

THE CONTROL OF RURAL MALARIA* — (*Contd.*)

SLOWLY DISSOLVING MINERAL POISONS

PART III

MOSQUITO larvae may be killed by many mineral substances and poisonous inorganic 'salts,' if these are dissolved in water. Older experiments made use of readily soluble salts, which brought about the death of larvae in a few hours. Most of these compounds, such as soluble cyanides and corrosive sublimate and readily soluble forms of arsenic, are extremely poisonous to men and animals. Although the possibility exists of using them in very weak solutions which might prove destructive to larvae and yet be harmless to fish and higher animals, the practical difficulty of regulating and maintaining the concentrations in continually varying volumes of water within the necessary limits, is insuperable. It was claimed for example that a concentration of 1 in 200,000 of cyanide of sodium might be used in wells. But he would be a brave man who drank their water, trusting that the equivalent of an oiling coolie had calculated the volume in each well and treated it with the calculated dose of cyanide. And the difficulty of measuring the volume of water and maintaining the proper concentration of poison in pools and ditches alternatively drying up, and flushed with rain, is much greater.

Must we conclude that mineral poisons are necessarily unserviceable? Let us, as in solving a problem in geometry, assume the thing done, and then work back to the conditions which enable us to do it. The ideal is evidently provided by a substance which is poisonous to mosquito larvae and harmless to higher animals in the concentrations required. We have such a substance in copper and its 'salts'. One condition of the problem is determined. But there remains the difficulty of regulating the concentration of copper. Must a Sanitary Inspector visit each pool for miles, plot its section, calculate the volume and add the required amount of copper in solution? And repeat the operation every time there is a fall of rain? He would be a busy man. Copper sulphate is, as a matter of fact, commonly used in reservoirs, though less with a view to killing mosquito larvae than to preventing blockage of the exit pipes by growth of slime and algae. The exact amount needed has to be calculated so as to give a concentration of about one part in a million. The waterworks engineer is competent to do this; but great harm results if the proper concentration is exceeded, water plants and fish being killed and causing the water to be fouled by

* By K. B. Williamson, M.A. & Diploma Agric. (Cantab), D.I.C. (Formerly Malaria Research Officer, F.M.S. and recently in charge of anti-malarial investigations Cameron Highlands), in *The Malayan Agri-Horticultural Association Magazine*. Vol. IV. No. 1, January, 1934 and Vol. IV, No. 2, April, 1934.

their putrid remains. If report is true, this happened some years ago in one of the Colony's lakes, where the supervisor towed a bag of bluestone behind a boat for a few hours, achieving all and more than he hoped for.

The solution of the problem, not alone for copper, is to use minerals or cheap commercial residues, which are technically though not absolutely insoluble, and which will automatically maintain a concentration sufficient to kill mosquito larvae within the period of a week or ten days through which they remain larvae. Pupae, owing to their hard horny covering, and to the fact that they do not feed, are only slowly killed even by strong concentrations of poisons.

The possible utilisation of little-soluble forms of copper, a preliminary account of which appeared in the Annual Report of the Malaria Advisory Board for 1932, is of particular interest. To take first the metal itself. It was first tested in a precautionary experiment made in England in 1921, the object of which was to ascertain whether copper gauze might be used without harmful effect upon larvae for periods up to three or four hours in an apparatus in which the effect of poisonous vapours was being tested. No harmful effect was observed within 16 hours. It was thereafter deemed safe to use cages made of brass gauze for experimental larvae to be placed in ricefields, and a number of these cages was constructed in 1924. But tests showed that many of the anopheline larvae placed in these cages in the laboratory died in a few days, although they were placed in a fairly large volume of water; and muslin cages were used instead in the outdoor experiments. These trials, like the earlier experiments, were merely precautionary, and gave no certain assurance that metallic copper was fatal to larvae. The question has therefore been re-investigated with critical control experiments during the past two years, with the result that it has been found that all larvae of *A. maculatus* die within five days, — and with few exceptions all within three days, — when copper or brass is present in the water; while in the most of the experiments none of the control larvae died. Similar results were obtained with various compounds of copper which are supposed to be insoluble, and their effect remained after months of washing in running water. On the other hand, little or no harm resulted to larvae kept in the presence of zinc, iron, or aluminium; and insoluble compounds of lead acted more slowly than those of copper. Minute traces of copper were detectable in the water by very delicate tests, metallic copper itself being slowly soluble. The practical problem is to procure cheap ores or residues slightly more soluble than most of the compounds tested in the laboratory, and which will ensure that the minute traces of copper needed to safeguard breeding waters will be maintained in spite of rain and seepage flow; and a search for these is being made.

