Many wells have been abandoned following the installation of piped water supplies. Filling them would be an effective solution. If wells have to remain available for possible reuse the introduction of larvivorous fish could also be considered. In places not subject to flooding, an effective and long-lasting solution is the application of a layer of polystyrene beads (p. 146).

Small pools of clean water are often found on construction sites and in the basements of buildings. They should be filled up or drained. In some cases larvivorous fish (p. 123) or larvicides (p. 128) such as oil are appropriate. Pools of relatively clean water are often formed near standpipes that do not have a proper drainage system, such as a gutter or a soakaway pit.

Breeding sites with polluted water

_Culex quinquefasciatus_, the vector of urban filariasis in some areas, breeds in on-site sanitation systems such as wet pit latrines, septic tanks, cesspits, cesspools, drains and canals containing stagnant water polluted with organic waste. They also breed in polluted water associated with home industries, for example in coconut husk pits. Other breeding sites are pools and disused wells used for dumping garbage. _Culex gelidus_, an important vector of Japanese encephalitis in south-east Asia, also breeds in polluted water. Pit latrines are the main breeding sites of blowflies (*Chrysomyia*), which are sometimes present in large numbers and may carry disease agents from faeces to food.

Pit latrines

Pit latrines, used for the disposal of human excreta, basically consist of a hole in the ground covered with a floor with a hole and surrounded by walls to provide privacy. The pits are normally dry in areas with dry porous soil. Only flies breed in dry pits. However, in areas with a high water table the pits contain water and often produce thousands of _Culex quinquefasciatus_. The improvement of sanitation leads ultimately to the development of water-borne systems whereby excreta are flushed through a short pipe to a septic tank or sewerage system.
Control measures

Improved design

Insect-proof covers prevent insects from entering or leaving pits (135). Lids of wood or metal do not fit tightly enough to be mosquito-proof. However, lids made of concrete can be cast in the holes in which they are to fit (Figs. 1.121 and 1.122).

Possible disadvantages

- The lid is relatively heavy, so it is difficult for children to lift.
- The edges of the lid are easily damaged, leading to loss of insect- and odour-proofing.
- Insects may enter and leave and odours may escape when the lid is lifted.
- The cost is high.

Pour-flush latrine with water seal (135). As for flush toilets, pit latrines can be provided with an S-bend water seal to prevent entry or exit of insects and the escape of odours (Fig. 1.123). Latrine slabs incorporating a water seal are widely available in Asian countries. The system has to be flushed with at least one litre of water and works best where people are accustomed to taking water with them to the toilet for washing. To avoid blockages and damage to the seal, solid objects should not be deposited in the latrine.

Ventilated improved pit latrine (135, 170–175). A ventilated pit latrine has a ventilation pipe fitted which draws away odours when an air current blows across the top of the pipe. Fresh air is sucked into the pit through the squat hole in the slab covering the pit.

The inside of a latrine building with a roof is relatively dark. Blowflies emerging in the pit are attracted up the vent pipe because it is better illuminated than the
squat hole. This method is partly effective against *Culex*. Because the top of the pipe is covered with flyproof netting, insects are unable to escape and eventually die.

For proper functioning it is essential that it is dark inside the latrine building. In rectangular structures, which have a door in one wall, care has to be taken to keep it properly closed, but there should be a gap, usually above the door, to allow air to enter. An open door reduces the effectiveness of the system by letting in daylight. Permanently dark conditions are ensured by building a doorless structure with a spiral ground plan (Figs. 1.124 and 1.125).

*Application of expanded polystyrene beads*

Polystyrene beads poured on to the water in a pit form a floating layer on the water surface. A complete layer 1–2 cm thick is sufficient to prevent mosquito breeding (p. 119). An additional advantage is the suppression of the odour that emerges from the pit. After faeces have dropped through it, the layer of beads reforms immediately. If a pit dries out the beads are buried under faeces. However, because of their buoyancy, the beads return to the surface when water enters the pit. The beads will last for several years provided they are not swept away by flooding.

