TVA MOSQUITO CONTROL 1934–1980—EXPERIENCE AND CURRENT PROGRAM TRENDS AND DEVELOPMENTS

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ABSTRACT. The mosquito control program of the Tennessee Valley Authority (TVA) spans a period of nearly 5 decades, beginning in 1933 when TVA was established. Mosquito control is an integral part of the management of TVA reservoirs for flood control, navigation, power production, recreation, fish and wildlife, water quality protection, and shoreline development and protection. The keystone of the mosquito control program is water level management, which is augmented by reservoir preparation and maintenance, aquatic weed control, and other environmental management measures to minimize the need for use of insecticides. Included in the program were major diking-and-dewatering installations and large-scale shoreline filling-and-deepening projects which continue to provide mosquito control benefits. In this review of experience, emphasis is upon evaluations of long-term effectiveness of various components of the program and their continued usefulness. The discussion of current trends and developments includes mosquito control on TVA reservoirs and floodplains, and the recently inaugurated program of demonstrations and technical assistance in the development of community mosquito control programs in the region.

INTRODUCTION

In 1933 the Tennessee Valley Authority (TVA) was created as a Government-owned corporation with responsibility to achieve in the Tennessee River drainage basin and adjoining territory "the maximum amount of flood control . . . the maximum development of the Tennessee River for navigation purposes . . . the maximum generation of hydroelectric power consistent with flood control and navigation . . . agricultural and industrial development . . . reforestation . . . the economic and social well-being of the people . . . and the maximum contribution to national defense" (Tennessee Valley Authority Act, 48 Stat. 58, May 18, 1933).

One of the techniques by which these objectives were to be achieved was the construction of a system of dams and reservoirs to permit integrated management of streamflows for useful purposes. Studies by Carter, LePrince, Griffitts, and others more than twenty years before TVA was established had demonstrated that impoundment of waters in the Southeastern United States vastly increased the potential for anopheline mosquito production; and hence, malaria transmission, unless appropriate control works are planned, designed, and operated (Carter 1944, Carter et al. 1916). As early as December 1922 one of the Valley States, Alabama, had adopted public health regulations governing the impoundment of water.

This earlier documented experience of others provided a good base upon which TVA could proceed promptly with planning for incorporation of malaria control in the design, construction, and operation of its water control projects. However, because of the large number, size, and multipurpose character of the projects involved, the TVA development presented a potential impounded water malaria control problem of unprecedented magnitude and complexity. By November 1933, approximately 6 months after TVA was established, plans for a comprehensive malaria control program had been developed (Unpublished Office Memorandum). The principal thrust of the

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program was the control of mosquito production on TVA reservoirs and associated TVA lands. Although other species were affected, the sole target species was the malaria vector *Anopheles quadrimaculatus*.

The TVA mosquito control program was initiated in the fall of 1934. At that time water resources in the Tennessee River watershed were largely undeveloped. Waterfront lands along the main river and major tributaries were sparsely populated except for a few urban developments, and malaria was a major public health problem. Since that time TVA has completed a multipurpose reservoir system to regulate the main river and major tributaries in the region; extensive development of reservoir shorelines for industrial, recreational, and residential uses has occurred; and no locally transmitted case of malaria associated with TVA reservoirs has been recorded since 1949. As these changes occurred, the mosquito control program was modified accordingly to meet current needs.

MULTIPURPOSE RESERVOIR SYSTEM

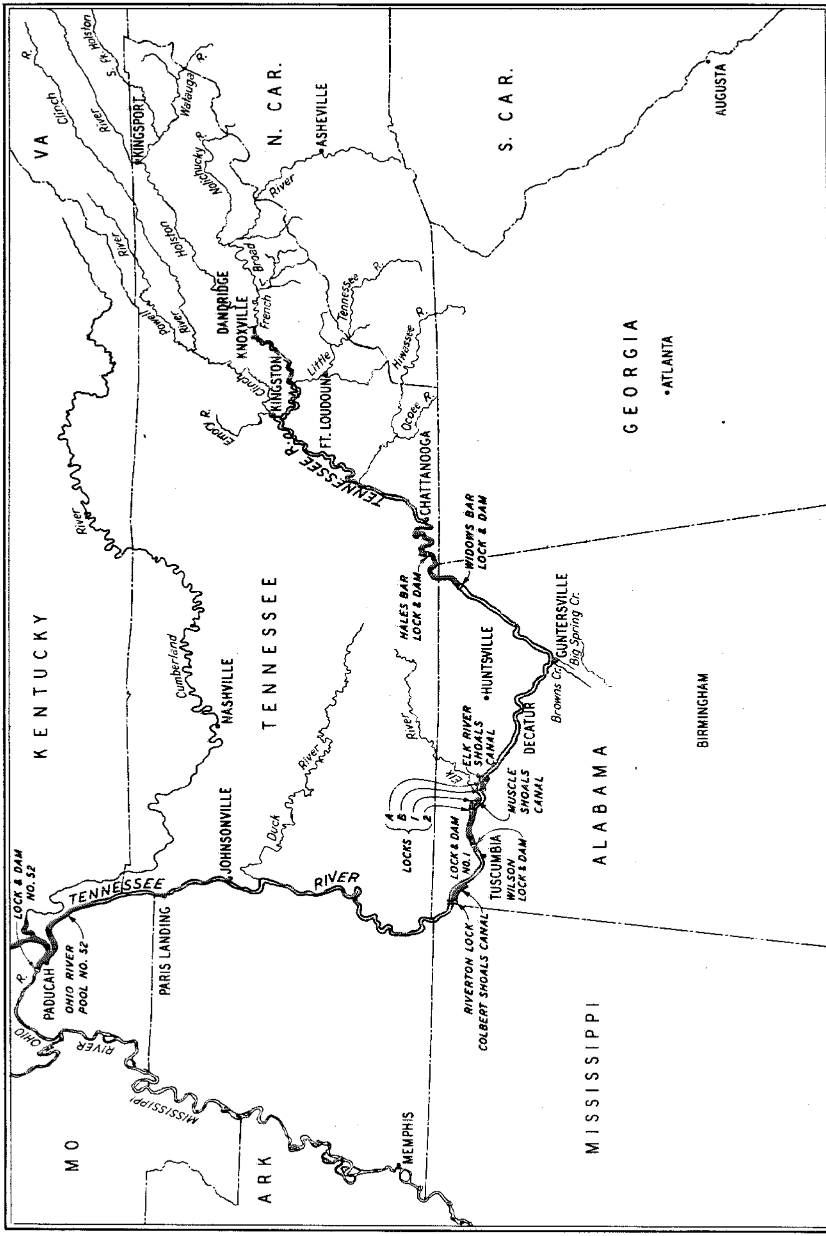
At the time TVA was established, development of the Tennessee River, with two exceptions, was limited to a series of low head dams and canals constructed solely for improvement of navigation (see Figure 1). The two exceptions were the Hales Bar Dam, 33 miles below Chattanooga and Wilson Dam at Muscle Shoals, Alabama. These two projects provided for both generation of hydroelectric power and improvement of navigation. The Hales Bar Dam, constructed by private interests, was completed in 1913. The Wilson Dam, constructed by the War Department, was completed in 1924. The lock for the Wheeler Dam project, located approximately 15 miles above Wilson Dam, was under construction when TVA was organized.

There are now 48 dams in the Tennessee River basin operating as a part of TVA's integrated water control system. Thirty-five are TVA dams, 30 of which are classified as major dams—9 main river projects and 21 tributary projects. The other 5 are classified as minor dams. The TVA reservoir system encompasses more than 11,000 miles of shoreline and 347,000 acres of surrounding lands under TVA ownership or control. The water control system for the Tennessee River developed by TVA is shown in Figure 2. The reservoirs of principal interest for mosquito control are the 9 main river projects. Pertinent data for these projects are given in Table 1. Ten additional small multipurpose nonpower dams have been constructed by TVA as a part of its comprehensive tributary area development program.

