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Enclosed is the "final" Generic Environmental Impact Report (GEIR) for the Massachusetts Mosquito Control Projects. The use of quotation marks around "final" denotes the Board's intention that there never will be an actual final version of this report. It is our goal to update this document on a yearly basis as new ideas and approaches to mosquito control become known, new pesticides or equipment come on the market or improved techniques are made available.

This GEIR will become a living document, which will change and improve over the years, rather than be a static report becoming outdated in a few short years. As these improvements come to the Board's attention, and are reviewed and found to be valid and useful, addendum will be issued in order to continually update the report.

Yours truly,

John Kenney
Chairman

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CERTIFICATE OF THE SECRETARY OF ENVIRONMENTAL AFFAIRS ON THE GENERIC ENVIRONMENTAL IMPACT REPORT

PROJECT NAME	Mosquito Control Program
PROJECT MUNICIPALITY	Statewide
PROJECT WATERSHED	Statewide
EOEA NUMBER	5027
PROJECT PROPONENT	State Reclamation & Mosquito Control Board

DATE NOTICED IN MONITOR: October 25, 1998

As the Secretary of Environmental Affairs, I hereby determine that the Generic Environmental Impact Report (EIR) submitted on this project adequately and properly complies with the Massachusetts Environmental Policy Act (M.G.L. c. 30, ss. 61- 62H) and with its implementing regulations (301 CMR 11.00).

On September 23, 1996 the Secretary of Environmental Affairs issued a Certificate on a Notice of Project Change filed by the State Reclamation and Mosquito Control Board (SRMCB) requiring that a Generic Environmental Impact Report (GEIR) be completed, for mosquito control in the Commonwealth. The Certificate contained an extremely detailed scope for the GEIR, developed in coordination with SRMCB. This GEIR, by responding to all of the items in that scope, provides an extremely useful summary of' current data, practices, and standards for mosquito control statewide. In particular, the GEIR establishes that Open Marsh Water Management (OMWM) shall serve as the preferred practice for physical controls in salt marshes. The GEIR also highlights certain areas in which further research will be necessary, and it.

1 - The State Reclamation and Mosquito. Control Board (SRMCB) is comprised of one representative each from the Departments of Environmental Management, Environmental Protection and Food and Agriculture proposes a system of annual updates, offering continued opportunities for review and comment on new information and proposals.

<u>Introduction</u>

The SRMCB oversees nine organized mosquito control projects (Berkshire County, Bristol County, Cape Cod, Central Massachusetts, East Middlesex County' Norfolk County, Plymouth County, Suffolk County and the North East Massachusetts Mosquito Control and Wetlands Management District) and appoints the Board of Commissioners for each project. These mosquito control projects have a total of 157 participating communities, primarily coastal. Thus, the focus of the GEIR and this Certificate are primarily upon salt marshes and their attendant pest mosquito problems. The remaining nonparticipating communities, mostly located in the central portion of the state practice no mosquito control, hire private contractors or have their own community-based mosquito control operations (e.g., the local public works department or health board).

The intent of the GEIR was to gather, in single document information on methods of mosquito control and eradication in Massachusetts, and the environmental impacts of those methods. The GEIR has accomplished the goal of disseminating information on current mosquito control practices, and it has established the basis for viewing OMWM as the preferred control technique in salt-water marshes.

Comments received from the Department of Environmental Protection (DEP) and the Division of Fisheries and Wildlife (DF&W), in particular, will provide a good basis for future GEIR updates.

However, the GEIR falls short of the ambitious goal of providing the basis for all future mosquito control projects implemented by the County Mosquito Control Projects. The SRMCB and, the GEIR acknowledge that additional study and research work is necessary to truly document ~he effectiveness of mosquito control techniques and their impact on the environment, particularly as they relate to freshwater projects. The report concludes that it will take a renewed and concerted effort, involving additional resources, to complete a mosquito control program "master guidance document" that best serves the public and protects the environment. To that end, the SRMCB plans to update the GEIR on a yearly basis as new ideas and approaches to mosquito control become known.

Saltwater Marsh Regulation Issues and MEPA

Established mosquito control projects are generally exempt from the Massachusetts Wetlands Protection Act (MWPA). However, Section 401 *of* the Federal Clean Water Act requires applicants wishing to discharge dredged *of* fill materials to obtain a certification or waiver from their state water pollution control agency. A Section 401 water quality certification is treated as a state permit for the purposes of establishing MEPA jurisdiction. Therefore, for projects involving new ditching such as that required for Open Marsh Water Management (OMWM), the MC proponent has been obliged to file an Environmental Notification Form (ENF) for, projects affecting at least 1,000 square feet of salt marsh or 5,600-sf- *of* bordering-vegetated wetlands (BVW). The MEPA regulations require the filing *of* an Environmental Impact Report (EIR) for any particular work site that might require the alteration of one or more acres of salt marsh or BVW.

In November 1995 the then-Essex County Mosquito Control Project (now the Northeast Massachusetts Mosquito Control and Wetlands Management District) filed an ENF requesting a waiver from the EIR requirement- (EOEA #10567). Based on a number *of* "findings and conditions" discussed below, a waiver from the EIR requirement was granted in February 1996. The most significant of those findings .was that the Essex County Mosquito Control Project established "Standards for Open Marsh Water Management" which were endorsed by the Environmental Protection Agency, the National Marine Fisheries Service, the Massachusetts Audubon Society and others. These standards are widely viewed as the least harmful to the environment (of the various control techniques) and most efficient non-pesticide method for controlling salt marsh mosquitoes. The-proponent also committed-' to conduct a review of ten years of OMWM in Essex County to provide a basis for comparison and evaluation of mosquito control effectiveness and impact to the environment. It is generally recognized that the principal concern associated with OMWM arises" from the disposal of the dredge material on the marsh and the potential for invasion of upland plants (particularly <u>Phragmites</u>) that can occur with even slight elevation increases (i.e." 1-2 inches).

Open marsh water management (OMWM) projects are now underway in Essex (EOEA #10567), Norfolk, and Plymouth counties and are being expanded to include all problem marshes in those counties. The need to convert grid ditch systems is likely to continue and the salt marsh alterations will likely exceed the one-acre EIR threshold at several locations. Based on the success of OMWM,

The establishment of "Standards for Open Marsh Water Management," the conclusions of this GEIR, - and the commitment to continue to monitor the effectiveness of OMWM on the control of mosquitoes and, its impact on the environment, I am proposing, in a -forthcoming issue of the Environmental Monitor, to publish a Draft Record of Decision that would modify" the ENF and EIR thresholds for OMWM projects2, subject, at a minimum, to the following standards and conditions:

2 The MEPA regulations at Section 11.01 (2) (b)"(3) under" Review Thresholds" state, in part, that the review thresholds do not apply to..." a project that is consistent with a Special Review Procedure review document, or other plan or document that has been prepared with the express purpose of assessing the potential environmental impacts from future Projects, has been reviewed under or approved by any Participating Agency, unless the' filing of an ENF and an EIR was required by a decision of the secretary on any such review document, plan or document."

* That the Northeast Massachusetts Mosquito Control and Wetlands Management District "Standards for Open Marsh Water Management" be used as the statewide standard for OMWM projects.

* That the salt marsh be inventoried for the presence of rare and endangered species as determined by the Natural Heritage and Endangered Species Program (NHESP) habitat maps. If a project falls within such an area, NHESP will then determine if the area to be altered is an actual wetland habitat for rare species.

* Compliance with Section 401 of the Federal Clean Water Act and Federal Coastal Zone Consistency.

* Improved record keeping with respect to treatment location, type, efficacy and post treatment monitoring. For example, there are old ditches that still effectively control mosquitoes therefore their effectiveness should be monitored prior to going ahead with OMWM.

<u>MC Projects Impact on Freshwater Wetlands</u>

Freshwater wetlands are the dominant system in which freshwater physical control take place. Typically, this work consists of maintaining (i.e., moving blockages from previously ditched areas) existing ditches designed to remove standing water from the wetland. Though reducing standing water reduces mosquito breeding, there has been little research concerning the overall effects of these alterations on the modified wetland. Therefore, increased efforts are necessary to examine the environmental effects of draining surface water from wetlands.

As stated above, most of the freshwater mosquito control projects are geared to removal of blockages, be they natural or influenced by man, in wetland areas earlier identified as significant mosquito breeding habitats. These projects usually are classified as maintenance projects and are therefore exempt from MEPA review pursuant to Section 11.01 (2) (b) (3). However, there is a significant amount of work that needs to be completed in order to determine whether such work is cost effective, and whether a specific alternative is the *one* least damaging to the environment. As the report acknowledges there has been no study to date of the costs and benefits of Massachusetts mosquito control programs. However, this work has been done in other states, most notably New Jersey, which should be helpful in answering the following questions raised in the GEIR:

1) Establishing substantive human annoyance thresholds

2) Documenting how human activity patterns relate to Human Annoyance Thresholds (HAT) and economic factors; 3) Determining the cost/benefit of control; and

4) Correlating densities of immature mosquito (i.e., larvae) with future levels of biting annoyance.

These issues should be addressed and reported *on* in future GEIR updates. EOEA is prepared to help in this regard.

Standards for Freshwater Wetland Physical Control

The GEIR indicates that the SRMCB still needs to determine the appropriate control measure standards for MC projects in freshwater wetlands (described in the report as Upland Water Management operational procedures). These standards will need to

The current provocations *for* execution of mosquito control techniques are generally as follows:

1. Larval populations - by dip count (up to 20 per sampling area) and based *on* the population #s/10 or 5 dips then a decision is made to either use a pesticide or water management strategy.

2. Adult populations - No adulticiding is to take place at a regularly scheduled or prescribed time or place. Instead spraying is done based *on* annoyances, such as *five* bites per night; more than *one* landing per minute; *or* two complainant calls per square mile of area be coordinated with the DEP's Storm water Policy Handbook and Storm water Technical Handbook. In addition, many physical control projects lack adequate records, both with respect to the justification of a specific project, and with respect to site plans. Therefore, the SRMCB should work toward requiring better record keeping and notification practices, as discussed in the DEP comment (and the Coastal Zone Management letter for salt marsh alterations).

Integrated Pest Management (IPM)

The GEIR indicates that the strengths of the Massachusetts mosquito control IPM include the availability of and willingness to use least-toxic materials and willingness of existing control programs to try new strategies. In addition, a successful IPM program requires strong control programs and good pretreatment monitoring. The weaknesses of the IPM have been linked to a lack of funds for research and implementation and a lack of basic ecological data on the effects of control strategies in use or being planned. I do note that all of the pesticides -(larvicides and pesticides) used by MC projects have been approved by and are registered with the US Environmental Protection Agency. Given the rigorous process to gain market approval for a pesticide as well as the evolving nature of pesticide development, I agree with the conclusions of the GEIR that, for now, advances in reducing the risk of chemical use must come from improved targeting and increased use of water management and/or biological control techniques as encouraged by the IPM technique.

Eastern Equine Encephalitis (EEE)

The Massachusetts Department of Public Health (DPH) is responsible for surveillance for EEE Virus, risk assessment, public information and education on EEE disease. DPH is also responsible for recommendations for wide aerial vector control, interventions. DPH published its "Vector Control Plan to Prevent Eastern (Equine) Encephalitis" on (August 7, 1991). That protocol will govern when the next EEE outbreak occurs. The DPH has also developed a monitoring program that should bring EEE into the IPM framework. I urge that this work continue in order to avoid the adversity that accompanied the 1990 aerial spraying.

GEIR Recommendations and Conclusions

In addition to the issues discussed above, GEIR updates should emphasize how MC programs will incorporate the IPM strategy of keeping human annoyance below specified thresholds. Standards for control methodology should favor source reduction (e.g., OMWM in salt marshes) whenever possible, and employ larvicide control only when source reduction is not effective. Projects should work closely with the DEP water quality certification program and the NHESP to improve notices and documentation, and to minimize negative impacts of source reduction.

It is clear that the SRMCB and the MC projects have a good handle on their data and research needs. The stumbling block to successful completion of the analysis appears to be primarily fiscal in nature. I am pleased with the SRMCB's commitment to provide yearly updates, and I expect that issues brought forward in this Certificate, as well as the comments from the DEP and DF&W, will be addressed in the first yearly update. The SMRCB should meet with MEPA prior to finalizing the content of the GEIR update.

State of Massachusetts

Generic Environmental Impact Report on Mosquito Control

Executive Summary

I. Introduction

A Generic Environmental Impact Report (GEIR), covering mosquito control activities within the State of Massachusetts, was mandated under the provision of Massachusetts General Laws Chapter 30A Section 61 by the Massachusetts Environmental Policy Act (MEPA) Regulation 301 CMR 10.32(5)(b) adopted on January 25, 1979. The State Reclamation and Mosquito Control Board (SRMCB), the state agency that oversees all local and regional mosquito control programs in Massachusetts, administers the GEIR. The SRMCB consists of one representative each from the Departments of Environmental Management, Environmental Protection, and Food and Agriculture. The latter member presently serves as the Chairman of the Board.

This GEIR serves five purposes:

1. It provides a historic summary of all public activities in Massachusetts related to mosquito control, including an account of how mosquito control in Massachusetts has rapidly evolved over the past ten years.
2. It describes and quantifies Massachusetts mosquito problems and assesses the effectiveness of past and current control programs.
3. It assesses the real and potential environmental impacts of past and current control practices and describes and evaluates alternative strategies.
4. It gives an IPM framework for mosquito control in Massachusetts and provides a series of operational standards for mosquito control practices.
5. It makes recommendations relative to the future organization and practice of mosquito control in Massachusetts.

II. History, Organization and Practice Of Mosquito Control In Massachusetts

A. Legislation and Regulation

1. State Laws

The first Act of major importance is Chapter 252 of the Massachusetts General Laws (MGL), which establishes the State Reclamation and Mosquito Control Board (SRMCB) and procedures for creating local control projects. As now amended, 252 includes the important earlier provisions of Chapters 199 and 699 of the Acts of 1960. The word improvement (of wetlands) as frequently used in the narrative for this Act is misleading. Modification or alteration would have been a more appropriate and objective term to describe wetland drainage and filling activities.

The second Act is the Wetlands Protection Act (Chapter 131 of MGL) which regulates activities in the aquatic and brackish habitats where most mosquitoes breed. However, organized mosquito control is generally exempt from the provisions of this State Law. Hence, the Federal Clean Water Act as administered by the U. S. Corps of Engineers, is the principal regulating mechanism for mosquito-control alterations in wetlands. Regardless of the general exemption, mosquito control is not exempt from checking for the presence of rare and endangered species through the Massachusetts Natural Heritage Atlas, which lists estimated habitat maps for all rare and endangered species as developed by the Natural Heritage Endangered Species Program (NHESP).

The third Act which influences mosquito control in the Endangered Species Act (Chapter 131A of MGL) which prohibits the “taking” of rare and endangered species. It also protects “significant habitats,’ requiring a permit request for any work done in such areas.

The fourth Act of importance to mosquito control activities is the Pesticide Control Act (Chapter 132B of MGL) which regulates pesticide use by mosquito control practitioners.

Three additional Acts have the potential to impact mosquito control. M.G.L., Chap. 91. Sections 1-63 -- Waterways does not deal specifically with mosquito control but it does cover variety of activities associated with wetlands. Mosquito control is specifically exempted from the provisions of Sections 19A, 59 and 59A of this law but not from other provisions. M.G.L., Chapter 40. Section 5 - Boards of Health and Supervision, contains clauses that address the issue of appropriating money at the municipal level for mosquito abatement. M.G.L., Chapter 132A. Sections 13-16, 18 -- Ocean and Coastal Sanctuaries Act, Section 14, is designed to is to protect designated ocean sanctuary from any "...exploitation, development, or activity that would seriously alter or otherwise endanger the ecology or the appearance of the ocean, the seabed, or the subsoil (of the sanctuaries), or the Cape Cod National Seashore." Mosquito control does not take place in these sanctuaries.

2. Federal Laws

Federal laws which directly impact on mosquito control activities are Sections 401 and 404 of the Clean Water Act and the Endangered Species Act. All other federal restrictions governing wetlands and pesticides are covered by Massachusetts laws which impose restrictions and requirements that are equal to or greater than those in comparable federal law. The exception in the case of Section 404 arises because the state laws governing the ditching of wetlands exempt mosquito control but the Federal Clean Water Act does not.

Section 401 (Clean Water Act: Water Quality Certification) requires applicants wishing to discharge dredged or fill materials to obtain a certification or waiver from their state water pollution control agency (Massachusetts Bureau of Resource Protection, Division of Wetlands and Waterways). The U. S. Army Corps of Engineers will not permit a mosquito-control project that does not have a water quality certification.

Section 404 of the Clean Water Act (1972), calls for a system of permitting to be carried out by the U.S. Army Corps of Engineers with a review of al! permit applications by appropriate state and federal agencies. The activities that involve mosquito control which require a permit under Section 404 are cutting or clearing new mosquito ditches in tidal areas below mean high water and/or placing material excavated from existing or new ditches on salt marshes or freshwater wetlands.

The Endangered Species Act is designed to protect threatened and endangered species as listed on the Natural Heritage Atlas. To date, several programs have had to modify their control effort to take into account endangered species.

B. Current Mosquito Control Programs in Massachusetts

1. Formal Mosquito Control Projects

Of the 351 Towns in Massachusetts, 157 (or 44.7%) currently belong to the 9 organized mosquito control projects. Each project is managed by a superintendent who is hired and supervised by a Board of Commissioners representing the towns included in the project. Board members are appointed by the Board of Reclamation for designated terms (usually 3-5 years). Boards generally meet once or twice monthly to authorize major expenditures and to review policy and program progress.

The SRMCB is made up of three members, one each from the Departments of Food and Agriculture, Environmental Management and Environmental Protection, and exercises responsibility over all 9 projects. All projects have a Board of Commissioners appointed by the SRMCB. They represent the various towns within each project and exercise general control over the project.

The Nine Mosquito Control Projects of Massachusetts are Berkshire County, Bristol County, Cape Cod, Central Massachusetts, East Middlesex County, Norfolk County, Plymouth County and Suffolk County Mosquito Control Projects and the North East Massachusetts Mosquito Control and Wetlands Management District (formerly Essex County MCP). Nantucket conducts saltmarsh mosquito control including larviciding and open marsh water management.

2. Other State Agencies

The State Division of Forests and Parks discontinued its own mosquito control program in. The North East Massachusetts Mosquito Control and Wetlands Restoration District (NEMMCWRD) adulticides Salisbury Beach State Park and Bradley Palmer State Park in Hamilton as the need arises.

The Massachusetts DPH is responsible for surveillance for EEE Virus, risk assessment, public information and education on EEE disease, as well as providing advice to the State Reclamation and Mosquito Control Board on appropriate risk management for EEE. DPH is also responsible for recommendations for wide area aerial vector control interventions in the event of an EEE Public Health Emergency.

3. Federal Property

No mosquito control is carried out by the U.S. Department of Interior on any government-owned land in Massachusetts. The Cape Cod National Seashore is perhaps the U.S. Park Service property with the most significant mosquito populations. Park Service biologists have conducted their own studies on the environmental impact of Cape Cod mosquito control activities (Portnoy 1983, 1984a, 1984b) in adjacent estuaries and have lobbied against certain ditch cleaning practices on environmental grounds.

The East Middlesex MCP has been controlling mosquitoes in Great Meadows National Wildlife Refuge since 1987. Annual aerial Bti applications targeted against spring *Aedes* species began in 1987 and applications to control *Aedes vexans* began in 1990. The National Park Service reservation area (Paul Revere's Ride) in East Middlesex County has been declared off limits to any mosquito control activity (by East Middlesex MC project) except for ditch cleaning.

The NEMMCWRD has completed OMWM projects on the Parker River Wildlife Refuge.

C. Overview of Mosquito Control Practices in Massachusetts

Development and tourism along the Massachusetts coast is predicated on an ability to control the hoards of saltmarsh mosquitoes. Massive hand-ditching projects in East Coast marshes that took place during the WPA programs of the great depression. These ditching schemes, while quite effective in reducing saltmarsh mosquitoes, were engineered to make work rather than for optimum biological efficiency.

Early saltmarsh mosquito control projects, such as the one on Cape Cod in the 1930's, were organized prior to the availability of synthetic pesticides following World War II and these projects expanded and maintained the WPA-dug ditch system as their main strategy for mosquito control. After DDT, BHC, and other organochlorine pesticides became available, they were used to both supplement larval control and, for the first time, to conduct residual spraying for adults. Aerial application of these pesticides became commonplace in the 1950's and early 60's. The commercial mosquito control oil, Flit ML0, was introduced and widely used during the 70's.

Chemical control in freshwater marshes followed a similar pattern to that in salt marshes. Treatment of catch basins, first with oils followed by organochlorines and organophosphates, dates back to the beginning of most Massachusetts projects.

Physical control was limited to drainage maintenance and expansion in both salt marshes and freshwater areas. Biological control was not conducted.

By the early 1980s, concerns over pesticide use and wetlands loss began to encroach on mosquito control. Grid ditching for larvae and malathion for adults was no longer a desirable one-two punch. Control trends during the eighties and early nineties included: changing from traditional chemicals, such as Abate and Flit MLO, to Bti and methoprene for larval control, changing from malathion to permethrin or resmethrin for adult control, and changing from open tidal ditching to open marsh water management for saltmarsh mosquito control.

Source reduction remained a mainstay of the projects during this time period. Coastal communities shifted away from ditch maintenance towards open marsh water management. An emerging difficulty for control programs is the rise in wet basins mandated by stormwater runoff regulations.

The evaluation of control effectiveness by projects remained a combination of public complaints, adult counts, larval counts, and cases of human disease.

Chemical control, including *Bacillus* products and IGRs, and source reduction, including open marsh water management, now dominate mosquito control in Massachusetts. Aerial applications of larvicide have been used by several programs and are increasing. Biological control has not been emphasized except to the extent that OMWM creates conditions under which biological control operates. Public education is a minor component of most programs.

Saltmarsh mosquitoes are the primary target of coastal programs, whereas inland programs target spring-brood and summer-reflood *Aedes*. *Coquillettidea perturbans* is restricted by larval habitat to areas near cattail marshes but is a big problem in those areas. It complicates control efforts because controlling the larval stage with methoprene is expensive and adulticiding provides only short-term control.

Vector mosquitoes are not the primary targets of Massachusetts control programs, though projects can respond to requests for aid from DPH in times of EEE emergencies. *Culiseta melanura* larval populations may be incidentally reduced by treatment programs that target swamp areas.

At present, policy issues revolve around wetlands protection, water quality preservation, and endangered species. A chronic source of discussion is mosquito control's exemption from many of the state-level wetlands protection acts, making the Federal Section 401 Water Quality Certification (administered at the state level) and the state and federal Endangered Species Acts the primary means of "controlling" source-reduction work. Stormwater runoff regulations have increased the number of wet basins (retention, wet detention) in many areas, on occasion creating breeding habitat

The EEE outbreak in 1990 highlighted a need for stronger DPH policies regarding emergency mosquito control. As a result, the Massachusetts Department of Public Health published "Vector Control Plan to Prevent Eastern (Equine) Encephalitis" (August 7, 1991) and implemented an extensive Public Education Program in 1991.

The combination of large, affluent human population (both permanent residents and visitors) and prolific pest mosquito populations near Massachusetts coastal marshes suggests that the public may always demand control programs to deal with this problem.

Open Marsh Water Management (OMWM) projects now underway in Essex, Norfolk, and Plymouth counties are being expanded to include essentially all problem marshes in those counties. The trend to convert grid-ditch systems to OMWM is likely to continue.

There are certain salt marshes where old ditches are effectively controlling mosquito production and perhaps where new OMWM activities might actually disrupt the marsh more than maintaining the status quo. Thus, OMWM plans should not be automatically prescribed for every saltmarsh without first examining this issue. Larviciding is still carried out in salt marshes.

Inadequate budgets, the inability to conduct more source reduction work and a lack of applied research into more environmentally sound mosquito-control practices continue to restrict the actions and effectiveness of mosquito control programs in Massachusetts.

III. Current Abatement Strategies and Their Impacts

A. Chemical Control

Twenty-six different insecticide formulation distributed among fifteen product lines were used for mosquito control in Massachusetts between 1993 and 1995 (Table 1). Eight of these formulations used Bti as the active ingredient, five were methoprene-based, three were resmethrin-based, two each were pyrethin-based or malathion-based, and there were one each of temephos, isoctedecanol, and mineral oil. Of these, Acrobe (Bti) and Vectobac AS (replaced by 12AS) are no longer produced. Arosurf-MSF (Isoctadecanol) was off the market for several years but is now available under the name Agnique MMF. Abate 4E was not used in either 1994 or 1995 and both the Malathion 10EC and the Resmethrin product (EPA reg. # 4-339-53853) were used in small amounts only

Of the insecticides used, all of the larvicides were classed as Category IV (Category I is the most toxic, Category IV the least) materials by EPA. Bonide Mosquito Larvicide, available but not used, is border line between Category III and IV. VectoLex CG, a new *Bacillus sphaericus* product, is Category IV. All adulticides are in Category III, with permethrin and resmethrin having essentially replaced malathion.

Chemical impacts include acute, direct impacts to target and non-target organisms, and chronic or indirect effects to target and non-target organisms. In general, acute toxicity effects are generally easiest to measure and avoid, particularly when the organism is large and the effect is death. However, less visible acute toxicity, such as

Table 1. Chemicals used in Massachusetts mosquito control, 1993 through 1995

Trade Name	EPA Registration Number	Active Ingredient(s)	% Active Ingredient	Toxicity Class	Other Warning Statements
LARVICIDES					
Abate 4E	241-132	Temephos	43	IV	
Acrobe[a]	62637-1-241	Bti[b]		IV	
Arosurf-MSF[c]	42943-8	Isooctadecanol	100	III	
Altosid					
Briquets	2724-375-64833	Methoprene	7.9	IV	
XR Briquets	2724-421-64833	Methoprene	1.8	IV	
Pellets	2724-448-64833	Methoprene	4.0	IV	
Bactimos					
Briquets	43382-3	Bti	10	IV	
Granules	37100-43-2217	Bti	0.2	IV	
Pellets	37100-42-2217	Bti	0.4	IV	
GB-1111	8898-16	Petroleum Hydrocarbons			
GB-1356	8898-16				
Teknar HP-D	2724-365-64833	Bti	0.8	IV	
Vectobac					
AS	275-52	Bti		IV	
12AS	275-66	Bti	1.2	IV	
Granular	275-50	Bti	0.2	IV	
ADULTICIDES					
Malathion 8EC	34704-119	Malathion	8	III	
Permanone 10EC	4816-688	Permethrin	10	III	
Permanone 31-66	4816-740	Permethrin	31	III	
Resmethrin	4-339-53853	Resmethrin		III	
Scourge 4+12	432-716	Resmethrin	4	III	RESTRICTED USE CLASSIFICATION Due to acute fish toxicity Retail sale to and use only by Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicators Certificate
		PBO	12		
Scourge 18+54	432-667	Resmethrin	18	III	
		PBO	54		
MATERIALS REGISTERED BUT NOT USED - LARVICIDES					
Altosid					
Liquid	2724-392-64833	Methoprene	5	IV	
Liquid Con	2724-446-64833	Methoprene	20	IV	
Bonide Mosquito					
Larvicide	4-195	Mineral Oil	98	III-IV	
VectoLex CG	275-77	*B. sphaericus*	50[d]	IV	
MATERIALS REGISTERED BUT NOT USED - ADULTICIDE					
Fyfanon ULV	4787-8	Malathion	95	III	

[a]No longer marketed
[b]*Bacillus thuringiensis* var. *israelensis*
[c]Now marketed as Agnique MMF

methoprene toxicity to Chironomid larvae in duck-breeding habitat (SPRP 1996), may cause harm in the short term, and, since it often goes unnoticed, may be harmful in the long run as well. Mosquito Control Programs have limited, but not removed, the threat of acute impacts to non-targets by using pesticides that are more specific to the target, less toxic to non-targets, and/or have a shorter persistence in the environment. The amount of pesticide used, as in the case of ultra-low-volume sprays versus mist sprays, has also been reduced.

Chronic effects that may occur include the long-term effect of the chemical on targets (development of resistance to the chemical) and non-targets (reduced reproductive success), and long-term effects caused by a change in the ecosystem brought about by removal of the target organism. The current assumption is that the mosquitoes controlled are those which have escaped the food web and which, therefore, may be eliminated without undue risk to the food web itself. That mosquitoes are remarkably productive cannot be denied. That removing millions of larvae from the food web of a salt marsh by the application of Bti has no effect on that ecosystem deserves additional study, as does the role of mosquitoes in the ecosystem, and the effect of mosquito control on that ecosystem.

Control personnel should take care to avoid chemical applications where mosquito larvae are not present or are present in very small numbers, should use control measures that do not harm existing predator complexes, and should limit control to areas where control is necessary, allowing natural cycles to continue in areas where human activity and the risk of disease transmission is slight. One argument made in favor of Altosid is that it does not kill the young larvae, leaving them available as food for the existing predator complex.

Barring the discovery of new materials, both adulticiding and larviciding are presently be conducted with the least risk imposing materials available for the foreseeable future. Advances in reducing the risk of chemical use must therefore come from improved targeting and increased use of water management and/or biological control techniques.

B. Biological Control.

Biological control includes attacks on the pest species by other species and manipulation of the pest species itself. Only the former has been used in Massachusetts. Note that, for the purposes of this GEIR, Bti, *Bacillus sphaericus* and methoprene are classified as chemical controls and open marsh water management is classified as a physical control. A case can be made for classifying each of these strategies as a type of biological control.

Biological control agents are grouped into three categories: predators, parasites and pathogens. Predators include both vertebrates and invertebrates and may attack both adult and immature stages of mosquitoes. In general, biological control is much more feasible in managing permanent water mosquitoes than temporary water forms.

There are three basic strategies for utilizing all biological control agents: 1) increasing existing natural enemy populations by habitat improvement, 2) one-time introduction of sustainable exotic agents from other regions or habitats, and 3) augmentation of natural or exotic enemy populations by repeatedly releasing non-sustainable, lab-reared (or field collected) organisms. To date only the first, increasing fish habitat through OMWM, has been used in Massachusetts. Bti could arguably be classified as a biological control agent but its application technique and mode of action functioning as a stomach poison more closely resemble a pesticide than a biological control agent *per se*. *Bacillus sphaericus* may more closely fit the model of repeatedly releasing non-sustainable lab-reared organisms as there is evidence to suggest that it recycles within the environment.

There are important reasons why biocontrol is not more widely used against mosquitoes. First, the differences in biology of the various species of mosquitoes make it unlikely that any one control agent will operate across a wide range of species. Second, mosquito breeding is wide spread, making it difficult for a biological control agent to find, or be placed in, all breeding areas. Third, predators such as bats and purple martins, may eat mosquitoes but prefer to eat other, larger insects. Finally, there is a high cost associated with sustained releases of a biological control agent and there are not, at this time, control agents available that require a single, or a few, releases to become established.

The impacts on biological control have not received much attention because biological control has not been exercised to any great degree in Massachusetts. However, one of the primary reasons *Gambusia* are not being used in Massachusetts is the fear that they might displace native species of fish, thus altering the natural biota, not by predation but by competition for the same resource.

C. Habitat Modification (Physical Control)

1. Salt Marshes. Open Marsh Water Management was originally developed for New Jersey salt marshes (Ferrigno 1970, Ferrigno and Jobbins 1968, Ferrigno et al. 1969), this strategy basically attempts to overcome the limitations of ditching by incorporating other water management strategies. Reservoirs (which permanently hold water and sustain larvivorous fish) are created in selected tidal pools or large shallow pans and are connected via small shallow ditches to surrounding mosquito breeding depressions. This customized

approach to marsh management represents the least deleterious and most efficient non-pesticidal method for controlling saltmarsh mosquitoes.

New England coastal wetlands have been heavily impacted by man (Shisler 1990). However, evidence concerning the negative impact of saltmarsh ditch maintenance activity is mixed. The principal concern is with disposal of the spoil on the marsh and the alleged invasion of upland plants that can occur with even slight elevation increases (i.e. 1-2 inches). OMWM effects are apparently limited (Wolfe 1996) but all alterations must be designed so that raised patches of marsh elder and other boundary plants are not created.

2. Freshwater Wetlands (exclusive of Vernal Pools). Palustrine wetlands, including emergent, scrub-shrub and forested wetlands, are the dominant system in which Massachusetts freshwater physical control take place. Typically, this work consists of maintaining existing ditching designed to remove standing water from the wetland, thereby reducing mosquito-breeding habitat. For most MCPs, this type of work (source reduction) makes up a large percentage of their control effort. Though reducing standing water certainly reduces mosquito breeding, there has been little research concerning the overall effects of these alterations on the modified wetland. Ditch systems can become problems in their own right, producing mosquitoes if left unmaintained. Most of these systems were never designed specifically for mosquito control and their other, primary function, such as removing runoff from large parking lots, may cause considerable damage to the ecosystem, leaving the MCP to clean up, or at least deal with, someone else's mess.

The majority of drainage systems currently maintained by MCPs were not initially constructed for mosquito control and the effort of MCPs today is almost entirely restricted to removing blockages to existing flows, rather than enlarging or straightening channels to increase flow. Road sand and yard waste represent two of the most common obstructions MCPs are called upon to remove from existing drainage networks. New developments also can cause dramatic changes in the sediment load in streams, despite regulations designed to prevent such problems. Road sand, yard waste and increased sediment load from development can all have impacts on a stream that are as greater or greater than regular ditch maintenance. Because MCPs are often involved in removing manmade sediments from streams, a system under appropriate ditch maintenance may function more closely to a natural system than one in which manmade wastes are allowed to accumulate unabated.

The three broad categories of wetlands alteration are outright loss, changes in the abiotic system and changes in the biotic community. Filling and/or draining wetlands to convert them to upland is a mosquito-control practice that has been all but eliminated in Massachusetts. There is no indication that MCPs are intentionally reducing wetland acreage in order to control mosquitoes. However, the fact that the wetlands boundary remains essentially unmoved by a mosquito-control alteration does not mean that changes to the ecosystem have not occurred.

Changes in the abiotic system and biotic community are deeply intertwined, though physical control most often causes abiotic changes which then cause biotic changes. For channels changes in flow rates, microhabitats, sediment load, sedimentation, and groundwater interactions can all occur. For wetlands (outside of channels) changes can include lost water-storage capacity, increased sedimentation and pollutant load, changes in water depth, and changes in groundwater hydrology.

When a stream is altered to improve water flow for the purpose of removing standing water, either within the stream or from adjacent wetlands, a number of changes may take place. By definition, improving water flow increases runoff. This, in turn, may decrease the surface-water storage capacity of the wetland system and decrease the capability of the wetland to retain load (suspended solids). This may increase the load of the water moving through the stream (Brown 1988). Increasing runoff into a given stream tends also to increase erosion, which further increases load (Williams & Feltmantle 1992). Not only may total flow be increased, but alteration tends to increase peak flow, which is associated with reductions in faunal diversity (Hynes 1972). Increased peak flow may also lead to faster drying in intermittent streams.

Maintenance for the purpose of reducing mosquito breeding also includes removing obstructions within streams. Tree branches and fallen trees are a particularly important part of the stream environment, providing food, living space, concealment from predators, protection from abiotic conditions and emergence sites (Ward 1992). Removing these obstructions diminishes the variability of the stream ecosystem.

The hyporheic zone, the interstitial space between the substrate particles in a stream bed, is an important part of the habitat for many stream species (Williams & Feltmantle 1992). Excessive drying can reduce the viability of the hyporheic zone.

Sedimentation, both within stream beds and in wetlands into which streams flow, is a problem because it can alter the stream bed composition, thereby altering the fauna, and can clog interstitial spaces, thereby reducing the hyporheic zone and/or reducing groundwater recharge. Sediments can also increase exposure to pollutants as they provide additional sites for pollutant binding while suspended, and then carry the pollutants to the benthic fauna. Sedimentation, however, results most often from sources other than mosquito-control activities, and it is the primary cause of maintenance work.

When new channels are constructed, they are typically designed to change standing-water wetlands to soil-saturated wetlands (New Jersey DEP 1997). Though this reduces mosquito breeding it can also adversely affect other organisms that require standing water for periods other than peak flow.

Increased drainage also has an effect on groundwater. Precipitation and inflow determine the amount of water initially available to a wetland for ground water recharge (Todd 1972). Increasing the amount of water removed from the wetland and/or stream prior to percolation downwards may decrease groundwater recharge.

What is most needed is a comprehensive understanding of the true ecological costs of physical alterations for mosquito control. This is particularly important because, although the environmental effects of pesticides receive the lion's share of concern, it is likely that the long-term effects of physical controls have a more profound effect on the environment than does pesticide use (Buchsbaum 1994). This may be especially true today with the switch from broad-spectrum, more-persistent pesticides to methoprene and Bti.

3. Vernal Pools. Vernal pools form in contained depressions in which water stands for a period of several months, generally from mid- to late winter through the spring. Water either comes in the form of snow melt or spring precipitation or can be a result of a rising water table. Some pools dry down within two or three months, others may only dry when the water table is lower than normal, resulting in a pool that is semi-permanent. Regardless, a key feature of vernal pools is that they undergo periods of dry down. Vernal pools may have permanent inlets but do not have permanent outlets (Kenney 1995). There are numerous obligate species for vernal pools, the most visible of which include fairy shrimp, the wood frog (*Rana sylvatica*) and several species of salamander (*Ambystoma* spp.).

Mosquito species such as *Ae. canadensis* and *Ae. excrucians* also use vernal pools for breeding. From a control perspective, vernal pools are important because, due to increasing protection, vernal pool habitat is often left undeveloped while the land adjacent to the pool is built up. As a result, many new developments surround known breeding sites. Regardless of the wisdom of developing so close to vernal pools, mosquito-control personnel are charged with controlling the mosquitoes coming from the pool.

4. Rare and Endangered Species. Operating under the assumption that it is rare and endangered species which are most likely to be lost from a wetlands system first, then reductions in habitat

diversity, alterations from the natural state, and frequent disturbances will all work against these species. Channelization of streams reduces diversity by removing obstructions, straightening the channel and increasing flood levels. Wetlands changed from standing-water to saturated-soil regimes have been drastically changed from their natural state. Maintenance is ongoing, as is the disturbance it causes.

However, to what extent does mosquito control contribute to the these problems? First, Massachusetts MCPs do not channelize streams, as their certification manual calls for following the existing meanders. Second, MCPs work neither in historically undisturbed, nor currently undisturbed streams. There is good reason to argue that there is no specific “natural” state that can be assigned a ditch dug by man and intermittently filled with road sand and grass clippings. Even with natural streams, the “natural” habitat in which they flow has long been altered and continues to be altered.

The Natural Heritage and Endangered Species Program (NHESP) was created in order to conserve and protect those plants and animals not hunted, fished, trapped or commercially harvested in the state. The program’s highest priority is to inventory rare and endangered species and to develop conservation plans through research, management and habitat protection for those species

The NHESP also reviews proposed alterations to wetlands habitats under the Wetlands Protection Act (M.G.L. c. 131, s. 40 and regulations 310 CMR 10.00). NHESP has produced a series of estimated habitat maps for rare and endangered species (Massachusetts Natural Heritage Atlas) which proponents of a given alteration are required to check. Should a project fall within an estimated habitat, NHESP will then determine if the area to be altered is actual wetland habitat for a state-listed species. The results of the NHESP determination are given to the inquiring MCP.

In Massachusetts, the species that have caused modifications in mosquito control practices are the Blue-spotted salamander (*Ambystoma laterale*), Mystic Valley amphipod (*Crangonyx aberrans*), and banded bog skimmer (*Williamsonia lintneri*). In addition, ditch maintenance in vernal pond areas has been curtailed to protect this type of habitat. Other animals for which concerns have been raised are the yellow-spotted turtle and osprey.

Under the current system mosquito-control maintenance activities are exempt from the Massachusetts Wetland Protection Act, leaving the federal 401 Water Quality Certification Act and both the Massachusetts and Federal Endangered Species Acts as a method for regulating maintenance. Unfortunately, water quality, while important, does not address the issue of changing habitat and the presence or absence of a rare or endangered species has little to do with the merits of a given drainage project. Again, a more comprehensive understanding of the true ecological effects of mosquito control is required to better determine the cost/benefit ratio for different types of mosquito control, including their effect on rare and endangered species.

Physical control by water management may increase predation, as in OMWM, or may eliminate predator and prey as when wetlands are drained to soil saturation. Mosquito breeding must be thoroughly documented before new work is done. Because disturbances may displace some species, and because predator species tend to rebound more slowly than their prey, maintenance work should be conducted only when necessary.

D. No Program

Many communities in Massachusetts have chosen to forego mosquito control. These town are usually outside of the enzootic EEE zone so the risk of human diseases transmitted by mosquitoes is viewed as practically nil by these communities. In addition, they are not located near salt marshes and their attendant pest mosquito problems. The mid-section of Massachusetts, where most no-control communities occur, also has a more rural character, less wetland , lower human populations, and a lower mean family income than most eastern areas with organized MCPs.

In addition to risk-benefit considerations, other criteria for weighing the control/no control option are 1) the feasibility of successfully reducing annoyance below the human annoyance threshold, and 2) the adequacy of community resources for reducing annoyance to acceptable levels.

It is difficult to measure the impact of choosing the no control option. The example of towns that have left, and later rejoined, mosquito control projects is perhaps the only available basis for estimating public opinion concerning such impact. However, no documentation of annoyance levels, cases of disease, recreational dollars spent, etc., was ever attempted in these towns when they had mosquito control versus when they did not.

The number of towns in MCPs declined in the late eighty's. Economic factors, not environmental concerns, were the dominant reason given for withdrawal. This trend has reversed itself significantly in the last several years. The 1990 EEE problem is probably one reason, coupled with the fact that several coastal programs tried the no-control option and found mosquito numbers rose quickly.

IV. IPM as it Relates to Mosquito Control.

A. Definition of IPM

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 in general the negative impacts of mosquitoes are reduction in outdoor use, particularly recreational, and disease transmission. These negative impacts are all ongoing in Massachusetts. 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. Other than exposure of non-targets to pesticides (unavoidable) none of these problems have been documented in Massachusetts.

Before an IPM program can be put in place, a strong organization must be in place. 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.

1. Surveillance and Monitoring. 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.

The habitats in which breeding occurs or in which the adult mosquitoes are most numerous must also be identified. Wetlands should be mapped as should drainage 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.

2. 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.

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.

3. Prevention and Control. Prevention refers to maintaining a pest population below the action threshold for control, whereas control refers to bringing a pest population back under the threshold for control. Source reduction is the primary prevention technique for mosquito control in that it directly reduces the area in which mosquitoes can breed. Maintaining water flow through drainage networks is the primary freshwater mosquito control technique while ditching used to be the primary prevention in salt marshes. Programs that do not stress source reduction cannot make long-term reductions in mosquito populations.

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.

Control, in the sense of killing mosquitoes, is dominated by chemical use for adult mosquito control. For larvae a combination of chemical control and OMWM (biological/physical control) is used.

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).

4. 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. IPM for Mosquitoes as it is Currently Practiced in Massachusetts.

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. No Project in Massachusetts has undertaken such an effort.

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.

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. 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.

The cost/benefit of various control options (e.g., permanent vs. temporary control) also has been evaluated

(Ofiara & Allison 1986a, 1986b) but this should not be confused with the cost/benefit of control programs.

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).

Overall, Massachusetts mosquito-control IPM strengths include, strong control programs, good pre-treatment monitoring, the availability of and willingness to use least-toxic materials and a willingness of existing control programs to try new control strategies. Weaknesses include a lack of funds for research into new strategies, a lack of funds to implement new strategies and a lack of basic ecological data on the effects of control strategies in use or being planned. A final wildcard is EEE which dramatically increases the stakes when attempting to determine the correct response. DPH has developed a monitoring program that should bring EEE into the IPM framework.

V. Standards For Mosquito Control

A. Standards for Monitoring and Control.

Pesticide applications in an IPM program require monitoring insect populations and comparing data with pre-established thresholds for treatment. In addition, post-treatment evaluation is required to ensure the treatment worked as planned and did not have unintended side-effects.

1. Larval Populations: The primary technique for larval population counts is the dip count. It is hard to standardize dipping technique but, for the purposes of this document, it is assumed that dips are taken in undisturbed pools (the field person is aware that disturbing the water and/or casting a shadow over the water will cause mosquitoes to dive, thereby lowering counts) known by the field personnel to be typical of the breeding area being monitored. For large-scale work, dipping will be done at permanent, marked (or easily located) dip stations. For small sites such as drainage basins and woodland pools, dips will be taken at random throughout the site. Up to twenty dips per site will be taken unless the count for treatment and/or water management is exceeded with a smaller number of dips. Specifics for various types of work are given in Table 2.

Table 2. Specifics for monitoring larval (& pupal) populations of mosquitoes for determining control.

	No Treatment	Pesticide Application	Water management	# Sites for large-scale work
Salt Marsh	<1 per 10 dips	1+ per 10 dips	5+ per dip[a]	1 dip station per 250 acres

Freshwater				
Ground	<1 per 5 dips	1+ per 5 dips	Variable	Not applicable
Aerial	<1 per 10 dips	1+ per 10 dips	Not applicable	1 dip station per 250 acres

[a]Numerous additional factors go into determining water management options for OMWM.

Projects have an obligation to ensure that all alterations function as intended without adverse effects on the environment. Post-alteration work for water management will also monitor vegetative re-growth, changes in fauna and notes on whether or not the hydrology of the site is as intended. When projects have historical data that establishes a pattern of breeding at a given site, they may conduct pre-treatment work.

2. Adult Populations. No adulticiding program will be conducted on a routine, pre-scheduled basis (i.e. once per week, regardless).

a. Monitoring for Adulticiding

Table 3. Adult mosquito monitoring techniques and thresholds for adulticiding.

Monitoring Mechanism	Rate to trigger adulticiding
Light traps	Human-biting mosquito counts exceed five per night
Landing counts	Landing count rates exceed one per minute
Complaint calls	When complaint calls exceed two per geographical area (this area will vary but assume approximately one square mile)

Projects should increase their efforts to understand the impact of adulticiding on mosquitoes. Projects should cross-reference complaint calls with adulticide applications and record the number of calls coming in the week before an application and in the following week (this work may be done during the winter for the previous season). In addition, projects should conduct before and after landing counts and/or light-trap counts for ten percent of their adulticide applications. Landing counts should be taken within 48 hours pre- and post-application at the same location both times. Light trap samples should be from the same trap and for the same time period before and after treatment. Where possible, non-treated areas similar to the treated area should be checked to determine population trends outside the spray zone.

B. Standards for Physical Control. Altering or eliminating mosquito breeding sites range from proper disposal of tires through analyzing drainage systems to creating entire new open marsh water management systems. Physical Control refers specifically to alterations to breeding habitat to prevent mosquitoes from maturing to adulthood. Physical Control is divided further into three types:

Source Elimination: Completely eliminating the breeding site not just the mosquito breeding. Source elimination is generally limited to breeding habitats created by humans in non-wetland areas.

Source Maintenance: Maintaining potential breeding sources in such a way that mosquitoes cannot become a problem.

Source Reduction: Reducing the ability of an area to breed mosquitoes. It differs from source maintenance in that the existing habitat is breeding mosquitoes whereas, if a maintenance program is running as designed, mosquito breeding should not occur. Once a source reduction project is completed, it will, in most cases, require at least some source maintenance in order not to return to being a mosquito-breeding habitat.

The Massachusetts DEP has recently (March 1997) issued a Stormwater Policy Handbook and a Stormwater Technical Handbook. These provide guidelines for stormwater management and should be used to determine appropriate control measures that MCPs should implement. Currently, the primary causes for concern regarding physical control is that there aren't always adequate records of the reasons for a specific maintenance project nor are there also adequate site plans by which it can be determined that increases in ditch cross-section and/or length are not occurring.

C. Standards for Chemical Control.

Projects must comply with regulations for aerial applications of pesticides.

For truck-mounted adulticiding, projects should notify the public through the print media, between March 1st and May 1st of each year, as to the areas that may be treated, the pesticide to be used and a number to contact for more information or to request exclusion from treatment.

As education is a primary aspect of an IPM program, projects are encouraged to develop educational flyers covering such aspects of their work as pesticide use, water management, and property-owner mosquito control. Flyers may either be developed in-house or be obtained from the state or other agencies. Aside from the pesticide applicator recertification requirements, programs are urged to provide opportunities for staff to increase their knowledge about mosquitoes, wetland, and mosquito control.

D. Standard Operating Procedures during EEE problem.

When surveillance data points to increasing levels of EEE risk, DPH notifies the SRMCB and regional MCP superintendents. The EEE Surveillance Program informs MCP superintendents of isolations of EEE in their districts and the districts, in turn, provide feedback to DPH regarding population and life stage indices for critical mosquito species. At certain defined interim levels of risk as outlined in the "Vector Control Plan," MCPs may be asked to increase their ground control larvicide and/or adulticide applications in response to increased EEE virus activity. The SRMCB is responsible for contracting with appropriate mosquito control applicators in the event that aerial EEE vector control is recommended by DPH.

VI. Recommendations

A. Legal, Organizational and Fiscal Aspects of Massachusetts Mosquito Control

The organizational structure and funding for Massachusetts mosquito control programs, be they regional or town based, rests predominately at the level of town government, although the state legislative bodies have a direct influences over eight of the nine MCPs' annual budgets (only East Middlesex is not so affected). In contrast, the overseer of mosquito-control activity in Massachusetts is the State Reclamation and Mosquito Control Board. This is a loose arrangement for delivering a public service that is best applied at a regional level. Lack of control effort in one town can greatly effect the efficiency of control efforts in neighboring towns.

Enabling legislation has been written in a patchwork manner so that there is currently little consistency from project to project. For example, towns in Barnstable County (and formerly in Berkshire) are all members of their respective regional MC project and no individual community may withdraw from the program without changing the legislation as did Chap. 119 of the Acts of 1982 in the case of Berkshire County. This provides an assurance of fiscal and organizational stability that is lacking in other programs. For example, the Essex County and Central Massachusetts projects both went through considerable upheavals in membership between 1988 and 1993. Fortunately, the other projects have remained remarkably stable over the past decade. Maintaining and improving stability, both in membership and funding, is a desirable goal.

This uncertain fiscal picture is further compounded by the fact that all MC projects in Massachusetts are seriously under-funded. In other states, with progressive MC programs, the per capita expenditure varies from $2 upward. In Massachusetts, it averages about $0.50 (based on $2 per household of 4 people). In addition, many other states provide supplemental state funds to encourage non-chemical control efforts and for supportive research and educational activities. No such state support exists in Massachusetts. When supplemental state support has come, it has been for chemical adulticiding in the wake of EEE threats.

To a large extent, funding dictates the control approaches that can be pursued. IPM, source reduction, 1arval control, and adult control represent the four major options in their order of decreasing cost and efficiency.

Thus, poorly funded programs are forced into more reliance on less efficient and more controversial techniques. Larger, better-funded, and stable regional projects can invest in better paid and trained employees, better surveillance and public education programs, and expensive equipment such as helicopters which can broaden the options for safer and more efficient larval control (e.g., granular larviciding with Bti and methoprene).

Given the fact that several different state agencies are concerned with mosquito control activities, the current system of interagency responsibility for overseeing MC activities (i.e., State Reclamation and Mosquito Control Board representing 3 different state agencies) is perhaps the best compromise arrangement. On the other hand, the level of general support services that projects and towns receive from this Board seems to be inadequate.

Recommendations

That new and comprehensive enabling legislation be drafted, reviewed, appropriately revised, and passed into law, which will bring all MC control activity in Massachusetts under the same organizational, fiscal and operational guidelines. This legislation should provide for the following:

1. The State Reclamation and Mosquito Control should have the following personnel:
   a. An Executive Director @ approximately $45,000 per year
   b. An Engineer @ approximately $35,000 per year
   c. An Entomologist @ approximately $35,000 per year

   Not only would this staffing permit the state to conduct research into mosquito control, it would provide a team for rapid response to EEE threats in communities that are not members of established MCPs. This staff would also provide services such as incorporating DEP stormwater management guidelines into Massachusetts MCP Upland Water management operational procedures.
2. An operations budget, above and beyond the normal needs of the SRCMB, for research and development. A minimum of $50,000 per year is suggested.
3. A competitive grant fund (funded by the state, administered by the Executive Director of SRMCB and advised by an ad hoc panel of outside experts) to support IPM related research and delivery programs within the state mosquito control enterprise. This should provide support for studies such as: cost/benefit analysis of mosquito-control programs; development of human annoyance thresholds (HAT); improved methods for monitoring and predicting mosquito population levels;

development, evaluation, and implementation o£ new, non-chemical mosquito management techniques (e.g., open marsh management and biological control); management of pesticide resistance, drift and other use exposures; impact of MC activities on surface and ground water, and on non-target organisms; and the biology and role of selected species in disease transmission.

4. The SRMCB should establish a committee to work with their staff to develop best management practices (BMPs) for all aspects of mosquito control, the results of their work being used to update the GEIR on a regular basis. The committee should include four mosquito-control superintendents, four representatives of environmental agencies (federal, state or private) and one at-large member to serve as chairperson. Their first order of business should be to develop a set of BMPs for freshwater drainage maintenance for mosquito control. These BMPs should establish strict definitions for projects in which the mosquito control exemption from the Wetlands Protection Act may be applied.

5. MCPs must have the authority to deny requests for maintenance work that does not have a mosquito-control component. Because these requests are often made by the same persons or municipalities which provide funding to the MCPs, the SRMCB must be willing to act as an appeals board, to which a request for work may be sent by an applicant in the event the mosquito control program denies the request.

6. Limit mosquito control activity to regionally based regional mosquito control programs which can be organized by the appropriate public vote. The SRMCB should organize the regional based mosquito control programs and appoint project or district commissioners. The SRMCB should select Commissioners from candidates proposed by authorized Boards/individuals from the cities and towns of the mosquito control projects or districts.

7. A flexible and appropriate system of tax assessment which allows for budgets that are adequate to provide for the implementation of the most contemporary and least risky strategies for controlling mosquitoes.

8. A legal system whereby all major zoning and construction plans in the Commonwealth are reviewed by the executive director of SRMCB and the appropriate county MC director for their potential impact on mosquito populations and human health.

B. Operational Aspects of Massachusetts Mosquito Control

Operational programs in Massachusetts could legally be using chemicals (approved by EPA and the Massachusetts Pesticide Board) that are significantly more hazardous than those used in current practice. This suggests that knowledge and sensitivity for the environment and human safety are generally being considered by the existing control programs. As already indicated, funding levels seldom allow projects to follow the optimum operational course. Despite these fiscal constraints, projects have significantly changed their operational methods in recent years toward more source reduction work such as the Open Marsh Water Management projects in Essex, Norfolk and Plymouth Counties. Most projects also use more selective and environmentally compatible larvicides such as Bti and methoprene.

The operational recommendations that follow are predicated on additional and adequate funding being available for implementation.

Recommendations

1. All MC Projects should build their programs around the IPM strategy of keeping human annoyance below threshold levels as given in the Standards of this GEIR.
2. Control methodology should be source reduction whenever possible and larvicidal control when it is not. Projects should work closely with the DEP water quality certification program and the Natural Heritage Endangered Species Program to minimize negative impacts of source reduction to wetland habitat and/or rare or endangered species. The most target-selective and environmentally compatible larvicides (e.g., Bti, methoprene) should be used whenever possible regardless of cost considerations.
3. Saltmarsh mosquito control efforts should emphasize OMWM. All OMWM proposals should include plans for filling many of the old grid ditches in Massachusetts salt marshes which do not function in a productive way and which must regularly be cleaned in order to prevent breeding in the ditches themselves. This will gradually eliminate the controversy over the continuing need to clean these ditches and the problem of what to do with the resulting spoil that is created.
4. Document location, length, and cross-section(s) of all drainage systems maintained by the project and have that information available in an easily understood format for public inspection.

Exemption from the permitting process extents only to those drainage systems for which adequate historical records of maintenance work exist.

5. The SRMCB should create a list of pesticides approved for mosquito control in Massachusetts. Adulticides should be from Categories III and IV and larvicides should be from Category IV.

6. Adulticiding should only be carried out in emergency situations involving disease threats or pest densities which consistently exceed the human annoyance threshold.

7. For large-scale adulticiding, only ULV-cold fogging should be used. For spot treatment around recreation areas or other areas where public events are to be held, portable mistblowers using permethrin as a residual pesticide can be used.

8. Aerial applications should be restricted to granular formulations in areas where drift could be a significant problem. Sometimes some drift is desirable so as to reduce the chance of gaps between application swathes. In such cases a liquid formulation may be a better choice. At this time liquid formulations are also significantly cheaper, making larger applications, and more effective control, easier. Increased use of helicopters for aerial larviciding in coordination with the use of drift-suppression agents and technologies should be encouraged (particularly for enhanced larval control in inaccessible habitats such as salt marshes, wooded swamps, vernal pools, etc.).

9. Projects should file a post-treatment report for aerial applications with the Pesticide Bureau which gives location and acreage actually treated. The pre-application forms do not always accurately represent what actually happened.

10. Chemical-use reporting needs to be monitored to ensure uniformity and accuracy in reporting. Previous reports contained such problems as no units are given on the 1993 through 1995 Cape Cod report for Bactimos (BTI), two different EPA registration numbers for Bactimos are given in the 1993 Cape Cod and Central Massachusetts MCPs reports, and briquets are variously reported in terms of number of briquets, pounds of briquets or pounds of active ingredient. The Pesticide Bureau should insist that yearly chemical-use reports be filled out according to standardized procedures. Reports should be checked as they come in to ensure that standardized reporting procedures are followed.

11. All pesticide storage areas should be equipped with smoke, fire and security systems. A standard procedure should be developed for the disposal of all insecticidal materials used in Massachusetts for mosquito control. The State Pesticide Board should encourage manufacturers of such products to market reusable containers. A standard procedure should be developed for the clean-up of accidental spills of insecticides. Proper use of absorbent materials and the disposal of such materials are necessary. Proper attire during formulation and application of insecticides should be made mandatory for all individuals involved in these processes.

C. Research Needs

There is a need in the mosquito control process in Massachusetts for a strong, operationally focused, research effort in freshwater wetlands, exclusive of chemical application techniques. This is not to condemn current research efforts, for we know more about EEE mosquitoes than ever before, have improved saltmarsh mosquito control dramatically, and have made improvements in both chemicals used and methods of chemical use over the past decade. But there is a need for research to assess the environmental impacts and efficacy of the current MCP programs relative to the freshwater environment.

Additional research on topics such as long-term effects of OMWM, economically viable control of *Cq. perturbans*, and mosquito control in endangered species habitats also require attention.

<u>Recommendations</u>

1. For water management practices, monitor impacts on animals on a case-by-case basis, depending on the site and establish vegetation transects to document changes in wetland vegetation.
2. Develop a unified data base that documents mosquito populations on an ongoing basis from regular monitoring sites. Establish state standards for monitoring mosquitoes and provide training to mosquito control project staff in data collection and management.
3. Conduct comparative studies with different management approaches (e.g. pesticide applications vs. water management).
4. Develop a Geographic Information System (GIS) with known breeding sites and areas of historical water management activities.
5. Qualify sites on the basis of need for control, based on breeding (potential or actual), mosquito

species, proximity to human activity, level and type of human activity, and type of wetland habitat affected.

6. Create an ongoing research partnership with NHESP to document wetland types, etc.. Mosquito Control Projects have knowledge and expertise about wetlands that could be invaluable to NHESP.

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II. INTRODUCTION

A Generic Environmental Impact Report (GEIR), covering mosquito control activities within the State of Massachusetts, was mandated under the provision of Massachusetts General Laws Chapter 30A Section 61 by the Massachusetts Environmental Policy Act (MEPA) Regulation 301 CMR 10.32(5)(b) adopted on January 25, 1979. The State Reclamation and Mosquito Control Board (SRMCB), the state agency that oversees all local and regional mosquito control programs in Massachusetts, administers the GEIR. The SRMCB consists of one representative each from the Departments of Environmental Management, Environmental Protection, and Food and Agriculture. The latter presently serves as the Chairman of the Board.

A special committee designated as the Citizen's Advisory Committee (CAC) was established under MEPA Regulation 301 CMR 10.10(3) to assist the SRMCB and the MEPA office in developing a scope of what should be included in the GEIR. Following the committee's preparation of the GEIR scope and SRMCB approval of this document, potential GEIR contractors were invited to submit proposals in 1985. A subcommittee of the CAC was appointed to screen GEIR proposals and make recommendations on the awarding of the contract. A contract agreement with the University of Massachusetts (Dr. J. D. Edman) was signed in September of 1985, and the initial Draft GEIR was prepared.

The CAC received comments on the initial Draft GEIR but no action was taken on the comments nor was a Final GEIR published. In 1995 this situation was brought to the attention of the Executive Office of Environmental Affairs and the SRMCB was instructed to complete the GEIR. Due to the substantial time lag between the original Draft GEIR and the renewal of the process, a Notice of Project Change was filed with the Massachusetts Environmental Policy Act Unit in July, and the revised Scope (Section I above) was approved September 23rd of the same year. Mr. George Christie, a private mosquito-control consultant, was hired by the SRMCB committee to rewrite the GEIR to conform with the new scope.

This GEIR serves five purposes:

1. It provides a historic summary of all public activities in Massachusetts related to mosquito control, including a account of how mosquito control in Massachusetts has rapidly evolved over the past ten years.
2. It describes and quantifies Massachusetts mosquito problems and assesses the effectiveness of

past and current control programs.

3. It assesses the real and potential environmental impacts of past and current control practices and describes and evaluates alternative strategies.

