MALARIA CONTROL IN THE TENNESSEE VALLEY

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INTRODUCTION

During the past ten years the Tennessee Valley Authority has transformed the Tennessee River and its tributaries into a vast series of man-made lakes. With the impounding of the Kentucky and Fontana Reservoirs during the coming season, the Authority will have in operation nine main river and fourteen storage reservoirs. In addition, several privately-owned reservoirs are operated in the system. With the completion of the construction program, the reservoirs will have a total water surface of some 735,000 acres and over 10,000 miles of shoreline. Although the major portion of the Tennessee River drainage system lies within the states of Tennessee and Alabama, five other states are also involved, namely, Kentucky, Virginia, North Carolina, Georgia, and Mississippi.

Experience over a period of years has proved that whenever water is impounded in the Southeastern United States favorable conditions are created for the production of **Anopheles quadrimaculatus**, the only important vector of malaria in this region. Failure to take this fact into consideration and to provide adequate control measures has frequently resulted in serious malaria transmission. In order to prevent such occurrences, the Authority carries out a carefully planned pre- and post-impoundage program of malaria control on each of its reservoirs. The program on each reservoir is developed independently with reference to the specific problems involved and in accordance with the regulations of the health department of the state in which the reservoir is impounded.

The technical planning, supervision, and appraisal of the program is carried out by a malaria control team consisting of a malariologist (M.D.), a biologist, and an engineer. This malaria control team is assisted in its planning and appraisal by a board of malaria consultants which includes the country's leading authorities on malaria control. Application of the program on the individual reservoirs is under the direction of resident sanitary engineers. Information for use in improving the economy and effectiveness of the program is also obtained through the efforts of a research staff which includes engineers, entomologists, parasitologists, botanists, limnologists, toxicologists, and epidemiologists. The research program includes investigations on the chemotherapeutics of malaria and on the biology and control of malaria mosquitoes and the littoral plants with which their production is associated. Of particular importance at the present time are investigations on the water level relationships of marginal plants, new methods and materials for use in adult spraying and larvicidal control, and development of more effective antimalarial drugs.

The malaria control program starts with the construction of the reservoir. The main phases of the program are reservoir preparation, permanent shoreline improvements, shoreline maintenance, water level management, and the application of larvicides. These phases are discussed individually in the following paragraphs.

RESERVOIR PREPARATION

The principal elements of reservoir preparation are reservoir clearance, marginal drainage, final reconditioning of the zone of fluctuation, and winter-time impoundage. Reservoir clearance (See Fig. 1) is not only a necessary antilarval measure, but may also be a requisite for removal of hazards to

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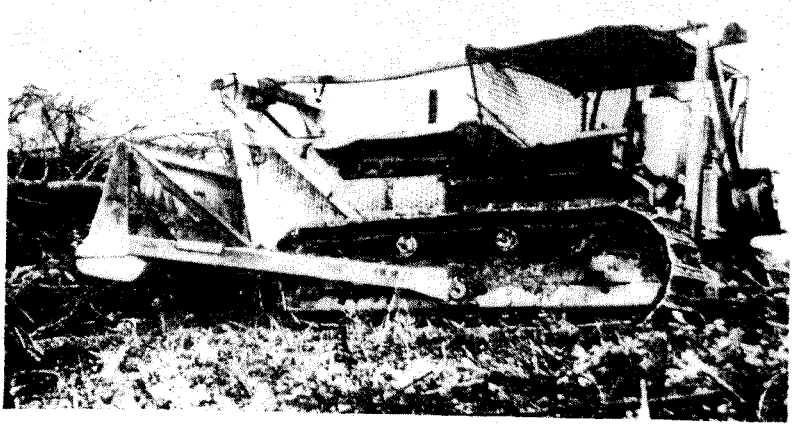
navigation and sources of objectionable drift which would accumulate at the dam. Reservoir clearance for malaria control is carried out in accordance with detailed specifications developed by the Authority and approved by the state health department. In addition to providing for the general clearing up to the normal maximum summertime water elevation, these specifications provide for certain special types of clearing, such as erosion clearing, clearing at heads of bights and indentations, clearing for airplane dusting, and selective clearing in the flood surcharge zone.