It may be remarked in passing that white arsenic, (arsenious oxide), when mixed in the proportion of five or ten per cent. with cement, has a long lasting effect, causing the death of larvae in a few days, even when it has been washed for months in running water; but the danger in the use of a strong poison like arsenic without the most careful regulation of its concentration makes it a much less desirable substance than copper. The amount of the latter needed to exterminate mosquito larvae is less than

could have any effect upon men or animals who drank the treated water by accident, and in stronger doses copper is a cure for the 'bloodless' condition known as anaemia, which follows malaria, — so that by medicating the water, it becomes both a preventive of malaria and a remedy for one of its ill-effects. We may envisage a time when the anti-malarial coolie will be encouraged to take a course of the waters which it is his task to treat.

Slow mineralisation promises a possibility of effective control which may reduce the labour cost of treating pools and seepages to a fraction of what it now is, and, with very small expenditure on material, enable distant danger spots to be freed from risk for many months by a single treatment. In this way expert control, which is now limited by its lack of funds and trained workers, might reach out a long arm, embracing areas many times greater than are at present controlled. But the method is clearly inapplicable to rapidly running water, and its usefulness in ponds and marshes is doubtful. On the other hand, the coppering of containers in towns threatened with yellow fever might be an invaluable aid in fighting the disease if it ever appears in this country.

This short review of the artificial methods which science has placed at the disposal of those who wage war against the mosquito prompts the reflection that too few of its resources have been made use of; and force is added to this opinion when we consider that apart from allowing natural shade plants to grow over ravines, none of the natural methods, next to be considered, are in general use. It may be surmised that our knowledge of the resources of science and of nature are small compared with what they may be expected to become in the future; for the powers that lie around us are unknown until they are experienced, or are disentangled by the imagination from the commonly admitted forces which prevent their recognition. No one can say with what means these yet undiscovered powers of Nature may provide us for checkmating malaria and other diseases.

The question remains, "How far are artificial methods, elaborated by science, likely to prove useful in controlling rural malaria?" Evidently a very potent drug or immunising agent may prove so, and we await its advent with hope, but by no means with complete confidence. Small-pox is now the only disease preventible by medical means on a wide scale, and until an equally powerful anti-malarial method is evident, no drug which merely cures malaria, and which has to be continuously administered, offers any prospect of eradicating it. Of the two classes of preventive measures against mosquitoes, it may be concluded that artificial ones, however effective they may become in the future, are less suited for dealing with rural malaria than the best among natural measures. They present the primary disadvantage that the transport of the material and apparatus needed to remote villages will always offer almost insuperable difficulties; to which the cost of their purchase and transport must be added; and the more powerful and refined the methods of control become, the greater will be the need for them to be carried out by skilled and highly trained operators. We must, suppose that when the resources of technical science come to be fully utilised, the range of its operations will be greatly extended, but not so greatly that the diminution of the plagues carried by mosquitoes can

be effected all over the countryside except by making use of the materials available in it, both in Malaya and elsewhere. This country is far advanced both in the theoretical anticipation, and the experimental application, of natural methods of control; and it will be profiting itself, and benefiting the world at large by its example, if it makes them the instruments of widely extended malaria-control throughout the country.

HERBAGE COVER

The best known and tested of these methods will be described in the continuation of this article, namely, fish-rearing, the rotting of vegetation, and sluicing; together with another natural method which may be specially mentioned here because it has only recently been tried, and is consequently known only to a few, while it deserves wide and general testing. This is the method of Herbage Cover. Its operation is simplicity itself. Shallow water up to a few inches deep is covered with plucked grass and herbage, or the leaves of trees from "belukar" or the jungle, with a few twigs inter-mixed so as to form a brushwood drain for running water. The herbage is well trampled under foot until it forms an almost solid wall a foot or more in height. The cover thus formed is long lasting, and, so far as observation has gone, it cannot be penetrated by egg-laying mosquitoes; it provides dense shade and, at least in stagnant water, sufficiently concentrated rotting to prevent the breeding of malarial species. While inapplicable to rapidly running streams or steep ravines which discharge strong flushes of storm water, very little dislocation of the herbage occurs in ordinary hillfoot or other drains, if their lower ends are provided with a double row of stakes to keep the solid mass of vegetation in position. Most of the storm water flows under it, and the remainder sometimes makes its way over the top.