The TVA reservoir system is operated for other purposes, as well as for navigation, flood control, and production of hydroelectric power. Such other purposes include providing municipal and industrial water supplies, regulating flows to minimize the effects of industrial and municipal effluents, including thermal discharges, control of mosquitoes and troublesome aquatic vegetation, and controlling flows and water levels for various recreational uses. Despite the obvious complexity of the process involved, TVA has consistently given careful consideration to mosquito control in scheduling seasonal and day-to-day operations of the reservoir system.

SCOPE OF PROGRAM AND SUMMARY OF EXPERIENCE 1934–1973

Prior to development of the Tennessee River by TVA, malaria control experience on major impounded water projects had been limited in general to 2 types of projects, namely (1) hydroelectric projects constructed in regions of steep or rolling topography, and (2) navigation projects in which the pool was confined principally to the natural banks of streams. Satisfactory malaria vector control on these types of projects could usually be



Navigation improvements on the Tennessee River prior to TVA.

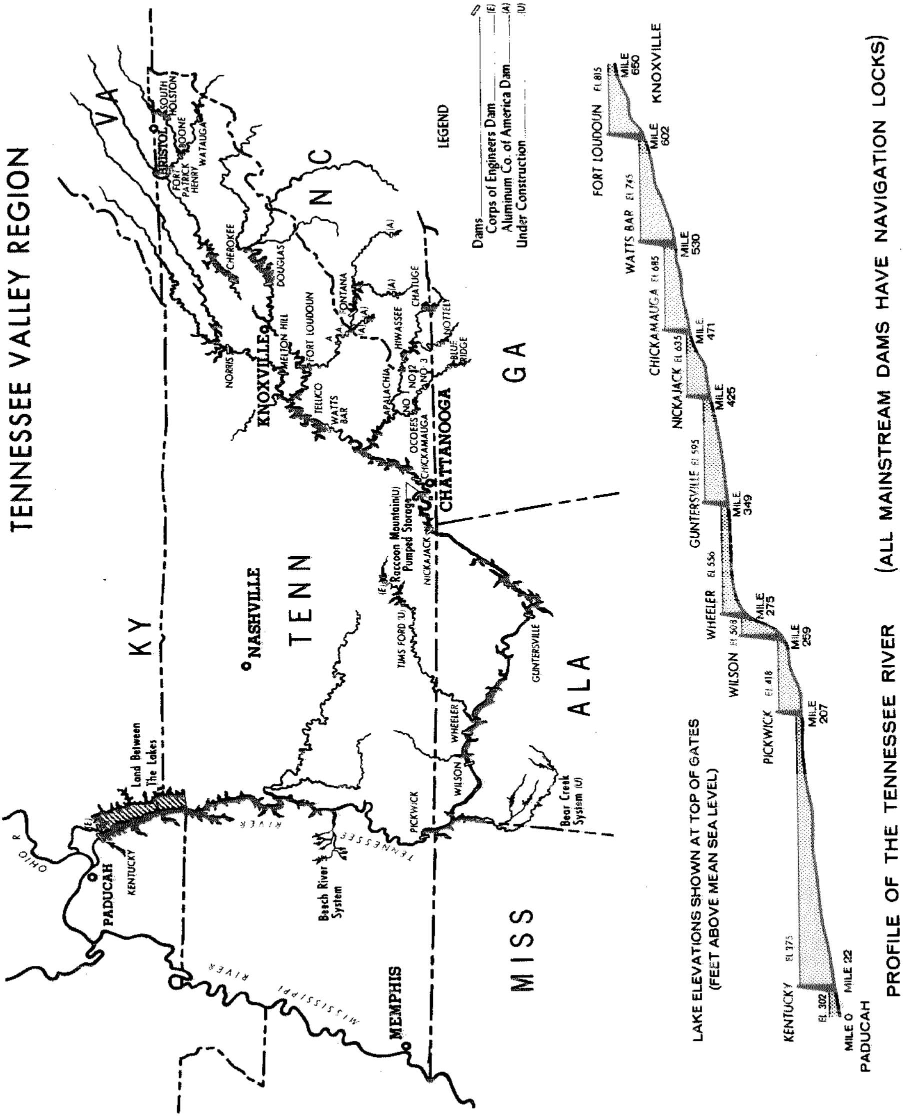

TENNESSEE VALLEY REGION
LEGEND
Dams
Corps of Engineers Dam (E)
Aluminum Co. of America Dam (A)
Under Construction (U)
VA
N C
GA
ALA
MISS
TENN
KY
NASHVILLE
KNOXVILLE
CHATTANOOGA
BRISTOL
PADUCAH
MEMPHIS
SOUTH HOLSTON
BOONE
FORT PATRICK HENRY
WATAUGA
CHEROKEE
DOUGLAS
NORRIS
MELTON HILL
FORT LOUDOUN
FONTANA
TELLICO
WATTS BAR
APALACHIA
HIWASSEE
CHATUGE
NOTTELY
BLUE RIDGE
OCOEES NO 1, NO 2, NO 3
CHICKAMAUGA
NICKAJACK
Raccoon Mountain(U) Pumped Storage
TIMS FORD (U)
GUNTERSVILLE
WHEELER
WILSON
PICKWICK
KENTUCKY
Land Between The Lakes
Bear Creek System (U)
Beech River System
OHIO R
TENNESSEE RIVER
MISSISSIPPI RIVER
LAKE ELEVATIONS SHOWN AT TOP OF GATES
(FEET ABOVE MEAN SEA LEVEL)
FORT LOUDOUN EL 815
WATTS BAR EL 745
CHICKAMAUGA EL 685
NICKAJACK EL 635
GUNTERSVILLE EL 595
WHEELER EL 556
WILSON EL 508
PICKWICK EL 418
KENTUCKY EL 375
EL 302
MILE 650 KNOXVILLE
MILE 602
MILE 530
MILE 471
MILE 425
MILE 349
MILE 275
MILE 259
MILE 207
MILE 22
MILE 0 PADUCAH
PROFILE OF THE TENNESSEE RIVER
(ALL MAINSTREAM DAMS HAVE NAVIGATION LOCKS)

Table 1. Facts about TVA main river reservoirs.

Reservoir	Location of dam above mouth of river (miles)	Closure of dam (date)	Lake elevation (feet above sea level) Normal minmum	Top of gates	Normal maximum	Length of lake (miles)	Length of lake shoreline (miles)	Area of lake (acres)
Kentucky	22.4	8–30–44	354	375	359	184	2,380	160,300
Pickwick Landing	206.7	2–8–38	408	418	414	53	496	43,100
Wilson	259.4	4–14–24	504.5	507.88	507.5	16	154	15,500
Wheeler	274.9	10–3–36	550	556.28	556	74	1,063	67,100
Guntersville	349.0	1–16–39	593	595.44	595	76	949	67,900
Nickajack[1]	424.7	12–14–67	632	635	634	46	192	10,370
Chickamauga	471.0	1–15–40	675	685.44	682.5	59	810	35,400
Watts Bar	529.9	1–1–42	735	745	741	96	771	39,000
Fort Loudoun	602.3	8–2–43	807	815	813	61	360	14,600

[1] Replaced Hales Bar Dam.

achieved by proper clearing of the basin before impoundage and provision for marginal drainage of the basin before impoundage and use of water level control, shoreline maintenance, and larvicides after impoundage.

The TVA program introduced a third type—the multipurpose project—one designed for navigation improvement, hydroelectric development, and flood control. When the TVA reservoir development program was begun in 1934, the application of the then recognized effective reservoir mosquito control measures was begun. At the same time epidemiological, biological, and engineering investigations were initiated to evaluate program effectiveness and to develop program improvements as development of the reservoir program progressed. At the outset, possible conflicts between malaria control procedures and fish and wildlife conservation were recognized and mechanisms established to coordinate the requirements of each (Bishop 1937). Cooperative investigations were conducted in 1939 and 1940 in the Wheeler Wildlife Refuge which had been established in Wheeler Reservoir in August 1938. These investigations provided a sound basis for adjudication of the purported conflicts that had arisen and for integration of future research and operational programs for the mutual benefit of mosquito control and fish and wildlife conservation interests. Provisional plans were made for a cooperative diking and dewatering project which was subsequently constructed in the Wheeler Refuge to provide for mosquito control and waterfowl management (Bishop 1940 and Hinman et al. 1941).

