Will LSM fill a gap in transmission suppression that is not met by current core methods?</p>
Available resources	<p>What staff are available or could be made available to conduct LSM?</p> <p>How much funding is available for LSM?</p>
Aquatic habitats	<p>What are the primary types of aquatic habitats that affect the area?</p> <p>What is the extent of larval sources (number and size) that affect the area?</p> <p>Are there other larval sources that are difficult or impossible to reach in the area?</p> <p>Are there anticipated changes in the size, number, location and density of different larval stages in these sources over the year (rainy vs dry season), and can seasonality be exploited to improve LSM efficiency?</p>
Adult vector ecology	<p>What are the primary vector species?</p> <p>What are the typical vector biting and resting habits?</p> <p>What is the status of vector resistance to insecticides used for potential or actual interventions, including larvicides, IRS and/or ITNs?</p>
Potential for LSM	<p>What is the impact of human activity on the occurrence or mitigation of larval sources?</p> <p>What is the proximity of larval sources to human habitations?</p> <p>What is the potential for elimination, modification or manipulation of aquatic habitats to reduce mosquito development?</p> <p>What is the potential for treatment of sources with mosquito larvicides?</p> <p>What is the potential for natural or introduced predators to augment control?</p> <p>What is the practicality of finding and treating all or key larval sources at various points in the year?</p> <p>What is the expected area needing treatment (total hectares per year) under dry season, rainy season and full year treatment?</p>

3.3 Assessing applicability

Using the information collected above, a decision can be made about the appropriateness of LSM for a given setting (Box 23). This decision should also consider that effective LSM will reduce adult mosquito production and therefore reduce reliance on adult control measures to prevent disease transmission.

Box 23. Applicability of LSM in different settings and circumstances

LSM is not a suitable strategy in all habitats and usually involves multiple methods of source reduction and treatment. Its role will differ depending on the target disease, the setting and the situation.

In general, LSM will likely be most cost-effective and efficacious in locations where aquatic habitats are relatively few, well defined, seasonal, readily accessible and possibly man-made, and in more temperate regions where larval development is more protracted. Such conditions are common in areas of low to moderate transmission, focal or epidemic malaria, or *Aedes*-borne disease transmission. These conditions occur frequently in urban areas, in desert fringes, at high altitude and in rural areas with high population densities.

LSM may also be appropriate in exceptional settings and under circumstances in which other vector control interventions would be inappropriate or have reached their maximum practical effect, such as in humanitarian crises with limited fixed housing (see Chapter 1).

For *Ae. aegypti* or *An. stephensi* in urban areas, source reduction will be a key approach to vector control. LSM may also have potential in managing insecticide resistance and transmission sustained by vector populations that bite or rest outdoors or bite in the daytime or early evening.

Table 5 provides an overview of the potential suitability of LSM in different socio-ecological settings, although local assessment may lead to different conclusions about suitability.

In the *WHO guidelines for malaria* (8), the following settings are identified as potentially the most suitable for larviciding as a supplementary measure implemented alongside ITNs or IRS:

- **urban areas:** where breeding sites (aquatic habitats) are relatively few, fixed and findable in relation to houses (which are targeted for ITNs or IRS); and
- **arid regions:** where aquatic habitats may be few and fixed throughout much of the year.

The guidelines recognize that larviciding will, in general, be most effective in areas where aquatic habitats are few, fixed and findable, and likely less feasible in areas where the aquatic habitats are abundant, scattered and variable. Determination of whether specific habitats are suitable for larviciding should be based on assessment by an entomologist.

Table 5. General suitability of LSM in different socio-ecological settings

Socio-ecological setting	Suitability for <i>Anopheles</i> spp.	Suitability for <i>An. stephensi</i>	Suitability for <i>Ae. aegypti</i> and <i>Ae. albopictus</i>	Rationale/considerations
Urban	Low to moderate	High	High	<i>An. stephensi</i> and <i>Ae. aegypti</i> mainly inhabit artificial containers. Urban LSM can be highly targeted and effective.
Peri-urban	Moderate	Moderate to high	High	Mixed natural and artificial habitats support multiple species. LSM may be feasible with strong mapping and local knowledge.
Rural irrigated/flood plain	High	Moderate	Low	Stable aquatic habitats (e.g., canals, ponds) favour <i>Anopheles</i> spp. LSM is suitable if habitat mapping is achievable.
Rural rain-fed/transient habitat	Moderate	Low to moderate	Low	Highly variable and short-lived habitats reduce LSM impact, unless stable habitats allow for seasonal interventions.
Arid/semi-arid (with artificial water storage)	High	High	High	Artificial water sources are predictable and accessible; LSM is well suited if habitats are few, fixed and findable.
Highland fringe/low transmission zones	Moderate	Moderate	Moderate	Focal aquatic habitats and low vector densities make LSM a valuable intervention in elimination settings.
Island/coastal	High	High	High	Geographical containment enhances habitat coverage and LSM feasibility.
Forest or jungle	Low	Low	Low	Numerous, dispersed and inaccessible natural habitats limit operational feasibility of LSM.
Humanitarian emergency (e.g., displacement camps)	Moderate	High	High	Populations often rely on water storage containers, supporting <i>Ae. aegypti</i> and <i>An. stephensi</i> populations. LSM can be rapidly deployed where habitats are centralized, especially in camps. Requires integration into emergency water, sanitation and hygiene and shelter response.

3.4 Baseline mapping of target areas

3.4.1 Mapping aquatic habitats and water bodies

Potential aquatic habitats should be mapped digitally using GPS-tagged information derived from the ground or from analysis of aerial imagery taken by drone, airplane or satellite to enable processing and analysis within GIS. Mapping information should

be recent enough to represent current hydrological conditions. There are numerous examples of drone technology, alongside field-based mapping teams, providing timely information on habitat location to support LSM:

- Côte d'Ivoire: a technical workflow combining drone surveys and entomological ground truthing was developed to map *An. funestus* habitats in rice paddies, showing that drone-derived indices (e.g., NDVI) could predict larval presence and inform targeted interventions (110).
- Peru: multispectral drone imagery accurately detected and classified *Anopheles* aquatic habitats with over 90% accuracy, outperforming manual mapping and offering a scalable tool for precise LSM in complex, forested landscapes (111).
- United Republic of Tanzania:
 - Area-wide larval source mapping in Zanzibar using drones was operationally feasible at scale, integrated into the existing malaria control programme; the importance of community acceptance, regulatory compliance and ongoing habitat monitoring was emphasized (112).
 - In Zanzibar, low-cost drones provided high-resolution imagery to locate and map standing water bodies; their deployment enabled the identification of previously undetected habitats, facilitating more effective and targeted larviciding efforts (113).
- Zambia: drones equipped with RGB cameras effectively identified potential aquatic habitats in rural settings, enabling rapid baseline mapping; manual verification was necessary due to vegetation cover and water turbidity, and capacity-building of local teams was emphasized (74).

The following steps have been identified for baseline mapping (114).

Step 1: Map all boundaries of target areas

Maps of the target area should be useful for management and field staff. Aquatic habitats can be logged by ground-based teams with high-precision hand-held GPS devices and maps created using computer software. Alternatively, drone imaging technology, remote satellite sensing or environmental DNA mapping can also be used to map vector aquatic habitats (Box 24). These mapping techniques ensure the identification and mapping of habitats in non-residential or industrial areas that may initially be missed. Good maps of the target area enable work to be shared equally among field staff.

Alternatively, maps can be created simply by members of the community without the use of electronic devices. Laminated aerial photographs (if available) should be taken into the field and used to sketch maps by hand. These can then be digitized using GIS if helpful (Figs. 4 and 5).

Box 24. Drone mapping of aquatic habitats in Mexico

In Chiapas, Mexico, a drone was used to map aquatic habitats for *Aedes* mosquitoes responsible for dengue, Zika virus and chikungunya transmission (115). The drone imaging allowed for the rapid identification of water-holding containers and other aquatic habitat hotspots, guiding targeted control measures.

Fig. 4. Example of (left) an “orthomosaic”, resulting from stitching together multiple drone photographs, and (right) a map that can then be passed to field teams with highlighted waterbodies (red) and access routes and locations

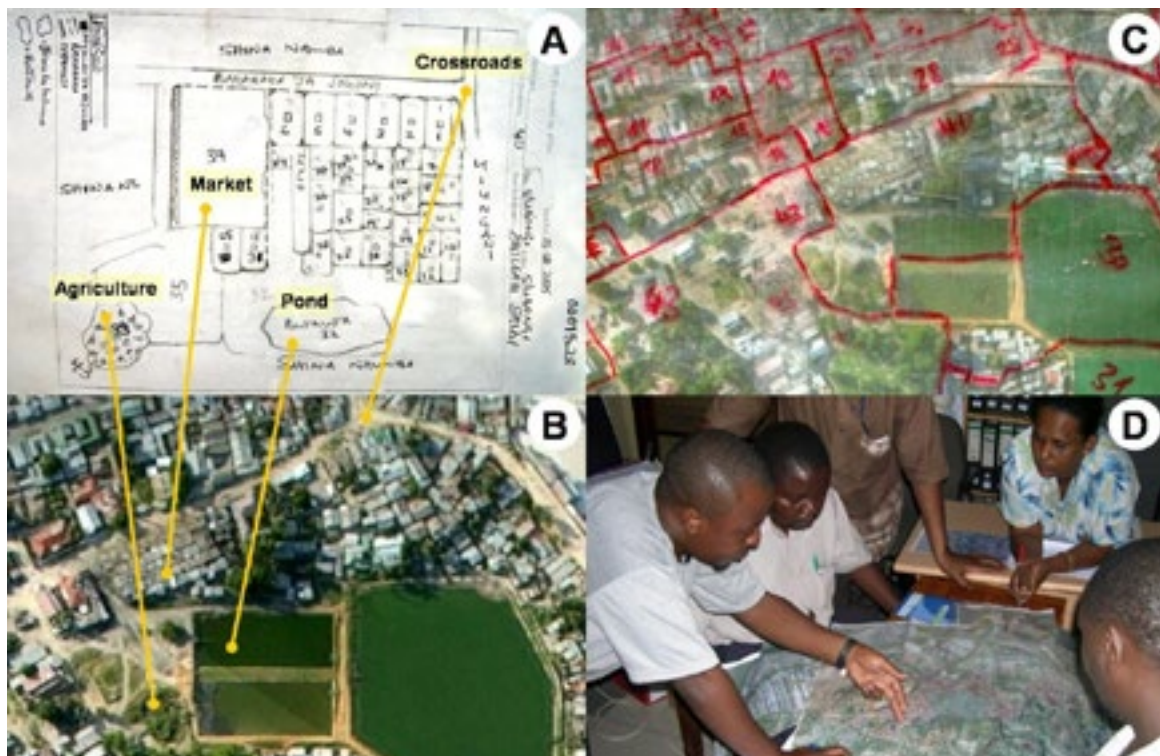
Stone Town



Two images showing drone photographs, the first shows the aerial photography alone, the second has waterbodies highlighted in red.

Source: extracted from Hardy et al. (113).

Fig. 5. Example of (A) sketch map, (B) aerial photograph, (C) field map and (D) programme planning from the Dar es Salaam Urban Malaria Control Programme



Four images showing a sketch map, an aerial photograph, a field map, and a group of planners from the Dar es Salaam Urban Malaria Control Programme.

Source: reproduced from Fillinger et al. (114).

Step 2: Divide target area into small implementation areas

The target area should be divided into small plots of land (grid mapping), each of which is assigned to a larval surveillance officer for larval surveillance. The size of the target area and plots depends on the terrain and the total number of habitats to be visited within a given time period (e.g., one week). For example, the target area size can vary from 0.5 km² to 5 km² per week in a rural area but may be smaller in an urban area due to the large number of potential artificial habitats. Plots must be small enough to enable unambiguous description of all habitats in the plot that can be easily identified by supervisors. Each plot can be described using a plot description form.

Step 3: Map all potential aquatic habitats

Each potential aquatic habitat found should be identified and documented using an aquatic habitat surveillance form (Annex 2), in conjunction with the plot description form and the area map. When an aquatic habitat is first identified, it should be assigned a unique number, which is retained even if it becomes dry. This may not be possible where many small potential habitats accumulate in a single area, such as small plastic discards in a domestic or community dump or unused tires in a junk yard. For these, one number can be assigned and the number of potential habitats can be estimated.

During the mapping process, each aquatic habitat (or group of habitats) should be described by habitat type, size (habitat perimeter < 10 m / 10–100 m / > 100 m) when water is at its largest extension and vegetation cover, since these can impact the choice of intervention and/or larvicide. When a habitat is revisited regularly, it is useful to note whether the habitat has changed from the last visit, if it is dry or wet on the date of the visit, the types of plants present (none/short/long/floating) and the depth of water (shallow/deep) (114). The volume of water should be noted if it can be estimated.

Decisions on the categories for aquatic habitat “type” should be tailored to the local vector ecology. In Dar es Salaam, United Republic of Tanzania, aquatic habitats for *Anopheles* vectors were classified according to the following 12 types (114): puddles and tire tracks; swampy areas; mangrove swamps, saltwater marshes; drains, ditches; construction pits, foundations, man-made holes; water storage containers; rice paddies; ridge and furrow agriculture; habitats associated with other agriculture; streams, river beds; ponds; and others. For the Dengue Action Response Team in north Queensland, Australia, 20 types were identified for *Ae. aegypti*, which include: rainwater tanks; roof gutters; fence posts or pipes; tarpaulin or black plastic; building construction material; earthmoving equipment; plant pot bases; drain taps; tires/rims; boats/cars; birdbaths/water features; pools/ponds; garden equipment/wheelbarrow; striking buckets; other small (< 2 L), medium (2–20 L) or large (> 20 L) containers; bromeliads; and palm fronds (116).

3.4.2 Baseline larval and adult surveillance

Baseline data on larval and adult populations should be collected ideally over the course of one year or throughout a full transmission season. If there are several transmission seasons, data collection should, at minimum, cover the primary transmission period. This will enable major aquatic habitats and vector species to be identified and LSM to be well planned and targeted. It also facilitates evaluation of the impact of the intervention. Details on conducting larval and adult *Aedes* and *Anopheles* surveys have been described in other documents, including the SOPs published by the Pacific Mosquito Surveillance Strengthening for Impact consortium (117).

3.5 Selecting interventions

More than one intervention can be implemented in an LSM programme, with different interventions targeting different aquatic habitats.

Wherever LSM is implemented, the order of priority for different LSM interventions should be as follows:

- Source reduction of aquatic habitats should be conducted wherever possible through direct action and community mobilization.
- Source treatment through larviciding or biological control should be conducted on those aquatic habitats that are not amenable to reduction.

Where larval sources cannot be effectively eliminated or altered, or during periods between the identification of the larval source and implementation of source reduction, treatment by larviciding or biological control can be used to control mosquito development in these habitats (Box 25).

Box 25. Selection of LSM interventions

Source reduction through container and waste management, environmental modification or environmental manipulation should, wherever feasible, be the primary methods to limit the availability of aquatic habitats of *Aedes* and *Anopheles* vectors.

Those habitats that cannot be (or are planned to be but have not yet been) controlled through these methods can be targeted with larviciding or biological control.

In general, these will be aquatic habitats that are relatively few, fixed and findable.

Therefore, source reduction is usually the priority LSM approach. Elimination of larval sources within the immediate vicinity of housing should be practiced whenever possible (118–120). This could focus on all potential habitats or could be targeted to known highly productive habitats (also known as key habitats or key containers), especially those located close to housing.

The decisions on which LSM interventions to implement, where and when are important and must be based on the specific setting. When choosing interventions, it is important to consider the following:

- **Efficacy and effectiveness:** will it reduce adult vector populations and reduce vector-borne disease transmission in the target area? Could biological challenges such as insecticide resistance undermine optimal impact?
- **Sustainability and scalability:** can implementation and impact be maintained beyond the pilot stage as an ongoing activity, and what are the implications of scale-up?
- **Cost:** what is the total cost for the product, labour, logistics (especially if frequent re-treatments or large capital expenditures are necessary) and M&E?
- **Cost-effectiveness:** how will it contribute to vector-borne disease transmission reduction in relation to other interventions?

- **Environmental impact:** can it have unintended negative impacts, e.g., does the water body provide a necessary water source for livestock or agriculture?
- **Community acceptance and engagement:** will there be any enablers or constraints to implementation related to community awareness, uptake, ownership, participation or compliance, and how can these be identified and managed?
- **Worker and community health safety:** are only WHO-prequalified larvicides being applied? What safety measures are in place for workers and community members if unintended exposure occurs?

3.5.1 Container and waste management

Management of habitats through their elimination or modification is used in most LSM campaigns and is particularly important for controlling container-inhabiting mosquitoes such as *Ae. aegypti* and *An. stephensi*. This management should generally be done before larviciding, such as through wide-scale community clean-up campaigns. There may also be significant lag time between planning and implementing source reduction, and rapid larviciding of highly productive habitats can be beneficial. Field teams would be expected to implement source reduction in conjunction with other LSM measures, such as larviciding, when visiting households. These activities should not only be limited to field teams but should also continuously involve the community wherever feasible.

Several methods are available for container and waste management, depending on the type and use of habitats and the water within them (examples provided in Table 6). Baseline surveys are needed to divide habitats into categories and/or types in order to develop clear guidance for field staff on the correct LSM approach(es) for each (121). This will also help to identify which are considered key habitats to prioritize for intervention if a targeted approach is to be taken (122). A proactive assessment of activities that encourage the creation of aquatic habitats could also be undertaken, with mitigation measures outlined.

The choice of intervention should be effective, practicable and appropriate to local circumstances. Community acceptance and household preferences will also govern which methods can be applied for the different habitat types.

Table 6. Examples of aquatic habitat categories and types for vectors common in some urban areas (including *Ae. aegypti*, *An. albopictus* and *An. stephensi*) and intervention options

Category	Aquatic habitat	Source reduction options	Source treatment options
Natural	Palm frond ^a		larvicide
	Bromeliad ^a	fill with sand	
	Tree hole ^a	fill with sand	larvicide
	Seashells	empty, move	
	Crab holes	fill	larvicide
	Coconut shells	empty, move	larvicide

Table 6. Examples of aquatic habitat categories and types for vectors common in some urban areas (including *Ae. aegypti*, *An. albopictus* and *An. stephensi*) and intervention options (cont.)

Category	Aquatic habitat	Source reduction options	Source treatment options
Large water storage containers	Rainwater tank	cover/add screen	larvicide, fish
	Well	cover/add screen	larvicide, fish
	Drum	empty, move, clean	larvicide, fish
	Cement tank	cover/add screen	larvicide, fish
	Cistern	cover/add screen	larvicide, fish
Small to medium containers	Bucket	empty, move, clean, turn over	
	Ice cream container	dispose, empty, move, turn over	
	Container, small	dispose, empty, move, turn over	
	Container, medium	dispose, empty, move, turn over, larvicide	
	Other plastic containers including rubbish	dispose, empty, move	
Household or garden implements	Lawn mower catcher	empty, move, turn over	
	Wheelbarrow	empty, move, clean, turn over	
	Garbage bin	empty, move, clean	
	Pots	empty, move	
	Kitchenware or utensils	empty, move	
	Refrigerator trays	empty, move	
	Animal water bowl	empty, clean, refill	
Water features or decorations	Pool	clean	larvicide
	Spa	clean	larvicide
	Pond		larvicide, fish
	Birdbath	tip out, turn over	larvicide
	Other water feature		larvicide
	Self-watering pots	fill outlet with sponge	larvicide
	Pot plant bases	remove, fill with sand	
Unintended water accumulation	Roof gutter	unblock	larvicide
	Boat	empty, move	larvicide
	Car body		larvicide
	Disused septic tank	cover/add screen	larvicide
	Drain sump or pit		larvicide
	Concrete slab	drain	larvicide
	Post		larvicide
	Black plastic/tarp	empty, move, dispose	
	Esky/chill box	empty, move, turn over	
	Unused tires	move, cover with tarp	larvicide

^a Collectively termed phytotelmata.

Source: adapted from Pacific Mosquito Strengthening for Impact (123).

Improvement and maintenance of urban infrastructure and basic services contribute to the reduction of available aquatic habitats, as large mosquito populations are often associated with poor water supply and inadequate sanitation and waste disposal services.

Improvement of water supply and water storage systems

Improving water supply is a fundamental method of controlling *Aedes* vectors, especially *Ae. aegypti*. To prevent water storage at the household level, water piped to households is preferable to water drawn from wells, communal standpipes, rooftop catchments and other water storage systems. However, potable water must be supplied reliably so that water storage containers that serve as aquatic habitats – such as drums, overhead or ground tanks, and concrete jars – are not necessary.

Mosquito-proofing of water storage containers

Water storage containers can be designed to prevent access by mosquitoes for oviposition. Containers can be fitted with tight lids, or, if rain-filled, tightly fitted mesh screens can allow rainwater to be harvested from roofs while keeping mosquitoes out. Removable covers should be replaced every time water is removed and should be well maintained to prevent damage that permits mosquitoes to get in and out. Expanded polystyrene beads used on the surface of water provide a physical barrier that inhibits oviposition in storage containers; water for household use can be drawn from below the surface from containers via a pipe with no risk of overflow. These beads can also be placed in septic tanks, which are sometimes exploited by *Ae. aegypti*.

Solid waste management

In the context of dengue vector control, “solid waste” refers mainly to non-biodegradable items of household, community and industrial waste. The benefits of reducing the amount of solid waste in urban environments extend beyond vector control, and applying many of the basic principles of waste management can contribute substantially to reducing the availability of *Ae. aegypti* aquatic habitats. Proper storage, collection and disposal of waste are essential for protecting public health. The basic rule of “reduce, reuse, recycle” is highly applicable. Efforts to reduce solid waste should be directed towards discarded or non-essential containers, particularly if they have been identified in the community as important mosquito-producing containers (Box 26). Solid waste should be collected in plastic sacks and disposed of regularly. The frequency of collection is important: Twice per week is recommended for housefly and rodent control in warm climates. Integration of *Ae. aegypti* control with waste management services is possible and should be encouraged.

It is also important to provide information on these activities to encourage and promote their uptake. Globally, recycling is on the increase. This practice places value on many items previously classified as waste products, leading to growth in the recycling market and profit for both small and large-scale businesses. However, although recycling can contribute to significant economic improvements, the recycling market can potentially have an impact on dengue vector populations. For there to be an impact, however, containers of importance must have value in the marketplace, be it real (e.g., plastics or tires for recycling) or created (e.g., beverage container deposit laws), and advertising and promotion must be sustained.

Box 26. The impact of proper waste management in India

In Thiruvananthapuram, Kerala, India, evaluation of solid waste management practices and the incidence of vector-borne diseases across 20 municipal wards indicated that areas with inadequate waste disposal and irregular garbage collection experienced higher rates of diseases such as dengue. The study emphasized that proper waste management, including timely collection and elimination of water-holding containers, is crucial for reducing mosquito aquatic habitats and controlling disease transmission (124).

Street cleansing

A reliable and regular street cleansing system that removes discarded water-bearing containers and cleans drains to ensure that they do not become stagnant and breed mosquitoes will help to both reduce aquatic habitats of *Ae. aegypti* and remove the origin of other urban pests.

Building structures

During the planning and construction of buildings and other infrastructure, including urban renewal schemes, and through legislation and regulation, opportunities arise to modify or reduce potential aquatic habitats of urban disease vectors, including *Ae. aegypti*, *Culex quinquefasciatus* and *An. stephensi* (Box 27).

Box 27. The impact of legislation on habitat reduction in Singapore

Under revised legislation in Singapore, roof gutters are not permitted on buildings in new developments because they are difficult to access and maintain. Moreover, property owners are required to remove existing gutters on their premises if they are unable to maintain them satisfactorily.

3.5.2 Environmental (habitat) modification and manipulation

Environmental modification is a permanent alteration to the environment, including landscaping, surface water drainage, filling and land reclamation, coverage of water storage containers with mosquito-proof lids or permanent slabs, and coverage of the water surface with a material that is impenetrable to mosquitoes (e.g., expanded polystyrene beads). This can also involve ensuring that culverts are included in road construction and that borrow pits or rock quarries used for brick making and gravel are filled or drained.

Environmental manipulation is a recurrent activity, including water level manipulation (e.g., stream flushing, keeping drains clear of vegetation so that water flows too fast to support mosquitoes).

If the major aquatic habitats can be dealt with through environmental modification and manipulation, this is likely to have a significant impact on the intensity of transmission. Despite high short-term costs, these interventions can be economical in the long term due to the longevity of protection, especially if costs can be shared across sectors (Box 28).

Sectors responsible for water resources and cultivation – particularly where irrigation is used – can play a critical role in managing potential mosquito aquatic habitats. Maintaining adequate flow within irrigation channels, such as by identifying and clearing blockages or managing reservoir outflows, can make downstream water bodies unsuitable for mosquito egg laying and larval development. Rapid drawdown of reservoir water levels can expose and dry out potential habitats along the shoreline, while raising water levels can drown or wash larvae away from vegetation at the edges. In some contexts, clearing vegetation from the margins of water bodies removes shelter that protects mosquito larvae from predators, although this is labour-intensive and can have negative ecological impacts.

Construction sites can also create unintended *Anopheles* or *Aedes* aquatic habitats. Excavated pits, ruts and ditches often collect rainwater; water stored on site for mixing materials can stagnate; and discarded items such as tires and buckets can hold water. Vector control programmes can collaborate with construction managers to promote site management practices that reduce or prevent the formation of standing-water habitats.

Local communities also play a vital role in modifying and managing potential *Anopheles* and *Aedes* immature habitats. Mobilizing and educating communities to identify and remove these habitats is an important vector control measure, particularly because residents can address habitats near their homes. Additional benefits include improved sanitation and the reduction of habitats for other disease vectors and nuisance mosquitoes.

Box 28. Successful environmental management in Zambia

Malaria was controlled in Zambian copper mines between 1929 and 1949 using vegetation clearance from the drains, river straightening, swamp drainage, oiling, house screening, some quinine prophylaxis, and a limited number of untreated bednets. The estimated cost of environmental management was US\$ 858 per death averted, which falls within the range documented for ITNs (US\$ 219–295) – assuming that the duration of effectiveness for environmental management is 10 years and three years for ITNs (109).

3.5.3 Larviciding

Larviciding encompasses the use of pesticide formulations (chemical or biological) to inhibit the emergence of adult vectors from the larval stage through chemical and physical modes of action. Larviciding programmes include the regular application of pesticide products to natural or artificial (container) water bodies that may serve as vector habitats. The impact of larviciding programmes to reduce local vector populations can be enhanced through optimizing:

- **product selection** for the scenario, considering types of water bodies, vector species, their resistance profiles and immature stages to be targeted, and residuality needs; and
- **product application** through blanket or targeted coverage of potential aquatic habitats, quality of application, and continuity of reapplication throughout the seasons of vector activity.

Types of water bodies and associated chemical and organic matter characteristics, intended use (consumption, cleaning, storage) and environmental factors

(temperature, food supply, light exposure) are important considerations in developing a larviciding programme (10).

Larviciding can be an attractive method for new or ongoing malaria control programmes, especially initiatives to address the emergence or spread of *An. stephensi*. The costs of larviciding may compare favourably with those for IRS and ITNs, especially in areas where malaria transmission is moderate and focal and where *Anopheles* aquatic habitats are accessible and discrete. In many areas of the world, larviciding is a key method for the prevention of dengue or other *Aedes*-borne diseases and is usually coupled with source reduction.