4. It gives an IPM framework for mosquito control in Massachusetts and provides a series of operational standards for mosquito control practices.

5. It makes recommendations relative to the future organization and practice of mosquito control in Massachusetts. The recommendations were formed in collaboration with the CAC and the SRMCB and were based on a joint review of the background information summarized Sections III through VII of this report.

III. HISTORY AND CURRENT ORGANIZATION AND PRACTICE OF MOSQUITO CONTROL IN MASSACHUSETTS

A. Legislation and Regulation

1. Overview

There are four basic legislative Acts which regulate mosquito control activities in Massachusetts. Often associated with each of these Acts are regulations (or CMR), which are developed by the state agency charged with administering the provisions of the legislative acts. These serve as the rules or policy used in the day-to-day enforcement of the Acts.

The first Act of major importance is Chapter 252 of the Massachusetts General Laws (MGL), which establishes the State Reclamation and Mosquito Control Board (SRCMB) and procedures for creating local control projects. As now amended, 252 includes the important earlier provisions of Chapters 199 and 699 of the Acts of 1960. The word improvement (of wetlands) as frequently used in the narrative for this Act is misleading. Modification or alteration would have been a more appropriate and objective term to describe wetland drainage and filling activities. Although the word "improvement" will be used in this report, in order to maintain continuity with the Act, the reader should be aware that "modification" would be a more accurate description.

The second Act is the Wetlands Protection Act (Chapter 131 of MGL) which regulates activities in the aquatic and brackish habitats where most mosquitoes breed. However, organized mosquito control is generally exempt from the provisions of this State Law. Hence, the Federal Wetlands Protection Act as administered by the U. S. Corps of Engineers, is the principal regulating mechanism for mosquito-control alterations in wetlands. Regardless of the general exemption, mosquito control is not exempt from checking for the presence of rare and endangered species through the Massachusetts Natural Heritage Atlas, which lists estimated habitat maps for all rare and endangered species as developed by the Natural Heritage Endangered Species Program (NHESP). NHESP also overseeing vernal pool certification, not by actively certifying pools itself, but by certifying pools brought to its attention by individuals or organizations such as the Vernal Pool Association.

The third Act which influences mosquito control in the Endangered Species Act (Chapter 131A of MGL) which prohibits the "taking" of rare and endangered species. It also protects "significant habitats,' requiring a permit request for any work done in such areas.

The fourth State Act of importance to mosquito control activities is the Pesticide Control Act (Chapter 132B of MGL) which regulates pesticide use by mosquito control practitioners. Except as already mentioned, Federal Laws do not generally influence local mosquito control practices except where Federal lands are involved. This is true because Massachusetts State Laws are generally more restrictive than their Federal counterparts.

What follows is a brief summary of State and Federal Laws and regulations which may relate to mosquito control activities.

2. State Laws

a. MGL Chap. 252 as currently amended - Improvement of Lowlands. it should be noted that there are ongoing efforts to modify this law, one in particular is designed to require IPM practices in mosquito control.

Sections 1-4. The State Reclamation and Mosquito Control Board (SRMCB) consists of 3 members representing the Departments of Food & Agriculture (DFA), Environmental Management (DEM), and Environmental Protection (DEP). The SRMCB is housed in the Department of Food & Agriculture. Members of the SRMCB (appointed by the commissioners of their respective departments) receive no additional compensation for their service on the SRMCB, but are entitled to any expenses incurred in the performance of their duties. Although not required by this statute, the SRMCB elects one member to serve as Chairman. The SRMCB has the authority, under this chapter, to (1) drain or flow (flood) a lowland with multiple ownerships, (2) remove obstructions in rivers or streams leading to low lands, or (3) eradicate (abate) mosquitoes in infested areas whenever it considers such activities to be necessary or useful. This chapter requires that the SRMCB make an annual report. Employees (engineers, assistants, agents, etc.) may be hired by the SRMCB to carry out the provisions in this chapter. These parties are empowered to enter any private land which the SRMCB wishes to examine or survey.

Section 4A. The Commonwealth, acting through a State department or the Metropolitan District Commission, and any municipality, may, in its proprietary capacity, take part in lowland improvements described in this chapter. In their governmental capacity, these agencies/municipalities may take such action when the public health, safety, or convenience will be promoted by lowland improvements. The improvements made must be in accordance with Section 5A of this chapter. A petition by proprietors for lowland improvement does not require a majority rule. The governing bodies of the agencies/municipalities must act on the petition. Notice of a hearing before the SRMCB will be given to all petitioners, governing bodies, and to all known proprietors whose land would be affected by such improvements. Municipalities are authorized to raise and appropriate money for the improvements.

Section 5. The majority (in either value or area) of proprietors of any area, may petition the SRMCB to improve the area. Upon receipt of the petition and appropriate fees, the SRMCB will investigate and survey the land to determine the practicability and advisability of the proposed improvements. If the improvements are deemed practicable and advisable, the SRMCB will give public notice of the petition in a regional newspaper and by registered mail to each known owner, stating the date of a hearing to be held by the SRMCB. After the hearing and upon the SRMCB's approval of the proposed improvements, the SRMCB will determine whether a reclamation district is necessary.

If a district is recommended, the SRMCB will appoint 3, 5, or 7 district commissioners to form a reclamation district. Commissioners will receive no more than ten dollars for each day of actual service plus compensation for expenses incurred in the performance of their duties. The district is responsible for paying such compensation and expenses, as well as the actual cost of improvements. The district must reimburse the SRMCB's contributors the money that was expended for improvements. However, this does not include any money that was given to the district for improvements, but returned to the SRMCB because it was not needed or used. The SRMCB may fire and hire commissioners for cause.

Section 5A. The SRMCB may determine that although improvements should be made, a reclamation district need not be formed. When the SRMCB is petitioned by an agency/municipality (as described in Section 4A), it will notify the petitioners of the estimated expense of the proposed improvements. Once money is received to cover the expense, the SRMCB will designate a name under which improvements will be made and sends the money to the State Treasurer who holds it in a special fund. When needed, the money may be disbursed on warrants drawn by the SRMCB. The SRMCB will appoint one or more commissioners to oversee the improvements. The commissioner(s) receive a compensation (fixed by the SRMCB), plus expenses incurred in the performance of their duties. The SRMCB has the authority to hire and fire commissioners for cause. Any excess funds are returned to the contributors (in proportion to their contributions). If funds contributed are insufficient to complete the improvements, the SRMCB will notify the contributors of their shares of the additional cost. Improvements will not continue until these additional funds are received by the SRMCB. In order to carry out the improvements, the SRMCB will have the powers conferred under Sections 2, 3, 4, 5 (except reimbursement of expenses), and 8. Commissioners have the powers conferred under Sections 12 and 13 (provided any property taken by eminent domain is taken in the name of the municipality, and the municipality (1) authorizes the taking, (2) assumes liability for damages, and (3) has complied with all laws concerning land taking). Money for which the municipality is liable may be contributed by persons benefited by the improvements, in proportion to their respective benefits, or otherwise. Any municipality which has withdrawn from a mosquito control project may, with approval of the board and upon such conditions as the board my prescribe, rejoin by public vote.

Section 5B. Local Boards of Health (in areas not in mosquito control districts), and mosquito control district commissioners may determine a mosquito breeding area to be a public nuisance. They may give the owner of the area a written notice stating that a mosquito breeding area exists on their land, causing a public nuisance. The notice should also give treatment methods and set a deadline for abatement. If the owner refuses to abate, the Board of Health or the mosquito control district commissioners may abate the nuisance (in a manner approved by the SRMCB). In doing so, they may hire all necessary assistants who may enter upon the land for abatement purposes.

Section 6. For the purpose of organizing a mosquito control district, the district commissioners will call a meeting of the proprietors of the lands to be improved. A majority in interest (in either property value or area) must be present at the meeting, otherwise the meeting will have no power to act. At the meeting, a temporary clerk and a moderator are elected. The moderator submits the question of organizing a reclamation district (under the provisions of this chapter) to the proprietors. If accepted by a majority vote, the proprietors will then elect, by ballot, a district clerk and treasurer (one year terms), as well as 3-member prudential committee (three years terms; one member is replaced every year). At each annual meeting, elections will be held to replace the clerk, the treasurer, and one member of the prudential committee. At meetings, the district may borrow money for necessary expenses, and may issue notes, payable in not more than two years. These notes are subject to the provisions of Section 10 and MGL Chapter 44. The proceeds will be held by the district treasurer.

Subsequent meetings will be called by the clerk at the request of the commissioners or at least two proprietors. If the clerk neglects or refuses to call the meeting, the meeting may be called upon a warrant from a justice of the peace. Notices of meetings must be posted in two or more public places or should be mailed to each proprietor 7 days before the meeting. Vacancies in the office of clerk, treasurer, or member of the prudential committee may be filled at any legal meeting. If necessary, the prudential committee may appoint a person to temporarily fill a position until an election can be held or until the officer is no longer disabled.

The prudential committee is in charge of expenditures for maintenance of the improvements, and exercises the authority conferred upon the district by law.

The treasurer receives the district's money (except as otherwise specified in Sections 6 to 14A). He/she makes payments under the direction of the district or the prudential committee, in accordance with the requirements of Sections 1 to 14B and MGL Chapter 44.

By-laws may be adopted by a district formed under this section. These by-laws are subject to the approval of the SRMCB. The district has the rights and powers authorized to it under Section 14A for carrying out and maintaining improvements. The members of the district are the owners of land lying within its limits.

A district will not be dissolved without authorization by the General Court. This authorization will not be given until a provision has been made for payment of the obligations of the district.

Section 6A. Any district established under this chapter may buy the following insurance coverages:

(1) liability for bodily injuries and damage to property;

(2) liability for workmen's compensation;

(3) fire insurance (covering, among other things, loss by destruction or damage to buildings or personal property);

and (4) motor vehicle collision insurance.

Section 7. Once a district is organized, the commissioners will make surveys and investigations and will prepare a plan delineating district boundaries and proposed improvements. They will determine the total expense of the proposed improvements, along with the percentage to be paid by each proprietor (determined by estimating the benefits less any damages caused by the improvements. The proprietor will be awarded any damages in excess of the benefits. The commissioners will report their plan and estimates to the SRMCB who will approve, disapprove or modify them.

The commissioners must also submit a copy of their determination to each proprietor (hand-delivered or by registered mail). A proprietor has 15 days in which to file any objections with the SRMCB. The SRMCB will notify all proprietors of the receipt of any objections within 30 days; and at least 7 days after this notice is given, the SRMCB will hold a meeting to consider the objections and to make a decision. If the proprietors are not satisfied with this decision, they may petition the County Superior Court.

Once the percentages to be paid by each proprietor have been determined, the SRMCB will record in the

Registry of Deeds (1) a description of the area to be improved; (2) a copy of a plan; and (3) an estimate of the amount to be assessed from each parcel.

Section 8. If the SRMCB feels that certain improvements will benefit public health as a whole and should, therefore, be paid by the Commonwealth, the SRMCB must separately estimate that part of the expense, to be included with other estimates under MGL Chapter 29, Section 4.

Section 9. After recording the description, plan and estimate (from Section 7), the commissioners will call a meeting to decide on the method of financing (options are included in Sections 10 and 11). Approval of proposed expenditures requires a majority vote of a body of proprietors representing a majority interest in both acreage and value of the district's area.

The district commissioners may petition the county commissioners to vote to pay for the first expenditures involved in making improvements. Upon approval, the county treasurer may issue bonds or notes, payable within 25 years to defray expenses. Payment of principal and interest will be made by the county and repaid to the county by the district.

Section 10. The district may vote to adopt any of three methods of financing. It may raise money, by assessment or contribution, and deposit the funds required to cover the estimated expenses with the State Treasurer (payments are made as provided in Section 14). The district may take out a temporary loan in anticipation of assessments from district members and, thereby, pay for the improvements as the work is performed. The district may issue notes or bonds, payable for the amount of the estimated expense, on condition that the initial payment is made within 5 years of the issue date, and that the entire amount is paid within 25 years.

Indebtedness is subject to MGL Chapter 44 and other MGL's applicable to notes and bonds of districts. Money received from the sale of notes and bonds will be deposited with the State Treasurer. The State Treasurer will credit the district account for any district expenses that benefit the public health of the Commonwealth. Money remaining after payment of the total expenses will be paid to the district treasurer to redeem outstanding notes and bonds.

Section 11. The district clerk will certify to the assessors the amount of money voted to be raised and paid annually (on account of the interest and principal due) along with the amount to be paid by each proprietor. A copy of this certification must be filed with the SRMCB. The certified amount will be assessed from the land of the proprietors and will be committed to the local tax collectors. Each week, the tax collectors will remit the money collected from the assessments to the district treasurer. Assessments will be considered a financial obligation under law, upon the recording of the description, plan and estimate (under Section 7), and will continue for two years as of July 1 of the year of assessment (i.e., reassessments are made every 2 years).

Section 12. If Sections 1-7 have been complied with, and payments for expenses have been arranged, the commissioners will carry out the improvements, as approved by the SRMCB. The commissioners may hire persons to perform the work under their direction. If improvements are for public use, the commissioners may take lands, easements, and rights in lands (under MGL Chapter 79), and may purchase and convey property within and beyond the limits of the Commonwealth if necessary. Any person damaged in his property (by an action under this and the following section), may recover damages from the district (as provided in MGL Chapter 79). These damages will constitute a part of the total expense of the improvements.

If the commissioners find it necessary to regulate water levels by operating floodgates or dams on the land of a person not a party to the proceedings (e.g., a person outside the district), the commissioners must give reasonable notice to the proprietor. The proprietor may appeal this work by petitioning the County Superior Court within 30 days after receipt of the notice. Until the appeal is determined, the commissioners must suspend the work.

The commissioners are required to submit to the SRMCB the bills incurred in meeting the cost of required improvements (under Section 14B), on a monthly basis. Once inspected and approved by the SRMCB, these bills will be rewarded to the County or State Treasurer who will make payment from available funds. The SRMCB must also approve bills for maintenance or further improvements reported by the prudential committee and the commissioners (as provided in Section 14A). Once approved, payment will be made by the district treasurer.

Section 14A. A reclamation district organized under this chapter may vote to undertake further improvements, and to incur debt (as provided in Section 10). Original improvements must be completed before this vote is passed. The district may also vote to request the SRMCB to appoint commissioners to carry out these further improvements (as provided in Section 5). Or, the district may authorize its prudential committee to carry out. these further improvements. In either case, both the prudential committee and the commissioners acting under this section will have the same powers as authorized under Section 5. The district will notify the SRMCB of their vote and the prudential committee/commissioners will submit to the SRMCB its/their plans for carrying out the improvements. Assessments from district members to pay for the improvements (modifications) will be made in the manner provided in Section 11.

Section 14B. No person obtaining additional water power or water by the work contemplated in Section 1 - 14B will gain the right to its use, nor may a person be entitled to compensation if the additional water is reclaimed. No water power may be developed by a district under this chapter except by vote of the district and approval of the SRMCB.

Anyone who obstructs or injures any structure constructed under the provisions of Sections 1 - 14B will be fined not less than ten dollars. In addition, the SRMCB may attempt to recover from the perpetrator any damages incurred. The provisions in Section 5A will govern the disposition of money recovered.

The mayor and aldermen or selectmen will receive two dollars for each day of service. The city or town clerk will receive (for recording the petition), the fee provided by Clause (68) of Section 34 of MGL Chapter 262.

Any party aggrieved by the mayor's and aldermen's or selectmen's refusal to make such an order, may petition the county commissioners. The county commissioners will proceed as if the petition had been originally filed with them.

Section 24. Greenhead fly control projects may be established, with the approval of the SRMCB, in any town or city along the seacoast, by vote of the city council/selectmen. By the same vote, any two or more adjoining cities or towns may form a district within their combined areas.

For these areas, the SRMCB will appoint 3 district commissioners. They will be paid a fixed compensation, not exceeding five dollars per day, along with other expenses incurred in the performance of their duties. Compensation and expenses will be paid by the district. The SRMCB may fire and hire Commissioners for cause. The duties of the commissioners will be established by the SRMCB.

Votes to form a district are binding for five years. Any city or town may vote to withdraw from the district within 60 days, but not less than 10 days, of any "anniversary date" of its original vote. They must notify the SRMCB within this time frame, as well.

Any city or town may vote to join an existing district, with the approval of the SRMCB.

Each project will determine its maximum annual budget, and will report its determination to the SRMCB. In the case of districts, the commissioners will make this determination. The SRMCB will, in turn, determine the proportionate share of the budget that each member municipality is to be held accounted for. The SRMCB will then report its determination to the treasurer of each member municipality.

One third of the budget will be paid by the member municipalities within a district in proportion to the salt marsh area within its boundaries. Another third will be paid by the Commonwealth. The final third will be paid by the member towns/cities within a district in proportion to their respective taxable valuations. A project consisting of a single municipality is not entitled to subsidy by the Commonwealth.

Payments of each municipality's share of the budget will be made to the State Treasurer. Towns/cities may also raise money in advance to anticipate its liability. These funds would be held by the State Treasurer, as well, and would be credited against the municipality's liability.

Projects will be allocated funds annually from the State Treasury to eliminate or control Greenhead flies in accordance with the predetermined control strategy (prepared and devised by the SRMCB to effect the greatest measure of relief). Such work must be performed under the direction and control of the SRMCB. Additional control efforts may be carried out as long as additional funding is provided, such as funds voluntarily deposited with the State Treasurer for such purposes.

b. MGL Chap. 132B -- Pesticide Control Act (From the Code of Massachusetts Regulations 333 CMR 2.00 -10.00)

General Information

The Massachusetts Pesticide Control Act was inserted as MGL Chap. 132B of the Acts of 1978 (Chapter 3) as an emergency law and took effect immediately. The purpose of the Act is to have the laws of the Commonwealth conform with federal requirements on registration and certification of pesticides as set forth in the Federal Insecticide, Fungicide, and Rodenticide Act, Public Law 92-516, as amended, (FIFRA), and the federal regulations thereunder. To this end, the Massachusetts Pesticide Control Act creates administrative mechanisms to regulate the labeling distribution, sale, storage, transportation, use and application and disposal of pesticides. The Massachusetts Act also establishes standards and sets forth prohibitions with regard to each regulatory function. The responsibility for implementing the commands of the Massachusetts Pesticide Control Act is distributed by the Act among three governmental bodies:

i. Department of Food and Agriculture (DFA). The DFA has been designated as the state lead agency for implementation and administration of the Act and the Massachusetts pesticide program.

The Act charges the DFA with a wide range of specific regulatory functions and empowers it to promulgate and adopt regulations, standards and forms as are necessary for implementation and administration. Among the duties assigned to the DFA by the Act are:

a. Entering into cooperative agreements and contracts in matters related to the Act and FIFRA.

b. Taking actions necessary to secure for the Commonwealth the benefits of FIFRA and other federal legislation.

c. Establishing advisory councils.

d. Declaring pests and devices to be subject to the provisions of the Act.

e. Establishing the fee and preparing and accepting the applications for experimental use permits.

f. Establishing requirements for licensing and supervising pesticide dealers.

g. Establishing requirements for certifying, licensing and supervising various categories of pesticide applicators.

h. Controlling both storage and disposal of pesticides.

i. Issuing administrative orders to prevent unreasonable adverse effects on the environment or violations under the Act.

j. Right of entry and inspection as needed to administer the Act. Within the DFA, the pesticide regulatory functions shall be under the administrative supervision of a Pesticides Program Director.

ii. Pesticide Board. The Act creates within the DFA a Massachusetts Pesticide Board.

The Board's responsibilities entail advising the Commissioner of Food and Agriculture with respect to the implementation and administration of the Act The Board also hears appeals of those aggrieved by the actions or decisions of the DFA or the Subcommittee of the Pesticide Board. The Act, additionally, assigns the Board the responsibility for approving a variety of departmental actions within the DFA. Among the actions requiring Board approval are:

a. All regulations, standards and forms proposed by the DFA to implement and administer the Act.

b. Appointment of the Pesticides Program Director.

c. Cooperative agreements and contracts with respect to the Act and FIFRA.

d. Establishment of advisory councils.

e. Declarations of pests and devices to be subject to the provisions of the Act.

The Commissioner of Food and Agriculture or his designee serves as the Chairman of the Pesticide Board. Other members include the Commissioner of Environmental Protection or his designee, the Commissioner of Fisheries, Wildlife and Recreational Vehicles or his designee, the Commissioner of Environmental Management or his designee, the Commissioner of Public Health or his designee, the Director of the Division of Food and Drugs or his designee and the seven persons appointed by the Governor, one of whom has been engaged in the commercial production of a plant-related agricultural commodity for at least the preceding five years on land owned or rented by him, one of whom has been an active commercial applicator of pesticides for at least the preceding five years, one of whom has expertise in the health effects of pesticide use, one of whom is a physician, one of whom is experienced in the conservation and protection of the environment, and two of whom represent the public at large. Each member is appointed for a period of four years, except for persons appointed to fill vacancies, who serve for the unexpired term.

The appointive members of the Board receive fifty dollars for each day or portion thereof spent in the discharge of their official duties and are reimbursed for their necessary expenses incurred in the discharge of their official duties.

iii. Subcommittee of the Pesticide Board. The Act creates a subcommittee within the Pesticide Board of the DFA.

The subcommittee is responsible for registering all pesticides for use in the Commonwealth and for issuing all experimental use permits.

The Director of the Division of Food and Drugs serves as the Chairman of the Subcommittee. Other members include the Commissioner of Food and Agriculture or his designee, the Commissioner of Environmental Management or his designee, and the Commissioner of Public Health or his designee, and one person appointed by the Governor, who has been actively engaged in commercial application of pesticides for at least the preceding five years who is a member of the Pesticide Board.

c. 333 CMR 10.03 (21-23) - Amendments of 1983.

Amendment (21) to the Pesticide Regulations provides a list of conditions that must be met prior to all non-agricultural pesticide applications by aircraft. It calls for public notification of abutting Landowners 2-10 days before the application as well as notification of the Department of Food and Agriculture and the contractor. Application sites must be recorded on U.S.G.S topographical maps and records kept for 2 years. Amendment (22) deals with the right of exclusion from pesticide applications of property owners and their tenants. Methods are outlined for requesting exclusion and for properly marking the boundaries of property to be excluded. Exclusion requests are not honored if public health or agricultural threats exist or if a recently introduced pest is being contained.

Amendment (23) requires a permit from the Department of Food and Agricultural for all private applications of pesticide by aircraft. Aerial applications for mosquito control are specifically exempted from this provision along with a few other classes of applications.

d. M.G.L., Chap. 91. Sections 1-63 -- Waterways

This law does not deal specifically with mosquito control but it does cover variety of activities associated with wetlands. Mosquito control is specifically exempted from the provisions of Sections 19A, 59 and 59A of this law but not from other provisions. As amended by Chap. 373 of the Acts of 1969, the Act makes provisions so that the use of oil for mosquito control in any lakes rivers, or tidal waters or flats under MGL 252 is exempt from the provisions of Section 59 and 59A of Chapter 91, provided it conforms to the rules and regulations and of the State Pesticide Board.

e. M.G.L., Chapter 40. Section 5 - Boards of Health and Supervision.

Clause (36) and (36C) have MGL Chapter 40 Section 5 refers to the appropriation of money by towns for mosquito abatement:

(Clause 36). At any town meeting, a town, whether or not a member of a mosquito control project, may appropriate money for lowland improvement (modification) and mosquito abatement. Outside agencies may be contracted by the Board of Health to carry out mosquito control, provided the SRMCB is notified. This outside agency is responsible for filing a detailed annual report of their mosquito control program with the SRMCB.

(Clause 36C). A town or city that is a member of a mosquito control project may appropriate money in addition to the amount assessed by the project for mosquito abatement. The abatement activities must, however, be carried out under the supervision and control of the mosquito control project.

f. M.G.L., Chapter 131. Section 40 - Wetlands Protection Act.

The Wetlands Protection Act controls the use of freshwater and coastal wetlands by establishing a public review and decision-making process through which certain activities affecting wetlands may be regulated. The Act is administered by local conservation commissions (or the mayor or selectmen of towns without conservation commissions), and the Department of Environmental Protection (DEP). Any proposed project that may affect a wetland area must be approved by the local conservation commission. The proponent must apply for a permit with the conservation commission and the DEP, who will evaluate the proposed project to determine whether any land is subject to the jurisdiction of the Act. The Act is complemented by 310 CMR 10.00, which provides the conservation commission, and DEP with standard definitions and procedures by which to implement the Act. Proposed alterations to wetland habitats of rare wildlife must also be reviewed by the Natural history & Endangered Species Program (see Endangered Species Act below).

Mosquito control activities are exempt from the provisions of the Wetlands Protection Act, provided that the activities are carried out in compliance with Clause (36) of Section 5 of MGL Chapter 40, MGL Chapter 252, or of any special act. Nonetheless, there is still some debate concerning whether the exemption applies only to the maintenance of existing structures or also includes new structures. (see page 25)

g. Section 40A of Chapter 131. Inland Wetlands Restriction Act. Section 105 of Chapter 130. Coastal Wetlands Restriction Act.

The Inland Wetlands Restriction Act, together with the Coastal Wetlands Restriction Act makes up the statutory basis of the Massachusetts Wetlands Restriction Program. The objective of both Acts is to promote and protect the public safety, property, wildlife, fisheries, water resources, flood plain areas, and agriculture by restricting or prohibiting the altering or polluting of inland and coastal wetlands. Although the areas and interests protected are basically the same as those protected by the Wetlands Protection Act, the Wetlands Restriction Acts set forth a planning program that is not dependent on a proponent's initiative to apply for a permit. Through the Massachusetts Wetlands Restoration Program, inland and coastal wetlands are mapped out in each city and town. After a public hearing, a Restriction Order is issued by the administering agency, which prohibits certain activities in the wetland areas. The Order is then recorded in the Registry of Deeds and is binding to all present and future owners of the property.

Two regulations, which correspond to the Acts, are 302 CMR 4 and 6. These regulations contain the rules for adopting coastal and inland wetland orders. The Department of Environmental Management is the legal authority for both Restriction Acts. However, the administrative responsibility has been taken on in recent years by the DEP. A statutory transfer of the Massachusetts Wetlands Restriction Program is pending.

Mosquito control, as authorized by MGL Chapter 252, is exempt from the Wetlands Restriction Act.

h. M.G.L., Chapter 131A. Massachusetts Endangered Species Act.

This Act prohibits the "taking" of rare plants or animals. This includes all plants or animals listed as Endangered, Threatened, or Special Concern by the Massachusetts Division of Fisheries and Wildlife. Fines and jail terms may be imposed for illegally taking a rare species. This Act also protects "significant habitats," which can be so designated after a public hearing process. Permits must be issued for any work in significant habitats.

The primary agency for determining rare species status and significant habitats is the Massachusetts Natural History & Endangered Species Program (NHESP) run from the office of the Division of Fisheries & Wildlife. NHESP has developed a series of Estimated Habitat Maps for state-listed rare species (contained in the Massachusetts Natural Heritage Atlas), which assist mosquito-control programs in determining the presence or absence of rare or endangered species.

Mosquito control activities are not exempt from the Endangered Species Act and care must be taken to ensure programs are in compliance with the Act. Both pesticide applications and storm water drainage are considered alterations and require permitting.

i. M.G.L., Chapter 132A. Sections 13-16, 18 -- Ocean and Coastal Sanctuaries Act

The following areas in Massachusetts are protected under the Act: the Cape Cod Ocean Sanctuary, the Cape Cod Bay Ocean Sanctuary, the Cape and Islands Ocean Sanctuary, the North Shore Ocean Sanctuary, and the South Essex Ocean Sanctuary. Section 13 of the Act demarcates the ocean sanctuaries, all of which extend approximately three miles seaward from a point on the mean low water line. The purpose of the Act, as described in Section 14, is to protect each ocean sanctuary from any "...exploitation, development, or activity that would seriously alter or otherwise endanger the ecology or the appearance of the ocean, the seabed, or the subsoil (of the sanctuaries), or the Cape Cod National Seashore."

The Ocean Sanctuaries Act does not require the issuance of permits other than those already required by law. In consequence, the Department of Environmental Management, the State agency authorized to oversee the Act, serves as a trustee rather than as a permitting agency. All other State and local permitting agencies are responsible for conducting their activities in conformation with the Act. Regulation 302 CMR 5.00 complements the Act.

Although not specifically exempted from the provisions of the Act, mosquito control activities are not performed within the boundaries of the ocean sanctuaries.

j. Acts of Enabling Legislation Establishing Mosquito Control Projects

Except for Cape Cod, all 10 current and disbanded MC Projects in Massachusetts were established after World War II when mosquito control first appeared both technically and economically feasible on a wide scale. The most recent were the Central Massachusetts and Suffolk County projects formed in 1973/74. Almost without exception, these projects were created as a result of lobbying efforts by local citizen groups who were concerned about both outbreaks of mosquito-borne disease (i.e. EEE) and biting annoyance created by high densities of mosquitoes. Local legislators and city selectmen or boards of health played roles in shepherding through the necessary legislation. The Cape Cod Chamber of Commerce was instrumental in the creation of the MC Project on the Cape. The Board of Reclamation often assisted local citizens and legislature with their efforts. especially in the case of the more recently established projects.

The East Middlesex and South Shore (disbanded in 1981) projects were formed under Chapter 252 of the General Laws. The remaining eight were created by special legislation (individual project descriptions below). An important change in the entering and leaving procedure was made in 1991 when state legislation required towns, upon joining a project, to commit to a minimum of a five-year membership. This provides both stability of funding to the projects and enables a more comprehensive pest management plan to be put in place (single-year memberships place emphasis on immediate results; multi-year memberships place emphasis on long-term results).

3. Federal Laws

Federal laws, which directly impact on mosquito control activities, are Sections 401 and 404 of the Clean Water Act and the Endangered Species Act. All other federal restrictions governing wetlands and pesticides are covered by Massachusetts's laws, which impose restrictions, and requirements that are equal to or greater than those in comparable federal law. The exception in the case of Section 404 arises because the state laws governing the ditching of wetlands exempt mosquito control but the Federal Clean Water Act does not.

a. Section 401. Clean Water Act: Water Quality Certification.

This section requires applicants wishing to discharge dredged or fill materials to obtain a certification or waiver from their state water pollution control agency (Massachusetts Bureau of Resource Protection, Division of Wetlands and Waterways). Section 401 is a federal mandate that is implemented by the state, resulting in some friction over precisely what does and does not require a water quality certificate and what issues the certification can and cannot address. The issue is rendered moot for mosquito control, however, as the U. S. Army Corps of Engineers will not permit a mosquito-control project that does not have a water quality certification. Section 401 provides DWW with the power to influence permit applications in two ways: by denial of the required water quality certification, and by issuing the water quality certification with limitations attached. To date, obtaining water quality certifications has not been particularly difficult for Massachusetts mosquito control programs.

b. Section 404. Clean Water Act (1972).

This Federal Act calls for a system of permitting to be carried out by the U. S. Army Corps of Engineers with a review of all permit applications by appropriate state and federal agencies. The mosquito-control activities, which require a permit under Section 404, are as follows:

a) Cutting or clearing new mosquito ditches in tidal areas below mean high water.

b) Placing material excavated from existing or new ditches on salt marshes or freshwater wetlands.

The Corps developed a draft plan in the early 1980's outlining procedures for issuing general permits for maintenance work (i.e. ditch cleaning) in existing mosquito ditches in each MC project. This plan was eventually shelved pending the preparation of a GEIR to serve as a guide. According to 1986 correspondence to the Norfolk County MCP from the Section Chief of the Regulatory Branch of the Operations Division, the Corps does not require a permit under Section 404 for ditch cleaning provided the spoil is scattered at a depth of no more than 3 inches.

The question of permit requirements for new construction in Massachusetts's salt marshes, such as the OMWM projects in Essex and Plymouth Counties, remains an ambiguous issue. The Audubon OMWM Manual (p. 2-2) indicates that, in addition to the Corps permit, permits are required from the Division of Waterways, Office of Environmental Affairs and a Letter of Consistency from the Office of Coastal Zone Management. Interagency correspondence suggests that even agency heads are unclear about the legality of any of these requirements when mosquito source reduction work is involved. However, in current practice the Corps is not issuing permits for OMWM projects without these two documents.

c. Endangered Species Act.

This act is designed to protect threatened and endangered species as listed on the National Historic Register Suffolk County has had to use Bti instead of Altosid in areas where the Blue-spotted salamander (*Ambystoma laterale)* and the banded bog skimmer (*Williamsonia lintneri*). Other projects, such as Bristol County MCP, have requested advice on osprey (Horseneck Beach in Westport) and the yellow-spotted turtle but have not had to modify their proposed work because of these animals. In both cases Bristol County was doing ditch maintenance. Should the project have been proposing larviciding or more extensive source reduction work, there is a chance that their request would have been denied.

With the Suffolk County larviciding program, the issue of the effects of Altosid, an insect hormone mimic, on reproduction in amphibians has been the driving force behind the decision to not allow its use. The scientific claims for such effects are limited and more research in this area is required.

In Plymouth County, proposed drainage maintenance was halted by the local conservation commission because they felt that the drainage threatened the pools themselves, regardless of the presence of endangered species. Whether or not all vernal pools deserve complete protection remains a matter for research and debate.

The net effect of the Endangered species act on mosquito control has been small, but has provided another means of analyzing the environmental effects of mosquito control. research on the effects of source reduction on non-targets is lacking and this lack should be addressed.

B. Current Mosquito Control Programs in Massachusetts

1. Formal Mosquito Control Projects

Of the 351 Towns in Massachusetts, 158 (or 45%) currently belong to the 9 organized MC. These projects and the towns included in each are illustrated topographically in Fig. 1. Each project is managed by a superintendent who is hired and supervised by a Board of Commissioners representing the towns included in the project. Board members are appointed by the Board of Reclamation for designated terms (usually 3-5 years). Members are unpaid except for up to $75 per meeting in expenses. Boards generally meet once or twice monthly to authorize major expenditures and to review policy and program progress.

Questionnaires were sent to each MC Project in both 1985 and in 1996 (copies in Appendix 1). The projects' responses to the questionnaire formed the basis for the following summaries.

The State Reclamation and Mosquito Control Board exercises responsibility over all 9 projects. This responsibility includes, but is not necessarily limit to, the following:

1. Review and approve budgets
2. Administer project funds (payroll, process purchases, etc.)
3. Review program plans
4. Appoint commissioners
5. Issue control policies and recommendations

6. Administer emergency control funds provided to projects from the governor's or legislators emergency funds
7. Provide advice and guidance when requested by projects or towns
8. Moderate disputes
9. Assist towns seeking to join or organize a formal project or to withdraw from an existing project
10. Serve as a liaison between projects and other state and federal agencies and in legislative matters

Most projects indicated satisfaction with the administrative arrangement and the current functioning of the SRMCB. Suggestions for improvement centered around the Board providing more comprehensive services to the projects (this would require more staff) and more efficient and responsive staff for dealing with project budgets. More formal meetings with all projects to foster better communication and occasional attendance of Board representatives at project commission meetings were a common theme.

All projects have a Board of Commissioners appointed by the SRMCB. They represent the various towns within each project and exercise general control over the project. Their specific role involves, but is not necessarily limited to the following:

1. Appoint the project superintendent
2. Approve the appointment of all permanent project personnel
3. Approve payroll and sign all invoices prior to processing by the SRMCB
4. Review and set policy
5. Review budgets and salaries
6. Serve as liaison between the project and the towns they represent
7. Provide advice to project superintendent
8. Moderate disputes

The projects find this administrative structure to be responsive and appropriate. The wide range of expertise represented by the commission membership brings a broad information base to bear on important financial and operational issues. The superintendents make all day-to-day operational decisions concerning when and where to institute control and what methods to use.

The Nine Mosquito Control Projects of Massachusetts (see Tables 1 and 2 for budget figures presented in descriptions):

Berkshire County Mosquito Control Project

Created under:	Chapter 456 of the Acts of 1945
Area included:	The towns of Becket, Hinsdale, Lanesboro, Otis, Richmond, and Sheffield and Stockbridge.
Annual Assessment:	35 cents on each one thousand dollars of taxable valuations; sums so expended in proportion to their respective valuations.
Amendment to Assessment:	Chapter 459 of the Acts of 1970--20 cents on each one thousand dollars of the equalized valuations; sums so expended in proportion to their said valuations.

Formed in post-War 1945 under the leadership of the State Senator from Pittsfield. This countywide project originally had 32 member towns. All except 8 of these towns withdrew in the early 80's after the passage of Proposition 2 1/2 and considerable negative publicity. One additional town left later on. Since 1985, four towns have joined the project and four have withdrawn. Of these one (Hinsdale) withdrew and then rejoined and another (Pittsfield) joined and then withdrew. The reasons for withdrawing centered on cost, while the reasons for joining centered on municipalities responding to resident complaints.

Spring hatch *Aedes* are the major problem experienced in this mountainous terrain. Some reflood *Aedes* and *Cq. perturbans* problems also exist. In 1985 approximately 70% of the budget was devoted to source reduction through hand cleaning of ditches. By 1996, approximately 70% of the budget is devoted to larviciding and adulticiding. The program is evaluated by all four standard monitoring methods.

Over the past decade increasing citizen concern regarding pesticide use has been the most important change faced by the project. At present, providing the desired control services under very tight funding is given as the most important challenge facing the project.

Bristol County Mosquito Control Project

Created under:	Chapter 506 of the Acts of 1956
Area included:	All the cities & towns comprising Bristol County
Annual Assessment:	15 cents on each one thousand dollars of taxable valuations; sums so expended in proportion to their respective valuations.
Amendment to Assessment:	Chapter 638 of the Acts of 1970--8 cents on each one thousand dollars of the equalized valuations; sums so expended in proportion to their said valuations.

All twenty towns in Bristol County make up this control project, which was formed in 1959 during a period of high pest densities and threat from EEE. Senator Parker of Taunton played a key role in organizing the project. Only one town (Dartmouth) subsequently withdrew from the project following negative publicity. It rejoined several years later during another EEE active period.

There are approximately 67,000 acres of fresh water swampland in Bristol County. As in the case of Norfolk and Plymouth Counties, this presents some unique problems. It has resulted in a large source reduction effort (78% of budget in 1995) and adulticiding (19%) over larviciding. Salt marsh mosquitoes have become an increasingly important part of the control program.   Spring *Aedes* and *Cq. perturbans* are major pest problems and concern with EEE transmission is ever present. Light trap counts and cases of human/animal disease are used to evaluate the effectiveness of the program.

Over the past decade Bristol MCP has been faced with the double squeeze of increasing concern over wetlands alterations and increasing concerns over pesticide use. With source reduction and adulticiding being the two primary control techniques used by Bristol MCP, such concerns go to the heart of the project's effectiveness. As an example, Bristol MCP switched from malathion to resmethrin for adulticiding due to public pressure to end the use of malathion. However, resmethrin is more costly, which brings to the fore the continuing difficulties of budgets. Bristol MCP, like many other projects, faces difficulties in implementing newer control strategies due to tight budgets.

<u>Cape Cod Mosquito Control Project</u>

Created under:	Chapter 379 of the Acts of 1930
Area included:	The town comprising Barnstable County
Annual Assessment:	25 cents on each one thousand dollars of their respective valuations.
Amendment to Assessment:	Chapter 209 of the Acts of 1975--9 cents on each one thousand dollars of the equalized valuations; sums so expended in proportion to their said valuations.

The Cape Cod project was organized through the efforts of the Cape Cod Chamber of Commerce, beginning in 1928. Their motivation was the enhancement of the recreational resources of the Cape. All 15 towns in Barnstable County have belonged to the project continuously since its formal creation in 1930. There are approximately 20,500 acres of salt marsh and 2,600 acres of freshwater wetlands on the Cape capable of supporting mosquito development.

The Cape Cod project has chosen not to use adulticides as part of their program. Larviciding and source reduction (maintenance on existing water systems) form the backbone of the project. The Cape project is currently conducting research into the use of native fish as biological control agents for mosquitoes. While larval surveys and larvicide applications are conducted during half of the year, the other half of the year is spent maintaining the current ditch systems (including work on pipes, culverts and sluiceways). Many towns' DPWs and Conservation Commissions utilize the project's expertise to help keep drainage systems open and running properly. Further, the Cape Cod project's work is recognized by the National Flood Insurance Program's Community Rating System as meeting the flood-plain maintenance requirements for towns to obtain lower flood insurance rates.

The Cape Cod project utilizes a Geographical Information System (GIS) that includes maps of all potential larval habitat, documentation of work done including larvicide application, and data from adult and larval surveys conducted at all mosquito development sites. Information from this system is used to write an annual report and is made available to the member towns.

This project also runs a greenhead fly control program. Over 600 blue box traps are placed on the salt marshes of Barnstable County every spring. Research was conducted by the project in the summers of 1992-1995 to determine the effectiveness of adding Octenol, an olfactory attractant to these traps. Success with that research has resulted in this project and others incorporating octenol into their greenhead fly trapping programs.

As an indication of the stability of the Cape Cod Project, all eighteen employees have over 4 years of experience with 50% of the employees having worked in mosquito control for over 15 years

Central Massachusetts Mosquito Control Project

Created under:	Chapter 583 of the Acts of 1973
Area included:	The area in Middlesex and Worcester Counties including the cities of Fitchburg, Leominster, and Marlborough and the towns of Ashland, Ayer, Berlin, Billerica, Blackstone, Boxborough, Chelmsford, Clinton, Dracut, Holliston, Hopedale, Hudson, Littleton, Lunenburg, Milford, Natick, Northborough, Sherborn, Shrewsbury, Southborough, Stow, Tewksbury, Westborough, Westford, and Wilmington.
Annual Assessment:	8 cents on each one thousand dollars of the cities' and towns' equalized valuations; sums so expended one quarter in proportion to their valuations and three quarters in proportion to their respective areas.

Twenty-eight towns make up this large project. It was organized in 1973 through the efforts of several town boards of health and concerned citizen groups. The Project has experienced significant turnover in membership. Two towns withdrew from the project early on but then rejoined. Seven other towns withdrew permanently prior to 1986, primarily as a result of Proposition 2 1/2 fiscal constraints and concern over pesticide use, though concerns about mosquitoes coming into the town from areas not being treated played a role in Hopkinton's decision to withdraw. However, Fitchburg, Lunenburg, and Leominster were joining during the same period, in each case due to a desire to be a part of a regional approach to mosquito control. Since 1986, an additional seven towns have withdrawn (Harvard, Lancaster, Boylston, Grafton, Groton, Northbridge and Shirley). The towns left for budgetary reasons and environmental concerns. Five towns have joined the project since 1989, two (Wilmington and Natick) because town programs were abandoned, one (Blackstone) because of bad mosquito problems, one (Dracut) because of positive feedback from member towns, and the fifth (Stow) because they liked the environmentally responsible control techniques of the Project. Towns can withdraw or rejoin by a vote at town meeting but joining towns also must be approved by the SRMCB, which may impose special stipulations.

Up to 10,000 acres of mixed, freshwater wetlands and a large number of catch basins and tires are treated with larvicide's (35% of total budget) and/or have source reduction work done (40% of budget). Spring hatch and reflood *Aedes*, and *Cq. perturbans* account for the bulk of the pest problems in this project. All standard monitoring methods are used to evaluate program effectiveness.

Central Mass has assembled an impressive staff, with six staff members holding BS or BA degrees and several personnel having more than 15 years of mosquito-control experience.

Over the past decade the Project has worked to reduce its use of adulticides and increased its applications of larvicides such as Bti. Water management has been geared towards maintenance but wetlands restoration is playing an increasing role. Given that many towns have withdrawn from the project due to budget constraints, developing a modern, cost-effective control program is the highest challenge currently facing the Project.

East Middlesex Mosquito Control Project

Created under:	MCL Chapter 252, section 5A in 1945. There is no specific Massachusetts Law or Act which names the East Middlesex Control Project.
Area included:	Twenty cities and towns in Middlesex and Norfolk Counties including Arlington, Bedford, Belmont, Brookline, Burlington, Cambridge, Framingham, Lexington, Lincoln, Melrose, Newton, North Reading, Reading, Sudbury, Wakefield, Waltham, Watertown, Wayland, Wellesley, and Weston.
Annual assessment:	Cities and towns voluntarily appropriate funding each year for mosquito-control services. Funding is carried over from one fiscal year to the next.

This project was organized in 1945 as a trust agency to provide mosquito control for 6 cities and towns. The original goals for the Project cited by the representatives of the 6 municipalities were to form a cooperative mosquito control program under the auspices of the State Reclamation Board. Policies for the Project were set by the Commission that would be comprised of representatives, appointed by the State Reclamation board, from each municipality. The primary reasons cited in 1945 for organizing the Project were the vector potential and nuisance caused by mosquitoes.

Currently the Project has 20 members. The newest municipalities to join the project have been North Reading (1991) and Melrose (1997). The twenty-member commission meets twice a year. Five Commissioners serve on the Executive Committee, which meets regularly. Funding is derived through voluntary appropriations. The Commission has a policy, which allows municipalities flexibility in choosing control methods. The Project recommends a control program for each municipality. The municipality then has control over which services it chooses to fund. Although this process has resulted in stable growth since 1983, the Project has historically had funding limitations because 33% of its area is urban with relatively minor mosquito pest problems.

Spring *Aedes* species, *Ae. vexans*, and *Cq. perturbans* are the major concerns in the district. *Culex* in urban areas are also a concern. Aerial larviciding against spring *Aedes* and *Aedes vexans* is the largest program in the district. Other programs include larviciding with a truck-mounted hydraulic sprayer and portable sprayers, catch basin larviciding in urban areas and adulticiding with truck-mounted ULV aerosol sprayers and portable aerosol and backpack mistblowers. Beginning in 1994, the Project entered into a cooperative agreement with the Essex County Mosquito Control project to use a backhoe and operator for East Middlesex ditch-maintenance operations. The Project continues to maintain ditches by hand in woodland areas. The Project maintains an extensive surveillance operation, which includes monitoring adult mosquitoes at 50 locations. The Project records extensive larval survey data to support it's larval control program. Beginning in 1995 the Project augmented its surveillance and record keeping programs by adding GIS mapping software.

North East Massachusetts Mosquito Control and Wetlands Management District
formerly Essex County Mosquito Control Project

Created under:	Chapter 516 of the Acts of 1958
Area included:	The area in Essex County not including any city or town already a member of an organized mosquito control project.
Annual Assessment:	15 cents on each one thousand dollars of taxable valuations; sums so expended one quarter in proportion to their valuations and three quarters in proportion to their respective areas.
Amendment of Assessment:	Chapter 679 of the Acts of 1970 -- eight cents on each thousand dollars of equalized valuation; on quarter in proportion to there said valuations and three quarters in proportion to their respective areas.

This seventeen-town project was established in 1965 after lobbying efforts by citizen groups who were concerned about pest mosquitoes. Prior to 1986 four towns (Essex, Merrimac, North Reading, Lynnfield) subsequently withdrew from the project by town meeting vote due to fiscal constraints and some negative publicity. One of these towns (Lynnfield) rejoined the following year due to a perceived increase in pest densities and threats to public health. Ten towns withdrew from the project in the late ‘eighties, primarily because of budget constraints. Four towns (Ipswich, Newburyport, Salisbury and Amesbury) have since rejoined, all because of public demand following the halt of control activity (length of time out of project varied from one to three years).

A high proportion of the Essex County MCP budget is devoted to salt marsh mosquito problems (60%) and this project has taken the lead in working with environmental interests to develop OMWM plans and studies in some of its marshes. Catch basins are treated with Altosid briquettes and all other larviciding is carried out with the bacterial toxin Bti. This is mostly in woodland vernal pools in the spring and in unmanaged salt marshes. The project does little adulticiding. It also administers a greenhead fly control program using box traps in several coastal towns. All monitoring methods (i.e., complaints, and light emergence traps, and landing/larval counts) are used to evaluate the effectiveness of the program and for daily decision-making.

Essex County has been a leading project in developing Open Marsh Water Management as a mosquito-control and marsh-restoration technique in the Northeast, and has pushed to develop a set of standards for mosquito control in such areas as uplands ditch maintenance that will both standardize control throughout New England and provide a better framework for the permitting process.

Not surprisingly for a Project with a forward thinking approach, Essex County’s program, over the past decade, has reduced adulticiding while implementing OMWM and increasing its ties with environmental agencies and groups. The loss of several towns has required a change in strategy from a regional to a municipal approach, a change not particularly desirable for area-wide control problems like mosquitoes. However, the challenge of revising the Project’s strategies and techniques has been met and its most important challenge today is meeting the demand for marsh restoration work while continuing to maintain a high standard for mosquito control.

Essex County MCP changed its name in 1996 to the North East Massachusetts Mosquito Control and Wetlands Management District, but it will be referred to as Essex County in this report as the name is new and may not be recognized by readers at this time.

Norfolk County Mosquito Control Project

Created under:	Chapter 341 of the Acts of 1956
Area included:	The area in Norfolk County not including any city or town already a member of an organized mosquito control project.
Annual Assessment:	20 cents on each one thousand dollars of taxable valuations; sums so e expended on half in proportion to their valuations and one half in proportion to their respective areas.
Amendment of Assessment:	Chapter 496 of the Acts of 1975--8 cents on each thousand dollars of equalized valuations; sums so expended one quarter in proportion to their valuations and three quarters in proportion to their respective areas OR three quarters in proportion to their valuations and one quarter in proportion to their respective areas, WHICHEVER IS THE LESSER AMOUNT.

Twenty-two towns formed this project in 1956 and three more joined in the early 80's after the South Shore project disbanded. Two towns (Milton and Norfolk) later withdrew by a vote at town meeting or city council. Norfolk rejoined just one year later only to withdraw and rejoin again about 10 years later. Withdrawal votes were fueled by environmental concerns over pesticide use and negative publicity. Efforts to rejoin were precipitated by public health threats, biting complaints, and ineffective in-house control programs. Norfolk did not lose towns during the late eighties, so has had stable membership for more than a decade.

Over half of the project budget is spent on source reduction work. In the '80's adulticiding was stressed over larviciding but this has changed and now larviciding, including aerial applications, far exceeds adulticiding. It is estimated that there are over 30,000 acres of freshwater swampland in Norfolk County, which can breed mosquitoes, but only 1,087 acres are treated for spring-hatch and 523 acres (there may be overlap) for summer reflood mosquitoes. Thirty-eight acres of salt marsh are under active control. All 4 standard surveillance methods are used to evaluate program effectiveness.

Over the past decade the project has faced increasing pressure from the public concerning pesticide use. The project has responded by providing a more localized response to fogging requests (no more town-wide applications are done), by increasing larval monitoring to better target larvicide applications, and by using Bti and IGR formulations for larviciding. In 1996, the Project purchased a third excavator for source-reduction work, went from five to nine field staff positions, hired two seasonal employees to improve their database information on wetlands and purchased computer mapping equipment to better target their control efforts.

These changes, while desirable environmentally, have their cost, and funding remains a primary concern.

In addition, environmental regulations likewise cause concerns, specifically when fueled less by scientific reason and more by emotional appeal.

Plymouth County Mosquito Control Project

Created under:	Chapter 514 of the Acts of 1957
Area included:	The area in Plymouth County not including any city or town already a member of an organized mosquito control project.
Annual Assessment:	25 cents on each one thousand dollars of taxable valuations; sums so expended on half in proportion to their valuations and one half in proportion to their respective areas.
Amendment of assessment:	Chap. 544 of Acts of 1970 -- 13 cents on each thousand dollars of equalized valuations; one-half in proportion to said valuation and one-half in proportion to their respective areas.

Twenty-one towns formed this project in 1958 during a period of major EEE threat. The Plymouth County Selectman's Association and local legislators led this movement to organize. Seven additional towns joined the project in the early 1980's when the South Shore project disbanded. Four of the original member towns withdrew by town meeting vote in the mid-sixties. Towns must have been a member for at least 3 years before they can vote to leave the project. Towns that withdrew did so primarily over concern for the impact of the wide-scale aerial spraying that the project was carrying out in the mid-sixties. The town of Halifax rejoined the project in 1985 after they determined that the Plymouth County project was more environmentally sound than the in-house program they had developed. Since that time, Abington, Hanover, Kingston, and Whitman have also rejoined. Bridgewater withdrew in 1990, due to budgetary concerns.

About 20% of the concern of this Project is with salt marshes. Water management, including OMWM efforts, is used to control most salt marsh *Aedes*. Spring and reflood Aedes receive a substantial amount of attention. *Cq. perturbans*, the cattail mosquito, causes a very significant problem but there are no recommended larvicides for this species at present. Although several projects contract for some aerial larviciding (and adulticiding in emergencies), Plymouth County is the only project, which owns fixed winged aircraft for doing its own aerial work. Ground adulticiding with resmethrin is still an important control strategy in this project because of inability to control the cattail mosquito, and other species developing in large woodland swamps, with larvicides. Up to 7,860 acres of Plymouth County's large acreage of swampland are treated with larvicide’s (Bti), targeted mainly against spring *Aedes*. The project evaluates its control effectiveness from complaints, landing counts, and larval counts.

The past decade has clearly been one of change at Plymouth. Malathion for adulticiding gave way to resmethrin and the larvicide Temephos was replaced by Bti. There has also been an increase in the number of member towns and increased service requests. Dr. Ludlam further notes that the State Reclamation Board has become stronger and there have been improved ties with the Massachusetts Department of Public Health. The most important challenge facing Plymouth today is the continued lack of a control strategy for *Cq. pertubans* in the larval stages.

Suffolk County Mosquito Control Project

Created under:	Chapter 606 of the Acts of 1973
Area included:	The area of Suffolk County comprising the cities of Boston and Chelsea.
Annual Assessment:	5 cents of each one thousand dollars of equalized valuations; sums so expended one quarter in proportion to their valuations and three quarters in proportion to their respective areas.

The Suffolk County project is the smallest in land area and encompasses Boston and Chelsea. The two other towns in Suffolk County, Revere and Winthrop, are members of the Essex County project, which predates this project. The project was organized in 1974 with strong leadership from legislators who were residents of the district and felt that a pest problem existed. Member town can withdraw from the project through a majority vote of the city council and mayor. Prior to the organization of the project, the Department of Housing Inspection contracted with a private applicator to do aerial spraying of salt marshes and the Parks Department did adulticiding with mistblowers.

About 30% of the mosquito problem is associated with salt marsh *Aedes* but no marsh management activities are carried out in the project's 200 acres of breeding salt marsh. Control is done with larvicide's. Another 130 acres of freshwater wetland breeding sites are also treated with larvicides, as are storm sewer catch basins. About 40% of the projects budget is devoted to adulticiding, the highest percentage of all the projects, but down for the 1980s. Program effectiveness is evaluated by complain levels, light traps, landing rates, and larval counts are used to evaluate the effectiveness of the program.

Over the past decade the project has used more Altosid for larviciding and reduced malathion use for adulticiding. Public pressure, both for increased spraying (to eliminate mosquitoes) and decreased spraying (to protect the environment) plays a strong role in the day-by-day operation of this populous project. There are also two MDC Reservations in which mosquito-breeding areas overlap endangered species habitat. Currently the project can use Bti in these areas but would prefer to switch to Altosid. Permission to make this switch has not been granted.

Budgets

Budgets for all projects for 1993 and 1994 fiscal years are provided in Tables 1 and 2. The standard break down by category as used by the SRCMB is adopted in these Tables. The data used in these Tables were provided by the projects themselves.

2. Non-Member Communities.

For the initial GEIR, all Massachusetts Town Boards of Health were sent a concerning their town's mosquito control activities and 326 (93%) eventually responded. Fifty-seven towns (about 38% of those responding) indicated they do some mosquito control: 34 carry out the control work themselves using town personnel and 23 contracts with private applicators. Nineteen (83%) of the 23 towns with contracted control provided detailed information on costs and pesticides used; 23 (68%) of the 34 town-operated programs provided this information.

The decision by non-member towns to do mosquito control work (which in almost all cases was temporary, chemical control) is made by a variety of authorities: 68% by the BOH, selectmen, mayor or other town officials, and 32% by a public vote. Citizen complaints and a perceived health threat both weighed heavily in decisions to do control work. Approximately 1/4 of the towns had some mosquito survey information available as an aid in the decision-making process. The major criteria used to assess the effectiveness of the control work undertaken was the post-treatment level of citizen complaints (95% of all towns). Other considerations were, in order of importance: larval counts, light trap counts, level of disease, and human landing counts.

Table 1. Budgets for Mosquito Control Projects for Fiscal Years starting in 1993 and 1994.

Budget Item	1993	1994
Berkshire County MCP		
Administration		
a. Personnel (wages & benefits)	30,000	30,000
b. Other (office supplies, travel, etc.)	500	500
Field Operations		
a. Personnel (wages & benefits)	10,700	10,700

b.	Pesticides	5,792	0
c.	New equipment	0	0
d.	Other (gas, supplies, etc.)	20,000	25,792
TOTAL		$66,992	$66,992

Bristol County MCP

Administration			
a.	Personnel (wages & benefits)	75,370	75,518
b.	Other (office supplies, travel, etc.)	46,918	47,888
Field Operations			
a.	Personnel (wages & benefits)	260,615	255,550
b.	Pesticides	34,377	31,610
c.	New equipment	6,125	17,412
d.	Other (gas, supplies, etc.)	24,121	20,162
TOTAL		$447,526	$448,140

Table 1. Budgets for Mosquito Control Projects for Fiscal Years starting in 1993 and 1994 (continued).

Budget Item		1993	1994
Cape Cod MCP			
Administration			
a.	Personnel (wages & benefits)	585,000	585,000
b.	Other (office supplies, travel, etc.)	5,000	5,000
Field Operations			
a.	Personnel (wages & benefits)	204,495	204,495
b.	Pesticides	38,000	38,000
c.	New equipment	35,000	35,000
d.	Other (gas, supplies, etc.)		
TOTAL		$918,511	$918,511
Central Mssachusetts MCP			
Administration			
a.	Personnel (wages & benefits)	123,201	125,817
b.	Other (office supplies, travel, etc.)	36,546	17,241
Field Operations			
a.	Personnel (wages & benefits)	286,348	286,144
b.	Pesticides	15,000	37,527
c.	New equipment	18,154	18,970
d.	Other (gas, supplies, etc.)	84,181	77,731
TOTAL		$563,430	$563,430
East Middlesex MCP[a]			
Administration			
a.	Personnel (wages & benefits)	64.190	64,995
b.	Other (office supplies, travel, etc.)	27,507	24,804
Field Operations			
a.	Personnel (wages & benefits)	119,156	116,734
b.	Pesticides	18,422	21,508
c.	New equipment	0	11,927
d.	Other (gas, supplies, etc.)	18,843	23,159
TOTAL		$248,118	$263,126
Essex County MCP			
Administration			
a.	Personnel (wages & benefits)	47,320	53,000
b.	Other (office supplies, travel, etc.)	7,000	7,000
Field Operations			
a.	Personnel (wages & benefits)	188,105	188,737
b.	Pesticides	10,000	28,000
c.	New equipment	0	13,000
d.	Other (gas, supplies, etc.)	25,685	37,231
TOTAL		$278,110	$326,968

[a]Rounded to the nearest dollar from reported figures.

Table 1. Budgets for Mosquito Control Projects for Fiscal Years starting in 1993 and 1994 (continued).

Budget Item		1993	1994
Norfolk County MCP			
Administration			
a.	Personnel (wages & benefits)	184,427	161,640
b.	Other (office supplies, travel, etc.)	60,482	60,472
Field Operations			
a.	Personnel (wages & benefits)	79,040	121,939
b.	Pesticides	4,617	186
c.	New equipment	19,520	26,369
d.	Other (gas, supplies, etc.)	57,331	45,556
TOTAL		$405,417	$416,162
Plymouth County MCP			
Administration			
a.	Personnel (wages & benefits)	127,217	144,700
b.	Other (office supplies, travel, etc.)	37,388	40,000
Field Operations			
a.	Personnel (wages & benefits)	243,318	256,514
b.	Pesticides	30,590	31,500
c.	New equipment	54,625	32,100
d.	Other (gas, supplies, etc.)	71,311	59,635
TOTAL		$564,449	$564,449
Suffolk County MCP			
Administration			
a.	Personnel (wages & benefits)	No Figures supplied	
b.	Other (office supplies, travel, etc.)		
Field Operations			
a.	Personnel (wages & benefits)		
b.	Pesticides		
c.	New equipment		
d.	Other (gas, supplies, etc.)		
TOTAL			

Table 2. Total Budgets for the nine MCPs.

County	1993	1994
Berkshire County	66,992	66,992
Bristol County	447,526	448,140
Cape Cod	918,511	918,511
Central Massachusetts	563,430	563,430
East Middlesex	248,118	263,126
Essex County	278,110	326,968
Norfolk County	405,417	416,162
Plymouth County	564,449	564,449
Suffolk County	No Figures Supplied	
TOTAL	$3,492,553	$3,567,778

The choice of control strategy to be used was generally made by the town BOH or town personnel directly responsible for control activities. About 1/4 of the towns left this decision to the private applicator contracted to do the control work. One-third consulted outside public advisor such as the Board of Reclamation or neighboring MC project superintendents. About 1/6 sought advice from private sources such as pesticide salespersons. A similar breakdown of sources was used by towns to make decisions concerning when, where and how to apply the prescribed pesticides, except in the case of public and private consultants who were used less (only by 1/4 and 1/10 of the towns respectively). The choice of chemical to be used for control was based largely on its safety to the environment. Two-thirds of the towns predicated their decision on this consideration. Other concerns such as cost, effectiveness, and ease/safety of application were much less important. None of these criteria were used in selecting pesticides by more than 10 of responding towns. Decisions on when and how often to apply larvicides were based on larval sampling in about 2/3 of the towns and on a calendar spray schedule in 1/3 of the towns. Adulticide applications were mainly based on public complaints or pre-established calendar schedules, but a little over 50% of towns were prepared to modify their application schedules depending on weather conditions. Twenty-nine percent of towns indicated that scheduled pesticide treatments had actually been canceled due to adverse weather or for other reasons.

