MOSQUITO CONTROL IN RESERVOIRS BY WATER LEVEL MANAGEMENT

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Water management, properly employed, is the most potent single measure that can be applied toward controlling mosquito production from a manmade impoundage. Water management for mosquito control means the manipulation of reservoir water levels in such a manner that the microhabitat normally favorable for mosquito production is either destroyed or the mosquitoes are prevented from developing beyond their larval stage. Before attempting to apply the principles of water management for the control of a particular species of mosquito in a particular reservoir, however, it is first necessary that the primary purpose of the reservoir and the water management problems associated with carrying out this primary purpose be clearly understood.

Dams are constructed and reservoirs impounded for any one of a wide variety of reasons. Such reasons might include domestic or industrial water supplies, flood control, irrigation, hydroelectric power, recreation or navigation, to mention only a few. Some reservoirs are termed multi-purpose in that they are constructed and operated to serve two or more principal interests. The particular purpose or purposes to be served by a reservoir dictate within certain limits the general type of water management schedule required to carry out its primary mission.

Water supply or irrigation reservoirs are constructed to store water during periods of high streamflow to assure an ample supply for use throughout the year as needed. The operation of such reservoirs is aimed, in general, toward maintaining the reservoir water level at or as near full pool elevation as possible consistent, of course, with supplying the demand for water. It is usually desirable, with respect to recreational reservoirs also, that near full pool elevations prevail especially during seasons when recreational activities are at their peak. Spilling of excess water is of no particular concern after the full pool elevations have been reached. Spilling at elevations below full pool, however, may at times be most undesirable.

On the other hand, a flood control reservoir requires an opposite type of operation. In order to carry out its designed mission, there must be ample storage space available when needed to collect and hold, at least temporarily, flood flows in excess of that which can be safely passed downstream. Following such a flood control operation, the reservoir must be lowered sufficiently through regulated discharge to place it in readiness again to temporarily store and regulate the next flood. Thus, the operation of a flood control reservoir is toward maintaining a minimum pool elevation rather than a full pool.

Operation of a reservoir designed to serve navigation interests demands that a certain channel depth be maintained at all times. In addition, sufficient water must also be available to operate the navigation locks. Navigation requirements, therefore, necessarily fix the minimum reservoir drawdown elevation. Operation of the reservoir at elevations above this minimum is not of too much concern to navigation as long as excessive flow velocities and too rapid rise and fall in stage are avoided. These latter considerations demand careful regulation of reservoir discharges to prevent swift currents and

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unduly large water level fluctuations downstream from the dam or in certain critical stretches of the reservoir.

Reservoir water management for hydro-electric power generation may at times be more complicated than those operations previously discussed. Theoretically, one acre-foot of water through one foot of head is capable of producing 1.025 kilowatt hours of electricity. Thus power generation depends upon both the volume of water and the head available. The most efficient operation also demands that all available water be passed through the turbines and not over the spillway. Water over the spillway is lost to power generation and also will tend to reduce the effective head at the dam by raising the elevation of the tailwater level. Depending upon many factors too numerous and too complicated to mention here, it may be beneficial from a power standpoint to operate at times over a wider range of reservoir water elevations than is normally planned. In the face of an expected increase in flows, for instance, it may be advantageous to draw heavily on a reservoir through turbine use. The possible loss in efficiency from such an operation which might result from a steadily decreasing head may be more than overcome by the ability to store the impending flows for future use rather than being forced to waste water over the spillway.

