VI. MOSQUITO CONTROL INTEGRATED PEST MANAGEMENT

A. Definition of IPM as it Relates to Mosquito Control.

1. Overview of IPM. Few ideas stir more debate in pest control than “Integrated Pest Management” (IPM). Everyone agrees it’s a good idea, but there agreement ends. For some it means, “No pesticides.” For others it means, “Extensive research followed by careful implementation.” For others it means, “Don’t spray when they aren’t there and use several different chemicals when you do spray.” What makes agreement so difficult is that all three definitions are, at least in part, correct.

For the purposes of this report, however, a simpler statement of IPM is in order. At its most basic IPM is:

> A system designed to reduce the negative impact of a pest species to an acceptable level while avoiding unnecessary additional problems (Virginia Cooperative Extension Service 1987).

For mosquito control the negative impacts of mosquitoes are reduction in outdoor use, particularly recreational, and disease transmission. Problems that have developed in the past are loss/degradation of valuable habitat, exposure of non-target organisms to pesticides, creation of new, sometimes worse, breeding habitat, and resistance of mosquitoes to pesticides in use. Of course, determining which of these problems is unnecessary is the crux of much debate over mosquito control.

IPM was originated as a pest control strategy for agricultural systems. It has been modified for urban systems under the name Urban Pest Management (UPM). UPM varies from IPM (modified from Olkowski et al. 1978, Horn 1992, and Christie 1994) in that:

1. UPM systems are generally more complex, particularly with regard to determining thresholds for control.
2. UPM takes place close to large numbers of people.
3. Control decisions are often made for aesthetic, not economic reasons.
4. Pests of human health require control even at small numbers.

Mosquito control falls between the classic agriculture-based IPM program and current UPM systems. Control of numerous species over a wide range of habitats is more complex than most agricultural systems (modification 1) and control work often takes place adjacent to (in the case of larviciding retention basins) or on (in the case of adulticiding) human populations (modification 2). In addition, mosquitoes, even when controlled for nuisance purposes, would be classified as pests of human health (modification 4). However, mosquito control decisions are not made for aesthetic purposes (modification 3) in a manner similar to tent caterpillars in a city park.

The important point here is not what to call mosquito control IPM or UPM or something entirely different (the term integrated mosquito management has been proposed (Anonymous 1995) but rather to make it clear that one cannot pick up bodily a system designed for agricultural systems and transplant it into mosquito control without accepting that modifications have to be made. That being said, the second important point is that the difficulty in arriving at a scientifically based, economically and environmentally sound control program should not be used as an excuse to avoid implementing mosquito integrated pest management.

2. Integrated Pest Management for Mosquitoes. Before an IPM program can be put in place, a strong organization must be in place. There is a huge difference between tossing some pesticide at possible breeding sites and conducting a full-fledged IPM program. The organization must be adequately funded, adequately trained and provided with the materials to do the job correctly. At a minimum expertise in mosquito biology, wetlands ecology, and program administration are required.

Adequate staffing and resources are only the first steps in creating an IPM program. The main step is in creating the analytical process whereby control decisions are made, evaluated and modified. This process can be divided into four steps: 1) Surveillance and Monitoring, 2) Establishing Thresholds for Action, 3) Prevention and Control and 4) Evaluation.

a. Surveillance and Monitoring (including identification). The initial step in IPM is to survey the existing pest population and monitor its occurrence over time. For mosquitoes, adult populations are monitored for their direct impact on people whereas larval populations are monitored for their potential impact after they emerge as adults. For adult populations, monitoring is used to determine if adulticiding is required and to identify the species of mosquito in a given area so that future larval control efforts can be directed at the appropriate breeding sites. Larval populations are monitored to determine if larviciding is required and/or if physical or biological controls are working. Larval counts also aid in determining what areas are candidates for water management. Monitoring should also take place post-control, in order to evaluate efficacy of various control measures.

Mosquitoes collected during monitoring must be identified, to the extent possible, to species. For adult mosquitoes, the species of adult will give a clue as to where larval monitoring should be focused. For larvae, enough non-pest species exist that field staff should be able to sight identify most of the common species to genera, primarily to avoid larviciding a non-pest species.