Most towns (ca. 80%) rely on newspaper and TV/radio announcements to inform the public of pending pesticide treatments. Twelve percent make no effort to inform the public at all. Fifty-three percent keep a list of beekeepers whose hives should be avoided but only 3% personally notify beekeepers of pending spray schedules. In most towns, beekeepers must rely on the same information provided to the general public, which means that 9-12% of towns provide beekeepers with no warning whatsoever. In contrast, 94% of towns polled make some provisions for people to request that their property not be sprayed.

Nantucket is one town that has started a program in the time period between the first draft GEIR and this draft. The program has included aerial and ground applications of Altosid, and extensive Open Marsh Water Management. Activity and expense peaked in 1992 and 1993 when the OMWM system was dug. Since then the town has conducted small amounts of larviciding in salt marshes. No work is done in freshwater areas and no adulticiding is done.

3. Other Programs

a. Department of Environmental Management

The Division of Forests and Parks discontinued its own mosquito control program in 1978 at the suggestion of the MEPA office pending the completion of an Environmental Impact Report of statewide mosquito control. From 1966-77, their mosquito control program consisted of adulticide treatments of state parks twice each summer coinciding with the heavy use periods of Memorial Day and July 4th. Applications were made with a mist blower and a mixture of methoxychlor (9 gal of 25% EC), malathion (1 gal of 57% EC) and water (40 gal). There was no attempt to evaluate the effectiveness of these applications, which were presumably carried out at night.

The Essex County Mosquito Control Program adulticides as required at the Salisbury Beach State Park and at the Bradley Palmer State Park in Hamilton.

b. Department of Public Health

The Massachusetts DPH is responsible for surveillance for EEE Virus, risk assessment, public information and education on EEE disease, as well as providing advice to the State Reclamation and Mosquito Control Board on appropriate risk management for EEE. DPH is also responsible for recommendations for wide area aerial vector control interventions in the event of an EEE Public Health Emergency. The Process for Risk Assessment and Management of EEE is outlined in the “Vector Control Plan to Prevent EEE” (See Appendix B, Vector Control Plan: Risk Assessment Section VI).

Every year DPH’s Eastern Equine Encephalitis Surveillance Program (EEESP) collects data to assess the risk of EEE. This is an on-going program, which is carried out at the State laboratory Institute in Jamaica Plain. Key variables used to determine the risk of EEE include precipitation levels, mosquito population abundance, and presence of EEE virus in mosquitoes, horses, and humans. The purpose of the DPH EEE surveillance effort is to assess risk and use this information to advise the SRMCB and the public of the relative risk of EEE in any given season. In addition, the DPH chairs the Pesticide Review Board, which regulates pesticide use in the state.

In 1956 the EEESP was established in southeastern Massachusetts by the U. S. Public Health Service (CDC), in cooperation with the Massachusetts DPH, for the study of EEE. A surveillance program has continued since 1957 to the present, with funding solely from DPH beginning in 1970. Surveillance for EEE consists of monitoring mosquitoes to determine population levels in relation to previous years' levels, especially *Cs. melanura, Ae. vexans, Ae. canadensis, Cq. perturbans,* and *Ae. sollicitans,* testing samples of mosquito populations for the presence of EEE and Highland J (HJ) virus (HJ is an arbovirus which does not cause human disease but which is an indicator of arboviral activity in the bird population), testing suspected EEE horse cases and screening suspected human cases of encephalitis, meningoencephalitis or other cases of clinical disease that may mimic symptoms of EEE virus infection. Information is also compiled on precipitation, groundwater levels, and surveillance data from other sites. The surveillance program keeps abreast of new developments in the study of EEE and has expanded its trapping effort in response to these developments.

In recent years DPH has funded studies in collaboration with local universities aimed at furthering our understanding of EEE. These have included an assessment of the focality of EEE transmissions; *Cs. melanura* host preferences studies and research aimed at identification of the principal avian reservoir host species for the amplification and perpetuation of the EEE virus. In 1997, mosquito trapping was expanded to include several bird roost studies postulated to be critical foci for amplification of EEE virus (Komar et al., unpublished).

Each year the EEESP prepares a summary of the past season's surveillance activities in November, and provides an early prediction of the next season with regard to the likelihood of the presence of EEE virus in the environment and the potential for transmission to humans based on key variables of precipitation, mosquito populations and prior years' EEE activity in mosquitoes, birds, horses and humans. This information is provided to the SRMCB, EOEA agencies, the State Legislature, Boards of Health and the general public. Vector control meetings are held as needed with eastern Massachusetts Mosquito Control District Superintendents and the SRMCB throughout the season.

Surveillance provides an early warning of the presence of EEE in the environment. The EEE Surveillance Program begins no later than the first week in June and continues through early October, unless a killing frost brings the mosquito season to an end earlier. This is a continuing program with an objective to provide epidemiological information on EEE virus and potential vectors of this disease to guide public health actions. EEE surveillance reports are issued weekly throughout the trapping season and provide a summary of weekly laboratory analyses for mosquitoes, horses and humans.

When EEE is found in trapped mosquitoes, supplemental surveillance activities are initiated. These may include increased trapping of bridge vector species (species that transmit the disease from birds to horses or humans) utilizing a variety of trapping methods, estimation of vector species larval abundance, and age structure determinations. Isolation of EEE also may trigger health alerts and advisories when appropriate.

The first emergency effort to control mosquitoes during a disease outbreak occurred in 1956 when $90,000 was made available from the governor's emergency fund for aerial adulticiding. In this effort 150,000 acres were sprayed with DDT. The EEE disease outbreak of 1973 led to an aerial ULV application of malathion in the late summer, when approximately 1.7 million acres in eastern Massachusetts were treated. In 1974 and 1975 approximately 82,000 acres were aerially treated. The cost of the 1973-75 vector control interventions was over $700,000. In the EEE outbreak of 1982-84, no state-funded aerial application was conducted, however, $150,000 was allocated from the governor's emergency fund to support intensified ground spraying. In 1990 another emergency aerial ULV malathion application occurred over the southeastern part of Massachusetts. In this intervention 524,096 acres were treated at a cost of approximately $800,000. All interventions were based upon the likelihood of multiple human cases of EEE. While the cost of EEE vector control interventions may appear high, the lifelong costs associated with just one residual case of EEE have been estimated at $3 million dollars (Villari et al. 1995).

c. Federal Lands

In general, states have no jurisdiction over federal property. Any mosquito control activity on U. S. government property in Massachusetts is only subject to federal laws and not to the laws of the commonwealth. Thus, the following description will be brief and informational only.

i. Parks, monuments, refuges, etc.

No mosquito control is carried out by the U. S. Department of Interior on any government-owned land in Massachusetts. The current philosophy of the U. S. Park Service and U. S. Fish and Wildlife Service seems to be adverse toward the initiation of pest control except in unusual circumstances, e.g., the campground in Everglades National Park, the Island Wildlife Refuge, etc. The Cape Cod National Seashore is perhaps the U. S. Park Service property with the most significant mosquito populations. Park Service biologists have conducted their own studies on the environmental impact of Cape Cod mosquito control activities (Portnoy 1983, 1984a, 1984b) in adjacent estuaries and have lobbied against certain ditch cleaning practices on environmental grounds.

The East Middlesex MCP has been controlling mosquitoes in Great Meadows National Wildlife Refuge since 1987. Annual aerial Bti applications targeted against spring *Aedes* species began in 1987 and applications to control *Aedes vexans* began in 1990. Prior to each application, the Eat Middlesex MCP submits data on pre-application larval populations. Following receipt of the data each year, Great Meadows National Wildlife Refuge issues a permit for the aerial application. The National Park Service reservation area (Paul Revere's Ride) in East Middlesex County has been declared off limits to any mosquito control activity (by East Middlesex MCP) except for ditch cleaning.

The Essex County MCP has completed OMWM projects on the Parker River Wildlife Refuge.

ii. Military Bases.

All U. S. Military bases have a pest control section, which often engage in some mosquito surveillance and control activity. In Massachusetts, Fort Devens has routinely carried out both larval and adult control. In the 1980s this has consisted of mist blowing with Malathion for adult control and Altosid briquettes for larval control. Hanscom Air Force Base joined the East Middlesex MC project in 1985 but still assists with surveillance and some control activities. None of the other military bases in Massachusetts (i.e., Barnes in Westfield, Westover in Chicopee, and Otis on the Cape) reported mosquito control activities in recent years.

d. Private Reserves.

There are several private reserves and estates in Massachusetts (e.g., Cranes Beach), which are frequently used by the public in one capacity or another. There is no indication that mosquito control is regularly practiced on any of these properties. It seems unlikely; therefore, that this represents a significant category of undocumented pesticide use or habitat modification for mosquito control, past or present. Certain MCPs include, by request, some reservation properties in their overall program but those activities are included in their program summaries.

C. Historical Overview of Mosquito Control Practices in Massachusetts

1. Practices prior to 1980

Development along the Eastern Seaboard, especially for tourism, was predicated on an ability to control the hoards of salt marsh mosquitoes. The earliest experimental work took place in New Jersey salt marshes in the late teens and early 1920's. These successes encouraged the massive hand-ditching projects in East Coast marshes that took place during the WPA programs of the great depression, with some 3,000 miles of ditching being dug in Massachusetts's salt marshes alone. These ditching schemes, while quite effective in reducing salt marsh mosquitoes, were engineered to make work rather than for optimum biological efficiency. Moreover, the value of estuarine ecosystems was unrecognized at the time.

Early salt marsh mosquito control projects, such as the one on Cape Cod in the 1930's, were organized prior to the availability of synthetic pesticides following World War II and these projects expanded and maintained the WPA-dug ditch system as their main strategy for mosquito control. After DDT, BHC, and other organochlorine pesticides became available, they were used to both supplement larval control and, for the first time, to conduct residual spraying for adults. Aerial application of these pesticides became commonplace in the 1950's and early 60's. However, coastal projects that were organized after the introduction of these modern pesticides still relied heavily on source reduction to manage salt marsh mosquitoes. Paris Green (an arsenical) and petroleum oils were developed as mosquito larvicide's for malaria control during World War II and also became popular in the U. S. after the war. Waste crank case oil was not infrequently used in mosquito control despite the fact that thin oils (e.g., diesel fuel) with a spreading agent provide for the greatest and most effective surface coverage. The commercial mosquito control oil, Flit MLO, was introduced and widely used during the 70's, but was taken off the market in the mid-80's. Arosurf-MSF, a monomolecular surface film was available for several years, starting in the mid-80, but was taken off the market. It is now (1997) being returned to the market as Agnique MMF (Henley, personal communication).

Abate (temephos), one of the few organophosphates registered for aquatic use, was introduced a few years later and shared the larvicide market with surface oils. The first new generation pesticide introduced for mosquito control was the growth regulator Altosid (methoprene), a juvenile hormone mimic. It has been widely used in mosquito control since the mid-l970's. Projects in the Northeast were slow to switch to this highly selective material, perhaps due to its delayed response and narrow window for control.

The choice of which larvicide to use is based equally on effectiveness and safety to the applicator and to the environment. Adulticiding is often predicated on public complaints. Weather conditions and field surveys also play a role in deciding when to schedule applications in most projects.

Chemical control in freshwater marshes followed a similar pattern to that in salt marshes. Treatment of catch basins, first with oils followed by organochlorines and organophosphates, dates back to the beginning of most Massachusetts projects.

Physical control was limited to drainage maintenance and expansion in both salt marshes and freshwater areas. Biological control was not conducted.

Controlling *Cs. melanura* larvae in large white cedar/red maple swamps was generally considered an impossibility so aerial adulticiding was adopted as the strategy of choice for vector control during epidemic threats. Projects within the main focus of EEE in southeastern Massachusetts were the only ones to routinely do aerial spraying. This work was gradually discontinued in the 1970's due to environmental concern over aerial adulticiding.

Projects have intermittently had the support service of a SMRCB entomologist. During 1976-81, a period when the projects had no entomological support from the SMRCB, an extension biting-fly specialist was available through a cooperative agreement with the University of Massachusetts. Each project contributed 0.5% of their annual operating budget as their share of support for this position, which was jointly funded by Massachusetts Cooperative Extension. The specialist developed control recommendations, evaluated new control methods, set up a statewide light trap surveillance program, and carried out other support services to the projects. Some controversy developed among projects, particularly over the control recommendations made by the specialist. Following his resignation, the SMRCB again hired an entomologist and the University position was discontinued.

2. Transitioning: from 1980 to 1995.

By the early 1980s, concerns over pesticide use and wetlands loss began to encroach on mosquito control. Grid ditching for larvae and malathion for adults was no longer a desirable one-two punch. Control trends during the eighties and early nineties include:

- Changing from traditional chemicals, such as Abate and Flit MLO, to Bti and methoprene for larval control (Table 3).

- Changing from malathion to permethrin or resmethrin for adult control (Table 3).
- Changing from open tidal ditching to open marsh water management for salt marsh mosquito control.
- Reduction in the number of towns belonging to Projects in the late 1980s. This trend has reversed in the past several years.

Table 3. A comparison, between the early 1980's and the mid-1990's of chemicals used by Massachusetts MCPs.

Active Ingredient	Toxicity Class	Used Between[a] 1981-1985	Used Between[a] 1993-1995
AS LARVICIDES			
Bacillus thuringiensis var. *israelensis*	IV	+	+++
Fenthion	II	-	N
Isooctadecanol[b]			
Malathion	III	+	N
Methoprene	IV	o	++
Methoxychlor	IV	++	N
Mineral Oil	III-IV	+++	o
Permethrin	III	-	N
Temephos	IV	+	-
AS ADULTICIDES			
Dibrom	II	+	N
Fenthion	II	o	N
Malathion	III	+++	-
Methoxychlor	IV	+	N
Permethrin	III	N	++
Resmethrin	III	-	+++

[a]+++ = Primary pesticide used
++ = Significant use
+ = Common but minor use
o = Infrequent use
- = Rarely used
N = Never used
[b]Discontinued product (Arosurf)

Altosid had come onto the market but acceptance was slow, both because it was hard to monitor the efficacy (larvae do not die for some time) and because of restrictions on the label against using in fish habitat. By the early '90s, however, it was in general use throughout Massachusetts. The extended-residual briquet form of Altosid was tested against *Cq. perturbans*, as was Arosurf-MSF, but results were mixed and the briquet's high cost prevents it from being an attractive control agent for large cattail areas. Trials with Altosid pellets were encouraging but this control technique is not being used in Massachusetts.

In contrast to Altosid, the biological pesticide *Bacillus thuringiensis* var. *israelensis* was quickly accepted by Massachusetts's projects when introduced in the early 80's. It is a mainstay of most programs, despite some problems in salt marshes and aquatic habitats high in organic matter. The latter problem may be solved by the recent (1996) introduction of *Bacillus sphaericus,* a new biological pesticide that is designed specifically for *Culex* breeding in high-organic-matter habitats.

Flit-MLO disappeared from the market and was replaced by Golden Bear oils. Arosurf-MSF was used in small amounts for several years before it too was taken off the market. It has recently returned to the market as Agnique MMF. Bonide Mosquito Oil (Mineral oil) is now available but not used. Source reduction remained a mainstay of the projects during this time period but coastal communities shifted away from ditch maintenance towards open marsh water management. An emerging difficulty for control programs was the rise in wet basins mandated by storm water runoff regulations. If improperly designed these can breed considerable numbers of spring-brood and/or summer reflood mosquitoes.

The evaluation of control effectiveness by projects remained a combination of public complaints, adult counts, larval counts, and cases of human disease.

All projects maintained a public education component and several expanded their programs.

Throughout this period, outside of inadequate budgets and the inability to do more source reduction work, the main operational problems voiced by most projects has been the lack of applied research support to assist them in evaluating new technology and solving certain ever-changing problems. For example, the cattail mosquito, *Cq. perturbans*, is a major pest and potential epidemic vector of EEE in most projects but there is presently no recommended method for controlling this mosquito.

D. Current Mosquito Control Strategies in Massachusetts

1. Overview

Chemical control, including *Bacillus* products and IGRs (Table 4), and source reduction, including open marsh water management, dominate mosquito control in Massachusetts (Tables 5 and 6). Aerial applications of larvicides have been used by several programs (Table 7) and is likely to increase. Biological control has not been emphasized except to the extent that OMWM creates conditions under which biological control operates. Public education is a minor component of most programs.

Salt marsh mosquitoes are the primary target of coastal programs, whereas inland programs target spring-brood and summer-reflood *Aedes* (Tables 8 and 9). *Coquillettidea perturbans* is restricted by larval habitat to areas near cattail marshes. However, in those areas its populations can be extremely high.

Vector mosquitoes are not the primary targets of Massachusetts control programs, though projects do respond to requests for aid from DPH in times of EEE emergencies. *Culiseta melanura* larval populations may be incidentally reduced by treatment programs that target swamp areas. East Middlesex MCP did conduct trials with Altosid pellets aerially applied in April, 1992 for *Cs. melanura* control and were successful (Henley 1992). This work has not been repeated in Massachusetts.

Policy issues have revolved around wetlands and water quality preservation and endangered species. A chronic source of discussion is mosquito control's exemption from many of the state-level wetlands protection acts, making the Federal Section 401 Water Quality Certification Act (administered at the state level) and the state and federal Endangered Species Acts the primary means of "controlling" source-reduction work. Storm water runoff regulations have increased the number of wet basins (retention, wet detention) in many areas, on occasion creating breeding habitat. Engineers and public officials involved in designing and approving such basins have been slow to acknowledge mosquito control as design criteria, though the relevant sections of the Storm water Policy Handbook and Storm water Technical Handbook released by DEP in March 1997 should be incorporated into MCP practices (see Appendix E for listing of relevant information).

The EEE outbreak in 1990 highlighted a need for stronger DPH policies regarding emergency mosquito control. As a result, the Massachusetts Department of Public Health published "Vector Control Plan to Prevent Eastern (Equine) Encephalitis" (August 7, 1991) and implemented an extensive Public Education Program in 1991.

Table 4. Pesticide use by Project, 1993 through 1995.

Pesticide	Catagory	Amount Used		
		1993	1994	1995
Berkshire MCP				
Altosid Briquets	IV	24.3 lb	5.8 lb	1.8 lb
Bactimos Granules	IV	534.0 lb	2124.0 lb	
Bactomos Pellets	IV	232.0 lb	2026.0 lb	2093.0 lb
Abate 4E	III		0.6 gal	
Arosurf-MSF	III	16.0 gal	5.0 gal	
Scourge 18+54	III	10.1 gal	25.0 gal	20.1 gal
Bristol County MCP				
Altosid Briquets	IV		0.57 lb	45.6 lb
Bactomos Pellets	IV	1593.0 lb	80.2 lb	2300.5 lb
Scourge 12+36	III	151.9 gal	190.6 gal	173.4 gal
Cape Cod MCP				
Altosid Briquets[a]	IV	9.5 lb	8.4 lb	11.0 lb
Bactomos Pellets	IV	20,710.0 lb	41,497.0 lb	43,174.0 lb
GB 1111	III	671.0 gal	704.0 gal	330.0 gal
[a]Totals reported as briquets coverted to lbs				
Central Massachusetts MCP				
Altosid Briquets	IV	231.9 lb	192.7 lb	106.2 lb
Bactimos Granules	IV	281.1 lb	115.9 lb	2829.1 lb
Bactomos Pellets	IV	1223.0 lb	3313.0 lb	81.0 lb
Vectobac Granules	IV	96.9 lb		
Vectobac 12AS	IV		225.7 gal	171.7 gal
Witco GB-1356	III	65.1 gal	95.2 gal	5.6 gal
Witco GB-1111	III			23. 5 gal
Scourge 18 + 54	III	342.6 gal	398.5 gal	388.5 gal
[a]Dry and liquid ounces as reported coverted to pounds or gallons respectively				
East Middlesex MCP				
Acrobe	IV		125.0 gal	
Altosid Pellets	IV		15.0 lb	10.9 lb
Altosid Briquets[b]	IV	69.9 lb	20.7 lb	33.7 lb
Altosid XR Briquets[b]	IV	17.1 lb		
Arosurf MSF	III	2.3 gal	3.0 gal	
Bactimos Granules	IV		12,880.0 lb	6,785.0 lb
Bactimos Pellets	IV	2,324.0 lb		
Vectobac G	IV	8,062.0 lb	720.0 lb	
Vectobac 12AS	IV	8.4 gal	22.9 gal	169.2 gal
Permanone 10EC	III	2.4 gal	2.1 gal	1.7 gal
Scourge 18 + 54	III	20.2 gal	26.0 gal	18.1 gal
[a]Dry and liquid ounces as reported coverted to pounds or gallons respectively				

Table 4. Pesticide use by Project, 1993 through 1995 (continued).

Pesticide	Catagory	Amount Used		
		1993	1994	1995
Essex County MCP				
Altosid Pellets	IV			70.5 lb
Bactimos Granules	IV	3.8 lb		252.2 lb
Bactomos Pellets	IV	1993.1 lb	4439.6 lb	887.5 lb
Permanone 31-66[a]	III	39.0 gal	42.5 gal	12.8 gal
Scourge 18 + 54[a]	III	10.1 gal	25.0 gal	20.1 gal
[a]Ounces as reported converted to gallons				
Norfolk County MCP				
Altosid XR Briquets	IV	0.1 lb[b]	2.8 lb	254.8 lb
Bactimos Briquets	IV	0.6 lb	1.8 lb	48.8 lb
Vectobac 12AS	IV	79.0 gal	2.6 gal	
Vectobac AS	IV			52.3 gal
Arosurf-MSF	III	406.7 gal	83.1 gal	149.0 gal
Scourge 18 + 54	III	45.8 gal	53.2 gal	52.7 gal
[a]Rounded to the nearest tenth from reported values				
[b]Reported value = 0.038 lb				
Plymouth County MCP, Ground-application Pesticide Use[a]				
Altosid XR Briquets	IV			17.5 lb
Bactimos Pellets	IV	357.0 lb	500.0 lb	50.0 lb
Bactomos Briquets	IV	1.8 lb[b]	10.3 lb[b]	17.2 lb
Vectobac 12AS	IV	17.5 gal	2.5 gal	
Teknar HP-D	IV		17.5 gal	20.0 gal
Scourge 18 + 54	III	110.0 gal	85.0 gal	70.0 gal
[a]See Table 7, Aerial Application of Pesticides for information regarding aerial applications.				
[b]Total reported as briquets converted to lbs.				
Suffolk County MCP, Ground-application Pesticide Use[a]				
Altosid Briquets[a]	IV	3.5 lb	4.8 lb	3.3 lb
Altosid XR Briquets[a]	IV	57.5 lb	0.1 lb	11.4 lb
Bactimos Pellets	IV	25.8 lb	31.0 lb	
Vectobac 12AS[b]	IV	3.9 gal	7.9 gal	5.1 gal
Malathion 8EC[b]	III	1.5 gal	1.9 gal	0.2 gal
Permanone 10EC[b]	III	0.1 gal	1.4 gal	0.8 gal
Resmethrin[c]	III	11.2 gal		
Scourge 18 + 54[b]	III	6.3 gal	12.1 gal	3.5 gal
[a]Totals reported as briquets converted to lbs.				
[b]Rounded to the nearest tenth from reported values.				
[c]EPA reg #4-339-53853				

Table 5. Project distribution of operations by control method as expressed as a percentage of the budget allocated (average for 1981-1985) or as a percentage of the project's operations (1994 and 1995).

Berkshire MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	33	Source reduction (excluding OMWM)	20	20
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	5		40	40
Chemical larviciding/pupiciding	50	Chemical larviciding/pupiciding(excluding IGRs)	0	0
		IGR larviciding (methoprene)	5	10
Adulticiding	10		30	20
Public Education	2		5	10

Bristol County MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	60	Source reduction (excluding OMWM)	75	78
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	6		2	2
Chemical larviciding/pupiciding	3	Chemical larviciding/pupiciding(excluding IGRs)	0	0
		IGR larviciding (methoprene)	0	0
Adulticiding	30		22	19
Public Education	1		1	1

Cape Cod MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	70	Source reduction (excluding OMWM)	Information	
		Open Marsh Water Management		
Biological larviciding (Bti)	21		not	
Chemical larviciding/pupiciding	4	Chemical larviciding/pupiciding(excluding IGRs)		
		IGR larviciding (methoprene)	Supplied	
Adulticiding	0			
Public Education	5			

Central Massachusetts MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	70	Source reduction (excluding OMWM)	40	40
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	5		25	25
Chemical larviciding/pupiciding	5	Chemical larviciding/pupiciding(excluding IGRs)	5	5
		IGR larviciding (methoprene)	5	5
Adulticiding	15		15	15
Public Education	5		10	10

Table 5. Project distribution of operations by control method as expressed as a percentage of the budget allocated (average for 1981-1985) or as a percentage of the project's operations (1994 and 1995) (continued).

East Middlesex MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	34	Source reduction (excluding OMWM)	26	42
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	28		44	37
Chemical larviciding/pupiciding	27	Chemical larviciding/pupiciding(excluding IGRs)	<1	0
		IGR larviciding (methoprene)	4	4
Adulticiding	10		25	16
Public Education	1		1	1

Essex County MCP

	% of Budget 1981-1985[a]		% of Operations 1994	1995
Source reduction	--	Source reduction (excluding OMWM)	20	15
		Open Marsh Water Management	29	28
Biological larviciding (Bti)	--		40	50
Chemical larviciding/pupiciding	--	Chemical larviciding/pupiciding(excluding IGRs)	0	0
		IGR larviciding (methoprene)	0	1
Adulticiding	--		10	5
Public Education	--		1	1

[a]No response

Norfolk County MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	54	Source reduction (excluding OMWM)	50	50
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	4		25	20
Chemical larviciding/pupiciding	13	Chemical larviciding/pupiciding(excluding IGRs)	0	0
		IGR larviciding (methoprene)	14	20
Adulticiding	25		10	8
Public Education	4		1	2

Plymouth County MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	25	Source reduction (excluding OMWM)	45	53.0
		Open Marsh Water Management	0	0.0
Biological larviciding (Bti)	5		30	25.5
Chemical larviciding/pupiciding	25	Chemical larviciding/pupiciding(excluding IGRs)	0	0.0
		IGR larviciding (methoprene)	0	0.5
Adulticiding	40		20	16.0
Public Education	5		5	5.0

Table 5. Project distribution of operations by control method as expressed as a percentage of the budget allocated (average for 1981-1985) or as a percentage of the project's operations (1994 and 1995) (continued).

Suffolk County MCP

	% of Budget 1981-1985		% of Operations 1994	1995
Source reduction	1	Source reduction (excluding OMWM)	5	5
		Open Marsh Water Management	0	0
Biological larviciding (Bti)	26		30	30
Chemical larviciding/pupiciding	25	Chemical larviciding/pupiciding(excluding IGRs)	0	0
		IGR larviciding (methoprene)	15	15
Adulticiding	46		40	40
Public Education	2		10	10

Table 6. Types of Control Activity,[1] by Habitat

	Salt Marsh	Spring Brood	Summer Re-Flood	Cattail
Berkshire County		C,F	C,F	
Bristol County	A	C	C	F
Cape Cod MCP	A,C,D,E	A,C,D,E	A,C,D,E	A,C,D,E
Central Massachusetts		A,C,E,F	A,C,D,E,F	A,C,D,E,F
East Middlesex		A,C,D	A,C,D	
Essex		B,C	A,C	A,C
Norfolk	A,C,D,F	A,C,F	A,C,D,F	F
Plymouth	A,C,D,F	A,C,F	A,C,F	F
Suffolk	C,D,F	A,C,D,F	A,C,D,F	F

[1]Types of control activities -- indicate the types of control activities carried out on each wetland type using the following categories:

A -- Source reduction
B -- OMWM
C -- Biological larviciding
D -- IGR larviciding
E -- Larviciding, non-IGRs
F -- Adulticiding

Table 7. Aerial application of Pesticides, 1993 through 1995

Project/Town	Dates	Time of day	Acreage	Pesticide	Rate	Target Area
1993						
East Longmeadow	4/26 - 5/12	Daylight	1,000	Vectobac 12AS	1 qt/acre	
E. Middlesex MCP	April 12-22	6 AM - 8 PM	2,017	Vectobac G	1 pt/acre	
				Bactimos Pellets	5 - 7.5 lb/acre	
Plymouth MCP[a]	April 12-16	4 AM -Noon	1,360	Vectobac 12AS	1 pt/acre	Spring Brood
	May 3-7	4 AM - Noon	1,400	Vectobac 12AS	1 pt/acre	Spring Brood
	May 10-14	4 AM - 9 AM	1,920	Vectobac 12AS	1 pt/acre	Spring Brood
1994						
Chelmsford	April 16-22	Dawn - 11 AM	700	Bactomis Granules	5 - 7.5 lb/ac	
East Longmeadow	May 5 - 12	Daylight	1,000	Vectobac 12AS	1 pt/acre	
E. Middlesex MCP	April 19-28	6 AM - 8 PM	2,700	Vectobac G	5 - 7.5 lb/ac	Wetlands
				Bactimos Granules	5 - 7.5 lb/ac	
	August 23-27	6 AM - 8 PM	1,000	Vectobac 12 AS	1 pt/acre	Flood Plain/ Wetland
				Acrobe	1 pt/acre	
Plymouth MCP[a]	April 18-22	4 AM - 9 AM	8,000	Bactimos Pellets	8 lb/acre	Spring Brood
	April 25-29	4 AM - 9 AM	16,000	Bactimos Pellets	8 lb/acre	Spring Brood
	May 2-6	4 AM - Noon	8,000	Teknar HP-D	1 pt/acre	Spring Brood
1995						
Chelmsford	April 16-22	Dawn - 11 AM	700	Bactomis Granules	5 - 7.5 lb/ac	
East Longmeadow	May 5 - 12	Daylight	1,000	Vectobac 12AS	1 pt/acre	
E. Middlesex MCP	April 12-22	6 AM - 8 PM	2,800	Vectobac 12 AS	1 pt/acre	
				Bactimos Granules	5 lb/acre	
Essex MCP	June 10-17	5 AM - Noon	1,400	Vectobac 12AS	1 qt/acre	Salt Marsh
	June 20-24	5 AM - Noon	1,000	Vectobac 12AS	1 qt/acre	Salt Marsh
	July 8-22	5 AM - 8:30 PM	1,000	Vectobac 12AS	1 qt/acre	Salt Marsh
	August 5-19	5 AM - 8:30 PM	1,400	Vectobac 12AS	1 qt/acre	Salt Marsh
Plymouth MCP	April 10-14	4 AM - Noon	11,000	Teknar/Acrobe	1 pt/acre	Spring Brood
	April 18-21	4 AM - Noon	11,000	Teknar/Acrobe	1 pt/acre	Spring Brood
	April24-28	4 AM - Noon	11,000	Teknar/Acrobe	1 pt/acre	Spring Brood
	May 1-5	4 AM - Noon	11,000	Teknar/Acrobe	1 pt/acre	Spring Brood
	May 8-12	4 AM - Noon	5,500	Teknar/Acrobe	1 pt/acre	Spring Brood

[a]These are actual treatments for Plymouth County. Forms filed with SRMCB were for more dates and larger areas than actually treated.

Table 8. Estimated wetlands acreage affected, by habitat, exclusive of adulticiding.

	Salt Marsh	Spring Brood[a]	Summer Re-Flood[a]	Cattail
Berkshire County	0	500	250	0
Bristol County — no figures given				
Cape Cod MCP — no figures given				
Central Massachusetts	0	10,000	5,000 to 10,000	2,000
East Middlesex	0	2,767	1,192	0
Essex	5,000	500	1,000	0
Norfolk	38	1,087	523	0
Plymouth	100	7,860	1,000	0
Suffolk	240	130	130	5
TOTAL	5,378	22,844	9,095	2,005

[a]There is overlap between acreage affected by spring brood and summer re-flood

Table 9. Percentage of control effort, from monitoring through adulticiding (includes source reduction), by breeding habitat by Project.

Habitat	% Effort 1994	% Effort 1995	Species targeted
Berkshire MCP			
Salt marsh	0	0	
Freshwater			
Spring re-flood	90	90	spring brood *Aedes*
Summer re-flood	10	10	*Ae. vexans*
Cq. perturbans	0	0	
Bristol County MCP			
Salt marsh	50	50	*Ae. sollicitans, Ae. cantator*
Freshwater			
Spring re-flood	30	40	*Ae. canadensis, Ae. excrucians, Ae. cinereus*
Summer re-flood	15	10	*Ae. vexans*
Cq. perturbans	5	0	
Cape Cod MCP			
Salt marsh	50	50	
Freshwater			
Spring re-flood	50	50	
Summer re-flood	0	0	
Cq. perturbans	0	0	

Table 9. Percentage of control effort, from monitoring through adulticiding (includes source reduction), by breeding habitat by Project (continued).

Habitat	% Effort 1994	1995	Species targeted
Central Mssachusetts MCP			
Salt marsh	0	0	
Freshwater			
Spring re-flood	40	40	*Ae. absrratus, Ae. excrucians*
Summer re-flood	30	20	*Ae.vexans, Ae. canadensis*
Cq. perturbans	30	40	
East Middlesex MCP			
Salt marsh	0	0	
Freshwater			
Spring re-flood	45	52	*Ae. abserratus, Ae. aurifer, Ae. canadensis Ae. cinereus, Ae. excrucians*
Summer re-flood	37	28	*Ae. vexans, Ae. trivittatus*
Cq. perturbans	13	14	
Essex County MCP			
Salt marsh	50	60	*Ae. sollicitans*
Freshwater			
Spring re-flood	5	5	spring brood *Aedes*
Summer re-flood	45	35	*Aedes* species
Cq. perturbans	0	0	
Norfolk CountyMCP			
Salt marsh	10	10	*Ae. sollicitans, Ae. cantator*
Freshwater			
Spring re-flood	60	60	*Ae. excrucians, Ae. abserratus, Ae. cinereus Ae. canadensis, Ae. vexans*
Summer re-flood	15	15	
Cq. perturbans	15	15	
Plymouth County MCP			
Salt marsh	20	20	*Ae. sollicitans, Ae. cantator*
Freshwater			
Spring re-flood	60	60	*Ae. excrucians, Ae. abserratus*
Summer re-flood[a]	10	10	*Ae. vexans, Ae. cinereus, Ae. canadensis*
Cq. perturbans[a]	10	10	

[a]1994 and 1995 were extremely dry years which resulted in lower than normal control efforts toward summer reflood and *Cq. perturbans*.

Table 9. Percentage of control effort, from monitoring through adulticiding (includes source reduction), by breeding habitat by Project (continued).

Habitat	% Effort 1994	1995	Species targeted
Suffolk CountyMCP			
Salt marsh	30	30	*Ae. sollicitans, Ae. cantator*
Freshwater			
Spring re-flood	22	22	*Ae. excrucians, Ae. abserratus, Ae. canadensis*
Summer re-flood	42	42	*Ae. cinereus, Ae. vexans*
Cq. perturbans	6	6	

2. Current Practice

a. Salt marsh Mosquitoes

The combination of large, affluent human population (both permanent residents and visitors) and prolific pest mosquito populations near Massachusetts coastal marshes suggests that the public may always demand control programs to deal with this intense annoyance problem. Most salt marshes that breed *Aedes* mosquitoes are now under management and, in most cases, the strategy is source reduction.

Open Marsh Water Management (OMWM) projects now underway in Essex, Norfolk and Plymouth counties are being expanded to include essentially all problem marshes in those counties. OMWM plans are developed and tailored to the specific circumstances of each individual estuary. The permitting and review process for these projects is time consuming. Thus, it will be some time before all marsh management will consist of this strategy even though it is currently the most environmentally sensitive and rational marsh management strategy for most situations. Public and State agency support for OMWM is solid. Wolfe's (1996) review article on the effects of OMWM provides a strong basis for accepting OMWM as the best salt marsh mosquito control technique currently available. Wolfe makes the interesting point that salt marsh mosquitoes are an increasing problem not because they are breeding in greater numbers than before, but because more people are choosing to live near the coast.

Regardless of the benefits of OMWM, maintaining grid ditch networks is still an important part of coastal programs. Grid ditches are aesthetically unattractive and some have clearly had some negative impact on the normal high salt marsh ecosystem. In contrast, evidence suggests that some ditched marsh may be more productive than unditched marshes (Shisler & Jobbins 1975). No qualitative studies on the impacts of grid ditching in Massachusetts have been done but clearly the habitat has been dramatically changed. Converting open systems to OMWM systems does create a more-nature, though still highly managed, system. In the interim, current ditch cleaning practice seems preferable to the increased use of larvicides.

There are certain salt marshes where old ditches are effectively controlling mosquito production and perhaps where new OMWM activities might actually disrupt the marsh more than maintaining the status quo. Thus, OMWM plans should not be automatically prescribed for every salt marsh without first examining this issue.

Larviciding is still carried out in salt marshes that are unditched or in which ditches are ineffective or unmaintained. Larvicides in current use include the biological pesticide Bti, the insect growth regulator Altosid, and surface oils. These are all pesticides that have lower risks associated with their use. Bti and Altosid have the least potential non-target effects because of their high selectivity for certain dipterous insects. Bti is not always as effective in highly organic salt marshes as it is in other habitats.

Adulticiding in coastal areas is often necessary because of the huge numbers of mosquitoes that breed on the marsh (a 99% kill with larvicide can still leave a lot of mosquitoes). Truck-mounted ULV application is the standard response, as is the case for freshwater adult mosquitoes discussed below.

b. Inland Freshwater Wetlands

Most projects do a considerable amount of source reduction work in freshwater wetlands. This activity consists primarily of ditch and culvert cleaning to discourage ponding along natural waterways and the resultant production of spring and reflood *Aedes.* Routine maintenance generally involves hand-cleaning of debris from drainage systems and brush removal where it is encroaching on the flow system. Machinery is not used for routine maintenance but is used where deteriorating conditions (a build-up of such sediments as road sand being a common example) require work that cannot be done by hand.

Larviciding is done with Bti products, Altosid or Golden Bear oil. The vast majority of larviciding is done after mosquito breeding has been documented. Most applications are made from the ground by backpack sprayer or by hand (briquets). Aerial applications to freshwater areas are limited, but increasing (Table 7). Pre-hatch work is done by several projects. In general the area must have a lengthy history of mosquito breeding.

Mosquito breeding in vernal pools, large acid swamps, and cattail/water willow ponds cannot be readily controlled by source reduction work. Even larviciding is often difficult in large or deep permanent swamps. Projects with a large acreage of these habitats (i.e., Norfolk, Plymouth and Bristol) still depend more on adulticiding than do projects whose larval sources are more accessible to larviciding. Helicopter application of granular larvicides is perhaps the only way to reach many of these habitats with larvicides, but this practice has been hampered in the past by the fact that flight plans had to be filed too far in advance. This problem was overcome by the East Middlesex MCP by filing the flight plan when flooding started, not when larvae were first seen. This carried the risk of requesting a treatment that turned out to be unnecessary but the predictability of *Ae. vexans* breeding after flooding is high. Regardless, changes made to the Pesticide Board regulations at the start of 1997 season to make it easier to conduct aerial work. Norfolk MCP is actively increasing its aerial application program.

Coquillettidea perturbans remains a problem for larval control. Slow-release Altosid formulations looked promising for the control of cattail mosquitoes (Walker 1987) but this technique is not being used today, most likely because of high cost. Altosid pellets have been used with some effect (Ranta et al. 1994) and this approach may make expanding *Cq. perturbans* larval control possible. Fortunately, this mosquito has not been a significant pest over the last several years in most projects (see Table 9 for low % of effort directed towards *Cq. perturbans*). In East Middlesex MCP, however, *Cq. perturbans* has continued to greatly exceed nuisance threshold levels, being the main nuisance species between mid-June and mid-July. In nine cities and towns of the East Middlesex MCP, there is at least one light trap site which annually records greater than 500 *Cq. perturbans* per night during the peak period for that species. Dry the dry summers of 1993, 1995, and 1997, *Cq. perturbans* has been the only significant mid-summer mosquito problem.

No source reduction programs are in place for the maple/cedar swamps in which *Cs. melanura* breeds. Larviciding these areas has had some success (Henley 1992, Woodrow et al. 1995).

No control programs target permanent-water breeding *Culex* or *Anopheles* except in cases where *Aedes* are breeding as well and in urban habitats (see below). With the exception of minor work with dumped tires, *Ae. triseriatus* is not targeted for control.

Freshwater wetlands have been the sites most likely to have control restrictions due to endangered species. Salamanders, turtles and dragonflies have all been cited as reasons to either forego work or to restrict larvicide choice. In at least one case, the existence of vernal pools alone, regardless of endangered species presence, was sufficient for the local conservation commission to halt drainage maintenance in the area.

c. Irrigated and Other Man-Made Reflood Habitats

Very little agricultural land in Massachusetts is irrigated. Those lands which are irrigated tend to have sandy soils with good percolating characteristics. Golf courses, athletic fields, etc., which temporarily flood and produce reflood *Aedes* are generally very accessible and larvicidlng is the common practice for dealing with the habitats. Source reduction is occasionally used to eliminate or limit breeding in these poorly graded and drained grassy habitats.

d. Urban Habitats

Most projects do both source reduction (cleaning and repairing) and larviciding work on storm drain catch basins to control *Culex* breeding. Slow release larvicide formulations are popular in these small enclosed habitats. This urban mosquito control activity is non-controversial. It is effective, but the real impact of these mosquitoes on biting annoyance is not clear (see Part IV).

Wet basins have emerged as a primary problem in areas of new development. Shallow-water basins often hold water long enough in the spring to breed *Ae. canadensis*. Basins that have deep water in the spring (one-plus feet) may not breed mosquitoes then but may dry down in July and be perfect *Ae. vexans* breeding sites after a heavy August rain. Basins that are deep all year round may have invasive cattail on which *Cq. perturbans* can develop. Only basins that hold water for a week or less, even during the wet spring months, will probably not produce mosquitoes and even these require maintenance to avoid wetlands type vegetative growth that eventually causes longer pooling. Two other problems with basins is that many are fenced off, so that they are difficult to monitor, and ownership is often hazy so that maintenance lapses. Prevention of mosquito breeding in basins must become a design consideration.

3. Current Policies

a. Requests for Control

Requests for control are almost invariably for adult mosquito control, though individuals may request that wetlands on or adjacent to their property be checked and larvicided. Requests for adulticiding are handled in varying ways by the projects (Table 10). In most projects, complaint calls are considered a valid form of determining spray schedules, if not on an immediate basis, certainly over the long term. Responding rapidly to complaint calls is considered a primary objective of many projects, as they are service organizations. Of course, their service is to the common public good, and individual requests should be judged on that basis. Whether all programs do so is not known.

Table 10. Adult Mosquitoes: Monitoring and Adulticiding Policies

	Techniques used to trigger adulticiding			
Project	Light Traps	Landing Count	Complaint Calls	Post-treatment Monitor
Berkshire	No	No	Yes (for local treat[a])	Reduction in calls
	Berkshire also stated that adulticiding is done on a pre-scheduled basis			
Bristol County	Not for Spray	No	Yes	Reduction in calls Reduction in light traps
Cape Cod	Yes, but no Adulticiding is done by Cape Cod			
Central Mass	Yes	3/min	Do landing count	Random re-checks
East Middlesex	100 human-biting	4/min (for local treat)	Supplement LT data	Not done
Essex	No	10+/min	5/square mile	Landing counts
Norfolk	Yes	2/min (for local treat)	Yes (for local treat)	Limited landing counts Reduction in calls
Plymouth	No	Informal	Yes	Staff observations Reports from residents
Suffolk	Yes	Yes	Do landing count	Informal checks

[a]Local treatment by hand-held or backpack sprayer only

Larviciding requests do not make up the majority of calls to MCPs. But, for example, East Middlesex MCP does receive calls for both larval control and information on how residents can control mosquitoes. In general these come as a result of their newspaper releases concerning larviciding or from residents who observe control crews in wetlands in the past (Henley, personal communication). Other programs most likely receive similar calls. In general, though, monitoring is based on historical knowledge and survey work by the MCP itself. When larvae are found, larviciding typically occurs.

Pre-hatch work, is an exception to the rule that larvae must be present and is conducted when the project superintendent feels there is sufficient historical data to justify applications prior to larval hatch.

b. Documentation for Control Implementation

All Projects keep records of complaint calls, most conduct light trapping and most conduct some landing counts (Table 10). Of the three, landing counts are the most casual, often being little more than a report that there are a lot of mosquitoes biting the field staff in a certain area. However, Berkshire County, Central Mass and Suffolk investigate each complaint call and take landing-count data.

Field workers record larval counts at the sites they visit. In some cases, they bring larvae back either for larval identification or for rearing to adults for ID. In many cases, the larvae are sight-IDed to genus and more specific identification is not done. Counts for aerial application and/or OMWM are much more detailed and generally involve taking a specific number of dips at a permanently situated sampling station.

An area that needs improvement is record keeping regarding aerial applications of larvicide. The general plans filed by projects with the state are not specific enough, as they tend to describe the maximum possible application acreage, rather than acreage actually treated. Projects do keep records of actual treatments and these should be filed with the state as a post-treatment report,

Record keeping for freshwater drainage maintenance is spotty and needs improvement. Without baseline data on channel cross-sections, it is impossible to monitor maintenance work to ensure that channels are not becoming larger.

c. Selection of Control Strategies

Control strategies may be selected at the project level for both short- and long-term work, and at the field worker level for short-term work. Examples of project-level long-term selections are the absence of adulticiding by the Cape Cod project and the strong push into wetlands restoration by the Essex County MCP. Short-term, project level decisions revolve around the choice of larvicides made available to field workers, aerial work, and the distribution of personnel among, surveillance, source reduction and pesticide application work. Project Superintendents use their experience, the input of their staff, professional journals, and any other resource that can guide them in creating a quality program.

An under-emphasized aspect of the selection process is the cost of each strategy. Strategies that cost more than is available will not be implemented. Ground application of larvicide is possible in larger areas than it is currently being done, however the manpower requirements are high. Altosid applications for *Cq. perturbans* populations control seem to be limited primarily due to cost.

Field staff are responsible for determining the need to treat a given site, the type of material to use (for example, briquets versus a liquid treatment in a series of vernal pools), and whether or not physical control (removing debris clogging a culvert) should be done immediately or can wait for non-breeding periods. The effectiveness of any program is directly linked to the skill of the field staff in determining the most appropriate response to current local conditions and their motivation to carry out the appropriate response effectively.

One of the goals of the GEIR is to help establish procedures for determining which control technique to use. However, a large amount of basic research into mosquito and wetlands ecology needs to be done to improve our basic understanding of the cause and effect relationships among the environment and the control procedures available.

d. Evaluation of Efficacy

No project has developed a comprehensive and comparable data base on mosquito densities to document the long term impact of control efforts on annoyance levels in their communities. While they might be faulted for this failure, such an effort requires resources that many projects do not have. Nearly all projects routinely operate light traps or make landing rate counts in order to monitor adult population levels. Just how these data are analyzed and used is not clear. No publicity or publications utilizing quantitative data on mosquito populations have been produced by any project. All projects seem to keep good records of how many complaints they receive annually from each section of their jurisdiction. Statistical treatment of these data would be difficult and appears to have not been attempted.

Larval sampling is routinely carried out by all projects before pesticide applications. Post-treatment checks are less common. However, one of the reasons the projects did not accept Altosid very quickly was that it was hard to tell if the treatment had worked (the larvae can take up to a week to die). From this it can be inferred that post-treatment monitoring was occurring. This is an area where a state-level entomologist would be of considerable help as she could carefully monitor larvicide applications with an eye towards developing more accurate delivery techniques and application rates for varying situations.

Post-treatment monitoring of adulticide applications is done on an *ad hoc* basis (Table 10). A drop off in complaint calls is the primary criteria by which adulticiding efficacy is judged. While aerial ULV applications are effective (Mount *et al*. 1996), truck-mounted ULV treatments depend heavily on proper weather conditions and on there being an adequate road network. The general attitude, with the notable exception of Cape Cod, is that the residents pay for mosquito control and adutlciding kills mosquitoes. Developing better evaluation techniques for efficacy of truck-mounted adulticiding would be a major step in improving mosquito control in Massachusetts.

e. Public Participation

All projects notify residents by press release or public notice of their intended control operations for the coming season. Most towns also notify the Departments of Health and the chief executive's office of the municipalities for which they do work of their plans for the season. In Norfolk, each health board receives a notice of which days of the week the project may be treating in their town. Maps are included. Suffolk takes the process one step further and notifies the mayor's office before each adulticide. With minor variations all projects do the same type of notification.

Requests for exclusion are handled virtually identically by all projects, with a list of exclusion sites given to drivers so that they know where to not treat. Maps of excluded properties are made available to the spray crews.

Multiple Chemical Sensitivity (MCS) is becoming an increasingly important concern to health officials as the number of individuals reporting disabilities linked to chemical exposure has increased dramatically over the past decade. Regardless, MCS has yet to become a major issue for mosquito control. In most cases, an individual with MCS can be accommodated by the standard exclusion request since most mosquito control programs do not, as a general rule, ask why an exclusion is requested. This lack of conflict, however, should not be taken to mean that MCS is a non-issue. Mosquito control programs are designed to protect people, not harm them, and individuals suffering from MCS deserve to have their needs addressed. At the same time, control programs must take into account the needs of those who do not suffer from MCS, yet do suffer from mosquito problems. So long as programs continue to work honestly and above-board with MCS suffers (and any other group which requests exclusion), and receives the same level of cooperation from those requesting exclusion, mutually acceptable solutions should continue to be the norm.

One source for additional information on MCS is:

MCS Referral & Resources, Inc.
508 Westgate Road
Baltimore MD 21229-2343
Telephone 410-362-6400
fax 410-362-6401

Public education is a vital component of a complete program but current education efforts represent only a tiny part of most projects (Table 5). Programs vary from distribution of handouts upon request to full-scale educational presentations, including videos and other visual aids (Table 11). In general, but not absolutely, the extent of the education program is a function of program size. It is not clear that all projects use the Fact Sheets currently available from DPH. These include "Eastern Equine Encephalitis", "Insect bites and Insect repellents", and "Mosquito Repellents" as well as a pamphlet "Bugged by Mosquitoes?"

E. Eastern Equine Encephalitis

1. Responsibility for Surveillance and Control.

Eastern Equine Encephalitis (EEE) is an alphavirus endemic to many passerine bird species found in freshwater swamp habitats. The virus is transmitted among wild bird populations in these areas by *Cs. melanura*, a mosquito species that feeds almost exclusively on birds. The freshwater swamp is the enzootic focus of EEE and under normal conditions the virus is restricted to this habitat, Occasionally, however, due to factors which include seasonal and yearly rainfall levels and temperatures, mosquito virus may "spill over" into mammalian populations. This phenomenon is due to the transmission of the virus from infected birds to mammals by one of more mosquito species which feed on both humans and birds. Species that transmit disease from normal reservoirs to accidental hosts are known as "bridge vectors". The Massachusetts mosquito species traditionally thought to be likely bridge vector species are *Cq. perturbans, Ae. vexans, Ae. sollicitans,* and *Ae. canadensis*. Recently published studies also suggest that *Anopheles* species and *Cx. salinarius* may be possible epidemic vectors (Edman et al. 1993; Vaidyananthan et al. 1997). EEE virus has been isolated from all of these species. The bridge vector(s) responsible for EEE transmission to humans has not, however, been unequivocally identified.

EEE is a rare form of encephalitis with a high rate of mortality. The overall case fatality rate is now about 30% and survivors often suffer lifetime disabilities. The severity of illness tends to be most grave at the extremes of age. Fatality rates are highest among the elderly and intermediate in children. Infants and children who survive the

Table 11. Public Education Programs.

Project	Visit Complaint Callers	Give Talks	Notes on Programs/Pamphlets Available
Berkshire	Yes	Yes	UMss Coop Extension Leaflet "Mosquitoes" the "Ten Commandments of Mosquito Control" Bookmark for schools
Bristol County	Yes	No	Supply information upon request
Cape Cod	Yes	Yes	Conducts school programs for all age groups, have developed and distribute an informational pamphlet, and routinely appear in local press.
Central Mass	Yes	Yes	News releases to member municipalities' press Project staff attend various meetings A video "Working for You", a display and a slide show are all available Pamphlets are distributed to Boards of Health and other offices and anyone else who requests them. School program for elementary schools.
East Middlesex	Yes	Yes	School eduation program (three grade groups: 1-3, 4-6, and 7+) Give talks upon request. 20-minute video DPH fact sheets Pamphlet on Mosquito IPM
Essex	Not mentioned	Not mentioned	Fact sheets available on request 3-panel display available to environmental groups Outreach through environemental groups
Norfolk	Sometimes	Yes	Fact sheets: IPM, Bti, Methoprene, The Facts about Mosquito Spraying Materials supplied to local Boards of health Provides interviews on Local Cable TV Personnel always available for town-sponsored meetings Has extensive school program Attend local health fairs
Plymouth	Sometimes	Yes	Speaker program: spokesperson available year-round for any community group Utilizes community channel on cable TV Pesticide information distributed to towns and available to residents upon request DPH fact sheets and pamphlet "Homeowner Mosquito Control" pamphlet
Suffolk	Yes	Yes (Schools)	Press releases in the spring Faxes to mayor prior to treatment

infection are most likely to be permanently neurologically impaired and often require lifelong supportive care.

Horse cases of EEE have been described as early as the nineteenth century in Massachusetts and human cases were likely to have occurred, although they were not recognized as EEE prior to 1938. Since the first recognized outbreak of human EEE in 1938, 74 cases have occurred in Massachusetts with cases disproportionately concentrated in the south-central and southeastern parts of the state.

Four multi-year outbreaks of human EEE have been recorded in the central-eastern and southeastern areas of Massachusetts,. Thirty-four (46%) cases were identified in 1938. Subsequent years of human EEE cases have been 1939 (1 case), 1955 (4 cases), 1956 (12 cases), 1970 (1 case), 1973 (2 cases), 1974 (3 cases), 1975 (1 case), 1982 (2 cases), 1983 (6 cases), 1984 (2 cases), 1990 (3 cases), 1992 (1 case), 1995 (1 case) and 1997 (1 case).

The two worst years for human cases of EEE (1938 and 1956) occurred before there was an EEE Surveillance Program. However, it is assumed that the virus carriage of mosquitoes, and mosquito populations, would have been unusually high compared to average levels of these indicators. Since the beginning of a prospective EEE Surveillance Program, there have been two years of extraordinarily high levels of virus carriage in mosquitoes, in 1973 and 1990. Although only a small number of human EEE cases were identified in 1973 (2 cases) and 1990 (3 cases), there were significant control interventions in each of the two outbreak years. Wide-area spraying with ULV malathion was done to reduce populations of the vector species.

In 1990, in response to surveillance data showing alarmingly high and increasing EEE virus levels in mosquitoes, multiple horse cases, and the risk of multiple human cases, the largest aerial application (ULV) of malathion in years was made over much of southeastern Massachusetts. Three people contracted the illness prior to the treatment and one died.

As a result of this outbreak, the Department of Public Health and the State Reclamation Board sought to strengthen ties between state and project officials and to better define their response to future outbreaks. While there was considerable controversy over what some felt to be an extreme response by the state, there can be no question that mosquito populations were effectively reduced by the application and that no new human cases of EEE occurred after the treatment. Mount et al. (1996) provide an excellent review of aerial applications of insecticide for mosquito control and conclude that ULV applications are efficacious, cost effective and can work over dense foliage or open housing. The results in 1990 in Massachusetts support these conclusions.

2. Effect of EEE on Projects

Of the nine Projects, Berkshire is outside the EEE risk area and Cape Cod and Essex County are defined as low-risk areas. The other Projects provide significant support for EEE monitoring and mosquito control. When requested larval and adult monitoring data are also supplied by the Projects to DPH. Bristol, Norfolk, Plymouth and East Middlesex MCPs traditionally increase truck-mounted aerosol applications in areas of high public use when DPH indicates elevated risk of EEE. These Projects also supply support for, or actually conduct, aerial applications for larval (Bti) or adult (malathion) mosquito control at the request of DPH.

Though the Projects do not target EEE vectors specifically, unless so directed by DPH, their general operations permit surveillance and control work to be carried out against vector species as necessary. As an example, East Middlesex has 50 CDC light traps set up through out its district, a portion of which monitor *Cs. melanura* populations. East Middlesex has also conducted aerial applications of Altosid pellets to control *Cs. melanura*. Emphasizing the problem of *Cq. perturbans*, however, East Middlesex has been unable to develop a larva control program to adequately deal with this potential vector.

A continuing source of friction is the definition of a nuisance versus a health threat. While several projects were formed as much because of the possibility of EEE as the nuisance factor, no project today considers preventing EEE to be their primary goal. Fortunately, DPH and the Projects in EEE areas work well together and a system of graduated responses (from regional ground control up to state-mandated aerial adulticiding) has been put in place.

IV. DESCRIPTION OF MOSQUITO SPECIES AND ABATEMENT HABITATS

A. Mosquito Species

1. General Biology

Mosquitoes belong to the family Culicidae of the Order Diptera (true flies), insects with one pair of clear wings. There are 167 North American species in 13 different genera (Darsie and Ward 1981). Of these, 46 in 9 different genera have been found in Massachusetts (Table 12). About one-half of these (from 5 different genera) may at times cause significant human annoyance in certain localities; the majority belong to the genus *Aedes*. No mosquito species feeds exclusively on humans. Those species that annoy humans feed on a wide variety of other mammals and occasionally on birds as well. Some non-human-biting species such as *Cs. melanura*, *Cs. morsitans* and *Cx. restuans* can be important in the maintenance of enzootic disease cycles in wildlife. Some of these diseases, e.g., Eastern equine encephalomyelitis (EEE), occasionally spill over into human populations via transient epidemic vectors.

Mosquito life cycles can be grouped into two basic types: permanent-water and temporary-water (or flood-water). Temporary-water species generally belong to the genus *Aedes* or *Psorophora* and present the major pest problem in Massachusetts. Adult females can readily be distinguished from permanent water forms because their abdomen terminates in a sharp point formed by the extended cerci. This group overwinters as dormant eggs laid singly by females (usually ca. 75-150/female) in the band of moist soil surrounding the evaporating temporary pools in which the larval stages developed. Hatch (stimulated by increased temperature or reduced O_2) occurs when these depressions are flooded by tides, rains, irrigation or flooding rivers. The eggs of most temperate flood-water species must undergo a prolonged cold-conditioning period prior to hatch so there is normally only a single generation early each season (univoltine species). In a few species such as the eastern saltmarsh mosquito, *Ae. sollicitans*, eggs laid in the earlier part of the season will hatch after only 2-4 weeks of conditioning so multiple generations (multivoltine) are commonplace. The terms generation and brood are not always synonymous because not all eggs hatch when flooding occurs, so that multiple <u>broods</u> may sometimes occur from a single <u>generation</u> of overwintering eggs. In Massachusetts, reflood species like *Ae. vexans*, *Ae. sticticus*, and *Ae. trivittatus* (and perhaps late spring-hatch species like *Ae. canadensis* and *Ae. cinereus*) may have multiple generations or just multiple broods caused by delayed egg hatch. In spring, larval development of temporary-water mosquitoes may require two months or more

Table 12. Systematic Index of the Culicidae of Massachusetts

Taxon		
Genus *AEDES*		
	Subgenus *Aedes*	
		cinereus (Meigen)
	Subgenus *Aedemorphus*	
		vexans (Meigen)
	Subgenus *Ochlerotatus*	
		abserratus (Felt & Young)
		atropalpus (Coquillett)
		aurifer (Coquillett)
		canadensis (Theobald)
		cantator (Coquillett)
		communis (De Gerr)
		decticus Howard, Dyar & Knab
		diantaeus Howard, Dyar & Knab
		dorsalis (Meigen)
		ercrucians (Walker)
		fitchii (felt & Young)
		implicatus Vockeroth
		intrudens (Dyar)
		provocans (Walker)
		punctor (Kirby)
		sollicitans (Walker)
		sticticus (Meigen)
		stimulans (Walker)
		taeniorhynchus (Wiedemann)
		trivittatus (Coquillett)
	Subgenus Protomacleaya	
		hendersoni Cockerall
		triserlatus (Say)
Genus *ANOPHELES*		
	Subgenus *Anopheles*	
		barberi Coquillett
		crucians Weidemann
		earlei Vargas
		punctipennis (Say)
		quadrimaculatus (Say)
		walkeri Theobald
Genus *COQUILLETTIDIA*		
	Subgenus *Coquillettidea*	
		perturbans
Genus *CULEX*		
	Subgenus *Culex*	
		pipiens Linnaeus
		restuans Theobald
		salinarius Coquillett
	Subgenus *Neoculex*	
		territans Walker
Genus *CULISETA*		
	Subgenus *Climacura*	
		melanura (Coquillett)
	Subgenus *Culicella*	
		morsitans (Theobald)
		minnesotae Barr
	Subgenus *Culiseta*	
		impatiens (Walker)
		inornata (Williston)
Genus *ORTHOPODOMYIA*		
		signifera
Genus *PSOROPHORA*		
	Subgenus *Grabhamia*	
		columbiae (Dyar & Knab)
	Subgenus *Janthinosoma*	
		ferox (von Humboldt)
	Subgenus *Psorophora*	
		ciliata (Fabricius)
Genus *URANOTAENIA*		
	Subgenus *Uranotaenia*	
		sapphirina (Osten Sacken)
Genus *WYEOMYIA*		
	Subgenus *Wyeomyia*	
		smithii (Coquillett)

while in summer it may be as brief as 4-6 days. Permanent-water mosquitoes deposit their eggs (generally a multi-egg raft of ca. 100-250 eggs except in the *Anopheles*) on the surface of permanent or semi-permanent (i.e. persists for several weeks) water and hatch occurs within 1-3 days. Populations are asynchronous compared to flood-water species (with several overlapping generations), and larval development tends to be longer. Some permanent water species (e.g., *Cq. perturbans, Cs. melanura* and *Cs. morsitans*) overwinter in a diapausing larval stage, but most overwinter as hibernating adult females that are fertilized, nulliparous (never having produced eggs), and non-blood-fed.

