

A REVIEW OF MALARIA CONTROL AND ERADICATION IN THE UNITED STATES¹

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It is said that malaria was brought to what is now the United States by early immigrants from England, France, and Spain where the disease was common. It did not become firmly established, however, until Negro slaves were imported from West Africa, bringing with them virulent strains of the malaria parasite. It then gradually spread, and by the time of the Revolutionary War malaria was common from Pennsylvania southward to Georgia and was carried westward as the pioneers moved inland. It also became highly prevalent in the French settlements along the Gulf Coast, as well as in southwestern Louisiana and eastern Texas following the immigration of Spanish colonists from Mexico.

By 1850, malaria had become established in practically every settlement from New England westward to the Columbia River Valley and from southernmost Florida to the inland valleys of California. Only northern New England, the Allegheny highlands, the Rocky Mountains, the great inland desert, and the Western Sierras had escaped. The southeastern states and the lower half of the Mississippi basin were highly malarious. Less so was the northern half of the country, where only 3-4 summer months were warm enough for incubation of the infection in the mosquito (Faust, 1951). The disease reached its climax about 1875, at which time it began to decline in the northern regions, but throughout the southern states it remained one of the most important diseases affecting man's health and welfare until well into the 20th century. An idea of how important it

was not so long ago can be gained from a study made by Dr. L. L. Williams, Jr. of records for the years 1934-36. He concluded from this study that death, disability, and unproductiveness caused by malaria at that time were costing the South \$500,000,000 annually (Williams, 1938).

Long prior to the discovery of the cause of malaria in 1880 and of its mode of transmission in 1897, it was well known that the disease was associated with wet, swampy areas, and a few astute observers also had associated it with mosquitoes. In summarizing control work during this early period, Dr. Mark Boyd states: "The 19th century witnessed many examples of the deliberate application of drainage for the prevention of intermittent and remittent fevers. We have no means of appraising the volume of such work, but sufficient accounts are preserved in the literature to indicate that it was considerable. One of the earliest significant instances is afforded by the action of the City of Savannah, Georgia, with relation to rice culture. In 1817—the city appropriated \$70,000 to purchase the right of cultivation of rice—in swamps—adjacent to the city. (after which) a marked reduction in deaths from autumnal disease immediately resulted." He cites a number of other instances of the observed diminution of malaria following land drainage, which was done principally in connection with agricultural development but also to some extent for general sanitary purposes. When the role of anopheline mosquitoes in malaria transmission was discovered, drainage, of course, moved from an empirical to a scientifically sound malaria control measure.

The first important *Anopheles*-oriented control work in this hemisphere was that of the U. S. Army in Cuba in 1901 during the American occupation. Major W. C.

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Gorgas, the Chief Sanitary Officer, enlarged the program for eliminating yellow fever mosquitoes to include an attack on anophelines, with equally satisfactory results in the case of malaria. In 1904, when the U. S. assumed control of the Canal Zone, Gorgas was made Chief Sanitary Officer. A program was organized which soon banished yellow fever, and after 1905 kept malaria at a negligible level (Boyd, 1949). Gorgas has been quoted as stating that in Panama "the anti-malarial work in order of its importance, consisted of drainage, brush and grass cutting, oiling, use of soluble larvicide, prophylactic quinine, screening and the killing of adult mosquitoes in the quarters of laborers" (Russell, 1955).

The earliest work in the United States directed specifically against *Anopheles* mosquitoes for malaria control usually is credited to Dr. A. H. Doty, Health Officer of the Port of New York, for work begun on Staten Island in 1901, and to Dr. A. N. Berkeley for work in some small towns near New York City in that same year. In both cases, successful results were claimed because malaria soon disappeared (Matheson, 1941). Credit for the first such work in the South is claimed by Dr. J. M. Barnett, who was employed in 1902 to "take charge" of health conditions in Pretoria, a sawmill town in Dougherty County, Georgia, where malaria was severe. He states: ". . . in a few weeks every house was screened, every bed was netted and all standing water within a half mile of the camp was drained. Larger bodies of water were oiled with crude oil every seven days. Quinine was given the inhabitants daily. This work was continued until 1904, with great improvement in health conditions." (Barnett, 1935).