The habitats in which breeding occurs or in which the adult mosquitoes are most numerous must also be identified. Wetlands should be mapped. With the recent rise in the number of drainage basins in new developments, an important aspect of mosquito control is to maintain an up-to-date list of all such basins and work with local building officials to discourage constructing mosquito-breeding basins.

A third component of monitoring is to classify the area in which control is to take place by human usage. Unless funding is not a constraint, the goal of surveillance and monitoring should be to produce a site list prioritized by the level of mosquito breeding and its proximity to humans.

b. Establishing Thresholds for Action. The goal of IPM is to keep pest levels below the Economic Injury Level (EIL). This is the level where the economic loss from pest damage exceeds the cost of control. In mosquito control, this is the Human Annoyance (or Disease) Threshold (HAT) and represents the highest biting density (or Disease Incidence) that most citizens in a community find tolerable. Intolerance is usually exemplified by people moving indoors, putting on repellent, leaving a campground etc.. HAT is generally the biting level above which most people prefer to pay to have the level reduced than put up with the annoyance. This level will vary from community to community and may be influenced by the species biting (Sjogren 1977), the time of day when annoyance occurs, and the duration of the period when HAT is exceeded.

In agricultural IPM programs, a 2nd pest density, the Economic Threshold (ET) is established and monitored by frequent and systematic sampling of the pest population. This is the so-called action level. It is the pest density that, if left unchecked, will result in the Economic Injury Level (EIL) being reached. It is a computer-assisted predictive level, (lower than the EIL) and is based on previous experience, populations of beneficials, time of year, etc. It is difficult to translate this management concept into mosquito control practice because the populations responsible for biting annoyance (adult females) differ from those that need to be monitored and controlled (larvae). Biting is not restricted to areas with the larval habitats and it is difficult to assess the future biting impact of any given larval population.

During the surveillance and monitoring phase, workers need to establish thresholds for the various control options they have. Thresholds may be established based on those found in the literature but will generally require local modification. Standard thresholds for adulticiding are generally given as complaint calls for a given area, landing counts (mosquitoes landing on an observer per minute) or light trap counts (number of human-biting mosquitoes collected per night). Standard thresholds for larviciding and/or water management are based on dip counts.

Thresholds need not be expressed in terms of existing mosquito populations. In the case of existing programs, the threshold for drainage maintenance will most likely be based on some variation from the existing cross-section of the system or some measure of water flow as compared to a previously established norm. Prevention cannot be based on existing mosquito populations but must be based on the potential for populations to develop.

Thresholds for action are influenced by economic factors. Only programs with sufficient operating funds can fully exploit the flexible control strategies generally found in a full IPM program. Programs strapped for funds may have no, or very high, thresholds for open marsh water management, because the high initial cost cannot be borne by the program.

Political realities also influence thresholds. Local populations vary widely in their acceptance of various control measures. In Massachusetts there are projects that adulticide on the basis of a single request and there is one project (Cape Cod) that does not adulticide at all. Human population density and behavior patterns also influence thresholds for action. Where budgets are limiting, funds will be earmarked for areas in which the most people will benefit. Seashore communities dependent on summer tourists will generally demand higher levels of control, hence, lower thresholds for action, than will thinly populated rural areas.

Finally, environmental factors are also included in establishing thresholds. Control measures that have little impact on non-target organisms can be conducted at lower thresholds than can control measures that have large impacts on non-targets. In addition, thresholds for action will be influenced by the sensitivity of the location in which control is to be conducted. An on-going example in Massachusetts is the use of Altosid (methoprene) in endangered-species areas. In Suffolk County Bti use is permitted, methoprene is not. Should Bti become significantly more costly than methoprene, the threshold (larvae per dip) for larviciding in the affected areas will most likely be raised.

In summation, the choice of control measures to use, and the extent to which a given control measure is used, is determined by the pest species and population, the environment in which the pest population is located, and human factors expressed in political and economic terms. Determining which control options are available and how much funding will be allocated to each, coupled with an understanding of the pest population, should allow action thresholds to be created.

c. Prevention and Control. As a general rule, prevention refers to maintaining a pest population below an action threshold for control, whereas control refers to bringing a pest population back down under the threshold for control. The line between the two, however, is blurred enough that there is little conceptual reason to separate them. Clearing a blocked ditch so that larvae are flushed out is a short-term control measure with long-term preventative effects.