Mosquitoes metamorphose into the winged adult stage within the nonfeeding pupal stage. The pupa is active and aquatic (called tumblers) and is resistant to most chemical control measures (suffocating surface films are an exception). It normally lasts only 2-4 days. Males generally pupate and emerge about 1 day ahead of females of the same cohort.

Mating most commonly occurs in twilight swarms within 2-3 days after females emerge. Most, but not all, females mate before they take blood. Both sexes feed frequently on plant nectar; females take blood in order to obtain protein for egg development. A few species are autogenous, meaning they do not need a blood meal to produce eggs. One Massachusetts species, the pitcher plant mosquito (*Wy. smithii*), never takes blood. Most females begin seeking hosts 2-4 days after emergence but some species (e.g., *Cs. morsitans*) may delay feeding for 2 weeks or more. Thus, the time period between adult emergence and the first egg laying (first gonotrophic cycle) is usually 7-10 days. Subsequent host-feeding to egg-laying cycles in most temperate species require 4-6 days.

Species that transmit disease (vectors) must feed at least twice, once to acquire the infection, and once to transmit it, unless the infection is acquired transovarially (into the egg while in the ovary) from their mother. This means that females must normally survive for 12-14 days in order to be a vector. If the extrinsic incubation period of the pathogen/parasite in the mosquito is longer than the gonotrophic cycle, as is often the case, the survival time required for transmission is even longer.

Most females do not survive beyond the first oviposition but a few individuals in all mosquito populations live a long time (i.e., several weeks). Exceptionally, overwintering adults live 5-7 months. Males generally survive for shorter periods than females and never overwinter.

2. Saltmarsh mosquitoes

The leading pest mosquito problem in coastal communities in Massachusetts is caused by two brackish water species, *Ae*. *sollicitans* and *Ae*. *cantator*. The latter species is abundant only in the early part of the season (mid-May to mid-June); *Ae*. *sollicitans* is the major target of most saltmarsh mosquito control efforts. Both species develop in pans in the high salt marsh (dominated by *Spartina* grasses) which are normally only flooded by moon tides. Heavy rains or high tides caused by unusual winds can also cause intermittent flooding in the high marsh. *Ae. cantator* tends to occur more in the extreme upland edge of the high marsh. This area is often quite fresh and may include plants such as cattails. Unmaintained mosquito ditching can become an important breeding area, as *Spartina alterniflora* prevents the ditches from draining and shallow water is held between moon tides.

Aedes taeniorhynchus is a third species that occurs in salt marshes, often in conjunction with *Ae. sollicitans*. Complicating the control picture further is *Cx. salinarius* which sometimes breeds in after heavy, late-summer rains. As a result, salt marshes generally require monitoring at least twice a month (once after the full-moon high tide and once after the new-moon high tide) as well as after any major rain event. With regard to saltmarsh mosquito control, one should always assume that there are huge numbers of eggs available to hatch after any flooding; any other assumption will result in broods being missed and adult mosquitoes swarming in numbers not easily understood by one who has not experienced them.

Uncontrolled populations of salt marsh *Aedes* often reach extremely high biting densities (i.e., 100+ females landing/minute). Adults may not be particularly long lived, but because moon tides occur so regularly and often, multivoltine *Ae*. *sollicitans* can be a problem throughout the summer season. Because the economies of coastal areas affected by this mosquito often depend heavily on summer tourism, the impact of saltmarsh mosquitoes is greatly magnified. This is reflected in the percent effort coastal projects spend on saltmarsh *Aedes* control (Table 9).

Salt marshes and the estuaries they feed are the principal nursery grounds for a variety of marine and brackish water organisms, including several commercial forms. Disrupting these vital wetlands to control saltmarsh mosquitoes can cause unintended, long-term problems.

3. Freshwater mosquitoes. The most severe and predictable late-spring to early-summer mosquito annoyance in all inland (and many coastal) areas is caused by several species of *Aedes* collectively referred to as spring-hatch or snow-pool mosquitoes, the most common of which is *Ae. canadensis*. These mosquitoes tend to

develop in similar aquatic situations (i.e., temporarily flooded woodland depressions including the flooded borders of permanent swamps and bogs) and have similar life cycles. They overwinter as dormant eggs and have a single, spring generation each year (univoltine). Adult mosquitoes are most active from late spring to mid summer; the females taking blood meals and depositing their eggs in the moist soil and leaf litter around the edges of the evaporating woodland pools in which they developed as larvae. They are part of a larger grouping of mosquitoes called temporary-water or flood-water species which all have eggs that hatch synchronously when flooded by rain, tide, snow melt or rising rivers. In this case, snow melt and spring rain fill the woodland depressions that are stocked with eggs, usually causing hatch sometime in early March. Mild conditions in late February and early March followed by severe cold, or spring precipitation, can reduce larval populations by freezing or flooding. As a result, considerable year-to-year population variation occurs.

Spring-hatch *Aedes* can be subdivided into two major groups, dark-legged and banded-legged, based partly on the physical appearance of biting females and partly on some minor differences in their life cycles. The dark-legged group hatch and emerge about 1-3 weeks ahead of the banded-legged group and seem to survive as adults for a shorter period of time. Some members of this group (e.g., *Ae. punctor*) become more abundant at more northern latitudes (coniferous forest zone) and at higher elevations (e.g., near the top of the Holyoke Range). When people enter the densely shaded daytime resting places of these mosquitoes, females attack more aggressively than do members of the banded-legged group such as *Ae. stimulans* and *Ae. canadensis*. Dark-legged *Aedes* appear to be the principal vectors of California group encephalitis viruses. These viruses overwinter inside the eggs of their mosquito vector (Calisher & Thompson 1983).

The banded-legged group often develop in the same pools and rest in the same wooded, daytime resting habitats as some species in the dark-legged group. However, they tend to disperse further from the larval habitat and, during the early evening biting peak of both groups, banded-legged females feed more readily in open and semi-wooded habitats than to dark-legged females. Some banded-legged females survive into August, and this group seems to be the principal vector of dog heartworm in Western Massachusetts.

Although the general larval habitat of both groups is similar, considerable variation in habitat occurs and some species are more restricted than others. For example, certain dark-legged *Aedes* are mainly found in association with cranberry (*Ae. aurifer*) or sphagnum (*Ae. decticus*) bogs. Spring woodland pools vary from small, shallow depressions formed by fallen trees to large, deep ravines in mountain bedrock and natural swales in forested flood plains. Permanent woodland or grassy swamps and bogs are also a common source of some members of the spring *Aedes* group.

a. *Aedes canadensis*. *Aedes canadensis* is perhaps the dominant spring-breeding mosquito in the Northeast. It's primary habitat is woodland vernal pools; pools that having standing water from snow-melt until early summer. Larvae can be collected even before the last frosts but development is slow during the cool spring months and adults usually do not emerge until near the end of May or in early June. Although *Ae. canadensis* is an active biter, it does not generally fly far from the woods in which it breeds. As residential areas have cut their way into the woods of Massachusetts, however, *Ae. canadensis* has become an increasing problem.

Aedes canadensis control is difficult because the pools in which it breeds are isolated from each other. A small woodlot can contain many pools, some of which may require field workers to cut through poison ivy, multiflora rose, and bull brier just to reach. Ground application of larvicide under such circumstances is tedious and, regardless of intent, often less than complete.

Aedes canadensis is predominantly univoltine, but a second brood (either delayed hatch of over-wintering eggs or early hatch of spring-laid eggs) can develop in early fall if rainfall is sufficient to partially fill the woodland pools. In such cases, treatment is nearly impossible, as a summer's growth of the above-mentioned plants, coupled with a dense canopy of leaves from the many shrubs that line the pools make getting to the pool, and placing the correct amount of pesticide in the pool, extremely difficult.

b. *Aedes vexans*. *Aedes vexans* is the most ubiquitous floodwater mosquito in North America and is the predominant summer reflood mosquito in Massachusetts. *Aedes vexans* is found in lake and river flood plains, shrub swamps, flooded meadows, and shallow grassy depressions associated with open habitats such as roadside ditches, pastures, golf courses and athletic fields. It will also breed in woodland pools and shallow cattail marshes, such as those that develop in some retention ponds. The first *Ae. vexans* are normally not on the wing before mid-June. Populations of *Ae. vexans* are unpredictable because they depend entirely on the frequency and spacing of major rains. Rainfall of 1 inch many produce some *Ae. vexans* but it usually requires 3" of rain within a short period of time (several days) to produce a large brood.

Larval broods of *Ae. vexans* have been observed as late as mid-September in Amherst. It is not always clear whether such late season broods result from the delayed and staggered hatching of eggs that are a year or more old or from the hatching of non-diapausing eggs laid earlier the same season. Brust and Costello (1967) and

Horsfall *et al* (1973) have shown that many species such as *Ae. vexans* lay some eggs that will hatch without cold conditioning. Sequential hatching of eggs is also well documented in five reflood *Aedes* species (i.e., *canadensis, cinereus, sticticus, trivittatus,* and *vexans*). Larval development is rapid, 4-6 days, and the pupal stage lasts for about 2 days. Hence, the window for effective larval/pupal control is narrow. Moreover, a large number of scattered pools all need to be treated within the same brief time span following major rains. Control efforts suffer from the same difficulties as described for *Ae. canadensis*, as *Ae. vexans* will often breed in mid-summer in the same pools used by *Ae. canadensis* in the spring.

c. Additional *Aedes* species

Lesser, but at times significant, populations of *Ae. triseriatus*, *Ae. trivittatus* and *Ae. sticticus* do occur in Massachusetts. Larvae of the latter two species are associated with ground pools in wooded or semi-wooded flood plains. Extremely heavy general rains sufficient to cause river flooding commonly proceed large populations of *Ae. trivittatus* and *Ae. sticticus*.

Aedes triseriatus is a treehole mosquito, breeding in the wild in holes left in trees when a branch breaks off and/or insect damage causes a part of the tree to rot out. Within the shaded forest it is a ready biter but it does not venture far from it's breeding areas. Because it's larval habitat is widely dispersed (and often well above the height that a person could reasonably be expected to reach), larval control is not possible. Fortunately, because it stays within the woods, control targeting *Ae. triseriatus* is rarely necessary.

Aedes triseriatus overwinter as eggs in the larval habitat; hatching occurs in early spring and development to the adult stage takes about 3 months. The first biting adults appear in late June in Massachusetts. Larval populations are often crowded and asynchronous so some emergence continues until early August. A second generation of larvae has been observed, especially in tires, where water is usually warmer and development is faster. However, it is doubtful that many adults from this generation are successful at this latitude. This mammal-feeding, diurnal species does not normally disperse far from its sylvan larval habitats. Biting adults are particularly active in the late afternoon, pre-twilight period (i.e., 4-7 PM).

If *Ae. triseriatus* stayed in the trees, it would be a minor pest, but it has become well adapted to breeding in tires, particularly where they are shaded. As a result, *Ae. triseriatus* can be a locally important pest wherever rimless tires are stored. Tire removal, and the prevention of illegal tire dumping along wooded roads, is an important part of mosquito control.

Aedes atropalpus is another natural container breeder, but it is associated with rock pools, especially those in exposed riverbeds. The northern form is autogenous for the first egg batch so it is a less bothersome daytime pest species than its southern sibling, *Ae*. *epactius*. This species has also become adapted to tires in the Midwest.

A new Asian container breeder, *Ae. albopictus*, has recently been introduced into the Southern United States (Texas), apparently via imported used truck tires (Moore 1986). This diurnal urban pest throughout Asia has already spread as far north as Indiana and is likely to appear in Massachusetts at some point (Nawrocki & Hawley 1987) Locations where used truck tires are brought in and stored for recapping are the most likely points of introduction. This species has mainly been found in tares in the United States to date. It is an efficient laboratory vector of many Western Hemisphere arboviruses (Shorter 1986).

d. *Culex* species. *Culex* mosquitoes have an ambiguous place in mosquito control in Massachusetts. On the one hand, they are commonly encountered as larvae in storm drains, cisterns, drainage basins and other contain-type situations but, on the other hand, the extent to which they cause biting problems for people and are involved in the transmission of disease, for example encephalitis between birds, is unknown. Species such as *Cx. territans* and *Cx. restuans* are certainly not pests of humans, but *Cx. restuans* may be involved in transmission of EEE between birds (it is common to pick up EEE in *Culex* pools in areas where it is present in *Cs. melanura* pools–the problem being that *Culex* pools are rarely sorted to species before testing).

Culex mosquitoes are multivoltine, having several generations per year. There can be considerable overlap among the generations. Adult females overwinter and are among some of the first mosquitoes to be seen in the spring. *Culex* mosquitoes do not bite during the day and are more active later at night than are most *Aedes* species.

The house mosquito, *Cx. pipiens*, breeds prolifically from mid to late summer in urban storm sewers, ornamental/wading/swimming pools, bird baths, plugged rain gutters, tires, car bodies, empty barrels, and other similar manmade containers. This species tolerates pollution, so the highest densities often occur in eutrophic water enriched by animal waste (e.g., sewage oxidation ponds). Multiple, overlapping generations (each requiring 8-10 days) occur in the same habitat. Mated but non-blood-fed females produced late in the season overwinter in underground sewers, basements, and other protected places.

The southern form, *Cx. pipiens quinquefasciatus*, feeds readily on both mammals and birds (Edman 1974), but the northern form, *Cx. pipiens pipiens*, which occurs in Massachusetts, is mainly associated with avian hosts. In large urban centers in the North, a less common autogenous form (*Cx. pipiens molestus*) exists. It readily attacks humans after the initial blood-free gonotrophic cycle is completed. This form has been documented in Boston, where it is associated with underground sewers and subway tunnels (Spielman 1973). *Cx. restuans* is often found in some of the same container habitats as *Cx. pipiens*.

Culex salinarius differs from the above-mentioned *Culex* species in that it is an active human biter and can occur in significant numbers. It's breeding habits are poorly understood as it is generally classed as a permanent-pool breeder but dense larval populations have been found in rain-fed pools in salt marshes in Rhode Island (salinities close to 0 ppm) and large adult populations existed in the coastal residential area of Bonnet Shores, RI in 1986 (Christie, personal communication).

The extent to which *Culex* species require control can be debated. Species such as *Cx. territans* almost certainly play no role whatsoever in either pest or disease problems. However, the ability to identify mosquito larvae to species is often not well developed and field identification can be difficult (though separating A*edes* from *Culex* requires little more than direct observation). Under such circumstances, treatment of any larval population is the general rule. Defining the role of *Culex* species in the magnification of EEE within the bird population would aid in determining the extent to which larval control of *Culex* should take place.

e. *Culiseta* species

Culiseta melanura occupies an interesting position in Massachusetts mosquito control in that it is the only known vector species in Massachusetts that is not also a significant pest. Therefore, controlling *Cs. melanura* in the larval stage, especially prior to documentation of EEE in adult *Cs. melanura* populations, is controversial in that the MCPs, as established, are not expected to target vector mosquitoes as a part of their routine work. The decision as to whether or not to attempt larval control would be made easier if *Cs. melanura* bred in habitats occupied by other pest species such as *Ae. vexans* or *Ae. canadensis*. Unfortunately, *Cs. melanura* breeds in a very specific habitat, the holes that develop around the roots of trees with cedar/maple swamps and is not routinely affected by treatment work for other species. In fact, because the holes are not interconnected and are often have only small openings, they are extremely difficult to treat even when the decision has been made to attempt larval *Cs. melanura* control.

Other *Culiseta* species exist in the state but have not been identified as vectors of disease or pests of humans.

f. *Coquillettidea* (formerly *Mansonia*) *perturbans*. Among a group of insects already disliked by humans, *Cq. perturbans* stands out as being particularly disliked by mosquito-control personnel. First, it is a large, aggressive biter that sparks complaint calls like few other mosquitoes and, second, because the larva lives attached to the stems of cattail, it is exceedingly difficult to monitor and control

In Massachusetts, *Cq. perturbans* has one generation per year. It overwinters in the larval stage (3rd instar) and adults begin to emerge in mid to late June, peaking in mid-July. Breeding occurs principally in cattail/water-willow ponds. These ponds are often caused by road, railroad, pipeline, power line, and parking lot construction next to natural wetland or seepage areas. Adults feed primarily during evening twilight periods on larger mammals situated in open pastures or in transitional habitats (Edman 1971). Birds are also attacked when they are available in the foraging habitat of this mosquito.

Coquillettidia perturbans presents unique control problems because larvae and pupae remain attached to the base of emergent plants at the bottom of deep ponds. Oxygen is obtained directly from the plant cells in which the modified air tube is imbedded. At this time there is no known effective larval control for *Cq. perturbans*, making adulticiding the only real choice for control in residential areas located near cattail marsh. For this reason, the present pollution-control fade of cattail ponds must be carefully monitored by mosquito-control programs. Wherever possible, manmade cattail drainage basins should be avoided or should be so constructed that, for a period of several weeks in late summer, no standing water is present in the basin. This will break the aquatic part of the life cycle.

Coquillettidea perturbans is a vector of EEE, compounding the problem of it's control by increasing the stakes in any decision not to control it.

g. Other freshwater species. Mosquitoes of the genera *Anopheles* and *Psorophora* can also be pests in Massachusetts. *Anopheles* mosquitoes differ from the other genera of mosquitoes in that, as larvae, they lie, upside down, on the under-surface of the water. They commonly inhabit more permanent waters and can sometimes be found along the edges of slow-moving streams. They are also fairly common later in the summer in puddles in dirt roads and other pools, often being found together with *Ae. vexans* and/or *Culex* species. *Anopheles* mosquitoes do not occur in the kinds of swarming numbers that *Aedes* mosquitoes do, but they enter houses more readily. They overwinter as adults and are some of the first mosquitoes to bite in the spring. Individual females are not uncommon in-house biters on the occasional warm day in spring.

Psorophora ferox, is a large, aggressive mosquito that breeds in the flood plains of overflowing summer rivers and streams. It is not common in the northeast but, where it is present, it is an unforgettable insect, both because of it's size and the painful bite.

B. Habitats in which mosquito control takes place.

An understanding of where mosquitoes breed and feed is essential to understanding mosquito control. Perhaps one of the most frustrating things to the mosquito-control professional is the misunderstanding within the general public as to where mosquito breeding occurs and where mosquito control should take place. To anyone who works in coastal mosquito control, the new homeowner, experiencing her first summer brood of saltmarsh mosquitoes, is a familiar, and somewhat sorry, sight. Calls concerning, "...that pond of my neighbor's" are far more common than, "I have some vernal pools in the wood lot behind me."

The following discussion will start with breeding areas (coastal and inland wetlands and, to some degree, surface water bodies) and progress to adult habitats (surface water bodies, recharge areas, upland areas and agricultural areas). Finally, sensitive environments will be discussed from both a breeding perspective and with regard to adult mosquito control.

1. Coastal Wetlands

a. Marine. The marine habitat for mosquito breeding is restricted to salt marshes, generally between the level of mean high water and high high tide. Below mean high water tidal flushing is too frequent and too strong for mosquitoes to successfully breed and above high high tide the water longer has sufficient salinity to breed saltmarsh mosquitoes. The plant species most frequently associated with mosquito breeding are the short-form *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii*. Tall-form *Spartina alterniflora* generally defines the lower breeding edge (except in blocked ditching where the tall form edges the ditch) and *Iva fructesens* generally defines the upland edge.

Aedes cantator is the most common species when salinities are low (0 to 10 ppt) as occurs in the spring and after heavy summer rains. *Aedes sollicitans* dominates the mid-summer months when salinities are high (10 ppt and up). However, there is considerable overlap between the two species and it is not difficult to collect both in the same dip of water. *Aedes taeniorhynchus* is less common than above two species. *Culex salinarius* seems to be restricted to rain-fed pools at the upland edge.

b. Brackish. Both *Phragmites communis* (tall reed) and *Typha* species (cattail) obscure the boundary between fresh and salt water. Salinities in the range of 1 to 5 ppt occur and *Ae. cantator* dominates this type of habitat. Cattail tends to indicate a fairly constant source of freshwater, such as a stream or spring, while

Phragmites tends to indicate pooling of water for temporary periods at a level just high enough to avoid salt-water influence except under storm conditions.

2. Inland Wetlands.

Freshwater wetlands vary tremendously in size and hydrology, from small damp spots in isolated wood lots, to broad wooded swamps to sheet flow of spring water down the sides of hills. Mosquito breeding tends to be maximized in areas of temporary, standing water but the number of species that breed in freshwater makes generalizations difficult at best.

Red-maple swamps are a significant source of *Ae. absserratus* and *Ae. canadensis*. Flood plains, flooded meadows and shrub swamps produce *Ae. excrucians* and *Ae. vexans*.

Vernal ponds have received particular attention both because they breed mosquitoes and because they are an important breeding site for amphibians and other semi-aquatic animals. These ponds are rarely more than one-to-two-hundred square feet in surface area, and remain flooded from snow melt until drydown in mid to late June. They breeds *Ae. absserratus, Ae. excrucians, Ae. canadensis, Ae. cinereus* and, if dry down is late or the pool is reflooded by rain, *Ae. vexans* and *Anopheles* species. If such a pool is located in a flood plain, it can breed *Ps. ferox* as well.

Larger, deeper swamps cause considerable difficulty because, although the number of mosquito larvae per square foot may be low than in the vernal ponds, the size of the swamp more than makes up for the difference. Further, access to the central areas of the swamp is extremely limited, making aerial application the only practical control technique. *Aedes absserratus* and *Aedes* canadensis are two primary pest mosquitoes that emerge from these swamps. As the swamps dry down, innumerable pockets of water are left among the tree roots and *Cs. melanura* becomes increasingly easy to find as the swamps dry.

Flood-plain marshes, wet meadows and swamps produce *Ae. excrucians* in the spring and *Ae. vexans* in the summer. Flood plains are ideally suited for *Ae. vexans* as peak flooding is delayed for a day or more after rainfall and areas remain flooded longer than in other areas. This creates ideal conditions for breeding. In the summer East Middlesex MCP has recorded up to 5,000 *Aedes vexans* per night at collection sites in close proximity to river flood plains.

Shrub swamps are much less common than forested swamps so are less a target for mosquito control on that basis. *Aedes excrucians* seems to be the pest mosquito most likely to be found in such sites, and *Cu. restuans* is also common.

The mosquito problem associated with marshes depends on water depth and the presence of cattail. A marsh more than a foot deep with an extensive stand of cattail will breed *Cq. perturbans* and be a constant source of difficulty to control personnel. If water levels are lower, and cattail is replaced by emergent grasses and rushes, then *Ae. canadensis* and *Ae. vexans* may be present. Again, *Culex* and *Anopheles* species are fairly common in this type of marsh.

A less-common type of wetland is the sloping, forested wetland caused by water seepage and typically having a ground cover of skunk cabbage. Mosquito breeding is not high in such places, the slope preventing significant pooling, but manmade disturbances, such as cutting a dirt trail across the face of the slope, can pool water and provide breeding habitat.

3. Surface Water Bodies. As opposed to the wetlands described above, in which surface water often disappears for at least part of the year, surface water bodies generally have standing or moving water year-round and have an extensive, open water surface.

a. Lakes and ponds. Few mosquitoes breed in the open water of lakes and ponds. Breeding does occur in the wetlands, particularly cattail, that border the lake or pond. In East Middlesex MCP, flood plains and cattail marshes located on the edges of lakes and ponds produce massive populations of *Ae. Excrucians, Ae. vexans,* and *Cq. perturbans* (Henley, personal communication). Small ponds which become covered with floating plants such as duckweed can breed *Culex territans* and *Anopheles* mosquitoes. Small, manmade ponds lacking fish populations can also breed mosquitoes, especially where emergent vegetation exists.

Although not significant breeding sites, lakes and ponds are areas where adult mosquitoes congregate. Several reasons probably play a role, from the availability of water to drink, to the fact that mammals and birds tend to come to water to drink also and, that there are often wetlands immediately adjacent to more open bodies of water.

One important point to make is that there are numerous types of gnats and midges that, to the untrained observer, look much like mosquitoes. These insects breed in the sand or mud edging ponds and lakes and can give the appearance of huge numbers of mosquitoes as the adults swarm among the vegetation. Early-season complaint calls are often based on observations of these, no-biting, insects.

The fauna of all open bodies of water, including rivers and streams discussed below, are particularly susceptible to broad-spectrum pesticides such as malathion and the pyrethroids group. Larval control is rarely an issue, but adulticiding near open water always carries some risk of non-target kills.

b. Rivers and streams. The current in the open water of rivers and streams makes mosquito breeding impossible in all but the slowest moving sections. Even here the predator complex in most cases is too well developed for mosquitoes to survive in any numbers. Again, however, the wetlands bordering the river are significant breeding sites. Some breeding also can take place in intermittent streams, once they have stopped flowing and before they dry down completely.

4. Recharge Areas. Recharge areas are those in which surface water percolates down to recharge aquifers or drains into reservoirs. The obvious concern in such cases is that pesticides used in such areas may move along with the water, causing contamination of the aquifer or reservoir. The primary pesticides for mosquito control, resmethrin and Bti, break down quickly and do not pose a water-quality risk to reservoirs. Of course, adulticiding over wetlands can kill wetland species directly, though ULV rates are low enough that such kills are infrequent.

a. Wetland. Because wetlands are wet due to the impermiability of the substrate, their addition to recharge areas is often less than that of surrounded, drier areas. Pesticides applied to wetlands, therefore, are not likely to cause contamination by percolation. However, because wetlands do store water which can then move out of the wetland as runoff, pesticides applied to such areas may move off-site, including into reservoirs.

b. Upland. Upland recharge areas rarely have significant mosquito breeding, because the water percolates downward quickly. The primary concern in such areas would be heavy rainfall immediately after a treatment for adult mosquitoes. In such cases there could be overland flow of runoff contaminated by pesticide washed from leaf surfaces.

5. Upland Areas. This is a catch-all category for all lands not defined as wetlands. Obviously, the majority of human developments are located on uplands and the majority of adulticiding takes place within upland areas. Perhaps unconsciously, pesticides used for adult mosquito control are designed to be relatively benign to the plants and vertebrate animals of Massachusetts. No material that caused robins or squirrels to drop in their tracks, or which killed maple trees, would ever be permitted for use in Massachusetts. This makes ULV sprays in such areas appear reasonably benign. However, simply because the larger species do not exhibit acute effects, does not mean that no effects occur. One clear question that cannot be answered is what long-term effects do regular

adulticide treatments have on the less-visible fauna of the typical suburban woodlot-meadow habitat in Massachusetts.

6. Agricultural Areas. The muddy hoof-prints of the milk cows around the water hole may well breed *Ae. vexans*, but the proper control in such cases must take into account the fact that food for human consumption is the primary purpose of the land in question. The Bti and IGR larvicides currently available are unlikely to cause problems in meat, dairy or crop production, but adulticides are a different story. Pesticide residues are limited even on non-organically grown produce and a late-summer application has the potential to cause problems for growers. Of particular concern are the backyard gardens of homeowners which cannot help but receive the drift from pesticide applications.

Agricultural enterprises of particular concern are apiaries and organic farms. Bees are susceptible to pesticides but the exposure to bees caused by mosquito control applications of resmethrin at night is minimal since the bees have already returned to their hives.

During the EEE vector control aerial applications of malathion, beekeepers were advised to cover their hives. The applications were scheduled for 2.5 hour windows after dawn and before dusk. The criteria used in determining the period of the spray window included daylight periods when mosquito activity would be optimal and bee activity would be minimal.

The owners of properly run organic farms have gone to great lengths to become certified as pesticide free. In most cases the farms are small and the business, at least in the first years, marginal. The problem with organic farms, under normal circumstances, is knowing they exist, not avoiding them once known. Massachusetts MCPs have systems in place so that organic farmers can heave their land excluded from pesticide applications. Problems can develop when the question of drift from nuisance spraying occurs, or when there is a public-health threat.

7. Sensitive environments and populations. Certain environments and populations have special considerations which require a more cautious approach to mosquito control. Some of these have been discussed above but there are others worthy of mention.

a. Urban. The urban environment requires special care due to the increased population density and the difficulty in ensuring that people know the benefits and the dangers associated with mosquito control.

b. Recreation. People who enjoy outdoor recreation areas often have a higher tolerance for mosquitoes and a lower tolerance for spray vehicles than does the population at large. On the other hand, resort communities may demand higher than normal levels of mosquito control in order to make their site more enjoyable to the public. In any event, areas in which summer recreation takes place tend to polarize the debate over control and provide increased political headaches for MCPs, even where mosquito control itself is relatively straightforward.

c. Sensitive individuals. There are several groups of people who are sensitive to pesticide applications. Some individuals with emphysema or asthma can be adversely affected by airborne pesticide applications and such individuals sometimes request that their property be excluded from spraying.

Individuals with Multiple Chemical Sensitivity (MCS) have contacted MCPs and requested exclusion from spraying. No project has reported difficulty working with these individuals to create acceptable no-treatment zones. The causes, systems, diagnosis, and treatment of MCS all remain in a great state of flux, so MCPs are well advised to work carefully with MCS individuals and pay attention to the changing medical knowledge concerning MCS.

d. Public and Private Wildlife Refuges and Conservation Areas. These areas are often excluded from mosquito control at the request of the property owner because mosquito control runs counter to the goal of preserving the area in as natural a state as possible. Exclusion is not always absolute, however, as sometimes environmentally friendly pesticides like Bti can be used or water management may be practiced where pesticide applications are not permitted. The best way to approach such areas is to contact property owners and discuss with them possible mosquito-control alternatives.

e. ACEC and areas with rare or endangered species. Whenever rare or endangered species are present, pesticide applications and/or wetland alterations need to be approved by the appropriate agencies (see discussion under Rare and Endangered Species under impacts of physical control below). In many cases they will be rejected out of hand.

f. Water supplies. As stated above under surface water bodies and recharge areas, open water and water that is destined for drinking supplies, whether through percolation into the groundwater or by flow into reservoirs, must be very carefully protected. Fortunately, it is rare indeed that water supplies are held in such a way as to breed mosquitoes. For water supplies in general, therefore, mosquito control must consist of influencing the design of such systems to avoid creating habitats that would produce mosquitoes.

C. Mosquitoes as Disease Vectors

Most of the 9 organized mosquito control projects in Massachusetts justify their activities (and claim benefits) in part on the disease threat to human and animal populations posed by vector mosquitoes. Control programs in Berkshire County and Cape Cod (Fig. 1) lie outside of the area historically affected by outbreaks of Eastern equine encephalomyelitis (EEE) and therefore do not justify or plan their programs to address this disease problem. Dog heartworm is recognized throughout the Commonwealth (Arnott & Edman 1978). California group viruses have also been found in mosquitoes. To date human illness attributable to these agents has not been identified in Massachusetts..

A major practical difficulty in addressing the vector mosquito problem in Massachusetts stems from the fact that the specific species responsible for transmission of disease agents to humans and domestic animals are often unknown. The enzootic vector of EEE among birds is clearly *Cs. melanura*, but the vector(s) to horses and humans is unknown. The cattail mosquito, *Cq. perturbans*, and the most common reflood species, *Ae. vexans*, are prime suspects. Other mammal-feeding *Aedes* such as *Ae. canadensis* also may be involved and perhaps even *Cs. melanura* feeds sufficiently on mammals under unusual circumstances to cause some transmission to these dead-end hosts (Nasci & Edman 1981a).

Based on isolations in other states (Calisher & Thompson 1983) and a few in Massachusetts (Walker 1984), it seems likely that the important California group viruses in the Northeast, i.e. LaCrosse and Jamestown Canyon, are transmitted by the treehole mosquito, *Ae. triseriatus*, and spring, woodland *Aedes*, respectively. Dog heartworm also may be spread primarily by spring *Aedes* but reflood *Aedes* (e.g., *Ae. sticticus* and *Ae. trivittatus*), *Cq perturbans*, *Cx. salinarius* and *Anopheles* spp. also may be involved in transmission of this parasite (Arnott & Edman 1978).

1. Eastern Equine Encephalitis

MCP's in Southeastern Massachusetts, i.e., Norfolk, Bristol and Plymouth Counties, face the greatest threat from this disease. During major epidemic years, virus activity extends northward from this enzootic focus into southern New Hampshire and westward into Rhode Island, Connecticut and Central Massachusetts. All projects except Berkshire County give considerable continuing attention to this potential problem. Upon occasion, projects may submit mosquitoes to the SLI for EEE virus analysis.

The enzootic foci of EEE are red maple/white cedar swamps. The largest adult populations of the enzootic vector, *Cs. melanura*, occurs in or near the localized swamps where this species develops. Most human and horse cases also occur in the immediate vicinity of these same swamp habitats. Still, at times this mosquito may disperse several miles from its larval habitat (Morris et al. 1980. Nasci 1980. Nasci & Edman 1984) and human/horse cases occasionally occur in upland areas. This mosquito is unusual in that it overwinters in the larval stage (4th or 3rd instar). Adults from this generation emerge in late spring (i.e., mid to late May). Two to three summer generations occur about one month apart, e.g., in late June, July and August, depending on water levels and temperature (Nasci 1980). EEE virus is generally not isolated from this mosquito until late summer. During epidemic years it tends to be isolated earlier, i.e., beginning in early July, but apparently never from the overwintering generation. The location of the virus from November to July remains a mystery. *Culiseta melanura* feeds only after dark and the vast majority of blood meals are obtained from passerine birds (Nasci & Edman 1981a). This sylvan mosquito feeds equally at ground level and at higher elevations in the tree canopy. Activity is concentrated just after dark and just before sunrise (Nasci & Edman 1981b). The morning flight activity peak does not seem to involve blood-feeding but rather the return to suitable daytime resting sites.

The isolation of EEE virus from the cattail mosquito *Cq*. *perturbans* during disease outbreaks (Crans, personal communication) has focused suspicion on this species at the most likely epidemic vector to horses and humans. *Ae*. *vexans* and *Ae*. *canadensis* are two other prime suspects for EEE virus transmission to humans and horses in Massachusetts. Like *Cq*. *perturbans*, they are major pests. Their biologies will be described along with the other pest species.

A new EEE threat may be developing in New England as *Ae. sollicitans*, long a known vector in New Jersey (Crans et al. 1991), was, for the first time, found to be EEE-positive in Connecticut in 1996 (Andreadis 1996). Crans (1991) gave a suggested cycle for EEE transmission to *Aedes sollicitans* in which *Cs. melanura* infected night-roosting glossy ibis, which were then fed upon by *Ae. sollicitans* while feeding in the salt marsh. Though the link between glossy ibis and *Ae. sollicitans* is tentative, there can be no question that *Ae. sollicitans* is a potent vector in New Jersey and could be an important vector in Massachusetts as well.

2. California encephalitis vectors

Jamestown Canyon virus has been isolated from both dark-legged and banded-legged spring *Aedes* in Massachusetts and neighboring New York State (Walker 1984, Calisher & Thompson 1983). LaCrosse virus is associated with the tree-hole species *Ae*. *triseriatus* in Eastern New York State, but it has not yet been found in Massachusetts. All suspect human cases of arboviral disease which are found not to be EEE are sent by the SLI to the CDC for a full arbovirus analysis. No California Group virus infections have been identified.

3. Dog heartworm

A wide variety of mosquito species are capable of vectoring this debilitating nematode parasite of canines. Coin lesions in human lungs can occur from accidental infection with this parasite (Adkins & Dao 1984, Deren & Feinberg 1984). Felines are more susceptible to infection than was previously thought because they apparently do not produce microfilaria (Fukushima et al. 1984). Natural infections have been found in three different species of spring *Aedes* in Massachusetts but other potential vectors cannot be discounted (Arnott & Edman 1978). The treehole mosquito, *Ae. triseriatus*, and three permanent water species, *Cx. salinarius*, *An. punctipennis* and *An. quadrimaculatus*, are all possible late season vectors.

King and Munro (1989) reported on a questionnaire sent to Plymouth County veterinarians concerning dog heartworm. Infect rates were reported as generally less than 5% but one veterinarian reported rates above 20%. With between 25,000 and 30,000 dogs in the reporting area, the estimated cost of yearly preventative treatments was $750,000.

V. CURRENT ABATEMENT STRATEGIES AND THEIR IMPACTS

A. Chemical Control

1. Overview of Chemical Control

a. General Toxicity of Pesticides.

Pesticides are placed in one of four categories based on their acute toxicity (Table 13). Category I pesticides are extremely toxic while Category IV materials can range from mildly toxic to non-toxic.

Pesticides are also classified as either "General Use" or "Restricted Use" materials. General Use pesticides are available for use either by the general public or by licensed applicators. Restricted Use materials may only be applied by certified applicators or licensed applicators working directly under the supervision of a certified applicator. While Restricted Use materials are generally more toxic than General Use ones, toxicity is not the only issue. For example, resmethrin-based ULV products (Scourge) have recently been placed on the Restricted-use list, not so much because of toxicity but because the mode of application (ULV area-wide treatments) means that incorrect applications can have wide-ranging effects.

Table 13. Toxicity Category of Pestcides used in Mosquito Control

Category	Signal Word Required on the label	Categories of Acute Toxicity			Probable Oral Lethal Dose for 150 lb. man	Antidote Statement Other Cautions[a]
		LD_{50} mg/kg		LC_{50} mg/l		
		Oral	Dermal	Inhalation		
I Highly Toxic	DANGER ☠ POISON	0 thru 50	0 thru 200	0 thru 0.2	A few drops to a teaspoon-ful	Skull and Crossbones "Call Physician Imme-diately" Antidote Statement
II Moderately Toxic	WARNING	from 50 thru 500	from 200 thru 2000	from 0.2 thru 2	>1 teaspoonful to one ounce	
III Slightly Toxic	CAUTION	from 500 thru 5000	from 2000 thru 20,000	from 2.0 thru 20	>1 ounce to one pint or one pound	
IV Relatively Non-toxic	CAUTION	>5000	>20,000	>20	Over one pint or one pound	

[a]All pesticide labels are required to include the statement, "Keep out of reach of Children."

from: pesticide Applicator Trainging Core Manual: Northeastern Regional Pesticide Coordinators and Manual 2, Vectorborne Disease Control Homestudy Counrse 3013-G: Center for Disease Control

Newer pesticides have muddied the pesticide classification system. Bti and *Bacillus sphaericus* are biological organisms yet their mode of action is through the creation of a toxin that is activated in the insect's midgut. For the purposes of pesticide classification and this GEIR, therefore, they are considered pesticides, not biological control agents. Methoprene is also a case of a material (an insect growth regulator) that, while not directly toxic, so alters the life cycle of the insect that death results. Again, methoprene (Altosid) is classified as a pesticide but is far removed from the classic chlorinated hydrocarbon and organophosphate pesticides of the past.

b. Pesticides used for Mosquito Control In Massachusetts

Twenty-six different insecticide formulation distributed among fifteen product lines were used for mosquito control in Massachusetts between 1993 and 1995 (Table 14). Eight of these formulations used Bti as the active ingredient, five were methoprene-based, three were resmethrin-based, two each were pyrethin-based or malathion-based, and there were one each of temephos, isoctedecanol, and mineral oil. Of these, Acrobe (Bti) and Vectobac AS (replaced by 12AS) are no longer produced. Arosurf-MSF (Isoctadecnol) was removed from the market but has just reappeared under the name Agnique MMF. Abate 4E was not used in either 1994 or 1995 and both the Malathion 10EC and the Resmethrin product (EPA rep # 4-339-53853) were used in small amounts only (Table 4 gives a break-down by Project of chemical use).

Of the insecticides used, all of the larvicides were classed as Category IV materials by EPA. Bonide Mosquito Larvicide, available but not used, is border line between Category III and IV. VectoLex CG, a new *Bacillus sphaericus* product, is Category IV. All adulticides are in Category III.

Many pesticides have dual actions. They are important in controlling injurious pests, but they may also present a hazard to species not considered to be pests in the environment. As a result, the concepts of "target" and "non-target" organisms have arisen. For example, in many freshwater systems, control measures may be taken against undesirable target organisms such as mosquito larvae or unwanted algae. Non-target organisms are those whose destruction is not intended but which may be affected. These non-target organisms may play key roles in aquatic ecosystems.

The distinction between target and non-target species is not absolute, because the same group may be non-target organisms in one area of the country but target organisms, under certain circumstances, in another area. For example, larvae of caddisflies (Trichoptera) and naiads of mayflies (Ephemeroptera) are important food sources for

Table 14. Chemicals used in Massachusetts mosquito control, 1993 through 1995

Trade Name	EPA Registration Number	Active Ingredient(s)	% Active Ingredient	Toxicity Class	Other Warning Statements
LARVICIDES					
Abate 4E	241-132	Temephos	43	IV	
Acrobe[a]	62637-1-241	Bti[b]		IV	
Arosurf-MSF[c]	42943-8	Isooctadecanol	100	III	
Altosid					
Briquets	2724-375-64833	Methoprene	7.9	IV	
XR Briquets	2724-421-64833	Methoprene	1.8	IV	
Pellets	2724-448-64833	Methoprene	4.0	IV	
Bactimos					
Briquets	43382-3	Bti	10	IV	
Granules	37100-43-2217	Bti	0.2	IV	
Pellets	37100-42-2217	Bti	0.4	IV	
GB-1111	8898-16	Petroleum Hydrocarbons			
GB-1356	8898-16				
Teknar HP-D	2724-365-64833	Bti	0.8	IV	
Vectobac					
AS	275-52	Bti		IV	
12AS	275-66	Bti	1.2	IV	
Granular	275-50	Bti	0.2	IV	
ADULTICIDES					
Malathion 8EC	34704-119	Malathion	8	III	
Permanone 10EC	4816-688	Permethrin	10	III	
Permanone 31-66	4816-740	Permethrin	31	III	
Resmethrin	4-339-53853	Resmethrin		III	
Scourge 4+12	432-716	Resmethrin	4	III	RESTRICTED USE CLASSIFICATION Due to acute fish toxicity Retail sale to and use only by Certified Applicators or persons under their direct supervision and only for those uses covered by the Certified Applicators Certificate
		PBO	12		
Scourge 18+54	432-667	Resmethrin	18	III	
		PBO	54		
MATERIALS REGISTERED BUT NOT USED - LARVICIDES					
Altosid					
Liquid	2724-392-64833	Methoprene	5	IV	
Liquid Con	2724-446-64833	Methoprene	20	IV	
Bonide Mosquito					
Larvicide	4-195	Mineral Oil	98	III-IV	
VectoLex CG	275-77	*B. sphaericus*	50[d]	IV	
MATERIALS REGISTERED BUT NOT USED - ADULTICIDE					
Fyfanon ULV	4787-8	Malathion	95	III	

[a]No longer marketed
[b]*Bacillus thuringiensis* var. *israelensis*
[c]Now marketed as Agnique MMF

trout and other valuable freshwater fish. In certain areas, these species of insects can occur in such large numbers that they become nuisance pests, and their immature stages are the target of planned control operations with pesticides.

The ideal situation in most control operations is to be able to destroy the undesirable species at pesticide concentrations that will have minimal adverse effects on the rest of the biota. However, some degree of contamination and hazard is assumed with nearly all pesticide use. The hazard to aquatic organisms and other wildlife species depends on the chemical and physical properties of the pesticide, type of formulation, rate and method of application, and characteristics of the receiving ecosystem system (Nimmo 1985).

Looking at the change in pesticide use by MCPs over the past decade (Table 3), all Category II insecticides have been phased out and Methoxyclor, the only organochlorine compound on the list in the early eighties, has likewise been dropped. Using malathion and permethrin for larviciding has also been discontinued and Bti and methoprene have taken over from Mineral Oil (Flit-MLO) as the dominant larvicides. For adulticiding, permethrin and resmethrin have essentially replaced malathion. Theses changes indicate that MCPs have responded to the desire of the public at large (including the staff of the MCPs incidentally) for materials with the lowest risks. The other conclusion to be drawn is that, until the discovery of new materials, both adulticiding and larviciding are presently be conducted with the materials that have the least overall risk. Advances in reducing the risk of chemical use must therefore come from improved targeting and increased use of water management and/or biological control techniques.

c. General Properties of Registered Mosquito Control Insecticides in Massachusetts, 1996.

Physical Properties. Using both water solubility and KoW, the following insecticides are classified as water insoluble or practically water insoluble; Bti, isooctadecanol, methoprene, petroleum oil/Flit MLO, pyrethrin I, resmethrin and temephos. Malathion is the most water soluble insecticide used (145 ppm). Nevertheless, it still has a relatively high partition coefficient (KoW 779) and because of its rapid environmental and metabolic degradation is not expected to bioaccumulate in any appreciable fashion as discussed below.

Insecticides which have little or no volatility are; Bti, *B. sphaericus,* malathion, methoprene, and temephos. Isooctadecanol and mineral oil are slightly volatile. Although pyrethrin I and resmethrin have appreciable vapor pressures, they are most likely to be bound to suspended organic matter or soil particulate in natural systems. If volatilization occurs, they are rapidly photodegraded.

Four of the insecticides have vapor densities less than 1.0 (relative index to air) and so could concentrate near the surface, resulting in increased exposure via inhalation. However due to the low vapor pressure of isooctadecanol and methoprene, these compounds are mot likely to be available for concentration. The pyrethroid insecticides, as discussed above, are rapidly degraded by photolysis if they become available which is not likely from environmental surfaces.

For specifics on a given insecticide, the reader should refer to the sample labels and Material Safety Data Sheet (MSDS) for that material, located in Appendix C.

Analytical Methodology (from: The Pesticide Manual 7th ed. Worthing & Walker, British Crop Protection Council. Lavenham, UK. 1983. For more detailed methods consult The Agrochemical Handbook, 2nd ed. 1983).

1. Bti and *B. sphaericus* are measured in international toxicity units/mg product (i.u.) relative to that of an appropriate standard product against *Trichoplusis ni* or *Aedes egypti* in standard bioassays. Assays based on the number of spores are not satisfactory.
2. Methoprene is analyzed by GLC or HPLC w/UV detection.
3. Isooctadecanol is analyzed by GLC.
4. Pyrethrin I is analyzed by GLC.
5. Resmethrin is analyzed by GLC.
6. Temephos is analyzed by GLC.
7. Malathion is analyzed by GLC.
8. Petroleum Oil is analyzed by GLC.

Transport, Persistence and Degradation in Soil, Air and Water. None of the insecticides used for mosquito control in Massachusetts are included on the 1987 EPA lists (I + II) of the 51 priority pesticide leachers.

Synergists and Inerts in Pesticide Products.

Synergists are compounds added to a pesticide that increase the efficacy of that pesticide. Relatively few combinations of insecticides and synergists lend themselves to practical use, either because the degree of improved performance is small or because too much of the expensive synergist is required, or both (Casida 1970). By the same token, no example of increased toxicity to man or useful animals under practical conditions has been reported (Hayes 1982).

In mosquito control, the synergistic effect of various compounds on pyrethrum and synthetic pyrethroids is well known. piperonyl butoxide (PBO) is the sole synergist used in Massachusetts. It acts as a substrate for the microsomal enzyme-NADPH2 system, which also metabolizes many drugs and insecticides. By serving as an alternative substrate for the detoxification enzyme of the insect, PBO prolongs the persistence of the insecticide so that a lower initial dose is effective (Casida et al. 1966, Kamienski & Casida 1970, Casida 1970).

"Inert" materials which are used as formulation aids in the insecticides applied by towns/BOHs and Projects for mosquito control in Massachusetts are categorized as follows: Powders, granular carriers, solvents and special effects materials.

Dustable powders generally contain l-l0% a.i. mixed with powdered minerals as carriers and diluents. For wetable powders, the same diluents and carriers can be used as for dusts. However for dispersible powders, a finer particle-size spectrum is necessary, the proportion above 40 um not exceeding a few percent. No powdered materials are currently in use in mosquito control in Massachusetts.

Granular formulations are made by either impregnation (soaking or coating) of granular carriers or by granulation of powdery mixtures of active ingredient and formulation aids. These two types differ in the active ingredient concentrations attainable. For both types, an active ingredient content of 20% is the maximum technically feasible. Included in the grouping are Bactimos briquets, granules and pellets (Bti), Vectobac granules (Bti) and Altosid briquets, XR briquets, and pellets (methoprene).

Liquid formulations such as emulsifiable concentrates, soluble concentrates and ULV use various organic solvents as diluents. Aliphatic hydrocarbons are poor solvents for most active ingredients and are therefore normally only used for very dilute formulations. Aromatic hydrocarbons are used frequently, the fractions C6 to C12 being favored (e.g., from technical xylene mixtures to substituted naphthalenes). Apart from the toxicity of benzene, their high flammability prohibits the use of lower aromatics. On the other hand, phytotoxicity frequently increases with increasing molecular weight. Ketones are excellent solvents for many organic compounds. Most of them are at least partially water soluble, so they are mainly suitable for formulating water-soluble and liquid-active ingredients. When they are used for the formulation of emulsifiable concentrates of solid, water-insoluble active ingredient, the active ingredient often crystallizes out during the preparation of the spray mix. This is caused by the solvent passing into the aqueous phase whereupon the active ingredient is precipitated in the "oil droplets" of the emulsion. Here ketones can normally only be used together with other, water-insoluble solvents as cosolvents.

This is also valid for alcohols and glycols and their ethers and esters as well as for highly polar aprotic solvents such as dimethylsulfoxide and dimethylformamide. Chlorinated solvents are only used to a very slight extent. Chlorobenzene is used occasionally; dichlormethane is used more frequently as a relatively non-toxic, highly volatile, and nonflammable solvent for hygiene and stored-product agents and for aerosols.

Emulsifiable concentrates used for mosquito control include the larvicide Abate 4E and the adulticides Malathion 10EC, Permanone 10EC, Permanone 31-66, Resmethrin, and the Scourge products.

With increasing public concern of off-site deposition of pesticides (e.g. aerial drift) and the movement of the pesticide industry away from organic compounds to biological insecticides, new formulation technology has emerged. Flowable concentrates not only reduce drift, but provide better coverage and greater adhesion to the substrate. Dried active ingredients are ground to a uniform particle size (usually 10 um) as either a dry, wet (H_2O) or oil suspension (which then is diluted with water for application). Included in this grouping are the Bti products Teknar flowable (Bti) and Vectobac AS and 12AS.

None of the direct nerve toxins (pyrethrin and resmethrin) have inert ingredients which appear on EPA/SAP List 1. Scourge (resmethrin) contains a List 2 compound (0.025% xylene) and 4-12% PBO and 12% Chevron 100 (a soybean oil diluent) as additional active ingredients.

None of the indirect nerve toxins (malathion and temephos) have inert ingredients which appear on the EPA/SAP List 1. Of the products which contain malathion, malathion 57% EC contains a List 2 compound, 31.5% and 36.55% xylene range aromatics, respectively. Temephos (Abate 4E) contains 39% Chevron 100 as an additional active ingredient.

None of the selective insect toxins (Bti and methoprene) contain any List 1 or 2 compounds. No other additional active ingredients are listed.

None of the physical toxins (isoocadecanol (Arosurf MSF/Agnique MMF and petroleum oils) contain any of the List 1 or 2 compound. Petroleum hydrocarbons as a group are included on List 2 as potential toxic inerts of pesticide products.

d. Pesticide Handling and Application

Pesticide storage varies considerably from project to project. Cape Cod uses only bagged Bti so no formulation work is necessary nor are there stringent storage requirements. Five projects store and formulate chemicals in an area within the main garage, generally separated by a wire cage (cabinets within a metal shed at Suffolk) from the main garage area. Ventilation fans operate either continuously or whenever the lights in the garage are turned on. Bristol, Central Mass and Essex all have separate buildings for pesticide storage and formulation. Central Mass mentioned that their structure was built in consultation with the local fire department and the State Pesticide Board. East Middlesex constructed its storage area from Department of Defense specifications.

All projects use pickup-truck mounted ULV sprayers for adulticiding. No thermal foggers remain in use. Backpack sprayers are used to apply liquid larvicides and, in some projects, adulticides. Granular materials are applied by hand or with cyclone-type spreaders. Briquet formulations are applied by hand. Additional information on the pesticides may be found on the sample labels and MSDS sheets in Appendix C.

Applicator certification is done by the Pesticide Bureau of the Department of Food and Agriculture. Mosquito control applicators are certified under the "Mosquitoes and Biting Flies" subcategory of "Public Health and Nuisance Control". Aerial Applicators are licensed separately. Ongoing training is required and many mosquito-control personnel attend annual meetings of the Northeastern Mosquito Control Association for such training. Specifics for certification and other applicator issues are covered in CMR 333: Pesticide Board.

Most of the pesticides used are extremely safe, so handling instructions are minimal. For Bti, mineral oil or Golden Bear oil, and metheprene products, work areas should be ventilated and eye protection and impervious gloves worn. With these materials applicators should also wash thoroughly after handing or applying them. With malathion, permethrin and resmethrin products safety goggles, chemical resistant gloves and a respirator should be worn when formulating spray material. Eyes should be flushed immediately and skin washed with soap as quickly as possible if accidental contact occurs. Vomiting should not be induced for resmethrin and permethrin products but should be induced for malathion. In all cases where resmethrin, permethrin or malathion is ingested, a physician should be contacted immediately.

2. Larvicides

a. Biologicals: Bti and *B. sphaericus*

i. *Bacillus thuringiensis* var. *israelensis*

Mode of Action. *Bacillus thuringiensis* (Bt) is a naturally occurring, gram positive, rod-shaped, spore-forming bacterium, which is pathogenic to the larvae of a number of insects species, especially Lepidoptera, when ingested by the larvae. Bti is also a pathogen to the larvae of some insects in the order Diptera (e.g., mosquitoes and midges). *Bacillus thuringiensis* var. *israelensis* Serotype H14 (Bti) is a biological insecticide produced during sporylation of this bacterium. The protein product of the H14 serotype (e.g., Bactimos, Vectobac and Teknar) is used to selectively control the larvae of mosquito and blackflies. It is a stomach poison which alters gut permeability to salts under alkaline conditions. This decreases feeding and development and eventually causes death by starvation (Hartley & Kidd 1983).

Fate in the Environment. The residual period for Bti has been estimated at 48 hr in water, as it gradually settles out or adheres to suspended organic matter (SCAMP 1987). As a natural part of the ecosystem, Bti degrades to complex but non-toxic organic compounds which are ultimately mineralized (Hartley & Kidd 1983).

Effects on Non-target organisms. There is no evidence of acute or chronic toxicity of the spore-crystal complex to amphibians (tree frog tadpoles, toad tadpoles, California newt), fish (mosquito fish, rainwater kill fish, two-spine stickleback) or birds. It is non-toxic to bees. Groups of organisms that have been reduced by Bti applications are from the suborder Nematocera of the order Diptera which includes species of the families Dixidae, Chironomidae, and Ceratopogonidae (Fisher & Rosner 1959, Garcia et al. 1980, Hartley & Kidd 1983, Worthing & Walker 1983). A recently completed study in Minnesota found Bti reduced chironomids, tipulids, ceratopogonids and stratiomyids. There is reason to believe this may have negative impacts on nesting ducks and their ducklings, for which chironomids make up a significant part of their diet (SPRP 1996).

When a small stream was treated at 0.5 ppm/15 min. (13°C) with an aqueous suspension of unformulated Bellon primary powder of Bti, in contrast to the sharp reduction (89%) in black fly larvae in the 20-350 m area below the treatment point, Surber samples indicated increases in mayfly (35%), caddisfly (47%), stonefly (75%), chironomid (19%), and elmid (242%) populations. No adverse effect on any of these non-target populations was evident following stream treatment (Molloy & Jamnback 1981). In laboratory and field studies conducted with Bti to determine its effect upon *Ae taeniorhynchus* and non-target organisms in a salt marsh, Bti killed over 99% of the mosquito larvae at concentration of 4.5 IU/ml and above. Out of 39 species collected prior to treatment, only a homipteran (true bugs), *Notonecta indica*, showed a significant decrease in population. However, this genus is known to fly from deteriorating habitats (Purcell 1981). Experimental testing has demonstrated no adverse effect against other aquatic insects including dragonflies, damselflies, mayflies, stoneflies, caddisflies, water beetles or true bugs. Other invertebrates such as Daphnia, cyclops, rotifers and crustaceans are also unaffected (SCAMP 1987).

Many acute toxicity/pathogenicity studies with various varieties of Bt have been conducted using several routes of administration in rats, rabbits, and guinea pigs. Among the various studies reviewed, the highest dose tested was 6.7×10^{11} spores per animal. There were no significant adverse effects associated with these studies (Castillo 1986). No acute toxicity was observed in rats gavaged with the maximum dosage of 2 billion spores of Bti H-14. No erythema or edema formation were observed after dermal exposure to 1.6 billion spores. All other parameters of the test animals were normal. There was no evidence that Bti H-14 multiplied on the abraded epidermis. No adverse effects were observed in rats given 80 million viable spores by instillation into the lungs. There was no histological evidence of multiplication of the organism in lung tissue. Instillation of 10 million Bti spores into the ocular cavity produced no eye irritation beyond 48 hr. No multiplication occurred in the ocular cavity (Castillo 1986). Acute, oral and dermal toxicity (LD_{50}) of Bti H-14 (Vectobac) is in excess of 30,000 mg/kg.

No allergenic response to *B. thuringiensis* was elicited in guinea pigs by introcutaneous injection, inhalation, or topical application to the intact or abraded skin (Hayes 1982).

Each of 18 persons ingested 1 g of a commercial *B. thuringiensis* preparation containing approximately 3×10^9 spores daily for 5 days on alternate days. In addition to ingestion, five of them inhaled 100 mg of the powder daily for 5 days. There were no complaints and no positive findings by physical and laboratory examination (Fisher & Rosner 1959). When Bt was applied by aircraft at a rate of 2 kg of preparation (3×10^9 organisms/g) per hectare (6×10^{12} organisms/hectare) the concentration of viable organisms in the air over the field exceeded background by 42.5 times on the day of application and by 22.5 times 5 days later (Castillo 1986). No complaints were received from eight men exposed for 7 months to fermentation broth moist bacterial cake, effluent, and the final powder in the course of commercial manufacture of the pesticide (Fisher & Rosner 1959, Hayes 1982).

A dose of 10^7 (i.e., 10 million) Bti organisms killed the test animals when injected introcerebrally (IC). Death was probably due to the massive i.c. inoculum and not any infective process. Most of the animals died within 24 hours (Castillo 1986).

The EPA's review of the toxicological data on Bti determined that no data gaps exist in the toxicology data base and no major environmental mammalian safety concerns (except for certain endangered species of Lepidoptera) were identified (Castillo 1986). Toxicological data specially required for biochemical and microbial pesticide registration including: immunotoxicology studies, infecticity studies, intracerebral test, tissue culture tests and virulence enhancement studies (EPA 1984, Marquis 1986). Bti is effective only against dipteran larval (mosquitoes and black flies) and is safe to the environment (Worthing & Walker 1983).

Bti is non-phytotoxic and has shown no effects on seed germination or plant vigor (SCAMP 1987).

ii. *Bacillus sphaericus*

Mode of Action. . *Bacillus sphaericus* is a naturally occurring bacterium, which is pathogenic to the larvae of many genera of mosquitoes. There are a number of strains of *B. sphaericus*, that being most toxic to mosquitoes is *B. sphaericus* 2363. Like Bti, it produces a toxin that must be ingested and partially digested before it becomes activated. *Aedes* mosquitoes are generally less susceptible to *B. sphaericus.* It is currently marketed as a granular larvicide by Abbot Labs under the trade name VectoLex CG and is of interest because it works better than Bti in highly organic waters often favored by *Culex* species (Abbott Laboratories 1996). Also of interest is the fact that it is not toxic to other dipterans, including blackflies. Its limited range of toxicity, while a blessing in some respects, has slowed development as the market for *B. sphaericus* is likely to remain small (Federici 1985).

Fate in the Environment. *Bacillus sphaericus* has a field life of between two and four weeks. The spores settle out of the water column in as little as two days though they settle more slowly than Bti, as they adhere less to suspended particulates. The spores can remain viable for months in the field (Yousten et al. 1992). *Bacillus sphaericus* may undergo limited recycling (reproducing itself within the larval gut of *Culex* species), especially in rich organic environments (Abbott Laboratories 1996, Karch et al. 1990).

Bacillus sphaericus is ingested by other filter-feeding arthropods (*Daphnia pulex* and *Cypris* sp.) It can germinate within the gut of these animals and may be spread by them through the environment. It does not seem to adversely affect them and they may play a role in recycling *B. sphaericus*, thereby increasing the length of control achieved from a single application. *Bacillus sphaericus* does not affect populations of the predator species *Cleon* *dipterium, Corixa punctat* and *Nepa cinerea.* (Karch et al. 1990). *Bacillus sphaericus* can be used in conjunction with the fungus *Lagenidium gigateum* (Orduz and Axtell 1991).

Effects on non-target organisms. *Bacillus sphaericus,* technical material, had acute oral and dermal LD_{50} values for rats of >5g/kg and >2g/kg respectively, making it a class IV larvicide. The technical material can be moderately irritating to the skin and eyes of people.

Toxicity tests on mallards, bluegills, and rainbow trout showed the material to be extremely save to these animals. Acute toxicity tests on freshwater invertebrates (daphnia and mayfly larvae) and salt marsh and bay species (sheephead minnow, shrimp and oysters) all indicate that the material is essentially non-toxic. Honey bees are not affected by *B. sphaericus* (Abbott Laboratories 1996).