Also, to quote the late Dr. Robert Matheson, "Probably the first city-wide organized malaria control in the United States, took place in Ithaca, New York, beginning after an epidemic of . . . malaria in 1904, when there were over 2,000 cases in a population of 13,000. The health officer was given authority to require every

physician to report each week every case of malaria and its location; to require a blood examination of every suspected case; to appoint an inspector and two assistants to find and eliminate anopheline breeding places; and to issue instructions as to how malaria is contracted, how to avoid infection and in regard to isolating patients." The work was eminently successful. "There were 1,000 cases in 1905, none in 1908, and since that time, Ithaca has been practically malaria free." (Matheson, 1941).

So much for some of the early claims to priority. It is quite probable that many other early efforts of the same nature occurred but failed to gain prominent recognition in the literature.

It generally is conceded that the field studies in malaria begun in 1912 by Dr. Henry R. Carter of the U. S. Public Health Service really initiated serious malaria control work in the South. These studies also were the basis for the later comprehensive malaria control programs in this country. The demonstrations by Dr. Carter and his associates, among whom was Mr. J. A. LePrince, who had organized the yellow fever and malaria control programs in Cuba and the Panama Canal Zone under Colonel Gorgas, were successful in arousing a great deal of interest. Health departments were slow, however, in undertaking malaria control, because the low economic status of affected communities made financing difficult. It was during this period that Dr. Carter first observed the larvicidal effect of fluctuating water levels in impoundments. Thus, he began promoting the use of water manipulation in malaria control—a measure which later, when combined with reservoir preparation and shore line maintenance, was to be used so effectively in the vast progressive malaria control program of the Tennessee Valley Authority (TVA).

Mosquito control for malaria prevention advanced greatly during World War I (1917-1918). Programs were carried on by the Army at its southern camps and stations, and extracantonment programs

were operated by PHS in 43 war areas over a total area of about 1200 square miles in 15 states. Some 1,750,000 civilians and 800,000 military personnel were protected. Many individuals who later were to become prominent in malaria control work participated in these activities, which included drainage, the use of oil larvicides, screening, and educational and other approaches.

During this period, mass treatment of infected persons as a public health measure was attempted in a large area of the Mississippi Delta region by Dr. C. C. Bass of the Tulane Medical School. A regimen of quinine administration, which became known as the "Standard Treatment," was developed. This was given gratis to infected persons in the study area in 1918, when 40 percent of the population suffered malaria attacks. The following year only 4 percent had attacks. However, when the people were urged subsequently to purchase the treatment, the response was disappointing and the program never gained ground (Boyd, 1941).

Following World War I, the Public Health Service continued to conduct malaria research and to promote control activities in malarious areas. By 1928, investigations or surveys had been conducted in 667 communities in 24 states; and control programs in 343 communities in 17 states had been carried on either directly or in cooperation with other health agencies (Herms and Gray, 1944). Among these, the Rockefeller Foundation figured prominently. For example, during 1920-1922 the Foundation cooperated in a program aimed at popularizing malaria control activities and encouraging health departments to build up control programs. Some 40 towns in 11 southern states participated in this endeavor, which is said to have provided malaria protection to over 300,000 persons at an annual per capita cost of 81 cents (Russell, 1955).

Research on control methods during this period resulted in the development of paris green as an anopheline larvicide by Drs. Barber and Hayne (1921) of PHS and in the use of airplanes for large-scale

distribution of insecticides for anopheline control by the Federal Bureau of Entomology (King and Bradley, 1926). These innovations greatly simplified anti-anopheline work.

During the depression years of the 1930's, drainage projects for controlling both disease-carrying and pestiferous mosquitoes became popular. Throughout this period, Federal, State, and local health agencies did much to promote and organize effective malaria control work. One summary states that under relief programs, a daily average of 211,000 men worked for 6½ years on anti-malaria drainage in an average of 250 counties. They dug 33,655 miles of ditch, which removed 544,414 acres of anopheline-breeding surface in the 16 southeastern states (Williams, 1941). This extensive work must have contributed importantly to malaria recession.