Source reduction is the primary prevention technique for mosquito control. Maintaining water flow through drainage networks is the primary freshwater mosquito control technique while ditching (previously) and open marsh water management (currently) are designed to eliminate the isolated, shallow pannes in which salt-marsh mosquitoes breed. Programs that do not stress source reduction cannot make long-term reductions in mosquito populations.

That being said, there are cases where source reduction is not possible. The most obvious are areas where source reduction would impact an endangered species or where the type of source reduction necessary would severely impact the wetland resource. In Massachusetts any alteration in such an area must undergo NHESP review. Less obvious but equally real are cases where property owners deny permission for source reduction projects or where the breeding area is simply too large for source reduction to be economically feasible.

Public education is a second vital component of prevention. An educated public should be more willing to cooperate in eliminating man-made breeding habitats, should better understand the trade-offs between the various available control techniques, and should be more willing to fund more expensive approaches if the expense can be justified by a better long-term benefit. A side benefit from public education is that lines of communication are usually strengthened, so that the economic and political aspects of mosquito control, areas often controlled by non-mosquito-control personnel, bear a stronger relationship to the realities of mosquito control.

Control, in the strict sense of killing mosquitoes, is dominated by chemical use. For adult mosquitoes, no current control alternative to pesticides exists. However, options exist for larval control. Biological control using mosquitofish is possible.

Expanding on the concept of control to understand that what is being controlled is the negative impact of mosquitoes, rather than mosquitoes themselves, then all efforts designed to reduce human exposure to mosquitoes constitute control. Public awareness becomes a vital component. This does not mean teaching people to live with mosquito bites. It does mean teaching people how to make informed decisions about mosquito control.

Thresholds are vital to the control process because only through thresholds can a rational response be made to unusual circumstances. A quality IPM program cannot "fail" in the strict sense because it has control techniques available for each step in pest population increase (or, in the case of a disease threat, each increase in the risk of contracting the disease). Source reduction is adequate when mosquito breeding is absent or low. Larviciding is triggered by increasing larval numbers. Localized adulticiding is triggered when adult populations pass a given threshold. Finally, aerial adulticiding is available when populations explode and/or the disease threat is high.

d. Evaluation. Each control step is evaluated for efficacy and future actions modified to improve control or reduce negative impacts. Field evaluation will generally use the same monitoring techniques described above and the important criteria will be changes in the mosquito population and/or environment. Over time, a steady state should develop where realistic thresholds trigger effective responses.

B. Aspects of IPM currently in place in Massachusetts mosquito control programs.

1. IPM Questionnaire.

Along with the general questionnaire sent to the projects in 1996, a separate page concerning IPM was included. In it, projects were requested to provide a definition of IPM and then either agree or disagree with a series of statements about IPM (Tables 15 and 16).

Table 15. Project responses to IPM Questionnaire as given.

Response	Agree	Disagree	No
14. Mosquito breeding outside the Program has an impact on adult mosquito populations within the Program.	7	1	
1. The Program already practices IPM.	6	1	1
4. Quantifying human annoyance is difficult	6	2	
2. The wide range of breeding habitats to be monitored makes implementing IPM difficult.	2	6	
3. The wide range of areas in which adult mosquitoes are a problem makes implementing IPM difficult.	3	4	1
5. Control techniques and options are more often determined by a vocal minority rather than the community average.	5	3	
6. Light trap catches are influenced by too many factors unrelated to mosquito population densities to be used as a reliable indicator of actual problems.	2	6	
7. Current funding provides a rough measure of a community's perceived need for mosquito control.	3	5	
8. Personnel shortages prevent collection of data required for IPM decisions.	4	4	
9. Knowledge gaps prevent implementation of IPM.	2	6	
10. The wide range of species of mosquitoes to be controlled makes implementing IPM difficult.	3	5	
12. Predicting adult mosquito populations from larval monitoring is not sufficiently accurate.	4	4	
13. Waiting until adult mosquitoes are biting is too late to initiate control.	4	4	
11. IPM is not possible in mosquito control.	0	8	