Intensive surveillance and treatment systems are required to maintain effective coverage of all potential aquatic habitats. Quality control and safety for **all** vector control products are critical elements of any vector-borne disease control programme. Poor-quality or non-prequalified products can waste financial resources and harm the environment. Routine application of larvicides by vector control personnel can reinforce the community perception that the government is responsible for all aspects of vector control and that residents have little or no responsibility. Therefore, engagement and mobilization of the community is encouraged before, during and after larviciding campaigns (see Chapter 4). Personnel involved in larviciding can serve as ambassadors for mosquito control and can often educate community members about their role in the process.

Selecting larvicides

Currently, there are five main groups of larvicides: oils and surface agents; synthetic organic chemicals; bacterial larvicides; spinosyns; and IGRs. WHO includes the evaluation of larvicide products as part of the procedures for the prequalification of vector control products, which involves the evaluation of the safety, quality and efficacy of each product submitted for assessment. The published list of WHO-prequalified vector control products presents the latest information on prequalified larvicide products and should be referred to when identifying products for consideration (44).

The selection of formulation type/product should be informed by several factors including, but not limited to:

- susceptibility of the target species to the active ingredient(s);
- regulatory status within the country or WHO prequalification status;
- aquatic habitat type and size;
- cleanliness of the water (if this can impact efficacy);
- extent and density of surrounding vegetation (if this can impact efficacy);
- target specificity;
- application flexibility of formulation;
- desired residual activity;
- ease of use;
- resources and equipment available versus those needed for deployment;
- worker safety;
- storage stability and requirements;
- shelf life;

- transport requirements; and
- total programme cost calculated as “per person protected per day or per year” (not simply based on purchase price per mass or volume of product).

It is important to note that not all larvicides are appropriate for use in drinking water or containers that may contain drinking water. Only those larvicide products that have been assessed and registered for use in drinking water in accordance with local, national or regional regulatory requirements should be used. These may potentially include formulations with the following active ingredients: Bti, Bs, diflubenzuron, novaluron, pyriproxyfen, spinosad, polydimethylsiloxane or temephos.

For those programmes planning to apply larvicides to drinking water, the WHO publication *Guidelines for drinking-water quality* (125) provides further relevant information, including safety assessments for different active ingredients and additional considerations for young children and bottle-fed infants.

As of January 2025, three larvicide products (two with pyriproxyfen and one with polydimethylsiloxane) with proposed directions for use in treated drinking water have been prequalified by WHO. More larvicide products with a proposed use in drinking water may be included in the list of prequalified vector control products if data are submitted by their manufacturers for WHO assessment and the supporting information demonstrates that the product and its uses meet the WHO standards for quality, safety and efficacy.

All products should be used in accordance with label recommendations. Larvicide formulations and the advantages and disadvantages of different options are provided below (126, 127).

Formulations

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

- aqueous concentrate (AC): water-insoluble insecticide suspended in water;
- emulsifiable concentrate (EC): solution of an insecticide in a liquid solvent that is applied by pouring or spraying over the water surface, most often using a portable sprayer; most commonly used formulations for organophosphates;
- suspension concentrate (SC): solid water-insoluble pesticides suspended in water to produce a flowable liquid product, which is applied undiluted or diluted with water depending on the active ingredient/formulation and application needs;
- water dispersible granule (WG): granules to be applied after disintegration and dispersion in water; 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 (GR): a free-flowing solid formulation of a defined granule size range ready for use, which allows for more direct penetration of dense aquatic vegetation than with liquid formulations; applied typically with portable blowers or by hand;
- matrix release (MR): a solid formulation that holds the active ingredient internally for gradual release into the aquatic habitat over time, possibly in the form of a disk or briquette designed for placement in the larval source.

Advantages and disadvantages

A brief description and the main advantages and disadvantages of each option are outlined below.

Synthetic organic chemicals

Organochlorine insecticides were discovered in the 1940s, leading to their widespread adoption for larval control. However, resistance emerged in the 1950s (2), and for this reason, as well as the discovery that these chemicals persist in the soil and tissues of plants and animals, they are no longer recommended for the control of larvae.

Organophosphates are synthetic organic chemicals that can kill mosquito larvae by interfering with the enzyme acetylcholinesterase, which is required to regulate nerve transmission in all organisms. Organophosphates are considered less persistent in the environment than organochlorine insecticides, and WHO considers certain insecticides within this class to be appropriate for vector control. Proper use in vector control poses low risks to human health, but careful assessment and monitoring are recommended. In particular, staff require training on how to correctly handle the concentrated material.

The organophosphate temephos is a brown, viscous liquid that is stable at ambient temperatures and effective in clean, moderately and heavily polluted water. It has been used extensively as a larvicide against blackfly larvae in the Onchocerciasis Control Programme in West Africa, against copepods in the Guinea Worm Eradication Programme, and against *Aedes* larvae in domestic water storage containers in dengue control programmes.

Pirimiphos methyl is an organophosphorus compound that is effective against many insects, including larvae, and has a long residual effect. It is relatively unstable in polluted water.

Pyrethroids may select for insecticide resistance in mosquitoes and are toxic to fish. Therefore, they must not be used for control of mosquito larvae (125).

Advantages:

- Operations can be carried out quickly.
- Larvicides can be applied with hand-held equipment for small-scale treatments.
- For large-scale treatments, agricultural sprayers or IRS hand-compression spray pumps may be used.

Disadvantages:

- Frequent reapplication may be required for shorter lasting formulations.
- Some larvicides are harmful to non-target organisms, including the natural predators of larvae.

Bacterial larvicides

Bacterial larvicides include products based on the insecticidal crystal proteins produced by Bti and Bs. Upon ingestion by mosquito larvae, these proteins are modified by enzymes in the larval midgut and bind with specific receptors on the midgut epithelium, resulting in pore formation and interruption of feeding and

homeostasis. This unique mode of action accounts for the specificity of bacterial larvicides and their utility in managing mosquito resistance to chemical insecticides.

When manufactured under proper controls and applied properly, bacterial larvicides present essentially no risk to the environment, workers, public health or local economies (114). The frequency of re-treatment with bacterial larvicides can range from one to four weeks for *Anopheles*, depending on the formulation, habitat, temperature and species. The typical re-treatment interval for Bti is 7–10 days. For maximum efficiency, the re-treatment interval should be determined by recovery of late fourth instar larvae to established thresholds or the first appearance of pupae. Bs formulations have been demonstrated to provide longer residual activity, with up to four-week re-treatment intervals in some habitats. Bti is effective where insects have developed resistance to synthetic and/or biochemical larvicides.

Bs is also a naturally occurring, spore-forming bacterium found in soil and aquatic environments throughout the world. Bs is more target-specific than Bti and can provide longer residual control than Bti in highly organic environments such as catch basins, sewage, waste lagoons, animal waste ponds and septic ditches. Possible explanations for the residual effect of Bs include recycling through germination, growth and new spore formation in the larval gut, non-target insect redistribution and the high buoyancy framework of the spore-crystal complex.

Bacterial larvicides differ from conventional chemicals or biochemicals in that identical strains produced under different conditions by different manufacturers will vary in their end-use product quality and biological performance. It is important to use WHO-prequalified bacterial larvicide products with specific strain numbers to ensure biological and performance equivalency (44).

Advantages:

- Operations can be carried out quickly.
- At the recommended doses, there is low toxicity to fish, birds, mammals and humans, and insects other than Diptera-Nematocera.
- They are safe for use in multiple habitats, including in drinking water and on irrigated crops.
- They are effective where mosquitoes have developed resistance to synthetic chemical larvicides.
- Extensive bacterial larvicide formulation options allow for various efficacy and residual objectives at the IVM programme level.

Disadvantages:

- Depending on the habitat type, the window of time for application may be narrower than for synthetic chemicals, as bacterial larvicides should be applied when larvae are present and actively feeding.
- Larvae must be feeding when the bacterial larvicide is present for it to be effective. (For mosquitoes, this is the first to the middle fourth instar; very late fourth instar larvae cease feeding as they prepare for pupation).
- In open, natural habitats, Bti breaks down quickly in the environment, so more frequent applications may be needed.

Spinosyns

Spinosad consists of spinosyn a and spinosyn d, which are metabolites extracted through fermentation using the bacterium *Saccharopolyspora spinosa*. Spinosad acts as a nicotinic acetylcholine receptor allosteric activator. It is available as an emulsifiable concentrate, dispersible tablets, granules and suspension concentrate, and has very low acute toxicity to mammals.

Advantages:

- Operations can be carried out quickly.
- There is low toxicity to fish, birds and mammals at the recommended doses.
- They are safe for use in multiple habitats, including in drinking water and on irrigated crops.
- No cross-resistance with synthetic chemical larvicides has been demonstrated.

Disadvantages:

- They are also used for agricultural pests, so agricultural products (with different formulations or concentrations) may be incorrectly repurposed for public health.
- They are not as target-specific as bacterial larvicides.
- They are toxic to non-target aquatic invertebrates and beneficial arthropods (e.g., bees).

IGRs

IGRs belong to two groups:

- Juvenile hormone mimics, such as methoprene and pyriproxyfen, prevent the development of larvae and pupae into adults.
- Chitin synthesis inhibitors, such as diflubenzuron and novaluron, kill larvae when they moult.

These products affect a broader range of invertebrate species than bacterial mosquito larvicides do and may exert a broader effect on ecosystems. Their use is therefore preferred in habitats that contain mosquito larvae and pupae but few other arthropods. More frequent re-treatment may be required certain IGRs, such as juvenile hormone mimics. In general, the efficacy of IGR formulations may last longer if applied as granules, microcapsules or briquettes in specific habitats (e.g., natural and artificial containers). The re-treatment interval may be longer relative to other larvicides.

Advantages:

- Operations can be carried out quickly.
- Long-lasting residual impact in specific habitats reduces the frequency of re-treatment.
- They are highly effective at extremely low dosages.
- They are safe for use in drinking water, and irrigated crops that have been treated can be safely eaten.
- They are effective where mosquitoes have developed resistance to synthetic chemical larvicides.
- There is very low toxicity to mammals, birds, fish and adult insects.

Disadvantages:

- High dosages (e.g., when accidentally overdosed for mosquito control) can be toxic to the immature aquatic stages of some non-target insects and to some crustaceans.
- The impact of treatment with hormone mimics is very difficult to monitor for the immature stages because larvae develop normally, and the impact can only be observed after evaluating adult emergence from pupae. Therefore, monitoring systems will need to be set up specifically for IGRs, as monitoring the effect of larvicides on mortality of larvae within 48 hours will not capture the full impact of IGRs.

Oils and surface films

These agents include petroleum distillates and monomolecular surface films such as isostearyl alcohol made from renewable plant oils or polydimethylsiloxane. Neem, an oil extract of seeds of the neem tree *Azadirachta indica* (larvicidal), has also been used.

These products form a very thin film on the water surface and act by inhibiting the ability of larvae to rest and breathe at the surface of the water, causing them to drown and interfering with adult emergence. Some products may also deter gravid females from laying eggs on treated surfaces. The efficacy and duration of efficacy of products of this larvicide type may be affected by wind or absorption by vegetation. These agents may affect other aquatic invertebrates that use the air–water interface for breathing, resting or egg laying. Non-target organism assessments may be appropriate when considering use of these products. Re-treatment is needed, usually weekly.

While there has been no evaluation of its wide-scale use against malaria or *Aedes*-borne diseases, the application of oil to water is one of the oldest forms of larval control. Monomolecular surface films were developed in the 1980s, and while several isostearyl alcohol products are available, they have not been used extensively in mosquito control programmes. Due to limited persistence, which necessitates re-treatment, and the associated relatively high cost in comparison to some other larvicides, their use has declined in mosquito control.

Advantages:

- Oil is visible on water, so it is easy to see where it has been applied.
- Oil is a relatively cheap and easy method of larval control for small water bodies such as borrow pits, pools, latrines and soak-away pits.
- Mosquitoes cannot develop resistance to oil.
- At recommended doses, oils and monomolecular surface films are not toxic to most non-target organisms, including mammals and fish.
- Combinations of monomolecular surface films with other larvicides such as Bti may significantly increase their efficacy.

Disadvantages:

- Monomolecular films may be difficult to see on water, so it is hard to know where they have been applied.
- They are expensive for large-scale treatment.
- Effectiveness is limited in the presence of vegetation and floating debris.
- Some may have relatively short-lived effect.

- Oils and monomolecular surface films can coat vegetation and may cause phytotoxicity.
- Oils and monomolecular surface films are readily dispersed by wind.

Fungi

The potential use of fungi to control mosquito larvae (and adults) has been investigated for numerous genera, including *Anopheles*, *Aedes* and *Culex*. Examples of entomopathogenic fungi considered for larviciding include *Metarhizium anisopliae* and *Beauveria bassiana*. These act through attachment to the larval body or through ingestion, which has been shown to increase mortality and delay larval development. While these tools are promising, evidence has been limited to laboratory and semi-field trials and has been insufficient to enable assessment of public health value. Additional research and evaluation will be required to inform the selection and incorporation of fungal-based larvicides into LSM campaigns for malaria and *Aedes*-borne diseases.

RNA interference

RNA interference represents a new class of biorational with the potential for public health vector control, particularly to mitigate the emergence and spread of vector insecticide resistance. Bacteria, yeast, algae and viruses can be employed to deliver RNA interference triggers to insects, such as through the release of lethal algae in confined natural waters that are common habitats of target vectors. Further evaluation of this approach using locally available microbial (e.g., algal) species is required in different settings to determine the potential for control of vector species and impact on the diseases they transmit.

Biological control

Biological control is the introduction of natural enemies into aquatic habitats, including predatory fish, predatory invertebrates, parasites and other disease-causing organisms. Biological control can be used for vector control in settings where aquatic habitats are well defined, water conditions are suitable, and chemical larviciding is not suitable (3). It is preferable to use indigenous species over exotic species, as they are adapted to the local environment and there is no risk of invasion.

Biological control agents include:

- larvivorous fish (predatory);
- *Toxorhynchites* spp. mosquito larvae (predatory);
- dragonfly larvae (predatory);
- diving beetles (Dytiscidae) (predatory);
- water boatmen (Corixidae) (predatory);
- backswimmers (Notonectidae) (predatory);
- cyclopoid copepods (predatory);
- nematode worms (parasitic);
- fungi (grow in the bodies of mosquito larvae and kill them); and
- *Azolla*, a free-floating fern that can completely cover water surfaces (usually prevents immature development).

The efficacy and cost-effectiveness of biological control is not well established and can differ widely between interventions, settings and implementation modes. Biological control can be combined with other interventions, such as habitat manipulation

and bacterial larvicides that do not harm the biological control agents. However, the use of biological control agents requires a thorough understanding of the local vector ecology. Use of larvivorous fish can be cost-effective, as demonstrated in Afghanistan and California, United States of America, especially where the local community is involved in maintaining fish stocks (128). Introduction of the larvivorous *Poecilia reticulata* fish into wells in Sri Lanka has been used to address incursive *An. stephensi*, although there is no available information on disease impact or cost-effectiveness (50). Wherever fish or other means of biological control are introduced into aquatic habitats, the impact should be assessed. There should be no intervention without evaluation.

Advantages:

- 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 for releases.
- Fish do not contaminate the environment and can be used in drinking water reservoirs.

Disadvantages:

- Natural predators are only effective if a large number of them become established. They may never provide comprehensive control (i.e., mosquito populations may be sustained at low levels), and 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.
- The 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 enough scale to evaluate their effectiveness.

3.6 Developing a plan of action

LSM must be tailored to the local setting. Wherever practical, priority should be given to source reduction through receptacle management and environmental modification or manipulation. Larviciding and biological control can be conducted if baseline data on aquatic habitats have been collected and an M&E system has been set up. Multiple LSM interventions can be applied in conjunction. Identification of appropriate interventions relies on a clear understanding of potential and actual aquatic habitats and their relative importance in the production of adult mosquito vectors of the disease targeted for control.

By the end of the initial planning process, an action plan should have been developed that indicates:

- geographical area targeted for LSM;
- rationale for applying LSM in the specific location, such as resistance to pyrethroids, outdoor or daytime biting, lack of ITN acceptance, etc.;
- target population to be protected;
- number and location of households to be targeted;
- number of locations for LSM implementation;
- disease burden and seasonality;
- target vectors and nature of larval sources;
- total area to be treated and frequency of treatment;
- organizational structure, including division of responsibility for interventions and M&E;
- methods of data management (i.e., GIS);
- surveillance methods for source identification and M&E;
- type, number, size and location of aquatic habitats;
- LSM methods to use;
- larvicide products required and quantities of each;
- frequency of visits;
- material, logistical and human resources needs, including for the supply chain, importing and warehousing of materials;
- general plan of events and specific time lines; and
- required budget.

The “Race to the starting line” tool provides a useful guide for developing a schedule of milestones that should be achieved to successfully begin campaign activities on an agreed start date. An adapted version is provided in Annex 3.

4. Conducting LSM

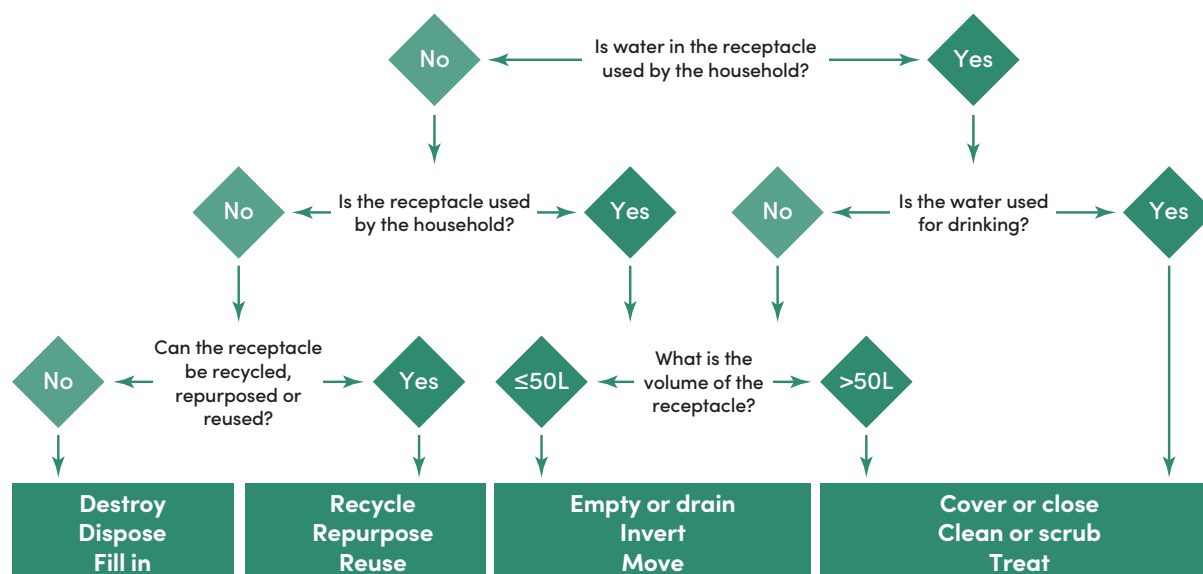
This chapter describes how to implement the five types of LSM outlined in the previous chapters: container and waste management, environmental modification, environmental manipulation, larviciding and biological control. Chapter 3 provides details regarding the considerations in deciding which LSM interventions (if any) are appropriate.

4.1 Container and waste management

Given the large number of options for managing artificial receptacles, field staff must be provided with clear information on how to manage each container type. This information should ideally consider the relative productivity of different container types and prioritize key habitats.

An example flowchart is provided in Fig. 6. This may be adapted for use by field teams depending on local conditions, such as key habitats.

Fig. 6. Example simple schematic of methods to manage habitats of container-inhabiting vectors such as *Ae. aegypti*



Box 29. Examples of regulations to promote container management on private properties

Singapore's historic success in controlling *Ae. aegypti* populations has been largely attributed to its robust legal framework. The country enforces the Control of Vectors and Pesticides Act, which empowers authorities to conduct inspections, issue fines, and mandate the elimination of mosquito aquatic habitats on private properties. This legislation ensures community compliance and facilitates proactive measures to prevent dengue outbreaks.

In Brazil, regulations to control the proliferation of *Ae. aegypti* focus on immature control in residential and public buildings. Health authorities have enforced rules requiring covered water storage and regular inspections to eliminate standing water. In certain states, penalties are imposed if homeowners or building managers fail to maintain water tanks and other structures.

4.1.1 Solid waste management

Integrating mosquito control with waste management services, such as those provided by the local council or municipality, is encouraged.

Used tires are common and sometimes highly productive aquatic habitats that may warrant special attention in urban areas. Discarded tires should be collected, recycled or disposed of according to local regulations. The sale of new tires may be regulated to encourage better management and disposal of old tires, such as by incorporating a disposal fee or deposit for reimbursement upon return. Tires can be recycled in a variety of ways, including for use as shoe soles, flooring, industrial rubber gaskets or household hardware (e.g., buckets, rubbish bins). Industrially shredded tires can be incorporated into road surfacing materials.

4.1.2 Improved water supply and storage systems

In urban areas, the use of cost-recovery mechanisms, such as the introduction of metered water, may encourage household collection and storage of roof catchment rainwater that can be harvested at no cost, resulting in the continued use of storage containers. Traditional water storage practices may also persist even when reliable supply is available. The installation of reliable piped water supply in houses should therefore be accompanied by a communication strategy that discourages traditional storage practices.

4.1.3 Built environment including street cleansing

Poor drainage, unmanaged construction and inadequate waste management can cause the proliferation of vectors. During the planning and construction of buildings and other infrastructure, including urban renewal schemes, and through legislation and regulation, opportunities arise to modify or reduce potential aquatic habitats of urban disease vectors, including *Ae. aegypti*, *An. stephensi* and *Culex* mosquitoes (Box 29).

Certain construction options can have a significant impact on the productivity of potential vector habitats (Box 30). For instance, in urban areas where domestic harvesting of rainwater is essential, the system to channel rainwater to storage wells or underground tanks from rooftops can be designed in a "V" shape, which would ensure the proper gradient for free flow of water and prevent vector development.

The WHO and UN-Habitat framework for responding to malaria in urban areas emphasizes the importance of LSM in the built environment by integrating vector control into urban planning and infrastructure development (7).

Box 30. Regulations for building projects in Singapore

Singapore has strict regulations under the Environmental Public Health Act and the Control of Vectors and Pesticides Act, which require proper maintenance of building structures to prevent mosquito proliferation. Buildings must have effective drainage systems, regular gutter maintenance, and no open containers or stagnant water areas. During construction, developers must take measures to prevent water from pooling on construction sites, and regular inspections are mandated to enforce compliance.

4.1.4 Filling in

Unused wells with stagnant or slow-moving water can create ideal habitats for some species of *Anopheles* and *Aedes* larvae due to minimal surface disruption and limited predator presence. These can be filled with locally available materials, such as sand, gravel or clay, to remove the water, or they can be sealed with a tight-fitting permanent cover to prevent mosquito egg laying and hatching (Box 31). For wells that must remain functional, larviciding or covering the well opening with a mesh screen can be effective approaches. In areas where there are numerous disused wells, a programme can be initiated in collaboration with municipal councils or public works to fill them in.

Box 31. Examples of filling in aquatic habitats in Kenya and Sri Lanka

In Kenya, abandoned fishponds often become highly productive aquatic habitats that could be readily filled in (129). Health considerations need to be factored into any development projects that involve water.

In response to the detection of *An. stephensi* in Sri Lanka, particularly in urban areas where this vector thrives, the Anti-Malaria Campaign implemented targeted environmental management strategies to prevent the re-establishment of malaria transmission. One such strategy involved the systematic filling in of potential aquatic habitats, such as unused wells, abandoned containers and other water-holding structures commonly found in urban settings. This proactive approach aimed to eliminate habitats conducive to the development of immature mosquito stages, thereby reducing the risk of malaria resurgence. These efforts were part of a broader IVM plan designed to maintain Sri Lanka's malaria-free status (50).

4.2 Environmental (habitat) modification

Habitat modification involves alteration of the environment to eliminate aquatic habitats. This type of modification has been defined in more detail as “a form of environmental management consisting in any physical transformation that is permanent or long-lasting of land, water and vegetation, aimed at preventing, eliminating or reducing the habitats of vectors without causing unduly adverse effects on the quality of the human environment” (3). The majority of content in this section has been extracted from the WHO publications *Manual on environmental management for mosquito control* (3) and *Vector control: methods for use by individuals and communities* (126).

Environmental modification can be a key component of LSM for *Anopheles* vector control, and before the advent of pesticides, it was the major method for malaria vector control. The engineering techniques for drainage and surface water management have been well developed and documented over the past century. More details on the techniques of environmental modification are provided below regarding impoundments, irrigation systems and natural streams; landfilling and grading; drainage; and well filling. Some of these activities are not usually core functions of vector-borne disease control programmes but fall to other sectors such as the public works departments (particularly water and waste management), ministries of agriculture and housing, and local government authorities.

In line with the Global Vector Control Response (4), it is strongly encouraged that every ministry of health (or equivalent) establish a multisectoral committee that may include representatives from the vector-borne disease control programme, as well as from the ministry of agriculture, ministry of the environment, public works, and other ministries and municipal agencies that may be involved with surface water management, road building, urban drainage and construction (including public, residential and business). Through the national IVM committee, the vector-borne disease control programmes should ensure that the principles and techniques of LSM, especially environmental modification, are known and adopted by other relevant agencies and departments involved in IVM efforts. Vector-borne disease control programmes should continue to work closely with these sectors to ensure implementation and to monitor the progress and impact of interventions against vector populations. An example of respective responsibilities for habitat modification by different agencies is provided in Table 7. Note that this table does not cover over interventions, e.g., larviciding.

Table 7. Partner responsibilities for habitat modification based on habitat type

Potential habitat type	Modification action	Example responsible agencies				
		Community	Water department	Municipality	Public works	Roads and transport authority
Residential blocks						
Wastewater evacuation/ septic tank without closure	Secure and block	●		○		
Open latrine/without closure	Close with slab	●		○		
Abandoned house	Demolish and fill	●		○		
Streets and access roads						
Main water supply network leak	Repair		●			
Secondary water supply network leak	Repair		●			
Wastewater collection	Extend	○	●			
Sewage network backup	Repair or clean	○	●			
Sewage pit backup/leak	Empty	●	○			
Stormwater collection on road surface	Fill and level					●
Stormwater collection on roadside	Fill and level					●
Unfilled trench or excavation	Fill and level					●
Uninhabited lots or lands						
Waste dump with water collections	Remove waste				●	
Tire dump	Remove waste				●	
Flooded excavation or filling zones	Fill and level			●		○
Construction pits (e.g., from brick production)	Fill and level			●	○	
Trench networks	Fill and level		●	○	○	
Abandoned wells	Fill		○	●		
Rural, farming or livestock areas						
Abandoned wells or pits	Fill	●				
Pits or trenches (e.g., around rice paddies)	Fill	●				

● indicates the preferred agency; ○ indicates other key agencies.

Source: adapted from the National Institute of Public Health, Dibouti (130).

4.2.1 Impoundments

Impoundments are water reservoirs stored behind dams, used for irrigation, supply of potable water or hydroelectric power. Well constructed dams will generally reduce malaria mosquito populations, as small aquatic habitats become amalgamated into one large, deep reservoir. Such reservoirs are generally not conducive to immature development, except where water is shallow at the margins or where there is floating vegetation that shields larvae.

Several 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; if reservoirs are not deep enough, high evaporation rates and drying can potentially leave behind shallow water conducive to being aquatic habitats. If possible, shallow bays should be deepened, for example, via a “cut and fill”, approach (see Fig. 7 for more detail). If this is not feasible, then large, shallow bays may be isolated using dikes and the land reclaimed through drainage (Box 32).