Another outstanding development in the 1930's was the initiation of the malaria preventive and control program by TVA. The TVA program included provisions for (1) technical planning, supervision, and appraisal by a team consisting of a medical malariologist, an engineer, and a biologist; (2) application of control measures under the supervision of resident sanitary engineers; and (3) research on the biology and control of *Anopheles*, integrated with operational work and aimed at developing improved control procedures. The soundness of this approach soon became evident, and the TVA program became a model on which much future work elsewhere was based.

About this time, Dr. L. L. Williams, Jr., saw a continuing need for careful planning and country-wide coordination of malaria control activities if real progress was to be made. In 1937, he designed a plan for control of malaria on a statewide basis and worked untiringly in promoting its adoption. It was due in no small measure to Dr. Williams' inspiring leadership that the attack on malaria was launched and was put well on the road to successful conclusion.

The plan developed by Dr. Williams

had four objectives: (1) the elimination of major foci of infection in each county; (2) prevention of manmade malaria; (3) maintenance of existing and of new control projects; and (4) education of the public. It called for each of the malarious states to organize a malaria control unit to promote and manage control activities. Each unit would be staffed by a team composed of a medical malariologist for epidemiologic work; a sanitary engineer to plan drainage, larviciding, and screening; an entomologist to make anopheline surveys; and one or more technicians to examine blood films (Williams, 1937).

Passage of the Social Security Act in 1935 and its extension in 1939 provided funds for the establishment of these malaria survey and control teams, and, by the end of the latter year, 12 states had such units and 4 others had personnel specifically designated to plan and initiate malaria control activities. This development, coming at a time when relief labor still was available to states to carry out the operations, undoubtedly greatly advanced sound environmental malaria control throughout the South.

With the advent of World War II, these newly-established State Malaria Control Units were to become a ready source of trained malaria control personnel for the Armed Forces. During the war, responsibility for malaria control activities in this country was divided between military authorities and the Public Health Service, as it had been during World War I.

To supervise and integrate its part of the work, the PHS established the office of Malaria Control in War Areas (MCWA) in 1942 under the direction of Dr. Williams. Headquarters were in Atlanta, Georgia, where divisions of Engineering, Epidemiology, and Entomology were concerned with overall planning and management. MCWA was, of course, the forerunner of the present Communicable Disease Center (CDC). As developed, the program was a cooperative one between the PHS and the various state health departments. These latter gave overall direction, while the Public Health Service established

policies, coordinated state activities, and furnished funds for personnel, equipment, and supplies.

Since the program was designed for the emergency, larviciding was the anti-anopheline method of choice. Oil, paris green, and pyrethrum emulsion all were used, as well as DDT after it became available. Drainage and appurtenant structures and filling were used only when necessary to permit effective control or when the cost would be no more than the cost of larviciding over a five-year period. Careful entomologic surveillance of projects was maintained, and the criterion of effective operations was the keeping of anopheline densities so low that the malaria transmission hazard was practically nil (Bradley, 1948).

During the period of maximal military preparation and industrial production, activities were carried on by MCWA near some 2200 localities of military concern in 19 different states. Federal costs from 1942 to 1945 totalled about \$25,000,000. This work, combined with that done by the military, is credited not only with preventing malaria in this country from interfering with the war effort (Andrews, 1951) but with nullifying the increase in national malaria prevalence that had been predicted for the early 1940's (Williams, 1941).

During 1943, military personnel were returning to their homes in this country. Among these were many who had contracted malaria overseas and, therefore, presented a potential for triggering outbreaks of malaria (Freeborn, 1944). To deal with this returnee problem outside its established program areas, MCWA set up mobile units for surveying, inspecting, and instituting control, if necessary. The mobile units operated in the vicinity of general hospitals, prisoner-of-war camps, and other stations where concentrations of malaria carriers were present. The units were also available at the request of States for the suppression of localized outbreaks.