Bacillus sphaericus is not phytotoxic (Abbott Laboratories 1996).

b. Methoprene

Mode of Action. Methoprene is an insect growth regulator (i.e., a synthetic analog of the juvenile hormone) which does not allow insects to mature from the larval stages into reproductively capable adults. It shows little or no effect on the adult or pupal stages of insect development. Unlike ordinary insecticides, this relatively non-persistent chemical exhibits morphological rather than direct toxic activities. Although its exact mode of action is not completely known, three modes have been investigated: 1) methoprene binds JH receptors resulting in extended juvenile forms which are not reproductively competent, 2) methoprene competitively inhibits catabolic metabolism of JH which extends juvenile forms etc., and 3) methoprene binds to its own receptors and extends juvenile forms (Matsumura 1985).

Fate in the Environment. Methoprene is relatively stable but nonpersistent in the environment (SCAMP 1987). It does not biologically magnify. In soil, methoprene rapidly degrades with a half-life of approximately 10 days. In plants its degradation principally involves ester hydrolysis, Odemethylation, and oxidative clearage of the double bond of the C4-position. In lucerne and rice, the principle metabolite is 7-methoxycitronellal. Methoprene is very susceptible to photolytic decomposition under environmental conditions. It is degraded to many photoproducts which are present in relatively low yield (<10%). The rapid degradation of methoprene and multiplicity of photolytic products are indicative of extensive photodegradability in the natural environment (Quistad et al. 1975).

Technical grade methoprene is stable >4 yr. in glass in the dark at 43° (Worthing & Walker 1983). Sterile aqueous 0.5 ppm solutions at 98% pure $[C_5\text{-}^{14}C]$ methoprene, buffered at various pH values, were found to be extremely stable to hydrolysis over 4 weeks at 20°C in the dark. No degradation (detectable limit 1%) was seen in sterile water at pH 5.7 methoprene was rapidly photoisomerized (t1/2-30 min.) to a final 2E:2% isomeric mixture of 44:56. The 2% isomer of methoprene has a much lower biological activity than 2E-methoprene itself, hence photoisomerization of methoprene in the field should quickly result in a nondegradative loss of about half the biological activity. Solutions of methoprene (0.5 ppm) were found to undergo photoinitiated decomposition to more polar products, to the extent of 15% in 2 days and 332 in 3 days at 20°C. Earlier experiments at 0.1 ppm at two temperatures (24 and 40°C) had shown no breakdown at 24°C and only 5% breakdown at 40°C, in 1 day (Schooley et al. 1975).

In pond water, the half-life of methoprene is approximately 30 hr at 0.001 ppm and 40 hr at 0.01 ppm. Incubation of (2E)-[C_{10}-^{14}C] methoprene for 3 days at 0.42 ppm generated three primary metabolites, the result of ester hydrolysis and/or O-demethylation. These metabolites and recovered methoprene were photoequilibrium mixtures of 2-ene double bond isomers (e.g., E and %). In another incubation experiment with (2E)-[C_5-^{14}C] methoprene at 0.66 ppm in a pond water sample of presumably different microflora, a completely different metabolite was identified as resulting from oxidative scission of the 4-ene double bond. The principle metabolite in the latter experiment was 7-methoxycitronellic acid.

Methoprene was rapidly degraded when a thin film (0.1 u) on glass was exposed to sunlight through glass. The half-life under these conditions was 6 hr. After exposure to sunlight for 27 hr, only 3% of the applied dose remained as methoprene and it was isomerized to a 50:50 mixture of (2E,4E) and (2%,4E)-methoprene. The recovery of only 72% of the applied radioactivity after 27 hr suggested photolysis of methoprene to volatile products which were lost by vaporization. Collection of vapors above the photolysate resulted in recovery of 13% of the applied radioactivity. The volatile constituents were resolved into methoxycitronellal (4%), methoprene (0.2%) and $^{14}C0_2$ (6%). Since only a trace amount of methoprene (0.2%) was detected in the condensed vapors, volatility of methoprene is not considered a major route for loss of radioactivity.

Effects on Non-target Organisms. Methoprene is non-toxic to bees, and relatively non-toxic to non-target species but shrimp and crabs may be killed (Hartley & Kidd 1983, SCAMP 1987). Methoprene does have some toxicity to the saltmarsh copepod *Apocyclops spartinus*, but the concentration of methoprene in the water required to cause transient reductions in the early life stages of the copepod is above that which should occur during routine mosquito control (Bircher & Ruber 1988). Methoprene did not adversely affect the copopods *Cyclops vernalis* and *Cyclops* *navus* in a Minnesota study but did reduce chironomids, tipulids, ceratopogonids and stratiomyids (SPRP 1996). As for Bti applications, reducing chironomid populations may have a long-term effect on nesting ducks.

The acute toxicity (96hr-LC_{50}) of methoprene to a variety of fish ranged from 1.6 ppm for rainbow trout to greater than 100 ppm for channel catfish (Johnson & Finley 1980).

In a model ecosystem study on the uptake and degradation of methoprene by bluegills, the fish had a surprisingly large amount of radioactivity after 4 to 6 weeks of exposure. If the radioactivity was due to the presence of parent methoprene, one would have concluded that the compound was bioaccumulated several thousand times. However, less than 0.l% of the measured radioactivity was in the form of methoprene and its primary metabolites, with the rest being present in such natural products like cholesterol, proteins, free fatty acids, and glycerides. With this correction factor, methoprene was bioconcentrated by bluegills to a moderate extent. In clean water, bluegills eliminated 93 to 95% of the accumulated body burden of methoprene in less than 2 weeks.

Two formulations of methoprene were applied aerially (0.1 lb a.i./acre) to rice fields in the Sacramento Valley of California. The level of control of *Cx. tarsalis* was assessed in emergence cages established before and after spraying in these and control fields. After spraying, the treated fields had about one half the rate of *Cx. tarsalis* emergence as did control fields. None of the non-target organisms examined exhibited population fluctuations which could be statistically attributed to the methoprene applications (Case & Washino 1978).

Locomotor activities of mosquitofish (*Gambusia affinis*) and goldfish (*Carassus auratus*) were monitored for a 2-week period in the presence of methoprene at concentrations approximately 10-fold greater than those generally recommended for application. Methoprene, the active ingredient in Altosid SR-10, at 0.2 ppm did not significantly alter the locomotor activity of either mosquitofish or goldfish (Ellgaard et al. 1979).

The acute oral toxicity (LD_{50}) of methoprene to mallard ducks was assessed as greater than 2000 ppm. However, treatment levels as low as 520 ppm produced signs of intoxication in mallards (Smith 1987). The eight-day dietary LC_{50} for chickens was greater than 4640 ppm (Hartley & Kidd 1983). Thus, methoprene shows only slight toxicity to fish and birds and is relatively non-toxic to non-target species (SCAMP 1987).

When the metabolic fate of methoprene was studied in a guinea pig, a steer, and a cow, a rather large percentage of the radiolabel was incorporated in the tissues and respired by the animals. In the urine and feces, a small amount of radiolabel was metabolized into free primary metabolites, somewhat more was incorporated into simple glucuronides, and a considerable quantity of radiolabel was found in polar compounds, possibly complex conjugates or polar biochemicals. No parent methoprene was found in the urine, but approximately 40% of the radiolabel in feces was contributed by unmetabolized methoprene. The formation of conjugates and the metabolism of methoprene was more extensive in the steer than in the guinea pig (Chamberlain et al. 1975). Samples of fat, muscle, liver, lung, blood, and bile from a steer which received a single dose of [C_5-^{14}C]methoprene were analyzed for radioactive residues. No primary methoprene metabolites could be characterized, but the majority (16-88%, depending on tissue) of the total tissue radioactivity was positively identified as [^{14}C]-cholesterol. Seventy-two percent of the bile radioactivity was contributed by cholesterol, cholic acid, and deoxycholic acid. Radioactivity from catabolized methoprene was also associated with protein and cholesteryl esters of fatty acids (Quistad et al. 1975).

Acute oral toxicity (LD_{50}) of methoprene in rats is greater than 34,000 mg/kg. That for dogs is greater than 5000-10,000 mg/kg. Dermal LD_{50} values of methoprene are greater than 3500 mg/kg for rabbits. It is nonirritating to both the skin and eyes of rabbits (Hartley & Kidd 1983, Worthing & Walker 1983). Methoprene has an inhalation LC_{50} value of greater than 210 mg/l in rat (Sine 1984). In 2-yr feeding trials, no methoprene-related effects were observed in rats at 5000 mg/kg diet and in mice at 250 mg/kg diet. No effects were observed at the highest rates tested: in 3-generation reproduction studies in rats (2500 mg/kg diet); teratogenicity in rabbits (500 mg/kg) or rats (1000 mg/kg); mutagenicity in rats (2000 mg/kg) (SCAMP 1987). Hollingsworth calculated the VSR for methoprene to be greater than 1,730,000. Methoprene is one of the most selective insecticides presently available (Wilkinson 1976).

Methoprene is not phytotoxic.

c. Oils

Petroleum oils are also known as mineral oils and refined grades have been called white oil. Petroleum oils are prepared by the distillation and refinement of crude mineral oils. Those used as pesticides generally distill >310°C to 335°C, namely; "light" (67-79%), “medium” (40-49%), and “heavy” (10-25%) (SCAMP 1987). They consist largely of aliphatic hydrocarbons, both saturated and unsaturated, the content of the latter being reduced by refinement. Recently, highly refined oils have been used as adjuvants to increase the effectiveness of some other pesticides (Hartley & Kidd 1983). Petroleum oils may be used as diluents for pesticides or by themselves

Petroleum oils are also used alone as insecticides. Inhalation of oils from the surface of water attacks mosquito larvae through their respiratory system. Death occurs due to reduced oxygen levels (hypoxia) and lack of feeding. Petroleum oils also enhance penetration of the insect cuticle by the insecticide. In bioassays of insecticidal compounds, selective toxicity has been noted to vary for the same compound depending on the nature of the carrier solvent and site of application. The degree to which a solvent induces rapid penetration through the insect cuticle has been termed its carrier efficiency. This carrier efficiency can be directly related to and is dependent on the physical properties of the solvent-insecticide combination. Differences in carrier efficiency have been attributed to the ability of the solvent to dissolve the outer layer of the insect epicuticle (Schouest et al. 1983).

Petroleum oils are used as surface treatments to prevent mosquitoes from breathing at the surface. Petroleum oils have been shown to be phytotoxic to plants so use instructions should be followed and oil used only during the dormant period (Hartley & Kidd 1983).

Petroleum oils/Flit ML0 are mineral oils used as diluent/adjuvant oils or as a physical toxicant which kills mosquito larvae via suffocation. Both are prepared by the distillation and refinement of crude mineral oils. Those used as pesticides generally distill >310°C. They may be classified by the proportion distilling at 335°C, namely: 'light' (67-79%), 'medium' (40-49%), and 'heavy' (10-25%) (Worthing & Walker 1983). Acute oral LD_{50} for rats and mice >4300 mg 'Actipron'/kg. No toxicological problem due to petroleum oils has been reported in practice. Tests have shown there is no risk of polynuclear aromatic compounds entering the food chain using mineral oils for insect control (Hartley & Kidd 1983).

In 1968, the Medical Research Council in the United Kingdom published its report, "The Carcinogenic Action of Mineral Oils," based on work done in several British universities. The most biologically active fractions (boiling range of 300-400°C) were distilled further. The carcinogenic activity appeared to occur in materials which boiled above 350°C (presence in lower-boiling fractions was possibly the result of azeotropism), and activity was still present in fractions boiling at 420°C. Over 40 chemical compounds were isolated from mineral-oil fractions, many for the first time, by repeated chromatography, complexing with picric acid and trinitrobenzene, and fractional crystallization. Further studies of the nature of the active compounds did not identify any single highly potent carcinogen. Several of the compounds separated were structurally similar to very potent carcinogens, and the total activity of the oil could be caused by the combined effect of several individually weak carcinogens (Kipling & Cooke 1984).

Albino rats were dosed orally by stomach tube at varying rates up to 10,000 mg FLIT MLO/kg BW and observed for mortality and signs of systemic toxicity for 14 days. The LD_{50} was never reached and it was concluded that the LD_{50} for FLIT MLO is above 10,000 mg/kg BW. A dose of one pint of FLIT MLO administered to a horse by stomach tube showed no gross reactions.

FLIT MLO was applied to the exposed abdominal skin of albino rabbits at dosage levels up to 3.16 g/kg BW. After 24 hr, the residue was removed, and the animals were observed for a total of 14 days after application. There were no deaths or signs of systemic toxicity at any dosage level tested. There was no dermal irritation to unabraded skin on any of the animals. A slight to moderate redness appeared on abraded skin. At the end of the 14-day period, the skin of all animals was completely clear of any signs of irritation.

Albino rats (10 male and 10 female) were exposed continually for 1 hr to an atmosphere containing an average of 200 mg FLIT MLO (aerosol) per liter (1) of air. Observations of mortality or signs of acute toxicity were made at intervals throughout the exposure, and the animals were observed for 14 days after exposure. There were no deaths during exposure or in the 14 days thereafter. During the post-exposure period the respiration rates of the animals seemed elevated initially, but returned to normal within 24 hr. A slight loss of fur occurred after a few days, but this effect had disappeared in all but four animals by the end of the study. Other superficial effects (exudate around the eyes, etc.) were observed but quickly disappeared.

FLIT MLO (0.1 ml) was placed in the left eyes (the right eyes served as a control) of nine albino rabbits. The eyes of three of the rabbits were irrigated after two seconds; those of another three after four seconds; the eyes of the remaining three were left unirrigated. Periodic observations for signs of eye irritation were made, with the last observation made 7 days after application. There was no evidence of systemic effect due to any of the applications. Eye irritation was slight and transient in all animals. All signs of the effect had cleared within four days following application. Examination on the seventh day confirmed the absence of any corneal damage. Ratings on the Draize scale, a common scoring system, were as follows: 4 at one and four hours, 2 at 24, 48, and 72 hours, and zero thereafter (Exxon 1973).

Bonide Mosquito Larvicide is a low-order, low-viscosity, highly saturated petroleum hydrocarbon mineral oil that enters mosquito larval breathing tubes and spreads over main tracheal trunks. These respiratory pathways twist and collapse reducing oxygen levels to tissues. Death is by hypoxia and lack of feeding. It is virtually identical to Flit MLO.

The residual periods of petroleum oils are relatively short. Tests have shown there is no risk of polynuclear aromatic compounds entering the food chain. No toxicological problems due to the use of petroleum oils for mosquito control have been reported in practice (Worthing & Walker 1983). It has some hazard to fish but little or no hazard to birds. Flit MLO has been evaluated to determine its effects on the aquatic environment. In a series of laboratory tests on grass shrimp, fiddler crabs, goldfish, bluegill, sunfish, fathead minnows, coho salmon, killifish, and domestic ducks, in which field applications of the larvicide were simulated and exaggerated, Flit MLO was found to have no adverse effects even at concentrations well above the recommended application rates of 1 to 5 gallons per acre (Exxon 1973).

Little or no hazard has been associated with the application of petroleum oils to beneficial and non-target invertebrates. Other Diptera that land on pools treated with oils will be pulled into the water due to the loss of surface tension and water beetles can often be observed crawling out of treated pools (Christie, personal observation). The flies clearly die, the beetles probably do not. Some hazard has been determined for honey bees.

Isooctadecanol (Arosurf MSF), is a surface-acting ethoxylated fatty alcohol (i.e., a nonionic surfactant) which forms a thin film over the surface of water creating a physical barrier due to reduced surface tension. This results in the suffocation of aquatic larvae and pupae (EPA 2/15/84). Foliar absorption, translocation in plants, and metabolism and persistence in plants is not available (EPA 2/15/84). Data on microbial breakdown shows that Arosurf MSF is degraded by unacclimated, mixed cultures of microorganisms from natural sources by shake culture methods. Although not available for Arosurf MSF, similar ethoxylates degrade under field conditions with the major route of degradation being hydrolysis at the ether linkage and subsequent oxidation of the alkyl chain to lower molecular polyethylene glycole-like materials which are ultimately mineralized to $C0_2$ and H_2O. The resultant average persistence for isooctadecanol has been determined to be 2-10 days (EPA 2/15/84). Although incomplete, the 96 hr - LC_{50} for Daphnia is reported as 1.9 ppm. Bioaccumulation data is also lacking but studies on closely related fatty acid and fatty alcohol ethoxylates in shellfish support the contention that the compound is rapidly cleared from aquatic invertebrates as inert metabolites.

Arosurf MSF was used in small amounts for several years in the late 80's and early 90's and is not currently being sold. It is included here both for historical purposes and in the off chance that it might become available again. As a surfactant, it forms a thin film over the surface of the water. Its mode of action is physical rather than chemical in that it reduces the water surface tension resulting in suffocation of the larvae and pupae.

These nonionic surface-active films spread into uniform, nearly monomolecular layers, and can not be seen because they are too thin to absorb light or cause iridescence due to reflective interference. Periodic observations indicated that wind velocity as low as 2-3 mph can push the film over the water surface to the downwind side or corner of a pond within minutes after treatment, thereby establishing areas of highly compressed film and areas of essentially no film (Levy et al. 1980). Average persistence for Arosurf MSF has been determined to be 2 to 10 days at recommended dosage rates (Miller 1984). Monomolecular films are biodegradable and have shown no adverse effects on mammals and several species of vertebrate and invertebrate aquatic organisms so these materials should not pose a threat to the environment or a health hazard to man.

An exemption from the requirement of a tolerance for the pesticide in or on fish, shellfish, irrigated crops, meat, milk, poultry and eggs, when used as a mosquito control agent in aquatic areas has been established under 40 CFR 18Q.1078. Studies on closely related fatty acid and fatty alcohol ethoxylates having various degrees of ethoxylation supported the clearance of the chemical as an inert ingredient and were also used in support of the exemption as an active ingredient (EPA 1984). Arosurf MSF demonstrates low mammalian toxicity (category III). Isooctadecanol has demonstrated low toxicity to fish, birds and other wildlife and non-target organisms. Acute toxicity (96hr-LC_{50}) of isooctadecanol to fish range from 98 ppm (rainbow trout) to 290 ppm for bluegill (Miller 1984).

Qualitative data on non-target animals and plants exposed to various dosages of Arosurf MSF during field trials to control mosquitoes have indicated that this film will cause little or no adverse effects to the environment. Some mortality of pupae and/or emerging adults of certain midge species (Chironomidae) breeding in aeration and decomposition ponds at sewage treatment systems was noted. However, significant mortality of midges was also observed in some control (untreated) sewage ponds containing a similar layer of natural surface scums. Therefore, the true impact of Arosurf MSF on the reduction of the midge population is not known. Adult dragonflies were observed to oviposit in water treated with Arosurf MSF and a *Gambusia* sp. was observed eating large lenses of floating Arosurf MSF with no apparent adverse affects. Field and laboratory tests indicated that predation and asexual reproduction of the mosquito planarian *Dugesia dorotocephala* (Woodworth) and the infectivity and development of the mosquito nematode *Romanomermis culicivora* (Ross and Smith) were not adversely affected by Arosurf MSF at surface dosages of 0.4-0.5 ml/m^2. Although no quantitative data were obtained concerning the effects of Arosurf MSF on the natural populations of animals and plants, general observations indicated that there appeared to be few long-term effects (Ward 1966).

Arosurf MSF was effective in reducing 3rd and 4th instars of *Ae. nigromaculis* and *Ae. melanimon* populations at 0.5 and 1.0 ml/m2 surface rates, averaging 88% and 96% mortality reduction, respectively. Non-target arthropods which showed acute lethal effects were corixids (*Corisella* spp.). Notonectids (*Notonecta unifascfata*), clam shrimp (*Eulimnadia* sp.), and *Tropisternus lateralls* beetle adults. Non-targets that did not exhibit mortality were mayfly (*Callibaetis* spp.) naiads, chironomid larvae and copepods (Takahashi et al. 1984).

Under field conditions, this film-forming substance produced a high level of control (90%+) of larvae and pupae of *Cx. tarsalis* at the rate of 0.5 to 0.75 gal/acre with no apparent effect on non-target organisms such as mayfly naiads, diving beetle adults, ostracods and copepods (Mulla et al. 1983).

d. Others

Temephos (Abate) is a non-systemic insecticide used as a relatively selective larvicide against mosquitoes, midges, gnats, punkies sand flies, thrips and black flies (SCAMP 1987). It has not been used in Massachusetts for several years. It is non-phytotoxic when used as recommended but is not generally used on plants (Hartley & Kidd 1983. SCAMP 1987). It has relative long residual action but short residual time in soils and water (SCAMP 1987). In plants, temephos is oxidized to the sulfoxide and, to a lesser extent, to the sulfone and mono- and di-orthophosphates. Further degradation proceeds very slowly (Hartley & Kidd 1983). In insects, the thiophosphate group and sulfur atom in the sulfide group of temephos undergoes a step wise oxidation. The oxidative compound is then hydrolyzed, and the final metabolite is 4,4'-dihydroxy diphenyl sulfone (Aizawa 1982). These reactions are highly species dependent which provides temephos's selective action.

Temephos has some hazard to non-target and beneficial insect but is highly toxic to honeybees by direct contact (topical LD_{50} is 1.55 ug/bee). It is also hazardous to crustaceans such as shrimp and crabs (SCAMP 1987). At 100-1000 ppb, temephos causes some reduction in °2 evaluation by algae (Verschueren 1983). The 96 hr - LC_{50} for temephos to crustaceans range from 45-82 ppb and the median threshold limit (TLm) for shrimp range from 249 ppb 2550 ppb. The LC_{50} values of temephos to non-target aquatic insects range from 1-2 ppb (Ephemeroptera) to 500-1000 ppb (Tricoptera) (1 hr-LC_{90-95}). The 96hr-LC_{50} value for stoneflies is 10 ppb (Verschueren 1983). Temephos (Abate 4E) did reduce populations of copepods and cladocerans in a test in man-made ponds but the populations recovered within several weeks. Ostracods were not affected (Fortin et al 1987).

Temephos is stable when stored at room temperature, moderately stable to hydrolysis in contact with aqueous alkali, but the rate of hydrolysis increases with pH. Optimum stability is at pH 5-7 with increased hydrolysis occurring at 2>pH>9 at rates depending on temperature. Temephos may be oxidized to the sulfoxide, the sulfone, and the mono- and dioxygen analogs. The sulfoxides and sulfones of the oxygen analogs have not been observed. Hydrolysis products include the thiophenol and the corresponding sulfoxide and sulfone (Reed 1982).

In a study using 3H-labeled temephos topically applied to bean plants, unchanged temephos comprised more than 70% of the terminal residues after 28 days. The sulfoxide comprised about 4% of the residues. The other oxidative metabolites were present in very small amounts. Conjugates of the hydrolysis products comprised the remaining residues. More than 90% of the applied activity remained after 28 days, indicating that residue decline is primarily the result of growth dilution (Reed 1982).

In laboratory studies, temephos has a half-life of 108 days in aqueous media. However, temephos degrades more rapidly in samples of reservoir, polluted brook, and puddle waters with half-lives ranging from 9-32 days. Temophos rapidly photodegrades to the sulfoxide and then to other oxidative and hydrolytic products. Sanders et al., (1981) reported concentrations ranging from 0.15 ug/l to 10 ug/l in small freshwater ponds 24 hr after application. Henry et al. (1971) measured temephos concentrations after simulating saltmarsh application rates (26 to 131 ug/l) and reported disappearance rates as a function of temperature. Temephos concentrations ranging from 16 ug/l to 34 ug/l were found in stagnant ponds after application by helicopter, with a half-life of approximately 5 hr (Lores et al. 1985). Peak concentration of temephos in water during early May occurred within 1 hr of treatment of a 4 EC formulation (mean approx. 20 ug/l) and within 8 hr of treatment with the 2G formulation (mean approx. 9 ugtl). The rate of degradation in water appeared to be affected by the initial solubility of temephos which is itself influenced by the application site, the water temperature and the formulation applied. These findings support a general half-life disappearance of 24 hr for the active ingredient under conditions found in local spring *Aedes* breeding habitat (Mackenzie et al. 1983).

Little data exists for soil degradation, but there are indications that certain soil bacteria are capable of causing rapid degradation of temephos to water-soluble hydrolysis products. The mean peak concentrations of temephos residues in sediments were in the 250-500 ug/kg range following a single early spring application of 90-100 g/ha and declined to negligible levels in 10 days (Mackenzie et al. 1983).

From an animal metabolism study, data from cattle indicate that temephos and its sulfoxide are interconvertible in animals. The sulfoxide was present in the milk of cows fed 20 ppm temephos and temephos was present in the milk of cows fed 5 ppm of the sulfoxide (EPA 1986). All of the oxidative metabolite of temephos are expected ChE inhibitors, but terminal residues appear to consist primarily of temephos and its sulfoxide (EPA 1981). When 3H-temephos was orally administered to rats, radioactivity reached a peak in the blood between 5 and 8 hrs and then dissipated with a half-life of about 10 hrs. Appreciable radioactivity was found only in the gastrointestinal tract and fat. Both in feces and in fat, most of the activity came from unchanged insecticide, but small amounts of the sulfoxide were present also. While traces of temephos were found in the urine, the principal urinary metabolites were sulfate ester conjugates of 4,4'-thiodiphenol, 4,4'-sulfinyl-diphenol, and 4,4'-sulfonyldiphenol. At least 10 other components could be extracted but were not identified. In the guinea pig, absorption apparently was less than in the rat, and biliary excretion of metabolites was demonstrated (Hayes 1982).

Temephos was dermally applied to cattle as a 0.l% spray and the cattle were slaughtered 7, 14, 28, 42, and 56 days after treatment. Temephos was not detected (<0.05 ppm) in any sample of muscle or liver, but was detected in the kidney at 0.08 and 0.13 ppm in 2 of the 3 animals slaughtered after 7 days. Temephos averaged 1.19 ppm in the fat of the 3 animals killed at 7 days and declined thereafter with a half-life of 6 days. Temephos sulfoxide was detected at levels of 0.39 and 0.09 ppm only in the fat of cattle killed 7 and 14 days, respectively, after treatment. In a study where ^{14}C-labeled temephos was sprayed on lactating goats, residues in the back fat were predominantly temephos. Residues in omental fat and milk were predominantly the sulfoxide with some sulfone and, in liver, residues of the sulfoxide and the sulfone were roughly equal. Other oxidative and hydrolytic metabolites were present in only small amounts. Therefore, metabolism and elimination of temephos is rapid with about 95% of a single oral dose eliminated in the urine and feces within 96 hours (EPA 1981).

The acute oral toxicity (LD_{50}) of temephos in rats is 770-13,000 mg/kg t8600 mg/kg), and 4000 mg/kg for mouse. Temephos has an acute dermal toxicity (LD_{50}) for rabbit of 1300-1930 mg/kg and greater than 4000 mg/kg for rats (Hartley & Kidd 1983, Worthing & Walker 1983). Temephos and malathion showed an approximately fourfold potentiation in rats when they are given together at levels approaching their LD_{50} values (Gaines et al. 1967). However, under other conditions no potentiation was observed between temephos and 23 other organic phosphorus compounds (Levinskas & Shaffer 1970). Temephos has a TWATLV value of 10 mg/m3. The threshold limit value of 10 mg/m3 indicates that occupational intake at a rate of 1.4 mg/kg/day is considered safe.

In a neurotoxicity study, hens were fed 230, 460, and 920 ppm temephos for 30 days. Microscopic examination of nerve tissues revealed no demyelination (Reed 1982). Temephos in a dosage of 500 mg/kg produced a rapid onset of leg weakness in chickens, from which survivors recovered within 36 days or less. An intake of 125 mg/kg produced very mild leg weakness, followed by prompt recovery. This sign was produced in 30 days at a dosage of 15.3 mg/kg/day but not in 108 days at a level of 7.4 mg/kg/day (Gaines et al. 1967). Thus, the effect of temephos in chickens is similar to that of malathion, and the lack of myelin loss in hens fed the compound at a dietary level of 920 ppm (about 53 mg/kg/day) for 30 days, as reported by Levinskas & Shaffer (1970), would be expected (i.e., low OPIDN hazard).

The subacute and chronic toxicity of temephos is detailed below. Temephos has been shown to inhibit ChE activity *in vivo*. In rats, subchronic oral doses as low as 6 ppm resulted in depressed red blood cell ChE activity. In dogs, subchronic oral doses of 500-700 ppm caused depressed red blood cell, plasma, and brain ChE activities. Subchronic oral dosing with temephos caused no observed effect on survival, food consumption, or tissue and organ histopathology in rats given up to 350 ppm in the diet, and in dogs given 500 or 700 ppm in the diet for 90 days. Weight gain was reduced in rats given 350 ppm in the diet. In a 30-day study with male rats fed 0, 250, 500, and 1000 ppm technical temephos, the NOEL was 250 ppm (which is equivalent to 12.5 mg/kg B.W./day) for any effect other than ChE inhibition, which was noted at all dose levels. Weight gain depression was the effect noted at 500 ppm and above. No adverse effects were noted at feeding levels up to 300 ppm in a 2-year rat study. However, ChE activities were not measured (EPA 1981).

Over a 90-day period, rats tolerated a diet containing 9 ppm of the sulfoxide with no apparent effect except inhibition of RBC ChE activity. No inhibition occurred at 3 ppm (Levinskas and Shaffer 1970). In a study with human volunteers, increasing doses of temephos (2 to 256 mg/day) or constant doses of 64 mg/day were ingested over a four week period. No alterations in red blood cell or plasma ChE activity and no clinical symptoms were observed (EPA 1981).

The reproductive and teratogenic effects of temephos are as follows. Male and female rats were started on diets containing 500 ppm temephos at mating. Dosage was maintained throughout mating, gestation, parturition, and lactation. There were no significant differences in number of litters produced, litter size, viability of young or the incidence of congenital defects between treated and control groups even though the dosage caused signs of poisoning in some rats (Gaines et al. 1967). In a second reproduction study, no compound-related effects on reproductive capacity were noted in rats fed 25 or 125 ppm of temephos. No effects were noted in the offspring (EPA 1981). Temephos at oral dosage levels as high as 2.5 mg/kg/day for 422 days or at 5 mg/kg/day for 186 days caused no ill effects in sheep or their lambs (McCarty et al. 1968).

No oncogenic effects were noted in a 2-year study with rats fed 0, 10, l00, and 300 ppm. There exists no mutagenicity data for temephos. The EPA Registration Standard for temephos states that toxicological data gaps related to reregistration of temephos for the food uses are a second oncogenicity study (in mouse) and teratogenicity and mutagenicity testing.

Acute toxicity (96hr-LC_{50}) of temephos in a variety of fish species range from 0.16 ppm (rainbow trout) to 34.1 ppm (fathead minnow). Test conditions and size did not appreciably change the toxicity of temephos to fish. Variations in pH from 6.0 to 9.0, hardness from 40 to 162 ppm, or size from 1 to 20 g gave a range of less than 4 mg/1 in 96hr-LC_{50} values. Flow-through tests for up to 15 days with cut-throat trout and lake trout produced $TILC_{50}$ (time-independent LC_{50}) values for temephos of 0.20 and 1.05 mg/1 (ppm) and cumulative toxicity indices (96hr-LC_{50} value divided by $TILC_{50}$ value) of 5.0 and 1.0, respectively. This indicates little or no cumulative action of temephos in fish (Johnson & Finley 1980).

Following the treatment of the Upper Volta River with Abate for the control of Simulium larvae, no fish died, but fish in the treated area were prone to easy capture. The catch per unit effort, and the number of species captured in the 24-hr period following treatment, were higher. Evidently, sublethal stress leading to under- or hyper-activity, make the fish an easy prey in nature and affect the stability of the population. When Abate was applied to River Oti in Ghana to control Simulium larvae, fish 300 m upstream from the point of application were normal, whereas fish at the site of application swam erratically. Fewer numbers and species were collected in the 24-hr period following application than before application, suggesting possible avoidance reaction of fish to Abate. Exposure to 96hr-LC_{50} of fenitrothion for 24 hr completely inhibited the learning ability of salmon perr; Abate at 5 mg/l retarded learning (Murty, Vol. II, 1986).

Acute oral toxicity (LD_{50}) of temephos for the bullfrog is greater than 2000 ppm (Smith 1987).

Acute oral toxicity (LD_{50}) of temephos for a variety of birds ranges from 18.9 ppm (California quail) to 270 ppm (chukar). Its dietary LC_{50} values range from 92 ppm (northern bobwhite) to 894 ppm (mallard duck). There are few data on its dermal toxicity. Mallard ducklings (12-24 hr of age) were fed diets treated with temephos for 7 days and housed in either heated or unheated brooders. High mortality occurred in the 100 ppm group housed in unheated brooders, but diets containing up to 10 ppm did not affect duckling survival (Fleming et al. 1985).

A reproductive study conducted with game-farm mallards fed 0, 1, and 10 ppm Abate 4E (temephos) did not result in treatment effects for hatching success, clutch size, fertility, nest attentiveness of incubating hens, and duckling avoidance behavior. However, the mean interval between eggs laid was greater for the 10 ppm group, and duckling survival to 21 days was significantly lower for both treatment groups than for controls (Franson et al. 1983).

There have been no published accounts of wildlife die-offs that have been related to field applications of temephos (Smith 1987). However, the 30-day EMLD (empirical minimum lethal dose, lowest daily oral dosage that produces 1-2 deaths over a 30 day period) for mallards (n - 22) is 2.5 mg/kg per day for both sexes. The resulting cumulative toxicity index for temephos is 79.4/2.5 - 32, indicating a high degree of cumulative action for an organophosphate in birds (Hudson et al. 1984).

3. Adulticides

a. Pyrethrum and Synthetic Pyrethroids

Pyrethrin I is insoluble in water, has appreciable vapor pressure but an extremely large partition coefficient (KoW) indicating that it is immobile in soil and migrants slowly, if at all. It is unstable in sunlight and rapidly hydrolyzed by alkali with loss of insecticidal properties. Photodecomposition of pyrethrin I as thin films on glass yields 11-15 products, none of which are insecticidal or of toxicological significance. Saponification (alkalihydro1ysis) of the pyrethrum mixture of ester products liberates 12-16 acids, again with the subsequent loss of insecticidal activity.

Many invertebrates and microorganisms are capable of metabolically detoxifying this natural insecticide. Although the levels of Pyrethrin I in water, air, and soil are not known, little is expected to persist because of its photolabile and biodegradable nature.

Similar to pyrethrin I, resmethrin decomposes rapidly on exposure to air and sunlight and is unstable in alkaline media. However, photolysis of the ester bond is a significant reaction for trans- and cis-resmethrin but apparently not for pyrethrin I. Resmethrin and other type I pyrethroids generally yield a large number and great variety of photoproducts, most of which originate from further reactions of the primary cleavage products. For example, the alcohol moiety liberated on photolysis of resmethrin degrades further to benzyl alcohol, benzaldehyde, benzoic acid and phenylacetic acid, the latter contributing to the unpleasant odor of photodecomposed resmethrin. The environmental and toxicological impact of these breakdown products are unknown at this time but due to the low rates and quantities used in mosquito control, they are not expected to be particularly significant.

As with pyrethrin I, resmethrin is rapidly biodegraded by invertebrates and microorganisms by established metabolic pathways. Although the levels of resmethrin in water, air, and soil are not known, little is expected to persist because of its photolabile and biodegradable nature.

Pyrethrins are potent, non-systemic contact insecticides causing rapid paralysis and knockdown with death occurring at a later stage of intoxication. Insecticidal activity is markedly increased by the addition of synergists such as PBO. Pyrethrins are not phytotoxic. Although toxic to bees, pyrethrins show less hazard than indicated by topical bioassays (approximately 1 ug/housefly) due to their repellent effect (Hartley & Kidd 1983). Pyrethrins are degraded in the environment by sunlight, chemical hydrolysis and by many invertebrate organisms via hydrolytic and oxidative metabolism. The approximate residual period for pyrethrins is 1-3 days on plants and similar short duration in soil and water (SCAMP 1987). No biological magnification has been shown. Degradative products have not been determined to be as toxic or more toxic than the parent pyrethrin compounds. Its toxicity (96hr-LC_{50}) to crustaceans range from 11 to 42 ppb and for nontarget aquatic insects approximately 1.0 ppb (Verschueren 1983).

The synthetic pyrethroid resmethrin is also a non-systemic, contact insecticide with fast knockdown similar in action to the natural pyrethrins (Hartley & Kidd 1983). Although sometimes formulated with synergists (e.g., piperonyl butoxide), resmethrin's toxicity is not enhanced in their presence (SCAMP 1987). Resmethrin is not phytotoxic if used as recommended. Resmethrin is toxic to bees, but field data indicates that ULV sprays of resmethrin are not hazardous to honeybee colonies in the area treated for adult mosquito control (Scourge Tech. Bull. 1986). *Daphnia magna* has an LC_{50} of 0.1 ppm (48 hr), *Penaeus* shrimp 1.25 ppb and the American oyster 1.79 ppm.

Piperonyl butoxide (3,4-methylene-dioxy-6propylbenzyl(heptyl) diethylene glycol ether) is used as a synergist in conjunction with pyrethrins and pyrethroids such as resmethrin. It is relatively stable to hydrolysis and UV irradiation. It is not toxic to bees or other beneficial insects and is degraded by invertebrates by oxidative attack on the carbon atom of the methylenedioxy group forming dihydroxyphenyl compound. Side-chain oxidations also occur. Elimination is by glucoside or amino acid conjugations (SCAMP 1987, Hayes 1982).

Pyrethrum and the synthetic pyrethroid resmethrin share a common mode of action as direct nerve toxins which interfere with nerve impulse generation via modulation of voltage-gated ion channels, particularly sodium and possibly calcium channels (Narahashi 1987, Clark & Brooks 1988).

As summarized by Hayes (1982), pyrethrum may be absorbed from the gastrointestinal tract and by the respiratory route. It is not absorbed to a significant degree through the skin. However, allergic reactions may result from this route of exposure. The esters constituting pyrethrum mixtures are rapidly detoxified by hydrolysis in the gastrointestinal tract and to some extent in the tissues of adult warm-blooded animals. The chrysanthemum monocarboxylic acid formed is excreted in the urine. Pyrethrins or their metabolites are not known to be stored in the body or to be excreted in the milk, but no study of the matter has employed modern methods. Partly because of their ready excretion, these compounds exhibit little clinical effect in animals following repeated exposure to moderate doses, but they or their metabolites do lead to liver changes in rats. Studies describe the very extensive metabolism that pyrethrins undergo, mainly in the liver. Various active ingredients undergo significantly different biotransformation. For example, within 48 hours of oral administration of ^{14}C-pyrethrin II to rats, 53% of the ^{14}C was recovered as exhaled $C0_2$, whereas only 0.3% of ^{14}C pyrethrin I was recovered in that form under the same circumstances. The corresponding proportions of ^{14}C recovered from the urine were 7 and 46%, for pyrethrins II and I, respectively. Some of the orally administered material is excreted in the feces, at least partially in metabolized form. Three compounds have been isolated from urine and identified by NMR and mass spectra. All three are produced by both pyrethrin I and II. All three are the result of oxidation of both the acid and alcoholic moieties leaving the main structure of the molecule intact (Elliott et al. 1972a, 1972b). So far the numerous compounds that result from hydrolysis of the esters have not been identified. The fact that the most severe cases of poisoning have been reported in infants suggests that very young children may not hydrolyze the pyrethrum esters efficiently. In any event, mammals show approximately the same susceptibility to injected pyrethrins as do cold-blooded animals, including insects (Gaudin 1937).

Acute oral LD_{50} values of pyrethrum in rats range from 584- 1500 mg/kg, 272-796 mg/kg for mice and 1500 mg/kg for rabbit (Farm Chemical Handbook 1988, Hartley & Kidd 1983, Hayes 1982). Lehman (1952) estimated that the fatal human dose might be 100 grams (1430 mg/kg) for a 70-kg man. Acute dermal LD_{50} values for rats are greater than 1500 mg/kg and for rabbits 5000 mg/kg. Dermatitis is possible in sensitive individuals from constituents of the flowers. Rats and dogs inhaled a concentration of 16 mg/m^3 of pyrethrins for 30 min. periods during 31 calendar days with only slight lung irritation (SCAMP 1987). Inhalation of pyrethrum at 6000 mg/m^3 for 30 min. caused only moderate lung congestion (Carpenter et al. 1980).

The subacute and chronic toxicity of pyrethrum is also low. Groups of 12 male and 12 female rats were fed pyrethrin in soybean oil at dietary levels of 0, 200, 1,000, and 5,000 ppm for 2 years. The daily dosages were, therefore, approximately 0, 10, 50, and 250 mg/kg, respectively. Even at the highest level pyrethrin had no significant effect on growth or survival. A slight though definite liver damage was observed, especially at the higher dosage levels (Lehman 1965). Dogs fed pyrethrins at a dietary level of 5,000 ppm for 90 days showed tremor, ataxia, labored respiration, and salivation during the first month of exposure (Griffin 1973). Ambrose & Robbins (1951) reported no effect in rats fed pyrethrins at a dietary level of 1000 ppm for two years, but tissue damage and gross signs of intoxication appeared at 5000 ppm. When pyrethrins were fed to rats at a dietary level of 1,000 or 5,000 ppm for 2 years, the liver lesions included bile duct proliferation and focal necrosis of the liver cells (Lehman 1965). Pyrethrins, especially synergized pyrethrins, produced enlargement, margination, and cytoplasmic inclusions in the liver cells of rats. At a dietary level of 1,000 ppm, pyrethrins and 10,000 ppm piperonyl butoxide, the changes were well developed in only 8 days, but were not maximal. The changes were proportional to dosage and similar to those produced by DDT. The effects of the two materials were additive (Kimbrough et al. 1968). No relevant pathology was detected in rats fed pyrethrins at a dietary level of 8,000 ppm for 5 weeks (Griffin 1973).

The sensitizing property of pyrethrins is apparently more evident in humans than in other animal vertebrates (Hayes 1982). When 200 people (177 women and 23 men) were patch tested with a 1% water dispersion of pyrethrins, no evidence of primary irritancy or of sensitization was found (unpublished report cited by FAO/WHO 1971). It must be noted, however, that both the formulation used and the duration of exposure were different from those that have caused the most severe dermatitis or sensitivity of any kind under practical conditions of exposure. There is little doubt that commercially available pyrethrin extracts are less sensitizing than native pyrethrum. However, apparently no study has been made to measure the difference in way that would be statistically valid. Mitchell et al., (1972) found all the active ingredients of pyrethrum, except pyrethin II, to be inactive on patch test in a patient who had a history of allergenic dermatitis to pyrethrum and who reacted positively to pyrethrum flower heads, powder extracts of the plant, and pyrethrosin. The no-effect level corresponds to a rate of 3600 mg/man/day (SCAMP 1987).

Pyrethrum has little or no reproductive or teratogenic hazard (Hayes 1982). Rabbits that received pyrethrins orally on days 8 to 16 of gestation at dosages as high as 90 mg/kg produced litters with no statistical increase in abnormalities (unpublished report cited by FAO/WHO 1971). When rats were fed pyrethrins at a dietary level of 5,000 ppm beginning 3 weeks before first mating, reproductive performance was not reduced, but the weights of weanlings were significantly lower than those of controls (Griffin 1973).

The synthetic compounds are more photostable, sometimes providing control for many weeks following a single field application. In addition, some of the synthetic pyrethroids are metabolized more slowly by both insects and mammals and hence have increased toxicity. Enhanced environmental and biological stability of these compounds have triggered needs for residue analysis and for understanding their potential toxicity to mammals (Marquis 1986).

Resmethrin was one of the first or "early" pyrethroid synthesized which is not halogenated nor does it contain a cyanophenoxybenzyl alcohol. Thus, its metabolism and pharmacokinetics are more similar to the pyrethrins than the more stable type II pyrethroids (e.g., fenvaleratte, cypermethrin, deltamethrin).

Resmethrin has an acute oral LD_{50} of 2700 mg/kg in rats and 4250 mg/kg in rats exposed to technical resmethrin (SBP-1382). The dermal LD_{50} value in rabbits is greater than 2000 mg/kg and greater than 3000 mg/kg in rats. Resmethrin was found to be non-irritating to skin and eyes (rabbits). SBP1382 is classified as a very mild conjunctival irritant. The inhalation (4 hr) for rats and dogs is established at greater than 9.49 g/m^3. No effect level was 420 mg/m3 (4 hr). The NOEL in rats for a subchronic inhalation study (90 days) is 0.1 g/m^3.

In 90 day feeding trials, rats receiving 3000 mg resmethrin/kg diet showed no ill effects. The NOEL (no observable effect level) for resmethrin in a 180-day subchronic feeding study in dogs is 10 mg/kg/day.

In three generation reproduction tests for resmethrin, the NOEL for rats is 500 ppm. No teratogenic effects are observed in rats receiving resmethrin at dosages up to 80 mg/kg/day, up to 25 mg/kg/day for rabbits and up to 50 mg/kg/day for mice. The NOEL for fetotoxicity is 40 mg/kg/day.

Although limited, two studies support the contention that resmethrin has little carcinogenicity hazard. In an 85-week mouse feeding/oncongenicity study, SBP-1382 was not oncongenic at 1000 ppm. In a 2-yr rat chronic feeding/ oncogneicity study, SBP-1382 was not oncogenic at 5000 ppm, the highest dose tested. The above data have been compiled from the following sources: Hartley & Kidd 1983, Worthing & Walker 1983, SCAMP 1987, Penick-Bio UCLAF Corp. 1986. Although overall evidence for chronic toxicity in mammals is limited, pyrethrin/pyrethroids still represents one of the safest classes of pesticides present available.

Because piperonyl butoxide (PBO) is included in various pyrethrum and pyrethroid (i.e., resmethrin) products used for mosquito control, the following mammalian toxicology is included. The acute oral toxicity (LD_{50}) for PBO in various mammal range from 3800 mg/kg (mouse) to 11,502 mg/kg in rat. Dermal LD_{50} for PBO in rabbit is greater than 1880 mg/kg. Although dermal absorption is poor, multiple inunction at 200 mg/kg may be fatal to animals. In a subchronic feeding study, rats tolerated without harmful effects 5000 ppm in the diet for 17 weeks; 10,000 ppm were endured through 3 successive generations with moderate toxic effects and; 25,000 ppm in the diet were fatal to rats in from 4 to 46 weeks. In 2-yr chronic feeding trials, rats receiving 100 mg/kg diet suffered no ill-effect. PBO is noncarcinogenic and the safe human tolerance for chronic ingestion is estimated at 42 mg/kg diet (Negherbon 1959, Worthing & Walker 1983).

Pyrethrins (pyrethrum) are highly toxic to fish (Hartley & Kidd 1983). Acute toxicity of pyrethrum as judged by 96hr-LC_{50} ranged from 13 ppb (channel catfish) to 58 ppb (bluegill). Temperature and pH of test solutions affected the biological activity of natural pyrethrins. Toxicity to channel catfish was 12-fold higher at 18°C than at 12°C. Toxicity increased in acid water (low pH); the 96hr-LC_{50} for bluegills was 41 ug/l (ppb) at pH 6.5 and 87 ug/l (ppb) at pH 9.5. Water hardness (44-314 ppm) had little influence on toxicity (Johnson and Finley 1980). Excellent control of larvae of *Cx. tarsalis* in experimental ponds was obtained at the rate of 1 pyrethrin tossits/ m2 (44 B ai/ha). At the same rate, satisfactory control (92%) of *Cx. peus* larvae was obtained in dairy waste-water lagoons in Riverside County, Ca. At the effective mosquito larvicidal rate (44 g/ha), mosquito fish, *G. affinis*, was affected when some tossits were placed with the fish in 0.9 m^3 screened cages. Five successive weekly treatments of *G. affinis* at the larvicidal rate and double that rate (44 and 88 g/ha) resulted in 37% and 67 % reduction of fish yield harvested 42 days after the first treatment compared to the yield obtained from the untreated ponds (controls), respectively. No marked effects on some of the non-target organisms such as dragonfly naiads, ostracoda, copepods, and Dixa midge larvae were noted. Mayfly naiads were eliminated at all rates applied, but recovered within 2-3 weeks after treatment.

Pyrethroids have very high insecticidal activity and have found wide use in the last few years. Though they are not persistent in the environment, their acute toxicity to fish is high. The cyano-substitution of the phenoxybenzyl alcohol moiety (as in cypermethrin and fenvalerate) enhances the toxicity of pyrethroids to fish.

Similarly, pyrethroids with (lR)-cis-isomers for the acid moiety are more lethal than the corresponding cis-,trans-racemates. Fenvalerate and permethrin are more toxic than many OC compounds, the 96hr-LC_{50} being 0.5 to 12.0 ug/l (ppb). Cold water fish were reportedly more susceptible than warm water fish to natural permethrins as well as synthetic pyrethroids.

Pyrethroids are metabolized in fish by both hydrolytic and oxidative processes. It appears that, in general, esterases are more important in metabolizing the trans-chrysanthemates of primary alcohols whereas oxidases are more important with the cis-chrysanthemates of primary alcohols. Pyrethroids are rapidly metabolized by fish (Murty, Vol. II 1986). Resmethrin (SBP-1382) is toxic to fish (Hartley & Kidd 1983) with an acute toxicity (96hr-LC_{50}) to freshwater fish ranging from 1.7 ppb (lake trout, bluegill) to 16.6 ppb (channel cat fish) (Johnson and Finley 1980). Resmethrin has a 96hrLC_{50} value of greater than 150 ppb for coho salmon (Verschueren 1983). Resmethrin was the least toxic pyrethroid against frogs (*Rana pipiens pipiens*) with a subcutaneous LD_{50} value of greater than 60 ppm (Cole and Casida 1983).

The acute oral toxicity of resmethrin to California quail has been determined to be much greater than 2000 ppm (Johnson and Finley 1980).

b. Malathion

Malathion is a non-systemic insecticide and acaricide that acts as a cholinesterase inhibitor. It is generally non-phytotoxic but may damage glasshouse cucumber, beans and certain ornamentals. Some varieties of apple, pear and grape may also be injured (Hartley & Kidd 1983). Its approximate residual period on plants is 5-10 days but has a short residual time in soils. Malathion is rapidly degraded *in vitro* by saltmarsh bacteria to malathion monocarboxylic acid (monoacid), malathion dicarboxylic acid (diacid) and various phosphothionates as a result of carboxyesterase cleavage. In addition, some expected phosphatase activity produces desmethyl malathion, phosphomono- and phospho-dithionates, 4-carbon dicarboxylic acids and the corresponding ethylesters (Verschueren 1983). In insects, malaoxon is the major metabolite formed by oxidative desulfuration at about 25% of all total. Predominant degradation is caused by hydrolysis in insects (Aizawa 1982). Biological magnification of malathion is not likely (SCAMP 1987).

Malathion presents some toxicity to beneficial insects including honey bees (Hartley & Kidd 1983). The topical LD_{50} for honey bees is 0.71 ug/bee (SCAMP 1987). The 96 hr-LC_{50} for non-target aquatic insects range from 1.1 to 10 ppb, and for crustaceans 0.76 ppb to 3000 ppb. The median tolerance limit (TLm) for the American oyster is 9070 ppb (48 hr) for egg and 2600 ppb (14d) for larval (Verschueren 1983).

Degradation of malathion in soil is quite rapid. It was found that after the application of malathion at 5 lb/acre only 15% of the applied dosage was recovered 3 days later. After 1 week, 95% of the applied malathion had disappeared. In Ludhiana, Palamput, and Kamma soils, malathion was 100% degraded 4 days with higher temperatures producing more rapid degradation (Laveglia & Dahm 1977).

Walker & Stojanovic (1973) also found that malathion was quite stable under neutral or acid pH conditions and that susceptibility to hydrolysis increased with increasing alkalinity. They demonstrated that malathion disappeared more rapidly under nonsterile than sterile conditions and indicated that malathion disappearance is stimulated by various microbiological systems in soil. Under sterile conditions, the observed malathion remaining in the Trinity loam, Okolona clay, and Freestone sandy loam after 10 days of incubation was 91%, 77% and 95%, respectively. In nonsterile soil, complete disappearance of malathion had occurred. Getzin and Rosefield studied the degradation of malathion in nonsterile, heat-sterilized, and gamma-sterilized soil. After 1 day, 97% of the malathion was degraded in the nonsterile soil, 90% in the irradiated soil, and only 7% in the autoclaved soil. Because of the rapid degradation in nonsterile soil, it was suggested that microorganisms were partly responsible for the degradation of the compounds. The difference between the amount of malathion decomposed in irradiated soil and autoclaved soil was attributed to nonviable, heat-labile substances. A stable, heat-labile enzyme, which catalyzed the hydrolysis of malathion to its monoacid, was partially purified. This esterase was extracted from irradiation-sterilized soil as well as from nonirradiated soil. When the partly purified enzyme was applied to the soil, it possessed many of the characteristics necessary for prolonged activity in a cell-free state in soil. It was less heat-labile than most enzymes, lost little or no activity upon prolonged storage, and survived desiccation in the soil. There have been many reports of microorganisms metabolizing malathion to various products. Carboxyesterase activity, which degrades malathion to its monoacid and diacid, is the predominant degradative pathway. Phosphatase activity also has been reported. Oxidative desulfuration and demethylation seem to be rather minor metabolic routes (Laveglia & Dahm 1977).

Walker (1976) reported that malathion dissipated rapidly in both sterile and nonsterile water in that only 3% of the added insecticide could be detected after 18 days incubation. The similarities between malathion degradation in the presence and absence of biologically active systems dictates that malathion disappearance is by purely chemical mechanisms. The effect of salinity on the degradation of malathion in estuarine water was determined by incubating the insecticide in sterilized seawater varying in salinity from O to 25 ppt. The degradation of malathion was found to be directly proportional to the length of incubation and to increasing salinity in this sterile system indicating direct chemical hydrolysis.

The organophosphate insecticides included in this classification share a common mode of action as potent indirect nerve toxins via inhibition of cholinesterases (ChE).

Acetylcholine (ACh), the neurotransmitter secreted by cholinergic neurons, allows for chemical transmission of nerve impulses across the synapse. Acetylcholinesterase (AChE) is the enzyme responsible for the breakdown of ACh, thereby terminating the electochemical connection between two nerve cells. Organophosphorus insecticides (OP) phosphorylate AChE in an irreversible reaction that inhibits the activity of AChE to hydrolyze the neurotransmitter at the nerve synapse. The accumulation of ACh results in continuous nerve firing and eventual failure of nerve impulse propagation. Respiratory paralysis is generally the immediate cause of death. Brain ChE activity is used in the diagnosis of OP poisoning with a reduction of 20% of normal activity indicating exposure. A ChE inhibition of 50% or more is considered the diagnostic threshold for determining the cause of death. Because of the irreversible nature of the pesticide-enzyme binding reaction characteristic of OP poisoning, recovery from a sublethal OP exposure depends on synthesis of more ChE. There is evidence that recovery of ChE activity in plasma is as fast or faster than in the brain (Hayes 1982).

In addition to anticholinesterase activity, some OP pesticides have other adverse biochemical effects. A number of have been determined to inhibit neurotoxic esterase, an enzyme that has not been isolated and whose biochemical and physiological functions in nerve tissue are unknown (Metcalf 1982). Organophosphate-Induced Delayed Neuropathy (OPIDN) has been recently reviewed (Marquis 1986). Little information is available on delayed neurotoxicity in wildlife species. However, species differences can be great and the capacity to produce delayed neurotoxicity is widespread among OP (Metcalf 1982).

Other sublethal biochemical effects have been described for OP, such as impaired reproduction in birds through possible hormonal effects and reduced tolerance to cold stress (Rattner et al. 1982a, 1982b). Embryotoxicity and teratogenic effects have been demonstrated for some OP (Hoffman & Albers 1983), and some have been shown to cause changes in brooding behavior or nest attentiveness of birds which could result in death of the young (Grue et al. 1983, Smith 1987). Central nervous system toxicity and noncholinergic effects of OP in mammals have been recently reviewed by Marquis (1986).

As summarized by Hayes (1982), the most striking difference between the metabolism of malathion and that of the majority of organic phosphorus compounds used as insecticides depends on the presence of two carboxy groups in malathion. Malathion is subject to the various kinds of metabolism that other organic phosphorus insecticides undergo, but the splitting of either carboxyester linkage renders the compound non-toxic. Details of the metabolism have been reported by O'Brien (1960) and by Heath (1961).

The excretion of absorbed malathion is rapid. When 25 mg of ^{14}C-labeled malathion was administered to each of six male rats, activity appeared in the urine within 2 hr, and 91.72% was eliminated within 24 hr while an additional 7.75% remained in the gastrointestinal contents. Excretion was mainly via the urine (83.44%) and partly by the feces (5.51%), but 2.77% was exhaled as carbon dioxide. No unmetabolized malathion could be detected 8 hrs after dosing (Bourke et al. 1968). In in vitro studies of human and rat liver, no important difference was found in ability to degrade malathion (Matsumura & Ward 1966) concentrations of 1 ug/l (ppb) of methoxychlor or MDE, Daphnia exposed for three generations grew and reproduced normally, but the emergence of mayfly nymphs was drastically reduced. In ponds treated with 10 to 40 ug/l (ppb) of methoxychlor, the total number of benthic organisms increased and species composition changed with chironomids becoming the dominant species. Neither survival nor growth of bluegills in the treated ponds was affected. However, most of the fish examined showed nonspecific liver degeneration and an accumulation of a muco- or glyco-proteinaceous material inside the major blood vessels. Regression of these effects had occurred by 56 days after treatment (Johnson & Finley 1980).

Greater sensitivity of young striped mullet than older juveniles to methoxychlor has been reported. Adult striped mullets had larger amounts of the residues, owing to the presence of a relatively higher percentage of body fat in the adult when compared with the juveniles. That it is the lipid content that confers a greater degree of tolerance of the larger fish to the DDT-type compounds is confirmed by the toxic concentrations of DDT, endrin, and malathion, to brook trout, cut-throat trout, and coho salmon of 1-g size and 1- to 2-g size. With DDT and endrin, there was reduction in the toxicity with in-crease in size, whereas no such difference in the toxicity of malathion to smaller and larger fish was found. Exposure to a 96hr-LC_{50} value of fenitrothion for 24 hr completely inhibited the learning ability of salmon parr and Abate at 5 mg/l retarded learning. DDT (OC) at 0.07 mg/l mildly enhanced learning whereas methoxychlor had no effect (Murty, Vol II, 1986).

Organophosphate insecticides have negligible chronic toxicity, but some have moderate to high acute toxicity in fish. The 96hr-LC_{50} of several organophosphate compounds to various species of North American freshwater fish are listed below:

The acute toxicity (96hr-LC_{50}) of malathion for a variety of fish species ranged from 62 ppb (red ear sunfish) to 12,900 ppb (black bullhead). In lake trout, fry (0.3 g) were twice as sensitive as fingerlings (4.5 g) to malathion. An increase in temperature from 10° to 21°C caused an 11-fold decrease in toxicity to the daphnid *Simocephalus*. However, an increase from 7° to 29°C caused a fourfold increase in toxicity to bluegills. Variations in water hardness did not appreciably alter the toxicity to fish or invertebrates. Mixtures of malathion with Baytex (fenthion), parathion, EPN, Perthane (ethylan), or carbaryl were synergistic in their toxicity to rainbow trout and bluegills. Combinations of malathion with DDT or toxaphene were only additive. Malathion has more-than-additive toxicity with more than half of the pesticides with which it was combined (Murty 1986) and is no longer used as a larvicide in Massachusetts.

Organophosphate compounds, because of their relatively higher water solubility, are in general taken up to lesser extent than organochlorines and eliminated faster. The time for achieving the highest levels of uptake and the extent of retention of OP residues by fish was directly related to the extent of persistence of a compound in water. Motsugo fish exposed to 0.6 to 1.2 ppm malathion, attained the highest body concentrations 2.4 mg/kg of malathion after 1 day. No malathion residues were found 24 hr after the exposure of pinfish to 75 ppb concentration. Only malathion monoacid was recorded in the gut (Murty 1986). With DDT and endrin, there was reduction in the toxicity with increase in size, whereas no such difference in the toxicity of malathion to smaller and larger fish was found. The natural degradation products of pesticides, in general, are less toxic than the parent compounds. But occasionally, the primary degradation product may be more toxic. The hydrolysis product of malathion, diethyl fumarate, was more toxic than the parent compound to the fathead minnows (Murty 1986).

Acute oral toxicity (LD_{50}) of malathion is 4100 mg/kg for rabbits and greater than 4000 mg/kg for rat_s (Hartley & Kidd 1983, Worthing & Walker 1983, Smith 1987).

Based upon the low toxicity of this compound, it would appear that a time-weighted average TLV of 10 mg/m3 is sufficiently low to prevent systemic effects (Hartley & Kidd 1983). Workers exposed to 84.8 mg/m3 experienced moderate eye irritation (SCAMP 1987). Hollingsworth has established a VSR for malathion of 38 (Wilkinson 1976).

Under subacute and chronic experimental conditions, malathion has been fed to rats for 104 weeks at levels as high as 5000 ppm in the diet with no gross effects. In 1.75 yr trials rats receiving 100 mg tech./kg diet showed normal weight gain. There was no effect found on blood ChE when malathion was fed to human volunteers for 47 days at the rate of 16 mg/man/day. Volunteers dosed dermally showed no change of blood ChE or other injury while exceeding an average of 47 mg/man/day and a maximum of 220 mg/man/day.