The most encouraging aspect of the answers is that none of the eight projects responding felt that IPM was not possible in mosquito control (Statement 11) and six of the eight felt they were already practicing some form of IPM (S1). On a less optimistic note, there was strong feeling that quantifying human annoyance is difficult (S4). Of the two (Cape Cod and East Middlesex) that did not think quantifying human annoyance is difficult, Cape Cod is dominated by the summer tourist season and is probably is not very hard to figure out whether or not mosquitoes should be controlled, the answer being, "Yes!" An additional concern when attempting to establish HATs is that most of the projects felt that vocal minorities have more say in mosquito control than does the community average (S5). There is little question that the HAT concept, while theoretically of value, may be based on incorrect assumptions about the driving forces behind control decisions.

Equally troubling from a control perspective is that most projects felt that mosquito breeding outside their

Table 16. Project responses to IPM Questionnaire sorted from highest number of "agree" responses to lowest.

Response	Agree	Disagree	No

14. Mosquito breeding outside the Program has an impact on adult mosquito populations within the Program.	7	1	
1. The Program already practices IPM.	6	1	1
4. Quantifying human annoyance is difficult	6	2	
5. Control techniques and options are more often determined by a vocal minority rather than the community average.	5	3	
8. Personnel shortages prevent collection of data required for IPM decisions.	4	4	
12. Predicting adult mosquito populations from larval monitoring is not sufficiently accurate.	4	4	
13. Waiting until adult mosquitoes are biting is too late to initiate control.	4	4	
3. The wide range of areas in which adult mosquitoes are a problem makes implementing IPM difficult.	3	4	1
7. Current funding provides a rough measure of a community's perceived need for mosquito control.	3	5	
10. The wide range of species of mosquitoes to be controlled makes implementing IPM difficult.	3	5	
2. The wide range of breeding habitats to be monitored makes implementing IPM difficult.	2	6	
6. Light trap catches are influenced by too many factors unrelated to mosquito population densities to be used as a reliable indicator of actual problems.	2	6	
9. Knowledge gaps prevent implementation of IPM.	2	6	
11. IPM is not possible in mosquito control.	0	8	

district has an impact on adult mosquito populations within their district (S14). The only project that did not was Cape Cod, which is more isolated than are the other projects. IPM programs that stress water management of larval populations must be flexible enough to allow projects to control adults mosquitoes coming in from other areas.

Looking at some specifics by project, Norfolk and Essex both agree with the three statements (S2, S3, and S10) relating to the wide range of mosquito habitats. Though these programs have both salt-marsh and freshwater components, their distribution of effort is not markedly different from Plymouth or Suffolk Counties, which disagreed with all three statements. Norfolk and Essex also were the two projects that agreed with the statement that, "Knowledge gaps prevent implementation of IPM" (S9). As both Norfolk and Essex MCPs are active in pushing for stronger, more ecologically sound mosquito control, their responses may be less an indication of their dissatisfaction with IPM and mosquito control and more an indication of their desire to see mosquito control IPM improved.

2. Mosquito Control IPM as practiced in Massachusetts today.

The strategy of IPM as developed for agricultural ecosystems is an ecologically-based concept (Axtell 1979). It has yet to be fully applied to mosquito management programs. IPM is a strategy for managing insect populations not a method for controlling them. It is more than integrated control which is simply the combining of several control methods. Mosquito control has a long history of integrating different control methods.

The general feeling among most MC practitioners is that any significant larval population within flight range of residential areas will probably result in some human annoyance and therefore should be controlled. Few MC programs in the U.S.A. have developed annoyance threshold levels for their communities. No Project in Massachusetts has undertaken such an effort. In the Metropolitan MC District in Minneapolis/St. Paul, it was found that the HAT was 2 bites/5 minutes between 7-9 PM on typical summer evening. Thus, the minimum goal of this District is to keep the human biting rate at or below 1 bite/5 minutes. This number is so low, however, that few projects are likely reach it consistently throughout their district. Therefore, whether or not a given breeding site is larvicided is more a function of economics than of absolute mosquito numbers.