Marginal drainage is an important element of reservoir preparation. Limesinks and other depressions located between maximum and minimum elevations are connected with the main reservoir by means of drainage ditches (See Fig. 2). This ensures that these marginal depressions may be subjected to the same water level management used on the main reservoir and also makes them accessible by boat for carrying out larvicidal and shoreline conditioning operations.

A relatively recent development in reservoir preparation has been the carrying out of a final reconditioning operation in the zone of fluctuation just prior to impoundage. On some of the larger reservoirs several years may be required to complete the reservoir clearance operations. As a result, there is considerable growth of coppice in the cleared fluctuation zone before

A. Ordinary reservoir clearance operations involve felling, limbing, topping, cutting, and separate piling and burning of logs and brush.

the time of impoundage. If not removed, this coppice will catch drift and flotage and create favorable conditions for the production of **Anopheles quadrimaculatus** during the initial season of impoundage; also, the woody tolerant species will continue to live and grow if they have attained sufficient height to be emergent. It has, therefore, proved highly desirable to thoroughly recondition the zone of fluctuation in the fall just prior to impoundage in order that the maximum of clean water surface may be obtained.



B. The use of the power rake has greatly decreased the cost of reservoir clearance. It eliminates the need for limbing, topping, cutting, and hand piling.

Fig. 1. Reservoir Clearance for Malaria Control.

It has been repeatedly demonstrated that the impoundage of a new reservoir during the summer creates ideal breeding conditions for **Anopheles quadrimaculatus** and may result in serious malaria transmission. The Authority, therefore, recommends that the initial impoundage be made during the winter months. During the last two years, the increased need for power in connection with the war effort has made it necessary to impound several reservoirs during the summer months. This was done without serious malaria transmission because of the application of emergency control measures, including special shoreline conditioning, oiling, airplane dusting, and water level management.

A detailed discussion of reservoir preparation will be found in the publications of Kiker and Stromquist (1939) and Hinman (1941).

SHORELINE MAINTENANCE

Following the impoundage of a reservoir, a program of shoreline maintenance is carried out. The principal elements of this shoreline maintenance program are annual shoreline conditioning, aquatic growth control, marginal grazing, and drainage maintenance.

The annual shoreline conditioning program provides for the removal of annual growth from the zone of fluctuation (See Fig. 3). Chief emphasis is placed upon the removal of coppice of water tolerant woody species, such as willow and buttonball, and the removal of stiff-stemmed annuals, such as giant ragweed. The production of coppice by water tolerant species, such as willow, may be effectively prevented by flush cutting the stumps and treating them with an herbicidal oil. The removal of small coppice and annual growth is carried out by means of area burning, horse- and power-driven mowers, and hand rebrushing. The maximum use of mowing and area burning decreases the cost of the operation.

Aquatic growth control operations are carried out against truly aquatic species, such as lotus (**Nelumbo lutea**) and cowlily (**Nymphaeae advena**). These species have been controlled successfully by recurrent cuttings with a Hockney type underwater weed-cutter (See Fig. 4). Successful control of marginal aquatics, such as alligator weed (**Achyranthes philoxeroides**), has been achieved through the application of herbicidal oils.

Marginal grazing has proved to be a very effective biological means of controlling the growth in the zone of fluctuation (See Fig. 5). The use of such shoreline grazing, therefore, is recommended wherever it fits into the over-all land use program. The benefits of this measure may be increased through the use of contour fencing and grazing rotation.

An annual maintenance of marginal drainage ditches is carried out in order to ensure their continued function. In the upper end of the Valley, such drainage maintenance usually consists in removing trees, trash, or other debris which has fallen into the ditches and might obstruct the passage of water through them. In certain sections in the lower end of the Valley

Fig. 2. Marginal drainage provides boat access to lateral depressions and makes it possible to regulate the water levels with those of the main reservoir. The above view shows a small limesink connected to the main body of a storage reservoir by means of a dragline ditch.

where the soil is sandy, there is also a considerable maintenance problem due to the silting-in of the drainage ditches.

Shoreline maintenance has been discussed in more detail by Hinman (1941).