In 1944, it was anticipated that the close of World War II hostilities might possibly reduce the malaria control program to one

of dealing with the returning malaria-carrier problem alone. The time was considered opportune, therefore, for launching a comprehensive nationwide program to be concerned not only with controlling isolated outbreaks caused by the returning malaria carriers, but with preventing such outbreaks by an all-out attack on the transmitting mosquito in the endemic foci throughout the malarious section of the U. S. Thus, the program would make progress toward eliminating the disease from the whole country.

In proposing such a program to the Congress, Dr. Williams stressed the inroads made on malaria in recent years as a result of both purposeful attack and fortuitous circumstance. He pointed out that the residuum of infection was clumped in apparently permanent foci in rural areas of southern valleys, coastal plains, and piedmont sections. It remained alive in these foci because of the easy accessibility of mosquitoes to poorly-housed humans living near extensive breeding places of *Anopheles quadrimaculatus*, the principal malaria-transmitting mosquito of the southern United States. He proposed that each such focus be found and eliminated as a reservoir of malaria (Williams, 1945).

Recommended procedures for this elimination work included drainage of prolific *quadrimaculatus* breeding places, if possible, and if not, larviciding them until all local infection died out; stimulation of householders to screen and mosquito-proof their houses; and the use of DDT for interior house spraying. Dr. Williams pointed out, however, that until the householders accepted interior spraying, the old proven methods of malaria control should not be abandoned. Suffice it to say here that the proposed program was accepted by the Congress; funds were provided; and what was to be known as the Extended Malaria Control Program began operations on January 1, 1945.

Relative to DDT, the first samples of this fabulous insecticide arrived at the Orlando, Florida, Laboratory of the Federal Bureau of Entomology and Plant

Quarantine in 1942. A staff of scientists under the direction of Dr. E. F. Knipping soon demonstrated the potency of DDT against our native mosquitoes, including the anophelines. Because early supplies of DDT were requisitioned by the military to combat insect-borne disease among troops overseas, its use in the U. S. was restricted. In 1945, however, DDT was made available for use by the PHS on the Extended Malaria Control Program. There was no need for any apprehension about the acceptance of DDT interior spraying by householders; it was welcomed by just about everyone—in many cases, not from any fear of malaria mosquitoes, but because of the quick and lasting relief it provided against flies, fleas, bedbugs, and roaches.

As organized, the Extended Program called for residual DDT spraying of all homes in rural areas, and anti-larval work around communities having 2,500 population or more in the 188 counties that had malaria mortality rates of 10 or more per 100,000 during the five-year period, 1938–1942. Most of these counties were located in the 13 southeastern states and contained approximately 1,000,000 rural homes. The remainder of the malaria problem was scattered among 649 counties having lesser rates of malaria mortality. In these 649 counties, the plan of attack included spraying of individual homes and adjacent premises whenever malaria was demonstrated.

The Extended Program operated until July 1, 1947, at a cost of \$11,500,000, 20 percent of which was furnished by the states. Its success in accomplishing its goals was considered to be outstanding (Andrews, 1951). During this period, 2,500,000 house-spraying applications were made in rural areas or small towns in 315 counties. The average number of sprayings per house varied from nearly two in 1945 to not quite one and one-half in 1947. The amount of time devoted to larviciding was minimal.

Back in 1943, before the Extended Program began, Dr. Williams had prepared a proposal for countrywide malaria eradica-

tion from the United States. The proposal was presented before the National Malaria Society and received the endorsement of that Society (J. W. Mountin, 1944). In 1946, with the end of the Extended Program approaching and in view of its phenomenal success, which provided convincing evidence of the efficacy of DDT in preventing malaria transmission, the PHS considered that the time was ripe for undertaking an eradication program as had been proposed in 1943. In addition to the success of the Extended Program, there were other conditions favoring eradication at the time. These included the lowest morbidity and mortality rates for malaria since a registration area was established in 1910; the spontaneous recession of the disease from the northern and central states, a general awareness of malaria among the people of the nation created by World War II, and a variety of other factors dependent on the prosperous economy and high standards of living then prevalent (Andrews, 1951).