The principal approach to control of malaria associated with TVA reservoirs was control of the production of the malaria vector, *An. quadrimaculatus*. Extensive investigations were conducted over a period of years to develop a comprehensive control program for the TVA reservoir system. During the early years of program development, in some situations, supplementary malaria control measures were required to deal effectively with the malaria problem. These measures included chemotherapy, house mosquito-proofing, and house spraying with DDT residual insecticide or nonpersistent type insecticides. In Kentucky Reservoir for malaria control, land rights were purchased to remove all habitable structures from the 1-mile zone of a large section of the reservoir and use of the land was limited to daytime occupancy during the malaria season.

The TVA malaria program was regularly and extensively documented from the beginning and was the principal basis for a comprehensive manual, "Malaria Control on Impounded Water," published by the U.S. Public Health Service and TVA in 1947.

With the subsidence and virtual disappearance of malaria by 1950, the use of supplementary malaria control measures as listed above was discontinued. However, as a preventive public health measure and because mosquitoes interfere with development and use of reservoir shorelines, malaria mosquito control operations were continued.

While the reservoir mosquito control program has undergone continuing refinement and modification, basic principles and key elements that evolved during the early years of program development continue to provide the basis for planning and application of control measures today. The TVA program relies primarily upon physical and naturalistic methods to control target species of mosquitoes. Every effort is made, within practical economical limits, to provide an environment that is unsuitable for production of significant numbers of mosquitoes and to minimize the need for repetitive maintenance and chemical control operations. Water level management is the keystone of the program, but its effectiveness depends, in large measure, upon proper preimpoundment preparation of the reservoir and in many cases postimpoundage reservoir maintenance operations.

WATER LEVEL MANAGEMENT. For a number of years water level management alone has very satisfactorily controlled anopheline mosquito production on many TVA reservoirs as a result of proper reservoir preparation and the further conditioning of the margins that resulted from routine reservoir water control operations. Supplementary control measures are required regularly, however, on Kentucky, Pickwick, Wilson, Wheeler, Guntersville, Nickajack, and Chickamauga Reservoirs.

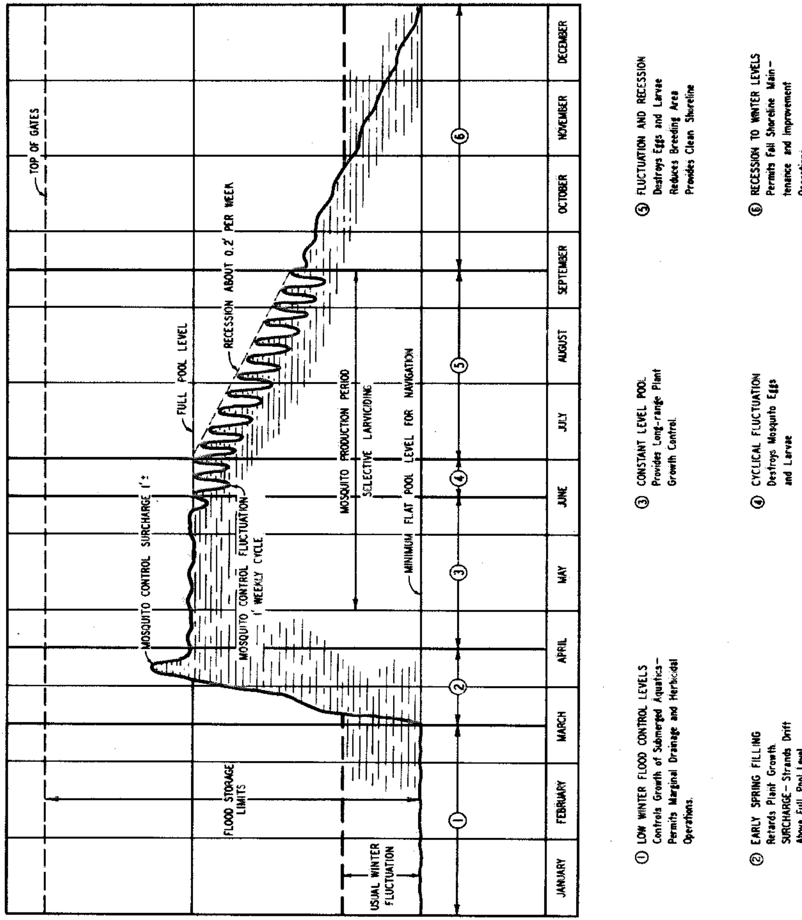
Figure 3 illustrates, in composite form, the mosquito control features of water level management for TVA main river reservoirs. As previously noted, reservoir water levels are not dictated solely by vector control needs. On most reservoirs it is not practicable to combine fluctuation with water level recession which is the desired technique. However, fluctuation or recession alone can be effective in the control of mosquitoes. Basic reservoir management requirements are compatible with the practice of fluctuation combined with recession on 4 main stream reservoirs. On these main river reservoirs, discharges are regulated in the early spring to operate the reservoir for a brief period (1 ft or more above normal) summertime full pool level (spring surcharge), to strand the winter accumulation of drift and flotage. After this surcharge the reservoir is maintained at full pool elevation until the 2nd or 3rd week in June to inhibit growth of marginal vegetation in the reservoir basin. The water level is then fluctuated through a cycle of 1 ft or more each week. Later in the summer, fluctuation, together with a gradual recession of 0.1 to 0.2 ft per week, provides a clean shoreline during the latter part of the season. With each fluctuation cycle, the water level is drawn lower than the preceding low level, and the high point of each cycle is also lower than that of the preceding cycle.

Four of the remaining main river reservoirs are operated on a weekly fluctuation cycle with no recession. Kentucky Reservoir, too large to permit a weekly fluctuation cycle, is operated on a gradual recession only.

Operation of most tributary or storage reservoirs follows a seasonal operating cycle as required for flood control and power operations. These reservoirs are generally held low in winter. Maximum filling in the spring and early summer is followed by a gradual recession during the remainder of the summer and fall months, creating clean shorelines unsuitable for mosquito production.

Operating the main river reservoirs at levels from 2 to 6 ft below full summer pool elevation during the fall and winter

MOSQUITO CONTROL FEATURES OF WATER LEVEL MANAGEMENT ON T VA MAIN RIVER RESERVOIRS



as dictated by TVA's flood control program, also permits marginal drainage and shoreline maintenance where required, and aids in controlling some of the growth of certain submerged or emerged aquatic plants, such as Eurasian watermilfoil, which contribute to mosquito production. However, it should be noted that in the Nickajack and Guntersville Reservoirs where the winter drawdown is limited to 2 ft, it is of lesser or no benefit in the suppression of Eurasian watermilfoil.

RESERVOIR PREPARATION AND MAINTENANCE. On the basis of experience beginning with impoundage of Wheeler Reservoir in 1936, preimpoundage reservoir preparation practices were refined and improved for succeeding projects to best meet the needs for mosquito control and other project purposes. Reservoir preparation specifications covering clearing and drainage requirements were developed for each project to fit the physical features and planned water level operations of the particular reservoir. Provisions for mosquito control include removal of all trees, bushes, and vegetation that would extend above the water surface of maximum drawdown level, special preparation in the fluctuation zone, excavation of drainage ditches to connect depressions in the fluctuation zone with the main reservoir, and final cleanup as may be required in certain shoreline areas just before impoundment (TVA and USPHSA 1947). Preimpoundage preparation of the Kentucky Reservoir impounded in 1944 also included large-scale shoreline topography alteration (filling and deepening) and the establishment of diking and dewatering projects which led to similar improvements in other reservoirs that had been impounded earlier (Bishop and Gartrell 1944).

