entomologists covering the rank span of 2nd Lieutenant to Colonel, a career field in which the entomologist combines entomological and military skills in support of the assigned mission of the Army Medical Service—which is ". . . the conservation of man power—the preservation of the strength of the military forces."

MALARIA CONTROL PROGRAM OF THE TENNESSEE VALLEY AUTHORITY

F. E. GARTRELL
Chief, Malaria Control Branch, Division of Health and Safety, TVA

The malaria problem confronted TVA as soon as it began planning for development of the Tennessee River. Prior reservoir impoundments in the southeastern United States proved, in virtually every instance, to be ideal breeding grounds for anopheline mosquitoes and resulted in serious epidemics of malaria. This was true of projects constructed in Alabama on the Cahaba River in 1910 and on the Coosa River in 1914. It was also true of reservoirs constructed on the Tennessee River itself at Hales Bar in 1912, at Lake Wilson in 1924, and at Widows Bar in 1926. These unfortunate experiences led to extensive investigations by the United States Public Health Service which are considered to be the starting point of present day knowledge of malaria control on impounded waters. In 1923, Alabama adopted regulations, which have since served as a model for many other states, requiring that any individual or private or municipal corporation apply malaria control measures in impounding water or raising the level of an existing pond.

In the early 1930's, despite advances in knowledge concerning the control of malaria, the disease still constituted one of the most important public health problems of the southeastern United States. For example, in 1934, a malaria survey was made of the proposed basin of Wheeler Reservoir and the area within mosquito flight range (one mile) of its margin. A total of 5,023 blood specimens were collected; of these, 35 per cent were found positive, the maximum rate reaching 65 per cent in 2 counties. In a survey by the Alabama State Health Department a year earlier around Lake Wilson, 23 per cent of the individuals tested were found positive for malaria. It goes without saying that such high malaria incidence results in economic losses which can retard seriously the development of a region.

TVA's plans for creation of a chain of artificial lakes, which presently cover more than 600,000 acres with over 10,000 miles of shoreline, in a region where malaria already existed to a serious degree offered an unprecedented control problem. Moreover, this problem was intensified by the multipurpose character of the system which was to be operated for flood control, navigation, and the generation of power, and would require flexibility in water level changes to meet the needs of all three purposes. No similar development had previously occurred in this country from which to draw experience.

To cope with this problem, TVA assembled a staff with special training in medical malariology, biology, and engineering. They were associated within a single division and given the responsibility of developing a malaria control program for the entire river development. Special consultants were called in from the United States Public Health Service, the Department of Agriculture, the Rockefeller Foundation, universities and other

agencies. In addition, the TVA staff has worked closely with the state and county health organizations of the Valley.

From the beginning, emphasis of the malaria control program has been upon measures directed at control of the vector, *Anopheles quadrimaculatus*. Every effort has been made to achieve the greatest possible integration between research into new methods of control and application of such research in actual control work on and along the reservoirs. New control ideas, whether originating with the TVA research staff, with the TVA field forces, or outside the agency, are first tested in the laboratory and subsequently tried on a small scale in the field; if they still appear promising, larger-scale field application is carried out before the method is incorporated into the program.

PROGRAM ELEMENTS

Reservoir Preparation

When TVA began its control work, the clearing of reservoirs and construction of marginal drainage ditches were recognized as standard practice. However, impoundment of the vast acreage contained in the shallow portions of the TVA main river reservoirs, in poorly drained areas with luxuriant plant growth, resulted in an unprecedented anopheline mosquito production potential. TVA accordingly undertook studies for the purpose of developing improved methods for conditioning these marginal portions of the reservoirs. The new developments adopted as a result of these studies include the low cutting of stumps, which results in less resprouting after impounding; the poisoning of willow stumps, which had been found to produce the most abundant and objectionable marginal growth; the final removal of marginal regrowth in the autumn prior to the initial impoundage; and special clearing practices for margins of reservoirs. In one reservoir, Kentucky, an extensive program of permanent shoreline improvement to eliminate potential mosquito breeding areas by deepening-and-filling and diking-and-dewatering was carried out prior to impoundage. The adoption of these improved procedures resulted in a much more effective reservoir preparation and decreased the cost of subsequent maintenance operations.

Water Level Management

By 1933, the year in which TVA was organized, it had already been established that water level fluctuation could be used as an effective method of mosquito control. Reliance at that time was placed chiefly upon a spring surcharge followed by cyclical fluctuation, or where this was not possible, upon seasonal water level recession. TVA undertook a series of initial experiments on a small pond to determine more effective methods of using water level management. Information obtained from these experiments was then applied on Lake Wilson as a proving ground, with periodic biological and engineering investigation of results, and over a period of years improved schedules have been developed. Water level regulation for malaria control has been successfully fitted into the operating schedules required for flood control, navigation and power.

