malathion tests of 1969–70 and the SBP–1382 tests described herein were conducted in the same area using the same testing procedures. In comparing the results of these two series of tests it is evident that SBP–1382 (3.33 lb. a.t./gal.) at 0.5 gph is 5–6 times more toxic to *C. nigripalpus* than malathion (9.7375 lb. a.t./gal.) at 1.0 gph based on the weight of actual toxicant discharged. Since satisfactory kill of *A. taeniorhynchus* was not obtained with SBP–1382, no comparison can be made with this species.

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ENVIRONMENTAL IMPACT AND MOSQUITO CONTROL WATER RESOURCE MANAGEMENT PROJECTS

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Increased potential for production of mosquitoes is an undesirable consequence of many types of water resource management projects. Control is required in many cases to safeguard public health and prevent nuisances that would interfere with full realization of the purposes for which the projects are undertaken. Such was the case when in 1933 the Tennessee Valley Authority began constructing a series of multipurpose dams (Figure 1) that would change the Tennessee River into a chain of reservoirs from its mouth to its tributary headwaters. Recognizing the potential hazard to public health associated with such a plan, TVA made control of malaria through control of the mosquito vector an integral part of the plan for developing the river. Surveys revealed that in the northern Alabama portion of the Valley more than a third of the population living within a mile or so of planned reservoir margins was infected with malaria. A staff of malariologists, biologists, and engineers was assembled to develop, plan, direct, and appraise the malaria control program. At an early stage in the development of the program, comprehensive field research was conducted to resolve questions about the potential impact of mosquito control measures on fisheries and wildfowl interests, and to integrate requirements for mosquito control into overall plans for developing and operating the water control system for the Tennessee River basin. The continuing TVA program of mosquito control evolved from this beginning.

The approach used by TVA and many others faced with similar problems is to seek satisfactory control of mosquitoes by means of ecological management—that is, by planning and applying primarily naturalistic or biological methods designed to control objectionable plant and animal species and to encourage production of desirable species.

Since enactment of the National Environmental Policy Act of 1969, attention has been directed from all fronts toward

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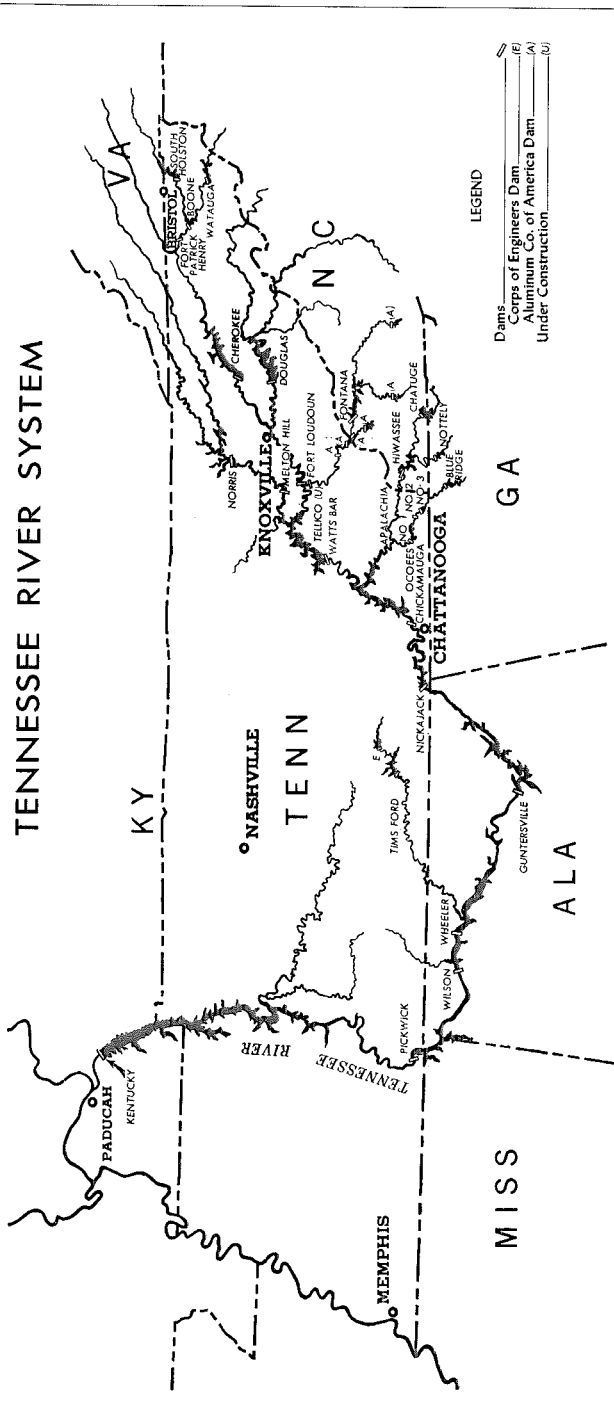

FIG. 1.—Tennessee River System, showing dams and reservoirs.

systematic assessment of the environmental impacts of major Federal actions that significantly affect the human environment to assure that environmental costs are recognized and accounted for in deciding upon the course of action to be followed. TVA is now reviewing its mosquito control program for this purpose and will report the results of this review in an environmental impact statement entitled "TVA Vector Control Program," which will soon be submitted to the Council on Environmental Quality.