DIKING AND DEWATERING. Eight diking and dewatering projects, having mosquito control as the primary objective, were constructed in the Kentucky Reservoir prior to impoundage. The projects were designed to separate potential large mosquito breeding areas from the main lake and to keep the areas dewatered during the mosquito breeding season by pumping. The areas were left uncleared. Where highway and railroad embankments traversed a dewatered area, which was the case for 3 of the larger projects, standing timber provided protection of these embankments from wave action thus permitting steeper slopes and savings in yardage and protection costs. These savings were a major consideration in the economic justification of the dewatering projects. The projects were recognized as having a great potential for management of wildlife. It was also recognized that the land inside the dikes would continue to have some value for agricultural use. These benefits began to be realized early in the life of the projects (Gartrell and Johnson 1950).

For the Kentucky Reservoir projects, pumping and maintenance costs were higher than expected from the beginning of operation because of excessive seepage, frequent filling of the areas by reservoir operation, and excessive streamflow in one of the areas where streamflow had not been diverted. Even with excessive pumping, the uncleared areas could not be kept dewatered to the extent needed for satisfactory mosquito control (Gartrell and Kiker 1948). Extensive use of larvicides was required in the diked areas. Pumping eventually was discontinued on all of the projects except the 3 traversed by highway and railroad fills. The other 5 were cleared as needed to operate the areas for mosquito control without pumping. Four were operated as lateral impoundages by gate manipulation without pumping. The diked areas were filled in early spring at high reservoir level, held as a flat pool above the level of the main reservoir, and drawn down in small incremental steps as needed for mosquito control and as reservoir levels permitted. In the 5th project, waterfowl program activities kept the entire project shoreline in cultivation as water levels receded and the project was allowed to fluctuate with the main reservoir. This mode of operation for these 5 projects provided more effective mosquito control at substantially less cost than when pumping was employed.

Four other diking and dewatering projects were developed on reservoirs after they had been impounded—2 in Wheeler Reservoir and 2 in Guntersville. The areas inside the dikes had been cleared as part of preimpoundage reservoir preparation, and waterfowl program activities served to further clean up the areas, provide excellent maintenance of internal drainage systems, and enhance effectiveness of mosquito control achieved by pumping. The larger of the 2 projects in Wheeler Reservoir (Harris-Sweetwater) was constructed as a cooperative project with the U.S. Fish and Wildlife Service and the Alabama Conservation Department, and operated on a shared cost basis. The other Wheeler project (Buckeye-Blackwell) was constructed and operated primarily for mosquito control, but it also benefits the Wheeler Wildlife Refuge of the U.S. Fish and Wildlife Service. The 2 small projects in Guntersville Reservoir were constructed, operated, and maintained by the Alabama Conservation Department primarily to serve wildlife management programs, but incidentally also serve mosquito control interests.

SHORELINE TOPOGRAPHY ALTERATION. The 8 shoreline alteration projects (filling-and-deepening or filling) constructed in Kentucky Reservoir prior to impoundage eliminated over 50 mi of shoreline and 1,625 acres of potential problem mosquito breeding habitats in the upper 3 ft of the normal fluctuation zone. This was the assumed zone of growth invasion. The projects required no maintenance and provided excellent mosquito control. Normal uses of the fill areas, except for row cropping, were permitted. In one project tree planting was done on the filled area to provide protection for a contiguous highway fill. Generally, the uses of the filled areas that evolved were determined by land use patterns of adjoining areas.

Favorable experience with these projects in Kentucky Reservoir led to major applications to mosquito control problem areas in a number of other TVA reservoirs (Wheeler, Guntersville, Nickajack, and Chickamauga) under post-impoundage conditions. The projects were designed for a 2- to 3-ft section depending upon the growth invasion zone in the reservoir.

The shoreline alteration projects contributed substantially to the effectiveness and overall economy of the TVA mosquito control program. Problems experienced have been related to reservoir aquatic growth problems which involve areas below the normal growth invasion zone. Beginning in 1966, the heavy infestation of Eurasian watermilfoil largely negated the mosquito control benefits of the topography alteration projects in the Guntersville and Nickajack Reservoirs.

POST-IMPOUNDMENT RESERVOIR MAINTENANCE

Reservoir maintenance operations for mosquito control consist principally of annual marginal growth control, drainage maintenance, and control of objectionable aquatic plants.

MARGINAL GROWTH CONTROL. In the early years of operation of TVA reservoirs, extensive operations were carried out each fall when water elevations were low. Certain plants which invade the fluctuation zone in summer were controlled by cutting or application of herbicides; however, herbicidal operations were a relatively small part of the total control operation. Cumulative beneficial effects of these operations and water level management served to limit the zone or marginal vegetation invasion to 1.5 to 2 ft below normal pool elevation. Concurrently, continuing studies served to limit control operations to problem areas where they could be justified by expected mosquito control benefits. Annual growth control operations were reduced from a peak of 33,400 acres in the fall of 1942, even before Kentucky Reservoir was impounded, to approximately 6,300 acres in the fall of 1950. The plant species of principal importance in the shoreline maintenance operations are black willow (*Salix nigra* Marsh) and buttonbush (*Cephalanthus occidentalis* L.). After careful analysis of operating experience, field observations of shoreline conditions, and review with the State health departments concerned, decision was made in 1951 to discontinue growth control operations in the upper one-half foot of the normal fluctuation zone. This decision was based on the fact that little benefit could be derived from the cutting operation in this zone due to resprouting, which occurs in the early spring before reservoirs are completely filled, and the relatively small proportion of time that the water is in this zone under usual water level schedules. It was recognized that this change would result in increased larvicidal requirements the next spring, but would be more than offset by savings in shoreline maintenance expense. Further modifications in the growth control operation were made in ensuing years. The period 1951–1972 (22 years) the annual acreage involved ranged from approximately 5,700 acres (1961) to 719 acres (1955), with an average of 2,625 acres.

MARGINAL DRAINAGE MAINTENANCE. Maintenance of marginal drainage systems is necessary to assure maximum effectiveness of water level fluctuation for mosquito control. During the early years of operation of TVA reservoirs, drainage maintenance was performed principally by handtool methods, which subsequently were largely replaced by dynamiting and mechanical methods. Annual drainage maintenance peaked in fiscal year 1945 when operations were performed on 156 mi. of ditches. During the period 1950–1973, drainage ditch maintenance ranged from 102 mi. in fiscal year 1953 to 12 mi. in fiscal year 1973, averaging 31 mi.

AQUATIC PLANT CONTROL. The TVA reservoirs were rapidly colonized by a variety of aquatic plants with varying potential effects on mosquito production. However, prior to 1960 when Eurasian watermilfoil was first identified in the Tennessee River system, only 2 species of aquatic plants with high mosquito production potential had colonized TVA lakes to the extent to justify continuing control efforts as part of the mosquito control program. The two species were lotus (*Nelumbo lutea pentapetala*) representative of the floating leaf type, and alligatorweed (*Alternanthera philoxeroides*) representative of the floating mat type of mosquito breeding habitat. While operations for control of these plants were important, they were never more than a relatively small part of the total mosquito control program.

Eurasian watermilfoil (*Myriophyllum spicatum* L.) proved to be the most troublesome aquatic weed to become established in TVA reservoirs. It is a rooted, submersed aquatic plant that can grow in water as deep as sufficient light for growth will penetrate (up to 15 ft.). After breaking the water surface, it forms a dense floating mat which provides an excellent habitat for mosquito production. When first identified in the Tennessee River system in 1960, its known distribution was confined to one large embayment and several small areas in the lower part of Watts Bar Reservoir. Despite control efforts (application of 2, 4-D formulations) initiated in 1961, by 1965 it had become well established in 3 downstream reservoirs (Chickamauga, Nickajack, and Guntersville) and rooted colonies were present in two more (Wheeler and Wilson). In addition, Melton Hill, an upstream reservoir on the Clinch River tributary was found to be infested. By the end of 1968 there were more than 25,000 acres of watermilfoil in seven TVA reservoirs, or 10% of their total surface area. Aerial photographs of Guntersville Reservoir taken in August 1968 showed watermilfoil mats covering 14,000 acres of water surface in this one reservoir (Unpublished Environmental Impact Statement, 1972).