Water level management is the most effective single malaria control measure. The schedule on the main river reservoirs includes: (1) raising the water above normal maximum summer level in late winter or early spring and then returning it to that elevation in order to strand the winter's accumulation of drift and flotage; (2) maintaining the water at the normal maximum summer elevation during the spring growth period to retard marginal vegetation; (3) cyclical fluctuation of the water levels about 1 foot at weekly intervals during the late spring and early summer in order to kill mosquito larvae by stranding them on shore or exposing them to natural enemies such as top minnows; and (4) combining a seasonal recession of about 0.1 foot to 0.2 foot per week with cyclical fluctuation in order to insure effective control of mosquito larvae during the peak of the mosquito breed-

ing season in the summer and early fall. On the storage reservoirs effective mosquito control is usually obtained through the use of wide seasonal recession.

Permanent Shoreline Improvements

Shoreline alterations to eliminate permanently the most serious mosquito breeding areas in the lower main stream reservoirs are being made. These shoreline improvements consist mainly of diking-and-dewatering and deepening-and-filling. The latter method consists of deepening the lower half of shallow mosquito breeding areas and placing the excavated earth on the upper portion of the area. Diking-and-dewatering consists of building dikes to separate large shallow areas from the lakes and installing pumps to remove water which accumulates behind the dikes.

Approximately 9,100 acres, 50 per cent of the total 18,200 acres proposed for permanent shoreline improvement measures in TVA reservoirs, have been completed.

Of the 9,100 acres completed, 4,960 acres are included in ten diking-and-dewatering projects, eight in Kentucky Reservoir and two in Wheeler Reservoir. Completion of the permanent shoreline improvement program was originally scheduled for fiscal year 1953, but work is being curtailed to accommodate more acute defense needs.

Insecticiding

In 1933, two larvicides were in general use for the control of malaria mosquitoes. One was a mixture of kerosene and black oil applied mainly by knapsack and occasionally by boat pumping units; the other was paris green, which was diluted with an inert substance and applied to the surface of the water by hand dusters. These procedures, on limited areas and under appropriate supervision, produced moderately effective results. The size of the projected TVA development, and particularly its tens of thousands of acres of shallow water not readily accessible from either shore or boat, required something better.

As initial steps in developing more effective insecticidal techniques, TVA adapted a water-oil pumping unit for applying the oil-kerosene mixture to the types of shoreline which could be reached by shallow-draft boats; an orchard-type duster for applying paris green from marine equipment; and facilities for the mixing and storage of larvicidal materials at convenient points about the reservoirs. Next, TVA investigated the possibilities of applying paris green from airplanes. The practicability of this method of application had been demonstrated on a limited scale in the 1920's by the U. S. Department of Agriculture. The method was never generally adopted, however, and equipment was lacking with which to put it into effect. TVA developed modified dust hoppers, together with methods for mixing paris green and its diluent, and for sacking and storage. When Wheeler Reservoir was impounded in 1937, it was possible, as a result of the collaboration of TVA technicians with personnel of other governmental agencies and commercial crop dusting organizations, to demonstrate successfully the superiority of airplane application of paris green from the standpoint of both economy and effectiveness.

During World War II, as DDT and other new and more effective insecticides appeared, TVA immediately tested them to determine their effectiveness in the control of anopheline mosquitoes, and to develop satisfactory formulations and equipment for their distribution by airplane, boat, and hand. The first airplane application of DDT for mosquito control was carried out by TVA in cooperation with the U. S. Department of Agriculture in 1943. Later, as the result of a cooperative project undertaken by TVA, the U. S. Department of Agriculture, and research units of universities working under grants from the Office of Scientific Research and Development, a new type of DDT solvent was used and an exhaust generator was developed for the production of an aerosol or mist-type spray

which could be readily adapted to small airplanes. Because of the small quantity of DDT thermal aerosol (0.1 lb. DDT per acre) necessary for satisfactory control and its more effective penetration of vegetation, this development increased tremendously the effectiveness and economy of airplane distribution. This was followed by development of spray equipment which reduced the normal application rate required to .05 lb. of DDT per acre. DDT applied by airplane as a spray has completely replaced all other methods of larviciding. Recent investigations have demonstrated that helicopters can be used satisfactorily for application of larvicides under conditions prevailing on TVA lakes, but they do not appear to be superior to the fixed-wing aircraft presently used. TVA uses helicopters for transmission line patrol and a demonstration is scheduled for the summer of 1951 on joint use of a helicopter for both transmission line patrol and malaria control, which if practical would result in economies to both programs, because of better utilization of equipment and pilots than is the case with present arrangements.