TVA MOSQUITO CONTROL PROGRAM. *Anopheles quadrimaculatus,* the malaria mosquito, is the chief disease vector associated with TVA impoundments. Uncontrolled, this mosquito could be a threat to public health as well as a detriment to full development of the recreational and industrial potential of the river system. The TVA program of vector control continues to be directed primarily toward the control of this mosquito. However, the program has been broadened in recent years to include measures for controlling floodwater mosquitoes, principally *Aedes vexans,* where control is required along reservoir margins to protect public health or alleviate a nuisance. So far such measures have been needed in no more than a half dozen areas during any one year.

TVA relies heavily upon naturalistic methods to control both malaria mosquitoes and pest mosquitoes. Every effort is made, within practical economic limits, to provide an environment that is unsuitable for production of significant numbers of mosquitoes. Many mosquito habitats are eliminated during preparation of the reservoir before impoundment. Care is taken to provide a clean water surface by removing vegetation that might break the water surface and debris that might later float to the surface and provide protection and food supply for mosquito larvae. After impoundment, the water level is managed in such a way that eggs, larvae, and pupae are stranded, destroyed, or exposed to natural enemies. Routine maintenance of marginal drainage systems, pumping of water from low areas behind dikes, operation of diked areas as lateral impoundages, and removal of plant regrowth help control mosquito production. Only when necessary to supplement these measures is chemical larvicide applied, and then only in very limited amounts.

The measures used by TVA to control disease vectors and pests were developed or improved through applied research conducted by the TVA staff and others. Many of the older program methods are described in the book "Malaria Control on Impounded Water" published jointly by TVA and the U. S. Public Health Service in 1947.[1] Newer ideas, methods, materials, and equipment have been incorporated into TVA control operations as they are proven through appropriate laboratory tests, small-plot tests, and large-scale field demonstrations. These developments are extensively reported in the technical literature.[2]

ENVIRONMENTAL IMPACT OF THE TVA MOSQUITO CONTROL PROGRAM. The TVA program for controlling mosquitoes has a beneficial impact upon the human environment. The danger of diseases transmitted by these vectors is eliminated or greatly reduced by the program, and the annoyance of objectionable pest species is reduced. While some necessary control measures may at times entail some undesirable effects upon some aspects of the environment, these are generally minor. The program is flexible; TVA continues to evaluate present practices and to search for improved methods that will achieve the desired improvement of the human environment with a minimum of adverse effects.

MALARIA MOSQUITO CONTROL. The major environmental impact of the program for controlling malaria mosquitoes on TVA reservoirs has been the virtual elimination of the hazard of malaria transmission in the vicinity of TVA reservoirs. Continuation of the program is necessary to help assure that malaria transmission does not again become a serious public health problem in the area and that the nuisance of mosquitoes does not interfere with economic development.

When a reservoir basin is cleared of vegetation and debris in preparation for impoundment, there are many benefits besides the control of malaria mosquitoes. A surface free of protruding logs and stumps or floating debris is aesthetically more attractive for some people and is safer for river traffic, pleasure boating, and other water-oriented recreational activities. When trees and brush cleared from the reservoir are piled above the maximum water level contour, they may provide shelter and habitat for a variety of wildlife. On the other hand, they may temporarily reduce the aesthetic appeal and potential uses of the shoreline. For instance, protruding stumps and logs are natural resting places for wood ducks, a variety of turtles, shorebirds, and some amphibians and reptiles. Burning trees, brush, and debris could, in some locations and under certain conditions, contribute to air pollution for a short time.

Drainage systems, in some locations, make shoreline areas dry enough for agriculture, public recreation areas, or upland game habitat. Adequately drained areas may be planted with desirable species of trees to change a marshy area into a valuable alternative use, a productive and attractive forest. It is recognized that marshes are also attractive and productive for some uses.[3]

Properly operated dewatering projects control mosquito production in the spring and summer, provide excellent habitat for wildlife and migratory waterfowl in the fall and winter, and, in some projects, permit regulated agricultural use. However, water level management for vector control in certain areas (particularly those in the Duck River unit on Kentucky Reservoir) being used in the Bureau of Sport Fisheries and Wildlife's waterfowl refuge program has caused a reduction in the flexibility desired for production of waterfowl food—hence, a reduction in potential for waterfowl development there.