Mosquito control was the primary concern when watermilfoil control operations were initiated. It soon became evident, however, that other interests were involved because the growth and spread of watermilfoil posed a serious threat to full utilization of the reservoirs affected. Heavy infestations disrupted water recreation and related land uses resulting in serious economic impacts on boat docks, marinas, lakeside motels, and restaurants. Such infestations also made shoreline residences less desirable, interfered with boating, skiing, fishing, and other water sports. In some situations public, private, and industrial water intakes were threatened. Because of the broad base of interests and magnitude of the operations involved, watermilfoil control was separated from the mosquito control program for program planning and budgetary purposes. However, both programs were directed by the same technical staff.

Extensive herbicidal treatment programs (in addition to routine applications) were completed in 1966 and 1969 in an effort to establish a level of control that could be maintained and which would reduce the impact of watermilfoil on all interests to tolerable levels. In 1966, 880 tons of 20% 2,4-dichlorophenoxyacetic acid (2,4-D) granular herbicide was applied by helicopter to 8,000 acres of watermilfoil in the seven infested reservoirs. During April and June of 1969, over 18,000 surface acres of Nickajack and Guntersville Reservoirs were treated by helicopter with about 170,000 gallons of dimethylamine (DMA) salt of 2,4-D. Substantial reductions in watermilfoil infestation were achieved in all reservoirs treated. For example, surveys in the fall of 1971 showed that infestation in the Guntersville Reservoir had been reduced to about 3,000 acres requiring control. For comparison in the spring of 1969, there was an estimated total of 19,000 acres of watermilfoil in Guntersville Reservoir.

LARVICIDAL OPERATIONS. Although TVA placed principal reliance for mosquito control upon biological or naturalistic control measures, extensive use was made of supplementary measures in the form of chemical larviciding. TVA larviciding practices underwent progressive changes through the years to reflect changing reservoir conditions, control requirements, and technological advances in chemical insecticides and techniques for application. During the 10-year period, 1933–1943, developments in larviciding techniques consisted principally of improvements in equipment for hand and boat application of kerosene and black oil larvicidal mixtures and airplane applications of paris green dust. As DDT and other more effective insecticides became available, TVA began testing the more promising ones and developing satisfactory equipment for their application. Airplane application of DDT was first carried out in 1943 by TVA in cooperation with the U.S. Department of Agriculture. Because of the demonstrated effectiveness of DDT at low rates of application (0.05–0.10 lb. per acre) and resulting economy of airplane distribution, DDT was adopted as the larvicide of choice for TVA mosquito control operations. The use of paris green dust for airplane applications was completely phased out by 1946 and boat applications of kerosene and black oil mixtures were discontinued in 1949. Initially, fixed wing aircraft equipped to produce an aerosol or mist type spray were used. Later, spray equipment was devised and replaced the aerosol generating equipment. In the early fifties, use of fixed wing aircraft was discontinued and helicopters already used by TVA for transmission line patrol were adapted for joint use for larvicidal applications. A change from DDT larvicide to temephos-Abate® larvicide for TVA mosquito control operations was made in 1967.

Through the years there was a general downward trend in larvicidal treatment requirements. A notable exception, however, was fiscal year 1969 when the all-time peak use occurred. In that year larvicidal treatment totaled more than 103,000 acres, due primarily to the heavy milfoil infestation prevailing at the time in Guntersville and Nickajack Reservoirs. The previous peak was 98,000 treatment acres in 1938. For the 12-year period beginning in 1937, annual treatment averaged approximately 70,000 acres, with a minimum annual treatment of approximately 46,000 acres. For the 20-year period 1949–1968 inclusive, the average was 31,200 acres, with a maximum 47,400 acres and minimum of 19,700 acres.

FLOODWATER MOSQUITOES. Measures to control the target species, *An. quadrimaculatus*, incidentally are effective in controlling other reservoir species. Notable exceptions are the several species of mosquitoes described as transient pool or floodwater species as well as some other permanent pool species. In 1956 a limited program was initiated to expand the TVA reservoir mosquito control program to include control of these other species "when their production in TVA waters constitutes a nuisance to sizable population groups or hazard to the public health" (Unpublished TVA Code). Mosquito abatement operations for species other than *An. quadrimaculatus* were to be initiated in a specific reservoir area only after (1) a thorough entomological investigation reveals that mosquitoes are being or will be produced in TVA water in significant numbers, that TVA waters are the dominant source of mosquito production in the area, and that the mosquitoes constitute a nuisance of significant proportions to sizable population groups or hazard to public health and well-being; and (2) it is determined that mosquito control is economically feasible. From 1956 through 1973, the program was largely experimental in nature and field operation costs for control of mosquitoes other than *An. quadrimaculatus* averaged less than 1% of mosquito control costs. However, the control experience gained, plus collateral research and investigation, pointed to the need and provided sound bases for increased emphasis upon other species of mosquitoes in addition to *An. quadrimaculatus* in TVA's total mosquito control effort (Breeland et al. 1961; Breeland and Pickard 1962, 1963; Moore and Breeland 1967; Cooney and Pickard 1974). This increased emphasis was reflected in a major program reorientation and revision in 1974.

PRESENT PROGRAM AND DEVELOPMENTS SINCE 1974

The overall objective of TVA's mosquito control program as defined in the 1974 revision is to safeguard the health and well-being of the Valley population affected by the production of mosquitoes on TVA lands and waters. The goal is to suppress mosquito populations at critical areas on TVA lands and waters below a level at which disease transmission and human annoyance occur. Control operations are limited to areas designated as critical on the basis of appropriate criteria.

Critical areas are defined as those locations requiring scheduled surveillance and control activities due to their particular characteristics relating to mosquito breeding potential. Criteria used in analyzing the critical nature of an area were: (1) sites where aggregations of people occur within mosquito flight range of a reservoir; (2) areas from which complaints originate; (3) areas in which control operations were required the preceding year; and (4) those areas which during the preceding year developed mosquito breeding potential. The application of these criteria resulted in reductions in the amount of program effort directed primarily for control of *An. quadrimaculatus* and commensurate increases in efforts directed to the control of other species. Foremost among this group is the class of mosquitoes described as transient pool or floodwater species. These species are of concern primarily because of their very pestiferous nature prompting numerous complaints and requests for control, and their potential for the transmission of encephalitis viruses and canine filariasis. *An. quadrimaculatus* and several companion species breeding in the permanent bodies of water (TVA reservoirs) are also major pests in some areas. In addition to the two large groups of mosquitoes receiving greatest attention (permanent pool and floodwater species), the domesticated or container breeding types attaining a level of prominence in the control program because of the increase in scope of TVA power plant construction activities which produce an abundance of temporary artificial breeding sites. It is this group of mosquitoes that elsewhere have most often been associated with disease outbreaks. Table 2 presents a list of the common target species occurring in the Tennessee Valley region which are of concern to TVA, and an indication of their pest or vector status.

In addition to the control operations performed on TVA lands and water, TVA provides technical assistance to communities, municipalities, industries, state and local health agencies, and other concerned groups in the establishment of mosquito abatement districts. Assistance of this nature enables TVA to promote a comprehensive program of mosquito control in the Valley.

The TVA mosquito control program consists of two major categories; operations (reservoir preimpoundment and postimpoundment activities and control operations for construction projects and other TVA facilities) and support studies which are discussed in following sections.