During the early years of TVA impoundages, there were certain limited areas in which adequate mosquito control was impracticable with any methods then available. It was therefore decided to employ the mosquito-proofing of houses within these areas as a temporary emergency measure until more permanent measures could be applied. Following the wartime demonstration of the effectiveness of wall sprays of DDT in eliminating flies and mosquitoes, spraying methods were developed which field tests demonstrated to be practicable in the TVA area. Thereafter, with the approval of appropriate state health departments, the residual spraying of all dwellings and other structures of premises with this material was substituted for mosquito-proofing maintenance. Beginning with the 1951 season, routine use of premises spraying in these areas is to be discontinued, and the areas are to be included in the regular anti-larval program. This change was made possible by the cumulative beneficial effects of water level management in controlling marginal vegetation, progress on permanent shoreline improvement, and increased effectiveness of larviciding techniques. Residual spraying of premises may be utilized whenever emergency situations indicate the need for additional malaria control measures.

Shoreline Maintenance

TVA's early experience with larvicides emphasized the costly and repetitive nature of that type of control. In its search for possible alternatives, TVA investigated the possibility of controlling vegetation along the margin of the reservoirs. It was soon found that annual shoreline conditioning not only increased the effectiveness of larvicides but limited the need for their application. At first, water-tolerant woody plants such as willow and buttonball and stiff-stemmed marginal weeds were cut by hand, but operations were gradually mechanized and area burning was developed for certain situations. Water level schedules have been effective in limiting the zone of marginal growth invasion to 1½ to 2 feet below normal pool elevation. Growth removal operations have been further limited by establishing the "shoreline maintenance line" approximately ½' below normal pool elevation, since experience has demonstrated that this is a practical procedure in light of water level schedules employed on the five reservoirs where growth removal operations are required. Drift removal is a minor operation and is limited to situations where it has accumulated to the extent that it constitutes a favorable mosquito breeding area. Recurrent cutting, first by hand and later mechanically, together with some use of conventional herbicides, proved moderately successful in the control of aquatic plants. With the advent of 2, 4-D, more effective means of controlling many such plants became possible. Formulations of 2, 4-D have been found to be effective in the control of black willow, trumpet vine, lotus, parrot's

feather, water primrose, water willow weed, cocklebur, and giant ragweed. Effective treatment has not yet been developed for alligator grass, buttonball, and cattail.

Drainage Maintenance

Maintenance of existing marginal drainage systems is required to assure maximum effectiveness of water level fluctuation for mosquito control. Dynamite is used extensively, but hand operations are also employed. Herbicides are used where willows and other plants tend to clog or retard the flow in the ditches.

SUMMARY OF MALARIA CONTROL MEASURES

With the exception of one area in Kentucky Reservoir where malaria control easements prohibit nighttime occupancy of the one-mile zone of the reservoir during the period May 1 to October 1, the TVA malaria control program is directed toward control of the vector, *Anopheles quadrimaculatus,* on TVA reservoirs. Water level management is the foundation of the control program, and malaria control needs have been integrated into schedules which meet the primary requirements of the projects for navigation, flood control, and power purposes. Water level schedules have been effective both by limiting marginal growth, which indirectly affects mosquito production, and by stranding mosquito larvae or exposing them in open water to wave action and natural predators. Of the twenty-four reservoirs in the TVA system, water level management alone provides satisfactory mosquito control on sixteen reservoirs; on two reservoirs only occasional and limited larvicidal operations are required; and routine seasonal larvicidal operations and other measures are scheduled on only six reservoirs. Larvicidal operations consist of application of DDT as spray by airplane at a rate of approximately 0.05 pounds of DDT per acre, with entire operation being handled by four fixed-wing airplanes. Shoreline maintenance operations include marginal growth removal, aquatic growth control, drainage maintenance and drift removal, with work being limited to those areas of highest anopheline production potential. Diking-and-dewatering and deepening-and-filling have been employed to eliminate some major mosquito breeding areas in the margins of TVA lakes, and a program is now in progress which is scheduled ultimately to improve the shoreline in all of the principal malaria mosquito breeding areas to the end that with normal water level management schedules only a minimum of supplementary control measures will be required. The program provides for use of DDT premises spraying for emergency situations where, for any reason, antilarval measures fail to provide satisfactory mosquito control.

Program Appraisal

In order to appraise the effectiveness of its control program, the Authority in cooperation with state health departments makes routine inspections of designated mosquito collecting stations during the mosquito season and carries out malaria surveys in areas adjacent to the reservoirs. The effectiveness of the mosquito control program is indicated by results of inspections during the 1950 season when 8,595 inspections were made and the average count per inspection was 1.7 female *Anopheles quadrimaculatus.* The results of the malaria blood film surveys likewise attest to the effectiveness of the control program. The results of the past two seasons showed all blood films to be negative, whereas in 1934 similar surveys showed 28 per cent were positive. Thus, despite the tremendous increase in malaria transmission potential resulting from the creation of the TVA chain of lakes, malaria control has been achieved to the extent that the reduction in malaria around TVA reservoirs has paralleled the general decline of malaria in the Southeastern United States.