The method is particularly effective for stagnant pools where the biochemical effects of the rotting vegetation are greatest, and in small seepages. Occasional renewal of the herbage, and the filling up of holes which form in it are needed, and a necessary precaution in the case of shallow pools or drains with shelving sides, is that the cover should extend to a foot or eighteen inches beyond their sides, so as to protect the surrounding ground which becomes flooded in rainy weather. Drains of this kind occur in the gutters which extend for miles along the inner side of the Highlands road, and which provide numberless breeding places for *A. maculatus*. They have been effectively dealt with where the precautions mentioned have been adopted; and in one case where a hillfoot drain and a series of pools were covered over, a notable improvement was brought about in the health of an adjacent coolie line, too far distant for regular anti-malarial work to be carried out near it. It is therefore probable that by this simplest, speediest and cheapest of all anti-malarial measures, much of the malaria of the hills and hill valleys might be stamped out, if measures were taken to teach it to villagers, and to organise and stimulate their efforts in the manner suggested in the previous article.

It should be realised that although in this country we are faced with one of the most serious malaria problems in the world, the fact that our chief malaria carrier, *A. maculatus*, in nine cases out of ten breeds in extremely shallow water, makes it one of the easiest of all species to control, provided that its obscure breeding places have been discovered. No words

can sufficiently emphasise the need for attracting and encouraging the most skilled larvae collectors, since without them all measures are futile, and serious sickness may arise from two or three small undiscovered pools. But the extremely shallow water in the seepages where *A. maculatus* is commonest may be altered beyond recognition and rendered unfit for it by very simple natural procedures. Therefore to limit effort to oiling, which is better suited for dealing with the malaria arising from ponds, marshes, and other large accumulations of water in other countries, is to disregard the help to be derived from local circumstances, and to fly in the face of reason and common-sense.

PART IV

METHODS BASED UPON PROCESSES OF NATURAL CONTROL

HERBAGE COVER

This method by a single operation, namely, packing green herbage tightly over and into shallow water, brings three influences to bear on it, each of which is by itself able to restrict greatly, and usually to prevent, the breeding of species such as *A. maculatus* which require light and at least fairly pure water in their breeding places. It

- (1) creates an almost or quite impenetrable barrier for adult mosquitoes.
- (2) densely shades the water.
- (3) causes harmful biochemical changes in it due to the rotting of green vegetation in the presence of too little air.
- (4) produces a dark-coloured and fertile deposit of soil when the cover is maintained for three or four months, with the result that a dense crop of weeds is liable to grow up, which gives more or less permanent shade. The alteration in the character of the soil also probably discourages the breeding of *A. maculatus*, since this species usually breeds in places where the soil contains very little organic matter.

Among malaria carrying anophelines, the shade factor is inoperative against *A. umbrosus*. The efficiency of concentrated rot is to be inferred from its having been effective in ponds, and from experiment in the laboratory where newly-hatched larvae of *A. maculatus* all died within a couple of days when placed in foul water from a bowl in which grass had been rotted for about three months. This proves that the effects of rotting vegetation are long lasting when the products of decay are not diluted or washed away. It is also probable that the rot acts in another way by deterring females bent upon egg-laying from doing so. There is indeed good reason for believing that the senses of mosquitoes are keener than our own. How else are females of *A. maculatus* for example able on dark nights to select with almost unerring accuracy the springs and seepages in which they lay their eggs?

It is to be remarked that the effects of rot, whether in the soil or water, are most harmful when it occurs in the absence of air, or with too little present, since oxygen derived from the air (or produced by the action of green water — (or other) plants in sunlight) is the great purifying agent in nature. The biochemical efficiency of the rot occurring in shallow stagnant water, crammed, as it is, full of decaying vegetation, and sheltered from light and wind under a cover of cut herbage is therefore about the greatest possible, and it far exceeds the minimum necessary for checking breeding.

The fact provides a conclusive refutation of the argument that methods of mosquito-control based upon biochemical changes should not be practically applied until the exact equivalents and quantities concerned have been ascertained and tabulated to the last decimal.