Small pools at reservoir margins should be drained and vegetation cleared from the sides. Reservoir margins should be as straight as possible to restrict their length. Off-takes from the reservoir of greater size than normal 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.

Box 32. Environmental engineering approaches by the Tennessee Valley Authority

The Tennessee Valley Authority, United States of America, implemented a range of environmental engineering approaches to reduce mosquito populations around its hydroelectric reservoirs, particularly targeting *Anopheles* mosquitoes associated with malaria transmission. Key strategies included reshaping reservoir margins to minimize shallow water zones by deepening or isolating them using “cut and fill” methods or diking off large, shallow bays. Margins were kept as straight as possible to reduce perimeter length and potential aquatic habitats. Vegetation around reservoir edges was removed, and small pools or seepage areas near dam bases were drained to eliminate standing water. The Tennessee Valley Authority also employed controlled water level fluctuations, using large off-takes to rapidly lower reservoir levels and strand larvae, while the discharged water was used to flush downstream irrigation channels. These practices formed an early example of large-scale habitat modification to support IVM. Power companies in the south-eastern United States of America have maintained mosquito control programmes as part of broader environmental management practices aimed at reducing mosquito populations around hydroelectric reservoirs. These practices target “blind coves” – small, sheltered inlets along reservoir margins that serve as residual habitats for *Anopheles* mosquitoes. These coves are easily accessible by boat, allowing for cost-effective larvicide application.

Fig. 7. "Cut and fill" project at Eagle Creek, Kentucky reservoir, Tennessee Valley Authority, 1947



A map showing the Kentucky reservoir and areas planned for environmental management.
Source: WHO *Manual on environmental management for mosquito control* (3).

4.2.2 Irrigation systems

Irrigation is the application of water to the ground to maintain soil moisture at levels required for crop production. However, poor design of irrigation systems is often associated with increased aquatic habitats for malaria vectors; for example, improper grading can cause water fluctuations at the margins (Box 33).

Box 33. Summary of features that make irrigation systems less conducive to vector breeding (see Fig. 8)

- use of safer irrigation methods such as mechanized or localized sprinkler irrigation;
- use of closed underground pipes rather than open canals to convey water;
- canal lining;
- good canal maintenance (e.g., clearing vegetation so that water flows, or growing bushes over canals to provide shade);
- intermittent irrigation and periodic drying;
- canal flushing;
- grading and levelling of the land to be irrigated; and
- good irrigation practices to prevent over-watering and water accumulating in pools.

In general, the types of irrigation design least likely to facilitate vector development are localized sprinkler (trickle or drip) irrigation, sub-irrigation and mechanized sprinkler irrigation. Furrow irrigation is generally preferable to flood irrigation. Drip-line irrigation has eliminated much of the standing water and water waste in irrigation systems in the western United States of America.

Open earth canals are often used to convey water but may be associated with problems such as seepage and vegetation growth. In addition, water flowing too slowly will support mosquito proliferation, whereas water flowing too quickly will create turbulence, which erodes the canal and leads 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 advantages of:

- reducing seepage, which saves water and reduces the amount of standing water for mosquito immature development;
- increasing water flow, which flushes aquatic stages away; and
- deterring the growth of plants that provide shelter for some vectors.

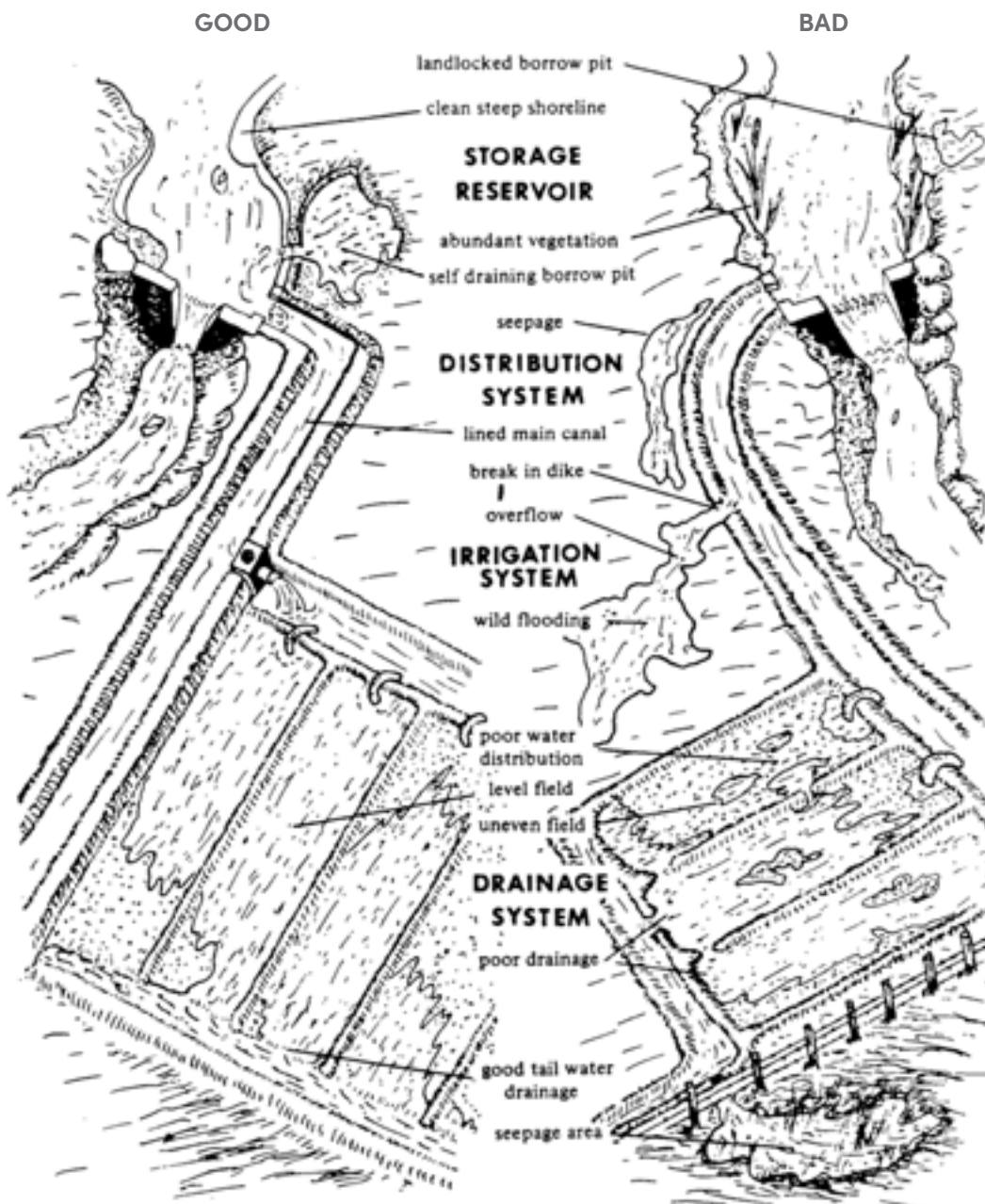
The provision of bridges may encourage people and domestic cattle not to cross drainage channels or canals, thereby limiting the creation of hoof- or footprints that may become aquatic habitats.

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 (Fig. 9). This approach has the double disadvantage that seepage from the canal may cause standing water to collect and borrow pits may fill with water, forming aquatic habitats. To avoid this, earth can be borrowed by stripping nearby land that lies at a relatively high elevation.

Underground pipes can replace open channels. These 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 from being carried into the pipes.

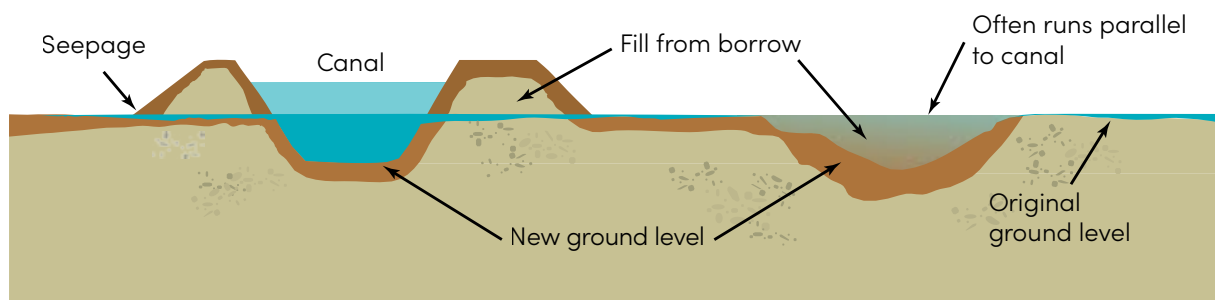
Irrigation based on land flooding is associated with a high risk of mosquito proliferation. Two precautions can help to mitigate this risk (although they cannot address uncontrolled flooding). Each flood period should not exceed a few days, and the area should be dried for at least one day afterwards. In addition, the border strip should be frequently levelled to ensure that there are no land depressions that could fill with water. While modifying water regimens can assist in reducing vectors, it is likely that larviciding will still be required as an intervention in flooded agricultural systems.

Fig. 8. Desirable and undesirable features of irrigation systems



A drawing demonstrating different features of irrigation and drainage systems. Source: WHO Manual on environmental management for mosquito control (3).

Fig. 9. Cross-section of a typical conveyance canal



A drawing demonstrating a conveyance canal and how earth can be moved to avoid standing water. Source: WHO Manual on environmental management for mosquito control (3).

4.2.3 Natural streams

Backwater pools and isolated seepage pools associated with natural streams can often form productive aquatic habitats, as can the streams themselves if water flow is sufficiently slow. Channels can be modified to increase water flow and to reduce bank erosion, floodway channels can be built to relieve natural streams from floodwaters, or the central channel can be deepened. The sides of channels can also be strengthened, ideally with gabions (galvanized steel wire mesh cases filled with stones or rocks), which are robust and flexible, or with solid revetments or retaining walls. Modification of natural streams to maintain flow should only be undertaken following an environmental impact assessment that confirms that any changes will not be detrimental to the local ecology or other hydrological aspects such as flood mitigation.

4.2.4 Landfilling and grading

Mosquito aquatic habitats such as abandoned ditches, ponds or borrow pits can be permanently removed by filling them in with soil, rubble, stones or ash. 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 necessary. Caution must be taken to avoid creating new aquatic habitats when collecting filling material (Fig. 10). Rubbish may be used as fill, obtained through collaboration with industrial or public works ministries to save costs. If rubbish is used, it should be managed to prevent the creation of additional public health problems, such as by compacting and covering it with earth to prevent fly breeding. Large areas can also be filled using environmentally safe waste from mining, harbour dredging or demolitions. 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 (Fig. 10).

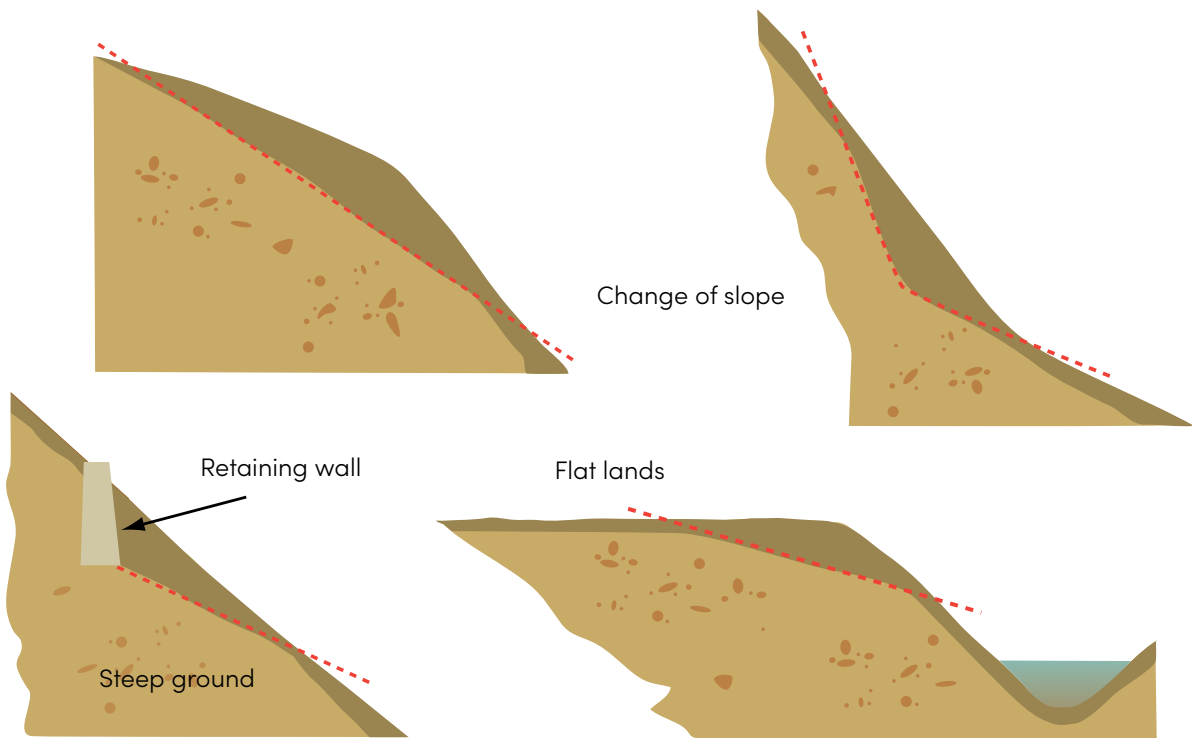
4.2.5 Drainage

Drainage is the removal of unwanted water on the surface or in the upper layers of soil (Fig. 11). Good drainage will remove standing water and can be achieved through the construction of open ditches with tidal gates, subsoil drainage and pumping. However, if poorly designed and maintained, the drainage systems used to remove wastewater in cities or for agriculture may become important sources of mosquitoes, especially if characterized by leakage, obstruction or small pools of residual standing water (Box 34).

Box 34. Summary of features that make drainage systems less conducive to vector breeding

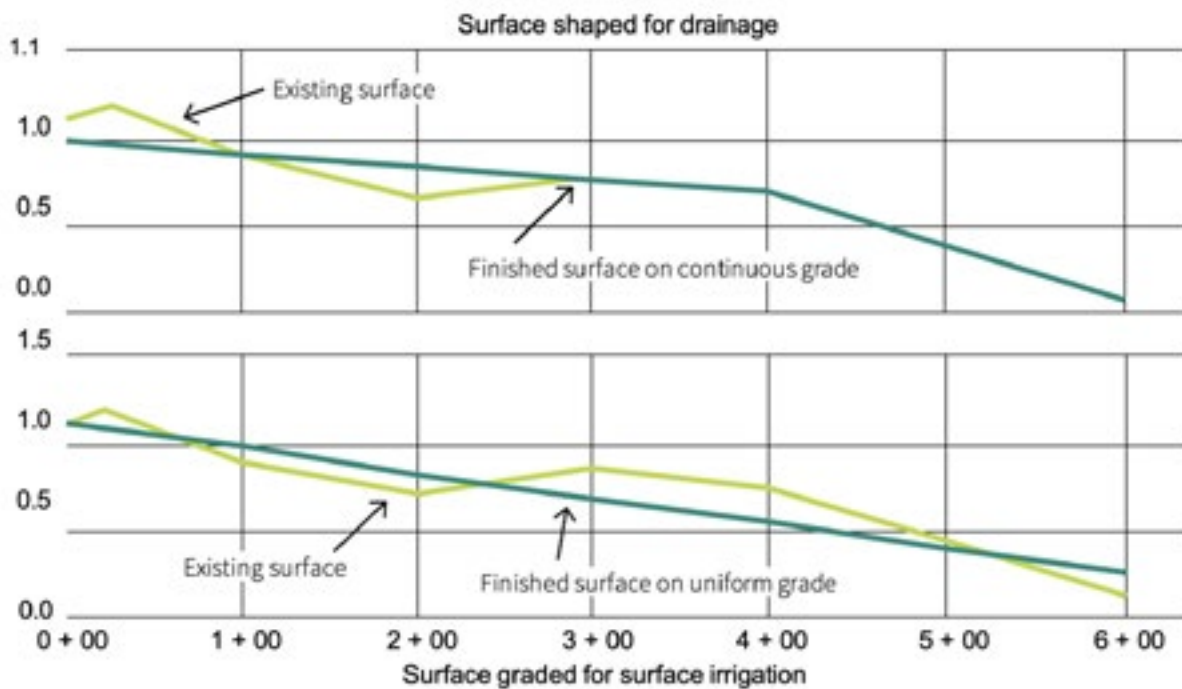
- use of subsoil drains rather than open ditches;
- lining of ditches;
- good alignment of ditches and avoidance of curves; and
- ditch flushing and maintenance (see section on habitat manipulation).

Fig. 10. Obtaining soil for filling without creating aquatic habitats



Four figures showing how the slope of the earth can be managed to avoid standing water.
 Source: WHO Manual on environmental management for mosquito control (3).

Fig. 11. Grading land for drainage and irrigation



Source: WHO Manual on environmental management for mosquito control (3).

Not only can existing drainage systems be adapted to reduce vector populations, but in certain settings close to human habitation, it may be appropriate to construct new drainage systems specifically for mosquito control (Box 35). In Zambia, drainage, filling, grading and planting of eucalyptus trees (which dry the soil) were successfully used to control vectors in a public park (131).

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 (126, 132).

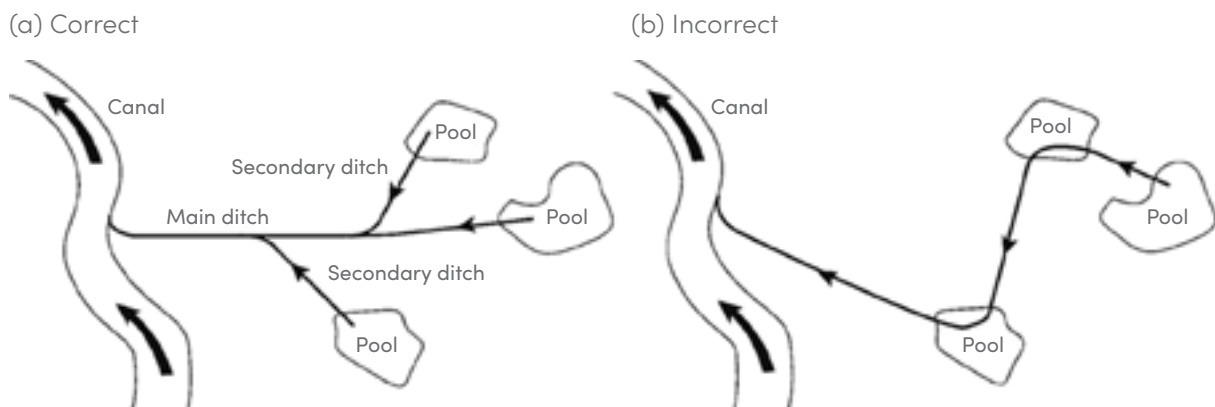
Box 35. Gradient draining in Spain

In Barcelona, Spain, gradient draining has been effectively used in urban areas prone to water accumulation. By minimizing areas where water can collect, such as in roadways, parks and construction sites, the city reduces potential habitats for vectors such as *Ae. albopictus*. This approach is integrated into urban planning and public works, forming a key component of the city's sustainable mosquito control efforts.

4.2.6 Open ditches

Open earth ditches are simple to construct. They prevent excess rainwater from accumulating on the ground and in 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). Ditches should be short and straight, avoiding sharp bends, to prevent erosion of their banks (Fig. 12). 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, providing a place for mosquitoes to breed.

Fig. 12. Correct (a) and incorrect (b) drainage of pools



Two figures demonstrating the correct and incorrect draining of three pools into a canal.

Source: *Vector control: methods for use by individuals and communities* (126).

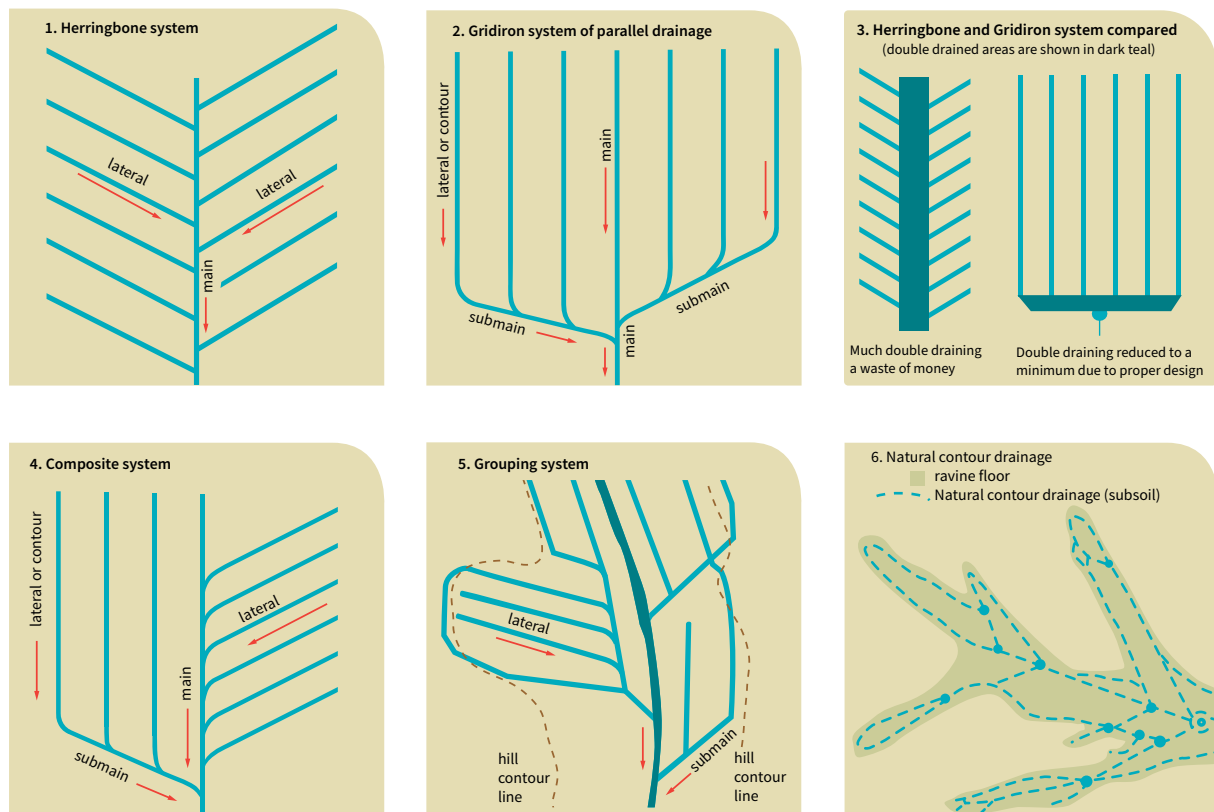
The layout of surface drainage systems is largely determined by the local topography and features such as roads or canals. Typical layouts of drainage systems are shown in Fig. 13. Comb, grid-iron and herringbone patterns are the most common layouts for flat, irrigated land.

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, whereas sandy soils require ditch sides with a slope of 40 cm horizontally per 10 cm vertically. For most soil, a slope of 10 cm per 10 cm or 20 cm per 10 cm is acceptable. 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. This earth 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 (Fig. 14).

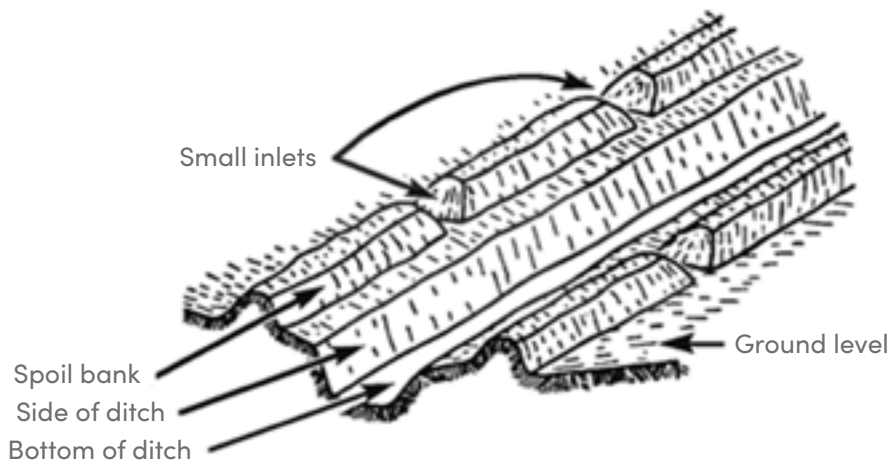
Lining ditches with concrete, brick or stone will increase costs but will increase the water flow, reduce plant growth and the build-up of silt, and increase durability, thereby reducing maintenance costs. Lining of earth ditches is essential in settings where rainfall is heavy. Stabilization of banks 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 (Fig. 15) can also be used with turf or concrete side-slabs laid above (Fig. 16). Banks should always be kept clear of vegetation.

Where the ditch narrows under a road or embankment via a culvert or pipe, a large gradient is required to prevent debris from accumulating (Fig. 17). 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.

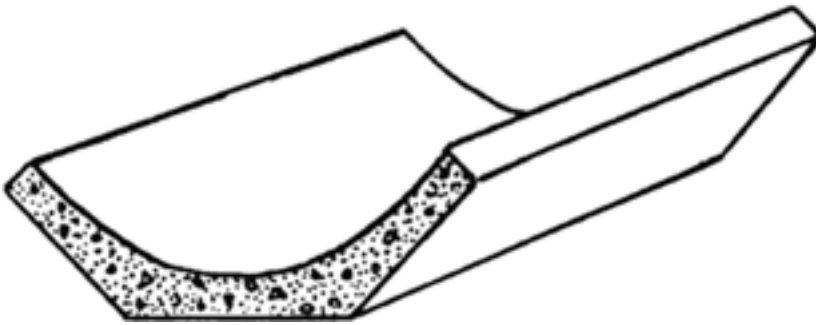
Fig. 13. Typical drainage system layouts (relevant for systems over approximately 1 hectare in width or length)



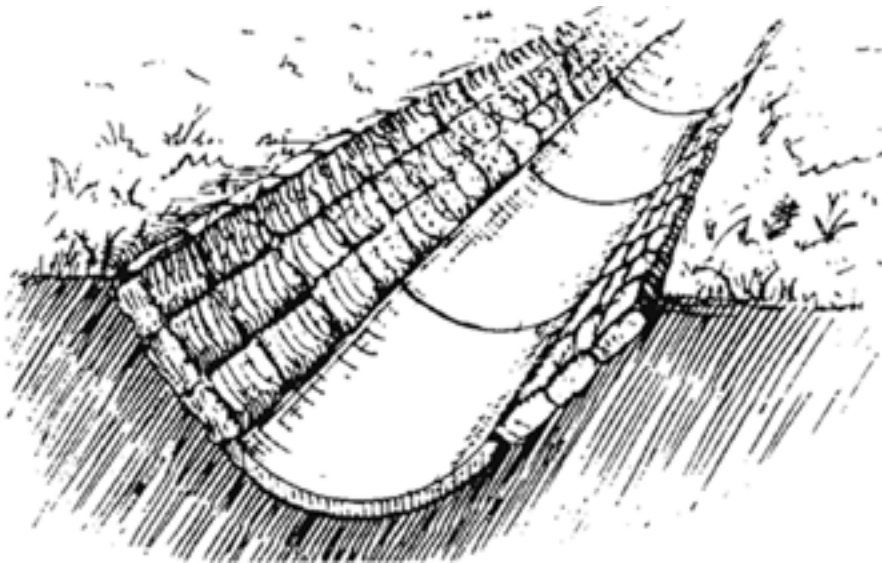
Six figures demonstrating different drainage systems, using blue lines to indicate drainage canals. Source: WHO *Manual on environmental management for mosquito control* (3).