Whereas there is no evidence that malathion is teratogenic in mammals, it does cause a characteristic syndrome of deformity in chickens that apparently depends on tryptophan metabolism and may be peculiar to the egg, which is closed system (Hayes 1982). When 1.17 to 29.20 mg of malathion was injected directly into the yolk of each egg, it often killed the embryo and deformed many of those that survived. When injections were made on days 8 to 12, half of the survivors lacked feathers or had only a few feathers on the abdominal region. When injections were made on days 6 or 7, 95% of the survivors were smaller than normal. When injections were made on days 4 or 5, the legs were half the proper size and the phalanges were permanently flexed in 95% of the survivors, and the maxilla was curved downward over the shortened mandible in 50% of cases. All of the hatched chicks had abnormal feathers, and some lacked feathers completely or in some areas. Most of the hatched chicks were about two-thirds normal size, and 6% were only one-fourth normal size (Greenberg & LaHam 1969). Tryptophan prevented the hind limb, beak, and feather defects and overall growth retardation in malathion-dosed embryos (Greenberg & LaHam, 1970). Application of 0.1 ml of 0.2 M nicotinamide or 0.1 ml of 0.1 M tryptophan simultaneously with malathion prevented development of the syndrome in all survivors, although the nicotinamide increased mortality. Tryptophan was also effective when injected into the yolk, and it was not toxic. It was speculated that malathion interferes with mobilization of tryptophan from yolk proteins, consequently decreasing synthesis of nicotinamide, which is essential for pyridine nucleotide-dependent reactions involved in differentiation of legs, beak, feathers, and other organs. Deformities of chicks can also be produced by feeding malathion to laying hens for 3 weeks at dietary concentrations up to 600 ppm (Ghadiri et al. 1967). However, the most likely problem for poultry is not teratogenicity but simple toxicity.

The hatchability of eggs was reduced when the hens were fed dietary levels of 1.0 ppm or higher but not 0.1 ppm (about 0.0058 mg/kg/day) (Sauter & Steele 1972).

Although malathion has been reported to produce delayed neuropathological syndrome in a human suicide attempt (Hierons & Johnson 1978), these findings are not substantiated in more sensitive animal models (Hayes 1982).

None of the 8 mutagenicity studies reported in NCI were positive for malathion. In general carcinogenicity/oncogenicity studies carried out by NCI, malathion was not implicated as a carcinogen (personal communication, Pesticide Bureau, DFA, Boston, MA). IARC concluded that malathion and its metabolite malaoxon were tested for carcinogenicity in mice and rats by administration in the diet. No evidence of carcinogenicity was found. Maddy (1984) ranks malathion in category 3 (negligible oncogenic potential, controversy as to any such potential, or not oncogenic).

Salmonids exposed to 120 to 300 ugtl (ppb) malathion showed AChE inhibition of 70 to 80%, and activity indices were reduced by 50 to 70% of that of unexposed fish. Goldfish exposed to sublethal levels of malathion showed a significantly reduced frequency of avoidance response at levels below that causing a reduced AChE activity. One-hour bath exposures of rainbow trout to sublethal levels of malathion caused severe tissue damage to the gills and minor nonspecific liver lesions. Ponds given four semi-monthly treatments during May-July at levels up to 0.02 mg/1 (20 ppb) produced no discernible effects on resident bluegill and channel catfish populations. Aquatic insect populations were significantly depressed at the high treatment level but not at the lower levels (Johnson & Finley 1980).

Irrespective of the exposure time and exposure concentration, the AChE activity of dying pinfish was reduced by 72 to 79%. Enzyme inhibition was higher in lethal exposures than in sublethal exposures. The observed correlation between brain AChE activity and deaths was considered to be of diagnostic value. After 3.5, 24, 48, or 72-hr exposure to 575, 142, 92, and 58 ppb of malathion, 40 to 60% of the pinfish died and the extent of inhibition of AChE was in the range of 72 to 79%. Following the exposure of brook trout and rainbow trout to malathion, the AchE levels were approximately 24 and 28% of those of the controls, and the fish had less than one third the ability of the controls to do work. Thus malathion, though not directly and immediately toxic, had a deleterious effect, owing to the impairment of the ability of the fish to maintain equilibrium, to search for food, and to avoid predators (Murty 1986). In their examination of population and ChE responses in Walleye exposed to malathion aerial sprays, Lockhart et al. (1985) found that cholinesterase activity fell to about 25% of prespray values within 12 hr after the first spray, and then gradually recovered to about 80% of prespray values over 2 weeks. The same pattern was evident after the second spray, but the inhibition of ChE activity was not quite as large. Fish captured for analysis showed no indication of the symptoms of OP poisoning. The population statistics indicated small temporary decreases in both catch per unit effort and weight gains after the first spray. Evidently a reduction in ChE activity to about 25% of preexposure levels was the approximate threshold for population effects caused by malathion.

The acute oral toxicity (LD_{50}) of malathion to various species of birds range from not toxic at 100 ppm (European starling, red-winged black bird) to 1485 ppm for mallard duck. Dietary LC_{50} values range from 2639 ppm (ringnecked pheasant) to greater than 5,000 ppm for mallard duck. Acute dermal LD_{50} values are not available (Smith 1987).

Malathion applied at 0.6 to 1.1 kg/ha (0.5 to 1.0 lb/acre) resulted in no observed mortality of wild birds in one study conducted, and bird counts after spraying were either higher or nearly the same as before spraying (Black & Zorb 1967). At applied rates of 852-1140g malathion/ha (12-16 oz/acre) to fields containing caged quail, no evidence of mortality or population changes of wild birds were observed (Smith 1987). After malathion was aerially applied to a forested watershed at the rate of 0.81 kg/ha, birds reacted to the spraying for 2 days without lasting effects and no effects on reptiles and amphibians were observed. However, populations of mice and chipmunks were reportedly reduced by at least 30% (Giles 1970). Tadpoles exposed to 5 mg/1 (5 ppm) malathion through a continuous-flow apparatus did not bioaccumulate levels that were toxic when fed to 2-week-old mallard ducklings in a single meal (Hall & Kolbe 1980). The predicted bioconcentration factor (BCF) for malathion is low.

Thus, malathion has moderate to slight acute oral toxicity to birds and there are no published reports of wildlife die-offs that can be attributed to the use of malathion. Its persistence and toxicity to birds is relatively low. However, malathion's toxicity has been reported to be potentiated by EPN treatment (Murphy 1969), and the interaction of these and other pesticides is not fully understood (Smith 1987).

B. Biological Control.

1. Introduction

Biological control includes attacks on the pest species by other species and manipulation of the pest species itself. The former includes the traditional biological control agents, predators, pathogens and parasites, whereas the later includes such techniques as sterile-male release and genetic manipulations.

Biological control agents are grouped into three categories: predators, parasites and pathogens. Predators include both vertebrates and invertebrates and may attack both adult and immature stages of mosquitoes. Helminth, protozoan and fungal parasites and microbial pathogens generally only invade immature stages, though mortality may not occur until the early adult stage. Parasitic water mites are an exception in that they attach to certain adults as they emerge from the pupal stage and apparently reduce adult survivorship if they are abundant (Lanciani & Boyett 1980) In general, biological control is much more feasible in managing permanent water mosquitoes than temporary water forms.

There are three basic strategies for utilizing all biological control agents: (1) increasing existing natural enemy populations by habitat alteration, (2) one-time introduction of sustainable exotic agents from other regions or habitats, and (3) augmentation of natural or exotic enemy populations by repeatedly releasing non-sustainable, lab-reared (or field collected) organisms. To date only the first, increasing fish habitat through OMWM, has been used in Massachusetts. Bti is sometimes classified as a biological control agent but its application technique and mode of action as a stomach poison more closely resemble a pesticide than a biological control agent *per se*. *Bacillus sphaericus* may more closely fit the model of repeatedly releasing non-sustainable lab-reared organisms as there is evidence to suggest that it recycles within the environment.

No other biological control agent is currently available for general field use, though experiments continue with may different organisms (see below). There are important reasons why biocontrol is not more widely used against mosquitoes. First, the differences in biology of the various species of mosquitoes make it unlikely that any one control agent will operate across a wide range of species. Second, mosquito breeding is wide spread, making it difficult for a biological control agent to find, or be placed in, all breeding areas. Third, predators such as bats and purple martins, may eat mosquitoes but prefer to eat other, larger insects. Further, even when abundant, they do not drive mosquito populations below levels that people generally find intolerable. Finally, there is a high cost associated with sustained releases of a biological control agent and there are not, at this time, control agents available that require a single, or a few, releases to become established.

Because of the limited application of biological control to mosquitoes in Massachusetts, the following discussion will focus primarily on the feasibility of control agents currently being studied for mosquito control. An important point to make regarding biological control is that the mosquito control have limited research capabilities. While conducting field evaluations of new control techniques is a desirable practice for any mosquito control program, the projects should not be expected to find and bring forward biological control agents without substantial help from research institutions such as the state university.

2. Predators

a. Introduction

In order for any predator to independently be an effective control agent, it must meet two important criteria: (1) its size and abundance in relation to the target species must be sufficient for it to kill or consume a high percentage of the prey population within a relatively short time period, and (2) its feeding behavior should be selective toward the prey species when it is present but allow it to utilize other food items when the target species is absent. These criteria are rarely met in full. Predators that are sufficiently large and/or abundant to have a major impact, usually lack feeding specificity. Conversely, those with feeding specificity are usually less abundant because their populations are regulated by a more restricted food supply. Vertebrate predators of insects have a clear size advantage but invertebrate predators tend to exist in much greater numbers.

Because of the limitations of predators as biocontrol agents, it is normally essential to continuously raise and release the predator to achieve field densities high enough to cause real reductions in the prey species. However, in some cases, manipulation of the environment to the advantage of natural predator populations can provide an adequate augmentation effect.

b. Vertebrate predators

<u>Fish</u>

Larvivorous fish are the oldest and perhaps most effective traditional biological control agent used against mosquitoes. In certain habitats they may, by themselves, provide adequate larval control throughout the breeding season. If not, pesticides such as BTI or methoprene which are non-toxic to vertebrates can be used in an integrated fashion with fish.

As already mentioned, the main reason open saltmarsh management strategies effectively control many saltmarsh *Aedes* in the Northeast is because this method provides access for the abundant estuarine populations of larvivorous killifish (*Fundulus* spp.) into the mosquito breeding pools in the high saltmarsh (Hruby & Montgomery 1986).

The mosquitofish *Gambusia affinis* is distributed widely throughout the warmer parts of the world and is the species most often reared and introduced into fresh water habitats for mosquito control. The biology and use of this fish in mosquito control was reviewed by Meisch (1985). It is an opportunistic feeder and avidly eats pupae and late-instar larvae of culicines and chironomids. It is most effective against *Culex* in unvegetated, permanent ponds but has been widely used in California and the Gulf States against ricefield *Aedes* and *Psorophora*.

Because *Gambusia* is so aggressive and fecund, it may replace important commercial or rare native fish species. This has raised environmental concern over the introduction of this fish into natural waters where it does not already occur. A recent article by Rupp (1996) has renewed this debate, both emphasizing real successes and real concerns over *Gambusia* use (see "Comments on 'adverse Assessments of *Gambusia affinis*'" (JAMCA 1996) and Boklund 1997, Eliason 1997, and Rupp 1997). Because it is not a native species of Massachusetts it may not be imported and released in state waters.

Outside of the mosquitofish, the common guppy (*Poecilia reticulata*) has received the most attention for mosquito control (Bay 1985). Comparative studies indicate that it is a less effective predator than Gambusia but it is more tolerant of polluted waters. Many other native fish have been explored for their mosquito control potential (Bay 1985). Studies in North Africa (Allo et al. 1985) suggest that malaria may be controlled through the annual introduction of native fish from streams into the manmade water storage tanks which produce the vector *Anopheles* in this region.

<u>Birds</u>

Many birds depend on insects as food and those which capture insects on the wing (e.g., the swallows), have been credited with consumption of significant numbers of mosquitoes. Purple martins specifically have been promoted on the basis of the claim that they often consume 10-12 thousand mosquitoes per day but Kale (1968) concluded on the basis of existing evidence that all claims of martins significantly reducing mosquito populations were unsubstantiated and, because of several biological facts, were unlikely to ever be demonstrated. The facts on which these conclusions were drawn are as follows:

(1) Mosquitoes were a negligible item in the diet of martins in the only two published studies in which the contents of martin gizzards were examined.

(2) None of the published statements appearing in the popular ornithological literature which attributes a mosquito-eating habit to martins is based on factual study or scientific reference. In fact, there is evidence that martins feed more on larger insects including species of dragonflies which may be predators of adult mosquitoes.

(3) Behavior patterns of mosquitoes and martins are such that they tend to not fly at the same height or at the same time. Thus, contact between the two is minimal.

(4) There is no evidence that any avian species can effectively control a pest insect upon which it feeds when the insect is at or near peak abundance.

Other Vertebrates

Mosquito control by insectivorous bats was tried in the early part of this century but without success (Kale 1968, Storer 1926). Bats continue to appear in the popular press as legitimate mosquito-control agents (Wright 1996) but are not considered worthwhile agents in Common-sense Pest Control (Olkowski et al. 1991), which is very thorough in its coverage of non-chemical control options, or in mainstream mosquito control (Mitchell 1992).

c. Invertebrate predators

Predators of mosquito eggs.

Evidence exists of predation on diapausing flood water mosquito eggs by mites and beetles, and on *Culex* egg rafts by fish (Collins & Washino 1985). Nonetheless, egg predation appears to be a relatively minor component of natural mosquito mortality and is not being studied for biological control.

Terrestrial insect and spider predators of mosquito adults

Predation on emerging and indoor resting adult mosquitoes has been readily observed but the impact of this mortality on populations is extremely difficult to assess. Certain spiders (especially Tetragnatha) and predatory flies (mainly Empididae, Anthomyiidae and Dolichopodidae) have been shown by precipitation tests to have consumed emerging mosquitoes (Collins & Washino 1985). In one British study, up to 28% of the spiders tested had eaten mosquitoes (Service 1973). Certain adult dragonflies reportedly capture mosquitoes on the wing but these observations have not been backed up by any controlled field studies. Synanthropic emesine bugs (Reduviidae) appears to be potentially important predators of indoor resting mosquitoes in the tropics. In sum, the prospect for enhancing or managing invertebrate predators for more effective adult control is not encouraging, especially in temperate regions.

Aquatic insect predators of mosquito larvae & pupae

Aquatic insect predators seldom occur in significant numbers in the temporary floodwaters that produce most pest mosquitoes. Studies of predation have therefore largely taken place in permanent ponds or semi-permanent habitats such as rice fields, rock pools or vernal woodland pools. The adult stage of most predaceous aquatic beetles and true bugs can fly (usually at night) so natural colonization of newly flooded habitats can occur in a matter of days. Development time for these insects is usually from several weeks to several months.

Among the beetles, the dytiscids (predaceous diving beetle), which are predaceous both as larvae and adults, are the most effective predators of mosquitoes. There is evidence from studies in rice fields that adult dytiscids selectively locate and colonize sites with locally high concentrations of mosquito larvae (Collins & Washino 1985). Mass production methods for dytiscids have never been developed. Whirligig beetles (Gyrinidae) only feed at the surface where they may prey on concentrations of emerging adult mosquitoes. Hydrophilids are only predaceous as larvae and seem to feed mainly on chironomid midges.

Only two aquatic families of true bugs, the back swimmer (Notonectidae) and pigmy back swimmer (Pleidae) have received serious consideration as mosquito control agents. Pleids are generally not abundant enough to have significant impact but notonectids can become quite dense in certain habitats. Mass rearing of the latter appears to be possible. Water boatmen (Corixidae) are also common and similar in appearance to backswimmers but they are mostly detritus feeders. Other predaceous aquatic Hemiptera that have been suggested as mosquito predators but which normally occur in insufficient densities to have much value as natural control agents include the giant water bugs (Belostomatidae), water scorpions (Nepidae), water measuring bugs (Hydrometridae) and the two family of surface-feeding, water striders (Gerridae and Veliidae).

Dragonfly naiads have been marketed commercially for mosquito control and at least one town in Massachusetts, and others in New Hampshire and Maine, have purchased dragonflies for mosquito control. In northern climates these insects require 1-5 years to mature, so they normally occur in permanent waters only. Furthermore, many are bottom feeders that seldom if ever come in contact with mosquito species that feed at the surface or in the water column. Most bottom-feeding mosquitoes (i.e. *Aedes*) occur in temporary water containing few if any dragonfly naiads. Another factor weighing against the mosquito control efficiency of these aquatic predators is the fact that they normally occur at low densities. Adults of many species are territorial and this seems to spatially limit population densities of naiads as well as adults. In certain habitats such as rice fields, naiads may become quite abundant but populations fluctuate greatly and their role in limiting populations of rice field mosquitoes is limited at best. No controlled, field studies have been done in which naiads have performed well as biological control agents.

The trichopteran *Limnephilus indivisus* may be an important predator of early spring *Aedes* in woodland swamps in Ontario but most caddisflies are omnivorous shredders rather than predators (Collins & Washino 1985, Merritt & Cummins 1985). Prospects for mass rearing and manipulating caddisfly larvae are not very bright. Many of the aquatic nematoceran relatives of mosquitoes contain groups with predaceous larvae. These include the families Chaoboridae, Chiromomidae, Ceratopogonidae, Tipulidae, Anthomyiidae, and others. Most are too small to consume many mosquito larvae. Predation on small, early instars occurs but it is far less efficient in reducing the numbers of adults than is predation on late instars and pupae. *Mochlonyx* (Chaoborid) predation on spring *Ae. communis* populations has been observed in woodland pools in Massachusetts (Edmans, personal communication) and in Europe (Chodorowski 1968). The impact of this small but voracious predator is unknown.

The insect predator with the most promise in mosquito control is another mosquito. Larvae of the non-biting genus *Toxorhychites* are large and effective predators of mosquitoes that develop in natural and man-made containers such as tires, tree holes, metal cans, and leaf axis (Steffan & Evenhuis 1981). Unfortunately, none of the 70 some species in this mainly tropical genus can survive the winters as far north as Massachusetts. Their use here would therefore require repeated, annual releases of lab-reared females. This is not warranted at the present time since container-breeding species generally do not represent the major nuisance or health threat in Massachusetts. This situation could change if *Ae. albopictus* becomes well established in used tires in the Northeast. Focks (1985) states that although it is possible to control or reduce certain species of container-breeding mosquitoes with inoculative or inundative releases of *Toxorhynchites*, the usefulness of this genus in practical, operational control programs has yet to be demonstrated.

<u>Other invertebrate predators of larvae and pupae.</u>

Among the non-insect predators of the immature stages of mosquitoes, only hydra (Cnidaria: Hydrozoa), flatworms (Platyhelminthes: Turbellaria) and copopods (Cyclopoida) have been studied in any detail.

Both hydra and flatworms can be easily mass produced and, unlike most predaceous insects, they can be maintained at high densities without cannibalism. In the laboratory, they kill far more larvae than they consume. Both groups produce semi-dormant eggs so they occur naturally in shallow temporary pools as well as permanent swamps and ponds. Detrimental effects on young fish have been reported when these predators are at high densities (Mulla & Tsai 1978).

Both of these predators have good potential as control agents in the Northeast but additional long-term field evaluations are needed. As with mosquito fish, the laboratory production, storage, and field translocation of these organisms requires a certain degree of sophistication, which is usually lacking at the local level. Currently, there are no commercial sources for the quantities that would be required for mosquito control applications.

Natural populations of predaceous cyclopoid copepods appear to limit the distribution of container breeding mosquitoes in certain tropical settings (Marten 1984). However, they have never been shown to be important predators in temperate regions or in other types of aquatic habitats. Therefore their potential for the biological control of pest and vector mosquitoes in Massachusetts appears to be nil.

3. Parasites and Pathogens

a. mermithid nematode parasites

Outside of bacteria, parasitic nematodes are the only natural parasites and pathogens that have ever achieved operational status in mosquito control. Known parasitic roundworms of mosquitoes now number over 20 species. The free-living, aquatic, preparasitic stage which hatches from the nematode egg, seeks out and penetrates the cuticle of host mosquito larvae. Larvae are usually killed in the last instar. In a few species, the mature worms are carried over in the adult mosquito and cause mortality when they exit during attempted pseudo-oviposition.

Romanomermis culicivorax (including most references to *Reesimermis nfelseni*) is the species that has been most extensively studied. Methodologies for the mass production and commercial preparation of this species have been developed and it was briefly marketed as Skeeter Doom in the late 1970'g. Low sales and problems with the shipping and shelf-life of viable eggs appear to have been the major factors which led to the marketing failure of this agent (Service 1983). Other economic drawbacks include host specificity which limits its effectiveness to only certain species (e.g., it is ineffective in cold, polluted or brackish water), and the lack of patent protection for companies investing in the production and marketing of this product. In addition, applicators need some special skill and training to effectively use this biocontrol agent. The tendency of this agent to naturally recycle once it is introduced into favorable aquatic habitats is beneficial from a control viewpoint, but it further reduces the long-term marketability and profit potential for private producers. It remains under study, however, as a recent article (Mijares et al. 1997) discussed the establishment of *R. culicivorax* in sewage settling ponds and natural ponds in Cuba.

On the biological plus side, mermithids appear to be highly compatible with a wide range of chemical pesticides and growth regulators. Moreover, they: 1) are non-specific and well suited to the life cycle of their mosquito host, 2) produce high levels of infection and mortality, 3) can be easily mass-produced and applied with standard spray equipment, and 4) offer no threat to non-target organisms or the environment.

There are species of mermithids which appear to be highly specific to spring snow-pool *Aedes* and to saltmarsh *Ae. sollicitans* (Petersen 1985). However, these worms have not been established and studied in the laboratory. Such species may have greater control potential in northern coastal states like Massachusetts than the more tropically adapted *R. culicivorax.*

Since the technology for using mermithids in mosquito control already exists, and there are numerous field trials documenting their control potential, the future availability and use of these biocontrol agents in operational programs seems to depend on changing economic and market forces (Petersen 1985).

b. Microsporidia

Virtually all mosquito species carefully examined have been found to harbor these parasites. Larvae are infected by ingesting the spore stage. Spores, which are produced at the end of the life cycle, have often proven difficult to induce and to reinfect larvae in lab cultures.   Few microsporidian life cycles are well enough known to assess biocontrol potential. Life cycles vary from simple to complex and often form the basis for the non-taxonomic grouping of these protozoan parasites. The simplest forms (Type I) occur mainly in terrestrial insects and even the one aquatic species known from mosquitoes (*Nosema algerae*), does not cause mortality until, the adult stage. For this reason *N. algerae* has limited potential for reducing pest problems but may impact on disease transmission by reducing survival and fecundity. Wild strains only persist in larval populations for short periods and cause little direct mortality. Type II microsporidia have simple, asexual life cycles similar to Type I forms and they also show little promise in mosquito control (Hazard 1985). Type III forms are dimorphic, have binucleate spores, and kill mosquitoes in the larval stage. Only one species (*Hazardia milleeri*) is known from mosquitoes and it seems to have low infectivity (Hazard 1985). Type IV microsporidia include many species from mosquitoes and have the most control potential. Infected larvae are usually killed but a few females survive and carry the infection via the ovary to the next generation. However, transovarial infection ceases after a single generation. Non-ovarian modes of transmission must exist but this issue along with the possibility of sexual reproduction and alternate hosts are as yet unresolved. Additional basic research is required before any microsporidian can be considered in the biocontrol of mosquitoes (Hazard 1985).

Tetrahymena and *Lambornella* (tetrahymenid ciliates)

The lack of a resistant resting stage and difficulty in culturing these ciliated protozoa has prevented the thorough study and evaluation of this group of potential biocontrol agents. Ongoing studies of *Lambornella clarki* in California treehole *Ae. sierrensis* should help to better assess the control value of these parasites in the near future (Anderson et al. 1986).

Helicosporidium

There is still debate concerning the proper classification of this spore-forming group of parasites; some believe they are primitive Ascomycetes fungi. There are only 3 reports of natural infections in mosquitoes. They appear to infect a wide range of species but also may infect non-target insects as well. High dosages of spores are required to infect older instars in the lab. Continuous cultures of these parasites do not exist so the basic research needed to evaluate their biocontrol potential is not forthcoming.

c. Fungal Pathogens

Coelomomyces

Many forms of pathogenic fungi have been known from both larval and adult stages of mosquitoes since the 1930's. However, it was not until the discovery of the obligate alternate host (i.e., microcrustacea) in the mid-70's that cultures and full-scale laboratory investigations were possible with *Coelomomyces* (Whisler et al. 1974, 1975). The rather complex life cycles of some species have recently been described and methods for in vivo culturing established. Before wide-scale field application can occur, mass in vitro cultivation of the infective biflagellate zygote stage needs to be developed. If *Coelomomyces*, and perhaps their copepod and ostracod intermediate hosts, are introduced into favorable habitats, the potential for natural recycling exists. However, too little is known about the host ranges and habitat requirement of most *Coelomomyces* to recommend any such introduction at the present time. Moreover, species of *Coelomomyces* do not routinely provide high and predictable levels of mosquito control. It is, premature to critically assess their potential as control agents to be used independently or as part of an integrated control program (Federici et al. 1985). Studies related to their evaluation as operational control agents have only recently been initiated and it is not likely that any *Coelomomyces* will be operational within the near future.

Lagenidium giganteum.

This mosquito-specific water mold is a very promising biological control agent, especially in fresh water and in warmer climates. This fungal pathogen can be mass produced on artificial media and can recycle in as little as 3 hours (McCray 1985). It has a resistant, dormant stage and infects a wide range of mosquito species. Unfortunately, it is not effective in polluted, brackish or colt waters. This limits its commercial value and it potential usefulness in northern and coastal states like Massachusetts (Service 1983).

Other Fungi

Fungi are among the commonest pathogens of insects and many other genera besides *Coelomomyces* and *Lagenidium* have been reported from mosquitoes. Of these, *Culicinomyces* and *Metarhizium* have received the most attention. Both groups infect a wide range of mosquito species but relatively high concentrations are required to cause infection. They can tolerate organic pollution and salinity but not high temperatures (i.e. above 30°C). These fungi can be grown on inexpensive artificial media but no resistant resting stage has been fount. Difficulty in achieving long term storage of infective stages and formulation problems remain as barriers to commercial production. Nonetheless, these fungi are a promising group of biocontrol agents which may provide new mosquito control tools in the future.

Erynia aquatica

Erynia aquatica is an Entomophthorales fungus, and is the only species of the genus known to infect the immature aquatic stages of mosquitoes. It was first discovered infecting *Ae. canadensis* and *Cs. moristans* larvae in woodland pools in Hartford County, Connecticut from late May to early June (Anderson & Ringo 1969). It has since been recovered in early May from *Ae. stimulans* in woodland pools near the village of Cambridge, New York (Molloy & Wraight 1982) and from *Ae. cantator* on May 21, 1981 in a shallow salt meadow pool in Milford, Connecticut (Andreadis & Magnarelli 1983). Most recently, is was discovered in 1995 and 1996 in a woodland pool in Bristol, Rhode Island (Christie 1997).

Steinkraus and Kramer (1989) collected *Ae. fitchii* larvae infected with *E. aquatica* from a semi-permanent woodland pool in Tompkins County, New York. They used infected pupae to successfully transmit the disease to emerging adult *Ae. aegypti,* on which resting spores of the fungus developed.

Erynia aquatica has characteristics which make it attractive as a microbial agent: it is capable of causing epizootics, has been found in both freshwater and brackish water mosquitoes and has a resting spore stage that may survive well in storage. Operating against it is the fact that it has only been found in cooler, springtime waters. One thought is that infected pupae may be removed from the original infestation site and placed in other, nearby pools. A fungus that kills in the pupal stage works against its own spread.

d. Bacterial pathogens

Bacillus thuringiensis var. *israelensis*

Bti Serotype H-14 has become an important biological larvicide following its discovery in the Negev desert in 1976. Within the last 5 years it has become widely used by the mosquito control projects in Massachusetts. It is now the larvicide of choice in many situations because of its host specificity, high and rapid mortality to many mosquitoes species, and its environmental safety. It is quite distinct from the Bt strains which infect lepidopterous insects. Its track record in controlling polluted-water *Culex* is mixed, apparently because it sinks to the bottom and the active moiety rapidly binds to organic particulates. Consequently, higher dosages are required to achieve good control in highly organic and deep-water situation. Saltmarsh mosquitoes generally require rates at the high end of the labeled application rates for effect control. Liquid, powder, granular and slow-release briquet formulations are commercially available.

Bti must be ingested to cause toxicity to filter-feeding mosquito larvae; pathology occurs in cells of the midgut wall. It is least toxic to 4th instars since they cease feeding at least 12 hours prior to pupation. The mosquito toxic ingredient of Bti preparations is the heat labile deltaentotoxin located in the proteinaceous parasporal crystalline inclusions synthesized concomitantly with the spore during sporogenesis. Once released in the environment, it biodegrades rapidly (it is usually only active 1-3 days) and this bacterium (gram negative Bacillaceae) does not recycle. This is considered the only major drawback of this highly effective mosquito pathogen but it has enhanced its commercialization (Lacey & Undeen 1986).

The biocidal activity of Bti toxin appears to be limited to larvae of certain families of nematocerous Diptera. A large number of laboratory and field tests have confirmed that all non-nematocerous, non-target organisms are virtually unaffected (Lacy 1985). All existing data indicate that the unaltered protoxin of Bti is also safe to vertebrates including humans (Lacey 1985). Further improvements in the efficacy and price competitiveness of this control agent, brought about by formulation changes and genetic engineering, are likely to occur in the near future. In addition, formulation of this agent with other compatible and perhaps synergistic agents such as juvenile hormone analogs (e.g. Altosid) is currently underway. Such mixture have two important advantages. They reduce the likelihood of mosquitoes developing resistance to either agent and, secondly, they widen the window for control since Bti is most effective against early instars and growth regulators against later instars.

Bacillus sphaericus.

Although only recently available, *B. sphaericus* may have greater control potential than Bti because of its ability to continue to recycle once it is introduced. It has many of the same beneficial attributes of Bti but all strains isolated to date are less effective against a wide range of species than is Bti. At the moment it is primarily marketed against *Culex* in high-organic waters but research is on-going in expanding its control potential.

e. Viral Pathogens

The biological control potential of both non-accluted (iridoviruses and densonucleosis viruses) and occludet (baculoviruses, cytoplasmic polyhedrosis viruses and entomopox viruses) viruses pathogenic to mosquitoes has recently been reviewed by Federicci (1985). It is sufficient here to simply paraphrase from the summary of this thorough review as follows:

Analysis of research conducted to date makes it clear that none of the viral pathogens of mosquitoes can currently be considered good candidates for mosquito management programs. The two main reasons for this assessment are that viruses discovered so far possess low infectivity for original or alternate hosts and there is no readily available method for mass production of virions. This apparent lack of control potential is most obvious when one considers that few field trails have been conducted with these agents even though the first one was discovered over 15 years ago. While it appears unlikely that viruses will be developed for mosquito control in the near future, they may prove to be extremely useful microbial agents in the long term, perhaps in 2 or 3 decades, once we learn how to manipulate them effectively. Biotechnology has the greatest potential for engineering new more useful biocontrol organisms among the viruses because of their simple molecular structure.

4. Pest Species Manipulation

A somewhat different approach to biological control is manipulation of the mosquito genome to either 1) induce reproductive failure (leading to population elimination) or 2) bring about permanent changes in the behavior or physiology of the target population so it no longer vectors disease or bites people. There are numerous theoretical mechanisms by which this could be accomplished. Following is a brief discussion of the three approaches that have been most commonly discussed and researched.

a. Sterile Insect Technique

The early and continuing success of the sterile male release program in eliminating the screwworm fly from the U.S. and Mexico has given rise to many investigations and new ideas for controlling other insects (inoculating mosquitoes) through the use of this or some other genetic technique. Except for fruit flies, this method has not yet been successfully applied to other insects in operational programs and the technique is not currently being pursued for mosquito control.

b. Incompatibility

Incompatibility resulting from a lack of fertility in sexual unions may occur due to a variety of genomic failures or due to the effort of bacteria-like symbionts to control the reproduction of host (Barr 1985). The feasibility of suppressing *Culex pipiens* through cytoplasmic incompatibility was demonstrated in a Burmese Village over 20 years ago (Laven 1967) but the practicality of this method has not been confirmed by any other field tests. Moreover, incompatibility factors have been isolated in only a few mosquito species to date.

c. Chromosomal Aberrations

There are several heritable chromosome rearrangements that can, in theory, be used to inject genetic load into a mosquito population and/or to effect a permanent change in the genetic makeup of the population. These aberrations can be used to 1) increase genetic lethal load (serility is limited to 50-80% because of the low chromosome number (three, in most mosquitoes) or 2) replace noxious species with harmless strains if appropriate viable homozygous rearrangements are available. The latter is perhaps only applicable in the case of important disease vectors. Naturally occurring aberrations can be screened for in wild populations but their frequency is greatly increased through exposure to mutagens.

Controlling mosquitoes through the use of chromosomal aberrations requires a major basic research effort and a target species that is easily colonized. This later requirement automatically eliminates many important species from consideration.

d. Competitive Displacement

The final, and somewhat abstract, strategy for controlling mosquitoes biologically is the ecologically based notion of displacing a noxious species by introducing a benign but more competitive (i.e. better adapted) exotic one. This idea has been suggested primarily to control container-breeding species like *Ae. aegypti*. However, benign mosquito species are difficult to find, as most mosquitoes that have become established (*Ae. aegypti, Ae. albopictus*) are as bad or worse than the species with which they compete (container-breeding *Culex* and *Ae. triseriatus*).

5. Other Control Approaches

a. Trap out techniques. All experience to date indicates that while various traps may be good sampling devices for adult mosquitoes, they are too inefficient and limited in their range to provide any benefit in reducing biting annoyances (Nasci et al. 1983). Work is ongoing on attractants (octanol) that would both greatly increase trap collections of mosquitoes and reduce non-targets trapped, but no products are marketed for this purpose to date.

Electrocutor traps (“Bug Zappers”) continue to be a popular item, with an estimated 1.75 million sold in the United States each year (Mitchell 1992) but they are extremely non-specific (mosquitoes generally make up less than 5% of the catch, and may be harmful to other insect species. They cannot be considered a part of any mosquito-control program.

b. Repellents. Personal protection through the use of mosquito repellents is an appropriate alternative to controlling the mosquito populations before they bite. This is especially true if the periods of annoyance are infrequent and brief and where the land areas are too vast and unpopulated to economically consider control programs.

The most commonly used mosquito repellent is DEET (N,N)(diethyl-metatoluamide) which has been formulated and sold under a variety of trade names (e.g., Off, Muskol, Cutters), in a variety of concentrations and as both aerosol sprays (usually ca 15%) and lotions (up to 100%). Laboratory tests have shown that maximum repellent duration (ca. 1-2 hours) is obtained with a concentration of ca. 50% so that higher concentrations do not provide appreciable advantages. The major disadvantage o£ DEET are:

1) relatively short protection time

2) somewhat offensive odor

3) damage to some fabrics and surfaces at higher concentrations

4) high cost

5) possible hazards from heavy use

Small children frequently have skin reactions to DEET. Small children are also most likely to be the individuals that develop meurotixicological symptoms from DEET. Thirteen of 14 cases of encephalopathy (toxicity of the central nervous system), found in publicly available reports by a recent review (Osimitz and Grothaus 1995), were in children 8 years old or younger. Three of these children died, all having used “heavy” amounts of repellent, even though the repellent in each case had DEET concentrations of 20% or less. Oral ingestion may have played a role in some of the cases. Osimitz and Grothaus (1995) concluded that there is no evidence that increased DEET concentration has an effect of the severity of symptoms. They also compared reports that the Poison Control Center received for DEET (6,724 in children under 6 years old during a five-year period) to laundry detergent reports (10,789 in 1989) and household bleach (16,169 in 1989), concluding that accidental exposure, while undesirably high, is in line with, or lower than, exposure to other household chemicals.

There is one unsubstantiated report in the Russian literature of carcinogenic effects in rats at high doses.

Three other repellent materials are in common use. Dimethyl phthalate (generally sold as 6-12) is not as effective as DEET against mosquitoes but still has a share of the market. Citronella-based repellents have long been marketed as candles or in oil-burning lamps. Citronella is also available as a repellent to be sprayed in skin and clothing (Natrapel). The third material (Avon skin-so-soft) is a popular bath oil that is not marketed as a mosquito repellent but has, through word of mouth, been recognized for its as yet uncharacterized mosquito repellent affect. It is as effective as DEET but it does not persist as long. On the other hand, it is much cheaper, smells better, and apparently does not damage any fabrics or surfaces. The active ingredient(s) of skin-so-soft has not been isolated or identified to date. It also has not undergone the EPA safety testing that other repellents have because it is marketed as a beauty aid rather than a pesticide (Note: repellents are classified as pesticides by EPA).

Electronic mosquito repellent devices which are periodically marketed in the U.S. (usually by mail order houses) are completely ineffective and are not based on any biological rationale (Foster & Lutes 1985, Mitchell 1992, Curtis 1994).

C. Physical Control

1. Types of Habitat Modification

a. Open marsh water management (OMWM)

Originally developed for New Jersey salt marshes (Ferrigno 1970, Ferrigno & Jobbins 1968, Ferrigno et al. 1969), this strategy basically attempts to overcome the limitations of ditching by the incorporation of other water management strategies. In particular, champaign pools or reservoirs (which permanently hold water and sustain larvivorous fish) are created (by backhoe, dragline or rotary ditcher) in selected tidal pools or large shallow pans and are connected via small shallow ditches to surrounding mosquito breeding depressions. If old ditches are re-dug and used as reservoirs, then plugs must be inserted at the tidal end to prevent drainage. This customized approach to marsh management represents the least deleterious and most efficient nonpesticidal method for controlling saltmarsh mosquitoes and has been adapted to New England conditions (Boyes and Capotosto 1980, Hruby et al. 1985, Christie 1990). A manual outlining this method was developed by the Massachusetts Audubon Society (Hruby and Montgomery 1986) and OMWM is currently being practiced by coastal projects in Essex and Plymouth Counties in Massachusetts. As of 1996, OMWM had become the accepted technique for new salt-marsh water management work, though maintenance work remains dominated by cleaning existing ditching, as opposed to conversion to OMWM.

b. Other Modification Strategies

Mosquito control efforts in Massachusetts predate modern chemical insecticides. Early control efforts consisted of source reduction work, mostly in salt marshes (see “History of Cape Cod Mosquito Control Project, 1928-1971”). This emphasis was largely abandoned when cheap and seemingly more effective organo-chlorine insecticides became available in the early 1950's. Early control programs capitalized on cheap WPA labor but they failed to achieve the level of control that the public has come to expect of modern control programs. Nonetheless, they serve as a reminder that mosquito control, from its earliest inception, considered and practiced control alternatives to synthetic chemical pesticides.

Except for new OMWM projects in salt marshes, mosquito control source reduction work now consists primarily of maintenance work on existing culverts, storm sewers and ditches. Very little new ditch construction has taken place in recent years. Ditch cleaning, which often involves excavating spoil with a backhoe or plow, is an activity which has drawn great concern when it takes place in estuarine environments. This is because many of the old grid ditches in the saltmarsh served no real purpose for mosquito control but they must be re-cleaned periodically or they themselves become shallow breeding areas for saltmarsh mosquitoes.

c. Origination of Requests for Physical Control.

The exemption from certain regulations enjoyed by mosquito control is a two-edged sword. On the one hand, it enables mosquito control projects to more quickly respond to drainage problems. On the other hand, it makes the heading "Mosquito Control" particularly desirable for drainage projects in which mosquito control is, at best, a marginal goal. This pressure can come from property owners, public officials, or from within control projects themselves. The pressure to conduct drainage work that does not have a mosquito-control component must be resisted.

The best interests of mosquito control programs are served by conservative application of the definition of mosquito control, as over-use of the wetlands exemptions may result in the loss of those exemptions. To this end, mosquito control programs, in conjunction with state and federal wetlands protection agencies, must develop a strong set of guidelines for alterations exempt from Wetlands Protection Act.

2. Ecosystem changes of non-target biota as a result of physical controls.

a. Salt Marsh .

New England coastal wetlands have been heavily impacted by man (Shisler 1990). However, evidence concerning the negative impact of saltmarsh ditch maintenance activity is mixed. The principal concern is with disposal of the spoil on the marsh and the invasion of upland plants that can occur with even slight elevation increases (i.e. 1-2 inches) (Miller and Egler 1950, Buchsbaum 1994). Ditching also permits *Spartina alterniflora* to invade the upper marsh (dominated by *Spartina patens* and *Distichlis spicata*) along the edges of the newly created ditches. There is evidence to support the claim that this increases marsh productivity (Buchsbaum 1994).

In 1979, staff biologists from the New England Division of the U.S. Army Corps of Engineers (DeSista & Newling 1979) carried out preliminary investigation in several Massachusetts salt marshes to explore the issue of spoil deposition and upland plant invasion. In many instances they found little plant invasion despite evidence of previous spoil deposition of 2 inches or more in depth on the marsh. In a few locations with minimal tidal influence, some invasion by species such as common ragweed (*Ambrosia artemisifulia*), march elder (*Iva frutescens*), and seaside goldenrod (*Solidago semprevirens*) had occurred over time. However, they concluded that it was not obviously correlated with the spoil itself but was perhaps caused by some other factor associated with the disturbance to the marsh. They recommended the sort of long-term monitoring studies which have as yet not been carried out in Massachusetts salt marshes.

Clarke et al. (1984) studied the effect of ditching and vegetation changes on the use of the saltmarsh by birds in Rowley, Massachusetts. They concluded that bird use of the marsh was negatively impacted by mosquito control ditching. This is in contrast to the studies of Shisler & Jobbins (1977) in New Jersey marshes where increase productivity was observed in ditched marshes. Daiber (1986) noted that, where ditches drain pannes, birds that need a constant water supply (American bittern, pied-billed grebe and American coot) may decline. Also noted was a case where spoil ridges invade by *Baccharis* and *Iva* caused gulls to seek less brushy areas for nesting. Scheirer (1994) encouraged mosquito control programs to develop water management partnerships with the U. S. Fish and Wildlife Service, especially for OMWM-type marsh restorations designed to improve migrant waterfowl habitat.

In a series of investigative reports by staff biologists from the National Park Service, the environmental impact of ditching and diking of salt marshes in the Herring River basin of Cape Cod National Seashore were investigated (Soukup & Portnoy 1983, Portnoy 1984a, 1984b). These reports held that Cape Cod marsh management practices were responsible for the freshening, stagnation, acidification and high sulfate and aluminum concentration in diked marshes. These authors suggest that the destruction of a thriving eel and herring fishery in Wellfleet was the direct result of these marsh disruptions. However, the main dike across the mouth of the Herring River (from Griffin Island to the Mainland) was constructed in 1909 with the main objective of providing for agricultural use of the basin. These structures are not typical of early mosquito marsh management practices in other coastal regions in Massachusetts. The impact may be largely reversible if dikes are removed and normal tidal flow is allowed to return to these areas. OMWM tailored to the unique characteristics of these small estuaries should be explored as a way to manage the *Ae. sollicitans* populations which are likely to replace the present *Ae. cantator* populations if tidal flow and normal vegetation and salinity are restored in these marshes.

Perhaps the most damaging assessment of ditching in salt marshes was the report of Bourn and Cottam (1950) in which they blamed open ditching for converting up to 90% of the *Spartina alterniflora* marsh along the Mispillion River in Delaware to *Baccharis*. However, Provost (1977) reported that the area had returned to *Sp. alterniflora* after navigational dredging of the river had ceased and concluded that it was the dredging of the main channel, not the marsh ditching, which had permitted *Baccharis* to invade the marsh (see Daiber 1986 and

Buchsbaum 1994 for reviews of this debate). Arguing against significant water-table lowering in salt marshes is the strong affinity for water exhibited by salt marsh soils. Because permeability is so low, the water table may be lowered only within a meter or so of the ditch itself (Balling and Resh 1982).

Grid ditching, even if not the marsh destroyer some claim it to be, still reduces standing water on the marsh and creates an unnatural and aesthetically unpleasing view. Open marsh water management was designed to more closely approximate the diversity of the natural marsh while eliminating the shallow pannes in which mosquitoes breed.

Wolfe (1996) reviewed the effects of OMWM on numerous tidal marsh resources. OMWM systems tended to enhance tidal exchange and salinity in marshes that were converted from grid ditching. Except where spoil piles were left (improperly) on the marsh, vegetation change was slight and favored salt-marsh species such as *Spartina patens* and *Distichlis spicata*. Small changes in elevation due to spoil deposition sometimes result in invasion by *Iva, Baccharis,* and *Phragmites*. Salt-marsh snails (*Melampus bidentatus*) have declined in some OMWM sites but not in others. Similar mixed observations have been made for marsh periwinkle (*Littorina irrorata)* and fiddler crabs (*Uca* species). Marsh fish populations are, by design, enhanced by OMWM. However, changes in species composition may occur where existing pools are deepened. Mummichogs (*Fundulus heteroclitus*)and spotfin killifish (*Fundulus luciae*) should decrease while sheepshead minnows (*Cyprinodon variegatus*), inland silversides (*Menidia menidia*) and rainwater killifish (*Lucania parva*) should increase (Talbot et al. 1986). The small reservoirs are not particularly attractive to birds and the minor changes in hydrology, flora and invertebrate fauna caused by OMWM do not cause significant changes in bird use on OMWM sites. Effects on mammals are not well documented. OMWM has had no long-term detrimental effects on water quality. As a result, Wolf concludes that, “Open Marsh Water Management is an environmentally focused management tool that is designed to be compatible with nature rather than compete with it.” Of course, the technique is new enough that long-term monitoring is required to ensure that altered sites remain functional salt marshes.

b. Freshwater Wetlands (exclusive of Vernal Pools). Palustrine wetlands, including emergent, scrub-shrub and forested wetlands, are the dominant system in which Massachusetts freshwater physical control take place. In the vast majority of cases, this work consists of maintaining existing ditching designed to remove standing water from the wetland, thereby reducing mosquito-breeding habitat. For most MCPs, this type of work (source reduction) makes up a large percentage of their control effort. Though reducing standing water certainly reduces mosquito breeding, there has been little research concerning the overall effects of these alterations on the modified wetland. Ditch systems can become problems in their own right, producing mosquitoes if left unmaintained. Most of these systems were never designed specifically for mosquito control and their other, primary function, such as removing runoff from large parking lots, may cause considerable damage to the ecosystem, leaving the MCP to clean up, or at least deal with, someone else’s mess.

The majority of drainage systems currently maintained by MCPs were not initially constructed by MCPs and the effort of MCPs today is almost entirely restricted to removing blockages to existing flows, rather than enlarging or straightening channels to increase flow. Most freshwater drainage is an inherited problem which requires intervention not because of mosquito-control activities but because of the activities of others. Road sand and yard waster represent two of the most common obstructions MCPs are called upon to remove from existing streams and drainage networks. New developments also can cause dramatic changes in the sediment load in streams, despite regulations designed to prevent such problems. Road sand, yard waste and increased sediment load from development can all have impacts on a stream that are as greater or greater than regular ditch maintenance.

Because MCPs are often involved in removing manmade sediments from streams, a system under appropriate ditch maintenance may function more closely to a natural system than one in which manmade wastes are allowed to accumulate unabated. The appropriate response by the MCP in such cases is not obvious because, although the problem, and its cause, may not be mosquito related, the mosquito control program may be the organization best equipped, both from and equipment and a training perspective, to rectify the situation.

Since mosquito control projects came into being in Massachusetts, the perceived values of wetlands have changed. Once shunned as disease-bearing waste lands, best suited for dumping, draining or filling, wetlands are now viewed in a much more positive way. They are important wildlife habitats, perform a myriad of water quality maintenance functions, and serve as flood control, erosion, ground-water recharge and water supply regulators (Tiner 1989). Mosquito control programs have been slow in adapting to the increased value accorded wetlands. On the one hand, long-residual and/or broad-spectrum pesticides are no longer used in wetlands in Massachusetts. On the other hand, there is real resistance to halting maintenance work in drainage networks that may be seriously damaging wetland habitat.

There has not been a great deal of work done specifically on the effects of physical control for mosquitoes on non-target organisms. Therefore the following discussion is based on the general effects that can be expected when wetland alterations are made. Care should be taken in extending these general concerns to mosquito control in Massachusetts. For example, channelization (straightening) of natural streams is not permitted in Masachusetts, where programs are required to follow the natural meanders of the stream. The three broad categories of wetlands alteration are outright loss, changes in the abiotic system and changes in the biotic community. Filling and/or draining wetlands to convert them to upland is a mosquito-control practice that has been all but eliminated in Massachusetts. There is no indication that MCPs are intentionally reducing wetland acreage in order to control mosquitoes. However, the fact that the wetlands boundary remains essentially unmoved by a mosquito-control alteration does not mean that profound alterations have not occurred.

Changes in the abiotic system and biotic community are deeply intertwined, though physical control most often causes abiotic changes which then cause biotic changes. For channels changes in flow rates, microhabitats, sediment load, sedimentation, and groundwater interactions can all occur. For wetlands (outside of channels) changes can include lost water-storage capacity, increased sedimentation and pollutant load, changes in water depth, and changes in groundwater hydrology.

When a stream is altered to improve water flow for the purpose of removing standing water, either within the stream or from adjacent wetlands, a number of changes may take place. By definition, improving water flow increases runoff. This, in turn, may decrease the surface-water storage capacity of the wetland system and decrease the capability of the wetland to retain load (suspended solids). This may increase the load of the water moving through the stream (Brown 1988). Increasing runoff into a given stream tends also to increase erosion, which further increases load (Williams & Feltmantle 1992). Not only is total flow increased, but alteration tends to increase peak flow, which is associated with reductions in faunal diversity (Hynes 1972).

The effects of increased flow and loading are many. At its most obvious, higher peak flows increase scouring of the stream bed by gravel and sand being transported by the water. Bottom dwelling animals are either affected on-site or swept downstream, leaving an impoverished community as flows return to normal (Hynes 1972). Increased flows can also remove organic matter, leaving a sandy bottom on which macrofauna is reduced (Ward 1992). As stated earlier, higher peak flows also encourage erosion, a process that can increase stream load long after sediment controls put in place during the actual drainage work are removed.

High levels of suspended solids alter the stream habitat by:

1. reducing light penetration

2. reducing primary production
3. altering the trophic structure
4. altering nutrient dynamics
5. changing thermal conditions
6. reducing oxygen levels (Ward 1992).

These effects can, in turn can have the following impacts on the stream fauna:

1. abrating respiratory epithelia
2. clogging respiratory structures
3. reducing feeding rates
4. reducing feeding efficiency
5. increasing exposure to toxins
6. reducing vision
7. inducing organisms to drift.

All of these effects can alter behavior patterns, change predator/prey interactions and change the outcome of inter and intra-specific competition (Ward 1992).

Maintenance for the purpose of reducing mosquito breeding also includes removing obstructions within streams. Tree branches and fallen trees are a particularly important part of the stream environment, providing food, living space, concealment from predators, protection from abiotic conditions and emergence sites (Ward 1992). They also provide varied microhabitats by deepening and slowing flow on the upstream side and often creating deeper pools on the downstream side. Removing these obstructions diminishes the variability of the stream ecosystem.

At the other end of the flow-rate spectrum, increasing peak flow may lead to faster drying in intermittent streams. The insect fauna (and biotic community in general) of intermittent streams does not overlap to a great extent with that of permanent streams (Ward 1992). As a general rule, this is because intermittent stream dwellers have evolved to deal with the drying down stream. Survival mechanisms include leaving the stream (swimming down stream or emerging as land-living forms), surviving in crayfish burrows or remaining pools of water, burying either at shallow depths or quite deeply into the substrate or hiding under rocks or leaflitter within or along the stream course (Ward 1992). Streams the dry more quickly, and stay drier longer, may disrupt all of these techniques as insects that emerge as adults may not have enough time to complete development (the primary example being mosquitoes themselves), remaining pools may decrease in size and number and shallow burrows and hiding sites under rocks and leaf litter may become too dry to support the fauna hiding there.

The effect of rapid drying brings up the aspect of the hyporheic zone. This is the interstitial space between the substrate particles in a stream bed. Within the hyporheic zone the macrofauna can find shelter from floods, drought and extreme temperatures, can find suitable and predictable conditions for immotile stages such as eggs, pupae and diapausing nymphs and larvae and, particularly for early instars, protection from predation. Gravel beds provide the best hyporheic zones and animals can often be found many feet down (Ward 1992). This hyporheic zone fauna can be an important source of recolonizing organisms after a stream bed is denuded (Williams & Feltmantle 1992). Excessive drying can reduce the viability of the hyporheic zone.

Sedimentation, both within stream beds and in wetlands into which streams flow, is a problem because it can alter the stream bed composition, thereby altering the fauna, and can clog interstitial spaces, thereby reducing the hyporheic zone and/or reducing groundwater recharge. Sediments can also increase exposure to pollutants as they provide additional sites for pollutant binding while suspended, and then carry the pollutants to the benthic fauna.

MCPs routinely conduct maintenance to remove sediments. Therefore, there is good reason to expect the overall effect of maintenance may be to reduce the negative impacts of sedimentation within the stream. In such cases, it would be preferential to develop systems designed to prevent the deposition of road sand into drainage systems, rather than to prevent the removal of that sand, once it has entered the system. Removing the dense, rotting masses of grass clippings that are dumped into streams by property owners should also improve overall stream quality.

Up to this point the discussion has focused on the stream itself, but freshwater wetland alterations are typically designed to change standing-water wetlands to soil-saturated wetlands (New Jersey DEP 1997). The obvious problem is that any organism that requires standing water for periods other than peak flooding, the wetland may become unusable. Mosquitoes fit this definition perfectly, but so do many other organisms. Many species of amphibians use temporary standing water for breeding and are becoming scarce as these habitats are eliminated.

Increased drainage also may have an effect on groundwater. Precipitation and inflow determine the amount of water initially available to a wetland for ground water recharge (Todd 1972). Increasing the amount of water removed from the wetland prior to percolation downwards can decrease the capacity of the wetland to recharge groundwater supplies. Not only can groundwater recharge within the wetland lowered, it can be lowered with the outflowing stream as well. During peak flows, water moves from the stream into the substrate and raises the water table (increases groundwater). As the flow declines, groundwater percolates back into the stream (if it does not, the stream dries out). By eliminating upstream reservoirs (wetlands), more water flows out of the system initially, leaving less water within the system. As water levels fall, groundwater discharge occurs sooner than might otherwise be the case. If nothing else, stream depth is liable to vary more widely after adjacent wetlands are reduced to soil saturation.

What is most needed is a comprehensive understanding of the true ecological costs of physical alterations for mosquito control. This is particularly important because, although the environmental effects of pesticides receive the lion's share of concern, it is possible that the long-term effects of physical controls may have a greater effect on the environment than does pesticide use (Buchsbaum 1994). This may be especially true today with the switch from broad-spectrum, more-persistent pesticides to methoprene and Bti.

New Jersey has recently updated it's Best Management Practices for Mosquito Control and Freshwater Wetlands Management and Massachusetts should look to such guidelines to establish a protocol for physical control in freshwater wetlands. At a minimum the common-sense requirements that all alterations be planned (not random), necessary, and desirable should be rigorously applied to all MCP water management projects regardless of whether they are defined as new or maintenance work. The North East Massachusetts MCP Standards for Ditch Maintenance (Appendix F) can be viewed as a starting point for a statewide protocol, though it fails to mention the need for sediment controls during maintenance work and leaves the MCP superintendent with wide latitude for determining the necessity of a given project. A response from the Massachusetts Audubon Society (also Appendix F) to these Standards provides additional comments which deserve consideration when a protocol is established.

c. Vernal Pools. Vernal pools form in contained depressions in which water stands for a period of several months, generally from mid- to late winter through the spring. Water either comes in the form of snow melt or spring precipitation or can be a result of a rising water table. Some pools dry down within two or three months, others may only dry when the water table is lower than normal, resulting in a pool that is semi-permanent. Regardless, a key feature of vernal pools is that they undergo periods of dry down. Vernal pools may have permanent inlets but do not have permanent outlets (Kenney 1995).

There are numerous obligate species for vernal pools, the most visible of which include fairy shrimp, the wood frog (*Rana sylvatica*) and several species of salamander (*Ambystoma* spp.).

The Massachusetts Division of Fisheries and Wildlife (Publication #15498-10-600-6-1-88C.R) has created guidelines for certifying vernal pool habitat on the grounds that many vernal pool species cannot successfully survive without vernal pools and that vernal pools are under pressure from continued development within the state. The certification program is coordinated by the Natural Heritage and Endangered Species Program (NHESP - see next section). "Automatic" protection is given to vernal pools only if they

1. occur either (a) within the 100 year inland flood plain or (b) on "isolated land subject to flooding" (as defined in the regulations at 310 CMR 10.57 (2)(b)); and

2. its existence and location has been certified by the Massachusetts Division of Fisheries and Wildlife.

Curiously, upland vernal pools are not granted the same protection but may be certified as vernal pools. The NHESP does not seek out pools to certify; it certifies submissions from the public. A guidebook for vernal pool certification (Wicked Big Puddles) is available to help those who wish to submit a vernal pool site for certification (Kenney 1995).

Mosquitoes, particularly *Ae. canadensis*, also use vernal pools for breeding. From a control perspective, vernal pools are important because, due to increasing protection, vernal pool habitat is often left undeveloped while the land adjacent to the pool is built up. As a result, many new developments surround known breeding sites. Regardless of the wisdom of developing so close to vernal pools, mosquito-control personnel are charged with controlling the mosquitoes coming from the pool.

d. Rare and Endangered Species. Hynes (1972) states three axioms of running water biotic communities:

1. The greater the diversity of the abiotic system, the greater the number of species within the system.

2. The more conditions deviate from the normal, the fewer species will be present, but those remaining will be present in greater numbers.

3. The longer a system is left undisturbed, the richer and more stable is the biotic community.

Operating under the assumption that it is rare and endangered species which are most likely to be lost from the system first, the above statements would suggest that reductions in habitat diversity, alterations from the natural state, and frequent disturbances will all work against these species. Channelization of streams reduces diversity by removing obstructions, straightening the channel and increasing flood levels. Wetlands changed from standing-water to saturated-soil regimes have been drastically changed from their natural state. Maintenance is ongoing, as is the disturbance it causes.

The key question is, however, to what extent does mosquito control contribute to the above problems. First, Massachusetts MCPs do not channelize streams, as their certification manual calls for following the existing meanders. Second, MCPs work neither in historically undisturbed, nor currently undisturbed streams. There is every reason to argue that there is no specific "natural" state that can be assigned a ditch dug by man and intermittently filled with road sand and grass clippings. Even with natural streams, the "natural" habitat in which they flow has long been altered and continues to be altered.

The Natural Heritage and Endangered Species Program (NHESP) was created in order to conserve and protect those plants and animals not hunted, fished, trapped or commercially harvested in the state. The program's highest priority is to inventory rare and endangered species and to develop conservation plans through research, management and habitat protection for those species. One such program that directly impacts mosquito control is the vernal pool certification program mentioned above.

The NHESP also reviews proposed alterations to wetlands habitats under the Wetlands Protection Act (M.G.L. c. 131, s. 40 and regulations 310 CMR 10.00). NHESP has produced a series of estimated habitat maps for rare and endangered species (Massachusetts Natural Heritage Atlas) which proponents of a given alteration are required to check. Should a project fall within an estimated habitat, NHESP will then determine if the area to be altered is actual wetland habitat for a state-listed species. The results of the NHESP determination are given to the inquiring MCP.

The Massachusetts Endangered Species Act (M.G.L. c. 131A and regulations 321 CMR 10.00) prohibits the "taking" of rare plants or animals. From a mosquito-control perspective, the most important definition of "taking" is disrupting nesting, breeding or feeding sites of animals or killing or cutting a plant. Aside from directly protecting rare or endangered species, this Act also allows areas to be designated "significant habitats." Alterations in "significant habitats" require a permit from the Division of Fisheries & Wildlife.

In Massachusetts, the species that have caused modifications in mosquito control practices are the Blue-spotted salamander (*Ambystoma laterale*), Mystic Valley amphipod (*Crangonyx aberrans*), and banded bog skimmer (*Williamsonia lintneri*). In addition, ditch maintenance in vernal pond areas has been curtailed to protect this type of habitat. Other animals for which concerns have been raised are the yellow-spotted turtle and osprey.

The presence of a threatened species need not prevent water management, however. In the East Volusia Mosquito Control District in Daytona Beach, Florida, OMWM was carried out in a salt marsh that contained the Atlantic salt marsh snake (*Nerodia clarkii taeniata*). An observer walked in front of the ditching machinery and work was halted until observed snakes left the area. In practice the snakes were difficult to spot and several were seen in the freshly cut ditches behind the ditcher. Two dead snakes were found, and assumed killed by the work. The dead snakes were handled as "incidental take" and placed on ice for delivery to the Florida Game and Fresh Water Fish Commission (Goode 1996). With an increased understanding of the ecosystems in which mosquito control takes place, mosquito control projects should improve their ability to work in areas containing endangered species with minimal impact to those species.

Under the current system mosquito-control maintenance activities are exempt from the Massachusetts Wetland Protection Act, leaving only the federal 401 Water Quality Certification Act and both the Massachusetts and federal Endangered Species Act as methods for regulating maintenance. Unfortunately, water quality, while important, does not address the issue of changing habitat and the presence or absence of a rare and endangered species has little to do with the merits of a given project.

Rare and endangered species will probably increase in their impact for several reasons. First, as data is collected on these species, additional species and additional habitats will most likely come under protection. Second, residential areas are creeping closer to wetlands areas. The net effect is that the clash between economic development and environmental protection will likely increase, with mosquito control being one component of an intense debate. Again, a more comprehensive understanding of the true ecological effects of mosquito control is required to better determine the cost/benefit ratio for different types of mosquito control.