PERMANENT SHORELINE IMPROVEMENT

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Fig. 3. Shoreline conditioning limits the production of **Anopheles quadrimaculatus** by providing a maximum of clean water surface. In the above view the area to the right was conditioned and that to the left was not.

improvement measures include diking and dewatering, cutting and filling, and land use restriction to daytime occupancy. Such permanent works for the control of **Anopheles quadrimaculatus** have been developed as a pre-impoundage operation in Kentucky Reservoir, which is to be impounded during the 1944 season, and involve some 14,000 acres or 70 per cent of the 20,000 acres of potential mosquito breeding surface around the margin of this reservoir. In other reservoirs, permanent improvement is being developed as a post-impoundage measure.

Diking and dewatering (See Fig. 6) is a particularly effective means of permanently eliminating the production of **A. quadrimaculatus**. The areas to be controlled are diked off and equipped with a system of drainage ditches and pumping units for removing the run-off. During the mosquito breeding season the areas are kept dewatered, thus preventing mosquito production. In many instances, it is possible to decrease greatly the malaria control cost allocation by utilizing the dikes as fills in the relocation of highways and railroads. Frequently, valuable land is retained for agricultural use through the application of this measure. In some instances, the areas are reflooded in the fall to provide resting and feeding grounds for migrating waterfowl and thus benefit the Authority's wildlife conservation program.

In smaller problem areas, it is frequently possible to use filling as a means of permanently removing the mosquito production hazard. The economy of this operation is benefited through the use of a combined cutting and filling operation which deepens part of the area and fills the remaining above the elevation of the normal maximum summertime water level.

In areas having a sparse population and limited agricultural use, it has

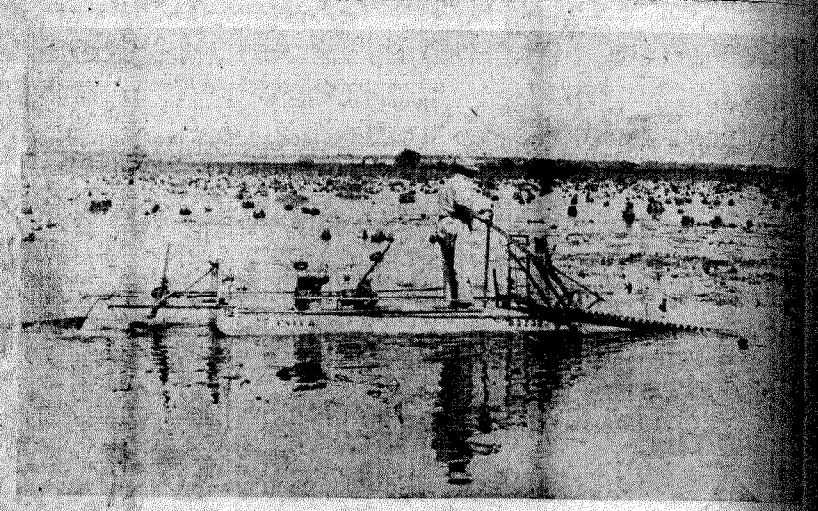

Fig. 4. Special aquatic growth control measures are directed at those species which extend the breeding areas out into the deeper waters. In the above view an underwater weed-cutter is being used to control cowlily (**Nymphaea advena**) by recurrent cutting.

been possible to prevent effectively malaria transmission through the restriction of land use to daytime occupancy. In the application of this measure all dwellings are removed from the one mile zone, and occupation of the area during the mosquito breeding season is permitted only during the daytime. Since **A. quadrimaculatus** bites only at night, malaria transmission is prevented by keeping people out of the area at night.

A more detailed discussion of permanent works for the control of anophelines on impounded waters has been given by Bishop and Gartrell (1940) in a paper presented at the recent meetings of the National Malaria Society.

HOUSE MOSQUITO-PROOFING

In certain situations it is possible to make effective use of house mosquito-proofing (See Fig. 7) as a secondary means of providing essential protection from malaria transmission. Where house mosquito-proofing is supported by shoreline conditioning and water level management, it is sometimes possible to substitute it for the more expensive, and often ineffective, larvicidal control. Effective reduction of malaria transmission through the use of mosquito-proofing has been brought about under the conditions of low malaria prevalence which have occurred during recent years, but it is desirable also to thoroughly test this measure under condition of epidemic malaria transmission. Recent information on mosquito-proofing for malaria control has been presented by Kiker (1941), Watson and Maher (1941), and Watson and Rice (1941).