Improvement of shallow shoreline areas by deepening and filling eliminates areas with high potential for mosquito production and at the same time produces other benefits. The deepened portion may permit game fish better opportunity to feed on forage fish. The filled portion may be improved for potential use as a public recreation area, for wildlife habitat, and for pasture. Deepening the shallow areas may sometimes, however, destroy some fish spawning areas or areas favorable for production of food for fish or wildlife. Such areas are, however, only a minute portion of the total habitat available and suitable for these purposes.

Water level management not only destroys mosquito eggs and larvae by stranding them onshore or exposing them to fish and other predators but also strands floating debris to provide a clean water surface. This greatly enhances the aesthetic appeal of the reservoir for most recreational activities.

Water level management may interfere with spawning of some fish species, but, after many years of such controlled fluctuations, there is no evidence of significant problems. Both sport and commercial fishing are excellent in TVA reservoirs. Also it has been reported that drawdown benefits sport fishing by concentrating forage fish in parts of the reservoir where little shelter is available from predators such as largemouth bass.[4]

Maintenance of shorelines by cutting buttonball and willow adversely affects some species of wildlife, such as prothonotary warblers and yellow warblers, which use this habitat for nesting; yet it has a beneficial effect on the habitat of others. Such shoreline clearance is often extended by TVA operations in areas being managed for Canada geese to furnish the "openness" these birds desire and provide an opportunity to plant these cleared areas to winter grasses, an important food item for Canada geese.

Piling the cut brush above the maximum pool level could interfere with some recreational uses of the shoreline or cause a temporary adverse aesthetic impact, but such brush piles also afford excellent shel-

ter for some species of upland game. Routinely, shorelines are maintained by mowing with rotary mowers so that there is no problem of waste disposal.

Only very small quantities of the herbicide 2,4-D are used to control regrowth of willow stumps. Its use to control infestations of Eurasian watermilfoil and other aquatic plants is described in detail in the TVA environmental statement "Control of Eurasian Watermilfoil (*Myriophyllum spicatum* L.) in TVA Reservoirs." [5]

Abate (O,O,O',O'-tetramethyl O,O'-thiodi-p-phynylene phosphorothioate), an organophosphate pesticide,[6] is the only larvicide used by TVA for mosquito control. Abate is a highly selective, nonpersistent, biodegradable pesticide[7] that has been used effectively by TVA and other agencies for 5 years or more with no observable adverse effects on the environment. The LD_{50} (the dose required to kill 50 percent of a group of animals under laboratory test conditions after a specified period of time) is 2000 mg/kg of body weight for rats, 1200 mg/kg of body weight for mallard ducks, 250 mg/kg of body weight for quail, and 170 mg/kg of body weight for pheasant chicks.[8] The LC_{50} (the concentration in water that will kill 50 percent of a test population of aquatic life under laboratory conditions) is 1.9 ppm in 24 hours for rainbow trout.[9] Values of the LC_{50} of Abate for malaria mosquito larvae vary from 0.001 to 0.0068 ppm.[8] Because Abate is so effective for malaria mosquito larvae, it can be applied at very low rates (0.004 pound of active ingredient per acre) that afford nearly a 300-fold safety factor to even the most sensitive fish tested (rainbow trout). There has been no evidence that Abate accumulates in soil or water under conditions of practical field usage.[8]

The rate of application of Abate used in the TVA programs (0.004 pound of active ingredient per acre) was determined through experimental research.[10] Results of this work demonstrated no evidence that Abate persisted in the soil or water. Water samples collected in the immediate area of application showed decreasing concentrations in the water 10 minutes to several hours after larviciding. Concentrations found were all less than 0.05 ppm, even immediately after application. The recommended maximum permissible concentration for organophosphorous pesticides in public drinking water supplies, based on the assumption of long-term continuous exposure, is 0.10 ppm.[11]

FLOODWATER MOSQUITO CONTROL. The program for controlling floodwater mosquitoes on TVA reserviors is efficacious in reducing populations of pest mosquitoes and other mosquitoes that breed in temporary aquatic habitats. It is still largely experimental.[12–14] Habitat modifications are largely confined to small test plots, and any effects of test measures are necessarily very limited and localized. Experiments with tilling the soil have shown that it reduces hatching of floodwater mosquito eggs and remains effective in limiting breeding for more than a year. If tillage were widely used as a control measure, precautions to prevent increased erosion might be necessary. Plantations of baldcypress trees eliminate mosquito habitat and change marshy lowlands to forests.[15] Chemical larvicides are being evaluated in an experimental program to provide a method for temporary control with minimum adverse environmental effects in certain limited areas where other methods are not feasible.