Fig. 14. Location and design of spoil banks

A drawing showing the key features of spoil banks including inlets, banks, and sides of the ditch.
Source: *Vector control: methods for use by individuals and communities* (126).

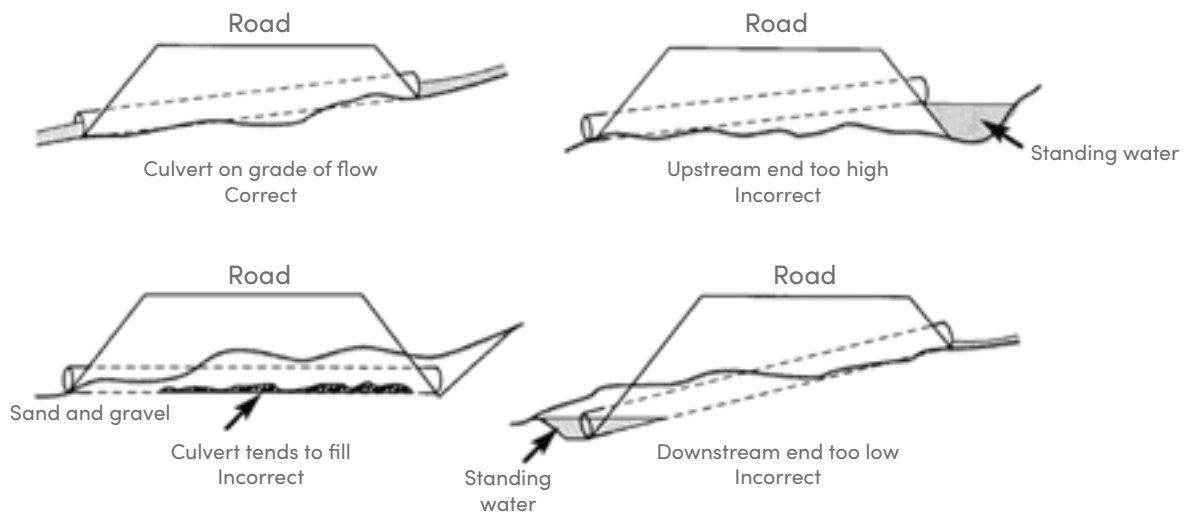
Fig. 15. Pre-cast concrete slab for lining ditch

A drawing showing a concrete slab design for lining ditches.
Source: *Vector control: methods for use by individuals and communities* (126).

Fig. 16. Ditch lined with pre-cast concrete slabs and turf side slabs

A drawing showing a ditch that has been lined with concrete and turf side slabs.
Source: *Vector control: methods for use by individuals and communities* (126).

Fig. 17. Culvert design



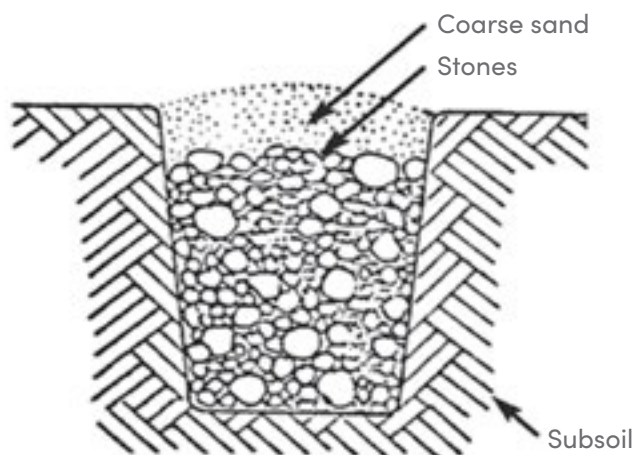
Four figures showing how drainage under a road can be done correctly, and incorrectly.
 Source: *Vector control: methods for use by individuals and communities* (126).

4.2.7 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. The cost of this approach limits its use in vector control. However, its advantages are that refuse or vegetation will not block the water flow, and it is not necessary to add larvicides or oils to discourage mosquito development. Subsoil drainage is often used in irrigated areas and can also be used to lower the groundwater table to prevent collection of surface water.

Subsoil drains can be most simply constructed by filling an open ditch with large stones that do not obstruct the water flow, and covering these with leaves, pine needles or sand to prevent silt or clay from accumulating at the bottom of the drain (Fig. 18).

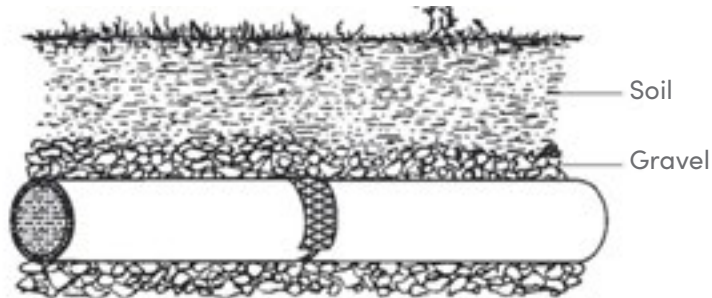
Fig. 18. Simple subsoil (French) drain



A drawing of a section of a subsoil drain, showing subsoil, stones, and coarse sand.
 Source: Kirby et al. (133).

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 (Fig. 19). The joints between pipes are not sealed, which allows water to enter. Silting is reduced by covering the upper surface joints with rubbish, leaves or roofing paper. The ideal gradient is 1:200 to 1:400. Pipes will need to be protected if they are close to the surface, using small bridges.

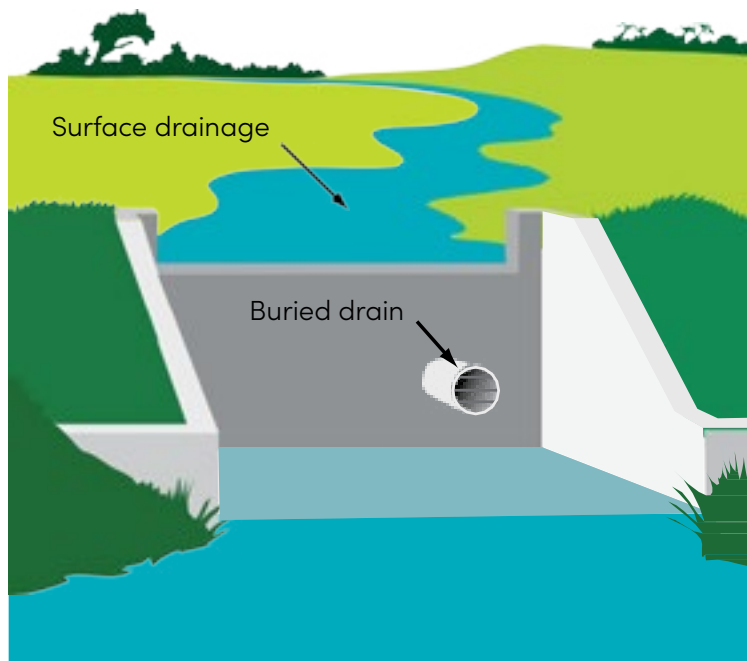
Fig. 19. Subsoil (buried conduit) drain constructed from ceramic tile pipes



A buried conduit drain that is made from ceramic tile pipes and buried in gravel under sand.
Source: *Vector control: methods for use by individuals and communities* (126).

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. If necessary, both subsoil and surface drainage can be combined (Fig. 20). Pump drainage may also be used in some settings; for example, where the 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.

Fig. 20. Drop structure for surface drainage and outlet for subsoil drain



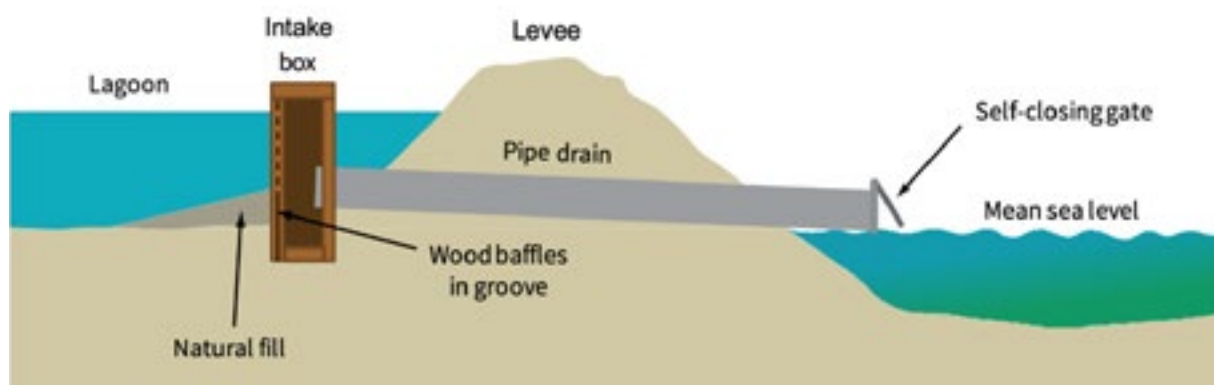
An image showing the positioning of an outlet drain in a drop structure.
Source: *WHO Manual on environmental management for mosquito control* (3).

4.2.8 Coastal swamp drainage

Some vector species such as *An. quadrimaculatus*, *An. coluzzii* and *An. atroparvus* can inhabit brackish coastal marshes, swamps and estuaries. There are examples of seawater intrusion into coastal areas that increase the salinity of the groundwater, enhancing suitability for salt-tolerant vector species such as *An. subpictus*, *An. sundaicus*, *An. melas* and *An. merus*. While varying the salinity of these waters can make the habitat unfavourable to some vectors (see section on environmental modification), a more permanent intervention is to construct embankments to aid coastal swamp drainage by preventing inundation with seawater. Pipes can be fitted in the embankment to allow water to drain at low tide (Fig. 21). The upper end of this pipe should be situated near the bed of the lagoon and the lower end should be slightly higher than mean sea level. The pipe should extend some way into the sea and be anchored there, ending sufficiently high above the seabed to prevent an influx of sand. The pipe should also be fitted with a self-closing gate to prevent inundation of seawater at high tide. Where the lagoon bed is very low, pumps will be needed for drainage (133).

Note the three-walled concrete intake structure, into which boards 15–20 cm wide may be slid to adjust the sill height of the opening as the lagoon naturally fills with silt. Self-closing gates should be monitored for debris and other conditions that can constrain proper opening and closing.

Fig. 21. Embankment and drain for coastal swamp drainage



A drawing showing an embankment with drain leading to the sea for coastal swamp drainage.

Source: WHO *Manual on environmental management for mosquito control* (3).

If it is not possible to construct an embankment and drain, an alternate system is to construct ditches that connect all low tide pools with the sea to ensure continuous inundation with seawater and to maintain salinity at a sufficiently high level to prevent mosquito development.

However, as coastal lagoons can represent critical habitats for many species, the potential detrimental effects should be considered before undertaking any modifications, such as through an environmental impact assessment.

4.2.9 Vertical drainage

In areas where the land is too flat to allow water to flow, and in silt or clay areas that are 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 they are protected by casing or filled with stones, gravel and coarse sand.

4.2.10 The “Lido system”

In areas 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 (120).

4.2.11 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. However, it is important to consider the broader impacts on the environment of introducing trees for control of water accumulation and vectors, such as the effect on groundwater aquifers.

4.3 Environmental (habitat) manipulation

Habitat manipulation is a form of environmental management aimed at producing temporary conditions that are unfavourable to the proliferation of vectors. Unlike habitat modification, habitat manipulation must be repeated to remain efficacious and is normally directed at one vector species. The majority of content in this section has been extracted from the WHO publications *Manual on environmental management for mosquito control* (3) and *Vector control: methods for use by individuals and communities* (126).

The following methods of habitat manipulation are described below: controlling water levels (including intermittent irrigation), stream flushing, shading, clearing aquatic vegetation, straightening and steepening shorelines, changing water salinity and water pollution.

4.3.1 Controlling water levels

Fluctuations in the water level in impoundments or irrigation systems reduce vector populations by: (i) discouraging the growth of plants that provide shelter for larvae along margins; (ii) displacing larvae from vegetation at margins so that they are more exposed to predators and water turbulence; and (iii) 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 30–40 cm.

However, some soils and vegetation complexes can hold water for several days and leave micro-habitats behind. In the tropics, floating vegetation may undermine the effectiveness of managing water levels for controlling mosquito development, e.g., the water hyacinth (*Eichhornia* spp.), water chestnut (*Trapa* spp.), water primrose (*Jussiaea* spp.), water lettuce (*Pistia* spp.), alligator weed (*Alternanthera* spp.), water milfoil (*Myriophyllum* spp.) and *Salvinia* spp. Where they are abundant, species such as these will require control, and follow-up monitoring will be important, as discussed later in this section.

Intermittent irrigation

In rice-growing areas, intermittent irrigation can control vector populations and is a legal requirement in some countries. If the ground is level with good drainage, paddy fields can be completely dried for 2–3 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; during this period, other methods of larval control will be required. The length of time between drying will need to be determined

by an expert. Intermittent irrigation may also be beneficial by increasing rice yields through the suppression of weed growth.

Intermittent irrigation has successfully controlled malaria in China, India and other areas of South-East Asia. In Sichuan Province, China, fields are flooded for a maximum of 100 days per year during the rice-growing season in the summer. During the winter, “dry” crops such as wheat or cash crops are grown. In India, intermittent irrigation has been combined with the application of neem tree (*Azadirachta indica*) extracts. Intermittent irrigation is less successful in controlling mosquitoes such as *An. gambiae* s.l., which rapidly re-colonize aquatic habitats after flooding and flourish in small residual puddles left after drying (134). In Sri Lanka, it is necessary to maintain water at a constant low flow to prevent pooling and the development of *An. culicifacies*. The local vector species needs to be assessed, however, because in some settings, a continuous flow of water may be conducive to the proliferation of certain species (120).

4.3.2 Stream flushing or sluicing

Flushing is used for small streams that have a sufficiently slow and continuous flow of water to enable mosquitoes to inhabit the margins. Periodic flushing with a large volume of water washes away eggs, larvae and pupae from the banks, or strands them at a higher level on dry land. Flushing also stirs up sediment at the bottom of the stream, which can bury aquatic mosquito stages and help slow the growth of new marginal vegetation. Despite the high initial investment required, flushing is a long-lasting method that requires little maintenance (Box 36) (132). 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 (120).

A small dam can be constructed at a point where the stream is narrow and banks are high in order to collect the water required for flushing. A sluice gate built into the dam can be opened once a week. Flushing should begin at the start of the peak mosquito season and end when the stream has dried up (8). The dam should be well designed to ensure that it does not itself support mosquito proliferation.

Box 36. Stream flushing in Sri Lanka

In Sri Lanka, stream flushing has been used as a vector control method to reduce populations of *An. culicifacies*, the primary malaria mosquito, particularly in river basins during dry seasons. The method involves releasing water from upstream reservoirs to flush out stagnant pools in streambeds, which are ideal aquatic habitats for mosquitoes. This technique was notably used during the 1934–1935 malaria epidemic and has since been integrated into broader environmental management strategies. While effective, it requires reliable water sources and coordination among local stakeholders to ensure sustainability.

4.3.3 Shading

Planting trees or shrubs along the banks of streams can control mosquitoes that prefer to breed in partial or full sunlight. This method has been successfully deployed to control *An. maculatus* in Assam, India (120). This method may also be suitable for control of *An. fluviatilis*, *An. sundaicus* and *An. minimus*. Harvesting of black mangrove (*Avicennia* spp.) trees from coastal swamps allows new emergent vegetation to grow, which can lead to the proliferation of the African vector *An. melas*. Planting new mangroves will shade the water and deter vector development. This, however, may not be practical under normal conditions.

4.3.4 Clearing aquatic vegetation and algal mats

Some mosquito species may be controlled by clearing water vegetation, as this removes shelter for larvae. This can be easily done by using rakes in small aquatic habitats and by applying herbicides or adding herbivorous fish such as the grass carp to larger aquatic habitats. This may be impractical in some settings such as swamp forests. Driftwood should also be removed from larger water bodies such as reservoirs.

4.3.5 Straightening and steepening shorelines

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

4.3.6 Changing water salinity

Vectors that breed in brackish waters in coastal marshes or lagoons may be controlled by introducing seawater into their aquatic habitats via sluice gates, culverts or channels to increase water salinity. This is feasible only where the vector species in question does not tolerate salt water and where rainfall is not excessively heavy. This method has been successfully used to control *An. farauti* in areas around Honiara in the Solomon Islands (120). Other species that can be targeted with this method include: *An. sudaicus* in Asia; *An. melas* and *An. merus* in Africa; *An. labranchiae*, *An. atroparvus* and *An. sacharovi* in the Mediterranean region; and *An. albimanus*, *An. aquasalis* and *An. grabhamii* in the Americas. Good knowledge of the salt tolerance of local vectors is required before deciding to use this form of vector control.

4.4 Larviciding

Larviciding is considered if habitats cannot be eliminated or modified through source reduction, if there is a significant time lag between source identification and implementation of source reduction, or if resources are not available for source reduction. For mosquito larval control, a wide range of insecticide formulations, such as liquid sprays, granules, pellets, tablets, briquettes and matrix-release products, can be applied depending on the location and type of habitat, the extent of the open bodies of water to be treated and the presence of vegetation covering the water surface. Care is needed to ensure that the correct dosage is applied and that the larvicide products used are suitable for treating water, especially drinking water for human or animal consumption. This section outlines how best to apply the correct dosage and appropriate formulation.

It may be preferable to begin larviciding initially in a small pilot area before expanding to the full target area; for example, in Dar es Salaam, United Republic of Tanzania, three wards were initially selected for larviciding based on the capabilities of staff and more wards were added later (114, 135). This approach has two advantages: (i) It allows the infrastructure for larviciding to be built up gradually and any problems to be resolved efficiently; and (ii) continued surveillance in non-intervention areas allows for more accurate assessment of the effectiveness of larviciding when it is first implemented. Monitoring before and after treatment is needed – initially to locate aquatic habitats and then to assess the impact of larval control interventions in the treated areas.

Larviciding should be conducted by separate teams from those responsible for larval surveillance (Figs. 2 and 3). For ground-based applications, each larval control officer could be given responsibility for larviciding in one plot. Supervisors should provide the mosquito control officers with a timetable for plots to visit each day, and the entire area should be searched for any sites containing water. In urban or peri-urban areas, all aquatic habitats should be targeted and treated if wet at the time of visit, irrespective of the presence or absence of larvae, and visited every week (114). If large water bodies are to be treated in rural areas, including by aircraft, it may be better to prioritize targets based on source productivity (see section 1.4.6).

4.4.1 Application of larvicides

WHO-prequalified larviciding products for control of mosquito larvae are listed on the WHO website (44). These products should be applied and managed based on the manufacturer's instructions for use.

Most larvicides can be applied by ground applicators using either ground equipment (boat, vehicle-mounted dry product spreader/liquid sprayer, handheld or backpack dry product spreader/liquid sprayer) or by hand under specific circumstances. In some cases, such as for extensive or hard-to-reach habitats (e.g., river flood plains), aerial application such as by unmanned aerial vehicles (e.g., drones) or conventional aircraft may be justified.

Typically, liquids can be applied in dilute or concentrated form. Dilute mixtures are usually used for application of high-volume sprays (10–100 L/ha) using large droplets (250–1000 μm volume median diameter [VMD]). Low-volume (LV) (2–10 L/ha) application of fine sprays, mists or aerosols (50–250 μm VMD) can be used for more concentrated mixtures. This technique applies the minimum amount of liquid (< 10 L/ha) and, if conducted correctly, results in substantial savings through its speed of application, lower handling costs and need for fewer staff. In addition, coverage of large surface areas can be achieved by taking advantage of downwind droplet distribution under appropriate atmospheric conditions. These small-drop applications can be used to distribute larvicide to large numbers of small receptacles in residential areas for dengue vector control.

4.4.2 Dosage

The dosage is usually expressed as the volume or weight of active ingredient applied per unit surface area of the water body or per volume capacity of the receptacle. Larvicide product labels provide instructions regarding dose ranges to be applied. These instructions should be followed. It is very important to calibrate the application to ensure correct dosing. When treating surface waters, calibration is normally based on equipment flow rate, swath width and forward speed during application. When treating large receptacles, dosing is achieved based on the volume capacity of the receptacle. A measured dose is then directly applied to the container.

For spraying wide areas with liquid larvicides to treat multiple small containers, the SOPs provided by product manufacturers should be followed. When applying larvicides to surface water bodies, the median droplet size of aqueous sprays should normally be larger than 250 μm to enable rapid fall-out of the droplets onto the water surface. However, application of liquid sprays to large aquatic habitats has also been successful with smaller droplets, e.g., using a mist with droplets in the range of 50–250 μm . If the water surface is obscured by dense vegetation, application of granules or pellets is preferred.

4.4.3 Equipment

Ground-based application

Larvicides can be applied using different types of sprayers, including compression, lever-operated, electric-powered knapsack sprayers or motorized mist blowers, or they can be applied with granule applicators for spot or broadcast treatments. Thermal fogging with water-based droplets may also be used to treat aquatic habitats. Wide-area, small-drop spray applications with motorized mist-blowers or truck-mounted foggers can also be used in urban and residential areas to target mosquito immatures in small receptacles and other inaccessible sites where water is present.

The choice of equipment, equipment calibration and applicator training are critical to the success of LSM operations. The choice of equipment will depend on a variety of factors:

- choice of larvicide formulation (liquid or granular);
- nature and size of targeted aquatic habitats;
- availability of fuel, oil and maintenance services for power equipment; and
- local capacity to securely store equipment that may be useful for agriculture or other pursuits.

Distribution of granules or pellets by hand may be sufficient for routine treatment of small sources. Direct placement of larvicides is also an option for receptacle treatment. Larger LSM operations will require the use of specialized equipment. This will certainly be true when liquid sprays are employed and for the application of granules to large areas.

For further details on appropriate equipment for applying larvicides, see the WHO publication *Equipment for vector control: specification guidelines* (67).

Aerial application

While aerial spraying can cover large areas, it requires investment in equipment, training and operational costs, which must be balanced against the scale of vector control needed. The suitability of methods for aerial application will depend on:

- the size, type, distribution and accessibility of target habitats;
- the level of precision required for effective application to habitat margins or specific zones;
- choice of larvicide formulation (liquid or granular) and its compatibility with aerial dispersal equipment;
- environmental conditions such as wind, humidity and temperature, which can strongly affect larvicide drift, dispersal and deposition; and
- availability of trained programme personnel, suitable drones or aircraft, and maintenance and support infrastructure, or commercial contractors who can comply with regulatory and contractual requirements, maintain appropriate insurance(s), and demonstrate consistent performance and reliability.

Aerial larviciding should complement other vector control strategies, such as ground-based source reduction and treatment. It is important to ensure adherence to local and national regulations regarding pesticide use, airspace management and environmental protection. Post-application monitoring is essential to confirm efficacy and assess potential impacts on non-target organisms.

4.4.4 Application of liquid sprays

Liquid larvicide sprays are used in many applications due to their efficiency and potential cost savings. High- or low-volume sprays can be selected depending on available equipment, type of habitat and specific application objectives. The availability of clean water for the preparation of sprays can be a limiting factor in some locations. Dense, emergent vegetation in aquatic habitats can 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 this type of application can be carried out in areas where these resources are limited. For high-volume hand application of liquid insecticides to aquatic habitats, compression or backpack sprayers (Fig. 22) fitted with a solid stream nozzle (Fig. 23) should be employed using the swathing spray (Figs. 24–26) or spot spray (Fig. 27) method.

Fig. 22. Examples of suitable spray equipment for high-volume hand application of liquid larvicides



Four examples of spray equipment for the application of larvicides.
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Fig. 23. Examples of solid stream nozzle configurations

Disk – no core



Solid stream



Two examples of spray nozzles, disk and solid stream nozzles.
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Swathing spray method

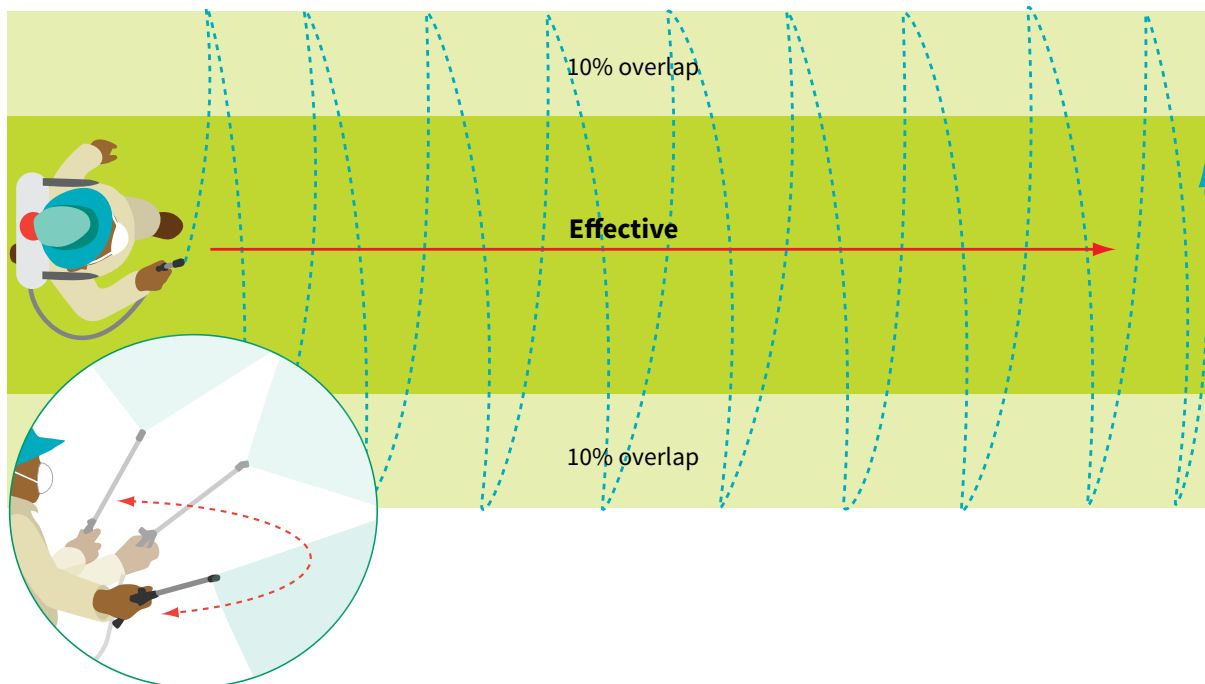
The swathing spray method takes advantage of a projected spray stream and oscillation of the spray wand by the applicator. This allows treatment of swaths of up to 10 m wide (with 180° sweep) with this equipment and is generally used for larval sources greater than 10 m² in size or areas containing multiple small sources (e.g., puddles, residual streambed pools and hoofprints) close to each other. Calibration of the swathing spray is based on measured swath width, walking speed and sprayer flow rate. In general, larvicide concentration in the spray mix is selected based on the calculated spray volume per surface area achieved (L/ha).

The calibration of manual high-volume swathing application of liquid sprays is based on:

- speed of travel (m/min);
- width of effective swath (metres wide);
- flow rate of sprayer (L/min); and
- concentration of product (g/L).

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 rate will depend on effective swath width, walking speed and sprayer flow rate (Fig. 24-26).