But the biochemical factor in control may be negligible in running water, even when it is covered with herbage, and any holes which may form in the cover should therefore be carefully filled at weekly or ten-day intervals.

Finally, it is important that a considerable proportion of the cover used should be green, since the patrescible proteins or albuminoids (a form of so-called organic nitrogen) which are present in living tissues are almost entirely absent from dead leaves and dry twigs, and the woody fibres present in these decompose much more slowly and with more doubtful effectiveness.

BIOCHEMICAL CONTROL THROUGH THE SOIL AND AGRICULTURE

There is growing evidence that the chemical constitution of the soil is important in determining the distribution of malaria, and of the species of anophelines which carry it. The immunity enjoyed by the coastal rice belt in Malaya is related to a high content of organic matter, including organic nitrogen, in its soils, coupled with imperfect drainage, which, by leaving the land water logged even in the fallow season, causes the decay of dead vegetable (as well as animal) matter to take place in the soil in the absence of air. It is significant that in this tract of country *A. maculatus* occurs practically only where isolated granite hills, like the ones at Jugra and Kuala Selangor, bring pure springs derived from and based upon mineralised soils poor in organic matter, to the surface. And as the history of Jugra shows, the vicinity of these hills is often very malarious.

The interest of the subject in reference to the control of rural malaria lies in the fact that as shown by Mr. Charlton Maxwell by examples from various parts of the world, in his book on Malaria Control, (Published by Messrs. Kyle, Palmer & Co., Ltd., Kuala Lumpur, price \$1/-) intensive agriculture, which enriches the soil, generally leads to a great diminution of malaria, and sometimes to its virtual extinction, as in England. The direct and indirect influence of cattle and pigs, which both contaminate and fertilise the soil, and attract mosquitoes away from man, is important in this connection. Incomplete drainage also may as in the case of our coastal soils sometimes be an important factor in effecting the control of malaria if it leads to water logging, and the growth of leguminous crops should, at least under these conditions, and in proportion as the organic nitrogen which they add to the soil is retained in it, to a greater or lesser degree act as a preventive of malaria.

The keeping of pigs in the Island of Pankor is said to have greatly reduced its incidence there, and it is probable that the pollution caused by the curing of fish has also materially helped to produce this result.

But what is agriculturally sound practice does not always diminish malaria. Irrigation for example, which does little or no harm on the organically rich paddy soil of Krian, is productive of a great deal of malaria on the poorer mineral soils of the Sudan and the Punjab. Taken as a whole the facts point to the conclusion that any long range policy for diminishing rural malaria should aim at enriching the soil by encouraging intensive agriculture, while at the same time increasing the number of cattle and pigs on the land. This should lead not only to decreased risk of infection, partly brought about by better housing due to increased prosperity; but the people, being better nourished, will be better able to resist attacks of malaria. This policy, known by the uncouth name of *bonification*, borrowed from the Italian, has led to a notable decrease of sickness in many places in Italy. Cattle tend to attract mosquitoes away from man, but the effect upon the soil of their dung is also probably sometimes important.

BIOLOGICAL CONTROL IN FISH PONDS

We have so far chiefly considered control effected by biochemical changes brought about by the bacteria and other micro-organisms which cause decay. More varied biological control, to which fish, predatory water-insects, and water-plants contribute, is possible, and is sometimes necessary, in fish ponds. Owing to their pollution most carp ponds probably cause little or no malaria; but they not infrequently are a serious nuisance owing to non-malarial mosquitoes breeding in them. Carp being vegetable and refuse feeders do little or nothing to diminish this nuisance. When the corruption in the ponds is not too great, larvae-eating fish, such as *Panchax* (the little fish with a white spot on its nose) can be very useful, but hardly any attempts are made to breed them in these ponds. Certain water-insects like water-boatmen, and the large active water-bugs (so classified because they suck the juices of their prey) are also extremely destructive to larvae. And water plants such as water lilies and duck weed, by covering up the surface of the water, sometimes leave very little of it free for larvae. The common yellow-flowered bladderworts are moreover able to capture and kill larvae in their numberless traps which their bladders form, and which serve the plants as stomachs. Very few larvae however are so captured and the rotting of dead fronds of these and other plants, such as the stone-worts (*Characeal*) is often more effective.