D. Food Web Effects of Mosquito Control.

Throughout their life cycle mosquitoes are a part of the food web, both as consumer s and prey. As larvae most species feed on algae, protozoa, and organic debris (Pennak 1953). As adults they drink nectar and the females of most species take blood meals from a wide variety of animals. Larval mosquitoes are eaten by an impressive array of animals (Bates 1949) while adult mosquitoes are taken by spiders, predatory flies, odonates, bats and birds (Collins and Washino 1985). Given that mosquitoes are so thoroughly embedded in the food web, the question arises as to the effect of removing a large percentage of the mosquitoes from that food web.

At first glance, the effect would appear to be large, particularly in habitats with dense larval populations. However, mosquitoes are r-strategists, in that they produce large numbers of eggs that develop quickly (when immersed in water) to adulthood. Most pest species seek out temporary and spatially disconnected habitats for breeding and can complete a breeding cycle long before an adequate predator complex can develop. Mosquitoes are, therefore, a highly unpredictable food source for predators, and predation rates must be equally unpredictable (this section will focus on predation, as parasites and pathogens are not widespread control agents in Massachusetts). This is borne out by the fact that mosquito predators are generalists which can readily switch to other prey when mosquitoes become scarce (Collins and Washino 1985). In a study in Florida, immature mosquitoes made up over 50% of the diet of several species of saltmarsh fish (*Fundulus confluentus, Lucania parva, Gambusia a. holbrooki*). But each of these species fed on other items as well, including copepods, shrimp, other fish and even some plant material (Harrington and Harrington 1961).

One important point regarding predation and larval broods is that the concepts of handling time and satiation come in to play (Varley et al. 1973). A predator must spend a certain amount of time with each prey. Hydrophilid larvae took several minutes to feed on larvae and pupae taken in a panne in Tiverton, Rhode Island (Christie, pers. observation). Not only does it take time to catch and eat the prey, but invertebrate predators are typically not much larger than the mosquito larvae they are attacking. Satiation must play a role in limiting predator take, particularly when mosquito numbers are high.

Predators can play an important role in regulating mosquito numbers in some situations. That mosquitoes are absent from waters with fish populations is well known. Less well known is the influence of chaoborid larvae, which can severely reduce mosquito populations in vernal pools (Morrison and Andreadis 1990). In this case the larvae are present in snow-melt pools for approximately two months, so predation has time to operate as a regulating mechanism.

Although adult mosquitoes are eaten by numerous predators, it is rare that they make up an appreciable proportion of the diet of any one predator. One exception is the spider *Tetragnatha montana* for which, in Poland, mosquitoes made up 74% in June and 62% in July of all prey captured (Collins and Washino 1985). Bats and purple martins are not effective mosquito predators nor do mosquitoes form a significant part of their diet.

From a mosquito-control perspective, the mosquitoes to be controlled are, for the most part, those which have escaped predation to become predators in their own right. In the absence of scientific data supporting the necessity of mosquitoes in the diets of specific animals, removing mosquitoes from the food web by chemical, biological or physical control remains an easily justifiable activity. Even so, control personnel should take care to avoid chemical applications where mosquito larvae are not present or are present in very small numbers, should use control measures that do not harm existing predator complexes, and should limit control to areas where control is necessary, allowing natural cycles to continue in areas where human activity and the risk of disease transmission is slight. One argument made in favor of Altosid is that it does not kill the young larvae, leaving them available as food for the existing predator complex.

Up to this point, the discussion has focused on the effect of chemical control (including *Bacillus* products and IGRs) of mosquito populations on other species. Within the context of biological control, one of the primary reasons *Gambusia* are not being used in Massachusetts is the fear that they might displace native species of fish, thus altering the natural biota, not by predation but by competition for the same resource.

Physical control by water management may increase predation, as in OMWM, or may eliminate predator and prey as when wetlands are drained to soil saturation. Mosquito breeding must be thoroughly documented before new work is done. Because disturbances may displace some species, and because predator species tend to rebound more slowly than their prey, maintenance work should be conducted only when necessary.

E. No Program

Another alternative strategy to current mosquito control practice is no control. Many communities in Massachusetts have chosen this option. These town are usually outside of the enzootic EEE zone so the risk of human diseases transmitted by mosquitoes is viewed as practically nil by these communities. In addition, they are not located near salt marshes and their attendant pest mosquito problems. The mid-section of Massachusetts, where most no-control communities occur, also has a more rural character, less wetland , lower human populations, and a lower mean family income than most eastern areas with organized mosquito control programs. In general, the view of these communities is that the anticipated benefits from mosquito control do not outweigh the anticipated costs and perceived risks.

A more precise way of polling the public and confirming this opinion would be through establishing the Human Annoyance Threshold (HAT) for the town. Communities in which the HAT is below the actual annoyance level should be persuaded to choose the no control option since justification for control is lacking unless a documented disease threat exists.

In some communities, biting annoyance is created by a combination of biting insects (i.e. mosquitoes, black flies, biting midges and tabanids) which require completely different control approaches. Many people do not recognize the difference between these insects, especially in dim evening light. It is critical to accurately identify the biting insects actually responsible for the human annoyance. In general, black flies and tabanids only cause annoyance during the daytime while mosquitoes and biting midges are most annoying from 6-10 PM. The HAT level for tabanids and biting midges is likely to be less than for mosquitoes because of their more painful bites.

Perhaps part of the reason why Berkshire County communities have supported a MC program while other Western Massachusetts communities have not, lies in the fact that this region supports many summertime outdoor activities (e.g. camps, resorts, golf courses, Tanglewood, etc.). In addition, this more mountainous region has a significant black fly annoyance problem superimposed on top of the mosquito problem. Vacationers are likely to have a lower HAT than permanent residents since they are spending more time and money on outdoor recreational activities.

In addition to risk-benefit considerations, other criteria for weighing the control/no control option are 1) the feasibility of successfully reducing annoyance below the HAT level, and 2) the adequacy of community resources for reducing annoyance to acceptable levels.

Towns with large areas of mosquito-producing freshwater wetland should recognize that effective mosquito control in these habitats is difficult at best and often impossible. As indicated earlier in this report, permanent wetlands do not usually produce large numbers of pest mosquitoes but in situations where they do, the public needs to be aware that these wetlands are a valuable resource that must be protected from significant perturbation and that options for mosquito control are therefore few. Community planning boards and zoning laws can and should be used to restrict residential development and other human activities from such wetland areas.

Towns with annoyance problems but with large land areas and thinly, scattered populations must understand that the same level of mosquito control achieved in more populated communities will cost them significantly more per capita. In many such cases, the economic status of the population means that insufficient tax dollars can be generated to adequately deal with the problem.

Nantucket provides an interesting case study. Mosquito control had lapsed in the early eighties. However, by 1989 saltmarsh mosquitoes were becoming a significant problem in the west and north areas of the island. The town began applying Altosid (including aerial applications of pellets in 1992) to control the mosquitoes while. getting the requisite permits for OMWM in several west-end marshes (Madaket, Warren's Landing Eel Point). The OMWM systems were dug in January 1993 (Christie 1993). It was hoped that the OMWM alone would be sufficient to control mosquitoes but large-scale breeding continued in the north end (Pocomo) and the low tidal range has hindered the effectiveness of the OMWM as dug. As a result, some lariviciding continues. The conclusion on Nantucket is that mosquito control against saltmarsh mosquitoes must be continued at some level in order to provide residents with the summer environment they want. However, Nantucket does not target freshwater mosquitoes at all and does no adulticiding. Nantucket and Cape Cod together indicate that adulticiding is not a requirement even in high-tourist areas.

It is difficult to measure the impact of choosing the no control option. The example of towns that have left, and left and later rejoined MC projects is perhaps the only available basis for estimating public opinion concerning such impact. No documentation of annoyance levels, cases of disease, recreational dollars spent, etc., was ever attempted in these towns when they had mosquito control versus when they did not. Thus, public complaints were apparently the main indication of the impact of the no control option that was used in guiding town decision making.

In the 1986 questionnaire, only about 10% of the towns in organized projects indicated that there had been controversy relative to leaving, joining, or rejoining a project. Those that had experienced controversy indicated that 4 factors were about equally involved. These were: 1) monetary constraints, 2) concern over the effectiveness of project control programs, 3) concern over the safety of the methods used by the project, and 4) concern over the environmental impact of the control procedures. Paradoxically, 86% of these towns indicated they were unwilling to spend more money (if legally possible) to obtain more effective control and 67% indicated unwillingness to spend more money to support less hazardous control methods. However, the bias of the people filling out the questionnaire sent to each town may have influenced these responses; no town in Massachusetts has actually polled their citizens on these questions. In fact, some towns within projects have taken advantage of new provisions which allow towns to collect additional money for MC activities which projects can then only spend in these towns.

Among towns that actually withdrew from MC programs, monetary constraints played a role in 73% of these decisions, followed by environmental concerns in 32% and concern over effectiveness in 27% of these cases. Towns that contemplated withdrawing but did not do so, indicated that monetary and effectiveness considerations dominated their concern.

The number of towns in MCPs declined in the late eighties. Economic factors, not environmental concerns, were the dominant reason given for withdrawal. This trend has reversed itself significantly in the last several years. The 1990 EEE problem is probably one reason, coupled with the fact that several coastal programs tried the no-control option and found mosquito numbers rose quickly.

Many towns in the Berkshire County and South Shore projects withdrew in 1981 mainly in response to Proposition 2-1/2 monetary constraints. The remaining 8 towns in Berkshire County subsequently chose to continue as a multi-town Project (Note: the town of Lanesborough rejoined in 1986, the city of Pittsfield rejoined in 1988, and other towns are contemplating reentry). South Shore actually disbanded as a project but by 1988 most towns had joined neighboring MC projects in Norfolk and Plymouth Counties. These actions suggest that these communities were not content with the no control option that resulted from the disbanding of their former project. Towns that voluntarily withdrew from MC projects but then later rejoined a project, did so for a variety of reasons. These were in order of their importance: increased public support for MC, increased mosquito annoyance, alleviation of monetary constraints, threat of EEE, improved methods and effectiveness of the project.

The Environmental Impact Statement (Sjogren 1977) prepared for the Metropolitan Mosquito Control District in Minnesota attempted to quantify the no control option for their community. Any attempt to develop similar estimates for Massachusetts would be meaningless given the lack of appropriate baseline data.

B. Biological Control.

1. Introduction

Biological control includes attacks on the pest species by other species and manipulation of the pest species itself. The former includes the traditional biological control agents, predators, pathogens and parasites, whereas the later includes such techniques as sterile-male release and genetic manipulations.

Biological control agents are grouped into three categories: predators, parasites and pathogens. Predators include both vertebrates and invertebrates and may attack both adult and immature stages of mosquitoes. Helminth, protozoan and fungal parasites and microbial pathogens generally only invade immature stages, though mortality may not occur until the early adult stage. Parasitic water mites are an exception in that they attach to certain adults as they emerge from the pupal stage and apparently reduce adult survivorship if they are abundant (Lanciani & Boyett 1980) In general, biological control is much more feasible in managing permanent water mosquitoes than temporary water forms.

There are three basic strategies for utilizing all biological control agents: (1) increasing existing natural enemy populations by habitat alteration, (2) one-time introduction of sustainable exotic agents from other regions or habitats, and (3) augmentation of natural or exotic enemy populations by repeatedly releasing non-sustainable, lab-reared (or field collected) organisms. To date only the first, increasing fish habitat through OMWM, has been used in Massachusetts. Bti is sometimes classified as a biological control agent but its application technique and mode of action as a stomach poison more closely resemble a pesticide than a biological control agent *per se*. *Bacillus sphaericus* may more closely fit the model of repeatedly releasing non-sustainable lab-reared organisms as there is evidence to suggest that it recycles within the environment.

No other biological control agent is currently available for general field use, though experiments continue with may different organisms (see below). There are important reasons why biocontrol is not more widely used against mosquitoes. First, the differences in biology of the various species of mosquitoes make it unlikely that any one control agent will operate across a wide range of species. Second, mosquito breeding is wide spread, making it difficult for a biological control agent to find, or be placed in, all breeding areas. Third, predators such as bats and purple martins, may eat mosquitoes but prefer to eat other, larger insects. Further, even when abundant, they do not drive mosquito populations below levels that people generally find intolerable. Finally, there is a high cost associated with sustained releases of a biological control agent and there are not, at this time, control agents available that require a single, or a few, releases to become established.

Because of the limited application of biological control to mosquitoes in Massachusetts, the following discussion will focus primarily on the feasibility of control agents currently being studied for mosquito control. An important point to make regarding biological control is that the mosquito control have limited research capabilities. While conducting field evaluations of new control techniques is a desirable practice for any mosquito control program, the projects should not be expected to find and bring forward biological control agents without substantial help from research institutions such as the state university.

2. Predators

a. Introduction

In order for any predator to independently be an effective control agent, it must meet two important criteria: (1) its size and abundance in relation to the target species must be sufficient for it to kill or consume a high percentage of the prey population within a relatively short time period, and (2) its feeding behavior should be selective toward the prey species when it is present but allow it to utilize other food items when the target species is absent. These criteria are rarely met in full. Predators that are sufficiently large and/or abundant to have a major impact, usually lack feeding specificity. Conversely, those with feeding specificity are usually less abundant because their populations are regulated by a more restricted food supply. Vertebrate predators of insects have a clear size advantage but invertebrate predators tend to exist in much greater numbers.

Because of the limitations of predators as biocontrol agents, it is normally essential to continuously raise and release the predator to achieve field densities high enough to cause real reductions in the prey species. However, in some cases, manipulation of the environment to the advantage of natural predator populations can provide an adequate augmentation effect.

b. Vertebrate predators

<u>Fish</u>

Larvivorous fish are the oldest and perhaps most effective traditional biological control agent used against mosquitoes. In certain habitats they may, by themselves, provide adequate larval control throughout the breeding season. If not, pesticides such as BTI or methoprene which are non-toxic to vertebrates can be used in an integrated fashion with fish.

As already mentioned, the main reason open saltmarsh management strategies effectively control many saltmarsh *Aedes* in the Northeast is because this method provides access for the abundant estuarine populations of larvivorous killifish (*Fundulus* spp.) into the mosquito breeding pools in the high saltmarsh (Hruby & Montgomery 1986).

The mosquitofish *Gambusia affinis* is distributed widely throughout the warmer parts of the world and is the species most often reared and introduced into fresh water habitats for mosquito control. The biology and use of this fish in mosquito control was reviewed by Meisch (1985). It is an opportunistic feeder and avidly eats pupae and late-instar larvae of culicines and chironomids. It is most effective against *Culex* in unvegetated, permanent ponds but has been widely used in California and the Gulf States against ricefield *Aedes* and *Psorophora*.

Because *Gambusia* is so aggressive and fecund, it may replace important commercial or rare native fish species. This has raised environmental concern over the introduction of this fish into natural waters where it does not already occur. A recent article by Rupp (1996) has renewed this debate, both emphasizing real successes and real concerns over *Gambusia* use (see "Comments on 'adverse Assessments of *Gambusia affinis*'" (JAMCA 1996) and Boklund 1997, Eliason 1997, and Rupp 1997). Because it is not a native species of Massachusetts it may not be imported and released in state waters.

Outside of the mosquitofish, the common guppy (*Poecilia reticulata*) has received the most attention for mosquito control (Bay 1985). Comparative studies indicate that it is a less effective predator than Gambusia but it is more tolerant of polluted waters. Many other native fish have been explored for their mosquito control potential (Bay 1985). Studies in North Africa (Allo et al. 1985) suggest that malaria may be controlled through the annual introduction of native fish from streams into the manmade water storage tanks which produce the vector *Anopheles* in this region.

Birds

Many birds depend on insects as food and those which capture insects on the wing (e.g., the swallows), have been credited with consumption of significant numbers of mosquitoes. Purple martins specifically have been promoted on the basis of the claim that they often consume 10-12 thousand mosquitoes per day but Kale (1968) concluded on the basis of existing evidence that all claims of martins significantly reducing mosquito populations were unsubstantiated and, because of several biological facts, were unlikely to ever be demonstrated. The facts on which these conclusions were drawn are as follows:

(1) Mosquitoes were a negligible item in the diet of martins in the only two published studies in which the contents of martin gizzards were examined.

(2) None of the published statements appearing in the popular ornithological literature which attributes a mosquito-eating habit to martins is based on factual study or scientific reference. In fact, there is evidence that martins feed more on larger insects including species of dragonflies which may be predators of adult mosquitoes.

(3) Behavior patterns of mosquitoes and martins are such that they tend to not fly at the same height or at the same time. Thus, contact between the two is minimal.

(4) There is no evidence that any avian species can effectively control a pest insect upon which it feeds when the insect is at or near peak abundance.

Other Vertebrates

Mosquito control by insectivorous bats was tried in the early part of this century but without success (Kale 1968, Storer 1926). Bats continue to appear in the popular press as legitimate mosquito-control agents (Wright 1996) but are not considered worthwhile agents in Common-sense Pest Control (Olkowski et al. 1991), which is very thorough in its coverage of non-chemical control options, or in mainstream mosquito control (Mitchell 1992).

c. Invertebrate predators

Predators of mosquito eggs.

Evidence exists of predation on diapausing flood water mosquito eggs by mites and beetles, and on *Culex* egg rafts by fish (Collins & Washino 1985). Nonetheless, egg predation appears to be a relatively minor component of natural mosquito mortality and is not being studied for biological control.

Terrestrial insect and spider predators of mosquito adults

Predation on emerging and indoor resting adult mosquitoes has been readily observed but the impact of this mortality on populations is extremely difficult to assess. Certain spiders (especially Tetragnatha) and predatory flies (mainly Empididae, Anthomyiidae and Dolichopodidae) have been shown by precipitation tests to have consumed emerging mosquitoes (Collins & Washino 1985). In one British study, up to 28% of the spiders tested had eaten mosquitoes (Service 1973). Certain adult dragonflies reportedly capture mosquitoes on the wing but these observations have not been backed up by any controlled field studies. Synanthropic emesine bugs (Reduviidae) appears to be potentially important predators of indoor resting mosquitoes in the tropics. In sum, the prospect for enhancing or managing invertebrate predators for more effective adult control is not encouraging, especially in temperate regions.

Aquatic insect predators of mosquito larvae & pupae

Aquatic insect predators seldom occur in significant numbers in the temporary floodwaters that produce most pest mosquitoes. Studies of predation have therefore largely taken place in permanent ponds or semi-permanent habitats such as rice fields, rock pools or vernal woodland pools. The adult stage of most predaceous aquatic beetles and true bugs can fly (usually at night) so natural colonization of newly flooded habitats can occur in a matter of days. Development time for these insects is usually from several weeks to several months.

Among the beetles, the dytiscids (predaceous diving beetle), which are predaceous both as larvae and adults, are the most effective predators of mosquitoes. There is evidence from studies in rice fields that adult dytiscids selectively locate and colonize sites with locally high concentrations of mosquito larvae (Collins & Washino 1985). Mass production methods for dytiscids have never been developed. Whirligig beetles (Gyrinidae) only feed at the surface where they may prey on concentrations of emerging adult mosquitoes. Hydrophilids are only predaceous as larvae and seem to feed mainly on chironomid midges.

Only two aquatic families of true bugs, the back swimmer (Notonectidae) and pigmy back swimmer (Pleidae) have received serious consideration as mosquito control agents. Pleids are generally not abundant enough to have significant impact but notonectids can become quite dense in certain habitats. Mass rearing of the latter appears to be possible. Water boatmen (Corixidae) are also common and similar in appearance to backswimmers but they are mostly detritus feeders. Other predaceous aquatic Hemiptera that have been suggested as mosquito predators but which normally occur in insufficient densities to have much value as natural control agents include the giant water bugs (Belostomatidae), water scorpions (Nepidae), water measuring bugs (Hydrometridae) and the two family of surface-feeding, water striders (Gerridae and Veliidae).

Dragonfly naiads have been marketed commercially for mosquito control and at least one town in Massachusetts, and others in New Hampshire and Maine, have purchased dragonflies for mosquito control. In northern climates these insects require 1-5 years to mature, so they normally occur in permanent waters only. Furthermore, many are bottom feeders that seldom if ever come in contact with mosquito species that feed at the surface or in the water column. Most bottom-feeding mosquitoes (i.e. *Aedes*) occur in temporary water containing few if any dragonfly naiads. Another factor weighing against the mosquito control efficiency of these aquatic predators is the fact that they normally occur at low densities. Adults of many species are territorial and this seems to spatially limit population densities of naiads as well as adults. In certain habitats such as rice fields, naiads may become quite abundant but populations fluctuate greatly and their role in limiting populations of rice field mosquitoes is limited at best. No controlled, field studies have been done in which naiads have performed well as biological control agents.

The trichopteran *Limnephilus indivisus* may be an important predator of early spring *Aedes* in woodland swamps in Ontario but most caddisflies are omnivorous shredders rather than predators (Collins & Washino 1985, Merritt & Cummins 1985). Prospects for mass rearing and manipulating caddisfly larvae are not very bright. Many of the aquatic nematoceran relatives of mosquitoes contain groups with predaceous larvae. These include the families Chaoboridae, Chiromomidae, Ceratopogonidae, Tipulidae, Anthomyiidae, and others. Most are too small to consume many mosquito larvae. Predation on small, early instars occurs but it is far less efficient in reducing the numbers of adults than is predation on late instars and pupae. *Mochlonyx* (Chaoborid) predation on spring *Ae. communis* populations has been observed in woodland pools in Massachusetts (Edmans, personal communication) and in Europe (Chodorowski 1968). The impact of this small but voracious predator is unknown.

The insect predator with the most promise in mosquito control is another mosquito. Larvae of the non-biting genus *Toxorhychites* are large and effective predators of mosquitoes that develop in natural and man-made containers such as tires, tree holes, metal cans, and leaf axis (Steffan & Evenhuis 1981). Unfortunately, none of the 70 some species in this mainly tropical genus can survive the winters as far north as Massachusetts. Their use here would therefore require repeated, annual releases of lab-reared females. This is not warranted at the present time since container-breeding species generally do not represent the major nuisance or health threat in Massachusetts. This situation could change if *Ae. albopictus* becomes well established in used tires in the Northeast. Focks (1985) states that although it is possible to control or reduce certain species of container-breeding mosquitoes with inoculative or inundative releases of *Toxorhynchites*, the usefulness of this genus in practical, operational control programs has yet to be demonstrated.

<u>Other invertebrate predators of larvae and pupae.</u>

Among the non-insect predators of the immature stages of mosquitoes, only hydra (Cnidaria: Hydrozoa), flatworms (Platyhelminthes: Turbellaria) and copopods (Cyclopoida) have been studied in any detail.

Both hydra and flatworms can be easily mass produced and, unlike most predaceous insects, they can be maintained at high densities without cannibalism. In the laboratory, they kill far more larvae than they consume. Both groups produce semi-dormant eggs so they occur naturally in shallow temporary pools as well as permanent swamps and ponds. Detrimental effects on young fish have been reported when these predators are at high densities (Mulla & Tsai 1978).

Both of these predators have good potential as control agents in the Northeast but additional long-term field evaluations are needed. As with mosquito fish, the laboratory production, storage, and field translocation of these organisms requires a certain degree of sophistication, which is usually lacking at the local level. Currently, there are no commercial sources for the quantities that would be required for mosquito control applications.

Natural populations of predaceous cyclopoid copepods appear to limit the distribution of container breeding mosquitoes in certain tropical settings (Marten 1984). However, they have never been shown to be important predators in temperate regions or in other types of aquatic habitats. Therefore their potential for the biological control of pest and vector mosquitoes in Massachusetts appears to be nil.

3. Parasites and Pathogens

a. mermithid nematode parasites

Outside of bacteria, parasitic nematodes are the only natural parasites and pathogens that have ever achieved operational status in mosquito control. Known parasitic roundworms of mosquitoes now number over 20 species. The free-living, aquatic, preparasitic stage which hatches from the nematode egg, seeks out and penetrates the cuticle of host mosquito larvae. Larvae are usually killed in the last instar. In a few species, the mature worms are carried over in the adult mosquito and cause mortality when they exit during attempted pseudo-oviposition.

Romanomermis culicivorax (including most references to *Reesimermis nfelseni*) is the species that has been most extensively studied. Methodologies for the mass production and commercial preparation of this species have been developed and it was briefly marketed as Skeeter Doom in the late 1970'g. Low sales and problems with the shipping and shelf-life of viable eggs appear to have been the major factors which led to the marketing failure of this agent (Service 1983). Other economic drawbacks include host specificity which limits its effectiveness to only certain species (e.g., it is ineffective in cold, polluted or brackish water), and the lack of patent protection for companies investing in the production and marketing of this product. In addition, applicators need some special skill and training to effectively use this biocontrol agent. The tendency of this agent to naturally recycle once it is introduced into favorable aquatic habitats is beneficial from a control viewpoint, but it further reduces the long-term marketability and profit potential for private producers. It remains under study, however, as a recent article (Mijares et al. 1997) discussed the establishment of *R. culicivorax* in sewage settling ponds and natural ponds in Cuba.

On the biological plus side, mermithids appear to be highly compatible with a wide range of chemical pesticides and growth regulators. Moreover, they: 1) are non-specific and well suited to the life cycle of their mosquito host, 2) produce high levels of infection and mortality, 3) can be easily mass-produced and applied with standard spray equipment, and 4) offer no threat to non-target organisms or the environment.

There are species of mermithids which appear to be highly specific to spring snow-pool *Aedes* and to saltmarsh *Ae. sollicitans* (Petersen 1985). However, these worms have not been established and studied in the laboratory. Such species may have greater control potential in northern coastal states like Massachusetts than the more tropically adapted *R. culicivorax.*

Since the technology for using mermithids in mosquito control already exists, and there are numerous field trials documenting their control potential, the future availability and use of these biocontrol agents in operational programs seems to depend on changing economic and market forces (Petersen 1985).

protozoan parasites

b. Microsporidia

Virtually all mosquito species carefully examined have been found to harbor these parasites. Larvae are infected by ingesting the spore stage. Spores, which are produced at the end of the life cycle, have often proven difficult to induce and to reinfect larvae in lab cultures. Few microsporidian life cycles are well enough known to assess biocontrol potential. Life cycles vary from simple to complex and often form the basis for the non-taxonomic grouping of these protozoan parasites. The simplest forms (Type I) occur mainly in terrestrial insects and even the one aquatic species known from mosquitoes (*Nosema algerae*), does not cause mortality until, the adult stage. For this reason *N. algerae* has limited potential for reducing pest problems but may impact on disease transmission by reducing survival and fecundity. Wild strains only persist in larval populations for short periods and cause little direct mortality. Type II microsporidia have simple, asexual life cycles similar to Type I forms and they also show little promise in mosquito control (Hazard 1985). Type III forms are dimorphic, have binucleate spores, and kill mosquitoes in the larval stage. Only one species (*Hazardia milleeri*) is known from mosquitoes and it seems to have low infectivity (Hazard 1985). Type IV microsporidia include many species from mosquitoes and have the most control potential. Infected larvae are usually killed but a few females survive and carry the infection via the ovary to the next generation. However, transovarial infection ceases after a single generation. Non-ovarian modes of transmission must exist but this issue along with the possibility of sexual reproduction and alternate hosts are as yet unresolved. Additional basic research is required before any microsporidian can be considered in the biocontrol of mosquitoes (Hazard 1985).

Tetrahymena and *Lambornella* (tetrahymenid ciliates)

The lack of a resistant resting stage and difficulty in culturing these ciliated protozoa has prevented the thorough study and evaluation of this group of potential biocontrol agents. Ongoing studies of *Lambornella clarki* in California treehole *Ae. sierrensis* should help to better assess the control value of these parasites in the near future (Anderson et al. 1986).

Helicosporidium

There is still debate concerning the proper classification of this spore-forming group of parasites; some believe they are primitive Ascomycetes fungi. There are only 3 reports of natural infections in mosquitoes. They appear to infect a wide range of species but also may infect non-target insects as well. High dosages of spores are required to infect older instars in the lab. Continuous cultures of these parasites do not exist so the basic research needed to evaluate their biocontrol potential is not forthcoming.

c. Fungal Pathogens

Coelomomyces

Many forms of pathogenic fungi have been known from both larval and adult stages of mosquitoes since the 1930's. However, it was not until the discovery of the obligate alternate host (i.e., microcrustacea) in the mid-70’s that cultures and full-scale laboratory investigations were possible with *Coelomomyces* (Whisler et al. 1974, 1975). The rather complex life cycles of some species have recently been described and methods for in vivo culturing established. Before wide-scale field application can occur, mass in vitro cultivation of the infective biflagellate zygote stage needs to be developed. If *Coelomomyces*, and perhaps their copepod and ostracod intermediate hosts, are introduced into favorable habitats, the potential for natural recycling exists. However, too little is known about the host ranges and habitat requirement of most *Coelomomyces* to recommend any such introduction at the present time. Moreover, species of *Coelomomyces* do not routinely provide high and predictable levels of mosquito control. It is, premature to critically assess their potential as control agents to be used independently or as part of an integrated control program (Federici et al. 1985). Studies related to their evaluation as operational control agents have only recently been initiated and it is not likely that any *Coelomomyces* will be operational within the near future.

Lagenidium giganteum.

This mosquito-specific water mold is a very promising biological control agent, especially in fresh water and in warmer climates. This fungal pathogen can be mass produced on artificial media and can recycle in as little as 3 hours (McCray 1985). It has a resistant, dormant stage and infects a wide range of mosquito species. Unfortunately, it is not effective in polluted, brackish or colt waters. This limits its commercial value and it potential usefulness in northern and coastal states like Massachusetts (Service 1983).

Other Fungi

Fungi are among the commonest pathogens of insects and many other genera besides *Coelomomyces* and *Lagenidium* have been reported from mosquitoes. Of these, *Culicinomyces* and *Metarhizium* have received the most attention. Both groups infect a wide range of mosquito species but relatively high concentrations are required to cause infection. They can tolerate organic pollution and salinity but not high temperatures (i.e. above 30°C). These fungi can be grown on inexpensive artificial media but no resistant resting stage has been fount. Difficulty in achieving long term storage of infective stages and formulation problems remain as barriers to commercial production. Nonetheless, these fungi are a promising group of biocontrol agents which may provide new mosquito control tools in the future.

Erynia aquatica

Erynia aquatica is an Entomophthorales fungus, and is the only species of the genus known to infect the immature aquatic stages of mosquitoes. It was first discovered infecting *Ae. canadensis* and *Cs. moristans* larvae in woodland pools in Hartford County, Connecticut from late May to early June (Anderson & Ringo 1969). It has since been recovered in early May from *Ae. stimulans* in woodland pools near the village of Cambridge, New York (Molloy & Wraight 1982) and from *Ae. cantator* on May 21, 1981 in a shallow salt meadow pool in Milford, Connecticut (Andreadis & Magnarelli 1983). Most recently, is was discovered in 1995 and 1996 in a woodland pool in Bristol, Rhode Island (Christie 1997).

Steinkraus and Kramer (1989) collected *Ae. fitchii* larvae infected with *E. aquatica* from a semi-permanent woodland pool in Tompkins County, New York. They used infected pupae to successfully transmit the disease to emerging adult *Ae. aegypti,* on which resting spores of the fungus developed.

Erynia aquatica has characteristics which make it attractive as a microbial agent: it is capable of causing epizootics, has been found in both freshwater and brackish water mosquitoes and has a resting spore stage that may survive well in storage. Operating against it is the fact that it has only been found in cooler, springtime waters. One thought is that infected pupae may be removed from the original infestation site and placed in other, nearby pools. A fungus that kills in the pupal stage works against its own spread.

d. Bacterial pathogens

Bacillus thuringiensis var. *israelensis*

Bti Serotype H-14 has become an important biological larvicide following its discovery in the Negev desert in 1976. Within the last 5 years it has become widely used by the mosquito control projects in Massachusetts. It is now the larvicide of choice in many situations because of its host specificity, high and rapid mortality to many mosquitoes species, and its environmental safety. It is quite distinct from the Bt strains which infect lepidopterous insects. Its track record in controlling polluted-water *Culex* is mixed, apparently because it sinks to the bottom and the active moiety rapidly binds to organic particulates. Consequently, higher dosages are required to achieve good control in highly organic and deep-water situation. Saltmarsh mosquitoes generally require rates at the high end of the labeled application rates for effect control. Liquid, powder, granular and slow-release briquet formulations are commercially available.

Bti must be ingested to cause toxicity to filter-feeding mosquito larvae; pathology occurs in cells of the midgut wall. It is least toxic to 4th instars since they cease feeding at least 12 hours prior to pupation. The mosquito toxic ingredient of Bti preparations is the heat labile deltaentotoxin located in the proteinaceous parasporal crystalline inclusions synthesized concomitantly with the spore during sporogenesis. Once released in the environment, it biodegrades rapidly (it is usually only active 1-3 days) and this bacterium (gram negative Bacillaceae) does not recycle. This is considered the only major drawback of this highly effective mosquito pathogen but it has enhanced its commercialization (Lacey & Undeen 1986).

The biocidal activity of Bti toxin appears to be limited to larvae of certain families of nematocerous Diptera. A large number of laboratory and field tests have confirmed that all non-nematocerous, non-target organisms are virtually unaffected (Lacy 1985). All existing data indicate that the unaltered protoxin of Bti is also safe to vertebrates including humans (Lacey 1985). Further improvements in the efficacy and price competitiveness of this control agent, brought about by formulation changes and genetic engineering, are likely to occur in the near future. In addition, formulation of this agent with other compatible and perhaps synergistic agents such as juvenile hormone analogs (e.g. Altosid) is currently underway. Such mixture have two important advantages. They reduce the likelihood of mosquitoes developing resistance to either agent and, secondly, they widen the window for control since Bti is most effective against early instars and growth regulators against later instars.

Bacillus sphaericus.

Although only recently available, *B. sphaericus* may have greater control potential than Bti because of its ability to continue to recycle once it is introduced. It has many of the same beneficial attributes of Bti but all strains isolated to date are less effective against a wide range of species than is Bti. At the moment it is primarily marketed against *Culex* in high-organic waters but research is on-going in expanding its control potential.

e. Viral Pathogens

The biological control potential of both non-accluted (iridoviruses and densonucleosis viruses) and occludet (baculoviruses, cytoplasmic polyhedrosis viruses and entomopox viruses) viruses pathogenic to mosquitoes has recently been reviewed by Federicci (1985). It is sufficient here to simply paraphrase from the summary of this thorough review as follows:

Analysis of research conducted to date makes it clear that none of the viral pathogens of mosquitoes can currently be considered good candidates for mosquito management programs. The two main reasons for this assessment are that viruses discovered so far possess low infectivity for original or alternate hosts and there is no readily available method for mass production of virions. This apparent lack of control potential is most obvious when one considers that few field trails have been conducted with these agents even though the first one was discovered over 15 years ago. While it appears unlikely that viruses will be developed for mosquito control in the near future, they may prove to be extremely useful microbial agents in the long term, perhaps in 2 or 3 decades, once we learn how to manipulate them effectively. Biotechnology has the greatest potential for engineering new more useful biocontrol organisms among the viruses because of their simple molecular structure.

4. Pest Species Manipulation

A somewhat different approach to biological control is manipulation of the mosquito genome to either 1) induce reproductive failure (leading to population elimination) or 2) bring about permanent changes in the behavior or physiology of the target population so it no longer vectors disease or bites people. There are numerous theoretical mechanisms by which this could be accomplished. Following is a brief discussion of the three approaches that have been most commonly discussed and researched.

a. Sterile Insect Technique

The early and continuing success of the sterile male release program in eliminating the screwworm fly from the U.S. and Mexico has given rise to many investigations and new ideas for controlling other insects (inoculating mosquitoes) through the use of this or some other genetic technique. Except for fruit flies, this method has not yet been successfully applied to other insects in operational programs and the technique is not currently being pursued for mosquito control.

b. Incompatibility

Incompatibility resulting from a lack of fertility in sexual unions may occur due to a variety of genomic failures or due to the effort of bacteria-like symbionts to control the reproduction of host (Barr 1985). The feasibility of suppressing *Culex pipiens* through cytoplasmic incompatibility was demonstrated in a Burmese Village over 20 years ago (Laven 1967) but the practicality of this method has not been confirmed by any other field tests. Moreover, incompatibility factors have been isolated in only a few mosquito species to date.

c. Chromosomal Aberrations

There are several heritable chromosome rearrangements that can, in theory, be used to inject genetic load into a mosquito population and/or to effect a permanent change in the genetic makeup of the population. These aberrations can be used to 1) increase genetic lethal load (serility is limited to 50-80% because of the low chromosome number (three, in most mosquitoes) or 2) replace noxious species with harmless strains if appropriate viable homozygous rearrangements are available. The latter is perhaps only applicable in the case of important disease vectors. Naturally occurring aberrations can be screened for in wild populations but their frequency is greatly increased through exposure to mutagens.

Controlling mosquitoes through the use of chromosomal aberrations requires a major basic research effort and a target species that is easily colonized. This later requirement automatically eliminates many important species from consideration.

d. Competitive Displacement

The final, and somewhat abstract, strategy for controlling mosquitoes biologically is the ecologically based notion of displacing a noxious species by introducing a benign but more competitive (i.e. better adapted) exotic one. This idea has been suggested primarily to control container-breeding species like *Ae. aegypti*. However, benign mosquito species are difficult to find, as most mosquitoes that have become established (*Ae. aegypti, Ae. albopictus*) are as bad or worse than the species with which they compete (container-breeding *Culex* and *Ae. triseriatus*).

5. Other Control Approaches

a. Trap out techniques. All experience to date indicates that while various traps may be good sampling devices for adult mosquitoes, they are too inefficient and limited in their range to provide any benefit in reducing biting annoyances (Nasci et al. 1983). Work is ongoing on attractants (octanol) that would both greatly increase trap collections of mosquitoes and reduce non-targets trapped, but no products are marketed for this purpose to date.

Electrocutor traps ("Bug Zappers") continue to be a popular item, with an estimated 1.75 million sold in the United States each year (Mitchell 1992) but they are extremely non-specific (mosquitoes generally make up less than 5% of the catch, and may be harmful to other insect species. They cannot be considered a part of any mosquito-control program.

b. Repellents. Personal protection through the use of mosquito repellents is an appropriate alternative to controlling the mosquito populations before they bite. This is especially true if the periods of annoyance are infrequent and brief and where the land areas are too vast and unpopulated to economically consider control programs.

The most commonly used mosquito repellent is DEET (N,N)(diethyl-metatoluamide) which has been formulated and sold under a variety of trade names (e.g., Off, Muskol, Cutters), in a variety of concentrations and as both aerosol sprays (usually ca 15%) and lotions (up to 100%). Laboratory tests have shown that maximum repellent duration (ca. 1-2 hours) is obtained with a concentration of ca. 50% so that higher concentrations do not provide appreciable advantages. The major disadvantage o£ DEET are:

1) relatively short protection time

2) somewhat offensive odor

3) damage to some fabrics and surfaces at higher concentrations

4) high cost

5) possible hazards from heavy use

Small children frequently have skin reactions to DEET. Small children are also most likely to be the individuals that develop meurotixicological symptoms from DEET. Thirteen of 14 cases of encephalopathy (toxicity of the central nervous system), found in publicly available reports by a recent review (Osimitz and Grothaus 1995), were in children 8 years old or younger. Three of these children died, all having used "heavy" amounts of repellent, even though the repellent in each case had DEET concentrations of 20% or less. Oral ingestion may have played a role in some of the cases. Osimitz and Grothaus (1995) concluded that there is no evidence that increased DEET concentration has an effect of the severity of symptoms. They also compared reports that the Poison Control Center received for DEET (6,724 in children under 6 years old during a five-year period) to laundry detergent reports (10,789 in 1989) and household bleach (16,169 in 1989), concluding that accidental exposure, while undesirably high, is in line with, or lower than, exposure to other household chemicals.

There is one unsubstantiated report in the Russian literature of carcinogenic effects in rats at high doses.

Three other repellent materials are in common use. Dimethyl phthalate (generally sold as 6-12) is not as effective as DEET against mosquitoes but still has a share of the market. Citronella-based repellents have long been marketed as candles or in oil-burning lamps. Citronella is also available as a repellent to be sprayed in skin and clothing (Natrapel). The third material (Avon skin-so-soft) is a popular bath oil that is not marketed as a mosquito repellent but has, through word of mouth, been recognized for its as yet uncharacterized mosquito repellent affect. It is as effective as DEET but it does not persist as long. On the other hand, it is much cheaper, smells better, and apparently does not damage any fabrics or surfaces. The active ingredient(s) of skin-so-soft has not been isolated or identified to date. It also has not undergone the EPA safety testing that other repellents have because it is marketed as a beauty aid rather than a pesticide (Note: repellents are classified as pesticides by EPA).

Electronic mosquito repellent devices which are periodically marketed in the U.S. (usually by mail order houses) are completely ineffective and are not based on any biological rationale (Foster & Lutes 1985, Mitchell 1992, Curtis 1994).

C. Physical Control

1. Types of Habitat Modification

a. Open marsh water management (OMWM)

Originally developed for New Jersey salt marshes (Ferrigno 1970, Ferrigno & Jobbins 1968, Ferrigno et al. 1969), this strategy basically attempts to overcome the limitations of ditching by the incorporation of other water management strategies. In particular, champaign pools or reservoirs (which permanently hold water and sustain larvivorous fish) are created (by backhoe, dragline or rotary ditcher) in selected tidal pools or large shallow pans and are connected via small shallow ditches to surrounding mosquito breeding depressions. If old ditches are re-dug and used as reservoirs, then plugs must be inserted at the tidal end to prevent drainage. This customized approach to marsh management represents the least deleterious and most efficient nonpesticidal method for controlling saltmarsh mosquitoes and has been adapted to New England conditions (Boyes and Capotosto 1980, Hruby et al. 1985, Christie 1990). A manual outlining this method was developed by the Massachusetts Audubon Society (Hruby and Montgomery 1986) and OMWM is currently being practiced by coastal projects in Essex and Plymouth Counties in Massachusetts. As of 1996, OMWM had become the accepted technique for new salt-marsh water management work, though maintenance work remains dominated by cleaning existing ditching, as opposed to conversion to OMWM.

b. Other Modification Strategies

Mosquito control efforts in Massachusetts predate modern chemical insecticides. Early control efforts consisted of source reduction work, mostly in salt marshes (see “History of Cape Cod Mosquito Control Project, 1928-1971”). This emphasis was largely abandoned when cheap and seemingly more effective organo-chlorine insecticides became available in the early 1950's. Early control programs capitalized on cheap WPA labor but they failed to achieve the level of control that the public has come to expect of modern control programs. Nonetheless, they serve as a reminder that mosquito control, from its earliest inception, considered and practiced control alternatives to synthetic chemical pesticides.

Except for new OMWM projects in salt marshes, mosquito control source reduction work now consists primarily of maintenance work on existing culverts, storm sewers and ditches. Very little new ditch construction has taken place in recent years. Ditch cleaning, which often involves excavating spoil with a backhoe or plow, is an activity which has drawn great concern when it takes place in estuarine environments. This is because many of the old grid ditches in the saltmarsh served no real purpose for mosquito control but they must be re-cleaned periodically or they themselves become shallow breeding areas for saltmarsh mosquitoes.

c. Origination of Requests for Physical Control.

The exemption from certain regulations enjoyed by mosquito control is a two-edged sword. On the one hand, it enables mosquito control projects to more quickly respond to drainage problems. On the other hand, it makes the heading "Mosquito Control" particularly desirable for drainage projects in which mosquito control is, at best, a marginal goal. This pressure can come from property owners, public officials, or from within control projects themselves. The pressure to conduct drainage work that does not have a mosquito-control component must be resisted.

The best interests of mosquito control programs are served by conservative application of the definition of mosquito control, as over-use of the wetlands exemptions may result in the loss of those exemptions. To this end, mosquito control programs, in conjunction with state and federal wetlands protection agencies, must develop a strong set of guidelines for alterations exempt from Wetlands Protection Act.

2. Ecosystem changes of non-target biota as a result of physical controls.

a. Salt Marsh .

New England coastal wetlands have been heavily impacted by man (Shisler 1990). However, evidence concerning the negative impact of saltmarsh ditch maintenance activity is mixed. The principal concern is with disposal of the spoil on the marsh and the invasion of upland plants that can occur with even slight elevation increases (i.e. 1-2 inches) (Miller and Egler 1950, Buchsbaum 1994). Ditching also permits *Spartina alterniflora* to invade the upper marsh (dominated by *Spartina patens* and *Distichlis spicata*) along the edges of the newly created ditches. There is evidence to support the claim that this increases marsh productivity (Buchsbaum 1994).

In 1979, staff biologists from the New England Division of the U.S. Army Corps of Engineers (DeSista & Newling 1979) carried out preliminary investigation in several Massachusetts salt marshes to explore the issue of spoil deposition and upland plant invasion. In many instances they found little plant invasion despite evidence of previous spoil deposition of 2 inches or more in depth on the marsh. In a few locations with minimal tidal influence, some invasion by species such as common ragweed (*Ambrosia artemisifulia*), march elder (*Iva frutescens*), and seaside goldenrod (*Solidago semprevirens*) had occurred over time. However, they concluded that it was not obviously correlated with the spoil itself but was perhaps caused by some other factor associated with the disturbance to the marsh. They recommended the sort of long-term monitoring studies which have as yet not been carried out in Massachusetts salt marshes.

Clarke et al. (1984) studied the effect of ditching and vegetation changes on the use of the saltmarsh by birds in Rowley, Massachusetts. They concluded that bird use of the marsh was negatively impacted by mosquito control ditching. This is in contrast to the studies of Shisler & Jobbins (1977) in New Jersey marshes where increase productivity was observed in ditched marshes. Daiber (1986) noted that, where ditches drain pannes, birds that need a constant water supply (American bittern, pied-billed grebe and American coot) may decline. Also noted was a case where spoil ridges invade by *Baccharis* and *Iva* caused gulls to seek less brushy areas for nesting. Scheirer (1994) encouraged mosquito control programs to develop water management partnerships with the U. S. Fish and Wildlife Service, especially for OMWM-type marsh restorations designed to improve migrant waterfowl habitat.

In a series of investigative reports by staff biologists from the National Park Service, the environmental impact of ditching and diking of salt marshes in the Herring River basin of Cape Cod National Seashore were investigated (Soukup & Portnoy 1983, Portnoy 1984a, 1984b). These reports held that Cape Cod marsh management practices were responsible for the freshening, stagnation, acidification and high sulfate and aluminum concentration in diked marshes. These authors suggest that the destruction of a thriving eel and herring fishery in Wellfleet was the direct result of these marsh disruptions. However, the main dike across the mouth of the Herring River (from Griffin Island to the Mainland) was constructed in 1909 with the main objective of providing for agricultural use of the basin. These structures are not typical of early mosquito marsh management practices in other coastal regions in Massachusetts. The impact may be largely reversible if dikes are removed and normal tidal flow is allowed to return to these areas. OMWM tailored to the unique characteristics of these small estuaries should be explored as a way to manage the *Ae. sollicitans* populations which are likely to replace the present *Ae. cantator* populations if tidal flow and normal vegetation and salinity are restored in these marshes.

Perhaps the most damaging assessment of ditching in salt marshes was the report of Bourn and Cottam (1950) in which they blamed open ditching for converting up to 90% of the *Spartina alterniflora* marsh along the Mispillion River in Delaware to *Baccharis*. However, Provost (1977) reported that the area had returned to *Sp. alterniflora* after navigational dredging of the river had ceased and concluded that it was the dredging of the main channel, not the marsh ditching, which had permitted *Baccharis* to invade the marsh (see Daiber 1986 and Buchsbaum 1994 for reviews of this debate). Arguing against significant water-table lowering in salt marshes is the strong affinity for water exhibited by salt marsh soils. Because permeability is so low, the water table may be lowered only within a meter or so of the ditch itself (Balling and Resh 1982).

Grid ditching, even if not the marsh destroyer some claim it to be, still reduces standing water on the marsh and creates an unnatural and aesthetically unpleasing view. Open marsh water management was designed to more closely approximate the diversity of the natural marsh while eliminating the shallow pannes in which mosquitoes breed.

Wolfe (1996) reviewed the effects of OMWM on numerous tidal marsh resources. OMWM systems tended to enhance tidal exchange and salinity in marshes that were converted from grid ditching. Except where spoil piles were left (improperly) on the marsh, vegetation change was slight and favored salt-marsh species such as *Spartina patens* and *Distichlis spicata*. Small changes in elevation due to spoil deposition sometimes result in invasion by *Iva, Baccharis,* and *Phragmites*. Salt-marsh snails (*Melampus bidentatus*) have declined in some OMWM sites but not in others. Similar mixed observations have been made for marsh periwinkle (*Littorina irrorata)* and fiddler crabs (*Uca* species). Marsh fish populations are, by design, enhanced by OMWM. However, changes in species composition may occur where existing pools are deepened. Mummichogs (*Fundulus heteroclitus*)and spotfin killifish (*Fundulus luciae*) should decrease while sheepshead minnows (*Cyprinodon variegatus*), inland silversides (*Menidia menidia*) and rainwater killifish (*Lucania parva*) should increase (Talbot et al. 1986). The small reservoirs are not particularly attractive to birds and the minor changes in hydrology, flora and invertebrate fauna caused by OMWM do not cause significant changes in bird use on OMWM sites. Effects on mammals are not well documented. OMWM has had no long-term detrimental effects on water quality. As a result, Wolf concludes that, "Open Marsh Water Management is an environmentally focused management tool that is designed to be compatible with nature rather than compete with it." Of course, the technique is new enough that long-term monitoring is required to ensure that altered sites remain functional salt marshes.

b. Freshwater Wetlands (exclusive of Vernal Pools). Palustrine wetlands, including emergent, scrub-shrub and forested wetlands, are the dominant system in which Massachusetts freshwater physical control take place. In the vast majority of cases, this work consists of maintaining existing ditching designed to remove standing water from the wetland, thereby reducing mosquito-breeding habitat. For most MCPs, this type of work (source reduction) makes up a large percentage of their control effort. Though reducing standing water certainly reduces mosquito breeding, there has been little research concerning the overall effects of these alterations on the modified wetland. Ditch systems can become problems in their own right, producing mosquitoes if left unmaintained. Most of these systems were never designed specifically for mosquito control and their other, primary function, such as removing runoff from large parking lots, may cause considerable damage to the ecosystem, leaving the MCP to clean up, or at least deal with, someone else's mess.

The majority of drainage systems currently maintained by MCPs were not initially constructed by MCPs and the effort of MCPs today is almost entirely restricted to removing blockages to existing flows, rather than enlarging or straightening channels to increase flow. Most freshwater drainage is an inherited problem which requires intervention not because of mosquito-control activities but because of the activities of others. Road sand and yard waster represent two of the most common obstructions MCPs are called upon to remove from existing streams and drainage networks. New developments also can cause dramatic changes in the sediment load in streams, despite regulations designed to prevent such problems. Road sand, yard waste and increased sediment load from development can all have impacts on a stream that are as greater or greater than regular ditch maintenance.

Because MCPs are often involved in removing manmade sediments from streams, a system under appropriate ditch maintenance may function more closely to a natural system than one in which manmade wastes are allowed to accumulate unabated. The appropriate response by the MCP in such cases is not obvious because, although the problem, and its cause, may not be mosquito related, the mosquito control program may be the organization best equipped, both from and equipment and a training perspective, to rectify the situation.

Since mosquito control projects came into being in Massachusetts, the perceived values of wetlands have changed. Once shunned as disease-bearing waste lands, best suited for dumping, draining or filling, wetlands are now viewed in a much more positive way. They are important wildlife habitats, perform a myriad of water quality maintenance functions, and serve as flood control, erosion, ground-water recharge and water supply regulators (Tiner 1989). Mosquito control programs have been slow in adapting to the increased value accorded wetlands. On the one hand, long-residual and/or broad-spectrum pesticides are no longer used in wetlands in Massachusetts. On the other hand, there is real resistance to halting maintenance work in drainage networks that may be seriously damaging wetland habitat.

There has not been a great deal of work done specifically on the effects of physical control for mosquitoes on non-target organisms. Therefore the following discussion is based on the general effects that can be expected when wetland alterations are made. Care should be taken in extending these general concerns to mosquito control in Massachusetts. For example, channelization (straightening) of natural streams is not permitted in Masachusetts, where programs are required to follow the natural meanders of the stream. The three broad categories of wetlands alteration are outright loss, changes in the abiotic system and changes in the biotic community. Filling and/or draining wetlands to convert them to upland is a mosquito-control practice that has been all but eliminated in Massachusetts. There is no indication that MCPs are intentionally reducing wetland acreage in order to control mosquitoes. However, the fact that the wetlands boundary remains essentially unmoved by a mosquito-control alteration does not mean that profound alterations have not occurred.

Changes in the abiotic system and biotic community are deeply intertwined, though physical control most often causes abiotic changes which then cause biotic changes. For channels changes in flow rates, microhabitats, sediment load, sedimentation, and groundwater interactions can all occur. For wetlands (outside of channels) changes can include lost water-storage capacity, increased sedimentation and pollutant load, changes in water depth, and changes in groundwater hydrology.

When a stream is altered to improve water flow for the purpose of removing standing water, either within the stream or from adjacent wetlands, a number of changes may take place. By definition, improving water flow increases runoff. This, in turn, may decrease the surface-water storage capacity of the wetland system and decrease the capability of the wetland to retain load (suspended solids). This may increase the load of the water moving through the stream (Brown 1988). Increasing runoff into a given stream tends also to increase erosion, which further increases load (Williams & Feltmantle 1992). Not only is total flow increased, but alteration tends to increase peak flow, which is associated with reductions in faunal diversity (Hynes 1972).

The effects of increased flow and loading are many. At its most obvious, higher peak flows increase scouring of the stream bed by gravel and sand being transported by the water. Bottom dwelling animals are either affected on-site or swept downstream, leaving an impoverished community as flows return to normal (Hynes 1972). Increased flows can also remove organic matter, leaving a sandy bottom on which macrofauna is reduced (Ward 1992). As stated earlier, higher peak flows also encourage erosion, a process that can increase stream load long after sediment controls put in place during the actual drainage work are removed.

High levels of suspended solids alter the stream habitat by:

1. reducing light penetration
2. reducing primary production

3. altering the trophic structure

4. altering nutrient dynamics

5. changing thermal conditions

6. reducing oxygen levels (Ward 1992).

These effects can, in turn can have the following impacts on the stream fauna:

1. abrating respiratory epithelia

2. clogging respiratory structures

3. reducing feeding rates

4. reducing feeding efficiency

5. increasing exposure to toxins

6. reducing vision

7. inducing organisms to drift.

All of these effects can alter behavior patterns, change predator/prey interactions and change the outcome of inter and intra-specific competition (Ward 1992).

Maintenance for the purpose of reducing mosquito breeding also includes removing obstructions within streams. Tree branches and fallen trees are a particularly important part of the stream environment, providing food, living space, concealment from predators, protection from abiotic conditions and emergence sites (Ward 1992). They also provide varied microhabitats by deepening and slowing flow on the upstream side and often creating deeper pools on the downstream side. Removing these obstructions diminishes the variability of the stream ecosystem.

At the other end of the flow-rate spectrum, increasing peak flow may lead to faster drying in intermittent streams. The insect fauna (and biotic community in general) of intermittent streams does not overlap to a great extent with that of permanent streams (Ward 1992). As a general rule, this is because intermittent stream dwellers have evolved to deal with the drying down stream. Survival mechanisms include leaving the stream (swimming down stream or emerging as land-living forms), surviving in crayfish burrows or remaining pools of water, burying either at shallow depths or quite deeply into the substrate or hiding under rocks or leaflitter within or along the stream course (Ward 1992). Streams the dry more quickly, and stay drier longer, may disrupt all of these techniques as insects that emerge as adults may not have enough time to complete development (the primary example being mosquitoes themselves), remaining pools may decrease in size and number and shallow burrows and hiding sites under rocks and leaf litter may become too dry to support the fauna hiding there.

The effect of rapid drying brings up the aspect of the hyporheic zone. This is the interstitial space between the substrate particles in a stream bed. Within the hyporheic zone the macrofauna can find shelter from floods, drought and extreme temperatures, can find suitable and predictable conditions for immotile stages such as eggs, pupae and diapausing nymphs and larvae and, particularly for early instars, protection from predation. Gravel beds provide the best hyporheic zones and animals can often be found many feet down (Ward 1992). This hyporheic zone fauna can be an important source of recolonizing organisms after a stream bed is denuded (Williams & Feltmantle 1992). Excessive drying can reduce the viability of the hyporheic zone.

Sedimentation, both within stream beds and in wetlands into which streams flow, is a problem because it can alter the stream bed composition, thereby altering the fauna, and can clog interstitial spaces, thereby reducing the hyporheic zone and/or reducing groundwater recharge. Sediments can also increase exposure to pollutants as they provide additional sites for pollutant binding while suspended, and then carry the pollutants to the benthic fauna.

MCPs routinely conduct maintenance to remove sediments. Therefore, there is good reason to expect the overall effect of maintenance may be to reduce the negative impacts of sedimentation within the stream. In such cases, it would be preferential to develop systems designed to prevent the deposition of road sand into drainage systems, rather than to prevent the removal of that sand, once it has entered the system. Removing the dense, rotting masses of grass clippings that are dumped into streams by property owners should also improve overall stream quality.

Up to this point the discussion has focused on the stream itself, but freshwater wetland alterations are typically designed to change standing-water wetlands to soil-saturated wetlands (New Jersey DEP 1997). The obvious problem is that any organism that requires standing water for periods other than peak flooding, the wetland may become unusable. Mosquitoes fit this definition perfectly, but so do many other organisms. Many species of amphibians use temporary standing water for breeding and are becoming scarce as these habitats are eliminated.

Increased drainage also may have an effect on groundwater. Precipitation and inflow determine the amount of water initially available to a wetland for ground water recharge (Todd 1972). Increasing the amount of water removed from the wetland prior to percolation downwards can decrease the capacity of the wetland to recharge groundwater supplies. Not only can groundwater recharge within the wetland lowered, it can be lowered with the outflowing stream as well. During peak flows, water moves from the stream into the substrate and raises the water table (increases groundwater). As the flow declines, groundwater percolates back into the stream (if it does not, the stream dries out). By eliminating upstream reservoirs (wetlands), more water flows out of the system initially, leaving less water within the system. As water levels fall, groundwater discharge occurs sooner than might otherwise be the case. If nothing else, stream depth is liable to vary more widely after adjacent wetlands are reduced to soil saturation.

What is most needed is a comprehensive understanding of the true ecological costs of physical alterations for mosquito control. This is particularly important because, although the environmental effects of pesticides receive the lion's share of concern, it is possible that the long-term effects of physical controls may have a greater effect on the environment than does pesticide use (Buchsbaum 1994). This may be especially true today with the switch from broad-spectrum, more-persistent pesticides to methoprene and Bti.

New Jersey has recently updated it's Best Management Practices for Mosquito Control and Freshwater Wetlands Management and Massachusetts should look to such guidelines to establish a protocol for physical control in freshwater wetlands. At a minimum the common-sense requirements that all alterations be planned (not random), necessary, and desirable should be rigorously applied to all MCP water management projects regardless of whether they are defined as new or maintenance work. The North East Massachusetts MCP Standards for Ditch Maintenance (Appendix F) can be viewed as a starting point for a statewide protocol, though it fails to mention the need for sediment controls during maintenance work and leaves the MCP superintendent with wide latitude for determining the necessity of a given project. A response from the Massachusetts Audubon Society (also Appendix F) to these Standards provides additional comments which deserve consideration when a protocol is established.

c. Vernal Pools. Vernal pools form in contained depressions in which water stands for a period of several months, generally from mid- to late winter through the spring. Water either comes in the form of snow melt or spring precipitation or can be a result of a rising water table. Some pools dry down within two or three months, others may only dry when the water table is lower than normal, resulting in a pool that is semi-permanent. Regardless, a key feature of vernal pools is that they undergo periods of dry down. Vernal pools may have permanent inlets but do not have permanent outlets (Kenney 1995).

There are numerous obligate species for vernal pools, the most visible of which include fairy shrimp, the wood frog (*Rana sylvatica*) and several species of salamander (*Ambystoma* spp.).

The Massachusetts Division of Fisheries and Wildlife (Publication #15498-10-600-6-1-88C.R) has created guidelines for certifying vernal pool habitat on the grounds that many vernal pool species cannot successfully survive without vernal pools and that vernal pools are under pressure from continued development within the state. The certification program is coordinated by the Natural Heritage and Endangered Species Program (NHESP - see next section). "Automatic" protection is given to vernal pools only if they

1. occur either (a) within the 100 year inland flood plain or (b) on "isolated land subject to flooding" (as defined in the regulations at 310 CMR 10.57 (2)(b)); <u>and</u>

2. its existence and location has been certified by the Massachusetts Division of Fisheries and Wildlife.

Curiously, upland vernal pools are not granted the same protection but may be certified as vernal pools. The NHESP does not seek out pools to certify; it certifies submissions from the public. A guidebook for vernal pool certification (<u>Wicked Big Puddles</u>) is available to help those who wish to submit a vernal pool site for certification (Kenney 1995).

Mosquitoes, particularly *Ae. canadensis*, also use vernal pools for breeding. From a control perspective, vernal pools are important because, due to increasing protection, vernal pool habitat is often left undeveloped while the land adjacent to the pool is built up. As a result, many new developments surround known breeding sites. Regardless of the wisdom of developing so close to vernal pools, mosquito-control personnel are charged with controlling the mosquitoes coming from the pool.

d. Rare and Endangered Species. Hynes (1972) states three axioms of running water biotic communities:

1. The greater the diversity of the abiotic system, the greater the number of species within the system.

2. The more conditions deviate from the normal, the fewer species will be present, but those remaining will be present in greater numbers.