ADVERSE ENVIRONMENTAL EFFECTS OF THE TVA MOSQUITO CONTROL PROGRAM THAT CANNOT BE AVOIDED. At present, there are no known adverse environmental effects of major significance. There are, however, several minor unavoidable adverse effects associated with some of the various activities necessary for vector control.

State regulations and public health considerations require that reservoir basins be cleared of brush and debris before impoundment. Disposing of this material by burning can temporarily contribute to local air pollution. Applicable state and

local regulations on burning are observed. Piling materials above the maximum pool level may cause an unpleasant visual impact until it is decomposed into humus and may temporarily interfere with certain land uses such as recreational access.

Water level management for mosquito control strands debris on the shoreline, leaves a progressively wider margin as drawdown progresses, and may interfere to some extent with a portion of the spawning season for some species of fish. Because of the timing of the water level fluctuations, however, this effect is minimized and apparently has not decreased the yield of sport fish. Drawdowns are made late in the fall after most species of fish have already spawned.

The effects of controlling the growth of aquatic plants with 2,4-D are discussed in the TVA environmental statement "Control of Eurasian Watermilfoil (*Myriophyllum spicatum* L.) in TVA Reservoirs."[5] These include possible presence of trace amounts of 2,4-D in water supplies, minor effects on nontarget aquatic plants, possible damage to terrestrial plants by drift of the herbicide from the treatment area, loss of food and shelter for some fish species, and loss of food and resting areas for waterfowl.

Shoreline improvements, such as deepening and filling, eliminate areas of shallow water and marsh vegetation that provide food and cover for some species of fish and wildlife or that serve as spawning areas for some species of fish.

ALTERNATIVES TO THE TVA MOSQUITO CONTROL PROGRAM. TVA's program of vector control is flexible so that alternative methods can be adopted if they prove superior to methods in use. A continuing program of research and testing is maintained to discover and develop alternative measures and to evaluate them in comparison with present practices. The goal of the TVA program is to use the most effective and economical controls that have the least adverse effect on the environment.

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EFFECT OF BEHAVIOR AND AGE OF INDIVIDUAL CICONIIFORM BIRDS ON MOSQUITO FEEDING SUCCESS[1]

H. W. KALE, J. D. EDMAN AND L. A. WEBBER

ABSTRACT. Several individuals of each of 7 species of ciconiiform birds were exposed overnight, individually in 8 x 8 x 8 foot cages with 300 *Culex nigripalpus*. Surviving mosquitoes were examined the following morning and engorgement rates (proportion of mosquitoes with blood meal) determined. Birds were tested as nestlings, fledglings, and adults. Some of the birds were observed closely to record behavioral responses to mosquito attack. Average engorgement rates on birds of the same species and age showed some variation, less for species that generally do not resist mosquito attack (great blue heron, black-crowned night heron), and more for species that do resist (white ibis, Louisiana heron, and cattle egret). In addition, nestlings of the little blue heron and snowy egret were exposed with mosquitoes and observed for defensive behavior at ages of 2–3, 5–6, 8–9, and 13–14 weeks. During the period from the 2nd to the 10th week of age in those species that resist mosquito attack as adults, an inverse relationship was found between the age of the nestling host and the proportion of mosquitoes that successfully obtain blood. This reduction in feeding rate was related to the hosts' maturation, both morphological (plumage cover) and behavioral (antimosquito activity).

INTRODUCTION

The factors affecting blood-feeding success of mosquitoes, as with most natural phenomena, are proving to be numerous and complex. Over a decade ago, Stamm (1958) observed that nestlings of the yellow-crowned night heron stood quietly and allowed scores of mosquitoes to feed on them while in nearby nests little blue heron, green heron, and Louisiana heron nestlings actively resisted mosquitoes and drove them away. Stamm suggested that individual traits of behavior may increase (or decrease) the exposure of these birds to mosquito bite and pointed out (Stamm, 1966) that the reaction of various bird species to mosquito annoyance and biting was in need of investigation.

Recently, we have shown that host behavior is important in determining the success or failure of *Culex nigripalpus* in obtaining a blood meal from ciconiiform birds (Edman and Kale, 1971). We have also studied in detail the physical activity (i.e., the various antimosquito behavior patterns) exhibited by these birds (Webber and Edman, 1972), and, more recently, we reported on the effect of mosquito density on this antimosquito behavior (Edman *et al.*, 1972). This paper reports on the effect of behavioral variation among individual ciconiiform hosts and the effect of host maturation (age) on the feeding success of *C. nigripalpus*.

METHODS

The 4-cage experimental aviary and observation cage used in these experiments and the procedures for rearing and maintaining mosquitoes have been described

[1] This investigation was supported by Public Health Service research grant AI–06587, from the National Institute of Allergy and Infectious Diseases.