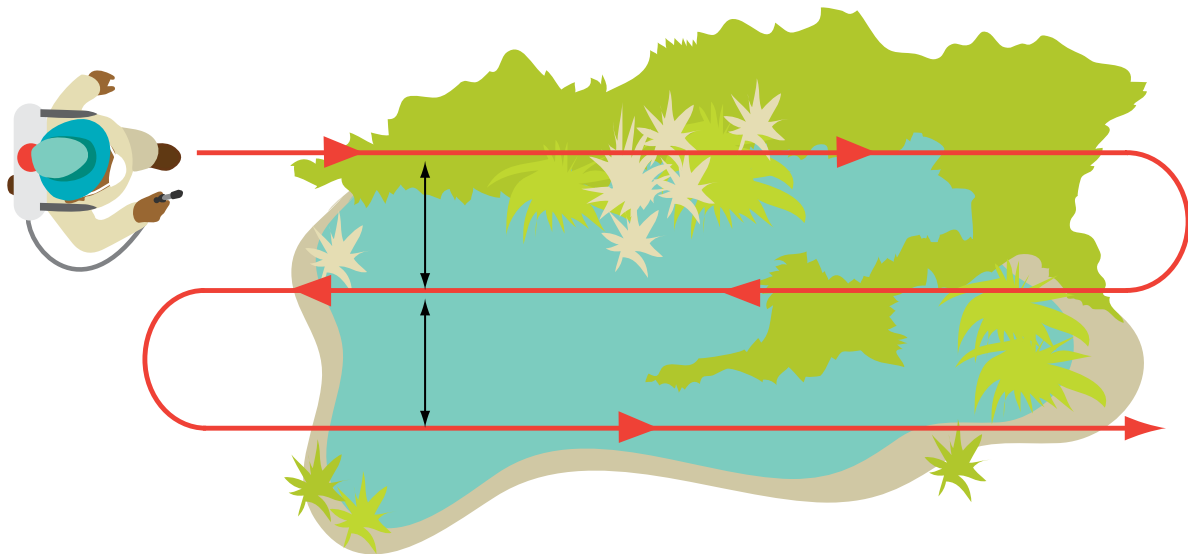
Fig. 24. Schematic of swathing spray method



An image demonstrating the back-and-forth swathing application of larvicides.

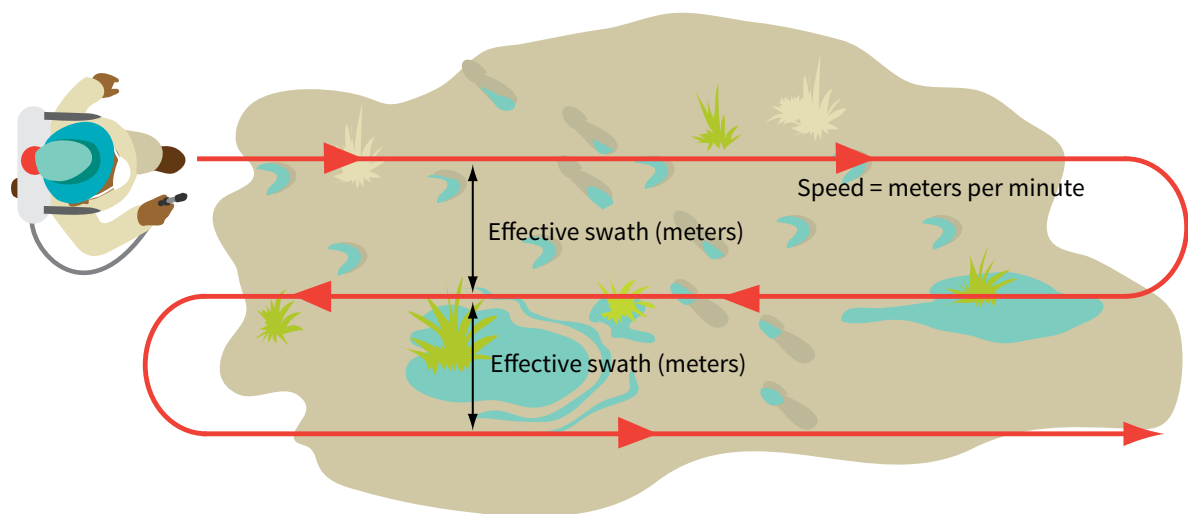
Source: *Larval Source Management: a supplemental measure for malaria vector control* (1).

Fig. 25. Application of swathing spray to a large larval source



An image demonstrating how a large larval source can be treated through repeated swaths.
 Source: *Larval Source Management: a supplemental measure for malaria vector control (1)*.

Fig. 26. Application of swathing spray to a concentration of small larval sources



An image demonstrating how small larval sources can be treated through repeated swaths.
 Source: *Larval Source Management: a supplemental measure for malaria vector control (1)*.

Spot spray method

The spot spray method is used to treat individual small sources rapidly (Fig. 27). Oscillation of the spray wand achieves even coverage of the source but is more directed to cover specific small sources, avoiding waste of larvicide.

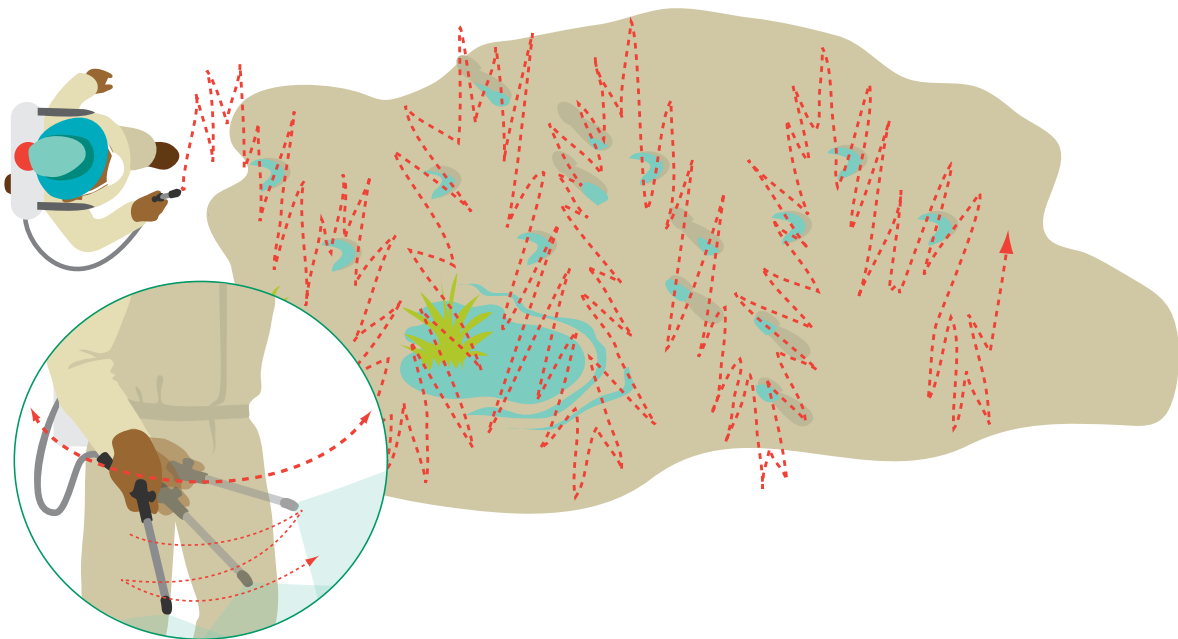
The calibration of manual spot application of liquid sprays is based on:

- time to spray (m^2/min);
- flow rate of sprayer (L/min); and
- concentration of product (g/L).

Often, it is most efficient to calibrate sprayers for both swathing spray and spot treatments, as both methods will need to be employed during daily treatments. In this case, spray concentration should be selected based on calibration for swathing spray, and applicators should be trained to mentally “time” their spot treatments to deliver sufficient material in spot treatments. For example, if a sprayer has been calibrated to deliver 20 L of total spray volume per hectare with a walking speed of 60 m/min and a 10 m swath, then the applicator is treating 600 m²/min (10 m² per second). In this case, the applicator should be trained to spray for less than 0.1 sec/m². This can take some practice, but it is usually quickly mastered by applicators.

Fig. 27. Schematic of spot spray method for individual larval sources less than 10 m² in size

Note that the spray wand is oscillated to cover the surface evenly with drops from a solid stream.



Oscillation of spray to treat individual larval sources less than 10 m₂ in size.

Source: *Larval Source Management: a supplemental measure for malaria vector control* (1).

LV and ultra-low volume (ULV) spray methods

For LV sprays of mosquito larvicides, power backpack and vehicle-mounted mist blowers or ULV sprayers can be used to disperse fine (small drop) sprays to target cryptic habitats and cover large areas (Figs. 28–30). With proper atmospheric conditions and spray strategies, large open habitats such as rice fields can be covered rapidly. These methods can also be used to treat multiple small sites, such as ground pools or animal hoofprints, covering large surfaces or aquatic habitats that exist within fenced compounds.

Truck-mounted ULV and backpack LV spraying of Bti AM65–52 WG was successfully used in a malaria elimination project on Tekong Island, Singapore (136). These methods have also been successfully used to control container *Aedes* spp.

Fig. 28. LV spraying of Bti AM65-52 WG for malaria vector control on Tekong Island



A technician conducting low-volume spraying with Bti to control larvae.
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Fig. 29. Truck-mounted LV spray equipment under test for coverage of wide areas



A truck with a mounted low-volume sprayer to treat large areas.
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Fig. 30. Truck-mounted ULV sprayer in operational use



A truck mounted ULV sprayer in operational use.
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Granule and pellet application

Solid formulations including granules and pellets are often required to penetrate emergent vegetation in larval sources. These formulations are applied undiluted and can be applied by hand without equipment. However, equipment, including manual rotary disk spreaders (Fig. 31), power backpack blowers (Fig. 32), vehicle-mounted rotary disk spreaders and blowers (Fig. 33), is useful for improving swath coverage, application efficiency and homogeneity of coverage. Hand-held spreaders typically deliver swath widths of 5–10 m. Calibration is based on measured swath width, walking speed and desired application rate.

Fig. 31. Hand-held rotary disk equipment for granule application

Hand-held rotary disk equipment for the application of larvicide granules.
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Fig. 32. Power backpack suitable for granule and pellet application

A backpack sprayer suitable for granule and pellet application.
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Fig. 33. Example of vehicle-mounted rotary spreader

A quad bike with a vehicle mounted rotary spreader.
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When using power backpack blowers (Fig. 32), the swathing spray method described above for liquid sprays is also applied. Swaths of 20–30 m can often be achieved depending on the formulation and equipment. This enables rapid coverage of large larval sources for teams of two applicators sharing responsibility for material transport and application.

Calibration of equipment flow rate is based on swath width, walking speed and desired application rate. Accurate calibration is essential for both efficacy and efficiency.

Aerial mapping and larvicide application

Ground-based LSM can be impractical and resource-intensive in large-scale areas or where aquatic habitats are difficult to locate and reach. Aerial larviciding can provide an alternative mechanism to apply larvicides in settings such as rice fields, irrigation systems, flood plains (Fig. 34) or wetlands, or in areas where there are cryptic aquatic habitats that are only identifiable and reachable by air. Dense aquatic vegetation, organ water storage tanks and rooftop sources may also be reached using drone technology.

Aerial larviciding has been used for decades and is a cornerstone of many nuisance mosquito control programmes targeting floodwater and saltmarsh-associated *Aedes* species in high-resource settings such as Australia, Germany and the United States of America (137). Aerial larviciding and adulticiding have been successfully employed to control or eradicate vectors of onchocerciasis, or river blindness, in Africa. Drone application for *Anopheles* has been tested in Madagascar, Rwanda and the United Republic of Tanzania (Box 37).

Aerial applications require extensive planning and the technical expertise of professional aerial applicators or drone operators. If increased programme capacity for operating new technological equipment (including drones) is not possible, it is important to have clarity on ownership and operation of the equipment by implementing agencies. Theoretically, existing capacity and technology for aerial spraying, particularly that used for agricultural applications, can be repurposed for vector-borne disease control, and valuable lessons from these experiences can inform operations moving forward. For instance, aerial applicators and drone operators currently treat agricultural crops in Africa and may be available and repurposed for public health applications. However, key questions remain unanswered related to the appropriateness, use and cost of this technology within operational programmes for the control of *Anopheles* and *Aedes* vectors in urban and rural settings. Environmental considerations will also be key, such as impacts on non-target organisms. Social acceptability and community engagement are also critical considerations, particularly for urban mosquito control where public concerns about aerial pesticide use can arise. The use of widely studied biorational larvicides in aerial operations, such as Bti and S-methoprene, helps to mitigate non-target impacts while addressing public health concerns.

As evidence from operational research expands – covering cost, efficacy, non-target impacts and acceptability – it is expected that more detailed guidance will be developed for the integration of aerial larviciding into *Anopheles* and *Aedes* control strategies.

Box 37. Aerial mapping of aquatic habitats in the United Republic of Tanzania

In Zanzibar, mapping accuracy and relative costs (for both *Anopheles* habitats and interventions) were compared over four months using drones and smartphones versus conventional ground-based methods. Results demonstrated that drones and smartphones improved the identification of aquatic habitats for operational LSM while being no more costly than ground-based approaches. Such evidence suggests that drone technology may represent a valuable tool for malaria control programmes planning to implement LSM.

Fig. 34. Example of drone application



Drone application of larvicide over irrigated agricultural land.
© Seth Irish

4.4.5 Care of equipment

Equipment design and maintenance should conform to WHO specifications, if available. Equipment should be tested before storage or calibrated accordingly before use and before being cleaned and dried, and a stock record should be made of its availability along with any spare parts required in the field. Field supervisors should ensure that equipment is properly dealt with following a day's operation, prior to night storage or transportation (133), including:

- removal and disposal of residual larvicide (except in the case of granular formulations);
- flushing of liquid application equipment at least three times with clean water so that all parts that come into contact with pesticide are cleaned; rinse water can be kept for use in diluting larvicides; and
- careful inspection of equipment and reporting of damage.

Each team of field staff should be supplied with the necessary tools to repair equipment as well as spare parts. A few members of staff in the area should be trained in the repair of equipment.

4.4.6 Safety considerations

When working with larvicides, hand and backpack sprayers should not be filled more than three quarters full. Staff should be well trained in the use of equipment and follow local licensing requirements where applicable. Larvicides and equipment should be

safely handled, and personal protective equipment should be used as indicated on the product label. This may include overalls, boots, gloves, face mask or respirator, eye protection and a hat or head covering when preparing and diluting concentrates and when applying insecticides. Bare hands should never be used to mix pesticides. Pesticides should be washed off clothing as soon as possible (132).

4.4.7 Frequency and timing of application

The timing of application must be tailored locally, as it is determined by the local species, seasonality of transmission, precipitation, exposure to the sun, water quality, residual efficacy of the larvicide, mode of action of the active ingredient and type of aquatic habitat. The supplier of the chosen larvicide will be able to provide more specific details regarding the frequency and timing of applications. In many cases, manufacturers will work with a control programme to optimize application to meet programme needs and public health requirements. In addition, this information will be adjusted during the piloting phase of the programme before large-scale application.

4.4.8 Storage and distribution of larvicides

Larvicides should be stored in a secure, central location with correct placement (e.g., off the ground) and proper stock management to prevent expiry of insecticides. The necessary quantities should be distributed to local stores or offices weekly for larvicides that require weekly application. Records of the amounts delivered and taken away should be kept at both the central and local stores. Stores should be dry and well ventilated. If a specially dedicated store is not available, locked cabinets may be used (133). Storage requirements, such as temperature and shelf life, need to be considered when choosing a specific larvicide formulation, e.g., liquid formulations of bacterial larvicides have a shorter shelf life under tropical conditions. In areas with high average temperatures, dry formulations that can be mixed with water on demand (e.g., WGs) or granular formulations are preferable, as they typically have a longer shelf life relative to liquid products. Another potential advantage of dry products is that they require less storage space in some cases, and shipment costs are reduced as their potency may be higher per unit of volume.

4.5 Biological control agents

Biological control is the introduction of natural enemies into aquatic habitats, including predatory fish, predatory invertebrates, competitors, parasites and other disease-causing organisms. This section explains how these biological agents can be used in LSM for *Anopheles* and *Aedes* vectors.

4.5.1 Predatory fish

While there is a large variety of biological control agents available, only larvivorous fish have been widely used in malaria vector control. However, there is currently no recommendation on the use of fish for *Anopheles* or *Aedes* control, as there is insufficient evidence to assess the efficacy and public health value of larvivorous fish for the prevention and control of malaria (8) or *Aedes*-borne diseases. This operational manual therefore does not specifically endorse the use of larvivorous fish. However, basic information is provided to ensure that programmes choosing to implement this potential form of biological control do so with the appropriate consideration. Further information is available elsewhere (128).

Selection of species

The following characteristics are preferable in larvivorous fish:

- small size to enable access to all parts of the aquatic habitat;
- preference for mosquito larvae over other prey at the water surface;
- high reproduction rate in small water bodies;
- local not exotic species; and
- tolerance to salinity, pollution, temperature fluctuations and transportation.

Species successfully introduced for the control of mosquito larvae have largely been tooth carp (Poeciliidae and Cyprinodontidae), including the guppy (*Poecilia reticulata*) and the top minnow or mosquito fish (*Gambusia affinis*). *Gambusia* is more appropriate for clean water, while *Poecilia* is more efficient in organically polluted water and in water at a higher temperature, such as in rice fields. Unlike *Gambusia*, *Poecilia* cannot survive temperatures below 10°C. The annual killifishes (*Cynolebias*, *Nothobranchius* and *Aphyosemion*) have desiccation-resistant eggs and are useful for aquatic habitats that dry out, for example, borrow pits and irrigated rice fields. The juvenile stages (but not the adults) of some species may eat mosquito larvae.

The geographical distribution of larvivorous fish of the tooth carp family (Cyprinodontidae) is as follows:

- Africa: *Aphanius*, *Aphyosemion*, *Epiplatys*, *Nothobranchius*
- Asia-Pacific Region: *Aplocheilus*, *Macropodus*
- Central and South America: *Fundulus*, *Jordanella*, *Rivulus*, *Gambusia*, *Girardinus*, *Heterandria*, *Poecilia (Lebistes)*, *Limia*, *Cynolebias*.

Exotic species should not be introduced into natural habitats, as they may displace native species or affect non-target organisms; instead, the suitability of local species should be assessed. Exotic species such as *Gambusia* may be appropriate for man-made aquatic habitats with no connection to the natural environment, such as water storage tanks, swimming pools, garden ponds or desert reservoirs.

Where there is abundant vegetation, the introduction of larger fish such as the carp (*Cyprinus carpio*), the giant gourami (*Osphronemus goramy*) or the tilapia (*Tilapia* or *Oreochromis mossambicus*), which uproot and eat plants, can help larvivorous fish to reach larvae. These larger fish can also serve as a source of food for the local population.

Some fish may be reared for both mosquito control and as food, such as cichlid fish (*Oreochromis mossambicus*, *O. niloticus* and *O. spiluris*) in Indonesia, Malaysia, Somalia and Sudan, and the common carp (*Cyprinus carpio*) and the grass carp (*Ctenopharyngodon idella*) in China and India. Larvivorous fish can also feed larger fish, which in turn may be eaten by the local population.

Rearing fish

In areas where larvivorous fish are found naturally in particular locations, these can be used as a source. To ensure a large supply of fish, they should be reared in large quantities in special breeding ponds. Ponds used to rear fish for food can be simultaneously used to rear larvivorous fish. Fish can be reared in ponds dug out of the

earth or in large cement tanks. Plenty of space and aquatic vegetation are essential to protect younger fish from older fish. Feeding with organic waste or animal manure can increase production, but the growth of algae (which leads to de-oxygenation) should be avoided. Care should be taken to not create mosquito habitats in the process of digging the ponds.

Transportation and distribution

Fish should be transported in containers with a volume of up to 40 L (e.g., plastic buckets, jerry cans) closed and two thirds full, or in strong plastic bags half full of water from the rearing pond. Numbers should be kept low in each container, e.g., 50 *Gambusia* in 8 L of water. Temperature should be kept steady (e.g., by wrapping containers in wet cloth, or by placing containers in wooden boxes or polystyrene boxes) and oxygen kept in adequate supply. Water from the final destination should be added to these containers before releasing the fish to allow them to gently acclimatize. Six *Gambusia* would be sufficient for a pool of 5–10 m² with few aquatic plants.

M&E

M&E activities are essential programme components when using fish as a biological control method for *Anopheles* and *Aedes* mosquito larvae in order to ensure the effectiveness, sustainability and ecological safety of fish-based interventions. M&E helps to assess factors such as predation efficiency, adaptation to local water conditions and potential impacts on native biodiversity. Regular evaluation also tracks fish survival, reproduction and population dynamics in target areas, informing decisions on habitat suitability, fish species selection, ongoing maintenance requirements and feasibility of scale-up. In addition, M&E is critical to mitigate any unintended ecological consequences, such as competition with native species or alterations to local food webs.

4.5.2 Predatory invertebrates

A range of predatory agents have been investigated for control of *Anopheles* and *Aedes* larvae, although this has often been limited to trials in laboratory, semi-field or specific field settings, rather than as part of large-scale implementation. Predators that have been investigated include flatworms, spiders, crustaceans, dragonflies and damselflies, aquatic and semi-aquatic true bugs and beetles, other mosquito species, plants, hydroids, leeches and caddisflies. A review of evidence on the use of these predatory agents for control of container mosquitoes is available elsewhere (138).

Copepods are small predatory crustaceans found in freshwater and brackish environments that feed on mosquito larvae and can be used to control immature mosquito populations in habitats such as water storage containers, irrigation ditches and ponds. Species such as *Mesocyclops* are effective against *Ae. aegypti* and *Ae. albopictus* in certain habitats, are easy to culture and deploy, and require minimal maintenance. However, their effectiveness is influenced by environmental factors such as water quality, water levels and predator competition. While copepods have shown success in operational settings, including a notable programme in northern Viet Nam that eliminated *Ae. aegypti* and interrupted dengue transmission in several communes (139), such outcomes have not yet been replicated elsewhere. Periodic reintroductions may also be needed for sustained control.

Therefore, local testing of predatory invertebrates is required prior to wider scale implementation for larval control.

4.5.3 Parasites and other disease-causing organisms

Similar to the use of predatory invertebrates, a broad range of parasites and other organisms that cause disease in mosquito larvae have been tested in laboratory, semi-field or specific field settings, rather than as part of large-scale implementation. Iridescent viruses, nuclear polyhedrosis viruses, cypoviruses, entomopox virus and densoviruses have been shown to infect and kill mosquitoes (140). Densoviruses have been proposed as a way to reduce mosquito populations through pathogenic interactions, but genetic strategies such as viral paratransgenesis offer new approaches (141). Fungus species belonging to various genera (e.g., *Coelomomyces*, *Smittium*, *Aspergillus*, *Culicinomyces*, *Beauveria*, *Metarhizium*, *Fusarium*, *Trichophyton*, *Tolytocladium*, *Anncaliia* and *Vavraia*) have shown potential to control *Anopheles* larvae. Oomycetes or water molds (e.g., *Leptolegnia*, *Pythium*) can also cause mortality in the field; for *Lagenidium giganteum*, a commercial product was available until 1999 (142). Parasitic mermithid nematodes also have potential for larval control, as these have been found in many *Anopheles* larvae after free-swimming pre-parasitic stages enter by penetrating the cuticle following hatching soon after they are laid (143).

There remains insufficient evidence to evaluate the public health value of these organisms against mosquito-borne diseases; therefore, WHO cannot develop an evidence-based recommendation – either for or against – deployment of this intervention.

4.6 Other forms of treatment

4.6.1 Polystyrene beads

Polystyrene beads have been investigated as a non-chemical method for controlling mosquito larvae in small, enclosed water bodies. The durable, lightweight and inexpensive beads float on the water surface and create a physical barrier, reducing oxygen exchange and preventing mosquito larvae from reaching the surface to breathe, ultimately leading to their suffocation.

The efficacy of polystyrene beads has been assessed in diverse habitats, including water storage containers, drains and ponds, with some studies noting reductions in larval populations. However, there are some concerns about long-term degradation, potential pollution and unintended effects on non-target organisms. Because they are easily blown or washed away, the beads can only be used at sites where the water remains confined by surrounding walls. Programmes intending to use this approach for mosquito control should therefore ensure that broader ecological impacts are adequately assessed.

Production and application of expanded polystyrene beads

Expanded polystyrene beads can be spread on water to form a floating layer. A layer 1–2 cm thick is sufficient to suffocate mosquitoes if it covers the surface completely.

Small balls (or beads) of expanded polystyrene pressed together in blocks are often used as packing material. Small quantities of beads can be obtained by breaking up and crumbling such blocks.

Larger quantities can be obtained from the petrochemical industry, which produces unexpanded polystyrene beads with pentane in solid solution in each bead. The beads are expanded by heating them to 100°C in steam or boiling water. The plastic softens and the pentane, which becomes gaseous, expands the beads to 30 times their


initial volume. The beads can be expanded in a suitably equipped factory and then transported in sacks or drums to the site of application. It is easier to transport the beads in their unexpanded form, particularly if long distances are involved. The beads can then simply be expanded near the site of application in boiling water in a cooking pot.

The unexpanded beads are added to the boiling water a cupful at a time, stirred and then removed from the water surface with a sieve. With this method, the beads expand to only 15–20 times their volume. It is important to keep the unexpanded beads sealed until the expansion process is undertaken to avoid leakage of the pentane, as this would reduce their final size. Beads with a diameter of 2 mm when expanded are the best for controlling mosquito larvae. Thirty litres of beads (about three bucketfuls) weigh about 1.25 kg and are sufficient to cover 3 m² of water (as in a typical pit latrine) at a thickness of 1 cm.

4.7 Community engagement and involvement

Effective LSM depends on community participation in identifying and eliminating aquatic habitats, adopting preventive behaviours, and supporting surveillance and control efforts. By fostering strong relationships and empowering communities, the effectiveness and sustainability of LSM programmes can be enhanced (see Table 8). Community engagement should be initiated well in advance of commencing deployment of LSM interventions and should be adapted based on the LSM strategy and intervention to be used. For technology-enabled LSM, such as the use of drones, additional engagement with community leaders and members (as well as relevant authorities) may be needed. This will help to mitigate against rumours, disinformation or misinformation that could undermine or complicate implementation.

Table 8. Different levels of community engagement and impact on decisions

	Inform	Consult	Involve	Collaborate	Empower
Public participation goal	To provide the public with balanced and objective information to assist them in understanding the problem, alternatives, and/or solutions.	To obtain public feedback on analysis, alternatives, and/or decisions.	To work directly with the public throughout the process to ensure that public concerns and aspirations are consistently understood and considered.	To partner with the public in each aspect of the decision, including the development of alternatives and the identification of the preferred solution.	To place final decision-making in the hands of the public.
Promise to the public	We will keep you informed.	We will keep you informed, listen to and acknowledge concerns and aspirations, and provide feedback on how public input influenced the decision.	We will work with you to ensure that your concerns and aspirations are directly reflected in the alternatives developed and provide feedback on how public input influenced the decision.	We will look to you for advice and innovation in formulating solutions and incorporate your advice and recommendations into the decisions to the maximum extent possible.	We will implement what you decide.
Increasing impact on the decision 					

Source: Adapted from *IAP2 spectrum of public participation* (144).

Engagement with community leaders and members will be required to develop a schedule for the LSM campaign, considering major holidays, farming practices, anticipated weather events (e.g., cyclone season) or other events that may impact implementation. This should be determined through consultation with relevant stakeholders to identify preferred dates and timelines for implementing LSM activities.