*Application of larvicides*

Oil (156), chemical larvicides such as fenthion and chlorpyrifos, and the bacterial larvicide *B. sphaericus* can be used to control mosquito larvae in pit latrines.
Fig. 1.124
Flow of air in a ventilated improved pit latrine (© WHO).

Fig. 1.125
Components of a ventilated improved pit latrine with mud-and-wattle walls and a thatched roof (176).
In liquid form they can simply be poured into the pits, but a better distribution over the surface is obtained by spraying. Laricides can be applied quickly and have an immediate effect. Their main disadvantage is the need for repeated applications, which in the long term may make this method costly. Oil and most chemical laricides remain effective for only a few weeks at most. B. sphaericus may remain active for up to eight weeks after application, especially at high dosages.

Oil has the advantage that it is widely available. Small quantities of waste oil may be obtained free of charge and are sufficient for the treatment of a latrine. Oil kills mosquito larvae only if the surface area is completely covered. On heavily polluted surfaces, however, oil does not always spread well and may be quickly destroyed.

The chemical laricides have to be applied in higher dosages than are needed for the treatment of unpolluted water. Compounds other than fenthion and chlorpyrifos may be used if available. Laricides should remain effective for at least a few weeks.

**Septic tanks**

In areas without a piped water-borne sewerage system, septic tanks are commonly used for the disposal of sewage. The watertight settling tanks receive wastes carried by water flushing down short sewers. Inside the tanks the waste separates into liquid and solid matter, the latter having to be removed at intervals. The liquid effluent may flow out of the tank through an outlet and is usually disposed of in a soakaway pit or led into a drain. The overflow sometimes forms a puddle in which mosquitos can breed. The tanks are inconspicuous but very important breeding places for *Culex* mosquitos. *Aedes* mosquitos may also be found in septic tanks. The mosquitos enter the tanks through the ventilation pipes and the water outlets (Fig. 1.126). Cracks or other openings in covers are commonly formed when tanks are opened for desludging and periodical inspections; these should be sealed immediately.

**Control measures**

- Cover the ventilation pipe with aluminium or stainless steel mesh screening.
- Ensure that the cover is effectively sealed; a practical solution is to cover it with sand; large gaps can be filled with foam rubber.
- A soakaway pit (see below) should be installed if excess water is periodically discharged from the tank.
- Close the outlet with material that can easily be removed.
- Apply oil, chemical larvicide or polystyrene beads if the above measures are not possible (see section on wet pit latrines). If polystyrene beads are used the outlet should be screened to prevent them from being flushed out.

**Soakaway pits**

In many rapidly expanding urban areas, there are few facilities for the disposal of wastewater. Under such conditions, householders may dig pits on or near their premises for the disposal of effluents. Water in soakaway pits tends to stagnate and can become a favourable breeding place for *Culex* and, less commonly, *Aedes*.

**Control measures**

- Fill the pit with small stones (Fig. 1.127).
- If the pit does not overflow regularly apply polystyrene beads (p. 119).
A soakaway pit that collects run-off water used for washing and bathing can be filled with small stones to prevent mosquitos from breeding.

Septic tanks often constitute important breeding places for Culex, which enter and leave through the ventilation pipe, the overflow outlet and improperly closed openings.

A soakaway pit that collects run-off water used for washing and bathing can be filled with small stones to prevent mosquitos from breeding.
Apply oil or chemical larvicides (p. 128) to the surface to obtain immediate short-term protection.

**Drainage systems**

Urban areas generally have two drainage systems, one for the disposal of sullage (washing) water and sewage and the other for the drainage of rainwater. Rainwater is often drained through a surface drainage system while sewage is disposed of via either an underground or a surface drainage system, the latter often merging with the rainwater drainage system. Underground systems may seem the best because they are not easily accessible to mosquitos. However, lids on the inspection sites are not always properly closed and when problems arise they are difficult to solve. The underground system may become blocked, overflow and form puddles in which mosquitos can breed. The surface drains often replace the underground system when it becomes clogged.