Fig. 5. Grazing is an effective biological means of marginal growth removal. The area to the right in the above picture was grazed while that to the left was not.

WATER LEVEL MANAGEMENT

Of all malaria control measures used by the Authority, none is more important than water level management. It is the backbone of the malaria control program and is the dominant factor in determining the effectiveness and economy of each season's operations. In developing water level management for malaria control on the Authority's reservoirs, it has been necessary to fit the schedule into the multipurpose use of the reservoirs, namely, flood control, navigation, and the generation of power. The water level management schedule now in use on most of the main river reservoirs of the Authority consists of four phases, each with a particular function (See Fig. 8). These phases are: (1) An early spring flood surcharge; (2) The maintenance of a relatively constant pool level; (3) The use of cyclical fluctuation without recession; and (4) The combined use of cyclical fluctuation and seasonal recession.

In the application of the flood surcharge phase, the water elevation is brought up into the flood surcharge zone for a brief period during the late winter or early spring. The water is then brought down to the normal maximum summertime pool elevation, thus stranding the winter's accumulation of drift and flotage. This helps to create clean water conditions at the beginning of the breeding season.

During the spring growth period, the water is held at a relatively constant level at the normal maximum summertime elevation. This prevents the invasion of marginal vegetation and thus provides for a clean shoreline during the period of maximum mosquito production; by narrowing the band of growth invasion, it also decreases the amount of growth removal necessary in the annual fall shoreline conditioning operation. The application of this measure is made possible by the fact that most of the marginal species

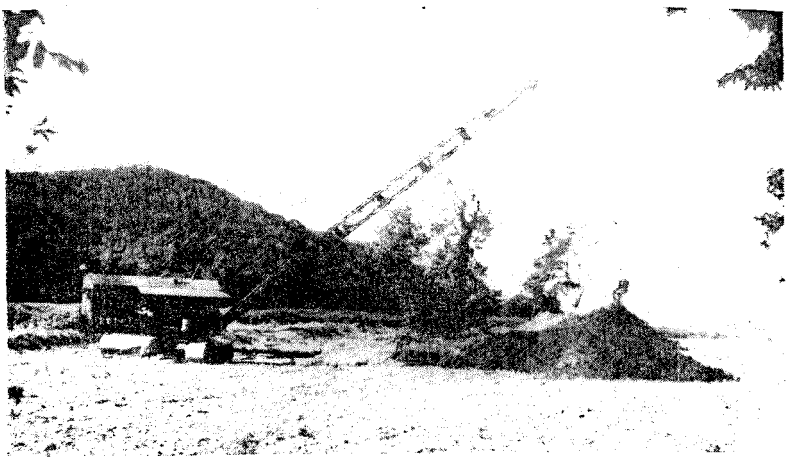

Fig. 6. Diking and dewatering is an effective means of permanent shoreline improvement. The above photograph shows the construction of a dike in the Duck River area of Kentucky Reservoir.

which are a problem in the Authority's reservoirs will not germinate or initiate growth until they are dewatered.

With the beginning of moderate mosquito production, the use of cyclical fluctuation without recession is initiated (See Fig. 9). In the application of this measure, the water elevation is lowered approximately one foot and then returned to the original level over a period of a week or ten days. At the bottom of the cycle, the water is brought down out of the marginal band of vegetation giving a clean shoreline. This appears to limit the production of **A. quadrimaculatus** in a number of ways, including the stranding of eggs and larvae, the creating of less favorable conditions for oviposition, and the exposing of larvae to natural enemies, such as **Gambusia.**

The use of a combined schedule of cyclical fluctuation and seasonal recession is initiated with the beginning of heavy production of **A. quadrimaculatus.** In the application of this measure, the water level is brought down a foot but returned only nine-tenths of a foot, thus giving a seasonal recession of about one-tenth of a foot a week. This seasonal recession serves to keep ahead of the gradual invasion of marginal vegetation and ensures that the water level will be brought out of the vegetation into a clean shoreline at the bottom of each weekly cycle. With the extended use of the constant pool level phase, it has been possible to limit the amount of seasonal recession, and, in general, two feet of seasonal recession or three feet over-all recession has proved adequate.