RESERVOIR PREIMPOUNDMENT ACTIVITIES. Through the years TVA reservoir preimpoundment practices as previously described have remained unchanged except for appropriate modifications for adaptation to individual reservoir conditions. Currently under study, however, is a proposal to leave large tracts of timber uncleared in the Columbia Reservoir project now under construction on the

Table 2. TVA mosquito control program—principal target species

Breeding habitat	Target species	Pest status	Vector Status Actual and probable
Reservoir impoundment	*An. quadrimaculatus*	usually	Malaria, canine filariasis
	An. punctipennis	usually	Canine filariasis
	Culex erraticus	usually	
Reservoir flood zone	*Aedes atlanticus*	infrequently	California encephalitis
	Ae. sticticus	constantly	Canine filariasis
	Ae. trivittatus	infrequently	California encephalitis
	Ae. vexans	constantly	Canine filariasis, Eastern equine encephalitis
	Psorophora ciliata		
	Ps. columbiae	constantly	Venezuelan equine encephalitis, St. Louis encephalitis
	Ps. cyanescens	constantly	
	Ps. ferox	constantly	Canine filariasis,
	Ps. varipes	constantly	
Artificial containers	*Cx. pipiens-quinquefasciatus*	constantly	Canine filariasis, St. Louis encephalitis
	Cx. restuans	usually	Canine filariasis, Western equine encephalitis
	Ae. aegypti	infrequently	Yellow fever, Canine filariasis, dengue
	Ae. triseriatus	constantly	California encephalitis, Canine filariasis
Transient pool	*Culiseta inornata*	infrequently	Western equine encephalitis, California encephalitis
Saline ponds	*Ae. sollicitans*	infrequently	Eastern equine encephalitis, Canine filariasis, Venezuelan equine encephalitis, Cache Valley virus

Duck River in middle Tennessee. This would represent a significant departure from traditional TVA reservoir clearing practices. The purpose of leaving the uncleared tracts is to enhance the fishery resources of the project. The original proposal involved approximately 1,600 acres in the 12,400-acre lake to be left uncleared to serve as fish attractors and shelters.

The study of the proposal now in progress includes consideration of the impact the action would have on mosquito control. The study is expected to result in a plan substantially less in scope than the proposal, but which still will provide desired attractors and fish shelters without undue impacts on mosquito control and other interests involved. An amendment to the Tennessee Impounded Water Act in 1975 specifically permits standing timber in reservoirs upon approval by the Wildlife Resources Commission. The Columbia Reservoir proposal evolved from the generally favorable experience from much smaller scale programs in other reservoirs carried out under special exceptions agreed to by state mosquito control authorities to allow standing timber to remain in specified reservoir basin areas as an enhancement to TVA and state fishery programs. Areas designated for consideration were evaluated by TVA mosquito control staff, and subsequent approval was dependent on a site-specific analysis in relation to the critical area criteria and the potential for mosquito breeding. These exceptions were made with the realization that additional supplemental mosquito control might be required. However, the potential need for remedial control was lessened by critical selection of sites, giving due consideration to site topography and the morphology of standing timber. For mosquito control interests, long narrow bands or small clumps of standing timber in deep water are more desirable than large blocks in shallow water particularly if open water occurs on all sides. Wind and wave action through standing timber plots reduces flotage entrapment and creates an environment that is undesirable for mosquito breeding; this effect is minimized in large plots where standing timber extends from shoreline to shoreline and especially where water is shallow allowing an abundance of undergrowth to penetrate the water surface.

Extensive data are available on the tolerance of timber species in the Tennessee Valley region to flooding (TVA and USPHS 1947, Hall and Smith 1955). In contrast, only limited data are available on the effects on mosquito production of leaving standing timber in reservoirs in the region. Studies are being conducted to compare the level of mosquito breeding in timbered embayments with that in sites cleared according to standard procedures. Preliminary data indicate that, at least during the first year of impoundment, mosquito production is significantly greater in the uncleared areas.

RESERVOIR POSTIMPOUNDMENT OPERATIONS. Water Level Management—Water level management continues to be the basic mosquito control measure applied in all TVA reservoirs. All other control measures play a supportive role, by either contributing to the effectiveness of water level management or by serving as a supplement as may be required to achieve the desired level of control. There have been no substantive changes in recent years in rule curve water level management schedules (operating guidelines) for reservoirs in the TVA system. The schedules continue to reflect manipulations for mosquito control, but it is important to note that mosquito control features of the schedules are directed primarily to the control of permanent pool mosquitoes, specifically *An. quadrimaculatus*. In some cases certain of the features may increase the potential for production of other species; in some situations the spring surcharge may result in heavy production of floodwater species.

Water level management provides satisfactory control of permanent pool species on most of the TVA reservoirs. Only the 7 lower Tennessee River Reservoirs (Kentucky, Pickwick, Wilson, Wheeler, Guntersville, Nickajack, and Chickamauga) regularly require application of supplementary mosquito control measures. However, to provide mosquito control for Land Between The Lakes (LBL), a national outdoor recreation area, TVA applies supplementary mosquito control measures on a portion of the Barkley Reservoir (Cumberland River) bordering LBL. (LBL is located between the Kentucky and Barkley Reservoirs and is bordered on the north end by the open navigation canal connecting the two reservoirs.)

DIKING AND DEWATERING PROJECT. The diking-dewatering projects provide mosquito control by water level management either by pumping or by gate manipulation without pumping. Although the projects were originally constructed and operated primarily for mosquito control, the bulk of the benefits derived from the projects accrued to wildlife management programs. A review of the 8 projects in Kentucky Reservoir and 2 projects in Wheeler Reservoir led to a conclusion that the full potential of the projects for support of wildlife interest still were not being realized. It was concluded also that better utilization for wildlife could be achieved without any loss of benefits to mosquito control (and highway and railroad fill protection where these interests are involved). These considerations led to assigning responsibility for operation and maintenance of the dewatering projects to TVA's organization responsible for wildlife development. This organization is now a part of TVA's Office of Natural Resources which also includes the organization responsible for mosquito and aquatic weed control. Responsibility for operation of the 2 Wheeler projects (Harris-Sweetwater and Buckeye-Blackwell) was transferred in fiscal year 1975. The West Sandy project was transferred in 1978 and the remaining seven projects in Kentucky Reservoir in fiscal year 1980. Present plans include resumption of pumping and operating on a dewatering mode in the Duck River, Perryville, East Perryville, Busseltown, and Gumdale projects, beginning with the Duck River project in 1980.

MECHANICAL CONTROL OF MARGINAL VEGETATION. Vegetative growth control increases the effectiveness of water level management as a mosquito control measure and in itself is a direct measure through the elimination of larval habitat. The 2 woody plants in TVA reservoirs of most concern to mosquito control are buttonbush (*Cephalanthus occidentalis*) and willow (*Salix* sp.). These plants generally invade no deeper than about 2 ft below normal full pool elevation. Left unchecked they often grow so tall and produce such dense canopy that application of larvicide by helicopter becomes ineffective and hazardous.

Woody plants and accompanying understory vegetation are controlled by mechanical mowing with farm type tractors mounted with rotary mowers. Mowing takes place annually, biannually, or triannually and is conducted routinely only on the lower mainstream reservoirs. Frequency depends upon the rate or regrowth and must be such that the rotary mowers can handle the growth that has occurred since the previous mowing. The shoreline growth control program is reviewed annually on an area-by-area basis according to the following criteria: (1) mosquito population indices per station over the last 3 years, (2) degree of human habitation and public use in close proximity of the area, (3) knowledge of mosquito complaints in the area or other problems obtained from TVA entomological records, (4) knowledge of the breeding habitat, (5) esthetic appeal related to providing a clean water surface in proximity to or bordering on public use areas, and (6) areas where growth may impede flow in ditches.

Growth removal operations for all reservoirs have been reduced to an average of less than 1,000 acres per year. For example, for fiscal year 1973 the total acreage was approximately 2,600, which was reduced to 750 for fiscal year 1978. Further reductions are being projected on the basis of preliminary findings from long range studies being conducted on mosquito production in relation to natural vegetation succession of areas dominated by buttonbush and advances being made in chemical methods for mosquito control in heavily canopied breeding habitats.