But generally speaking none of these agencies can be relied upon singly to abolish mosquito-breeding completely. Wisdom lies in setting as many of them at work as the particular conditions will permit. In this way the desired end of completely abolishing all mosquito-breeding for a period of about two years during which the observations lasted, was attained in the carp ponds constructed at Tanah Rata; and a further investigation of them by specialists might throw more light upon the complicated causes which led to this result, and so prove useful elsewhere.

In one respect the experiment was critical. Contrary to anticipation it was found possible to check the breeding of *A. maculatus* completed by biochemical means alone in several of the ponds where the concentration of rotted grass and herbage was greatest, although an average of about ten thousand gallons of water continued to run through them daily. This fact provides convincing proof that the same result can be obtained with ease and certainty in stagnant water. More than twenty years have passed since Sir Malcolm Watson prophesied that the rotting of vegetation would provide a solution of this country's rural malaria problem, and anticipated the time when current anti-malarial procedure would seem like burning the house down in order to cook the pig; but nothing has been done to give practical effect to his wisdom.

NEED FOR COMBINED OPERATIONS

The example we have considered shows how natural control lends itself to the combination of a variety of effective causes which operate together and reinforce one another.

The method of herbage cover provides a striking and beautiful illustration, for by a single operation it brings into play the controlling influences of a mechanical barrier, shade, and biochemical change. The principle is however capable of extension and more deliberate application. Steps should be taken deliberately to set as many controlling influences as possible at work in the same place, and to apply different methods in different places, even though they may be close together. This is already done when, for example, part of an area to be controlled is drained dry and the remainder is oiled. But a great deal more might be done in the way of varying the methods in use, especially by making more use than at present of simple and cheap natural methods of control.

If any method, however, whether oiling, sluicing, or any other is pushed to extremes and applied in places to which it is not suited it becomes expensive.

What the economists call the law of diminishing returns comes into operation. Correct judgment in applying anti-malarial methods is therefore quite as important as the methods themselves. Only a few examples of these principles can be given here. Others will suggest themselves to the reader, and in the course of work:

(A) COMBINED CONTROL IN A SINGLE BREEDING PLACE

1. The growth of shade plants should be encouraged so as to provide permanent protection against *A. maculatus*, no matter what other means of control are in temporary use. Sluiced channels lend themselves to this procedure since flushes of water, unlike oil, usually do not damage, but rather encourage the growth of vegetation.
2. Varied biological effectives including fish, water-insects, water-plants and biochemical factors should, as has been seen, be made to work together to establish permanent control in ponds.

3. Fish ponds should everywhere be established at the heads and along the course of the dangerous irrigation channels (*jalan ayers*) in hill rice valleys; and should be used to sluice the channels. The emptying out weekly (effected through suitable screens and nets which retain the fish) if most of the water in the ponds should in itself greatly reduce the risks from mosquito breeding, and costs should be more than recovered from the yields of fish, and the increased economic energy of the cultivators, resulting from more nourishing diet, decreased infection from, and greater resistance to, malaria. The irrigation channels themselves should be emptied and dried whenever possible.
4. Other sluiced channels elsewhere should whenever necessary and possible be polluted from factory refuse or from the soap from bathing pools and laundries, etc. They might perhaps be used as a means of distributing small quantities of oil to danger spots at which obstructions diverted the oil (as well as soap, etc.), to pools and seepages at the sides of the channels.
The idea that anti-malarial practice should be made the sport of rival methods and factions is clearly foolish and harmful.

(B) VARIED CONTROL IN A SINGLE AREA

Correct procedure often varies from yard to yard in a single small area, for example there may be: *ravines*, best left shaded, but if cleared, requiring oiling, sluicing, etc., according to their size and particular circumstances: *diffused seepages*, requiring to be channeled if they cannot be drained dry, small channels being sluiced, or they, and small pools being covered with herbage, stones and earth, etc. In a case reported by Dr. Wolfe from Kuala Kangsar it was possible to deal effectively, by a cover of herbage without damage to the crop, with a drain leading to a rice field where *A. maculatus* was breeding: *ponds*, to be dealt with as above indicated: and *dead water* in stagnant ditches and pools, and water-logged marshes, etc., where no anopheline mosquitoes breed, and which are usually indicated to the eye by dull brown water and the presence of brown scums of iron. Natural biochemical control is completely effective in these dead water situations and, until they can be drained, these spots only need to be kept under observation. They sometimes form a large part of a supervised area, and the practice of promiscuously oiling them is wasteful and productive of no good.