The surface drains should have a gradual slope along their course to enable a sufficiently rapid flow of water to prevent mosquito breeding and blockages. Once blockages start to form, the water flow is retarded and complete blockage of the drains becomes likely. Together with the dumping of garbage in drains this creates favourable conditions for breeding by *Culex* and other mosquitos. If surface drains are partly covered, inspection, cleaning and maintenance are made more difficult.

**Control measures**

- Make sure that inspection openings of underground drains are properly closed.
- Ensure that the system is properly maintained and repairs are carried out promptly.
- Remove dirt, debris and other obstacles in the system to allow the water to flow freely (Fig. 1.128).
- Flush the drains periodically with clean water to remove dirt and debris and destroy mosquito breeding sites; this may be practicable in areas where water is abundant (e.g. by the sea).
For an immediate short-term solution, apply oil or chemical larvicide (p. 128) to the places where larvae are observed.

**Habitats in the field**

Several species of disease-carrying mosquito breed away from the domestic environment, both in naturally occurring habitats, such as swamps, rivers, creeks, lakes and ponds, and in man-made habitats, such as reservoirs, irrigation systems, irrigated fields and borrow-pits. Breeding in man-made habitats can sometimes be prevented by proper planning and design to make them unsuitable as breeding sites or to facilitate the implementation of control measures.

Effective larval control in rural areas requires a thorough understanding of the behaviour and breeding sites of the target species. Control activities should be planned, designed and supervised by experts in vector control so as to avoid mistakes and the waste of valuable resources. On some sites, such as swamps, rivers and lakes, these activities may have to be carried out by specialized teams. However, for the smaller breeding sites the involvement of local health services, communities, farmers and others is often essential to secure control.

The most important targets of control methods are the malaria-carrying *Anopheles* mosquitoes, which breed in a wide variety of habitats. Other targets are the *Mansonia* vectors of brugian filariasis which breed in swamps and pools, and the *Culex* vectors of Japanese encephalitis which breed mainly in rice fields and adjacent ditches.

Larval control measures usually have to be carried out over an area with a radius of 1.5–2 km from human habitations, the maximum flight range for most species of mosquito. In some areas the transmission of disease and the breeding of mosquitoes are largely limited to well-defined periods of the year, during which control efforts are particularly important.

**Swamps and marshes**

In many countries, swamps have become less important as breeding sites for mosquito vectors of disease as a result of land reclamation associated with urban and rural development.

*Control measures*

*Source reduction*

If swamps prove to be breeding sites they may be filled if relatively small and close to towns. Filling is usually uneconomic if swamps are extensive and there are no large settlements within flight range. Breeding sites can be drained (p. 114) and dried out by reducing the amount of water going into swamps or by increasing the rate of drainage. The input of water can in some cases be reduced by digging interceptor drains around the outer edges of swamps, usually at the foot of a hill (Fig. 1.129). In other cases drainage ditches may be made across swamps. Sometimes a dam can be constructed at the lower end of a swamp, causing conversion of the swamp into a deep lake in which larvivorous fish can be kept. Shallow marshlands and plots of land with a high water table can be dried out by planting eucalyptus trees (p. 119).
Larvicides
Larvicides are sometimes used in emergency situations. Granular formulations are most suitable, because they are easy to disperse and fall through vegetation into the water. Ultra-low-volume sprays (p. 132) may be applied by hand- or vehicle-carried mistblowers or by aircraft, the latter being used for quick action in extensive areas that are difficult to enter by other means. If fogging is conducted at the upwind side of a swamp, the wind will carry the particles into it over a considerable distance. Seasonal marshes that become submerged during and after the wet season may be treated with slow-release formulations (briquettes) of insect growth regulators (p. 134).

Lakes and reservoirs
If breeding occurs in lakes and reservoirs it normally takes place along the margins in shallow places protected by vegetation from fish, waves and excessive sunlight.