On one of the main river reservoirs (Lake Wilson), which has a high generating capacity and a low storage capacity, satisfactory mosquito control has been achieved through the use of weekly cyclical fluctuations of about two feet without seasonal recession. The high generating capacity installed in this dam makes it possible to provide weekly fluctuations of this amplitude without spilling any water.

Fig. 7. House mosquito-proofing is an important aid in preventing malaria transmission. The above view shows a well-built screened door and walls covered with kraft paper.

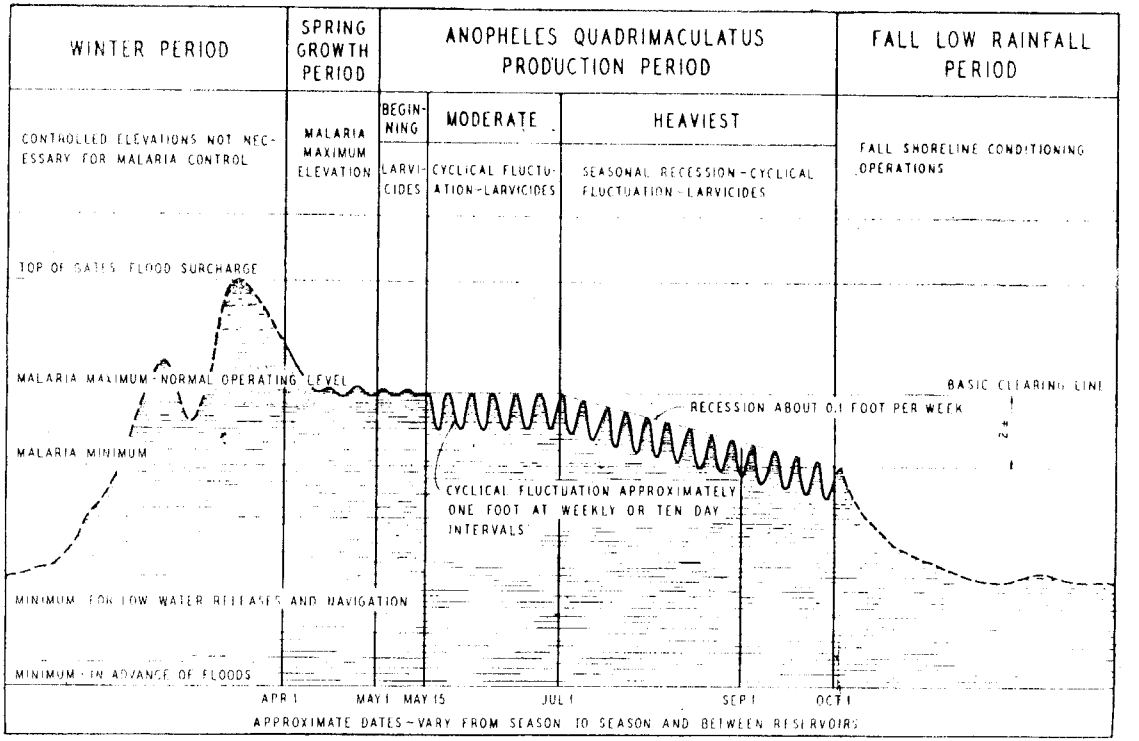

Fig. 8. Desirable features of water level management for malaria control onmain river reservoirs.

A. Water level at the normal maximum summertime elevation.

B. Water level drawn down one foot below the normal maximum summertime elevation.

Fig. 9. Cyclical fluctuation of water levels is an effective means of controlling production of **Anopheles quadrimaculatus.**

On the storage reservoirs, the water level management schedule is limited to seasonal recession alone. In the normal use of these reservoirs they are filled during the rainy spring period and gradually drawn down during the summer season. This gradual summer drawdown maintains a clean shoreline and thus provides satisfactory control. Serious production of **Anopheles**

quadrimaculatus on the storage reservoirs usually occurs only during abnormal periods of summer floods during which the water level is brought back up into the marginal vegetation.