WIDE RANGE OF EFFECTIVENESS OF BIOCHEMICAL INFLUENCE

The foregoing summary has made it clear that, contrary to popular opinion, water itself is, or may be made, an influence restricting mosquito-breeding. In fact it is not an overstatement of the truth to say that most kinds of water are unsuited to the needs of most species of mosquitoes, and that Nature restricts particular species to a more or less narrow range of breeding places. Apart from sunlight and shade, the most widely effective of her instruments are the biochemical changes brought about by micro-organisms. These are operative everywhere, and the controlling influence

they exert, either upon mosquitoes in general, or upon particular species, extends to every kind of water. The number of breeding places they put out of bounds for malaria-carrying anophelines in general is very great indeed, and for particular species still greater. The effectiveness of biochemical influences due to the bacteria in soil and water is far greater than that of all other biological agents including larvae-eating fish, although being easily seen at work, these attract more popular attention. To take the most familiar example, which in this country is also the most important one, fish are entirely absent both from the surface pools which *A. maculatus* avoids, and from the seepages it selects; and few predatory insects are to be found in either. But almost all those that there are, are present in the water which are the nurseries of its larvae, and not in those from which they are absent.

METHODS BASED UPON THE MOVEMENT OF WATER

It remains to review very briefly the not inconsiderable possibilities of control offered by the dynamic effectiveness of water in motion.

(1) AGITATION OF THE WATER SURFACE

Mosquito-larvae are frightened from feeding, and they, as well as pupae cannot breathe the air they need, when the water they are in is agitated. Moreover since all anopheline, and most culicine, mosquitoes lay their eggs actually on the water they require it to be still. In accordance with these facts larvae and pupae are not to be found in water which is much troubled by wind or waves. Artificial agitation therefore suggests itself as a promising means of preventing breeding in small accumulations of water when circumstances rule out other methods of control such as oiling or pollution; and the method might be applied even in ponds where water power, such as might be provided by their outfall, is available. Models of agitators based on this idea were exhibited by Dr. Jacques and myself at the last two annual exhibitions of the Malayan Agri-Horticultural Association but full-sized constructions have not so far been tested in actual breeding places. A few observations made by Dr. Scharff and myself however go to show that where water splashes, or is sprayed, on to gardeners' pools, larvae will not appear within a few yards of the disturbance. *A. maculatus* very commonly breeds freely in these ponds, which cannot be oiled, and the whole subject offers a promising field for contriving and constructive ingenuity and experimental investigation.

(2) ANTI-MALARIAL SLUICING

RESULTS IN THE HIGHLANDS

This method proved completely effective both in small and medium sized ravines in the Cameron Highlands, as well as in quite flat drainage channels about a yard in width. In fact no larvae were ever found below sluice gates in the sluiced channels after one or two flushes had run through them. This is the more surprising since there as elsewhere small larvae commonly appeared in oiled channels (outside the unoiled main experimental area, which was at Tanah Rata) between oiling intervals. The method therefore proved superior to oiling, a fact

difficult to account for, but which may possibly be explained by disturbance of the soil in the beds of the channels having altered the properties of the water in them, and rendered it repugnant to egg laying females. A dense growth of algae in most of the sluiced channels, subsequent to sluicing being started, supports the view that some significant change was produced by it. The fact that no larvae were found in the channels, some of which were under regular observation for about two years, disposes of the fear that under these conditions they might be washed away and presented as living sacrifices to neighbours at lower levels. Evidence from fragments of match stick showed that many larvae must get stranded at the sides both of grassy drains, and of ravine beds. Where the fish was spread out, as occurred at the foot of one of the ravines where there was a flat expansion the tendency to stranding was even greater. This suggests that shallow expansions placed at intervals along the course of flat drains might sometimes increase the effectiveness of flushes.

In addition to sluice gates opened once or twice weekly by hand, automatic tippers discharging rather less than four and sixty gallons respectively at frequent intervals, day and night, were tested. They were designed, and the original models were made by Mr. J. P. K. Wilkins, and, though difficult to keep in order, they proved completely effective in narrow artificial channels. The larger tippers when tested in small incompletely canalised shaded, ravines in the lower Highlands, though manifestly discharging too little water, gave exactly the same counts of larvae, as similar ravines did when were oiled.