In planning the eradication program, the approach selected was what was termed "attritional eradication," which was to be effected by concurrent reduction of the human carriers and the anopheline vectors of the malaria parasite. As a result, transmission would become less and less likely, the malaria morbidity trend would necessarily be downward, and, if this trend were maintained, incidence ultimately would reach the zero point and endemic malaria would be eradicated (Andrews and Gilbertson, 1948). It was proposed to effect such a decline in transmission by promoting improved diagnosis and treatment of cases and by reducing the household density of anopheline mosquitoes with residual insecticides according to the procedures evolved during the Extended Malaria Control Program.

A second phase of the eradication program, that of preventing the revival of malaria endemicity, was to be carried on by surveillance and prevention teams assigned to State health departments, whose responsibility would be to appraise all reported or discovered cases of malaria

and upon verification, to make such investigations as the circumstances warranted, to see that infected individuals were promptly and effectively treated, and to make sure that their homes and those of others within flight range of the vector were sprayed with DDT.

The plan was proposed to the Congress in 1946. It was thought at this time that the work might be completed and malaria could be eradicated in five years if existing levels of Federal and other funds for malaria control were continued. It was expected that 50 percent of costs would come from Federal funds and 50 percent from State and local sources. Following eradication, a federally-aided program of surveillance and prevention was planned—to continue until it could be taken over entirely by the States. The plan was accepted; and on July 1, 1947, the National Malaria Eradication Program was initiated by the PHS in cooperation with 13 states, viz: Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, Missouri, North Carolina, South Carolina, Oklahoma, Tennessee, and Texas (Andrews, 1951).

Field activities were carried on in much the same manner as on the Extended Program; i.e., CDC established broad general policies in accordance with directives and appropriations of the Congress, while the States administered and managed the program. For performing this function, "State CDC Activities" organizations were formed in each state as a supplement to and part of the State health department. Federal funds were used to buy materials and spraying and transport equipment, and to pay salaries of professional personnel; State and local funds generally were used to supply labor.

The usual practice was to apply a 5 percent DDT emulsion at the rate of 200 mg./sq. ft. to the interiors of homes and privies. At the start of the program two applications per season were made, but later—as the lasting quality of DDT in such situations was determined—only a single treatment was made in many areas. Both hand and power sprayers were used,

the former for treating scattered homes and the latter where houses were close together. To assure that uniform and proper coverage was being obtained, careful attention was given to the training of supervisors and crews and to the mixing of emulsions and calibration of spray nozzles.

An important feature of the work was the service provided by the staff of the CDC Technical Development Laboratories in working out solutions to operational problems, and developing procedures designed to improve the efficiency and economy of field operations. The general use of these and other advanced procedures and practices, which were developed as the work progressed, was encouraged by centralized training courses for supervisory personnel, followed by the decentralized training of other personnel in the project areas.

The county was the usual unit of operation, with communities of 2500 or more excluded. Approval of counties for work, which for the Extended Malaria Program was based on an average reported annual mortality rate of 10 per 100,000 from 1938-1942, inclusive, was reduced to 5 per 100,000. As mortality became virtually eliminated in many counties, the criteria were further adjusted so that, after 1948, spraying was done only in counties which had, in addition to the 5 per 100,000 death rate during 1938-1942, a reported mortality rate of 1 or more per 100,000 from 1943 to 1946. Also eligible were counties with a death rate of 4 or more for this period irrespective of previous mortality experience, as well as rural homes within one mile of malaria cases which had been confirmed by State health department laboratories.

The total house sprayings during the 1945-1952 period came to just over 6,500,000 and the total cost approximated \$27,500,000, of which nearly \$9,000,000 was provided by the States.