3. The longer a system is left undisturbed, the richer and more stable is the biotic community.

Operating under the assumption that it is rare and endangered species which are most likely to be lost from the system first, the above statements would suggest that reductions in habitat diversity, alterations from the natural state, and frequent disturbances will all work against these species. Channelization of streams reduces diversity by removing obstructions, straightening the channel and increasing flood levels. Wetlands changed from standing-water to saturated-soil regimes have been drastically changed from their natural state. Maintenance is ongoing, as is the disturbance it causes.

The key question is, however, to what extent does mosquito control contribute to the above problems. First, Massachusetts MCPs do not channelize streams, as their certification manual calls for following the existing meanders. Second, MCPs work neither in historically undisturbed, nor currently undisturbed streams. There is every reason to argue that there is no specific “natural” state that can be assigned a ditch dug by man and intermittently filled with road sand and grass clippings. Even with natural streams, the “natural” habitat in which they flow has long been altered and continues to be altered.

The Natural Heritage and Endangered Species Program (NHESP) was created in order to conserve and protect those plants and animals not hunted, fished, trapped or commercially harvested in the state. The program’s highest priority is to inventory rare and endangered species and to develop conservation plans through research, management and habitat protection for those species. One such program that directly impacts mosquito control is the vernal pool certification program mentioned above.

The NHESP also reviews proposed alterations to wetlands habitats under the Wetlands Protection Act (M.G.L. c. 131, s. 40 and regulations 310 CMR 10.00). NHESP has produced a series of estimated habitat maps for rare and endangered species (Massachusetts Natural Heritage Atlas) which proponents of a given alteration are required to check. Should a project fall within an estimated habitat, NHESP will then determine if the area to be altered is actual wetland habitat for a state-listed species. The results of the NHESP determination are given to the inquiring MCP.

The Massachusetts Endangered Species Act (M.G.L. c. 131A and regulations 321 CMR 10.00) prohibits the “taking” of rare plants or animals. From a mosquito-control perspective, the most important definition of “taking” is disrupting nesting, breeding or feeding sites of animals or killing or cutting a plant. Aside from directly protecting rare or endangered species, this Act also allows areas to be designated “significant habitats.” Alterations in “significant habitats” require a permit from the Division of Fisheries & Wildlife.

In Massachusetts, the species that have caused modifications in mosquito control practices are the Blue-spotted salamander (*Ambystoma laterale*), Mystic Valley amphipod (*Crangonyx aberrans*), and banded bog skimmer (*Williamsonia lintneri*). In addition, ditch maintenance in vernal pond areas has been curtailed to protect this type of habitat. Other animals for which concerns have been raised are the yellow-spotted turtle and osprey.

The presence of a threatened species need not prevent water management, however. In the East Volusia Mosquito Control District in Daytona Beach, Florida, OMWM was carried out in a salt marsh that contained the Atlantic salt marsh snake (*Nerodia clarkii taeniata*). An observer walked in front of the ditching machinery and work was halted until observed snakes left the area. In practice the snakes were difficult to spot and several were seen in the freshly cut ditches behind the ditcher. Two dead snakes were found, and assumed killed by the work. The dead snakes were handled as "incidental take" and placed on ice for delivery to the Florida Game and Fresh Water Fish Commission (Goode 1996). With an increased understanding of the ecosystems in which mosquito control takes place, mosquito control projects should improve their ability to work in areas containing endangered species with minimal impact to those species.

Under the current system mosquito-control maintenance activities are exempt from the Massachusetts Wetland Protection Act, leaving only the federal 401 Water Quality Certification Act and both the Massachusetts and federal Endangered Species Act as methods for regulating maintenance. Unfortunately, water quality, while important, does not address the issue of changing habitat and the presence or absence of a rare and endangered species has little to do with the merits of a given project.

Rare and endangered species will probably increase in their impact for several reasons. First, as data is collected on these species, additional species and additional habitats will most likely come under protection. Second, residential areas are creeping closer to wetlands areas. The net effect is that the clash between economic development and environmental protection will likely increase, with mosquito control being one component of an intense debate. Again, a more comprehensive understanding of the true ecological effects of mosquito control is required to better determine the cost/benefit ratio for different types of mosquito control.

D. Food Web Effects of Mosquito Control.

Throughout their life cycle mosquitoes are a part of the food web, both as consumer s and prey. As larvae most species feed on algae, protozoa, and organic debris (Pennak 1953). As adults they drink nectar and the females of most species take blood meals from a wide variety of animals. Larval mosquitoes are eaten by an impressive array of animals (Bates 1949) while adult mosquitoes are taken by spiders, predatory flies, odonates, bats and birds (Collins and Washino 1985). Given that mosquitoes are so thoroughly embedded in the food web, the question arises as to the effect of removing a large percentage of the mosquitoes from that food web.

At first glance, the effect would appear to be large, particularly in habitats with dense larval populations. However, mosquitoes are r-strategists, in that they produce large numbers of eggs that develop quickly (when immersed in water) to adulthood. Most pest species seek out temporary and spatially disconnected habitats for breeding and can complete a breeding cycle long before an adequate predator complex can develop. Mosquitoes are, therefore, a highly unpredictable food source for predators, and predation rates must be equally unpredictable (this section will focus on predation, as parasites and pathogens are not widespread control agents in Massachusetts). This is borne out by the fact that mosquito predators are generalists which can readily switch to other prey when mosquitoes become scarce (Collins and Washino 1985). In a study in Florida, immature mosquitoes made up over 50% of the diet of several species of saltmarsh fish (*Fundulus confluentus, Lucania parva, Gambusia a. holbrooki*). But each of these species fed on other items as well, including copepods, shrimp, other fish and even some plant material (Harrington and Harrington 1961).

One important point regarding predation and larval broods is that the concepts of handling time and satiation come in to play (Varley et al. 1973). A predator must spend a certain amount of time with each prey. Hydrophilid larvae took several minutes to feed on larvae and pupae taken in a panne in Tiverton, Rhode Island (Christie, pers. observation). Not only does it take time to catch and eat the prey, but invertebrate predators are typically not much larger than the mosquito larvae they are attacking. Satiation must play a role in limiting predator take, particularly when mosquito numbers are high.

Predators can play an important role in regulating mosquito numbers in some situations. That mosquitoes are absent from waters with fish populations is well known. Less well known is the influence of chaoborid larvae, which can severely reduce mosquito populations in vernal pools (Morrison and Andreadis 1990). In this case the larvae are present in snow-melt pools for approximately two months, so predation has time to operate as a regulating mechanism.

Although adult mosquitoes are eaten by numerous predators, it is rare that they make up an appreciable proportion of the diet of any one predator. One exception is the spider *Tetragnatha montana* for which, in Poland, mosquitoes made up 74% in June and 62% in July of all prey captured (Collins and Washino 1985). Bats and purple martins are not effective mosquito predators nor do mosquitoes form a significant part of their diet.

From a mosquito-control perspective, the mosquitoes to be controlled are, for the most part, those which have escaped predation to become predators in their own right. In the absence of scientific data supporting the necessity of mosquitoes in the diets of specific animals, removing mosquitoes from the food web by chemical, biological or physical control remains an easily justifiable activity. Even so, control personnel should take care to avoid chemical applications where mosquito larvae are not present or are present in very small numbers, should use control measures that do not harm existing predator complexes, and should limit control to areas where control is necessary, allowing natural cycles to continue in areas where human activity and the risk of disease transmission is slight. One argument made in favor of Altosid is that it does not kill the young larvae, leaving them available as food for the existing predator complex.

Up to this point, the discussion has focused on the effect of chemical control (including *Bacillus* products and IGRs) of mosquito populations on other species. Within the context of biological control, one of the primary reasons *Gambusia* are not being used in Massachusetts is the fear that they might displace native species of fish, thus altering the natural biota, not by predation but by competition for the same resource.

Physical control by water management may increase predation, as in OMWM, or may eliminate predator and prey as when wetlands are drained to soil saturation. Mosquito breeding must be thoroughly documented before new work is done. Because disturbances may displace some species, and because predator species tend to rebound more slowly than their prey, maintenance work should be conducted only when necessary.

E. No Program

Another alternative strategy to current mosquito control practice is no control. Many communities in Massachusetts have chosen this option. These town are usually outside of the enzootic EEE zone so the risk of human diseases transmitted by mosquitoes is viewed as practically nil by these communities. In addition, they are not located near salt marshes and their attendant pest mosquito problems. The mid-section of Massachusetts, where most no-control communities occur, also has a more rural character, less wetland , lower human populations, and a lower mean family income than most eastern areas with organized mosquito control programs. In general, the view of these communities is that the anticipated benefits from mosquito control do not outweigh the anticipated costs and perceived risks.

A more precise way of polling the public and confirming this opinion would be through establishing the Human Annoyance Threshold (HAT) for the town. Communities in which the HAT is below the actual annoyance level should be persuaded to choose the no control option since justification for control is lacking unless a documented disease threat exists.

In some communities, biting annoyance is created by a combination of biting insects (i.e. mosquitoes, black flies, biting midges and tabanids) which require completely different control approaches. Many people do not recognize the difference between these insects, especially in dim evening light. It is critical to accurately identify the biting insects actually responsible for the human annoyance. In general, black flies and tabanids only cause annoyance during the daytime while mosquitoes and biting midges are most annoying from 6-10 PM. The HAT level for tabanids and biting midges is likely to be less than for mosquitoes because of their more painful bites.

Perhaps part of the reason why Berkshire County communities have supported a MC program while other Western Massachusetts communities have not, lies in the fact that this region supports many summertime outdoor activities (e.g. camps, resorts, golf courses, Tanglewood, etc.). In addition, this more mountainous region has a significant black fly annoyance problem superimposed on top of the mosquito problem. Vacationers are likely to have a lower HAT than permanent residents since they are spending more time and money on outdoor recreational activities.

In addition to risk-benefit considerations, other criteria for weighing the control/no control option are 1) the feasibility of successfully reducing annoyance below the HAT level, and 2) the adequacy of community resources for reducing annoyance to acceptable levels.

Towns with large areas of mosquito-producing freshwater wetland should recognize that effective mosquito control in these habitats is difficult at best and often impossible. As indicated earlier in this report, permanent wetlands do not usually produce large numbers of pest mosquitoes but in situations where they do, the public needs to be aware that these wetlands are a valuable resource that must be protected from significant perturbation and that options for mosquito control are therefore few. Community planning boards and zoning laws can and should be used to restrict residential development and other human activities from such wetland areas.

Towns with annoyance problems but with large land areas and thinly, scattered populations must understand that the same level of mosquito control achieved in more populated communities will cost them significantly more per capita. In many such cases, the economic status of the population means that insufficient tax dollars can be generated to adequately deal with the problem.

Nantucket provides an interesting case study. Mosquito control had lapsed in the early eighties. However, by 1989 saltmarsh mosquitoes were becoming a significant problem in the west and north areas of the island. The town began applying Altosid (including aerial applications of pellets in 1992) to control the mosquitoes while. getting the requisite permits for OMWM in several west-end marshes (Madaket, Warren's Landing Eel Point). The OMWM systems were dug in January 1993 (Christie 1993). It was hoped that the OMWM alone would be sufficient to control mosquitoes but large-scale breeding continued in the north end (Pocomo) and the low tidal range has hindered the effectiveness of the OMWM as dug. As a result, some lariviciding continues. The conclusion on Nantucket is that mosquito control against saltmarsh mosquitoes must be continued at some level in order to provide residents with the summer environment they want. However, Nantucket does not target freshwater mosquitoes at all and does no adulticiding. Nantucket and Cape Cod together indicate that adulticiding is not a requirement even in high-tourist areas.

It is difficult to measure the impact of choosing the no control option. The example of towns that have left, and left and later rejoined MC projects is perhaps the only available basis for estimating public opinion concerning such impact. No documentation of annoyance levels, cases of disease, recreational dollars spent, etc., was ever attempted in these towns when they had mosquito control versus when they did not. Thus, public complaints were apparently the main indication of the impact of the no control option that was used in guiding town decision making.

In the 1986 questionnaire, only about 10% of the towns in organized projects indicated that there had been controversy relative to leaving, joining, or rejoining a project. Those that had experienced controversy indicated that 4 factors were about equally involved. These were: 1) monetary constraints, 2) concern over the effectiveness of project control programs, 3) concern over the safety of the methods used by the project, and 4) concern over the environmental impact of the control procedures. Paradoxically, 86% of these towns indicated they were unwilling to spend more money (if legally possible) to obtain more effective control and 67% indicated unwillingness to spend more money to support less hazardous control methods. However, the bias of the people filling out the questionnaire sent to each town may have influenced these responses; no town in Massachusetts has actually polled their citizens on these questions. In fact, some towns within projects have taken advantage of new provisions which allow towns to collect additional money for MC activities which projects can then only spend in these towns.

Among towns that actually withdrew from MC programs, monetary constraints played a role in 73% of these decisions, followed by environmental concerns in 32% and concern over effectiveness in 27% of these cases. Towns that contemplated withdrawing but did not do so, indicated that monetary and effectiveness considerations dominated their concern.

The number of towns in MCPs declined in the late eighties. Economic factors, not environmental concerns, were the dominant reason given for withdrawal. This trend has reversed itself significantly in the last several years. The 1990 EEE problem is probably one reason, coupled with the fact that several coastal programs tried the no-control option and found mosquito numbers rose quickly.

Many towns in the Berkshire County and South Shore projects withdrew in 1981 mainly in response to Proposition 2-1/2 monetary constraints. The remaining 8 towns in Berkshire County subsequently chose to continue as a multi-town Project (Note: the town of Lanesborough rejoined in 1986, the city of Pittsfield rejoined in 1988, and other towns are contemplating reentry). South Shore actually disbanded as a project but by 1988 most towns had joined neighboring MC projects in Norfolk and Plymouth Counties. These actions suggest that these communities were not content with the no control option that resulted from the disbanding of their former project. Towns that voluntarily withdrew from MC projects but then later rejoined a project, did so for a variety of reasons. These were in order of their importance: increased public support for MC, increased mosquito annoyance, alleviation of monetary constraints, threat of EEE, improved methods and effectiveness of the project.

The Environmental Impact Statement (Sjogren 1977) prepared for the Metropolitan Mosquito Control District in Minnesota attempted to quantify the no control option for their community. Any attempt to develop similar estimates for Massachusetts would be meaningless given the lack of appropriate baseline data.

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

Natural Wetlands. 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.

Reservoirs and dug ponds. 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.

Storm catch detention and retention basins, ornamental pools, tires, and other man-made containers. 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.

VII. STANDARDS FOR MOSQUITO CONTROL

A. Standards for Monitoring and Control: Pesticide applications in an IPM program require monitoring insect populations and comparing data with pre-established thresholds for treatment. In addition, post-treatment evaluation is required to ensure the treatment worked as planned and did not have unintended side-effects.

1. Larval Populations: The primary technique for larval population counts is the dip count. It is hard to standardize dipping technique but, for the purposes of this document, it is assumed that dips are taken in undisturbed pools (the field person is aware that disturbing the water and/or casting a shadow over the water will cause mosquitoes to dive, thereby lowering counts) known by the field personnel to be typical of the breeding area being monitored. For large-scale work, dipping will be done at permanent, marked (or easily located) dip stations. For small sites such as drainage basins and woodland pools, dips will be taken at random throughout the site. Up to twenty dips per site will be taken unless the count for treatment and/or water management is exceeded with a smaller number of dips. Specifics for various types of work are given in Table 17.

a. Larval Identification. Field identification of larvae to genus is desirable. The following genera should be recognizable most of the time: *Aedes, Anopheles, Coquillettidea, Culex, Culiseta, Psorophora,* and *Uranetaenia*. Programs should rear out sufficient numbers of larvae (or identify larvae to species) to allow correlation between adult mosquito species and larval populations. Because there may be situations where treatment will depend on the species (as opposed to the genus) present, programs are encouraged to have a staff member trained in larval (4th instar) identification

b. Pre-control Larval Monitoring. Larval populations are monitored to determine whether or not control is required and, if so, whether short-term or long-term control is preferred. Criteria for water management in salt marshes are given in more detail in Appendix D. Projects should develop their own criteria for freshwater water management work, though some guidelines are given below under standards for physical control.

Table 17. Specifics for monitoring larval (& pupal) populations of mosquitoes for determining control.

	No Treatment	Pesticide Application	Water management	# Sites for large-scale work
Salt Marsh	<1 per 10 dips	1+ per 10 dips	5+ per dip[a]	1 dip station per 250 acres
Freshwater				
Ground	<1 per 5 dips	1+ per 5 dips	Variable	Not applicable
Aerial	<1 per 10 dips	1+ per 10 dips	Not applicable	1 dip station per 250 acres

[a]Numerous additional factors go into determining water management options for OMWM.

c. Post-control or post-alteration monitoring will be conducted as follows:

Treatment Technique	Evaluation Sites	Time Period	Number of Dips
Aerial applications	each dip station	within two business days.	Ten dips
Ground applications	one of every ten sites	within two business days	Ten dips
Water management	each dip station	for two years post-alteration	Three dips

d. Additional Water Management Requirements. Projects have an obligation to ensure that all alterations function as intended without adverse effects on the environment. Post-alteration work for water management (Appendix 4 for OMWM) will also monitor vegetative re-growth, changes in fauna and notes on whether or not the hydrology of the site is as intended.

e. Pre-hatch Work. On occasion, pre-hatch treatment is desirable. In such cases, the project should have historical data that establishes a pattern of breeding at a given site. Pre-treatment work is limited to Category IV larvicides.

2. Adult Populations. No adulticiding program will be conducted on a routine, pre-scheduled basis (i.e. once per week, regardless).

a. Monitoring for Adulticiding

Monitoring Mechanism	Rate to trigger adulticiding
Light traps	Human-biting mosquito counts exceed five per night
Landing counts	Landing count rates exceed one per minute
Complaint calls	When complaint calls exceed two per geographical area (this area will vary but assume approximately one square mile)

b. Considerations for adulticiding. Adulticide applications for mosquito control require particular care as they are generally made with rather broad-spectrum pesticides (for example, resmethrin is of concern near fish waters) in areas of high human use. Pesticide aerosols, while an effective technique for using small amounts of pesticide to impact large numbers of mosquitoes, also increase concerns over drift into non-target areas such as apiaries and organic farms. As is always the case, reading and following the pesticide label is essential. Also, adulticide operators should have a map of no-treatment zones with them on their routes and they should be aware of variations in weather conditions (high wind) that would affect, or even cancel, a treatment.

c. Further notes on complaint calls. Because different people complain at different mosquito population levels, program personnel will conduct landing counts and/or place light traps within adulticide zones at intervals throughout the season to determine what mosquito population levels are triggering what levels of complaint calls. Chronic complaint callers should be checked by conducting landing counts and/or hanging light traps at the location of the complainer.

d. Adult Identification. Light trap mosquitoes should be sorted and up to 100 individuals (randomly selected from the larger pool) should be identified, where possible, to species. If trap counts are being used to monitor water management work, species identification (particularly of *Aedes*) is more critical than if traps are being used for adulticide monitoring.

At least ten mosquitoes from each landing count should be identified to species.

Complaint callers should be asked the time of day at which biting occurs.

e. Post-Adulticide Monitoring. Although determining the exact effect of a given adulticide application is difficult, projects should increase their efforts to understand the impact of adulticiding on mosquitoes. Projects should cross-reference complaint calls with adulticide applications and record the number of calls coming in the week before an application and in the following week (this work may be done during the winter for the previous season). In addition, projects should conduct before and after landing counts and/or light-trap counts for ten percent of their adulticide applications. Landing counts should be taken within 48 hours pre- and post-application at the same location both times. Light trap samples should be from the same trap and for the same time period before and after treatment. Where possible, non-treated areas similar to the treated area should be checked to determine population trends outside the spray zone.

Projects should keep a log of complaint calls received post-treatment Such complaints may be of non-target effects such as fish or bird kills, or of human exposure to the treatment. While establishing a link between an adulticide application and a specific problem is very difficult, such complaints may provide insight into the efficacy of the application or may alert control projects to problems with spray equipment, treatment timing and/or treatment area.

C. Standards for Physical Control. Altering or eliminating mosquito breeding sites range from proper disposal of tires through analyzing drainage systems to creating entire new open marsh water management systems.

All mosquito control programs should create a map of their area of responsibility on which they have roughly demarcated endangered species estimated habitats and significant habitats as listed in the Natural Heritage Atlas. This should be referred to before any maintenance or new work is done and specific maps within the Atlas checked when work is taking place near such an area. Any work with such an area, must go through NHESP.

For this section Physical Control refers specifically to alterations to breeding habitat to prevent mosquitoes from maturing to adulthood. Physical Control is divided further into three types:

Source Elimination: Completely eliminating the breeding site not just the mosquito breeding. Source elimination is generally limited to breeding habitats created by humans in non-wetland areas.

Source Maintenance: Maintaining potential breeding sources in such a way that mosquitoes cannot become a problem.

Source Reduction: Reducing the ability of an area to breed mosquitoes. It differs from source maintenance in that the existing habitat is breeding mosquitoes whereas, if a maintenance program is running as designed, mosquito breeding should not occur. Once a source reduction project is completed, it will, in most cases, require at least some source maintenance in order not to return to being a mosquito-breeding habitat.

Although the three types of Physical Control blend into one another, there is value in recognizing the difference, particularly between maintenance and reduction. Here the critical issue is the need to document mosquito breeding. While unwarranted ditching is not desirable, neither is it desirable to prevent maintenance of existing ditching to the point where mosquito breeding begins in an area that has been mosquito free in the past. It is important to stress that no mosquito-control activity that would result in the permanent loss of true wetland (as opposed to temporarily flooded areas resulting from human mismanagement) can be accepted as a standard practice.

1. Source Elimination.

a. Tires. All mosquito-control programs should have a system in place for contacting departments of public works within the project so that the tires can be removed. Where tires are being intentionally stored, projects should attempt to contact the property owner and explain the breeding potential of the tire dump. Projects are not responsible for ensuring compliance with tire-disposal regulations; their sole responsibility is education of property owners and notification of appropriate local authorities.

b. Blocked drainage. In this situation, the assumptions are that the stagnant water would not be present if not for the blockage and that the drainage in question has not been part of an on-going maintenance program (see source maintenance below). In this case, mosquito breeding must be documented within the blocked ditching for mosquito control programs to re-open the ditch (without mosquito breeding the ditch may be re-opened by Highway or Public Works Departments for drainage reasons).

c. Residential problems. Such situations would include pools, refuse dumps, tire tracks, and other localized, man-made problems. As is the case with tire removal, projects can only advise property owners of the breeding potential and/or notify the appropriate authorities of a problem.

d. Drainage basin design. A primary tenet of IPM is to avoid creating pest problems through good planning. Projects are strongly recommended to make available to local agencies the specifications for drainage basin design located in Appendix 5. Projects should evaluate various basin designs for breeding potential and should educate local officials about the problems basins can cause.

2. Source Maintenance

a. Stormwater runoff and ditch maintenance. A primary goal of any mosquito control program is to monitor existing drainage to ensure that it is working as designed. Within existing drainage, any blockage may be removed regardless of mosquito breeding. As an example of the type of guidelines projects should use for this type of work, the standards for the North East Massachusetts Mosquito and Marsh Restoration Project are given in Appendix F.

Record keeping for maintenance purposes should be improved. Projects should maintain at their headquarters a list of all drainage that is monitored and maintained. This list should include location and approximate cross-section and length. Projects should also maintain a record of when and where maintenance was done. In instances where ditching has not been maintained, and no historical documentation of maintenance exists, the projects should request a review of the proposed work by DEP's Water Quality Certification program to ensure compliance.

In the long run, projects should develop priority lists for ditch maintenance based on the potential for mosquito breeding, the proximity of human activity, the ecological cost in reduced wetland benefits from the area being drained, and the relative value or scarcity of the wetlands resource affected. Maintenance should be based on breeding potential and ecological factors.

Drainage basin maintenance is also included within this area. Some basins that do not produce mosquitoes when maintained properly, will become breeding sources if left unmaintained. Projects should conduct yearly checks of drainage basins to ensure that pooling within the basin is not increasing to a point where breeding may occur. In deeper basins, invasion by cattail or emergent grasses might also create breeding habitat.

Basin ownership and maintenance responsibility are often difficult to determine. Mosquito Control Programs need to remind the appropriate authorities that basin maintenance is an important issue and should be monitored by the Building Inspector's office or other responsible agency.

b. Salt-marsh Ditching. It is generally not recommended that the open ditch systems be maintained as is. however, projects will self-determine the need for maintenance of existing ditching versus conversion to OMWM, understanding that conversion is preferred.

c. Waste Disposal. Projects are not responsible for waste disposal but they can and should monitor areas known for problems with either tire dumping and/or improper general waste disposal, particularly where it blocks drainage. The purpose of this work is not to get projects involved in policing dump sites, but rather to get them to move from a passive strategy of treating known tire piles to an active strategy of eliminating such areas and preventing their return.

3. Source Reduction.

a. Open Marsh Water Management. Open Marsh Water Management (OMWM) is the preferred technique for salt-marsh source reduction. When done properly, OMWM can result in virtual elimination of breeding without any loss of wetland. Although each project with salt marsh will develop its own standards, the standards of the North East Massachusetts Mosquito Control and Wetlands Management District are included as Appendix 4 as guidelines for establishing an OMWM system that will comply with all state and federal regulations.

New open tidal ditch systems are not recommended except as an integral part of an OMWM system.

b. Freshwater wetlands. Source reduction in freshwater systems, exclusive of existing drainage networks, does not have an equivalent to OMWM in salt marshes. At this time there can be no standards for water management within freshwater systems except that any such work must be evaluated by the appropriate authorities on a case-by-case basis.

An additional consideration is wetlands replication, the process by which existing wetlands may be altered and new wetlands created. While mosquito control projects should not be the authors of such work, they will be involved in monitoring such areas. Further, reclassifying some areas as wetlands replication sites may well alter the extent to which water management work and/or larviciding can or should be done. For this reason, projects should be made aware of all wetlands replication projects. As with drainage basin design, projects should likewise develop a working relationship with town Zoning Boards and Building Inspectors so that mosquito control programs are included in the review process for wetlands restoration, replication or creation projects.

c. Cattail control. In order to prevent increases in *Coquillettidea perturbans,* projects should discourage the creation of deep-water (two feet plus) cattail marshes (Drainage basins) in residential areas. Failing in that, projects should request that such marshes be designed so that water may be drained from the marsh for a period of several weeks in late summer.

D. Standards for Biological Control.

1. Larvivorous fish. OMWM is dependent on native fish immigrating into the newly created ditch and reservoir system. Projects should explore the idea of stocking native fish species in deep-water drainage basins.

2. Other biological control agents. Exclusive of the Bti and *Bacillus sphaericus* products (listed here under pesticides), there are no current biological control agents available for use for mosquito control in Massachusetts other than larvivorous fish. Mosquito control programs in Massachusetts are not research institutions and cannot be expected to develop biological control agents without extensive research support. Should research uncover possible control agents, projects are encouraged to experiment with them.

E. Standards for public notification, public awareness and education.

1. Public Notification.

Projects must comply with regulations for aerial applications of pesticides.

For truck-mounted adulticiding, projects should notify the public through the print media, between March 1st and May 1st of each year, as to the areas that may be treated, the pesticide to be used and a number to contact for more information or to request exclusion from treatment.

All projects should maintain, either at their headquarters or at a designated public library, a copy of this GEIR and copies of the labels and MSDSs of all the pesticides they use. it is further recommended that they include copies of any educational materials they have put out.

2. Public Awareness and Education. As education is a primary aspect of an IPM program, projects are encouraged to develop educational flyers covering such aspects of their work as pesticide use, water

management, and property-owner mosquito control. Flyers may either be developed in-house or be obtained from the state or other agencies. Examples of educational materials may be found in Appendix 7.

3. Staff Development. Aside from the pesticide applicator recertification requirements, programs are urged to provide opportunities for staff to increase their knowledge about mosquitoes, wetland, and mosquito control. Membership in professional organizations, accessing information through university Libraries or the Internet, and developing good working relationships with federal, state and local officials whose tasks overlap that of mosquito control are all good ways to improve the knowledge and performance of staff.

F. Standards for EEE monitoring and DPH liaison.

1. Role of Programs in EEE Surveillance.

The MA DPH in cooperation with the Executive office of Environmental Affairs (EOEA) and the regional mosquito control districts of eastern Massachusetts developed the "Vector Control Plan to Prevent Eastern Equine Encephalitis (1991, currently being revised). This plan outlines and defines policy for vector control of mosquitoes that transmit the EEE virus and provides guidance for the coordination of state, regional, and local efforts during EEE outbreaks, This plan requires the active cooperation of MCDs in the EEE Risk Area. At clearly defined levels of EEE risk, based upon surveillance data collected by DPH, MCDs are asked to assist DPH in assessing vector species abundance levels and control options in their communities. The cooperative efforts of the MCDs working with DPH helps effect targeted, species-specific vector control when warranted. At the Level of EEE Public Health Emergency (see Appendix B), the MCDs work in conjunction with DPH to carry out all phases of the control effort.

2. Standard Operating Procedures during EEE problem.

When surveillance data points to increasing levels of EEE risk, DPH notifies the SRMCB and regional MCD superintendents. The EEE Surveillance Program informs MCD superintendents of isolations of EEE in their districts and the districts, in turn, provide feedback to DPH regarding population and life stage indices for critical mosquito species. At certain defined interim levels of risk as outlined in the "Vector Control Plan," MCDs may be asked to increase their ground control larvicide and/or adulticide applications in response to increased EEE virus activity. The SRMCB is responsible for contracting with appropriate mosquito control applicators in the event that aerial EEE vector control is recommended by DPH.

VIII. SUMMARY AND RECOMMENDATIONS

A. Legal, Organizational and Fiscal Aspects of Massachusetts Mosquito Control

The organizational structure and funding for Massachusetts mosquito control programs, be they regional or town based, rests predominately at the level of town government, although the state legislative bodies have a direct influences over eight of the nine MCPs' annual budgets (only East Middlesex is not so affected). In contrast, the overseer of mosquito-control activity in Massachusetts is the State Reclamation and Mosquito Control Board. This is a loose arrangement for delivering a public service that is best applied at a regional level. Lack of control effort in one town can greatly effect the efficiency of control efforts in neighboring towns.

Enabling legislation has been written in a patchwork manner so that there is currently little consistency from project to project. For example, towns in Barnstable County (and formerly in Berkshire) are all members of their respective regional MC project and no individual community may withdraw from the program without changing the legislation as did Chap. 119 of the Acts of 1982 in the case of Berkshire County. This provides an assurance of fiscal and organizational stability that is lacking in other programs. For example, the Essex County and Central Massachusetts projects both went through considerable upheavals in membership between 1988 and 1993. Fortunately, the other projects have remained remarkably stable over the past decade. Maintaining and improving stability, both in membership and funding, is a desirable goal.

This uncertain fiscal picture is further compounded by the fact that all MC projects in Massachusetts are seriously under-funded. In other states, with progressive MC programs, the per capita expenditure varies from $2 upward. In Massachusetts, it averages about $0.50 (based on $2 per household of 4 people). In addition, many other states provide supplemental state funds to encourage non-chemical control efforts and for supportive research and educational activities. No such state support exists in Massachusetts. When supplemental state support has come, it has been for chemical adulticiding in the wake of EEE threats.

To a large extent, funding dictates the control approaches that can be pursued. IPM, source reduction, 1arval control, and adult control represent the four major options in their order of decreasing cost and efficiency. Thus, poorly funded programs are forced into more reliance on less efficient and more controversial techniques. Larger, better-funded, and stable regional projects can invest in better paid and trained employees, better surveillance and public education programs, and expensive equipment such as helicopters which can broaden the options for safer and more efficient larval control (e.g., granular larviciding with Bti and methoprene).

Given the fact that several different state agencies are concerned with mosquito control activities, the current system of interagency responsibility for overseeing MC activities (i.e., State Reclamation and Mosquito Control Board representing 3 different state agencies) is perhaps the best compromise arrangement. On the other hand, the level of general support services that projects and towns receive from this Board seems to be inadequate.

<u>Recommendations</u>

That new and comprehensive enabling legislation be drafted, reviewed, appropriately revised, and passed into law, which will bring all MC control activity in Massachusetts under the same organizational, fiscal and operational guidelines. This legislation should provide for the following:

1. The State Reclamation and Mosquito Control should have the following personnel:
   a. An Executive Director @ approximately $45,000 per year
   b. An Engineer @ approximately $35,000 per year
   c. An Entomologist @ approximately $35,000 per year

   Not only would this staffing permit the state to conduct research into mosquito control, it would provide a team for rapid response to EEE threats in communities that are not members of established MCPs. This staff would also provide services such as incorporating DEP stormwater management guidelines into Massachusetts MCP Upland Water management operational procedures.
2. An operations budget, above and beyond the normal needs of the SRCMB, for research and development. A minimum of $50,000 per year is suggested.
3. A competitive grant fund (funded by the state, administered by the Executive Director of SRMCB and advised by an ad hoc panel of outside experts) to support IPM related research and delivery programs within the state mosquito control enterprise. This should provide support for studies such as: cost/benefit analysis of mosquito-control programs; development of human annoyance thresholds (HAT); improved methods for monitoring and predicting mosquito population levels; development, evaluation, and implementation o£ new, non-chemical mosquito management techniques (e.g., open marsh management and biological control); management of pesticide resistance, drift and other use exposures; impact of MC activities on surface and ground water,

and on non-target organisms; and the biology and role of selected species in disease transmission.

4. The SRMCB should establish a committee to work with their staff to develop best management practices (BMPs) for all aspects of mosquito control, the results of their work being used to update the GEIR on a regular basis. The committee should include four mosquito-control superintendents, four representatives of environmental agencies (federal, state or private) and one at-large member to serve as chairperson. Their first order of business should be to develop a set of BMPs for freshwater drainage maintenance for mosquito control. These BMPs should establish strict definitions for projects in which the mosquito control exemption from the Wetlands Protection Act may be applied.

5. MCPs must have the authority to deny requests for maintenance work that does not have a mosquito-control component. Because these requests are often made by the same persons or municipalities which provide funding to the MCPs, the SRMCB must be willing to act as an appeals board, to which a request for work may be sent by an applicant in the event the mosquito control program denies the request.

6. Limit mosquito control activity to regionally based regional mosquito control programs which can be organized by the appropriate public vote. The SRMCB should organize the regional based mosquito control programs and appoint project or district commissioners. The SRMCB should select Commissioners from candidates proposed by authorized Boards/individuals from the cities and towns of the mosquito control projects or districts.

7. A flexible and appropriate system of tax assessment which allows for budgets that are adequate to provide for the implementation of the most contemporary and least risky strategies for controlling mosquitoes.

8. A legal system whereby all major zoning and construction plans in the Commonwealth are reviewed by the executive director of SRMCB and the appropriate county MC director for their potential impact on mosquito populations and human health.

B. Operational Aspects of Massachusetts Mosquito Control

Operational programs in Massachusetts could legally be using chemicals (approved by EPA and the Massachusetts Pesticide Board) that are significantly more hazardous than those used in current practice. This suggests that knowledge and sensitivity for the environment and human safety are generally being considered by the existing control programs. As already indicated, funding levels seldom allow projects to follow the optimum operational course. Despite these fiscal constraints, projects have significantly changed their operational methods in recent years toward more source reduction work such as the Open Marsh Water Management projects in Essex, Norfolk and Plymouth Counties. Most projects also use more selective and environmentally compatible larvicides such as Bti and methoprene.

The operational recommendations that follow are predicated on additional and adequate funding being available for implementation.

Recommendations

1. All MC Projects should build their programs around the IPM strategy of keeping human annoyance below threshold levels as given in the Standards of this GEIR.
2. Control methodology should be source reduction whenever possible and larvicidal control when it is not. Projects should work closely with the DEP water quality certification program and the Natural Heritage Endangered Species Program to minimize negative impacts of source reduction to wetland habitat and/or rare or endangered species. The most target-selective and environmentally compatible larvicides (e.g., Bti, methoprene) should be used whenever possible regardless of cost considerations.
3. Saltmarsh mosquito control efforts should emphasize OMWM. All OMWM proposals should include plans for filling many of the old grid ditches in Massachusetts salt marshes which do not function in a productive way and which must regularly be cleaned in order to prevent breeding in the ditches themselves. This will gradually eliminate the controversy over the continuing need to clean these ditches and the problem of what to do with the resulting spoil that is created.
4. Document location, length, and cross-section(s) of all drainage systems maintained by the project and have that information available in an easily understood format for public inspection. Exemption from the permitting process extents only to those drainage systems for which adequate historical records of maintenance work exist.
5. The SRMCB should create a list of pesticides approved for mosquito control in Massachusetts. Adulticides should be from Categories III and IV and larvicides should be from Category IV.

6. Adulticiding should only be carried out in emergency situations involving disease threats or pest densities which consistently exceed the human annoyance threshold.

7. For large-scale adulticiding, only ULV-cold fogging should be used. For spot treatment around recreation areas or other areas where public events are to be held, portable mistblowers using permethrin as a residual pesticide can be used.

8. Aerial applications should be restricted to granular formulations in areas where drift could be a significant problem. Sometimes some drift is desirable so as to reduce the chance of gaps between application swathes. In such cases a liquid formulation may be a better choice. At this time liquid formulations are also significantly cheaper, making larger applications, and more effective control, easier. Increased use of helicopters for aerial larviciding in coordination with the use of drift-suppression agents and technologies should be encouraged (particularly for enhanced larval control in inaccessible habitats such as salt marshes, wooded swamps, vernal pools, etc.).

9. Projects should file a post-treatment report for aerial applications with the Pesticide Bureau which gives location and acreage actually treated. The pre-application forms do not always accurately represent what actually happened.

10. Chemical-use reporting needs to be monitored to ensure uniformity and accuracy in reporting. Previous reports contained such problems as no units are given on the 1993 through 1995 Cape Cod report for Bactimos (BTI), two different EPA registration numbers for Bactimos are given in the 1993 Cape Cod and Central Massachusetts MCPs reports, and briquets are variously reported in terms of number of briquets, pounds of briquets or pounds of active ingredient. The Pesticide Bureau should insist that yearly chemical-use reports be filled out according to standardized procedures. Reports should be checked as they come in to ensure that standardized reporting procedures are followed.

11. All pesticide storage areas should be equipped with smoke, fire and security systems. A standard procedure should be developed for the disposal of all insecticidal materials used in Massachusetts for mosquito control. The State Pesticide Board should encourage manufacturers of such products to market reusable containers. A standard procedure should be developed for the clean-up of

accidental spills of insecticides. Proper use of absorbent materials and the disposal of such materials are necessary. Proper attire during formulation and application of insecticides should be made mandatory for all individuals involved in these processes.

C. Research Needs

There is a need in the mosquito control process in Massachusetts for a strong, operationally focused, research effort in freshwater wetlands, exclusive of chemical application techniques. This is not to condemn current research efforts, for we know more about EEE mosquitoes than ever before, have improved saltmarsh mosquito control dramatically, and have made improvements in both chemicals used and methods of chemical use over the past decade. But there is a need for research to assess the environmental impacts and efficacy of the current MCP programs relative to the freshwater environment.

Additional research on topics such as long-term effects of OMWM, economically viable control of *Cq. perturbans*, and mosquito control in endangered species habitats also require attention.

Recommendations

1. For water management practices, monitor impacts on animals on a case-by-case basis, depending on the site and establish vegetation transects to document changes in wetland vegetation.
2. Develop a unified data base that documents mosquito populations on an ongoing basis from regular monitoring sites. Establish state standards for monitoring mosquitoes and provide training to mosquito control project staff in data collection and management.
3. Conduct comparative studies with different management approaches (e.g. pesticide applications vs. water management).
4. Develop a Geographic Information System (GIS) with known breeding sites and areas of historical water management activities.
5. Qualify sites on the basis of need for control, based on breeding (potential or actual), mosquito species, proximity to human activity, level and type of human activity, and type of wetland habitat affected.
6. Create an ongoing research partnership with NHESP to document wetland types, etc.. Mosquito Control Projects have knowledge and expertise about wetlands that could be invaluable to NHESP.

IX. WRITTEN COMMENTS ON GEIR

NOTE: CONTACT THE STATE RECLAMATION AND MOSQUITO CONTROL BOARD TO OBTAIN COPIES OF THESE DOCUMENTS

A. Comments on Notice of Project Change (1996).

B. Comments on Spring 1997, Rough Draft.

C. Comments on Final Rough Draft (1997-98).

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APPENDIX A

GENERAL ENVIRONMENTAL IMPACT REPORT

1996 QUESTIONNAIRE
MASSACHUSETTS MOSQUITO CONTROL PROGRAMS

NOTE: CONTACT THE STATE RECLAMATION AND MOSQUITO CONTROL BOARD TO OBTAIN COPIES OF THIS DOCUMENT.

APPENDIX B

DPH EEE RISK ASSESSMENT, RISK CATEGORIES, STRATEGY FOR VECTOR CONTROL
(from the Vector Control Plan to Prevent EEE)

VI. RISK ASSESSMENT

The potential risk for EEE disease in humans is categorized into one of four levels according to an assessment of EEE surveillance data from the current and previous year. The risk levels are (1)Low (2)Moderate (3)High and (4)Public Health Emergency. Under Risk Levels 2, 3 and 4, the characterization of risk includes a definition of areas of concern. The concept of "area of concern" is important in defining the magnitude of the EEE risk and selecting appropriate intervention options. There are three components within the conceptual construct of area of concern: study area, risk area and treatment area.

(1) The study area is the geographical area where most human and equine EEE cases in Massachusetts have occurred. This area is shown in Figure 3 and includes Plymouth, Norfolk, Suffolk, Bristol, Middlesex and Essex Counties. Personal protection measures are emphasized in this area through a public information campaign that intensifies at each level of risk.

(2) The risk area is the geographical area where most of the human EEE cases have occurred. This area is shown in Figure 4 and includes Plymouth, Bristol and Norfolk Counties, and parts of Middlesex and Suffolk Counties. Vector control efforts may be implemented by state agencies or Regional Mosquito Control Districts within this area. Vector control efforts may be extended outside of this area, if surveillance data indicate the probability of multiple human EEE cases occurring outside the area of historical disease prevalence.

(3) Treatment areas are defined by EEE surveillance data and are used to guide vector control efforts. The basic cell is defined by a mosquito trap site and is approximately 100,000 acres. These treatment cells are calculated to be the set of "best-fit" polygons that represent the areas around trap sites. The area for treatment will be defined by the GIS polygon inclusive of all towns with more than 20% of their area within the unit. Vector control intervention will be dependent upon viral isolation from mosquito pools trapped at the DPH site. The treatment area for a positive EEE virus isolation from a horse or human is defined by a circle approximately 2 miles in radius around the case. Within a treatment area, larviciding is recommended in areas where significant

levels of vector species larvae are present, and treatment would be expected to reduce adult emergences in proximity to large numbers of people. Adulticiding of a treatment cell is recommended if predetermined risk indices are met and significant numbers of vector species adults are present.

At a Moderate or High level of EEE risk, vector control is considered within an area following identification of EEE virus in the environment. Following a positive finding supplemental surveillance is done to assess the need for a vector control intervention. Additional trapping will be implemented in the treatment area to determine the age structures and population abundance of vector species. Larval surveys may also be initiated after significant rainfall events.

EEE occurs disproportionately by area within eastern Massachusetts. The human cases of EEE by county have been 25 in Plymouth, 19 in Norfolk, 13 in Middlesex, 9 in Suffolk, 5 in Bristol, 1 in Essex, 1 in Barnstable, and 1 in Hampden. A disease prevention strategy must respond to this disproportionate distribution of risk by providing supplemental mosquito control funding (and/or state or federal assistance delivered through independent contractors) for high risk areas and by coordinating efforts among Mosquito Control Districts that share common risk areas. The epicenter of EEE appears to be the contiguous area where Plymouth, Norfolk and Bristol Counties join. This area should be the primary target of coordinated mosquito control efforts under the direction of a state office. In the event that fiscal, staff, and equipment resources available to regional mosquito control districts are insufficient, the state must be prepared to assist in the effective control of mosquitoes to help prevent or minimize human EEE cases.

RISK CATEGORIES

(1) LOW - A LOW LEVEL OF EEE RISK exists if all of the following conditions are met:

Current Season

1. EEE virus isolates in *Cs.melanura* <10
2. Population of *Cs. melanura* below long-term mean

Previous Season

1. No human or horse cases
2. *Cs. melanura* below long-term mean
3. EEE virus isolates <20

At this level surveillance activities are routine and supplemental control efforts are not recommended. Mosquito control efforts should be standard in accordance with established plans for integrated pest management (IPM). IPM is an ecologically based strategy for managing insect populations with the goal of keeping pest levels below predetermined threshold levels. Mosquito Control District (MCD) IPM programs may include source reduction, ground or truck spray adulticide, larvicide, and other control activities in response to human annoyance thresholds (HATs) as determined by the MCDs operating under the State Reclamation and Mosquito Control Board.

(2) MODERATE - A MODERATE LEVEL OF EEE RISK exists if any of the following conditions exist:

Current Season

1. EEE virus isolates from *Cs. melanura* >10
2. *Cs. melanura* populations approaching long-term mean
3. 1-2 presumptive or confirmed horse cases

Previous Season

1. 1-2 human cases or 2-4 horse cases
2. *Cs.melanura* population above the long-term mean
3. EEE virus isolates from *Cs. melanura* >20

At this level, mosquito control interventions should be directed only against those species suspected as epidemic vectors (capable of EEE virus transmission to humans). Regional mosquito control efforts should be intensified only in EEE virus positive treatment areas. These efforts may include larviciding and ground or truck spray adulticiding based upon surveillance data that indicates significant larval and/or adult populations of bridge vector species.

(3) HIGH - A HIGH LEVEL OF EEE RISK exists if any of the following conditions exist:

Current Season

1. Confirmation of 1 human case
2. 3 or more presumptive or confirmed horse cases
3. *Cs. melanura* population above the long term mean and MIR in Cs.melanura >1
4. EEE virus isolate from bridge vector species

Previous Season

1. 2 or more confirmed human cases or 5 or more presumptive or confirmed horse cases.

These indices trigger intensive surveillance of bridge vector species and recommendations for state-funded vector control interventions which may include ground or targeted aerial larviciding and/or adulticiding. Treatments would be undertaken only in EEE virus positive treatment areas, defined by EEE virus isolates and horse or human cases, as surveillance of bridge vector populations indicate.

(4) PUBLIC HEALTH EMERGENCY - DPH will forward a recommendation immediately to the Governor's Office to declare a PUBLIC HEALTH EMERGENCY in the event that any of the following conditions exist:

Current Season

1. 2 human cases are confirmed
2. More than 10 horse cases are confirmed

Surveillance data indicating that multiple human cases of EEE will occur without intervention

These criteria will be considered sufficient for a recommendation that an emergency be declared, if they occur at a time when seasonal and biological conditions present a continuing high risk of EEE human disease. The declaration of an Emergency may trigger state supported mosquito control efforts using wide area aerial application of mosquito larvicide or adulticide. A recommendation for a wide area aerial adulticide application will be made only if surveillance data indicate a risk of multiple human cases and biological conditions are favorable for continuing risk. When such control strategies are recommended, treatment areas will be defined by DPH surveillance data. Areas targeted for aerial pesticide application will immediately be notified and all media sources utilized to alert residents to the timing and scope of the application. Environmental monitoring will be done before and after treatment and rare and endangered species habitat excluded from the spray zone in affected areas. In addition a 500-1000 foot setback will be observed when spraying around water bodies. The objective of this option is to cause a significant reduction in all species capable of EEE transmission. This intervention is successful if the target species are temporarily reduced thereby interrupting the amplification of the virus within its avian reservoir. The timing of this late season option is critical and is intended to be a one-time intervention.

VII. STRATEGY FOR VECTOR CONTROL

A vector control plan must be safe, economical, minimize environmental effects, and minimize the risk of human EEE disease. To achieve these ends, the plan must be, to the maximum extent possible, geographically and vector species specific. Vector control measures are chosen according to species, seasonal and climatic conditions, and vector life stage indices.

Three options will be available for vector control: larviciding; targeted small scale adulticiding; and wide-area aerial adulticiding; with specific activities chosen by analysis of surveillance data. Treatment areas will be defined by mosquito trap sites and/or human/equine case locations. Within a treatment area, the use of larviciding or adulticiding interventions will be guided by additional field information and surveillance data to limit the area of intervention to the extent possible, taking into account the uncertainty of risk data. All state supplemented vector control interventions will be done under the authority of Regulation 304-CMR. Section 50.08 (3)(a).

The number of mosquito species that potentially could serve as epizootic vectors of EEE is extensive; however the three species most often thought to be responsible for human and equine infection are *Coquillettidia perturbans*, *Aedes vexans* and *Aedes sollicitans* (Tsai 1991). Recent studies suggest that *Anopheles* species and *Culex salinarius* should also be considered as epidemic EEE vectors (Edman et al 1993, Vaidyanathan et al. 1997). An historical analysis of the epidemidology of EEE in Massachusetts and mosquito abundance and isolation data indicate that *Ae. vexans*, *Ae. canadensis* and *Cq. perturbans* are likely vectors involved in human disease transmission in Massachusetts. *Ae. sollicitans* may also be a vector for cases located closer to the coast, and may be targeted in areas where known human and/or equine cases have occurred.

Cq. perturbans, a permanent water species, breeds in cattail marsh areas, common in the disturbed sections of wetlands. This species has one generation per year, emerging by mid June and reaching peak populations by early to mid July. An aggressive human biter, *Cq. perturbans* presents a difficult control problem because its larvae develop attached to the roots of emergent vegetation in permanent marsh areas. The insect growth regulator methoprene in the form of slow release Altosid formulations has proven to provide effective larval control of this mosquito (Sjogren et al. 1986). This chemical is relatively nonpersistent in the environment and exhibits morphological rather than direct toxic action by interfering with larval development.

Aedes vexans, *Aedes sollicitans*, and *Aedes canadensis*, are reflood mosquitoes whose abundance levels are directly related to rainfall and floodwater or moon tide events sufficient to flood intermittently flooded oviposition areas. All of these species may exhibit peak populations mid to late summer concurrent with peak EEE virus activity in birds and may be treated at the larval stage using the biological control product, *Bacillus thuringiensis* var. *israelensis* (Bti). The success of such applications, may be hampered, however, by the small treatment window available due to rapid larval development and by the difficulty of application through the dense canopy and thick underbrush of late summer. Bti is a natural microbial agent toxic to most mosquito and blackfly larvae. It is non-toxic to bees but some mortality to other Diptera has occurred at mosquito-control application rates. In all EEE vector interventions standardized larval surveys will be conducted pre and post application.

Aedes vexans is the most predominant summer reflood mosquito in Massachusetts. The appearance of this species is dependent on the frequency and spacing of major rains. Broods have been observed from the latter part of June throughout the summer and into the fall. Although the window for effective larval treatment is narrow due to the rapid development of this species, *Bti* applications have been used successfully for control.

Aedes sollicitans breeds in the high salt marsh that is normally only flooded by moon tides at the full and new moon. *Aedes sollicitans* is an aggressive biter know to travel great distances from its breeding habitat. This species can be effectively controlled with *Bti* and treatment is made easier by the predictability of its life cycles. *Aedes canadensis* is primarily a univoltine species that appears from late spring through mid summer. A second brood can develop in early fall if rainfall is sufficient. These mosquitoes develop in temporarily flooded woodland depressions and vernal pools that are often inaccessible, particularly late in the summer, due to heavy underbrush making ground control difficult if not impossible to accomplish. Due to the heavy tree canopy and dense underbrush of this habitat, aerial larval control of *Aedes canadensis* is also very difficult.

Anopheles mosquitoes inhabit permanent water, and may be found along the edges of slow moving streams. In the latter part of the summer they may also be found in temporary pools and puddles caused by summer rainfall. *Culex salinarius* is classified as a permanent water species. This species is multivoltine with peak populations occurring late in summer. *Cx. salinarius* is an active human biter and although mammalophagic, it is more likely than other potential epidemic species to feed on birds thus increasing its chances of a playing a role in EEE virus transmission (Vaidyanathan et al 1997). The larvicide *Bacillus sphaericus* has been found to be effective against *Culex* species. *Bacillus sphaericus* is a naturally occurring bacterium with the same mode of action as Bti but with an even more narrow toxicity range. This larvicide is more effective than Bti in the highly organic water favored by *Culex* species. The spores of this bacterium are slowly removed from the water column and *B. sphaericus* may undergo limited recycling in certain environments thereby increasing its availability to target organisms. Granular formulations of *B. sphaericus* have been found to work effectively against Anopheles species (Arrendondo et al. 1990). Altosid formulations have also been used successfully as larval control agents.

Small-area, targeted, ground or aerial adulticiding with ULV malathion or resmethrin may also be utilized if specific risk conditions are met. This effort will be aimed at all potential vector species in the target area where population and life stage studies indicate treatment is required. Wide-scale aerial adulticiding may only be employed during a public health emergency if it is determined that use of such treatment is needed to prevent further human disease transmission.

An effective adulticide provides a sufficient reduction in vector species such that there is insufficient time for reinfection of a subsequent brood of vector species before the end of the mosquito season. Late season risk following a wide area intervention is usually limited by lack of virus availability in avian species, the low probability of significant numbers of infectious human biting mosquitoes surviving, and cooler weather that limits the activity of mosquitoes.

All state supplemented aerial adulticide treatments will use ULV malathion. A comprehensive review of aerial applications of insecticide for mosquito control concludes that ULV applications are efficacious, cost effective and can be used effectively over dense foliage or open housing (Mount et al. 1996). Malathion has been chosen because of its effectiveness against adult mosquitoes and its relative safety for humans and other vertebrates (Edman and Clark 1990). The efficacy of all adulticiding treatments will be determined by a comparison of pre and post-spray DPH trap site mosquito abundance levels.

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APPENDIX C

GENERAL ENVIRONMENTAL IMPACT REPORT

PESTICIDE LABELS AND MSDS
MASSACHUSETTS MOSQUITO CONTROL PROGRAMS

NOTE: CONTACT THE STATE RECLAMATION AND MOSQUITO CONTROL BOARD TO OBTAIN COPIES OF THIS DOCUMENT.

APPENDIX D

GENERAL ENVIRONMENTAL IMPACT REPORT

NORTHEAST MASSACHUSETTS MCP STANDARDS FOR OPEN MARSH WATER MANAGEMENT

NOTE: CONTACT THE NORTHEAST MASSACHUSETTS MOSQUITO CONTROL AND WETLANDS MANGAMENT DISTRICT TO OBTAIN COPIES OF THIS DOCUMENT.

APPENDIX E

STORMWATER MANAGEMENT

The following is a brief summary of information relevant to mosquito control found in the three state publications:

Stormwater Management. Volume One: Stormwater Policy Handbook. (March 1997)

Stormwater Management. Volume Two: Stormwater Technical Handbook. (March 1997)

> Both prepared by the Massachusetts Department of Environmental Protection and the Office of Coastal Zone Management.

Massachusetts Erosion and Sediment Control Guidelines for Urban and Suburban Areas.

> Prepared by the Franklin, Hampden and Hampshire Conservation Districts and available through the Department of Environmental Protection.

These documents should be referenced directly for more detailed information.

The two concerns addressed by these publications are water quality (pollutants) and water quantity (flood control). They are primarily concerned with preventing pollutants from flowing into waterways and wetland systems, and with controlling runoff from developed sites. For mosquito control, therefore, the regulations are generally not directly applicable (except in rare cases of new construction) but come into play when MCPs are asked to conduct mosquito control within these constructed systems. This results in the odd situation where Best Management Practices for stormwater management are not evaluated for their mosquito-breeding potential. However, failing to address mosquito control in the design phase may result in a larger-than-necessary number of stormwater management systems that contribute to mosquito problems. In endemic eastern equine encephalitis areas, creating additional breeding habitat for bridge (bird-to-human) vectors such as *Cq. perturbans* or *Ae. vexans* is unwise. Wet (Retention) Basins and Constructed [Stormwater] Wetlands may do precisely that.

A significant limitation of the handbooks for mosquito control is that they discuss new construction of manmade systems only. Maintenance of existing and/or natural systems is not discussed. The Erosion and Sediment Control Guidelines should be referred to for information about working in and around existing drainage though even here the issue of maintenance within the existing channel is not discussed.

Four issues regarding stormwater management exist for MCPs and are addressed in order of importance (most important first).

1. The expectation that MCPs will maintain drainage systems even when MCP actions did not cause the problem (road sand into a stream).

Standard #9 of the "Stormwater Management Form" (page 1-11 of the Policy Handbook), relates to the Operation/maintenance plan for control designs. Although this particular form is optional, the requirement for a maintenance plan should not be. Where MCPs will be expected to monitor for mosquito breeding, they should have access to the maintenance plan for the stormwater system in question and should be able to request maintenance on-site where mosquito breeding is caused by a breakdown in the system's operation. Suggested maintenance requirements for each BMP are given in the Technical Handbook. MCPs should also be able to request system alterations in the event a system is continually breeding mosquitoes.

Where maintenance responsibility is clear-cut, maintenance work should be done by the responsible party. Unfortunately, the vast majority of drainage channels have no official maintenance plan and MCPs have routinely assumed or been assigned responsibility for maintenance. In these cases, MCPs should, wherever possible, adhere to the maintenance requirements as given for the BMP that most closely describes the system in question. In most cases this will be the Drainage Channel.

2. The erosion and sediment control standards relating to (exempted) maintenance work done by MCPs.

Despite the fact that MCP maintenance work is exempted from the Wetlands Protection Act, the best interests of the MCPs are served by minimizing disruption during maintenance work. Temporary erosion and sediment controls should be used when necessary. Vegetation bordering the channels should be left as undisturbed as possible. Again BMPs for maintenance in existing systems should be developed.

3. System design and the extent to which mosquito breeding is considered prior to construction.

BMPs for stormwater management in urban and suburban areas must include some consideration of mosquito-breeding potential. That the current publication does not is an indication of the need to improve communication between mosquito control and other agencies involved in stormwater management. The best place to practice mosquito control in manmade drainage systems is in the design phase. Clearly there is cause for concern over the BMP Constructed [Stormwater] Wetlands, where pools ranging from 6 to 18 inches deep are <u>desired</u>.

4. New construction by MCPs.

New drainage construction is not exempted from the Wetlands Protection Act and MCPs should refer to the policy and technical handbooks when designing any new work.

APPENDIX F

GENERAL ENVIRONMENTAL IMPACT REPORT

NORTHEAST MASSACHUSETTS MCP STANDARDS FOR DITCH MANAGEMENT

NOTE: CONTACT THE NORTHEAST MASSACHUSETTS MOSQUITO CONTROL AND WETLANDS MANGAMENT DISTRICT TO OBTAIN COPIES OF THIS DOCUMENT.

APPENDIX G

GENERAL ENVIRONMENTAL IMPACT REPORT

EDUCATIONAL FLYERS REGARDING MASSACHUSETTS MOSQUITO CONTROL PROGRAMS

NOTE: CONTACT THE STATE RECLAMATION AND MOSQUITO CONTROL BOARD TO OBTAIN COPIES OF THIS DOCUMENT.

APPENDIX H

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Continuing Education:
Courses in Environmental Planning and Community Development, Dept. of Community Planning, URI 1987-88

EXPERIENCE: Director of the **Portsmouth** Vector Control Program (14 years), and of mosquito control programs for **Tiverton** (13 years), **Warren** (11 years), **Bristol** (9 years), **Lincoln** (8 years), and **Westerly** (5 years). Currently assisting **Warwick** Mosquito Control Program (12 years).

Mosquito Control Consultant for **Nantucket**, **MA** 1990 - 1993, 1996 - 1998.

Have designed and marketed elementary-school-level classes in Entomology.

Assisting **Warwick** in implementation of city-wide integrated pest management program 1993-1995.

MEMBER:	American Mosquito Control Association	13 Years
	Northeastern Mosquito Control Association	13 Years
	Member, Board of Directors:	1994-1997
	Entomological Society of America	7 Years

EDITORIAL EXPERIENCE: Editor: Northeaster. The newsletter of the Northeastern Mosquito Control Association.

SELECTED PUBLICATIONS: Christie, G. D. 1995. Guidelines for the use of pesticides on city-owned property. Warwick, RI. 54 pp.

Christie, G. D. 1993. Business and political skills in mosquito control. Wing Beats. 4(3): 17-18.

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MOSQUITO CONTROL TALKS (all talks at the Annual Meeting of the Northeastern Mosquito Control Association unless otherwise noted)

1996 Information on a Fungal pathogen of *Aedes canadensis* in Vernal Pools.
Mosquito Control through Marsh Restoration in Portsmouth, RI
1995 Killer Pathogen, Probably Fungus, appears in Bristol, Rhode Island
1994 Community-level Application of IPM for Medically Important Arthropods
65th Annual meeting, Eastern Branch, Entomological Society of America
1993 When the Edge Meets the Middle: Mosquito Breeding during Intermittent Tides
Open Marsh Water Management on Nantucket
1992 Reaching out for Resource Tools and Development
Altosid Pellets in Nantucket
1991 Report on Mosquito Control in Rhode Island
Monitoring Mosquito Populations for Eastern Equine Encephalitis in 1991 in Rhode Island
1990 Encephalitis in Tiverton, Rhode Island
1989 Open Marsh Water Management in Portsmouth, RI
55th Annual Meeting, American Mosquito Control Association
1987 Private [business] Mosquito Control Endeavors
1986 Overview of Mosquito Control in Portsmouth, RI.