APPLICABILITY AND COSTS OF SLUICING

The trend and emphasis of the foregoing argument will have made it clear that neither sluicing nor any other anti-malarial procedure is of universal application. Like every other method of larval control it is subject to the law of diminishing returns, and it is cheapest and most effective in small channels. It is particularly suitable for dealing with *A. maculatus* in the majority of its natural breeding places, like small springs and seepages, when they contain flowing water, the seepages requiring to be canalised. The costs of constructing and setting sluice gates, and of constructing reservoirs to serve them rises in considerably higher ratio than the breadth of the water channels to be sluiced, and there are actually many more larvae to every ten yards of small trickles of water, than are found in large streams, where breeding places are often restricted to side pools separated by half a mile or so if they occur at all. Most of the sluice gates used were built in the laboratory at a cost in material, (which consisted of small ten cent packing cases and hard vulcanised sheet rubber, wire and hinges), of a dollar, more or less; and they lasted with occasional repairs for a year or more. Cheap but more solid wooden sluice gates constructed on a similar principle were also used, and when made of steel they cost only about four dollars. Sluicing carried out in this way is very cheap, and after channels and reservoirs have been dug, very little labour is needed to operate and maintain the sluices. It is also the only possible method of dealing with ravines encumbered by cut timber which renders their water inaccessible to oiling.

FUTURE DEVELOPMENTS OF SLUICING

Enough has been said to show that the natural but somewhat crude idea that the effectiveness of sluicing is entirely, or even mainly, due to larvae being washed away by the current is not always true. Frequent small automatic disturbances of the water level may prove as effective as violent floods, produced by the sudden discharge of large volumes of water; with attendant risk of erosion where the side of the channels are soft. On the other hand large flushes may be needed in large channels. They cannot be produced automatically by tipping devices, owing to the necessarily very limited size of tippers. Automatic discharge from reservoirs of large size is needed.

Apparatus without complications of pulleys or levers, and giving large or small, immediate or deferred, flushes, and worked entirely by water power (one form of which, made from bamboo pipes and rubber sheet, might be constructed without difficulty in kampongs) was designed and tested in the laboratory. But owing to the interruption of my work before final experiments could be made, at a time when progress was most rapid, it has not yet been possible to test the effectiveness of these contrivances for actually controlling breeding.

RURAL SUBSOIL DRAINAGE

When it is effective, sub-soil drainage, besides conferring automatic immunity from mosquito-breeding, is productive of gain, since it increases the fertility of garden and field soils in cultivable areas, and raises the rental of urban building land. But, as ordinarily practised, its costs are prohibitive in rural districts, except when money from general revenues is poured into small rural areas, as has been the case in rural Singapore and Penang. Great technical skill is also needed in the laying of the pipes used, and in maintaining them in working order; and they very often become blocked with solid masses of roots. Particular interest therefore attaches to methods of sub-soil drainage which give less opportunity for blockage by roots which make use only of locally available material obtainable free. Whichever of the following methods is used *the drains must be covered with tightly packed earth, preferably clay*: The following alternatives are available:

1. *Stone or rubble drains*.—Like the following method this is an old and very effective method of agricultural drainage, too little used in anti-malarial work. Stones are however not always obtainable, and in one way or another are liable to be costly.
2. *Ordinary brush-wood drains*.—In Great Britain they have been known to last for fifteen or twenty years, but this could not be hoped for in the tropics.
3. *Mole-plough drains*.—These consist of earth tubes made in stiff clay soil, and can only be constructed when this is present, and a powerful tractor is available. The method is being tested by Mr. Sands at the Alor Star aerodrome.
4. *Dr. Struthers' and Dr. Wolfe's bamboo-pipe drains*.—These are proving successful respectively in Pahang and Perak.