Further community engagement can be supported through religious, sporting or special interest groups, and farmer cooperatives in order to disseminate information on an upcoming or ongoing LSM campaign. Mass media, such as television, radio or newspapers, can also be used along with social media to disseminate key messaging on interventions, their purpose and required community actions to support LSM implementation.

For ground-based interventions, field teams are well positioned to engage with and educate community members on ways to eliminate potential aquatic habitats within their environment. During household visits, it is very important for the field staff to receive authorization from an adult who lives in the household before beginning any engagement or vector control activities. Field staff should not enter the household if only minors are present.

4.7.1 First household visit

Each team should anticipate that the first larvicide/environmental clean-up visit to each household will take longer than subsequent visits. This occurs mainly because it will be the first time that vector control technicians obtain consent for participation in the vector control interventions and then spend time communicating a variety of messages to the household about how to eliminate or alter aquatic habitats within the residence.

During the first visit, the following activities should be conducted, adapted to local customs and cultural practices:

- Field staff should display identification cards or wear uniforms to identify who they are working for.
- Field staff should present themselves in a courteous, friendly and respectful manner to the head of the household, explaining to the inhabitants who they are representing, what actions they intend to carry out and why.
- Approval should be provided by the head of the household (or an appropriate senior household member) through informed consent. All inhabitants must be informed of the intended entrance to the property by the field team.
- The head of the household should be provided with a household registration card or similar unique record or identifier that will be used for future engagement purposes.
- The field staff should fill out the data collection form, adding information about containers with water located as they are found.
- The technician should commence inside the dwelling and observe, register and treat all aquatic habitats that are treatable in line with established SOPs.
- Once all the internal areas of the house have been completed, the field staff should proceed to work on the outside of the house and similarly observe, register and treat all aquatic habitats in the peri-domestic area.

- The field staff should suggest to the head of the household how to eliminate potential aquatic habitats, such as through the disposal of non-usable water containers they wish to get rid of.
- At the end of the visit, the field staff must put the date and his/her signature on the household registration card and leave this with the head of the household, informing them that it should be retained in a safe place for follow-up visits.
- The field staff is finished with the visit and notifies the head of the household when the team will return to complete further activities.

4.7.2 Follow-up household visits

It is recommended that programmes support field staff visits to households monthly or more frequently depending on the interventions and work plan. During these subsequent visits, the field team will be able to complete their responsibilities more quickly, given that the preliminary introduction and knowledge sharing will have already taken place. Field staff may not need to repeat general information about diseases, vectors and vector control, although all queries by household members should be adequately addressed. Field staff should provide ongoing communication and reinforce key behaviours during each visit, as appropriate.

4.7.3 Communication priorities

During community engagement and household visits, field staff should focus on communicating the following to community leaders and members:

- the diseases being targeted and how they are transmitted;
- interventions to be used and how they are expected to work to prevent vector biting and disease;
- how, where and when the interventions will be implemented, such as source reduction combined with larviciding to be implemented simultaneously and repeatedly;
- any safety or security considerations for the interventions;
- proper procedures for interventions requiring community engagement, such as source reduction;
- responsibility of households, such as allowing access by larviciding teams or continuing with source reduction between team visits; and
- other actions that can be taken to avoid vector biting and disease(s).

Messaging should be designed for the target audience and adapted to each community based on the cultural and linguistic context, an understanding of where communication efforts are needed and identified gaps in prevention behaviours. Too many messages can confuse audiences and result in a lack of, or inappropriate, action.

Community mobilizers, vector control technicians and supervisors should be ready to inform targeted communities on the above points. Fact sheets or a summary of common questions and answers may serve as useful resources to have on hand during community engagement activities and household visits.

5. M&E and review of LSM

This chapter provides brief information on how to monitor, evaluate and review LSM activities, and current evidence gaps. It is important to acknowledge up front that it is difficult to define universally applicable and consistent M&E approaches for LSM due to the diversity of interventions and local ecologies, which necessitate varied implementation strategies, and also considering the primarily community (rather than personal) benefit offered by LSM (25).

General concepts on M&E for vector control have been outlined in the WHO *Operational manual for indoor residual spraying* (6), which can be referred to for further detail.

5.1 M&E

M&E is integral to vector control operations to document procedures, progress and impact, and to support data-driven decision-making at all levels of the programme. Robust M&E systems must be embedded within LSM programmes to ensure that scale-up decisions are evidence-based and responsive to the local vector ecology and programme capacity. While this requires significant financial and technical resources – including epidemiological and entomological expertise – this is necessary to confirm that investments in LSM are generating sufficient epidemiological impact or, conversely, to identify if resources would be better allocated to other vector-borne disease control efforts.

An M&E plan should be developed that incorporates the different types of LSM to be implemented and can inform the expanded or adjusted implementation of LSM in relation to other vector control interventions. For instance, if the LSM programme is based on larviciding, it is necessary to monitor (among other aspects) whether (i) the larvicide is efficacious against the target mosquito larvae (i.e., larvae are dead after 24 hours or development into adults is otherwise arrested); (ii) larval control personnel are in the field applying larvicide according to their schedule; (iii) adult vector densities are significantly reduced compared to baseline and are kept at a low level throughout the year; and (iv) there are any changes in biting exposure or emergent gaps in protection.

The WHO reference manual on malaria surveillance, monitoring and evaluation (145) provides further information on appropriate M&E systems and indicators for LSM for the prevention and control of malaria, although these can be adapted or added to for other vector-borne diseases. M&E indicators for IVM have also been provided (146).

5.1.1 Design of M&E programme

The M&E plan should focus on the collection of essential data to optimize operations and inform expansion or adjustment. Key programmatic priorities should be identified, and the plan should be structured accordingly to address these priorities. Key components of M&E for LSM are outlined below.

Quality control of the method or product: determining whether the intervention prevents proliferation of the target vectors

Not all LSM interventions are equally effective. Even among larvicides, products can vary in their stability, their potency and how they persist in the water column where they are available to be ingested by the target mosquito (*Anopheles* are surface feeders, whereas *Aedes* typically feed throughout the water column). There must be quality control of all insecticides used in vector control, particularly bacterial larvicides. WHO-prequalified products should be used. If programmes or projects elect to use products that are not prequalified, it is imperative that quality still be monitored.

The WHO publication *Guidelines for laboratory and field testing of mosquito larvicides* (147) provides comprehensive guidance on how to carry out laboratory studies and small-scale and large-scale field trials to determine the efficacy, field application rates, and operational feasibility and acceptability of a mosquito larvicide. This guidance may be subject to update as new types of larvicides become available.

If a programme lacks a laboratory, field trials of formulated products can be performed on a small scale against target mosquitoes, preferably in representative natural aquatic habitats or, if such trials are not feasible, under simulated field conditions. For instance, for field testing Bti against wild *An. gambiae* s.l., large plastic bowls filled with water with a little soil added provide ideal oviposition sites (148). After a few days, wild mosquitoes will have laid eggs in the bowls and wild *An. gambiae* s.l. larvae will have hatched. (If this does not occur, a standard number of early [first and second] and late [third and fourth] instar larvae from wild-caught blood-fed mosquitoes could be introduced to the bowls). Different concentrations of larvicide are then added to the bowls, with some bowls left untreated to serve as controls. At daily intervals, the number of *Anopheles* larvae of early or late instars can be checked to see how effective the larvicide is relative to the untreated bowls.

It is important to make these assessments independently from those manufacturing or selling the larvicides so that the programme manager can be confident that the larvicide works well under local conditions with local mosquitoes.

Monitoring of operations: reporting on containers managed, larviciding and habitats modified or manipulated

A good system of reporting which habitats have been modified, manipulated or treated is essential, and, ideally, this should capture all actions by public health teams and the community. In urban areas, such as where the majority of *Ae. aegypti* or *An. stephensi* habitats are artificial receptacles in and around households, data on habitat availability and interventions can be captured through house-to-house surveys. In rural areas with scattered or numerous natural habitats for *Anopheles*, ground-based surveys may be needed, although these can be augmented with GIS mapping of habitats (Table 9).

Programmatic activities, such as daily larvicide use by mosquito control officers, should be recorded and reported to supervisors. To do so, mosquito control officers should record the following information in a standard form or data platform (Annex 2): date; location visited for LSM; total weight or volume of larvicide received for the day; total weight of larvicide remaining at the end of the day; and calculated weight of larvicide used for the day. Data should be recorded for every day that larval control is conducted.

Supervisors can monitor larvicide use with information collected in these paper forms or electronic platforms. Larvicide use can also be cross-checked at both local and central stock facilities. This will enable new stock to be ordered and shipped in sufficient time.

Source reduction activities by other sectors, community groups, members or volunteers should also be recorded and reported in the same system if possible.

Table 9. Example operational indicators for LSM against *Anopheles* in two settings

LSM against <i>An. stephensi</i> using larvicide dispensed by backpack sprayers or calibrated spoons and source reduction	LSM using Bti in rice fields for <i>Anopheles</i> spp. using drones
<ul style="list-style-type: none"> • Amount of larvicide used (kg) • Average number of properties visited per cycle • Average number of aquatic habitats treated per cycle by direct application • Average number of aquatic habitats treated by backpack spraying • Average number of larval sources reduced • Population protected by LSM • Number of people trained to deliver LSM 	<ul style="list-style-type: none"> • Surface area of rice fields targeted (ha) • Surface area of rice fields sprayed (ha) • Spray progression based on target (%) • Population protected • Total number of Bti cannisters used per cycle • Average number of Bti cannisters used per day • Spray rate (g/ha) • Bti consumption (ha/bottle)

Quality assurance of the implementation: checking field application of LSM

LSM, including larviciding, should be considered a continuous learning activity. Source reduction and larvicide applicators learn where the local mosquito aquatic habitats are and improve their effectiveness from one round to the next. Nonetheless, it is essential for the LSM programme manager to have full confidence in the applicators. For this reason, an independent group of assessors can be used to check the quality of the LSM programme. This information can then be fed back to the programme manager for corrective action. As exemplified in Dar es Salaam, United Republic of Tanzania (114), assessors who were independent of the programme reported on whether the applicators followed their schedule correctly, whether they entered all the stipulated areas, how habitats were searched for larvae, and how they interacted with residents.

Random larval spot-checks to monitor the larviciding applicators' performance should be carried out in treated areas throughout the transmission season(s) to determine the proportion of habitats containing early and late instar larvae. This could be a fixed proportion or a minimum number of aquatic habitats within every applicator's area that should be checked at least once per month. For instance, this could be 10% of all habitats, 30–40 habitats, or all habitats at 20 households, depending on habitat abundance and distribution, sampling method and size of the area. Inspection of sites should take place 1–2 days after the habitats have been treated with larvicide. The results from this spot-checking will inform the programme manager of the performance of the applicators. In addition, sentinel sites may also be checked in an untreated area at a distance from the treated area to monitor seasonal fluctuations in mosquito numbers in the absence of the intervention.

Impact of the programme: vector-borne disease transmission and vector populations

It is important to monitor the impact of LSM on vector-borne disease transmission, where possible. Routine data from health facilities on cases confirmed by microscopy, rapid diagnostic test or PCR will provide some insight but may not be a reliable indicator of infection rates or the impact of LSM on pathogen transmission. These data can be augmented with active case detection or seroprevalence surveys, although these may not be feasible in operational programmes. Moreover, distinguishing the epidemiological impact of LSM relative to other control measures will be difficult, especially if there are changes in other interventions such as improved diagnosis and treatment, distribution of ITNs or implementation of IRS.

Entomological measures can be useful proxies of LSM impact in operational settings.

Adult stage

A proximate measure of the impact of the LSM programme is adult mosquito population densities in the target area (145, 146). This will show, first and foremost, whether the LSM programme has been able to locate and treat most of the aquatic habitats in the target area or if additional unseen or missed habitats are still contributing to adult vector populations and potentially to vector-borne disease transmission. The simplest way to do this for *Anopheles* vectors is by collecting adult mosquitoes indoors, using CDC light traps operating next to individuals sleeping under an ITN, human landing catches or pyrethrum spray knock-down catches in the early morning. However, these collections are less efficient for species that bite in the early evening or outdoors, or have low attraction to traps such as *An. stephensi*. For *Aedes* vectors, adult collections can be done through indoor aspiration collections, with gravid *Aedes* traps or through outdoor sweep nets, depending on the species.

To reduce the risk of spillover, whereby mosquitoes from untreated areas fly into treated areas, it is important to establish a network of about 30 houses at the centre of the treated area. These houses should be sampled weekly during the transmission season. If possible, it would also be beneficial to sample from a similar number of houses in an untreated area nearby but beyond the expected flight range of the target vectors in order to determine the reduction in mosquito densities achieved by LSM. Preferably, all houses should be randomly selected so that the average intensity of transmission in the area is captured.

Human landing catches and human serological markers of mosquito saliva antibodies can indicate changes in exposure to mosquito bites in malaria and arbovirus transmission settings and may have particular use where case incidence is low or underreported. However, their application for evaluating LSM impact within operational settings is currently constrained by practical and ethical challenges.

Immature stages

Immature larval surveys conducted through house-to-house surveys are a common method for monitoring the impact of LSM programmes targeting *Anopheles* and *Aedes* vectors. These aim to detect mosquito larvae and pupae in aquatic habitats in order to evaluate temporal changes in vector presence or abundance (Box 38).

For *Aedes* vectors, immature indices such as the Breteau index (number of containers positive for immatures per 100 houses), container index (proportion of water-holding containers positive for immatures) and house index (proportion of houses with at least one positive container) are widely used in urban dengue control programmes. However, these traditional indices are qualitative and often poorly correlated with

adult mosquito densities or transmission, particularly for *Ae. aegypti*, which often inhabits a wide range of small and large habitats that produce variable numbers of adults. Pupal indices, which quantify the number of pupae per person or per area, have been proposed as more reliable proxies of adult vector abundance and dengue risk, since the pupal stage immediately precedes adult emergence.

Quantitative *Aedes* immature surveys that identify and monitor key containers – specific container types that consistently produce a high proportion of *Aedes* immatures – offer a cost-effective strategy to measure and optimize LSM impact. Targeting these high-productivity aquatic habitats can increase intervention efficiency, especially in resource-limited settings where complete elimination of all aquatic habitats is impractical. However, key container types can vary by setting and season, and their identification requires detailed habitat inspections and accurate population estimates. Quantitative surveys remain under-utilized in most operational settings.

For *Anopheles* vectors, aquatic habitat mapping and density measurements inform operational targeting in rural or peri-urban environments. These surveys provide practical, low-cost tools to inform LSM implementation and track intervention reach, especially where adult vector surveillance is not feasible. However, their utility for evaluating LSM impact is limited by the dynamic and often transient nature of *Anopheles* aquatic habitats, which vary by season, species and ecological conditions. Moreover, larval presence or abundance does not necessarily reflect the adult productivity of a habitat. Surveys may also fail to capture cryptic or inaccessible aquatic habitats, leading to underestimation of residual risk. Estimating larval densities in *Anopheles* habitats is also complicated by the large surface area and heterogeneity of aquatic habitats such as ponds, rice fields and temporary rain pools. As a result, while larval surveys are useful for guiding LSM operations, they may not provide a reliable stand-alone metric for measuring intervention impact and should ideally be complemented by adult vector data or entomological transmission indicators where feasible. In addition, while the presence of immatures after treatment can indicate intervention failure, in some settings, it may reflect newly colonized habitats or incomplete coverage. These limitations highlight the need to complement immature surveys with adult mosquito surveillance or epidemiological indicators when evaluating LSM impact.

Box 38. Immature surveys

During immature surveys, it is very important to record early-stage larvae (first and second instars), late-stage larvae (third and fourth instars) and pupae separately. Depending on the timing and type of LSM intervention, an abundance of late-stage larvae or the presence of pupae can indicate LSM intervention failure.

Monitoring the resistance of local vectors to chemical or biological insecticides

Bioassays for larvicides, including biological larvicides

Larval bioassays, in which larvae (of known age or instar) are exposed to treated water for 24 hours or 48 hours, are used to assess resistance. Procedures for larval bioassays for *Anopheles* and *Aedes* mosquitoes are available from WHO (101, 149).

Two approaches can be used: determining dose-response values or tests against a discriminating concentration. In both cases, each treatment should be replicated four or more times and compared with an equal number of controls that are set up simultaneously in dechlorinated tap water (with any organic solvents added).

Determining dose-response values

Larvae are exposed to a wide range of insecticide concentrations to test the activity range of the insecticide. After determining the mortality of larvae in this range of concentrations, a narrower range of concentrations is used to determine the lethal concentration (LC) that results in 50%, 90% and 99.9% mortality (LC_{50} , LC_{90} , $LC_{99.9}$ values, respectively). The same procedure is carried out with a susceptible strain that is kept in an insectary colony. LC values are calculated from a log dosage-probit mortality regression line using computer software programmes. The resistance ratio is the ratio produced when the LC_{50} value of the field-collected strain is divided by the LC_{50} value of a susceptible strain. When the resistance ratio is less than 5, the field population is considered susceptible; when the resistance ratio is between 5 and 10, mosquitoes are considered to have moderate resistance; and when the resistance ratio is greater than 10, the mosquitoes are highly resistant.

Tests against a discriminating concentration

Alternatively, a rapid assessment of the resistance status of a field population can be attained by assessing mortality against the discriminating dose. For instance, the discriminating concentration for temephos has been established as 0.012 mg/L.

If necessary, the discriminating concentration can be calculated using the results of bioassays run against a susceptible strain. The discriminating concentration is calculated as twice the $LC_{99.9}$ value of the susceptible strain that is kept in an insectary colony. When interpreting the results, the same classifications apply as for discriminating concentration bioassays with adults. Mortality of 98–100% indicates susceptibility, 90–97% is considered possible resistance and less than 90% is confirmed resistance.

Bioassays with IGRs

IGRs have a delayed action on treated larvae. Juvenile hormone mimics interfere with the transformation of late instar larvae into pupae and then into adults. Chitin synthesis inhibitors inhibit cuticle formation and affect all instars and immature stages of the mosquito.

In IGR tests, mortality is assessed every two or three days until adult emergence or until there is mortality in immature stages. An accurate initial count of larvae is essential because of the cannibalistic or scavenging behaviour of larvae during the long exposure period. Larvae should be provided with a small amount of food every two days. The effect of IGRs on mosquito larvae is expressed in terms of the percentage of larvae that do not develop into successfully emerging adults, termed adult emergence inhibition (EI%). The bioassays are conducted in the same manner as the dose-response bioassays for larvicides, as outlined above.

In sum, M&E strategies for LSM programmes must be tailored to the specific LSM methods employed and adapted to the diverse ecological settings. Differences in vector ecology, habitat stability and urban versus rural contexts – along with variations in implementation scale and design – will influence the choice of indicators and the frequency and mode of M&E data collection.

As outlined above, LSM programmes should integrate both immature habitat surveillance and adult mosquito monitoring. Surveillance activities may build upon systems already used for baseline entomological assessments and be adapted for routine use through scheduled monitoring or spot-checks during the intervention period.

To ensure sustainability and scalability, M&E systems should be simple, locally owned and embedded within existing surveillance or health information systems where

possible. Capacity-building for larval surveillance officers, supervisors and data managers – including SOPs and regular supervisory feedback – is critical to maintain data quality and ensure that the system supports adaptive LSM implementation.

5.1.2 Data management

Effective data management is critical for the success of LSM operations targeting *Anopheles* and *Aedes* vectors. It ensures that programmatic data are accurately recorded, promptly reviewed and used to inform real-time operational decisions.

Field data – such as larval presence, habitat type, intervention coverage and timing – should be collected daily using standardized forms, whether paper-based or digital. Supervisors should review these data within 24 hours to guide any necessary reapplication or adjustments, and develop aggregated weekly summaries. At the programme level, data should be centralized in an electronic database capable of generating automated summaries, maps and visual reports to support M&E and accountability.

Ensuring timely feedback loops, consistent data quality checks and integration with existing vector surveillance systems strengthens the responsiveness and impact of both *Anopheles* and *Aedes* LSM programmes.

Data forms

The following forms may be used as standards within an LSM programme, although supplementary or specialized forms may be required depending on the LSM methods and approach used. Once these forms have been trialled for use in the field and adapted, they can be converted into electronic data input forms with automatically generated summaries, visualizations and analyses. Timely reporting and review at all levels is essential to ensure operational responsiveness and enable programmatic impact.

Household identification card

Where ground-based LSM operations are conducted and the majority of habitats are found in and around houses, each household can be issued a household identification card during the first visit. These cards may be used by teams conducting LSM to track activities, as well as by those distributing ITNs or conducting IRS. This card is used to assign a unique identification number to each home to track the household in monitoring systems, including where data are digitally collected. These cards can be printed on one side only and stapled or tacked to the doorframe or other visible area of a visited household. An example form is provided in Annex 2.

Household habitat and LSM survey form

Households in targeted areas are likely to be visited multiple times a year for source reduction or larviciding. At each household, the field staff will collect primary data on the household survey form or using electronic methods. An example form is provided in Annex 2. Detailed instructions for each question on the form should be provided to the field staff in their training.

Daily LSM team form

LSM teams should complete forms each day to summarize key details of all household visits. These should be provided each day to the LSM supervisor, for example, for paper-based forms, in pre-labelled folders for each ward or operational unit. An example form is provided in Annex 2.

Weekly LSM supervisor form

Supervisors should review daily LSM team forms and survey forms within 24 hours of submission and should compile weekly summary sheets to be submitted to the LSM programme manager. An example form is provided in Annex 2.

Monthly LSM programme manager checklist

The LSM programme manager should conduct a completeness and accuracy check of weekly LSM supervisor forms using a standardized checklist. The summary totals from each supervisor's weekly report should be entered into a central electronic database ideally configured to automatically generate key statistics, charts and visualizations. These summaries can be distributed monthly to managers and decision-makers, allowing for system-wide performance review and early identification of implementation gaps or weaknesses.

Area-wide treatment form

Where large-scale ground- or aerial-based treatments are conducted beyond residential areas, it is imperative to collect data on what was applied, where and when. Reliable identification and tracking of each habitat can be challenging, but GPS location can be helpful for mapping. Relevant data should also be provided to local authorities, as required by local regulations.

Data transport

Where paper-based forms are used, the process for transporting these from the field to the point of data entry will depend on the supervisory hierarchy in the field. The process and needs should be defined by the M&E officer and the programme manager, with responsible parties trained on this.

Data entry and cleaning

Regardless of the LSM intervention, data should be reviewed daily to enable timely identification of issues within the programme that require immediate attention, re-training or other corrective action.

Data should be entered into a computer-based database either manually or automatically, using mobile data collection as often as feasible. Data should be frequently reviewed, cleaned, saved and backed up. Daily data entry is ideal, with the cleaned database accessible by the LSM supervisor or M&E officer to determine progress and identify if any action is required.

Computers, tablets or smartphones that are suitable for the data collection system may need to be procured. Mobile modems and data plans may also be needed. If the budget permits, additional useful items include backup batteries or power supplies for laptops, extra chargers for laptops or tablets, and a surge protector for the laptop's charger connection.

Where data are collected on paper forms, data entry assistants may need to be hired, such as on a seasonal or temporary basis, depending on programme capacity.

Indicators

Key indicators have been identified for the different LSM types (Table 10) (145). Immatures include larvae and pupae, with larvae reported by early (first and second) or late (third and fourth) instars.

Table 10. Key M&E indicators for different LSM types

Indicator	Outcome(s)	Source reduction						Source treatment			
		Container and waste management				Environmental management		Larviciding		Biological control	
		Destruction and disposal	Emptying and cleaning	Moving, inverting and covering	Otherwise physically blocking egg laying	Environmental manipulation	Environmental modification	Chemical	Biological	Fish	Biological agents
Immature vector aquatic habitats											
Habitat availability	Number of aquatic habitats present in an area, per habitat type	x	x	x	x						
Habitat occupancy	Number of habitats with immatures present in an area, per habitat type		x	x	x						
Larval and/or pupal density	Number of immatures collected or estimated, per individual habitat					x	x	x	x	x	x
Key habitats (relative productivity)	Proportion of all immatures collected or estimated in an area, per habitat type	x	x	x	x	x	x	x	x	x	x
Adult vector composition											
Density	Number of adult female vectors collected, usually per sampling method and unit time	x	x	x	x	x	x	x	x	x	x
Adult vector behaviour											
Human biting rate	Number of adult female vectors that attempt to feed or are freshly blood-fed, per person per unit time	x	x	x	x	x	x	x	x	x	x
Indoor resting density	Proportion of adult female vectors collected resting indoors (and in outdoor structures sampled), usually per human-hour	x	x	x	x	x	x	x	x	x	x
Adult vector insecticide resistance											
Resistance frequency	Proportion of adult female vectors alive after exposure to insecticide							x	x		

5.2 Review

5.2.1 Annual operational review

LSM operational reviews should be undertaken annually or at the end of each deployment round to determine whether all aspects of the operation have been carried out according to the plan of action. This includes outcomes from pilot implementation, which are essential to inform decisions on if, where and when to scale up the LSM programme.

Details of reviews provided for IRS operations generally apply to LSM programmes, such as the need to report on coverage, timing, equipment, expenses, incidents and lessons learned. Further details can be accessed in the WHO *Operational manual on indoor residual spraying* (6).

5.2.2 Strategic review and recommendations

At the conclusion of an LSM programme, an evaluation of operations, quality control, quality assurance and impact should be conducted, as outlined above. This should include information on the extent, timing and quality of implementation, coverage relative to targets, entomological indicators, and changes in vector-borne disease incidence or prevalence. This information can be used to generate recommendations to improve future LSM activities and identify any needs for training or research activities.

Periodic programme strategic evaluations take place once a programme has been running over several transmission seasons. These evaluations bring together all operational information collected to enable assessment of the broader programme components, such as cost, policy, management structure and organization, effectiveness and efficiency of the intervention, and programme performance and sustainability. These evaluations help to identify trends, strengths and weaknesses that could be instrumental in making decisions about future expansion of interventions or reduction of target areas and objectives.

These reviews, therefore, inform any necessary updates to the LSM strategy and operations based on previous experience, lessons learned and the evolving situation.

5.3 Evidence gaps

Several key evidence gaps exist for LSM, some of which have been identified in the WHO *guidelines for malaria* (8). Key research needs include:

- further evidence on the epidemiological and entomological impacts of different LSM methods in relation to the presence or absence of other interventions and across different settings (with different vector species and aquatic habitats);
- further evidence on the potential harms/unintended consequences of different interventions;

- information on the utility and accuracy of new technologies for identifying and monitoring aquatic habitats;
- information on the utility and cost of new technologies for delivering larviciding;
- detailed descriptions of the interventions deployed, as well as aquatic habitat types and vector species targeted, and assessment of the impact of the intervention on the water conditions of the aquatic habitats, i.e., properties of the habitat that the intervention aims to modify, such as water flow, volume, sunlight penetration, salinity or other physical conditions;
- evidence on contextual factors (i.e., acceptability, feasibility, resource use, cost-effectiveness, equity, values and preferences) related to environmental modification and/or manipulation; and
- evidence on the impact (incidence and/or prevalence) and potential harms/unintended consequences of the use of larvivorous fish.

The process and requirements for evaluating LSM interventions are beyond the scope of this operational manual. Product developers and researchers planning to generate evidence for LSM intended to support WHO guideline development or revision should refer to relevant WHO guidance and processes (150).