Consistent with other influencing factors such as climatic conditions, water temperatures and shoreline topography, the type of reservoir water management followed in any given reservoir will determine the prevalence and type or types of mosquitoes occurring in that reservoir. Mosquito production in a reservoir may be considered, therefore, as an undesirable by-product obtained in the process of operating the water levels of a reservoir to accomplish its primary purpose. But, just as certain water management practices can create biological conditions which favor mosquito propagation, the water itself can also be employed in most instances to limit or completely eliminate such mosquito-producing situations. Water management "tools" such as weekly cyclical fluctuation and seasonal recession have been successfully employed on reservoir mosquito control programs for a number of years. Their effectiveness and economy have been well documented. From the foregoing brief discussion of the several types of reservoirs, however, it should be apparent that each individual reservoir presents specific problems with respect to the application of water management for mosquito control. The degree of effectiveness which can be achieved through such a program on a particular reservoir will depend chiefly on the following factors:

(1) How well the specific water management requirements for mosquito control can be identified in advance.

(2) How closely these requirements can be incorporated into an over-all reservoir water management schedule without materially interfering with or adversely affecting operations necessary in carrying out the primary purpose of the reservoir.

(3) The development of a system of communication whereby the day-to-day water management needs for mosquito control can be made known and can be weighed along with other considerations by those responsible for making decisions concerning management of the reservoir water levels.

Much has been said, written, and published during the past 20 years concerning the use made of water management by the Tennessee Valley Authority in controlling the production of *Anopheles quadrimaculatus* mosquitoes on its system of reservoirs. The manner in which the salient water management features of *A. quadrimaculatus* control are integrated into the over-all TVA reservoir water management plan, however, may not be so widely known or understood.

The TVA plan for the development of the natural resources of the Tennessee River Valley called for the construction of a series of dams to impound the main river from a point near Paducah, Kentucky, to Knoxville, Tennessee, a distance of some 650 river miles. In addition, reservoirs were also to be constructed on the principal tributary streams. The plan was unique in many respects. The concept of operating a multi-purpose reservoir was relatively new in the early thirties and there was no precedent for operating so large a system of such reservoirs, nine of which would form a continuous chain in the main Tennessee River. The reservoirs were to serve the primary purposes of flood control, navigation, and power. Superimposed upon the water management problems presented by these primary considerations was the need to control malaria transmission in the areas contiguous to these reservoirs. This meant the use of water management to control the production of *A. quadrimaculatus* mosquitoes in the reservoirs.

Eight years elapsed between the impounding of Wheeler, the first main river reservoir constructed by TVA, and Kentucky Reservoir, the last link in the main river chain. These years were spent in identifying the water management needs of each program interest and attempting to reconcile requirements which at first appeared to be somewhat conflicting at times. Recommendations by each program interest were studied by what is now the TVA Division of Water Control Planning in the light of over-all needs and benefits, always giving priority to the main statutory objectives. Temporary schedules of water management operations were set up as each reservoir was completed and impounded. It was often necessary during this period, however, to make departures in the planned management to facilitate construction of the dams. Periodic contacts made in the beginning of TVA reservoir operations were expanded so that by 1942 direct lines of communication between the malaria control staff and the water control planning staff had been established administratively within TVA. This permitted the day-by-day needs of malaria control to be considered along with the needs of the primary programs. Also, the effect on malaria control of any proposed temporary departures from scheduled operations could be discussed. In February 1945, from the experience gained during these construction years, TVA officially adopted the Multiple-Purpose Reservoir Operations water management charts which are still in use today. Each reservoir has its own individual characteristics which are reflected in its operation chart. The chart for Pickwick Reservoir, however, contains the main features which are typical of the water management schedules followed by TVA on its main river reservoirs.