Although many MC programs regularly monitor adult population levels (with light traps and landing counts) they do it to evaluate larval control effectiveness and the need for adulticiding; not to determine when immediate larval control is needed as in the case of agricultural IPM programs. However, light trap counts, landing rates and complaint calls are used to create a general picture of the need for mosquito control and projects with long-term experience develop larviciding plans based on this historical data.

It would be beneficial if techniques for predicting future adult biting annoyance from larval counts could be developed. One way this could be accomplished by marking different larval populations (for example with Geimsa stain) and then assessing the subsequent contribution of marked females to the population biting humans in neighboring areas (Fish & Joslyn 1984, Joslyn et al. 1985). A simpler technique is to mark adults with a fluorescent dust, release them at the breeding site, and attempt to recover them in adjacent biting areas (Morris, et al. 1991). This can show which areas are being affected by which breeding areas. The drawback to these types of is the need to do it for each species in question and, due to the large number of site-specific variables, for many breeding sites. Regardless, studies like this would require a research element not present in the current Massachusetts system.

Assessment of the cost/benefits resulting from outdoor recreational activities have been dealt with extensively in the literature (Pierce & Napier 1977, Beardsley 1971, Moeller et al. 1976). The theoretical basis for most of these analyses is found in general welfare theory (Pierce 1971, Prest & Turvey 1965, Walsh & Williams 1969). When applied to the assessment of economic benefits, these analyses represent attempts to establish the consumer surplus" (Blaug 1968). This surplus represents the consumers willingness to pay" (WIP) for a specific service or facility e.g., a mosquito-free campground or park. Once determined, the WIP is used as a proxy for benefits emanating from the service (Mishan 1976). John et al. (1987) established the WIP for a Texas community to be $22.44 per household ($18.96 per renter household). Once the benefits and costs of mosquito control are assessed, it is possible to establish Economic Thresholds (e.g., the mosquito density at which the cost of control is equal to the value (estimated benefits) forthcoming from the controls (Edens & Cooper 1974, Edens 1977).

A major concern in all of these cost/benefit analyses is that they compare dollar costs of various control techniques or discuss consumer willingness to pay but they do not address ecological costs associated with mosquito control. Due to the lower and more specific toxicities of newer pesticides, water management may not always be less ecologically damaging than pesticide application.

There is no study to date of the costs and benefits of Massachusetts mosquito control programs. There is good reason to believe, even if such studies were done, that the results would reflect local, current thought, as opposed to some underlying “true” cost/benefit for mosquito control. Variables that would affect perceived cost/benefit include relative economic strength of the local community and of the state, recent weather patterns and their influence on mosquito breeding, the rate and direction of development within the community, and the techniques available for mosquito control. Regardless of the underlying variability of any cost/benefit analysis, working towards an understanding of the costs and benefits of mosquito control is desirable. The following information would aid in such work:

1) Establish human annoyance thresholds (HAT)
2) Document how human activity patterns relate to HAT and economic factors
3) Determine cost/benefit analysis of control (willingness to pay)
4) Correlate HAT with a standard non-biting sampling method (e.g. light trap)
5) Correlate densities of immatures with future levels of biting annoyance

6) Establish the ecological costs of various control techniques.

The cost/benefit of various control options (e.g., permanent vs. temporary control) also has been evaluated in recent papers (Ofiara & Allison 1986a, 1986b) but this should not be confused with the cost/benefit of control programs.

3. Improving Physical Control.

Reducing pesticide use is not a primary goal of IPM (Robinson 1996). Reducing unnecessary pesticide applications and improving the effectiveness of pesticide applications are goals, and improving our knowledge of how a system works often results in pesticide-use reduction, but there is nothing in the concept of IPM that mandates reducing pesticide use. Indeed, at Essex County, when they established a landing count rate of 1 per five minutes for adulticiding, they found that the total area that qualified for adulticiding jumped dramatically (Walter Montgomery, personal communication). That being said, pesticide use remains an issue and improving non-chemical controls is a desirable goal.