Control measures
Water-level fluctuation
Sometimes it is possible to construct a dam with a sluice at the outlet of a lake, as is usual in man-made reservoirs. This allows the water level to be raised and lowered (p. 121) at intervals. Keeping the water at a high level kills terrestrial vegetation on the shore. The level is kept as low as possible during the mosquito breeding season so as to strand mosquito larvae and floating objects along the margins and to inhibit the growth of aquatic plants. This leaves a clean margin
Coastal swamps and lagoons

Swamps and pools often occur behind coastlines, which are filled with seawater during spring tides but which are not subject to daily tidal action. As with freshwater swamps they can be filled or drained if this is economically feasible. Alternatively, automatic sluice gates can be constructed which let water out at low tide but prevent the influx of seawater at high tide. A simpler solution is to connect swamps and pools to the sea by ditches or culverts. This provides tidal action and the alternating presence of fresh and salt water, which prevents the development of suitable breeding habitats for most mosquito species (other than Anopheles melas in West Africa) (Fig. 1.130).

To control pest mosquitos (especially Aedes species) breeding in tidal salt marshes, granular insecticides are sometimes used; they release insecticide only after flooding, which coincides with the hatching of the eggs.

around the lake which does not offer any suitable breeding sites. The water level is raised and lowered at intervals of 7–10 days, less than the time needed for the development of the aquatic stages of the mosquito. Where needed this measure can be supplemented by the removal of accumulations of floating debris and vegetation.

Larvicides
Larvicides can be applied from a boat with a spraying machine.

Rivers and creeks
Mosquitos breed in quiet places close to the banks of rivers and creeks where there is protection from currents by obstacles, protruding roots, plants and so on. Effective control of larvae is generally difficult because of the large areas to be covered. Careful study is required to find out the exact location of the breeding sites.
Control measures

Source reduction
Breeding sites may be reduced in some cases by removing obstructions and vegetation from the edges of the rivers and smoothing and increasing the gradients of the banks to increase the water velocity. In the dry season, pools may form in river beds (Fig. 1.131). If breeding occurs in such pools they can be drained into the main stream. Some smaller pools may be filled up.

Larvicides
Pools in river beds may be treated with larvicides (p. 128) that are not toxic to fish, or to other animals or humans using the water for drinking. In pools that dry out quickly, one application is sufficient. In pools that are likely to exist for a month or longer it is advisable to apply a slow-release formulation, e.g. temephos sand granules, to avoid the need for frequent reapplication.

Small creeks
Some success has been obtained in the control of Anopheles maculatus, a vector of malaria in parts of south-east Asia, which breeds in forest creeks in hilly areas. The breeding of this mosquito can sometimes be prevented by spraying quiet places and pools in the creeks with larvicidal oil or a chemical larvicide that does not harm fish (p. 128). In a few places small dams have been built upstream of breeding sites. The water collected behind the dams is released at intervals to flush out larvae (p. 121) and destroy breeding habitats. The dams, which are either hand-operated or automatic, provide a long-lasting solution without high recurrent costs.
Ponds

Permanent ponds containing unpolluted water are commonly used for breeding by *Anopheles* and *Mansonia*. *Mansonia* occurs only in the presence of aquatic vegetation to which the larvae and pupae can attach.

**Control measures**

**Filling**

Earth for filling can sometimes be obtained from a deep pond to be used for the cultivation of fish (p. 114). In most cases, however, filling is too costly and may even be unacceptable where ponds are used as water supplies.

**Larvivorous fish**

Larvivorous fish are effective in long-lasting control of mosquito larvae in ponds (Fig. 1.132; p. 123). The shorelines of ponds should be made steep and water plants along the edge should be removed to enable the fish to reach the larvae (p. 122). In addition, carp or gouramis can be introduced to eat the vegetation. It may be possible to deepen one end of the pond so that the fish can survive if the water level falls in the dry season.

**Removal of water plants**

The removal of water plants renders ponds temporarily unsuitable for breeding by *Mansonia* (Fig. 1.132; p. 122) (177, 178).
Removal of vegetation along margins and steepening shorelines
These measures reduce the breeding of most mosquito species temporarily by taking away protective cover and removing shallows (Fig. 1.132; p. 122).