5. *Dr. Waugh Scott's lalang and stick drains.*—Since this article was in the press I have been privileged to be shown by himself the original and important development he has made in estates near Sungei Siput. I was also shown herbage-covered drains which had remained effective up to one year, with only one renewal of herbage. Sub-soiling however is likely to be more permanent, and therefore more useful. The drains are made by placing thin sticks two feet or so in length, lengthwise in the drains, to a height of a foot or more. These are then thatched with tufts of lalang, several inches in thickness and earth, preferably clay is packed over the lalang, so as to leave a channel for storm water. The method is proving very effective in flat drains up to two or three yards in width. Brown and scummy water is to be seen below some of the covers, indicating that controlling biochemical influences are at work even in gently running water. They probably have their origin in the rotting of the lalang under conditions which completely exclude air, but its main function is to act as a filter, to keep the spaces between the sticks free from silt, which might otherwise be washed through the covering earth and tend to block the drains. A particularly important subsidiary feature of the method is that side seepages in and near the banks of the drains, up to two or three yards in diameter, are covered in a similar way, the sticks being laid so as to slope downwards when seepages half way up the banks have to be dealt with. In one estate the whole of the work had been done by only two "oiling" coolies, who are in danger of failing to justify their honorary title. Therefore the work has been done at no extra cost, and there is a monthly saving of oil, and avoidance of the risks which always exist that oiling may not be carried out efficiently. Since sticks (or brush-wood) are obtainable everywhere, even more easily than bamboo pipes, and call for less care and labour to prepare and to lay them, this method promises to be remarkably helpful and deserves wide trial in kampongs and estates. When medical health officers are proving the usefulness of simple methods such as this and that of bamboo-piping there can be no reason why they should not be applied to the saving of life far beyond the possible range of their personal control.

CONCLUSION AND SUMMARY

We have seen that the special suitability of natural methods of control to rural conditions lies in the fact that they make use only of material obtainable everywhere free of cost throughout the country, namely its soil and vegetation, and the water itself in which mosquitoes breed. Natural methods of control are not inferior to artificial ones like oiling. On the contrary they provide long lasting, and in some cases permanent, immunity. The rural problem is not the problem of estates and Sanitary Board areas, where effective control of malaria has already been attained by older methods applied with thoroughness and skill. Their partial supersession by natural methods is entirely a matter for the personal judgment of those in responsible charge of these areas, to whom the public owes a

debt which it inadequately appreciates. It is however reasonable to expect that those responsible should be given and avail themselves of facilities for becoming acquainted with tried new methods; and should be provided with the appliances they need in order to apply them. In these respects the organisation of anti-malarial work lags far behind that of the fighting services, with their numerous schools of instruction, and departments of supply and ordnance, which teach the use of new weapons, and make them available. But the malaria-carrying mosquito is a subtle, and, over most of the area of this and every other country, an unchallenged and deadly foe. The reader need not be reminded that malaria is still the chief cause of mortality in Malaya. Almost all of this occurs in uncontrolled areas. But this is far from being the whole story. Malaria is not usually a quickly fatal disease. The economic loss it occasions through sickness is disproportionate to the deaths it causes, and has been estimated at between fifty and sixty millions sterling annually for the British Empire. Malaya is one of the most malarious countries in the world, and her position is particularly serious, because, while she needs to grow much more of her food than at present, malaria exacts a heavy toll from the land already cultivated, and hems it in, and checks agricultural expansion. This is mainly, though not entirely, due to the ravages of *A. maculatus*, which for some unexplained reason is more virulent here than in other countries. But it has not been heretofore realised that, since it usually breeds in very little water, which is often running, it is particularly easy to eradicate from at least a large proportion of its natural breeding places by simple methods such as vegetable pollution, herbage cover, sluicing and cheap sub-soiling.

Nothing worth while however can be achieved without a determined effort to organise the villagers to help themselves on some such lines as were sketched in the first of these articles. Medical men are too few and too much needed elsewhere to do the work alone. It can only be carried through by the co-operation in an enlightened policy of Administrative, Educational, Agricultural and other officers, high and low. The immediate need is to demonstrate the possibility of villagers with the necessary instruction and supervision, combating and controlling malaria in a few selected kampongs and their surroundings. Nothing, and nowhere else will do. Co-operative societies, schools, training colleges, and village school-masters can help in the good work.

In these non-technical articles, while endeavouring to do justice to all concerned, and to every method, I have stated my reasoned conviction that there is both great need for the long overdue application in the fight against malaria of methods of natural control, in the investigation of which Malaya has been a pioneer, and also great hope in applying them fearlessly and without prejudice, especially in the country's large uncontrolled rural areas, where they offer the only practicable remedy. In working for this end, while urging pursuance of the wise and beneficent, but now perhaps forgotten policy which would achieve it, I am only continuing what I was chosen, and brought to Malaya, to do.