DRAINAGE MAINTENANCE. Marginal drainage maintenance is a necessity for achieving maximum benefits of a good water level management program for mosquito control. Drainage systems constructed during the preimpoundment phase of reservoir preparation may function properly for years, but eventually most ditches require some degree of maintenance. Systems receiving routine periodic maintenance will continue to function indefinitely for little expense while neglected systems fail quickly and are expensive to restore.

Drainage surveys are conducted routinely to obtain data for annual marginal drainage programs. New ditches are often required in addition to maintenance requirements. Over the past few years an increasing beaver (*Castor canadensis*) population over the lower portion of the Valley has reduced effectiveness of many drainage systems by construction of dams within the ditches. It is practically a futile effort to remove the dam and not remove the beaver colony through a trapping program. Dams removed one day can be restored in a very short period of time. The construction and maintenance of marginal drainage ditches along TVA shorelines are performed utilizing mechanical equipment such as backhoe or dragline, dynamite, herbicide, and hand labor. Dynamite ditching is a method used extensively in the past and one used today where possible. The use of dynamite near developed lake properties often results in numerous complaints and claims for minor damages which may or may not have been caused by the detonation. Nevertheless, dynamite is an economical method of maintaining an existing drainage system and of establishing a new one. The work is usually performed during late fall or early spring when ground conditions are most suitable. A major advantage of dynamite ditching is the lack of spoil material requiring proper disposal.

Machine ditching with a backhoe is an economical substitute for dynamite ditching. The use of a backhoe provides wide latitude in selecting the width and depth of ditching. Another advantage is that the equipment can be used in the wintertime when the ground is frozen. Special accessories such as dual wheels give the equipment considerable versatility in negotiating moist soils.

Hand labor is used sparingly due to the high cost. It is usually limited to short segments where dynamite or machine maintenance is not practical.

Herbicide is used in the ditch maintenance program to control heavy growth of aquatic weeds that reduce the efficiency of the drainage systems. The most troublesome plant in this respect is parrotfeather (*Myriophyllum brasiliense*) which is controlled with applications of 2,4-D. One application per year is usually sufficient to keep the growth in check.

MOSQUITO POPULATION MONITORING. Population data are obtained on the density and distribution of 2 permanent pool breeding species of *Anopheles* and at least 1 species of *Culex*. *An. quadrimaculatus*, *An. punctipennis*, and *Cx. erraticus* are the three dominant pest species breeding in TVA impoundments and are monitored on primarily a weekly frequency at about 82 established stations in as many critical areas. Of the approximately 16,267 mosquitoes collected during 1,114 inspections in fiscal year 1979, 83.7% were *An. quadrimaculatus*, 12.5% *An. puntipennis*, and 2.9% *Cx. erraticus* (see Table 3).

Adult activity is monitored by inspection of standardized diurnal resting stations. This standardization of stations, which was accomplished as part of the program revision in 1974, allows not only a comparison of a station with itself during a season or over a period of years, but it also permits interstation comparison on

Table 3. Adult mosquitoes collected from diurnal resting stations—1979.

Species	No. specimens
Anopheles barberi	3
An. punctipennis	2,037
An. quadrimaculatus	13,616
Aedes atlanticus	2
Ae. sticticus	1
Ae. triseriatus	1
Ae. trivittatus	3
Ae. vexans	4
Culex erraticus	468
Cx. pipiens-quinquefasciatus	13
Cx. restuans	56
Cx. territans	59
Psorophora ciliata	1
Ps. ferox	3
Total	16,267

Number stations	82
Number inspections	1,114
Average number per inspection	14.6
Number species	14

a Valley-wide basis. It is recognized, however, that it is unlikely that a standardized station will be equally attractive to all mosquito species of interest. Thus, results with regard to relative numbers may be biased toward a single species. For the TVA standardized station, the bias probably favors *An. quadrimaculatus*.

A standard station consists of a cluster of three 1-foot wooden cubes (boxes) open at one end to allow entrance and exit of adult mosquitoes. Each box in the cluster, which is attached to a tree in a shaded wooded area of the breeding habitat, is inspected usually on a weekly frequency and the number and kinds of adult mosquitoes present recorded. If adults are observed, a larval inspection utilizing the standard dipper technique is conducted in the most probable breeding habitat. When significant numbers of larval mosquitoes are recorded at a station, the information is reported by telephone to control headquarters at Muscle Shoals, Alabama.

A larval density of 0.25 or better per dip is considered significant and is used as the basis for prescribing larvicide applications; larval densities above this level can be expected to produce adult mosquito complaints. Adulticiding is conducted primarily in response to complaints and in areas where adult mosquito populations are excessive and expected to result in complaints. TVA operates a toll-free action line available for the public to receive answers to questions, comment on a proposed TVA action, or to have problems or complaints investigated. Most mosquito complaints are received through the Citizen Action Line.

Several species of floodwater types of mosquitoes are problems in a number of critical areas and their relative density and distribution are determined from an analysis of mosquito ova extracted from soil samples which are collected in oviposition zones of reservoir floodplains. *Ae. vexans, Ae. sticticus*, and *Psorophora ferox* are the primary floodwater species, occasionally accompanied by *Ae. atlanticus, Ae. trivittatus, Ps. varipes*, and *Ps. cyanescens*. Approximately 800 soil samples, 6 inches square by 1 inch thick, are collected and processed annually. The data obtained from these samples, particularly that portion related to ground contour elevation location of the ova within the flood plain, are essential in anticipating flooding of the habitat with the resultant production of mosquitoes and necessity for control.

LARVAL CONTROL. The need for larvicidal applications for control of permanent pool types of mosquitoes is based on the species, adult density, distribution of larval specimens, their proximity to critical areas, and current and forecast water levels. Larviciding consists of aerial applications of temephos-Abate® insecticide dispersed by helicopter at rates between .004 and .012 lb. of active ingredient per acre depending on the species present. Concentrated temephos (43% technical grade) is mixed with an aromatic petroleum solvent (methylated naphthalene) at the ratio of 1:37 which produces a 1.13 percent finished spray to be applied at the rate of 4.83 to 14.49 oz. per acre. In fiscal year 1979 approximately 24,800 acres were treated by helicopter applications of Abate. Over 60% (15,114 acres) of the acres treated were in Guntersville Reservoir.

Planning for larvicidal control for floodwater species is based on data obtained from the extraction of mosquito ova from soil samples collected during the winter months. Larvicidal control plans are formulated for the following spring. As reservoir lake levels reach the elevation at which eggs were recorded, dipper sampling is conducted to verify egg hatch and larval production. If significant numbers of mosquito larvae are present (0.25 or greater per dip) 10% granular formulations of chlorpyrifos-Dursban® or Abate are applied by helicopter at label rates. Granular formulations are required to penetrate the foliar canopy which covers the majority of the breeding habitat in the floodplain areas. Dursban granules are applied at the rate of .05 lb. of ai per acre while Abate granules are applied at the rate of .10 lb. of ai per acre utilizing a helicopter-mounted Simplex aerial seeder. In smaller woodland or pastureland pools, granular Dursban is applied more economically from the ground using back-pack type power blowers. In fiscal year 1979, larvicide was applied to 303 acres for floodwater mosquito control.

ADULT CONTROL. Continued refinement of the program as revised in 1974 recognized that in spite of effective operation of the above described mosquito control activities, adult mosquitoes were still a problem in numerous areas as indicated by frequent complaintts. Consequently, a program was established to conduct adulticiding primarily in response to complaints. When adulticiding is required, malathion is applied as a ULV concentrate from truck-mounted cold aersol generators (Leco® and London Aire®) equipped with positive volume control systems. Malathion is released at the rate of 0.5 oz. per linear mile traveled. In fiscal year 1979 adulticiding was conducted in areas totaling 10,021 acres. Adulticiding is an effective method of providing local temporary relief in situations which cannot be handled by other means. However, it is supplemental in the TVA program to all other operations and is employed only as a measure of last resort.