The minimum flat pool level was set by navigation requirements to assure at least a nine-foot navigable channel at all times for river transportation. From studies of rainfall, runoff, flood frequencies and histories, it was determined that major basin wide floods in the Tennessee Valley occur chiefly in the winter and early spring months. Major floods on the main river have been limited almost exclusively to the months of December through April with the highest frequency in March. To provide flood storage space during this potential flood period, Pickwick Reservoir is held from 4 to 6 feet below normal full pool elevation from December to mid-March. Storage space below normal full pool in the other main river reservoirs ranges from a minimum of 2 feet in Guntersville to a maximum of 7.5 feet in Chickamauga. The generation of power is not materially affected by this operation since the effective head at all dams but Kentucky remains approximately the same except during actual flood control operations. The head at Kentucky Dam is 5 feet less since it is lowermost in the reservoir chain. This low water during the winter is helpful to malaria control in that it attenuates the growth of submerged aquatics in the reservoirs. The exact date to begin filling the reservoirs in the spring is determined by present and prospective streamflow conditions with the aid of current weather forecasts and longer range weather outlooks. The ideal time to initiate filling is after the last danger of flood has passed but before the normal spring rains have appreciably diminished. The decision to begin filling is arrived at by the Division of Water Control Planning primarily on the basis of flood control considerations but with the full knowledge of the adverse effects delayed filling might have on both power and malaria control. Power is interested, of course, in filling the reservoirs while sufficient water is still available so as to have the water for use during the low flow season later in the year. Malaria control desires a full pool before the growing season becomes well advanced to prevent growth of vegetation in the exposed portion of the reservoir basin.

Upon filling to full pool elevation, a flood surcharge is provided. This is a malaria control operation, although some minor benefits to navigation and power may result. The water is raised above full pool, by one foot or more where practicable, and returned rapidly to strand accumulations of drift and flotage upon the reservoir margin above full pool elevation. In effect, this is a mechanical cleaning operation.

The constant pool phase which follows is extremely beneficial to malaria control as a long-range marginal plant growth control operation. Since an ample supply of water is usually available at this time for power generation, this full pool phase of the water management schedule does not adversely affect the power program.

Mosquito production at first occurs sporadically. As production becomes more generalized, weekly fluctuation cycles of about one foot in depth are initiated simultaneously at the request of malaria control on all the main river reservoirs except Kentucky. It takes about ten days to two weeks to set this operation in full motion. It is accomplished through a complex system of shifting power loads so that as one reservoir is being drawn down, the one immediately downstream is filling. As long as no water is spilled in carrying out this operation, cyclical fluctuation does not adversely affect the power program since the average head available at each dam remains essentially the same.

The next step in the TVA water management schedule is water level recession. Recession provides excellent immediate *A. quadrimaculatus* control by continually drawing the water below the marginal band of vegetation and thus maintaining a clean shoreline. Coming as it does in the latter part of the growing season, the chances for further invasion of significant plant growth into the reservoir are lessened. Recession benefits power by making water available for generation without substantial change in effective head during the late summer and fall dry season when river flows are normally lessening. Also, to reach the required flood control elevations by December, recession provides for the use of water previously stored, usually without the necessity of spilling. Malaria control takes advantage of the lower lake levels in the fall to perform shoreline improvement and maintenance operations. Last year the Malaria Control Branch began a joint study with the TVA Division of Power Operations to determine if any net gains to TVA operations could be realized through delayed recession. As a result, recession was delayed on Watts Bar and Fort Loudoun Reservoirs on an experimental basis for two months beyond the present guide curve schedules. The results looked good and the experiment is to be repeated this year. From studies on other reservoirs, however, possible over-all gains from delayed recession do not appear promising.

Last year also, TVA broadened the scope of its mosquito control program to include, in certain limited situations, the control of floodwater mosquitoes. Studies to date indicate that the over-all water level management schedules now in use by TVA are effective in controlling these mosquitoes. It is the occasional necessary deviation from normal operation that may be significant with respect to floodwater mosquito production. The need for special operations does occur from time to time on any reservoir. Unusually heavy rainfall in June, a barge stranded on a mud bank outside of the channel, bridge construction or emergency repairs at a dam, or other special situations may all require temporary departures from guide curve operations. It is at these times that the close liaison which TVA provides between its water control and mosquito control staffs becomes of utmost importance.

An operations schedule which embodies the needs of all interests together with a system by means of which day-to-day needs may be considered is required to assure the most effective reservoir water management for mosquito control.