Most organized MC projects in Massachusetts engage in source reduction activity. Current source-reduction efforts generally consist of cleaning and repairing ditches and other water control structures built previously rather than with the construction of new structures. New construction is limited by State and Federal wetland protection laws and regulations. Also, the economics of source reduction programs is an important consideration. The higher initial cost of this semi-permanent control strategy must be amortized over the multiple years of anticipated benefit. It cannot be implemented at all when limited annual budgets prevent MCPs from acquiring the large up-front capitol sums that are needed for major source reduction projects. Another shortcoming of the current regulations, as they apply to mosquito control, is they fail to adequately differentiate between natural and manmade wetlands.

One major advance already underway is vastly improved mapping through Geographic Information Systems (GIS). GIS wetlands mapping can both aid mosquito control agencies in determining control priorities but can be used by mosquito control agencies to integrate their work with other land-use agencies (Guthe 1993). Very detailed maps can also be made when planning water management projects (Gettman 1995).

a. Saltmarsh management

There are two major strategies for managing tidal waters to achieve control of saltmarsh mosquitoes: (1) long-term flooding or impoundment of the high marsh to prevent mosquito egg laying and encourage larvivorous fish, or (2) drainage of the high marsh to prevent water from standing for the 6+ days required for the completion of mosquito larval development. Some combination or modification of these two might be considered as a third strategy. Permanent or seasonal impounding of the entire high marsh is not a viable option in New England's grassy salt marshes with wide tidal fluctuation (Provost 1969).

Early source reduction work in grassy salt marshes consisted of grid ditches, initially dug by hand. .Everyone concerned now seems to agree that such a blanket approach to saltmarsh ditching is overly destructive and less effective than more customized designs though the actual impacts have been debated (Bourn & Cottam 1950, Lesser et al. 1976, Provost 1977, Daiber 1986, Buchsbaum 1994). This approach is no longer practiced or recommended, but many of these old, square-bottomed ditches still criss-cross Massachusetts salt marshes. Many have become silted-in shallow depressions in which mosquitoes breed. To avoid this, some MC projects continue to clean and maintain at least some of the old grid ditches.

Contour ditching grew out of the realization that grid ditches often fail to flush with the tides and therefore, unless continuously maintained, they eventually silt in and form breeding. Contour ditches are more strategically placed and follow the natural topography of the marsh. Contour ditching schemes are essentially integrated extensions of natural tidal creeks and they better take into account the hydrodynamics of tidal marshes. Although they are a more intelligent approach to ditch design, they are still ineffective in preventing mosquito breeding in many shallow pans and isolated, irregular depressions which characterize the upper part of many Massachusetts salt marshes.

An obvious alternative to maintaining grid or contour ditching would be to upgrade the grid-ditch systems to OMWM systems. In a Rhode Island salt marsh such a conversion consisted of creating a reservoir within an existing ditch, cleaning out those sections of ditch that functioned as connectors from the reservoir to breeding pannes, and using the spoil to fill in ditching that was not serving a mosquito-control function. As a result, breeding densities of hundreds per dip were reduced to virtually none and larviciding practically eliminated (Christie, personal communication). This type of work is occurring in Massachusetts but could probably be increased.

b. Fresh water management

<u>Natural Wetlands</u>. Over the past decade there has grown up a tremendous force for the preservation of all wetlands, the “no-net-loss” policy. This policy is based on three assumptions:

1) each and every wetland is of infinite value

2) that all wetlands are of equal value

3) that any actions or other properties sacrificed to maintain a wetland must have less value than the wetland itself. (Gates 1995).

The challenge for mosquito control programs is to ensure that a more balanced set of assumptions comes to the fore as our understanding of wetlands, mosquitoes, and vector control increases. No IPM program for mosquito control can be adequately developed if the areas in which control takes place are off limits to manipulation. Just as mosquito-control personnel must become more aware of the ecological costs of mosquito control, so too must advocates of wetlands preservation become more aware of the benefits of mosquito control.

Most permanent wetlands offer few options for water management. Draining or filling natural wetlands are no longer considered acceptable practices. Extensive existing drainage networks are currently maintained by the Mosquito Control Projects but new ditching is rarely permitted. Most existing systems were not originally dug with mosquito control in mind. Unfortunately, a ditch system, once in place, almost invariably breeds mosquitoes if it is not maintained. A primary goal for mosquito-control programs and state agencies should develop criteria for continued drainage maintenance, using the New Jersey guidelines (New Jersey DEP 1997) and the North East Massachusetts Mosquito Control and Wetlands Management District "Standards for Ditch Maintenance" as starting points.