WEED CONTROL. TVA's principal herbicidal operation for aquatic weed control is directed at control of Eurasian watermilfoil. As previously discussed, this program provides large scale benefits for mosquito control and the amount of mosquito breeding associated with Eurasian watermilfoil in critical areas is given consideration in arriving at the treatment priorities. Chemical control of this aquatic plant is accomplished by applying the DMA salt of 2,4-D at the rate of 2 ppm. Application is made using boom sprayers and submersed trailing hoses from conventional outboard motor-powered boats and airboats. In fiscal year 1979, 3,630 acres were treated at an average cost of approximately $100 per acre. Restrictions on winter drawdown in the Guntersville and Nickajack Reservoirs seriously limit the effectiveness of the control program. Watermilfoil persists as a particularly severe problem in these reservoirs and is a major factor in the extensive larvicidal operations required for mosquito control. As a part of the mosquito control program, herbicidal operations are used on a limited basis to unclog drainage ditches. They are used also to control colonies of certain types of aquatic plants (American lotus, parrot-feather, pondweeds) where they provide mosquito breeding habitats in limited areas of some reservoirs.

TVA CONSTRUCTION PROJECTS AND FACILITIES

The mosquito control staff provides on call service for investigating mosquito problems and providing for control at TVA major construction projects and facilities located throughout the TVA region. In situations where continuous breeding occurs or where frequent broods are produced such as small potholes, sumps and pits at construction sites, and other artificial breeding sites, Dursban 10CR granules are applied according to the label.

In rare instances where mosquito breeding occurs in sensitive environments such as package waste treatment plants, pyrethrin Tossits® are effectively used without causing damage to the degradation organisms.

SUPPORT STUDIES. The support studies portion of the program provides recommendations on control methods and procedures based on the results of controlled experiments. Studies include an investigation of both long- and short-range methods of control involving the development of pesticide and nonpesticide techniques. The results of completed studies are applied directly to operational revisions and refinements of control activities. A brief summary of current studies follows.

TREE PLANTING FOR MOSQUITO CONTROL. Studies are continuing on the evaluation of planned stocking of baldcypress trees (*Taxodium distichum*) in reservoir embayments as a means of controlling production of anopheline species through habitat conversion. Preliminary results indicate that the shading effect produced by the trees eliminated most of the understory vegetation thereby creating an environment unsuitable for mosquito breeding. Observations made by Smith et al. (1969) of tree plantings made in 1935 and 1936 for mosquito control demonstrated that mosquito production in mature stands of baldcypress was less than in open vegetated embayments where repetitive maintenance was required to suppress mosquito populations. Furthermore, of the culicine type of mosquitoes which were present in the tree plots, 98% were *Cx. territans* which are not known to bite man. Similar studies are in progress to evaluate tree planting for control of mosquitoes in floodplain areas. Sycamore (*Platanus occidentalis*) trees planted in a heavy mosquito infested area of Hiwassee Reservoir are being evaluated as a mosquito control agent. Breeland and Pickard (1962) determined that as invading bottomland hardwood trees through natural succession became dominant in what was originally an open, grassland pasture type habitat, the composition of the floodwater mosquito fauna changed. The several aggressive and vicious biting migratory species, which characteristically inhabit open, grassland vegetation communities, were gradually replaced by less pestiferous species which remain near their woodland breeding grounds.

SOIL TILLAGE FOR FLOODWATER MOSQUITO CONTROL. Soil tillage involving mechanical plowing followed by disking is being evaluated as a nonchemical cultural method of controlling mosquito production in grassland type depressions and floodplains. Extensive field tests have produced preliminary control percentages ranging from 73 to 100% with 90 the average for all test plots. Supporting laboratory tests have demonstrated that the control effect is produced as a result of egg displacement downward into the soil with subsequent coverage by varying depths of soil. Larvae which emerge from eclosed eggs are trapped in the soil and do not reach the surface. Soil coverage of 0.5 in. or more completely controls larval production.

SUSCEPTIBILITY OF TARGET MOSQUITOES TO INSECTICIDES AND EFFICACY BIOASSAYS. Populations of anophelines and other species of lake breeding mosquitoes are monitored continuously for their susceptibility to operationally applied larvicides. Susceptibility is monitored using the standard WHO test so that early detection of resistance can be achieved. Over 20 species of mosquitoes in the United States are resistant to various insecticides and it is imperative that changes in susceptibility be documented so that large sums of money are not expended in using ineffective chemicals. Concurrently with the above tests, field bioassays of operationally applied larvicides are conducted to ensure quality and efficacy of treatments and to ensure minimal effects on nontarget organisms.

In support of these bioassays, laboratory analyses of water samples are performed to ensure that undesirable residues do not exist.

CHEMICAL CONTROL TECHNIQUE DEVELOPMENT. Because of the rapid development of resistance in mosquitoes and the limited availability of suitable alternative insecticides caused by EPA use restrictions, TVA maintains a limited program to evalute candidate compounds and to develop systems and techniques of delivery so that, on short notice, a new compound or delivery technique can be rapidly assimilated into the control program. Present studies include an evaluation of water mixed Abate spray formulations when compared with the standard petroleum solvent mixtures. Associated with these evaluations is an appraisal of the storage and shelf life capacities of both types of spray mixtures. If water mixed sprays of Abate can be applied effectively from the air, significant savings in solvent costs can be realized.

Studies are also in progress to evaluate the compound methoprene, a non-organophosphate insect growth regulator, as an aerially applied larvicide. If necessary, the compound could be an excellent substitute for control of organophosphate resistant mosquitoes.

VECTOR CONTROL TECHNICAL ASSISTANCE

In response to numerous requests for assistance, a program was initiated in 1973 to provide aid to communities, municipalities, health agencies, industries, etc., in establishing effective mosquito abatement programs which fall outside of TVA's direct mosquito control responsibilities. The program consists of surveying by TVA to evaluate and define the problem, training of local personnel in survey procedures and habitat identification, demonstrating effective control techniques, recommending control strategy and cost estimates, and evaluating project success.

Associated with this community assistance program is an activity that provides for an emergency response by TVA to a public health crisis. Response includes not only technical advisory assistance, but also the actual conduct of necessary control operations. Assistance of this type from other agencies or groups is virtually nonexistent in the Valley. Both phases of the technical assistance program (the planned cooperative projects and the emergency response) enhance and complement TVA operations by extending mosquito abatement beyond TVA lands and waters and establishing a more comprehensive program for the Valley region.

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DILUTE AQUEOUS EMULSIONS OF FENITROTHION AND MALATHION APPLIED WITH A HUDSON PORTA-PAK® AGAINST *AEDES AEGYPTI*

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ABSTRACT. Reduced quantities of insecticide can be used to achieve cost-effective, household (= intradomiciliary) control of *Aedes aegypti* adults by means of a back pack mist blower applying ULV quantities of diluted aqueous emulsions (ULV/E) of OP compounds.

INTRODUCTION

The use of high concentrate ultra-low-volume (ULV/C) fenitrothion and malathion insecticidal sprays for control of adult *Aedes aegypti* in both household (= intradomiciliary) and aerial applications has been documented for many parts of the world. Dispensing equipment has ranged from aircraft fitted with Micronair® atomizers to hand-held turbines and knapsack misters. Trials with a Hudson portable back pack mist blower in Indonesia applying 180 ml AI malathion and 460 ml AI fenitrothion/ha have been described (WHO Unpublished document 1976). Dosage rates have varied from 249 g/ha AI to 1322 g/ha.

Other studies (Giglioli 1979, Giglioli et al. 1979) on air sprays have demonstrated that ULV solutions or emulsions (ULV/S or ULV/E) are more effective than sprays of ULV concentrates (ULV/C) since they approximate more closely the biological optimum size spray (BOSS) droplet spectrum (Himel & Uk 1975) and provide a better target droplet sufficiency (TDS) (Giglioli, unpublished) than technical concentrates (ULV/C).

As an alternative to the use of high concentrations, which are expensive, more likely to have an adverse environmental impact and may affect the aesthetic sensibilities of the homeowner, diluted emulsion concentrates (ULV/E) were tested under household conditions.

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