Hess and Kiker (1943) have recently given a detailed review of the water level management schedules for malaria control on the Authority's reservoirs.

APPLICATION OF LARVICIDES

In developing its malaria control program, the Authority has attempted to make increased use of the more effective and less costly permanent and naturalistic methods of controlling **A. quadrimaculatus** and to decrease the use of larvicides; however, it is still necessary to provide for the application of larvicides as an emergency measure and for routine use in certain areas where other measures do not produce adequate control. The larvicides used are Paris green and oil. These are applied by means of airplane dusting, boat oiling and dusting, and hand oiling and dusting. For airplane dusting, the Paris green is diluted with soapstone at the rate of about 1:4. Less concentrated mixtures may be used for hand dusting. The larvicidal oil consists of a mixture of 9 parts kerosene to 1 part black oil. The black oil serves chiefly as a marker for gauging visually the concentration in the oil water stream.

Airplane dusting (See Fig. 10) is the most economical means of applying larvicides and is particularly applicable to extensive shallow areas which are inaccessible by boat and too large for hand treatment. Boat oiling (See Fig. 11) and dusting is generally used for the treatment of relatively narrow bands of vegetation along shorelines which are unsuitable for airplane dusting. Hand oiling and dusting is used for the treatment of small areas which

Fig. 10. On the cleared reservoirs of the Tennessee Valley Authority, airplane dusting is the most efficient means of applying anopheline larvicides to the larger breeding areas.

are inaccessible by boat and too small for airplane dusting.

Recent developments in the use of airplane dusting for malaria control have been discussed by Kruse, et al (1943).

SUMMARY

With the completion of the present construction program, the Tennessee Valley Authority will have in operation over twenty reservoirs with a total water surface of some three quarters of a million acres and a shoreline of over ten thousand miles. An appropriate program of malaria control is put into operation on each of the reservoirs where conditions are suitable for the production of sufficient numbers of **Anopheles quadrimaculatus** to create a malaria transmission hazard. This malaria control program is carried out in accordance with regulations of the health departments of the various states involved. The technical planning, supervision, appraisal, and development of the program is provided by a malaria control team consisting of a malariologist, biologist, and an engineer. Application of the program on individual reservoirs is under the direction of resident sanitary engineers. The main phases of the malaria control program are reservoir preparation, permanent shoreline improvement, shoreline maintenance, water level management, and the application of larvicides. Primary emphasis is placed upon the use of naturalistic measures, such as water level management and permanent shoreline improvement, in preference to artificial measures, such as the application of larvicides.

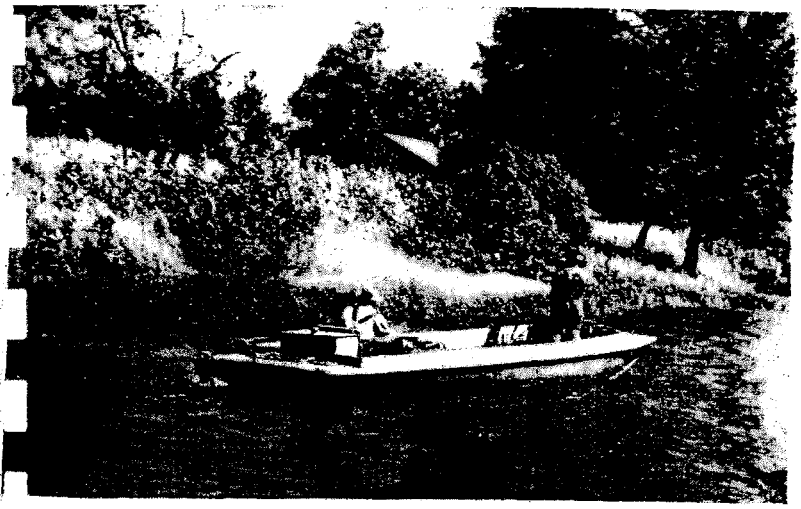

Fig. 11. Larvicidal oils are applied by boat to narrow bands of vegetation such as that shown in the above illustration.