The prospect for source reduction activity in the thousands of acres of wooded swamps common throughout the eastern third of Massachusetts is slim. The primary vector mosquito, *Cs. melanura*, produced in these swamps is essentially an after dark, passerine bird feeder, and is unlikely to transmit EEE to humans and horses (Nasci & Edman 1981a, Morris et al. 1980). Therefore, any effort to control this mosquito is perhaps misplaced, though some success has been had with aerial applications of Altosid pellets (Henley 1992). If the vector(s) of EEE virus to mammals were known, control efforts directed against this mosquito would be a more logical and efficient way to interrupt disease transmission during threatened epidemics. The most likely candidates for such attention are *Cq. perturbans, Ae. vexans,* and *Ae. canadensis*.

Vernal pools are both a valuable resource and a reliable source of mosquitoes. Their size makes them more amenable to habitat modification but their value as nurseries for amphibians and other semi-aquatic animals makes their preservation important. In rare cases, however, ditching (when possible) or filling small woodland pools in close proximity to human populations may provide sufficient benefits to outweigh the loss of some of these temporary aquatic habitats. Vernal-pool certification by NHESP will, over time, bring under protection of the Division of Fisheries and Wildlife those vernal pools which should be left undisturbed. Most vernal pools slowly fill in naturally while new ones are constantly being created in the root cavities created by blown over trees. Massachusetts forests are currently maturing so 'blowdowns' and new vernal pools may be increasing.

Populations of tree-hole *Ae. triseriatus* seldom reach serious densities in Massachusetts at present but this could change. Because this species is a daytime biter, adapts readily to discarded tires, and is a potential vector of La Crosse encephalitis, it bears careful monitoring. The city of La Crosse in Wisconsin has mounted an effective campaign to nearly eliminate human cases of LAC encephalitis by simply removing old tires and other small water-holding containers and filling in tree holes near residential areas (Parry 1983). This model for source reduction of tree-hole mosquitoes is undoubtedly the most effective way to presently deal with *Ae. triseriatus* in areas where it becomes a localized problem species.

<u>Reservoirs and dug ponds</u>. The majority of small permanent ponds and lakes in Massachusetts are man-made. They were created by dredging natural seepage areas or by damming streams. Many Massachusetts reservoirs are old, having been built to provide power and water for adjacent factories built between the middle of the 19th century and the depression years of this century. Some have become badly silted and eutrophic. Nearly all of these bodies of water create some mosquito habitat, at least along vegetated shorelines and in shallow upper reaches distal to the dam. *Anopheles* and *Culex* are the principal mosquitoes associated with these wetlands and, when cattail or water willow invade along the shoreline, *Cq. perturbans* become established as well. Also, small permanent ponds or reservoirs within wooded habitats often hatch large broods of univoltine Aedes along leaf-packed borders during spring flooding.

Older dams seldom have flexible water level control structures. Thus, well-established principles for managing mosquitoes in impounded waters (Edman 1964) can not be applied in most Massachusetts reservoirs. All new and rebuilt structures should include adequate control capabilities so that water level management can become a mosquito control option in all impoundments in the future. The main features of water level control plans are: (1) maximum pool levels when flood-water *Aedes* are laying eggs, (2) gradual summer drawdown with weekly surcharges to strand floating debris and keep water out of the shoreline vegetation that protects *Culex* and *Anopheles* larvae from wave action and predators, and (3) during the spring egg hatch period, keep pool levels from rising above the levels maintained during the previous year's univoltine *Aedes* egg-laying period.

Grass and scrub marshes created by drainage disruption. Most serious pest/vector problems associated with these habitats are created in situations where vegetation favorable to the cattail mosquito, *Cq. perturbans* has invaded the marsh. This mosquito is difficult to control by conventional larvicides, is an aggressive biter of humans and domestic animals, and may play a role in EEE epidemics. Spring *Aedes*, and summer Anopheles and *Cx. salinarius* problems may be associated with these marsh habitats as well. Also, a univoltine bird feeder, *Cs. moristans*, which may play a role in enzootic cycles of EEE virus (Morris and Zimmerman 1981), breed principally in this category of wetland.