Oil and chemical larvicides
These can be applied to the water surface for a quick effect of short duration (p. 128). Slow-release formulations, such as briquettes of methoprene (p. 135) or B.t. H-14 (p. 136), last a month or longer. Care should be taken not to use a compound that could kill naturally occurring predator insects and fish. Herbicides are sometimes used to destroy the plants to which Mansonia larvae attach themselves.

Borrow-pits
Soil is used in rural areas of many countries for the construction of houses and roads. It is collected from pits that are usually located outside villages. The pits may collect rainwater or seepage water and provide breeding places for a number of mosquito species. Older pits containing vegetation are usually better breeding sites than freshly dug pits.

Control measures
Filling
Soil for filling up borrow-pits can sometimes be obtained from village fish ponds that are being deepened or expanded (p. 114) (177, 179–181). Alternatively, borrow-pits can be used for the disposal of household rubbish or industrial waste, such as sawdust and cinders (179). The rubbish should be covered with a layer of soil to prevent exposure of potential water containers, such as bottles and cans, or access of flies and rats to the rubbish.

Drainage
A row of borrow-pits may be drained with ditches into one single pit, so that only one wet pit remains to be dealt with.

Application of oil and larvicides
This provides a quick solution of short duration. However, slow-release briquettes of methoprene (p. 135) or B.t. H-14 (p. 136) last 1–4 months and may be sufficient to cover most of the breeding season. Once the pits dry out the briquettes stop releasing larvicide, but under favourable circumstances may be reactivated when the pits are again filled with water. If the water is used for drinking by animals or humans the larvicides should be safe for use in drinking-water; temephos, B.t. H-14 and methoprene could be considered.

Larvivorous fish
Because the pits are likely to dry out from time to time, larvivorous fish are usually not appropriate for the control of larvae. However, the so-called instant fish (p. 127), whose eggs can survive dry seasons and which mature in one wet season, may be suitable under such conditions (181).
Accumulations of water near roads

The construction of roads on causeways often leads to the blocking of transverse streams. This prevents natural drainage of the land and may result in the formation of large ponds alongside the roads (Fig. 1.133). Water also accumulates in borrowpits along roads that were used for the construction of the causeway. For example, the construction of highways through the Amazon forest created numerous suitable breeding sites for the malaria vector *Anopheles darlingi*.

Control measures

- Construct culverts through the causeway allowing streams to continue on their natural courses.
- Use larvivorous fish and larvicides.

Irrigation systems and irrigated fields

Wet rice cultivation (paddy rice) and other activities involving irrigation may create suitable breeding places for some *Anopheles* mosquitoes that transmit malaria and for some *Culex* mosquitoes, such as *Culex tritaeniorhynchus*, which transmit Japanese encephalitis in Asia.

Mosquitoes often find breeding sites in or near irrigation systems that have been poorly constructed, managed and maintained (Fig. 1.134). Breeding may occur in irrigation channels and ditches between vegetation growing along the margins. Holes in the beds of channels provide breeding places when there is no water flowing through them. Leaks may provide breeding sites in puddles outside the channels. The prevention of breeding in irrigated fields is difficult because of the very large surfaces of standing water often available to mosquitoes.
Fig. 1.134
Good and bad features often found in irrigation systems (adapted from 182).
Control measures

Construction and maintenance
The bottoms of channels and ditches should be smooth with a gentle slope so that no stagnant water remains when they dry out. Proper maintenance should prevent leakages from sluices and the dykes and linings of fields and channels. Breeding in ditches and irrigation channels filled with water can be reduced by making the banks steeper and removing water plants. This helps to speed up the flow of water and expose the larvae to larvivorous fish and other predators.