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Annex 1. Case studies

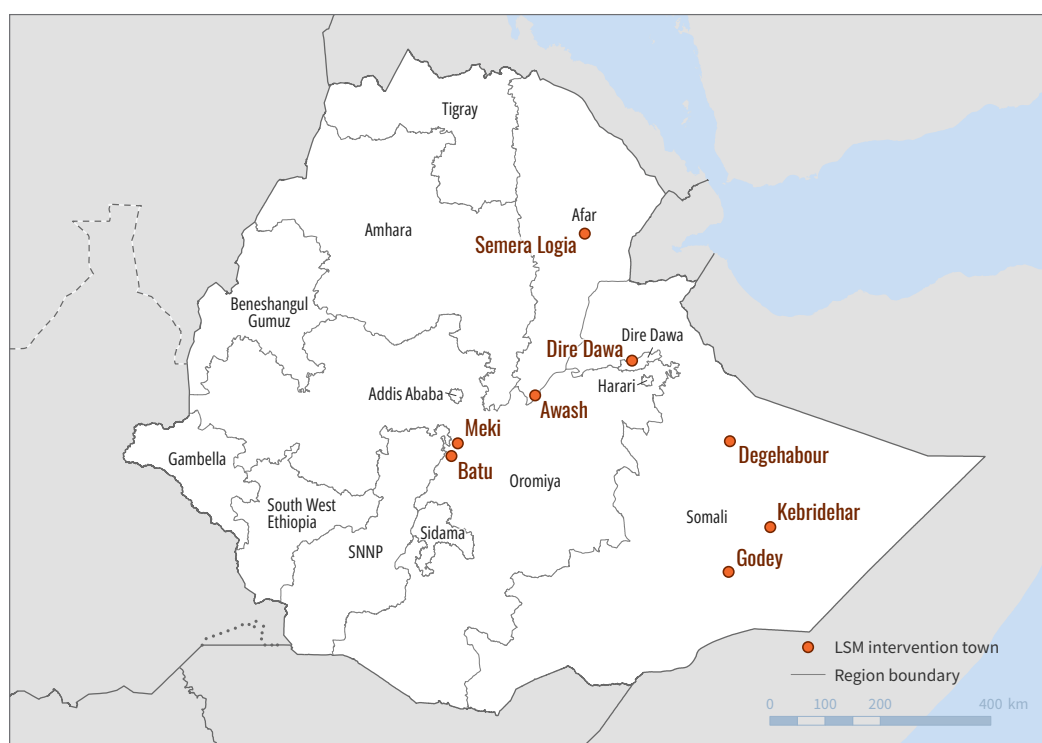
Case study 1. LSM for *An. stephensi* in Ethiopia

The invasive malaria vector *An. stephensi* was first detected in Ethiopia in 2016 (1). By 2024, the species had been found in over 50 sites – primarily in the eastern, north-eastern and central parts, but spread across the country (2). With *An. stephensi* currently reported in eight African countries, WHO has urged Member States that have already detected the vector or that are at risk to enhance vector surveillance and implementation of interventions directed against *An. stephensi*, with an emphasis on LSM (3). The U.S. President’s Malaria Initiative (PMI) Ethiopia team, in collaboration with the Ethiopia Ministry of Health/Malaria and Other Vector Borne Disease Prevention and Control Desk, initiated enhanced *An. stephensi* surveillance in 2018, finding the over 50 sites with positive detections. In addition, PMI supported pilot implementation of LSM in eight towns (Awash, Batu, Degehabur, Dire Dawa, Gode, Kebri Dehar, Meki and Semera Logia) beginning in August 2022 (4).

Background

Site characteristics: LSM was implemented in eight towns (Fig. A1.1) where *An. stephensi* was prevalent. All towns were located at altitudes below 2000 m. The towns had manageable numbers of artificial container aquatic habitats typically used by the species and suitable for larviciding. In seven of the eight towns where LSM was implemented, all kebeles (subsections of the town) were targeted. The exception was Dire Dawa, the second largest city in Ethiopia, where LSM was implemented in three out of nine kebeles, which were considered the hotspots of malaria transmission in the city. The three targeted kebeles were selected based on the larval survey data showing the greatest occurrence of *An. stephensi* aquatic habitats.

Fig. A1.1. PMI-supported LSM implementation towns in Ethiopia



Climate: in Ethiopia, the main rainy season is from June to September. A short rainy season occurs between March and April. Mean annual rainfall varies, ranging between 300 mm and 2000 mm. The temperature also varies from -15°C in the highlands to above 25°C in the lowlands.

Primary and secondary vectors: the main malaria vector in Ethiopia is *An. arabiensis*, which is commonly found during and after the rainy seasons. The other species is the invasive *An. stephensi* that has recently been associated with malaria outbreaks in eastern Ethiopia (5). Some secondary malaria vectors in Ethiopia include *An. pharoensis*, *An. funestus* s.s. and *An. nili*. Infective malaria parasites have also been detected in *An. coustani*.

Main types of aquatic habitats: in its invasive range thus far, *An. stephensi* is typically found in large artificial container habitats such as cisterns, birkas, water tanks, and discarded container habitats (e.g., tires) commonly found in urban areas (6). The species can also breed in natural habitats such as puddles and slow-moving streams.

Malaria transmission: about 75 million people (70% of the total population) in Ethiopia live in areas at risk for malaria transmission. Transmission is seasonal and varies geographically across the country (7). The primary malaria parasites are *Plasmodium falciparum* and *P. vivax*, although *P. malariae* is also found.

An. stephensi mosquitoes have been found to be infected with *P. falciparum* and *P. vivax*, indicating that the species is an efficient vector to transmit the two major malaria parasites in the country (8). *An. stephensi* can also sustain transmission during the dry season due to its breeding habits; therefore, transmission is maintained throughout the year in contrast to the seasonal transmission of the native African malaria vectors.

LSM activity

Structure of the control programme: the LSM project targeted 87 309 residential, commercial, government and nongovernment properties across eight towns. The PMI-supported project hired 34 community mosquito collectors (CMCs) to conduct entomological surveillance and 300 community vector control technicians (CVCTs) to visit every property every two weeks and apply the appropriate treatment (larvicide application directly via spoons or backpack sprayer, or source reduction) to each potential aquatic habitat.

Baseline mapping and data collection: enumeration of properties (residential, commercial or communal structures where people live, work or gather) and aquatic habitats was conducted before LSM implementation to identify the number and types of aquatic habitats present in and around each property, and to quantify the material and human resources required. The exercise identified nearly 1 million aquatic habitats across more than 87 000 properties (90% of which were residential). The average number of potential aquatic habitats per property ranged from three to 35.

LSM: during the biweekly property visits, the CVCTs checked all aquatic habitats found and recorded the number of habitats with and without larvae or pupae. Any larvae present were identified to genus and collected from temporary containers with high density (greater than 10 larvae per dip). All aquatic habitats found were recorded on the data collection form (which included collection of geocoordinates). The habitats were then either treated with larvicide (Bti) or source reduced (Fig. A1.2).

Fig. A1.2. Community vector control technician spraying a cistern



A technician spraying larvicide into a water storage container.

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Entomological surveillance: larval and pupal collections were conducted by CMCs weekly, with 2–4 collections (depending on town) before the intervention (baseline) and for every week of the intervention period to assess the impact of the intervention on larval density and habitat positivity rates. These habitats were not treated.

Each CMC collected larvae from 10 “permanent tracked” habitats each week by taking 20 dips from each habitat using a standard dipper. There was a total average of 289 permanent tracked habitats across the eight towns. Each CMC also conducted larval sampling from 20 randomly selected habitats per week in each town, for a total of about 800 aquatic habitats per week across the eight towns.

CVCTs also collected larvae and pupae during the visits but recorded the larvae only by genus. Samples were kept in collection jars and transported to the local insectary. Anopheline and culicine mosquito larvae were collected from the aquatic habitats and anophelines were raised to adults for species identification. Anopheline larvae were also categorized as early and late instars and recorded in the standard data collection form designed for this pilot.

Adult collections were also carried out weekly by CMCs. Adult mosquitoes were collected from different resting sites, such as human dwellings both indoors and outdoors (sleeping places, under eaves, in cracks and crevices, and under vegetation), animal shelters, and pit valves using Prokopack aspirators.

Funding: this activity was funded by the United States Agency for International Development (USAID)/PMI.

Impact

Entomological outcomes: data collected from the baseline to the end of the projected intervention period demonstrated that LSM had an impact on entomological indicators. Averaged across the eight towns, the larval density of *Anopheles* mosquitoes (predominantly *An. stephensi* – about 70%) decreased from 18.7 larvae per 20 dips at baseline to 3.3 larvae per 20 dips post-intervention. The larval density of *Culex* and *Aedes* mosquitoes also declined post-intervention. For all mosquito genera, larval density post-intervention was significantly less compared to the baseline ($p < 0.05$). Overall, pupal density of all mosquito genera also declined from 2.8 pupae per 20 dips at baseline to 0.2 pupae per 20 dips post-intervention. The proportion of aquatic habitats that were positive for any mosquito larvae (habitat positivity rate) declined from 0.7 at baseline to 0.1 post-intervention.

Sustainability: the LSM programme transitioned to a local government-led community-based approach in all eight towns between July 2023 and January 2024. PMI continues to support the transition through provision of technical assistance and limited materials (including larvicide), with plans for support to be scaled down over time.

Factors contributing to success

The following factors contributed to the success of the programme in Ethiopia:

- Appropriate areas were selected for the LSM intervention. Most of the aquatic habitats were artificial container habitats that could be mapped, targeted and tracked for LSM intervention.
- The short rainy season at most sites also enabled the teams to successfully implement the programme and limit the number of habitats created due to rain.
- Property enumeration was critical for the success of this activity, enabling the team to quantify material and human resources needs, develop implementation plans and monitor progress against targets.
- CVCTs and CMCs were recruited from the local communities; they were trusted by homeowners and motivated to deliver results.
- Municipal authorities were involved in planning, recruiting and supervising LSM, and they remained highly engaged through the provision of resources needed to sustain community-based LSM (with limited support from PMI).
- Several larvicide manufacturers were highly engaged in the process of selecting appropriate products for the Ethiopian context and troubleshooting persistently positive aquatic habitats.

Challenges

- The residual life of Bti was short and required frequent application, which made the activity a resource-intensive operation.
- In certain areas (e.g., locations with higher temperatures, where the duration of aquatic stages is shorter, or in flowing water sources), adult mosquitoes emerged before the subsequent round of application.
- A larvicide shortage was also reported, which forced a change in the strategy to treating only positive habitats instead of all habitats. However, this shortage was brief and had no major implications for the impact of the intervention.
- Workforce attrition was also a persistent challenge.

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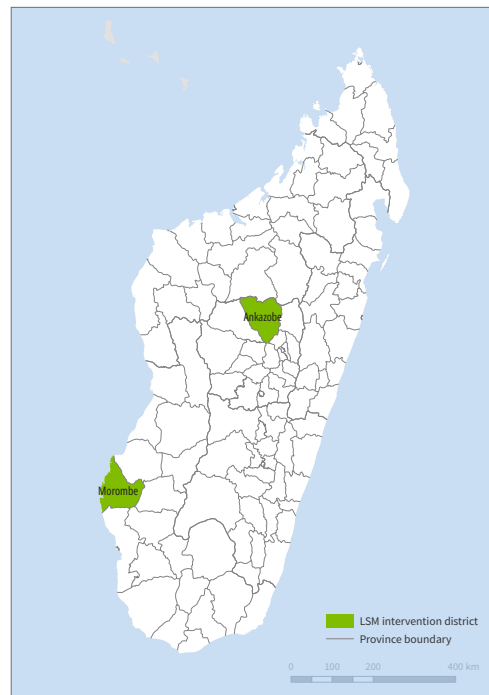
Case study 2. LSM in rice fields in Madagascar

Madagascar faces major health challenges, with severe malaria among the top five causes of mortality. Malaria epidemiology varies across the country; however, the entire population is considered to be at risk for the disease. Despite high coverage of ITNs and IRS in certain districts, there are regions of Madagascar that continue to have high malaria burden, which has been shown to be associated with aquatic agriculture (i.e., proximity to rice fields) (9), and outdoor-biting and -resting mosquito behaviour patterns (10). LSM can be used as a complementary vector control tool in addition to ITNs and IRS, which target indoor biting and resting. In 2022, PMI assessed the feasibility and community acceptance of mapping aquatic habitats and implementing LSM using drones in rice fields, and its contribution to existing vector control programmes in two malarious districts of Madagascar.

Background

Site characteristics: in close collaboration with the National Malaria Control Program and PMI, two districts were selected for the LSM activity: Morombe District, located on the south-west coast of the Atsimo-Andrefana Region, and Ankazobe District, located in the Analamanga Region in the Central Highlands (Fig. A1.3). These districts were selected due to the high malaria burden, longitudinal data indicating outdoor biting, the presence of aquatic agriculture (rice fields) within 1 km of human dwellings, and a short rainy season (approximately five months).

Rice is the main food crop in Madagascar, and rice farming is a key economic activity that supports the country's food security. The districts of Morombe and Ankazobe have different models for rice farming. Rice cultivation in Morombe District is independent of the rainy season because it is irrigated by the Bas Mangoky canal. This enables the local population to have two seasons of rice cultivation in the year (January to June, and August to December). In the Ankazobe District, rice cultivation depends on the rainy season from November to May. The area is rural, and rice fields are scattered on a plateau surrounded by mountain ranges in most areas.

Fig. A1.3. Map of Madagascar showing districts of Ankazobe and Morombe

Climate: Madagascar's climate is tropical, with regional variations and two distinct seasons: (i) a hot, rainy season from November to April, with the highest rainfall in December and January; and (ii) a dry season from May to October, with the least rainfall in September and October. Annual average precipitation countrywide is 1500 mm but varies widely from region to region. Average annual temperatures are 23–27°C along the coast and 16–19°C in the highlands.

Primary and secondary vectors: primary vectors include *An. gambiae s.s.*, *An. arabiensis* and *An. funestus*. Other important vectors in Madagascar include *An. coustani*, *An. mascarensis* and *An. squamosus/cyddipis* (11), which have been known to be outdoor-biting and -resting mosquitoes that thrive in aquatic agricultural settings.

Main types of aquatic habitats: rice fields and aquatic agriculture are highly productive habitats for malaria vectors in Madagascar due to the presence of vegetation and stagnant water (12, 13).

Malaria transmission: Madagascar's 29 million residents are at risk for malaria, which is primarily transmitted December–April and caused by *P. falciparum*. Malaria prevalence among children under the age of 5 is estimated at 7.5%, and incidence is estimated at 57 per 1000 population per year, although the burden is heterogeneous (11).

LSM activity

Structure of the control activity: the activity was carried out in three phases: drone mapping, selection of aquatic habitats, and aerial spraying of larvicides and supervision. The implementation of aerial larviciding in rice fields was conducted in partnership with a drone operating company, AerialMetric, along with USAID/PMI, the Ministry of Health, the Ministry of Agriculture and Livestock, the Ministry of Environment and Sustainable Development, fokontany chiefs, community health workers, community members and rice farmers.

Baseline mapping: AerialMetric carried out photographic mapping using drones to locate the water bodies and identify the specific intervention areas from July to December 2021. Orthophotographs, digital elevation models and contour maps were produced to delineate potential aquatic habitats. Of the 39 fokontany (towns) in Morombe and Ankazobe that were mapped, 17 were selected for this study: 11 in Ankazobe and six in Morombe. All targeted fokontany were selected based on the following criteria: the presence of rice fields, endemicity, areas outside of protected and organic farming zones, accessibility, habitat suitability, and available funds for LSM.

LSM: aerial spraying of the biological larvicide Bti using high-capacity drones was conducted biweekly from February to July 2022. In collaboration with AerialMetric, six DJI Agras T30 drones were modified to spray the larvicide on the rice fields at a flow rate of 1.5 L/min using a 3% larvicide suspension. The drones were programmed to fly at an altitude of 3 m at a speed of 15 km/h and deliver 5–7 m of swath overlap to ensure full coverage of the target area.

Entomological surveillance: larval and adult surveillance was conducted before and during each spray cycle, in addition to baseline data collection one month prior to spraying and post-intervention monitoring.

- Larval sampling: ten dips using 350 mL dipper were done at each selected aquatic habitat for a total of 3.5 L of aquatic habitat water, following WHO guidelines (14).
- Adult sampling: data on species composition, vector densities and vector behaviour were collected using human landing catches for two consecutive nights in three houses per site per month both indoors and outdoors. Indoor resting collections were also performed using Prokopack aspirators and/or mouth aspiration in 10 houses per site monthly; both Prokopack and mouth aspiration methods were used for collections outdoors from resting places such as pits, tree holes, and zebu pens at each site on one day per month. CDC light traps were also used at each site outdoors for two nights to capture mosquito diversity. All mosquitoes collected through each method were morphologically identified to genus. *Anopheles* mosquitoes were identified to species or species complex by microscope.

Larvicide spray quality assessment was also conducted during each spray cycle by exposing larvae to some quantity of water from treated rice fields collected right after spraying.

Funding: this activity was funded by USAID/PMI.

Other malaria control interventions: as part of Madagascar's national strategic plan (2023–2027), an IVM strategy is promoted that includes vector surveillance, insecticide resistance management, continuous and mass distribution of ITNs, geographically targeted IRS, and LSM.

Impact

Entomological outcomes: over the monitoring period, a significant reduction in larval density was observed, with 95–96% larval reduction in Morombe and 96–97% in Ankazobe in the first two days post-treatment for each spray cycle. A reduction in mosquito biting rate was recorded at all sprayed sites compared to baseline.

Anopheles gambiae s.l. was the dominant vector collected from all sites using all collection methods for both outdoor and indoor collections, except with CDC light traps in Ankazobe where only 11 specimens were collected. Further analysis is under way to conduct molecular identification of species from adult collections.

The larval bioassays conducted with both Bti stock solution and water from the implementation sites showed high mortality between 24 and 48 hours.

Acceptability survey: this qualitative analysis revealed widespread community acceptance of the drone larviciding in rice fields in Madagascar using Bti. Perceptions of rice field workers and owners included lack of harm to fish or humans, increased crop yields, decrease in the mosquito population and buzzing sounds, and limited disruption of their time in the rice fields (15).

Factors contributing to success

Drone mapping of habitats allowed for high-resolution planning of operations and significantly reduced field time compared to land-based ground truthing methods.

The activity's success was due to close and coordinated collaboration among all partners, which included the following:

- Local authorities: the National Malaria Control Program, Ministry of Agriculture and Livestock, and the Ministry of Environment and Sustainable Development actively participated in courtesy and advocacy visits, community dialogues and training of mobilizers, as well as supervision activities to ensure timely and quality implementation of larviciding activities.
- Community mobilizers: social mobilization was conducted by integrating the fokontany chiefs, community health workers, rice farmers and representatives of the Federation of Mangoky Users' Associations.
- AerialMetric: acquisition of flight permits, planning, mapping and implementation of LSM activities were conducted in close collaboration with AerialMetric.

Challenges

Challenges encountered included:

- high operational cost of larviciding via drones;
- short residual efficacy of the larvicide used;
- impact of weather events such as cyclones; and
- less stable aquatic habitats in rain-fed rice fields than in irrigated rice fields, leading to fluctuations in target areas.

Case study 3. LSM in rural and urban Rwanda

The core vector control interventions implemented in Rwanda include ITNs and IRS (16, 17). LSM is recommended for implementation in the context of IVM to address transmission by outdoor-resting and -biting mosquitoes, malaria transmission hotspots, insecticide resistance and other mosquito-borne diseases (17, 18). LSM was initiated and implemented in Rwanda for the first time in 2015 as an experiment in a rural setting covering 93 ha. It targeted the key mosquito aquatic habitats ranging from rice fields, hill water dams, inter-crop water drains and pits for watering vegetable farms contingent to the rice fields (18). Two other pilots were implemented in peri-urban areas of Kigali, the capital of Rwanda. This programme was run from July 2020 to April 2021 and February 2023 to January 2024, targeting similar aquatic habitats over 336 ha and 956 ha, respectively (19). These two pilots used a combination of hand application and drone-based technology for biweekly application of larvicide. All three pilots used VectoBac® WDG. Site selection was guided by three main criteria: malaria incidence, the nearby highly agglomerated human settlements, and availability of funds (Fig. A1.4) (18).

Fig. A1.4. Selection of LSM sites based on localities with highly agglomerated human settlements in suburban Kigali (as an example for LSM performed, July 2020 to April 2021)

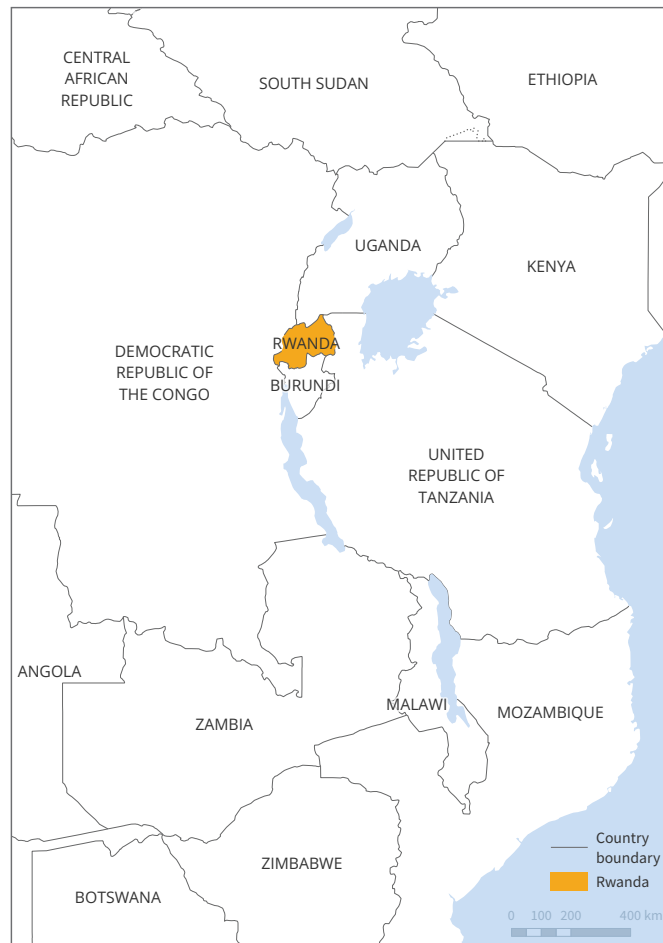


A map showing areas targeted for larval source management.

Background

Topography: Rwanda is located in the great lakes region of central Africa, between 1°4' and 2°51' south latitude and 28°63' and 30°54' east longitude. It is bordered by Burundi, the Democratic Republic of the Congo, Uganda and the United Republic of Tanzania (Fig. A1.5).

Climate: the climate is subequatorial temperate with average annual temperature varying from 15°C to 27°C. The average annual rainfall is 1250 mm in a bimodal rainfall pattern alternating with two dry seasons. Rwanda is characterized by a high density of rivers and streams, and several lakes surrounded by wetlands.

Fig. A1.5. Map of Rwanda

Malaria vectors: the main malaria vectors are *An. arabiensis*, *An. gambiae s.s* and *An. funestus*. Resistance to pyrethroid insecticides was first confirmed in *An. gambiae s.l.* in 2013 and is more prevalent in highly endemic districts in lowland areas.

Malaria parasites: *P. falciparum*, *P. ovale* and *P. malariae* cause malaria disease, and *P. falciparum* constitutes 97–99% of malaria infections.

Main types of aquatic habitats: main aquatic habitats include rice fields, inter-crop water drains in wetlands, pits from mining sites or vegetable growing farms, hill trenches for controlling soil erosion, rainwater dams, non-covered containers in peri-domestic settings, floods during heavy rains and water puddles (Fig. A1.6).

Fig. A1.6. Main mosquito aquatic habitats targeted with larviciding using Bti

Aquatic habitats that may be targeted for larviciding.

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Malaria transmission: malaria transmission is perennial with two peaks occurring in May/June and December/January, following the respective peaks of the rainfall seasons. The entire population of the country is at risk for malaria transmission.

LSM activity

Structure of the control programme: Rwanda developed its IVM strategy in 2013, and LSM was defined as an important vector control intervention to complement the core vector control interventions. It was recommended in situations where mosquito aquatic habitats are well defined, for instance in urban areas, as well as in valley areas where extreme climatic conditions such as flooding and human activities tend to create significant mosquito aquatic habitats. Understanding of the ecology of vectors and their aquatic habitats was identified as a prerequisite for an effective LSM programme. Later, LSM was integrated into National Malaria Control Program policies and strategies. LSM activities include habitat manipulation, habitat modification, larviciding and biological control. From 2015, different larviciding interventions have been implemented in targeted settings, including: countrywide environmental management through monthly community works, locally named “Umuganda”, biological control using larvivorous fish (*Tilapia* spp.) targeting water dams and irrigation channels, and larviciding using Bti (VectoBac® WDG) sprayed by hand or using drones.

Environmental management: environmental management includes habitat modification and habitat manipulation. It is implemented under the IVM strategy through collaboration with the Ministry of Local Government and subnational leaders. Training-of-trainer events occurred in all 30 districts and sector (subdistrict) levels for implementation of environmental management through identified targeted groups (schools, cooperatives of rice farmers, miners, local leaders, etc.).

Biological control: biological control is implemented using larvivorous fish (*Tilapia* spp.) through collaboration with the Ministry of Agriculture and Animal Resources (aquaculture department) and the private sector. The biological control targets the water dams used for different purposes and the irrigated channels of rice fields.

Larviciding: based on the lessons learned, best practices and entomological impacts of larviciding from the three pilot phases in Rwanda, larviciding was integrated as a supplemental vector control intervention in the national policy, strategy and guidelines for malaria control. Larviciding is implemented using hand applications or drone technology guided by habitat mapping data from existing known water bodies using drones or other mapping technologies, including satellite images. The scale-up of larviciding in six districts covering 3600 ha has been highlighted in the strategic plan, and proposals have been developed and submitted to potential partners for funding. Furthermore, LSM using environmental management is being scaled up

countrywide using subnational administrative entities, partners, community-based organizations and community members at the village level. For implementation, cascade training-of-trainers sessions at the district and sector levels were performed in collaboration with local government and partners. At the subsector level, training focuses on targeted groups (such as village leaders, cooperatives, schools, churches and mosques and other community-based organizations) to promote awareness and effective implementation of environmental management.

Entomological monitoring: during the three pilot phases, entomological monitoring was performed by the Rwanda Biomedical Centre for both adult and larval mosquitoes every two weeks to evaluate the impact of larviciding. Adult mosquitoes were collected in at least 20 houses selected from either the intervention or control villages with separate teams using CDC light traps and pyrethrum spraying catching methods.

The intervention villages were separated from control villages by at least 5 km. The larval monitoring used dipping methods following longitudinal transects, and sampling plots were geolocated and separated by 100 m for the first phase and by 200 m for the second and third larviciding phases.

Epidemiological impact: the first and third larviciding phases did not include the evaluation of epidemiological impact. However, this was included in the second pilot phase, performed five months following distribution of pyrethroid-piperonyl butoxide nets in the intervention and control areas. Monthly malaria cases were collected from health centres and the registers of community health workers of 15 villages (of which 12 were intervention sites and three were adjacent control sites). After 10 months of larviciding, there was a reported 33.1% decline in malaria incidence in the intervention sites compared to the control sites (those receiving piperonyl butoxide nets only through universal mass net distribution) that was attributable to the added effect of larviciding.

Funding: the first larviciding phase was funded by NWO-WOTRO Science for Global Development (Dutch development organization) to monitor the impact, and Valent Biosciences LLC contributed a donation of required larvicide (VectoBac® WDG). The other two phases were funded by the Government of Rwanda and two local organizations (Society for Family Health (SFH) – Rwanda, and Charis UAS for drone services).