In 1951, CDC began gradually withdrawing from active participation in the operational phases of the eradication programs in some of the states and began

shifting its interests to surveillance and prevention. It did, however, continue to give technical guidance as necessary to programs which continued under State and local support. On July 1, 1952, CDC participation in operations ceased altogether, and all of its interests were shifted to surveillance and prevention activities. These are still continuing.

Before taking up what happened to malaria during the period that these large-scale control and eradication programs were underway, it should be pointed out that prior to 1949, when the surveillance and prevention activities of the eradication program began, malaria statistics were grossly inaccurate. In commenting on this situation as it applies to the period under consideration, Dr. Justin M. Andrews stated, "Malaria was known to be epidemic in the South in the 1930's when parasite rates of up to 50% were not uncommon among school children in the rural sections of many counties, although related levels of illness were not being reported. During the 1940's this *under* reporting situation gave way to one of *over* reporting, for it became evident that numbers of cases then being reported greatly exceeded demonstrable prevalence." (Andrews, 1951).

Now as to what happened to malaria—according to the reports.

In 1935, when the WPA drainage program was beginning, about 4,000 deaths from malaria were reported for the United States. Thereafter, an overall continuing decline began. In 1942, the first year of our participation in World War II and the beginning of the MCWA program, only 800 deaths were reported; in 1945, the last year of the war, 400; in 1947, the end of the Extended Malaria Control Program, 200; and in 1952, the last year of Federal operations under the Eradication Program, 25. This steady decline continued. During the past five years the highest number of malaria deaths reported for any one year was four, in 1963. All of these resulted from infections contracted in Africa. Last year, 1965, only two deaths from malaria were reported, both

as a result of infections acquired overseas.

Malaria morbidity also has shown an overall progressive decline. In 1935, about 135,000 cases were reported; in 1942, 60,000 cases; in 1947, 15,000; in 1950, 2,000. The decline then was interrupted temporarily by relapses in servicemen returning from Korea, and in 1952, 7,000 cases were reported. This source of malaria cases ended when the military began the primaquine treatment of returnees from malarious areas while they were enroute home on sea transports. The morbidity decline then was resumed and continued steadily until 1959, in which year only 67 cases were reported. In 1960, the next year, the decline in cases was interrupted again, this time by a relatively small rise, which appears to have peaked in 1964 when 171 cases were reported. This last rise was caused not alone by relapses among returning servicemen, but by an increasingly large number of cases in U. S. citizens who became infected with the disease while abroad and also by cases among foreign visitors to this country. In 1964, for instance, of the 171 cases reported, 119 were in civilians and 52 in servicemen; 41 of the civilian cases were among foreigners. The cases originated in 40 different countries around the world, principally those of Asia and Africa. Three cases were acquired in the United States.

Now as to the situation regarding eradication. During the past five years, the malaria surveillance activities of CDC in cooperation with State health departments have been conducted with such thoroughness that every reported case of the disease has been located and appraised as to type and how, where, and when the transmission occurred. A total of 629 cases was reported for the period, of which 87½ percent (or 551) were accepted as bona-fide malaria. Of these, only 23 were judged to have been acquired in the United States. Seven of the 23 were induced cases—acquired from blood transfusions or by drug addicts from contaminated needles—and three were relapses. Of the remaining 13 cases, 5 were introduced,

that is, they were acquired by mosquito transmission from imported cases and not from any natural foci of infection in this country; and 8 were classed as "cryptic," that is, they represented isolated cases for which the source was obscure. None of the 13 cases was associated with a secondary case insofar as exhaustive epidemiologic investigation could uncover, and there were no time and place relationships among any of the cases which would indicate a common source of infection.

From the foregoing it would appear that all foci of natural infection in the United States have been eradicated and that the country long has been free from endemic malaria. The problem remaining is to prevent its reestablishment, for such must be guarded against as long as the disease prevails in other parts of the world. That problem, I confidently expect, will be dealt with as efficiently in the future as in the past by the exhaustive epidemiologic sleuthing activities of State epidemiologists in collaboration with the Malaria Surveillance Unit of CDC.

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