Intermittent irrigation
During certain periods of the cropping cycle, rice plants do not have to be submerged continuously. It is therefore possible to dry the fields once a week for 2–3 days in order to kill larvae (152, 178). This is only feasible if the farmer has sufficient water to irrigate the field again after having drained it. The fields have to be level and very well drained so that they dry out completely after the inflow of water has been stopped. In some places the rice crop may improve with this system of irrigation. The most effective periodicity of the alternating wet and dry cycles has to be determined by an expert since it depends on the type of irrigation, soil texture, variety of rice plant and other factors. Experts would also have to determine the possibility of any negative side-effects, such as an increase in floodwater mosquitoes.

A problem in the application of intermittent irrigation is the need to keep fields flooded during the first 2–3 weeks after transplanting the rice seedlings to permit them to establish themselves. During this period, mosquitoes can be controlled with one of the other methods. If larvivorous fish are used, deep pools are needed in the fields or ditches to allow the fish to survive during dry periods. Intermittent irrigation has to be used simultaneously for all rice fields over a large area throughout the entire cropping season (152). In some countries, the drying out of fields at intervals has been legally imposed on farmers (154).

Floating ferns
Free-floating water ferns (Azolla) can form thick layers of vegetation which completely cover large areas of water. In China and India, Azolla is cultivated as a fertilizer and animal feed. If a high degree of coverage of a rice field is achieved it offers the extra benefit of mosquito control (183–185). It is important to obtain good coverage before the usual peak in mosquito breeding. In many situations this is difficult to achieve because of fluctuating water levels.

Larvivorous fish
Paddy fields can be made suitable for rearing fish for food and for larval control if the dykes are made stronger and higher than usual, allowing water to be retained to the desired depth. Inlets and outlets of water should be screened with a wire grille to prevent fish from escaping. A deeper pond or trench is needed near the outlet to provide shelter for the fish when the field dries out or when the fish are not foraging in the shallow water among the rice plants. A problem that may occur is the predation of fish by birds such as herons. If insecticides of the organochlorine group, such as DDT, dieldrin or lindane are applied in rice fields to control agricultural pests, they may accumulate in the fish, rendering them unfit for
human consumption. Some insecticides, especially those of the pyrethroid group, are very toxic to fish.

Keeping fish in rice fields may have a positive effect on rice production: several fish species eat the weeds that compete with rice plants; fish excrement fertilizes the soil; fish stir up the soil and improve the access of oxygen to the roots of the plants (148, 152, 186–188).

Some suitable fish species are:

— tilapia (*Oreochromis mossambicus*); the fingerlings (young stages) feed on mosquito larvae and grow rapidly;
— carp (*Ctenopharyngodon idella, Cyprinus carpio*); these eat weeds and, when small, mosquito larvae;
— guppy (*Poecilia reticulata*);
— mosquito fish (*Gambusia affinis*);
— panchax (*Aplocheilus panchax*); these are commonly found in paddy fields and ditches in south-east Asia.

**Larvicides**

The use of larvicides is costly, and requires special equipment and trained staff because of the large surfaces to be covered. Larvicides have been applied from fixed-wing aircraft, helicopters, and by hand with the aid of portable knapsack sprayers (p. 128). The resistance of mosquitos to insecticides is a problem in some areas. Another disadvantage is the potential harm to other organisms such as larvivorous fish and predator insects (dragonfly larvae). The application of *Bacillus thuringiensis* H-14 (p. 136) or insect growth regulators (p. 134) would avoid the problems of resistance and harmful side-effects. They have to be applied in a special formulation to prevent the particles from sinking to the bottom. The surface-feeding *Anopheles* larvae are killed only if the particles remain at the surface, where dispersion is improved by adding a spreading agent. Floating granular formulations remain on the surface and release toxic particles over a period of several weeks, but their effectiveness may be reduced if the wind blows them to one side of the field. The use of larvicidal oil also avoids the problem of resistance and usually does not harm fish, although some aquatic predator insects may be affected.

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**Selected further reading**


Slide sets for training in vector biology and control\(^1\)


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\(^1\) Available from Distribution and Sales, World Health Organization, 1211 Geneva 27, Switzerland.