Other malaria control interventions: two core vector control interventions are implemented in Rwanda. IRS is deployed in 13 out of the 30 districts countrywide. ITNs are distributed with universal coverage in non-targeted IRS districts and to targeted groups including pregnant women and children under 5 years of age in IRS districts. Supplemental interventions focus on mosquito repellents, using social marketing channels.

Impact

Larviciding showed significant impacts on the following outcomes:

- substantial reduction in the abundance and density of larval and adult mosquito populations, particularly *Anopheles* species (19, 20);
- significant reduction of malaria incidence, with the specific contribution of larviciding estimated at 33.1% over the impact of ITNs comparing the intervention and control villages (19);

- a high level of community ownership and acceptance of larviciding intervention, particularly owing to Bti safety for spray operators and the drastic reduction of nuisance mosquito biting, which enabled farm workers to tend to rice farms until late evening without the fear of contracting malaria (21, 22); and
- community engagement and willingness to financially contribute to the LSM programme and malaria control (23).

Factors contributing to success

The factors contributing to the success of the programme included:

- high community acceptance and engagement to support larviciding from the first experiment phase;
- government and local partner engagement to support LSM; and
- testimonies from rice farmers on an increase in rice yields due to the reduction of nuisance mosquito biting and malaria incidence which had enabled more time for tending to the rice.

Challenges

The main challenges encountered were as follows:

- Coverage of upstream irrigation water dams and rice fields by hand spray operators during the first three months of the rice growing cycle was inadequate. The latter was due to flood water during periods of heavy rain or watering the rice fields. This made spraying difficult for the spray operators, as they would sink into the soil of the rice fields. The low coverage of peri-domestic mosquito aquatic habitats jeopardized the impact on control of *Culex* mosquito populations.
- There were challenges with mobilizing funds to sustain or scale-up larviciding and to respond to growing community requests for the intervention.

Case study 4. LSM in Ghana

Malaria remains a leading cause of morbidity and mortality in Ghana. Despite the widespread implementation of preventive measures such as ITNs and IRS, malaria remains prevalent, especially in rural and urban fringes where mosquito aquatic habitats are abundant. The persistence of malaria may be attributable to the increasing trend of outdoor mosquito biting and evening activities conducted with limited personal protection, leading to greater outdoor exposure. Although proven effective, ITNs and IRS primarily target mosquitoes that bite indoors, leaving a gap in protection. In response, LSM was introduced to complement the existing vector control strategies by targeting the aquatic stages of the mosquito life cycle, thereby reducing the adult mosquito population capable of disease transmission.

Background

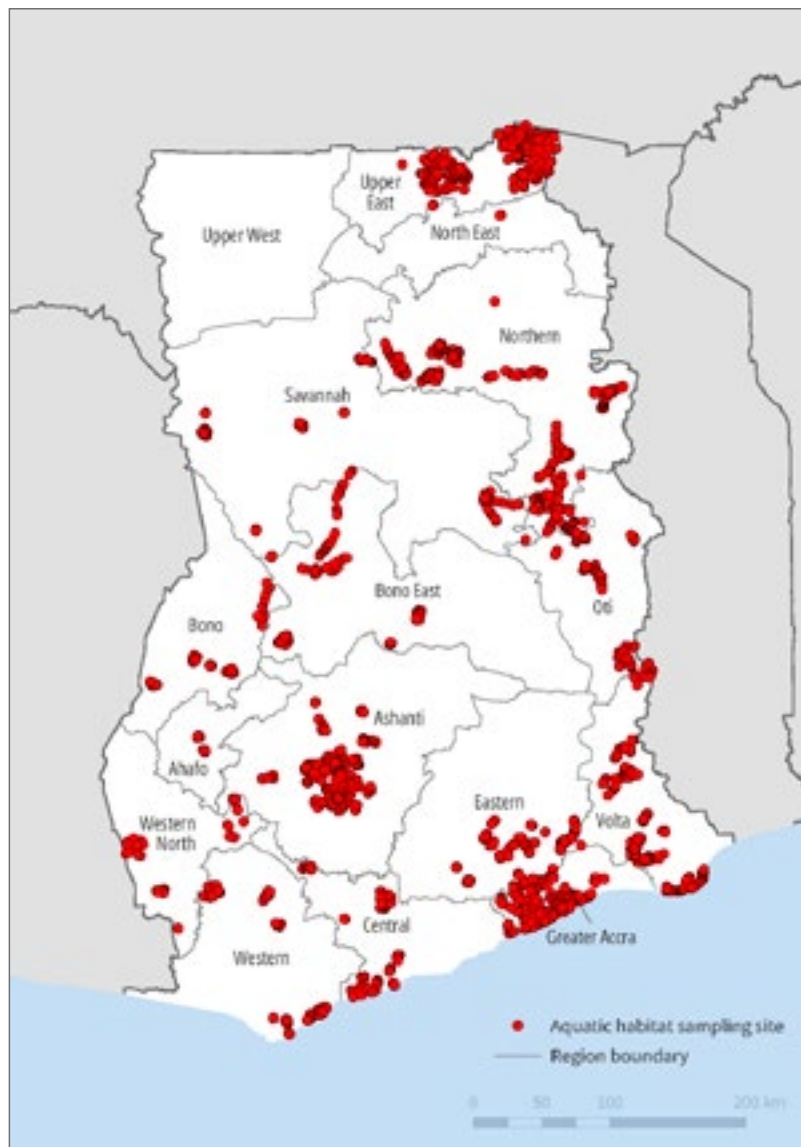
Site characteristics: LSM in Ghana involves larvicide application and environmental management (mainly desilting of drains and ditches). Environmental management is conducted in all 260 districts nationwide, while larviciding is implemented in 133 districts across 14 of the 16 regions. LSM is a key component of Ghana's broader IVM strategy. The activities are concentrated in peri-urban areas around major cities such as Accra and Kumasi, as well as towns such as Bolgatanga and Tamale. In addition, rural areas with dams and agricultural irrigation systems are targeted for this intervention.

Climate and aquatic habitats: Ghana experiences a tropical climate with two major seasons – wet and dry – with more pronounced seasonality in the regions in the north. The variability in rainfall impacts the breeding patterns of mosquitoes, with a notable increase in aquatic habitats during the wet season. Typical aquatic habitats include ephemeral pools such as roadside ditches, perennial water bodies such as swamps and ponds, dams, rice fields and urban drainage systems.

Primary vectors: the main vectors responsible for malaria transmission in Ghana are *An. gambiae* s.s. and *An. funestus*, whose breeding is heavily influenced by environmental conditions and human activities. However, in an effort to reduce populations of nuisance biters and vectors for other vector-borne diseases, Ghana's LSM programme also targets aquatic habitats that are typically not occupied by *Anopheles* larvae, such as more polluted urban drainage systems.

Baseline surveys: some LSM activities have been implemented since 2009. However, the revised approach with National Malaria Elimination Programme involvement began in 2019, with a nationwide mapping exercise conducted in September (wet season) of that year to geolocate and characterize aquatic habitats. Mapping was conducted by spray operators in all 16 regions. Data were collected digitally using KoboCollect (Fig. A1.7). About one third of the habitats were roadside ditches/drains and another third were perennial habitats such as swamps and ponds. Additional information on mosquito genus, life cycle stage and habitat size was also collected (data not shown).

Fig. A1.7. Map illustrating point locations of mosquito aquatic habitats identified during the baseline survey conducted in 2019



LSM activity

Structure of the control activity: the LSM initiative in Ghana is fully funded by the Government of Ghana through the Ministry of Health. The implementation of LSM is led by the National Malaria Elimination Programme in partnership with Zoomlion Ghana Limited, a private waste and sanitation company with a nationwide presence. The initiative focuses primarily on larviciding but also includes environmental management practices such as habitat modification and manipulation, as well as community education. Collaborating partners include research and academic institutions for M&E studies.

Larviciding: larviciding began in July 2020 using biological control agents such as Bti (VectoBac® 12AS). The implementation leverages collaboration with local health directorates, environmental health officers and community stakeholders to ensure widespread community acceptance and participation. Biolarvicides are applied weekly to all found aquatic habitats using motorized backpack sprayers. However, weekly application proved operationally difficult; therefore, beginning in 2021, the programme transitioned to using Bs biolarvicide with a 28-day residual life.

M&E: entomological and epidemiological surveillance was conducted in 14 sentinel sites representing the three ecological zones of the country (Fig. A1.8). One site was chosen to represent each of the 14 districts. Seven of these sites were designated as intervention districts for larviciding, and the remaining seven served as control districts. Baseline entomological surveys were conducted in all sites in June 2020, and baseline epidemiological surveys took place in 2019. Follow-up entomological surveys were conducted in 2023 (September–November) and epidemiological follow-up surveys occurred in 2020–2023. Operational monitoring indicators included the number of found aquatic habitats that were sprayed. Entomological indicators included larval density, adult density (CDC light traps) and sporozoite rates. Epidemiological indicators included confirmed malaria cases as a percent of outpatient department data extracted from the District Health Information System 2, verified through case register review at the health centres. In addition, cross-sectional studies were conducted in children under the age of 5 in selected communities within the health facility catchment areas.

Fig. A1.8. Location of intervention sites receiving larviciding and control sites that just received standard of care



Impact

Entomological indicators: the density of mosquitoes at the intervention sites was 71% less than at control sites (Table A1.1). The same collection effort was used in both site types.

Table A1.1. The number of mosquitoes captured with CDC light traps in control and intervention sites during the three-month follow-up survey in 2023

Species	Sep-23			Oct-23			Nov-23		
	Control	Intervention	P value	Control	Intervention	P value	Control	Intervention	P value
<i>Anopheles</i>	348	37	<0.0001	361	130	<0.0001	390	189	<0.0001
<i>Culex</i>	2322	431	<0.0001	2490	510	<0.0001	3299	1070	<0.0001
<i>Aedes</i>	5	0	0.063	0	294	<0.0001	0	4	0.125
<i>Mansonia</i>	0	0		0	0		35	3	<0.0001

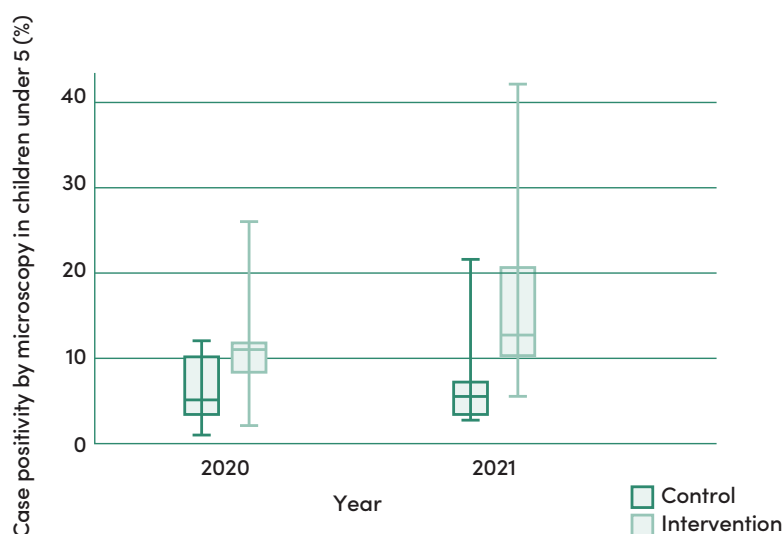
A total of 1000 *An. gambiae s.l.* and *An. funestus* mosquitoes were examined for the presence of circumsporozoite proteins in their salivary glands. The overall sporozoite rate was less in control districts than in intervention districts (Table A1.2).

Table A1.2. The percentage of *Anopheles* mosquitoes collected during the three-month follow-up surveys (September–November 2023) that were positive for sporozoites in control and intervention areas

Sites	Number examined	Number positive for <i>P. falciparum</i>	Sporozoite rate (%)	P-value
Control	700	8	1.2	<0.0001*
Intervention	300	2	0.7	
Total	1000	2668	71.2	

Epidemiological indicators: a decrease in malaria was not detected using any of the indicators from health facility registers or from the cross-sectional surveys. No differences in indicators between the control and intervention sites were apparent (Fig. A1.9). However, there was significant variability in these indicators and overlap between the estimates in both groups.

Fig. A1.9. Slide positivity rate, confirmed by microscopy, in children under 5 years old in cross-sectional surveys performed in control and intervention communities



Factors contributing to success

Key factors included:

- strong governmental support and funding;
- effective partnership with Zoomlion Ghana Limited for operational execution; and
- community engagement and education initiatives to enhance participation and compliance.

Challenges

Despite the strategic implementation, several challenges persisted, including:

- logistical issues related to the distribution and application of larvicides;
- financial constraints impacting the scale and sustainability of operations;
- community resistance due to insufficient awareness of the benefits of LSM; and
- inability to reach all habitats in a district, despite high coverage of found habitats.

Conclusion and future directions

While LSM presents a promising addition to malaria control in Ghana, as evidenced by its impact on mosquito abundance and infection prevalence, its long-term effectiveness depends on several critical factors: a robust process and impact monitoring plan, sustained funding, community acceptance, and integration with other vector control strategies. Continuous monitoring and adaptation based on entomological and epidemiological data will be crucial to optimize the impact of LSM on malaria reduction in Ghana. To enhance these efforts, the National Malaria Elimination Programme is currently exploring technological advancements to improve the identification and treatment of aquatic habitats. In addition, the programme is revising its evaluation strategy to ensure a more comprehensive assessment of LSM's effectiveness.

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Annex 2. Forms

Form 1. Household identification card

Date card issued _____

District/Municipality _____ Parish/Ward _____ Village/Suburb _____

Head of household _____ Household ID No. _____ GPS: Longitude _____ Latitude _____

Date inspected	Number of occupants		No. habitats dry	No. habitats wet	No. habitats reduced	No. habitats treated	Treatment details and comments (e.g., larvicide/agent used, timing for repeat treatment)	Team Lead name	Treatment checked
	Adults	Children							

Date _____ Comments _____

Date _____ Comments _____

Date _____ Comments _____

Annex 3. Additional tools

Tool 1. LSM programme timeline planning tool

This was adapted from the “Race to the starting line” tool developed by USAID/PMI (1).

Country: X Date Updated:	Weeks until start of spray campaign									0	Name of person responsible	Notes
	9	8	7	6	5	4	3	2	1	Start date		
Due Date (Deadline)												
Activity												
Headquarter procurement of larviciding supplies and equipment												
Local procurement of supplies and equipment												
Susceptibility tests for insecticides												
Residuality tests for insecticides												
Pre-season environmental compliance assessment for each operation site: x operation sites (health centres) in x municipalities (x days)												
Micro-planning meeting with Ministry of Health and health centres (x days)												

	Weeks until start of spray campaign									0	Name of person responsible	Notes	
	9	8	7	6	5	4	3	2	1	Start date			
Country: X Date Updated:													
Work plan to address environmental compliance deficiencies: (x days at the most, included x health centres)													
Vehicle usage and transport plan													
Logistics/materials distribution & dispatch plan (x days)													
Seasonal personnel payment plan													
Solid waste storage & disposal plan													
Larviciding performance targets													
Recruitment of vector control technicians, team leaders, supervisors, and data entry clerks													
Training of trainers (x days)													
Certification of storage areas (x days)													
Training of storekeepers (x days)													
Larviciding calendar													
Larviciding supervision and monitoring plan													

Tool 2. LSM programme supervision checklist

This was adapted from the “Race to the starting line” tool developed by USAID/PMI.

Category	Question	Follow-Up
PPE	Is the VC technician wearing proper PPE (closed-toe shoes, long-sleeved shirt, long pants)?	If at least one item is missing, instruct the VC technician that he/she cannot continue larviciding until he/she conforms to PPE standards.
Morning Preparation	Does each VC technician have his/her assigned bottle of Bti, five blank sheets of VC data collection forms, a clipboard, a flashlight, measuring tape (or the equivalent), measuring spoons (or the equivalent), calculator, and a larva sample collection net? <i>The sample net is not to be used to actually collect samples from the houses but as a way to thoroughly evaluate each potential aquatic habitat for the presence of larvae and/or pupae, particularly for habitats that are dark or deep.</i>	If the VC technician is missing any of the essential items, immediately contact his/her VC TL to ensure that extra materials are secured from the warehouse and distributed to the VC technician as needed.
Morning Preparation	Has the VC TL informed each VC technician of where the team will be going that day and which sectors will be visited? <i>VC technicians should know what their responsibilities are at the beginning of each day, especially if they are visiting houses for the second or third time.</i>	If the VC technicians have not been informed of their geographical responsibilities for the day, pause the team’s activities and instruct the VC TL to inform the VC technicians of the expected geographical reach for the day.
Homeowner Sensitization	Did the VC technician appropriately introduce him/herself? <i>This includes: introducing the ZAP Project (and the fact that is funded by citizens of the United States of America), the VC technician’s purpose for coming to the home (source inspection and larviciding with Bti for the prevention of mosquito growth), the frequency with which he/she will be coming (monthly), encouraging the homeowner to ask any questions.</i>	If the introduction is not sufficient, instruct the VC technician on the complete recommended introduction before entering the household. This can be tailored based on which visit the VC technician is conducting (first versus third versus tenth).

Category	Question	Follow-Up
Homeowner Instructions	<p>Did the VC technician give appropriate instructions to the homeowner on what to do with treated containers in the time between monthly larviciding visits?</p> <p><i>This should include instructions to thoroughly wash all sinks and barrels (if possible) at least every seven days. Additionally, homeowners should be instructed to retain a bottle or bucket of treated water prior to fully washing the sink/barrel. Once the sink/barrel has been washed, this treated water should be reintroduced to the source in order to mix with any water later added to the source. Finally, treated water should not be used for drinking, but can be used for cooking, bathing and other tasks where it is not directly ingested.</i></p>	If the instructions are insufficient, instruct the VC technician on the proper information needed by the homeowner for treated containers.
Homeowner Instructions	<p>Did the VC technician give appropriate instructions to the homeowner on how to identify and remove any impermanent potential aquatic habitats?</p> <p><i>This should include instructions for the homeowner to be vigilant after the receipt of water as well as after rains for any small impermanent potential aquatic habitats (planters, tires, small bottles, etc.). Additionally, the homeowner should understand that elimination of an aquatic habitat does not simply mean dumping any standing water, but removing the potential habitat entirely from an area where it could gather/retain water.</i></p>	If the instructions are insufficient, instruct the VC technician on the proper information needed by the homeowner for impermanent/eliminable containers.
Homeowner Instructions	<p>Did the VC technician inform the homeowner that he/she would be returning in one month?</p>	If the VC technician did not inform the homeowner that he/she would be returning in one month, inform the homeowner that the VC technician will be returning each month and remind the VC technician that this piece of information is essential to building the trust between the homeowner and VC team member.

Category	Question	Follow-Up
Volume Measurement	<p>Did the VC technician appropriately calculate the volume of a container that was to be treated by either using a tape measure or asking the homeowner of the volume? Length x width x height.</p> <p><i>Note that one or more of these may need to be somewhat estimated if the homeowner does not know the theoretical volume of the container (e.g., a 500 L barrel) or if the container is oddly shaped. Note also that the VC technician should be calculating the theoretical volume of the container, not the actual amount of water currently in the container.</i></p>	<p>If the VC technician is not appropriately calculating the volume of the container, stop him/her, instruct him/her on the appropriate way to calculate the volume, and calculate the volume with the VC technician to ensure that the correct volume is calculated. Remind the VC technician that the volume has implications for the amount of Bti to be applied.</p>
Treatment	<p>Did the VC technician apply the equivalent of 3 mg of Bti per litre of theoretical volume of an immovable/permanent container?</p> <p><i>Ask the VC technician how much Bti he/she plans to apply to the container before he/she actually applies it. Verify if this is correct before allowing the VC technician to proceed.</i></p>	<p>The VC technician should be measuring the Bti to be applied based on the theoretical volume calculated at a rate of 3 mg of Bti per litre of theoretical volume of container.</p>
Larvae/Pupae Inspection	<p>Did the VC technician appropriately and thoroughly inspect each and every aquatic habitat for the presence of larvae and/or pupae, ending each inspection with the larvero?</p> <p><i>As a best practice, the VC technician should be using his/her provided flashlight to look along all sides of each container, look in each corner, and, as best as he/she can, look in the bottom edges of the container and along the walls. After a visual inspection, for especially dark or deep habitats, VC technicians should attempt to collect small samples to ensure that no larvae and/or pupae are present. The sample should be discarded immediately after inspection.</i></p>	<p>If the VC technician did not thoroughly look at each container, instruct the VC technician to revisit the containers he/she missed and observe the method that he/she uses to evaluate each container, drawing his/her attention to the walls, edges, corners and depths of each container. Be sure to revisit previously evaluated sources for a more thorough inspection.</p>
Data Collection	<p>Are VC technicians appropriately filling out the VC data collection form during each visit?</p> <p>Things to look for: one line per habitat; volume calculated for each habitat; one household name, one household status, one set of population information per household (not per source); treatment status per habitat (i.e., per line); larvae and pupae survey per habitat (i.e., per line)</p>	<p>If the VC technician is not correctly filling out the form, stop him/her and talk him/her through appropriate data entry protocols for the VC data collection form. For additional information, refer him/her back to the VC data collection instruction manual.</p>

PPE: personal protective equipment; VC: vector control; TL: team leader

Tool 3. SOP for container-inhabiting larvae and pupae collections

This has been adapted from the VectorLink SOP for *An. stephensi*.

Purpose

This SOP outlines the procedures for larval and pupal collection for container-inhabiting mosquitoes to help identify the most productive aquatic habitats and determine larval indices to inform targeted intervention and reduce vector population density.

Equipment and materials

- dipper
- netting
- pipettes
- enamel trays
- bowls
- bottles/vials/ buckets
- beakers
- mosquito cages
- dog biscuits
- yeast powder
- torch
- filter papers
- pencil/pen
- hand lens

Safety

Hazards: list items that are risks, e.g., manual handling, sharps, chemical, biological, radiation

- Hazard – no obvious risk.

Risk controls: list the controls in place to minimize or lower the risk level, e.g., use of personal protective equipment, use of item/chemical restricted to trained persons, specific training and induction processes, designated waste disposal guidelines, etc.

- Risk control – none needed under normal conditions.

Procedures

1. To determine the presence/absence of container-inhabiting mosquitoes in new urban areas, select those sites around port of entry and transportation corridors and conduct immature surveillance.
2. In each site, inspect potential larval and pupal habitats. Make sure that all potential habits are surveyed during the survey including natural and artificial water receptacles (examples in Fig. A3.1).
3. Record the geographical coordinates, altitude, size, type and other characteristics of the aquatic habitats listed in the larva and pupa data collection form.

Fig. A3.1. Potential aquatic habitats



A collection of potential aquatic sites such as wells, storage containers, and tires.

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- The larval collector must approach the aquatic habitat carefully, as any disturbance will cause the larvae and pupae to swim downwards and become inaccessible. It is important that the collector does not cast a shadow on the water. If the larvae and pupae move, it may be necessary to stand quietly until they swim back up.
- In the case of large containers, use a standard 350 mL capacity mosquito dipper or a white plastic pan with the same capacity attached to an extendable aluminium or wooden handle to sample larvae and pupae. Pour the water from the dipper through a sieve and transfer the larvae and pupae to an appropriate container for transport to the laboratory. In small aquatic habitats where dippers are not effective, pour the entire contents of the water container through a sieve and transfer larvae to a sealable container for transport back to a laboratory for species identification. Small containers include discarded tires, buckets and paint cans. Discard the water.
- Take one dip at a time from each water collection and visually observe for the presence or absence of mosquito larvae (Fig. A3.2). The dipper should be lowered gently at an angle of about 45° to minimize disruption and either skim the top of the water or gently lower it to cause the water and nearby larvae to

flow into the dipper. Care should be taken not to spill water when raising the dipper from the water. If the aquatic habitat is positive for mosquito larvae or pupae, count the number of larvae and pupae per dip and transfer into a well labelled bottle/small bucket or Jerrycan with cover. Take 20 dips per positive large container habitat to determine larval/pupal density. If found co-inhabiting with other mosquito species, note the number of larvae and pupae of each genus to determine the immature density of the container. The dips are to be taken from the margins of the aquatic habitats, as larvae and pupae are generally found along the edges of the water surface. If no larvae or pupae are found with the first few dips, change the position and take up to 10 dips before classifying the aquatic habitat as negative. Record all aquatic habitats visited (negative and positive) on the data collection form.

- All specimens collected from a particular aquatic habitat should be kept in one bottle/vial or other collection container.
- Record the number of positive containers as well as the number of water-filled containers inspected in the larvae and pupae data collection form.
- Determine larval/pupal density of each individual habitat as the number of immatures per dip or per 20 dips as deemed necessary (i.e., total number of larvae and pupae collected/number of dips taken).
- When transporting larvae for long distances, do not cover the container. If covered then open the container at intervals (e.g., every two hours). Ensure that there is about 1–2 cm space in the collection container to allow air for larvae and pupae to breathe.
- Maintain the larvae in trays or bowls in the insectaries (permanent or temporary) and feed them with dog biscuit or yeast powder.
- Label the trays or bowls with the location and aquatic habitat from which specimens were collected.
- Check the bowls for pupae twice per day and remove them from the larval trays shortly after they have formed. Place them inside a mosquito rearing net or mosquito cage that is closed.
- Identify adults emerged from field-collected larvae and pupae to species level using the Coetzee 2020 standard identification key (2).

Fig. A3.2. *An. stephensi* larval collection



A technician sampling an open water storage container for larvae.

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Calculate indices

- **Larval density:** is the mean number of larvae. It is estimated as the total number of larvae collected divided by the total number of aquatic habitats investigated.
- **Relative breeding index:** provides a comparative metric of habitat suitability by dividing the number of habitats positive for the target species by the total number of habitats positive for any mosquito breeding.
- **Container index (larval positivity):** is defined as the total number of containers found with larvae divided by the total number of surveyed containers multiplied by 100. The container index can be calculated for all target vector species or for one particular species.

Quality control

Not applicable.

References¹

1. Zika AIRS project larviciding and source reduction guidelines. Bethesda: United States Agency for International Development (https://pdf.usaid.gov/pdf_docs/PA00TZZR.pdf).
2. Coetzee M. Key to the females of Afrotropical *Anopheles* mosquitoes (Diptera: Culicidae). *Malar J.* 2020;19(1):70 (<https://doi.org/10.1186/s12936-020-3144-9>).

¹ References were accessed on 13 January 2026.

Annex 4. Approach to Development

The 2026 revised version of this document was developed using the 2013 original publication as its foundation. Revisions were initially informed by an informal online opinion survey conducted in March 2024 which gathered input from 80 technical experts. Drawing on the findings of this survey, subject matter experts were identified and invited to participate in the revision process based on their specialised knowledge in areas flagged for update.

Experts were organised into working groups for feedback on specific chapters aligned with their respective areas of expertise. Key themes were discussed during an initial online consultation to determine priorities and scope. Chapter working groups met remotely to deliberate on required updates and review document drafts. Decisions were reached by consensus during online consultations, with informal minutes circulated to all peer reviewers to allow those unable to attend to provide additional comments; voting was reserved for unresolved points of contention, with WHO retaining final decision-making authority.

All external experts submitted Declarations of Interest, which were reviewed to identify any actual or perceived conflicts; where conflicts were identified, the relevant individual was excluded from discussions and their input disregarded for the affected sections. No conflicts were found that would compromise the objectivity or independence of contributors across the sections on which they provided input.

The process of content development was coordinated by Tessa Knox who led consultations and the integration of expert feedback into the revised version. Document finalisation and layout was coordinated by Seth Irish.

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