There are two potential habitat management strategies for eliminating breeding associated with these wetlands and neither is popularly practiced. One involves removing the vegetation which supports breeding (e.g., cattails). This can be done with a dragline provided the vegetation is still restricted to the pond border. Alternatively, selective herbiciding or hand removal when invasive plants like cattails first become established along the shore may be effective in some situations. A second management strategy is to correct the drainage disruption which created the wetland situation in the first place. This may be as simple as installing or lowering a culvert. In contrast, it may be so complex and expensive that it is not a viable option. When feasible, restoring natural drainage will permanently eliminate the wetland. This may be considered unacceptable despite the fact that these wetlands are man-made and of limited life expectancy. The builders of roads, railroads, and power or pipe lines are responsible for the majority of these wetlands. Expecting contractors to retroactively address, at great expense, the public health and nuisance problems that they have created is perhaps unrealistic. However, all new construction which involves significant changes in topography and natural drainage should be reviewed by an agency such as the SRMCB to assess impact on water flow and creation of new wetlands which may produce pest/vector mosquitoes.

Roadside ditches and tire ruts. A major source of reflood *Aedes* are ditches that fail to completely drain because of a lack of culverts or culverts that are located above the level of the ditch bottom. Heavy equipment and tractor tires leave permanent ruts in soft turf which is another major source of reflood breeding sites associated with ditches and low-lying fields. Both of these categories of man-made wetlands can be prevented by proper engineering, construction, and maintenance practices. Where these breeding sites already exist, they can be permanently eliminated by appropriate lowering of culverts and regrading work. Tapered cement aprons at both ends of culverts and cement linings in the bottom of roadside ditches in residential areas with poor drainage characteristics can also assist in preventing the creation of these breeding sites. Municipal and state road crews should be cautioned against mowing when the sod is too soft to fully support mowing equipment without creating depression in the ditch bottom.

<u>Storm catch detention and retention basins, ornamental pools, tires, and</u> <u>other man-made containers</u>. Good sanitary practices promoted through homeowner education can eliminate most of the water-holding vessels which support container-breeding mosquitoes. The policy of many landfills to charge extra for accepting used rubber tires and appliances has created undesirable stockpiles in many backyards or illegal dumping along isolated roadsides. Tires can be eliminated as breeding sources by cutting 3-4 large holes on either side, but those most likely to dump tires illegally are least likely to care about creating breeding habitat. Tire dumps create a special problem that can best be dealt with through recycling plants which are now being built in many areas. Retreading operations frequently stockpile large numbers of used tires that are awaiting processing. If tires are stored in open sunlit area, they will not be colonized by *Ae. triseriatus*. *Culex pipiens*, which will colonize sunlit containers and underground catch basins are not a major pest or vector problem in Massachusetts. *Culex salinarius* is the only *Culex* frequently taken in mid to late summer human biting collections in the Northeast and it does not normally breed in catch basins or other containers. The urban autogenous form of *Cx. pipiens* (i.e. *molestus*) reportedly bites humans (Spielman 1973) but outdoor pest populations of this form are not well documented in the Northeast. In any event, well designed and regularly cleaned catch basins should not retain runoff water. Cities in Massachusetts with old sewer systems still contain many catch basins which produce *Culex*. The actual pest status of mosquitoes produced in catch basins should be well established by each community prior to control considerations. New detention and retention basins are frequently built around new malls and similar large construction site to manage rainwater and protect nearby wetlands from runoff pollution and siltation. In many cases these basins are becoming a mosquito problem (*Culex, Anopheles, Aedes,* and even *Coquillettidia*). Better design and maintenance could help to alleviate this growing problem.

About 12 years ago the Asian tiger mosquito, *Ae. albopictus*, was accidentally introduced into Texas, presumably via used tires from northern Asia (Moore 1986). Since its introduction, this day-active, man-biting pest and potential vector species has spread into 17 states including several in the North. It has been found in Maryland and may appear in Massachusetts. Biting densities of 30 per minute already have been reported in

Texas, Louisiana and Illinois. This species is most common in tires but will occupy a variety of man-made containers. Its control is likely to become an important priority in the Northeast within a few years.